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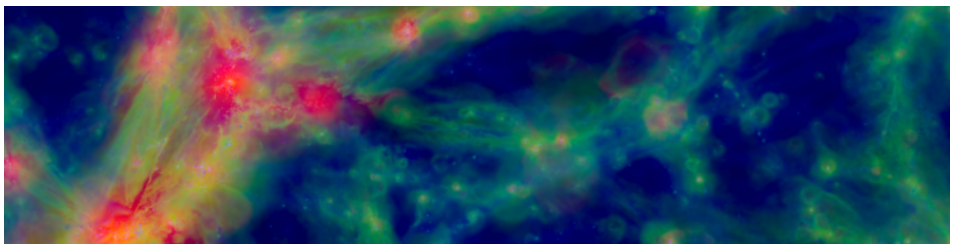

Book of Abstracts

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Indirect Detection / **151**

A Probabilistic Catalogue of Unresolved High Latitude Fermi LAT Sources

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A highly significant and spatially extended excess of GeV gamma-rays has been observed by Fermi LAT in the Inner Galaxy. While the excess's spectrum and morphology are consistent with a dark matter annihilation interpretation, the excess has also been interpreted to be the emission from a population of unresolved point sources. We present a Bayesian method for producing probabilistic catalogues to constrain the population of point sources below the Fermi LAT detection limit. To validate our method, we apply it to the high latitude Fermi LAT data and constrain the population of point sources down to 6×10-11 ph/cm2/s in 1-3 GeV, significantly below the 3FGL detection threshold ~2×10-10 ph/cm2/s. The probabilistic catalogue constrains the slope of the flux distribution of sources to be 1.8±0.2, agreeing with results obtained using non-Poissonian template fitting. The talk by Tansu Daylan will further present the probabilistic catalogue inferred using the Inner Galaxy Fermi LAT data.

Low Mass WIMP Searches / **42**

A low-mass dark matter search using ionization signals in XENON100

Andrea Tiseni[1]

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XENON100 is a liquid xenon dual phase time projection chamber (TPC) built to search for rare collisions with WIMP particles. The TPC detection principle allows for measurements of WIMP-induced recoils through two signals: a prompt scintillation signal and an ionization signal. In previous XENON100 analyses the recoil energy was determined using the size of the scintillation signal. WIMPs with a mass below 10 GeV/c^2 create recoils only up to a few keV, resulting in an ionisation signal lower than a few hundred photoelectrons and a scintillation signal that is often not detectable.

By dropping the requirement of a scintillation signal and using only the ionization signal to determine the interaction energy, we perform a low-mass dark matter search using an exposure of 30 kg x yr, corresponding to the data acquired between February 28th, 2011 and March 31st, 2012. We lowered the energy threshold for detection to 0.7 keV for nuclear recoils using only the ionisation signal, searching for dark matter induced nuclear recoils in the energy interval between 0.7 keV and 9.1 keV. Because a complete background model cannot be constructed without a scintillation signal, an exclusion limit is computed under the assumption that every event passing our selection criteria could be a dark matter event. We derive a limit on the spin-independent WIMP-nucleon cross section that excludes WIMPs with a mass of 6 GeV/c^2 above $1.2x10^{-41}$ cm^2 at 90 % confidence level.

Theory / **129**

A non-relativistic effective theory approach to dark matter direct and indirect detection

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Direct detection (DD) experiments and Neutrino telescopes (NT) will play a pivotal role in shedding light on the nature of dark matter during the next decade. An effective theory approach is a solid strategy to interpret DD experiments and NT observations when the momentum transferred in the dark matter scattering by nuclei is small compared to the mass of the particle mediating the interaction. In this talk I compare a recently developed non-relativistic effective theory for dark matter-nucleon interactions to current DD and NT data, including the observation of a modulation signal in the nuclear recoil energy spectrum reported by the DAMA collaboration. Emphasis will be placed on the strength of the proposed effective theory approach and on how it compares to the standard paradigm for the analysis of dark matter search experiments.

Neutrinos and Dark Sector / **115**

A search for bosonic dark matter with the MAJORANA DEMONSTRATOR

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The MAJORANA Collaboration has assembled an array of high purity Ge detectors to search for neutrinoless double-beta decay in ^{76}Ge with the goal of establishing the required background and scalability of a Ge-based next-generation tonne-scale experiment. The MAJORANA DEMONSTRATOR consists of 44 kg of high-purity Ge (HPGe) detectors (30 kg enriched in ^{76}Ge) with a low-noise p-type point contact (PPC) geometry. The detectors are split between two modules which are contained in a single lead and high-purity copper shield at the Sanford Underground Research Facility in Lead, South Dakota. The first module has been operating since June 2015 and the second is currently being commissioned. The low energy threshold achieved with the PPC HPGe detectors, combined with the low backgrounds of the DEMONSTRATOR, give the experiment a compelling low-energy physics program with sensitivity to dark matter and axion searches. We present the results of searches for bosonic dark matter and other rare event searches using data from the commissioning and first physics runs that improve upon existing limits.

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APPEC

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Noble Gas / **145**

An Effective Field Theory Search for Dark Matter with the Large Underground Xenon Experiment

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The Large Underground Xenon (LUX) dark matter search is a 350-kg (250-kg active) mass dual-phase xenon-based time projection chamber that operates by detecting light and ionization signals from particles incident upon a xenon target. With its 2013 report of the world's first sub-zeptobarn spin-independent WIMP-nucleon cross section limit, LUX emerged as a frontrunner in the field of dark matter direct detection. In December 2015, LUX released an updated analysis of its 2013 dataset leading to an overall 23% increase in sensitivity for high-mass WIMPs and even more significant improvement for low-mass WIMPs. However, tension between experiments and the absence of a definitive positive detection suggest it would be prudent to search for WIMPs outside the standard spin-independent/spin-dependent analyses. Recent effective field theory work has identified a complete set of 14 possible independent WIMP-nucleon interaction operators restricted only by basic symmetries. These operators produce not only spin-independent and spin-dependent nuclear responses but also novel nuclear responses such as angular-momentum-dependent and spin-orbit couplings. Here we report on the extension of the LUX analysis to search for all 14 of these interactions, comment on the possible suppression of event rates due to operator interference, and show that under this new framework, LUX again exhibits world-leading sensitivity.

Axion / **95**

Axion and axion-like particle searches in LUX

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The Large Underground Xenon (LUX) experiment is a 350 kg liquid xenon time projection chamber (TPC) designed to directly detect galactic dark matter.
Xenon detectors present suitable features to detect dark matter candidates other than WIMPs, such as axions, because of the extremely low radioactivity background for electronic recoils they can provide.
LUX can probe both axions coming from the Sun and axion-like particles (ALPs) moving within our Galaxy, thanks to their coupling to electrons, via the so called axio-electric effect.
Although theoretically well motivated, axions have yet to be detected experimentally.
We present a theoretical introduction on the two axion models: the solar axions and the galactic ALPs.
An overview on what the axion signal looks like in LUX follows.
The status of the axion analysis on LUX Run 3 data will be presented, together with a description of the relevant LUX background.

Annual Modulation / **25**

Background Subtracting the Search for Annual Modulation in CDMS II

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Weakly Interacting Massive Particles (WIMPs) are one of the leading candidates for the undetected mass component comprising ~27% of the observable universe. An excess in the nuclear-recoil event rate measured by a detector, combined with an annual periodicity introduced by the revolution of the Earth about the Sun, is an important indicator of the direct detection of particle dark matter. The Cryogenic Dark Matter Search (CDMS) experiment uses semiconductor crystals to search for WIMPs scattering from atomic nuclei through the simultaneous measurement of ionization and athermal phonons. This technique has achieved excellent discrimination between nuclear recoils (expected for WIMP interactions) and radioactively induced electron recoils, enabling a sensitive search for an annually modulating signal. Building upon the initial search for annual modulation in CDMS II in 2012, I will discuss results updated to include subtraction of the dominant backgrounds, and describe implications for interpretations of other direct search experiments.

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Background studies in SuperCDMS

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Laboratories and Low Background / 116

Background studies in SuperCDMS

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The purpose of the Super Cryogenic Dark Matter Search (SuperCDMS) experiment is to detect germanium nuclei recoiling after interacting with weakly-interacting massive particles from the galactic halo. It consists of a 9.2 kg germanium target arranged in fifteen single-crystal detectors, and it has been operating at Soudan Underground Laboratory between March 2012 and December 2015. Given the very low rate of the expected signal a good knowledge of the backgrounds is crucial for the data analyses and to properly interpret the results. In this presentation I will be showing the several studies being carried out to understand the backgrounds at SuperCDMS Soudan. In addition, the predicted backgrounds for the future SuperCDMS experiment at SNOLAB will be also discussed.

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Background survey for the CYGNUS dark matter detector

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There is ample evidence from astronomical and cosmological data for the existence of dark matter. The exploration of its nature is pursued by a whole range of experiments, including cosmological surveys, particle colliders, direct and indirect detection experiments.

Direct detection experiments have stringent background requirements due to the presence of environmental radioactivity and cosmic background in the same energy region as nuclear recoils from

dark matter particles. Nonetheless, the discovery of minority-carriers and the first background-free limit from the DRIFT detector has shown that direct dark matter experiments are now limited by their size, not their background.

We present the results of a background survey for the future CYGNUS detector. Background simulations for different materials and environmental conditions are used to place restrictions on the prototype design.

Theory / 23

Bayesian study of cosmic ray propagation: evidence against homogeneous propagation and implications for indirect detection of dark matter

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I will present the results of Galbayes, the largest ever fully-numerical neural-network-assisted study of the cosmic ray (CR) propagation parameters. We show that in the most commonly-used diffusion-reacceleration model there is significant tension between the propagation parameters that govern protons and antiprotons, vs the light elements including B/C, which are customarily used to calibrate CR propagation codes for all species. This is due to the larger distances probed by protons and antiprotons, and suggests that the intergalactic medium is significantly different over such scales. This result has far-reaching implications in searches for dark matter, which mainly focus on electrons and protons (and their antiparticles), and are therefore using wrongly-calibrated models. I will discuss the impact of these results, as they imply 1) cosmic ray constraints using local antiprotons make use of improperly-calibrated CR propagation models; and 2) Propagation models of the galactic centre based on local results are most likely wrong, as the IGM properties are very different. This is based on results of arXiv:1602.02243.

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Bolometric Detection of Dark Matter

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Bolometric detection at cryogenic temperatures is a very a powerful technique to detect the nuclear recoils induced by the collision of WIMPs from our galactic halo on a laboratory target. The possibility to combine the phonon signal with either an ionization or scintillation signal results in an efficient rejection of the background from electron recoils. The excellent energy resolution opens the possibility of lowering the threshold for an optimal coverage in the search of WIMPs with masses below 10 GeV, were these bolometers lead the way. The present detectors, their results and the future planned improvements are presented.

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Bose-Einstein Condensation of Dark Matter Axions

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It has long been known that axions produced by vacuum realignment during the QCD phase transition in the early universe form a cold degenerate Bose gas and are a candidate for the dark matter. More recently it was found that dark matter axions thermalize through their gravitational self-interactions and form a Bose-Einstein condensate (BEC). On timescales long compared to their rethermalization time scale, almost all the axions go to the lowest energy state available to them. In this behaviour they differ from the other dark matter candidates. Axions accreting onto a galactic halo fall in with net overall rotation because almost all go to the lowest energy available state for given angular momentum. In contrast, the other proposed forms of dark matter accrete onto galactic halos with an irrotational velocity field. The inner caustics are different in the two cases. I'll argue that the dark matter is axions, at least in part, because there is observational evidence for the type of inner caustic produced by, and only by, an axion BEC.

Laboratories and Low Background / 136

Boulby Underground Laboratory: Status and plans

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Boulby is the UK's deep underground science facility, operating in a working potash and salt mine in the North East of England. Boulby has hosted the UK's dark matter search studies for many years including the NAIAD, DRIFT and ZEPLIN programmes. Dark Matter search studies continue at Boulby with the DRIFT programme, R&D for DM-Ice and LZ material screening with the growing Boulby Underground Germanium facility (BUGs). The facility also has a growing multi-disciplinary science programme in areas including geology, geophysics, climate and environment studies, development of mining and space exploration technologies and studies of life in extreme environments on Earth and beyond. A new underground facility is currently being built at Boulby to host the growing science programme for the decades to come. This talk will will give details of the new underground facility and summarise the current Boulby science programme and future plans.

Summary:

Boulby is the UK's deep underground science facility, operating in a working potash and salt mine in the North East of England. Boulby has hosted the UK's dark matter search studies for many years including the NAIAD, DRIFT and ZEPLIN programmes. Dark Matter search studies continue at Boulby with the DRIFT programme, R&D for DM-Ice and LZ material screening with the growing Boulby Underground Germanium facility (BUGs). The facility also has a growing multi-disciplinary science programme in areas including geology, geophysics, climate and environment studies, development of mining and space exploration technologies and studies of life in extreme environments on Earth and beyond. A new underground facility is currently being built at Boulby to host the growing science programme for the decades to come. This talk will will give details of the new underground facility and summarise the current Boulby science programme and future plans.

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Boulby Underground Laboratory: Status and plans

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Noble Gas / **75**

Calibration of the DEAP-3600 Dark Matter Detector

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DEAP-3600 is a single phase liquid argon (LAr) dark matter experiment, located 2 km underground at SNOLAB, in Sudbury, Ontario. The detector has 1 tonne fiducial mass of LAr. Calibration of the DEAP-3600 experiment with optical and tagged radiation sources is ongoing. Two systems are used to characterize the overall detector optical response and to monitor the properties of the PMTs. The first consists of a diffuse laserball lowered in the interior of the detector prior to filling with liquid argon. The second is installed permanently in the detector and operational throughout the lifetime of the experiment and injects light using fibre optic cables. In order to study detectors energy response, internal Ar-39 background from natural argon in the detector and a tagged Na-22 source are used. The latter is also used in order to understand the position response of the detector. The Na-22 source and a tagged AmBe neutron source are used to study the detector's pulse shape discrimination against electronic background and to understand de- tector response to nuclear recoil events. The projected background level is < 0.6 events in an exposure of 3000 kg-years, allowing sensitivity to 10^{-46} cm^2 at 100 GeV/c^2 mass. In this talk an overview of the DEAP-3600 calibration system is given and most recent calibration data are shown.

Noble Gas / **29**

Calibration of the LUX Dark Matter Experiment

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The LUX dark matter experiment is a 350 kg dual-phase liquid xenon time projection chamber located at the Sanford Underground Research Facility, South Dakota. LUX's primary science run is now complete, and its response to both electron and nuclear recoils across a wide range of energies is the subject of on-going study. This work is critical to interpretation of any potential WIMP signal.

I will discuss the range of innovative calibration techniques developed and used in LUX and their results, with a focus on the D-D Neutron Generator calibration. This is a novel procedure that uses a beam of 2.45 MeV mono-energetic neutrons fired directly into the detector to perform in-situ measurements of the light and charge yields of liquid xenon, at energies lower than ever before. The resulting ultra-low energy calibrations of the nuclear recoil signal yields are essential for the discovery potential of the latest data, as well as being a confirmation of the detector response used for the first LUX WIMP search analysis. Furthermore, they allowed a new limit on dark matter properties to be published late last year from a reanalysis of the first science run data, showing improved low mass WIMP sensitivity.

Directional / **89**

Carbon nanotubes as a target for directional WIMP detection

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Large arrays of aligned carbon nanotubes (CNTs), open at one end, could be used as target material for the directional detection of weakly interacting dark matter particles (WIMPs).
As a result of a WIMP elastic scattering on a CNT, a carbon ion might be injected in the body of the array and propagate through multiple collisions within the lattice.
The ion may eventually emerge from the surface with open end CNTs, provided that its longitudinal momentum is large enough to compensate energy losses and its transverse
momentum approaches the channeling conditions in a single CNT. A proper choice of the angle formed between the WIMP wind apparent orientation and the direction of parallel CNTs would therefore provide the capability to identify this WIMP wind direction. We present here the results of calculations and simulations for an array of aligned CNT and derive some constraints on the CNT target efficiency. We also introduce an experimental method to demonstrate and measure the actual CNT target efficiency to channel ions and derive the sensitivity for an ideal detector in a region of low mass WIMPs ($\approx$ 11GeV).

Low Mass WIMP Searches / **40**

Charge migration study of a massive cryogenic Ge detector for the detection of light dark matter using the Neganov-Luke Effect

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The EDELWEISS-III collaboration aims to increase the sensitivity for light dark matter ($\sim 1 - 10\,\mathrm{GeV/c^2}$) by lowering the energy threshold of its detectors. One technique is to operate the massive high purity cryogenic Germanium detectors at high electric fields (up to $50\,\mathrm{V/cm}$). Particle interactions create electron and hole pairs, which drift to the electrodes and produce phonons on their way. This leads to an amplification of the heat signal, proportional to the applied voltage (Neganov-Luke effect).
As charge trapping effects in the bulk and the surface can appreciably degrade the signals, it is important to have a good understanding of the charge migration processes in the Germanium crystals and to find an optimal voltage configuration for the detectors.
This contribution presents the results of a detailed study of the detector performance in the high electric field case, including measurements with an EDELWEISS-type detector at ground level. Various voltage configurations were analysed and the experimental data were compared to the results of a hot carrier transport simulation.

Axion / **120**

Cold Dark Matter Axion Search with a Dipole Magnet

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The CAST-CAPP/IBS experiment is a joint effort between the CERN Axion Solar Telescope (CAST) collaboration [1] and the Center for Axion and Precision Physics Research (CAPP/IBS) [2], searching for cold dark matter axions.
In this project, tunable rectangular cavities are inserted in the 9T CAST dipole magnet, an LHC prototype, at CERN.
The traditional haloscope technique suggested by Sikivie [3] is, for the first time, applied in a rectangular geometry configuration, rather than the usual cylindrical geometry. The status and expected sensitivity of the experiment are presented.

[1] CAST Collaboration, K. Zioutas et al., Phy. Rev. Lett. 94 (2005) 121301.
http://capp.ibs.re.kr/html/capp_en/
P. Sikivie, Phys. Rev. Lett. 51, 1415 (1983).

Axion / **127**

Commissioning of the Generation-2 Axion Dark Matter eXperiment (ADMX) with near quantum noise limited amplifiers

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University of Washington, ADMX uses the most sensitive microwave receiver in the world to look for QCD Axions that convert into microwave photons in the presence of a strong magnetic field. Axion is also a compelling cold dark matter candidate. ADMX is starting its Generation-2 run in the summer of 2016 with upgrades including a dilution refrigerator and tunable quantum noise limited amplifiers. These upgrades aim to increase the sensitivity of the experiment while decreasing the thermal noise of the system by cooling it up to sub-K temperatures. This talk will give an overview of the commissioning status of ADMX and what it hopes to achieve in terms of sensitivity with these newly added components.

Axion / **49**

Conceptual design of a third-generation axion detector

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The Axion Dark Matter eXperiment (ADMX) is conducting a search for dark-matter axions trapped in the halo of the Milky Way Galaxy. Axions, originally postulated to solve the strong CP problem in particle physics, would have been created as cold (non-relativistic) very weakly interacting particles in the early stages of the expansion of the universe. If their mass is in the range 2 to 50 μeV, axions could be a significant component of the dark matter in the universe. The discovery of the axion, or

placing limits on its abundance, would therefore have very important implications for understanding the nature of dark matter, which is one of the most significant problems in contemporary physics. Axions can be detected by their conversion to microwave photons in a strong magnetic field. This process was discovered by Sikivie in 1983 and is the basis of many searches for axions and axion-like particles.

The ADMX experiment employs a high-Q, 200 litre microwave cavity that can be tuned slowly through the expected axion mass range. The cavity is held at low temperatures in a field of about 7 T. If the density of axions is close to the value required to account for all of the dark matter in our Galaxy, the signal detected would be of the order of 10-22 W. SQUID preamplifiers followed by broad-band cooled HEMT amplifiers are used to obtain the required sensitivity. The frequency is swept at a rate of the order of 2 MHz/day.To date, ADMX has ruled out axions with masses in the 2.0-3.6 μeV range ($f = mc^2/h$ of 480-860 MHz) that would be predicted by the stronger of two standard axion models.

The second-generation of ADMX is commissioning a dilution refrigerator to enable 100 mK temperatures for cavity and SQUID thereby increasing the signal-to-noise ratio by 20x, allowing the full band of the expected axion mass and coupling space, even in the case of pessimistically coupled models. Expected noise temperature is 150 mK.

A conceptual design and associated technology development for a third-generation axion cavity detector, optimized for searches for the case where the axion mass is above the range searched by the current ADMX, say in the 10 to 50 μeV mass range (3 to 12 GHz) will be described. The detector sensitivity is proportional to B2V, so that the dilemma for searches at higher frequencies is that cavity dimensions are comparable to the wavelength, so that the cavity becomes smaller as frequency goes up. The loss of volume can be addressed by increasing the magnetic field strength, say to 25-40 T.

At the same time, a method of combining two or more cavities is being developed. The signals emitted from, a modest number of nominally identical cavities are combined together in phase and brought to the front end of the low-noise amplifier. All the cavities must resonate at the same frequency for the combination to be effective. A locking scheme using phase modulated RF signals and reflection measurements, known as the Pound or Pound, Drever, Hall (PDH) reflection locking method is being investigated. This method is used by LIGO, VIRGO, and other gravitational wave experiments to bring multiple optical cavities into mutual resonance.

Summary:

The next generation microwave cavity experiment to search for dark-matter axions must search for higher mass axions. The detectors must use stronger magnetic fields and multiple microwave cavities. A conceptual desgin for such a detector will be described.

Theory / **149**

Constraints from renormalisation of the Minimal Dark Matter model

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Minimal dark matter with a fermionic electroweak quintuplet is a phenomenologically valid dark matter model. I will discuss constraints coming from the renormalisation of this theory, namely vacuum stability, the location of the Landau pole, and the intra-multiplet mass splittings. In particular, I will demonstrate some subtleties and pitfalls in the phenomenologically crucial problem of calculating the mass splittings via a typical iterative pole mass calculation, as is standard in spectrum generator routines. This problem has implications for Wino-like dark matter and any electroweak extension of the standard model in which intra-multiplet mass splittings are an essential part of the theory.

Theory / **18**

Correction of the Reconstruction of the Velocity Distribution for Low-Mass WIMPs

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In this talk, I show at first the effect of a non-negligible threshold energy on the reconstruction of the one-dimensional velocity distribution of Galactic WIMP Dark Matter by using our model-independent data analysis procedure. Then I will discuss the modification of our expressions for correcting this effect for light WIMPs and present some numerical results of our Monte-Carlo simulations.

Indirect Detection / **21**

Cosmic-ray antideuteron searches

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Recent years have seen increased theoretical and experimental efforts towards the first-ever detection of cosmic-ray antideuterons, in particular as an indirect signature of dark matter annihilation or decay. In contrast to indirect dark matter searches using positrons, antiprotons, or gamma-rays, which suffer from relatively high and uncertain astrophysical backgrounds, searches with antideuterons benefit from very suppressed conventional backgrounds, offering a potential breakthrough in unexplored phase space for dark matter. The presentation will review dark matter theories that can be probed with antideuterons, the challenges for the interpretations of antideuteron signals, and the experimental efforts toward cosmic antideuteron detection.

Other Techniques / **5**

Cryogenic phonon-scintillation detectors with PMT readout for rare event search experiments

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Cryogenic phonon-scintillation detectors (CPSD) for rare event search experiments require reliable, efficient and robust photon detectors that can resolve individual photons in a scintillation event. We report on a cryogenic detector containing a scintillating crystal, equipped with an NTD-Ge phonon

sensor and a photon detector based on a low-temperature photomultiplier tube (PMT) that is powered by a Cockcroft–Walton generator. Here we present results from the characterisation of two detector modules, one with CaWO4, the other with CaMoO4 as scintillator. The energy resolutions (FWHM) at 122.1 keV for the scintillation / PMT channel are 19.9% and 29.7% respectively for CaWO4 and CaMoO4 while the energy resolutions (FWHM) for the phonon channels are 2.17 keV (1.8%) and 0.97 keV (0.79%). These characteristics compare favourably with other CPSDs currently used in cryogenic rare-event search experiments. The detection module with PMT readout benefits
from the implementation of a well-understood, reliable, and commercially available component and improved time resolution, while retaining the major advantages of conventional CPSD, such as high sensitivity, resolving power and discrimination ability.

Directional / **157**

D3 - milli, a Negative Ion Time Projection Chamber (NITPC) prototype with pixel readout

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Building on the success of operating Time Projection Chambers (TPCs) for directional neutron detection the D3 project is designing a Negative Ion TPC (NITPC) as a directional dark matter detector prototype with high definition (HD) pixel chip readout. In addition SF6 has recently been proposed as a possible replacement for the CF4/CS2 negative ion mixture and it has been observed that gain is achievable in a SF6 based detector. We seek to design a detector which allows for maximum drift length, uses Gas Electron Multipliers (GEMs) for amplification, and the ATLAS FE-I4b chip for ionization readout. Such a design would allow for 3-D tracking with powerful background suppression and could serve as “unit-cell” for a large, future, directional detector.

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Dark Forces in the Sky: signals from Z' and the Dark Higgs

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Co-author(s): Nicole F. Bell [1] ; Rebecca K. Leane [1]

[1] *The University of Melbourne*

We consider the indirect detection signals for a self-consistent hidden U (1) sector, containing a fermionic dark matter candidate, dark gauge boson and a Dark Higgs. The presence of an additional scalar, the Dark Higgs, provides a mass generation mechanism for the dark sector particles and is required to avoid unitarity violation at high energies. It also opens up a new process that can probe regions of parameter space which is not possible with other commonly considered s-wave annihilation processes. We examine the phenomenology of the sector with a focus on this new process, and
determine the limits on the model parameter space from Fermi data on Dwarf Spheriodal Galaxies and other relevant experiments.

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Dark Matter Detectors and the Neutrino Wall

Malcolm Fairbairn[1]

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I will talk about the problem of neutrinos as a difficult background for dark matter direct detection experiments. I will present new work describing ongoing efforts to mitigate against this background. I will also talk about embracing the problem and using dark matter detectors to do neutrino physics, in particular I will describe tests of solar physics and the standard model which can be performed in this way and how such experiments can constrain new BSM physics in the neutrino sector.

Noble Gas / **76**

Dark Matter Search at the Multi-Ton Scale with XENONnT

Michelle Galloway[1]

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The XENONnT dark matter experiment aims for the direct detection of weakly-interacting dark matter particles (WIMPs) with an order of magnitude higher sensitivity than its predecessor, XENON1T. By utilising the existing infrastructure of the XENON1T experiment, currently in commissioning at the Laboratori Nazionali del Gran Sasso (LNGS), an upgrade to a multi-ton scale detector can be rapidly realised. The new detector consists of a dual-phase (liquid/gas) time-projection chamber with double the liquid xenon mass and ~35% larger photosensor coverage than the current generation. The upgrade significantly minimises material-induced backgrounds, with internal backgrounds residing at the level of astrophysical neutrinos. This improvement allows for higher statistics of an initial XENON1T WIMP signal as well as the possibility to probe other physics channels with better sensitivity. This presentation will describe the design, preparation, and expected physics reach of the XENON program at the multi-ton scale.

Annual Modulation / **61**

Dark Matter annual modulation with CUORE-0 and CUORE

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The Cryogenic Underground Observatory for Rare Events (CUORE) is a ton-scale neutrinoless double beta decay experiment based on TeO2 cryogenic bolometers that is currently in the last stage of construction at the Gran Sasso National Laboratory (LNGS).
Its primary goal is to observe neutrino-less double beta decay of 130Te, with a projected sensitivity reaching the inverted hierarchy region of the neutrino mass, but thanks to the ultra-low background and large projected exposure, CUORE could also be suitable to search for Dark Matter exploiting the expected signal annual modulation signature provided a low energy threshold is achieved.

Waiting for CUORE commissioning, new tools for lowering the CUORE energy threshold have been developed and tuned using data acquired with CUORE-0, a single-tower CUORE prototype recently

concluded. They include a new low-threshold trigger, low energy calibration, event selection, efficiencies evaluation and stability checks.

Preliminary data of the CUORE-0 analysis and prospects for CUORE will be also discussed here.

Theory / 9

Dark Plasma simulations

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We present the results of N-body/smoothed particle hydrodynamics simulations of galaxy cluster collisions with a two component model of dark matter, which is assumed to consist of a predominant non-interacting dark matter component and a 20\% mass fraction of dark plasma. Dark plasma is an intriguing form of interacting dark matter with an effective fluid-like behavior, which is well motivated by various theoretical particle physics models. We find that by choosing suitable simulation parameters, the observed distributions of dark matter in both the Bullet Cluster (1E 0657-558) and Abell 520 (MS 0451.5+0250) can be qualitatively reproduced. In particular, it is found that dark plasma forms an isolated mass clump in the Abell 520 system which cannot be explained by traditional models of dark matter, but has been detected in weak lensing observations. Main results presented in http://arxiv.org/abs/1603.07324

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Dark Stars: Dark Matter Annihilation can power the first stars

Katherine Freese[1]

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Abstract: The first phase of stellar evolution in the history of the
Universe may be Dark Stars (DS), powered by dark matter heating rather than
by nuclear fusion. Weakly Interacting Massive Particles, which may be their
own antipartners, collect inside the first stars and annihilate to produce
a heat source that can power the stars. A new stellar phase results, a Dark
Star, powered by dark matter annihilation as long as there is dark matter
fuel, with lifetimes from millions to billions of years. Dark stars are
very bright diffuse puffy objects during the DS phase, and grow to be very
massive. In fact, we have found they can to grow to 10^5-10^7 solar masses with luminosities 10^9-10^11 solar luminosities. Such objects will be observable with James Webb Space Telescope (the sequel to HST). Once the dark matter fuel is exhausted, the DS becomes a heavy main sequence star; these stars eventually collapse to form massive black holes that may provide seeds for supermassive black holes observed at early times as well as in galaxies today.

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Dark energy and new interactions in the dark sector

Carsten van de Bruck[1]

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In this talk I will review models in which a dark energy scalar field mediates a fifth force between dark matter particles. In such theories, the accelerated expansion of the universe is due to the energy density of the scalar field while its field value determines the dark matter particle mass. I will discuss motivations for such models and describe their cosmological consequences.

7

Dark matter searches with PICO: An overview and the recent results.

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The PICO collaboration uses superheated detector technology in order to detect WIMP interactions and has deployed a 2 litre (PICO-2L), and a 32 litre (PICO 60) bubble chamber detector in the SNOLAB underground laboratory. A second WIMP search experimental run with PICO-2L was conducted last summer after carefully controlling for particulate contamination, and the obtained results clearly show the absence of the previously observed anomalous background. This background-free run set the world's leading limits on spin-dependent WIMP interactions and provided crucial guidance for their future bubble chamber detectors. The details on the PICO detector technology along with the recent results from PICO-2L will be presented.

Noble Gas / 3

Depleted Argon for Large Scale Dark Matter Searches

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Dark matter searches through the limit provided by neutrino-induced nuclear recoils will require background-free exposures of several hundreds of tonnes per year. With its powerful power of rejection of beta/gamma background in favor of the selection of nuclear recoil and low internal background, depleted argon is the ideal target for this endeavor.

On the heels of the successful procurement of 150 kg of ultra-low background underground argon, the DarkSide Collaboration has developed a program for large scale collection of underground argon and its further abatement by active isotopic depletion. I will described status and progress of our effort. I will also describe its impact on DarkSide-20k, a 30 tonne depleted argon detector proposed for installation at LNGS and design to perform a dark matter search with a background-free search 100 tonne*year exposure.

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Devil in the Detail – Calibration of Dark Matter Detectors

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I will discuss some of the techniques currently in use for the direct calibration of the response of dark matter detectors. This will include both nuclear recoil and electron recoil events. I will focus on the most innovative and entertaining techniques that have been developed which have allowed the accurate measurement of the response of detectors to dark matter and to a range of backgrounds. I will also survey the many pitfalls to developing this understanding which have sometimes lead to the premature discovery of dark matter signals.

Noble Gas / 58

Differential capacitive measurement and monitoring sensors for the LUX-ZEPLIN dark matter detector

Author(s): Kathryn Boast[1]

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[1] *University of Oxford*

Corresponding Author(s): kathryn.boast@physics.ox.ac.uk

Two-phase liquid noble gas detectors for rare event search experiments require a precise knowledge of the liquid-gas interface position. This is often provided through liquid level monitoring sensors. In this talk I will report on a newly developed method of differential capacitive measurement that can be employed in capacitive sensors. The feedback circuit design enables the measurement of small changes in picofarad capacitances to femtofarad precision while suppressing the effect of the nanofarad capacitance of the cables used. The feedback mechanism employs multiple amplifiers with the loop gain of the feedback circuit suppressing the cable capacitance. This enables the design of capacitive liquid level sensors and position sensors, which will monitor shrinking during the cooling of LUX-ZEPLIN.

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Direct detection and the neutrino floor

Ciaran O'Hare[1]

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The search for WIMP dark matter by direct detection faces an encroaching background due to coherent neutrino nucleus scattering. In this talk I will review the various types of neutrino that are backgrounds to direct detection - Solar, supernovae and atmospheric neutrinos - and explain how their presence results in the theoretical limit known as the neutrino floor. The proximity of the neutrino floor to the sensitivity of existing and near future experiments is highly dependent on the uncertainty in the ingredient parameters of the expected signal. In particular, astrophysical uncertainties are crucial to understand when attempting to distinguish WIMPs and neutrinos. I will also outline a possible approach for circumventing the neutrino floor by utilising the unique directional signatures of the WIMP and Solar neutrino event rates.

Summary:

- Direct detection
- Neutrinos
- Astrophysical uncertainties
- Directional detection

Based on 1604.03858 and 1505.08061

Directional / **103**

Directional Dark Matter Detection with MIMAC

Daniel Santos[1]

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In order to perform Directional DM detection, low energy nuclear recoil tracks have to be detected. The MIMAC collaboration has recently reported the first detection of 3D nuclear tracks coming from the Radon progeny confirming the possibility to perform this kind of measurement with an ionization quenching measurement on these heavy nucleus. The nuclear recoils produced by monochromatic neutron fields have been detected by a MIMAC chamber allowing the experimental determination of the electron-nuclear recoil discrimination at the same time that the angular distribution of the Fluorine recoils produced by the neutron elastic collision has been experimentally described.
A new facility called COMIMAC has been developed at the LPSC (Grenoble) to perform the 3D characterization of nuclear recoil tracks of known kinetic energies. The first measurements will be reported showing clear differences with respect to the best simulation available.

Summary:

In order to perform Directional DM detection, low energy nuclear recoil tracks have to be detected. The MIMAC collaboration has recently reported the first detection of 3D nuclear tracks coming from the Radon progeny confirming the possibility to perform this kind of measurement with an ionization quenching measurement on these heavy nucleus. The nuclear recoils produced by monochromatic neutron fields have been detected by a MIMAC chamber allowing the experimental determination of the electron-nuclear recoil discrimination at the same time that the angular distribution of the Fluorine recoils produced by the neutron elastic collision has been experimentally described.
A new facility called COMIMAC has been developed at the LPSC (Grenoble) to perform the 3D characterization of nuclear recoil tracks of known kinetic energies. The first measurements will be reported showing clear differences with respect to the best simulation available.

Directional / **38**

Directional Dark Matter Detection with the DMTPC Experiment

Gabriela Druitt[1]

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Direction reconstruction provides a unique way to positively identify signal interactions induced by dark matter particles, thanks to the motion of the earth through the galactic dark matter halo. Directional information can additionally serve as a powerful discriminant against neutron (and neutrino-induced) backgrounds that have the same final-state signature as a signal interaction. The Dark Matter Time Projection Chamber (DMTPC) uses gas-based TPC technology, with both optical and charge readout, to measure the directional anisotropy of nuclear recoils induced by particles traversing the detector volume. Here, we present preliminary results from the 1m3 DMTPC detector prototype, as well as background rejection and directional sensitivity studies.

Indirect Detection / 53

Discovery of a new extragalactic population of energetic particles

Author(s): Thomas Lacroix[1]

Co-author(s): Anthony Brown [2] ; Céline Boehm [3] ; Jamie Graham [2] ; Joseph Silk [1] ; Paula Chadwick [2]

[1] *Institut d'Astrophysique de Paris*

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Radio galaxies are active galactic nuclei containing supermassive black holes with misaligned relativistic jets. Centaurus A (Cen A) is the closest known gamma-ray emitting radio galaxy. In this talk I will report the discovery of a hardening in the *Fermi*-LAT gamma-ray spectrum of the core of Cen A above 2.4 GeV, as well as evidence for variability below 2.4 GeV. These properties strongly support the hypothesis that the low energy component originates from leptons in the jet, while the additional source of very high energy particles near the core of Cen A must originate from a different cosmic-ray population. I will show that the observed gamma-ray spectrum is compatible with either a spike in the dark matter halo profile or a population of millisecond pulsars. This work constitutes the first robust indication of new gamma-ray production mechanisms in active galaxies and provides a tantalizing hint for the clustering of heavy dark matter particles around black holes.

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EDELWEISS: R&D and perspectives for 2017 and beyond

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Starting from the achieved sensitivity of EDELWEISS-III with its FID800 Ge detector technology, we present the planning and actions for the next measurement phase. This will concentrate on the usage of Ge bolometers with voltage-assisted amplified heat signals (so-called Neganov-Luke mode)

to explore the parameter space for low mass WIMPs (down to m~1GeV). Significant improvements in sensitivity can be realised with a moderate exposure of 350 kg.d within the next 2 years. Beyond 2017, the most promising approach to gain further sensitivity towards the neutrino floor is a joint effort to install Ge bolometers in the SuperCDMS cryogenic infrastructure to be built in SNOLAB. Current R&D activities, sensitivity projections and the EDELWEISS-EURECA project towards the SNOLAB cryogenic facility will be presented.

Theory / **148**

Effective Field Theory of Dark Matter: a Global Analysis

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An effective field theory (EFT) approach allows us to describe WIMP interactions as point-like, regardless of the specific fundamental theory at higher energies. We consider simultaneously all phenomenologically relevant EFT operators for scalar DM and perform a global statistical analysis. We identify the most probable regions of the theory parameter space compatible with experimental constraints on the relic density as well as with direct and indirect detection experiments.

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End

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Annual Modulation / **146**

Event rate modulation in XENON100 -results and prospects.

Bart Pelssers[1]

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Periodic variations in the event rate of direct detection experiments can be a signal of dark matter. An event rate modulation with a period of one year, annual modulation, can be explained as an effect of the Earth's orbital motion and the Earth-Sun system moving through the galactic dark matter halo.
The XENON collaboration has performed a search for event rate modulation using ~225 livedays of data from the XENON100 detector. The study showed no statistically significant modulation at any period up to 500 days. The interpretation of the best fit modulation as a dark matter signal is disfavoured due to its phase being inconsistent with the phase expected from the galactic dark matter halo. The analysis also excludes the DAMA/LIBRA annual modulation at 4.8 sigma.
More data are being added in order to reach an even higher sensitivity. Secondly a new background model is being constructed which includes more information about the various time dependent background contributions.

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Exploring the physics frontier with the MAGIC Telescopes: Indirect dark matter searches

Joaquim Palacio Navarro[1]

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Since the beginning of operation, the MAGIC Cherenkov telescopes have been a powerful tool for exploring the Physics frontier, addressing topics such as the nature of dark matter, and its distribution in the Universe, or the search for quantum gravitational effects in photon propagation. I present here an overview of status and results of the main MAGIC fundamental Physics projects, specially focusing on dark matter searches. Among the recent MAGIC results there is the most constraining limits to the WIMP annihilation cross-section for particle masses above few hundred GeV, from observations of dwarf spheroidal (dSph) galaxies. This MAGIC result has been later combined with Fermi-LAT observations of dSphs, obtaining limits for dark matter particle masses between 10 GeV and 100 TeV, the widest mass range ever explored by a single gamma-ray analysis. The combined analysis improved the previously published Fermi-LAT and MAGIC results by up to a factor of two at certain masses. I will also show the results obtained on a campaign performed on the Perseus cluster and argue how optimal this object can be for exploring the parameter space of decaying dark matter candidates. We apply a likelihood analysis that has been optimized for exploiting the spectral and morphological features expected in the dark matter signal for each of this objects. In the case of Perseus, this allowed us to reach sensitivities to decay lifetimes into bb_bar of 10^25 s for dark matter masses of 1 TeV, almost one order of magnitude stronger than previous MAGIC results.

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First results from the LUX-ZEPLIN simulated detector electronics response.

Cees Carels[1]

[1] *University of Oxford*

LUX-ZEPLIN (LZ) is a two-phase xenon dark matter direct detection experiment due to be built in the Sanford Underground Research Facility (SURF) in Lead, South Dakota, USA. It will be among the most sensitive experiments of its kind, putting new constraints on the WIMP-nucleon interaction cross-section. The design of the analogue electronics signal chain consists of photomultiplier tubes, cabling, and dual-gain amplifiers. After digitisation and triggering, data are stored in a bespoke format. A preliminary simulation has been made of the LZ detector electronics signal chain, enabling a first simulation of the complete process from detector physics events to analysed waveform data – paving the way to study non-standard events. Furthermore, the detector electronics response simulation allows making estimates of event data volumes and data rates. In this poster we present first results from the new detector electronics response simulation, demonstrating simulated waveform output and comparing to measured data from the electronics chain test-setup.

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Galactic Cold Dark Matter from First Principles

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We show that fluid dynamics applied to galactic Cold Dark Matter (CDM) leads to a family of purely theoretical galactic density profiles that includes the popular Navarro-Frenk-White profile, and diverge at the halo core. When CDM is treated as a Bose-Einstein condensate, the resolution of the fluid dynamics equations leads to a finite halo core, hence avoiding the "cuspy halo problem" found in CDM numerical models. The mass of the CDM particle is predicted to be of the order of 10^−24eV, the same order of magnitude as what predicted in ultra-light scalar CDM models but obtained via a completely different and independent approach.

Indirect Detection / **33**

Gamma-ray emission and the dark matter content of the dwarf galaxy Reticulum II

Savvas Koushiappas[1]

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I will present results on the analysis of gamma-ray emission from the recently discovered dwarf galaxy Reticulum II. Using Fermi-LAT data and a suite of background models we quantify the probability that the observed gamma-ray emission is due to background. Reticulum II is found to have the most significant gamma-ray emission from any other known dwarf galaxy. I will also discuss the dark matter content of Reticulum II as derived from kinematic studies of its member stellar population and show that Reticulum II has a dark matter halo similar to other nearby dwarf galaxies. If the gamma ray emission is due to dark matter annihilation, the annihilation cross section is consistent with the s-wave relic abundance cross section. I will conclude by discussing further tests that are needed in order to ascertain the likelihood of this emission to be due to a conventional astrophysical interpretation.

Theory / **107**

Gauge Invariance and Simplified Models with Scalar Mediators

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Up to a few year ago the standard paradigm for Dark Matter search at LHC was the use of Effective Field Theories. It was pointed out, however, that the validity of the EFT approach might be questionable at LHC. Because of this, recently the both theory and experimental communities switched to the use of "Simplified Models", that are models that contain only renormalizable interactions. To keep them "simple", they make some assumptions, such as that DM interacts with SM particles only through one mediator, or that, in case there are more than one, that one is much lighter than all others and consequently is a good approximation to consider only the lightest one. In this talk, we explore the consequences of gauge invariance concerning the Simplified Models with a Scalar mediator exchanged in the S-channel. We will see that gauge invariance requires necessarily 2 or more mediators to be the portal to DM, and one of them may be the Higgs. We will try to explore and discuss all possible options, taking into account Direct Detection, Collider and Flavor constrains.

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Highlights on signals from Dark Matter particles

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The present status of direct detection of Dark Matter (DM) particles will be summarized, with particular care to the DAMA model-independent DM annual modulation results. Arguments on comparisons will be addressed showing that there is large room for compatibility between positive signals and negative hints, considering both the different adopted procedures and techniques, the different experimental observables, the different exposures, the existing experimental and theoretical uncertainties and the widely open scenarios for astrophysical, particle and nuclear Physics aspects. Recent results on diurnal investigation, Earth shadow effect and on some model dependent corollary analysis will also be introduced. Realistic experimental perspectives will be, finally, addressed with attention to some particular cases.

Summary:

The present status of direct detection of Dark Matter (DM) particles will be summarized, with particular care to the DAMA model-independent DM annual modulation results. Arguments on comparisons will be addressed showing that there is large room for compatibility between positive signals and negative hints, considering both the different adopted procedures and techniques, the different experimental observables, the different exposures, the existing experimental and theoretical uncertainties and the widely open scenarios for astrophysical, particle and nuclear Physics aspects. Recent results on diurnal investigation, Earth shadow effect and on some model dependent corollary analysis will also be introduced. Realistic experimental perspectives will be, finally, addressed with attention to some particular cases.

Theory / 60

How to calculate direct detection exclusion limits that are consistent with gamma rays from WIMP annihilation in the Milky Way halo

Anne Green[1]

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When comparing constraints on the WIMP properties from direct and indirect detection experiments it is crucial that the assumptions made about the dark matter (DM) distribution are realistic and consistent. If the Fermi-LAT Galactic centre GeV gamma-ray excess was due to WIMP annihilation, its morphology would be incompatible with the Standard Halo Model that is usually used to interpret data from direct detection experiments. I will describe recent work (in collaboration with David Cerdeno, Mattia Fornasa and Miguel Peiro) in which we calculate exclusion limits from direct detection experiments using self-consistent velocity distributions, derived from mass models of the Milky Way where the DM halo has a generalized NFW profile. We use two different methods to make the mass model compatible with a DM interpretation of the Galactic centre gamma-ray excess. Firstly, we fix the inner slope of the DM density profile to the value that best fits the morphology of the excess. Secondly, we allow the inner slope to vary and include the morphology of the excess in the data sets used to constrain the gravitational potential of the Milky Way. The resulting direct detection limits differ significantly from those derived using the Standard Halo Model, in particular for light WIMPs, due to the differences in both the local DM density and velocity distribution.

Other Techniques / **66**

Inelastic WIMP-nucleus scattering to the first excited state of ^{125}Te: a possible search with CUORE

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Detailed nuclear-structure calculations were made to predict the rate of the M1 excitation of ^{125}Te from the $1/2^+$ ground state to the first excited $3/2^+$ state at 35.5-keV, by the collision with WIMPs in our galactic halo. A complete calculation of the relevant spin structure was performed in the framework of the shell model. The valance space included the orbits: $1g_{7/2}$, $2d_{5/2}$, $1h_{11/2}$, $3s_{1/2}$, and $2d_{3/2}$. There will be 43 kg of ^{125}Te in the present version of CUORE, and the predicted rate is very interesting. In fact the predicted rate is significantly faster than that estimated in 1988 by Ellis, Flores and Lewin, although our calculation of the rate in ^{83}Kr was similar to their estimate. The predicted rate in ^{125}Te as well as a brief discussion of the principles of operation of the CUORE detector will be given.

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Introduction to IDM2016

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KELHAM ISLAND AND EDALE VISITS

Indirect Detection / **52**

KWISP : the radiation pressure sensor

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One of the remaining puzzles in physics is the composition of the Universe. Now days we believe that it is made of about 5% ordinary matter, 25% dark matter and 70% of dark energy. Our knowledge about the nature of the dark constituents of the Universe is very feeble. They were introduced to explain some observational data. In particular the dark energy was introduced to explain the observed acceleration in the expansion rate of the Universe. One of the possible mechanisms would be the existence of a light scalar field. To render it compatible with General Relativity in the solar system and "fifth force" searches on Earth they have to be screened. One possibility is a so called "chameleon" mechanism which renders their effective mass dependent on the local matter density.

In case they exist they can be produced in the Sun and detected on Earth by a suitable sensor. The detection mechanism relies on the equivalent of the radiation pressure, where solar chameleons impinge on a mobile surface and transfer momentum to it which displaces it from the equilibrium position. Such a sensor has been built and first on-beam tests have been performed at CERN in the CAST experiment. It is based on a thin silicon nitride micro-membrane placed inside a Fabry–Perot optical cavity. By monitoring the cavity characteristic frequencies it is possible to detect the tiny membrane displacements caused by an applied force. Its application to experiments in the Dark Energy sector, such as those for Chameleon-type WISPs, is particularly attractive, as it enables a search for their direct coupling to matter.

Low Mass WIMP Searches / **14**

LOW ENERGY NEUTRINO PHYSICS AND DARK MATTER SEARCHES WITH SUB-KEV GERMANIUM DETECTORS

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LOW ENERGY NEUTRINO PHYSICS AND DARK MATTER SEARCHES WITH SUB-KEV GERMANIUM DETECTORS

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Germanium ionization detectors with sensitivities as low as 100 eVee 1 open a new windows for the studies of neutrino interactions and properties [2] as well as to search for light WIMP Dark Matter [3]. The TEXONO and CDEX Collaborations has been pursuing this research program at the Kuo-Sheng Neutrino Laboratory (KSNL) in Taiwan and Jinping Underground Laboratory (CJPL) in China. We will present highlights of the detector characterization and performance in the energy domain where the amplitude of physics signals is comparable to those due to fluctuations of pedestal electronic noise 1, as well as the status on light WIMP searches [3] and studies of neutrino-nucleus coherent scattering [4].

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3. H. B. Li et al., Phys. Rev. Lett. 110, 261301 (2013) ; Q. Yue et al., Phys. Rev. D 90, 091701(R) (2014) ; S. K. Liu et al., Phys. Rev. D 90, 032003 (2014) ; W. Zhao et al., arXive:1602.02462 (2016).
4. S. Kerman et al., arXive:1603.08786 (2016).

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Latest AMS results on the properties of elementary particle fluxes and flux ratios in primary cosmic rays

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The fluxes and flux ratios of charged elementary particle in cosmic rays are presented. In the absolute rigidity range ~60 to ~500 GV, the antiproton, proton, and positron fluxes are found to have nearly identical rigidity dependence and the electron flux exhibits a different rigidity dependence. Below 60 GV, the antiproton-to-proton, antiproton-to-positron and proton-to-positron flux ratios each reaches a maximum, and in the range from ~60 to ~500 GV, these flux ratios show no rigidity dependence. These are new observations of the properties of elementary particles in the cosmos, which provide additional information on the origin of the rare cosmic-ray cosmic ray spices.

Directional / 195

Latest results from the DRIFT dark matter detector

Neil Spooner[1]

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The DRIFT (Directional Recoil Identification From Tracks) experiment is the world leading directional dark matter detector in terms of sensitivity, searching for a galactic signature from WIMP-induced nuclear recoils. DRIFT has been running background free for over a year and the latest results from this data will be presented, along with recent studies on the directional capabilities of the detector and prospects for the future.

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Latest results on indirect dark matter searches with IceCube

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Dark matter could be detected indirectly through the observation of neutrinos produced in dark matter self-annihilations or decays. Data collected with the world's largest neutrino telescope, IceCube, has been searched for such signatures and stringent constraints have been placed on dark matter models. Limits on spin-dependent and spin-independent scattering of dark matter with nucleons based on the absence of an excess neutrino flux from the center of the Sun and Earth will be reported. Searches for dark matter annihilations in the Galaxy carried out with multiple years of IceCube data will be presented. The talk will conclude by summarizing the discovery prospects at IceCube and proposed upgrades, PINGU and IceCube-Gen2.

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Latest status of the 3.5 keV line as a Dark Matter candidate

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The unidentified emission line from galaxies and cluster at 3.5 keV discovered in 2014 remains an interesting candidate for a dark matter decay signal. I will briefly review the existing work and arguments, and then present and discuss the current status of this signal and the latest results, such as the studies of the Draco satellite galaxy and the Perseus galaxy cluster.

Axion / **90**

Launching the Axion Research at CAPP in Korea

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The main research focus of the IBS Center for Axion and Precision Physics Research (CAPP) is to establish a state-of-the-art axion experiment in Korea and to search for relic axion particles converting to microwave photons in a resonant cavity submerged in a strong magnetic field. The initial stage of building our axion experiment, CULTASK (CAPP Ultra Low Temperature Axion Search in Korea) is completed at KAIST (Korea Advanced Institute for Science and Technology) with successful installation of two new dilution refrigerators (one with 8T superconducting magnet) which could lower the temperature of cavities to less than 50 mK. A resonant cavity (10 cm OD) and the support structure were fabricated and installed with the frequency tuning system employing a sapphire rod driven by a piezoelectric actuator. I will discuss the status and progress of CULTASK, soon to be complete with a DAQ and monitoring system, and future plans.

Theory / **139**

Less-simplified models of dark matter for direct detection and the LHC

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We construct models of dark matter with suppressed spin-independent scattering cross section utilizing
the existing simplified model framework. Even simple combinations of simplified models can exhibit interference effects that cause the tree level contribution to the scattering cross section to vanish, thus demonstrating that direct detection limits on simplified models are not robust when embedded in a
more complicated and realistic framework. In general for fermionic WIMP masses > 10 GeV direct detection
limits on the spin-independent scattering cross section are much stronger than those coming from the LHC.
However these model combinations, which we call less-simplified models, represent situations where LHC
searches become more competitive than direct detection experiments even for moderate dark matter mass. We

show that a complementary use of several searches at the LHC can strongly constrain the direct detection
blind spots by setting limits on the coupling constants and mediators' mass. We derive the strongest limits for combinations of vector + scalar, vector + "squark", and "squark" + scalar mediator, and present
the corresponding projections for the LHC 14 TeV for a number of searches: mono-jet, jets + missing energy, and searches for heavy vector resonances.

Low Mass WIMP Searches / **37**

Light WIMP search with a high-pressure gaseous TPC: The TREX-DM projec

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The most appealing Dark Matter particle candidates are Axions and WIMPs.
The WIMP lower-mass end (around 10 GeV) is a relatively unexplored parameter space region, lately attracting increasing interest of the community, and potentially within reach of current detector technologies.
Exceeding the upper bounds on the WIMP-nucleon spin-independent cross-section at such low masses requires the use of very low-threshold,
low-background detectors preferably using light nuclei as target material, while only a moderate exposure is required. TREX-DM is a high-pressure, argon or neon-based gaseous TPC, with Micromegas readouts, that could fulfill such challenging requirements. A detailed description of the experiment´s status will be given, including the prospects for its operation at the Canfranc Underground Laboratory from 2017.
The upgrades and challenges that need to be carried out for its underground operation need to be addressed will be presented. Finally, we will show a preliminary background model based on Geant4 plus detector response simulation, and we will derive the projected sensitivity of the experiment.

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Light sterile neutrino search with reactor experiments

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Several anomalies were reported by neutrino oscillation experiments in the past few years. The most momentous explanation conjoining these anomalous observations is the existence of a light sterile neutrino. Although not interacting weakly, a sterile neutrino would participate in the lepton flavor mixing and therefore distort the oscillation patterns predicted by the three flavor paradigm.
Global fits favor a squared mass difference of $\Delta m^2 \sim 1\mathrm{eV}^2$ and a mixing angle of $\sin^2 2\theta \sim 0.1$, i.e. of similar size as the smallest mixing angle θ_{13}.

Being an intense and heavily monitored source of electron antineutrinos, nuclear reactors are well-suited to study neutrino oscillation parameters. The most recent observation supporting the sterile neutrino hypothesis is known as the "reactor antineutrino anomaly". A re-evaluation of the neutrino

flux emitted by nuclear reactors resulted in a $\sim 6\%$ deficit in the observed-to-predicted event ratio in the data collected by 19 short-baseline ($L \leq 100\,\mathrm{m}$) reactor experiments. Upcoming reactor experiments will consequently operate at even shorter baselines of 10 meters and less, where a distinct oscillation pattern in space and neutrino energy could be detected. Observing this smoking gun signal would unambiguously prove the existence of sterile neutrinos.

In this talk an overview on reactor experiments aiming to discover eV^2 sterile neutrinos will be presented. Their detection technologies will be discussed, details on the current status and discovery prospects will be given.

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Liquefied Noble gases: an optimal target for the Dark Matter search and more.

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In this talk the main features of the Liquefied Noble gases will be reported and discussed.
Then an overview of the experimental applications is presented and an emphasis will be put in discussing the Liquefied Noble gases as optimal active target in the field of the Dark Matter search.

Theory / 56

Looking for Dark Matter in the Earth's Shadow

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Direct detection experiments aim to detect the interaction of Galactic Dark Matter (DM) with terrestrial nuclei. But many of these DM particles will pass through the Earth before reaching the detector. During this transit, they may interact and scatter, altering their distribution at the Earth's surface. I will sketch the first fully self-consistent calculation of this 'Earth-Shadowing' effect, taking into account DM particle deflection and assuming the most general DM-nucleus interactions. Remarkably, in some scenarios, Earth-Shadowing can actually *increase* the DM flux, while in others the flux is depleted. I will explore the impact this has on current constraints on light DM and on strongly interacting DM, as well as hinting at some interesting diurnal and directional signatures.

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Looking for the identity of the dark matter in our cosmic neighbourhood

Carlos Frenk[1]

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There are competing claims that the dark matter may have already been discovered through the annihilation of cold dark matter or the decay of warm dark matter. Both hypotheses result in indistinguishable model universes on the large scales probed by temperature anisotropies in the microwave background radiation and the clustering of galaxies. The identity of the dark matter, however, manifests itself in the properties of small, dwarf galaxies. I will discuss predictions from cosmological simulations for the properties of these galaxies for different types of dark matter and discuss whether astronomical observations can, in principle, distinguish amongst them.

Laboratories and Low Background / **57**

Low Background Factilities at CUP

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The IBS Center for Underground Physics in Daejeon, Korea supports a number of low-background rare-event physics experiments including the KIMS-Nai and LZ dark matter searches, the AMoRE double beta decay search, and the NEOS short-baseline reactor-neutrino oscillation experiment. As with all such experiments, reduction of background rates from long-lived radioactive decays and cosmogenic sources is critical to success and is central to almost all aspects of experimental design. By bringing together multiple related collaborations in one center, CUP is in a great position to develop a broad infrastructure for background reduction and radioactivity assay. I will report on the status of assay and background-control facilities at CUP including developments in direct gamma counting, alpha counting, and mass spectroscopy.

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Low background facilities at CUP

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Laboratories and Low Background / **27**

Material screening programme for the LZ experiment

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When constructed, the LZ experiment will represent the most sensitive dark matter detector to date. In order to reach this sensitivity, the selection of materials used in construction is of paramount importance. The LZ collaboration has developed a wide ranging suite of materials screening instruments in both the US and the UK to characterise the intrinsic radioactivity of all components that will be used in the experiment. This assay programme includes screening for both fixed (U,Th,K) and

mobile (Rn) contaminants in materials. It is through the variety of techniques used and the number of instruments available that we will be able to fully understand and minimise the radioactive backgrounds from materials in LZ.

This talk will give an overview of the LZ screening facilities and will discuss recent assay results of some of the larger items (including the identification of the lowest background titanium assayed to date) that will be used in the construction of the LZ experiment.

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Material screening programme for the LZ experiment

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Noble Gas / 73

Measurement of the absolute reflectance of PTFE immersed in liquid xenon

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The response of a liquid xenon (LXe) detector based on scintillation is strongly dependent on the light collection efficiency, which in turn is critically dependent on the reflectance of the surfaces that surround the active volume. To improve the light collection in WIMP-search detectors using LXe as the sensitive medium, the active volume is usually surrounded by polytetrafluoroethylene (PTFE) reflector panels, used due to its very high bi-hemispherical reflectance (BHR) – even at the short wavelength ($\lambda = 178$ nm) scintillation light of LXe. Data are available in the literature for the reflectance of PTFE in gas or in vacuum for wavelengths above 175 nm (up to 2500 nm). Nevertheless, extrapolations using these data for the reflectance of PTFE when immersed in LXe are systematically lower than those obtained indirectly by comparing Monte Carlo simulations with the calibration data from detectors such as LUX, ZEPLIN-II and XENON-10.

In this work, which contributed to the overall R&D effort towards the LUX-ZEPLIN (LZ) experiment, we present experimental results obtained with a dedicated setup for the absolute reflectance of three different PTFE samples (including the material used in LUX) when immersed in LXe. These results confirm that very high BHR values ($\geq 97\%$) can be achieved, enabling very low energy thresholds in these detectors.

Laboratories and Low Background / 26

Measurement of the tritium background in the EDELWEISS-III germanium detectors

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The EDELWEISS collaboration has operated an array of 24 germanium detectors, with the objective of performing a low WIMP mass search with a total exposure close to 3000 kgd. The experiment is located in the Laboratoire Souterrain de Modane (LSM) and protected by an overburden of rock of 1800m (4800 mwe) that reduces the cosmic ray flux down to 5 μ/m2/d.
The energy resolutions achieved with these detectors and the reduction of the external gamma-ray background have made possible for the first time to measure the intensity of the tritium spectrum in germanium detectors. I will describe the aspects of the EDELWEISS-III setup relevant for the measurement, along with the data selection and its analysis. The results will be presented and interpreted in terms of tritium production by cosmic rays.

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Measurement of the tritium background in the EDELWEISS-III germanium detectors

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Axion / **128**

Microbulk Micromegas as x-ray detectors for axion searches in IAXO

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The International Axion Observatory (IAXO) is a proposed 4th generation axion helioscope that will look for axions and ALPs originating in the Sun via the Primakoff conversion of the solar plasma photons. The baseline detection technique for IAXO are ultra-low background Time Projection Chambers (TPC) with a thin window for the entrance of x-rays and pixelated Micromegas readout, manufactured with the microbulk technique. We will describe the latest results with one such detector in the IAXO pathfinder detection system in operation at the CERN Axion Solar Telescope (CAST), where it has been combined with an x-ray telescope. The prospects to reach levels of background below 10^-7 c/keV/cm2/s needed for IAXO will be discussed, to be demonstrated by a prototype detector and shielding that is now under construction at the Zaragoza University. This activity is part of the IAXO-D0 project to prove the detector experimental parameters for IAXO.

Axion / **194**

Monodromy Dark Matter

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Light pseudo-Nambu-Goldstone bosons (pNGBs) such as, e.g. axion-like particles, that are non-thermally produced via the misalignment mechanism are promising dark matter candidates. An important feature of pNGBs is their periodic potential, whose scale of periodicity controls all their couplings. As a consequence of the periodicity the maximal potential energy is limited and, hence, producing the observed dark matter density poses significant constraints on the allowed masses and couplings.
In the presence of a monodromy, the field range as well as the range of the potential can be significantly extended.
As we argue in this paper this has important phenomenological consequences. The constraints on the masses and couplings are ameliorated and couplings to Standard Model particles could be significantly stronger, thereby opening up considerable experimental opportunities.
Yet, monodromy models can also give rise to new and qualitatively different features. As a remnant of the periodicity, the potential can feature pronounced “wiggles”. When the field is passing through them quantum fluctuations are enhanced and particles with non-vanishing momentum are produced. Here, we perform a first analysis of this effect and delineate under which circumstances this becomes important.

Laboratories and Low Background / **188**

Muon backgrounds at underground laboratories

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NEWAGE direction-sensitve direct dark matter search

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NEWAGE is a direction-sensitive direct dark matter search experiment. NEWAGE uses a micro-TPC with a detection volume of 30 by 30 by 40 cm^3 read by one of the MPGD variations, \mu-PIC. We have been performing underground measurement since 2013 with a new detector NEWAGE-0.3b’. We published the best direction-sensitive limits in PTEP (2015) 043F01s with 30 days’ live time data. We continued the measurement and the results from half-a-year data will be presented.
In order to improve the sensitivities, we are developing a low-radioactive \mu-PIC and a negative-ion TPC. These recent activities to improve the sensitivity will also be reported.

Low Mass WIMP Searches / **108**

NEWS (New Experiment With Sphere)

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The NEWS (New Experiment With Sphere) collaboration look for the low energy events using spherical gaseous detectors. The main characteristics of this detector are: low energy threshold (≈10's of eV) and the possibility to use large range of target mass, from helium to xenon. I will present experimental set-up and results of calibration run taken by the Sedine detector, a low background prototype, installed at the Laboratoire Souterrain de Modane (LSM). I will also present the main feature of the detector NEWS, which will be installed at Snolab next year.

Directional / **65**

NITEC: a Negative Ion Time Expansion Chamber for directional Dark Matter searches

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We will present an R&D project for the realization of an original and innovative detector for directional Dark Matter searches, that will combine the advantages of a Negative Ions Time Projection Chamber (NITPC) with the benefits of triple GEM amplification and pixelated readout (GEMPix). In a NITPC, negative ions drift rather than free electrons, drastically reducing diffusion thanks to their higher mass. This is why we want to combine for the first time this concept with one of the most advanced readout: the GEMPix, a triple GEM detector coupled to a Medipix ASIC board, able to provide excellent spatial, energy and time resolutions, developed by LNF. Its sensitivity to single ionization cluster could allow the NITPC, together with the slow motion of the anions, to function effectively as a Time Expansion Chamber, hence NITEC, providing improved position and energy resolution. We will present preliminary measurements of NITEC performances with common electron-drift gas mixtures (Ar:CO2 and Ar:CO2:CF4) and the first negative ion operation with SF6 (Ar:CO2:SF6 mixture).

Theory / **19**

Neutralino dark matter at TeV scale revisited

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In this talk we will discuss the relic density and indirect signals from CRs and diffuse gamma rays of TeV-scale neutralino dark matter in the pMSSM. A recently developed framework enables us to calculate the Sommerfeld-enhanced relic density in general MSSM scenarios, properly treating mixed states and multiple co-annihilating channels as well as including off-diagonal contributions. We will present the results of a thorough investigation of certain regions of parameter space, focussing in particular on departures from the well known pure wino scenario: namely the effect of sfermion masses being non-decoupled and of allowing non-negligible higgsino or bino components in the lightest neutralino. The results reveal a number of phenomenologically interesting but up

to now unexplored regions of parameter space. Near the regime where the Sommerfeld enhancement is resonant the combined effect of non-decoupled sfermions and non-negligible mixing allows the close-to-wino neutralino to satisfy the diffuse gamma-ray constraints, simultaneously having correct thermal relic density and improving the fits to the AMS-02 antiproton data.

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Neutrino physics with dark matter detectors

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I will discuss the prospects for separating dark matter and neutrino interactions in direct searches, and for using these searches to study the properties of neutrinos and their astrophysical sources.

Axion / 96

New method for setting a bound on the product from 14.4 keV solar axions

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Co-author(s): Dawei Li [1] ; Frank Avignone [1]

[1] *University of South Carolina*

Axions coupled to quarks can be produced in the solar core by the decay of thermally excited nuclear states. Here we consider 14.4 keV axions from Fe-56 detected by coherent Bragg-Primakoff conversion to x-rays in crystals. The locus of points that satisfy the Bragg condition lie on a set of circles, one for each reciprocal vector, on the celestial sphere, and as the path of the Sun crosses one of these circles conversion of axions to x-rays is possible. The time over which the Bragg condition is satisfied is determined by the angular size of the solar core, and is on the order of a minute. The unique timing of events effectively increases the signal to background ratio by a factor of 1000 or more. We expect that and accurately oriented detector like CUORE operating for one year could set a bound $g_{an}g_{a\gamma\gamma} < 10^{-18}\text{GeV}^{-1}$.

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New results on low mass WIMPs search with the EDELWEISS-III experiment.

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The EDELWEISS-III experiment, located in the low background environment, the Frejus laboratory, used an array of twenty-four 800g detectors to search directly the Dark Matter under the form of

WIMPs. Data have been taken during 8 month with these heat-and-ionization cryogenic detectors fully covered with interleaved electrodes to improve the near surface events rejection.

We present the limits on the spin-independent WIMP-nucleon cross-section for WIMP mass below 30 GeV from a fiducial exposure of 582 kg.d. The results represent a factor 10 to 40 improvement relative to EDELWEISS-II, due in part to the experimental resolutions that made possible a reduction of the analysis threshold down to 2.5 keV.

We also present the current developments aimed at making the experiment to be more sensitive to WIMP mass in the range 1 to 15 GeV with the use of Luke-Neganov amplification.

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New techniques for a wicked problem: Indirect dark matter searches with photons

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I will present several new methods that we currently employ to make progress in indirect dark matter searches. (1) A wavelet fluctuation analysis of gamma-ray data from the inner Galaxy. Using this method we find strong support for the millisecond pulsar (MSP) hypothesis of the Fermi GeV excess in the Galactic bulge. I will discuss ongoing efforts and plans to search for new pulsar populations with VLA, GBT and MeerKAT. (2) A new approach to model the Galactic diffuse gamma-ray emission with SkyFACT (Sky Factorization with Adaptive Constrained Templates). This new tool allows a rapid fit with hundred thousand of parameters, which are required to adequately describe the gamma-ray data down to the shot noise level. I will show preliminary results on the GeV excess and low-latitude emission of the Fermi bubbles. (3) Differential Fisher Information. I will discuss an agnostic top-down approach to strategy development in indirect dark matter searches, based on a full-sky Fisher forecast.

Directional / 8

Nuclear Emulsions for WIMP Search (NEWS)

Nowadays there is compelling evidence for the existence of dark matter in the Universe. A general consensus has been expressed on the need for a directional sensitive detector to confirm, with a complementary approach, the candidates found in “conventional” searches and to finally extend their sensitivity beyond the limit of neutrino-induced background. We propose here the use of a detector based on nuclear emulsions to measure the direction of WIMP-induced nuclear recoils. The production of nuclear emulsion films with nanometric grains has been recently established. Several measurement campaigns have demonstrated the capability of detecting sub-micrometric tracks left by low energy ions in such emulsion films with nanometric grains. Innovative analysis technologies with fully automated optical microscopes have made it possible to achieve the track reconstruction for path lengths down to one hundred nanometres and there are good prospects to further exceed this limit. The detector concept we propose foresees the use of a bulk of nuclear emulsion films surrounded by a shield from environmental radioactivity, to be placed on an equatorial telescope in order to cancel out the effect of the Earth rotation, thus keeping the detector at a fixed orientation toward the expected direction of galactic WIMPs. We report the performances and the schedule of the NEWS experiment, with its one-kilogram mass pilot experiment, aiming at delivering the first results on the time scale of five years.

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Overview and status of LUX-ZEPLIN

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The LUX-ZEPLIN (LZ) experiment is a Generation 2 multi-tonne dark matter direct detection experiment that will operate 4850 feet underground at the Sanford Underground Research Facility in Lead, South Dakota. It will use a 7 tonne liquid xenon TPC to search for the low energy recoils of xenon nuclei as they collide with our local galactic dark matter. LZ builds upon the demonstrated response to ~few keV nuclear recoils and the excellent self-shielding properties of liquid xenon and scales the TPC design beyond all existing and underway experiments. In addition, an optically separated and instrumented xenon skin layer (between the inner TPC and the walls of the cryostat) and a surrounding external liquid scintillator detector provide powerful rejection of gamma-rays and neutrons from internal sources. Materials screening and in-house purification of the liquid xenon then ensure that LZ meets the strict radioactivity constraints needed to achieve a WIMP search sensitivity to a spin independent cross section of 3E-48 cm^2 (at 40 GeV/c^2). With the construction phase well underway, LZ is on course to start physics data taking in 2020. In this talk I will give an overview of LZ, discuss the physics reach for both WIMPs and other non-WIMP signals, and present the current status of the experiment.

Summary:

Overview talk on behalf of the LUX-ZEPLIN collaboration.

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Overview of Axion Searches

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Axions are well motivated both by particle phenomenlogy and by the dark matter problem, In this talk, I will survey the key techniques and experiments currently searching for evidence of axions in our galactic halo, originating from the sun, or produced in the lab, and the effort to probe the wider parameter space of axion–like particles. Finally, I consider some possible future directions in the continuing quest to shed light on this interesting sector.

Summary:

An overview of the current state of play in experimental searches for axions and axion-like particles

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Overview of Dark Matter Searches with the Fermi-LAT

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Approaching its 8th year of operation, the Fermi Large Area Telescope (LAT) provides a window to study potential dark matter (DM) gamma-ray processes with unprecedented sensitivity. Lacking any significant detections, it has yielded important limits on the nature of the DM particle, even beginning to challenge the paradigm of thermally-produced weakly interacting massive particle (WIMP) DM. The state of LAT constraints on WIMP and other DM candidates will be reviewed, along with the most promising potential signals, observations of newly discovered DM targets, and projections for future LAT Collaboration analyses.

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PandaX-II 500kg Liquid Xenon Dark Matter Exp in Jinping, China

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PandaX-II 500kg liquid xenon dark matter experiment in Jinping, China has been running since spring 2016. In this talk, I will describe the experiment, the result of the first physics commissioning run, and the future plan of the experiment.

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Particle dark matter: what it is and how to determine its properties

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Among several WIMP candidates for dark matter, a supersymmetric neutralino with mass around 1 TeV and well defined properties (higgsino-like) has emerged as an attractive and natural candidate in light of measured Higgs boson properties and ensuing implications for supersymmetry. On the other hand, for a wide range of WIMPs, if a dark matter signal is measured in direct or indirect search experiments, or both, working out ensuing WIMP properties may prove to be rather challenging.

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Physics Case for Axion or ALP Dark Matter

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Axions and axion-like particles (ALPs) may be non-thermally produced in the early universe and survive as constituents of dark matter. We describe their theoretical motivation and their phenomenology. A huge region in parameter space spanned by their couplings to the Standard Model particles and their masses can give rise to the observed cold dark matter abundance.

Laboratories and Low Background / 124

Planning for underground sites in Korea

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The status of underground activities of Y2L in Korea is reviewed. And a new underground laboratory is planned at an active iron mine. A plan for the underground laboratory will be explained with the facilities under consideration.

Theory / 22

Plasma dark matter direct detection

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Dark matter might exist in the Milky Way as a dark plasma. Such dark matter arises in models where dark matter originates from a hidden sector featuring a massless 'dark photon', including mirror dark matter. In such a scenario, the implications for direct detection experiments are very different from the more commonly studied case of WIMP dark matter. In particular electron recoils can be the dominant process leading to keV energy depositions in detectors. In addition, large annual modulation and sidereal daily modulation signals become characteristic features of such dark matter. The possibility that plasma dark matter might be the origin of the DAMA annual modulation signal is also discussed, along with the expectations of what might be expected in the near future from other experiments.

This work is based on recent work including: arXiv:1512.06471 (in collaboration with J. Clarke), arXiv:1412.0762 (in collaboration with S. Vagnozzi), arXiv:1407.4213.

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Position Reconstruction in the DEAP-3600 Detector

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DEAP-3600 is a single phase liquid argon dark matter experiment, based at SNOLAB, in Sudbury, Ontario. A sensitivity to spin-independent WIMP-nucleon interactions at a cross section of 10-46cm2 is projected at 100GeV WIMP mass. This poster discusses the position reconstruction algorithms in DEAP-3600. Event reconstruction is designed for a spherical liquid scintillator detector with PMTs arranged for 4π coverage. Detector simulation is used to parametrise the variation of expected event topology in charge and time with position and energy, and the difference between observed and expected topology is minimised during event reconstruction. The algorithms are benchmarked using data taken during detector commissioning.

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Prediction of the existence of an other Universe which may correlate with WMAP data and supported by Planck measurements

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In our preceding publication we have provided an improved symmetric model of DWT for Big Bang and investigated how it fits to experimental findings. We have concluded that the visible, dark, total matter and dark energy content ratios in percentages of the world are 5, 21, 26, 74.These theoretical predictions having 15% relative deviation fit to the WMAP data (5,22,27,73).
Taking into account the Planck experimental data for CMB power spectra we can see a more asymmetric scenario. To achieve better fit we have to suppose a double Big Bang event where our Universe and with about 1/3 total energy content an other smaller one universe was created. These considerations provide in our model the ratios of 6, 24, 32, 68 for visible, dark matter, matter and dark energy, respectively.
The Planck experimental data from CMB power spectra are 5, 27, 32, 68 percents, respectively. If there were no other universe emitted in Big Bang the experiemental ratios would be by our model: 5-6, 15-18, 20-24, 76-80 percents, respectively. We can say that already WMAP data showed slight indication for the presence of an other universe in Big Bang, but the more accurate Planck measurements emphasized this possibility.
Recently we do not observe an other universe in our one, they most probably had separated during the inflationary process. Taking into account an other independent measurement for thermal fluctuation distribution of CMB provides further support of our prediction and may provide additional details of the born of the other baby universe. The anomalous temperature fluctuation spectra of WMAP were supported by more accurate measurements of Planck experiment. It is the existence of a warmer region in the Southern Hemisphere with a Cold Spot. This is also in strong coincidence with our theoretical prediction of existence an other Universe, which we call VILLAZ.
Even these findings tell us that in the Eridanus super void direction can be the region of the overlapping merge of the two universes before the smaller one left our one and took some small material of which remnant is the Eridanus super void with smaller temperature. This can indicate that supposing simultaneos birth the smaller universe could became more supercooled during inflation or gravitation atttraction also could play role when disconnected our larger universe leaving a void in the structure. The void was about 3 % of our Universe and 8% energy-matter contribution to the other universe. If this concern is right the VILLAZ already left our universe during inflation process. The warmer region can be explained by the heating effect of merging of two universes during the Inflation epoch. In case of simutaneous origin this phenomenon helps to get some specific ideas for the initial conditions of the Bigbang. In this case we get 5 % and 26 % and 32 % and 68 % for the characteristic data in good agreement with Planck measurements. A double Big Bang can be interesting to discuss in the frame of the Inflation scenario.

Neutrinos and Dark Sector / 168

Present and Future Observations of the 3.5 keV Line

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I summarize recent constraints on dark matter candidate particles that produce X-ray emission lines, with an emphasis on the sterile neutrino. This includes a discussion of the candidate dark matter feature at ~3.55 keV discovered by stacking XMM-Newton spectrum of 73 galaxy clusters — a method that minimizes statistical and systematic uncertainties. The implications for identifying the dark matter particle and for physics beyond the Standard Model are discussed. I also indicate the uncertainties and caveats that remain with respect to the significance of the line and its interpretation as originating from dark matter decay. I look forward to future work that can narrow down the possible interpretations.

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Primordial Black Holes

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Primordial black holes are black holes that may have formed in the early Universe. Their masses span potentially a range from as low as the Planck mass up to many orders of magnitude above the solar mass. Besides their conceptual importance regarding our understanding of quantum effects and gravity, they may provide the dark matter. In order to constrain this possibility, a proper understanding of their formation mechanism is crucial. In my talk, after a general introduction on primordial black holes, I will discuss recent investigations on this issue, including so-called critical collapse, non-sphericity and non-Gaussianity. Furthermore, I will discuss how to properly compare extended primordial black-hole mass spectra to observational constraints, such as those deriving from recent microlensing surveys.

Indirect Detection / 126

Probing dim point sources in the inner Milky Way using PCAT

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Poisson regression of the Fermi-LAT data in the inner Milky Way reveals an extended gamma-ray excess. The anomalous emission falls steeply away from the galactic center and has an energy spectrum that peaks at 1-3 GeV. An important question is whether the signal is coming from a collection of unresolved point sources, possibly old recycled pulsars, or constitutes a truly diffuse emission component. Previous analyses have relied on non-Poissonian template fits or wavelet decomposition of the Fermi-LAT data, which find evidence for a population of dim point sources just below the 3FGL flux limit. In order to be able to draw conclusions about the flux distribution of point sources at the dim end, we employ a Bayesian trans-dimensional MCMC framework by taking samples from the space of catalogs consistent with the observed gamma-ray emission in the inner Milky Way. The software implementation, PCAT (Probabilistic Cataloger), is designed to efficiently explore that catalog space in the crowded field limit such as in the galactic plane, where the model PSF, point source positions and fluxes are highly degenerate. We thus generate fair realizations of the underlying MSP population in the inner galaxy and constrain the population characteristics such as the radial and flux distribution of such sources.

Axion / **79**

Progress on the ARIADNE axion NMR experiment

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The Axion Resonant InterAction Detection Experiment (ARIADNE) is a collaborative effort to search for short-range spin-dependent couplings between nuclei resulting from the QCD axion, using a technique based on nuclear magnetic resonance. The aim is to detect monopole-dipole interactions between the spin of 3He nuclei and a rotating unpolarized tungsten attractor. I will discuss the basic principle of the experiment and the current experimental status, as well as several of the anticipated technical challenges.

Indirect Detection / **165**

Prospects for Indirect Dark Matter Searches with Hyper-Kamiokande

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The Hyper-Kamiokande experiment is a proposed next-generation water Cherenkov detector. It will consist of two cylindrical tanks, with a fiducial volume of 400 ktonnes, observed by 20 inch high quantum efficiency PMTs with 40% photocathode coverage. Hyper-K will be able to perform indirect WIMP searches, looking for signals from the Sun, the Earth, and the galactic centre. In such areas, WIMPs can be trapped by gravitational potentials and annihilate on other WIMPs. Such annihilations produce neutrinos that can be observed by Hyper-K as an excess above that which is expected from atmospheric neutrinos. Hyper-K will improve the sensitivity of such indirect WIMP searches above the limits that have already been obtained by Super-Kamiokande. Additionally, the high photocoverage gives Hyper-K excellent sensitivity to the low momentum region and low mass WIMPs.

Laboratories and Low Background / 51

Radon Monitoring and Mitigation

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For rare event searches, the control of inherent backgrounds is essential. Radon remains one of the most prevalent and crucial of these backgrounds for both operating and planned experiments. In this talk I will discuss some of the on-going efforts to monitor and mitigate the impact of radon looking towards a next generation of detectors.

Laboratories and Low Background / 91

Radon Screening for Low Background Experiments

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Radon is a big source of background for many experiments in particle physics, such as searches for dark matter. The facility at Sheffield has undergone recent improvements to the radon screening sensitivity. This will be discussed along with some recent work with Durridge to improve the background from the RAD7 radon detector used in the screening system.

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Radon monitoring and mitigation

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Radon screening for low background experiments

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Radon is a big source of background for many experiments in particle physics, such as searches for dark matter. The facility at Sheffield has undergone recent improvements to the radon screening sensitivity. This will be discussed along with some recent work with Durridge to improve the background from the RAD7 radon detector used in the screening system.

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Recent Results from DarkSide-50

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The DarkSide-50 dark matter detector is a two-phase argon TPC installed at Laboratori Nazionali del Gran Sasso at the center of two nested veto detectors, a 30-tonne liquid scintillator neutron veto and a 1,000-tonne water Cherenkov muon veto. While operating in 2014 with a fill of argon extracted from the atmosphere, DarkSide-50 demonstrated its capability to operate in a background-free mode even in presence of the strong radioactive background due to the 39Ar isotope. Today DarkSide-50 is the only noble liquid dark matter detector operating in background-free mode. In 2015 DarkSide was filled with 150 kg of argon extracted from deep underground reservoirs, allowing DarkSide-50 to make the most sensitive measurement of the 39Ar activity in underground argon. This underground argon was then used to set the strongest WIMP dark matter limit using liquid argon, to date. Overviews of the DarkSide program and of the recent results from DarkSide-50 will be presented, as well as plans for next a generation dual-phase liquid argon TPC.

Low Mass WIMP Searches / 97

Recent results and prospects of CDEX at the China JinPing Underground Laboratory

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The CDEX Collaboration has been pursuing a research program on low mass dark matter searches at the China JinPing Underground Laboratory, located in Sichuan, China, with about 2400 m of rock overburden. We report on the results of low mass WIMPs and axion-like particles searches with a p-type point-contact germanium detector. The exclusion constraints on the WIMP-nucleon spin-independent and spin-dependent coupling as well as solar axion and axion-like particles are derived based on 335.6 kg-day of data from CDEX-1. The experimental details and CDEX-10 program will be described. Some research activities including germanium detector fabrication, crystal growth as well as low-noise low-background electronics, coupled with underground site, towards the goals of the direct detection of light WIMPs and double beta decay experiment will be discussed.

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Recent results from XMASS

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1. Detector Characteristics

2. Signal Sensitivity
3. Background
4. Results on Dark Matter Searches using nuclear recoils and e/¥$gamma$ signals

Summary:

XMASS is a single phase liquid xenon detector primarily aiming to detect dark matter particles. Total mass of the detector is about 850 kg and surrounded by 642 low background PMTs. The amount of the lights detected is 14¥sim15 pe/keV. XMASS is sensitive not only to nuclear recoils but also to e/¥$gamma$ signals.
Results on searches for the low mass WIMPs by a modulation analysis and for other dark matter candidates will be presented. Those searches based on the e/¥$gamma$ signals demonstrate the diversity and advantage of the XMASS experiment.

The sensitivity of the future detector, called XMASS1.5 with 6 ton total and 3 ton fiducial mass, will also be discussed.

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Recent status of the China Jinping Underground Laboratory (CJPL)

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China JinPing Underground Laboratory (CJPL) is the deepest operational underground laboratory in the world which has about 2400 m of rock overburden, an excellent facility for conducting low event-rate experiments. Two DM experiments (CDEX and PandaX) run in and competitive physical results have been published. CJPL-II laboratory is under construction which the hall volume is about 24 times more than the CJPL-I and will be finished by the end of 2016. We will present an overview of CJPL-I and the recent development of CJPL-II. Some possible users of CJPL-II space in the future will be discussed, including DM, DBD, Neutrino, Astroparticle physics, as well as the interdisciplinary researches.

Directional / **6**

Recoil Directionality Studies in Two-Phase Liquid Argon TPC Detectors

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Projects attempting the direct detection of WIMP dark matter share the common problem of eliminating sources of background or using techniques to distinguish background events from true signals. Although experiments such as DarkSide have achieved essentially background free exposures through careful choice of materials and application of efficient veto techniques, there will still be a high burden of proof to convince the greater scientific community when a discovery is claimed. A directional signature in the data would provide extremely strong evidence to distinguish a true WIMP signal from that of an isotropic background. Two-phase liquid argon time projection chambers provide an experimental apparatus which can both be scaled to the ton-scale size required to accommodate the low cross-section expected for WIMP interactions and have an anisotropy that

could be exploited to evaluate the polar angles of the resulting nuclear recoils from WIMP collisions with target atoms. Two signals are acquired for each event: prompt scintillation light in the liquid argon (S1), and a second signal (S2) produced by electrons created along the recoil track which are drifted upward by a uniform electric field and extracted to the gas phase. Electrons which quickly recombine with ions contribute to the S1 signal, while those that escape contribute to S2. The efficiency of recombination and thus the ratio of ionization to scintillation light depends on the angle between the nuclear recoil and the electric field of the TPC. The ReD project at Università di Napoli Federico II will use a small novel Geiger avalanche photo-diode time projection chamber to study and calibrate the potential of polar angle sensitivity in liquid argon with mono-energetic neutrons. SiPMs will be used in place of PMTs to improve light collection efficiency and spatial resolution. The recoil energy will be assessed by detecting the scattered neutrons with liquid scintillator counters placed at angles of interest. If a directional effect exists, then recoils with the same energy but different initial polar angles relative to the electric field should show different ratios of scintillation and ionization light.

Other Techniques / **150**

Reinventing the Bubble Chamber: A New Design for PICO-40L and PICO-500

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The PICO collaboration has made significant progress in our understanding of the anomalous background events observed in bubble chamber dark matter searches. It is now understood that the background events are intrinsic to the technology, arising from the use of a normal fluid buffer layer to stabilize the surface of the superheated liquid in the bubble chamber. A new, simplified bubble chamber design has been developed that eliminates the use of a buffer liquid and is expected to eliminate the anomalous background events entirely. Plans, status, and projected dark matter sensitivity will be presented for a 40 liter demonstration device currently under construction and for the proposed PICO-500 bubble chamber.

Axion / **164**

Results from the CASCADE microwave light shining through a wall experiment

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Co-author(s): Graeme Burt [1] ; Matti Kalliokoski [2] ; Nathan Woollett [1] ; Peter Williams [3] ; Swapan Chattopadhyay [4]

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Light shining through a wall experiments can be used to make measurements of photon-WISP couplings. The first stage of the CASCADE experiment at the Cockcroft Institute of Accelerator Science and Technology is intended to be a proof-of-principle experiment utilising standard microwave

technologies to make a modular, cryogenic HSP detector to take advantage of future high-power superconducting cavity tests. This talk presents the latest results of the CASCADE LSW experiment showing a peak expected exclusion of approximately 1×10^{-8} in the mass range from 1.96μeV to 5.38μeV, exceeding current limits. Near-field effects are also discussed.

Annual Modulation / **135**

Results from the DM-Ice17

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Astrophysical observations give overwhelming evidence for the existence of dark matter. While the DAMA collaboration has asserted that they observe a dark matter-induced annual modulation signal, other direct detection dark matter experiments have yet to confirm this observation. DM-Ice17, a prototype experiment consisting of 17kg of NaI(Tl) detectors, has been continuously operating at the South Pole for over 4 years demonstrating the feasibility of a low-background experiment in the Antarctic ice. The results from DM-Ice17 and future prospects for DM-Ice will be presented.

Indirect Detection / **114**

Revealing the nature of dark matter with Milky Way dwarf satellite galaxies

Author(s): Mei-Yu Wang[1]

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The dwarf galaxies surrounding the Milky Way provide a unique and powerful way to explore the nature of dark matter. They are the most extreme dark matter dominated objects known to us with central mass to light ratios typically of the order of tens to hundreds. Through measurements of their stellar kinematics, we can study their dark matter content in exquisite precision. This allows us to probes their halo structure that is sensitive to different dark matter physics such as warm dark matter, self-interaction, and decay instabilities. In this talk, we present frameworks that address these questions by combining high-precision stellar kinematic measurements with state-of-art cosmological N-body simulations and detailed kinematic modeling. We demonstrate that the properties of the dark matter are linked to the mechanisms that drive satellite galaxy and halo evolution such as infall time and the effects of tides. In the CDM scenario some dwarf galaxies explicitly require to be shaped under significant gravitational tidal forces, which will leave imprints on their stellar distribution and kinematics. We also determine the optimized kinematic observational strategies for achieving precision measurement of dark matter contents in newly discovered faint dwarf galaxies with current and future spectroscopic follow-up facilities, and forecast their constraining power on

WIMP dark matter models. We discuss how these results are driving advances in both astronomy and particle physics, and having the potential to shed lights on the nature of dark matter.

Other Techniques / **141**

Run II of the PICO 60 experiment

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PICO 60 is a 32 litre bubble chamber for dark matter search that was operated with 38kg CF_3I in until May 2014. In summer 2016 PICO 60 was refilled with C_3F_8 and is currently being operated at SNOLAB. Between the first and second run new a water system, an internal filtration system and a refurbished muon veto system were added to the detector. The detector is now read out by four fast cameras which enabled to fill the detector to full active liquid capacity for the first time. In addition, a new 32 litre fused silica vessel was cleaned, verified and installed in the hope of mitigating the particulate related background observed in the previous run of PICO 60. A status report and updated sensitivity projections will be shown.

Annual Modulation / **94**

SABRE: WIMP Modulation Detection in the Northern and Southern Hemisphere

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The SABRE (Sodium iodide with Active Background REjection) experiment aims to detect WIMP dark matter by its annual modulation signature. Such a modulation has been measured by the DAMA/LIBRA experiment in NaI(Tl) crystals. However, the interpretation as WIMP signal is controversial due to contradicting results by other experiments with different target materials.

Using an array of high-purity Na(Tl) crystals submerged in an active liquid scintillator veto, SABRE aims to shed light onto the controversy. Twin detectors in the northern hemisphere (LNGS, same as DAMA) and southern hemisphere (SUPL, Australia) will reduce systematic effects and allow to study a potential signal in more detail. This talk will give an overview on the experimental design, the current status including progress on crystal growing, and an outlook on future plans.

Neutrinos and Dark Sector / **163**

SBND: Searching for Sterile Neutrinos and More with Fermilab's Short-Baseline Near Detector

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The Short-Baseline Near Detector (SBND) is one of three liquid argon time projection chamber detectors to be situated along the Booster Neutrino Beamline (BNB) at Fermilab and form the Fermilab Short-Baseline Neutrino (SBN) Program. SBND is scheduled to begin operations in 2018. The detector will be situated at merely 110 m from the BNB proton target, which is an ideal location for recording an unprecedentedly large number of neutrino interactions in the energy range of 0.5-1 GeV, and for serving as a high-precision BNB neutrino flux monitor. This is critically necessary for a high-sensitivity search for light (~0.1-10 eV^2) sterile neutrino oscillations that SBND will perform as a part of the Fermilab SBN program. Besides searching for light sterile neutrinos, SBND will also be able to search for light (<1 GeV) dark matter and provide constraints to other exotic physics. This talk will describe the current status of SBND and its physics capabilities.

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SUMMARY and END

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Neutrinos and Dark Sector / **121**

Search for Accelerator-Produced sub-GeV Dark Matter Particles in MiniBooNE

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Cosmological observations indicate that our universe contains dark matter (DM), yet we have no measurements of its microscopic properties. To detect DM with mass below 1GeV, the sensitivity limit of current direct-detection experiments, and one can use accelerators to search for lower mass boosted DM. With high beam intensity and existing neutrino detectors, the Fermilab Booster Neutrino Beamline (BNB) offers this opportunity. One such experiment, MiniBooNE was originally designed to look for electron neutrino appearance signals from muon neutrino beam, and demonstrated high performance to measure neutral current elastic scattering.
In 2014, the BNB was operated to send protons directly to the beam dump which suppresses neutrino flux and allows a low-background search for sub-GeV DM. In this talk, we present analysis techniques, predicted sensitivity, and preliminary results from the DM search of MiniBooNE along some ideas for future DM searches using the BNB.

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Search for dark matter with DEAP-3600

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DEAP-3600 is a single-phase liquid argon detector, which searches for dark matter particle interactions with 1 tonne fiducial target mass (3.6 tonnes total) contained in an ulta-pure acrylic vessel

viewed by 255 high quantum efficiency photomultiplier tubes. It is located 2 km underground at SNOLAB, in Sudbury, Ontario.

Radioactive backgrounds are controlled through pulse-shape discrimination in case of electromagnetic backgrounds (demonstrated with a smaller 7-kg prototype DEAP-1) and with a combination of excellent radiopurity, shielding and fiducialization for neutron and alpha backgrounds.

The target sensitivity to spin-independent scattering of Weakly Interacting Massive Particles (WIMPs) on nucleons of 10^{-46} cm^2 will allow an order of magnitude improvement in sensitivity over current searches at 100 GeV/c^2 WIMP mass.

Commissioning of the DEAP-3600 detector is now complete and physics data taking is starting. This talk will present an overview and status of the project, including early results demonstrating the detector performance.

Neutrinos and Dark Sector / 143

Search for heavy neutral leptons with the near detector complex ND280 of the T2K neutrino experiment at J-PARC

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T2K (Tokai-to-Kamioka) is a second-generation long-baseline accelerator experiment that studies neutrino oscillations using an intense beam of muon neutrinos produced by the the 30 GeV proton synchrotron at J-PARC. The near detector complex ND280 consists of different sub-detectors, including time-projection chambers (TPCs), scintillator tracking detectors and calorimeters, operated inside a magnetic field. The detector thus provides unique tracking capabilities to identify various outgoing products. Hence the presence of the intense neutrino beam from mainly π/K parents combined with ND280 tracking apparatus opens up the possibility to study not only neutrino interactions but to search for "new physics" as well. This talk is focused on the search for the so-called Heavy Neutral Leptons (HNLs, heavy neutrinos) by means of the T2K ND280. HNLs with masses below the electroweak scale are considered in some extensions of the Standard Model (e.g. νMSM) in order to address the present open questions: neutrino oscillations and masses, dark matter and the baryon asymmetry of the Universe. In the mass range of < 500 MeV/c2 these heavy neutrinos can be produced in pion or kaon decays, and further decay themselves into charged particles, hence allowing for their detection in a detector media. Probing the kaon parents' decays allows one to study a wider mass range of heavy neutrinos. By using the TPC volumes (filled with argon gas) to search for heavy neutrino events it is possible to significantly reduce the backgrounds coming from interactions of active neutrinos. A detailed simulation of the HNL flux was performed for the T2K ND280 layout and the detector performance was studied with respect to the reconstruction of heavy neutrino vertices. It is shown that with the current ND280 dataset (~1x1021 POT) one can obtain bounds on the HNL mixing parameters comparable to those of the CERN PS191 experiment, which, together with the BNL E949 data, put the most stringent constrains on HNLs with masses in the range 140 MeV/c2 < mHNL< 450 MeV/c2. Furthermore the T2K ND280 data can be used to improve the current experimental limits in the mass region close to the kaon mass.
In addition the talk will also briefly review the T2K potential for searching for other possible "new physics" signals.

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Search for low-mass WIMPs with CRESST

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The CRESST-III (Cryogenic Rare Event Search with Superconducting Thermometers) experiment, located in the Gran Sasso underground laboratory (LNGS, Italy), aims at the direct detection of dark matter (DM) particles. Scintillating $CaWO_4$ crystals operated as cryogenic detectors are used as target material for elastic DM-nucleus scattering. The simultaneous measurement of the phonon signal from the $CaWO_4$ crystal and the emitted scintillation light in a separate cryogenic light detector is used to discriminate backgrounds from a possible dark matter signal. This technology is particularly sensitive to small energy deposits induced by light dark matter particles, allowing the experiment to probe the low-mass region of the parameter space for spin-independent DM-nucleus scattering with high sensitivity.
Most recent results from the CRESST-II experiment are presented, setting the world best limit for masses < 1.7 GeV/c^2, with an nuclear recoil energy threshold of 307 eV.
In the CRESST-III experiment each detector module consists of a ~ 24 g $CaWO_4$ target crystal and a 20x20 mm2 Silicon-on-Sapphire light detector. This configuration will allow to reach an energy threshold of ~100 eV. In phase 1 of the CRESST-III experiment, 10 detector modules with a total target mass of 240 g will be operated. The experiment is currently in its commissioning phase and data-taking is expected in 2016. The status of the experiment and the projections of the sensitivity on spin-independent DM-nucleus scattering for the current phase and for the future upgrades are also presented.

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Searches for Dark Matter particles at the Large Hadron Collider

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Dark Matter can be produced in large amounts in pp collisions at the Large Hadron Collider (LHC) assuming it interacts non-gravitationally with Standard Model particles. While Dark Matter escapes direct detection at the LHC, it leaves a distinct signature of significant missing transverse momentum. In this talk, recent results from the ATLAS and CMS detectors will be presented, based on events with large missing transverse momentum accompanied by a variety of other objects such as jets, photons, heavy-flavor quarks, weak gauge bosons, or Higgs bosons. These measurements are complementary to those obtained in direct and indirect Dark Matter detection experiments.

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Searching for Signals of Dark Matter in the Gamma-Ray Sky

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Indirect detection experiments, which search for gamma rays produced in dark-matter annihilation or decay, provide a promising avenue for discovering and characterizing the dark matter. I will review the current status of such searches with data from the *Fermi* Large Area Telescope. I will specifically highlight new analysis methods that have helped to shed light on the debate regarding the excess of GeV photons in the Inner Galaxy, and discuss how these methods are currently being used to characterize the dark-matter contributions to the Isotropic Gamma-Ray Background.

Axion / **117**

Searching for ultralight dark matter with atomic spectroscopy and magnetic resonance

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Axions, axion-like particles (ALPs), dilatons, and other ultralight (masses from 10-4 down to 10-23 eV) particles have been discussed as possible candidates for dark matter. An interesting feature of these ideas is that they lead to predictions of potentially observable transient and oscillating effects. I will describe how we are looking for these as well as the relation of such experiments to tests of fundamental
symmetries (P, CP, T, CPT ...). For up-to-date information on our various experiments in this area (CASPEr, GNOME, differential atomic-dysprosium clock, etc.), please refer to the web pages [1,2].

1 https://budker.uni-mainz.de/
http://budker.berkeley.edu/

Summary:

I will talk about new experiments to search for ultralight dark matter.

Indirect Detection / **45**

Signatures of Self-Interacting Dark Matter in the Sun

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Galactic dark matter may scatter on solar nuclei and become captured in the gravitational field of the Sun. I will present our recent and ongoing work on the indirect detection signals arising from the hypothetical solar population of dark matter. The focus of our study is dark matter charged under a hidden U(1)-gauge symmetry.

Directional / **118**

Simplified charge readout technology for a massive directional WIMP search telescope (CYGNUS-TPC)

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Recent computational results suggest that massive directional dark matter detectors have potentials to probe WIMPs beyond the neutrino floor. Even in a case of WIMP detection claim by conventional detectors before the neutrino floor, a proposed massive directional WIMP search telescope called CYGNUS-TPC can be used to unambiguously confirm the source of the signal. Hence, there is a global effort toward building this ton scale directional WIMP search detector with sensitivity to probe these parameter spaces. But one key issue to consider in the design process is the cost and capability of the readout technology to be used. In this talk, WIMP search data obtained with a cubic meter scale directional detector when operated in a simplified readout mode will be presented. The results from this data analysis indicate that simplified readout technology with full detector fiducialisation and 3D track reconstruction at cheaper cost can be used in the design of the CYGNUS-TPC detector.

Laboratories and Low Background / **16**

Simulation of the Electromagnetic Backgrounds in the CRESST-II Experiment

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Many astronomical observations proved that around 27 % of our universe is made up of dark matter. However, the exact nature of it has not been exactly understood. CRESST is one of several experiments dedicated to find dark matter particles through direct detection. CRESST-II detector modules based on scintillating CaWO4 crystals and operated at mK temperatures have the ability to detect light dark matter particles and to actively suppress the dominating beta/gamma backgrounds originating from natural radioactivity and cosmogenic activation. Especially for light dark matter particles generating low recoil energies, the background discrimination is more challenging. Thus, precise knowledge of the background is crucial for this regime.
In this contribution, we will present the status of the Monte-Carlo studies of the electromagnetic background components observed within CRESST-II Phase 2, data taking phase of which has been finished almost a year ago. The results of these studies will be important inputs for the future phases of CRESST, like the upcoming CRESST-III Phase 1, to either detect a dark matter signal or to improve the limits for a null result. In addition, the results of the simulations can be a starting point for future detector developments towards better background suppression.

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Simulation of the electromagnetic backgrounds in the CRESST-II experiment

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Axion / **138**

Status and Future of ADMX

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The Axion Dark Matter eXperiment (ADMX) is a cavity haloscope search for dark matter axions. The Gen 2 version ADMX has the goal of being sensitive to even the pessimistically coupled axions in the well motivated 1-10 GHz frequency region. This will be a significant improvement over previous cavity searches, and have a good chance of discovering the axion, or ruling out an interesting parameter space. I will discuss the ADMX Gen 2 program highlighting recent commissioning, near term-data taking, long term search strategies, and challenges and technologies involved with reaching higher frequencies.

Summary:

The Axion Dark Matter eXperiment (ADMX) is a cavity haloscope search for dark matter axions. The Gen 2 version ADMX has the goal of being sensitive to even the pessimistically coupled axions in the well motivated 1-10 GHz frequency region. This will be a significant improvement over previous cavity searches, and have a good chance of discovering the axion, or ruling out an interesting parameter space. I will discuss the ADMX Gen 2 program highlighting recent commissioning, near term-data taking, long term search strategies, and challenges and technologies involved with reaching higher frequencies.

Annual Modulation / **68**

Status and Prospects of ANAIS-112 at the Canfranc Underground Laboratory

Author(s): María Luisa Sarsa[1]

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The ANAIS (Annual Modulation with NaI(Tl) Scintillators) experiment aims at the confirmation of the DAMA/LIBRA signal using the same target and technique at the Canfranc Underground Laboratory, in Spain. 112.5 kg of ultrapure NaI(Tl) crystals will be used as target, divided into 9 modules, 12.5 kg mass each, and coupled to two high efficiency photomultipliers. Present status and prospects of ANAIS will be reported.

Axion / **169**

Status of ALPS2

Mikhail Karnevskiy[1]

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I will present the status of the ALPS2 experiment, a new search for axion-like particles that builds upon the successes of the original ALPS experiment and increase projected sensitivity to new physics by 3 orders of magnitude.

Axion / **100**

Status of the ADMX-HF Extreme Axion Experiment

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Axions are a leading dark matter candidate, and may be detected by their resonant conversion to a monochromatic RF signal in a tunable microwave cavity permeated by a strong magnetic field. The Axion Dark Matter eXperiment – High Frequency (ADMX-HF) serves both as a innovation platform for cavity and amplifier technologies for the microwave cavity axion experiment, and as a pathfinder for a first look at data in the 20 – 100 μeV (~ 4 – 25 GHz) range. Now named the Extreme Axion Experiment in its operational phase, X3 is a collaboration of Yale University, where the experiment is sited, the University of California Berkeley, Colorado University, and Lawrence Livermore National Laboratory; it is a small but highly capable platform where advanced concepts can be developed and vetted in an operational environment. The experiment is built on a superconducting solenoid magnet (9 T, 17.5 cm ∅ x 40 cm) of high field uniformity, and a dilution refrigerator capable of cooling the cavity and amplifier to 25 mK. In its initial configuration, the microwave cavity is made of high purity electroformed copper, tunable between 3.6 – 5.8 GHz. The cavity is coupled to a Josephson Parametric Amplifier; JPAs are ideally suited for the 5 GHz range, being broadly tunable and exhibiting near-quantum-limited noise temperature. Construction and commissioning was completed in 2015, and the experiment embarked on its first data production run in January 2016, which will conclude this summer. This talk will give an overview of the design and operational experience of the experiment, and a preliminary report on its first data. R&D oriented to significantly increase the sensitivity of the microwave cavity experiment will also be reviewed, including a squeezed-vacuum state receiver, very high-Q cavities, and photonic band-gap resonators. This work was supported under the auspices of the National Science Foundation, under grants PHY-1067242 and PHY-1306729, the Heising-Simons Foundation under grant 2014-182, and the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Annual Modulation / 144

Status of the COSINE experiment

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The KIMS and DM-Ice group under the name of the COSINE collaboration work together to search for nuclear recoils by Weakly Interacting Massive Particle in the NaI(Tl) crystal scintillators at the Yangyang underground laboratory in Korea, targeting at a sensitivity comparable to the DAMA/LIBRA dark matter experiment. The main goal of the COSINE experiment is to confirm or dispute the annual modulation signature claimed by DAMA/LIBRA. The COSINE Phase-I which consists of a total crystal mass of 106~kg submerged in the 2300~liters of scintillating liquid as an additional veto has just begun data-taking. In this presentation, the status of the COSINE experiment including the shielding construction, calibrations and initial detector performance will be discussed.

Directional / 152

Status of the Directional Dark Matter Detector Project (D^3)

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The D^3 project has been investigating gas Time Projection Chambers with charge readout via pixel chips, a candidate technology for future directional Dark Matter searches. We have constructed a number of small prototypes over several years, and are now at a stage where the detectors operate stably over long time scales, and the 3-D ionization distribution from nuclear recoils can be imaged in detail. This enables new background rejection techniques, such as obtaining the absolute position of nuclear recoils from the transverse diffusion of the ionization cloud. I will review the most interesting results to date, and comment on the feasibility of constructing much larger, future detectors, with the ultimate goal of probing WIMP-nucleon cross-sections below the neutrino floor.

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Status of the XENON1T project

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The XENON1T detector has been recently deployed at Laboratori Nazionali del Gran Sasso. The experiment features, as target for dark matter, a two-phase Xenon Time Projection Chamber with a 2-tonne active mass. Its unprecedented dimension and the expected low background will allow XENON1T to reach, with a 2 t·y exposure, a sensitivity to spin-independent WIMP-nucleon interactions of about 1.6·10^-47 cm^2 for a 50 GeV/c^2, an improvement of about two orders of magnitude with respect to its predecessor XENON100. I'll report about the status of the detector commissioning.

Axion / 85

Status, physics case and prospects of the International Axion Observatory (IAXO)

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Axions are a natural consequence of the Peccei-Quinn mechanism, the most compelling solution to the strong-CP problem. Similar axion-like particles (ALPs) also appear in a number of possible extensions of the Standard Model, notably in string theories. Both axions and ALPs are very well motivated candidates for the Dark Matter, and in addition would be copiously produced at the sun's interior. They have been invoked to solve a number of unexplained observations in astrophysics. These particles are object of increasing interest by experimentalists. A relevant effort during the last decade has been the CAST experiment at CERN, the most sensitive axion helioscope to-date. Here I will present a novel initiative born as a large-scale ambitious follow-up of CAST: the International Axion Observatory (IAXO). IAXO will be a fourth generation axion helioscope. As its primary physics goal, IAXO will look for solar axions or ALPs with a signal to background ratio of about 5 orders of magnitude higher than CAST. For this IAXO envisions a large superconducting toroidal magnet designed optimizing the axion helioscope figure of merit, extensive use of x-ray focusing optics and low background x-ray detectors. IAXO will venture deep into unexplored axion parameter space, thus having discovery potential. IAXO has also potential to host additional detection setups. Most interestingly, the large magnetic volume of IAXO could be used to detect relic axion

or ALPs potentially composing the galactic halo of Dark Matter. IAXO has the potential to serve as a multi-purpose facility for generic axion and ALP research in the next decade.

Neutrinos and Dark Sector / 80

Sterile Neutrino Dark Matter Interpretations of the Unidentified 3.5 keV Line

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I will give an overview of the analyses leading to the recent detection of X-rays from clusters of galaxies and Andromeda consistent with monoenergetic photons from dark matter decay such as that predicted from sterile neutrino dark matter. I shall discuss these signals' potential verification in the very near future. Sterile neutrino dark matter interpretations have implications for outstanding problems in galaxy formation. The direct detection of sterile neutrino dark matter would require novel methods.

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Strategies for a directional detection of Dark Matter.

Author(s): Camille Couturier[1] ; Daniel Santos[1]

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The directional detection of Dark Matter (DM) proposes to use the existing anisotropy in the angular distribution of the DM-induced recoils in the galactic coordinates to distinguish it from mostly isotropic background. This anisotropy arises naturally from the relative motion of the Solar system within the DM halo.
Several techniques have been proposed for a directional detection, including emulsion plates, crystal scintillators, low-pressure gaseous TPCs, columnar recombination in high-pressure gaseous Xenon TPCs, solid-state detectors, DNA-based detectors and graphene-based heterostructures.
After a brief review of these strategies, we will discuss the motion of an ion recoiling due to the elastic scattering by a DM particle. Monte-Carlo simulations can be used to emulate this motion in different sensing materials. We propose a new figure of merit to measure the preservation of the initial direction information in a given detecting material, allowing a quantitative comparison of the different directional detection strategies.

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Stretching the WIMP paradigm: Direct detection techniques for light-weight WIMPs.

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A review of the current technologies for reducing the energy threshold of direct detection dark matter experiments, with special emphasis on solid state detectors. The goal of this field over the next decade is to reach the neutrino floor in all mass ranges, but doing so for masses less than a GeV/c2 is not only hard, but also stretches the definition of the WIMP candidate. Both established experiments and dedicated low-mass searches are discovering new methods for discriminating and reducing backgrounds. This effort, coupled with lower energy thresholds, are making inroads in this difficult region.

Directional / **63**

Studies on ZnWO4 crystals for the direction-sensitive dark matter search

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As it was reported that ZnWO4 scintillator has the directional sensitivity, we had started to study on ZnWO4 for the dark matter search. To begin with, we investigated responses to alpha particles and measured the wavelength and the decay constant of the scintillation light using a (2mm)^3 crystal. Then we are investigating a (9mm)^3 crystal and some (1cm)^3 crystals. We also mention some plans for making larger crystals and another types of crystals.

Noble Gas / **134**

Supernova Neutrino Physics with Xenon Dark Matter Detectors: A Timely Perspective

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Dark matter detectors using liquid xenon have reached the tonne-scale with XENON1T, giving them good sensitivity to supernova (SN) neutrino signals via coherent elastic neutrino-nucleus scattering. We perform an S2-only analysis of the expected supernova neutrino signal for four different SN progenitors with different masses and nuclear equations of state in existing and upcoming dual-phase xenon experiments. We show that a SN burst can be detected at more than 5 sigma significance up to 25 kpc, 40 kpc and 70 kpc from Earth for XENON1T, XENONnT/LZ and DARWIN sized detectors. We also show that the SN neutrino light curve, neutrino differential flux and total energy emitted into neutrinos can be reconstructed with small error bars. As xenon detectors are sensitive to all neutrino flavours, they provide complementarity information to traditional neutrino detectors that are sensitive to a single flavour.

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TPC monitoring sensors for LUX-ZEPLIN dark matter experiment

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One of the experimental techniques used for the direct detection of dark matter with noble liquids is the two-phase liquid/gas time projection chamber (TPC). In order to achieve optimal discrimination between nuclear and electron recoils in WIMP searches, large experiments have found it increasingly important to monitor continuously and precisely the detector operating conditions including liquid level, physical position, and both acoustic and electromagnetic environments. In the LUX-ZEPLIN (LZ) project, a range of monitoring sensors such as level sensors, position sensors, acoustic sensors and loop antennae will be deployed to achieve this. We report on the development of these sensors and their performance tests in the LZ system test platform constructed at SLAC.

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Ten years of PAMELA in orbit

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In ten years of data taking in space, the experiment PAMELA has shown very interesting features in cosmic rays, namely in the fluxes of protons, helium, electrons, that might change our basic vision of the mechanisms of production, acceleration and propagation of cosmic rays in the Galaxy. In particular, remarkable and stimulating have been the measurements of cosmic antiproton and positron fluxes that have allowed the nature of dark matter to be probed in a new way, suggesting new ideas and setting strong constraints to the models. The continuous particle detection is allowing a constant monitoring of the solar activity and detailed study of the solar modulation for a long period, giving important improvements to the comprehension of the heliosphere mechanisms.

PAMELA is also measuring the radiation environment around the Earth, and discovered an antiproton radiation belt.

Neutrinos and Dark Sector / 123

The COHERENT Neutrino Experiment

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The Coherent elastic scattering of neutrinos off nuclei was predicted over 40 years ago after the realization of the neutral weak current. This standard-model process remains unobserved due to the

daunting technical requirements: very low nuclear recoil energy thresholds, intense sources/large target masses, and low backgrounds. Employing state-of-the-art low-energy-threshold detector technology coupled with the intense stopped-pion neutrino source available at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL), the COHERENT Collaboration aims to measure CEvNS and to use it as a tool to search for physics beyond the standard model. A suite of detector systems (CsI[Na] and NaI[Tl] scintillating crystals, p-type point-contact germanium detectors, and single-phase liquid argon (LAr) is being deployed in the basement of the SNS, taking advantage of decades of detector development in the dark-matter direct-detection community. The first-phase of the COHERENT multi-detector approach will enable unambiguous discovery of CEvNS and test for non-standard neutrino interactions. This systematic characterization of low-threshold recoil detectors will validate experimental background and detector-response models, given that CEvNS of natural neutrinos is an irreducible background for dark matter WIMP searches.

As secondary goals, COHERENT will perform measurements of the charged-current cross sections on I, Pb, Fe, and Cu; the last three of which result in the emission of background-inducing fast neutrons. The measurement of this cross section on lead also has implications for supernova neutrino detection in the HALO supernova neutrino detector.

Laboratories and Low Background / **88**

The Canfranc Underground Laboratory

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The Laboratorio Subterráneo de Canfranc (LSC) is the second largest deep underground facility in Europe. It is located in north of Spain under the Pyrenees at about 2500 m.w.e. depth. LSC has been in full operation since 2010. At LSC 1600 square meters underground are available for research. The LSC is equipped with a number of service facilities to support installation and commissioning of experimental set-ups. The LSC is a multi-disciplinary research infrastructure. Research activities are carried out on neutrino physics, direct dark matter detection, low background counting, geophysics and life in extreme environment. In the talk a review of the infrastructure and research activities will be given.

Noble Gas / **36**

The DARWIN Dark Matter experiment

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The end of the evolution of dual phase xenon TPCs will be the DARk matter WImp search with liquid xenoN – the DARWIN experiment. In this talk I will discuss the primary physics goal of DARWIN: the exploration of the full experimentally accessible WIMP cross section and mass parameter space before coherent neutrino interactions dominate the count rate. The aim is to obtain a few times 10^{-49}cm^2 sensitivity for the WIMP nucleon cross section at a WIMP mass of 50 GeV/c^2.

I will focus on the detector design that will be based on a combination of existing well-developed techniques, with possibly new low-background light detectors that may replace PMTs. The scientific success of the DARWIN depends crucially on the ability to suppress backgrounds: both from

external neutron and gamma sources and most importantly from internal sources of radon and krypton.

If the challenges in construction and backgrounds are conquered, DARWIN will become the most sensitive liquid xenon WIMP detector ever built.

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The Dark Energy Universe

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The present universe is full of dark energy. This observation is now vexing physicists across the world, leading to much theoretical and experimental research. I will review the evidence for dark energy that has dominated the last 15 years in cosmology. I will then looking forward to the next decade and summarise some of the amazing experiments scientists will have available to tackling this mysterious phenomenon.

Summary:

Invited Talk

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The KATRIN neutrino mass experiment

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The objective of the Karlsruhe Tritium Neutrino experiment (KATRIN) is the measurement of the effective electron neutrino mass with an unprecedented model-independent sensitivity of 200 meV/c^2. This will improve present limits by one order of magnitude and allow to constrain the role of relic neutrinos as hot dark matter in structure evolution.
A non-zero neutrino mass in the sub-eV range induces only a minute deviation of the β-decay spectrum close to the kinematic endpoint. In the case of KATRIN, high-purity molecular tritium is used as β-emitter. The components of KATRIN, a high intensity windowless tritium source (~10^{11} Bq), and a huge 24-m long electrostatic spectrometer (MAC-E-filter) with an energy resolution of 1 eV at the β-endpoint of 18.6 keV guarantee high precision spectroscopy. The overall 70-m long setup is presently being commissioned at the Karlsruhe Institute of Technology (KIT) by an international collaboration of about 150 scientists.
This talk describes the goals and challenges of the experiment and reports on the progress in the ongoing commissioning of the experiment. Initial background results from one year of spectrometer operation will be presented.
The unique spectroscopic quality of the data close to the endpoint will allow to also investigate eV-scale sterile neutrinos, as suggested by the so called reactor anomaly, for example. The initial measurements at reduced source intensity will be used to investigate keV-scale sterile neutrinos by measuring over a wider energy range and looking for a corresponding characteristic kink-like structure in the energy spectrum.
We acknowledge the support of the Helmholtz Association (HGF), the German Ministry for Education and Research BMBF (05A14VK2) and the Helmholtz Alliance for Astroparticle Physics (HAP).

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The LUX dark matter search

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The LUX experiment searches for direct evidence of galactic dark matter. Located roughly 1.5 km underground at the Sanford Underground Research Facility in Lead, South Dakota (USA), the heart of the experiment is a 250 kg active liquid-xenon target, instrumented as a dual-phase (liquid/gas) time projection chamber capable of 3-D position reconstruction and nuclear recoil discrimination. The initial science results using 95 live-days exposure reached a record-setting sensitivity to Weakly Interacting Massive Particles (WIMPs), excluding WIMP-nucleon couplings greater than 5.6e-46 cm^2 for WIMPs of mass 33 GeV. Following this result, LUX has performed detailed calibrations and has recently completed accumulating a new exposure in excess of 300 live days. I discuss implications of the LUX results and present the current status of this search.

Noble Gas / 156

The LZ System Test Program

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The LUX-ZEPLIN (LZ) experiment is a direct dark matter experiment utilizing a liquid xenon time projection chamber (TPC). An LZ system test platform has been constructed at the SLAC National Accelerator Laboratory to develop and validate technologies and instrumentation required by LZ. The testing goal is to ensure that LZ can meet its high voltage and purification requirements, as well as exercising a variety of LZ subsystems, from calibration source injection to PLC modules and slow control software. An overview of the LZ system test platform will be presented here along with results from its first runs.

Laboratories and Low Background / 99

The Modane Underground Laboratory (LSM), multi-disciplinarily low radioactivity platform

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The Modane Underground Laboratory (LSM) is located 1700 m (4800 m.w.e) below Fréjus peak (Alpes chain) mountain in the middle of the Fréjus tunnel between France/Italy. The LSM is a multi-disciplinary platform for the experiments requiring low radioactivity environment. Several experiments in Particle and Astroparticle Physics, low-level of High Purity of Germanium gamma

ray spectrometry, biology and home land security hosted in the LSM. It's equipped by Anti-Radon facility where all of the detectors are under Radon depleted Air. I'll present the LSM structure and briefly reviewed of all experiments are installed in.

Neutrinos and Dark Sector / **11**

The PADME experiment

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The long standing problem of reconciling the cosmological evidence of the existence of dark matter with the lack of any clear experimental observation of it, has recently revived the idea that the new particles are not directly connected with the Standard Model gauge fields, but only through mediator fields or "portals", connecting our world with new "secluded" or "hidden" sectors. One of the simplest models just adds an additional U(1) symmetry, with its corresponding vector boson A'. All SM particles will be neutral under this symmetry, while the new field will couple to the charged particles of the SM with an effective charge εe, so that this new particle is often called "dark photon".

Additional interest arises from the observation that A' in the mass range $1\,\mathrm{MeV/c^2}$ to $1\,\mathrm{GeV/c^2}$ and coupling $\varepsilon \sim 10^{-3}$, would justify the discrepancy between theory and observation for the muon anomalous magnetic moment, $(g{-}2)_\mu$. This possibility has been recently disproved in the hypothesis that the A' decays to SM particles only, on the contrary if A' decays to dark sector particles, almost all of the available experimental constraints can be evaded and the dark photon is still a valuable explanation for the muon $(g-2)_\mu$ anomaly.

Due to the weak experimental signature, the search for invisibly decaying A' requires carefully designed dedicated experiment. At the end of 2015 INFN has formally approved a new experiment, PADME, to search for invisible decays of the A' at the DAFNE Linac in Frascati. The experiment is designed to detect dark photon produced in positron on fixed target annihilation (e^+e^-A') decaying to dark matter by measuring the final state missing mass. The collaboration aims to complete the design and construction of the experiment by the end of 2017 and to collect $\sim 10^{13}$ positron on target by the end of 2018, thus allowing to reach the $\varepsilon \sim 10^{-3}$ sensitivity up to a dark photon mass of $\sim 24\,\mathrm{MeV/c^2}$.

Neutrinos and Dark Sector / **166**

The SHIP Experiment at CERN

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SHIP is a new general purpose fixed target facility, whose Technical Proposal has been recently reviewed by the CERN SPS Committee and by the CERN Research Board. The two boards recommended that the experiment proceeds further to a Comprehensive Design phase in the context of the new CERN Working group "Physics Beyond Colliders", aiming at presenting a CERN strategy for the European Strategy meeting of 2019. In its initial phase, the 400GeV proton beam extracted from the SPS will be dumped on a heavy target with the aim of integrating $2{\times}10^{20}$ pot in 5 years. A dedicated detector, based on a long vacuum tank followed by a spectrometer and particle identification detectors, will allow probing a variety of models with light long-lived exotic particles and

masses below O(10) GeV /c^2. The main focus will be the physics of the so-called Hidden Portals, i.e. search for Dark Photons, Light scalars and pseudo-scalars, and Heavy Neutrinos. The sensitivity to Heavy Neutrinos will allow for the first time to probe, in the mass range between the kaon and the charm meson mass, a coupling range for which Baryogenesis and active neutrino masses could also be explained. Another dedicated detector will allow the study of neutrino cross-sections and angular distributions. ν deep inelastic scattering cross sections will be measured with a statistics 1000 times larger than currently available, with the extraction of the F4 and F5 structure functions, never measured so far and allow for new tests of lepton non-universality with sensitivity to BSM physics. This latter detector will also allow to detect dark matter particles coming from dark photon decays in a so far unexplored range of masses and couplings.

Laboratories and Low Background / **140**

The SNOLAB Facility and Current Program

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Many of the outstanding questions in astroparticle and subatomic physics today require the ultra-quiet environment provided by deep underground research facilities. SNOLAB is one such facility, based at a depth of 2km in the Vale Creighton mine near Sudbury, Ontario. In this environment, cosmic radiation induced backgrounds are minimized to levels allowing the operation of sophisticated experiments. The status of the lab will be discussed as well as several current and future experiments.

Summary:

The status of the SNOLAB facility and the current and future experiments will be discussed.

Laboratories and Low Background / **81**

The Sanford Underground Research Facility

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The former Homestake gold mine in Lead, South Dakota, has been transformed into a dedicated facility to pursue underground research in rare-process physics, as well as offering research opportunities in other disciplines such as biology, geology and engineering. The Sanford Underground Research Facility (SURF) includes two main campuses at the 4850-foot level (4300 m.w.e.) – the Davis Campus and the Ross Campus – that host a range of significant physics projects: the LUX dark matter experiment, the MAJORANA DEMONSTRATOR neutrinoless double-beta decay experiment and the CASPAR nuclear astrophysics accelerator. Furthermore, a new Ross Campus laboratory dedicated to critical material assays for current and future experiments is also operational, with two high purity germanium detectors online and additional instruments planned. Plans to accommodate future experiments at SURF are well advanced and include the next generation direct-search dark matter experiment LUX-ZEPLIN (LZ) and the Fermilab-led international Deep Underground Neutrino Experiment (DUNE) at the Long Baseline Neutrino Facility (LBNF). SURF is a dedicated research facility with significant expansion capability.

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The SuperCDMS High Mass WIMP Search

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There is overwhelming evidence that the Universe contains a significant non-luminous, non-baryonic matter component. The Weakly Interacting Massive Particle (WIMP) is a well motivated candidate for this dark matter. We expect WIMPs to interact with terrestrial targets at a low rate through keV-scale nuclear recoils. The SuperCDMS experiment, located in Soudan Underground Laboratory, collected data between March 2012 and May 2014 to search for WIMPs. The target mass consisted of Ge crystals cooled down to approximately 50 mK and instrumented with ionization and phonon sensors. We present the status of an optimized search for WIMPs with masses above 10 GeV.

Axion / **153**

The highs and lows of the QCD axion

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The QCD axion has been proposed more than 30 years ago to explain the smallness of the neutron's dipole moment. It is an excellent Dark Matter candidate and the search for it has been ongoing ever since its conception. In my talk I will describe two experiments that will explore complementary parts of the axion's parameter space. When the axion's Compton wavelength is tens of microns up to several centimeters, it can be detected through the monopole-dipole and dipole-dipole interaction it mediates in matter. In our ARIADNE proposal, the tiny effect of this interaction can be measured using polarized He-3. When the axion's Compton wavelength is larger than a kilometer, it matches the size of astrophysical black holes and its presence can be diagnosed through the superradiance effect that causes BHs to spin down. During this process, a cloud of axions forms a gravitational atom around the BH nucleus. Monochromatic gravitational waves produced by atomic transitions in this cloud turn BHs into astrophysical beacons that are well within the reach of Advanced LIGO experiment — after discovering gravitational waves, Advanced LIGO may also diagnose the existence of a new particle.

Directional / **170**

The spherical TPC for light-WIMP and low energy neutrino physics search

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The detector consists of a large spherical gas volume with a central electrode forming a radial electric field. A small spherical sensor located at the center is acting as a proportional amplification structure. This new concept has been proven to operate in a simple and robust way and allows reading large volumes with a single read-out channel. I will present results on WIMP search taken in the LSM underground laboratory in Neon gas and sub-keV energy threshold using a 60cm high pressure detector. The versatility of the target (Ne, He, H) opens the way to search for ultra light dark matter WIMPs down to 100 MeV.
Such a device would open the way to detect the neutrino-nucleus interaction or supernova detection.
I will mention prospects for ultra-low background high pressure detector and the optimization of such detector for a competitive double beta decay experiment using Xe-136 high-pressure target.

Annual Modulation / **87**

The status of KIMS experiment

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The Korea Invisible Mass Search (KIMS) collaboration had searched for WIMP dark matter signals using an array of ultra-pure CsI(Tl) crystals. Recently KIMS group is actively developing ultra-pure NaI(Tl) crystal to confirm or reject the DAMA/LIBRA claim of an annual modulation signature. For the future of low-mass WIMP detection, KIMS collaboration has started developing cryogenic detector technology based on Oxide crystals. In this presentation, I will summarize activities of KIMS collaboration in various aspects about background reduction, detector development as well as physics achievement.

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The status of the DAMIC experiment at Snolab

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The DAMIC (Dark Matter in CCDs) experiment is optimized for low-mass WIMP searches ~ 5 GeV, by using thick, high-resisitivity CCDs with noise below 2 e- (RMS) to achieve ionization energy thresholds below 50 eVee. DAMIC-100 is an upgraded version consisting of 100-gram array of CCDs currently being commissioned at SNOLAB. In this talk, I will present the most recent performance studies and background levels achieved with the experiment, as well as our sub-KeV measurements of the nuclear recoil quenching factor. Our most recent search for WIMPs with DAMIC-100 detectors will also be presented.

Directional / **155**

The technical improvements on NEWS experiment

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Nuclear Emulsions for WIMP Search (NEWS) is a directional dark matter search experiment using full solid detector.
We developed original super-high-resolution nuclear emulsion called Nano Imaging Tracker (NIT) which can detect around 100 nm tracks. We also constructed a new composite readout system for such extremely short tracks. Some recent background rejection techniques also showed remarkable improvement. These developments provide low energy tracking, high angular resolution, and good scalability.
In this talk, I will report on our detector potential, recent R&D status and future prospects of our technology.

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Toward minimal assumptions for WIMP dark matter

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The study of particle dark matter candidates has seen a trend toward making the smallest number of assumptions on the particle physics and the astrophysics of dark matter. I will present an overview of how this goal is being pursued in the theory and phenomenology of weakly-interacting massive particles as dark matter.

Laboratories and Low Background / 189

Underground neutron backgrounds

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Theory / 39

Unitarisation of EFT Amplitudes for Dark Matter Searches at the LHC

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We propose a new approach to the LHC dark matter search analysis within the effective field theory (EFT) framework by utilising the K-matrix unitarisation formalism. This approach provides a reasonable estimate of the dark matter production cross section at high energies and hence allows to put reliable bounds on the cut-off scale of relevant operators without running into the problem of perturbative unitarity. We exemplify

this procedure for the effective operator D5 in monojet searches of dark matter in the collinear approximation. We compare our bounds to those obtained using the truncation method and identify a region of parameters where the unitarisation prescription leads to more stringent bounds.

Theory / **147**

Update on Higgs portal dark matter and global fits

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I will describe the latest technological advances in bringing together complementary probes of dark matter in wholistic, statistically consistent, large-scale global fits to dark matter theories with the GAMBIT framework. I will then detail the latest combined impacts of all searches on popular theories for dark matter including singlet models interacting with the Standard Model through the so-called 'Higgs portal', and the lightest neutralino in supersymmetry.

Noble Gas / **102**

Updated Analysis in the PandaX-II Experiment

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The PandaX (Particle AND Astrophysical Xenon) project is a staged xenon-based underground experiment at the China Jin-Ping Underground Laboratory. In Feb 2016, the second phase half-ton-scale experiment, PandaX-II, released the dark matter search result from the commissioning run with a 306 × 19.1 kg-day exposure. After a krypton distillation campaign, the data taking of the experiment was recently resumed.

Summary:

In this talk, I will present some updated details of the PandaX-II analysis including event reconstruction, detector calibration and understanding of the detector responses, and various types of background events in the detector.

Indirect Detection / **30**

Warm intergalactic medium or warm dark matter?

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We reconsider the problem of determining the warmness of dark matter from the growth of large scale structures. In particular, we have re-analyzed the previous work of Viel et al 2013, based on high resolution Lyman-alpha forest spectra. In fact, the flux power spectrum exhibits a cut-off below ~ 1.5 Mpc/h, this may be explained by the temperature of the intergalactic medium (IGM) or be due to the free-streaming of dark matter particles. We show that if the IGM temperature at high redshifts was low enough (rising at later times) then the data indeed prefer warm dark matter. Assuming this broader range of thermal histories, we find that mWDM >= 2.1 keV for thermal relic at 95% CL (mNRP >= 12 keV for non-resonantly produced sterile neutrino). We discuss an independent method that would allow to exclude the influence of WDM on observable small-scale structures, or would lead to the discovery of WDM. We also determine values of lepton asymmetry making resonantly produced 7 keV sterile neutrinos consistent with the data.

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Welcome address by Sheffield Pro-Vice Chancellor

Low Mass WIMP Searches / 131

What atomic physics can contribute to light dark matter direct detection

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Light Dark Matter (LDM) is an interesting and well motivated alternative to WIMP as a dark matter candidate. Because of its light mass, electron recoil could become a better signal for LDM detection than nuclear recoil. We have applied an *ab initio* method, MCRRPA, to atomic ionization by neutrino or LDM to Ge, Xe and other targets with better than 10% accuracy. The neutrino-atom ionization is important to constrain new physics in the neutrino sector and to control the solar neutrino background for experimental collaborations such as LZ and DARWIN. In DM ionization, we have analytically solved the hydrogen case, which serves an important case study for our future *ab initio* calculations using realistic targets.

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XENON100 run combination results

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Weakly interacting massive particles (WIMPs) are a very promising explanation for the nature of dark matter. The XENON100 experiment aims to detect WIMP-nucleon interactions using a dual phase time projection chamber (TPC) with a total liquid xenon target of 62kg. This talk will focus on the final analysis for spin independent and spin dependent WIMP-nucleon interactions of XENON100 where the three major science datasets are combined into a single result. In addition to the first presentation of a yet unpublished science
campaign, various improvements to the analysis will be highlighted, which allow us to produce the most robust and strongest result of XENON100.

Directional / **20**

ZnWO4 anisotropic scintillator for directionality technique

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Low-background anisotropic scintillators can be reliable detectors to investigate those Dark Matter (DM) candidates inducing just nuclear recoils, through the directionality technique.
The directionality is based on the study of the correlation between nuclear recoils direction and Earth motion in the galactic rest frame.
In an anisotropic detector, the signal induced by those
DM candidates inducing just nuclear recoils is expected to change with a peculiar behavior as a function
of the sidereal time. Among the anisotropic scintillators, the $ZnWO_4$ has unique features and is an excellent candidate detector. In particular, both the light output and the scintillation
pulse shape depend on the impinging direction of heavy particles with respect to the crystal axes; these two features can be independently exploited to study the directionality and to statistically discriminate recoils to gamma/beta radiation (that gives no anisotropic effect). In the talk the developments and the perspectives of the low background ADAMO pioneer experiment to exploit deep underground the directionality approach by using anisotropic $ZnWO_4$ scintillators as well as its complementarity to existing positive results will be discussed.