CYGNUS 2019

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Dip. di Fisica - Edificio G. Marconi

Book of Abstracts

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Anisotropic response of ZnWO4 crystal for neutrons

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ZnWO4 crystal was reported that the scintillation light output has the direction dependence on the crystal orientation. Thus we are developing a direction sensitive dark matter detector utilizing the anisotropic response of ZnWO4 crystal.
In this talk, we will present results of the measurement of the quenching factor and anisotropic response of the ZnWO4 crystal for mono-energetic neutron source provided by the National Institute of Advanced Industrial Science and Technology, in Japan.

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NEWAGE/CYGNUS-KM

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Latest results on NEWAGE and status of the CYGNUS-KM will be presented.

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CYGNUS negative ion gas study

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Gas study on SF6 will be reviewed.

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Columnar Recombination Study in High Pressure Xenon Gas for Direction-sensitive Dark Matter Search

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Columnar recombination is a phenomenon that recombination is promoted when a direction of electric field and that of an ionizing particle track are aligned.
If this phenomenon occurs for low energy nuclear track, direction-sensitive dark matter search with large target mass and spin-independent sensitivity can be realized.
We report on the measurement of columnar recombination in a high pressure gas detector filled with 8 atm xenon using 5.4 MeV alpha particle.
We measured both scintillation and ionization to study columnar recombination.
Since the recombination photons are emitted several microseconds after de-excitation emission, we divided the scintillation photons into fast and slow components.
The fast component did not show angular dependence, on the other hand, the slow component increased when the angle of alpha particle is aligned with the electric field.
The result indicates that the track angle relative to the electric field can be reconstructed from scintillation time profile.

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Carbon Nanotubes as anisotropic target for dark matter

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Directional detection of Dark Matter particles (DM) could be accomplished by studying either ion or electron recoils in large arrays of parallel carbon nanotubes. For instance, a MeV mass DM particle could scatter off a lattice electron, resulting in the transfer of sufficient energy to eject the electron from the nanotube surface. The electron can eventually be detected whenever an external electric field is added to drive it from the open ends of the array. This detection scheme would offer an anisotropic response and could be used to select an orientation of the target with respect to the DM wind. A compact sensor, in which the cathode element is substituted with a dense array of parallel carbon nanotubes, could serve as the basic detection unit which - if adequately replicated -would allow to explore a significant region of light DM mass and cross-section. A similar detection scheme can be devised in case DM would scatter on the surface of a CNT and a carbon ion might be ejected –allowing to investigate the existence of a few GeV mass DM particle.

We report about the Monte Carlo simulations of such a system and the R&D towards a prototype detector.

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Study of the Operation Stability of a prototype for CYGNO experiment

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CYGNO experiment is working at the construction of 1 cubic meter TPC, based on Optical Readout of Gas Electron Multipliers (GEMs) for Directional Dark Matter search. This kind of research demands for very long data-acquisition runs and thus for a high operation stability and reliability. A 7 litre sensitive volume prototype was kept for 10 days in the working conditions, while its response to natural radioactivity was continuously monitored together with all voltages and currents. Even if few times per day the currents drawn started to increase because of micro-discharges in GEM channels, these events could be safely recovered by an automated high voltage cycle. The detector operated at full efficiency for 10 days without showing any deterioration or instability, with a total dead time, due to recovery procedures, lesser than 6%.

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ReD: a SiPM based LAr TPC for directionality studies

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The Recoil Directionality project (ReD) aims to characterize the light and charge response of a liquid argon (LAr) dual-phase Time Projection Chamber (TPC) to neutron-induced nuclear recoils. The main goal of the project is to probe for the possible directional dependence suggested by the SCENE experiment. Furthermore, ReD will have the possibility to study the response of a LAr TPC to very low-energy nuclear recoils.
ReD consists in the irradiation of a miniaturized LAr TPC with a neutron beam at the INFN, Laboratori Nazionali del Sud (LNS), Catania. Neutrons are produced via the reaction p(^{7}Li,^{7}Be)n from a primary ^{7}Li beam delivered by the TANDEM accelerator of LNS. A ΔE/E telescope, made by two Si detectors, identifies the charged particles (^{7}Be) which accompany the neutrons emitted towards the TPC. The core detector of ReD is a small custom-made double phase LAr TPC, having sensitive volume of $5 \times 5 \times 5$ cm^3. The ReD TPC uses all the innovative features of the DarkSide-20k design: in particular the optoelectronic readout based on SiPM and the cryogenic electronics. It is thus a valuable test bench of the technology which is being developed for DarkSide-20k and for the future project Argo. Neutrons scattered from the TPC are eventually detected by using an array of nine 3-inch liquid scintillator (LSci) detectors. All LSci are placed such to tag recoils having the same energy, i.e. the same scattering angle with respect to the incident neutron, but different angle with respect to the drift field of the LAr TPC, thus allowing to search for a possible directional response.

The integration of the three detector systems was performed within two test beams on 2018, using the TANDEM accelerator of LNS. Neutrons were produced by sending a ^{7}Li 28 MeV beam onto a set

of CH_2 targets having thickness between 150 and 250 $\mu g/cm^2$. The physics measurement is expected to take place during 2019. This contribution will report about the current status of the project and on the short- and medium-term plans.

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The CYGNO/INITIUM TDR Status Report.

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G. Mazzitelli on behalf of CYGNO/INITIUM collaboration

The design of the CYGNO/INITIUM project, aimed to prove the capability of a high resolution gaseous TPC with sCMOS (scientific CMOS) optical readout for near future directional Dark Matter searches, is under development and a Technical Design Report is foreseen by the end of the year. The status of the design, progress and open issues are presented and discussed.

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An EFT approach to light dark matter detection with 4He

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We employ the recently developed effective theories for superfluids to describe the interaction between the helium-4 phonon and a dark matter particle. In this language we compute the rate and differential distributions for the process of emission of one or two phonons by the passing dark matter. Such information are key to the possible design of new detectors to search for sub-GeV dark matter using helium-4. In particular, the process of emission of a single phonon is highly anisotropic and could allow for directional detection.

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ZnWO4 anisotropic scintillators for directionality technique

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Low-background anisotropic scintillators can be reliable detectors to investigate - through the directionality technique - those Dark Matter (DM) candidates inducing just nuclear recoils.
The directionality technique for such a kind of candidates is based on the study of the correlation between the nuclear recoils direction and the Earth motion in the galactic rest frame. In an anisotropic detector, the signal 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 instead gives no anisotropic effect). Developments and perspectives of the low background ADAMO pioneer project to exploit deep underground the directionality approach by using anisotropic $ZnWO_4$ scintillators as well as its complementarity to existing positive results will be mentioned.

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Particle Dark Matter constraints: the effect of Galactic uncertainties

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The interpretation of results from in/direct dark matter (DM) searches depend on the adopted DM distribution within the target. In particular, the reconstruction of the DM profile in the Milky Way proceeds from astrophysical observations, all affected by quantifiable uncertainties. I will show how with a full data-driven analysis, actual uncertainties on the relevant astrophysical observations of such quantities (such as e.g. the Sun's Galactocentric distance) affect the interpretation of in/direct detection (or lack thereof). I will present a practical tool to propagate uncertainties on astrophysical quantities into the DM particle parameter space, based on developments of the analysis presented in https://arxiv.org/abs/1612.02010.

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Tests of eco-friendly gas mixtures in GEM based detectors with optical readout

Authors: Davide Piccolo[1]; Davide Pinci, Igor Abritta Costa, Alice Apponi, Elisabetta Baracchini, Fabio Bellini, Stefano Bianco, Luigi Benussi, Gianluca Cavoto, Emanuele Di Marco, Giulia D'Imperio, Giovanni Maccarrone, Michela Marafini, Giovanni Mazzitelli, Andrea Messina, Luciano Passamonti, Davide Piccolo, Francesca Pucci, Francesco Renga, Filippo Rosatelli, Giuseppe Rossi, Sandro Tomassini[None]

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Abstract
Modern imaging detectors can exploit the scintillation light produced in MPGDs during electron avalanche multiplication. Using gas mixtures with scintillation light spectra compatible with the quantum efficiency of CCD or CMOS cameras, an optical readout can be implemented and a 2-dimensional image of the track can be reconstructed. In The Cygno project, a TPC for directional dark matter searches and neutrino scattering measurements, a three GEM layers detector is used as amplification device and the light produced during the multiplication process is detected by a sCMOS camera. The TPC is operated with a mixture of Helium and CF4. Recently the European community has banned many freon gases because of their high pollution impact to the atmosphere. Our group has started a study to test eco-friendly gases to replace the CF4 in such kind of applications. The

setup used to collect data and preliminary results obtained in terms of amplification factors and of light production will be presented by using some of the more interesting ecological gas mixtures selected on the market.

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Analysis machine and method for NEWSdm experiment

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NEWSdm experiment is a directional dark matter search experiment with super fine grained emulsion called NIT. The experiment aim to detect the direction of dark matter signal by recording sub-μm scale tracks of recoiled nucleus by dark matter with NIT.However, to get track information, we need not only to record tracks but also to readout them.Therefore, tracks in NIT is need to readout by scanning system .NIT works as detector only when it combine with scanning systems.Now a days, we use multiple scanning machine and analysis method to reject background events and to get detail track information.In this presentation, I will talk about the recent development status of scanning systems and the analysis flow of NEWSdm.

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The progress of NEWSdm experiment in Italy

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The NEWSdm experiment uses fine-grained nuclear emulsion as a tracking detector with superior spatial resolution.
Background rejection is a common problem for dark matter search experiment towards their scale-up. Serious backgrounds in the nuclear emulsion are fake physical signals, represented by contaminated dust.
We constructed a new facility at the LNGS. It is world-first underground production facility of nuclear emulsion, and we are trying a production under clean environment and filtering of materials as a primary measure of dust reduction.
Analytical methods are also studying. To derive much information from the microscope, we analyze light polarization and colors. In addition to reasonable selection, we are studying machine learning method connects all information by direct learning from images.
I will introduce recent progress of new kind of studies for background reduction.

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The CYGNO experiment: status report

Author: Davide Pinci, Igor Abritta Costa, Alice Apponi, Elisabetta Baracchini, Fabio Bellini, Stefano Bianco, Luigi Benussi, Gianluca Cavoto, Emanuele Di Marco, Giulia D'Imperio, Giovanni Maccarrone, Michela Marafini, Giovanni Mazzitelli, Andrea Messina, Luciano Passamonti, Davide Piccolo, Francesca Pucci, Francesco Renga, Filippo Rosatelli, Giuseppe Rossi, Sandro Tomassini[None]

The CYGNO experiment is a 1~m^3 gas TPC for directional dark matter searches, as a prototype toward the 100-1000~m^3 CYGNUS network of underground experiments. In such a TPC, electrons produced by dark-matter-induced nuclear recoils will drift toward and will be multiplied by a three-layer GEM structure, and the light produced in the avalanche processes will be readout by sCMOS cameras, providing a 2D image of the event with a resolution of a few hundred micrometers. Photomultipliers will also provide a simultaneous fast readout of the time profile of the light production, giving information about the third coordinate and hence allowing a 3D reconstruction of the event, from which the direction of the nuclear recoil and hence the direction of the incoming particle can be inferred. Such a detailed reconstruction of the event topology will also allow a pure and efficient signal to background discrimination.

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Towards a gas filtration setup for future ultra-sensitive SF6 gas based rare-event physics experiments.

Author: Robert Renz Marcelo Gregorio[1]

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The gas SF_6 has become of interest as a negative ion drift gas for use in directional dark matter searches. However, as for other targets in such searches, it is important that contamination can be removed, because problems with signal detection can arise from contaminants such as radon and impurities. Radon contamination can produce unwanted background events, and impurities such as water and nitrogen can capture interaction-produced electrons, preventing these electrons from detection. In this work, we demonstrated the filtration of radon (up to 87%), water (up to 79%) and nitrogen (up to 89%) from SF_6 by using Sigma-Aldrich molecular sieves. The filtration of contaminants were investigated in separate experiments using a *DURRIDGE* RAD7 for radon detection and a *Hiden Analytical* residual gas analyser for monitoring impurities. A molecular sieve filtration system for an SF_6 gas-based experiment has been designed. This system is planned to be tested with a miniature Multi-Wire Projection Chamber (MWPC), which contains SF6, to quantify the efficiency of the molecular sieve in reducing gain deterioration due to contaminants over time. In addition to benefits in signal detection, the molecular sieve filtration system can also be applied to reduced the amount of SF_6 used by purifying and recycling it. This is a step towards reducing the amount of SF_6 , the most potent greenhouse gas, planned for use in future large scale directional dark matter experiments.

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Directional Dark Matter Detection with High Definition 3D Charge Readout

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I will summarize the work that has been done at the University of Hawaii over the past few years with small gas TPCs exploiting high definition HD pixel charge readout. Our first WIMP-nucleon scattering limit, obtained during a surface run of eight small TPCs optimized for directional neutron detection, will be presented and the implications discussed. Future plans will also be discussed as time permits.

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How high is the neutrino floor?

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As the sensitivities of dark matter direct detection experiments improve, they will soon encounter a new source of background, due to coherent elastic neutrino-nucleus scattering (CEvNS). In this talk, I will discuss how the CEvNS rate could vary in certain simplified models of new physics, raising the level of the so-called neutrino floor. I will discuss current constraints on these models, and the implications these could have for direct detection experiments in the near future.

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Toward Directional Detection of Dark Matter Using Spectroscopy of Quantum Defects in Diamond

Authors: Mason Marshall[1]; Raisa Trubko[2]; Pauli Kehaiyas[3]; Matthew Turner[2]; David Phillips[1]; Surjeet Rajendran[4]; Alex Sushkov[5]; Ronald Walsworth[1]

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We propose a method to identify weakly interacting massive particle (WIMP) dark matter via induced nuclear recoil in diamond. This 100 nm damage cluster induces stress in the crystal, shifting the energy levels of nearby quantum defects. Crucially, the direction of the track left by the recoil allows us to determine the incoming direction of the particle enabling the possibility of distinguishing between dark matter particles and backgrounds such as solar neutrinos. To measure these damage tracks we will use spectroscopic interrogation of quantum defects such as NV centers in diamond along with other nanoscale imaging techniques. Here we present the proposed technique along with measurements of the pre-existing stress variations in diamond. This method could allow for directional detection of WIMP-induced nuclear recoils at solid-state densities, enabling probes of WIMP parameter space below the solar neutrino floor.

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Characterisation of the novel MM-THGem architecture in SF6

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The MM-THGem is an amplification device analogous to a ThGem which uses meshes to shape the electric field within the holes. It is hoped this device can reduce the instability and tendency to spark seen in conventional thick gems. Results from runs with ^{55}Fe and α sources in low pressure SF_6 are presented.

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Status of the CYGNUS TPC Effort

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I'll give a review of the CYGNUS proto-collaboration gas TPC effort. The CYGNUS concept here is to establish a world-wide array of gas TPCs ultimately capable of searching for WIMP dark matter with nuclear recoil directionality and hence reach below the so-called neutrino floor. Such technology also has the potential to distinguish nuclear recoils from electron recoils even in the low energy regime below ~10 keVee and hence also opens the prospect for low mass WIMP searches with particle identification capabilities. The physics motivation, recent progress and prospects for this concept will be presented including the status of the collaboration and a summary of recent R&D. A particular advance is the use of helium and hydrogen as target gas additives. This extends the sensitivity to low mass dark matter and opens the possibility of operation at atmospheric pressure.

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A GEM-MWPC Hybrid Readout for Negative Ion Drift

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We present progress on development of a new low background charge readout plane for use in directional dark matter detectors based on low pressure SF-6 negative ion gas. This form of readout aims to provide the advantages of thick Gas Electron Multipliers as a means to producing high avalanche gain, with a simple wire readout that can provide low noise operation. Results are presented for operation of a test set-up using a CERN-produced thick GEM and a wire array mounted 1mm from the surface of the GEM, including observation of alpha tracks and gain.

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CYGNUS TPC Update

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An update is presented of recent CYGNUS TPC collaboration activities. The CYGNUS concept here is to establish a world-wide array of gas TPCs ultimately capable of searching for WIMP dark matter with nuclear recoil directionality and hence reach below the so-called neutrinos floor. Such technology also has the potential to perform recoil discrimination in the low energy regime below ~10 keV and hence also open the prospect for low mass WIMP searches with nuclear recoil discrimination. Progress and prospects for this concept will be presented including the status of the collaboration and a summary of recent R&D towards the goals of CYGNUS TPC. A particular advance is the use of He as a target additive gas to the negative ion gas SF-6. This opens the possibility of operation at atmospheric pressure.

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Polarization effects of transversal and longitudinal optical phonons in bundles of multi-wall carbon nanotubes.

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We report on the polarization analysis of the Raman spectrum of highly aligned multi-wall carbon nanotubes (MWCNTs). A simple model considering the average angle distribution across the MWCNT axes accounts for the observed angular dependent Raman mode intensity. The model results fully fit the experimental data, allowing to derive an average waving angle of about 37° around the MWCNT axes, and allow to explain the apparent discrepancy of previous experiments reported in the literature.We believe that the present study would provide a simple effective spectroscopic method to prove physico-chemical and specific morphological characteristic of carbon nanotubes.

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