# LIDINE 2024: LIght Detection In Noble Elements

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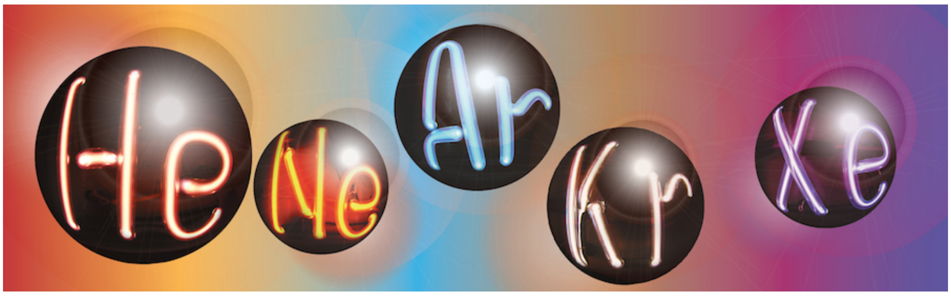


# Book of Abstracts

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## PoWER: A new concept for the DUNE FD3 Photon Detection System

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The Deep Underground Neutrino Experiment (DUNE) aims to probe CP violation in the neutrino sector and identify the neutrino mass hierarchy. In addition, using the DUNE Photon Detection System (PDS) can aid in reconstruction using charge information, improving the search for proton decay, observing supernova neutrino bursts, and studying solar neutrinos. DUNE will employ liquid argon time projection chamber (LArTPC) detector technology, consisting of far and near detectors 1300 km from each other. The far side will be composed of four modules, where the first two modules use horizontal drift single-phase LArTPC and vertical drift single-phase LArTPC. The third module (FD3) will also be a vertical drift single-phase LArTPC in a 13 m x 13 m x 60 m volume with a cathode plane inserted in the middle and the charge collection performed by two anode planes. We propose a novel concept for the FD3 PDS, the Polymer Wavelength shifter and Enhanced Reflection - PoWER. In this concept, we cover the field cage entirely with polymeric wavelength shifting foils (PolyEthylene Naphthalate –PEN). The light will be detected by large arrays of SiPMs mounted on the membrane. We use the same optimization of the ganging schemes developed for previous Far Detectors and cold electronics. In addition, we use a combination of standard and VUV-sensitive SiPM to use the LAr buffer between the field cage and membrane as an active veto. We also use large plastic panels lined up with an Enhanced Specular Reflector (ESR) (reflectivity 95% in the visible) installed on the membrane to improve the detection probability. The cathode will also be (partially) covered with PEN and, eventually, reflector. A 4% active coverage with photosensors over the membrane should allow for improvements in the low energy physics range probed in DUNE, especially regarding supernova neutrinos (~10 MeV). We present a preliminary study using a Monte Carlo simulation, including a Light Map for photons generated inside FD3.

**Light/Charge Readout / 2**

## Characterization of the Hamamatsu R12699-106-M4 2-inch Photomultipliers in MarmotX and XAMS

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The novel square Hamamatsu R12699-106-M4 2-inch photomultiplier tubes (PMT) feature a four-anode readout in a single low-profile package with a high photocathode coverage (about 75%). This makes them attractive as potential light detectors in future liquid-xenon based direct detection dark matter experiments, such as DARWIN/XLZD. The low-profile reduces buoyancy and therefore the amount of material required close to the xenon target. The multi-anode readout allows for a single high voltage cable, further reducing material and potential backgrounds. I will show results from the MarmotX facility at the University of Zurich, where these PMTs were first characterized in liquid xenon (LXe) cryogenic conditions. I will then discuss the performance of the PMTs in the XAMS time projection chamber at Nikhef.

**Poster Session / 3**

## Impact of p-Terphenyl Surface Density on the Efficiency of Filters

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We studied the conversion efficiency of Vacuum Ultra Violet light of PTP films as a function of their thickness. The PTP films were coated on dichroic filters or glasses at the Leptons Laboratory, Universidade Estadual de Campinas, using the vacuum evaporation technique. The arrangement of the filters within the evaporation chamber was done to ensure different levels of pTp deposition, with those closer to the center having higher density levels. Surface density measurements were conducted by pre- and post-deposition weighing of the filters. Relative measurement of the conversion efficiency of VUV light by the PTP films were done in a vacuum monochromator with a deuterium lamp, which produces monochromatic light with wavelengths ranging from 110 nm to 400 nm. These are all relative measurement with respect to a reference sample. The goal of this set of experiments is to understand the impact of PTP thickness on filter efficiency. Furthermore, the study employs Atomic Force Microscopy (AFM), profilometry, and X-Ray diffraction tests to analyze the structural and morphological effects, which can also impact the efficiency of the film. While ongoing, preliminary findings suggest a discernible correlation between PTP surface density and the filter efficiency.

**Poster Session / 4**

## Towards combination of charge and light readout at O(10) MeV energies in DUNE

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The Deep Underground Neutrino Experiment (DUNE) is an experiment under construction that will employ 10-kt scale liquid-argon-TPC technology to do precision measurements of neutrino oscillations. Apart from the determination of CP violation in neutrino interactions, one of the main scientific goals of DUNE is the detection of neutrinos from a supernova burst. It is imperative to maximise the potential of the detector for extracting information for these rare events. The use of light signals to aid the calorimetry of neutrino interactions provides such potential.

We will present current efforts to demonstrate the application of combined calorimetry in one of the DUNE prototype detectors at CERN. The ground-level placement of the detector allows collection of large samples of cosmic-ray muons stopping within its volume. Michel electrons from muon decay can be identified in both the ionization charge and scintillation light, serving as a proxy for supernova neutrino interactions at O(10) MeV energies. The method for demonstrating combined calorimetry and its associated challenges will be introduced. We will also summarise the current analysis status and future prospects

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## X-ARAPUCA PDE FOR DUNE FD-VD

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DUNE is a long-baseline (1300 km) neutrino experiment hosted at FNAL aimed at measuring neutrino mass ordering and CP violation by observing neutrino oscillations. DUNE will deploy four Liquid-Argon Time-Projection-Chamber (LArTPC) detectors with a combined mass of approximately 70 kT. The reconstruction of particle interactions, both from the beam and other sources, is achieved by collecting ionization electrons and scintillation photons (128 nm) with the TPC and the Photon Detection System (PDS). In order to fulfill the physics requirements of the experiment, the PDS needs to efficiently and uniformly collect light across the 62 x 15 x 14 $m^3$ detector volume, achieving an average yield of at least 20 PE/MeV. For the case of DUNE's 1st far detector module with vertical drift direction (FD-VD), the system relies on 672 (60 x 60 $cm^2$) X-ARAPUCA (XA) sensors, which trap photons inside a highly reflective box by shifting VUV light to the visible regime. The trapped photons are then guided by a wavelength-shifting bar to a surrounding silicon photomultiplier array for detection. An intensive R&D campaign, involving multiple international institutions, has optimized the design and component selection for the next-generation XA. The XA has been characterized using a dedicated cryogenic setup at CIEMAT, which liquefies gaseous argon inside a vessel containing all necessary components. The design contemplates a set of 6 calibrated reference sensors, 3 light fibers that connect to an external laser, and 3 radioactive 241Am sources strategically connected to the device to independently measure the absolute Photon Detection Efficiency (PDE). Several configurations for FD-VD have been studied, including single and double-sided XAs and pTP-coated substrates.

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## DUNE Photon Detection System

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The Deep Underground Neutrino Experiment (DUNE) has a broad physics program primarily aiming to probe CP violation in the neutrino sector and to identify the neutrino mass hierarchy. In addition, the search for proton decay, the observation of supernova neutrino bursts, and the investigation of solar neutrinos are also goals of the DUNE, which can be enhanced by the Photon Detection System (PDS).

Using Liquid Argon Time Projection Chamber (LArTPC) detector technology, the experiment plans to observe neutrino interactions inside the detectors located 1300 km away from Fermilab's Long-Baseline Neutrino Facility, where the neutrinos are produced. The experiment consists of two parts: the far and near detectors. The far site will be made of four modules. The first module is a vertical drift single-phase LArTPC, and the second module is a horizontal drift single-phase LArTPC. The configurations of the other modules are still being discussed.

To detect the passage of neutrinos, the LArTPC identifies the charge and light created by the interaction of neutrinos with liquid argon, which are detected by the wire planes on the instrumented anode and the PDS, respectively. This presentation will discuss the current status of the photon detection system of the first two modules, which use a modification of the so-called X-ARAPUCA.

This system consists of dichroic filters and wavelength shifters, creating a trap to detect the scintillation photons of 127 nm in liquid argon. The X-ARAPUCA of the first module is called SUPERCELL,

and it consists of a geometry of 488x100 mm², whereas the MEGACELL is the second module version, with an active area of 60x60 cm². This latter configuration also represents a significant technological advancement. Since half of the modules are placed on the cathode at high voltage, they are powered and read out using innovative power-over-fiber and signal-over-fiber techniques. Meanwhile, the other half will be put in a membrane behind the field cage, with a total transparency of around 70%.

Thanks to an intense R&D campaign conducted in several labs and in ProtoDUNE runs at CERN, the PDS system has been optimized and validated.

**Light/Charge Readout / 8**

## Charge-Light Matching of Ambient Low-Energy Activity in the DUNE Near Detector Prototypes

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The Deep Underground Neutrino Experiment (DUNE) uses the Liquid Argon Time Projection Chamber (LArTPC) technology to study the neutrino oscillation phenomenon using a long baseline. Beyond neutrino oscillations, the project has a broad and extensive physics program. To ensure precise and accurate spatial and calorimetric resolution in the DUNE LArTPCs, it is important to be able to calibrate the detectors. An interesting prospect for calibration of the DUNE LArTPCs lies in utilizing the naturally occurring radioactivity present in liquid argon, e.g. 39Ar beta decays, which provide an abundant, uniform, and low-energy calibration source. However, the full reconstruction of the position and energy of such decays in LArTPCs is often difficult. This is largely due to the low scintillation light emitted by the low-energy decays and the large distances between the decays and the photon detectors. If the charge and light information for these decays can be detected, it would allow for full reconstruction and would open up multiple new avenues for calibrations that otherwise would not be possible with just charge alone. Results from a study of the reconstruction of the ambient low-energy activity using charge and light information in the DUNE near detector prototypes will be presented. The extent to which low-energy activity can be reconstructed in these prototypes will be discussed. In addition, a method for achieving high selection purity using appropriate data cuts, along with a method of measuring selection purity, will be described. Applications of the high selection purity samples will be shown, including using them as a probe of electric field uniformity in the detectors.

**Detector techniques / 9**

## Exploring N2 Capturing in Liquid Argon using Li-FAU Mol Sieve in the Iceberg Cryostat

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Liquefied ultra-pure noble gases are typically the chosen target for neutrino and dark matter experiments. Commonly, the required grade of purity of such cryogenic liquids in terms of oxygen contamination (< 100 ppt), which makes it necessary for the Gaseous Argon (GAr) and/or the Liquid Argon (LAr) to circulate through adsorption columns filled, typically, with BASF Cu-0226S and Mol Sieve 4A for capturing oxygen gas and water. Another requirement that emerged during the design of LBNF-DUNE is the purity of the LAr in terms of nitrogen concentration, as it was observed that both nitrogen and oxygen contamination concentrations in the LAr can cause the reduction of the LAr scintillation light emission. In particular, a decreasing behavior in the lifetime and the relative amplitude of the slow component is relevant from concentrations of 1 ppm of nitrogen and 0.1 ppm of oxygen. Recently, exploratory experiments performed in the Liquid Argon Purification Cryostat (PuLArC- ~ 90 L of LAr) at IFGW/Unicamp had been successfully used to purify LAr from nitrogen using an innovative solid adsorbent based on a Li-FAU Molecular Sieve. Here, we report experiments of nitrogen capturing in LAr carried out at the Iceberg Cryostat (~ 3000 L of LAr) at Fermilab. For the experiments, several controlled injections of nitrogen gas were made into the Iceberg cryostat, and the impurity concentrations in the LAr (both for nitrogen and oxygen) were monitored using a calibrated gas analyzer connected to the Iceberg during the purification process. The experimental data confirmed that the Li-FAU is capable of capturing the nitrogen gas from the LAr. A numerical methodology based on the mass and energy balances of the system was applied to better understand the behavior of the adsorption process and to help with the scale-up of the process. A Pore Diffusion Model (PDM) coupled with parameter optimization was proposed to predict the nitrogen concentration in the Iceberg cryostat over time. The model parameters applied in this work were determined based on experimental data acquired in the PuLArC. The model was able to accurately reproduce the data from the Iceberg, indicating that the mathematical model could be a valuable tool to design and operate the GAr/LAr system of LBNF-DUNE. Finally, the reported results of the experiments performed in the Iceberg unequivocally confirmed the Li-FAU capacity to capture nitrogen from LAr, invoking the discussion about the possibility of this adsorbent being used in other LAr-based experiments at Fermilab and CERN. It was possible to predict from simulations the necessary time to reach the required purity from an initial contamination concentration and also the number of purification cycles until solid saturation.

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## Production and Characterization of Veto Photon-Detection Units for the DarkSide-20k Experiment

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The DarkSide-20k experiment, currently under construction at the Gran Sasso National Laboratory (LNGS), represents a significant advancement in the field of direct Dark Matter (DM) detection. Utilizing a liquid argon dual-phase time projection chamber (LArTPC) with a 20-tonne fiducial mass, DarkSide-20k is designed to extend the sensitivity limits in the search for Weakly Interacting Massive Particles (WIMPs), a leading dark matter candidate. A critical component of this experiment is the active veto system, which acts as a shield against external environmental noise to minimize background and enhance the accuracy of DM detection. The system features advanced silicon photomultiplier (SiPM)-based cryogenic photosensors for light readout, making the large mass of LAr in the detector one of the most promising current technologies for DM detection. Universities and research institutes in the UK and Poland are responsible for producing and testing 150 veto Photon Detection Units (vPDUs) that will be fitted on the Inner and Outer Veto. I will discuss the status of the production and characterization of the vPDUs, along with the quality assurance and quality control (QA/QC) procedures implemented to ensure the reliability and efficiency of the photon-detection systems.

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## Mass test setup for the DUNE FD1 SiPMs characterization and first results

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The Deep Underground Neutrino Experiment (DUNE) is an upcoming neutrino physics experiment that will answer some of the most compelling questions in particle physics and cosmology. The DUNE Far Detector (FD) exploits silicon photomultipliers (SiPMs) to detect scintillation photons produced by the interaction of charged particles in the liquid Argon time projection chamber (LarTPC). Light signals are indeed extremely important to determine one of the spatial coordinates of the interaction and also allow to trigger non-beam events.
The SiPMs are photosensors consisting of a matrix of single-photon avalanche diodes operating in the Geiger-Mueller region. Their high sensitivity and dynamic range, as well as the possibility to fill large surfaces with high-granularity sensors, makes them an ideal choice for the DUNE FD photodetection system.
An international consortium of research groups is currently engaged in systematic quality assurance tests of all the sensors that will be installed in the FD to control their specifications. A custom set-up, CACTUS (Cryogenic Apparatus for Continuous Tests Upon SiPMs), has been developed at Ferrara and Bologna Universities-INFN sites to automatically perform the tests for a large number of sensors in parallel. This system can characterize up to 120 SiPMs simultaneously both testing their mechanical and thermal resistance, and measuring the complete current-voltage curve for each sensor at room and cryogenic temperatures. These data allow to extrapolate the quenching resistor and the breakdown voltage, the key operating parameters of the SiPMs.
Furthermore, the CACTUS test facility allows for dark noise characterization through a custom-made fixed threshold amplifier-discriminator system.
Until now, more than 13000 arrays of 6 sensors each, produced by Hamamatsu Photonics K.K., have been fully tested by the laboratories involved in the measurements, showing a failure rate of 0.3%.

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## Status of the LUX-ZEPLIN Dark Matter Experiment

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The LUX-ZEPLIN (LZ) experiment is a dark matter direct detection experiment operating almost a mile underground at the Sanford Underground Research Facility in Lead, South Dakota. LZ uses a 7 active-tonne dual-phase xenon time projection chamber primarily designed to detect weakly interacting massive particles (WIMPs), a well-motivated class of dark matter candidate. This talk will give the status of the LZ experiment and report the latest on its searches for dark matter and other new physics phenomena.

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## Calibration and Timing Performance of the Light Detection System in the ICARUS Detector

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ICARUS is the largest Liquid Argon Time Projection Chamber (LArTPC) in operation and serves as the Far Detector of the Short Baseline Neutrino (SBN) program at Fermilab. It aims to investigate the possible existence of sterile neutrinos with $\Delta m^2 \approx 1$ eV$^2$ using the Booster Neutrino Beam (BNB) and explore physics beyond the Standard Model with the Neutrinos at the Main Injector (NuMI) beam. The ICARUS light detection system, comprising 360 TPB-coated large-area Photo-Multiplier Tubes (PMTs), is crucial for triggering and event reconstruction. Due to its shallow installation, the detector is exposed to a high flux of cosmic rays, necessitating precise timing to reject background events and align neutrino interactions with the beam time profile. This talk will detail the timing inter-calibration procedures for the ICARUS light detection system, which achieve sub-nanosecond resolution. Additionally, the performance of the system in reconstructing the timing of neutrino interactions from the BNB and NuMI beams will be discussed. The results highlight the effectiveness of the ICARUS light detection system in enhancing the detector's capability for precise and reliable neutrino selection.

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## Gd-PMMA: a novel neutron tagging technology for low background detectors

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Low background detectors, such as those used in direct dark matter searches, require high-efficient neutron veto to reject nuclear recoil backgrounds. Gadolinium-doped polymethyl methacrylate (Gd-PMMA) has emerged as a promising solid neutron tagging material, with high hydrogen content for moderating neutrons and gadolinium content for capturing thermal neutrons and exploiting subsequent emission of high-energy gamma rays. This talk introduces a novel Gd-PMMA material based on a complex compound called gadolinium methacrylate, which will be used in the DarkSide-20k experiment, a direct dark matter search experiment with liquid argon.
The Gd-PMMA will serve as both a neutron tagging material and the main structural material of the dual-phase argon Time Projection Chamber (TPC) in the DarkSide-20k detector. This design allows for the Gd-PMMA to be located as close as possible to the detector's active volume to tag any possible neutrons from intrinsic backgrounds. With liquid argon buffers on both sides of the Gd-PMMA, gamma rays released during neutron capture can be effectively detected. To maximize neutron veto efficiency, a ~1% gadolinium mass fraction with 15 cm thick Gd-PMMA surrounding the TPC's active volume is required. Radiopurity control of this material is also being studied to ensure its suitability for use in low-background experiments.

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## Electric Fields and their Effects in the LUX-ZEPLIN Experiment

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Dual-phase noble liquid time projection chambers (TPCs) are at the forefront of direct dark matter detection experiments. Their functionality hinges on a meticulously designed homogeneous electric field structure defined by electrodes, material properties, and the relative permittivities of gas and liquid. These fields impact recombination processes within the target liquid (e.g xenon) and influence the drift path of ionisation electrons (S2 signal). This, in turn, affects both position reconstruction (combined with S1 signal) and the crucial discrimination between background-like electronic recoils and signal-like nuclear recoils. Furthermore, high voltage elements in these TPCs exhibit occasional anomalous electron or photon emission, a phenomenon attributed to field emission but lacking a deeper understanding. This talk delves into the multifaceted role of electric fields within the LUX-ZEPLIN (LZ) TPC. By employing data-driven and simulation techniques, we aim to illuminate charge transport mechanisms, energy-position reconstruction, and potential sources of this anomalous emission. This improved understanding will be crucial for designing and optimising future generations of dark matter detectors beyond LZ.

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## The UV Laser Calibration System for measuring the electric field in the SBND detector

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The Short-Baseline Near Detector (SBND) is a LArTPC approximately 110 meters from the Fermilab's Booster Neutrino Beam (BNB) intended to measure neutrino cross sections and aid in excess electron-like neutrino searches.
The electric field inside the SBND-TPC may have distortions due to a number of reasons, such as the space charge effect. The space charge effect comes from the abundance of cosmic rays that ionize the argon, producing copious positive argon ions. In this case, we need an alternative solution to determine the electric field distortion inside the TPC volume and compensate for the possible distortion in the spatial information. The UV calibration system is one such attempt to determine the electric field distortion inside the TPC using the UV laser beam.
In my talk, I will give a brief overview of the UV laser calibration system for SBND, how we can use lasers to determine the Electric field distortion, the hardware, the methodology for deriving spatial distortion and the first laser run tracks.

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## Introducing APEX: a new concept for DUNE module 3 far detector photon detection system

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The Deep Underground Neutrino Experiment currently under construction in the US will be a long-baseline neutrino oscillation experiment dedicated to determining the neutrino mass ordering and to measure the CP violation phase in the lepton sector. DUNE will also perform studies of non-beam physics such as atmospheric neutrinos, bursts from supernovae and nucleon decays in which photon detection systems will play a major role in triggering and also provide calorimetric measurements. For the second phase of DUNE, two additional detector modules will be added in the far detector complex in the Sanford Underground Research Facility. We present the Aluminum Profiles with Embedded X-ARAPUCA (APEX) concept as an advanced proposal for the photon detector system of the third DUNE far detector module. This system aims to have an optical coverage of approximately 60% made viable by the technology advancement achieved by the DUNE collaboration on the use of non-conductive optical fibers for power and signal readout of the photon detector units. Such large coverage will provide enhanced light collection capabilities at MeV-scale energy deposit level per interaction and optimal energy reconstruction resolution up to the GeV scale. The attained electrical isolation of the detector units with low noise levels allows for a complete instrumentation of the field cage walls with satisfactory segmentation as the readout scheme envisages a much larger than typical number of channels to be adopted. We discuss the main features of the system, first estimates on its expected performances, potential for physics measurements and prototyping plans for R&D.

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## CHARMS250: A Cryogenic Front-End ASIC for Low-Noise Readout of Light or Charge Signals

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In this talk we present CHARMS250, a next-generation cryogenic front-end application specific integrated circuit (ASIC) designed in a 65 nm process for low-noise readout of charge or light signals generated within noble liquid time projection chambers (TPCs). The design of CHARMS250 is evolved from the LArASIC chip, which was manufactured in a 180 nm process and has been selected as the first component in the 3-ASIC readout solution for Phase I of the Deep Underground Neutrino Experiment (DUNE). CHARMS250 comprises of 16 channels of programmable pre-amplification and pulse shaping stages that provide a voltage readout proportional to the input signal. It is designed for operation at temperatures ranging from room temperature (RT) down to liquid nitrogen temperature (LNT), i.e., 77 K, with large capacitance detectors (up to hundreds of picofarads). The charge gain fo r the pre-amplification stages can be set to 60, 100, 180, or 320, corresponding to voltage-to-charge gain after the pulse shaping filter of 4.7, 7.8, 14 or 25 mV/fC, for reading out input signals up to 300 fC, 180 fC, 100 fC, and 56 fC, respectively . The pulse peaking time can be set to 0.25 µs, 0.5 µs, 1.0 µs, or 2.0 µs. Additionally, features such as local generation of bias voltages and extended digital assistance of analog functions provided over an I2C interface are included in CHARMS250 for improved robustness against process variability. Simulations with both RT and cryogenic temperature transistor model parameters indicate that CHARMS250 provides a highly linear voltage readout (INL < 0.1%) for input charge up to 300 fC with a power consumption ranging between 6-11 mW per channel, depending on the choice of the output buffering. The simulated baseline equivalent noise charge (ENC) at liquid argon temperature is less than 500 electrons for a detector capacitance of 160 pF and all supported pulse peaking time values. Potential applications for CHARMS250 include light/charge readout of the Far Detector (FD) 3/4 in Phase II of DUNE, charge readout in the future circular lepton collider (FCC-ee), light readout in nEXO, and the silicon-based active target and liquid xenon calorimeters in PIONEER.

**Poster Session / 19**

## Study of geometric efficiency of photon detection in LArTPC using Monte Carlo simulation

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**Study of geometric efficiency of photon detection in LArTPC using Monte Carlo simulation**

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**Abstract**

The Deep Underground Neutrino Experiment (DUNE) is a leading-edge international experiment, which aims to answer some of the open questions in neutrino physics and, consequently, contribute to the investigation of several fundamental questions about the nature of matter and the evolution of the universe. The DUNE far detector uses a liquid argon time projection chamber (LArTPC) to reconstruct neutrino interactions by detecting charged particles and light signals. Particularly, the light detection system is a fundamental part of the detector, responsible for triggering the detector and determination of initial time of events,and might also contribute to particle identification and calorimetric purposes. Computational simulations are important tools that can be used to investigate the mechanisms of production, detection, and propagation of photons in the LArTPC, helping in the prediction and optimization of photon detection efficiency in the detection system. In this work, Monte Carlo computer simulations were performed using the GEANT4 program to determine the detection efficiency of photons under different geometric conditions in the LArTPC. Simulations were carried out by varying the angular detection parameters as well as the distance between the emission point and the photo-detection system. The results allowed the estimation of photon detection efficiency under the investigated geometric conditions. Additionally, the angular and distance correction factors for theoretical attenuation model (based only on photon transmission) were determined.

**Poster Session / 20**

# Reporting on wavelength shifters sublimation on high vacuum

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Liquid noble detectors are highly dependent on wavelength shifter materials, such as p-Terphenyl (pTP) and tetra-phenyl-butadine (TPB). These materials are key to the DUNE's far detector (for the former) and the DUNE's near detector, the SBDN and ICARUS (for the latter), for instance. Given their significance, it is of extreme importance to fully comprehend and characterize these compounds to optimize experimental techniques and enhance detector performance.
Our investigation reveals a novel phenomenon where commonly used wavelength shifters can undergo spontaneous sublimation when exposed to high vacuum. This work presents our findings on the sublimation behavior of pTP and TPB under such extreme conditions. We have quantified the sublimation rate of these substances as a function of pressures and temperatures, and assessed this phenomenon's influence on the growth of these materials, affecting their physical properties. Furthermore, we have studied the impact of variations in the characteristics of pTP and TPB thin films, such as sample thickness and growth rate, on the sublimation process.

Based on our results, we propose methodologies to mitigate the sublimation effects during the production and storage of wavelength shifter thin films. These insights could improve the reliability and efficiency of these materials in advanced photodetection systems, cheapening the creation of experiments necessitating these technologies, and creating new possibilities for particle detection

**Poster Session / 21**

## Precise Magnetic Field Mapping of the EMPHATIC Phase 1 Magnet with COMSOL

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EMPHATIC (Experiment to Measure the Production of Hadrons At a Test beam In Chicagoland) is a Fermilab-based table-top size experiment focused on hadron production measurements. Flux is a limiting systematic for all neutrino cross section measurements by current experiments and we rely on a-priori predictions of the flux for analyses, including measurements of neutrino oscillations, neutrino-nucleus cross sections, and beyond-the-Standard Model searches. These flux predictions rely on simulations of the production and focusing of hadrons in and downstream of the neutrino production target, resulting in 10-20% uncertainties. The goals of the experiment are to address gaps in our understanding of hadron-scattering and hadron-production cross sections with better than 10% measurements and the first-ever measurement of the hadron spectrum downstream of a target and horn.

A compact Halbach array magnet with B.dl˜0.2 Tm is used to measure the momentum of the secondary particles. The Phase 1 Halbach array magnet is a ˜104 kg, 3 layer magnet with a total of 48 uniformly magnetized components of Neodymium (NdFeB N52) permanent magnets resulting in a dipole magnetic field. Hall probe data was taken for the central cylindrical bore of the magnet and a field map was constructed that showed a spatial asymmetry. COMSOL Multiphysics® Software is used for modeling the magnet and constructing the corresponding magnetic field map. We present a fitting approach where the hall probe data is used to determine a 1mm-spacing map of the entire volume of the magnet using COMSOL. The new map will allow for linear interpolation within the volume, and expand the map to outside the measurement volume, thus increasing the acceptance and precision of EMPHATIC's tracking system.

**Detector techniques / 22**

## Advances on MagLITe photo-collection efficiency

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Photodetection systems in liquid noble element experiments often utilize external wavelength shifter films deposited over optical elements; however, this method is susceptible to issues such as loss of efficiency, cross-contamination, and mechanical and chemical stress. Our research group has developed MagLITe (Magnesium fluoride Light collection Improvement technique) to address these challenges.

MagLITe involves applying a transparent, VUV-compatible, Magnesium Fluoride layer over the external wavelength shifter. This top layer is designed to be hard, and durable, protecting the underlying structure, while also increasing photo-collection efficiency through thin film interference.

Recent advancements in MagLITe have focused on improving the quality of the optical interface between layers by advancing deposition techniques and better controlling surface roughness.

In this work, we will discuss the recent improvements in deposition protocols that have significantly boosted the efficiency of light collection. We will present detailed measurements and results from our latest experiments, highlighting the enhanced capabilities of the MagLITe technique.

**Poster Session / 23**

## Exploring Polyethylene Naphthalate (PEN) as a potential substitute for Tetraphenyl Butadiene (TPB) in scintillation light detection

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TPB is the standard wavelength shifter used in liquid argon/xenon experiments to convert scintillation light from deep UV to visible wavelengths, where typical photodetectors have non-negligible light detection efficiency. While TPB offers high light conversion efficiency, its use presents challenges: it is an organic powder that is difficult to deposit as a thin film on substrates like glass or reflector films, particularly for stable performance in cryogenic conditions as a wavelength shifter. As a result, deploying TPB over large detector volumes is difficult, highlighting the need for novel materials for the next generation of experiments.

PEN, a polyester easily manufactured as thin sheets, could simplify the coverage of large volumes with wavelength shifters. Previous measurements have shown that commercial grades of PEN have approx. 50% light conversion efficiency relative to TPB. Encouraged by these results, we conducted a large-scale measurement of a 4 $m^2$ PEN + ESR reflector combination foil in a liquid argon environment, using a two-tonne LAr dewar to assess its stability over two weeks. This step is crucial for validating PEN as a viable substitute for TPB. In this poster, I will describe the measurement setup and present the initial results on the stability of PEN as a wavelength shifter in liquid argon.

**Poster Session / 24**

## Effects of the annealing process on the physical properties of p-Terphenyl films deposited on dichroic filters for X-Arapuca.

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The quality, durability, and efficiency of a thin film heavily depend on surface cleaning procedures, deposition mechanisms, and pre- and/or post-deposition heat treatment. The annealing process, in turn, allows for the molecular rearrangement of the film, promoting its molecular chains to attain their most stable state possible, which can enhance the aforementioned properties. This study reports the results obtained for different annealing temperatures at fixed times. The selected samples underwent a standard cleaning procedure using a 3% Extran solution in deionized water, followed by drying with $N_2$ and oven-drying at 100 °C for 3 hours. The deposition method employed was

Vacuum Thermal Evaporation, conducted under a vacuum of approximately $1.5\times10^{-5}$ mbar, with the substrate rotating and samples placed centrally on the substrate. Two standard samples were selected as control parameters, with their crystalline and morphological structures examined via atomic force microscopy (AFM) and X-ray diffraction (XRD). For the crystalline structure analyses was utilized a XRD Shimadzu LabX XRD-6000 equipment, using Cukα radiation. The experiment was done in Bragg-Bretano geometry with θ−2θ scan. For the morphological analyzing, was utilized an AFM Veeco Innova equipment, with $(4.0\times4.0)\ m^2$ scanning of sample surfaces. For the annealing procedure, a muffle furnace programmed with specific heating ramps for each selected annealing temperature was used. All annealed samples had their crystalline and morphological structures examined before and after the annealing process to investigate the effects of thermal treatment on the molecular reorganization of the PTP layer on the surface. Efficiency analyses are being conducted using a vacuum monochromator equipped with a deuterium lamp, generating monochromatic light ranging from 110 nm to 400 nm in wavelength. Additionally, the annealed samples are undergoing cryogenic immersion to study the films adhesion behavior throughout the annealing process. Preliminary results are currently being acquired and analyzed, aiming to understand whether these procedures can contribute to optimizing the adhesion mechanisms and efficiency of the film on the dichroic filter surface.

**Signal reconstruction and identification / 25**

## Photo diffusion in LArTPCs through a telegrapher equation

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We consider the relativistic photon diffusion equation for unbounded media of Lemiux et al, to which we present an analytical solution in terms of the physical parameters of a LArTPC. We account for photon absorption at the boundaries through physical considerations, instead of a boundary value problem. Then we compare our results to several Geant4 simulations and analyze the results and discuss the possibility of application for an actual detector.

**Poster Session / 26**

## Updated parameters of the LArQL model

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The need for a microscopic description of scintillation light generation in liquid argon becomes increasingly desirable with the upcoming operation of large scale LArTPCs in the next decade. While a detailed mathematical account of the process is still to be achieved, a phenomenological model for simultaneously treating ionization and scintillation, LArQL, has been successfully employed to

describe the range of electric fields from 0 to 0.75 kV/cm and dE/dx from 2 to 40 MeV/cm providing the anti-correlation between the free ionization charge and scintillation light. A reanalysis of the original model parameter values has been performed within a global fit procedure and will be presented.

**Poster Session** / **27**

## Status of APSAIA Installation in the SBND experiment

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The Short-Baseline Near Detector (SBND) is one of three Liquid Argon Time Projection Chamber (LArTPC) neutrino detectors positioned along the axis of the Booster Neutrino Beam (BNB) at Fermilab, as part of the Short-Baseline Neutrino (SBN) Program. Located only 110 m from the BNB target, it will precisely characterize the neutrino flux before oscillations take place. The Photon Detection System in SBND integrates 120 photomultiplier tubes (PMTs) and 192 X-ARAPUCAs, each composed of a dichroic filter window on a highly internally reflective box equipped with silicon photomultipliers (SiPMs), half of which are VUV-sensitive and the other half are visible light sensitive (VIS). In terms of the readout system, 16 X-ARAPUCAs will be read by the APSAIA (Arapuca Power Supply and Input Amplifier) and 96 by the ARARA (Arapuca Analog Readout Amplifier). This presentation will discuss the current status of the APSAIA installation in the SBND experiment.
The APSAIAs, responsible for power supply the SiPMs and amplify their output signals, were installed directly on the flanges of SBND's cryostat, on the warm side. Each board includes 8 channels, each containing one amplifier and one power supply for the SiPMs. Since each APSAIA ARAPUCA has 2 outputs, each APSAIA is responsible for 4 ARAPUCAs. Serial communication allows the possibility to control the level of the SiPMs bias and the gain of the amplifiers via an RS232 serial port. The output connectors are designed to interface with the CAEN V1730 digitizer, featuring MCX connectors for each channel. The power supply input and serial port share a single RJ connector. The supply voltage for the SiPMs is adjustable remotely from 20V to 60V with a resolution of 100 mV. A microcontroller, connected to an RS232C port, manages operations and has an internal memory that retains and applies the operating conditions at startup.
This setup ensures precise control and reliable operation of the SiPMs, contributing to the overall accuracy and efficiency of the SBND's photon detection capabilities.

**Applications** / **28**

## Characterization of low energy argon recoils with ReD and ReD+

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The Recoil Directionality project (ReD) within the Global Argon Dark Matter Collaboration characterized the response of a liquid argon (LAr) dual-phase Time Projection Chamber (TPC) to neutron-induced nuclear recoils, to measure the charge yield at low-energy. The charge yield is a critical

parameter for the experiments searching for dark matter in the form of low-mass WIMPs and measurements in Ar below 10 keV are scarce in the literature. ReD was designed to cover the gap down to 2 keV.

The ReD data taking took place in 2023 at the INFN Sezione di Catania. The TPC was irradiated by neutrons produced by an intense <sup>252</sup>Cf fission source in order to produce Ar recoils in the energy range of interest. The energy of the nuclear recoils produced within the TPC by (n,n') scattering was determined by detecting the outgoing neutrons by a dedicated neutron spectrometer made of 18 plastic scintillators. The kinetic energy of neutrons interacting in the TPC was evaluated event-by-event by measuring the time of flight. Data analysis is currently being finalized, but it has been confirmed that ReD collected and characterized a sample of nuclear recoils down to 2 keV, thus meeting its design goal.

The ReD effort will be further extended by a new project, ReD+, funded by a PRIN grant from the Italian Ministry of Research. ReD+ is designed to push the sensitivity down to 0.5 keV, by using the same conceptual design of ReD and improved components. A new TPC is being re-designed and optimized in order to increase the signal rate and the signal-to background ratio, which limited the sensitivity of ReD.

In this contribution, we describe the experimental setup and the preliminary results from the data analysis of ReD, as well as the perspectives to further lower the coverage down to the sub-keV range with ReD+.

**Light/Charge Readout** / **29**

## Quality control of PEN wavelength shifter for DarkSide-20k veto

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Efficient Wavelength Shifters (WLS) are crucial for liquid Argon (LAr) detectors. As the LAr detectors grow larger in volume, the scalability of WLS becomes an important concern. Tetraphenyl butadiene (TPB), which is the most common WLS in use, becomes impractical for LAr detectors with more than 100 mˆ2 of surface area due to its high cost and energy requirements.

DarkSide-20k veto detector will utilise nearly 200 mˆ2 of polyethylene naphthalate (PEN) wavelength shifter, available in form of large polymeric foil, a convenient alternative to TPB, albeit with approximately 50% reduced wavelength shifting efficiency. For quality assurance purposes, one needs to test multiple PEN samples from the DarkSide-20k production batch at cryogenic temperatures.

For this purpose, a new Argon Gas Setup (ArGSet) has been recently commissioned. In this setup, we exploit the Argon scintillation (128 nm) as excitation for measuring the wavelength shifting efficiency of the material under investigation.

In this work, we will present the results of the measurements of PEN for DarkSide-20k as well as comment on other alternative wavelength shifters for the future detectors.

**Signal reconstruction and identification** / **31**

## Neutron capture event selection using light and charge matching in the second DUNE Far Detector (FD2) module prototype at CERN

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Neutrons from the cavern in the DUNE Far Detector present a significant background in the low energy regime of a few MeV. Additionally, neutrons appear as the final state product in many low energy neutrino interaction channels in argon. Identifying the neutron capture signature is crucial for the DUNE low energy program. Neutron capture in argon releases a cascade of gamma rays, with the total energy summing to a monochromatic 6.1 MeV, making it a viable candidate for absolute energy scale calibration. The DUNE FD2 prototype uses X-ARAPUCA technology for photon detection and Charge Readout Planes (CRPs) for charge detection. The same X-ARAPUCA technology and CRPs will be used for the DUNE FD2 light and charge readout. A commercial pulsed neutron source was used to generate a beam of neutrons. As the neutrons enter the active volume, a fraction of them is captured by argon, releasing a gamma cascade, which produces light and charge detected by the Photon Detection System (PDS) and the CRPs, respectively. In this talk, the initial results of neutron capture signature identification in liquid argon at the DUNE FD2 prototype will be presented.

**Signal reconstruction and identification / 32**

## Scintillation Imaging with Coded Aperture Masks

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Most conventional noble liquid detectors employ scintillation light as either a timing signal for a TPC or as a calorimetric measurement, or both. Its relative amplitude and timing on multiple detectors can also be used to approximately locate an interaction.
Scintillation imaging goes a step further. By developing a suitable optical system, coupled with finely segmented SiPM arrays, it is possible to build photographic cameras that capture images of the primary scintillation light.
In absence of a TPC, scintillation imaging alone can provide vertexing and tracking information, while combined it can enhance resolution and rate capability (which is a concern for near detectors located on powerful neutrino beams).
Both Xe and Ar scintillate in the VUV range, imposing stringent requirements on the optical system and SiPMs. By replacing a traditional set of lenses with a coded aperture mask, a thin and compact camera with both deep and wide field of view can be created, at the modest cost of additional offline processing.
The latest results from simulation and reconstruction of neutrino interactions in a LAr detector equipped with these cameras will be presented. This work was supported by Grant "PRIN 2022KJZSYB".
A review of the applications, such as in DUNE/SAND, and the development status of key enabling technologies, such as a large, low power cryogenic ASIC and VUV-enhanced Backside Illuminated SiPMs will also be included.

**Poster Session / 33**

## Study of Ionization Form Factor: Insights from Argon and Xenon Targets

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In the context of the search for dark matter scattering signals with the nucleus, experiments using liquefied noble gases, such as argon (LAr) and xenon (LXe), play a significant role. The direct detection of dark matter particles with masses above 1 GeV/c² has already been extensively explored. Attention now turns to the low-mass region. An attractive opportunity in this region is the observation of signals from a possible interaction of light dark matter with electrons in the target material. Due to the high detection efficiency of S2 electroluminescence signals, even at low energies, scattering between light dark matter and electrons becomes a channel of great interest.

In this work, I present a study on the ionization form factor of argon and xenon atoms, essential for calculating the expected DM-electron scattering event rate in current detectors, along with the kinematic limitations imposed by the standard galactic dark matter halo model.

**Poster Session / 34**

## Comparing the performance of CuO dispersive media for O2 capturing in Liquid Argon

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In this work, we have explored the potential of oxygen capture in Liquid Argon (LAr) of the innovative CuO dispersive layered double hydroxide media (R-LDH) and the Ce-doped R-LDH. Low-temperature experiments in the LAr Purification Cryostat (PuLArC) at IFGW/Unicamp were performed using LAr circulation through two filters, one containing the R-LDH (or the Ce-doped R-LDH) material and the other the BASF commercial copper material (Cu-02265 - proposed as a reference O2 getter media by Fermilab) for comparison. Interestingly, the experiments performed in PuLArC revealed that the R-LDH and Ce-doped R LDH innovative medias were capable of capturing O2 from recirculating LAr in PuLArC. For instance, the R-LDH media reduced the O2 contaminants concentration to 80% of its initial values after 200 min of LAr circulation. As for the reference media BASF Cu-S0226, this media reduced the O2 concentration to 40% of its initial value in the same time window. The performance/kg of the studied media will be compared and we will discuss the putative higher potential of the innovative Ce-doped and pure R-LDH media for O2 capturing in LAr which may invoke further tests of these media in larger scale LAr cryostats, possibly at Fermilab and CERN.

**Applications / 35**

## The DarkSide-20k experiment

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DarkSide is a graded experimental project based on low background radiopure argon with the aim of the direct dark matter searches to probe the dark matter parameter space down and into the neutrino fog.
The experiment is presently under construction at INFN Gran Sasso National Laboratory.
The detector is constituted by a dual-phase liquid argon time-projection-chamber, acting as inner detector, made of low-radioactivity acrylic containing 50 tonnes (20 tonnes fiducial) of depleted (low Ar-39 content) argon and an optical read-out using Silicon Photomultipliers (SiPMs) and it is surrounded by two veto detectors respectively filled with 32 tonnes of depleted argon and 650 tonnes of atmospheric argon.
Several innovative technical solutions will be adopted for leading to outstanding sensitivities for direct dark matter searches.
In this context the design of the detector will be described, the ongoing activities as well as the current status of DarkSide-20k will be reported and the expected sensitivity will be discussed.

**Light/Charge Readout / 36**

## New candidate polymeric wavelength shifters for noble liquid detectors

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Scale-up of light collection scheme is a major challenge for the future multi-tonne detectors with surface area of many hundreds or even thousands of square meters. Large-format polymeric wavelength shifting foils are a compelling alternative to traditional vacuum evaporated coatings. Inspired by the success polyethylene naphthalate (PEN), which already finds use in large liquid argon detectors, other polymers have been surveyed that have not been considered before for this application. Some new candidates, exhibiting similar property of blue excimer fluorescence emission, have been identified and characterized. First measurement results will be reported; at room temperature with near UV excitation, as well as in cryogenic conditions under vacuum ultraviolet excitation, in conditions representative for the application.

**Detector techniques / 37**

## The 2.6m-high Xenoscope TPC: design, assembly, and first results

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The DARWIN project aims to build and operate a next-generation observatory for dark matter and neutrino physics, featuring a time projection chamber (TPC) with a proposed active target of 40 t of liquid xenon (LXe). Xenoscope is a full-scale vertical demonstrator for the future DARWIN detector built at the University of Zürich. Its main objective is to demonstrate electron drift over unprecedented distances in LXe in a dual-phase TPC. The cylindrical R&D detector has a diameter of 16 cm diameter and a total drift length of 2.6 m, corresponding to the foreseen height of DARWIN. The TPC is instrumented by an array of 192 VUV-sensitive 6x6 mm2 SiPMs (Hamamatsu VUV4 MMPCs) with a custom 12-channel summed readout. The array is placed above the active target and operated as a light readout for the proportional scintillation signals of the TPC.
This talk will present the design and assembly of the dual-phase TPC of Xenoscope, with special focus on its array of VUV SiPMs, as well as its first recorded data and results.

**Light/Charge Readout / 38**

## Properties of charge recombination in liquid argon

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Liquid argon is an excellent medium for detecting particles, given its yields and transport properties of light and charge. The technology of liquid argon time projection chambers has reached its full maturity after four decades of continuous developments and is, or will be, used in world class experiments for neutrino and dark matter searches. The collection of ionization charge in these detectors allows to perform a complete tridimensional reconstruction of the tracks of charged particles, calorimetric measurements, particle identification. This work proposes a novel approach to the problem of charge recombination in liquid argon which moves from a microscopic model and is applied to the cases of low energy electrons, alpha particles and nuclear recoils. The model is able to describe precisely several sets of experimental data available in the literature, over wide ranges of electric field strengths and kinetic energies and can be easily extended to other particles.

**Light/Charge Readout / 39**

## Advancements in SiPM Technology for Cryogenic Detectors for Dark Matter and Neutrino Research

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Silicon PhotoMultipliers (SiPMs) are being explored as potential photosensors employed in detectors operating at low temperatures, such as noble liquid (argon or xenon) experiments used in direct dark matter searches and neutrino physic investigations. Several studies have been conducted to optimize the features of these silicon photosensors, and many tests have been performed to improve the performances of SiPMs. In particular, the enhancement of photon detection efficiency is an essential requirement for dark matter and low-energy neutrino detection.

In the present work, we will review the historical transition from the first studies, through extensive R&D efforts, to the recent initial applications in real experiments at cryogenic temperatures.

An examination of the main SiPMs parameter behavior in cryogenic environments will be carried out, and the state-of-the-art of cryogenic SiPMs will be reported. We will then discuss the achieved performance of cryogenic SiPMs within ongoing detectors and their application in future experiments.

**Signal reconstruction and identification / 40**

## Improvements on Monte Carlo Scintillation Simulations

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In this work, the algorithm for simulating scintillation is examined, particularly the one used in the Geant4 toolkit. Being widely adopted in experimental particle physics, Geant4 became the standard for detector simulation, including those based on noble elements, which in turn are used due to their scintillation properties. Geant4 algorithms for scintillation physics are 20 years old and have seen just a couple of updates during this time. Here, we examine the current algorithm and its shortcomings, including percent-level systematic biases that we all need to be aware of. We also exemplify a particular situation where some materials can produce a significant bottleneck during a simulation's runtime. Finally, we propose changes that address these issues and perform a comparative analysis with the current algorithm.

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## Simulation of PEN materials for future use in argon-based detectors

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Liquid argon-based scintillation detectors are essential for dark matter searches and neutrino physics. The light detection in such detectors is still an object of research for large volumes. Liquid argon scintillation light is generated in the vacuum ultraviolet region, so it can undergo Rayleigh scattering and absorption before it gets detected. Using wavelength shifters may improve the light collection by converting the scintillation light to wavelengths that are less susceptible to such effects. Polyethylene Naphthalate (PEN) plastic scintillator, an optically transparent thermoplastic polyester commercially available, is a potential self-vetoing structural material in low-background physics experiments. In this work, we investigate the efficiency of PEN sheets using Geant4 simulations. These results will be used to guide future experimental setups with the same goal.

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## First signals of the X-ARAPUCA –APSAIA in SBND

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The SBND (Short Baseline Near Detector) is the near detector of the Short Baseline Neutrino Program (SBN) at Fermilab. Positioned 110 meters from the neutrino beam, the SBND will gather extensive data on neutrino-argon interactions. The SBND experiment utilizes the Liquid Argon Time Projection Chamber (LArTPC) technology for detection.

The Photon Detection System (PDS) consists of a passive element, Wavelength-Shifting Reflective plates coated with TPB at the cathode of the TPC, and two active elements: 8-inch Hamamatsu Cryogenic PMTs and the X-ARAPUCA system.

The entire X-ARAPUCA system was produced and assembled in Brazil at UNICAMP in collaboration with CTI. It comprises 192 modules, with half sensitive to vacuum ultraviolet (VUV) light and the other half to visible light. The readout system employs two types of customized electronics: APSAIA, developed with UNICAMP and CTI, and ARARA, developed in collaboration with the University of Michigan and Fermilab. The CAEN V1740 digitizer modules were provided by CIEMAT and UNICAMP.

Currently, we are in the commissioning phase of the experiment, and this work will present the first signals from the X-ARAPUCAs, including both VUV and visible readouts using the APSAIA front-end electronics.

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## Welcome

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**Closing Remarks & Discussion / 48**

## LIDINE 2025 Proposal: Hong Kong

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## Discussions

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## Closing

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## Neutrinoless double-beta decay search with the LEGEND experiment

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## Enhanced electroluminescence in LXe on thin strips

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Single-phase noble-liquid detectors have been proposed as a potential solution to the limitations introduced by the liquid-gas interface of dual-phase time projection chambers.

Following our previous research on electroluminescence (EL) production in liquid xenon (LXe) using a classical microstrip plate design, we report our findings on the operation in LXe of a microstrip plate with a virtual cathode (VCC) design and 2-um-wide parallel anode strips deposited on one face.

Electrons extracted from alpha-particle tracks induce EL in the intense non-uniform electric field in the vicinity of the strips. The signals produced (S2) are recorded along with the primary scintillation ones (S1) by a PMT immersed in the liquid. Moreover, the intense field near the strips induces charge avalanches, which are also detected. We find that this strip-plate configuration provides enhanced light and charge yields as well as better electrical stability at higher potentials than a plate with interlaced anode and cathode strips deposited on the same face. We will present our preliminary results on the operation of a VCC plate with a semi-conductive glass substrate (s8900), demonstrating its superior photoyield - reaching hundreds of photons/ionization electrons. The impact of the substrate material on the performance of the device will also be discussed.

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## Poster Award