LIDINE 2021: LIght Detection In Noble Elements

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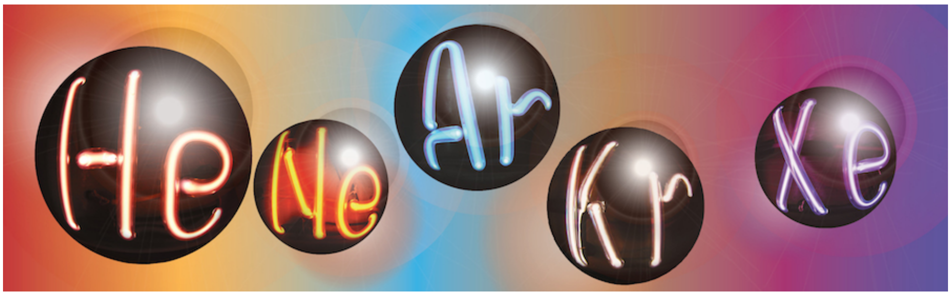

Book of Abstracts

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Applications (2B) / 1

Xenon-Doped Liquid Argon Scintillation for Positron Emission Tomography

Authors: Alejandro Ramirez[1]; Michela Lai[2]; Xinran Li[3]; Andrew Renshaw[1]; Masayuki Wada[4]; Azam Zabihi[4]

Co-authors: Davide Franco [5]; Federico Gabriele [6]; Cristiano Galbiati [7]; Hanguo Wang [8]

[1] *University of Houston*

[2] *INFN Cagliari*

[3] *Princeton University*

[4] *AstroCeNT*

[5] *Laboratoire APC*

[6] *INFN Laboratori Nazionali del Gran Sasso*

[7] *Princeton University*

[8] *University of California Los Angeles*

Corresponding Author: aramir52@cougarnet.uh.edu

Positron Emission Tomography (PET) is used to observe metabolic processes within patients. It works by reconstructing the annihilation origin of incident gamma rays produced by a positron emitting tracer. However, inefficiencies of current PET technology, such as the use of photomultiplier tubes, can result in poor imaging. In addition, current PET scanners possess a small field of view which limits the sensitivity. We propose 3Dπ: a full body, Time of Flight (TOF) PET scanner using Silicon Photomultipliers (SiPM) coupled with a Xenon-doped Liquid Argon (LAr+Xe) scintillator.

We simulated this design using Geant4 while following the National Electrical Manufacturers Association's evaluation tests for performance assessment. We will present results that highlight a 200-fold increase in sensitivity, spatial resolutions comparable to commercial PET scanners and produce PET images from 15-30 second scans, faster than traditional 30-35-minute scans. Further studies will involve optimizing the layer thickness of LAr+Xe. Moreover, scintillation induced ionization electrons can produce Cherenkov radiation along with the LAr+Xe scintillation light.

We will discuss strategies to characterize this other signal in Geant4 to improve the timing resolution of our scanner. With the LAr+Xe scintillator and SiPMs of 3Dπ, we can use the precise TOF info of gamma rays to improve the localization of individual positron annihilations, and as one example benefit, provide low-dose PET scans for patients who may be at high risk for exposure to radiation.

Light/Charge Readout (1C) / 3

Wavelength-Shifting Performance of Polyethylene Naphthalate Films in a Liquid Argon Environment

Author: Ryan Dorrill[1]

Co-authors: Bryce Littlejohn [1]; Jonathan Asaadi [2]

[1] *Illinois Institute of Technology*

[2] *University of Texas at Arlington*

Corresponding Author: dorrill1@gmail.com

Liquid argon is commonly used as a detector medium for neutrino physics and dark matter experiments in part due to its copious scintillation light production in response to its excitation and ionization by charged particle interactions. As argon scintillation appears in the vacuum ultraviolet (VUV) regime and is difficult to detect, wavelength-shifting materials are typically used to convert VUV light to visible wavelengths more easily detectable by conventional means. Here we present recent measurements of the wavelength-shifting and optical properties of poly(ethylene naphthalate) (PEN), a proposed alternative to tetraphenyl butadiene (TPB), the most widely-used wavelength-shifter in argon-based experiments. The measurements were performed in a custom cryostat system with well-demonstrated geometric and response stability, with 128˜nm argon scintillation light used to examine various PEN-including reflective samples' light-producing capabilities, as well as their stability. The best-performing PEN-including test reflector was found to produce 34% as much visible light as a TPB-including reference sample, with widely varying levels of light production between different PEN-including test reflectors.

Detector Techniques (4B) / 4

Measurement of the underground argon radiopurity for Dark Matter direct searches

Author: Pablo Garcia Abia[1]

[1] *CIEMAT*

Corresponding Author: pablo.garcia@ciemat.es

A major worldwide effort is underway to procure the radiopure argon needed for DarkSide-20k (DS-20k), the first large scale detector of the new Global Argon Dark Matter Collaboration. The Urania project will extract and purify underground argon (UAr) from CO2 wells in the USA at a production rate of 300 kg/day. Additional chemical purification of the UAr will be required prior to its use in the DS-20k LAr-TPC. The Aria project will purify UAr using a cryogenic distillation column (Seruci-I), located in Sardinia (Italy). Assessing the UAr purity in terms of Ar-39 is crucial for the physics program of the DarkSide-20k experiment. DArT is a small (1 litre) radiopure chamber that will measure the Ar-39 depletion factor in the UAr. The detector will be immersed in the active liquid Ar volume of ArDM (LSC, Spain), which will act as a veto for gammas from the detector materials and the surrounding rock. In this talk, I will review the status and prospects of the UAr projects for DarkSide-20k.

Light/Charge Response (1B) / 5

Preliminary studies towards spectroscopic-based particle discrimination in Ar

Author: Vicente Pesudo Fortes[1]

Co-authors: Edgar Sánchez-García [1]; Pablo García-Abia [1]; Roberto Santorelli [1]; Rodrigo López-Manzano [1]; Diego González-Díaz [2]; Luciano Romero [1]; Juan José Martínez-Morales [1]

[1] *CIEMAT*

[2] *U. Santiago de Compostela*

Corresponding Author: vicente.pesudo@ciemat.es

Noble elements are the active medium of choice for several among the most important neutrino and dark matter experiments being built now. The foreseen next generation, besides going bigger, would benefit from any feature not-yet exploited of this technology.

With this goal, we performed a time-resolved spectroscopic study of the VUV/UV scintillation of gaseous argon as a function of pressure and electric field, by means of a wavelength sensitive detector operated with different radioactive sources.

Our work conveys new evidence of distinctive features of the argon light which are in contrast with the general assumption that, for particle detection purposes, the scintillation can be considered to be largely monochromatic at 128 nm (second continuum).
The wavelength and time-resolved analysis of the photon emission reveal that the dominant component of the argon scintillation during \blue{the} first tens of ns is in the range [160, 325] nm. This light is consistent with the third continuum emission from highly charged argon ions/molecules. This component of the scintillation is field-independent up to 25 V/cm/bar and shows a very mild dependence with pressure in the range [1, 16] bar. The dynamics of the second continuum emission is dominated by the excimer formation time, whose variation as a function of pressure has been measured. Additionally, the time and pressure-dependent features of electron-ion recombination, in the second continuum band, have been measured. This study opens new paths toward a novel particle identification technique based on the spectral information of the noble-elements scintillation light.

Detector Techniques (3A) / 6

Proposal of a Geiger-geometry Single Phase Time Projection Chamber as Potential Detector Technique for next-generation large-scale dark matter search detector

Author: Qing Lin[1]

[1] *University of Science and Technology of China*

Corresponding Author: qinglin@ustc.edu.cn

Dual phase time projection chamber using liquid xenon as target material is one of most successful detectors for dark matter direct search, and has improved the sensitivities of searching for weakly interacting massive particles by almost five orders of magnitudes in past several decades. However, it still remains a great challenge for dual phase liquid xenon time projection chamber to be used as the detector in next-generation dark matter search experiments (~50 tonne sensitive mass), in terms of reaching sufficiently high field strength for drifting electrons, and sufficiently low background rate. Here we propose a single phase liquid xenon time projection chamber with detector geometry similar to a Geiger counter, as a potential detector technique for future dark matter search, which trades off field uniformity for less isolated charge signals. In this talk, I will talk about the concept of such Geiger-geometry single phase TPC (GG-TPC). I'll show preliminary studies of field simulation and signal reconstruction, which show that such single phase time projection chamber is technically feasible and can have sufficiently good signal reconstruction performance for dark matter direct search.

Detector Techniques (3A) / 7

Latest Results from the Xenon Breakdown Apparatus

Authors: Reed Watson[1]; Daniel McKinsey[None]; Ibles Olcina[2]

[1] *University of California, Berkeley*

[2] *UC Berkeley*

Corresponding Author: watson_james@berkeley.edu

The Liquid Xenon Time-Projection Chamber (LXe TPC) is a leading technology in the fields of dark matter direct detection and neutrinoless double-beta decay searches, due in no small part to its scalability. The next generation of LXe TPCs intend to extend their drift lengths while maintaining their high operational electric fields (100s of Volts per cm). This increase in high voltage requires understanding how the risk of electrostatic discharge (ESD) correlates with various engineered quantities. To this end, the Xenon Breakdown Apparatus (XeBrA), a 5 Liter spark chamber with adjustable large area electrodes and transparent viewports, collected data on ESD in LXe under a variety of different conditions. Effects such as conditioning, pressure, ramp rate, stressed area, and surface finish were investigated. Data regarding the production of light and charge preceding an ESD were collected, along with novel position reconstruction of the associated plasma streamers using a pair of high frame rate cameras. In this talk, I present preliminary results from XeBrA and discuss the evidence collected for field-emission initiating breakdowns.

Light/Charge Readout (4A) / 8

XENONnT light sensors: performance and reliability

Author: Giovanni Volta[1]

Co-author: XENON collaboration

[1] *University of Zurich*

Corresponding Author: gvolta@physik.uzh.ch

XENONnT is a dark matter direct detection experiment, currently in commissioning phase, located at Laboratori Nazionali del Gran Sasso. It utilizes a TPC filled with 8.5 t of liquid xenon of which 5.9 t instrumented with 494 3-inch Hamamatsu R11410-21 photomultiplier tubes (PMTs) divided into two arrays, placed at the top and bottom of the active volume. The light sensors have been selected after a testing campaign to ensure a reliable response and a time-stable functioning. These operations are briefly summarized, while the discussion is focused on the current PMT performance.

Light/Charge Response (1B) / 9

LArQL: A phenomenological model for treating light and charge generation in liquid argon

Authors: Franciole Marinho[1]; Laura Paulucci[2]; Flavio Cavanna[3]; Dante Totani[None]

[1] *UFSCar*

[2] *UFABC*

[3] *Fermilab*

Corresponding Author: franciole@gmail.com

Experimental data shows that both ionization charge and scintillation light in LAr depend on the deposited energy density (dE/dx) and electric field (⊠). Moreover, free ionization charge and scintillation light are anticorrelated, complementary at a given (dE/dx, ⊠) pair. We present a phenomenological model, called LArQL, that provides the anticorrelation between light and charge and also its dependency on the deposited energy as well as on the electric field applied. The model is built with three parameters to be fitted to data: ionizations per energy unit, number of excitations/ionizations, and the fraction of escaping electrons, as function of deposited energy. LArQL modifies the Birks (or Box) charge model considering three aspects: 1. at ⊠ = 0, escaping electrons are taken into account; 2. just above ⊠ = 0 field extracted electrons are added; 3. at higher fields, escaping electrons tend to zero and the Birks model is recovered. Deviations from current Birks Law are observed only for LArTPC operating at low ξ and for heavily ionizing particle (stopping protons). The model presents a satisfactory description at dE/dx and field ranges for interacting particles in LArTPCs and fits well the available data. Improvements via data sets compilation and "global" fits are also interesting features of the model.

Light/Charge Readout (1C) / 10

The DUNE Vertical Drift Photon Detection System

Author: Laura Paulucci, for the DUNE Collaboration[None]

Corresponding Author: lapaulucci@gmail.com

The Deep Underground Neutrino Experiment (DUNE) is a long baseline neutrino experiment designed to mainly investigate oscillation parameters, supernova physics and proton decay. Its far detector will be composed of four liquid argon time projection chamber (LArTPC) underground modules, in South Dakota-USA, which will detect a neutrino beam produced at Fermilab, 1300 km away, where a near detector will be in place. The second DUNE far detector module, Vertical Drift, will be a single phase LArTPC with electron drift along the vertical axis with two volumes of 13.5 m x 6.5 m x 60 m dimensions separated by a cathode plane. The charge collection will be performed by two anode planes, each composed by stacked layers of a perforated PCB technology with electrode strips placed at the top and bottom ends of the module. The photon detection system (PDS) will make use of large size X-Arapuca tiles distributed over three detection planes. One plane will consist of a horizontal arrangement of double side tiles installed on the high voltage cathode plane and two vertical planes, each placed on the longest cryostat membrane walls. A light active coverage of 14.8% over the cathode and 7.4% over the laterals should allow improvements in the low energy physics range that can be probed in DUNE, especially regarding supernova neutrinos (˜10 MeV). We present the initial characterization of the Vertical Drift PDS using a Monte Carlo simulation and preliminary studies on its reconstruction capabilities at the MeV scale. The information obtained with the PDS alone should allow determination of a neutrino interaction region with a precision of at least 65 cm for events with deposited energy above 5 MeV and the deposited energy can be reconstructed with precision better than 10%.

Light/Charge Response (1B) / 11

Scintillation and ionisation response of the ReD double-phase argon TPC

Author: Marco Rescigno[1]

Co-author: Pablo Garcia Abia [2]

[1] *INFN/Roma*

[2] *CIEMAT*

Corresponding Authors: pablo.garcia@ciemat.es, marco.rescigno@roma1.infn.it

The Recoil Directionality (ReD) experiment aims to investigate the directional sensitivity of argon-based Time Projection Chambers (TPCs) via columnar recombination to nuclear recoils in the energy range of interest (20–200 keV) for direct dark matter searches. Directional information is an essential requisite for correlating a candidate dark matter signal with the expected "wind" of dark matter from the Cygnus constellation. As part of the DarkSide programme, the ReD collaboration has designed and constructed a double-phase argon TPC and fully characterised its performance using various gamma-ray and neutron sources. The key novel feature of the ReD TPC is a readout system based on cryogenic Silicon Photomultipliers (SiPMs), which offer a higher photon detection efficiency relative to typical cryogenic photomultipliers. Here we report on measurements of the scintillation light yield and ionization gain performed over five months of continuous operation. We present a phenomenological parameterisation of the electron-ion recombination probability in liquid argon (LAr) that describes the anti-correlation between scintillation and ionisation signals measured by ReD as a function of drift field for electron recoils between 50–500 keV and fields up to 1000 V/cm.

Finally, a likelihood analysis is performed in order to study the directional response of the ReD TPC to neutrons of known energy and direction.

Signal Reconstruction (3C) / 12

Simulations of Geometric Aspects for ARAPUCA Designs

Authors: Marcio Rostirolla Adames[1]; Andre Steklain[1]; Francisco Ganacim[1]

[1] *UTFPR*

Corresponding Author: marcioadames@utfpr.edu.br

The photon detection system of DUNE Far Detector (FD) is based on ARAPUCA technology. The new version of ARAPUCA, named X-ARAPUCA, will be used in the first and second modules. As the second module is based on vertical drift, the design of the X-ARAPUCA needed to be changed and simulation studies are fundamental for the optimization of the device. This work presents the simulation studies of the design, size, shape, and SiPM positioning inside the reflective cavity.

We designed a Python module that creates the geometry for the simulations based on given parameters such as size of the detector, numbers of SiPM and others. The physics of photons inside the X-ARAPUCA is simulated by a ray-tracer written in C++ using an uniform grid as acceleration structure. Our simulations focus on reflections and refractions using Snell's law on the interfaces and the total internal reflections inside the Wavelength Shifting Plate, that absorbs every incoming photon and re-emits them in a random direction.

The simulation shows that the highest efficiency is reached for thin X-ARAPUCA with a square shape. Better efficiency is obtained for larger modules if one considers the number of SiPM per cm^2 of the active collection area. Rectangular modules are more efficient when the SiPMs are positioned on the short side.

Light/Charge Response (1B) / 13

Xenon doping of Liquid Argon in ProtoDUNE Single Phase

Author: Niccolo' Gallice[1]

[1] *Università degli Studi di Milano - INFN Milano*

Corresponding Author: niccolo.gallice@mi.infn.it

The Deep Underground Neutrino Experiment (DUNE) will be the next generation long-baseline neutrino experiment. The far detector is designed as a complex of four LAr-TPC (Liquid Argon Time Projection Chamber) modules with 17 t of LAr each. The development and validation of its technology is pursued through ProtoDUNE Single Phase (ProtoDUNE-SP), a 770 t LAr-TPC at CERN Neutrino Platform. Crucial in DUNE is the Photon Detection System that will enable the trigger of non-beam events - proton decay, supernova neutrino burst, solar neutrinos and BSM searches - and will improve the timing and calorimetry for neutrino beam events. Doping Liquid Argon (LAr) with Xenon is a well known technique to shift the light emitted by Argon (128 nm) to a longer wavelength (175 nm) to ease its detection. The largest Xenon doping test ever performed in a LArTPC was carried out in ProtoDUNE-SP. From February to May 2020, a gradually increasing amount of Xenon was injected to compensate for the light loss due to air contamination. The response of such a large TPC (770 t of Liquid Argon and 440 t of fiducial mass) has been studied using the ProtoDUNE-SP Photon Detection System (PDS) and a dedicated setup installed before the run.
Here we introduce the Xenon doping technique as well as the specific detector components developed for this campaign and the results of the study with particular regard to the modification of

the scintillation signal, the uniformity of the light collection and the efficiency of the wavelength-shifting mechanism.

Light/Charge Response (1B) / 14

Measuring the Rayleigh Scattering Length of Liquid Argon in ProtoDUNE-SP

Author: Kyle Spurgeon[1]

Co-author: Denver Whittington [1]

[1] *Syracuse University*

Corresponding Author: klspurge@syr.edu

ProtoDUNE-SP was a single-phase liquid argon time projection chamber - a prototype for the first far detector module of the Deep Underground Neutrino Experiment (DUNE) with an active volume of 700 tons operating until 2020. It was installed at the CERN Neutrino Platform and took particle beam and cosmic ray data over its two year lifespan. Liquid argon scintillation light is still an active subject of study with open questions about the impact of scattering and absorption in such a large detector. Here, we combine ProtoDUNE-SP cosmic-ray data with its large photon detector coverage and large drift volume to measure the Rayleigh scattering length of liquid argon. We also lay the groundwork for investigating Rayleigh scattering of scintillation light from xenon-doped liquid argon.

Light/Charge Readout (3B) / 15

Scintillation light detection in the 6-m drift length ProtoDUNE Dual Phase liquid argon TPC

Author: Inés Gil-Botella[1]

[1] *CIEMAT Madrid*

Corresponding Author: ines.gil@ciemat.es

The Deep Underground Neutrino Experiment (DUNE) is a leading-edge experiment for long-baseline neutrino oscillation studies, neutrino astrophysics and nucleon decay searches. ProtoDUNE-Dual Phase (DP) is a 6x6x6 m3 liquid argon time-projection-chamber (LArTPC) operated at the CERN Neutrino Platform in 2019-2020 as a prototype of the DUNE Far Detector. In ProtoDUNE-DP, the scintillation and electroluminescence light produced by cosmic muons in the LArTPC is collected by photomultiplier tubes placed up to 7 m away from the ionizing track. In this talk, we will present the performance of the ProtoDUNE-DP photon detection system, comparing different wavelength-shifting techniques and the use of xenon-doped LAr as a promising option for future large LArTPCs. The scintillation light production and propagation processes are analyzed and compared to simulations, improving understanding of the liquid argon properties.

Light/Charge Readout (3B) / 16

Development of analog signal transmission in LAr for DUNE

Author: Sabrina Sacerdoti[1]

[1] *APC-Paris,France*

Corresponding Author: sabrina.sacerdoti@cern.ch

The Deep Underground Neutrino Experiment (DUNE) is currently investigating a new prototype design for its second Far Detector module. The new concept proposes a Vertical Drift LArTPC, with a cathode at mid-height in the detector and anodes made of printed circuit boards, located at the top and bottom of the detector.
In this context, the design of the Photo-Detection System (PDS) needs to be revisited, opening a window of opportunity for further optimization and new developments. It is envisaged to distribute the photo-sensors (x-Arapuca) on the cathode surface. Such a system is required to operate within high-voltage surfaces, with both power supply and signal delivered using non-conductive materials. The aim of this talk is to describe the on-going work to collect and read-out the signal of the photo-sensors, which are re-shaped into large tiles containing 160 SiPMs each. A new ganging scheme for the SiPMs is introduced. In particular, this talk will focus on the proposed option to read out the sensors using an analog optical transmitter, that should ensure the transmission of the signals - with a wide dynamic range - to the outside of the cryostat to be digitized.

Light/Charge Response (1B) / 17

Predicting transport effects of scintillation light signals in large-scale liquid argon detectors

Authors: Patrick Green[1]; Diego Garcia-Gamez[2]; Andrzej Szelc[3]

[1] *The University of Manchester*

[2] *University of Granada*

[3] *University of Edinburgh*

Corresponding Author: patrick.green-3@postgrad.manchester.ac.uk

Liquid argon is being employed as a detector medium in neutrino physics and dark matter searches. A recent push to expand the applications of scintillation light in Liquid Argon Time Projection Chamber neutrino detectors has necessitated the development of new methods of simulating this light. The presently available methods tend to be prohibitively slow or imprecise due to the combination of detector size and the amount of energy deposited by neutrino beam interactions. In this talk we present a semi-analytical model to predict the quantity of argon scintillation light observed by a light detector based only on the relative positions between the scintillation and light detector. Our proposed method can be used to simulate light propagation in large-scale liquid argon detectors such as DUNE or SBND. This talk is based on Eur. Phys. J. C 81, 349 (2021), and will expand on the methods presented there applying them to other detector mediums such as liquid xenon or xenon-doped liquid argon.

Poster in Gather.Town / 18

Scintillation-based background rejection methods in large scale LArTPCs

Authors: Anyssa Navrer-Agasson[1]; David Marsden[None]; Andrzej Szelc[None]; Patrick Green[None]; Stefan Soldner-Rembold[None]

[1] *The University of Manchester*

Corresponding Author: anyssa.navrer-agasson@manchester.ac.uk

Large scale single-phase liquid argon time projection chambers (LArTPCs) such as DUNE can achieve MeV-scale thresholds, making them sensitive to solar and supernova neutrinos. In this energy region,

low energy activity from radiological sources can be a dominant background. LArTPCs can make use of the scintillation light to discriminate against radiological backgrounds. This talk will present rejection methods exploiting the scintillation light in LArTPCs. We studied a range of detector configurations and rejection approaches based on the properties of the light (pulse shape discrimination) and/or on the detector design.

Signal Reconstruction (3C) / 19

Demonstration of ~ns timing resolution in MicroBooNE Photon Detection System

Author: Dante Totani[1]

[1] *University of California, Santa Barbra*

Corresponding Author: dtotani@ucsb.edu

The MicroBooNE detector, located in the Booster Neutrino Beamline (BNB) at Fermilab, has been operating since 2015 as part of the Short Baseline Neutrino (SBN) program. MicroBooNE's Liquid Argon Time Projection Chamber is accompanied by a Photon Detection System (consisting of 32 PMTs) used to measure the argon scintillation light and determine the timing of the neutrino interactions. This work will demonstrate the analysis techniques developed to improve the timing resolution of the light signals to $\mathcal{O}$(ns). The result obtained allows MicroBooNE to access the 2ns neutrino pulse structure of the BNB for the first time, which enables significant enhancement of cosmic background rejection for all neutrino analyses. Furthermore, the ns timing resolution opens the door for searching new long-lived-particles (i.e. Heavy Neutral Lepton, Higgs Portal Scalars) as we develop light-based trigger systems for future large LArTPC experiments, namely SBN and DUNE.

Light/Charge Readout (1C) / 20

Direct detection of argon scintillation light using VUV-sensitive silicon photomultipliers

Author: Teal Pershing[1]

[1] *Lawrence Livermore National Lab*

Corresponding Author: pershing1@llnl.gov

In recent decades, argon-based particle detectors have become a widely-used technology for numerous applications, including dark matter searches and neutrino measurements. For these detector designs, WaveLength Shifters (WLS) such as tetraphenylbutadiene (TPB) are used to shift argon's scintillation light from the hard UV (128 nm) to visible wavelengths. In particular, the use of PhotoMultiplier Tubes (PMTs) in argon-based detectors can require WLS for successful light detection and event reconstruction. Recently, Hamamatsu has produced a line of Silicon PhotoMultipliers (SiPMs) which show appreciable photon detection efficiencies down to 100 nm; deploying such photosensors in an argon-based detector could bypass the need for wavelength shifting materials. This talk will present the measurement ongoing at LLNL to demonstrate direct detection of argon scintillation light using Hamamatsu's VUV-sensitive SiPMs, as well as quantify their performance (gain, cross-talk, photon detection efficiency, etc.) for future deployment in argon-based detectors.

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Signal Reconstruction (2C) / 21

Salting as a bias mitigation technique in LUX-ZEPLIN (LZ)

Author: Tyler Anderson[1]

[1] *SLAC*

Corresponding Author: tylerja@stanford.edu

As LZ prepares to push the limits of known physics and improve our understanding of the nature of dark matter, it is important to ensure that these gains are not mistakenly influenced by human biases towards achieving such results. Such biases often appear in the process of analysis when unconsciously or consciously expecting certain outcomes. Many techniques for avoiding these biases have been employed over the years including blinding and using hidden parameters. LZ will be using a method known as salting, in which fake signal events are injected into our data stream and removed after analysis is complete. In this presentation I will explain the historical motivations for pursuing bias mitigation, the process through which LZ salts its data, and some results after salting LZ's simulated mock data challenges.

Detector Techniques (3A) / 22

Mind the (gas) gap: a single-phase liquid xenon TPC

Authors: Adam Brown[1]; Fabian Kuger[1]; Marc Schumann[1]

[1] *University of Freiburg*

Corresponding Author: adam.brown@physik.uni-freiburg.de

One of the most significant challenges for future dual-phase xenon TPCs is achieving the high, uniform electric field needed in the gas layer. One solution is to avoid using gaseous xenon and instead to create the secondary scintillation within the liquid itself, in a single-phase xenon TPC. Within micrometres of thin wires, the electric field is high enough to enable VUV scintillation. Avoiding the gas gap can provide a workaround to some of the technical challenges facing larger TPCs. At the same time, it opens up new detector design possibilities by relaxing the requirement that electrons are drifted upwards and facilitates analysis based on counting electrons. We discuss some of these advantages and present experimental results from a small single-phase demonstrator TPC with 10 µm anode wires.

Poster in Gather.Town / 23

Simulating and Validating the X-ARAPUCA light sensors

Authors: Gustavo Valdiviesso[1]; Anibal Thiago Bezerra[1]; Ana Amélia Machado[2]; Ettore Segreto[2]

[1] *Universidade Federal de Alfenas Unifal-MG*

[2] *Unicamp*

Corresponding Author: gustavo.valdiviesso@unifal-mg.edu.br

Brazil's native people have an ingenious trap to catch birds called arapuca. Our ARAPUCA is a light trap that increases the collection area of regular SiPMs by making use of wavelength shifters and a dichroic filter. Its latest iteration, the X-ARAPUCA, will be used alongside PMTs in Short-Baseline Near Detector (SBND) and as the standalone photon detector in the Deep Underground Neutrino Experiment (DUNE). The SBND is part of the three-detectors Short-Baseline Neutrino (SBN) Program,

search for a possible sterile neutrino in short-baseline oscillations (with SBND located at 100m from the source), while DUNE will look for signs of CP-violation in long-baseline (1300km) oscillations, among other items in a rich physics program. Contributing with both experiments, we developed detailed simulations of each optical element, from which we highlight the dichroic filter and the wavelength shifters. While the backbone of the simulation uses Geant4, these two elements were implemented from scratch to ensure they would represent our device. The models were individually validated using dedicated characterization data and the resulting simulation reproduces the physical device behavior without the need for a back-fitting calibration. In this presentation we will elaborate on the computer models and the validation processes for each element and compare the resulting full simulation with the X-ARAPUCA's most recent tests.

Signal Reconstruction (3C) / 24

Neutrino Backgrounds in Future Liquid Noble Element Dark Matter Direct Detection Experiments

Author: Pietro Giampa[1]

[1] *SNOLAB*

Corresponding Author: pgiampa@snolab.ca

Experiments that use liquid noble gasses as target materials, such as argon and xenon, play a significant role in direct detection searches for WIMP(-like) dark matter. As these experiments grow in size, they will soon encounter a new background to their dark matter discovery potential from neutrino scattering off nuclei and electrons in their targets. Therefore, a better understanding of this new source of background is crucial for future large-scale experiments such as ARGO and DARWIN. In this work, we study the impact of atmospheric neutrino flux uncertainties, electron recoil rejection efficiency, recoil energy sensitivity, and other related factors on the dark matter discovery reach. We also show that a significant improvement in sensitivity can potentially be obtained, at large exposures, by combining data from independent argon and xenon experiments.

Poster in Gather.Town / 25

Scintillation light yield of solid Xenon

Author: Marco Guarise[1]

[1] *University of Ferrara*

Corresponding Author: grsmrc@unife.it

Scintillation properties of rare gas materials are of primary importance for the next generation dark matter and neutrino experiments. Above the liquid phase of such elements, also solid crystals can be used for suitable detection schemes but unfortunately only sporadic data regarding the luminescence properties of Xenon at temperatures uder its melting point are present in literature. In this contribution, we present a study of the scintillation light yield of Xenon in the solid phase at different temperatures in the range (30–160)K. This study has been carried out exploiting the light emission from solid Xenon consequent to the energy release of cosmic rays in the crystal.

Applications (2B) / 26

First Results from the Light only Liquid Xenon experiment

Author: Austin de St. Croix[1]

Co-authors: Fabrice Retiere [2]; Thomas Brunner [3]; Simon Viel [4]; Marc-André Tetrault [5]; Soud Al Kharusi [3]; Bindiya Chana [4]; Liang Xie [2]; Pietro Giampa [6]; Mayur Patel [7]; Ben Tores-Kulik [2]; Thomas McElroy [8]

[1] *Queens University/TRIUMF*

[2] *TRIUMF*

[3] *McGill*

[4] *Carleton University*

[5] *Université de Sherbrooke*

[6] *SNOLAB*

[7] *TRIUMF/Simon Fraser University*

[8] *University of Alberta*

Corresponding Author: austindestecroix@gmail.com

This talk will present results from the first liquid xenon dataset of the Light only Liquid Xenon (LoLX) experiment, collected in June of 2021. LoLX aims to investigate both scintillation and Cherenkov light emission in liquid xenon for applications in rare event searches and PET. The detector consists of 24 Hamamatsu VUV4 Silicon Photomultipliers (SiPM) arranged in an octagonal cylinder. A needle holds a Strontium 90 beta source in the detector center, which produces the scintillation and Cherenkov light. Longpass optical filters are placed in front of 22 SiPMs to separate the less abundant Cherenkov light from the VUV scintillation light. In addition to studying light production in liquid xenon, LoLX also aims to characterize external cross-talk (eXT) between SiPMs at various geometries. eXT occurs when IR photons produced during a charge avalanche in one SiPM trigger avalanches in a different SiPM. This acts as correlated noise across channels, thus characterizing eXT is crucial for rare event searches using large arrays of SiPMs. Future experimental phases of LoLX will upgrade the SiPM and digitizer scheme to attain sub nanosecond timing resolution with the goal of performing temporal separation of the Cherenkov and scintillation light, which may lead to improving time-of-flight PET imaging.

Applications (2B) / 27

Low Energy Physics Sensitivity in a Radiopure DUNE-like Detector

Author: Eric Church[1]

[1] *PNNL*

Corresponding Author: eric.church@pnnl.gov

With radiopurity controls and small design modifications a kton-scale liquid argon time projection chamber similar to DUNE could be used for enhanced low energy physics searches. This includes improved sensitivity to supernova and solar neutrinos, and even weakly interacting massive particle dark matter, and a possibility of 0nubb detection with large Xe316 doping. This talk will present initial simulation studies to optimize the design and evaluate physics sensitivities. It will also discuss the tools being developed to support a large-scale radiopurity assay campaign necessary to construct such a detector.

Light/Charge Readout (1C) / 28

Amorphous Selenium based VUV Photodetector for use in Liquid Noble Detectors

Author: Jonathan Asaadi[1]

[1] *University of Texas at Arlington*

Corresponding Author: jonathan.asaadi@uta.edu

Photon detectors which are sensitive to the vacuum ultraviolet (VUV) scintillation light produced in noble element particle detectors is an area of active research and development. In particular, searching for photoconductive materials which are capable of converting VUV light to charge could open the doorway to a potentially game changing solution of an integrated charge and light (Q+L) sensor for large area pixel based noble element detectors.In this talk, we present the study of amorphous selenium based photodetectors capable of operating at cryogenic temperatures and show the first measurements and characterizations made with these devices using a VUV source in a cryogenic environment.

Detector Techniques (4B) / 29

Development of a Pulsed VUV Light Source With Adjustable Intensity

Author: Austin McDonald[1]

[1] *University of Texas at Arlington*

Corresponding Author: austin.mcdonald@uta.edu

Precise characterization of photodetectors sensitive to vacuum ultraviolet (VUV) require a calibration source able to:i) produce and transmit photons in the VUV (128nm - 200nm), ii) control the light intensity and reliably obtain single photon transmission, iii) produce a pulsed photon emission so as to correlate the source with the VUV readout.In this talk, we will present the development of gas based pulsed spark. This source emits VUV light in the range produced by noble element detectors and is coupled with a gas based attenuator capable of delivering single photon intensities to the device under test. We will present the first data taken with this device as well as highlight some of its recent applications in the development of novel VUV photon detectors.

Applications (1A) / 30

Status of the LZ Dark Matter Experiment

Author: Sally Shaw[1]

[1] *UCSB*

Corresponding Author: sally@physics.ucsb.edu

The fundamental nature of our universe is still mostly unknown: 84% of the matter in the universe is dark and qualitatively different to everything we understand via the Standard Model. Terrestrial experiments devoted to detecting interactions of dark matter particles have not yet seen a convincing signal, but we may be on the cusp of discovery. The LUX-ZEPLIN experiment (LZ) will be the largest dark matter detector of its kind, consisting of a 7T liquid xenon target, an 2T active skin veto and a 17T gadolinium-loaded liquid scintillator neutron veto. With science data taking beginning this year, LZ will probe theoretically well-motivated regions of dark matter phase space to reach areas currently unexplored; the predicted spin-independent cross section is 1.4x10-48cm2 for a 40 GeV/c2 mass WIMP. I will give an overview of the LZ experiment and its current status.

Light/Charge Response (2A) / 31

Electronic versus nuclear recoil discrimination in liquid xenon with PIXeY

Author: Vetri Velan[1]

Co-author: PIXeY Collaboration

[1] *University of California, Berkeley*

Corresponding Author: vvelan@berkeley.edu

The two-phase liquid/gas xenon time projection chamber is one of the leading technologies for dark matter direct detection. A crucial part of using this technology is being able to classify energy deposits as nuclear recoils (NR) or electronic recoils (ER). This allows upcoming experiments like XENONnT and LZ to mitigate ER backgrounds like Rn daughters and solar neutrinos. I will present an analysis of ER-NR discrimination, using data from the PIXeY (Particle Identification in Xenon at Yale) experiment. PIXeY was an R&D-scale xenon TPC that operated at drift fields between 50 and 2000 V/cm; its data allows us to study discrimination across this wide range of fields, as well as its dependence on recoil energy.

Signal Reconstruction (2C) / 32

A first-principles approach to electron-ion recombination in liquid xenon

Author: Olivia Piazza[None]

Co-authors: Daniel McKinsey ; Vetri Velan [1]

[1] *University of California, Berkeley*

Corresponding Author: piazza.olivia@berkeley.edu

A simulation was developed to explore the micro-physics of electron-ion recombination and recombination fluctuations in liquid xenon detectors. Generating primary mono-energetic particles between 100eV and 10keV with a drift field of 50V/cm to 2000V/cm, the model characterizes recombination events and predicts ionization yields. Of particular interest, the simulation utilizes realistic electron transport kinematics and the Cohen-Lekner 'hot electron' framework to describe the reduced influence of the liquid structure of xenon on the scattering of low energy electrons. Results obtained can be useful in the search for dark matter candidates and neutrino detections.

Light/Charge Readout (4A) / 34

The ABALONE Photosensor

Authors: Valerio D'Andrea[1]; Riccardo Biondi[2]; Alfredo Davide Ferella[3]; Joern Mahlstedt[4]; Giulia Pieramico[5]

[1] *UnivAQ & LNGS*

[2] *LNGS*

[3] *UnivAQ*

[4] *Stockholm*

[5] *UniRoma1 & LNGS*

Corresponding Author: valerio.dandrea@lngs.infn.it

The ABALONE is a new type of photosensor produced by PhotonLab with cost effective mass production, robustness and high performance. This modern technology provides sensitivity to visible and UV light, exceptional radio-purity and excellent detection performance in terms of intrinsic gain, afterpulsing rate, timing resolution and single-photon sensitivity.
The new hybrid photosensor, that works as light intensifier, is based on the acceleration in vacuum of photoelectrons generated in a traditional photosensor cathode and guided towards a window of scintillating material that can be read from the outside through a silicon photomultiplier (SiPM).
In this contribute we present the characterization of the ABALONE operated at room temperature for the evaluation of the gain as function of the electric field, the response in time and the single-photoelectron spectrum. In order to better understand the experimental results, we performed the simulation of the photosensor by reproducing the electrostatic field, by tracking the accelerated photoelectrons and their interaction in the scintillation window.
Soon we plan to operate the ABALONE in a Xe environment. Details of future tests and possible applications in the context of next-generation astroparticle physics experiments (e.g., DARWIN) will be also discussed.

Light/Charge Readout (4A) / 35

R&D and characterization of wavelength-shifting reflectors for LEGEND-200 and for future LAr-based detectors

Author: Gabriela Rodrigues Araujo[1]

[1] *University of Zurich*

Corresponding Author: gabriela@physik.uzh.ch

The new design of the LAr veto of the LEGEND-200 neutrinoless double beta decay experiment, as well as many other LAr-based detectors, require materials that can efficiently shift VUV light to the visible range while being reflective to visible light. For the LAr veto of LEGEND-200, 14 square meters of the reflector Tetratex (TTX) were coated in-situ with tetraphenyl butadiene (TPB). For even larger detectors, TPB coating becomes more challenging and plastic films of polyethylene naphthalate (PEN) could be an option to ease scalability. In this context, we characterized the specific sample of the wavelength-shifting reflector (WLSR) from LEGEND-200 and investigated the light yield from the combination of a PEN film with the reflector TTX. Samples from both WLSRs were measured with spectrophotometers, observed with a microscope, and then characterized in a LAr setup equipped with a VUV sensitive photomultiplier. Parameters such as the reflectance, absorption length and light yield of the samples (as well as of the setup and its materials) were measured, such that the intrinsic quantum efficiency of PEN and TPB in LAr (at 87K) could be estimated.

Light/Charge Readout (4A) / 36

Usage of PEN as self-vetoing structural material with wavelength shifting capabilities in the LEGEND experiment

Author: Luis Manzanillas[1]

[1] *Max Planck Institute for Physics*

Corresponding Author: manzanil@mpp.mpg.de

Polyethylene naphthalate (PEN) is an interesting industrial plastic for the physics community as a wavelength-shifting scintillator. Recently, PEN structures with excellent radiopurity have been successfully produced using injection compression molding technology. This opens the possibility

for the usage of optically active structural components with wavelength shifting capabilities in low-background experiments. Thus, PEN holders will be used to mount the Germanium detectors in the LEGEND-200 experiment. The ongoing R&D on PEN will be outlined with a focus on the evaluation of its optical properties. In addition, the ongoing efforts for further application of PEN in the LEGEND-1000 experiment will be presented.

Detector Techniques (3A) / 37

A proposal to use neutron captures as a source of ultra-low energy nuclear-recoils in liquid xenon

Author: Chami Amarasinghe[1]

Co-authors: D. Q. Huang [1]; Maris Arthurs [1]; Ruben Coronel [1]; Wolfgang Lorenzon [1]; Yi Liu [1]; Richard Raymond [1]

[1] *University of Michigan*

Corresponding Author: amarascs@umich.edu

We propose a technique for an ultra-low energy nuclear-recoil measurement in liquid xenon using thermal neutron capture. The measurement uses the recoils imparted to xenon nuclei during the de-excitation process following neutron capture, where the promptly emitted γ cascade can leave the nuclei with up to 0.3 keV$_{nr}$ of recoil energy. A successful measurement of the quanta yields below this point will contribute to a greater sensitivity for liquid xenon experiments that will benefit from a lower energy threshold, mainly those searching for light WIMPs and coherent neutrino-nucleus scattering. We describe the proposed measurement and its feasibility for a small (sub-kilogram) LXe detector that is optimized for a high scintillation gain, and a pulsed neutron source.

Light/Charge Readout (1C) / 39

Assembly and characterization of a large area VUV sensitive SiPM array for the nEXO TPC teststand at Stanford

Author: Jacopo Dalmasson[1]

[1] *Stanford University*

Corresponding Author: jdalmass@stanford.edu

One of the important variables to optimize for a successful detection of the neutrinoless double-beta decay is the energy resolution at its Q-value. nEXO is a proposed tonne-scale experiment aiming to search such decay for the isotope Xe-136. It exploits the anticorrelation between ionization and scintillation of xenon to improve the ultimate energy resolution. A major factor affecting the resolution is the fluctuation of charge and light ultimately collected.
In a time projection chamber (TPC) detector, the electron collection efficiency is usually close to one. Conversely, the collection of photons can vary dramatically depending, along with other factors, on the overall light-sensitive area of the detector.
The Stanford liquid xenon TPC is a teststand planning to host the first VUV large area (˜200cm2) SiPM array. The setup firstly aims to study the feasibility of such system with dedicated readout electronics and ultimately to investigate how a better light collection affects the detector performances, important prototyping step for nEXO.
In this talk, I will report on the status of the assembly of this photodetector array, along with characterization measurements and comparison with simulation.

Light/Charge Response (2A) / 40

Characterization of alpha and beta interactions in liquid xenon

Authors: Florian Jörg[1]; Dominick Cichon[2]; Guillaume Eurin[2]; Teresa Marrodán Undagoitia[2]; Natascha Rupp[2]

[1] *Max-Planck-Insitut für Kernphysik*

[2] *Max-Planck-Institut für Kernphysik*

Corresponding Author: florian.joerg@mpi-hd.mpg.de

Experiments used for rare-event searches have seen an impressive increase of sensitivity over the past decades. Among the most sensitive detector types used in direct dark matter searches are dual-phase xenon time projection chambers (TPCs). To develop a signal model for such detectors, the response of the medium to interactions of different particle types needs to be known to a high accuracy. While several measurements for interactions of electrons, photons and neutrons were reported in the past, the literature is sparse when it comes to the interaction of alpha particles with liquid xenon.

The Heidelberg Xenon (HeXe) dual-phase xenon TPC has been used to study the relative scintillation and ionization yield of low energy electrons from a $^{83m}\mathrm{Kr}$ source, as well as from alpha particles emitted by dissolved $^{222}\mathrm{Rn}$. Furthermore, a measurement of the electron drift velocity has been carried out. The different electric field configurations applied during the measurements were simulated by a detailed three dimensional model of the TPC using COMSOL Multiphysics. The measurements span over a wide range of fields within 7.5 V/cm up to 1.64 kV/cm, whereas special emphasis was put on the low-field regime.

Light/Charge Response (2A) / 41

Absolute experimental primary scintillation yield in Xe for electrons and alpha particles

Authors: C. M. B. Monteiro[1]; J. M. R. J. M. R. Teixeira[2]; P. A. O. C. Silva Silva[2]; R. D. P. Mano Mano[2]; D. González-Díaz[3]; C.A.O. Henriques Henriques[2]

[1] *Departament of Physics, University of Coimbra*

[2] *Physics Department, University of Coimbra*

[3] *University of Santiago de Compostela*

Corresponding Author: cristinam@uc.pt

Xenon scintillation has been widely used in recent particle physics experiments. However, information on primary scintillation yield in the absence of recombination is still scarce and dispersed. The mean energy required to produce a VUV scintillation photon (Wsc) in gaseous Xe has been measured to be in the range of 30-120 eV. Lower Wsc-values are often reported for alpha particles when compared to those for electrons produced by gamma or x-rays, being this difference still not fully understood.
We performed a systematic experimental study of the absolute primary scintillation yield in Xe at 1.2 bar, using a Gas Proportional Scintillation Counter. The simulation model of the detector's geometric efficiency was benchmarked through the primary and secondary scintillation produced at different distances from the photosensor. Wsc-values were obtained for gamma- and x-rays with energies in the range of 5.9-60 keV, and for 2-MeV alpha particles. No significant differences were found in the values for alpha particles and for electrons.

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Detector Techniques (4B) / 42

Development and characterization of a slow wavelength shifting coating for background rejection in liquid argon detectors

Author: David Gallacher[1]

Co-author: Marcin Kuźniak [2]

[1] *Carleton University*

[2] *AstroCeNT / CAMK PAN*

Corresponding Author: dgallacher@snolab.ca

Alpha decays occurring on surfaces of a liquid argon (LAr) detector, particularly in locations where light collection is incomplete, can result in prompt apparent low-energy events that reconstruct similar to dark-matter induced nuclear recoil events. Alphas and nuclear recoils preferentially excite argon into the singlet state, which decays with a characteristic time of ~6 ns. To convert the argon scintillation light to visible, a wavelength shifter, TPB, is typically used due to its short (O(ns)) re-emission time, that will preserve the LAr scintillation timing. By coating the problematic detector surface with a wavelength shifting coating with a decay time constant much longer than the LAr singlet time, the pulse-shape of alpha decays from these regions will be modified by the coating, with O(10^5) rejection efficiency expected. We describe the development of a pyrene-doped polymeric wavelength shifting film for the DEAP-3600 experiment, which will be deployed in the next major physics run after the completion of a suite of hardware upgrades to the detector. We will present an overview of the alpha background rejection technique using the long-time constant wavelength shifter coating, the development and testing of the films to ensure cryogenic stability for operation in a LAr environment, and the suite of characterization measurements of the film's critical operational parameters, including relative photo-luminescent quantum yield, emission spectrum, and characteristic decay time

Light/Charge Response (2A) / 43

Preliminary Tests of Dual-Phase Xenon-Doped Argon Mixtures in the CHILLAX Detector

Authors: Eli Mizrachi[1]; Ethan Bernard[2]

Co-authors: Jingke Xu [2]; Teal Pershing [3]

[1] *University of Maryland at College Park*

[2] *Lawrence Livermore National Laboratory*

[3] *Lawrence Livermore National Lab*

Corresponding Authors: emiz@umd.edu, bernard5@llnl.gov

Utilizing xenon as a dopant at the 10^{-5} level in the gas region of a dual-phase argon time projection chamber (TPC) presents the enticing prospects of faster and longer wavelength electroluminescence response to ionization electrons. This light can then be directly detected by UV-sensitive SiPMs without the use of fluorescent wavelength-shifting materials. These advantages would improve sensitivity to low energy nuclear recoils, which kinetically favor argon over xenon; examples include coherent neutrino-nucleus scattering (CENNS), and the possibility of light WIMP dark matter interactions. However, operating such a detector imposes the novel technical requirement of cryogenic

systems which must prevent xenon from partitioning between the liquid and gas phases. This has compelled the development of CoHerent Ionization Limits in Liquid Argon and Xenon (CHILLAX), a new xenon-doped, dual-phase argon detector. This talk will survey the physics implications of xenon-doped argon TPCs, and describe the special cooling and circulation systems in CHILLAX. It will conclude with an overview of the current status of the detector and recent cryogenic tests performed..

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Light/Charge Readout (1C) / 44

Overview and Current Status of the X-ARAPUCA Light Collection System in SBND

Author: Polina Abratenko[None]

Corresponding Author: polina.abratenko@tufts.edu

The Short-Baseline Near Detector (SBND) is a Liquid-Argon Time Projection Chamber (LArTPC) currently under construction at Fermilab. SBND is one of three detectors that make up the Short Baseline Neutrino (SBN) program, which aims to investigate the excess of low-energy electron-like events observed by the MiniBooNE and LSND experiments, as well as perform high-precision neutrino-argon cross section measurements. SBND plans to use a novel light collection system which includes X-ARAPUCA devices, made up of a series of dichroic and wavelength-shifting filters that collect photons using SiPMs. This X-ARAPUCA system is also the light collection technology planned for the future DUNE experiment. This talk will give an overview of the X-ARAPUCA system in SBND as well as cover the current status of testing and implementation.

Light/Charge Readout (3B) / 45

Characterization of the DUNE photodetectors and study of the event burst phenomenon

Author: Tommaso Giammaria[None]

Corresponding Author: gmmtms@unife.it

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 detectors employ silicon photomultipliers (SiPMs) to detect light produced by charged particles interacting in a large liquid argon time projection chamber (LArTPC).
The SiPMs are photosensors consisting of an array of single-photon avalanche diodes (SPAD) operating in Geiger mode. The choice of employing solid state photodetectors stems from their high sensitivity and dynamic range, as well as the possibility to fill large surfaces with high granularity.
An international consortium of research groups is currently engaged in a systematic comparison of the performances of the SiPM models that have been custom developed for DUNE by two manufacturers. Such detailed studies, which include gain measurements and a structure study of the dark count rate at 77K, are meant to determine the best choice of the photodetection system for DUNE, as well as characterize the response of the chosen detectors for the DUNE simulation. Moreover, an investigation of a newly observed phenomenon, consisting in fast bursts of events separated by a short time interval and collected in individual SiPMs, is being carried out, which potentially impacts the design of future models and their implementation in particle physics experiments. This poster presents the main results in terms of characterization of the SiPMs that will be employed in DUNE, as well as of our studies of the novel bursts phenomenon.

Poster in Gather.Town / 46

Measurements of the X-Arapuca single-cell light detection efficiency.

Authors: Henrique Souza[1]; Ettore Segreto[2]

Co-authors: Ana Amélia Machado [2]; Rafaela R. Sarmento [2]; Maria Cecilia Queiroga Bazetto ; Laura Paulucci [3]; Franciole Marinho [4]; Vinicius L. Pimentel ; Fred L. Demolin [2]; Greg de Souza [2]; Anderson Campos Fauth [2]; Marco A. Ayala-Torres

[1] *University of Campinas*

[2] *Unicamp*

[3] *UFABC*

[4] *UFSCar*

Corresponding Authors: henriquevieira.souza@gmail.com, segreto@ifi.unicamp.br

The X-Arapuca (XA) supercell is the basic unit of the Photon Detection System (PDS) of the Deep Underground Neutrino Experiment (DUNE). In total, 1,500 X-Arapuca with approximate dimensions of 210 x 12 cm^2 will be installed on the anode planes of the liquid argon time projection chamber (LArTPC). In the XA light trap device, the liquid argon scintillation light (with wavelength around 127 nm) is absorbed by a thin layer of para-Terphenyl (pTP) coated on a dichroic filter window which constitutes its acceptance window. PTP re-emits photons around 350 nm, above the filter cutoff. The light which enters the XA is downshifted again by the inner wavelength shifter plate (WLS plate) to a wavelength around 430 nm. The cut-off of the dichroic filter is placed at 400 nm: this allows the pTP shifted light to enter in the X-Arapuca and to trap the fraction of photons which escape from total internal reflection in the WLS plate. The light is collected by an array of silicon photo-sensors (SiPM) coupled at the edges of the WLS plate. In this work, we present the first characterization of the photon detection efficiency of an X-Arapuca prototype sizing 10 x 7.5 cm^2 in Brazil, where the X-Arapuca was exposed to alpha particles, cosmic muons and gammas in liquid argon. Operating the SiPMs at +5 and +5.5 V over the breakdown voltage, an efficiency ranging from 2.2% to 2.3% and from 2.7% to 3.1% was found, respectively.

Detector Techniques (4B) / 47

Fluorescence light yield and time constants of acrylic (PMMA) excited with UV light

Authors: Emma Ellingwood[1]; Hicham Benmansour[1]

Co-authors: Philippe Di Stefano [1]; Peter Skensved [1]

[1] *Queen's University*

Corresponding Author: emma.ellingwood@queensu.ca

Rare-event searches, like those for dark matter or neutrinoless double-beta decay, go to extreme lengths to mitigate various forms of background. Acrylic (poly(methyl methacrylate) or PMMA) is frequently used as a container for scintillating liquids in rare-event searches. Weak fluorescence has been observed in certain types of PMMA at room temperature, introducing a potential source of background. Building on previous work presented at LIDINE 2019, by using the optical cryostat with large numerical aperture located at Queen's University, we quantify the light yield of the acrylic used in the DEAP dark matter search from room-temperature down to 4 K, and express it relative to the common wavelength shifter TPB. We also study the time constants involved.

Detector Techniques (3A) / 48

A new high voltage cable feedthrough concept for future dark matter and neutrino experiments

Author: Pablo Garcia Abia[1]

[1] *CIEMAT*

Corresponding Author: pablo.garcia@ciemat.es

Physics experiments featuring liquid noble gas time projection chambers are becoming larger in scale. Consequently, their high voltage (HV) requirements have increased as well, making conventional design HV feedthrough (FT) impracticable. A new concept for an HV cable FT usable in a cryogenic environment is presented in this talk. It features a co-extruded multi-layered coaxial cable fabricated with a single material and relies on the ability to develop a plastic material with tunable resistivity.

Light/Charge Response (1B) / 49

Delayed electron emission in DarkSide-50 double phase liquid argon TPC

Author: Pablo Garcia Abia[1]

[1] *CIEMAT*

Corresponding Authors: masayuki@camk.edu.pl, pablo.garcia@ciemat.es

Dual-phase noble gas Time Projection Chambers (TPCs) suffer from spurious electron background events at the lowest detectable energy region. This background is reported in liquid xenon TPCs and some of the causes are discussed in the literature. Understanding its origin is of paramount importance as this background sets the analysis threshold and affects the most sensitive part of the region of interest for low mass dark matter searches.

We report the spurious electron background events observed in the liquid argon TPC in the DarkSide-50 experiment. We found two different electron populations based on time correlation with preceding events: simultaneous emission and delayed emission. The majority of the former can be associated with photoionization effects. The mechanism of the latter is not clear, but our observations indicate that they are related to the impurity level in the TPC measured via the electron lifetime.

Signal Reconstruction (3C) / 50

Photon detection probability predictionusing one-dimensional generative neural network

Author: Wei Mu[1]

Co-authors: Alexander Himmel [1]; Bryan Ramson [1]

[1] *Fermilab*

Corresponding Author: muve@outlook.com

Photon detection is important for liquid argon detectors for direct dark matter searches or neutrino property measurements. Precise simulation of photon transport is widely used to understand the probability of photon detection in liquid argon detectors. Traditional photon transport simulation within the framework ofGeant4brings extreme challenge to computing resources with kilo-tonne-scale liquid argon detectors and GeV-level energy depositions. In this work, we propose a one-dimensional generative model which bypasses photon transport simulation and predicts the number of photons detected by particular photon detectors at the same level of detail asGeant4simulation.The application to photon detection systems in kilo-tonne-scale liquid argon detectors demonstrates this novel generative model is able to reproduceGeant4simulation with good accuracy and 20x-50xfaster. This generative model can be used to fast predict photon detection probability in huge liquid argon detectors like ProtoDUNE or DUNE.

Light/Charge Readout (3B) / 51

Pyrene-polystyrene wavelength shifters for liquid argon experiments

Author: Hicham Benmansour[1]

Co-authors: Peter Skensved [1]; Philippe Di Stefano [1]; Emma Ellingwood [1]; Quentin Hars [1]; David Gallacher [2]

[1] *Queen's University*

[2] *Carleton University*

Corresponding Author: 19hb25@queensu.ca

Some WIMP dark matter experiments use liquid argon (LAr) as the target material for its high scintillation light yield and good background discrimination. Particle interactions in the LAr produce scintillation light at 128 nm which must go through a wavelength shifting (WLS) material to be detected by standard photomultiplier tubes. Tetraphenyl-butadiene (TPB) is a common WLS for LAr based detectors, including DEAP-3600, due to its high light yield and fast scintillation time. Pyrene-polystyrene thin films have been proposed as a complementary WLS for rejection of pathological backgrounds in the detector because it has a long scintillation time and high light yield relative to TPB. Light from particle interactions that reach the pyrene coating will produce a pulse signature distinct from interactions of light with TPB.

We present the characterization of the fluorescence properties of these pyrene coatings, such as the light yield, fluorescence time, and spectra, as a function of temperature. These measurements were taken at the Queen's University optical cryogenic test facility to characterize these films down to 4 K.

Light/Charge Readout (3B) / 52

Increasing photodetector light collection with metalenses

Authors: Chris Stanford[1]; Roxanne Guenette[1]; Carlos Escobar[2]; Adam Para[2]; Benjamin Lawrence-Sanderson[2]; Augusto Martins[1]; Justo Martín-Albo[3]; Michelle Stancari[4]; Taylor Contreras[5]

[1] *Harvard University*

[2] *Fermilab*

[3] *Instituto de Física Corpuscular*

[4] *Femilab*

[5] *Harvard*

Corresponding Author: cstanford@g.harvard.edu

We present a design concept and preliminary results for a method to increase the light collected by a sparse array of SiPMs by placing a metalens in front of each photodetector. A metalens is a flat lens that uses nanostructures on the surface to focus incident light. Metalenses offer similar focusing

power to traditional lenses, but with reduced bulk and cost, and can be mass-produced in industry nanofabrication facilities. Their use could allow the next generation of large-scale physics detectors to obtain an increase in their light collection and further their science reach while simultaneously reducing the required number of readout channels needed to meet their design goals.

Detector Techniques (4B) / 53

CrystaLiZe: A Solid Future for LZ

Authors: Scott Kravitz[1]; Peter Sorensen[None]; Scott Haselschwardt[None]; Hao Chen[None]; Shilo Xia[None]; Ryan Gibbons[None]

[1] *Lawrence Berkeley National Lab*

Corresponding Author: swkravitz@lbl.gov

Radon and its daughter decays continue to limit the sensitivity of WIMP direct dark matter searches, despite extensive screening programs, careful material selection and specialized Rn-reduction systems. This problem is only expected to worsen as experiments grow in size. For liquid xenon TPCs, we propose to address this through crystallizing the xenon. Once solid, the xenon will no longer admit external Rn into the bulk, allowing existing Rn to decay away. These decays can also be efficiently vetoed using the time structure of the decay sequence and the fixed position of daughter isotopes. In this case, the limiting background for WIMP searches would be neutrinos from the sun and from cosmic ray muons. In this talk, I will argue that an instrumental radon tag in a crystalline xenon TPC, perhaps as an upgrade to LZ, may be the quickest path to reaching the neutrino floor and present preliminary results from a solid xenon test stand which indicate its viability as a detector medium.

Light/Charge Response (2A) / 54

Scintillation yield from electronic and nuclear recoils in superfluid helium-4

Authors: Ryan Smith[1]; SPICE/HeRALD Collaboration[None]

[1] *UC Berkeley*

Corresponding Author: ryansmith63@berkeley.edu

Superfluid He-4 is a promising target material for direct detection of low mass (< 1 GeV) dark matter. Signal channels for dark matter - nucleus interactions in superfluid helium include prompt photons, triplet excimers, rotons and phonons, but measurement of these signal strengths have yet to be performed for low energy nuclear recoils. A study of scintillation yield from electronic and nuclear recoils was carried out in superfluid He-4 at 1.75 K, with deposited energy in the range of 50-1000 keV. Scintillation from a 16 cm^3 volume of superfluid He-4 was read out by six PMTs immersed in the superfluid, each individually biased by a Cockcroft-Walton generator. Elastic scattering of 2.8 MeV neutrons (produced by a deuterium-deuterium neutron generator) from superfluid He-4, with a liquid organic scintillator module used as far-side detector, was used to determine the scintillation signal yield for a variety of nuclear recoil energies. Yields of both prompt and delayed scintillation components were measured and compared to a semi-empirical microphysical model. For comparison, Compton scattering of Cs-137 gamma rays from the superfluid He-4, with NaI scintillators used as far-side detectors, was used to determine the scintillation signal yield of electronic recoils.

Light/Charge Response (2A) / 55

Scintillation and optical properties of xenon-doped liquid argon

Authors: Christoph Vogl[1]; Mario Schwarz[1]; Xaver Stribl[1]; Johanna Grießing[1]; Patrick Krause[1]; Stefan Schönert[1]

[1] *Technical University of Munich*

Corresponding Author: christoph.vogl@tum.de

Liquid argon (LAr) is widely employed as a scintillator in rare-event searches. Its optical and scintillation properties, as well as the impact of impurities, are being studied extensively by many groups world-wide. LAr scintillation light exhibits a main emission wavelength of 128 nm, which makes propagation and detection challenging because of short attenuation lengths and low quantum efficiencies of photo sensors in the VUV spectral range.

Previously, we have determined the attenuation length of purified liquid argon for its own scintillation light to be larger than 110 cm at a wavelength of 128 nm [1, 2]. Already in 1982 Kubota et al. [3] investigated the impact of xenon doping of LAr. Recently, we have studied the emission spectrum and time distribution dependent on the xenon concentration [4].

Here, we present our latest study of xenon-doped LAr with focus on the primary photon yield, the effective triplet lifetime and attenuation length, with xenon concentrations ranging from 3 ppm to 300 ppm. The scintillation and optical properties were measured simultaneously with the *LLAMA* [5] instrument operated inside *SCARF*, a 1 ton LAr test stand, and the xenon concentrations using *IDEFIX*, a dedicated mass spectrometer setup.

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Detector Techniques (3A) / 56

Understanding the impact of high voltage electrodes on low-energy dark matter searches with the LZ dual phase xenon TPC

Author: Ryan Linehan[None]

Corresponding Author: rlinehan@stanford.edu

To observe signals from low-energy nuclear recoils, including WIMP-xenon scatters, the LZ dark matter detector must maintain strong drift and extraction fields within its dual-phase xenon time projection chamber (TPC). These fields are established by a set of four stainless steel wire mesh high voltage electrode grids that span the full width of the TPC. During operation at their design voltages, these grids will achieve wire surface fields well above 20 kV/cm. These high fields can produce spurious charge signals and signals from real radioactive decays with atypical light-to-charge ratios, both of which can lead to low-energy backgrounds in LZ science data. This talk will present studies of possible grid contributions to electron backgrounds in the low-energy regime, with a focus on two specific sources: field-induced emission and radiogenic emission.

Detector Techniques (4B) / 57

Purification of large volume of liquid argon for the LEGEND-200 experiment

Authors: Grzegorz Zuzel[1]; Stefan Schoenert[2]; Christoph Vogl[2]; Patrick Krause[2]; Laszo Papp[2]; Malgorzata Haranczyk[1]; Tomasz Mroz[1]

[1] *Jagiellonian University*

[2] *Technical University Munich*

Corresponding Author: grzegorz.zuzel@uj.edu.pl

The LEGEND-200 experiment is under construction at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy. Its main goal is a background-free search for neutrinoless double beta decay of Ge-76. Up to 200 kg of bare high purity germanium (HPGe) detectors with enrichment in Ge-76 beyond 86% will be deployed in liquid argon (LAr). The LAr will serve as cooling medium for the detectors as well as a passive and an active shield. For the latter the LAr instrumentation will be composed of light guiding fibers connected to silicon photomultipliers detecting scintillation light of argon. It has been already shown in the GERDA experiment that the LAr veto was a very powerful tool for background rejection and minimization. Details of the LAr veto system will be presented in a dedicated talk.
The scintillation properties of LAr (attenuation length, triplet life time) are worsened by presence (at a sub-ppm level) of electronegative impurities such as oxygen, water and nitrogen due to quenching and absorption processes. As a consequence, the efficiency of the LAr veto may be significantly influenced. In order to achieve best possible performance of the veto, LAr will be purified during initial filling of the LEGEND-200 cryostat.
The design, construction and performance of a system capable to purify 65 m3 (91 tons) of liquid argon to sub-ppm level will be presented. The quality of the processed liquid is monitored in real time by measuring the triplet life time and simultaneous direct measurement of concentrations of impurities like water, oxygen and nitrogen down to 0.1 ppm. Scintillation properties of LAr filled into the cryostat are also be determined in real time by a dedicated apparatus (LLAMA). For the LAr filled into the cryostat the measured triplet life time is in the range of 1.3 mico_s. If needed, the LAr purification system may be also used later to purify LAr filled in the cryostat in the loop mode. A dedicated cryogenic pump has been installed on its bottom. The pump is capable to circulate the LAr between the purification system and the cryostat.

Signal Reconstruction (2C) / 58

Physics Modeling of Xenon and Argon detectors with the Noble Element Simulation Technique (NEST)

Author: Kirsten McMichael[1]

[1] *Rensselaer Polytechnic Institute*

Corresponding Author: mcmick@rpi.edu

The Noble Element Simulation Technique (NEST) is a C++ package with optional GEANT4 integration and a Python equivalent (nestpy) that accurately simulates the scintillation, ionization, and electroluminescence processes in xenon and argon. Using a combination of empirical and first principle methods, NEST models the intrinsic physics of noble detectors while maintaining a format that is accessible and customizable for users. I will present key results including energy resolution and light and charge yields of various interactions with noble elements. I will also discuss recent and future updates to the code including further development of the argon model, improvements to the ER model, and new modeling to describe the W-value discrepancy between NEST and the EXO-200 results.

Poster in Gather.Town / 59

A Monte Carlo detector response model for solar neutrino absorption on 40Ar in DEAP-3600

Author: Andrew Erlandson[1]

[1] *Carleton University*

Corresponding Author: andrew.erlandson@snolab.ca

DEAP-3600 is a liquid argon (LAr) scintillation detector designed to search for Weakly Interacting Massive Particles (WIMPs) at SNOLAB. Beyond the search for dark matter, the DEAP-3600 detector is also intrinsically sensitive to charged current interactions on 40Ar from 8B solar neutrinos. Here we present the expected detector response to high energy delayed coincidence events resulting from neutrino absorption on the ˜3.2 tonne target mass. We exploit the Marley event generator in conjunction with a full optical simulation of the DEAP-3600 detector using the Reactor Analysis Tool (RAT). Through the delayed coincidence channel, we expect an event yield of (4.69 ± 0.43) events in a 7.20 tonne-year exposure in DEAP-3600.

Signal Reconstruction (2C) / 60

Optical Modeling and Position Reconstruction for DarkSide-20k

Author: Pablo Garcia Abia[1]

[1] *CIEMAT*

Corresponding Authors: pablo.garcia@ciemat.es, poehlmann@ucdavis.edu

DarkSide-20k is a next-generation direct dark matter search experiment under construction at the Gran Sasso National Laboratory (LNGS) in Italy. The core of the detector is a two-phase liquid argon time projection chamber designed to probe WIMP interactions down to the neutrino floor. To ensure the 200 ton-year exposure has zero instrumental backgrounds, low-radioactivity underground argon is used as the detector medium. Backgrounds from detector surfaces are primarily rejected through fiducialization, which requires accurate reconstruction of event vertices. Monte Carlo simulations of interactions within the detector have been used to study the position reconstruction resolution of DarkSide-20k. In this talk, I present the detector optical model and discuss the performance of machine learning-based position reconstruction algorithms on simulated DarkSide-20k datasets.

Detector Techniques (3A) / 61

Detection of Electroluminescence in Liquid Xenon with a Radial Time Projection Chamber

Authors: Yuehuan Wei[1]; Jianyang Qi[2]

[1] *University of California San Diego*

[2] *UCSD*

Corresponding Authors: ywei@physics.ucsd.edu, jiq019@ucsd.edu

The dual-phase xenon Time Projection Chamber (TPC) is one of the most successful techniques for rare event searches. It detects both primary scintillation and ionization signals from particle interactions in liquid xenon (LXe) . The ionization electrons are converted into electroluminescence in the gas xenon, subsequently detected by the same photo-sensors for the primary scintillation. However, it gradually becomes more and more challenging to build the TPCs with very large diameter while requiring sub-mm flatness of the gas gap. Here we developed a Radial TPC (RTPC) which can create and detect the electroluminescence directly in liquid xenon. It can simplify the design of the TPC by replacing the large diameter electrodes with a single wire in the axial center. The design of a liquid xenon RTPC and its first performance will be presented.

Signal Reconstruction (3C) / 62

Study of the luminescence of He/CF4 mixture for the CYGNO detector

Author: Andrea Messina[1]

[1] *Sapienza Università di Roma & INFN*

Corresponding Author: andrea.messina@uniroma1.it

Innovative experimental techniques are needed to further search for dark matter weakly interacting massive particles. The ultimate limit is represented by the ability to efficiently reconstruct and identify nuclear and electron recoil events at the experimental energy threshold. Gaseous Time Projection Chambers (TPC) with optical readout are very promising candidates thanks to the 3D event reconstruction capability of the TPC technique and the high sensitivity and granularity of last generation scientific light sensors. The Cygno experiment is pursuing this technique by developing a TPC operated with He/CF4 gas mixture at atmospheric pressure equipped with a Gas Electron Multipliers (GEM) amplification stage that produces visible light collected by scientific CMOS camera. The optical approach has so far only exploited the light produced during the avalanche processes in the GEM channels. In this contribution, we discuss recent measurements performed by the CYGNO collaboration which show the first evidence of additional luminescence in He/CF4 induced by electrons accelerated by a suitable electric field. The electron and photon yield has also been studied for gas mixtures with a small percentage of isobutane. We give an overview of the CYNGO project presenting the performances in terms of energy and spacial resolution of prototype detectors that have been built and operated so far. Finally, we illustrate the plan to construct a 1m3 demonstrator expected in 2021/22 aiming at a larger scale apparatus in a later stage.

Light/Charge Readout (4A) / 63

CMOS based SPAD Arrays for light detection in rare event search experiments

Author: Michael Keller[1]

Co-author: Peter Fischer [1]

[1] *Heidelberg University*

Corresponding Author: michael.keller@ziti.uni-heidelberg.de

Experiments searching for rare physics events using scintillation in liquid noble gases are steadily increasing in size. They require detector systems capable of measuring individual optical photons with excellent efficiency while covering large areas. In addition, the radioactive background introduced by such systems must be extremely low. We propose SPAD arrays based on CMOS technology as a possible solution for such an application case. This technology allows for manufacturing SPADs and the associated CMOS readout logic side by side, creating a fully functional photon detector system

one a single silicon die. No further discrete components in direct vicinity and only few digital signals are required to operate a chip so that large areas can be covered in a straight forward way with very low material budget. We have developed a chip architecture which offers a very low power dissipation and a high fill factor. We have operated a prototype chip with different SPAD geometries at low temperatures of $100/160\mathrm{K}$ and measured dark count rates of $0.01/0.1\,\mathrm{Hz}$ per mm^2 of active SPAD area, respectively. Our data driven readout architecture has an idle power consumption of only $1.75\,\mathrm{mW}$ and a signal dependent contribution of about $15\,\mu\mathrm{W}$ per 1000 hits per second. Based on these results we propose a full detector concept to cover large areas with high fill factor requiring only 7 electrical signals for operation.

Light/Charge Readout (4A) / 64

Very-thick transparent GEMs with wavelength-shifting capability for noble element TPCs

Authors: Marcin Kuźniak[1]; Diego González-Díaz[2]

[1] *AstroCeNT / CAMK PAN*

[2] *IGFAE*

Corresponding Author: mkuzniak@camk.edu.pl

A new concept for the simultaneous detection of primary and secondary scintillation in time projection chambers is described. Its core element is a type of very thick GEM structure machined from a wavelength shifting material and supplied with PEDOT:PSS-based transparent electrodes.

Such a device is scalable to very large surface areas needed by future generations of noble element TPCs. Because of its optical properties it can significantly improve the light collection efficiency, energy threshold and resolution of conventional micropattern gas detectors as well as wire mesh TPCs.

Production, optical and electrical characterization, first measurements performed with the new device will be reported. Further tests and R&D steps will also be discussed.

Detector Techniques (4B) / 65

Modeling the Effect of Impurities on the Electron Lifetime in Liquid Xenon for nEXO

Author: Ako Jamil[1]

[1] *Yale University*

Corresponding Author: ako.jamil@yale.edu

nEXO is a 5 tonne liquid xenon (LXe) time projection chamber (TPC) planned to search for the neutrinoless double beta decay of ^{136}Xe with a target half-life sensitivity of about 10^{28} years. Electrons from an event within the TPC will be drifted up to $1.3\,\mathrm{m}$ and to ensure minimal charge loss nEXO aims to reach an electron lifetime of $10\,\mathrm{ms}$. This lifetime is inversely proportional to the concentration of electro-negative impurities, for which multiple species with different attachment cross-sections may be important. Various sources for impurities such as diffusion out of commonly used plastics, desorption from metal surfaces and leaks to atmosphere were investigated. This talk will go over measurements of outgassing from plastics and relevant parameters to extrapolate to the effect impurities have on the electron lifetime in large liquid xenon detectors.

Light/Charge Response (1B) / 66

Primary Scintillation in Ar-based Mixtures Aimed at Providing a T0-signal in DUNE ND-GAr

Authors: Diego González-Díaz[1]; Pablo Amedo[2]; Sara Leardini[3]; Angela Saa-Hernandez[3]; Justo Martin-Albo[4]; Fernández David José[3]; Gonzalez David[3]

[1] *University of Santiago de Compostela*

[2] *Instituto Galego de Física de Altas Enerxías (IGFAE, USC)*

[3] *IGFAE*

[4] *IFIC*

Corresponding Author: diegoglezdiaz@gmail.com

The usage of optical information is ubiquitous in neutrino detectors, essential for spill-assignment, background suppression, and triggering. Enabling an independent and complete physics program at the ND-GAr component of DUNE's near detector suite will undoubtedly benefit from this feature. We discuss in this presentation the prospects towards simultaneous readout of ionization and scintillation signals in ND-GAr and the R&D currently performed in this direction. In particular, we will focus on the scintillation of Ar-based mixtures at high pressure.

Detector Techniques (3A) / 67

Prospects of S2 analysis in single-phase liquid xenon TPCs

Authors: Fabian Kuger[1]; Francesco Toshi[1]

[1] *Albert-Ludwigs Universität Freiburg*

Corresponding Author: fabian.kuger@physik.uni-freiburg.de

Proportional scintillation in liquid is a possible alternative scheme for charge-to-light signal conversion in future large-size liquid xenon TPCs. Based on detailed simulations we explore the implications on charge signal (S2) analysis arising from this fast scintillation process. The peaked signals allow precise reconstruction of the individual electrons and thus a quantized measure of the S2 strength. Counting the number of electrons significantly improves the S2 resolution for small signals, relevant for low-energy ER studies and sub-GeV WIMP searches. The direct measurement of the electron arrival times improves S2-only reconstruction of the event depth and allows for powerful discrimination between single site and multiple site interactions. We discuss these prospects in the context of a future multi-ton liquid xenon experiment such as DARWIN, assuming a single-phase design with minimal change compared to state-of-the-art dual-phase detectors.

Light/Charge Response (2A) / 68

Band and Time - Resolved Scintillation for Alpha and Beta Particles in Xenon, as a Function of Pressure and Electric Field

Authors: Angela Saa-Hernandez[1]; David Gonzalez[2]; David Jose Fernandez[2]; Diego González-Díaz[None]; Edgar Sánchez-García[3]; Pablo Amedo[4]; Roberto Santorelli[3]; Sara Leardini[2]

[1] *IGFAE*

[2] *IGFAE, Universidade de Santiago de Compostela*

[3] *CIEMAT*

[4] *Instituto Galego de Física de Altas Enerxías (IGFAE, USC)*

Corresponding Author: sara.leardini@usc.es

In standard conditions, Xenon is the only gaseous element with a naturally occurring isotope undergoing double-beta decay. Hence exploiting a gaseous TPC as a tool for accurately reconstructing the topology of bb0nu events is very natural. When considering i) sensitivity to the lifetime of the decay and ii) energy resolution to separate it from regular bb2nu events, a high pressure electroluminescence TPC self-suggests. At the moment, the NEXT TPC is the most advanced implementation of this idea, relying deeply on common-wisdom assumptions like the monochromaticity of both primary and secondary scintillation (around 172nm), the lack of charge recombination for beta-events, or the validity of density-scalings for secondary scintillation. Looking into the future, the unambiguous elucidation of these phenomena becomes necessary in view of the upcoming ton and multi-ton scale experiments aimed at completely exploring the inverted hierarchy of neutrino masses.

Motivated by this, we conducted systematic measurements of S1 and S2
signals in a mini-TPC read out with wires, for varying pressures (1-10bar), pressure-reduced electric fields (0-100V/cm/bar) and wire voltages (up to 4kV). Systematic measurements of the time constants and scintillation yields obtained in these conditions will be presented, for alpha and beta sources in the VUV, UV and visible bands, and its impact on next generation xenon TPCs discussed.

Signal Reconstruction (3C) / 69

Neutral bremsstrahlung calculations for TPCs

Authors: Pablo Amedo[1]; Diego González-Díaz[None]; C.A.O. Henriques[None]; J.M.R. Teixeira[None]; C.D.R. Azevedo[None]; Ángela Saa Hernandez[None]; J.M.F. dos Santos[None]; C.M.B. Monteiro[None]

[1] *Instituto Galego de Física de Altas Enerxías (IGFAE, USC)*

Corresponding Author: pablo.amedo@gmail.com

Neutral bremsstrahlung (NBrS) in the gas phase of Argon and Xenon TPCs has been measured recently, with little ambiguity, by groups in Novosibirsk and Coimbra/Santiago. While its implications for future experiments are intriguing, and so far open-ended, a lack of reliable calculations precludes the full exploitation of the phenomenon.

We have recently created a simulation module in the electron-transport code Pyboltz,implementing the original theoretical framework introduced by Buzulutskov et al., and showed an excellent description of NBrS data. The framework, soon to be accessible through GitHub, allows calculations of NBrS in any noble element mixture, as well as in weakly-quenched mixtures, at all electrical fields of interest below the excitation thresholds. For illustration purposes, we will present results obtained in cases of interest, discuss the analytical limits, future improvements, and the scope of this project.

Signal Reconstruction (3C) / 70

Boosting background suppression in the NEXT experiment through Richardson-Lucy deconvolution

Authors: Ander Simón Estévez[1]; Lior Arazi[1]; Yair Ifergan[None]

[1] *Ben-Gurion University of the Negev*

Corresponding Author: aretno@gmail.com

The NEXT collaboration aims to observe neutrinoless double beta decay in gaseous 136Xe using a high pressure gaseous Xe time projection chamber with signal amplification by means of electroluminescence (EL). One of the advantages of the technique is that it allows for track reconstruction making use of a sensor plane equipped with SiPMs located nearby the EL region. However, the signals recorded in the TPC are degraded by electron diffusion and spread of light produced in the EL process, limiting the potential of the detection scheme.

We have recently developed an improved reconstruction procedure based on the Richardson-Lucy deconvolution, an iterative algorithm well-known in image processing and de-blurring. Deconvolution allows reversing the smearing mechanisms in the NEXT TPC and significantly enhances the definition of reconstructed tracks. Consequently, detector performance is strongly boosted, with a five-fold improvement in background rejection demonstrated on experimental data.

In the talk we will detail the algorithm application in the context of the NEXT experiment with a focus on the performance in NEXT-White, a 50 cm TPC currently operating underground at Laboratorio Subterráneo de Canfranc. We will describe the procedure applied to characterize the optical response of the chamber by obtaining the point spread function that best describes the observed signals. We will also discuss the potential of the algorithm to ease the tracking hardware requirements of future detector iterations.

Signal Reconstruction (2C) / 71

Measurement of the Scintillation Light Triggering Efficiency in MicroBooNE

Author: Vincent Basque[1]

[1] *Fermilab*

Corresponding Author: vbasque@fnal.gov

The MicroBooNE Liquid Argon Time Projection Chamber (LArTPC) has been collecting data since 2015 as part of the Short-Baseline Neutrino (SBN) program using the Booster Neutrino Beam (BNB) at Fermilab. Its primary physics goal is to contribute to addressing the elusive eV-scale sterile neutrino anomaly. MicroBooNE records and utilises both the ionisation charge and scintillation light produced inside the TPC to reconstruct its events. The latter is collected through a plane of PhotoMultiplier Tubes (PMTs) and is used for accurate event timing and cosmic muon rejection. A data-driven method to estimate the scintillation light triggering efficiency from prompt scintillation light for low energy cosmic muons will be presented. Results obtained from this method are crucial for many analyses that aim to measure low energy interactions, and inform triggering strategies in LArTPCs in the SBN and future DUNE programmes.

Light/Charge Readout (3B) / 72

The SBND Photon Detection System

Author: Vincent Basque[1]

[1] *Fermilab*

Corresponding Author: vbasque@fnal.gov

The Short-Baseline Near Detector (SBND) is a 112 ton Liquid Argon Time Projection Chamber (LArTPC) that will be part of the Short-Baseline Neutrino (SBN) program at Fermilab. The SBN programme's main goal is to resolve the eV-scale sterile neutrino short-baseline anomaly. SBND will measure the un-oscillated beam flavour composition at an unprecedented number of neutrinos due to its proximity to the beam target. One of the major features of SBND will be its state of the

art photon detection system. The active system will consist of photomultiplier tubes, as well as X-ARAPUCA devices, placed behind the wire planes providing a high granularity light collection. The active system will be enhanced by highly reflective panels covered with the wavelength shifting compound tetra-phenyl butadiene (TPB) inserted into the cathode plane. The combination of the active system and enhancers in SBND will ensure a high and more uniform light yield throughout the detector which will help to enable low energy physics triggering. This talk will provide an overview of the photon detection system of SBND and its current status.

Light/Charge Readout (3B) / 74

Track imaging in noble liquid detectors

Authors: Alessandro Montanari[1]; Valerio Pia[None]

[1] *Istituto Nazionale di Fisica Nucleare - Sezione di Bologna*

Corresponding Author: alessandro.montanari@bo.infn.it

Large volumes of liquid Argon or Xenon constitute an excellent medium for the detection of Neutrino interactions and for Dark Matter searches. The established readout method for large noble liquid detectors is based on charge collection in a Time Projection Chamber, triggered by the scintillation light produced by Ar (128˜nm) or Xe (185˜nm).
This scintillation light can however also be used to attempt a direct reconstruction of charged particle tracks, provided the photon sensor has imaging capabilities. The primary benefit of this technique is rate capability, especially relevant for the near detectors of accelerator based experiments.
The design of such an imaging detector, however, presents several challenges: the performance of both current single photon detectors and conventional optical elements in the Vacuum UV is generally inferior compared to the visible spectrum; a large number of densely packed detectors and their dedicated readout electronics must be operated at cryogenic temperatures; the optical system must provide a sufficiently wide and deep field of vision and a large aperture, in order to minimize the amount of detectors for a given fiducial volume.
Silicon PhotoMultipliers (SiPMs) are the ideal photosensor for this application, since their noise is suppressed at cryogenic temperature and they can be fabricated in large arrays composed of many small pixels; their lower VUV sensitivity is also being addressed by suppliers with optimized designs.
The large channel count requires the development of a dedicated cryogenic ASIC, for which several steps have been taken. Multiple options exist for optical systems, which offer different compromises between ease of construction, performance and deployment on specific detector geometries.
In this contribution we will present the simulation of novel optical systems and the performance of small scale prototypes. The progress on larger prototypes and the simulation of realistic detector geometries will also be reported.

Applications (2B) / 75

Status and perspectives of the PETALO project

Author: Paola Ferrario[1]

[1] *Donostia International Physics Center (DIPC)*

Corresponding Author: paola.ferrario@dipc.org

PETALO (Positron Emission Tof Apparatus with Liquid xenOn) is a novel concept for positron emission tomography scanners, which uses liquid xenon as a scintillation medium and silicon photomultipliers as a readout. The large scintillation yield and the fast scintillation time of liquid xenon makes it an excellent candidate for PET scanners with Time-of-Flight measurements. In this talk I will review the status of the PETALO project, which is now commissioning the first prototype, devoted to demonstrate the potential of the concept, measuring the energy and time resolution and to test

technical solutions for a complete ring. The prototype consists in an aluminum box filled with liquid xenon, with two arrays of SiPMs on opposite sides facing the xenon. A beta+ emitter source generating 511-keV pairs of gammas is placed in a central port and the SiPMs record the scintillation light produced by the gamma interactions, allowing for the reconstruction of the position, the energy and the time of the interactions. Finally, I will discuss the potential of a total-body PET based on this technology.

Signal Reconstruction (2C) / 77

Characterizing electroluminescence region of the NEXT high pressure gaseous xenon TPC with Kr gas

Author: Jonathan Haefner[1]

[1] *Harvard University*

Corresponding Author: jhaefner@g.harvard.edu

The NEXT experiment is a neutrino physics program searching for neutrinoless double beta decay using high pressure gaseous xenon time projection chambers (HPGXeTPC). The HPGXeTPC technology offers several advantages, including excellent energy resolution, topological event discrimination, and calibration with gaseous, radioactive krypton. We will discuss the power of this calibration technique for characterizing the electroluminescence region, where S2 signals are produced. We discuss the impact of variation in the voltage on light production and event detection, as well as demonstrating capability to extract structural information about the EL gap from Kr calibration data. We will furthermore show an improved understanding of diffusion related effects in our detector.

Light/Charge Readout (4A) / 78

Improved quality tests of R11410-21 photomultiplier tubes

Authors: Luisa Hoetzsch[1]; Adam Brown[2]; Joern Mahlstedt[3]; Vasile Cristian Antochi[3]; Laura Baudis[4]; Julian Bollig[2]; Ranny Budnik[5]; Dominick Cichon[1]; Jan Conrad[3]; Alfredo Davide Ferella[6]; Michelle Galloway[4]; Shingo Kazama[7]; Gera Koltman[5]; Hagar Landsman[5]; Manfred Lindner[1]; Teresa Marrodán Undagoitia[1]; Bart Pelssers[3]; Giovanni Volta[4]; Oliver Wack[1]; Julien Wulf[4]

[1] *Max-Planck-Institut für Kernphysik*

[2] *University of Freiburg*

[3] *Stockholm University*

[4] *University of Zurich*

[5] *Weizmann Institute of Science*

[6] *University of L'Aquila*

[7] *Nagoya University*

Corresponding Author: luisa.hoetzsch@mpi-hd.mpg.de

Photomultiplier tubes (PMTs) are often used in low-background particle physics experiments, which rely on an excellent response to single-photon signals and stable long-term operation. In particular, the Hamamatsu R11410 model is the light sensor of choice for many detectors utilising xenon as target material. In the past, this PMT model has shown issues affecting its long-term operation, including light emission and the degradation of the PMT vacuum through small leaks, which can lead to spurious signals known as afterpulses. In this talk, we present an improved PMT testing procedure that includes newly developed tests targeted at the detection of intermittent light emission as well as vacuum degradation. The use of both new and upgraded facilities allowed us to test in

total 368 new PMTs for the XENONnT detector in a cryogenic xenon environment. We exclude the use of 26 of the 368 tested PMTs and categorise the remainder according to their performance. Given that we have improved the testing procedure compared to XENON1T, yet we rejected fewer PMTs, we expect significantly better PMT performance in XENONnT.

Applications (2B) / 79

A 10-kg LAr bubble chamber for sub-keV nuclear recoil detection – Update and Calibration Strategies

Author: Eric Dahl[1]

Co-author: SBC Collaboration

[1] *Northwestern University*

Corresponding Author: cdahl@northwestern.edu

The Scintillating Bubble Chamber (SBC) Collaboration is developing noble liquid bubble chambers for the detection of sub-keV nuclear recoils, enabling both high-exposure GeV-scale dark matter searches and CEvNS measurements using reactor neutrinos. Nuclear recoils (NRs) in these chambers produce both a single bubble and a coincident flash of scintillation light, while electron-recoil (ER) backgrounds produce scintillation only. The physics reach of these chambers depends critically on what NR bubble nucleation threshold can be achieved while remaining ER-blind. This threshold will be explored with SBC's first physics-scale device: a 10-kg LAr bubble chamber, now under construction, that will operate in the MINOS tunnel at Fermilab. I will give an update on the status of this chamber and describe the calibration strategies we will use to measure the chamber's sensitivity to nuclear recoils with energies down to 100-eV.

Applications (2B) / 80

HeRALD: A Superfluid Helium Sub-GeV Dark Matter Detector

Authors: Roger Romani[1]; SPICE/HeRALD Collaboration[None]

[1] *UC Berkeley*

Corresponding Author: rkromani@gmail.com

HeRALD, an experiment within the SPICE/HeRALD collaboration, is a proposed sub-GeV scale dark matter detector based on a target of superfluid helium 4 and monitored by a Transition Edge Sensor based readout system. Several promising readout channels exist, including through monitoring quasiparticle (phonon and roton) and atomic (singlet photon and triplet) excitations. The quasiparticle channel (measured through the detection of quantum evaporated helium atoms) is of particular interest for low mass dark matter direct detection, with sensitivity to DM as light as 1 MeV. I will describe the proposed experiment and the potential reach of both shovel ready and future detectors, as well as recent R&D progress.

Light/Charge Readout (3B) / 81

Assembly and test of a prototype nEXO charge-readout module with built-in, cryogenic ASIC readout

Author: Evan Angelico[1]

[1] *Stanford University*

Corresponding Author: eangelic@stanford.edu

The nEXO experiment aims to discover neutrinoless double beta decay of xenon 136, with a lifetime sensitivity goal of greater than 10ˆ28 years. Compared to using long cables to transmit signals outside of the detector, mounting amplification and digitization circuitry directly on detector submodules reduces noise and improves measurement fidelity. A cryogenic application specific integrated circuit (ASIC) called CRYO ASIC has been designed by SLAC and fabricated for direct attachment to the nEXO charge readout modules. In this talk, the electrical characteristics of the nEXO charge readout will be discussed along with ASIC performance considerations. A prototype nEXO charge-readout module with attached ASIC has been assembled and operated in a liquid xenon time projection chamber; this module's performance using a full chain of ASIC-controlling circuit boards will be presented.

Applications (1A) / 82

Noble Element Detectors for Rare Event Searches (Keynote)

Author: Jingke Xu[1]

[1] *Lawrence Livermore National Laboratory*

Corresponding Author: xu12@llnl.gov

Particle detectors with noble element targets have grown increasingly popular in rare event search physics experiments. The use of noble gases as the interaction medium enables high purity, large mass, and multi-channel signal detection in these experiments. When operated underground, noble element detectors have achieved extremely low background levels, and unprecedented sensitivity to rare interactions such as those arising from neutrinos and (as yet hypothetical) dark matter particles. In this presentation, I will review the benefits and challenges of rare event detection with noble elements, and discuss their applications in ongoing and planned experiments. In particular, I will focus on the experiments in which the interactions do not deposit significant energy, and discuss the R&D required to further lower the achievable energy thresholds in these experiments.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Detector Techniques (4B) / 83

The LZ Krypton Removal Chromatography System

Author: Andrew Ames[1]

Co-author: The LZ Collaboration

[1] *SLAC, Stanford University*

Corresponding Author: dreames@stanford.edu

Trace radioactive noble gases are a source of electron recoil backgrounds in liquid xenon dark matter experiments, and cannot be mitigated by self-shielding. Naturally occurring krypton, which contains trace amounts of the beta emitter krypton-85, is found in commercially available research-grade xenon at a level of 1-100 parts-per-billion. In the LZ dark matter experiment, we require the xenon in the detector to contain no more than 300 parts per quadrillion krypton. This limit reduces the rate of electron recoil events from krypton-85 to be comparable to the solar neutrino contribution. To achieve this, krypton is removed from the xenon using gas charcoal chromatography prior to its deployment in the detector. In this talk, I will present an overview of the krypton removal chromatography system, which was designed, built and operated by LZ at SLAC.

Applications (2B) / 84

Status and prospects of the NEXT experiment

Author: Lior Arazi[1]

[1] *Unit of Nuclear Engineering, Ben-Gurion University, Beer-Sheva, Israel*

Corresponding Author: larazi@bgu.ac.il

NEXT is a staged experimental program aiming at the detection of neutrinoless double beta ($\beta\beta0\nu$) decay in ^{136}Xe using successive generations of high-pressure gaseous xenon time projection chambers. The collaboration is presently concluding four years of operation of NEXT-White, a radiopure 50-cm diameter and length TPC operated with enriched xenon at 10 bar, at the Laboratorio Subterráneo de Canfranc. NEXT-White has successfully demonstrated the two key features of the technology, namely excellent energy resolution (1% FWHM at the Q-value of the decay) and highly effective topological-based background discrimination and served to provide an independent measurement of the ^{136}Xe two-neutrino double beta decay half-life. The next stage of the program is NEXT-100, planned for construction in 2022, which will be twice larger than NEXT-White, and operated with 97 kg of enriched xenon at 15 bar, with half-life sensitivity on the scale of 10^{26} y. NEXT-100 will be superseded by a tonne-scale detector with a sensitivity of 10^{27} y around 2026. Parallel to the incremental increase in TPC size, the collaboration pursues an extensive R&D program to develop the capability of detecting the ^{136}Ba daughter resulting from ^{136}Xe double beta decays inside a running TPC using single molecule fluorescence imaging. This effort can lead to a background-free search for $\beta\beta0\nu$ decay on the tonne-scale, with half-life sensitivities close to 10^{28} y. This talk will present the status of the program, summarizing our experience with the NEXT-White TPC, provide an overview of the barium-tagging activities, and outline the future steps of the experiment.

Detector Techniques (4B) / 85

Barium Tagging for the NEXT Neutrinoless Double Beta Decay Program

Author: Karen Navarro[1]

Co-author: Ben Jones [1]

[1] *University of Texas at Arlington*

Corresponding Author: ben.jones@uta.edu

The NEXT collaboration is pursuing a phased program to search for neutrinoless double beta decay (0nubb) using high pressure xenon gas time projection chambers. The power of electroluminescent xenon gas TPCs for 0nubb derives from their excellent energy resolution (<1%FWHM), and the topological classification of two electron events, unique among scalable 0nubb technologies. Xenon gas detectors also also offer a further opportunity: the plausible implementation of single barium daughter ion tagging, an approach that may reduce radiogenic and cosmogenic backgrounds by orders of magnitude and unlock sensitivities that extend beyond the inverted neutrino mass ordering. In this talk I will present recent advances in the development of single ion barium tagging for high pressure xenon gas detectors. Topics to be covered will include advances in single ion microscopy in high pressure gas, molecular sensor development including color-shifting and turn-on barium chemosensors,

methods for concentrating ions to sensors and/or actuating sensors to ions, and plans for demonstrator phases that aim to prove barium tagging in-situ, on a 3-5 year timescale.

Light/Charge Readout (4A) / 86

The Bubble-Free Liquid Hole-Multiplier: a New Concept for Primary and Secondary Scintillation Detection in Noble-Liquid Detectors

Authors: Arindam Roy[1]; Gonzalo Mertinez-Lema[1]; Amos Breskin[2]; Lior Arazi[1]

[1] *Unit of Nuclear Engineering, Ben-Gurion University, Beer-Sheva, Israel*

[2] *Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel*

Corresponding Author: arindamroy207@gmail.com

The bubble-assisted liquid hole-multiplier (LHM) concept, introduced several years ago, has been thoroughly investigated as a detection element for primary (S1) and secondary (S2) scintillation light detection in noble-liquid TPCs. The basic LHM idea relies on a CsI-coated perforated electrode immersed in the liquid, with a bubble of the liquid vapor trapped underneath. Radiation-induced Ionization electrons liberated in the liquid and S1 VUV-induced photoelectrons from the CsI photocathode are collected into the holes; as they cross the liquid-vapor interface into the bubble they generate intense electroluminescence (EL) signals.
In this contribution, we will discuss a new, simpler, concept – the *bubble-free* LHM. Here, the liquid-vapor interface lies above the perforated electrode, which now has CsI on its bottom face; the electrode is fully immersed within the liquid, with no bubble underneath. Ionization electrons created in the drift volume below the electrode and S1-induced photoelectrons emitted from the photocathode are focused into the holes from below and pass through them with nearly no losses. A strong field above the electrode (taking here the role of the "gate" in conventional dual-phase TPCs) ensures transmission of the electrons into the vapor phase, where they produce intense S1 and S2 EL signals. The main advantages of this concept are that single-VUV photon detection efficiencies can potentially be of the order of 20%, and that individual VUV photons generate large EL signals which cannot be faked by dark counts. Bubble-free imaging LHMs can therefore allow the use of VUV SiPMs or CMOS sensors, despite their high dark-count rates.
The talk will describe the basic principles of the new concept and summarize our current experimental results in LXe. These include photoelectron extraction efficiency into LXe, electron focusing efficiency into the LHM holes of both ionization electrons and photoelectrons, and the transfer efficiency of electrons towards the liquid-vapor interface. These results validate the new concept, providing a promising basis towards further studies and future applications.

Light/Charge Readout (3B) / 87

Organic photosensors for detection of VUV scintillation light

Author: Michael Febbraro[1]

Co-authors: Sabrina Cheng [1]; Kate Hausladen [1]; Austin McDonald [2]; Jonathan Asaadi [2]

[1] *Oak Ridge National Laboratory*

[2] *University of Texas at Arlington*

Corresponding Author: febbraro@umich.edu

Organic semiconductors have gained considerable attention in recent years for use in a wide range of applications from OLEDs, OFETs, to optical sensors. They can be prepared on rigid as well as flexible substrates over large areas through low-cost fabrication techniques with performance rivaling low-noise silicon photodiodes. These properties make them a potentially attractive option

for future large-area noble element detectors. In this talk, we will address the feasibility of using organic semiconductors for vacuum ultraviolet (VUV) scintillation light detection. The prospects and challenges of using organic semiconductor technologies will be discussed. We will present first measurements on cryogenic operation of organic photodiodes and ongoing R&D into making these devices sensitive to VUV scintillation light.

Detector Techniques (3A) / 88

Dielectric Strength of Noble and Quenched Gases for High Pressure Time Projection Chambers

Author: Logan Norman[None]

Corresponding Author: logan.norman@mavs.uta.edu

Dielectric breakdown strength is one of the critical performance metrics for gases and mixtures used in large, high pressure gas time projection chambers. We have experimentally studied dielectric breakdown strengths of several important time projection chamber working gases and gas-phase insulators over the pressure range 100 mbar to 10 bar, and gap sizes ranging from 0.1to 10 mm. Gases characterized include argon, xenon, CO2, CF4, and mixtures 90-10 argon-CH4,90-10 argon-CO2and 99-1 argon-CF4. We developed a theoretical model for high voltage breakdown based on microphysical simulations that use PyBoltz electron swarm Monte Carlo results as input to Townsend- and Meek-like discharge criteria. This model is shown to be highly predictive at high pressure, out-performing traditional Paschen-Townsend and Meek-Raether models significantly. At lower pressure-times-distance, the Townsend-like model is an excellent description for noble gases whereas the Meek-like model provides a highly accurate prediction for insulating gases.

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Low Threshold Operation of the Scintillating Xenon Bubble Chamber

Author: Matthew Bressler[1]

[1] *Drexel University*

Corresponding Author: matthewjohnbressler@gmail.com

A scintillating bubble chamber with pure xenon was first operated in 2016 and has previously demonstrated coincident bubble nucleation and scintillation detection at thermodynamic thresholds above 4 keV. We now report on operation of the xenon bubble chamber at thermodynamic thresholds as low as 0.5 keV, including tests of bubble nucleation associated with gammas, and sensitivity to low energy neutrons from a ^{88}Y-Be photoneutron source at thresholds around 1 keV. Additionally, these results again demonstrate coincident bubble nucleation and scintillation with 252Cf and background neutrons, and the scintillation channel allows us to make an efficient background-reducing cut for a nuclear recoil efficiency analysis, which is ongoing.

Applications (1A) / 90

GammaTPC: a LAr TPC for MeV Gamma Rays

Author: Tom Shutt[1]

[1] *SLAC*

Corresponding Author: tshutt@slac.stanford.edu

I will describe GammaTPC, a proposed new LArTPC MeV gamma ray instrument concept. The MeV gamma ray sky is essentially unexplored due to the challenge of measuring multiple Compton scatters over a large detector volume. A TPC with low Z material has significant advantages for this measurement, and enables a relatively inexpensive detector with large mass and thus high sensitivity in the current era of sharply reduced costs of launching mass to space. A novel ultra low power, fine-grained charge readout is needed to match or exceed the imaging capabilities of currently proposed missions based on Si (or Ge) strip technology. Key developments are also needed for space deployment.

Light/Charge Response (1B) / **91**

Long afterglow: physical and chemical effects of impurities in bulk media and on surfaces in Ar and Xe detectors.

Author: Sergey Pereverzev[1]

[1] *Lawrence Livermore National Laboratory*

Corresponding Author: pereverzev1@llnl.gov

As field of application of noble elements detectors is expanding, it is becoming important to understand effects related to presence of impurities. Here we present several examples of known energetic long-living molecules which can be produced in detectors under action of ionizing radiation and UV light.
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-824442-DRAFT

Detector Techniques (4B) / **92**

Results from the Xeclipse Liquid Purification Test System for XENONnT

Author: Joseph Howlett[None]

Corresponding Author: jh3226@columbia.edu

As liquid xenon detectors grow in scale, novel techniques are required to maintain sufficient purity for charges to survive across longer drifts. The Xeclipse test facility at Columbia University was built to test the removal of electronegative impurities through cryogenic filtration powered by a liquid xenon pump, making possible a far higher mass flow rate than gas-phase purification through hot getters. This talk will outline the results of this R&D, which were used to guide the design and commissioning of the XENONnT liquid purification system. Thanks to this innovation, XENONnT has achieved an electron lifetime greater than 10 milliseconds in an 8.5 ton target mass, perhaps the highest purity ever measured in a liquid xenon detector.

Light/Charge Response (1B) / **93**

Study of Charge and Light Correlation in Electron Beam Energy Response in DUNE's prototype ProtoDUNE-SP LArTPC

Author: Zelimir Djurcic[1]

[1] *Argonne National Lab*

Corresponding Author: zdjurcic@anl.gov

The Deep Underground Neutrino Experiment (DUNE) is a cutting-edge experiment for neutrino science and proton decay studies. The single-phase liquid argon prototype detector at CERN (ProtoDUNE-SP) is a crucial milestone for DUNE that will inform the construction and operation of the first, and possibly subsequent 17-kt DUNE far detector modules. We have studied the response of DUNE LArTPC prototype detector ProtoDUNE-SP to test beam positrons via both ionization and scintillation signals. We searched for (anti) correlation between fluctuations of both scintillation and ionization in liquid argon, on event-by-event basis. Preliminary results, to be presented at the conference, reveal anti-correlated statistical fluctuation between scintillation and ionization in liquid argon.

Signal Reconstruction (2C) / 94

Measurement of the total neutron cross section on argon in the 30 to 70 keV energy range

Author: Tyler Erjavec[1]

Co-authors: Bob Svoboda [2]; Emilija Pantic [2]; Jingo Wang [3]; John Ullmann [4]; Julie He [2]; Junying Huang [2]; Leon Pickard [2]; Luca Pagani [2]; Michael Mocko [4]; Michael Mulhearn [2]; Sofia Andringa [5]; Yashwanth Bezewada [2]

[1] *University of California Davis*

[2] *University of California at Davis*

[3] *South Dakota School of Mines and Technology*

[4] *Los Alamos National Laboratory*

[5] *Laborat{\'o}rio de Instrumenta{}{\c c}{\~a}o e F{\'i}sica Experimental de Part{\'i}culas*

Corresponding Author: terjavec@ucdavis.edu

The use of liquid argon as a detection and shielding medium for neutrino and dark matter experiments has made the precise knowledge of the cross section for neutron interactions on argon an important design and operational parameter. Nevertheless, there has been a lingering discrepancy between the total cross-section in the 30-70 keV region given in the Evaluated Nuclear Data File (ENDF) and the single measurement done in the 1990's by an experiment optimized for higher energy. This discrepancy is significant in that the former predicts a large negative resonance in the region while the measurement did not report such a feature, giving rise to significant uncertainty in the penetration depth of neutrons through liquid argon. This talk presents results from the Argon Resonant Transport Interaction Experiment (ARTIE) at the Los Alamos Neutron Science Center (LANSCE), the first dedicated experiment optimized for this energy region. The ARTIE measurement of the total cross-section as a function of energy confirms the existence of a negative resonance in this region, but not quite as deep as the ENDF prediction.

Applications (2B) / 95

Searches for new physics with a stopped-pion source at the Fermilab accelerator complex

Authors: Jacob Zettlemoyer[1]; Matthew Toups[1]

[1] *Fermilab*

Corresponding Author: jzettle@fnal.gov

The PIP-II complex at Fermilab is slated for operation later this decade and can support a MW-class $\mathcal{O}$(1 GeV) proton fixed-target program in addition to the beam required for DUNE. Proton collisions with a fixed target could produce a bright stopped-pion neutrino source. The addition of an accumulator ring allows for a pulsed neutrino source with a high duty factor to suppress backgrounds. The neutrino source supports a program of using coherent elastic neutrino-nucleus scattering (CEvNS) to search for new physics, such as sensitive searches for accelerator-produced light dark matter and active-to-sterile neutrino oscillations. A key feature of a program at the Fermilab complex is the ability to design the detector hall specifically for HEP physics searches. In this talk I will present the PIP-II project and upgrades towards a stopped-pion neutrino source at Fermilab and studies showing the sensitivities of a $\mathcal{O}$(100 ton) liquid argon scintillation detector with a standard PMT-based light detection system to the physics accessible with this source.

Applications (2B) / 96

The liquid argon scintillation detection system for LEGEND-200

Authors: (co-authors added later)[None]; Stefan Schönert[1]

[1] *TUM*

Corresponding Author: schoenert@ph.tum.de

The LEGEND-200 experiment at LNGS will search quasi-background free for the neutrinoless double-beta decay in ^{76}Ge. Bare high-purity Ge detectors enriched in the isotope ^{76}Ge are operated in liquid argon, which serves as a coolant and active shielding. Background events are identified by their interaction typologies. The key to search background-free for $0\nu\beta\beta$ decays is the identification of events which deposit simultaneously energy in the germanium detectors and in the liquid argon. The latter interactions are identified by scintillation light at 128 nm wavelength. The LAr instrumentation consists of two concentric, wavelength-shifting green fiber barrels coated with TPB that shift the photons from the primary LAr light at 128 nm to the green. The photons are read out with arrays of SiPMs at the ends of the fibers. Due to the close proximity of the LAr instrumentation to the Ge detectors, strong restrictions apply with respect to the radioactivity of the components. Many commercially available components (e.g., packaging of SiPMs) exceed this limitation. This talk will present the design, construction, and first performance of a wavelength-shifting, ultrahigh-purity LAr scintillation detection system which will be operated in the LEGEND-200 experiment.

Light/Charge Readout (4A) / 97

A novel cryo-resilient wavelength shifter material for the DUNE X-Arapuca light concentrator

Authors: Carla Maria Cattadori[1]; Brizzolari Claudia[2]

[1] *INFN Milano Bicocca*

[2] *Univesrita' di Milano Bicocca*

Corresponding Author: claudia.brizzolari@mib.infn.it

DUNE is a long-baseline accelerator experiment currently in construction at Fermilab and SURF (South Dakota).
The science objectives of DUNE are the study of CP violation in the neutrino sector, the identification of the neutrino mass hierarchy, observation of supernova neutrino bursts and the search for proton decay.

The DUNE physics reach are remarkably enhanced by the DUNE Photon Detection System (PDS), which is based on a light concentration technology named X-Arapuca: at its core a polymeric slab acts both as secondary wavelength shifter and as lightguide to the photosensors.

In this talk, we will present the latest results achieved in the framework of the DUNE PDS Consortium activities, on the R&D and production of a photon downshifting (WLS) polymeric material, alternative to the off-shell baseline product, for both the Dune Horizontal and Vertical Drift modules and for SBND: it is an high performing low cost material, that allows to cover the large surfaces required in DUNE.
It will be discussed how the new WLS material enhances the light efficiency and cryo-reliability of the X-Arapuca with respect to the baseline WLS, and how it may be adapted for the Xe doping of Liquid Argon. Moreover the talk will review the strategies adopted to optimize the light trapping and the optical coupling of the WLS slab to the SiPMs. This to match the required photon detection efficiency for the detection of supernova neutrino bursts, while allowing for a reduced number of SiPMs per unit area of the X-Arapuca device, hence reducing the power dissipated in LAr by the power over fiber technique.

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Development Towards a Camera Readout Tracking Plane for the NEXT Collaboration

Author: Nicholas Byrnes[1]

[1] *University of Texas Arlington*

Corresponding Author: byrnes.nicholas@mavs.uta.edu

Neutrinoless double beta decay (0⊠⊠⊠) is an extremely rare nuclear decay that occurs when two neutrons in a nucleus simultaneously beta decay without producing any antineutrinos. If observed, 0⊠⊠⊠ would be the rarest decay process observed, and long target half-lives of 10^{28} years necessitate development of new background suppression and signal identification methodologies. The NEXT collaboration is searching for this decay using gaseous ^{136}Xe, a xenon isotope capable of undergoing double beta decay, and is pursuing an aggressive R&D campaign to develop techniques that may allow for ton-scale detectors with effectively zero background. One such way that this is being explored is via the Camera Readout And Barium-tagging (CRAB) technique, which will use a VUV Image Intensifier coupled to a single high speed, high quantum efficiency TimePix camera to directly image the VUV track light while coincidentally detecting the barium daughter isotope produced when ^{136}Xe decays. This approach is intended to circumvent technical challenges associated with densely multiplexed SiPM planes for tracking and yields a detector concept that can be upgraded to incorporate to a low voltage barium tagging cathode in a second phase. We will show preliminary results from CRAB-0, a system at the University of Texas at Arlington using a Hamamatsu imagEM X2 EMCCD camera coupled into a prototype VUV Image Intensifier, imaging in 10 bars of Xe gas with high resolution in two dimensions; and discuss progress toward the demonstrator phase, NEXT-CRAB, at Argonne National Laboratory that will enable three dimensional track imaging with the VUV without internal electronics or sensors.

Poster in Gather.Town / 99

Role of a-Se device configuration in UV detection efficiency characterized by Time of Flight

Author: Kaitlin Hellier[1]

Co-authors: Emmie Benard [2]; Shiva Abbaszadeh [1]

[1] *University of California, Santa Cruz*

[2] *Arizona State University, University of California, Santa Cruz*

Corresponding Author: khellier@ucsc.edu

Amorphous selenium (a-Se) detectors have made significant advances in the last few decades, with applications in X-ray, UV, and visible light detection and potential for high energy particle detection. A vertical architecture, in which light passes through a transparent conductor to the a-Se layer, is common in commercial devices; however, a lateral structure, in which light passes only through the selenium positioned between two contacts, presents an opportunity for improved device performance and application. In this work we compare the performance of vertical devices with a-Se thicknesses of 5, 10, and 15 um and lateral devices with electrode spacing of the same distances, using time of flight (TOF) and conversion efficiency, and introduce optical slits for lateral structures as a way to better perform carrier specific TOF in a-Se devices.

Applications (1A) / 100

Sensitivity of the nEXO neutrinoless double beta decay experiment

Author: Brian Lenardo[1]

[1] *Stanford University*

Corresponding Author: blenardo@stanford.edu

The nEXO experiment is a proposed next-generation search for the neutrinoless double beta decay ($0\nu\beta\beta$) of Xe-136. The detector will be a 5-tonne, monolithic liquid xenon TPC with a target enriched to 90% in the isotope of interest. In this talk, we will discuss a new evaluation of the experiment's sensitivity to $0\nu\beta\beta$, given recent updates to the detector design and improved modeling of the signal readout. Specific improvements include detailed, data-driven modeling of signal development in the charge readout tiles (and subsequently improved modeling of the energy and position reconstruction), the development of new machine-learning analyses to improve signal/background separation, and an updated detector geometry. We will discuss how these changes lead to a projected 90% CL exclusion sensitivity on the $0\nu\beta\beta$ halflife of 1.35×10^{28} yrs in nEXO, approximately two orders of magnitude beyond existing experimental limits.

Signal Reconstruction (2C) / 101

Lightmap reconstruction in nEXO with an internal xenon 127 source

Author: Clarke Hardy[1]

[1] *Stanford University*

Corresponding Author: cahardy@stanford.edu

The nEXO experiment is a planned ton-scale liquid xenon time projection chamber (TPC) designed to search for neutrinoless double beta decay (0vBB) with a half-life sensitivity beyond 10^{28} years. Optimal energy resolution in nEXO requires the precise reconstruction of the scintillation light signal, corrected by the position- and time-dependent light collection efficiency (or "lightmap") throughout the active volume. An injected xenon 127 source is being considered for the lightmap reconstruction as it allows for in-situ calibrations of the light response, particularly in the center of the TPC where the use of external sources is limited by the attenuation of gammas in the liquid xenon. Multiple potential techniques for lightmap reconstruction are being explored, including a neural net and a kernel smoothing algorithm. This talk will present projections of the lightmap reconstruction capability from simulated xenon 127 decays and a discussion of the techniques involved.

Signal Reconstruction (3C) / 102

Nucleation efficiency of nuclear recoils in bubble chambers

Author: Daniel Durnford[1]

Co-author: Marie-Cécile Piro [1]

[1] *University of Alberta*

Corresponding Author: ddurnfor@ualberta.ca

Bubble chambers using liquid xenon (and liquid argon) have been operated (resp. planned) by the Scintillating Bubble Chamber (SBC) collaboration for GeV-scale dark matter searches and CEvNS from reactors. This will require a robust calibration program of the nucleation efficiency of low-energy nuclear recoils in these target media. Such a program has been carried out by the PICO collaboration, which aims to directly detect dark matter using C_3F_8 bubble chambers. Neutron calibration data from mono-energetic neutron beam and AmBe source has been collected and analyzed, leading to a global fit of a generic nucleation efficiency model for carbon and fluorine recoils, at thermodynamic thresholds of 2.45 and $3.29\,\mathrm{keV}$. Fitting the many-dimensional model to the data (34 free parameters) is a non-trivial computational challenge, addressed with a custom Markov Chain Monte Carlo approach, which will be presented. Parametric MC studies undertaken to validate this methodology are also discussed. This fit paradigm demonstrated for the PICO calibration will be applied to existing and future scintillating bubble chamber calibration data.

Applications (2B) / 104

Precision CEvNS measurements with liquid argon scintillators for COHERENT

Author: Daniel Joseph Salvat[1]

[1] *Indiana University*

Corresponding Author: dsalvat@iu.edu

The COHERENT collaboration has deployed a suite of low-threshold detectors in a low-background corridor of the ORNL Spallation Neutron Source to measure coherent elastic neutrino nucleus scattering (CEvNS) on an array of nuclear targets employing different technologies. This has produced CEvNS cross section measurements with CsI and liquid argon scintillator detectors. These measurements confirm the N^2-dependence predicted by the Standard Model and have enabled searches for non-standard interactions and accelerator-produced dark matter. We aim to construct and deploy a ton-scale liquid argon detector to provide precision measurements of the CEvNS cross section, improve our search for dark matter, and investigate charged-current interactions in argon. In this talk, we will present an overview of the COHERENT experiment with a focus on our liquid argon program.

Poster in Gather.Town / 105

Measurement of the Light-Yield in MicroBooNE with Isolated Protons

Author: Jiaoyang Li[1]

[1] *the University of Edinburgh*

Corresponding Author: jiaoyang.li@ed.ac.uk

The MicroBooNE detector is an 85-ton active mass Liquid Argon Time Projection Chamber (LArTPC) located on-axis along the Booster Neutrino Beam (BNB). It serves as a part of the Short-Baseline Neutrino (SBN) program at Fermilab, which was primarily designed to address the eV-scale sterile neutrinos. The primary signal channel in the LArTPC is ionisation, but the argon also emits large quantities of scintillation light. Prompt scintillation light in MicroBooNE is recorded with an array of 32 PhotoMultiplier Tubes (PMTs). The scintillation light is used to determine the timing of neutrino interactions and to reject cosmic-ray activity.We present a new method of measuring the light-yield using isolated proton events, which enables a position-dependent light-yield measurement to map the response of the detector across its volume. This method can be used to calibrate the light response in large-scale LArTPC detectors as well as to test assumptions used in simulating scintillation light.

Light/Charge Readout (4A) / 106

Polyethylene naphthalate wavelength shifter development and comparison with TPB using 2PAC

Author: Cenk Turkoglu[1]

[1] *AstroCeNT*

Corresponding Author: cturkoglu@camk.edu.pl

The number of rare event search experiments using liquid argon as the active volume is increasing. As the scintillation light emitted from liquid argon following the interactions peaks at 128 nm, a wavelength shifter (WLS) is required for efficient detection of such signals. In the experimental setup dubbed 2PAC (2 Parallel Argon Chambers) operated at LNGS, two identical liquid argon detectors are used to compare two WLS candidate materials: PolyEthylene Naphthalate (PEN) and TetraPhenyl Butadiene (TPB). In each chamber, the inner surface is covered with specular reflectors and one of the candidate WLS, while SiPMs are used as photosensors, covering approximately 1% of surface area, in order to imitate the configuration of the future large scale detectors. Experimental results of the light yield from both chambers, supported by the Geant4 simulations, will be discussed and compared, giving the first low temperature comparison of the wavelength shifting efficiencies of PEN and TPB in a true 4pi geometry, and the highest reported so far PEN conversion efficiency from an industrial grade of PEN. Future R&D plans for PEN as WLS will also be discussed.

Light/Charge Readout (1C) / 107

Charge and Light Sensing in Noble Liquid TPCs (Keynote)

Author: Veljko Radeka[1]

[1] *Brookhaven National Laboratory*

Corresponding Author: radeka@bnl.gov

Noble liquid time projection chambers (TPCs) are of interest for experiments in the quest to answer some most basic questions in both particle and nuclear physics. The charge and light in both LAr and LXe in response to particles of interest are at the limits of detection sensitivity and accuracy of their respective charge sensing electrodes and light sensors, such as silicon photomultipliers (SiPMs). Both will be applied on a large scale in terms of the sensitive areas covered with fine segmentation and large numbers of signal channels. All TPCs under design or planned will depend critically on the use of low noise electronics immersed in the cryogenic liquid ("cold electronics") to be operated for a decade or longer. Valuable experience has been gained from the already seven years of operation of the TPC with the lowest noise so far, the MicroBooNE. Some highlights of the experience with

charge sensing in that TPC will be presented. The two proposed and planned experiments, DUNE second 10-kton LAr module and nEXO 5-ton LXe TPC will present similar charge sensing signal-to-noise challenges, but much more severe light sensing challenges. This is due to the very large areas of SiPMs required. Methods to address the light sensing challenge, to achieve single-photoelectron sensitivity on an array of SiPMs where the avalanche charge signal is deposited on a capacitance of tens of nanofarads, will be described and the results presented.

Applications (1A) / 108

LArTPC for Neutrino Detection (Keynote)

Author: Elena Gramellini[1]

[1] *Fermi National Accelerator Laboratory*

Corresponding Author: elenag@fnal.gov

The Liquid Argon Time Projection Chamber (LArTPC) represents one of the most advanced experimental technologies for physics at the Intensity Frontier due to its full 3D-imaging, excellent particle identification and precise calorimetric energy reconstruction. Reviewing current experimental efforts and potential technology upgrades, this talk summarizes the exciting physics we can explore using LArTPCs.

Applications (1A) / 109

Introduction

Author: Kaixuan Ni[1]

[1] *UCSD*

Corresponding Author: nikx@physics.ucsd.edu

Closing Remarks / 110

Closing Remarks, Poster Awards, Next Conference, etc.

Light/Charge Readout (3B) / 111

Optical Light Collection Amount Studies for Dedicated Measurements

Author: A. Carolina Garcia B.[None]

Corresponding Author: gbcarolinaa@gmail.com

In long baseline Neutrino experiments like T2K, NOVA and the future DUNE, the Far Detector includes a Photon Detection System to help identify the physics signals from the noise presented. The signals correspond to the physical processes produced when a neutrino or antineutrino beam is sent from the near detector. When data is taken, one or multiple processes can be presented in a signal,

and also one or multiple neutrinos can produce a signal, therefore, High Energy Physics methods and others are used to establish the correspondences and to identify the properties and characteristics of the processes. In the case of NOVA and DUNE, the photon detection system is built for a Liquid Argon chamber, and they share a common analysis tool which is LArSoft. In this presentation, one of the variables of the Photon Detection system is discussed, the Optical Hits module, which gives us the Optical Light Collection Amount. A fictitious detector is used to show how dedicated measurements can be done and how this variable can be used for the Calibration and Commissioning of the Photon Detection System.

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Conference Photo on Zoom