LIDINE 2019: LIght Detection in Noble Elements

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Book of abstracts

Table of contents

Light/charge response / 0

Fast component re-emission in Xe-doped liquid argon.

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Liquid argon (LAr) is widely used in scintillation detectors for neutrino physics, Dark Matter search and other applications. As a scintillator, the LAr provides very efficient pulse shape discrimination (PSD) between different types of particles due to the significant difference in decay time and relative intensities of the fast and slow components. The significant disadvantage of LAr is that the wavelength of scintillation lies in the VUV range (~128 nm). A common and the easiest solution of this problem is to use wavelength shifters (WLS). An elegant idea is to add small amount of Xe into LAr which can work as a volume-distributed WLS. In previous studies, it was shown that with low Xe concentrations up to 300 ppm by mass there is no evidence of the fast component re-emission. And PSD analysis cannot be applied without additional WLS.
We present the first direct experimental confirmation of the fast component re-emission in LAr doped with xenon. This effect was studied at various Xe concentrations up to ~3000 ppm. The rate constant of the energy transfer for the fast component was quantified. It was shown that at high Xe concentration the PSD efficiency is better in comparison with either pure LAr or LAr with TPB combined with Xe. The stability of LAr+Xe mixture was tested for the first time at high Xe concentration during the long continuous run.

Light/charge readout / 1

Ion transport model for large LArTPC

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High single photoelectron (SPE) rates have been recently observed in several large LArTPC detectors at surface. These single photons are background that could limit the LArTPC capability for low energy physics. To understand the origin of the high SPE rate, we developed a model focusing on the slowly moving positive and negative ions (space charge) - induced by the ionization of cosmic rays and electron attachment to impurities in LAr. Our model can predict the electric field distortion due to the presence of space charge that is well matched to measurements. More importantly, the model contains two new processes that contribute to producing photons from the interactions of the ions, which provide a plausible explanation for the observed high single PE rate. Model predictions compared with data from the ProtoDUNE experiment will be shown.

Detector techniques / 2

Purity Monitors in protoDUNE Dual-Phase

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Liquid argon TPCs require a high level of purity (below 1 ppb, i.e. 6 ms lifetime) for ionisation charges to drift long distances. The most sensitive commercially available Residual Gas Analysers (RGA) can only go down to 10 parts per billion (ppb) oxygen equivalent impurities and their use is only restricted to gas measurements. Purity may be also estimated by using muon tracks—when the detector is not underground—but this is only possible when the cryostat is fully filled and a certain level of purity is achieved. More over, space-charge effects may distort the lifetime measurement. For these reasons, custom-made devices, called purity monitors, may be of great help if installed directly in the cryostat or somewhere along the recirculation system. In my talk I will describe how purity monitors work, with specific reference to the purity monitors installed and operated in the protoDUNE dual-phase at CERN.

Light/charge response / 3

Measurement of the scintillation and ionization response of liquid xenon at MeV energies in the EXO-200 experiment

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Liquid xenon (LXe) is employed in a number of current and future detectors for rare event searches. In this contribution, I will present the measurement of absolute scintillation and ionization yields in LXe generated by gamma interactions from various radioactive calibration sources at MeV energies over a range of electric fields in the EXO-200 experiment, designed to search for neutrinoless double beta decay in Xe-136. These data are used to measure the W-value, defined as the average energy required to produce either an electron-ion pair or a photon in the LXe. Detailed measurements of the absolute charge and light yields, as well as the recombination fluctuations in the number of electrons and photons produced by MeV scale electron recoils are useful for predicting the performance of future neutrinoless double beta decay detectors employing LXe.

Applications / 4

The COHERENT experiment and status of the CENNS-10 liquid argon detector.

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Coherent elastic neutrino-nucleus scattering (CEvNS) is recently discovered process by the COHERENT collaboration at the SNS accelerator facility in ORNL. Liquid argon detector CENNS-10 is one of the tools for the further CEvNS study. In this talk, we make a short overview of the COHERENT experiment and describe the status the CENNS-10 detector. The main focus of this talk will be at light detection system and its upgrade. First results will be presented. Possible improvements for the further stage of the experiment will be discussed.

5

Performance Studies of PandaX dual phase xenon TPCs

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The PandaX project, located at China Jin-Ping underground Laboratory (CJPL), aims to search for dark matter WIMP signals with dual phase xenon TPCs. The PandaX-II detector took physics data from 2016 to 2018 and has established itself as one of the most effective dark matter direct detection experiments. After physics runs concluded, we conducted a series of detector performance runs, including running PMTs with low gain mode, signal dependence on drift field, etc. In this talk, I will give an overview of PandaX program and such performance studies. Emphasis will be given to low gain runs to extend detector's response at higher energy.

Light/charge response / 6

The NEXT-DEMO++ detector: R for low diffusion mixtures

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One of the most promising technologies to search for neutrinoless double beta decay (0nubb) is a high pressure xenon gas (HPXe) time projection chamber (TPC) with electroluminescent (EL) amplification. The key advantages afforded by HPXe-EL TPC technology are very good energy resolution and event topology reconstruction allowing for the identification of 2 electron events indicative of bb decays. The current imaging performance is limited by the diffusion of the ionization electrons during drift. The DEMO++ detector was built to study different gas mixtures that could reduce diffusion and hence improve the position resolution of event reconstruction and, thus, improve the signal identification when compared with the current NEXT detectors using pure xenon. In this talk, I will describe the DEMO++ experiment, its scientific objectives and the performance in its first months of operation.

Signal reconstruction / 7

Position reconstruction using photon timing for the DEAP-3600 dark matter experiment

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DEAP-3600 is a single-phase liquid argon dark matter detector being operated 2 km underground at SNOLAB, Sudbury, Canada. The detector consists of 3.3 tonnes of ultra-pure liquid argon in a spherical acrylic cryostat instrumented with 255 photomultiplier tubes. Natural radioactive contamination can cause alpha decays originating in the acrylic vessel or TPB wavelength shifter, or gamma rays that may induce Cherenkov light. Reconstruction of the position of the interactions taking place in the detector uses information about the number of photoelectrons detected in each PMT and when they were detected. Including this information in our suite of cuts allows us to identify and remove almost all surface background events.

Dark matter search results from the first year of operation will be presented. A method of event position reconstruction emphasizing photon timing will be discussed.

Signal reconstruction / 8

A complete simulation of the X-ARAPUCA device for detection of scintillation photons

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The concept of the ARAPUCA device is relatively new and involves increasing the effective area for photon collection of SiPMs by the use of a box with highly reflective internal walls, wavelength shifters, and a dichroic filter to allow the light to enter the box and not the leave it. There were a number of tests showing the good performance of this device. Recently an improvement on the original design was proposed: the inclusion of wls bar inside the box to guide photons more efficiently to the SiPMs. We present a full simulation of the device using Geant4. We have included all the material properties that are available in the literature and the relevant properties for photon propagation available in the framework. Main results include estimates of detection efficiency as a function of the number and placing of SiPMs, width of the wls bar, attenuation in the bar, and the existence of a gap between the bar and the SiPMs. The estimated efficiency for a device of 200mm x 80mm x 6mm and 8 6x6 mm2 SiPMs is of order 3%. The ARAPUCA simulation has been validated in a number of experimental setups and is a useful tool to help making design choices for future experiments.

Light/charge response / 9

Measurement of liquid argon scintillation and ionization response on nuclear recoils under electric fields up to 3 kV/cm

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Liquid argon scintillation detector is known to offer attractive features for various physics projects such as dark matter searches and neutrino-related experiments. One of the key quantities in these projects is the scintillation response on nuclear recoils (NR) in the energy of a few tens of keV and below. The response is known to depend on the recoil energy and applied electric fields. Although these properties are measured by several groups, systematic understanding and discussions including low energy and high electric field are not deeply given by them so far.

In this talk, we present the measurement of scintillation and ionization efficiencies for a few tens of keV NR under electric fields ranging from 0 to 3 kV/cm. Calibration data is taken with radioactive isotopes including 252Cf neutron source with a small size double phase detector. We also discuss the liquid argon response to ionization particles based on traditional models (e.g., TIB model and Doke-Birks model) and an additional measurement with low energy gamma ray sources (37Ar and 241Am).

Light/charge readout / 10

Bubble-assisted Liquid Hole Multipliers in LXe and LAr: towards "local dual-phase TPCs"

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The bubble-assisted Liquid Hole Multiplier (LHM) is a novel concept for the combined detection of ionization electrons and scintillation photons in noble-liquid detectors. It is based on a perforated electrode, such as the Gaseous Electron Multiplier (GEM) or a Thick Gaseous Electron Multiplier (THGEM), immersed in the noble liquid. Heating elements generate a vapor bubble, supported stably underneath the electrode. Radiation-induced ionization electrons from the liquid volume drift into the electrode's holes, cross the liquid-vapor interface into the bubble and induce electroluminescence (EL). The top surface of the electrode is optionally coated with a CsI photocathode; radiation-induced UV-scintillation photons extract photoelectrons that induce EL in a similar way. Event localization is obtained with pixel readout elements located underneath the LHM detector.

The mechanism, yielding EL of ~400 photons/electron/4pi in LXe, proved to be stable over weeks of continuous operation. Energy-resolution values surpassing those of current dual-phase LXe TPCs (e.g. 5.5% RMS for alpha-particle-deposited 7,000 primary electrons) were reached; time resolutions in the nanosecond scale were measured for scintillation events comprising a few hundred photoelectrons. Accurate imaging (event reconstruction RMS ~200 μm) was demonstrated for the EL patterns, with silicon photomultipliers immersed in LXe. The operation of the LHM in LAr has recently been demonstrated for the first time, with copious light yield. The merit of the bubble-assisted LHM lies in the tight confinement of the liquid-vapor interface within the electrode's holes, which may offer a more uniform response in large-area detectors, compared to that of the classical dual-phase TPCs.

In this talk, we shall present the basic principles of the LHM concept, highlight the results in LXe and show our first results of LHM operation in LAr. We will discuss the physics processes involved and the potential benefits of this "local dual-phase TPC" concept in future DM searches and neutrino-physics experiments.

Light/charge response / 11

Effect of an Electric Field on Liquid Helium Scintillation

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With the discovery in the late 1950s of scintillation in liquid helium resulting from the passage of charged particles, many subsequent experimental and theoretical studies have been carried out to further understand the light production mechanism and the behavior of ions and neutral species in the medium. Recently, there has been renewed interest in using liquid helium in particle detectors for a diverse range of experiments. These include the search for the neutron electric dipole moment (nEDM), the measurement of the neutron-decay lifetime, solar neutrino detection, and the search for dark matter. With such broad applications, many properties of the scintillation remain to be explored. Of particular interest is how the ionization densities and charge distributions produced by different types of charged particles affect the scintillation signal produced in a region of a high electric field. The question is especially pertinent for the proposed nEDM experiment at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. I will discuss the ongoing R effort at Los Alamos National Laboratory to measure and understand the dependence of the scintillation light produced by different particles (alphas, electrons, protons, tritons) when the liquid is subjected to fields of 10's of kV/cm over a wide range of temperatures (0.4 K – 3 K) and pressures.

Light/charge readout / 12

Light detection in DarkSide-20k

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The Darkside aims at the direct detection of WIMPS using a dual phase liquid Argon TPC.
The next generation experiment, Darkside-20k, will push the fiducial mass liquid argon to 20 tonnes. The light detection is a crucial part of the project; DS-20k will use, instead of the standard PhotoMultipliers, the Silicon PhotoMultipliers (SIPMs). This kind of photo-sensors will permit an higher photo-detection efficiency and a lower background, compared to standard PMTs. The TPC will be outfitted with more about 200,000 SiPMs, designed by FBK and made by LFoundry, grouped into 8280 single-channel, 25 cm^2 Photo Detection Module (PDM)s. We will present the performance of the photo-sensors and the design of the DS-PDM; the strategy to scale from the R to the massive production will be discussed too.

Light/charge readout / 13

Light and charge readout for the DARWIN project

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The DARWIN project aims at realizing a low-background, low-threshold astroparticle observatory, based on a multi-ton liquid xenon (LXe) time projection chamber. The baseline design foresees two arrays of photosensors installed above and below the target to record the prompt and proportional scintillation signals. The collaboration is pursuing an extensive R program to identify the optimal technology fulfilling the main requirements, namely high sensitivity and low-radioactivity. The ongoing R activities within the DARWIN program will be highlighted and some details will be discussed.

Applications / 14

ALARM: A mini Liquid Argon Radiation Monitor

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Detecting illicit radiological materials in cargo at ports of entry is a major concern for security agencies. The most widely used technologies include large area plastic scintillators for gamma-ray detection and 3He proportional gas detectors for neutron detection. These systems have a few major disadvantages, namely the low intrinsic energy resolution of plastic scintillator and the insensitivity of 3He to fast neutrons. 3He proportional gas detectors are most sensitive to thermal neutrons and therefore require large amounts of moderating material to detect fast neutrons, such as those produced via spontaneous or induced fission. Moreover, the cosmic background of thermal neutrons is highly sensitive to both the local and space climate. As a result, fluctuating backgrounds can lead to high false positive rates. Canadian Nuclear Laboratories is exploring the use of liquid argon (LAr) to simultaneously detect neutron and gamma radiation for this application. LAr detectors have generally good energy resolution due to the high light yield of LAr scintillation. In addition, LAr has recently been shown to produce the most powerful pulse shape discrimination of any scintillator. Presented here is the design and a Monte Carlo study of the expected performance of a ~10 kg LAr detector viewed by 2 Hamamatsu R5912-Y001 cryogenic PMTs immersed in LAr.

Light/charge response / 15

Study of luminescence mechanism by neutral bremsstrahlung in gaseous argon.

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Secondary scintillation light (S2 signal) in two-phase detectors has been used for the direct dark matter search and neutrino experiments. In general, electrons extracted from liquid phase produce excimers in gaseous phase that emit VUV S2 signal. As typical electric field is several kV/cm, the emitted light is proportional electroluminescence. On the other hand, recent research suggested that the S2 signal in argon has another mechanism of luminescence, called "neutral bremsstrahlung", created even by relatively low electric field (a few kV/cm). The neutral bremsstrahlung light is thought to have a wide range wavelength spectrum, from UV to NIR and directional emission, but few experimental studies have been established to understand the mechanism.
In this talk, we report detailed measurements of neutral-bremsstrahlung-induced-S2-signal (and also VUV S2 signal) in argon, and discuss about its existence/properties and the possible utilization of this neutral bremsstrahlung-induced-signal.

Signal reconstruction / 16

Noble Element Simulation Technique v.2.0

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The Noble Element Simulation Technique (NEST) is a comprehensive mostly-empirical standalone package for complete and accurate simulation both the scintillation light and ionization yields of noble elements for many particle types (nuclear recoils, electron recoils, alphas, etc.). In compare to NEST v.1.0, the v.2.0 version can operate both with the GEANT4 library and as a command-line tool.

Significant number of updates to the NEST models, which substantially improved the package, are presented. Practically all data on interactions with gas, liquid and solid xenon media available worldwide have been taken into consideration in development of the current models. First preliminary models for NR and ER for argon version of NEST are also discussed.

Light/charge response / 17

Surface background rejection techinque for liquid argon dark matter detectors using a thin scintillating layer

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DEAP-3600 is a direct dark matter detection experiment located at SNOLAB in Sudbury, Canada, that has been collecting dark matter search data with a 3200kg liquid argon target since 2016, with the current best sensitivity for dark matter with argon [1]. The Global Argon Dark Matter Collaboration, formed in 2017, is working towards a phased approach with an ultimate next generation multi-hundred tonne liquid argon dark matter detector. Due to the large detector size, surface background mitigation is of particular importance for increasing signal acceptance.

A new research facility is being developed at Carleton University (Located in Ottawa, Canada) for R of noble liquid detector experiments (Carleton Noble Liquid Detector Lab, or COLD Lab). A 30kg liquid argon cryostat equipped with two 64-Channel Hamamatsu SiPMs for scintillation light readout will be used to test a novel technique for surface background rejection [2] by implementing a long lifetime scintillation layer at the surface and using pulse shape discrimination to identify surface events. The status of this experiment will be discussed.

[1] - DEAP Collaboration, Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB, 2019, submitted to PRD, arXiv:1902.04048

[2] - M. Boulay, M Kuzniak, Technique for Surface Background Rejection in Liquid Argon Dark Matter Detectors using Layered Wavelength-Shifting and Scintillating Thin Films, 2019, Submitted to Nuclear Instruments and Methods A, arXiv:1903.00257

Detector techniques / 18

Light detection system in protoDUNE dual phase detector

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The CP violation phase in the leptonic sector is one of most interesting parameter yet to be measured to complete the neutrino puzzle, together with the neutrino mass hierarchy determination. The DUNE (Deep Underground Neutrino Experiment) project is currently being designed to fulfill these goals in the next decade. The oscillation of a muon neutrino beam made at FERMILAB will be measured 1300 km away in SURF (Stanford Underground Research Facility) laboratory with 4x10 kt Liquid Argon TPC modules. Two technologies are foreseen for these giant detectors: single and dual phase. For the latter, a small layer of gas argon enables the electron amplification before their collection. In order to optimize the design of these two technologies at such large scale, two large prototypes (~6x6x6 m3) have been constructed in the CERN neutrino platform to be exposed to hadron beam and cosmic rays.

In ProtoDUNE-DP, the scintillation light will be collected by 36 cryogenic PMT installed underneath the cathode with an acceptance optimized pattern. An internal light calibration system to monitor the PMT gain and response has been installed and will be presented. The status of the protoDUNE-DP commissioning will be reviewed. Trigger and analysis strategies to monitor the argon purity, scintillation light production and propagation parameters will be presented. Finally, the photon detection system design foreseen for the DUNE Far Detector DP module will be described.

Light/charge response / 19

Analysis of the light production and propagation in the 4 tonne dual-phase demonstrator

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The Deep Underground Neutrino Experiment (DUNE) is a new generation long-baseline neutrino detector conceived to measure the CP violation phase, neutrino mass hierarchy and search for supernova neutrino burst and proton decays. The detector will consist of four 10-kton Liquid Argon (LAr) Time Projection Chambers using both single and dual- phase (DP) technologies. The latter provides charge amplification before collection in the gaseous phase. In order to optimize these two designs, large prototypes are being constructed at CERN. For the dual phase, a 4 tonne demonstrator of 3x1x1 m3 took cosmic data in 2017 and exhibited good performance in terms of charge and light collection.

In the demonstrator, 5 cryogenic photomultipliers were installed with different configurations in terms of base polarity and wavelength shifting methods. During the 4-tonne demonstrator operation, scintillation light data have been collected during several months of operation in different drift and amplification fields configurations. An overview of the 3x1x1 light detection system performance will be presented. External Cosmic Ray Taggers provided track reconstruction even in the absence of drift field. Hence, scintillation and electroluminescence light properties could be studied under various field conditions. The LAr purity has been monitored with the slow component. Comparisons with Monte Carlo light simulation gave sensitivity to the Rayleigh scattering length. All these results will be presented in this talk.

Detector techniques / 20

AVOLAR. A high voltage generator for liquid argon time projection chambers.

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A massive liquid argon (LAr) based time projection chamber (TPC) is the current choice for neutrino physics and dark matter experiments. Because of its typical drift length of several meters, relatively large cathode voltages are desirable to provide a sizeable drift field. Current designs are based on feedthroughs with high voltages (HV) limited to several hundred kV. The present work proposes a novel method to produce higher voltages inside the detector.
It is based on a Van de Graaff HV generator where the charge transporting belt is replaced by a cryogenic LAr flow. Negative charge is injected in liquid by means of a grounded sharp point facing a positive voltage electrode with a high speed LAr stream in between. The LAr flow transports the charge to the cathode through an insulating pipe. There the charge is extracted with a metallic mesh. The LAr flux is driven by a cryogenic helium pump with unidirectional valves assuring a continuous flow. The LAr operational temperature is maintained by a pressurized liquid nitrogen deposit with automatic filling. The whole system is installed within a Dewar container filled with LAr reproducing the typical TPC conditions.
This design has no mobile parts, so it is very robust and can be easily embedded within the structural support of a TPC cathode.
A prototype of this HV generator has been constructed at Ciemat (Madrid), and is currently being characterized. This R will be presented and the preliminary results will be discussed.

Light/charge readout / 21

First dual-phase xenon TPC with SiPM readout and its ultra-low energy calibration with 37-Ar

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As part of the R towards the ultimate dark matter observatory DARWIN, we conduct tests with novel silicon photomultipliers (SiPM) for vacuum ultra violet (VUV) light being a promising alternative to traditionally used photomultiplier tubes. In particular, we are operating a small-scale dual phase (liquid/gas) xenon time projection chamber (TPC) instrumented with VUV-sensitive SiPMs from Hamamatsu for light and charge readout, being the first in the field. After a successful commissioning in Summer 2018, in this talk, we present the results from 83m-Kr calibration data to proof the principle of the detector design with the new photosensors. Moreover, we will show the analysis from a recently performed low-keV energy calibration with 37-Ar gas at the energy threshold of the detector.

Light/charge readout / 23

X-ARAPUCA @ UNICAMP

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The X-ARAPUCA represents the baseline design for the Ṕhoton Detection System of the DUNE single phase far detector. It is an improvement of the ARAPUCA concept which allows for a higher detection efficiency, for the simplification of the design and for a reduction of the risks for prolonged operation in liquid argon.
The detection efficiency of the X-ARAPUCA has been estimated with a series of tests performed at UNICAMP in the cryogenic facility of the Laboratorio de Leptons. The results of the latest tests will be presented together with the short term program for the development of the X-ARAPUCA program.

Detector techniques / 24

High pressure xenon electroluminescent TPC for the NEXT experiment and its future developments

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The Neutrino Experiment with a Xenon TPC (NEXT) searches for the neutrino-less double beta decay of Xe-136 using a high pressure gas TPC with electroluminescent amplification. The current generation of the technology Next-White (NEW) has been operating successfully at Laboratorio Subterráneo de Canfranc (LSC) since late 2016. Recent publications have demonstrated sub-percent FWHM energy resolution at Qßß energies and the power of the topological rejection afforded by this technology.
In this talk, we will give an overview of the recent results harvested by NEW after the first year of low background operations with both depleted xenon and 136-enriched xenon. From there we will describe NEXT-100 and the R efforts already underway to further improve the background rejection capabilities of the technology. Construction of NEXT-100 will start later this year with commissioning planned for 2020 at LSC. At the same time, efforts are underway to improve background rejection using low diffusion gas mixtures, cold gas operation, or barium tagging.

Signal reconstruction / 25

Scintillation light response, reconstruction, and calibration in MicroBooNE with four years of data

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The MicroBooNE experiment employs a liquid argon time projection chamber (LArTPC) operating on the surface to record neutrino interactions from Fermilab's neutrino beamlines. Neutrino analyses rely on the use of scintillation light collected from the detector's photo-multiplier tube (PMT) array. A detailed understanding of light production and the detector's response to scintillation light is therefore essential. This work will present the techniques employed to reconstruct and calibrate scintillation light signatures in MicroBooNE. We will further present studies of the detector's light response in a variety of different conditions from the four years of detector operations, including purity and HV field strength. The work presented will be of interest to the upcoming multi-year and decade-long SBN and DUNE programs respectively.

Signal reconstruction / 26

Use of scintillation light to identify neutrino interactions in MicroBooNE

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MicroBooNE is a neutrino experiment which employs a liquid argon (LAr) time projection chamber (TPC) to record neutrino interactions from Fermilab's neutrino beamlines. The experiment's primary objective is to study low-energy νe interactions from the Booster Neutrino Beamline (BNB). Sitting on the surface, the detector is affected by a continuous rate of cosmic-rays. This leads to one neutrino interaction for every 104 cosmic rays observed in the TPC, making it difficult to isolate neutrino interactions in the detector using charge alone. MicroBooNE's trigger makes use of prompt scintillation light and plays an essential role in both performing strong background rejection and significantly reducing data-rates. Furthermore, a series of novel techniques relying on scintillation light are used to isolate beam-induced activity. A first data-driven evaluation of MicroBooNE's trigger efficiency, and a description of light-based neutrino identification techniques such as "flash-matching" will be presented. This work serves as the foundation of successful neutrino analyses in LArTPC detectors and is therefore of interest to the broader short- and long-baseline neutrino programs being launched at Fermilab.

Light/charge readout / 27

CMOS based SPAD Arrays for the Detection of Rare Photon Events at Cold Temperatures

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We propose to use Single Avalanche Photo Diodes (SPADs) fabricated in a CMOS technology for readout of rare photon events. This allows the integration of tailor-made readout electronics onto the same piece of silicon. Compared to a solution with SiPMs and a separate readout ASIC, the proposed approach is mechanically much simpler, requires less electrical interconnections, consumes significantly less power and is probably cheaper. We have developed an array of 88 x 88 SPADs with a full frame readout and have operated it successfully in liquid nitrogen. We found a promising rate of <20 dark counts per second and per mm2 of active area and observed an additional background at the edge of the array, which we attribute to photons emitted by active circuitry. We have then developed a SPAD array adapted to low event rates with focus on high fill factor, low power dissipation and minimal circuit activity by implementing a data driven architecture. Several SPAD geometries will allow us to study the influence of SPAD shape and size on dark count rate. We will report on the measurements obtained so far with the 88 x 88 array and present the new architecture.

Light/charge readout / 28

The Light Only Liquid Xenon experiment: Physics goals and analog electronics

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The Light Only Liquid Xenon (LoLX) experiment aims to investigate both scintillation and Cherenkov light emission in liquid xenon. The first phase of LoLX consists of 24 Hamamatsu VUV4 Silicon Photomultipliers (SiPM) arranged in an octagonal cylinder where optical filters will be used to separate Cherenkov and Scintillation light produced by a Strontium 90 beta source and Polonium 210 alpha source. Agreement with GEANT4 simulations can validate both photon transport in the simulation and the accuracy of reflectivity measurements made at TRIUMF, which are implemented in the simulation. In addition, phase 1 of LoLX aims to characterize cross-talk between opposing SiPMs as this process can falsely contribute to the measured light signal. Future phases will upgrade the SiPM and digitizer scheme to attain sub nanosecond timing resolution allowing both the temporal separation of the Cherenkov and scintillation light, and investigation of pulse shape discrimination using the prompt light signal. Future plans exist for a liquid argon version of the experiment, LoLA, to precisely determine time constants in argon. This talk will give an overview of the LoLX experiment and detail the analog electronics used for the first phase of the detector.

Light/charge readout / 29

Study and characterization of WLS for ARAPUCA to DUNE experiment

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The Deep Underground Neutrino Experiment (DUNE) photon detection system has as principle of operation the detection of scintillation light generated in liquid argon. A new technology called ARAPUCA (Argon R & D Advanced Program at UNICAMP) has recently emerged, a device that acts as a light trap using SiPMs as photodetector elements and this system capture photons with visible wavelengths. The use of wavelength shifters (WLS) in light collecting systems for detection of particles (neutrinos) is considered of great importance because the scintillation of the photon produced in liquid argon occurs at ultraviolet wavelengths. The main objective of the work was to explore and characterize different substrates, WLS and deposition methods to assist in understanding the behavior of visible light detection components (WLS).

Light/charge readout / 30

Development of SiPM photosensor and frontend readout for nEXO

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nEXO is a proposed 5-tonne liquid xenon detector in search of neutrinoless double beta decay. Both the light and charge signals from interactions in the TPC will be collected. The collaboration has identified Silicon photon multipliers (SiPMs) as the devices of choice for the detection of scintillation photons. Achieving high photon detection efficiency, low intrinsic device noise, and low readout noise are all essential for reaching the detector performance and physics goal for the experiment. In the talk, I will discuss the nEXO baseline design for the photosensors and recent R work on device characterization, reflectivity measurement, and cryogenic readout development.

Signal reconstruction / 31

A semi-analytic method to predict the light signals in liquid argon detectors

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Liquid argon is being extensively employed as the detector technology in neutrino physics and Dark Matter searches. Although at the running conditions of these detectors similar amounts of electrons and photons are generated, the bulk of the physics output in neutrino experiments comes from the charge signals, reserving the use of light for triggering purposes only. To push the Liquid Argon Time Projection Chamber (LArTPC) technology beyond its current limitations, an extension in the applications of the scintillation light information is being explored. This is requiring the development of advanced light simulation approaches. Previous methods struggle with the combination of detector size and energy deposited by beam neutrino interactions, making them either excessively slow or imprecise, and prohibitively memory consuming. In this work we present a semi-analytical model to simulate the scintillation light that alleviates most of the previously mentioned issues. Based only on the positions of the event and light detector we estimate the light signals with a precision of the order of a 10%. We also provide a method to predict the distribution of arrival times of photons up to a distance of 14 metres. Our proposed method can be used to simulate light propagation in large scale liquid argon detectors such as DUNE or the SBN programme.

Light/charge readout / 32

Photoluminescence response of acrylic (PMMA) and teflon (PTFE) to ultraviolet light.

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The liquid argon (LAr) and liquid xenon (LXe) targets of rare-event search experiments are often surrounded by acrylic (PMMA) or teflon (PTFE); these plastics have been reported to exhibit low-intensity phototoluminescence when excited by visible or ultraviolet (UV) light. In this work, we investigated whether the UV photons from the scintillation of LAr (128 nm), or LXe (178nm), or from Cherenkov light, could induce low-intensity photoluminescence of the PMMA and PTFE used, respectively, in the DEAP-3600 and in the LUX experiments. The understanding of this nuisance photoluminescence plays an important role in these experiments, since unexpected photoluminescence could change the time and energy reconstruction of events.

To quantify the possible photoluminescence of these materials, we measured it relative to the fluorescence response of the wavelength shifter tetraphenyl-butadiene (TPB), for excitation light from 130 nm to 300 nm. To quantify this response for this broad excitation range and at different temperatures, we used three experimental setups: i) a vacuum ultraviolet monochromator with a deuterium VUV light source, ii) a commercial spectrophotometer with a xenon flash lamp, and iii) an optical cryostat with a UV pulsed LED.

The first setup was sensitive enough to measure photoluminescence signals at the level of a fraction of a percent of the efficiency of TPB in shifting VUV light to the blue region. The measurements at room temperature with UV light from 200 to 300 nm indicated that acrylic might fluoresce when excited by 280 nm light. This was further investigated with a 280 nm UV LED at temperatures from 300K down to 4K. The fluorescence spectrum of acrylic was measured and its temperature-dependent wavelength shifting efficiency was quantified relative to TPB's.

33

Towards High-Efficiency VUV Silicon Photo-Detectors

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Silicon Photo-Multipliers (SiPMs) have surfaced as a valuable alternative to standard Photo-Multiplier-Tubes (PMTs) for the detection of scintillation light in Liquid Noble based experiments, which are a crucial component of many fundamental-physics and particle-astrophysics experiments. However, current Photo-Detection-Efficiency (PDE) values range between 5% to 25%, at peak emission wavelength for Xenon (178 nm) and Argon (128 nm). In this talk, we will present the current R effort to develop a digital integrated silicon photo-sensor with PDE bigger than 40% in the deep VUV range. Such a device would be an ideal candidate for future low-background Liquid Noble experiments. We will first present the new technology, the 3dSiPM and explain how digital integration is achieved, and then we will show how the VUV efficiency is boosted for these new devices.

Light/charge response / 34

A Gas Proportional Scintillation Counter with Krypton filling

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A Gas Proportional Scintillation Counter filled with pure krypton and with a Large Area Avalanche Photodiode (LAAPD) as the photosensor was studied. Values of energy resolution below 10% for 5.9 keV X-rays were obtained with this prototype. This value is much better than the energy resolution obtained with MPGDs with krypton filling. The krypton scintillation and ionization thresholds were found to be about 0.7 and 3.3 kV/cm/bar, respectively. With this setup it is possible to compare the pulse amplitudes generated by the VUV photons and the 5.9-keV X-rays interacting directly in the LAAPD. Thus, one can calculate the number of charge carriers produced by the scintillation pulse and, hence, the number of photons impinging the LAAPD. The value of the scintillation amplification parameter obtained, defined as the number of photons produced per drifting electron per kilovolt, was 117 photons/kV. This value is only about 15% lower than what has been obtained for xenon, and significantly higher (40%) than what has been obtained for argon.

Detector techniques / 35

An overview of the optics and energy reconstruction in DEAP-3600

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The DEAP-3600 experiment has been taking physics data at SNOLAB since mid 2016. During this time, over 6 tonne-years of data has been acquired. The physics goals of DEAP require the suppression of backgrounds (radiogenic and cosmogenic) to be sensitive to high mass WIMP-nucleon interactions. To that end, a full characterization of the detector response and consistent calibrations are performed. Recently, the results of a 231 live-day data set were published which demonstrated powerful pulse shape discrimination, position reconstruction, and the most sensitive exclusion of WIMP masses on argon above 30 GeV/c2. This talk will discuss the optical calibrations for the 255 LAr-facing PMTs, energy scale determination using Ar39 and higher energy gamma lines, using the triplet lifetime to monitor detector stability, and a discussion of the optical model.

Light/charge readout / 36

Tetraphenyl Butadiene Emanation and Bulk Fluorescence from Wavelength Shifting Coatings in Liquid Argon

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Liquid argon time projection chambers (LArTPCs) play a central role in modern neutrino physics and dark matter searches. As well as being an excellent active medium for time projection chamber operation, liquid argon is also a bright scintillator, with a yield of tens of thousands of photons per MeV. This scintillation light is emitted in the vacuum ultraviolet (VUV) range (128 nm) which presents challenges for its detection. Traditionally this has been solved employing the organic compound tetraphenyl butadiene (TPB) which serves as a wavelength shifting coating to convert VUV light into a visible range. We study the stability of three types of popularly employed TPB coatings under immersion in liquid argon. TPB emanation from each coating is quantified by fluorescence assay of molecular sieve filter material after a prolonged soak time. Two of the coatings are shown to emanate a detectable concentration of TPB into argon over a 24 hour period, which corresponds to tens of parts per billion in argon by mass. In an independent setup, the dissolved or suspended TPB is shown to produce a wavelength shifting effect in the argon bulk. Interpretations of these results and implications for present and future liquid argon time projection chamber experiments are discussed.

Detector techniques / 37

QPix Technology: Research and Development towards kiloTon scale pixelated LArTPC

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Future long baseline neutrino experiments such as the Deep Underground Neutrino Experiment (DUNE) call for the deployment of multiple multi-kiloton scale liquid argon time projection chambers (LArTPCs). To date, two detector readout technologies are being studied in large-scale prototype detectors: the single phase (SP) and dual phase (DP) detectors using projective charge readout wire based anode planes. These projective readout technologies come with a set of challenges in the construction of the anode planes, the continuous readout of the system required to accomplish the physics goals of proton decay searches and supernova neutrino sensitivity, and the 2D projective reconstruction of complex neutrino topologies.

The Q-Pix concept (arXiv: 1809.10213) is a continuously integrating low-power charge-sensitive amplifier (CSA) viewed by a Schmitt trigger. When the trigger threshold is met, the comparator initiates a 'reset' transition and returns the CSA circuitry to a stable baseline. This is the elementary Charge-Integrate / Reset (CIR) circuit. The instance of reset time is captured in a 32-bit clock value register, buffers the cycle and then begins again. What is exploited in this new architecture is the time difference between one clock capture and the next sequential capture, called the Reset Time Difference (RTD). The RTD measures the time to integrate a predefined integrated quantum of charge (Q). Waveforms are reconstructed without differentiation and an event is characterized by the sequence of RTDs. In quiescent mode the RTDs will be evenly spaced with time intervals of seconds between RTDs with an event signaled by the appearance of a sequence of varying μs RTDs. This technique easily distinguishes the background RTDs due to 39Ar decays (which also provide an automatic absolute charge calibration) and signal RTD sequences due to ionizing tracks. Q-Pix offers the ability to extract all track information providing very detailed track profiles and also utilizes a dynamically established network for DAQ for exceptional resilience against single point failures. A number of novel ideas could be pursued to allow the Q-Pix design to be an integrated tracking/photo-detector. One such more speculative notion is the exploration of coating the dielectric surface with a type of photo-conductor which would respond to the VUV light incident on the surface. When struck by a VUV photon, the photoconductor would have electrons elevated into the conduction band and move in the electric field toward a pixel button. Initial R and simulation work on the Q-Pix concept will be presented in this work.

Light/charge readout / 38

Single photon rate observation and first calorimetric energy reconstruction of beam events from LAr scintillation light in protoDUNE-SP.

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ProtoDUNE Single Phase at CERN is the large scale prototype for the far detector of the future DUNE experiment.
ProtoDUNE and its photon detector system (PDS) has been in stable operation since Oct. 2018 at the CERN Neutrino Platform.
Single photon signals are identified and the observed single PE rates will be presented here for the first time as a function of electric field in the LAr volume and at different values of LAr purity.
Stability in time of the measured rates will also be reported. Origin and production mechanisms for the observed single photon rates will be discussed.
Test beam data in the energy range of sub-GeV to a few GeV were collected in fall 2018 providing a set of key measurements.
Particles (electrons, protons, pions, muons and kaons) are identified combining informations from a set of beam-line detectors (Time of Flight, Cherenkov) and TPC reconstruction.
Results of the protoDUNE-SP Photo Detector System response are presented, in particular with the Arapuca component, providing first calorimetric energy measurements and particle ID of beam events from LAr scintillation light signals.

Detector techniques / 39

ARIADNE: A novel optical readout approach for two-phase liquid argon TPCs

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ARIADNE is an experiment pioneering novel optical readout technologies for future two-phase liquid Argon TPCs.

The charge multiplication process in a THick Gaseous Electron Multiplier (THGEM) also produces many photons. Instead of reading the charge signal, ARIADNE detects the photons that are produced. Optical readout has the potential for cost savings and simplification when compared to traditional strip-based charge readout approaches.

The optical readout used by ARIADNE has recently undergone a transformative upgrade. The new readout approach allows for the simultaneous spatial and temporal detection of photons using a camera based on the Timepix3 ASIC. This new approach provides natively 3D pixel-based readout of the TPC volume. Data driven readout provides chip level zero suppression, enabling very high readout rates with compact raw data.

Results from operation of the ARIADNE detector at the CERN T9 beamline and cosmic muon operation at Liverpool will be presented. A detailed description of the novel optical readout approach will be given, along with an outlook of possible future applications.

Signal reconstruction / 40

The Energy Linearity and Resolution Performance of the XENON1T two-phase Xenon Time Projection Chamber in the KeV to MeV Range

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XENON1T, containing 2 ton of liquid xenon (LXe) as sensitive target, is the most sensitive experiment of its type in the search for Dark Matter. In this talk, we show how to overcome the challenges in the signal readout and reconstruction towards the application of this detector for another rare event search, that for 0vbb of Xe-136 which require excellent energy resolution at the 2.458 MeV decay energy. The software reconstruction techniques developed for XENON1T have enabled us to achieve a world-leading energy resolution down to 0.8% (sigma/E) at 2.5 MeV.

Signal reconstruction / 41

Optical Properties of Liquid Argon measured by the PDS in ProtoDUNE-SP

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Last fall, the first in a pair of full scale prototypes of DUNE, the ProtoDUNE Single Phase (ProtoDUNE-SP) experiment recorded signals from particles of various momenta provided by the CERN SPS accelerator as well as particle tracks from cosmic sources. ProtoDUNE-SP is composed of three major sub- detectors which, when coordinated temporally, give highly precise position and timing information for particles entering the volume. Using the ProtoDUNE-SP Cosmic Ray Tagger (CRT) as a trigger and cosmic tracks identified in the Time-Projection Chamber (TPC), various properties of the scintillation medium can be measured including the attenuation length. This talk will focus on the details of those measurements as performed by the ProtoDUNE-SP PDS.

Detector techniques / 42

R toward next-generation liquid xenon experiments

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As noble liquid time projection chambers (TPC) grow in size, it becomes more challenging to maintain the sufficiently large electric field in the drift volume and efficient prompt light collection, both of which are important for dark matter detector performance. I will report on first results from two new systems at Lawrence Berkeley National Laboratory, designed for investigations of the light collection (IBEX) and high voltage behavior (XeBrA) in noble liquids. IBEX is a liquid xenon cell used for measurement of the angular distribution of light reflected off of submerged polytetrafluoroethylene (PTFE) samples to investigate microphysical models of reflection in this context. We observe a noticeable specular component to the reflection in LXe, displaying features consistent with total internal reflection above the critical angle. The Xenon Breakdown Apparatus (XeBrA) is a 5-liter cryogenic chamber built to characterize high voltage behavior in liquid xenon and argon. It enables detailed, reproducible studies of dielectric breakdown and the onset of electroluminescence for electrode areas of up to 30 cm2 . Combined with previous studies, we confirm the dependence of dielectric breakdown on the stressed electrode area. Results from IBEX and XeBrA will guide future TPC design.

Applications / 43

Photon Detection System for ProtoDUNE Single Phase

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Detection of 128nm scintillation photons in the Deep Underground Neutrino Experiment (DUNE) Liquid Argon Time Projection Chamber (LArTPC) Far Detector modules is critical for the overall success of its physics program. DUNE's full-scale single-phase LArTPC prototype, ProtoDUNE-SP, is outfitted with 60 photon detector modules, supporting three different designs: 29 "double-shift"" light guides, 29 "dipped-coated" light guides, and 2 "S-ARAPUCA" arrays, all with SiPM (SensL and Hamamatsu) readout. ProtoDUNE-SP has been in operation since August 2018, with data from exposure to test-beam particles, cosmic rays and LED calibration signals. We discuss the commissioning, operation, and calibration of the ProtoDUNE-SP PDS, as well as preliminary performance results focusing on the double-shift modules.

Light/charge response / 44

Electroluminescence Yield in Low-diffusion Xe-He Gas Mixtures

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The NEXT experiment aims to search for the hypothetical neutrinoless double-beta decay from the 136Xe isotope using a high-pressure xenon TPC. The discrimination of events through the topological signature of primary ionization trails is a major asset for the experiment, limited mainly by the high electron diffusion in pure xenon. Helium admixtures with xenon can be an attractive solution to reduce electron diffusion by the more efficient momentum transfer from the electrons to the He atoms compared to the more massive Xe atoms. We have measured the electroluminescence (EL) yield of Xe–He mixtures in the range of 0 to 30% He and demonstrated a small impact on the EL yield for the addition of He to pure Xe. For a typical reduced electric field of 2.5 kV/cm/bar in the scintillation region, the EL yield is reduced by ~ 2%, 3%, 6% and 10% for 10%, 15%, 20% and 30% He concentration, respectively, a reduction that is lower than what was expected from simulation results presented in the literature. The impact of the addition of He on EL statistical fluctuations is negligible, within the experimental uncertainties. Nevertheless, one has also to take into account the impact of the He addition on the TPC sensitivity as a result of the corresponding Xe mass reduction.

Applications / 45

DArT, a detector for measuring the 39Ar depletion factor

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The DarkSide-20k (DS-20k) experiment is a 50-ton active argon detector which plans to operate radio-pure underground argon (UAr) for dark matter direct searches. A major worldwide effort is on-going in order to procure the radio-pure argon required for this experiment (Urania and Aria projects). DART is a small (~1 L) chamber that will measure the depletion factor of 39Ar in UAr. The detector will be immersed in the LAr active volume of ArDM (LSC, Spain), which will act as a veto for gammas stemming from the detector materials and from the surrounding rock. Data taking is planned for 2019. In this talk, I will review the status and prospects of the DArT project.

Applications / 46

A Xenon Detector for the LUX-ZEPLIN (LZ) dark matter experiment

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I will present the status of the LZ experiment, which is under construction at the Sanford Underground Research Facility (SURF). I shall focus in particular on the liquid xenon detector at the core of LZ, which is in the final stages of assembly at the Surface Assembly Laboratory at SURF. I will highlight the design and implementation of key features that drive the sensitivity of the experiment, including scintillation and ionisation detection thresholds and control of backgrounds.

Light/charge readout / 47

The single-photon response of photomultiplier tubes to xenon luminescence

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Liquid xenon time projection chambers are the most sensitive dark matter detectors in the mass range 10 GeV – 10 TeV. They have, to date, all used quartz-windowed photomultiplier tubes (PMTs) to detect the primary and secondary VUV scintillation light produced by low-energy particle interactions. Despite promising developments in newer technologies such as VUV silicon photomultipliers (SiPMs), traditional PMTs remain well suited for rare event detection in this wavelength range, and we review some of the reasons why. The interaction of VUV photons with the PMTs differs from that of visible photons. We present here the characterisation of the single-photon response of these devices, in particular the Hamamatsu R11410-22 PMTs used in the forthcoming LUX-ZEPLIN (LZ) experiment. This includes the double photoelectron emission from a single xenon photon, and measurements to characterise undersized single-photon responses. Finally, we discuss the potential to improve signal efficiency and sensitivity to low-energy interactions from the exploitation of these effects.

Light/charge readout / 48

Polyethylene naphthalate film as a wavelength shifter in liquid argon detectors

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Polyethylene naphthalate (PEN), an optically transparent thermoplastic polyester commercially available as large area sheets or rolls, is proposed as an alternative wavelength shifter to the commonly-used tetraphenyl butadiene (TPB). Evidence suggests that PEN has the fluorescence yield and timing very close to that of TPB. It is therefore a possible replacement for TPB in liquid argon neutrino detectors, and also a promising candidate for dark matter detectors. Advantages of PEN are discussed in the context of scaling-up existing technologies to the next generation of very large ktonne-scale detectors. Its simplicity has a potential to facilitate such scale-ups, revolutionizing the field.

Light/charge readout / 49

Wavelength-Shifting Reflective Foil System in SBND

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The Short-Baseline Near Detector (SBND) is a Liquid Argon Time Projection Chamber (LArTPC) and forms a part of the Short-Baseline Neutrino (SBN) program at Fermilab. SBN, with its three detectors, will try to address the elusive short-baseline eV scale sterile neutrino anomaly. Due to its proximity to the beam target, SBND will observe an extremely high rate of un-oscillated neutrinos. One of the major feature of SBND will be its state of the art light detection system. The active system will consist on photomultiplier tubes and R ARAPUCAs placed behind the wire planes while the passive elements will be located on the opposite side. These will consist of highly reflective panels covered by the wavelength shifting compound tetra-phenyl butadiene (TPB) inserted into the cathode plane. These wavelength-shifting reflective panels will increase the light yield as well as make the light collection uniform across the drift region of the active volume. Future studies of its performance will provide an important contribution to not only the SBN program but also R for the Deep Underground Neutrino Experiment (DUNE). This talk will provide a review of the whole process of production, preparation, and installation of the panels into SBND as well as some projected performance studies.

Detector techniques / 50

Injection and removal of the calibration isotope 37Ar in the XENON1T detector

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Diluting a 37Ar radioactive source into the liquid xenon is an excellent method for the uniform calibration of the active volume of liquid xenon detectors with a source of discrete electron recoils at very low energies. The isotope decays into 37Cl via electron capture emitting a cascade of Auger electrons and soft X-rays, resulting in a point-like interaction with an energy deposit of 2.8 keV or 270 eV that can be tremendously useful to understand the response of the detector near its detection threshold. However the relatively long half-life, 35 days, poses a serious concern for the use of this technique in low-background experiments, and the removal in a reasonably short time must be ensured in some other way. In Autumn 2018 a calibration test with the XENON1T detector has been performed, injecting a controlled activity of 37Ar isotope via the XENON1T gas system and demonstrating the full removal in less than one month by means of the same cryogenic distillation column that the experiment uses to remove krypton. This outcome suggests that this calibration technique can be safely used also during the commissioning of the upcoming XENONnT experiment, as well as between two science runs. We describe in this talk the production of the 37Ar source by neutron capture on a high-purity 36Ar sample, performed at the TRIGA neutron reactor in Mainz, the dosing procedure to control the activity injected in the detector, and the result of the distillation process.

51

Ultra-low energy response of the XENON1T detector

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In Autumn 2018 a calibration test with a 37Ar source diluted in liquid xenon has been performed in the XENON1T experiment. Besides providing the proof that the isotope can be quickly removed by means of cryogenic distillation, this test provided a large statistics of 37Ar events, collected during the almost two weeks of data-taking before the beginning of the distillation and observed uniformly distributed in the active volume. The 37Ar isotope undergoes electron capture with a half-life of 35 days, and the emitted cascade of Auger electrons and soft X-rays results in a point-like interaction with an energy deposit of 2.8 keV or 270 eV, for the case of a K-shell or a L-shell electron capture, respectively. This represented a unique opportunity to study the response of the XENON1T detector to an electron recoil of a well-defined and ultra-low energy, in a regime where asymmetric distributions are observed, especially for the scintillation light response, and detector threshold effects play a role. This talks reports about these observations and provides an interpretation on the basis of the current models of the liquid xenon light and charge response.

Signal reconstruction / 52

Simulation of the argon response and light detection in a dual-phase TPC

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G4DS is the GEANT4-based Monte Carlo simulation for the DarkSide program, tuned on the data of the DarkSide-50 experiment. It includes: a tuned optical model, for the description of the detector non uniformities at the percent-level; the accurate simulation of the scintillation time profile, used for pulse shape discrimination; an effective model for the ionization and scintillation mechanism in liquid argon. This tool, combined with the additional data from dedicated calibration experiment, provides a comprehensive model to describe the response of liquid argon in dual-phase TPCs. I will review the calibration procedure and discuss some application for for the DarkSide experiments.

Light/charge readout / 53

Integrated front-end electronics for single photon counting in cryogenic dark matter detectors

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Single-photon detection can provide an alternative method to readout SiPM instrumenting liquid noble Time Projection Chambers employed in dark matter detection searches. In this approach, the sensor is segmented into a sufficient number of independent cells, so that the number of photons impinging on each sensing element is small enough to avoid signal pile-up. A simple and low power binary electronics can thus be used to capture the individual photons. In this way, signal digitization can be brought into the cold volume without the need of complex large dynamic range ADCs. Only digital data are hence exchanged between the cold and warm section of the experiment. Furthermore, digital data can be easy multiplexed and serialized, thereby reducing the number of fibers required for data transmission. The segmentation reduces also the sensor capacitance. As a consequence, the same signal-to-noise ratio can be achieved with lower current per front-end channel, maintaining the overall power dissipation comparable to that required in solutions adopting analog summing of SiPM signals.
ALCOR (A Low-power Circuit for Optical Readout) is a first prototype of a 32-channel mixed-signal ASIC optimised for the readout of SiPMs at low temperature. The chip, designed in a 110 nm CMOS technology, is implemented in an area of 4.95x3.78 mm2. The arrival time of each photons is recorded with a time-to-digital converter (TDCs). An average event rate of up to 5 MHz per channel can be handled. A regulated common-gate input stage acts as the interface between the sensor and the rest of the chain. Then the signal is conditioned by two amplifiers with programmable gain and shaping time. Two leading edge discriminators with configurable threshold generate the trigger CMOS signals that are fed to the channel digital control block. A coarse time stamp, derived from a binary 15-bit counter on-channel, is generated while four low-power TDCs, generate the fine counter information of 9-bit. The clock frequency can be up to 320 MHz. In this condition, the TDCs have a binning of 50 ps and a dead-time of 150 ns. The power consumption is less than 5 mW per channel. Each channel occupies an area of 500 um x 500 um. Data generated is a 32-bit payload that includes the time-stamp, the channel ID, and the specific TDC address. Generated data are collected to the periphery and transmitted off-chip using 4 LVDS drivers. In addition to the single-photon counting mode, each channel can be configured to operate also in Time-over-Threshold (ToT) mode.
Building blocks of the ALCOR chip such as the front-end amplifier and digital test structures to asses possible issues of using digital standard cells in cryogenic conditions have been implemented on silicon. The complete chip will be submitted in fall 2019.
At the conference, the experimental results of the test structures will be presented and the architecture of the ALCOR chip will be discussed in detail.

Light/charge readout / 54

Characterisation and tests of the ABALONE photosensor

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The ABALONE photosensor has been invented and proposed as a new vacuum photodetection device with all the potentials to replace the photomultiplier tube technology. It consists of only three monolithic glass components, sealed together by a specifically developed thin-film adhesive. At the Stockholm University, we are closely in contact with the inventor, Prof. Daniel Ferenc at UC Davis, and are in possession of one such device. We are carrying out both laboratory measurements on our sample sensor and simulations to model the basic characteristics of the device. The preliminary results of our study will be presented. The performances of the fused silica ABALONE photosensor will be outlined in the context of future astroparticle physics experiments, including DARWIN and others involving noble liquids.

Applications / 55

The SBND Photon Detection System

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SBND (Short-Baseline Near Detector) will be a 112 ton liquid argon TPC neutrino detector located 110m from the target of the Fermilab Booster Neutrino Beam. SBND, together with the MicroBooNE and ICARUS-T600 detectors at 470m and 600m, respectively, make up the Fermilab Short- Baseline Neutrino (SBN) Program. SBN will search for new physics in the neutrino sector by testing the sterile neutrino hypothesis in the 1 eV^2 mass-squared region with unrivalled sensitivity. SBND will measure the un-oscillated beam flavour composition to enable precision searches for neutrino oscillations via both electron neutrino appearance and muon neutrino disappearance in the far detectors.

The SBND detector photon detection system is designed to exploit the high scintillation yield of liquid argon, and tackle the unique challenges that this medium presents. This composite system comprises both photomultiplier tubes and novel ARAPUCA and X-ARAPUCA devices. The physics contribution to SBND as well as the the R aspects of its design are discussed in this talk, with an outlook to future implementation.

Signal reconstruction / 56

Calorimetry for low-energy electrons using charge and light in the LArIAT liquid argon TPC

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Precise calorimetric reconstruction of 5-50 MeV electrons in liquid argon time projection chambers (LArTPCs) will enable the study of astrophysical neutrinos in DUNE and could enhance the physics reach of oscillation analyses. LAr scintillation light has the potential to improve energy reconstruction compared to charge-based measurements alone. Presented in this talk are results which demonstrate light-augmented calorimetry for low-energy electrons in a LArTPC using a sample of Michel electrons from decays of stopping cosmic muons in the LArIAT experiment at Fermilab. Michel electron energy spectra are reconstructed using both a traditional charge-based approach as well as a more holistic approach that incorporates both charge and light. A maximum-likelihood fitter is developed for combining these quantities to achieve optimal energy resolution. A sample of isolated electrons is simulated to better determine the energy resolution achieved by LArIAT, which has a light yield (LY) of 18 pe/MeV and a wire readout signal-to-noise (S/N) of ~50. Samples are then generated with varying wire noise levels and LYs to gauge the impact of light-augmented calorimetry in larger LArTPCs. At a charge readout S/N ~ 30, for example, the energy resolution for electrons below 40 MeV is improved by ~10%, ~20%, and ~40% over charge-only calorimetry for average light yields of 10 pe/MeV, 20 pe/MeV, and 100 pe/MeV, respectively.

Detector techniques / 57

Long term operation with the DarkSide-50 Detector

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DarkSide is a staged experimental project based on radiopure argon aiming at direct dark matter detection.
The DarkSide-50 detector is currently operating underground at the Gran Sasso National Laboratory.
DS-50 detector is a dual-phase, 50 kg, liquid argon time-projection-chamber readout by 38 cryogenic PMTs (Hamamatsu R11065), surrounded by an active liquid scintillator veto and contained in a water Cherenkov detector acting as a muon veto.
DS-50 has been been operating continuously since 2013, first with atmospheric argon and subsequently filled in 2015 with argon from an underground source, allowing a reduction of the Ar-39 isotope by more than a factor 1000.
Features of the DS-50 detector will be described, long term operations and stability will be reported and its performances in scintillation light detection will be discussed.
Results on dark matter searches obtained with DarkSide-50 detector will be shown.

Light/charge readout / 58

FBK Silicon photomultipliers for liquid noble gases cryogenic operation

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Fondazione Bruno Kessler (FBK) has continuously developed and improved silicon photomultiplier technologies: in particular, one with peak efficiency in the blue region of the spectrum (near-ultra-violet, NUV), another one in the green (red-green-blue, RGB).
Over the last years there has been a growing interest in silicon photomultipliers applications at cryogenic temperatures (e.g.: for the detection of scintillation light from liquefied noble gases in rare-events experiments).
The design of a silicon photomultiplier that can be operated in such conditions poses several challenges. At very low temperatures, tunneling is the dominant mechanism for dark count generation and a further decrease in temperature does not lead to primary noise reduction. Moreover, the increase of after-pulsing probability causes a reduction of the useful operating range of the detector; finally, the strong temperature dependence of the polysilicon quenching resistor results in a large increase of the microcell recharge time.
In order to overcome the above-mentioned issues, a dedicated silicon photomultiplier technology has been designed and fabricated in FBK: the NUV-HD-Cryo. SiPMs made in such technology reach primary dark count rates of about 10 mHz/mm2 below 100K and an after-pulsing probability of about 15% when biased at 6V above breakdown.
In this contribution, the latest results from the cryogenic characterization of such technology will be reviewed.

Light/charge response / 59

The propagation of scintillation light in Liquid Argon

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The properties of the propagation of scintillations light in the liquid argon, at \lambda ~128 nm wavelength, has been experimentally investigated in a dedicated setup at CERN. The velocity of scintillation photons has been measured for the first time in the liquid argon. The obtained result is then used to derive the index of refraction and the Rayleigh scattering of the liquid argon at VUV region. Such measurement provides a key ingredient for the interpretation of data from the current and next generation large mass liquid argon detectors as those dedicated to the search for rare events such as neutrinos or Dark Matter. Furthermore the improvement on the understanding of the scintillation light propagation represent a benchmark for the multiple theoretical models and simulations for the next generation of detectors.

Light/charge readout / 60

Developments in PMT and MPPC/SiPM technologies for light detection in noble elements.

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Established in 1953, Hamamatsu Photonics has built a reputation worldwide for producing class-leading photodetectors in vacuum tube and solid state technologies. Having continually improved detector technology over half a century in line with key international experiments, Hamamatsu has pioneered the development and evolution of some of the world's most capable low-light sensors.
With the ever more stringent requirements on equipment, Hamamatsu has had push technological boundaries to maintain a position on the cutting edge of optoelectronics development.
As photomultiplier tubes begin to be succeeded by solid state technologies such as Silicon Photomultipliers, the research community is faced with ever more options for low level light and single photon detection. With the latest generations of Vacuum UV enhanced SiPMs/MPPCs coming into use, we explore the state of development of two contrasting technologies and consider their use detecting scintillation light from liquid noble gases.
Having proved instrumental in many high-profile nuclear and high energy physics experiments, Hamamatsu Photonics continues to champion development in vacuum tube and semiconductor technologies for the scientific community.

61

Welcome and local information

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62

Welcome Reception

63

Workshop dinner

64

Closing remarks

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65

FERS: a distributed and scalable Front-End Readout System for large detector arrays.

Mr. ABBA, Andrea [1]

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This talk will present the new Front-End Readout System (FERS), which is a
scalable and distributed front-end & data acquisition system for large detector arrays. It consists in a compact and easy-deployable solution integrating front-ends based on ASICs, A/D conversion, data processing, synchronization and readout.
The solution perfectly fits a wide range of detectors such as SiPMs,
multianode PMTs, Silicon Strip detectors, Wire Chambers, Gas Tubes, etc…
ASIC based system allows to achieve a very high density channels readout
solution reducing the power dissipated by each channel.

Review talks / 66

Dark matter overview

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Review talks / 67

Neutrino overview

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68

Deep Science at Boulby Underground Laboratory: Ultra-low background science and science support capabilities at the UK's deep underground science facility

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For more than three decades UK astrophysicists have been operating experiments to search for Dark Matter 1100m below ground in a purpose-built 'low-background' facility at Boulby mine in the North East of England. This facility - the Boulby Underground Laboratory - is one of just a few places in the world suited to hosting these and other science projects requiring a 'quiet environment', free of interference from natural background radiation. The race to find Dark Matter continues and Boulby currently supports the DRIFT/CYGNUS directional dark matter detector programme and operates a growing suite of high sensitivity Germanium detectors for material screening for future Dark Matter detectors (inc. LZ) and other rare-event studies. In the meantime the range of science projects looking for the special properties of deep underground facilities is growing and new projects operating at Boulby range from astro & particle physics to studies of geology/geophysics, climate, the environment, life extreme environments on Earth and beyond. This talk will give an overview of the Boulby Underground Laboratory, the science currently supported and plans for science at Boulby in the future. The talk will also describe facilities and support systems for any future studies seeking access to an ultra-low background environment for low background detector development or other purposes.

69

Discussion session summaries

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