

XeSAT2022 - International Workshop on Applications of Noble Gas Xenon to Science and Technology

Coimbra University, Physics Department

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Main auditorium



Chairs:

José Matias Lopes, Coimbra University

Dominique Thers, SUBATECH

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Introduction, conference opening
Tuesday, 24th of May 2022, 09:40

(Key Note) Dark Matter Direct Detection with Noble Liquid Detectors

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Detection of a dark matter signal in an ultra-low background terrestrial detector will provide the most direct evidence of its existence and will represent a ground-breaking discovery in physics and cosmology. Among the variety of detectors for dark matter direct detection, noble liquid detectors hold the highest potential for discovery thanks to their proven scalability of target mass and superior background reduction capability. To-date, liquid xenon time projection chambers have shown to be the most sensitive, with unprecedented ultra-low background even with targets at the multi-tonne scale. I will present an overview of the ongoing and forthcoming searches based on multi-tonne scale LXe and LAr TPCs worldwide.

(Invited) Xenoscope — a full-scale vertical demonstrator for the DARWIN Observatory

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The DARWIN observatory is a proposed next-generation experiment to search for particle dark matter and other rare interactions. It will operate a 50 t liquid xenon detector, with 40 t in the time projection chamber (TPC). To inform the final detector design and technical choices, a series of technological questions must first be addressed. I will describe a full-scale demonstrator in the vertical dimension, Xenoscope, which was constructed at the University of Zurich. The main goal is to achieve electron drift over a 2.6 m distance, which is the scale of the DARWIN TPC. Other applications of the facility include R&D on the high voltage feedthrough for DARWIN, measurements of electron cloud diffusion, as well as measurements of optical properties of liquid xenon. Xenoscope will also be available as a test platform for the DARWIN collaboration to characterise new detector technologie.

(Invited) Air Liquide, how rare gases challenge us and allows us to open a new gate on Big Science Rare Gases: a critical challenge for Science and Industry

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The recent geopolitical crisis has underlined the weakness of the supply chain for several essential products but also for rare gasses.

This talk, presented by Amandine Marc and Luc Gaffet from Air Liquide company will focus on the noble gas challenges and business. After a brief introduction on Air Liquide group and rare gas activity, Amandine and Luc will give you some keys to understand the xenon market, and by comparison to other activities, the relatively weak position of the big science market in this game.

Then, we will explain our challenge with Argon for Big science, focusing, among others, on the CERN Neutrino platform, or the forthcoming supply challenge for the DUNE project in South Dakota.

At the end we will present our recent development in the He3 activity which was mandatory for the group and a key element to develop a global strategy to address the emerging quantum computing market. This example could be inspiring to solve potential supply chain issues facing research activity. Then, Amandine and Luc will open a debate to better understand what are the challenges you face when it comes to sourcing rare gases and, see how we could, together, imagine potential solutions to define a sustainable supply chain for noble gas.

SiPM readout of Xenoscope, a full-scale DARWIN vertical demonstrator

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The DARWIN project aims to build and operate a next-generation observatory for dark matter and neutrino physics, featuring a time projection chamber (TPC) with a proposed active target of 40 t of liquid xenon (LXe) [1,2]. As an R&D facility to test fundamental components of the future detector, Xenoscope, a full-scale vertical demonstrator with 350 kg of LXe and up to 2.6 m electron drift length was built at the University of Zurich [3]. Its main objective is to demonstrate electron drift over unprecedented distances in LXe, first in a purity monitor setup with charge readout, followed by a dual-phase TPC. In this later phase, an array of 192 VUV-sensitive 6x6 mm² SiPMs (Hamamatsu VUV4 MMPCs) with a 12-channel readout will be placed above the active target and operated as light readout for the proportional scintillation signals in the TPC.

This talk will present the Xenoscope facility and the design and development of its SiPM top array, from the structural and electronic design of the array in the setup, the characterization of the SiPM sensors, their installation and performance.

[1]: DARWIN: towards the ultimate dark matter detector, J. Aalbers et al. (DARWIN), JCAP 11, 017 (2016), 1606.07001.

[2]: A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics, J. Aalbers et al., arXiv 2203.02309

[3]: Xenoscope – a full-scale vertical demonstrator for the DARWIN observatory, L. Baudis et al 2021 JINST 16 P08052

The development of hermetic quartz chamber for future low background liquid xenon detectors

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Liquid xenon detectors have been one of the leading technologies in low radioactive background experiments. For these low background detectors, Rn and its daughters are current major background to be improved.

Toward the future experiment, the idea of hermetic Time Projection Chamber (TPC) is to build fully isolated inner detector volume with VUV-transparent quartz and shield Rn atoms emanated from detector components such as stainless steel, light sensors or cables. R&D studies with small chamber are ongoing in Nagoya University towards the future experiment. In this talk, the status and future plans of this R&D project will be presented.

(Invited) The XENONnT experiment: recent status and updates

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XENONnT is a direct dark matter search experiment using 8.5 tons of liquid xenon located at Laboratori Nazionali del Gran Sasso (LNGS), Italy. After the successful decommissioning of the previous experiment, XENON1T, XENONnT has been constructed and commissioned until spring 2021. Since then, science data taking and analysis is ongoing towards the first result. In this talk, a summary of recent status and updates of the experiment will be reported.

(Invited) MEG II experiment and liquid xenon detector

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The MEG II experiment aims to discover the charged lepton flavor violation decay, $\mu^+ \rightarrow e + \gamma$, using high intensity continuous muon beam in the Paul Scherrer Institute. The MEG II detector consists of the liquid xenon detector for gamma-rays, the spectrometer and timing counter for e^+ , and the detector for background identification (Fig. 1). In 2021, commissioning run using muon Michel decays and pilot physics run using continuous muon beam were conducted with full number of channel read out for the first time.

The liquid xenon detector measures the energy, timing and position of gamma-rays. Liquid xenon is filled in a cryostat and generates scintillation lights by incident gamma-rays. The scintillation photons are detected by photo sensors attached on the cryostat wall. On the incident face of gamma-ray, 4092 VUV-sensitive MPPCs produced by the Hamamatsu Photonics K.K. are used, and 668 VUV-sensitive PMTs are attached on the other faces. The detector stability during beam time was monitored using alpha-rays, cosmic-rays, and mono-peak (9 MeV and 17.6 MeV) gamma-rays. Detector responses such as position dependence, energy resolution, and timing resolution were also studied using gamma-rays from pion decay (55 MeV, 83 MeV) in special run of charge exchange between charged pion and liquid hydrogen target in addition to 9 MeV and 17.6 MeV mono-peak gamma-rays.

In the presentation, these detector study results are reported. Detection efficiency decrease of SiPMs during beam time in 2021 was observed from alpha-ray data. We tried to recover the decrease by warming up the SiPMs using hot water circulation. This recovery process and result are also presented.

Currently the commissioning is successfully done and the detector is ready for taking physics data. The plan and prospects are shown in the presentation.

(Invited) Status of the LUX-ZEPLIN (LZ) Experiment

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LUX-ZEPLIN (LZ) is a direct dark matter experiment, primarily designed to search for WIMPs, installed 1.5 km underground at the Sanford Underground Research Facility in Lead, South Dakota. It features a two-phase xenon time projection chamber with an active mass of 7 tonnes, surrounded by an instrumented xenon “skin” and a liquid scintillator outer detector which are used as active vetoes. The entire setup is installed inside a tank of ultra-pure water to shield it from external radiation. LZ will reach an unprecedented sensitivity to the WIMP-nucleon spin-independent cross-section of $1.4 \times 10^{-48} \text{ cm}^2$ for a $40 \text{ GeV}/c^2$ mass WIMP after a 1000 live day run, using an inner fiducial mass of 5.6 tonnes with minimal gamma-ray and neutron backgrounds. This is an improvement of more than one order of magnitude over the current best results. This talk will provide an overview of the experiment and report on its status.

(Invited) Searching for Majorana neutrinos with nEXO

Authors: Andrea Pocar¹; Thomas Brunner²; nEXO collaboration; Julien Masbou³

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nEXO will search for neutrinoless double beta ($0\nu\beta\beta$) decay in 5 tonnes of xenon enriched to 90% in the $\beta\beta$ -decaying isotope xenon-136 [1]. The observation of $0\nu\beta\beta$ decay would imply lepton number non-conservation of an otherwise conserved quantity in nature. At the same time, it would require neutrinos and anti-neutrinos to be the same particle, i.e., a Majorana fermion, a unique property among fundamental particles of the Standard Model. The observation of $0\nu\beta\beta$ decay could occur via different underlying microphysics. A unique mass mechanism exists for Majorana particles that could explain why neutrinos are so light and link the neutrino mass with the $0\nu\beta\beta$ decay rate.

nEXO operates with 5 tonnes of liquid xenon (LXe) in single-phase in a cylindrical time-projection chamber (TPC) with diameter and height of about 1.3m [1]. The nEXO TPC measures the energy, position, and topological multiplicity of each event. By the simultaneous event-by-event detection of ionization and scintillation nEXO will have an anticipated energy resolution of better than 1% at the $\beta\beta$ endpoint with a projected $0\nu\beta\beta$ decay half-life sensitivity of 1.35×10^{28} years (90%CL) after 10 years of lifetime [2].

The ionization electrons are recorded by a segmented anode plane at one end of the TPC [3]. The prompt VUV scintillation photons (175 nm) are recorded by a $\sim 4.5\text{m}^2$ array of VUV-sensitive silicon photomultipliers (SiPMs) mounted on the cylinder barrel surface [4]. Both detection systems will be immersed in the LXe, along with the front-end readout electronics. An extensive nEXO R&D program has focused on two SiPM options: VUV4 Multi-Pixel Photon Counter (MPPC) from Hamamatsu Photonics Inc. (HPK) and VUV-HD SiPM from Fondazione Bruno Kessler (FBK). Both devices meet nEXO's requirements. Integration of SiPMs into larger modules is currently being detailed.

The status of nEXO's photodetector and charge readout system will be presented along with measured performance parameters and a general overview of the nEXO technology.

References

[1] nEXO Collaboration (S. Al Kharusi, et al.), arXiv:1805.11142v2 (2018)

[2] nEXO Collaboration (G Adhikari et al.), J. Phys. G: Nucl. Part. Phys. 49, 015104 (2022).

[3] nEXO Collaboration (Z. Li, et al.), JINST 14, P09020 (2019)

[4] nEXO Collaboration (G. Gallina, et al.), NIMA 940, 371 (2019)

0ν2β session 1, chair Julien Masbou
Tuesday, 24th of May 2022, 16:20

(Invited) Searching the Grail: A background free $bb0\nu$ experiment using Ba^{2+} tagging in a High-Pressure Xenon Chamber

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If the neutrino hierarchy is normal, the search for neutrinoless double beta decay, will need to be extended to reach a sensitivity of 10^{27} or even 10^{28} y. This will require exposures in the range of tens of ton year, but more importantly, a background free experiments, since even the slightest background will spoil their sensitivity. In this talk I will argue that such a background free experiment can be achieved by detecting the two electrons and the Ba^{2+} ion emitted in the decay of Xe-136 in (delayed) coincidence.

(Invited) Neutrinoless double-beta decay in a high-pressure gaseous Xenon-136 TPC: the PandaX-III experiment

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The PandaX-III (Particle And Astrophysical Xenon Experiment III) experiment aims to search for Neutrinoless Double Beta Decay (NLDBD) of ^{136}Xe at the China Jinping underground Laboratory (CJPL, Province of Sichuan, China), in order to study the Majorana nature of the neutrino. PandaXIII exploits the tracking capability of high pressure gaseous time projection chamber (TPC) to effectively identify NLDBD events and suppress background. The TPC will contain 140 kg of enriched Xenon-136 at 10 bar. Fine pitch micro-pattern gas Micromegas detectors will be used to measure the ionization induced by NLDBD events, and reconstruct their energy and their track topology. They provide a good energy resolution and a millimeter level spatial resolution. A 20 kg scale prototype TPC with 7 Micromegas modules was built and commissioned in the SJTU laboratory at Shanghai.

An overview of recent progresses of the PandaX-III experiment will be presented, including results from the prototype TPC, a view on the preparation of the data reconstruction and analysis, and a status of full TPC construction.

Energy Resolution of the LZ detector to High Energy Electronic Recoils

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The LUX-ZEPLIN (LZ) detector, currently operating at the SURF laboratory (South Dakota, USA), is a 10-ton liquid xenon dual-phase time projection chamber designed to search for dark matter particles. Due to its large mass and low backgrounds, the LZ scientific program also includes the search for the neutrinoless double beta decay of ^{136}Xe , highlighting the importance of achieving good energy resolution at ^{136}Xe Q value of 2.46 MeV.

In this work, the detector's energy resolution is presented for single scatter interactions, with emphasis on the high energy search region (>2 MeV). The detector demonstrates a linear response to electron recoils in the 160–2700 keV energy range. A novel technique to correct the non-uniformity of the light collection in a scintillation detector, based on the knowledge of the light response functions of individual photosensors, will be described. The use of this technique allows to achieve state-of-the-art energy resolution for the whole fiducial volume at a very early phase of the detector operations. The comparison of the measured energy resolution in the 160–2700 keV energy range with other liquid xenon particle detectors and the predictions of the NEST model will also be presented.

R2D2: a xenon TPC for neutrinoless double beta decay search

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The search for neutrinoless double beta decay could cast light on one critical piece missing in our knowledge i.e. the nature of the neutrino mass. Its observation is indeed the most sensitive experimental way to prove that neutrino is a Majorana particle. The observation of such a potentially rare process demands a detector with an excellent energy resolution, an extremely low radioactivity and a large mass of emitter isotope. Nowadays many techniques are pursued but none of them meets all the requirements at the same time. The goal of R2D2 is to prove that a spherical high pressure TPC filled with xenon gas could meet all the requirements and provide an ideal detector for the $0\nu\beta\beta$ decay search. The prototype has demonstrated an excellent resolution with argon at low pressure and test at higher pressure are ongoing. The xenon recuperation and recirculation system is under commissioning and results in xenon will be obtained soon. In addition, the light readout has been recently tested. In the proposed talk the R2D2 results obtained with the first prototype will be discussed as well as the project roadmap and future developments.

(Invited) DarkSide-20k and the Future Liquid Argon Dark Matter Program

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DarkSide run since mid 2015 a 50-kg-active-mass dual phase Liquid Argon Time Projection Chamber (TPC), filled with low radioactivity argon from an underground source and produced world class results for both the low mass ($M_{WIMP} < 20\text{GeV}/c^2$) and high mass ($M_{WIMP} > 100\text{GeV}/c^2$) direct detection search for dark matter.

The next stage of the DarkSide program will be a new generation experiment involving a global collaboration from all the current Argon based experiments. DarkSide-20k, is designed as a 20-tonne fiducial mass dual phase Liquid Argon TPC with SiPM based cryogenic photosensors, and is expected to be free of any instrumental background for an exposure of >100 tonne x year. Like its predecessor, DarkSide-20k will be housed at the INFN Gran Sasso (LNGS) underground laboratory, and it is expected to attain a WIMP-nucleon cross section exclusion sensitivity of $7.4 \times 10^{-48} \text{ cm}^2$ for a WIMP mass of $1\text{TeV}/c^2$ in a 200 t yr run. DarkSide-20k will be installed inside a membrane cryostat containing more than 700 t of liquid Argon and be surrounded by an active neutron veto based on a Gd-loaded acrylic shell. The talk will give the latest updates of the ongoing R&D and prototype tests validating the initial design.

A subsequent objective, towards the end of the next decade, will be the construction of the ultimate detector, ARGO, with a 300 t fiducial mass to push the sensitivity to the neutrino floor region for high mass WIMPs.

(Invited) DUNE Experiment and Large Volume LAr Detectors

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The Deep Underground Neutrino Experiment (DUNE) is an international world-class experiment dedicated to addressing mysteries at the forefront of neutrino physics. A new neutrino beamline at Fermilab will deliver the world's most intense neutrino beam to the near and far detectors. Massive Liquid Argon TPCs are used at the near and far sites to detect neutrinos and perform neutrino oscillation measurements. A multi-purpose near detector complex will further provide a rich ancillary science program for the DUNE utilizing the high intensity neutrino beam. This talk will focus on the Liquid Argon detector technologies used in both the FD and the ND-LAr detectors.

(Invited) Status of DEAP-3600 and development of the ARGO dark matter experiment

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The direct detection of dark matter particle interactions is one of the most important topics in particle physics - a positive measurement would provide unambiguous evidence of the particle nature of dark matter in the Universe. The DEAP-3600 dark matter search experiment contains 3.3 tonnes of active liquid argon and has to date resulted in the most sensitive search for high-mass WIMPs using argon [1] and the first search with sensitivity to Planck-scale dark matter [2]. In this talk we will present the current status of the DEAP-3600 experiment at SNOLAB, currently undergoing upgrades in advance of a new liquid argon data collection run. We will also present status of R&D towards an ultimate detector that will employ a 300-tonne sensitive target of liquid argon, ARGO, being developed within the Global Argon Dark Matter Collaboration.

[1] R. Ajaj et al (DEAP Collaboration), Phys. Rev. D 100, 022004 (2019)

[2] P. Adhikari et al (DEAP Collaboration), Phys. Rev. Lett. 128, 011801 (2022)

The XEMIS project, a three gamma imaging detector for medical Applications

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The XEMIS project (XEnon for Medical Imaging System) aims to use the single phase liquid xenon technology and (β^+ , γ) radioactive emitters to make functional medical images. Compared to conventional imaging system, a hundred fold reduction of injected activity with the same image resolution is expected.

This project is divided into three main stages. Stage one, XEMIS1, demonstrated the ability of the liquid xenon to be used as a detection medium through a first prototype. Angular resolution of 4 degrees has been reached that allowed to go to the next stage. Second stage, XEMIS2 under progress, must validate the capability of the camera to image small animals. For this purpose, a new prototype has been designed and is now under construction at the University Hospital of Nantes. An adapted geometry has been defined to enable images of mice or specific phantom. Third stage, XEMIS3, is foreseen to image human whole body.

During the talk, the principle of the XEMIS project will be introduced. Then a focus on the XEMIS2 detector to present the design and the construction progress will be discussed in details. First, the mechanical design, driven by the constraints related to the xenon in liquid state and to the technology choices, will be presented. Then, the charge and the light DAQ system will be discussed through the data flux from the front-end preamplifier dedicated chip to standard storage disc. And finally, first data analysis for detector calibration and monitoring will be shown.

Liquid xenon for nuclear medical imaging: outlooks on instrumentation

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The Light only Liquid Xenon (LoLX) collaboration is a multidisciplinary R&D effort aiming to finely characterize LXe's properties and that of modern photosensors adapted to its short scintillation wavelength. The end target is to provide in-depth information on this radiation detection medium and modern instrumentation for their application in several fields such as astroparticle physics experiments and medical imaging devices. Positron emission tomography (PET) is one such application, where LXe's appealing properties include an excellent light yield coupled to very fast decay time when compared to most commercial, room temperature scintillation crystals used in PET. While the slow charge drift time in TPC configurations significantly diminishes the counting rate, this acquisition channel coupled with scintillation readout makes it possible to achieve sub-mm 3D position resolution of the gamma interactions, a feat not yet achieved with scintillation crystals. Furthermore, LXe is transparent to the full Cherenkov spectrum, a potential path to reach 10 ps timing resolution in PET, and thus direct image reconstruction.

The talk will begin by an overview of LXe systems in nuclear medical imaging and compare them with recent research and commercial PET scanners. The review will highlight challenges in instrumentation common to both future LXe and room-temperature scanners, and highlight the LoLX efforts to experimentally determine if LXe can achieve the 10-ps time resolution goal for time-of-flight PET.

Overview and Status of the PETALO project

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PETALO (Positron Emission TOF Apparatus with Liquid xenOn) is a new concept in the field of Medical Imaging aiming to demonstrate that liquid xenon (LXe) together with a SiPM-based readout and fast electronics, provide a significant improvement in PET-TOF technology. Liquid xenon allows a continuous medium with a high stopping power for 511-keV gammas as well as a uniform response avoiding most of the geometrical distortions of conventional detectors based on scintillating crystals. In addition, SiPMs enable a fast and accurate measurement of the energy with a small noise contribution at the low temperatures required from LXe. PETit, the first PETALO prototype built at IFIC (Valencia), started operation in July 2021. It consists of an aluminum box with a unique volume of LXe and two planes of SiPMs that register the scintillation light emitted in xenon by the gammas coming from a Na22 radioactive source. After some months of data taking PETit is expected to demonstrate the potential of the technology, providing measurements of the most relevant features: reconstruction of the position, energy and time of the interactions.

3DП, A Total-Body Positron Emission Tomography scanner, using Xenon-doped Liquid Argon detector

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A good alternative to pure liquid argon (LAr) in scintillation detectors is Xenon-doped liquid argon. By doping the LAr with xenon, the long-lifetime component of the LAr scintillation light can be suppressed, allowing for the scanner to handle higher data rates, and hence higher patient doses, if required for a given application. Also, the most modern photosensors to date have very low efficiency for detecting light at LAr wavelength (128 nm). The photon detection efficiency (PDE) is well above 40% at 420 nm [1], above 20% at 172 nm [2] and above 12% at 128 nm [3]. Initial studies have shown that as the xenon concentration is increased the light yield that was measured by the photosensors used in these studies increased and the energy resolution improved as the concentration of xenon was increased, an expected result due to the fact that a fraction of the scintillation light is now emitted at the 172 nm wavelength of xenon scintillation, which is more efficiently converted to visible light by the TetraPhenylButadiene (TPB) as a wavelength shifter [4,5]. 3DП is a novel design of Time Of Flight Positron Emission Tomography, TOF-PET, with LAr and silicon photomultiplier (SiPM) as the scintillator - photosensor system. This project is an application in medical physics of the DarkSide collaboration [6,7], whose main aim is the direct detection of dark matter particles via LArliquid Argon targets. The preliminary results of the Monte Carlo simulation, demonstrate that scanner system performance, according to NEMA NU 2-2018 standardized guide, is comparable to that of commercial scanners.¹

Keywords: Noble liquid detectors, Scintillators, Argon, Xenon, TOF-PET

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GPU-based optical simulation of the DARWIN detector

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Understanding propagation and detection of scintillation light is critical for maximizing the discovery potential of next-generation liquid xenon detectors that use dual-phase time projection chamber technology. This talk describes a detailed optical simulation of the DARWIN detector implemented using Chroma, a GPU-based photon tracking framework. Advantages of the framework are discussed, followed by the description of several studies investigating variations on the baseline detector design aimed at maximizing efficiency and minimizing the time of light collection. Results of the studies are presented.

Rugged and radiopure amplification structures for large-area xenon chambers read out through electroluminescence

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Large scintillation gaps are desirable for electroluminescence chambers with ultimate energy resolution and single-electron counting characteristics, whereas large-area amplification structures are needed for next-generation ton-scale experiments. We present systematic studies of a custom designed structure (Field-Assisted Transparent Gas Electroluminescence Multiplier, or FAT-GEM), consisting of a hole matrix on an acrylic plate. The structures, produced at CERN and AstroCeNT/CAMK PAN workshops following different fabrication techniques, are radiopure and mechanically robust, allow manufacturing on large areas and are amenable to tiling in a seamless manner (i.e., no dead regions).

In this presentation we will present a systematic characterization with an x-ray source and comparison with simulations for different FAT-GEM architectures. As a self-supported structure allows for optimization of the point-spread function, increasing the light collection efficiency and implementing wavelength-shifting capabilities, the potential of this technological solution is very broad. We will present first results of such ‘active’ designs and prospects, including the use of PEN, TPB and ESR reflectors incorporated into the structure.

Wire Electrode Test and Simulation for the DARWIN experiment

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The DARK matter Wimp search with liquid xenon (DARWIN) observatory is a future dark matter detector aiming at reaching the sensitivity for WIMP at the neutrino floor and covering the mass range from 5 GeV/c² to above 10 TeV/c² [1]. The observatory uses the technology of a dual-phase time projection chamber (TPC) with 40 t active volume of liquid xenon (LXe) for the detection [1]. The electrodes of the TPC is one of the vital components that allows 3D position reconstruction of the signal and thus benefits the event selection processes. One aspect of the electrode that affects the signal amplification in the gaseous phase of the TPC is the sagging level of the wire. We performed 2D electrostatic simulation to quantify and correlate the effect of sagging on the signal, so as to foster the decision on acceptable sagging level in the context of the 2.6 m electrode in the context of DARWIN TPC. We also tested the mechanical properties of the candidate materials for the electrodes at different temperatures, including temperature close to LXe temperature.

This talk will briefly introduce the DARWIN experiment, the concepts of electrodes considered, and the methods and current results for the simulation and characterization work.

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Charge detection via proportional scintillation in a single-phase liquid xenon TPC

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Dual-phase liquid/gas xenon TPCs are a well-established detector technology to search for WIMP Dark Matter. Nevertheless, the homogenous detection of the charge signal via proportional scintillation will be challenging at the scale of the next-generation detectors due to the size of the TPCs. The detection of the charge signal in the liquid phase of a single-phase TPC might be an option to circumvent this issue. In Freiburg we successfully operate a single-phase TPC demonstrator which exploits proportional scintillation in the strong electric field around thin wires. Some of the most recent results will be presented in this talk.

The PANCAKE Detector Development Platform for multi-ton LXe Detectors

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Liquid xenon (LXe) time projection chambers (TPCs) are the leading detector technology for searches for dark matter in form of WIMPs. The next generation LXe-based dark matter detector will be superseding current detectors in size and sensitivity, covering the entire accessible parameter space for WIMP masses above a few GeV/c². The technical realization of the central low-background TPC with a diameter of about 2.6m will be challenging due to the size of the detector, the low-temperature operation, and the required radiopurity levels. The PANCAKE detector development platform at the University of Freiburg will be used to develop and test flat TPC components with diameters up to 2.6m. We will present the platform, that can accommodate up to 400kg of LXe, and first results from the commissioning phase.

(Invited) AXEL: high pressure xenon gas time projection chamber for neutrinoless double beta decay search

Author: Sei Ban¹

Co-authors: Atsuko Ichikawa.^{K2}; Yoshihisa Iwashita³; Yukimasa Kashino³; Yasuhiro Nakajima⁴; Kazuhiro Nakamura³; Kiseki Nakamura²; Shuhei Obara²; Hibiki Shinagawa²; Bungo Sugashima³; Masashi Yoshida⁵

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The AXEL (A Xe ELECTroluminescence) project aims to search for neutrinoless double beta (0νββ) decay of ¹³⁶Xe using high xenon gas time projection chamber. Electroluminescence (EL) mode is used to readout the ionization signal in order to achieve high energy resolution. We have developed a new modularized cellular readout method called "Electroluminescence Light Collection Cell (ELCC)". Cells are made as holes penetrating an PTFE board sandwiched by a thin electrode plate with holes and a mesh. The cell interval is 10 mm. Ionization electrons are drifted and pulled into the cells by the electric field and generate EL lights, then EL photons are detected by VUV-sensitive SiPMs attached to that cell (Fig. 1). It has uniform sensitivity for entire region of the detector because all ionization electrons are once pulled into cells. Its rigid structure is an advantage to enlarge the detector. We built a large size prototype detector with 180 L volume and 672 ch readout. The detector performance was evaluated with 8 bar xenon gas. As a source having similar energy as the signal (2458 keV), gamma-rays with energy of 1836 keV from ⁸⁸Y is used to evaluate the energy resolution. Achieved energy resolution is 0.92 % (FWHM) at 1836 keV. This corresponds to 0.78 % (FWHM) when extrapolated to 2458 keV. Event topology is also reconstructed as shown in Fig. 2. In the presentation, the performance of this detector will be reported.

The construction of a new detector with 1000 L volume is on going, aiming to take physics data. I will also present the status and prospect of this new detector.

**(Invited) The NEXT experiment for $\beta\beta 0\nu$ searches: status and perspectives
status**

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Neutrinoless double beta decay is a hypothetical rare process that violates lepton number conservation and implies the Majorana nature of neutrinos, which could also give insight into their absolute mass scale. The NEXT collaboration searches for such decay with Xe-136, exploiting high-pressure xenon gas TPCs with electroluminescent amplification. The principal trademarks of the experiment include an excellent energy resolution at the Q_{bb} (<1% FWHM), as well as a highly defined topology reconstruction of events, that boosts the signal-over-background discrimination. Once the datataking period of the NEXT-White demonstrator has ended, its latest results are presented here. Apart from that, the status of NEXT-100 and prospects for ton-scale and beyond R&D comprise an important part of the talk.

OV2β session 2, chair Julien Masbou
Thursday, 25th of May 2022, 10:30

(Invited) Neutrinoless double-beta decay search results from KamLANDZen with 1 ton-year ^{136}Xe exposure

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KamLAND-Zen is a neutrinoless double-beta decay search experiment using a large size liquid scintillator (LS) detector (KamLAND). We started KamLAND-Zen 800 phase with 745 kg of Xenon in 2019.

We achieved to conduct an extremely low radioactive background experiment by reducing the radioactive impurities in the newly fabricated 25-um-thick and 3.8-m-diameter nylon film container for the Xe-loaded LS and developing strong spallation background rejection techniques. The dominant background after all the analytic background rejection is the Xe-spallation product by a cosmic-ray muon, even though our experiment is taken place 1000-m-underground. In the presentation, the new result of KamLAND-Zen 800 with 1 ton-year ^{136}Xe exposure will be presented with the estimation and the measurement of the long-lived Xe-spallation product.

(Invited) Emission of Single and Few Electrons in XENON1T and Limits on Light Dark Matter

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Double-phased LXe TPCs, are characterized by an exceptional sensitivity for the detection of small charge signals, derived from the ionization of xenon atoms, down to the level of one electron. These detectors are sensitive to the inelastic quantum processes occurring at the atomic level and, par excellence, to the ionization process of even a single atom. Nevertheless, delayed single and few-electron backgrounds are emerging as a major instrumental background in LXe TPCs. These electron-trains appear to derive from a multitude of quantum processes in the atomic level of LXe, for many yet unknown reasons. This instrumental background is dominant for the search of leptonically interacting dark matter particles with mass in the sub-GeV scale, emerging in the framework of so-called, "hidden sector" theories, predicting a leptophilic DM with a mass in $O(\text{MeV})$, that could interact with atomic electrons of the target causing inelastic atomic processes, such as ionization. Since the origin delayed electron backgrounds remains unknown, a model accurately describing their phenomenology is missing. In this work, based on the data of the XENON1T detector, we investigate their origin as well as their basic spatial and temporal characteristics. The observed intensity of delayed electron backgrounds shows that the resulting emissions are correlated, in time and position, with high-energy events preceding them even for time intervals of $O(\text{ms})$. This empirical knowledge allows us to select volumes and times in the detector when the rate of correlated delayed electron emission is minimal in order to perform a low-background search for DM. This allows us to push our analysis threshold down to a single detected electron, thereby extending previous S2-only searches to lower masses.

After removing the correlated backgrounds, we observe rates $< 30 \text{ events}/(\text{electron} \cdot \text{kg} \cdot \text{day})$ in the region of interest spanning 1 to 5 electrons. We derive 90% C.L. upper limits for dark matter-electron scattering, direct detection limits on the electric dipole, magnetic dipole, and anapole interactions, and bosonic dark matter models, excluding new parameter space for dark photons and solar dark photons.

(Invited) Gaseous detectors for neutrino Physics at the ESS, the GanESS project,

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The recent detection of the coherent elastic neutrino-nucleus scattering (CEvNS) opens the possibility to use neutrinos to explore physics beyond standard model with small size detectors. However, the CEvNS process generates signals at the few keV level, requiring of very sensitive detecting technologies for its detection. The European Spallation Source (ESS) has been identified as an optimal source of low energy neutrinos offering an opportunity for a definitive exploration of all phenomenological applications of CEvNS. In this project I propose to apply the high pressure gas TPC technology to the detection of the CEvNS process at the ESS. This will require the development of very low-energy detectors and to improve the current knowledge of the quenching factor for nuclear recoils in gas at keV energies. The major goal of this project is to build a 20 kg xenon gaseous detector and operate it at the ESS, such detector will provide more than 7,000 CEvNS events per year, overtaking the sensitivities of much larger detectors in current spallations sources.

(Invited) Studies of Neutral Bremsstrahlung emission in Xenon

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We have measured, for the first time in pure xenon, non-excimer-based secondary scintillation, Neutral Bremsstrahlung (NBrS), in a dedicated setup based on a Gas Proportional Scintillation Counter. The emission of NBrS by drifting electrons occurs even for electric field values below the gas excitation threshold. We have shown the presence of NBrS in the NEXT-White TPC, at present the largest optical HPXe-TPC in operation.

Moreover, for field values above 1 kV/cm/bar, as typically employed for electroluminescence (EL), there is consistent evidence that NBrS is present with an intensity about two orders of magnitude lower than conventional, excimer-based, EL.

Our data show excellent agreement with calculations of NBrS yield.

Despite fainter than EL, in pure xenon, this new source of emission has to be accounted for in Xe optical TPCs and may play an important role in future single-phase LXe TPCs.

A measurement of the mean electronic excitation energy of liquid xenon

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Liquid xenon is widely deployed as target in particle detectors for rare event searches. The measurement of the occurring scintillation light and ionisation charge caused by a particle interaction allows for the determination of the associated recoil energy. A precise reconstruction of the deposited energy requires calibrations of the energy scale of the detector by means of radioactive sources. However, a microscopic calibration, i.e. the translation from the number of excitation quanta into deposited energy, also necessitates good knowledge of the energy required to produce single scintillation photons or ionisation electrons in liquid xenon. The sum of these excitation quanta is directly proportional to the deposited energy in the target. The proportionality constant is the mean excitation energy and is commonly known as W -value. We present a measurement of this work function with electronic recoil interactions in a small dual-phase xenon time projection chamber. Our result is based on calibrations at $O(1-10\text{ keV})$ with internal ^{37}Ar and $^{83\text{m}}\text{Kr}$ sources and single electron events. We obtain a value of $W = 11.5 - 0.3 + 0.2$ (syst.) eV, with negligible statistical uncertainty, which is lower than previously measured at these energies. If further confirmed, our result will be relevant for modelling the absolute response of liquid xenon detectors to particle interactions.

The DireXeno Experiment - Measuring the Temporal and Directional Structure of Scintillation from Liquid Xenon

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The scintillation process from Liquid Xenon (LXe) plays a major role in particle detectors. Features of it are used to estimate the energy and the type of the detected particle. An accurate model of the particle energy deposition in the LXe medium and the scintillation following it is crucial for the detector's background discrimination power and its sensitivity. DireXeno is an experiment that aims at studying the temporal and directional pattern of scintillation from LXe. The heart of the apparatus is a 1cm radius LXe target which is observed by 20 PMTs that surround it. The target is irradiated by gamma and neutron sources. We present here a process that we developed which utilizes a trained neural network to estimate the times of the photon emissions in a scintillation event based on the signals acquired by the PMTs. We show the average temporal structure of scintillation events with an emphasis on its variation with the interaction energy and type. This enables us to study a model of the temporal structure which incorporates the exponential components of the two excited states of LXe with the non-exponential recombination response, which is energy dependent.

Primary scintillation in Xe for electrons and alpha-particles

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Xenon scintillation has been widely used in rare event detection experiments, such as neutrinoless double beta decay and dark matter [1,2]. Yet, experimental values on the primary scintillation yield in the absence of recombination remain scarce and dispersed. The mean energy required to produce a vacuum ultraviolet scintillation photon (W_{sc}) in gaseous xenon has been measured in the range of 30-120 eV [3]. Lower W_{sc} -values are often found for alpha particles when compared to electrons produced by gamma or x-rays, being this difference not understood. We carried out a systematic study of the absolute primary scintillation yield in Xe at the atmospheric pressure, using a Gas Proportional Scintillation Counter. A simulation model of the detector's geometric efficiency was developed and benchmarked using waveform-shape analysis of primary and secondary scintillation signals. W_{sc} -values in the range of 30-50 eV were obtained for gamma and x-rays with energies from 5.9 up to 60 keV, and for ~2 MeV alpha particles. No significant differences were found between alpha particles and electrons.

The MICRORADON Project

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The radioactive background induced by ^{222}Rn and its progeny is often the main constraint on the sensitivity of many low-energy and very low-count experiments in particle and astroparticle physics, and requires a radon concentration at the level of a few atoms per m^3 or per tonne. In this context, the objective of the MICRORADON project is to study the fundamental properties of Radon, under the particular and extreme conditions encountered in the next generation of experiments. The presence of ^{222}Rn is a particularly important constraint when the detection medium is Xenon, as these two atoms have very similar covalent radii, a parameter that governs capture on adsorbent materials. In addition, there is a great lack of data on the main properties of Radon in Xenon, such as transport and emanation. In this talk, we will present some preliminary results on Radon capture, transport and emanation in the presence of Xenon, obtained at CPPM - Marseille in the framework of the MICRORADON project.

Studies of primary and secondary scintillation yield in krypton

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The krypton electroluminescence yield was studied, at room temperature, as a function of electric field in the gas scintillation gap. A large area avalanche photodiode has been used to allow the simultaneous detection of the electroluminescence pulses as well as the direct interaction of x-rays, the latter being used as a reference for the calculation of the number of charge carriers produced by the electroluminescence pulses and, thus, the determination of the number of photons impinging the photodiode. An amplification parameter of 113 photons per kV per drifting electron and a scintillation threshold of 2.7 Td ($0.7 \text{ kV cm}^{-1} \text{ bar}^{-1}$ at 293 K) was obtained, in good agreement with the simulation data reported in the literature. On the other hand, the ionisation threshold in krypton was found to be around 13.5 Td ($3.4 \text{ kV cm}^{-1} \text{ bar}^{-1}$), less than what had been obtained by the most recent simulation work-package. The krypton amplification parameter is about 80% and 140% of those measured for xenon and argon, respectively. The electroluminescence yield in krypton is of great importance for modeling krypton-based double-phase or high-pressure gas detectors, which may be used in future rare event detection experiments. Preliminary results for the primary scintillation yield in gaseous krypton will also be presented.

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Time and band-resolved scintillation in time projection chambers based on gaseous xenon

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Scintillation in modern xenon detectors makes use, almost exclusively, of the xenon second continuum, but there is nowadays abundant evidence of other subdominant contributions like the third continuum or neutral bremsstrahlung, whose characteristic features are dominant in some conditions, and that might be technologically usable. We report time and band-resolved measurements of the primary and secondary scintillation in xenon obtained (simultaneously) with a mini-TPC, over a range of pressures 1-10bar, electric fields (0-100V/cm/bar in the drift region and up to the onset of multiplication in the electroluminescence region) and particle types (alphas, betas). Geant4 simulations allow us to obtain absolutely normalized yields of these phenomena in the conditions described.

Dual-Polarity Ion Drift Chamber: Experimental results with Xe-SF6 mixtures

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A new experimental system was recently developed by our group to measure the mobility of both positive and negative ions: the Dual-Polarity Ion Drift Chamber (DP-IDC) [1]. This new system is intended to foster the understanding of transport properties of ions in gases, as these are especially relevant for the performance of gaseous detectors, namely in large volume ones, in particular for the development/optimization of the performance of Negative Ion Time Projection Chambers (NITPCs) for rare event searches such as the experiments CYGNUS, XENON or NEXT. The optimization/finetuning of gas mixtures for such detectors gains special relevance as the drift of negative ions in these detectors can significantly affect the signal formation, the tracking capability, and spatial resolution, eventually limiting their rate capability. In addition, a comprehensive understanding of the different ion species expected in particular gas mixtures can also be of extreme importance as it may allow identifying potential minority charge carriers (negative ions) which are the basis for the development of additional internal trigger methods in NITPCs while enabling to further reduce the background on such detectors. In this work, we present a description of the experimental setup and technique used, and the initial studies carried out in mixtures of interest in NITPCs, namely in Xe-SF6 mixtures, whose interest has attracted attention as a possible alternative in searches for the neutrinoless double-beta decay.

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