The 22nd international workshop on Next Generation Nucleon Decay and Neutrino Detectors (NNN23)

Wednesday, 11 October 2023 - Friday, 13 October 2023

Procida

Book of Abstracts

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Calibrating DUNE –The Largest LArTPC Ever To Be Built

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The Deep Underground Neutrino Experiment, DUNE, is a next-generation, long-baseline, neutrino experiment, and flagship project for the U.S. It is poised to perform some of the most precise measurements of the properties of neutrinos in order to elucidate their role in the outstanding matter-antimatter asymmetry. DUNE will make use of the world's most intense neutrino beams produced by the Fermi National Accelerator Lab in Batavia, Illinois and propagate them towards a far detector located 1300 km away and 1.5 km underground at the Sanford Underground Research facility (SURF) in Lead, South Dakota.
At a nominal 70 kilotons of liquid Argon, the DUNE far detector will be the largest Liquid Argon Time Projection Chamber (LArTPC)-based neutrino observatory in the world. The level of precision required to answer the questions sought after by DUNE, result in unprecedented requirements in our understanding of the detector response. We must therefore, carefully address various systematic uncertainties, particularly those in position and energy reconstruction of neutrino interactions and their byproducts. I will talk about the challenges involved in calibrating the largest LArTPC ever to be built and elaborate on the sophisticated calibration systems, tailored for DUNE, to provide the precision required to achieve future breakthrough discoveries.

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Theoretical Overview of Neutrino Oscillations

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Experimental Overview of Neutrino Oscillations

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Nucleon decay: theory and experimental overview

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Overview of Reactor neutrinos experiments

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Neutrino-nucleus interactions

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Overview SN neutrinos

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High-energy astrophysical neutrinos

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Neutrinoless double beta decay

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Results and Prospects from Atmospheric and Solar Neutrinos

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AI and ML in Neutrino Physics

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Overview of neutrino mass measurements

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Combined neutrino oscillation analysis between Super-Kamiokande and T2K

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Status of NOvA

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T2K latest oscillation analysis and cross-section results

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Status of DUNE

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Status of HK

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The JUNO Experiment: Status and Prospects

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JUNO is a neutrino experiment aiming to detect antineutrinos emitted from nuclear reactors and from the inner layers of the Earth, as well as neutrinos from galactic and extragalactic sources. It comprises an active target mass made of 20 kton organic liquid scintillator, monitored by more than 40000 photosensors. JUNO aims to shed light on several open questions in fundamental particle physics and astrophysics. Among others, to determine the neutrino mass ordering with a confidence greater than 3 sigmas, to measure with sub-percent precision three of the neutrino oscillation parameters, to improve the current limits on the proton lifetime, to help addressing the solar metallicity problem, to detect the diffuse supernova neutrino background and to be ready to detect a core-collapse supernova neutrino burst, and to investigate several theories predicting physics beyond the Standard Model.

In this talk I will provide an overview of the status of the detector construction and of the ongoing commissioning activities. I will also report updated sensitivity estimates to the main JUNO Physics goals.

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Status of SK

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Status and perspective of ICARUS at the Fermilab Short-Baseline Neutrino Program

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The ANTARES and KM3NeT neutrino telescopes: status and perspectives for neutrino physics and astrophysics

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The ANTARES neutrino telescope was operational in the Mediterranean Sea from 2006 to 2022. The detector array, consisting of 12 lines with a total of 885 optical modules, was designed to detect high-energy neutrinos covering energies from a few tens of GeV up to the PeV range. Despite the relatively small size of the detector, the results obtained are relevant in the field of neutrino physics and astrophysics due to the good angular resolution of the telescope.
KM3NeT is a research infrastructure housing the next generation of Cherenkov neutrino telescopes. It consists of two detectors (ARCA and ORCA) currently under deployment in two locations in the Mediterranean Sea. Although both telescopes are based on the same detection technology, their key science goals are different: ARCA (located off-shore Sicily, Italy) aims at studying neutrinos with energies in the TeV–PeV range coming from distant astrophysical sources. ORCA (located off-shore Toulon, France) is optimized for neutrino physics studies at 1–100 GeV energies, providing information on their fundamental properties.
This presentation will give an overview of the legacy results of ANTARES and an overview on the KM3NeT infrastructure, the detector performances, the basic analysis techniques. We will also show, among others, the expected sensitivities for the complete detector configuration on the search for cosmic neutrino sources with ARCA, the sensitivity to the neutrino mass ordering and the measurement of the neutrino oscillation parameters with ORCA. In addition, by searching for an excess of coincidences above the optical background, KM3NeT can detect low energy neutrinos coming from Galactic Core-Collapse SuperNova. I discuss how the uniquely complex structure of the optical modules in the KM3NeT would allow this wide physics and astrophysics program.

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Latest neutrino oscillation results and prospect from IceCube

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The IceCube Neutrino Observatory, together with its DeepCore sub-array, detects large amounts of atmospheric neutrinos in the GeV to TeV energy range, enabling measurements of the muon-neutrino disappearance and tau-neutrino appearance channels of neutrino oscillations over a wide

range of baselines up to 12000 km. In the energy range of DeepCore between 5 GeV and 150 GeV in particular, these measurements provide independent and complementary constraints in the atmospheric oscillation parameter space probed by long-baseline accelerator experiments. This talk presents the latest neutrino oscillation results from the IceCube Collaboration that include larger datasets, improved detector calibration and more sophisticated event reconstruction methods than previous atmospheric neutrino measurements. It also gives an outlook on future high-precision measurements that will be facilitated by the IceCube Upgrade, an additional infill array whose deployment is slated to begin during the 2025-2026 Antarctic summer season.

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Neutrinoless double-beta decay search with the LEGEND experiment

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Neutrinoless double-beta decay is a nuclear decay, given as (A,Z) –> (A,Z+2)+2e-, that violates total lepton number conservation by two units. Its observation would have deep consequences in the understanding of our Universe. It would prove that neutrinos have a Majorana component, it would help to understand the origin of the neutrino mass and constrain its absolute mass and help to understand the matter-antimatter asymmetry in the Universe. Due to this very reach scientific harvest, a strong experimental program is underway to search for this transition with many proposed experiments using different technologies.
In the talk the LEGEND experiment, which uses 76Ge as the isotope of interest, will be described. We will start describing its first stage, LEGEND-200, which is now taking data at the Laboratori Nazionali del Gran Sasso of INFN in Italy, and then the status of the future final step, LEGEND-1000. The goal of LEGEND-200 is to reach a sensitivity in the half-life of the neutrinoless double-beta decay of 76Ge of about 10^27 yr in terms of both setting a 90% C.L. limit and achieving a 50% chance to make a 3 sigma discovery, thanks to a projected background index of 0.6 cts/(FWHMtyr) and an exposure of 1 t*yr. LEGEND-1000 aims for a sensitivity of beyond 1028 yr by operating 1 tonne of enriched germanium detectors for an exposure of more than 10 tyr at a background index of about 0.025 cts/(FWHM*tyr). Thanks to this sensitivity LEGEND-1000 will be able to explore the entire inverted mass ordering region

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Searching for neutrinoless double beta decays with nEXO

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Neutrinoless double beta decay ($0\nu\beta\beta$) is a hypothetical nuclear process which, if observed, would have far-reaching implications in particle physics. Being a lepton number violating process, the observation of $0\nu\beta\beta$ is direct evidence for physics beyond the Standard Model. In addition, it would prove that neutrinos are Majorana particles, and contribute to the determination of the neutrino mass scale. nEXO is a proposed next-generation experiment that will search for $0\nu\beta\beta$ of ^{136}Xe. nEXO plans to use a liquid xenon time projection chamber that employs 5 tonnes of xenon, isotopically enriched to 90% in ^{136}Xe. Ionization electrons and scintillation photons will be detected by segmented anode tiles and silicon photomultipliers, respectively. These will enable event-by-event reconstruction of event energy, position, and topology which will be used in a multi-parameter analysis to search for $0\nu\beta\beta$ events. The projected sensitivity of nEXO to the ^{136}Xe $0\nu\beta\beta$ half-life is 1.35\times10^{28}$ years after 10 years of data-taking. The nEXO project is being developed by a collaboration of 34 institutions from 9 countries. In this talk, an overview of nEXO will be presented followed by a description of the conceptual design and an update of the R&D status.

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Updated Results from the Daya Bay Experiment

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Latest results from MINERvA

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Addressing the challenge of neutrino interaction uncertainties in Hyper-Kamiokande

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Neutrino Physics Program at NA61/SHINE

Future neutrino oscillation experiments demand a precise estimation of neutrino flux. The leading flux uncertainty comes from inadequate understanding of primary and secondary hadron-nucleus interactions. The NA61/SHINE experiment at CERN's Super Proton Synchrotron measures various hadron production processes with the goal of reducing the flux uncertainty of current and future accelerator-based neutrino beams. This contribution will present NA61/SHINE's recent hadron production measurements, current data-taking, and future plans for the neutrino physics program.

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MicroBooNE's latest results

MicroBooNE is an 85-tonne active volume liquid-argon time projection chamber located in the Booster Neutrino Beam and NuMI beam at Fermilab. It was operational from 2015 to 2020 and collected the largest neutrino-argon interaction dataset to date. The primary goals of MicroBooNE are to understand the low-energy excess observed by MiniBooNE, make precise measurements of neutrino interactions on argon, and search for beyond-the-Standard-Model physics. In this talk, I will present some of the latest results from MicroBooNE, with an emphasis on neutrino-argon cross-section measurements.

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T2K ND280 Upgdrade

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SC Report

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LArPix and LightPix: Scalable electronics for very large detectors

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Future neutrino experiments and rare event searches require exceptionally large detectors with high granularity. I will discuss LArPix, which provides an integrated detector system (amplification, triggering, digitization, and multiplexed readout) that has been designed to scale in excess of 10^6 channels. Results from the production of 0.5 million LArPix channels and performance in a ton-scale liquid argon time-projection chamber will be presented. To achieve this we had to overcome issues in noise, waste heat, cryogenic-compatibility, reliability, and scalability. I will also discuss progress with LightPix, a variant designed to support scalable readout of large arrays of silicon photomultipliers in cryogenic environments.

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Temperature Monitoring Systems for Phase-I DUNE Far Detector Modules

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The Deep Underground Neutrino Experiment (DUNE) is an international project for neutrino physics and proton decay searches, currently in the design and construction stages. When built, the world's most intense neutrino beam will cross the two detectors composing DUNE. The near detector, placed close to the beginning of the beam line located at Fermilab, will measure the un-oscillated neutrino flux. In the far site, ~1300 km away, a much larger detector, comprising four liquid argon time projection chambers (LArTPCs) of 70Kton, will record the oscillated neutrino flux at a depth of ~1.5 km at the Sanford Underground Research Facility (SURF) in South Dakota. To achieve its scientific goals, DUNE relies heavily on the precise operation of its massive detectors, making temperature control and monitoring critical factors for optimal performance. Two different technologies are approved to be the base of the temperature monitoring systems (TMS) for the first two far detector (FD) modules to be installed during Phase-I. In the FD-I, ~1000 high-precision platinum resistance thermometers (PRTs) distributed across the entire volume are calibrated to record minute fluctuations in temperature of the other of ~2 mK, allowing for real-time monitoring and analysis of the system's thermal behaviour. Due to the vertical configuration of the electric in the FD-II module, around 600 fibre Bragg gratings (FBG) sensors will be vertically monitoring the active volume, providing similar temperature resolution as PRTs in the FD-I. Also, of the order of ~400 PRTs will monitor critical temperature features at strategical points in the FD-II outside the active volume, where electric field is less intense. We discuss ongoing R&D efforts to enhance the temperature monitoring system for even greater precision and efficiency. The potential improvements include the integration of machine learning algorithms for predictive maintenance and adaptive control to temperature fluctuations in real-time.

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Distinguishing between Dirac and Majorana neutrinos using temporal correlations

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In the context of two flavour neutrino oscillations, it is understood that the 2×2 mixing matrix is parameterized by one angle and a Majorana phase. However, this phase does not impact the oscillation probabilities in vacuum or in matter with constant density. Interestingly, the Majorana phase becomes relevant when we describe neutrino oscillations along with neutrino decay. This is due to the fact that effective Hamiltonian has Hermitian and anti-Hermitian components which cannot be simultaneously diagonalized (resulting in decay eigenstates being different from the mass eigenstates). We consider the PT symmetric non-Hermitian Hamiltonian describing two flavour neutrino case and study the violation of Leggett-Garg Inequalities (LGI) in this context for the first time. We demonstrate that temporal correlations in the form of LGI allow us to probe whether neutrinos are Dirac or Majorana. We elucidate the role played by the mixing and decay parameters on the extent of violation of LGI. We emphasize that for optimized choice of parameters, the difference in K4 (K3) for Dirac and Majorana case is ~15% (~10%).

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Physics potential of detecting B8 solar neutrinos at JUNO

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The Jiangmen Underground Neutrino Observatory (JUNO) stands at the pinnacle of next-generation neutrino research, harnessing the most extensive liquid scintillator developed. Boasting a photocathode coverage of 77.9% and an exceptional 30.1% photo-detection efficiency via MCP-PMTs, JUNO is distinctively positioned with unmatched energy resolution.
While B^{8} solar neutrinos have been explored by the SuperKamioka, SNO, and Borexino experiments, their lowest threshold remains at 3 MeV, constrained by detector size or light yield. However, JUNO, with its grand scale and high light yield, promises to push this detection threshold to 2 MeV, thereby probing the intriguing transition region of the MSW effect into the vacuum scenario.
This presentation offers a comprehensive evaluation of JUNO's potential in detecting B^{8} solar neutrinos through the neutrino-electron elastic scattering (ES) process, as well as the charged-current (CC) and neutral-current (NC) channels on nucleus. With ten years of data, JUNO aims to improve the B^{8} neutrino flux, \Delta m_{21}^{2} and sin^{2}\theta_{12} measurements. Furthermore, JUNO' s capability to measure \Delta m_{21}^{2} using B^{8} neutrinos and reactor antineutrinos lays

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First result of a search for astrophysical electron antineutirino in SK-Gd experiment

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Since 2020, Super-Kamiokande (SK) detector has been updated by loading gadolinium (Gd) as a new experimental phase, 'SK-Gd.'In the SK-Gd experiment, event selection with delayed coincidence using neutron capture signal, such as inverse beta decay of electron antineutrinos, is improved thanks to high cross-section and high energy gamma-ray emission of thermal neutron capture on Gd.
In July 2022, the observation with 0.01% of Gd mass concentration was completed, and currently, an updated phase with 0.03% mass concentration is in operation. We report the first result of a search for astrophysical electron antineutrinos flux for the energy range of O(10) MeV in SK-Gd with a 22.5×552 kton×day exposure at 0.01% Gd mass concentration. Finally, the future prospect for the DSNB search in SK-Gd is discussed.

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Recent results on proton decay searches in Super-Kamiokande

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We would like to report on the recent results on proton decay searches in Super-Kamiokande (SK). We will cover the updated results since NNN19 using the pure water detector phase data, including

the flagship modes: $p\rightarrow e^{+0}$, $p\rightarrow^{+0}$, and $p\rightarrow K^{+}$.
There are many theories which predict different nucleon decay modes, and therefore it is important to experimentally search for various decay modes other than those flagship modes to determine the physics beyond the Standard Model of particle physics. Searches for $p\rightarrow^{+}K^{0}$ and $p\rightarrow e^{+0}$ are updated by improving data analyses such as event reconstruction algorithms or systematic error estimations.
Some theory [1] predicts that the $p\rightarrow e^{+00}$ decay rate could be comparable to the $p\rightarrow e+{}^{0}$ one in a model-independent manner. We searched for $p\rightarrow e^{+00}$ and $p\rightarrow^{+00}$ for the first time in SK and the new results will be shown. We optimized the event selections with an additional ^{0} in the final state with respect to $p\rightarrow e^{+0}$, $p\rightarrow^{+0}$. All the pure water phase data (SK I-V) were used in these searches.

[1] "Three-body decays of the proton", PRD 23 7 (1981).

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The front-end electronics of the Hyper-Kamiokande Far Detector.

Hyper-Kamiokande (HK) is the successor of the Super-Kamiokande (SK) experiment; HK has a world class physics programme including accelerator neutrino beam as well as search for proton decays and neutrino from sun, atmosphere and astrophysical sources. HK will be using the same 295 km baseline as T2K (Tokai2Kamioka) but with a larger Far Detector (FD) fiducial mass than SK and a higher beam intensity obtained by upgrading the J-PARC proton accelerator. The FD is a 258 kton water-Cherenkov consisting of a 68m (diamaeter) by 71m (height) cylindrical-shape water tank. The FD is divided into 2 parts: an *Inner Detector* (ID), instrumented by 20000 20" PMTs, surrounded by an *Outer Detector* (OD), consisting of 3600 3" PMTs looking outwards and acting as a *veto* for the ID.

This contribution describes the front-end electronics developed for the ID; the key point of the circuit is the design relying on discrete commercial Integrated Circuits. The circuit is divided into 3 sections: the first is the *input receiver*, which matches the impedance, buffers, and shapes the PMT input signal; following the receiver there are the *timing* and *integration* paths: the *timing* path consists of a fast discriminator which provides a trigger signal marking the beginning of a hit; the *integration* path converts the charge of the hit into a voltage level, which is then sampled by an ADC.

An FPGA implements a 250~ps resolution TDC which time-stamps the analog triiger signal and reads the slow ADC that digitizes the integrated charge. The digitized hits are then formatted into packets and sent through a 3Gb/s high speed copper link to a close-by board, which, in turn, transmits data on a optical link to the DAQ backend.

This work will describe in details both the circuit working principle and its performance quantitative evaluation.

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Water-Cherenkov Test Experiment (WCTE) and beam tests of July 2023

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The Water-Cherenkov Test Experiment (WCTE) is a prototype water Cherenkov detector which will be placed in the T9 beam area at CERN, operated with a low momentum (200-1200 MeV/c) $\pi^{\pm}$, $\mu^{\pm}$, $e^{\pm}$ and p^{+} particle flux. The main purpose of this experiment is to prove the new technologies that are being developed for the next-generation water-Cherenkov experiments, especially for the far detector and intermediate (IWCD) detectors of the Hyper-Kamiokande project, along with properly modeling the detector response and studying physical processes such as Cherenkov light profile produced by secondary particles, charged pion hadronic scattering or secondary neutron production and tagging, the latter chiefly during the phase where gadolinium (Gd) will be loaded with the ultra-pure water in the $\sim$40 tonne detector tank.

The design and construction of the stainless steel cylinder, the 102 multi-photomultipliers (mPMTs), each consisting of 19 PMTs to detect the signal emitted by the produced particles after the interaction of the incoming particle with the water filling the tank, and other physical parts of the detector, as well as simulation packages and analysis strategy, are currently in their final stages of development, just after beam testing took place last July. During this period, a second configuration was tested, using bremsstrahlung γ from a radiator as a gamma source, in order to study detector response and the ability to separate γ from electrons. This set up has a permanent magnet to bend the initial e^{+}/e^{-} so it can be measured in a hodoscope to determine the energy of the gammas.

Data taking period with WCTE is scheduled for summer 2024, and the WCTE collaboration is working towards the start of assembly for the WCTE detector in November 2023.

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Latest Results from the CUORE experiment

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The Cryogenic Underground Observatory for Rare Events (CUORE) is the first bolometric experiment searching for 0νββ decay that has successfully reached the one-tonne mass scale. The detector, located at the LNGS in Italy, consists of an array of 988 TeO2 crystals arranged in a compact cylindrical structure of 19 towers. CUORE began its first physics data run in 2017 at a base temperature of about 10 mK and has been collecting data continuously since 2019, reaching a TeO2 exposure of 2 tonne-year in spring 2023. This is the largest amount of data ever acquired with a solid state cryogenic detector, which allows for further improvement in the CUORE sensitivity to 0νββ decay in 130Te. In this talk, we will present the new CUORE data release, based on the full available statistics and on new, significant enhancements of the data processing chain and high-level analysis.

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CUPID a next generation bolometric 0νββ decay experiment

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Neutrinoless double-beta decay (0νββ) is a key process to address some of the major outstanding issues in particle physics, such as the lepton number conservation and the Majorana nature of the neutrino. Several efforts have taken place in the last decades in order to reach higher and higher sensitivity on its half-life. The next-generation of experiments aims at covering the Inverted-Ordering region of the neutrino mass spectrum, with sensitivities on the half-lives greater than 1E27 years. Among the exploited techniques, low-temperature calorimetry has proved to be a very promising one, and will keep its leading role in the future thanks to the CUPID experiment. CUPID (CUORE

Upgrade with Particle IDentification) will search for the neutrinoless double-beta decay of 100Mo and will exploit the existing cryogenic infrastructure as well as the gained experience of CUORE, at the Laboratori Nazionali del Gran Sasso in Italy. Thanks to 1596 scintillating Li2MoO4 crystals, enriched in 100Mo, coupled to 1710 light detectors CUPID will have simultaneous readout of heat and light that will allow for particle identification, and thus a powerful alpha background rejection. Numerous studies and R&D projects are currently ongoing in a coordinated effort aimed at finalizing the design of the CUPID detector and at assessing its performance and physics reach.
In our talk, we will present the current status of CUPID and outline the forthcoming steps towards the construction of the experiment.

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A light and reliable software solution for data processing tasks within the underwater vessel in Hyper-Kamiokande

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One of the requirements of the front-end electronics in the HK experiment is that it must be designed to be placed inside the water vessels due to the detector size, which amounts to a total of ~40,000 inside photo-sensors. Otherwise, the cables connecting to the roof would be too heavy and long, which would cause a reduction in signal amplitude and quality degradation. This solution poses several challenges, one of them being the inability to replace, maintain or repair a broken module easily. Thus, the system must have mechanisms that increase its fault tolerance such as redundant components and failure control mechanisms.
To overcome this problem, the front-end electronics will be placed inside the water, close to the photo-sensors allowing for shorter and lighter cables.
The aim of this talk is to discuss a reliable software solution that performs all the required tasks for processing the data acquired by the digitizer from the PMTs and send it to an external datacenter: (1) Manage the data coming from the digitizer ensuring that it is correctly buffered in the DPB (Data Processing board) main memory (2) Read the buffered data, package it in a TCP/IP frame and send it through a redundant fiber optics link. (3) Receive timing information for timestamping and clocking purposes and send it reliably to the digitizer (4) Redundant system boot up and remote access to ensure 24/7 operation and perform firmware updates.
The chosen system will be a DPB sporting a state-of-the-art Xilinx FPGA-based architecture: Zynq Ultrascale+, where a powerful ARM64 CPU is combined in the same silicon die with FPGA cells to bring both flexibility and power to instantiate any hardware core that suits the needs of the experiment without compromising compatibility with Linux, the chosen embedded operative system to support these software tasks.

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Primordial black hole dark matter evaporating on the neutrino floor

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Primordial black holes are hypothetical Black Holes generated in the first instants of the Universe life. Focusing on Primordial Black Hole masses in the range $[5 \times 10^{14} - 5 \times 10^{15}]$ g, we point out that the neutrinos emitted by PBHs evaporation can interact through the coherent elastic neutrino-nucleus scattering producing an observable signal in multi-ton Dark Matter direct detection experiments. The envisaged high exposures for the next-generation facilities allow us to limit Primordial Black Hole abundance today, improving the existing neutrino limits obtained with Super-Kamiokande. We also quantify how Primordial Black Holes would modify the "neutrino floor".

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Sensitivity to core-collapse supernovae neutrino signals in DarkSide-20k

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DarkSide-20k (DS-20k) will explore the dark matter WIMP hypothesis with a dual-phase time projection chamber detector filled with 50 tonnes of low-radioactivity liquid argon extracted from underground sources. Besides the primary physics goal of DS-20k, the low-energy threshold (~1 keV) of the detector will allow it to observe neutrinos from core-collapse supernovae (CCSN) via coherent elastic neutrino-nucleus scattering (CEνNS). In this way, DarkSide-20k will produce a flavour-blind measurement of the unoscillated neutrino flux from a CCSN providing the normalisation for current and future giant detectors which are mostly sensitive to electron (anti-)neutrinos. In addition, DS-20k will be able to join the network of the SuperNova Early Warning System 2.0 (SNEWS2.0), providing additional input for triangulating core-collapse supernovae.

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Status of the SNO+ Experiment

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SNO+ is a multipurpose liquid scintillator detector located at SNOLAB in Canada. The primary focus is to search for neutrino-less double beta decay of 130Te but, prior to isotope loading the experiment has been operated with a pure water, and now a pure liquid scintillator target. This poster will present the current status and performance of the experiment and recent results including first demonstration of event-by-event direction reconstruction in a large scale liquid scintillator detector.

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Multi-PMT modules for the Hyper-Kamiokande experiment.

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The Hyper-Kamiokande (HK) is the next-generation long baseline neutrino experiment currently being constructed in Japan. It will have two underground water-Cherenkov detectors - the 260 kt far detector and approx. 1 kt intermediate detector (IWCD). The Water Cherenkov Test Experiment (WCTE) at CERN will evaluate different technologies and methodologies used in water Cherenkov detectors. It will have approx. 100 multi-PMT modules inside a water tank measuring about 3.8 meters in diameter and 3.6 meters in height, containing around 41 tonnes of water.

The poster will present the ongoing development of multi-PMT modules intended for deployment in both HK and WCTE. The multi-PMT unit comprises nineteen Hamamatsu Photonics R14374 3-inch PMTs and associated front-end electronics, all enclosed within a watertight pressure vessel. Two configurations of multi-PMTs will be used in Hyper-Kamiokande - power-optimized far-detector version and IWCD version, optimized for a high rate of incoming events. The poster will provide insights into the production process of the multi-PMT system, encompassing assembly procedures and quality assurance protocols. A dedicated section will cover the multi-PMT electronic system, including the high-voltage supply, the front-end cards, and the digitizer board. Moreover, we will explain the techniques for assessing the electronic performance and optical characteristics of the 3-inch PMT and whole multi-PMT module. Lastly, we will present data from quality assurance assessments conducted on a representative module.

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Are there critical aspects in the time, energy and angular distributions of SN1987A?

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Supernova neutrinos have enormous importance for ongoing research in astrophysics, nuclear and particle physics. However, existing simulations of this complex event, although increasingly sophisticated, still do not guarantee with sufficient confidence a reliable description of the emission. In this situation, it seems important to study as accurately as possible the only such event observed so far with neutrino telescopes: those of SN1987A. With these considerations, we are setting up a refined analysis, taking into account the many acquisitions of the past decades. In this poster we present the model describing the energy distributions, in the various phases of emission, and verify its adequacy to describe the characteristics of the neutrino emission of SN1987A, namely, the distributions in energy, time and angle.

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CUPID a next generation bolometric $0\nu\beta\beta$ decay experiment

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Neutrinoless double-beta decay ($0\nu\beta\beta$) is a key process to address some of the major outstanding issues in particle physics, such as the lepton number conservation and the Majorana nature of the neutrino. Several efforts have taken place in the last decades in order to reach higher and higher sensitivity on its half-life. The next-generation of experiments aims at covering the Inverted-Ordering

region of the neutrino mass spectrum, with sensitivities on the half-lives greater than 1E27 years. Among the exploited techniques, low-temperature calorimetry has proved to be a very promising one, and will keep its leading role in the future thanks to the CUPID experiment. CUPID (CUORE Upgrade with Particle IDentification) will search for the neutrinoless double-beta decay of 100Mo and will exploit the existing cryogenic infrastructure as well as the gained experience of CUORE, at the Laboratori Nazionali del Gran Sasso in Italy. Thanks to 1596 scintillating Li2MoO4 crystals, enriched in 100Mo, coupled to 1710 light detectors CUPID will have simultaneous readout of heat and light that will allow for particle identification, and thus a powerful alpha background rejection. Numerous studies and R&D projects are currently ongoing in a coordinated effort aimed at finalizing the design of the CUPID detector and at assessing its performance and physics reach.
In our talk, we will present the current status of CUPID and outline the forthcoming steps towards the construction of the experiment.

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Quantum-gravity effects for Icecube neutrinos

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The hunt for neutrinos from Gamma-Ray Bursts (GRBs) could also be significant in quantum-gravity research, since they are ideal probes of the microscopic fabric of spacetime. One of the most studied candidate effects of quantum gravity is in-vacuo dispersion, an energy-dependent correction to the speed of ultrarelativistic particles, and in a recent studywe investigated the hypothesis that some neutrinos detected by the IceCube observatory might be GRB neutrinos, with their travel times affected by in-vacuo dispersion.
We adopted a statistical approach seeking to establish that at least some IceCube neutrinos are GRB neutrinos, finding that the presently available data, while insufficient for drawing any conclusions, are encouraging for in-vacuo dispersion.

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SBND status and prospects

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A Multipurpose Graph Neural Network for Reconstruction in LArTPC Detectors

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The Exa.TrkX Graph Neural Network (GNN) for reconstruction of liquid argon time projection chamber (LArTPC) data is a message-passing attention network over a heterogeneous graph structure, with separate subgraphs of 2D nodes (hits in each plane) connected across planes via 3D nodes (space points). The model provides a consistent description of the neutrino interaction across all planes.

The GNN initially performed a semantic segmentation task, classifying detector hits according to the particle type that produced them. Performance results will be presented based on publicly available samples from MicroBooNE. These include both physics performance metrics, achieving ~95%

accuracy when integrated over all particle classes, and computational metrics for training and for inference on CPU or GPU.

We will also present recent work extending the network application to additional LArTPC reconstruction tasks, such as cosmic background and noise filtering, interaction vertex position identification, and particle instance segmentation. Early results indicate that the network achieves excellent filtering performance without increasing the network size, thus demonstrating that the set of learned features are somewhat general and relevant for multiple tasks.

Prospects for the integration of the network inference in the data processing chains of LArTPC experiments will also be presented.

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Deep Learning techniques to search for rare processes in LArTPC-based neutrino experiments

The current and next-generation liquid argon time projection chamber (LArTPC) detectors offer a great opportunity to search for rare, beyond-Standard Model (BSM) physics such as baryon number violation. During operation, these detectors generate high-resolution images of particle interactions, making them well-suited for applying and leveraging deep learning techniques to search for rare signals within their data. This talk will discuss ongoing research and development (R&D) aimed at developing data-driven data selection for LArTPC detectors—a major challenge particularly for large-scale detectors such as the future Deep Underground Neutrino Experiment due to its exorbitant data rate—with the objective of developing real-time data selection schemes as well as offline data analysis for rare signals with very high accuracy and computational performance. As part of the latter, the talk will focus on recent results from a deep learning-based analysis of MicroBooNE data, making use of a sparse convolutional neural network (CNN) and event topology information to search for argon-bound neutron-antineutron transition-like signals, which demonstrates the capability of LArTPCs in achieving high signal efficiency and strong background rejection when leveraging advances in image analysis techniques.

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Machine Learning Techniques for the Event Reconstruction: the JUNO Experiment

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Closing remarks

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The ENUBET monitored neutrino beam for high precision cross section measurements

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Monitored neutrino beams represent a powerful and cost effective tool to suppress cross section related systematics for the full exploitation of data collected in long baseline oscillation projects like DUNE and Hyper-Kamiokande. In the last years the NP06/ENUBET project has demonstrated that the systematic uncertainties on the neutrino flux can be suppressed to 1% in an accelerator based facility where charged leptons produced in kaon and pion decays are monitored in an instrumented decay tunnel. In this talk, we will present the final results of this successful R&D programme. The collaboration is now working to provide the full implementation of such a facility at CERN in order to perform high precision cross section measurements at the GeV scale exploiting the ProtoDUNEs as neutrino detectors. This contribution will present the final design of the ENUBET beamline that allows to collect $\sim 10^4$ ν_e and $\sim 6\times 10^6$ ν_μ charged current interactions on a 500 ton LAr detector in about 2 years of data taking. The experimental setup for high purity identification of charged leptons in the tunnel instrumentation will be described together with the framework for the assessment of the final systematics budget on the neutrino fluxes, that employs an extended likelihood fit of a model where the hadro-production, beamline geometry and detector-related uncertainties are parametrized by nuisance parameters. We will also present the results of a test beam exposure at CERN-PS of the Demonstrator: a fully instrumented 1.65 m long section of the ENUBET instrumented decay tunnel. Finally the physics potential of the ENUBET beam with ProtoDUNE-SP and plans for its implementation in the CERN North Area will be discussed.

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Combined Super-Kamiokande and KamLAND pre-supernova alarm

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The Super-Kamiokande (SK) and the Kamioka Liquid-scintillator Antineutrino Detector (KamLAND) experiments are neutrino observatories located in the Kamioka mine in Japan. A pre-supernova (preSN) alarm has been launched by SK in 2021, aimed at detecting neutrinos produced during the silicon-burning phase of massive stars before a core-collapse supernova (CCSN) occurs. Since 2015, KamLAND has been running its own preSN alarm. Detecting preSN neutrinos will not only provide early warnings for nearby CCSNs, but it will also help understand the processes leading to them and determine the neutrino mass hierarchy. In order to improve the sensitivity of preSN neutrinos and to extend early warning to CCSN, SK and KamLAND have launched a joint alarm system. The details of the joint alarm are presented as well as the expected increase in sensitivity for combining the results from both experiments.

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T2K GEANT4 Beam Simulation

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T2K has successfully developed a beam Monte Carlo simulation called Jnubeam for the neutrino flux prediction in both near and far detectors, which are essential for neutrino oscillation and cross section analyses. Jnubeam is based on the no longer maintained GEANT3 package, which is difficult to support. The current simulation also uses the software FLUKA to simulate the hadronic production from the interactions of the proton beam in the target. We are developing a replacement beam simulation based on GEANT4, which will describe the physics from proton interactions in the T2K target through to muons and hadrons decaying, producing neutrinos for the flux predictions. Simulation results for validation against NA61/SHINE data, neutrino flux predictions using GEANT4,

and comparisons with FLUKA/GEANT3 simulations are presented.