XX International Workshop on Neutrino Telescopes

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Istituto Veneto di Scienze, Lettere ed Arti

Book of Abstracts

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Recent results from the DANSS experiment

Co-authors: Igor Alekseev [1]; Mikhail Danilov [2]

[1] *Individual Scientist at Neutrino 23 - NRC "Kurchatov Institute"*

[2] *LPI (Moscow)*

Corresponding Authors: igor.alekseev@itep.ru, danilov@lebedev.ru

New results from the DANSS experiment on the searches for sterile neutrinos are presented. They are based on 7 million inverse beta decay events collected at 10.9, 11.9, and 12.9 meters from the 3.1 GW reactor core of the Kalinin Nuclear Power Plant in Russia. Additional 1 million of antineutrino events further improves the sensitivity for the sterile neutrino mixing parameter below 0.01 for a sterile neutrino mass around 1 eV. Obtained limits exclude practically all sterile neutrino parameters preferred by the recent BEST results for Δm2 below 5 eV2. Additional data will allow to test the statistical significance of the DANSS best-fit point in case of the 4-neutrino scenario which was 2.35σ. The neutrino spectrum dependence on the 239Pu fission fraction is presented. It agrees with the predictions of the Huber-Mueller model. Using this dependence, the ratio of cross sections for 235U and 239Pu was extracted. It also agrees with the Huber-Mueller model and somewhat larger than in other experiments. The reactor power was measured using the IBD event rate during 6.5 years with a statistical accuracy of 1.5% in 2 days and with the relative systematic uncertainty of about 0.5%. The neutrino oscillation analysis using the predictions for the absolute antineutrino flux from the reactor with a conservative systematic error of 5% excludes practically all sterile neutrino parameter space preferred by the recent BEST results as well as the best fit point of the Neutrino-4 experiment. Status of the DANSS upgrade will be presented. This upgrade should allow DANSS to test in a model independent way the Neutrino-4 claim of the observation of sterile neutrinos and to scrutinize even larger fraction of the sterile neutrino parameter space preferred by the recent BEST results. The cosmic muon flux dependences on temperature and pressure are also presented.

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Results from FASER

Co-authors: David Casper [1]; Savannah Shively

[1] *University of California Irvine*

Corresponding Authors: sshively@uci.edu, dcasper@uci.edu

FASER, the ForwArd Search ExpeRiment, is an LHC experiment located 480 m downstream of the ATLAS interaction point, along the beam collision axis. FASER and its sub-detector FASERnu have two physics goals: (1) to detect and study TeV-energy neutrinos, the most energetic neutrinos ever detected from a human-made source, and (2) to search for new light and very weakly-interacting particles. FASER was designed, constructed, installed, and commissioned during 2019-2022 and has been taking physics data since the start of LHC Run 3 in July 2022. This talk will present the status of the experiment, including detector design, detector performance, and first physics results from Run 3 data.

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Reexamination of Kamiokande-II data in 1987

Author: Yuichi Oyama[1]

[1] *KEK/J-PARC*

Corresponding Author: yuichi.oyama@kek.jp

Three new analyses related using old Kamiokande data recorded in 1987 are reported.
The first analysis is for 11 neutrino events in the Kamiokande-II SN1987A data. It is well known that there is a seven second gap between the 9th and 10th event. It is pointed out that no cosmic ray muon event with a rate of 0.37 Hz was detected during this period. Furthermore, no low-energy background event, which mostly originates from radioactivity with a rate of 0.15 Hz, was detected. The probability of detecting no SN1987A neutrino, no cosmic ray muon, and no low-energy background for this period is less than 0.112%. The possibility that the "seven second gap"was dead time of the Kamiokande-II data acquisition cannot be excluded.
The second analysis is for upward-going muons. High-energy neutrinos from SN1987A were searched for using upward-going muons recorded by the Kamiokande-II experiment and the IMB experiment. Between 1987 August 11 and October 20, and from an angular window of 10° radius, two upward-going muon events were recorded by Kamiokande-II, and also two events were recorded by IMB. The probability that these upward-going muons were explained by a chance coincidence of atmospheric neutrinos was calculated to be 0.27%. This shows possible evidence of high-energy neutrinos from SN1987A.
The third analysis is about a curious upward stopping muon event. The time interval from the previous event, which is thought to be a typical cosmic ray muon, is only 37.48 micro-second. The expected event rate of (cosmic ray muon followed by upward-going muon within 37.48micro-second) is 0.00092 event-pairs/year. It is natural to consider a causal relationship between two events, and such event pairs were searched for in the Kamiokande event sample.

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Dark Matter - Neutrino Scattering at the Galactic Center

Author: Diyaselis Delgado[1]

[1] *Harvard University*

Corresponding Author: ddelgado@g.harvard.edu

Evidence for the existence of dark matter strongly motivates the efforts to study its unknown properties. Additionally, the origin of high-energy astrophysical neutrinos detected by IceCube remains uncertain. If dark matter and neutrinos couple to each other, we can search for a non-zero elastic scattering cross section. The interaction between an isotropic extragalactic neutrino flux and dark matter would be concentrated in the Galactic Center, where the dark matter column density is largest. The flux of high-energy neutrinos would be attenuated by this scattering, and the resulting signal, with correlated energy and arrival direction, can be observed in IceCube. Using the seven years of IceCube data, we perform an unbinned likelihood analysis, searching for several potential DM-neutrino interaction scenarios.

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Probing pseudo-Dirac neutrinos using supernova neutrinos

Author: Manibrata Sen[1]

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

Corresponding Author: manibrata@mpi-hd.mpg.de

Ever since the discovery of neutrinos, we have wondered if neutrinos are their own antiparticles, and whether lepton number is violated or not. One remarkable possibility is that lepton-number

violation in the Standard Model is soft. In such scenarios, neutrinos have a pseudo-Dirac nature with a tiny mass difference between active and sterile states, having oscillations driven by this tiny mass difference. Such oscillations can only be visible over very long distances. In this talk, I will discuss how analyzing the neutrino data from SN1987A in the light of active-sterile oscillations can present a mild preference for such oscillations. Notably, the same data is able to exclude some of the tiniest mass differences for neutrinos constrained so far. I will further discuss the prospects of using the ever-present diffuse supernova neutrino background as a laboratory to test the possible, albeit tiny, violation of lepton number.

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Latest Results from the CUORE experiment

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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The CUPID double beta decay experiment

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 10^{27} 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 ^{100}Mo 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 Li_2MoO_4 crystals, enriched in ^{100}Mo, coupled to 1710 light detectors CUPID will have a 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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Trinity: The PeV Neutrino Observatory

Corresponding Author: michele.doro@unipd.it

The Trinity Observatory is a proposed UHE-neutrino detector with a core-energy range of 10^6 GeV - 10^10 GeV, bridging the observational gap between IceCube and UHE radio detectors. Trinity is a system of 60x5 degree^2 wide field-of-view air-shower imaging telescopes that detect Earth-skimming tau neutrinos from mountain tops. Trinity's primary science objectives are point-sources, the diffuse astrophysical neutrino flux, and the detection of cosmogenic neutrinos. Over a ten-year observation period, Trinity will detect about 60 diffuse UHE neutrinos if the astrophysical neutrino spectrum does not turn over. Trinity will provide critical measurements to study flavor physics and neutrino cross-sections at energies that are out of reach for accelerators. I present the project's status focusing on the Trinity Demonstrator, a one-square-meter air-shower imaging telescope on Frisco Peak, Utah, to demonstrate the technology and understand potential backgrounds. In addition, I discuss the discovery potential of diffuse and source UHE neutrinos with the Demonstrator, one Trinity telescope, and the completed system.

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SNO+: Current results and 0νββ prospects

Author: Ana Sofia Inacio[1]

[1] *University of Oxford*

Corresponding Author: ana.carpinteiroinacio@physics.ox.ac.uk

SNO+ is a large multipurpose experiment located in the SNOLAB underground laboratory in Sudbury, Canada. With an extensive physics programme focused on many neutrino physics topics and nucleon decay searches, the ultimate goal of SNO+ is the search for the neutrinoless double beta decay of ^{130}Te. After a commissioning phase with water as the target medium, whose data allowed measurements of solar neutrinos and the detection of reactor antineutrinos, SNO+ is now filled with 780 tonnes of liquid scintillator. The higher light yield of the scintillator enhances the physics capabilities of the experiment, and the physics program including reactor, geo and solar neutrinos is underway. The data is also being used to quantify backgrounds and understand the detector response in preparation for the neutrinoless double beta decay search, when the scintillator is loaded with tellurium at 0.5% by weight. This talk will highlight the recent results of the SNO+ experiment and discuss the prospects for the neutrinoless double beta decay searches.

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BINGO proposals for background reduction in $0\nu2\beta$ bolometric experiments

Author: Hawraa Khalife[1]

[1] *IRFU (CEA Paris-Saclay)*

Corresponding Author: hawraa.khalife@cea.fr

BINGO is a project dedicated to explore new methods for background reduction in experiments searching for $0\nu2\beta$ decay. It is based on bolometers, one of the most promising techniques to search for $0\nu2\beta$. CUORE and CUPID-Mo/0 are the main bolometric experiments that have shown the most relevant limiting factors on $0\nu2\beta$ sensitivity. Surface αs are the main source of background in CUORE, and this contribution has been mitigated in CUPID-Mo/0 using dual heat-light channels, i.e., a main scintillating absorber embedding the $0\nu2\beta$ isotope facing a light detector. In this case, the surface α rejection is achieved thanks to the lower α light output compared to β/γ. However, there are still other background components that limit the sensitivity of the experiments, such as pile-ups due to random coincidences of physical events, external γ background and β surface radioactivity. BINGO proposed technology aims at reducing the background index down to 10^{-5}counts/(keV kg

yr) in the region of interest, thus boosting the sensitivity on the effective Majorana neutrino mass. This can be achieved by: (i) having a revolutionary detector assembly with a reduction of the passive materials facing the detector; (ii) increasing the light detector sensitivity thanks to Neganov-Luke amplification; (iii) using a cryogenic active shield, based on BGO scintillators with bolometric light detector readout surrounding the experimental volume. In this talk we will describe the listed approaches in details and the most recent results of the prototype tests will be present as well.

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QUEST-DMC: detection of sub-GeV dark matter with nanowires in a superfluid He-3 calorimeter

Author: Paolo Franchini[1]

[1] *Royal Holloway University of London - Lancaster University*

Corresponding Author: p.franchini@lancaster.ac.uk

Several independent observations suggest that there is more mass in the Universe than has been directly observed. Dark matter is a hypothetical new form of matter that does not interact with the electromagnetic field and has a very weak interaction with ordinary baryonic matter. WIMPs (weakly interacting massive particles) are a dark matter candidate currently widely investigated in experiments, but most experiments are constrained to spin-independent interactions in the 10–100 GeV/c2 mass range.

QUEST-DMC (Quantum Enhanced Superfluid Technologies for Dark Matter and Cosmology) is a newly formed collaboration, between Lancaster, Oxford, Royal Holloway University of London, and Sussex Universities, supported through the Quantum Technologies for Fundamental Physics UK programme.

QUEST-DMC will use superfluid He-3 as a dark matter collision target, aiming to reach the world-leading sensitivity to spin-dependent interactions of 0.1-1 GeV/c2 mass dark matter candidates.

Here we discuss a simulation of the superfluid He-3 bolometer's energy sensitivity, and argue that recoil energy of <10 eV can be detected using nanomechanical resonators, controlling the dominant sources of background and using quantum sensors readouts as SQUIDs.

We report the recent development of dark matter bolometers based on these studies and the first results obtained from running the bolometers at the Lancaster micro-kelvin facilities, highlighting the future prospects in terms of spin dependent and spin independent sensitivity for this promising dark matter investigation.

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Latest results from the searches of ultra-high energy neutrinos at the Pierre Auger Observatory

Authors: Srijan Sehgal[1]; for the Pierre Auger Collaboration[None]

[1] *University of Wuppertal*

Corresponding Author: sehgal@uni-wuppertal.de

Besides detecting ultra-high-energy (UHE) cosmic rays, the Pierre Auger Observatory offers a remarkable exposure to neutrinos above 10^{17}eV. Since the beginning of data taking, the Observatory has been involved in setting up some of the most stringent upper limits to the neutrino flux in the

UHE range. During this time it has also been involved in various multi-messenger follow up searches of transient events.

This talk aims to give an overview of the ongoing work regarding the search for UHE neutrinos at the Pierre Auger Observatory. Updated upper limits to the diffuse flux of UHE neutrinos will be shown. Additionally, the latest results from UHE neutrino searches from binary black hole mergers will be presented. Furthermore, the capabilities of Pierre Auger Observatory in constraining Beyond Standard Model scenarios will be discussed.

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The MicroBooNE neutrino cross section program

Author: Elena Gramellini[1]

Co-author: Chris Higenberg

[1] *University of Manchester*

Corresponding Authors: chilgenb@umn.edu, elena.gramellini@manchester.ac.uk

The MicroBooNE liquid argon time projection chamber (LArTPC) experiment operated in the Fermilab Booster Neutrino and Neutrinos at the Main Injector beams from 2015-2021. Among the major physics goals of the experiment is a detailed investigation of neutrino-nucleus interactions. MicroBooNE currently possesses the world's largest neutrino-argon scattering data set, and more than 30 ongoing analyses are studying a wide variety of interaction modes. This talk provides an overview of MicroBooNE's neutrino cross-section physics program, including investigations of exclusive pion final states and rare processes, novel cross section extraction methods, and measurements with both muon and electron neutrinos from the BNB and NuMI beamlines.

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

Author: Giuseppe Matteucci[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: giuseppe.matteucci@na.infn.it

DarkSide-20k (DS-20k) will probe the dark matter WIMP hypothesis by looking for WIMP-nucleon elastic scattering with a dual-phase time projection chamber (TPC) 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 (of about 0.5 keV for nuclear recoils) of the detector will allow it to observe neutrinos from core-collapse supernovae via the coherent elastic neutrino-nucleus scattering (CEvNS). In this way, DarkSide-20k will produce a flavour-blind measurement of the unoscillated neutrino flux from a SN 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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Calibration of the KM3NeT detector

Author: Giorgio Maria Riccobene[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: riccobene@lns.infn.it

As of today, The KM3NeT detector comprises today more than 540 Optical Modules (approximatively 17000 31"photomultiplier tubes, PMTs) deployed in the abysses of the Mediterranean Sea. KM3NeT is designed to search for astrophysical high energy neutrino signals through detection of Cherenkov photons emitted along the paths of the charged particles produced in high energy neutrino interactions.
The equalisation of gain and time synchronisation of the PMT array and monitoring of the positions of the optical modules are the main tasks to be accomplished by the detector calibration.
In this talk the present the calibration methods, principles, tools and results at state of the art. In details we will discuss: the White Rabbit-based architecture for time calibration and recent transition from broadcast to point-to-point implementation; the custom acoustic positioning system and recent results from laser beacon and newly designed calibration lines equipped with oceanographic probes

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The photo-detection system and double calorimetry in DUNE

Author: Giulia Brunetti[1]

[1] *UniMIB - INFN-MIB*

Corresponding Author: giulia.brunetti@cern.ch

The Deep Underground Neutrino Experiment (DUNE), the next generation long-baseline neutrino experiment, comprises a suite of Near Detectors and four Far Detectors based on the Liquid Argon TPC technology which is enhanced by a powerful Photon Detection System (PDS) that records the scintillation light emitted in Argon. Besides providing the timing information for an event, which is necessary for reconstructing the drift coordinate of ionizing particle tracks, photon detectors can be effectively used for other purposes including calorimetric energy estimation.
The two observables generated from energy deposition by particles in liquid Argon are charge and light. Therefore, a calorimetric measurement to determine the energy of neutrino beam events can be performed by exploiting the complementarity of the two.
The visible energy can also be estimated by using charge information alone, however, only electrons escaping recombination and reaching the wire planes can be used so corrections must be applied for this loss. As charge and light are anti-correlated and their sum is directly proportional to the total energy deposited the advantage of using both and is that the correction for recombination is no more necessary. When using the light information we profit as well from a detailed end-to-end simulation of our photodetection system.
I will present an overview of DUNE PDS and the results obtained for calorimetric measurements in the DUNE horizontal-drift Far Detector by combining charge and light in pure liquid Argon.

Neutrino Telescopes / 20

Overview of ANTARES, the first Mediterranean Sea telescope

Author: Chiara Poirè[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: cpoire@unisa.it

The ANTARES neutrino telescope was located in the Mediterranean Sea, not far from Toulon (France). It was operational from 2007 to 2022, before being dismantled. Its instrumented volumeof 0.01 km^3 equipped with photomultipliers made it possible to detect neutrinos with energy from some GeV to PeV. The location of ANTARES allows for an advantageous view of the Southern sky in the search of Galactic neutrino sources. ANTARES has searched for a diffuse flux or individual sources of astrophysical neutrinos produced in cosmic-ray interactions, and also for the presence of dark matter in massive celestial objects from the annihilation or decay of dark matter into neutrinos. Furthermore, ANTARES has been involved in a multi-messenger program which included searching for neutrinos in coincidence with promising transient astrophysical events, as well as triggering electromagnetic follow-up observations of interesting neutrino candidates by sending alert messages to the astronomical community. ANTARES data allowed to study other topics, such as the search for relic massive magnetic monopoles and nuclearites, as well as the study of atmospheric neutrinos and neutrino oscillations. In this talk, the latest and principal ANTARES results, which cover the fields mentioned above, will be presented.

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Imaging Neutrino interactions with Liquid Argon scintillation light at the DUNE Near Detector Complex

Author: Valentina Cicero[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: cicero@bo.infn.it

The Deep Underground Neutrino Experiment (DUNE) has among its primary goals the determination of the neutrino mass ordering and the possible CP-violating phase in the neutrino mixing matrix.
The System for On-Axis Neutrino Detection (SAND) at the DUNE Near Detector complex includes a novel liquid Argon detector - GRAIN - designed to image neutrino interactions using scintillation light produced in AR by charged particles, eliminating the dependence on slow charge collection of LAr TPCs. An innovative optical readout system based on SiPM matrices is being developed.
In this talk, the current design of GRAIN, its physics goals, the development of its optical elements and image reconstruction algorithms, and preliminary results from a cryogenic demonstrator will be presented.
The challenges of this novel approach will also be discussed, including limited photon detector and optical element performance, and the cryogenic photosensor readout.

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The race for the Neutrino Mass Ordering

Author: Stephen Parke[1]

[1] *Fermilab*

Corresponding Author: parke@fnal.gov

On Friday, 5/12, I gave the Wine and Cheese seminar at Fermilab titled "The race to the Neutrino Mass Ordering".
The slides are here https://indico.fnal.gov/event/59268/

In this talk I argued that when JUNO's measurement of Delta m^2_atm (31 or 32 or ee) is 1\% or better (which will happen very quickly)
then when combined with Delta m^2_atm from T2K and NOvA disappearance will give us a Delta

Chisq between the two mass orderings, IO and NO, will exceed 9, in a combined fit with JUNO, T2K, NOvA and SuperK. So by Neutrino 2026 (or maybe Neutel 2025) we should know the mass ordering at better than 3 sigma. A hint of this can be seen in the 2022 NuFit plot (bottom right panel). http://www.nu-fit.org/sites/default/files/v52.fig-chisq-dma.pdf Replacing Daya Bay which is a 2.4% measurement with a new 1% JUNO measurement will greatly effect this plot.

The comparison of nu_e disappearance to nu_mu disappearance as a way to determine the mass ordering was first discussed in our 2005 paper https://arxiv.org/abs/hep-ph/0503283 This paper also was the first to defined Delta m^2_{ee}. We will update this in a paper in the next month or so and certainly before Neutel 2023.

If there is interest I could give a version of this talk explaining this development as plenary talk at Neutel 2023. For now I would keep the same title "The race to the Neutrino Mass Ordering".

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Low-energy recoil with the Recoil Directionality (ReD) Experiment

Author: Simone Sanfilippo[1]

Co-authors: Giuliana Fiorillo [2]; Luciano Pandola [2]; Marco Rescigno [2]

[1] *Istituto Nazionale di Fisica Nucleare - LNS*

[2] *Istituto Nazionale di Fisica Nucleare*

The Recoil Directionality project (ReD) within the Global Argon Dark Matter Collaboration aims to characterize light and charge response of a liquid argon (LAr) dual-phase Time Projection Chamber (TPC) to neutron-induced nuclear recoils. The ReD project is now focusing on the detailed study of the response of the LAr TPC to very low-energy nuclear recoils (a few keV). The charge yield from nuclear recoils is a critical parameter for searches of dark matter in the form of low-mass WIMPs: these searches are performed by using the S2-only approach, based on the measurement of the ionization signal alone. Furthermore, the ReD TPC uses all the innovative features of the design of the DarkSide-20k experiment: in particular the optoelectronic readout based on SiPMs and the cryogenic electronics. It is thus a valuable test bench of the technology which is being developed for DarkSide-20k and for the future project Argo. The TPC is irradiated by neutrons produced by an intense Cf252 fission source to produce 40Ar recoils in the energy range of interest. The energy of the nuclear recoils produced within the TPC by (n,n') scattering is determined by detecting the scattered neutrons within a dedicated neutron spectrometer made of 18 1-inch plastic scintillators deployed at about 15°. The kinetic energy of neutrons interacting in the TPC is evaluated event-by-event by measuring the time of flight between a BaF2 detector located close to the Cf252 source, which tags the primary fission event by detecting the accompanying radiation, and the neutron spectrometer. Data with the Cf252 source are being taken during the Winter of 2023 at the INFN Sezione di Catania. The experiment will be complemented by calibrations with low-energy internal sources of Kr83m and Ar37 diffused inside the TPC.In this contribution, we describe the experimental setup and the preliminary results from data analysis.

Flash Talks / 24

Noise modeling for the multi-PMT digital optical modules of the IceCube Upgrade

Author: Nora Feigl[1]

[1] *Humboldt University of Berlin*

Corresponding Author: nora.feigl@desy.de

The IceCube Upgrade, to be installed in 2026, is a low-energy extension of the DeepCore detector part of the IceCube in-ice Cherenkov neutrino telescope at the South Pole. The Upgrade will improve the detection of neutrino interactions in the GeV range by deploying nearly 700 new multi-PMT digital optical modules in a high-density configuration. This allows for more precise measurements of fundamental physics phenomena such as neutrino oscillations and searches for beyond the Standard Model physics. In this talk, I will discuss an important background to consider for these low-level signals: the intrinsic noise caused by radioactive decays in the optical module's glass components. This background is modeled using GEANT4, which accounts accurately for correlated hits on short time scales across PMTs within a single module and can be calibrated against measurements of the module testing prior deployment. Also under investigation is the approach to model the noise with a neural network.

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Neutrino Mass Ordering using Atmospheric Neutrino Oscillations with IceCube DeepCore

Author: Maria Prado Rodriguez[1]

[1] *University of Wisconsin-Madison*

Corresponding Author: mvprado@wisc.edu

Neutrino Mass Ordering (NMO) studies explore the unresolved fundamental question of whether the neutrino masses follow a normal ordering (m3>m2>m1) or an inverted ordering (m2>m1>m3). IceCube is an ice-Cherenkov neutrino detector deployed about 1.5 kilometers below the surface of the South Pole. Using DeepCore, a more densely instrumented volume of ice near the bottom of the detector, we study the ordering by a measurement of the oscillation patterns of a 9.28-year sample of atmospheric neutrinos. The main goals of this work include analyzing the NMO at higher neutrino energies relative to Super-Kamiokande and long-baseline experiments as well as observing neutrino-Earth matter effects, both of which will play a distinctive role in NMO global fit studies. Another goal includes preparing for a measurement of the ordering using the superior IceCube Upgrade instrumentation, a fully-funded extension of DeepCore that is estimated to be deployed in the 2025-2026 Antarctic summer.

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Supernova detection and triggering with the DUNE Far Detector

Author: Pablo Barham Alzás[1]

[1] *CERN*

Corresponding Author: pablo.barham@cern.ch

Core-Collapse Supernovae are violent astrophysical events that are an abundant source of neutrinos of all flavours. The study of neutrinos from this source can give us insights into the nature of the core-collapse mechanism and into neutrino physic topics.

The Deep Underground Neutrino Experiment (DUNE) is a future multi-purpose neutrino experiment under construction in the US. One of it's main objectives is the detection and study of neutrinos from astrophysical sources, including the next galactic Core-Collapse Supernovae. DUNE will be especially sensitive to the ν_e component of the neutrino flux among present and future neutrino experiments.

A key component to reach this objective is an efficient trigger system. In this work we present the supernova trigger algorithm designed for the Photon Detection System (PDS) of the DUNE Far Detector, and the resulting sensitivity efficiency.

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Flavor Identification for Atmospheric Neutrinos in JUNO

Authors: Rosmarie Wirth[None]; Zhen Liu[1]

[1] *Institute of High Energy Physics*

Corresponding Authors: rosmarie.wirth@desy.de, liuzhen@ihep.ac.cn

The Jiangmen Underground Neutrino Observatory (JUNO) aims to determine neutrino mass ordering with a 20-kton liquid scintillator detector. To enhance its sensitivity, JUNO will combine the measurements of low-energy reactor antineutrinos and atmospheric neutrinos in the GeV region. The sensitivity from the atmospheric neutrino measurement relies on the performance of neutrino flavor identification, which is a very challenging task in a liquid scintillator detector.
This flash talk will present a machine learning approach for the high-efficiency and high-purity flavor identification for atmospheric neutrinos in large unsegmented liquid scintillator detectors like JUNO. Our approach utilizes not only the topological properties of atmospheric neutrinos characterized by PMT waveform features, but also event-level information such as those from captured neutrons. Preliminary results show that this approach has great potential for utilizing atmospheric neutrinos to unearth JUNO's capabilities.

Data Science and Detector R&D / 28

Overview of the 2 x 2 Demonstrator: A Pixel-Based LArTPC Prototype for the DUNE Near Detector

Author: Richard Diurba[None]

Corresponding Author: rdiurba@fnal.gov

The Deep Underground Neutrino Experiment (DUNE) is a future long-baseline neutrino oscillation experiment featuring a far detector site at the Sanford Underground Research facility with 70 kT of liquid argon and a near detector site with multiple detector technologies used at the Fermi National Accelerator Laboratory (Fermilab). The near detector (ND) site includes a liquid argon detector (ND-LAr) that will use 35 modular detectors for a total of 70 time projection chambers that are optically isolated. The proposed 3 m x 7m x 5 m detector will use the pixel-based readout and optical separation to identify individual neutrino interactions in the high-intensity environment that could contain over 50 neutrino interactions per beam spill. The pixel-based readout gives it the unique advantage of fully native three-dimensional reconstruction, a feature not possible with wire readout arrays. DUNE has been building a prototype of ND-LAr with four modular prototypes in a 2 by 2 array, named the 2x2 Demonstrator. Construction has been ongoing since 2021 and coincided with the commissioning of the modules using cosmic-ray data taken at the University of Bern. All four completed modules are being installed in the NuMI neutrino beam at Fermilab in 2023. Upon the start of neutrino beam data-taking, the 2x2 Demonstrator will be the first neutrino experiment to use modular, pixel-based liquid argon time projection chambers. The talk will cover the detector concept and design, summarize the commissioning data-taking period, and discuss the neutrino physics goals of the 2x2 Demonstrator.

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First demonstration of O(ns) timing resolution in the MicroBooNE liquid argon time projection chamber

Author: Dante Totani[1]

[1] *University of California, Santa Barbara*

Corresponding Author: dtotani@ucsb.edu

MicroBooNE is a neutrino experiment located in the Booster Neutrino Beamline (BNB) at Fermilab, which collected data from 2015 to 2021. MicroBooNE's liquid argon time projection chamber (LArTPC) is accompanied by a photon detection system consisting of 32 photomultiplier tubes used to measure the argon scintillation light and determine the timing of neutrino interactions. Analysis techniques combining light signals and reconstructed tracks are applied to achieve a neutrino interaction time resolution of O(1ns). The result obtained allows MicroBooNE to access the nanosecond beam structure of the BNB for the first time. The timing resolution achieved will enable significant enhancement of cosmic background rejection for all neutrino analyses. Furthermore, the ns timing resolution opens new avenues to search for long-lived-particles such as heavy neutral leptons in MicroBooNE, as well as in future large LArTPC experiments, namely the SBN program and DUNE.

Neutrino Properties / 30

First Results of the LEGEND-200 experiment: Searching for Neutrinoless Double Beta Decay with High-Purity Germanium Detectors

Author: Valerio D'Andrea[1]

[1] *INFN Roma Tre*

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

The LEGEND experiment is designed to search for the neutrinoless double beta (0νββ) decay of the germanium isotope Ge-76. This decay, if observed, would establish the Majorana nature of neutrinos and reveal lepton number non-conservation. The first stage of the experiment, LEGEND-200, has recently completed its commissioning phase and transitioned to physics data taking in March 2023. LEGEND-200, situated within the underground facility of INFN Laboratori Nazionali del Gran Sasso in Italy, can accommodate approximately 200 kg of enriched high-purity germanium detectors. The experiment offers a discovery sensitivity for the half-life of the 0νββ decay surpassing 10^27 years within five years of data taking. The germanium detectors are immersed in an instrumented liquid argon (LAr) cryostat that shields against gamma radiation and operates as an active veto system. Additionally, the cryostat is surrounded by a water tank, providing an extra layer of neutron shielding and muon veto capabilities. In my talk, I will present the initial results of the LEGEND-200 experiment. I will discuss the performance of the germanium detectors and the LAr instrumentation and about the effectiveness of the techniques for background mitigation, such as the LAr veto and the pulse shape discrimination. I will show the actual background levels in the region of interest for searching for the 0νββ decay during the first months of data taking. Finally, I will also describe plans of ongoing preparations for the second stage of the experiment, LEGEND-1000, which aims to scale the detector mass up to 1 tonne. This ambitious endeavor is driven by the objective to increase the experimental sensitivity to discover the 0νββ decay at the level of 10^28 years.

Data Science and Detector R&D / 31

Multi-Calorimetry in Light-based Neutrino Detectors

Author: Yang HAN[1]

[1] *Sun Yat-sen University*

Corresponding Author: hany88@mail.sysu.edu.cn

Neutrino detectors are amongst the largest ever built photonics systems, where the neutrino detection is inexorably linked to the challenging detection of scarce photons. The tremendous progresses in neutrino physics over past several decades are inseparable from the evolution of the detector photonics interfaces to yield ever higher precision and richer detection information. The measurement of the energy of neutrinos, referred to as calorimetry, is required today to be controlled to the per-mille level precision, thus leading to further innovation in specialized photonics. In this talk, a novel design, with the publication to be released soon, is presented that detectors can be endowed with multiple photonics interfaces for simultaneous multiple light detection to yield high-precision calorimetry. This multi-calorimetry approach opens the novel notion of dual calorimetry detectors as an evolution from the single calorimetry setups used for most experiments so far. The dual calorimetry design exploits unique response synergies, including correlations and cancellations, to yield the unprecedented mitigation of today's dominant response systematic effects. The dual calorimetry design has been adopted by JUNO experiment and could shed light on the design of future neutrino detectors.

Neutrino Telescopes / 32

The Radio Neutrino Observatory in Greenland: Design and Construction

Author: Delia Tosi[1]

[1] *UW Madison*

Corresponding Author: delia.tosi@icecube.wisc.edu

The Radio Neutrino Observatory - Greenland (RNO-G) is currently under construction in proximity of Summit, 3216 m above sea level.
The observatory consists of an array of independent stations, each including both a deep component (with fifteen vertically and horizontally polarized antennas in three 100m-deep boreholes, configured partially as a phased array trigger) and a shallow component (with nine Log-Periodic Dipole Antennas just below the surface, for cosmic ray identification and reconstruction). All the antennas are readout by a central Data Acquisition unit that has been designed and developed to be low-noise and low power in the 80-750MHz bandwidth.
Each station is autonomous and relies on a renewable-energy power system and built-in wireless communications to transfer data to Summit station. Currently 7 of 35 planned stations have been installed and are in operation. This talk will review the instrument design, status, and initial performance of these stations and plans to complete the construction of the full RNO-G array.

Data Science and Detector R&D / 33

Low Energy Neutrino Physics with THEIA and EOS

Corresponding Author: hans.steiger@tum.de

Future ktonne-scale, scintillation-based neutrino detectors, such as THEIA, plan to exploit new and yet to be developed technologies to simultaneously measure Cherenkov and scintillation signals in order to provide a rich and broad physics program. These hybrid detectors will be based on fast timing photodetectors, novel target materials, such as water-based liquid scintillator (WbLS), and spectral sorting. Besides an overview on THEIA's program for low energy astroparticle and particle physics this talk also gives an overview on a currently realized demonstrator experiment, called EOS. This novel detector with an approximately 4-tonne target fiducial volume is under construction at the UC Berkeley and LBNL (Lawrence Berkeley National Laboratory). The detector will provide

a test-bed for these emerging technologies required for hybrid Cherenkov/Scintillation detectors. Furthermore, EOS will deploy calibration sources to verify the optical models of WbLS and other liquid scintillators with slow light emission, to enable an extrapolation to ktonne-scale detectors. This input will support the development of advanced techniques for reconstructing event energy, position, and direction in hybrid detectors significantly. After achieving these goals, EOS can be moved near a nuclear reactor or in a particle test-beam to demonstrate neutrino event reconstruction or detailed event characterization within these novel detectors.

Flash Talks / 34

Vertex and energy reconstruction in JUNO

Author: Wei Jiang[1]

Co-author: Guihong Huang [2]

[1] *IHEP*

[2] *Wuyi University*

Corresponding Author: jiangw@ihep.ac.cn

JUNO will be the world's largest liquid scintillator detector for studying neutrino physics and exploring new physics. The primary physics goal of JUNO is to measure neutrino mass ordering (NMO) with reactor neutrinos, which requires a high energy precision. The goal and challenge of the event reconstruction is to reach the accuracy limit of sophisticate detectors. This talk introduces the reconstruction methods for positrons in JUNO. The principles and preliminary performances of the likelihood based data-driven vertex and energy simultaneously reconstruction method will be presented.

Data Science and Detector R&D / 35

LArRI: a new setup for Liquid Argon Refractive index measurement

Author: Bianca Bottino[1]

Co-authors: Alice Campani [1]; Federico Ferraro [1]; Ruggero Caravita ; Simone Copello [2]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *Universita' di Genova, INFN*

Corresponding Author: bianca.bottino@ge.infn.it

Liquid argon, widely used as the active target in neutrino and dark matter experiments, is a scintillator with a light yield of approximately 40 photons/keV. The scintillation spectrum is centered at 128 nm, and the attenuation length is of the order of meters, depending on the purity. The addition of small amounts of xenon (approximately 10 ppb) allows for shifting the scintillation peak to 178 nm, without compromising the light yield. The longer wavelength simplifies the development of imaging systems by allowing the use of dichroic filters or lenses.

A precise knowledge of its optical properties in the VUV range can be exploited to improve the performances of liquid argon-based experiments, especially when the involved mass exceeds one ton. Moreover, the refractive index becomes a crucial parameter for the development of imaging systems.

LArRI (Liquid Argon Refractive Index) aims to directly measure the refractive index of liquid Argon (as well as other cryogenic liquids) in the VUV spectrum, using an interferometric technique. In particular, the refractive index is obtained by comparing two interference patterns, created in vacuum and in liquid, acquired with cryogenic silicon photomultipliers.
In this talk we present the first results obtained, both in liquid nitrogen and in liquid argon, using a mercury lamp emitting at 254 nm and 184 nm.

Neutrino Telescopes / 36

CNO solar neutrino detection with Borexino: directionality measurement and spectral analysis

Author: Luca Pelicci[1]

[1] *Forschungszentrum Jülich and Aachen University*

Corresponding Author: lucapelicci@gmail.com

Borexino was a large liquid scintillator experiment designed for real-time detection of low-energy solar neutrinos, located at the underground Laboratori Nazionali del Gran Sasso in Italy. During more than ten years of data taking, it has measured all the neutrino fluxes produced in the proton-proton chain, i.e. the main fusion process accounting for 99 % of the energy production of the Sun. Moreover, the last stages of Borexino data taking were devoted to the first observation of solar neutrinos emitted from the Carbon-Nitrogen-Oxygen (CNO) fusion cycle, in which the reactions producing neutrinos are catalyzed by carbon (C), nitrogen (N), and oxygen (O). To disentangle signal and background rates, a multivariate analysis has been performed by simultaneously fitting energy and radial distributions of the events. The key difficulty of this measurement is represented by the 210Bi contaminating the liquid scintillator, which is constrained in the multivariate fit by independently determining an upper limit on its contamination.
More recently, Borexino has developed a new technique, called "Correlated and Integrated Directionality" (CID), to exploit the fast directional Cherenkov information for sub-MeV solar measurements. This method exploits the correlation between the known position of the Sun and the direction of reconstructed photons. In particular, Cherenkov hits originated by solar neutrino interactions exhibit a clear correlation with the position of the Sun, while isotropic scintillation and background events don't. Borexino has demonstrated the validity of this new method by providing the first directional measurement of sub-MeV 7Be neutrinos. In this talk, we present the first observation of the CNO solar neutrinos with CID and thus, without any prior knowledge on the 210Bi contamination using all Borexino data. Furthermore, this result is combined with an improved two-dimensional multivariate analysis of the Phase III dataset, leading to an unprecedented level of precision for CNO neutrino measurement.

Neutrino Telescopes / 37

JUNO's sensitivity to 7Be, pep and CNO solar neutrinos

Author: Apeksha Singhal[1]

[1] *Forschungszentrum Jülich and RWTH Aachen University*

Corresponding Author: a.singhal@fz-juelich.de

The multipurpose JUNO Experiment located in China, whose central detector uses 20 kt liquid scintillator, is on track to completion of construction in 2023. Its primary goal is to determine the Neutrino Mass Ordering by leveraging its large target mass and excellent energy resolution of 3% at 1 MeV. The unique properties of JUNO position it to have a large potential for real-time solar neutrino measurements. A sensitivity study is performed considering all potential sources of backgrounds at various radiopurity levels, along with a full simulation of the detector response using reconstructed

variables. Our results indicate that in most radiopurity level scenarios, JUNO will be able to improve the current best measurements of ^{7}Be, *pep* and CNO solar neutrino fluxes. Furthermore, JUNO has the potential to measure individually for the first time the rate of the two main components of the CNO neutrino flux, namely the ^{13}N and ^{16}O solar neutrinos. This talk will summarize the strategy used for the estimation of the JUNO sensitivity to ^{7}Be, *pep*, and CNO solar neutrinos above the 0.45 MeV threshold and share the final results.

Neutrino Properties / 38

Hadron Production Measurements for Neutrino Experiments at NA61/SHINE

Author: Yoshikazu Nagai[1]

[1] *ELTE*

Corresponding Author: yoshikazu.nagai@cern.ch

In current measurements of neutrino properties with accelerator-based neutrino experiments, neutrino flux uncertainties represent a leading systematic uncertainty. Neutrino beams are created from the decays of hadrons produced in hadron-nucleus interactions. Primary and secondary hadron production processes are the leading source of the flux uncertainty. To constrain the neutrino flux uncertainty arising from hadron production, external hadron production data are crucial. The neutrino program of the NA61/SHINE experiment at CERN's Super Proton Synchrotron conducts a series of dedicated measurements for this purpose.

In this talk, we will first present recent hadron production measurements used for the precise determination of neutrino flux needed by T2K and the Fermilab long-baseline neutrino experiments. We will then review the recent data collection status with the upgraded NA61/SHINE facility. Lastly, we will discuss the prospect for future measurements including the possibility of a low-energy beamline to extend the physics program for accelerator-based and non-accelerator neutrino experiments.

Neutrino Properties / 39

Probing New Physics Beyond the Neutrinoless Double-Beta Decay of Ge-76

Author: Sofia Calgaro[1]

[1] *University of Padova & INFN Padova*

Corresponding Author: sofia.calgaro@studenti.unipd.it

The GERmanium Detector Array (GERDA) experiment at the Laboratori Nazionali del Gran Sasso (LNGS, Italy) searched for the lepton-number-violating neutrinoless double-beta ($0\nu\beta\beta$) decay of ^{76}Ge. The potential discovery of such phenomenon would have significant implications in cosmology and particle physics, helping unrevealing the Majorana nature of neutrinos.

The main feature of the GERDA experimental design consisted in operating an array of bare germanium diodes enriched in ^{76}Ge in an active liquid argon shield. Started in December 2015, Phase II physics run reached an unprecedentedly low background index of 5.2×10^{-4} counts/(keV kg yr) in the signal region, collecting an exposure of 103.7 kg yr while being in a background-free regime. When combined with the result of Phase I, no signal was observed after 127.2 kg yr of total exposure. A lower bound on the half-life of $0\nu\beta\beta$ decay in ^{76}Ge was set at $T_{1/2} > 1.8 \times 10^{26}$ yr (90% C.L.), which coincides with the median expectation under the no signal hypothesis.

Additionally, the ultra-low background environment of GERDA motivated the search for other Beyond the Standard Model (BSM) processes. BSM searches included probing the emission of light exotic fermions or Majorons, Lorentz violation effects, bosonic keV-scale dark matter interactions, and baryon number violating single- and multi-nucleon decays.

This contribution will review the GERDA experiment design employed to reach the final $0\nu\beta\beta$ result, together with the rich program of BSM physics searches beyond the $0\nu\beta\beta$ decay.

Neutrino Properties / 40

Atmospheric neutrino oscillations at JUNO

Author: Gaosong Li[1]

[1] *Institute of High Energy Physics, Chinese Academy of Sciences, China*

Corresponding Author: ligs@ihep.ac.cn

The Jiangmen Underground Neutrino Observatory (JUNO) will complete the detector construction and start to take data in 2024. Its primary goal is to determine the neutrino mass ordering (NMO) using reactor neutrinos with an unprecedented 20 kton liquid scintillator (LS) detector. Around ten atmospheric neutrino interactions are expected everyday in the JUNO detector and they can provide additional sensitivity to NMO. Reconstruction of atmospheric neutrinos in LS is the foundation for the oscillation analysis. The collaboration has made use of popular neutrino interaction generators to model neutrino-nuclei interactions in LS. Advanced machine learning techniques have been utilized to reconstruct the atmospheric neutrino directionality and energy, using the rich information embedded in the large number of photo-sensors in the JUNO detector. Neutrino flavor identification performance can be enhanced by the excellent neutron tagging capability in LS detectors. In this talk, the latest developments on all aspects of the atmospheric neutrino oscillation analysis and the physics potential to NMO sensitivity will be presented.

Flash Talks / 41

Reconstruction of Atmospheric Neutrino's Directionality and Energy in JUNO

Authors: Xiaohan Tan[1]; Zekun Yang[1]

[1] *Shandong University*

Corresponding Author: zkyang@mail.sdu.edu.cn

The Jiangmen Underground Neutrino Observatory (JUNO) is a next-generation neutrino experiment currently under construction in southern China. Its primary objective is to determine the neutrino mass ordering (NMO). While reactor neutrinos are the main source of sensitivity to NMO at JUNO, atmospheric neutrino oscillations can provide independent sensitivity, and enhance its overall sensitivity in the combined analysis. However, accurately reconstructing atmospheric neutrinos in such a large liquid scintillator detector presents a significant challenge with conventional methods. In this flash talk, I present a novel method of reconstructing atmospheric neutrinos in JUNO and it is applicable to other liquid scintillator detectors. This method uses machine learning techniques to reconstruct multiple quantities like atmospheric neutrinos'directionality and energy, based on features extracted from waveforms reflecting the relationship between PMT hit charge and time. Performances using this method with JUNO simulation are reported.

Data Science and Detector R&D / 42

Towards the implementation of the ENUBET neutrino cross section experiment at CERN

Co-author: Fabio Pupilli [1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: mcelwee@lp2ib.in2p3.fr

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 $\sim 6\times10^5$ 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.

Neutrino Telescopes / 43

Neutrino flux observation of the next galactic core-collapse supernova in the COSINUS dark matter detector

Author: Matthew Stukel[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: matthew.stukel@gssi.it

The COSINUS (Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches) is a NaI based dark matter search that will perform a model-independent cross-check of the long-standing DAMA/LIBRA result. The experiment is currently under construction at the Laboratori Nazionali del Gran Sasso, Italy and will use NaI crystals operated as scintillating calorimeters. These detectors will be placed at the centre of a 7x7 m cylindrical water tank (approx. 268 tonnes), which acts as a passive shield against ambient and cosmogenic backgrounds. Additionally, the water tank will be instrumented with 28 photomultipliers arranged around the tank. This allows for active detection of Cherenkov radiation induced by impinging particles. In this presentation we explore the detection capabilities and sensitivity of the COSINUS experimental setup to the neutrino flux from core-collapse supernovae. The neutrino detection channels and potential available for Na-23 and I-127 isotopes present in the scintillating crystals will also be discussed.

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Investigating Neutrino Oscillations with Reactor Antineutrinos in JUNO

Author: Andrea Serafini[1]

Co-author: JUNO Collaboration

[1] *University of Padua & Istituto Nazionale di Fisica Nucleare*

Corresponding Author: andrea.serafini@infn.it

The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kton multi purpose underground liquid scintillator detector currently under construction in the Guangdong Province of South China and scheduled for completion in 2023. By featuring a 78% photon sensor coverage achieved via a primary calorimetry system consisting of 17,612 20 inch PMTs and an additional calorimetry system of 25,600 3 inch PMTs, JUNO is expected to enable an unprecedented 3% energy resolution at 1 MeV, aiming at the determination of the neutrino mass ordering.

The main detector is located at a baseline of about 52.5 km from eight nuclear reactors, a distance that will enable to resolve for the first time the interference pattern between the solar and atmospheric oscillation modes. In this respect, thanks to its unprecedented size and energy resolution, JUNO will enable the simultaneous observation of the Δm^2_{21}, Δm^2_{31}, $\sin^2\theta_{12}$, and $\sin^2\theta_{13}$ oscillation parameters and is expected to determine the first three to a world leading precision better than 0.5% within six years of data collection. The new precision will represent a tenfold improvement over the existing limits for these three parameters.

In this talk I will present the role of JUNO in a new era of precision in the neutrino sector which will put to the test the flavor mixing neutrino framework and pave a way to more precise searches for physics beyond the Standard Model.

Flash Talks / 45

Sensitivity study of invisible decay modes of neutrons with JUNO

Author: Yuxiang Hu[1]

Co-authors: Gaosong Li [2]; Liangjian Wen [3]

[1] *IHEP*

[2] *Institute of High Energy Physics, Chinese Academy of Sciences, China*

[3] *Institute of High Energy Physics*

Corresponding Author: huyuxiang@ihep.ac.cn

As an underground multi-purpose neutrino detector with 20 kton liquid scintillator, Jiangmen Underground Neutrino Observatory (JUNO) currently under construction in southern China has great potential to detect the nucleon decay, which now remains as a key signature of Grand Unified Theories. The nucleon decay provides a direct observation of baryon number violation process that can contribute to understand the matter-antimatter asymmetry of the Universe. Although it has been the focus of many experiments over the past several decades, no experimental evidence to date for nucleon decay. Since the JUNO LS target consists of about 88% ^{12}C and 12% ^{1}H, the invisible decays of neutrons from the s-shell in ^{12}C will result in a highly excited nucleus. It has been found that some de-excitation modes of the excited nucleus can produce time- and space-correlated triple coincidence feature in LS detector. This poster reports the JUNO sensitivity to search for invisible decay modes of the neutron. Based on MC simulations, we made comprehensive estimates for all possible backgrounds, including accidental triple coincidences from inverse beta decays, natural radioactivity and cosmogenic isotopes. The correlated backgrounds from atmospheric neutrino neutral current events have also been evaluated. We use the Pulse Shape Discrimination (PSD) and Multi-Variate-Analysis (MVA) techniques to suppress backgrounds further. A preliminary sensitivity result of neutron invisible decays at JUNO will be presented.

Neutrino Telescopes / 46

Combined KM3NeT-ARCA and ANTARES searches for point-like neutrino emission

Authors: Aart Heijboer[1]; BARBARA CAIFFI[2]; Giulia Illuminati[2]; Matteo Sanguineti[2]; Rasa Muller[1]; Sandra Zavatarelli[2]; Thijs van Eeden[1]; Vladimir Kulikovskiy[2]

[1] *Nikhef, National Institute for Subatomic Physics*

[2] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: matteo.sanguineti@ge.infn.it

Neutrino telescopes are the instruments for the detection of high energy cosmic neutrinos. The ANTARES detector operated offshore Toulon (France) for 16 years until 2022, while KM3NeT-ARCA infrastructure is under construction in Southern Italy.
The ANTARES telescope was composed of 12 strings, each equipped with 75 optical modules. Each optical module contained one 10"photomultiplier tube to detect the faint light produced by neutrinos interacting in the surrounding water. Similarly, the KM3NeT-ARCA detector will count 230 strings of 18 optical modules, each containing 31 3"photomultipliers.
In recent years, there has been a growing interest in studying potential sources of neutrinos, as these sources can provide valuable information about the most extreme phenomena in the Universe. This contribution will showcase the analysis of the combined data sample from ANTARES and the first two years of KM3NeT-ARCA to detect high energy cosmic neutrinos from point-like sources.

Flash Talks / 47

Creating a high purity astrophysical neutrino sample below 100 TeV using IceCube starting track events

Author: Sarah Louise Mancina[1]

Co-author: Manuel Silva [2]

[1] *Univeritá degli Studi di Padova*

[2] *University of Wisconsin-Madison*

Corresponding Author: mancina@pd.infn.it

It has been common practice to select for muons that start inside a neutrino detector in order to reject atmospheric backgrounds in lower energy neutrino experiments. However, IceCube was designed to use the Earth as an atmospheric muon veto by selecting for events which come from the northern equatorial sky. Using the Earth as a muon shield allows us to increase the fiducial volume by placing the strings holding the IceCube optical modules approximately 125 m apart. This sparse instrumentation makes distinguishing starting muon track events from the multitude of incoming atmospheric muons in the southern sky difficult. However, the starting track morphology has the advantage that atmospheric neutrinos from the southern sky with energies above 100 GeV have an increasing probability of being chaperoned into the detector by muons from the same air shower. Using our novel technique to select for muon tracks that start inside the detector, we can reject both the atmospheric muons and atmospheric neutrinos by the light from their muon chaperones. This atmospheric neutrino veto creates a sample of starting muon neutrino events with a high astrophysical purity below 100 TeV in the southern sky, which is not possible in the northern sky. We will provide a brief summary of the techniques used to generate this starting track event selection within IceCube. We will also cover the results from the diffuse astrophysical neutrino flux and neutrino source searches using this selection, as well as, future physics prospects with starting tracks in IceCube.

Flash Talks / 48

Searching for Gamma-Ray Counterparts of IceCube Neutrino Events in the AGILE Public Archive

Authors: Elena Gasparri[None]; Rosa Poggiani[1]; Carlotta Pittori[2]; Fabrizio Lucarelli[3]; Paolo Giommi[4]

[1] *PI*

[2] *Istituto Nazionale di Fisica Nucleare*

[3] *INAF-OAR & ASI-SSDC*

[4] *Agenzia Spaziale Italiana*

Corresponding Author: elena.gasparri@gmail.com

The search for gamma ray counterparts of IceCube neutrino events is crucial for understanding the role of blazars as candidate sources of cosmic neutrinos. We have searched the counterparts for IceCube neutrinos events in the interval from 2018 to 2020 in the AGILE gamma-ray satellite public archive.
We present the candidate sources in the regions centered on the detected neutrinos and their light curves and Spectral Energy Distributions, providing estimates of the gamma ray flux above 100 MeV for the AGILE detections. The possible associations of neutrino events with blazars are discussed.

Neutrino Telescopes / 49

The Radio Neutrino Observatory in Greenland: Performance and Prospect

Author: Felix Schlüter[1]

[1] *IIHE - ULB*

Corresponding Author: felix.schluter@icecube.wisc.edu

The Radio Neutrino Observatory - Greenland (RNO-G) is dedicated to search for ultra-high-energy (UHE) neutrinos with energies above 10 PeV by observing radio pulses from neutrino interactions in the Greenland ice shield. The detector will consist of 35 autonomously operating stations, each equipped with 24 antennas, deployed over an area of about 50 km^2. With an estimated sensitivity of $E^2\Phi \approx 10^{-8}$ GeV/cm^2/s/sr in 5 years, RNO-G will allow to test a variety of cosmogenic neutrino flux models and has the potential to discover the first neutrino with an energy above 10 PeV. Its unique location in the northern hemisphere makes it complementary to any future or current UHE neutrinos observatories in Antarctica and will provide valuable information for multi-messenger searches in the northern sky.

In this talk, we will discuss the scientific potential of RNO-G to detect UHE neutrinos from a diffuse emission as well as from transient sources. We will present current efforts to implement a fast follow-up analysis to react on alerts from other observatories and contribute to multi-messenger campaigns. Finally, we will highlight first measurements from seven already installed stations.

Flash Talks / 50

Neutrino flavor evolution in dense astrophysical sources

Author: Marie Cornelius[1]

Co-authors: Irene Tamborra [2]; Shashank Shalgar [2]

[1] *Niels Bohr Institute, University of Copenhagen*

[2] *Niels Bohr Institute*

Corresponding Author: marie.cornelius@nbi.ku.dk

Neutrinos play a fundamental role in core-collapse supernovae and compact binary mergers. In such dense environments, the coherent forward scattering of neutrinos on each other makes the flavor evolution a non-linear phenomenon. Using a quantum-kinetic approach, we model the neutrino flavor transformation in the presence of neutrino advection, neutrino-matter collisions, and neutrino self-interactions. In this talk, I will explore the impact of inhomogeneities arising in the matter background and temporal perturbations in the fast flavor evolution.

Neutrino Telescopes / 51

The Search for High Energy Neutrino Emission from X-ray Bright Seyfert Galaxies with IceCube

Authors: Ali Kheirandish[1]; Hans Niederhausen[2]; Qinrui Liu[3]; Shiqi Yu[None]; Theo Glauch[4]; Tomas Kontrimas[4]

[1] *Pennsylvania State University*

[2] *Michigan State University*

[3] *Queen's University*

[4] *Technische Universität München*

Corresponding Author: tomas.kontrimas@icecube.wisc.edu

IceCube recently observed neutrino emission from the nearby active Seyfert galaxy NGC 1068 in the TeV energy range. This finding suggests that active galactic nuclei (AGN) could be a source type contributing to the diffuse high-energy astrophysical neutrino flux. The dense environments near the supermassive black holes and the acceleration of cosmic rays in the coronae offer suitable conditions for producing high-energy neutrinos. Such environments can be examined by disk-corona models. In this search, we use disk-corona models to predict the neutrino emission flux from the Seyfert galaxies based on their observed keV X-rays luminosity. In this contribution, we report the results of searches for neutrino emission from X-ray bright Seyfert galaxies using 10 years of IceCube data.

Neutrino Telescopes / 52

Prospect for the Detection of the Geo-neutrino Signal with JUNO

Author: Zhao Xin[1]

[1] *Institute of High Energy Physics, CAS*

Corresponding Author: xinzhao@ihep.ac.cn

The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kton multi-purpose liquid scintillator detector which is located at a 700-m underground laboratory in the south of China (Jiangmen city, Guangdong province). The primary goals of JUNO are to determine the neutrino mass ordering and precisely measure the neutrino oscillation parameters. In addition, the massive volume of the JUNO detector will allow to record more geo-neutrino events in a year than all previous detectors

have accumulated to date, which will improve our understanding of the heat budget of Earth and its composition.
This talk will report the latest studies of the geo-neutrino sensitivity including the measurement of the total geo-nuetrino signal, individual contributions from U and Th and their ratio, as well as the potential to observe the mantle geo-neutrino signal.

Data Science and Detector R&D / 53

Prototyping the SoLAr dual readout LAr TPC to enable solar neutrino detection program

Co-authors: Anja Gauch ; Jan Kunzmann [1]

[1] *University of Bern*

Corresponding Authors: anja.gauch@lhep.unibe.ch, jan.kunzmann@lhep.unibe.ch

SoLAr is a next-generation liquid argon time protection chamber (LAr TPC) detector aimed at detecting solar neutrinos. It uses and drives the latest technologies needed to expand the detectable energy range to the MeV regime. In addition to proper background rejection and suppression SoLAr creates the possibility to detect the "hep branch"directly for the first time. SoLAr will collect the light and charge deposits in argon on the same pixelated anode plane, creating the possibility to localize events using combined charge and light measurements for tracking. A first prototype of the SoLAr detector proving the concept of collecting light and charge on one plane was constructed and took cosmic-ray data in October of 2022. This talk will give an introduction to the concept of SoLAr, and the operation of the first SoLAr prototype.

Neutrino Telescopes / 54

Neutrinos in XENONnT dark matter experiment

Author: Emanuele Angelino[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: emanuele.angelino@to.infn.it

The XENONnT experiment, which is the current phase of the XENON project, located at Laboratori Nazionali del Gran Sasso (Italy), aims to directly detect WIMP dark matter employing a dual-phase TPC with a 5.9 tonnes liquid xenon target. The first science run collected a total exposure of more than 1 tonne-year. The search for nuclear recoils induced by WIMPs, performed with a blind analysis, showed no significant excess and the ultra-low background achieved in XENONnT allowed the most sensitive searches for electronic recoils produced by solar axions and bosonic dark matter. The XENONnT experiment can also perform several neutrino searches besides dark matter, which will be illustrated. The neutrino magnetic moment, for which limits can be set, would enhance the elastic scattering of solar neutrinos with xenon electrons. Even without this enhancement, solar *pp* neutrinos could be observed via the ordinary elastic scattering off electrons.
Solar neutrinos are expected to induce nuclear recoils through coherent elastic scattering off xenon nuclei. The detection of this process, never observed for solar neutrinos, would be possible for ^{8}B neutrinos in XENONnT with increased exposure. In this way, supernova neutrinos can also be detected, resulting in a rise in the rate monitored by the triggerless data-acquisition system. Given the double-beta decaying ^{136}Xe with 8.9% abundance in the target mass, the XENONnT detector is sensitive to the neutrinoless double-beta decay of this isotope. The expected sensitivity is not competitive with dedicated experiments but demonstrates the feasibility of this search in the next-generation LXe dark matter detectors.

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Probing Nuclear Effects in QE-like Neutrino Scattering at MINERvA

Author: Steven Manly[1]

[1] *University of Rochester*

Corresponding Author: steven.manly@rochester.edu

The MINERvA experiment at Fermilab presents results from quasielastic-like (QE-like) ν_μ interactions on a variety of nuclear targets in the medium energy (<E_ν >~6~GeV) NuMI neutrino beam. In the analysis described here, events are used where protons are cleanly reconstructed. Cross section and cross section ratio results from events produced on C, CH, H_2O, Fe, and Pb targets are presented as a function of muon, proton, and transverse kinematic imbalance variables. These variables are sensitive to nuclear effects. All of the presented observations are compared to predictions from a series of widely used neutrino event generators with different options and tunes. Qualitatively, the spread of simulated results tends to cover the data. However, none of the simulations consistently describe the data. While some of the trends and comparisons will be discussed, an important aim of this talk is to demonstrate for the neutrino community the breadth of these results and their potential utility for constraining models.

Neutrino Properties / 56

Impact of light sterile neutrinos on the interpretation of NOvA and T2K results

Author: Antonio Palazzo[1]

Co-author: Sabya Sachi Chatterjee [2]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *IPhT CEA-Saclay*

Corresponding Author: antonio.palazzo@ba.infn.it

We study in detail the impact of a light sterile neutrino on the interpretation of the recent data of the long baseline experiments NOνA and T2K, assessing the robustness/fragility of the estimates of the standard 3-flavor parameters with respect to the perturbations induced in the 3+1 scheme. We find that all the basic features of the 3-flavor analysis, including the weak indication ($\sim$1.4σ) in favor of the inverted neutrino mass ordering, the preference for values of the CP-phase $\delta_{13} \sim 1.2\pi$, and the substantial degeneracy of the two octants of θ_{23}, all remain basically unaltered in the 4-flavor scheme. Our analysis also demonstrates that it is possible to attain some constraints on the new CP-phase δ_{14}. Finally, we point out that, differently from non-standard neutrino interactions, light sterile neutrinos are not capable to alleviate the tension recently emerged between NOνA and T2K in the appearance channel.

Neutrino Properties / 57

Neutrino reconstruction analysis at ICARUS detector

Author: Maria Artero Pons[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: maria.arteropons@pd.infn.it

Liquid Argon Time Projection Chamber (LArTPC) detectors offer charged particle imaging capability with impressive spatial resolution. Precise event reconstruction procedures are mandatory in order to fully exploit the potential of this technology.
After a successful three-year physics run at the underground LNGS - INFN laboratory, ICARUS was refurbished and subsequently moved to Fermilab to begin to operate as the far detector in the Short-Baseline Neutrino Program (SBN). ICARUS has entered the physics run phase and is presently collecting large statistical samples for its proposed physics analysis program.
In this presentation we will show ICARUS event selection, reconstruction and analysis algorithms that are currently being used. First studies have been performed with a well defined sample of ν_μ CC quasi elastic interactions, showing promising and robust results of fully reconstructed neutrino events. Detailed investigations are undergoing on particle identification, particle vs shower discrimination, calibration corrections and many other topics, which will be reported here.

Neutrino Telescopes / 58

Observation of High-Energy Neutrinos from the Galactic Plane

Author: Mirco Hünnefeld[1]

[1] *TU Dortmund University*

Corresponding Author: mirco.huennefeld@tu-dortmund.de

IceCube has discovered a flux of astrophysical neutrinos and presented evidence for the first neutrino sources, a flaring blazar known as TXS 0506+056 and the active galaxy NGC 1068. However, the sources responsible for the majority of the astrophysical neutrino flux remain elusive. High-energy neutrinos can be produced when cosmic rays interact at their acceleration sites and during propagation through the interstellar medium. The Galactic plane has therefore long been hypothesized as a neutrino source.

In this contribution, new results are presented for searches of neutrino sources utilizing an improved cascade dataset that builds upon recent advances in deep-learning-based reconstruction methods. This work presents the first observation of high-energy neutrinos from the Milky Way Galaxy, rejecting the background-only hypothesis at 4.5σ. The neutrino signal is consistent with diffuse emission from the Galactic plane, potentially in combination with emission by a population of sources.

Neutrino Properties / 59

CONUS experiment: new results and the upgrade campaign to CONUS+

Corresponding Author: christian.buck@mpi-hd.mpg.de

The CONUS experiment (COherent elastic NeUtrino nucleus Scattering) aims at coherent elastic neutrino-nucleus scattering (CEvNS) with germanium detectors in the Brokdorf Nuclear Power Plant (KBR, Germany). Four 1kg modules were placed 17m from the 3.9GW reactor core, monitoring an energy regime down to sub-keV with a background rate of ~10 per day per keV. Data taking was finished and latest results will be shown. The upgrade, CONUS+, is installed in the Leibstadt Nuclear Power Plant (KKL) in Switzerland. The status of the installation and its potential will also be shown.

Neutrino Telescopes / 60

Seasonal Variations of the Atmospheric Neutrino Flux measured in IceCube

Author: Karolin Hymon[1]

Co-author: Tim Ruhe [1]

[1] *TU Dortmund University*

Corresponding Author: karolin.hymon@tu-dortmund.de

The IceCube Neutrino Observatory measures high-energy atmospheric neutrinos with high statistics. These atmospheric muon neutrinos are produced in cosmic ray interactions in the atmosphere, mainly by the decay of pions and kaons. The rate of the measured neutrinos is affected by seasonal temperature and pressure variations in the stratosphere, which are expected to increase with the particle's energy. In this contribution, seasonal energy spectra are obtained using a novel spectrum unfolding approach, the Dortmund Spectrum Estimation Algorithm (DSEA+), in which the energy distribution from 125 GeV to 10 TeV is estimated from measured quantities with machine learning algorithms. We determined the seasonal spectra differences with respect to the average annual flux from 11.5 years of IceCube's atmospheric muon neutrino data.

Flash Talks / 62

Core-Collapse Supernova Neutrino Observation in JUNO

Author: Yibing Zhang[1]

[1] *IHEP*

Corresponding Author: ybzhang@ihep.ac.cn

The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose neutrino experiment currently being constructed in China. Its main physics goal is to determine the neutrino mass ordering and achieve precision measurements of oscillation parameters by utilizing a liquid scintillator detector with a target mass of 20 kilotons. JUNO is capable of recording a significant amount of data on the neutrinos produced during and before the next Core-Collapse Supernova (CCSN) burst. This talk will include the performance of the CCSN monitoring system and the potential of the reconstruction of energy spectra of all CCSN neutrino flavours via detecting various interactions in JUNO.

Neutrino Theory & Cosmology / 63

Neutrinos from dense environments, non-radiative neutrino decay and the diffuse supernova neutrino background

Author: Maria Cristina Volpe[1]

[1] *CNRS/INP et APC*

Corresponding Author: volpe@apc.univ-paris7.fr

"Neutrinos from dense environments, non-radiative neutrino decay and the diffuse supernova neutrino background"

M. Cristina Volpe (CNRS/INP and APC, Paris)

In this talk I will first describe the frontiers of our knowledge on neutrino flavor evolution in dense media - core-collapse supernovae, binary neutron star mergers, early universe - and mention connections to other domains, in particular quantum information theory and computing [1,2]. How neutrino change flavor, in astrophysical and cosmological environments, is tightly linked to known and unknown neutrino properties. I will focus on the case of non-radiative neutrino decay and its importance for future observations, in particular the upcoming discovery of the diffuse supernova neutrino background and its interpretation [3,4].

[1] M. Cristina Volpe, "Neutrinos from dense: flavor mechanisms, theoretical approaches, observations, new directions", Review of Modern Physics, arXiv: 2301.11814.

[2] J. Froustey, C. Pitrou, M.Cristina Volpe, "Neutrino decoupling including flavour oscillations and primordial nucleosynthesis", JCAP 12 (2020) 015, arXiv: 2008.01074.

[3] P. Ivanez-Ballesteros, M. Cristina Volpe, Neutrino nonradiative decay and the diffuse supernova neutrino background}, PRD D 107 (2023) 2, 023017, arXiv: 2209.12465.

[4] P. Ivanez-Ballesteros, M. Cristina Volpe, in preparation.

Neutrino Properties / 64

HOLMES , an experiment for measuring the neutrino mass

Author: Elena Ferri[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: elena.ferri@mib.infn.it

Measuring neutrino mass is challenging in nowadays particle physics and astrophysics. Direct measurements using electron kinematics in beta decays are the only theory-independent method. A possible approach for directly measuring the neutrino mass is the calorimetric one. Calorimeters measure the energy released by decays, except the neutrino fraction. However, they face limitations in balancing statistical sensitivity and background. Given the small fraction of events falling the in the region of interest, to achieve a high experimental sensitivity on the neutrino mass it is important to have a high activity combined with a very small undetected pile-up contribution. HOLMES is an experiment aiming to measure neutrino mass with 1 eV sensitivity using electron capture of 163Ho. To achieve its targets, HOLMES employs 1000 TESs with custom ion implantation and microwave multiplexing for readout. HOLMES has optimized its detectors and multiplexing, and the ion implanter is ready for low-dose implantation. This progress allows increasing the activity in the detectors and studying the heat capacity due to 163Ho concentration. This contribution presents HOLMES' status, including initial results from implanted detectors and the experiment's overall outlook.

Neutrino Properties / 65

T2K latest neutrino oscillation results

Author: Adrien Blanchet[1]

[1] *Uni. Geneva*

T2K is a long baseline neutrino experiment which exploits a neutrino and antineutrino beam produced at the Japan Particle Accelerator Research Centre (J-PARC) to provide world-leading measurements of neutrino oscillation. Neutrino oscillations are measured by comparing neutrino rates

and spectra at a near detector complex, located at J-PARC, and at the water-Cherenkov far detector, Super-Kamiokande, located 295 Km away.

The latest T2K results include multiple analysis improvements. A new beam tuning has been developed, based on improved NA61/SHINE measurements on a copy of the T2K target and including refined modeling of the beam line materials. Improved modeling of systematic uncertainties due to neutrino-nucleus interactions have been implemented, including a more sophisticated treatment of the region of low-energy transfer to the nucleus and tuning from electron-scattering data. New selections at ND280, with proton and photon tagging, are also exploited to reach better control of such systematic uncertainties.

Furthermore, a new sample is added at the far detector requiring the presence of a pion in muon-neutrino interactions. It is the first time that a pion sample is included in the study of neutrino disappearance at T2K and, for the first time, a sample with more than one Cherenkov ring is exploited in the T2K oscillation analysis, opening the road for future samples with charged- and neutral-pion tagging. The inclusion of such a sample assures proper control of the oscillated spectrum on a larger neutrino-energy range and on subleading neutrino-interaction processes.

T2K is also engaged in a major effort to perform a joint fit with the Super-Kamiokande neutrino atmospheric measurements and another joint fit with NOvA. Such combinations allow to lift the degeneracies between the measurement of the CP violating phase δ_{CP} and the measurement of the ordering of the neutrino mass eigenstates. Results and prospects of such joint fits will be discussed.

Neutrino Properties / 66

T2K results on neutrino cross-sections

Co-author: Liu Shilin [1]

[1] *Stony Brook University*

Corresponding Author: shilin.liu@stonybrook.edu

Precise knowledge of how neutrinos interact with matter is essential for measuring neutrino oscillations in long-baseline experiments. At T2K, the near detector complex measures neutrino interactions to constrain cross-section models for oscillation studies and to characterise the beam flux. The near detector complex provides a platform for performing neutrino-nucleon cross section measurements. The design of the ND280 near detector allows for a variety of cross section measurements on different targets to be performed. The additional WAGASCI near detector at a different off-axis angle features an increased Water/Carbon target ratio. Finally, the on-axis INGRID detector can be combined with ND280 and WAGASCI to measure the cross-section at different neutrino energies and to further constrain the nuclear models for different targets.

Recent cross section measurements from the near detector complex will be presented. The latest measurements of pion production in ND280, including measurements of transverse pion kinematics, and an improved analysis of coherent pion production making use of an anti-neutrino sample for the first time, will be shown. The first measurement of cross section without pions in the final state at the WAGASCI off-axis angle will be presented, as well as the first combined measurement of ND280 and INGRID allowing the first simultaneous measurement of cross-section at different neutrino off-axis angles, energies and different detectors on the same flux.

Data Science and Detector R&D / 67

Assembly, test and analysis development of the T2K upgrade

Corresponding Author: weijun.li@physics.ox.ac.uk

The near detector of T2K (ND280) is undergoing a major upgrade. A new scintillator tracker, named superFGD, with fine granularity and 3D-reconstruction capabilities has been assembled at J-PARC. The new Time Projection Chambers are under construction, based on the innovative resistive Micromegas technology and a field cage made of extremely thin composite walls. New scintillator panels with precise timing capability have been built to allow precise Time of Flight measurements.

The detector is currently in the assembly phase following a detailed effort of characterization during detector production. The results of multiple tests of the detectors with charged beams, neutron beam, cosmics and X-rays will be presented. Among these results, we could mention the first measurement of neutron cross-section with the superFGD and the first detailed characterization of the charge spreading in resistive Micromegas detectors.

Thanks to such innovative technologies, the upgrade of ND280 will open a new way to look at neutrino interactions thanks to a significant improvement in phase space acceptance and resolution with an enhanced purity in the exclusive channels involving low-momentum protons, pions and neutrons. Sensitivity results and prospects of physics capabilities will be also shown.

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Photon Analyses in MicroBooNE

Co-author: Xiao Luo [1]

[1] *UCSB*

Corresponding Author: xiaoluo@ucsb.edu

The MicroBooNE experiment is an 85-ton active volume liquid argon time projection chamber (LArTPC) neutrino detector situated in the Fermilab Booster Neutrino Beam (BNB). Leveraging the unique capabilities of LArTPC technology to distinguish photons from electron electromagnetic showers, MicroBooNE has achieved the world's most sensitive search for neutrino-induced single-photon production. In this talk, we will present a comprehensive overview of these results, as well as recent advancements in our search for single-photons. These include a more model-independent approach utilizing inclusive photon searches, as well as a targeted search for NC coherent-like single-photon production.

Neutrino Properties / 71

The cosmogenic background rejection of the ICARUS detector at Fermilab.

Author: Francesco Poppi[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: poppi@bo.infn.it

The Short Baseline Neutrino Program at Fermilab aims to confirm or rule out the existence of sterile neutrinos at the eV mass scale. The program will perform the most sensitive search in both electron-neutrino appearance and muon-neutrino disappearance channels along the Booster Neutrino Beamline. The far detector, ICARUS-T600, is a high-granularity Liquid Argon Time Projection chamber located at 600 m from the Booster neutrino target and at shallow depth, thus exposed to a large flux of cosmic particles. In this presentation, I will talk about the Cosmic Ray Tagger system performance during the first physics run of the ICARUS detector. I will also present the ICARUS cosmogenic background rejection achieved exploiting the timing synchronization of the external Cosmic Ray tagger system and the scintillation light Photon-Detection System inside the liquid argon volume.

Neutrino Telescopes / 72

Large neutrino telescope Baikal-GVD: recent status

Author: Rastislav Dvornicky[1]

[1] *Comenius University in Bratislava*

Corresponding Author: dvornicky@fmph.uniba.sk

The Baikal-GVD is a large neutrino telescope being constructed in Lake Baikal. Recently it is the largest operating neutrino telescope in Northern Hemisphere. The winter expedition of the year 2023 concludes in the three-dimensional array of 3 456 photo-sensitive units (optical modules) installed in total. The data collection is allowed by the design of the experiment while being in a construction phase. In this contribution the design and the basic characteristics of the Baikal-GVD detector are reviewed. Some preliminary results on diffuse neutrino flux measurements with the partially completed detector will be presented.

Neutrino Telescopes / 73

Search for physics beyond the Standard Model with IceCube

Author: Carlos Perez de los Heros[1]

[1] *Uppsala University*

Corresponding Author: cph@physics.uu.se

The IceCube Neutrino Observatory at the South Pole is the world's largest neutrino telescope, but it can be also considered as one of the largest particle detectors ever built, providing a unique window to physics beyond the Standard Model at energies unreachable in man-made accelerators. It can cover a wide range of neutrino energies, from few GeV to PeVs, and also detect other particles that will emit light when traversing the detector. Its physics program spans from dark matter searches to neutrino oscillations, tests of fundamental laws and searches for monopoles, among others. This talk will cover recent results and future prospects of BSM searches with IceCube.

Neutrino Theory & Cosmology / 74

Global constraints on non-standard neutrino interactions with quarks and electrons

Author: Salvador Urrea González[1]

[1] *IFIC, University of Valencia*

Corresponding Author: ugonsal@ific.uv.es

We derive new constraints on effective four-fermion neutrino non-standard interactions with both quarks and electrons. This is done through the global analysis of neutrino oscillation data and measurements of coherent elastic neutrino-nucleus scattering (CEvNS) obtained with different nuclei. In doing so, we include not only the effects of new physics on neutrino propagation but also on the detection cross section in neutrino experiments which are sensitive to the new physics. We consider both vector and axial-vector neutral-current neutrino interactions and, for each case, we include simultaneously all allowed effective operators in flavour space. To this end, we use the most general parametrization for their Wilson coefficients under the assumption that their neutrino flavour structure is independent of the charged fermion participating in the interaction. The status of the

LMA-D solution is assessed for the first time in the case of new interactions taking place simultaneously with up quarks, down quarks, and electrons. One of the main results of our work are the presently allowed regions for the effective combinations of non-standard neutrino couplings, relevant for long-baseline and atmospheric neutrino oscillation experiments.

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Unveiling the mysteries of neutrinoless double beta decay: exploring Nuclear Matrix Elements and their impact on Majorana mass sensitivities.

Authors: Federica Pompa[None]; Jing-Yu Zhu[None]; Thomas Schwetz-Mangold[1]

[1] *Karlsruhe Institute of Technology*

Corresponding Author: federica.pompa@ific.uv.es

Nuclear Matrix Elements (NME) are a crucial input for the interpretation of neutrinoless double beta decay data. A representative set of recent NME calculations from different methods is taken, and a combined analysis of the available data performed in order to investigate the impact on the current and future sensitivities on the effective Majorana mass. A crucial role is played by the recently discovered short-range contribution to the NME, induced by light Majorana neutrino masses. Depending on the NME model and the relative sign of the long- and short-range contributions, the current 3⊠ bounds change, and the sensitivity of next-generation experiments can be either pushed beyond the inverted mass ordering region or never reach this one.
Furthermore, perspectives on the possibility to distinguish between different NME calculations by assuming a positive signal and by combining measurements from different isotopes is presented.

Data Science and Detector R&D / 76

KM3NeT/ARCA seafloor network infrastructure

Author: Simone Biagi[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: simone.biagi@lns.infn.it

KM3NeT is a multi-site detector devoted to the detection and study of cosmic neutrinos and their sources in the Universe and to the measurement of the neutrino oscillation parameters. Two underwater detectors are under construction in the Mediterranean Sea: ARCA (offshore Portopalo di Capo Passero, Italy) and ORCA (offshore Toulon, France). ARCA will comprise more than 200 detection units, floating structures anchored on the seafloor with a height of 750 m, equipped with a total of 128,000 photomultiplier tubes to detect the feeble light cone produced after the neutrino interactions. The detector must operate continuously for about 20 years without maintenance since its topology does not allow the recovery of assets. The Phase-1 of the project, currently in operation with 21 out of 31 detection units deployed and providing data in real-time, will be completed by the end of 2023. ARCA Phase-2 has started with the installation of a DCFO (Direct Current - Fibre Optic) system, which is composed of an onshore 100 kW power feeding equipment, a "Y"-shaped electro-optical cable with 48 fibres and two copper conductors, a cable termination frame equipped with four 10 kW medium-voltage converters, 16 electrical and 16 optical ROV mateable connectors. A major step for the deployment of the ARCA subsea infrastructure was the construction and installation of the junction boxes, which allow for the connection of several detection units to a single cable termination frame port, through a network of electro-optical cables laid on the seafloor. High-reliability criteria (including component selection, process control, and strategic redundancy adoption) are used for power electronics, optical routing, and amplification controls. In this talk, the main technological

efforts accomplished in the last years will be presented, along with an overview of the entire ARCA infrastructure, comprising both underwater and onshore parts.

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Calibration system of the JUNO experiment

Author: Jiaqi Hui[1]

[1] *Shanghai Jiao Tong University*

Corresponding Author: huijiaqi@sjtu.edu.cn

The Jiangmen Underground Neutrino Observatory (JUNO) is the largest liquid scintillator detector in the world and it is under construction in Jiangmen city in South China. The JUNO Central Detector is an acrylic spherical vessel with an inner diameter of 35.4 m, filled with 20 kton liquid scintillator. The entire scintillator volume is monitored by approximately 17,600 20-inch and 25,600 3-inch photomultiplier tubes. It is designed to determine the neutrino mass ordering, measure the solar neutrino fluxes, detect supernova neutrinos, etc. A comprehensive calibration strategy is developed to achieve an unprecedented effective energy resolution (better than 3% @1MeV) and energy scale (better than 1%), by deploying multiple radioactive sources/laser source in various positions inside and outside of the Central Detector. The strategy of the JUNO calibration system has been optimized based on the results of Monte Carlo simulations from the calibration sub-systems data. This flash talk will present details of the JUNO calibration system and simulation results that help to achieve an excellent
energy resolution of 3%/sqrt(E(MeV)) and an accuracy of the energy scale at 1% level or better.

Neutrino Telescopes / 78

Gamma-ray and neutrino diffuse emissions of the Milky-Way: what do they imply ?

Authors: Pedro De la Torre Luque[1]; Daniele Gaggero[2]; Dario Grasso[2]; Antonio Marinelli[2]

[1] *Oskar Klein Centre, Stockholm University*

[2] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: dario.grasso@pi.infn.it

Being for centuries a magnificent and enigmatic presence in the night sky the Milky Way became during the last decades the target of multi-messenger observations at increasing energies.
In this talk we will focus on its γ-ray and neutrino diffuse emissions which recently has been both observed up to the PeV.
One of the main aims of these measurements is to understand the origin and the propagation of Galactic cosmic-rays.
In this framework, it is striking that the γ-ray diffusion emissions measured by LHAASO has been found more intense and harder than predicted by conventional cosmic-ray propagation models as it was also found —less prominently —at lower energies.
The possible forthcoming discovery of the neutrino counterpart of such emission would imply its hadronic origin hence disfavouring unresolved leptonic sources, as pulsars and TeV halos, to be responsible of such an excess.
We will show that a physically motivated cosmic-ray propagation scenario featuring non-homogeneous transport, which has been developed over the latest years to reproduce γ-ray observations in different regions of the Galaxy, provides a consistent description of γ-ray and neutrino measurements up to the PeV as well as high energy cosmic ray data beyond that energy.

Neutrino Properties / 79

Atmospheric neutrino oscillations with IceCube: Recent results with DeepCore and future potential with the Upgrade

Author: Kayla Leonard DeHolton[1]

[1] *Pennsylvania State University*

Corresponding Author: kayla.leonard@icecube.wisc.edu

The IceCube DeepCore detector located at the South Pole has been collecting GeV-scale atmospheric neutrino data for the past decade. At these energies, Earth-crossing muon neutrinos have a high chance of oscillating to tau neutrinos. DeepCore is able to measure the atmospheric oscillation parameters with a precision comparable to accelerator-based experiments, while also complementing accelerator measurements because it probes longer distance scales and higher energies, well above the tau lepton production threshold. In recent years, DeepCore's measurement of the atmospheric oscillation parameters have improved significantly due to improvements in background rejection, reconstruction techniques, particle identification, and modeling of systematic uncertainties, in addition to extra years of data.

IceCube's ability to measure these parameters will undergo further significant improvements with the construction of the IceCube Upgrade in the 2025-2026 Antarctic season. The IceCube Upgrade will consist of 7 additional densely-instrumented strings within the DeepCore region, and the additional modules will greatly increase detector performance for GeV-scale neutrinos. In combination with the existing decade of DeepCore data, the IceCube Upgrade will provide world-leading sensitivity to atmospheric muon neutrino disappearance, atmospheric tau neutrino appearance, and the neutrino mass ordering.

Neutrino Theory & Cosmology / 80

Earth tomography with supernova neutrinos at future neutrino detectors

Authors: Olga Mena Requejo[1]; Rasmi Hajjar Muñoz[2]; Sergio Palomares-Ruiz[3]

[1] *IFIC (CSIC-UV)*

[2] *SSM - IFIC (CSIC-UV)*

[3] *IFIC (UV-CSIC)*

Corresponding Author: rasmi.hajjar@ific.uv.es

Earth neutrino tomography is a realistic possibility with current and future neutrino detectors, complementary to geophysics methods. The two main approaches are based on either partial absorption of the neutrino flux as it propagates through the Earth (at energies about a few TeV) or on coherent Earth matter effects affecting the neutrino oscillations pattern (at energies below a few tens of GeV). In this work, we consider the latter approach focusing on supernova neutrinos with tens of MeV. Whereas at GeV energies, Earth matter effects are driven by the atmospheric mass-squared difference, at energies below ~100 MeV, it is the solar mass-squared difference what controls them. Unlike solar neutrinos, which suffer from significant weakening of the contribution to the oscillatory effect from remote structures due to the neutrino energy reconstruction capabilities of detectors, supernova neutrinos can have higher energies and thus, can better probe the Earth's interior. We shall revisit this possibility, using the most recent neutrino oscillation parameters and up-to-date supernova neutrino spectra. The capabilities of future neutrino detectors, such as DUNE, Hyper-Kamiokande and JUNO are presented, including the impact of the energy resolution and other factors. Assuming a supernova burst at 10 kpc, we show that the average Earth's core density could be determined within ⊠10% at 1σ confidence level, being Hyper-Kamiokande, with its largest mass, the most promising detector to achieve this goal.

Data Science and Detector R&D / 81

Next-generation CEvNS experiments at the ESS and beyond

Author: Mark Lewis[1]

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

Corresponding Author: mark.lewis@dipc.org

The recent detection of coherent elastic neutrino-nucleus scattering (CEvNS) creates the possibility of using neutrinos to explore physics beyond the Standard Model with small-size detectors. However, the CEvNS process generates signals at the few-keV level, requiring sensitive detector technologies. High-yield neutrino sources, including the European Spallation Source (ESS) and nearby power reactors, have been identified to provide a unique opportunity for a definitive exploration of all phenomenological applications of CEvNS.
A number of different detector approaches are currently under development for deployment at these facilities. These next-generation technologies will be able to observe the process with a lower energy threshold and better energy resolution than current detectors. Combining their observations will allow for a complete phenomenological exploitation of the CEvNS signal. In particular, these measurements will not be statistically limited due to the synergy between larger neutrino fluxes and these improved detectors.
In this talk, I will present the main projects currently being developed to detect CEvNS with precision, focusing on two main spheres: efforts at the ESS like the CoSI project, which employs cryogenic undoped CsI crystals, and its sister GanESS, a high-pressure gas TPC; and efforts at the Ringhals nuclear plant utilizing the largest, lowest-threshold, Ge diodes in the world.

Neutrino Properties / 82

The latest Daya Bay oscillation results and reactor neutrino flux and spectrum results

Author: Zhe Wang[1]

[1] *Tsinghua University*

Corresponding Author: wangzhe-hep@tsinghua.edu.cn

The Daya Bay Reactor Neutrino Experiment is located next to six commercial nuclear reactors, each of which has a max thermal power of 2.9 GW. The experiment consists of two near experimental halls and one far experimental hall. The power-weighted baselines to the six power reactors are about 500 m and 1.7 km for the near and far halls, respectively. Each near hall has two antineutrino detectors (ADs) and the far hall has four ADs. All eight ADs have an identically designed nested structure with 20 tons of gadolinium-loaded liquid scintillator in the center, 22 tons of liquid scintillator in the middle, and mineral oil outside for shielding. The Daya Bay Reactor Neutrino Experiment discovered a non-zero value for the neutrino mixing angle theta13 in 2012. Since then, Daya Bay continues to provide the leading determination of this small mixing angle. With the data, the experiment also presents the crucial measurements of the reactor neutrino flux and spectrum. In this talk, I will present the latest Daya Bay oscillation results and reactor neutrino flux and spectrum results.

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Euclid Spectroscopic Image Simulations and Reconstruction

Author: Francesca Passalacqua[1]

Co-authors: Stefano Anselmi [1]; Andrea Begnoni [1]; Bianca De Caro [1]; Stefano Dusini [1]; Louis Pierre Marie Gabarra [1]; Alessandro Renzi [1]; Chiara Sirignano [1]; Luca Stanco [1]; Antonino Troja [1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: francesca.passalacqua@pd.infn.it

Euclid is a European Space Agency (ESA) mission, designed to investigate the nature of Dark Energy and Dark Matter. It will measure the position and the redshift of billions of galaxies to map the dark matter distribution with unprecedented accuracy. The satellite launch will take place in summer 2023 and the data taking will last for six years covering one-third of the entire sky. Euclid data will strongly constrain cosmological parameters, including the sum of the neutrino masses.

To attain the desired level of precision in parameter estimation, meticulous management of systematic effects is indispensable. These effects have both hardware and astrophysical origins: the former includes detector nonidealities and telescope response; the latter includes cosmic rays, background light, and signal contamination from different sources.

In order to quantify the efficiency in the redshift reconstruction, we have developed the Spectroscopic Pipeline Runner and INput Generator (SPRING) which runs pixel-level simulations and performs the data processing through Euclid spectroscopic pipeline. SPRING is a runner of Euclid official codes suitable for quantifying systematics. It allows us to simulate both realistic images of the sky and non-astrophysical sources to properly evaluate instrumental effects.

Thus, SPRING is a key tool to evaluate the purity and efficiency in the redshift evaluation which has consequences on the matter power spectrum and in the estimation of the total neutrino mass.

Flash Talks / 85

Challenges in read-out electronics for neutrino physics: the Super-FGD

Author: Lorenzo Giannessi[1]

Co-authors: Sebastien Cap [1]; Yannick Favre [1]

[1] *University of Geneva*

Corresponding Author: lorenzo.giannessi@unige.ch

In Long baseline neutrino experiment, systematics uncertainties on oscillation parameters critically depend on our knowledge of neutrino interactions. It is therefore crucial to precisely measure neutrino-nucleus cross sections at the near detector to improve our constraints on the far detector observations, as well as enhancing our modelling of neutrino-nucleus interaction. For this reason, the T2K collaboration is upgrading the near detector (ND280) with four additional state-of-the-art technology subdetectors: a time of flight detector (TOF), two high-angle TPCs (HATPC), and the super fine grained detector (Super-FGD), that will significantly improve the neutrino detection capabilities. Among those, the Super-FGD is the most ambitious project, consisting of more than 2 millions scintillator cubes read by optic fibers along three directions, allowing three-dimensional track reconstruction in a 2-tons fiducial mass detector. The remarkable advantages are low proton detection momentum threshold, neutron detection ability, 4π angular acceptance. A crucial element for the success of this detector is the Front-End electronics to read the nearly 60 thousands optic fiber channels. The read-out electronics comprises 221 Front-End Boards (FEB) based on the CITIROC chips, handling 256 channels each and organized in 16 crates.
This work presents the design validation, characterisation, and serial hardware testing of the the FEBs, designed by the University of Geneva and LLR (Paris). First, I present an extensive study of the FEB performance, assessing the dynamic range capabilities. Furthermore, I present the first FEB commissioning using a cosmic rays scintillator detector. Finally, I illustrate the test-bench that I developed for the mass testing of the 221 FEBs that will be employed in the Super-FGD, featuring hardware problem detection and localisation. For completeness, integration test results are also presented, validating the synchronous operation of multiple FEBs.

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Probing Dark Energy through Euclid Cross-Correlation Analysis

Author: Bianca De Caro[1]

[1] *INFN-Pd*

Corresponding Author: bdecaro@pd.infn.it

Euclid experiment will allow us to derive constraints on cosmological parameters and perform model selection through cross-correlation measurements between Cosmic Microwave Background (CMB) and Large Scale Structure (LSS). In this work we focalize on the detection of the late Integrated Sachs-Wolfe effect in order to constraint relevant cosmological parameters as the dark energy parameters and sum of neutrino masses by means of a Needlet-based cross-correlation observable.

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Searching for neutrino electromagnetic signatures with CEvNS and Dark Matter detectors data

Author: Nicola Cargioli[1]

Co-authors: Carlo Giunti [2]; Christoph Andreas Ternes [2]; Francesca Dordei [3]; Matteo Cadeddu [2]; Mattia Atzori Corona [2]; Walter M. Bonivento [4]; Yiyu Zhang ; Yufeng Li [5]

[1] *Università degli Studi di Cagliari/Istituto Nazionale di Fisica Nucleare*

[2] *Istituto Nazionale di Fisica Nucleare*

[3] *INFN CA*

[4] *INFN Cagliari*

[5] *Institute of High Energy Physics, Chinese Academy of Sciences*

Corresponding Author: nicola.cargioli@ca.infn.it

Neutrinos are the most elusive particles in the Standard Model, and many of their properties have not yet been fully understood. Among them, neutrino electromagnetic properties such as neutrino charge radius, magnetic moment and milli-charge have become objects of extensive research. Consequently, there is a pressing need for experiments capable of precisely probing them at a high precision level.
In this presentation, I will discuss the status of the constraints on the aforementioned properties coming from experiments designed to measure coherent elastic neutrino nucleus scattering (CEvNS) and xenon-based dark matter detectors, which are sensitive to the elastic scattering of solar neutrinos off atomic electrons. I will present the latest constraints obtained by the combined analysis of the COHERENT data on CsI and LAr detectors with the recent results from the CEvNS observation at the Dresden-II power plant site with a germanium detector [1]. Then, I will discuss the results coming from the LUX-ZEPLIN dark matter detector [2], focusing on the non-negligible impact of adopting different theoretical descriptions for the neutrino interaction with atomic electrons.
Finally, I will show that the recent LUX-ZEPLIN data allows us to set a very competitive limit on the neutrino magnetic moment when compared to the other laboratory bounds, namely μeff<1.1×10−11 μB at 90% C.L., which improves by almost a factor of three the Borexino Collaboration limit and represents the second best world limit after the recent XENONnT result. Moreover, exploiting the so-called equivalent photon approximation, we obtain the most stringent limit on the neutrino millicharge, namely |qeff|<1.5×10−13 e0 at 90% C.L., which represents a great improvement with respect to the previous laboratory bounds.

[1] M. Corona et al. JHEP 09 (2022) 164, Arxiv: 2205.09484
[2] M. Corona et al. Phys. Rev. D 107 (2023) 5, 053001, Arxiv: 2207.05036

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CLOUD: A New Generation of Neutrino Science at Chooz

Author: CLOUD Collaboration[None]

Co-author: Anatael Cabrera [1]

[1] *IJCLab / CNRS-Université Paris-Saclay*

Corresponding Author: anatael@in2p3.fr

The new ***CLOUD*** experiment, supported by the eponymous international collaboration (16 academic institutions and EDF), will be presented for the first time. *CLOUD* relies on the first ever ~10-ton ***LiquidO*** detector, which will be deployed at the new Chooz's "*ultra-near detector*" site, located at ~30 m from one of the nuclear reactors with minimal overburden. With ≥10,000 antineutrino interactions per day and an expected signal-to-background ≥100, *CLOUD* is designed for unprecedented fundamental physics. The ***CLOUD-I*** addresses the fundamental physics programme associated with the primary goal of the fully-funded (EIC & UKRI) ***AntiMatter-OTech*** innovation-based project that aims to develop non-intrusive industrial reactor monitoring. Also under active exploration, the subsequent ***CLOUD-II*** and ***CLOUD-III*** are independent neutrino scientific programmes exploring novel solar and geo-neutrino detection methodologies otherwise impossible today. The proposed presentation would thus describe the next generation of Chooz-based experiments within the scientific prospect of the large ***SuperChooz*** experiment —also under exploration.

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New sensors for acoustic neutrino detection

Author: Ernst-Jan Buis[1]

Co-authors: Ed Doppenberg [2]; Jan de Vreugd [2]; Peter Toet [2]; Rob Jansen [2]; Sander Von Benda-Beckmann [2]

[1] *NIkhef and TNO*

[2] *TNO*

Corresponding Author: ernst-jan.buis@tno.nl

The scientific prospects of detecting cosmic neutrinos with an energy close or even higher than the GKZ cut-off energy has been discussed extensively in literature. It is clear that due to their expected low flux, the detection of these ultra-high energy neutrinos (E_ν > 10^{18} eV) requires an telescope with an effective detection volume larger than 100 km^3. Acoustic detection may provide a way to observe these ultra-high energy cosmic neutrinos, as sound induced in the deep sea by their loss travels undisturbed for many kilometers so that a large neutrino telescope can be established. To realize such a telescope, acoustic detection technology must be developed that allows for a large deep sea sensor network.

Fiber optic hydrophone technology is a promising means to establish large a scale sensor network with the proper sensitivity to detect the small signals from neutrino interactions. The combination of the sensitivity and the cost-effective implementation of hydrophones may prove to be an enabler for a large scale deployment that is required for an acoustic neutrino telescope. TNO is involved in the development of the fiber optic hydrophone technology that can be operated in the deep sea with the required sensitivity. In parallel, we develop the full simulation chain required for telescope concept design and sensitivity calculations. Based on the measured hydrophone transfer function and noise sources as recorded in the deep sea, we develop strategies for the signal reconstruction both on single waveforms as well as event reconstruction in a future telescope.

In this talk we report on the progress of i) the development of hydrophone including a static pressure compensation mechanism and of ii) the neutrino signal simulations and methods to extract the signal from background.

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Probing feebly interacting particles from solar nuclear reactions with JUNO

Author: Giuseppe Lucente[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Corresponding Author: giuseppe.lucente@ba.infn.it

Solar nuclear reactions can occasionally produce feebly interacting particles (FIPs) X that escape the solar interior without further interactions. In this talk, we focus on the second stage of the solar proton-proton chain and evaluate the fluxes of monochromatic 5.49 MeV FIPs produced by the p(d,He3)X reaction, analyzing the potential to detect them with the forthcoming large underground neutrino oscillation experiment Jiangmen Underground Neutrino Observatory (JUNO). In particular, we forecast the JUNO sensitivity on different combinations of the axion couplings and on hidden vectors, identifying the regions of the parameter space where current terrestrial bounds will be improved.

Plenary Session / 93

Opening

Author: Mauro Mezzetto[1]

[1] *INFN-PD*

Corresponding Author: mezzetto@pd.infn.it

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High energy neutrino astrophysics - highlights

Corresponding Author: halzen@icecube.wisc.edu

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Neutrino masses, mixing and leptonic CP violation - Theory and tests in future experiments

Corresponding Author: petcov@sissa.it

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Nuclear Astrophysics

Corresponding Author: k.langanke@gsi.de

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The race for mass hierarchy

Corresponding Author: parke@fnal.gov

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Euclid Space Telescope

Corresponding Author: rene.laureijs@esa.int

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Double Beta Decays: Status and Perspectives

Corresponding Author: matteo.agostini@ucl.ac.uk

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Commemorating Ettore Fiorini

Corresponding Author: oliviero.cremonesi@mib.infn.it

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La Forza Nascosta (Theatrical Performance, in Italian with English subtitles)

The show offers a view of 20th-century Physics through the eyes of four protagonists: American astronomer Vera Cooper Rubin, Austrian nuclear physicist Marietta Blau, Chinese particle physicist Chien-Shiung Wu and Italian Milla Baldo Ceolin.

Neutrino Telescopes / 103

Observations of High-Energy Astrophysical Neutrino Fluxes with IceCube

Corresponding Author: wiebusch@physik.rwth-aachen.de

In 2013, IceCube detected a diffuse flux of astrophysical neutrinos between a few TeV up to multiple PeV.
Meanwhile, this flux has been established in multiple detection channels with high significance, and with added data the accuracy of these observations have been improved in the recent years. The

observed flux is a combination of extragalactic and galactic origin and indications are found that the energy spectrum is more complex than a simple power-law. Interpreting the observations across the detection channels is difficult because of differing energy range, flavor sensitivity, sky coverage, and experimental uncertainties. Therefore, the goal for a global analysis is improving the overall understanding of the observed fluxes by combining the results of the different channels within one consistent analysis. This talk will summarize recent results of the different detection channels as well as initial results from the global analysis.

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Realtime Alerts and Archival Searches for Time-Evolving Neutrino Flares Using the IceCube Gamma-Ray Follow-Up (GFU) Platform

Author: Sarah Louise Mancina[1]

[1] *Univerità degli Studi di Padova*

Corresponding Author: mancina@pd.infn.it

The discovery of a high energy neutrino from IceCube coincident in time with flaring activity in gamma-rays from TXS 0506+056 solidified neutrinos as an integral part of the emerging field of multimessenger astrophysics. From the direction of the source, an archival neutrino flare was also identified and contributed to the significance of TXS 0505+056 as a neutrino source. An alert stream for time-evolving neutrino flares comprised of sub-threshold events had been developed for IceCube; however, TXS 0506+056 was not among the considered sources due to a lack of redshift information. These flare alerts were optimized to look for AGN flares from nearby sources such that imaging air Cherenkov telescopes (IACTs) could follow-up the alerts by looking for high energy gamma-ray emission. Therefore, lists of sources for each IACT were developed and monitored for neutrino flares. Additionally, an all-sky version of the alert was developed to provide a model independent search but requires a higher threshold to trigger an alert due to the increased number of trials. In this presentation, we discuss the structure of the alert platform and also give results from archival searches using the analysis. We will also cover future developments for this neutrino flare alert stream including improving the performance and also expanding the scope.

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First result of a search for Diffuse Supernova Neutrino Background in SK-Gd experiment

Author: Masayuki Harada[None]

Corresponding Author: pc3g4sej@s.okayama-u.ac.jp

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, low-energy electron antineutrinos via inverse-beta decay can be searched with efficient neutron identification thanks to high cross-section and high energy gamma-ray emission of thermal neutron capture on Gd. Until July 2022, the observation is operated with the 0.01% Gd mass concentration. The neutron capture fraction on Gd is about 50% at that time. We report the first search result for the flux of astrophysical electron antineutrinos 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 of the initial stage of SK-Gd.

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Super-KamiokaNDE- physics & astrophysics

Corresponding Author: mposiada@fuw.edu.pl

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Solar Neutrinos, Borexino and beyond

Corresponding Author: barbara.caccianiga@mi.infn.it

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Sterile Neutrino searches at reactors

Corresponding Author: david.lhuillier@cea.fr

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Status and perspectives of KM3NeT

Corresponding Author: coniglione@lns.infn.it

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SuperNovae Neutrino Observatories

Corresponding Author: luca.pattavina@lngs.infn.it

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Astrophisical sources of high-energy neutrinos

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The T2K Experiment

Corresponding Author: thomas.holvey@physics.ox.ac.uk

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The NOvA Experiment

Corresponding Author: kirk.r.bays@gmail.com

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Short Baseline Neutrino Oscillations at Fermilab

Corresponding Author: varanini@pd.infn.it

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The JUNO Experiment

Corresponding Author: y.malyshkin@gsi.de

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The Hyper-KamiokaNDE Experiment

Corresponding Author: nataly.ospina@uam.es

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DUNE at LNBF

Corresponding Author: c.touramanis@liverpool.ac.uk

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ESSNuSB at ESS

Corresponding Author: tord.ekelof@physics.uu.se

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Neutrino Experiments at CERN

Corresponding Author: giovanni.delellis@na.infn.it

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Physics Beyond the Standard Model with Neutrinos

Corresponding Author: mbustamante@nbi.ku.dk

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Direct Neutrino Mass Measurements

Corresponding Author: josephf@mit.edu

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Towards a Unified Model of Neutrino-Nucleus Interactions

Corresponding Author: omar.benhar@roma1.infn.it

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Towards a global analysis of absolute neutrino masses

Corresponding Author: eligio.lisi@ba.infn.it

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Cosmological limits on neutrino masses and species

Corresponding Author: omena@ific.uv.es

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What we are learning from the LIGO/VIRGO signals

Corresponding Author: dvorkin@iap.fr

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Multimessenger Astrophysics

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The Einstein Telescope

Corresponding Author: michele.punturo@pg.infn.it

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Perspectives for Ultra High Energy neutrinos

Corresponding Author: karle@icecube.wisc.edu

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New Neutrino Telescopes and Networking Initiatives

Corresponding Author: christian.spiering@desy.de

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The Hubble Constant Tension

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A multi-cubic-kilometer neutrino telescope in the Western Pacific Ocean

Author: Donglian Xu[1]

[1] *Tsung-Dao Lee Institute Shanghai Jiao Tong University*

IceCube's groundbreaking discovery of an all-flavor diffuse, extragalactic neutrino flux has ignited a new era in astrophysics. This revelation, coupled with the identification of potential neutrino sources, has spurred the development of next-generation neutrino telescopes with significantly enhanced sensitivity. These upcoming detectors aim to decipher the enigma behind the diffuse neutrino flux sources, unveil the origin of cosmic rays, and search for physics beyond the Standard Model over cosmic scales. Amid the global efforts to construct advanced neutrino observatories, a telescope situated near Earth's equator uniquely offers access to the entire neutrino sky. In this talk, we will discuss a successful pathfinder experiment, which has identified and characterized a promising site in the Western Pacific Ocean (northwest of South China Sea). We will also present the conceptual design of the future TRIDENT neutrino telescope, its key performance and projected timelines.

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Istituto Veneto delle Scienze, Lettere ed Arti

Plenary Session / 133

Department of Physics, Padova University

Corresponding Author: elisa.bernardini@pd.infn.it

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INFN, Sezione di Padova

Corresponding Author: roberto.carlin@pd.infn.it

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Local Organizing Committee

Corresponding Author: mezzetto@pd.infn.it

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Conclusions

Corresponding Author: mezzetto@pd.infn.it