

A short report of the NNN

Marcio R. Adames^{1*}

 ¹Federal University of Technology — Paraná, Curitiba, Paraná, Brasil

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Outline

- **Next Generation Nucleon Decay and Neutrino Detectors**
- Day one
- Day two
- Day three
- Day four
- Day five

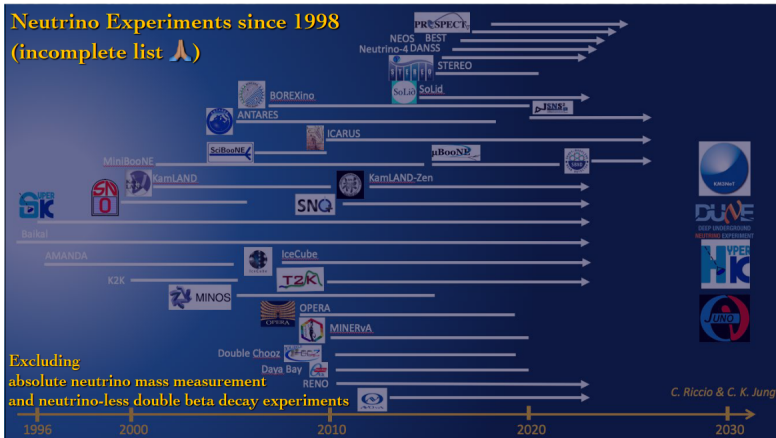
Next Generation Nucleon Decay and Neutrino Detectors

Next Generation Nucleon Decay and Neutrino Detectors

History of the NNN

Chang Kee Jung

Neutrino Experiments since 1998 (incomplete list 🙏)

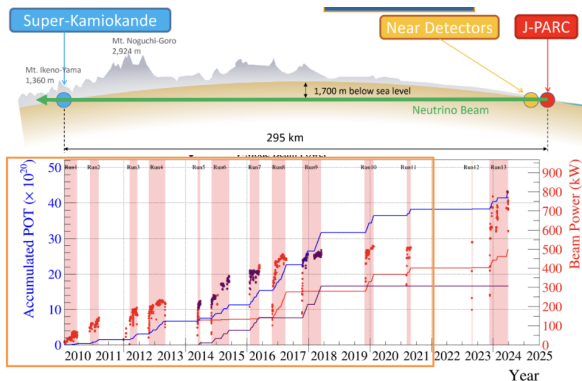


- Story of the origins of the conference.
- The proton decay searches gave us neutrino detectors.

Day one

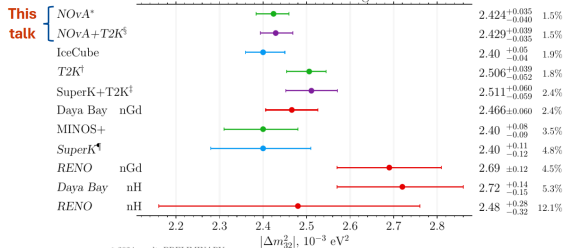
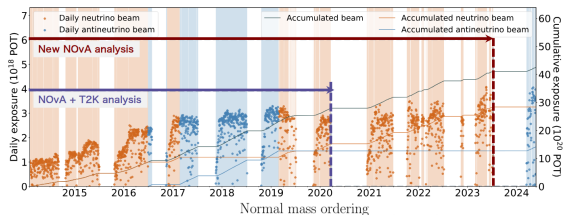
T2K latest results and future prospects

Jianrun Hu



- New T2K oscillation analysis includes 10% more data in neutrino mode and improved detector systematics.
- CP conservation rejected at 90%.
- First joint oscillation analysis of SK atmospheric + T2K accelerator neutrino has been performed.
- A limited rejection of inverted mass ordering at 90%.
- CP conservation rejected at $\sim 2\sigma$ (depending on the analysis).
- First joint oscillation analysis of NOvA+T2K shows no strong preference on mass ordering.

New Results from the NOvA experiment & the joint-fit with T2K - Zoya Vallar



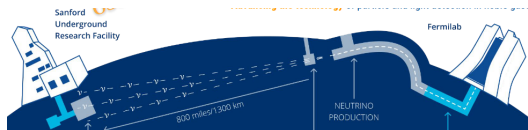
NOvA + T2K analysis:

- Excellent precision on Δm_{32}^2 . No strong mass ordering preference.
- $\delta_{CP} = \pi/2$ lies outside 3σ C.I. for both orderings. If inverted ordering, CP conserving points lie outside 3σ C.I.

New NOvA analysis:

- Doubled neutrino data set. New samples, simulation and systematics update featured in this analysis.
- Leading single experiment precision on Δm_{32}^2 . 87% preference for Normal Mass Ordering.

Deep Underground Neutrino Experiment: DUNE, Current Status and Perspectives - G. Valdivieso



DUNE goals:

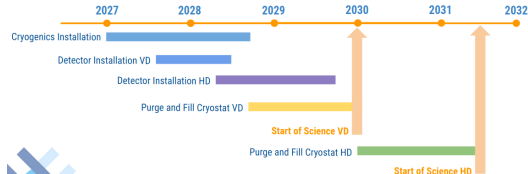
- Determine the neutrino mass ordering (sign of Δ_{31}); the octant of θ_{23} (above or below 45°); if CP is violated in the leptonic sector (measure δ_{CP}); if the 3 flavor mixing + MSW model is correct.

Construction update:

- Caverns were inaugurated (huge);
- Second run of ProtoDUNE was completed a few weeks ago.

Brazilian contribution:

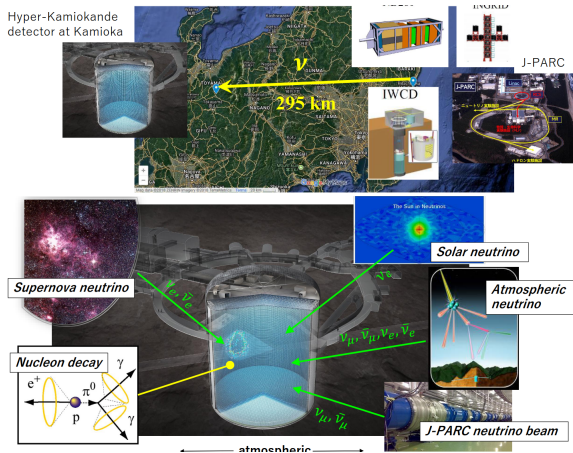
- The HD PDS (X-Arapucas).
- Cryogenics for the far detector.



Status of the Hyper-Kamiokande Experiment

Yousuke Kataoka

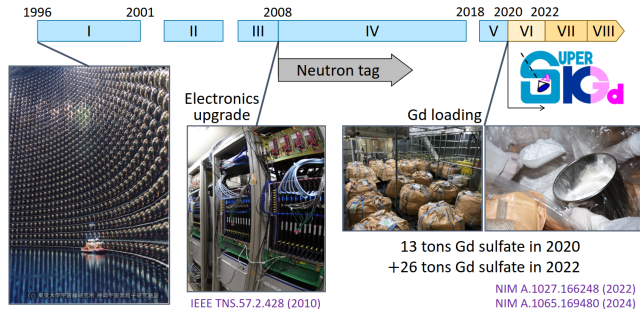
Hyper-Kamiokande detector at Kamioka



- HK is the 3rd generation Water Cherenkov Detector in Kamioka (20 times larger statistics than SK).
- HK improve physics sensitivities for various targets.
- HK construction is on-going on schedule and will start operation in 2027.
- Great capabilities for Nucleon Decay Search.

SuperK latest results and future prospects

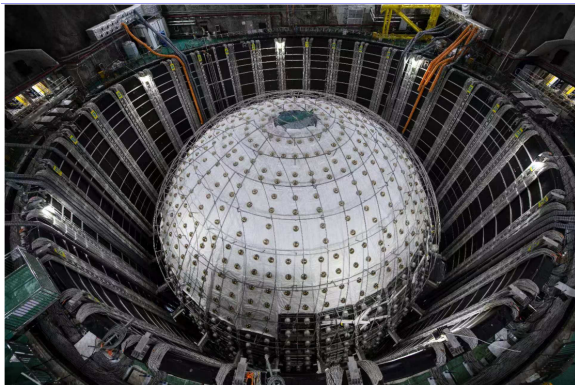
Shintaro Miki



- Atmospheric neutrinos: Analyzed full pure-water data set. Prefer normal ordering with $CL_s = 0.077$. SK-Gd data analyses ongoing. Sensitivity to MO is improved by 33%.
- DSNB: Update the flux limit with SK-Gd data. Spectral fit shows 2.3σ excess to null.
- Reactor: First positive observation in SK, correlated with reactor power.
- Nucleon decays: Updates in two modes: $n \rightarrow \mu\pi^0$ and $p \rightarrow e^+X$. (No signal excess found)

JUNO status and future prospects

Prof. Xiaonan Li



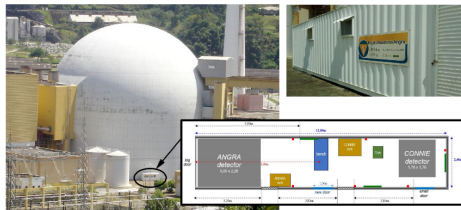
Although the project delayed, many challenges were overcome and the installation is nearing its end.

Commissioning shows that the performance of (part of) components/detector is better than the requirement.

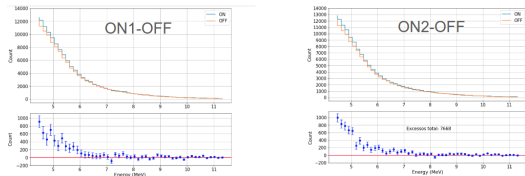
Expect to start filling phase in December of this year.

Latest results from the Neutrinos-Angra Project

Pietro Chimenti



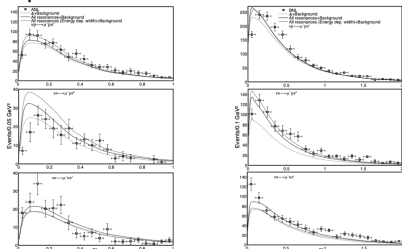
- Neutrinos Angra is successfully monitoring the Angra-II nuclear reactor since 2020.
- The project has been entirely conceived, designed, constructed and run in Brazil. Small local projects are important for Brazilian science.
- Neutrino detectors are also efficient neutron detectors. This can be used to monitor spent fuel movements near the plant.



Clear Excess of reactor ON periods with respect to reactor OFF.

Weak pion production in neutrino-nucleus scattering. - Alejandro Mariano

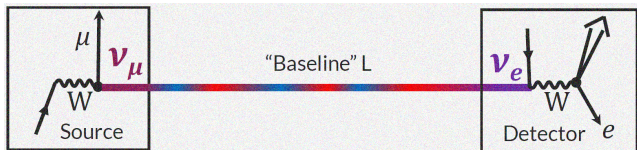
π prod. on N.



- We have calculated the total cross section for weak pion-production on nucleons.
- We also developed a model to describe quasi elastic (QE) ν and $\bar{\nu}$ ($\sim \text{GeV}$) scattering by nuclei within a nuclear matter quantum hydrodynamics relativistic approach. We introduced the effect of ground-state correlations (GSC) through a momentum distribution calculated perturbatively, and also final-state interactions (FSI) using a perturbed nucleon and Δ propagators dressed by a self-energy with nucleon-nucleon and Δ -nucleon correlations.
- The model takes into account of 2p2h and 3p3h excitations in addition to the CCQE 1p1h ones. Results are promising, and the model worked quit well. It is clear that now to analyze weak pion production (CC π) on the detector nucleus, many additional effects appear regards the production on nucleons.

Overview of neutrino oscillations

David Vanegas Forero



Neutrino Experiment=Source+Detector,
separated the CORRECT baseline



Solar

Homestake, GALLEX/GNO,
SAGE, Borexino

SuperKamioande (SK), SNO

KamLAND (LBL reactor)



Atmospheric

SuperKamioande (SK)

IceCube DeepCore (DC)



Accelerator(LBL)

K2K, MINOS

T2K, NOvA



Reactor(km)

Daya Bay

RENO

- Tunable source or that can be characterized
- Multiple detectors (ND, FD)

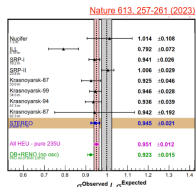
ALL 3-neutrino osc. parameters (& ordering) are aimed to be measured at future neutrino experiments (given the important improvement in precision).

This is not the full story: Massive neutrinos imply BSM physics

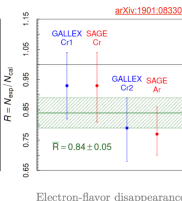
- BSM physics searches already been performed at Osc. Exps.
- With significant improvement in precision, subleading effects could be found for at neutrino oscillation Exps.

PROSPECT-I final oscillation results and PROSPECT-II physics goals and detector design - Ohana B. Rodrigues

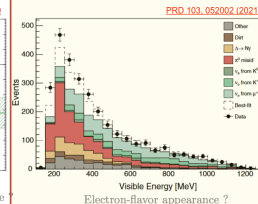
Reactor Antineutrino Anomaly



Gallium Anomaly



LSND/MiniBooNE Anomaly



We have set world-leading limits on sterile neutrino oscillations with the final PROSPECT-I dataset

- Neutrino-4 BF ruled out at $> 5\sigma$
 - Gallium Anomaly allowed $\Delta m^2 < 10\text{eV}^2$ rule out at 95% C.L.
 - Leads global SBL electron-flavor disappearance limits over most of the $3 - 10\text{eV}^2$ phase space
- PROSPECT-II robustness give us the chance to push even further the borders of knowledge we currently have in the field.



Goals: - Search for sterile neutrino oscillations; - Precise measurement of the ^{235}U antineutrino spectrum

Direct Neutrino Mass Measurements

Alessandro Schwemmer

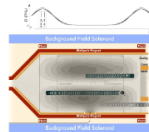
KATRIN

- New **leading upper limit** from **KATRIN**: $m_\beta < 0.45$ eV
- **Continue** measuring, target **sensitivity** $m_\beta < 0.2$ eV
- **R&D** phase started for **atomic source** and **micro-calorimeters**



Project 8

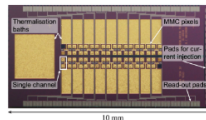
- First **frequency-based** upper limit from **Project 8**: $m_\beta < 155$ eV
- Development of **large-volume CRES** and **atomic source**



ECHo and HOLMES

- New / updated results: $m_\beta < 19$ eV (ECHo) and $m_\beta < 28$ eV (HOLMES)

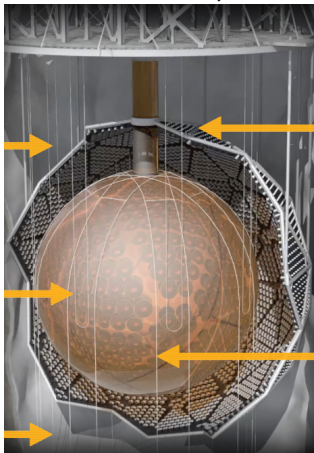
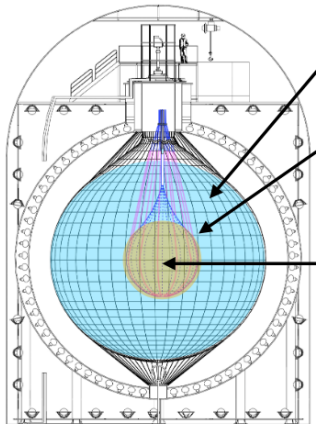
→ Increase **number of detectors** and **activity**



- Perform electron spectroscopy. Count e^- in the last eV.
- Measurement of cyclotron frequency from trapped electrons.
- Performed using low-temperature micro-calorimetry.

Neutrinoless double beta decay: status and prospects of searches with liquid scintillator detectors - José Maneira

Kamland-Zen Detector The SNO+ experiment



Neutrinoless double beta decay (only for Majorana neutrinos) a very high priority search:

- Complementary to CP violation searches in neutrino oscillations

Liquid scintillator technique has many advantages:

- High mass, low backgrounds, scalability, target-out measurements

SNO+ is already taking high quality liquid scintillator data.

The precise inverse beta decay

Giulia Ricciardi

Inverse beta decay (IBD)



*by far the most important mechanism
of interaction of low-energy
antineutrinos*



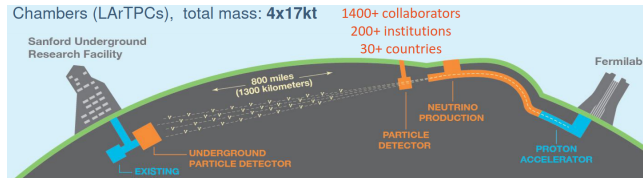
Calculation of the amplitude

**precision of theoretical cross section
crucial for high statistics experiments**

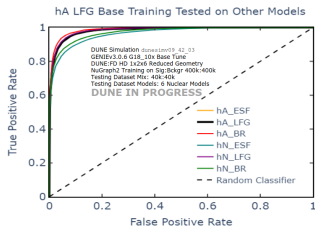
GR, Vissani & Vignaroli JHEP 08 (2022) 212

The new calculations improved the determination of the cross section and assessment of uncertainty! (in comparison to the 2003 commonly used calculations)

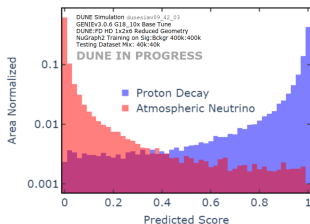
Application of NuGraph to Proton Decay for Event Classification ... in DUNE - Tyler Stokes



94.88% Event Recall | 0.96 to 0.98 AUC

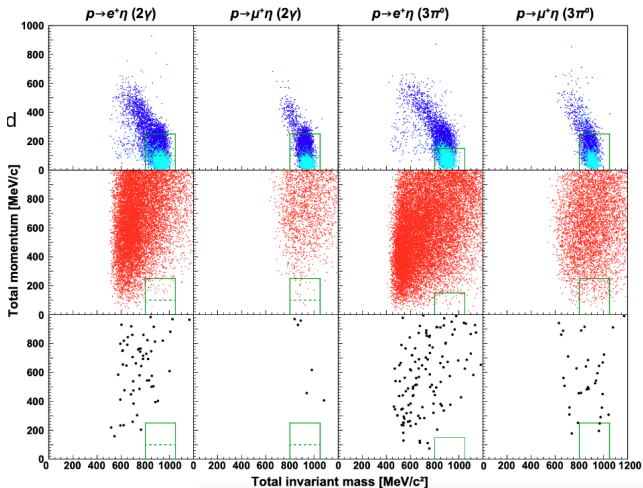


NuGraph Classification Score Distribution



- NuGraph is a Graphical Neural Network originally designed for semantically classifying detector hits;
- The network has been expanded to perform event classification for proton decay;
- Iteration over nuclear model configurations can provide a conservative estimate of nuclear model uncertainty;
- NuGraph performance is very encouraging! (0.98 Area Under the Curve).

Search for proton decay via $p \rightarrow e^+ \eta$ and $p \rightarrow \mu^+ \eta$ in Super-Kamiokande - Natsumi Taniuchi



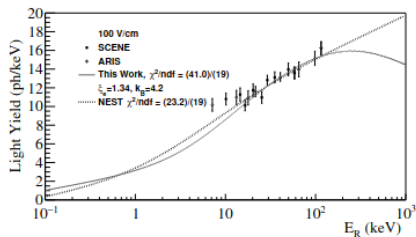
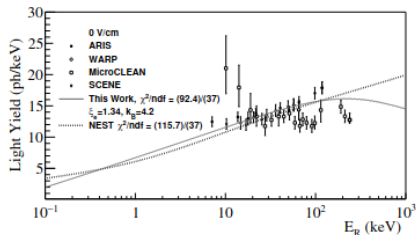
Why eta? $p \rightarrow e^+ \eta$ and $p \rightarrow \mu^+ \eta$

- Similar to golden $p \rightarrow e^+ \pi_0$: 3 e-like rings
- High efficiency: all decay products are detectable
- Back-to-back emission: monochromatic momentum of η (~ 310 MeV/c)

Number of candidates consistent with background prediction.

No indication of proton decay. New lifetime estimates.

Light and Charge yield study in LAr for Sub-keV energies up to 1 MeV - Youssef Sarkis Mobarak

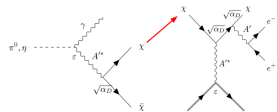
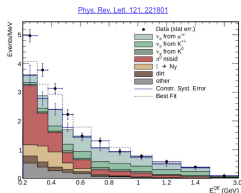
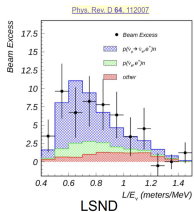


- We present a first principles approach study based on an integral equation for interactions in pure LAr.
- We give a physical interpretation of ε_e that allow to describe the N_{ex}/N_i ratio as function of energy and field.
- With just one parameter, $C_{LAr} = 0.37 \pm 0.07 (V/cm)^{\delta_{LAr}}$ we can describe data for LAr and LXe. Usfull for phenomenology studies.
- The model for Charge yield have a better match with data than NEST, thanks to Bates-Griffing process.
- The publication with a software to produce outputs soon.

Day three

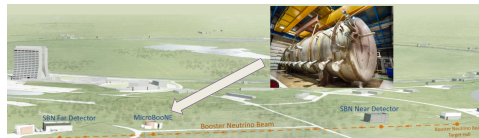
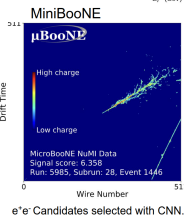
MicroBooNE Latest Results and Future Prospects

Christopher Thorpe



Dark matter particle χ produced in decays of n^0 and η s produced in the NuMI target.

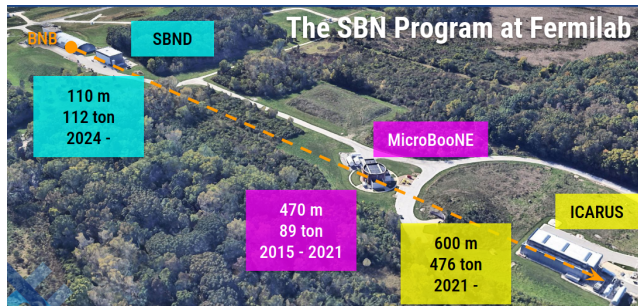
These propagate to MicroBooNE where they interact, producing a dark photon which decays to e^+e^-



MicroBooNE is LArTPC with a wide ranging physics program covering oscillations, BSM, neutrino-nucleus cross sections, reconstruction, and LArTPC detector physics. We have:

- a number of results probing the MiniBooNE and LSND anomalies (disfavour ν_e expl.).
- produced a number of results searching for BSM particles produced in our neutrino beams (exclude new regions).
- may infer protons in tracks.

Status of the Short-Baseline Near Detector at Fermilab - Gustavo Valdivieso



SBND (and SBN) Science Goals: Sensitive search for sterile neutrino through oscillations; Precision neutrino-nucleus interactions studies; Beyond Standard Model physics searches.

- Data taking began early in July 2024.
- Physics SBND: Sterile Neutrino Searches; Neutrino-Argon Interactions; BSM physics searches.
- World leading statistics for many processes (in three years).
- X-Arapucas - Specialized photon sensors developed in Brazil.

SBND Timeline



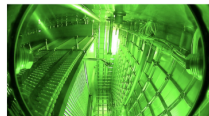
September 2022
Detector assembly completed



December 2022
Detector transported



April 2023
Detector lowered

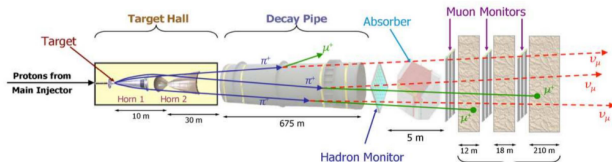


March 2023
LAr filling completed

Hadron Production Experiments

Lu Ren

How to Make a Neutrino Beam



EMPHATIC

Experiment to Measure the
Production of Hadrons At Testbeam
In Chicagoland

Located at Fermilab Test Beam Facility (FTBF)

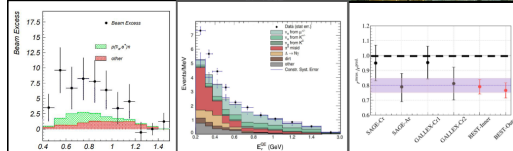
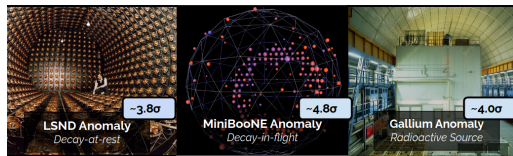


NA61/SHINE
The SPS Heavy Ion and Neutrino
Experiment

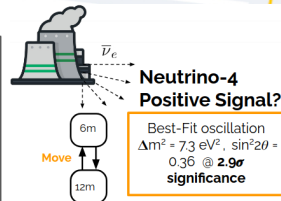
Located at CERN SPS North Area

- Measurements of hadron production are critical to constraining the neutrino flux;
- EMPHATIC and NA61/SHINE are two complementary hadron production experiments;
- Both aim to improve flux predictions for current and future: Accelerator-based neutrino experiments, Atmospheric neutrino experiments and Spallation neutron source neutrino experiments

Short-Baseline Anomalies and Sterile Neutrinos: where we stand and where we're going - Mark Ross-Lonergan

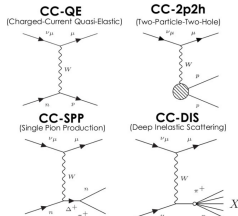


All **individually** consistent with neutrino oscillations
with a mass difference $\Delta m^2 \sim \mathcal{O}(1 \text{ eV}^2)$



- The vanilla 3+1 sterile neutrino interpretation of the anomalies is very much in trouble;
- Regardless of your belief in an eV scale sterile neutrino, the anomalies have survived scrutiny and still need explanations!
- Current and next-gen SBL neutrino experiments acting as portal to the dark sector is a thriving direction, motivated at first by anomalies but now as a field in their own right!

Role of near detectors: near-to-far extrapolation



S.Dolan, NOW2022

- Talked about the importance of determining (true) E_ν and how current and future experiments can do it.
- Current experiments: fixed near detectors can constrain flux & cross section with required precisions.
- Next generation experiments: Movable detectors need to be able to measure true E_ν dependence of cross sections; directly measure (anti-)electron neutrino cross sections.

DOE Project Scope – Far Site - Unicamp-SP-Brazil - In-kind contribution to LBNF-DUNE



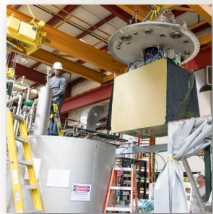
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LAr Purification for LBNF-DUNE Fluid Dynamics

Analysis of LAr Purification... - Prof. Dirceu Norlier



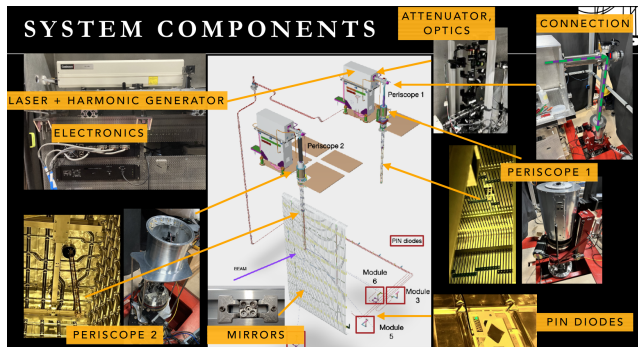
PuLArC (UNICAMP)



ICEBERG (Fermilab)

- Contaminants (N_2 , O_2 and H_2O) in argon significantly affect experimental results.
- Argon is purified using a filtering media (which captures O_2 and H_2O).
- Typical filters can't remove N_2 , it must be kept low in the argon purchasing specification.
- An effective removal of N_2 impurities during liquid argon circulation was not known and it is desirable.
- Developed a Li-FAU zeolite media that can filter the three contaminants.
- Developed detailed models and simulations for the purification system.
- The proposed model was able to match the experimental results obtained with the ICEBERG cryostat.

The ionisation laser calibration system for DUNE - José Maneira



- DUNE measurements rely on a very good energy performance;
- Calibrations are important to measure model parameters and check reconstruction performance.
- Calibrations will make use of several natural and deployed sources;
- DUNE has proposed a series of improvements over the MicroBooNE laser system, that are being tested at ProtoDUNE;
- Construction, installation and commissioning of PD-HD system completed at CERN. Taking data now!
- Next: PD-VD. And then... far detector construction!

Novel LArTPC technologies for near detectors

Zoya Vallari

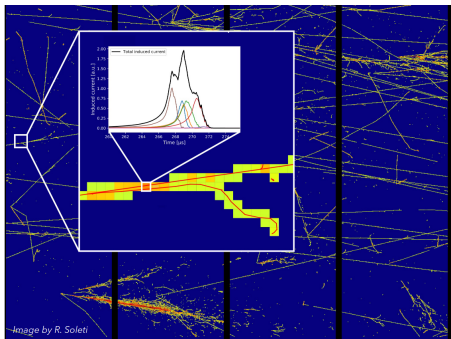


Image by R. Soley

Caltech

ZOYA VALLARI, NNN 2024

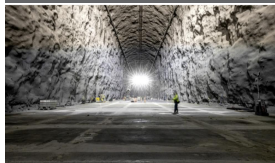
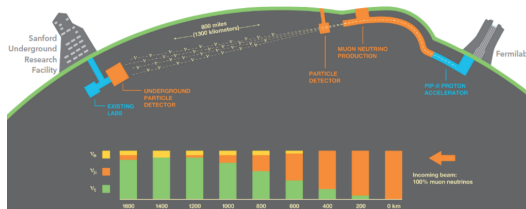
OCT 31, 2024 42

We are excited to embrace the challenge of “too-many-neutrinos” in the precision era of neutrino physics. We aim to capture every neutrino interaction—pixel by pixel!!

To cope with the extremely high-multiplicity environment of the most powerful accelerator neutrino beam, DUNE ND-LAr employs multiple advanced technologies for next-generation LArTPCs:

- $\sim 14\text{M}$ pixels across a 5×7 array of TPC modules.
- Central cathode.
- Two anode planes of PCB tiles with gold-plated pixel pads and LArPix ASICs on opposite sides.
- Optically segmented modular design with 50 cm drift.
- Resistive shell field cage with light detection modules on the side.

DUNE Far Detector: current and new technologies - Andre F. Steklain Lisboa



- Far site excavation is complete
- Next: Building & Site Infrastructure work until mid-2025
- Cryostat warm structure is on its way to US from CERN to be installed in 2025-26
- Far Detector installation in 2026-27
- Purge and fill with argon in 2028
- Physics in 2028 or early 2029
- Beam physics with Near Detector 2031



DUNE is a long-baseline oscillation experiment and neutrino observatory:

- Unique and complementary reach in oscillations, MeV-scale neutrinos, and BSM searches.
- DUNE Far Detector is essential to achieve its scientific goals.
- DUNE has an active prototyping program, with excavation complete and components under construction → start of science in this decade.
- See also other Talks and Posters from DUNE!

COHERENT: Latest Results and Future Prospects

Jonathan Link

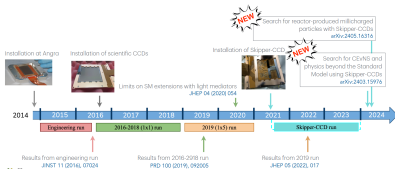


- CEvNS is the process of a neutrino scattering off of a nucleus without changing its internal structure.
- CEvNS is a Standard Model prediction, it should in fact exist and it should be tested for.
- Coherent is a suit of detectors located at the Spallation Neutron Source at Oak Ridge National Laboratory.
- The main aim of the COHERENT collaboration is to make direct measurements of CEvNS.
- CEvNS were detected in Cesium Iodide detectors (updated in 2022). Also detected by other detectors.

Coherent Neutrino-Nucleus Scattering Experiment - CONNIE - Carla Bonifazi



Angra - Brazil



- Skipper-CCDs showed to be very promising for detecting low-energy processes
- Excellent performance in 2021-2023 with flat background and 15 eV energy- threshold
- New CEvNS limit with 18.4 g-days is comparable to previous with larger exposure.
- New competitive limits on vector mediator, DM modulation and millicharged particles.
- The experiment started its next phase with a 16-sensor Multi-Chip-Module.

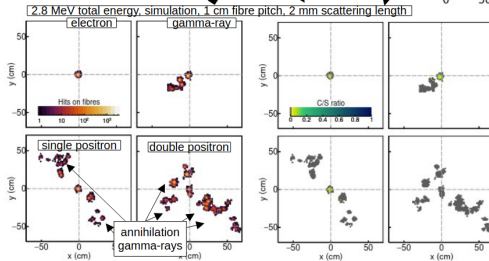
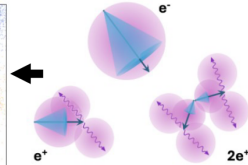
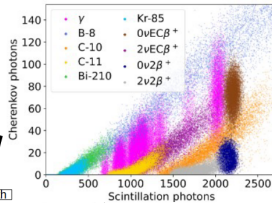
Novel Scintillation Detector - Stefan Schoppmann



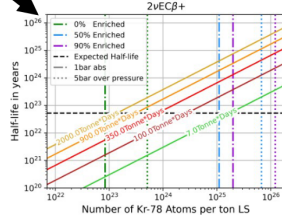
NuDoubt⁺⁺: Search For Double Beta Plus Decays



Combining hybrid and opaque scintillators
 → improved discrimination techniques to measure double positron decays
 → using coated wavelength shifters (OWLS) to double light readout
 → high pressure krypton loading
 → arXiv:2407.05999



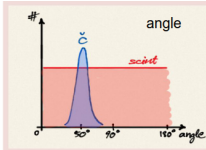
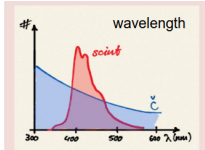
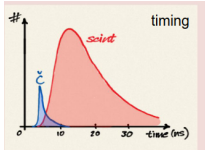
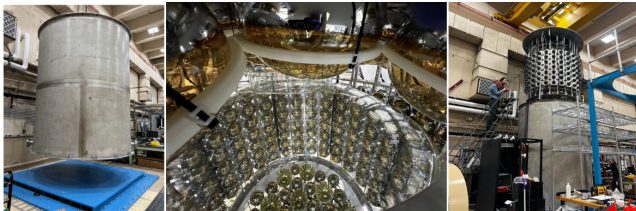
within one calendar year of operation:



→ 5 σ detection of $2\nu\text{EC}\beta^+$ / $2\nu2\beta^+$

→ limits on $0\nu\text{EC}\beta^+$ / $0\nu2\beta^+$ improved by factor 1000

The Eos experiment - Lu Ren



- Eos is a performance demonstrator of the hybrid neutrino detection concept. (Cherenkov and scintillation light)
- Installation finished in March and commissioning completed in May 2024.
- Just completed water-phase calibration data-taking and filling of WbLS (Water based Liquid Scintillator) is in progress.
- Will provide valuable input to future kilo-ton scale hybrid detectors, such as Theia.

The future of neutrino astronomy with TAMBO

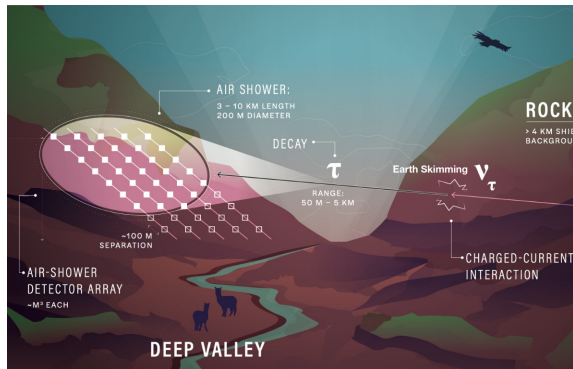
Pavel Zhelnin

Science goals of TAMBO

Discover new ν point sources

Constrain the astro flavor ratio
by measuring ν_τ component

Characterize the 1-100 PeV
 ν flux



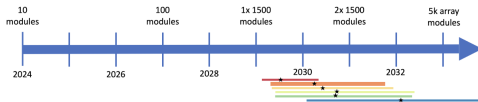
TAU AIR-SHOWER MOUNTAIN-BASED OBSERVATORY (TAMBO) • COLCA VALLEY, PERU

What's next for TAMBO

- Release full simulation ~ 99%
- Hardware development
 - Scintillator construction
 - DAQ system
- Deployment to test sites (US, Peru)
- Interested in joining? Contact (me or Carlos Argüelles) at pzhelnin@g.harvard.edu or carguelles@g.harvard.edu



TAMBO simulation development team

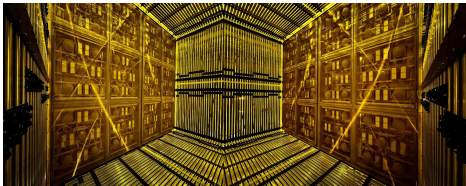


Day five

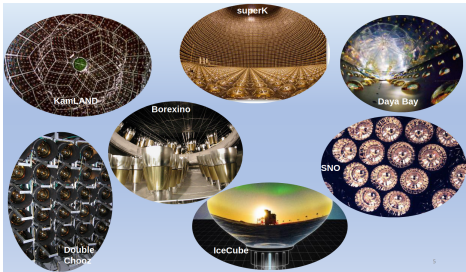
Day five

Photon detection in neutrino physics

Ettore Segreto



196 small X-ARAPUCAs installed in the SBND detector at Fermilab



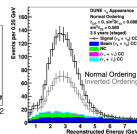
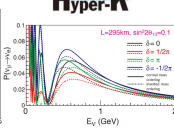
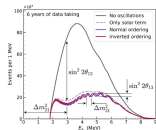
- Light detection plays a central role in neutrino physics.
- PMT still widely used by the community.
- New technologies are emerging and are being considered/used by some of the next generation experiments.
- New developments and new ideas need to be pursued and encouraged.
- New sensors and detection technique will enable the discoveries that are in front of us.

ANNIE - The Accelerator Neutrino Neutron Interaction Experiment - Matt Wetstein



- ANNIE has achieved many important technical firsts: First detection of neutrinos with Gd-water (beam?); First detection of neutrinos with an LAPPD; First detection of neutrinos with WbLS.
- Gained considerable operational experience w/ these technologies.
- Made significant progress on the reconstruction tools.
- First data with LAPPDs shows powerful imaging capabilities.
- ANNIE is now in a unique position to measure neutrino-nuclear cross sections in water - complementary and synergistic the the LAr short baseline program at FNAL.

Systematics in Next Generation Oscillation Experiments - Joe Walsh



Model Driven

Use data to constrain systematic models – Can help you understand underlying physics

Need adequate model freedoms to describe data

Significant risk of model dependent bias in results

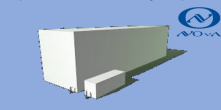


Data Driven

Use data from one detector to more directly make predictions for a functionally identical or similar

Avoids model dependencies

Still need to understand any possible differences between very similar detectors like size, flux, or geometry



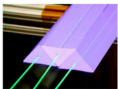
Next generation experiments will be systematically dominated

- Need robust models and measurements to remain unbiased.
- Near detectors are a powerful tool for characterizing our sources.
- Prototypes help us understand the performance of these technologies.
- External measurements by dedicated experiments are valuable.
- Model-independent approaches can reduce our susceptibility to bias.

We can do the work now to prepare for the data we will very rapidly collect with these new 10s kt to 100s kt scale detectors and high intensity sources.

Scintillator detectors: SuperFGD, MINERvA, LiquidO - Hikaru Tanigawa

Scintillation detectors

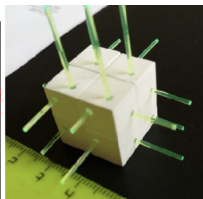
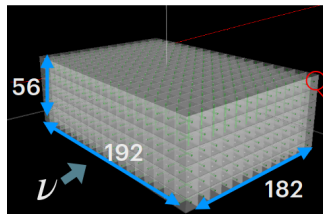


	MINERvA	SuperFGD	LiquidO
technology (segmentation)	Scintillator strip	Scintillator cube	Opaque liquid scintillator
timeline	Data taking in 2009-2019	Data taking started in 2023	R&D since 2013, First experiment (CLOUD) approved
energy scale	multi-GeV acc. neutrino	GeV acc. neutrino	multi-purpose MeV-GeV

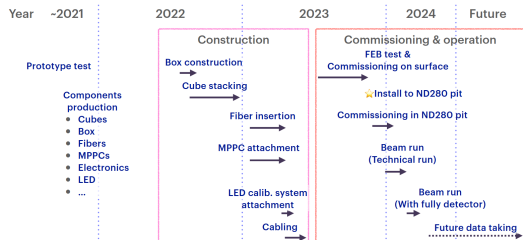
Reviewed 3 types of scintillator detectors.

- MINERvA: Scintillator strips, 8t (inner active region); Data taking completed, performance is very well understood; Actively publishing interesting physics results.
- SuperFGD (T2K Near Detector): Scintillator cubes, 2t; High granularity $\rightarrow 4\pi$ acceptance, low threshold; High readout channel density; Just started physics data taking, working on performance studies.
- LiquidO: Opaque liquid scintillator; Light ball formation $\rightarrow$ self-segmented detector; MeV-GeV application; Good scalability $\rightarrow$ large scale reactor neutrino experiments CLOUD (5-10t), SuperChooz (O(10kt)).

SuperFGD “A high-granularity detector for improved neutrino interaction measurements in T2K” - Hokuto Kobayashi

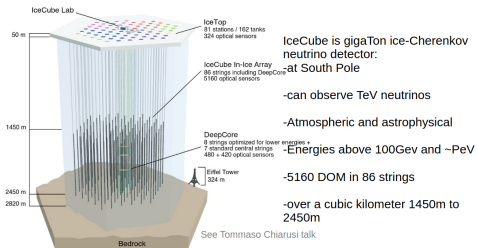
cubes($2 \times 2 \times 2$)

History of SuperFGD



- The SuperFGD consists of scintillation cubes and read-out lights from 3-directions. (Gives short tracks detection and 4π acceptance).
- We constructed and commissioned the SuperFGD. (Cube & box → Fiber & MPPC → Calibration system → Cable → "Commissioning with electronics" → "operation")
- Initial detector calibration and evaluation were performed. (Gain(~ 15 ADC/p.e.) and light yield(for MIP, ~ 45 p.e.) are obtained. Further understanding of the detector performances is in progress.)
- From June 2024, we started stable operation to take neutrino beam data with the fully upgraded ND280. (Physics analysis with upgraded ND280 is on going.)

Constraining the (3+2) sterile neutrino scenario with the IceCube experiment. - Alexander Argüello Quiroga



	$\sin^2 2\theta_{24}$	$\sin^2 2\theta_{25}$	$\Delta m_{41}^2 [\text{eV}^2]$	$\Delta m_{51}^2 [\text{eV}^2]$	$\Delta \chi^2$
Case (A) from Ref. [35]	2.8×10^{-2}	1.5×10^{-2}	1.32	13.9	4.32
Case (B) from Ref. [36]	9.1×10^{-2}	6.8×10^{-2}	0.46	0.77	36.43

- Anomalies in the SBL, reactor and Solar experiments could indicate the presence of sterile(s) neutrinos;
- In principle the number of sterile neutrinos is free;
- To IceCube, more sterile states means more resonances that also means stronger constraints;
- Only 4 parameter are needed to get a conservative constraint;
- We performed a binned Poisson likelihood analysis with various systematics and statistical uncertainties;
- The bounds were compared with the allowed regions of the SBL (A) and (B)
- Case (A) is compatible with IceCube data; Case (B) seems in tension

Neutrino decoherence in Normal matter

Prof. Sarira Sahu

- In this work we have considered the effects of the non-forward neutrino scattering processes on the propagation of neutrinos in a normal matter background.
- We calculated the contribution to the imaginary part of the neutrino thermal self-energy (2-loops) from the non-forward neutrino scattering processes.
- A precise prescription is given to determine the jump operators.

Thank you all for the great workshop!!!