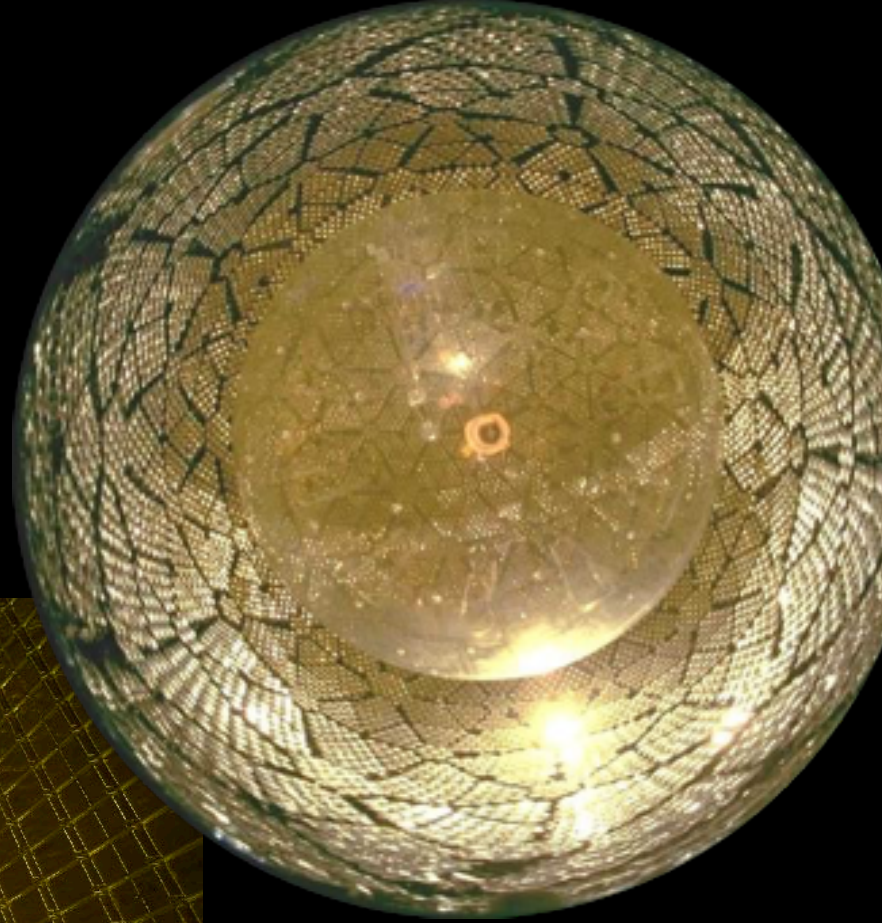
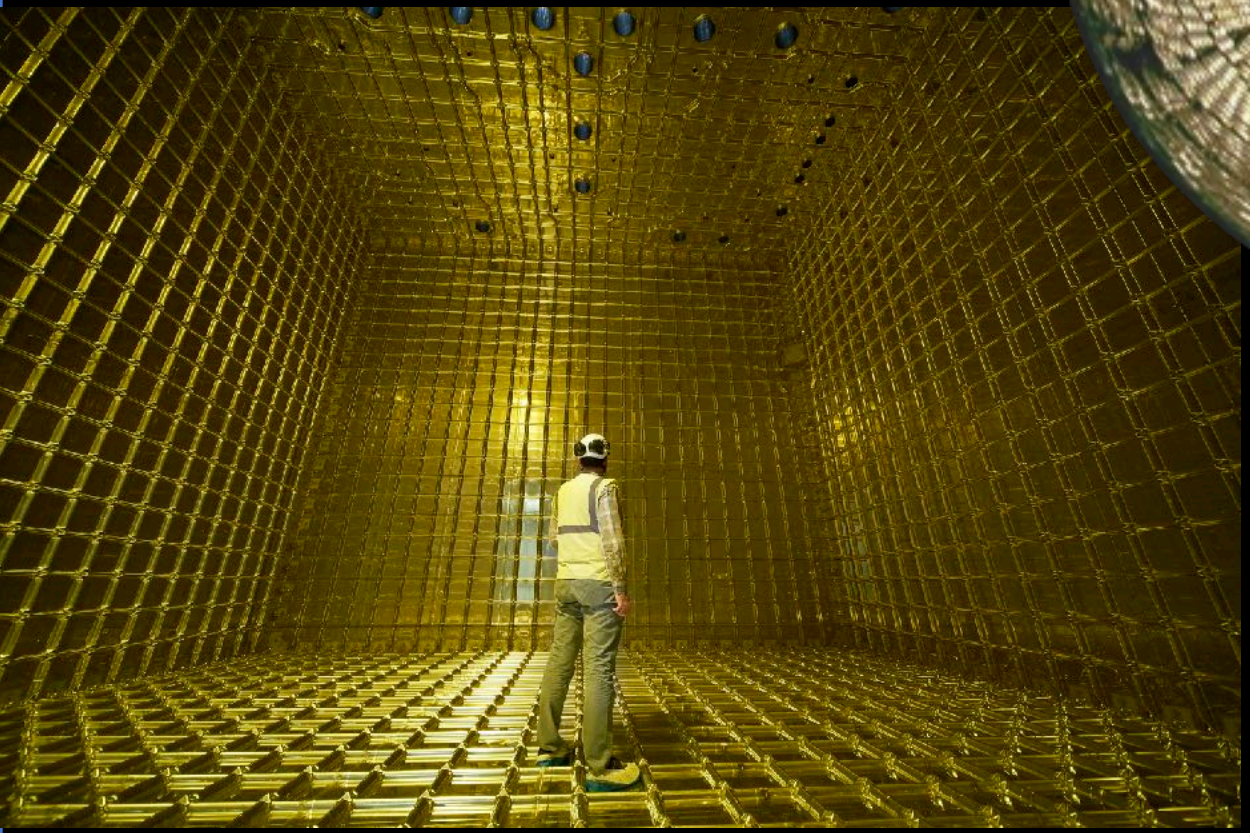
LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Neutrino Physics: SNO+ and DUNE





Jornadas do LIP
Coimbra, Julho 2022

José Maneira

LIP Neutrino Physics group, Jornadas 2020, Braga

LIP coordination, SNO+:

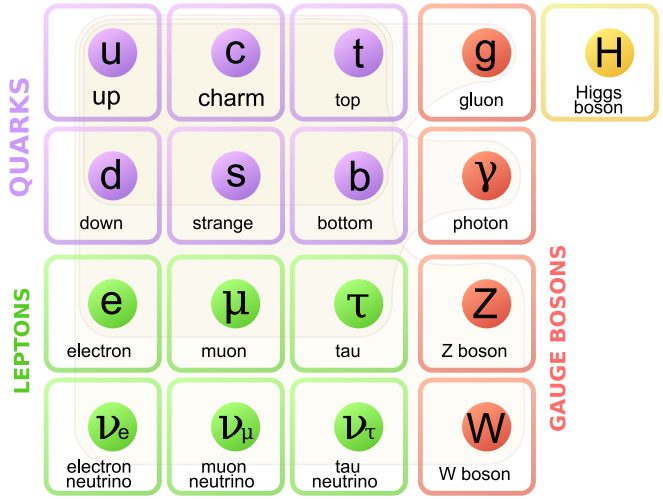
- Backgrounds, Overall Analysis: V. Lozza
- Water phase Analysis: N. Barros
- Antineutrino Physics: S. Andringa
- Board chair, Exe. C., Source Review: JM
- Optics (until 2022): JM, NB

LIP coordination, DUNE:

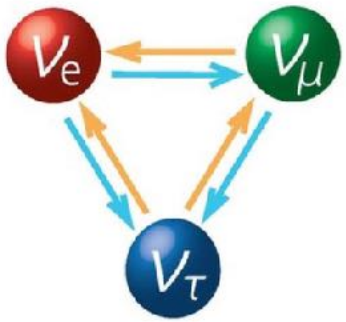
- Calibration and Cryogenic Instrumentation Consortium: JM

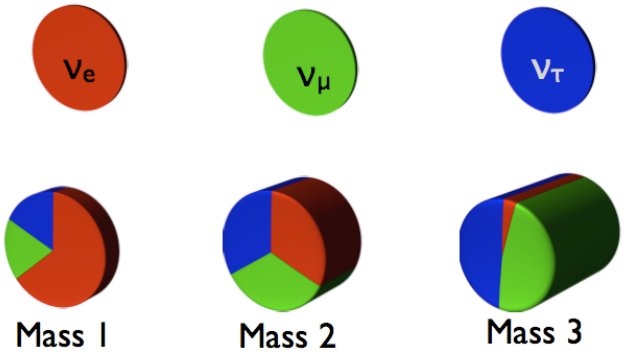
1 MSc, 2 PhD students, 8 researchers. Both @ Lisbon and Coimbra

Neutrino Physics



Neutrino Oscillations





- flavor states $|\nu_\alpha\rangle = \sum_k U_{\alpha k} |\nu_k\rangle$ • mass states

$\nu_\alpha = \nu_e, \nu_\mu, \nu_\tau$ $\nu_k = \nu_1, \nu_2, \nu_3$

PMNS matrix

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{-i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

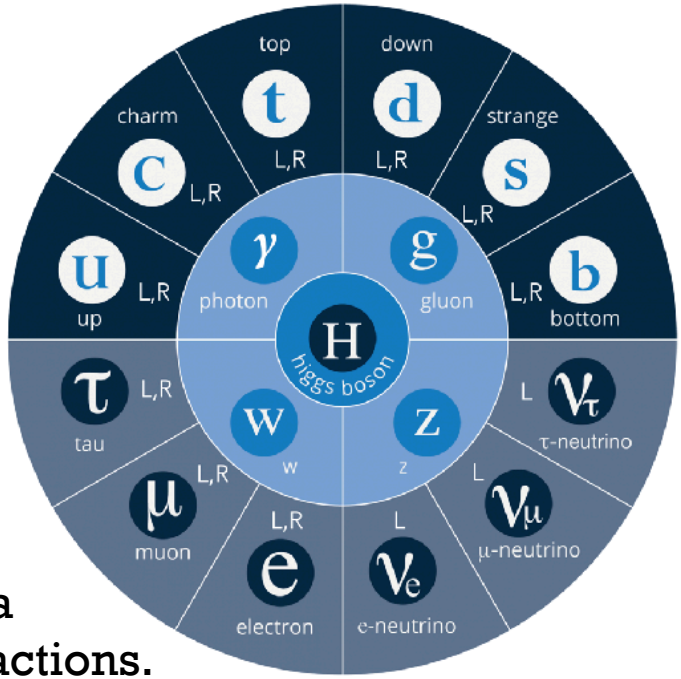
$\theta_{23} \approx 49^\circ$
$40 < \theta_{23} < 52^\circ (3\sigma)$

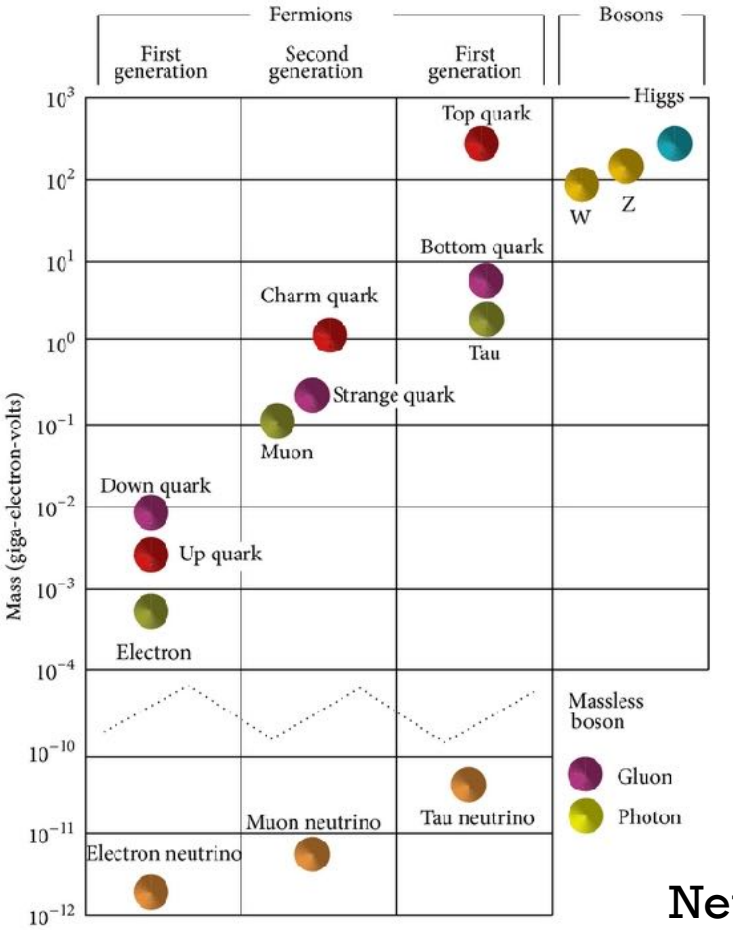
$\theta_{13} \approx 8.6^\circ$

$\theta_{12} \approx 33.4^\circ$

Solar, atmospheric, reactor and accelerator experiments provide consistent support for this framework.

What we know, and don't, about neutrinos



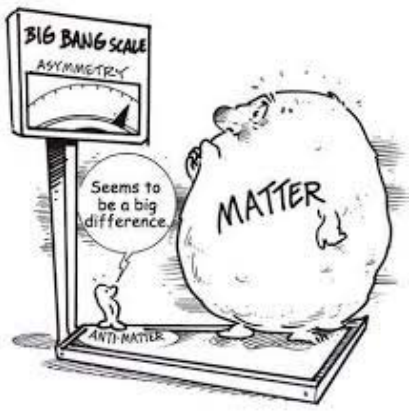


Coupled to e, μ, τ via charged weak interactions. Flavor mixing (oscillations) due to non-zero mass.
Are oscillations the same for neutrinos and antineutrinos?

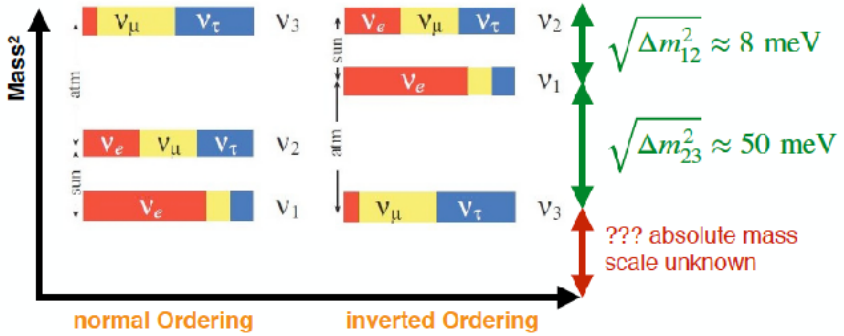
The only neutral elementary fermion.
Can it be its own antiparticle?

Very, very small masses.
Why so small? Due to Higgs or See-saw?

Neutrino abundance in the Universe similar to photons (10^9 x baryons)
What role did they play in Big Bang?
Matter/antimatter asymetry?



The next big questions ?

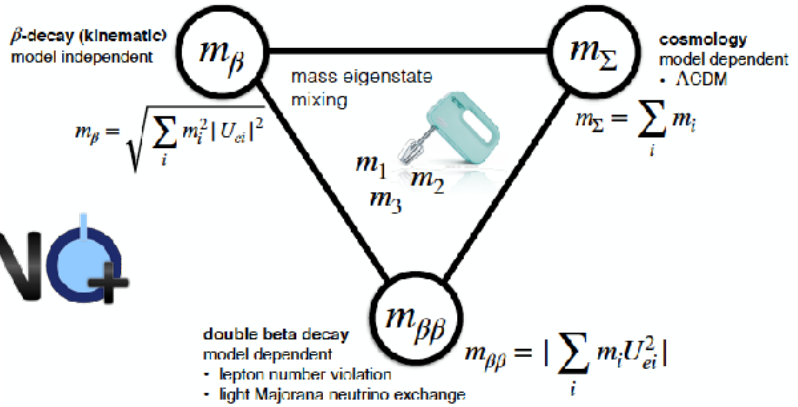


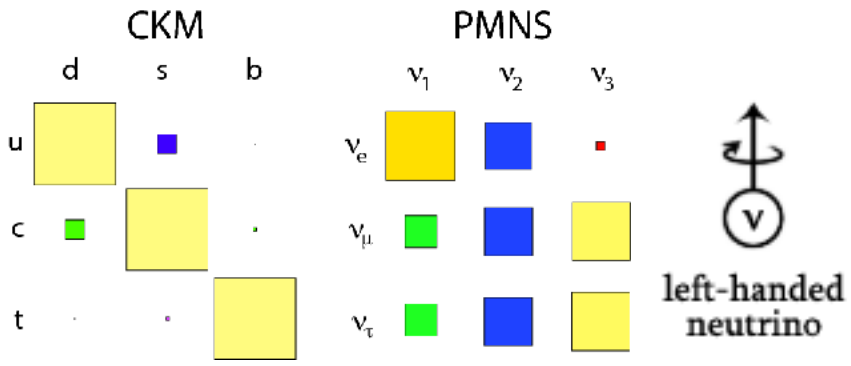
What is the ordering of the neutrino masses?
matter effects in oscillations @DUNE

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Are neutrinos Majorana? What is the effective $m_{\beta\beta}$?
Many upcoming Neutrino-less Double Beta Decay Experiments (SNO+, …)

SNO+



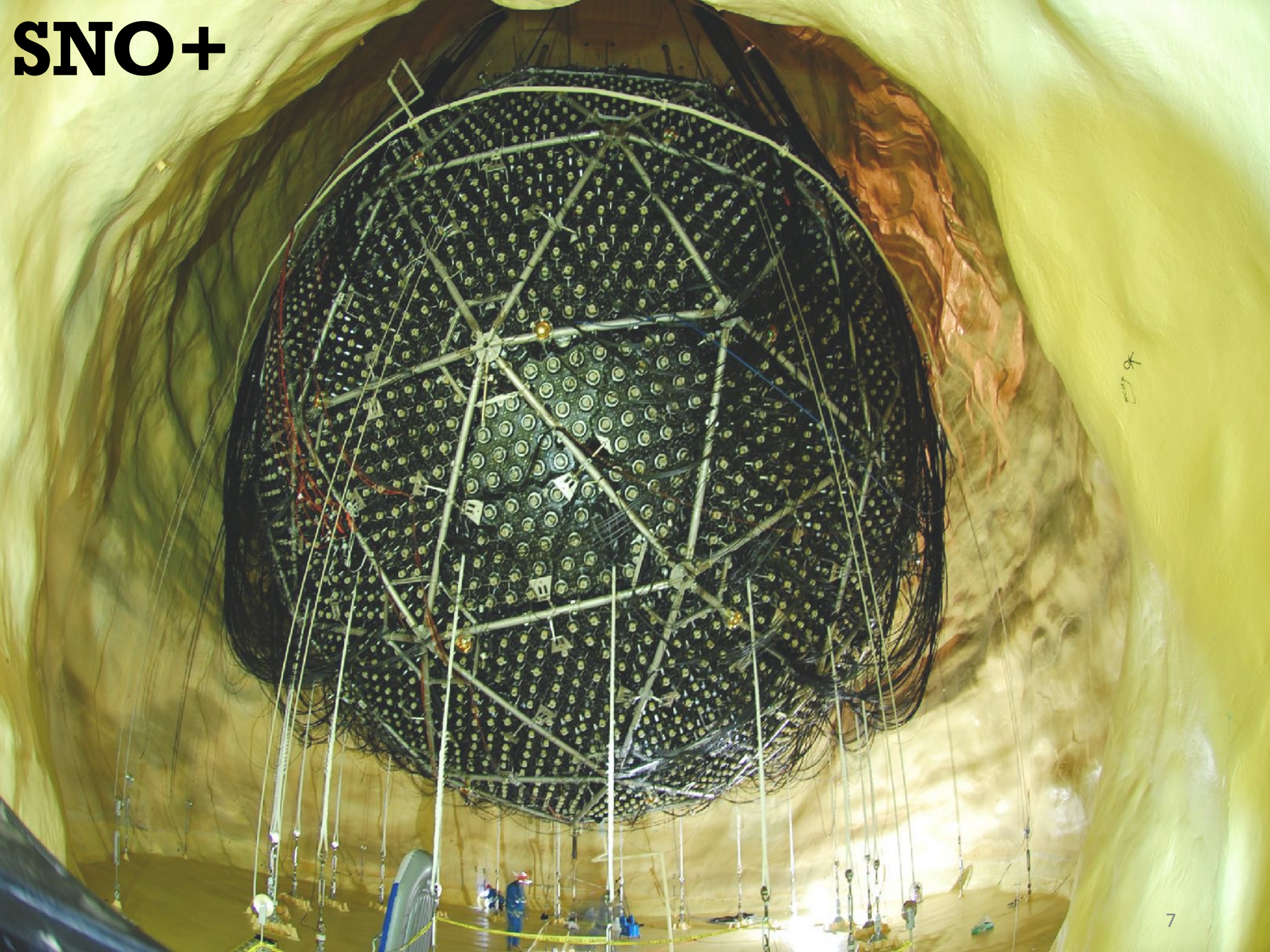


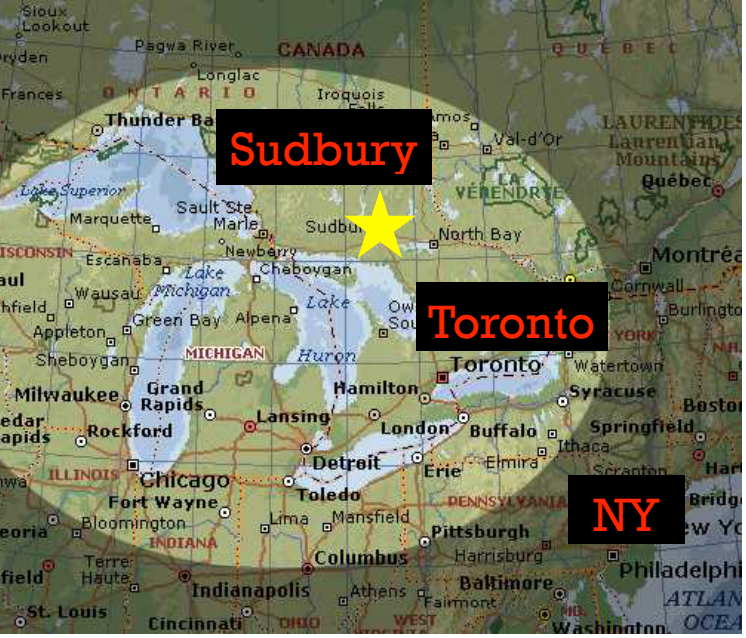
$J_{quarks} = 3x10^{-5}$ $J_{leptons} = 0.03 \sin \delta_{CP}$

Is there CP violation in leptons? Is it enough to explain the dominance of matter?
precision oscillations
ν vs anti-ν @DUNE

DEEP UNDERGROUND NEUTRINO EXPERIMENT

SNO+



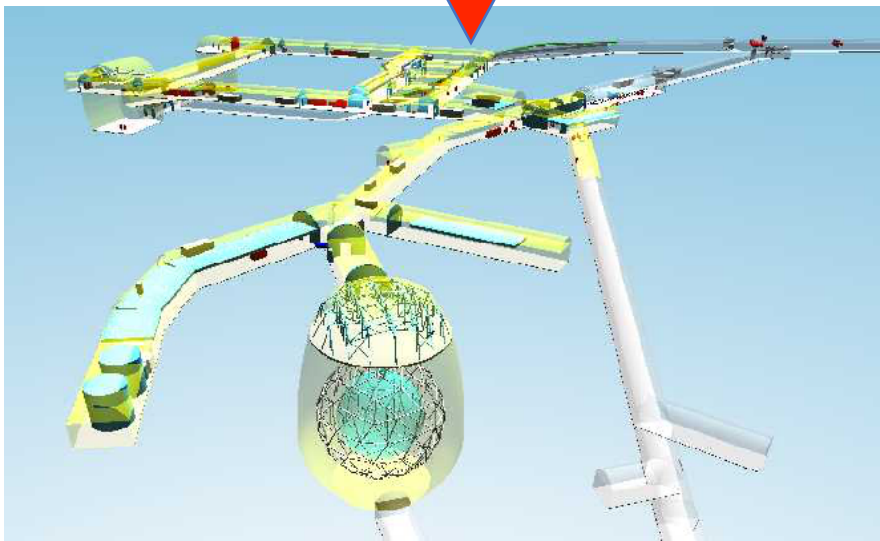


SNOLAB

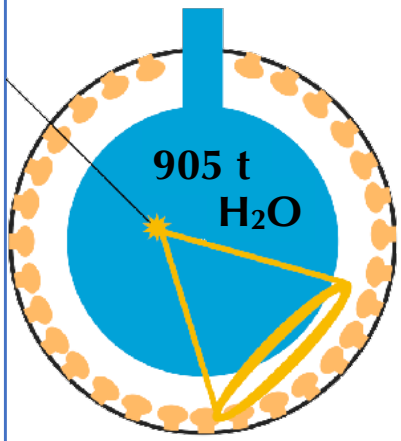
Site of the original Sudbury Neutrino Observatory (SNO)

2 km deep!

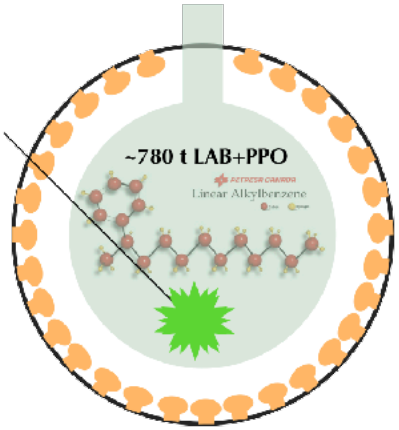
Deepest clean lab in the world. Ideal conditions for neutrino physics (and DM search)



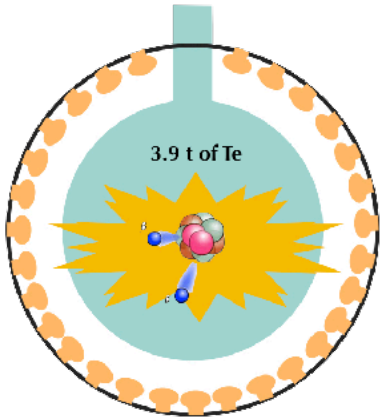
SNO+ Detector and phases



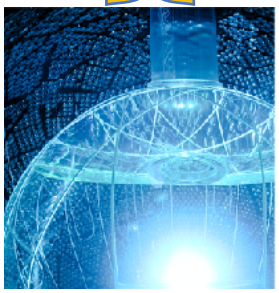
1. Water phase 2017-2019



2. Scintillator phase. Started April 2022



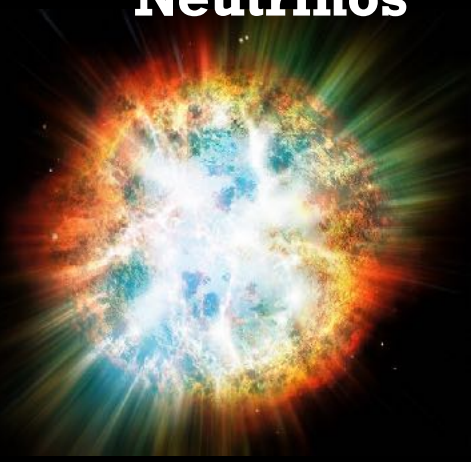
3. Tellurium phase. From 2024 on



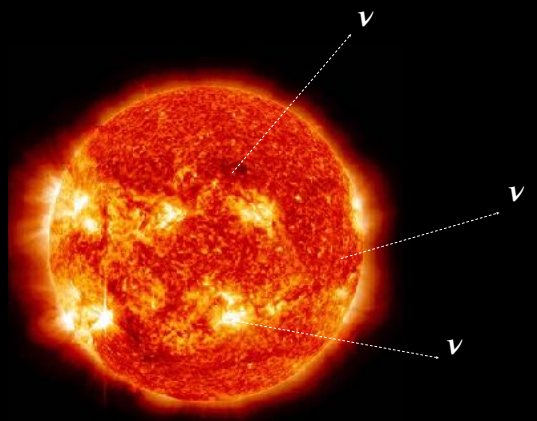
1.5 Partial-fill phase. Most of 2020.

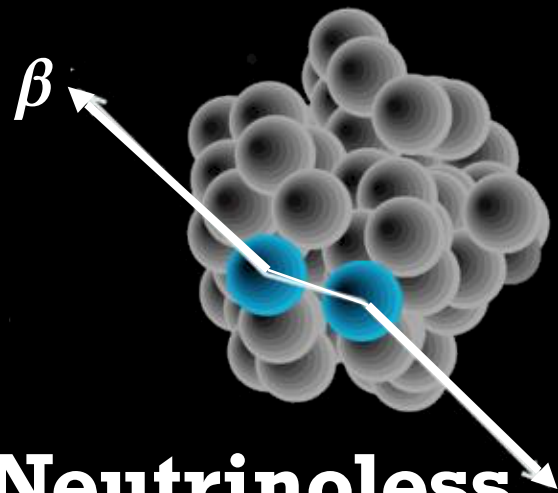
Physics Program

Supernova Neutrinos



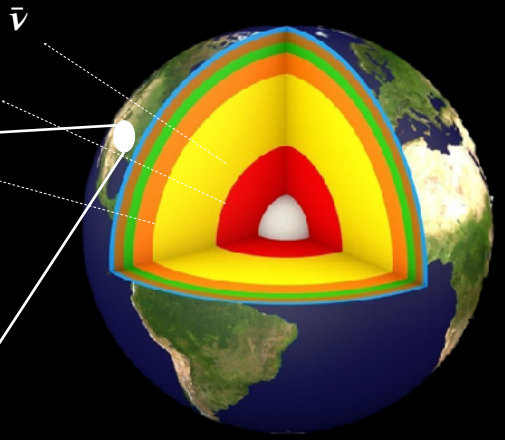
Solar Neutrinos

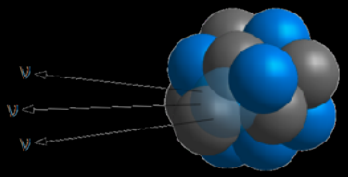




Neutrinoless Double Beta Decay

Geo-neutrinos



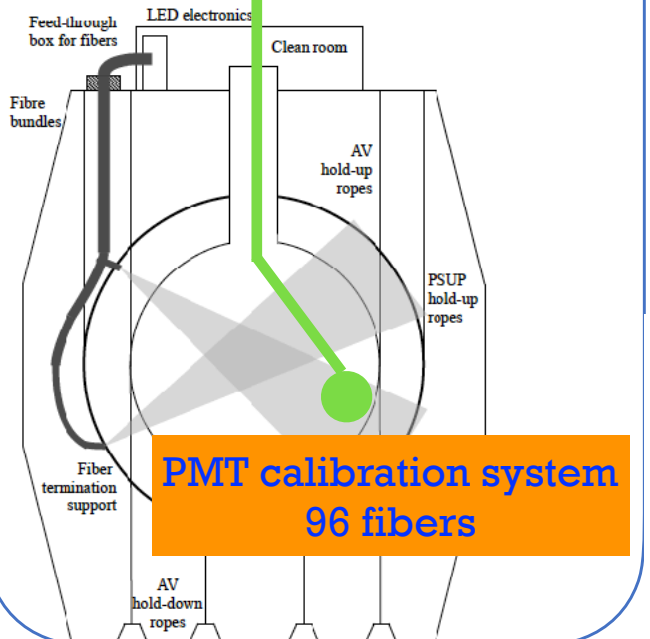


Invisible Nucleon Decay

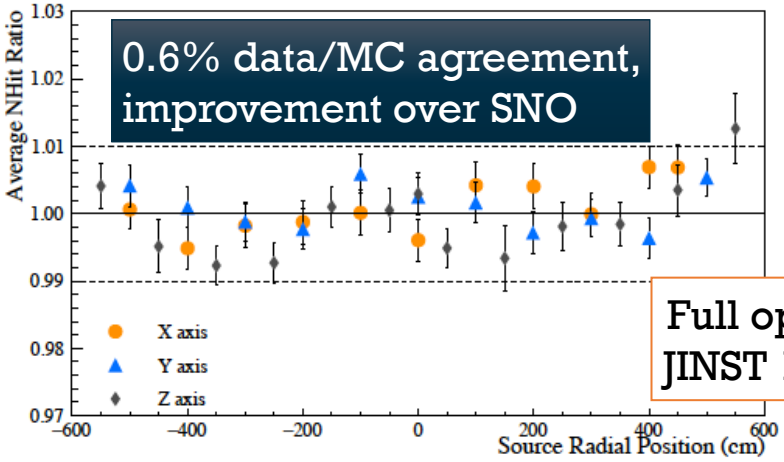
Reactor Anti-Neutrinos

Calibrations @LIP

Internal source system

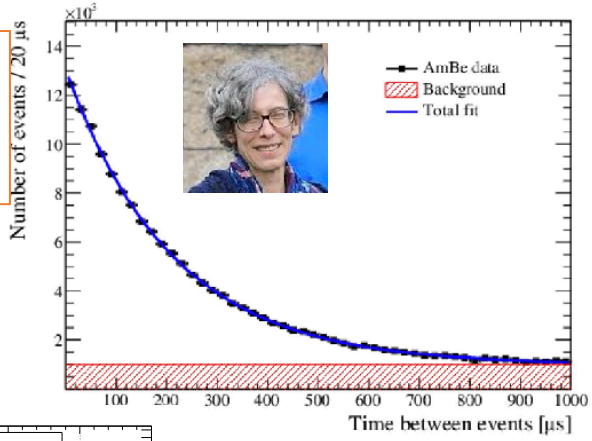


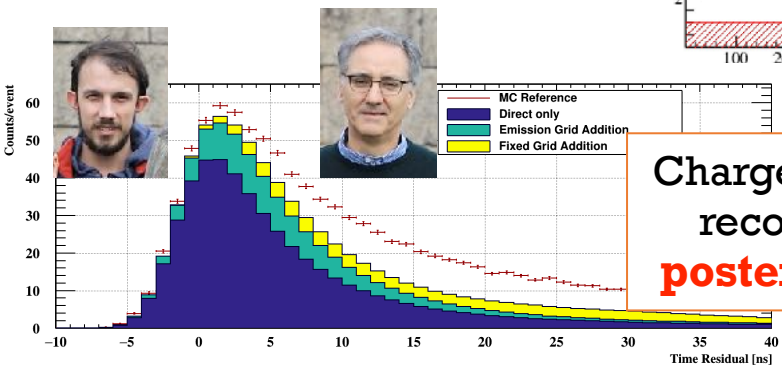
PMT calibration system
96 fibers



Full optical calibration
JINST 16 P10021 (2021)

Highest neutron detection efficiency (50%)
PRC 102, 014002 (2020)

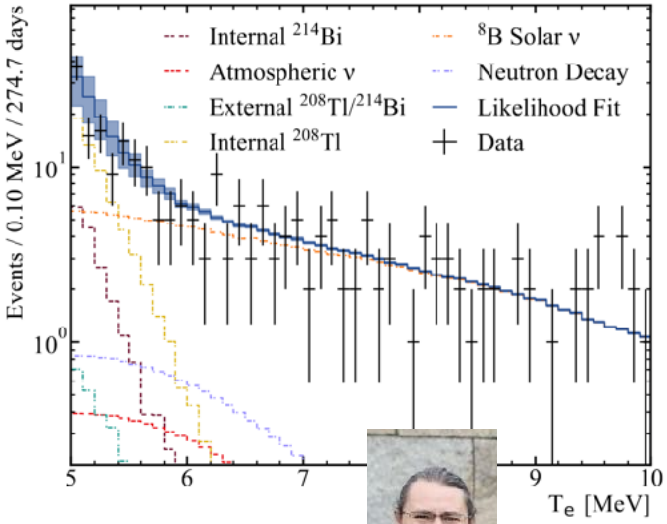


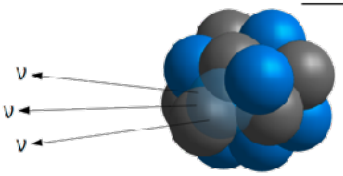


Charge/time model and reconstruction. **See poster by J. Antunes!**

Physics highlights

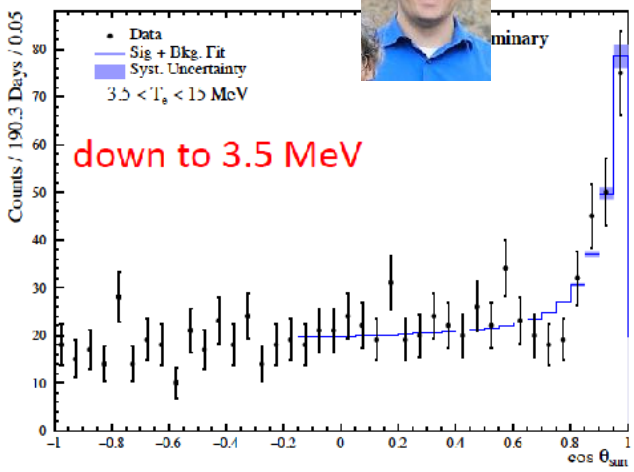
First observation of reactor (anti-)neutrinos with a pure water detector. Upcoming!



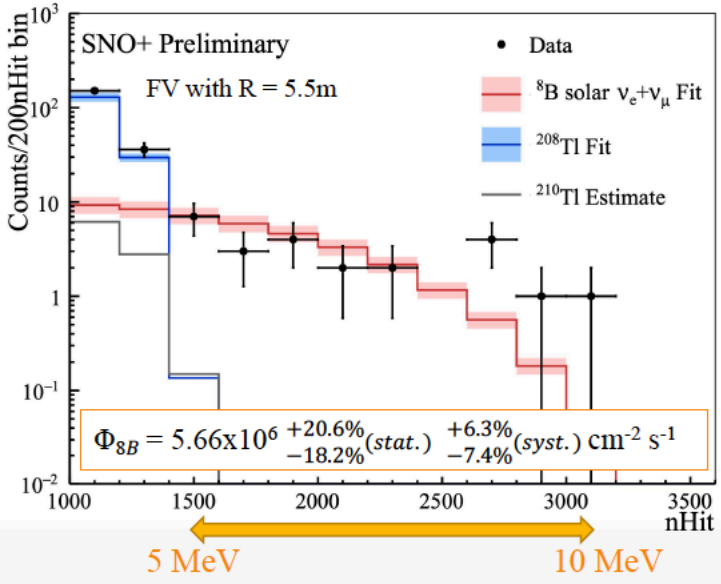


Decay Mode	Partial Lifetime Limit	Existing Limits
n	9.0×10^{29} y	5.8×10^{29} y [5]
p	9.6×10^{29} y	3.6×10^{29} y [6]
pp	1.1×10^{29} y	4.7×10^{28} y [6]
np	6.0×10^{28} y	2.6×10^{28} y [6]
nn	1.5×10^{28} y	1.4×10^{30} y [5]

Invisible nucleon decay limits improved by about a factor of 3. PRD 105, 112012 (2022)

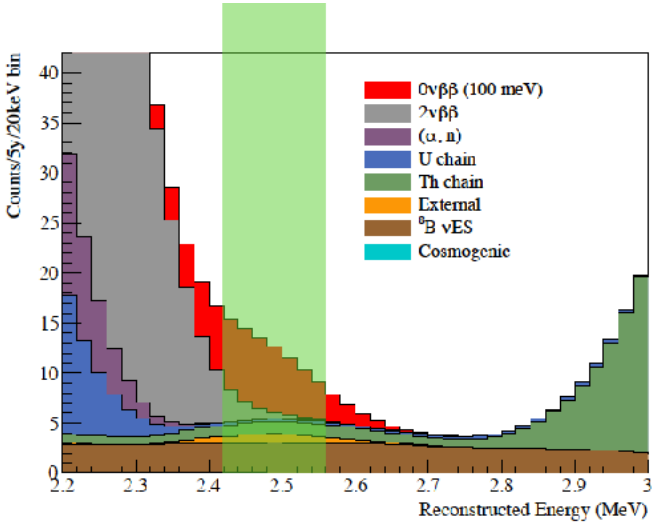


Low threshold solar neutrino meas., update to PRD 99, 012012 (2019)

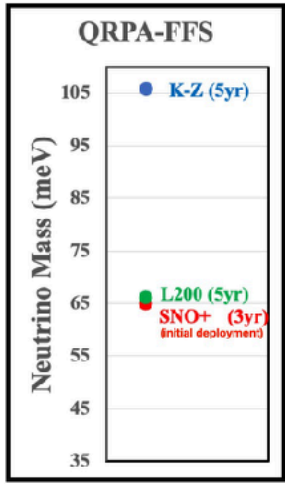


First solar neutrino measurement in partial fill.

Double Beta Decay in SNO+



- Half-life sensitivity 2×10^{26} yr (3y)
  - About 10x better than CUORE current limit with same isotope
- Highly competitive field
  - KamLAND-Zen at that level, but mass limit highly dependent on NME
  - Upcoming Legend-200: 10^{27} yr sensitivity. Schedule…

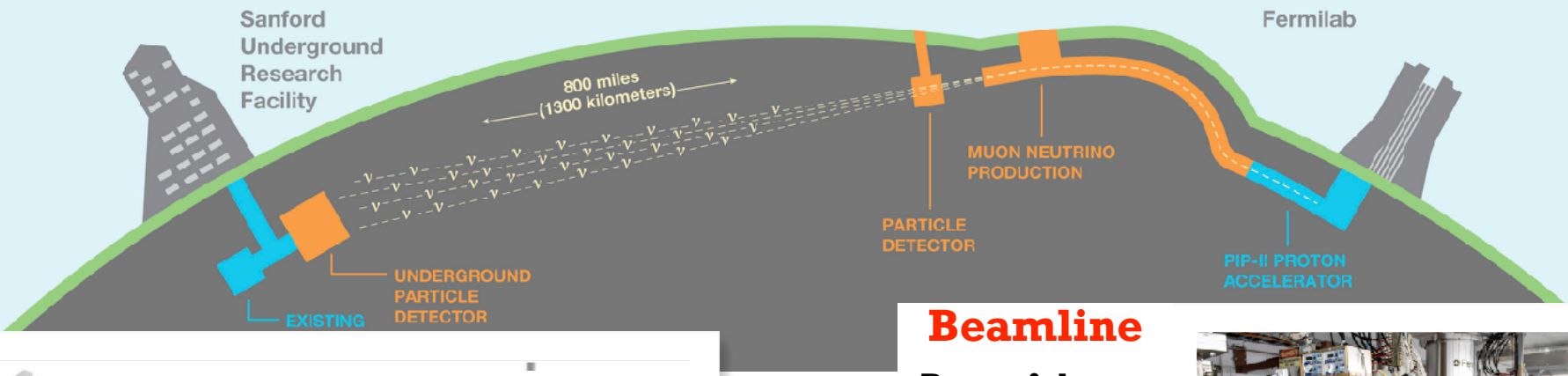


- Loading Tellurium in liquid scintillator
  - Low intrinsic backgrounds (solar ν dominate)
  - Large amounts of ^{130}Te (1.3 tons)
  - Novel technique developed by SNO+. Main challenges: stability, optics
    - Further R&D needed for 1.5% loading
  - Underground Purification plants under commissioning. 0.5% loading 2024


@camaramunicipaldelisboa.tumblr.com
06 - 07 June 2022
Lisbon, Portugal
Double Beta Decay:
The Road to
Normal Hierarchy Sensitivity
Scientific Committee
Fabio Bellini, Sapienza University of Rome & INFN
Fernando Ferroni, Gran Sasso Science Institute & INFN
José Maneira, LIP Lisboa
Maura Pavan, University of Milano Bicocca &INFN
Nuno Barros, LIP Lisboa & Coimbra
Valentina Lozza, LIP Lisboa

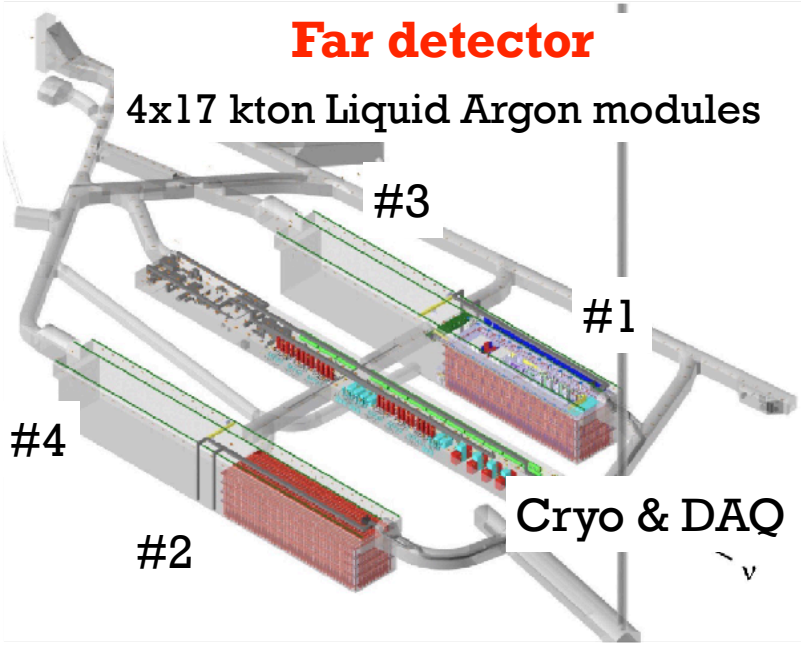

DUNE

DEEP UNDERGROUND NEUTRINO EXPERIMENT



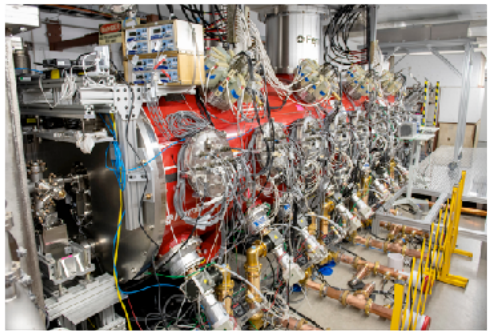
Far detector

4x17 kton Liquid Argon modules



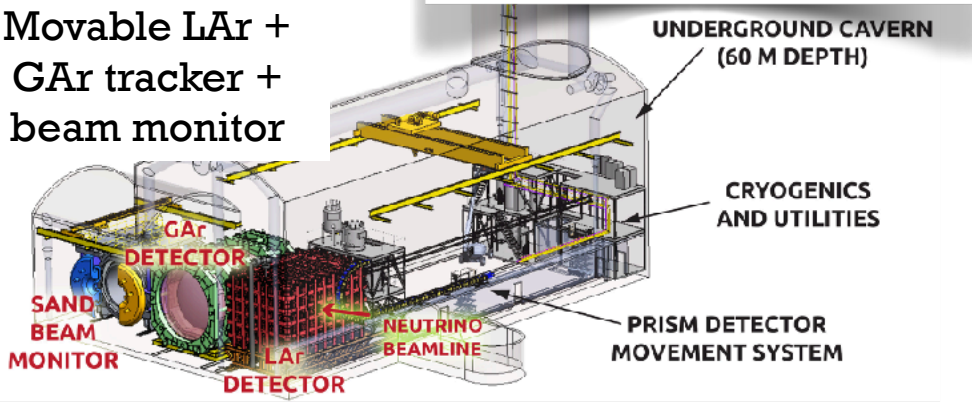
Beamline

Powerful new proton injector

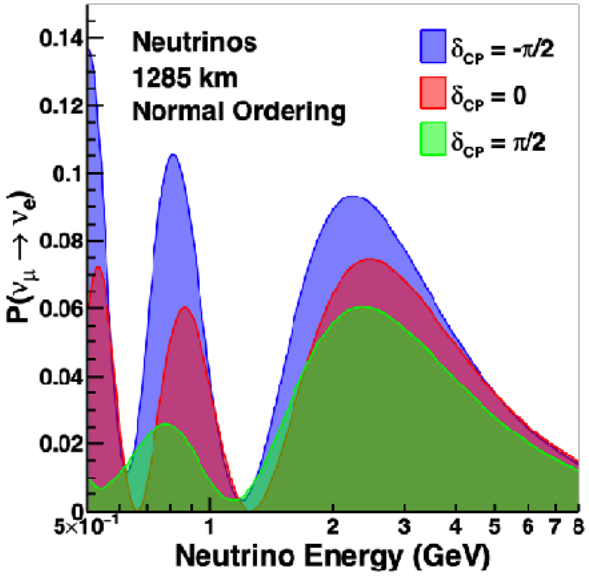


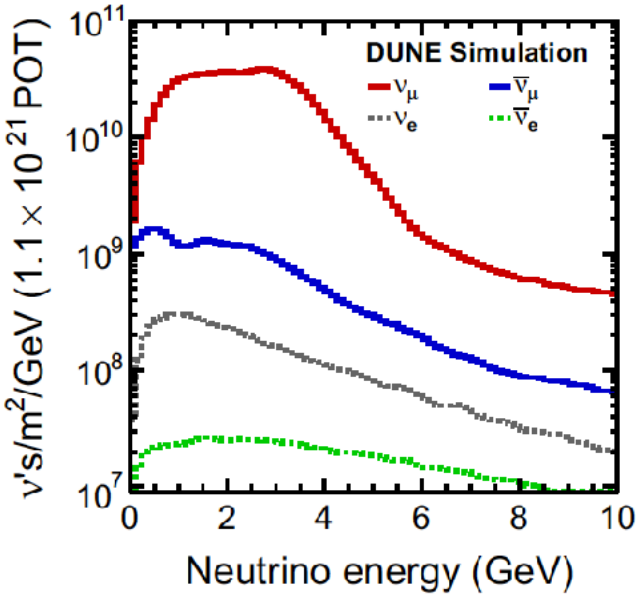
Near detector

Movable LAr + GAr tracker + beam monitor

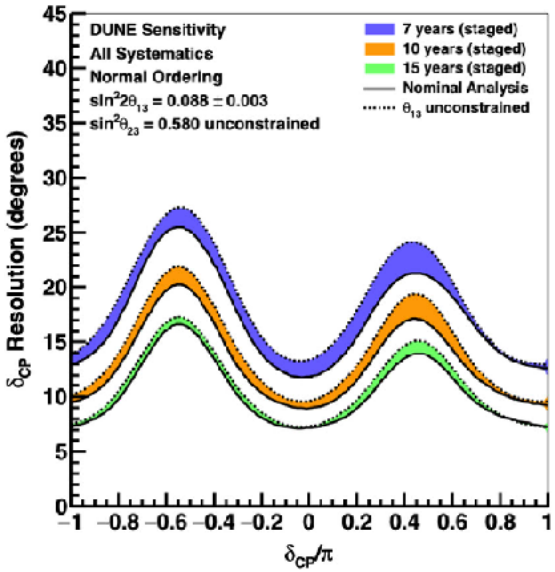


Neutrino oscillation prospects





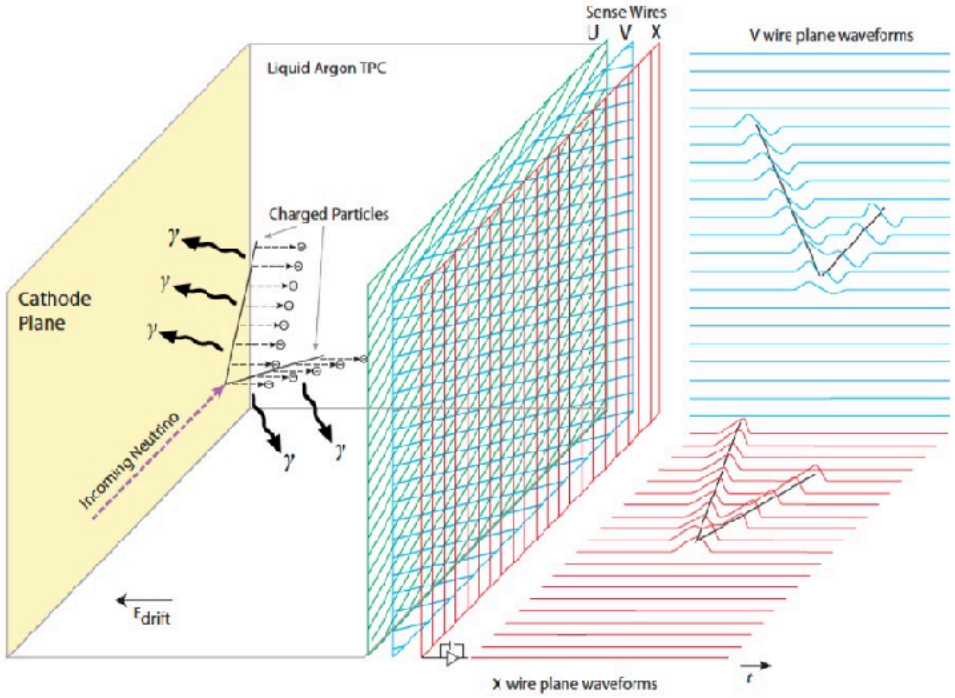
- ν_e appearance in a wide-band intense ν_μ beam (and anti-ν)
- CP violation and hierarchy effects stronger in different energy regions. DUNE can measure both.

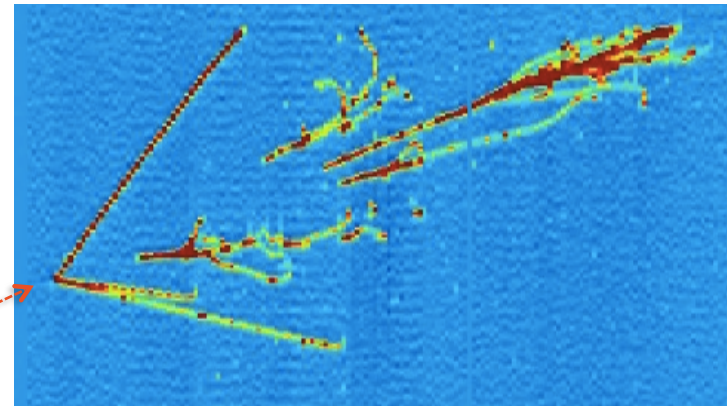


CP violation phase sensitivity

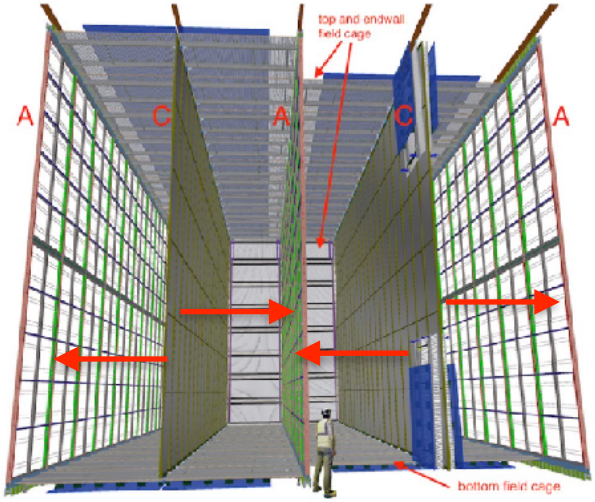
- Plus a rich program of Supernova Neutrino physics, nucleon decay search, BSM beam physics

Liquid Argon TPC



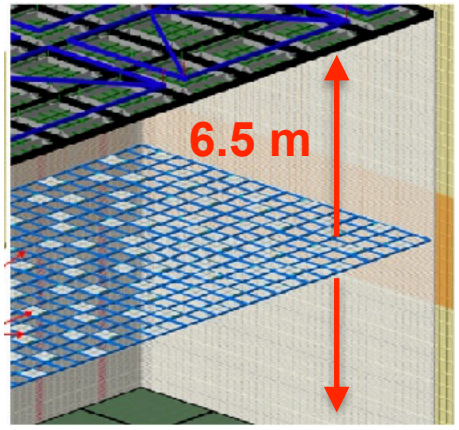


- LAr TPC advantages
  - 3D tracking with few mm resolution
  - Excellent calorimetry
  - Particle ID via dE/dx, range, topology
- Event reconstruction
  - Convolutional Neural Networks
  - Ideal ground for Machine Learning



Far Detector #1
Horizontal Drift
Readout in wire planes

3.6 m

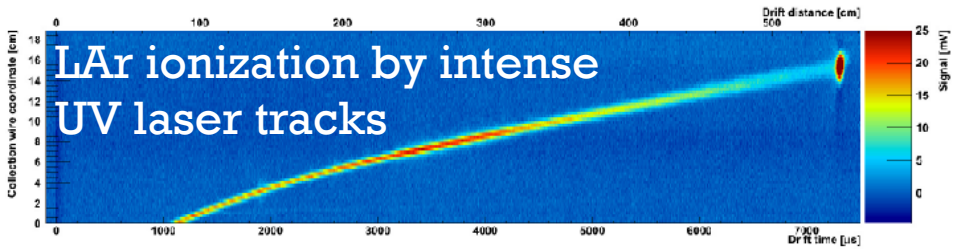


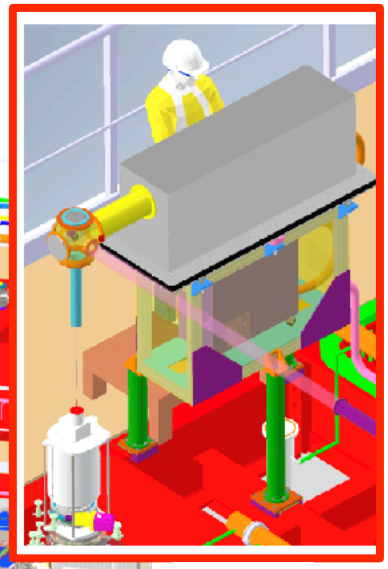
Far Detector #2
Vertical Drift
Readout in PCB planes

ProtoDUNE(s) at CERN

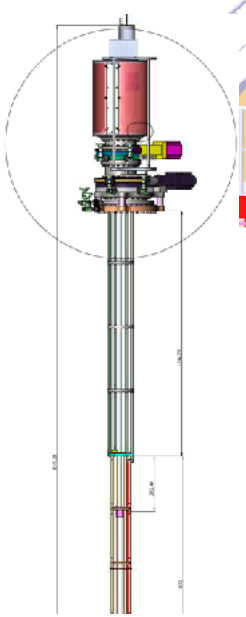
Operated 2018-2020
New run 2022-2023 to test final design choices

Laser calibration

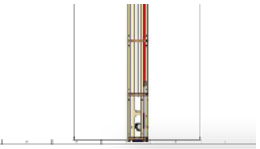


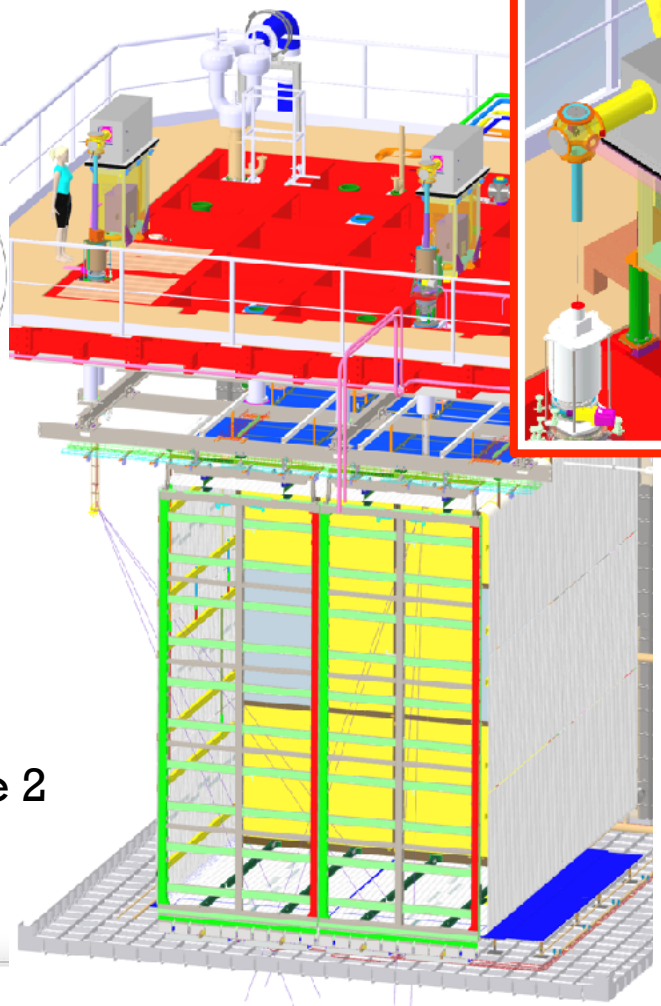


Laser Box

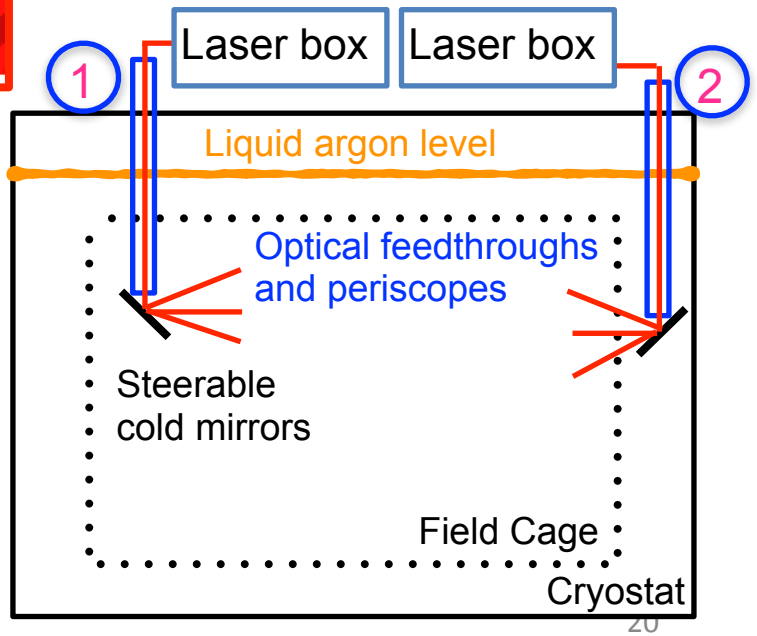


Periscope 2





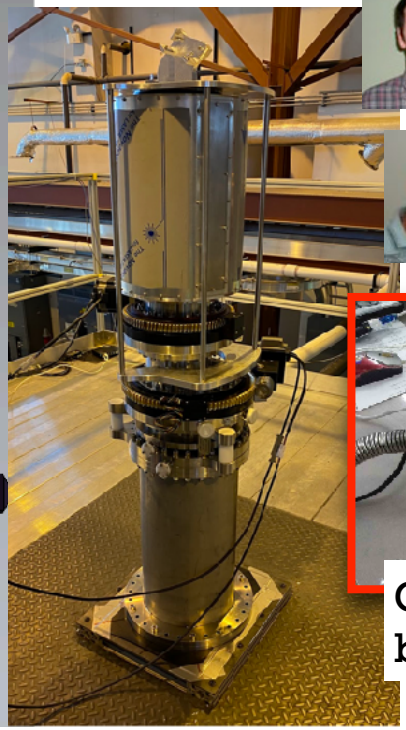
- Laser system for DUNE FD improves MicroBooNE
- Prototypes to be tested at ProtoDUNE
  - P1: internal, retractable
  - P2: external, extra movement



ProtoDUNE systems

- Designed/built by LIP+LANL
- Many parts of periscopes 1 and 2 built and tested at LIP. Fantastic work by MW/DL !
- Full assembly and cryo tests at LANL
- Installation at CERN in August!

Periscope 2 feedthrough built at LIP, assembled at LANL

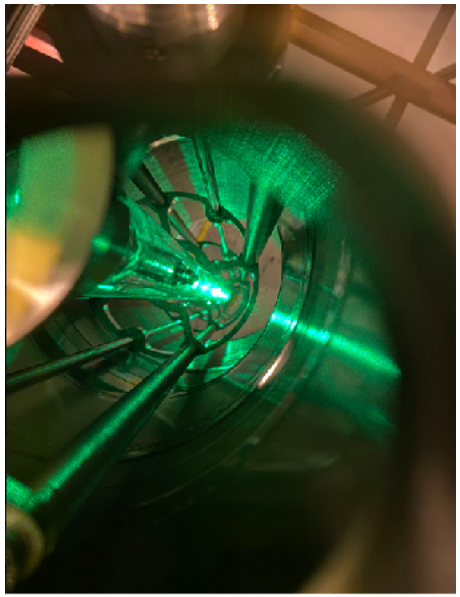


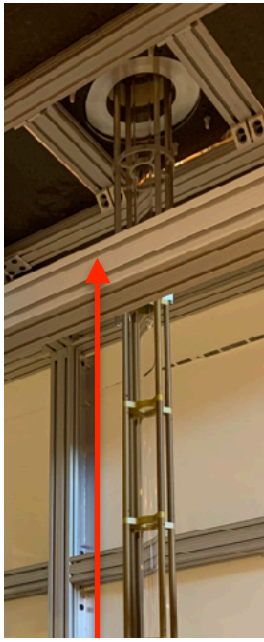
Jorge Moreira

Custom wide electrical break, good He seal

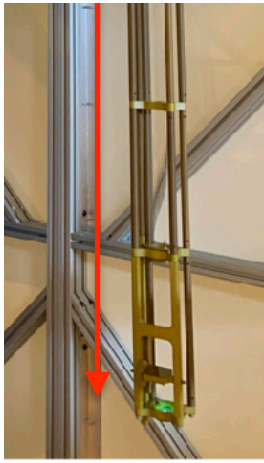
Tests of motor control and precision (better than 1 mm @ 5m)

Tests at LANL



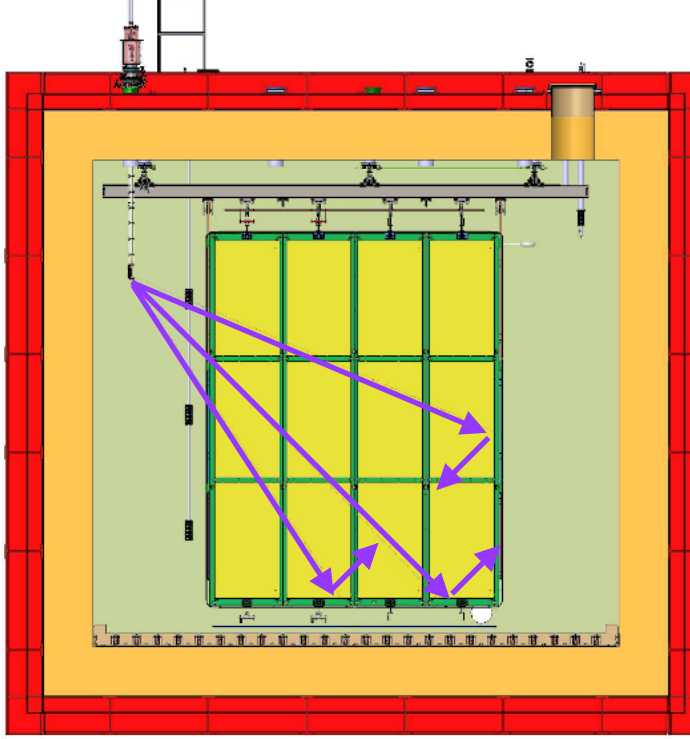


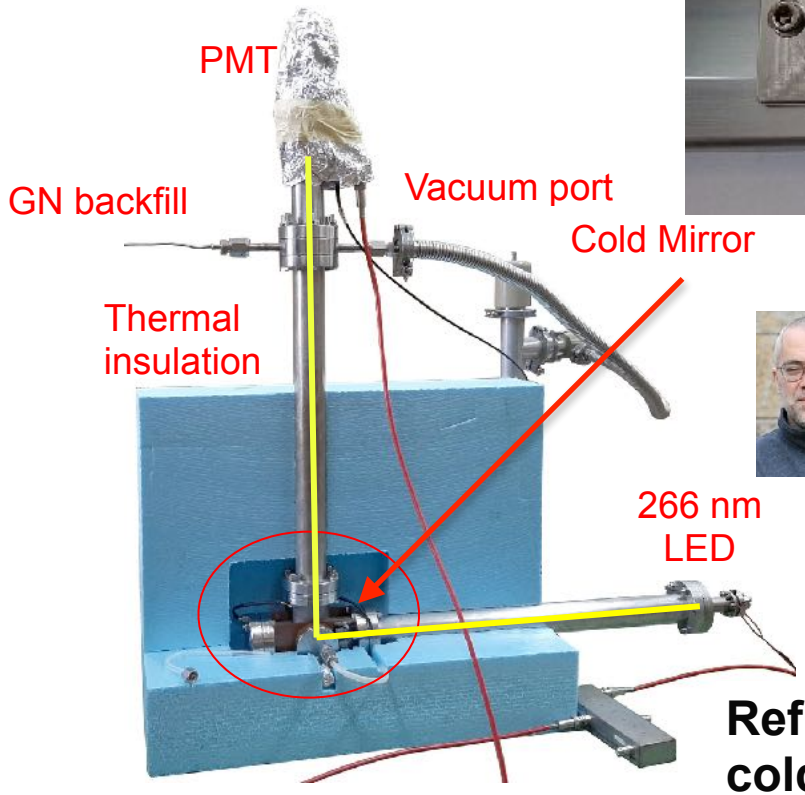
Visible here: half of 3.6 m periscope



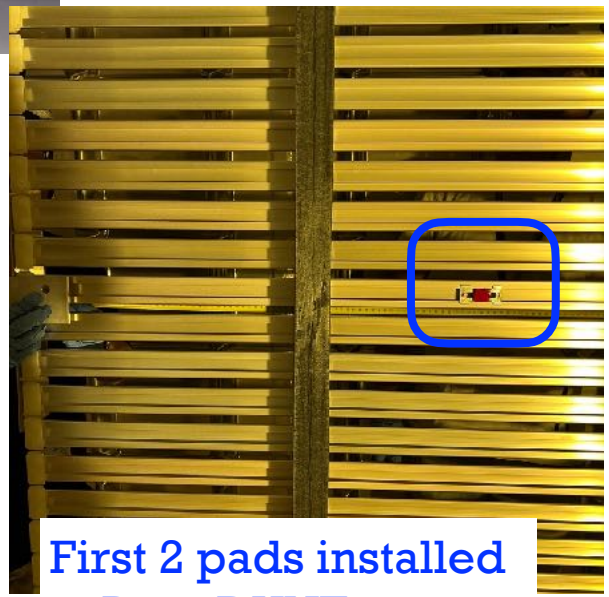
Laser Beam Location System

- 4 target pads for alignment
- UV mirrors: beam OK when we see reflections





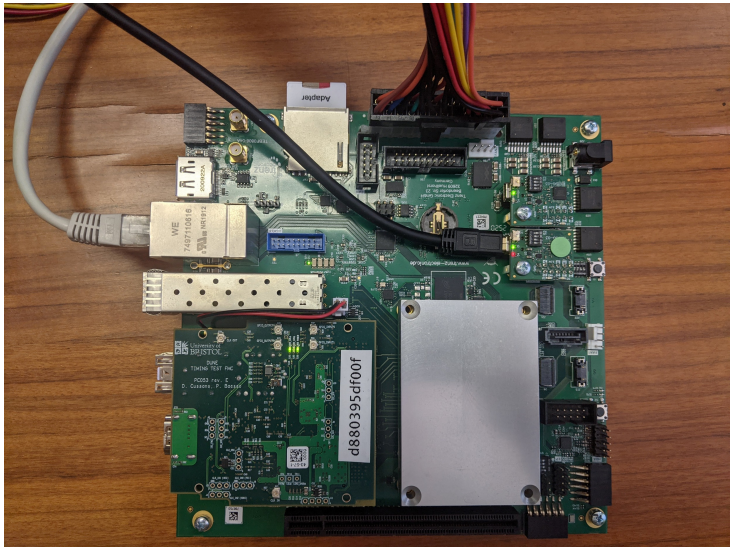
Reflectivity in cold = room T

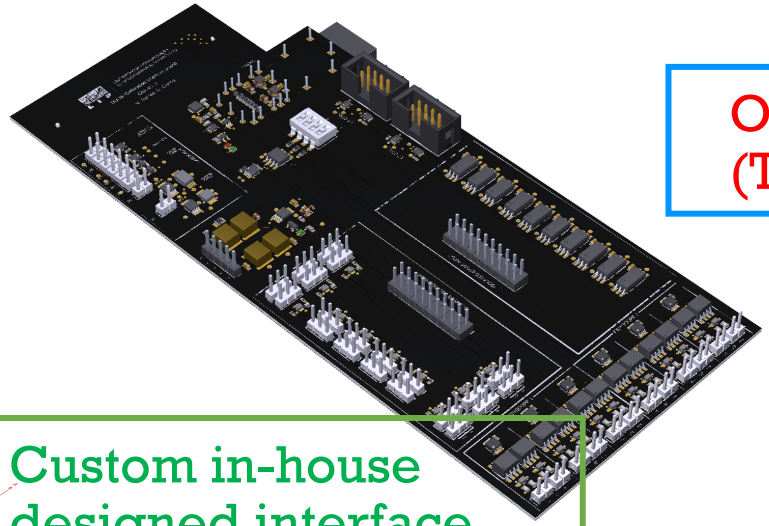


First 2 pads installed at ProtoDUNE

Laser Control Electronics

- Single-point interface and coordination for
  - Operation/sync of all calibration components - laser, motors, optics
  - Central DAQ and Slow Control. Timestamp, beam direction for data reduction





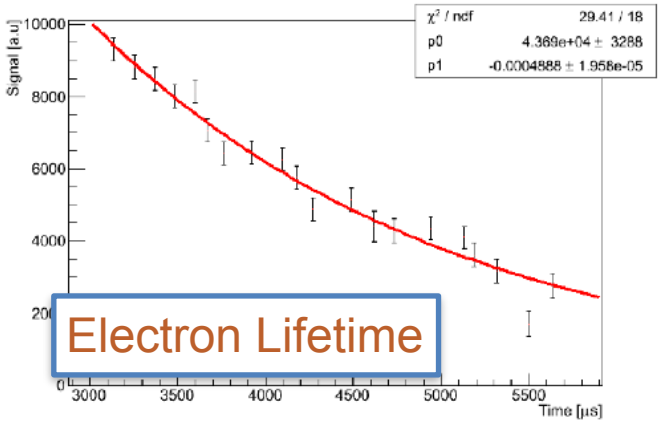
Custom in-house designed interface board

Off-the-shelf motherboard (Trenz TEBF0808) + SoC (Xilinx UltraScale+)

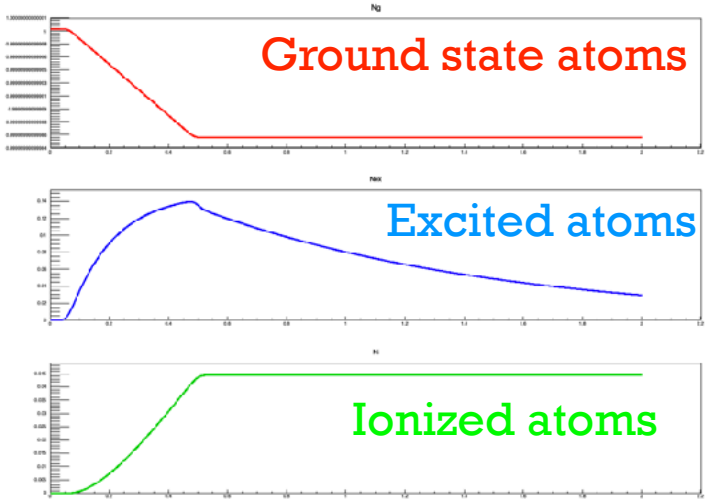
- Full LIP responsibility
  - Hardware design
  - FPGA programming
  - Implementation of software applications

Laser ionization model

- Current laser beam model based on muons with MS off, OK for simple track position
- But we aim to do charge-based measurements (electron lifetime). Need charge evolution along track !



- Developing a more detailed model, collaborating with Univ. de Alfenas, Brazil
- Numerical solution of equations describing excitation, ionization
- Then interface with LArSoft
- Basis for data analysis



Next steps

- SNO+
  - Stable detector until Te fill. Plenty of opportunity for solar, reactor neutrinos analyses

- DUNE
  - Very busy with laser system construction. Next months crucial to test the system
  - Then data analysis!