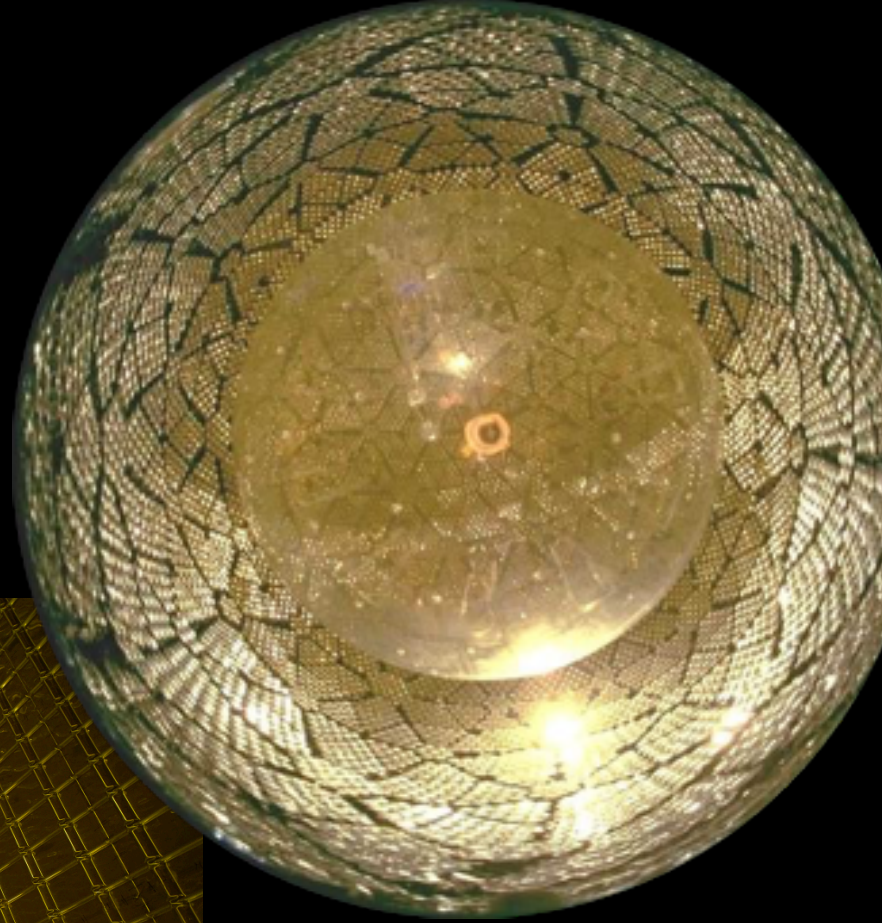
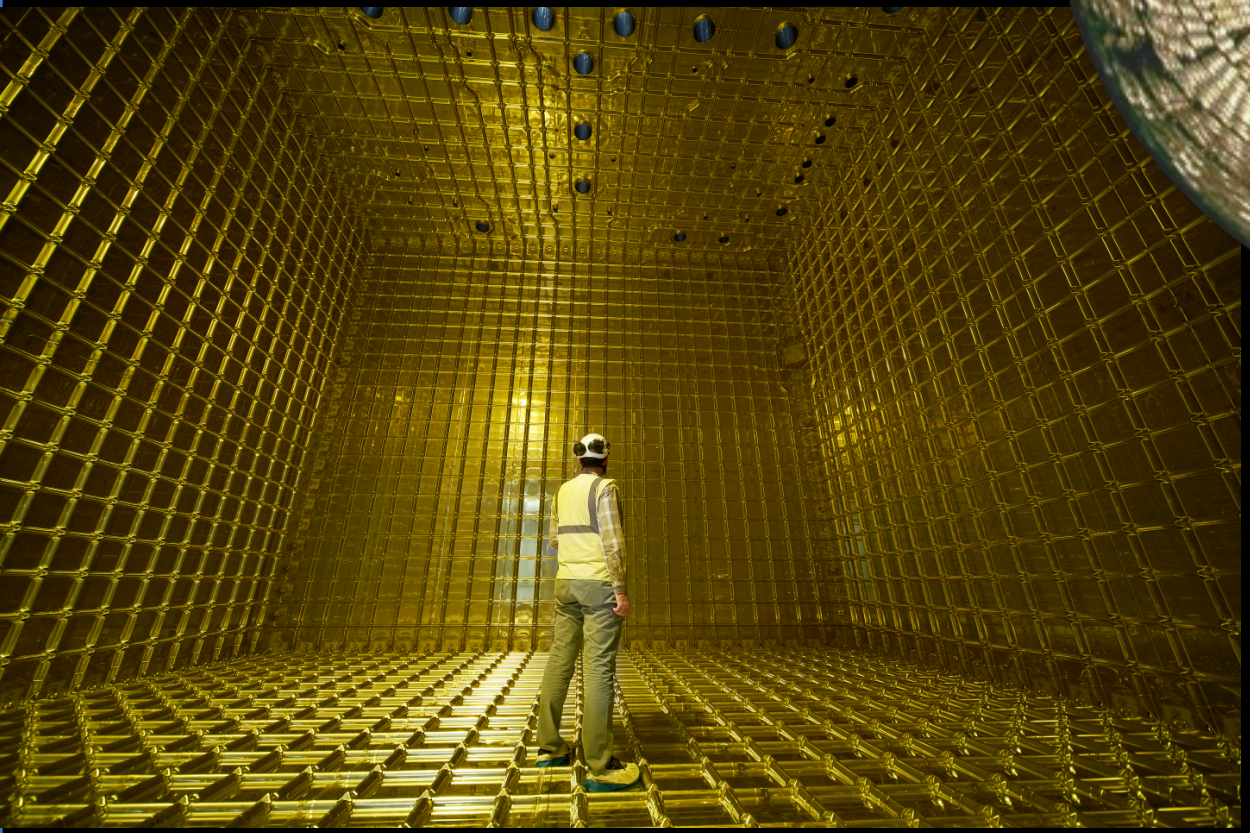
LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Research Opportunities with the SNO+ and DUNE experiments





Mini-School on Particle and Astroparticle Physics - May 2022

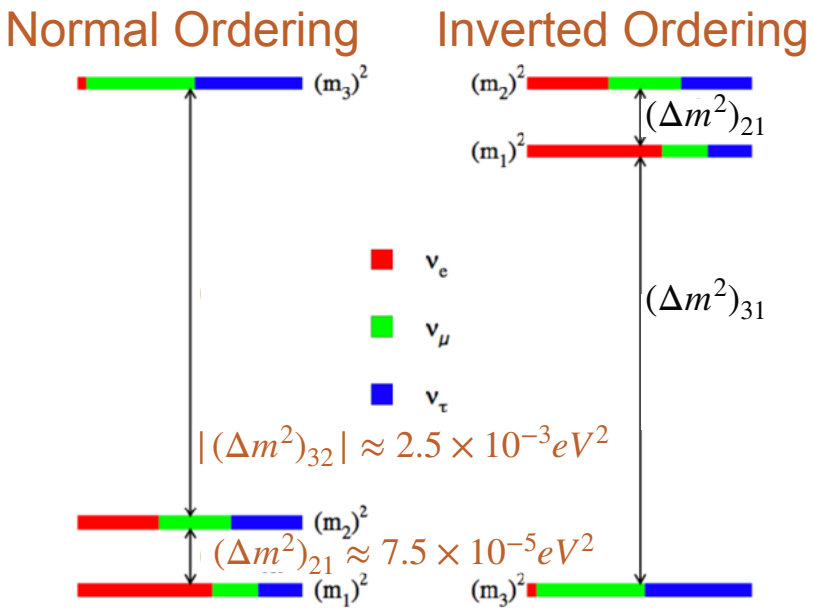
José Maneira (LIP)

Refresher

- Dedicated Neutrino physics talk by Nuno Barros on monday
- https://indico.lip.pt/event/1192/contributions/4072/attachments/3285/5112/nbarros_neutrinos_May2022.pdf

N. Barros@ Sudbury Neutrino Observatory
Photo credit: JM

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

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

$\theta_{23} \approx 49^\circ$ $\theta_{13} \approx 8.6^\circ$ $\theta_{12} \approx 33.4^\circ$

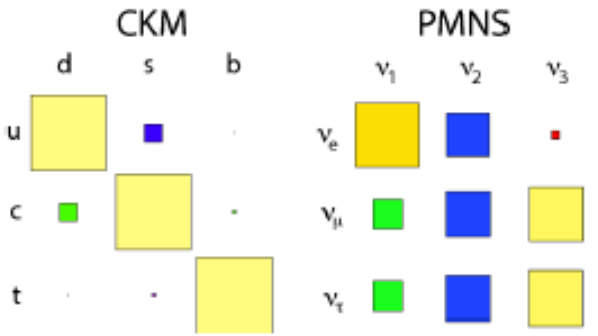
$40 < \theta_{23} < 52^\circ (3\sigma)$

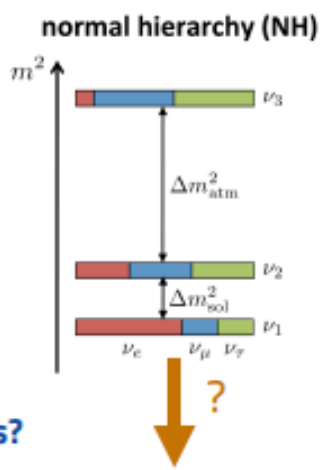
Solar, atmospheric, reactor and accelerator experiments provide consistent support for this framework.

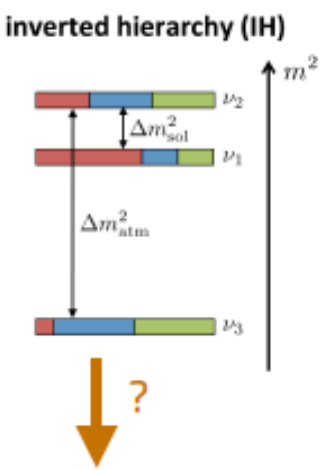
What haven't we learned yet about neutrinos

Many questions waiting for answers!

- **Do neutrinos and antineutrinos oscillate in the same way?**
  - Do they violate the CP symmetry?
- **What is the ordering of their masses?**
- **What are the precise values of the neutrino mixing parameters?**
  - Why are these parameters so different from the quarks?







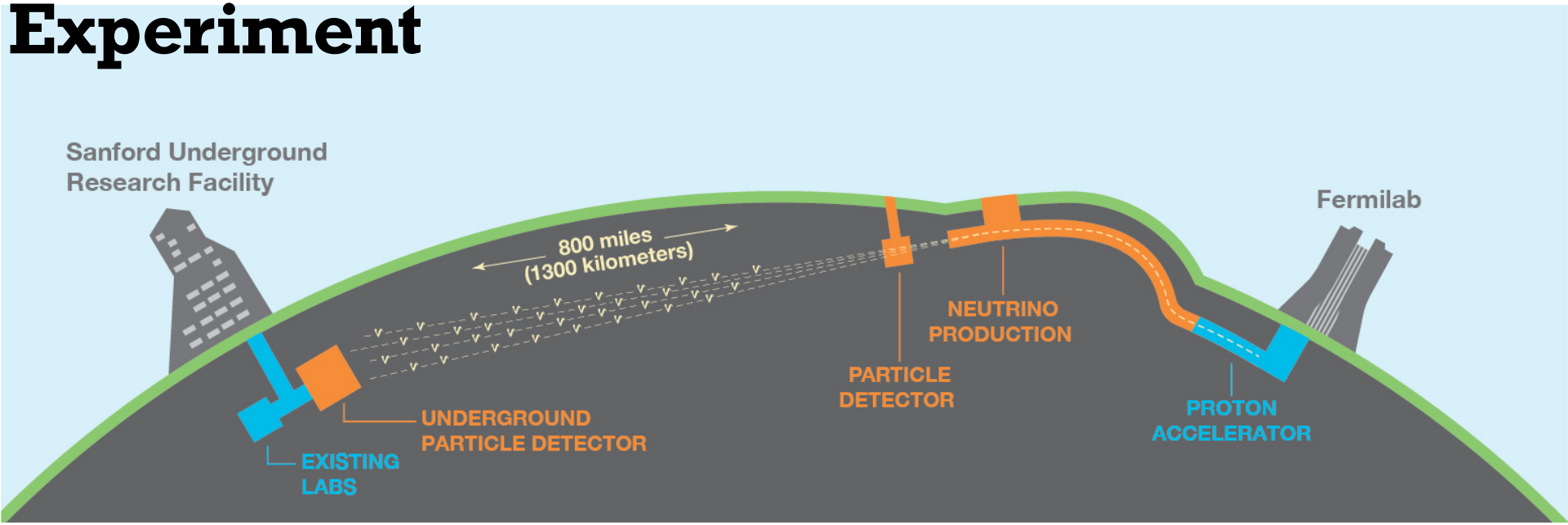
- **What is the absolute mass of the neutrinos?**
- **Are neutrinos Majorana or Dirac particles?**
  - Are neutrinos their own antiparticles?

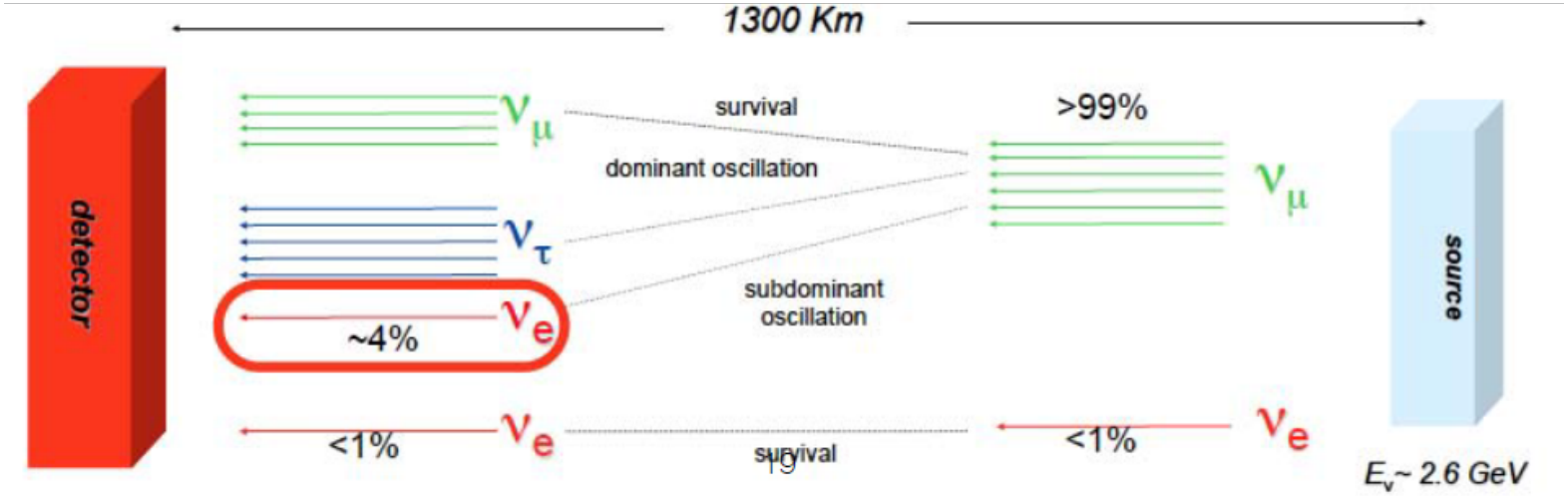
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

SNO+


DUNE

The Deep Underground Neutrino Experiment

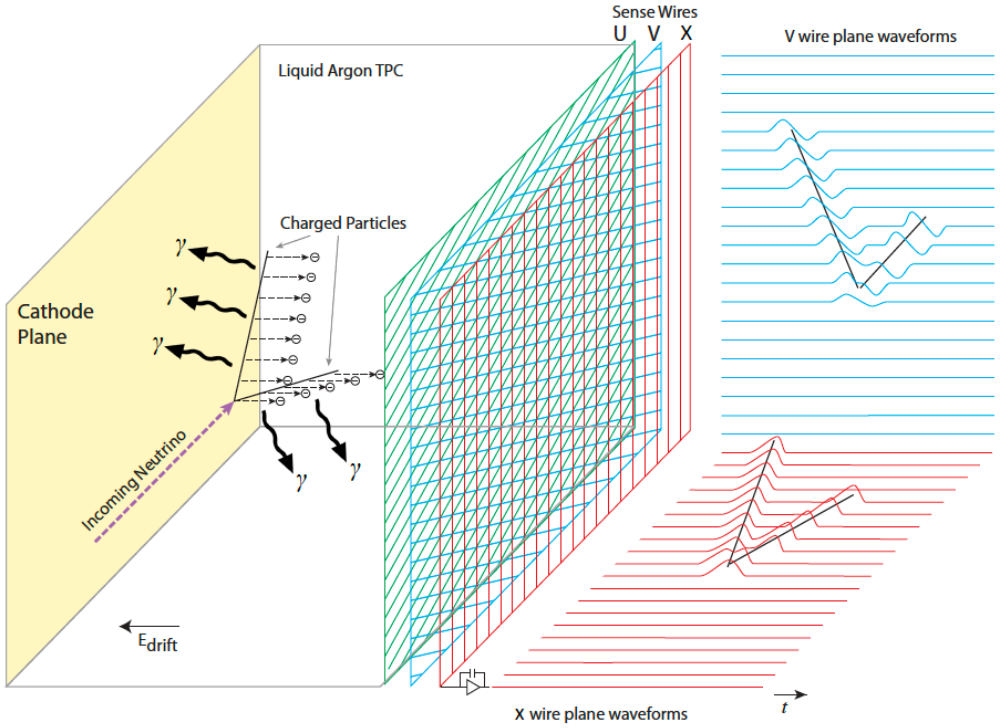




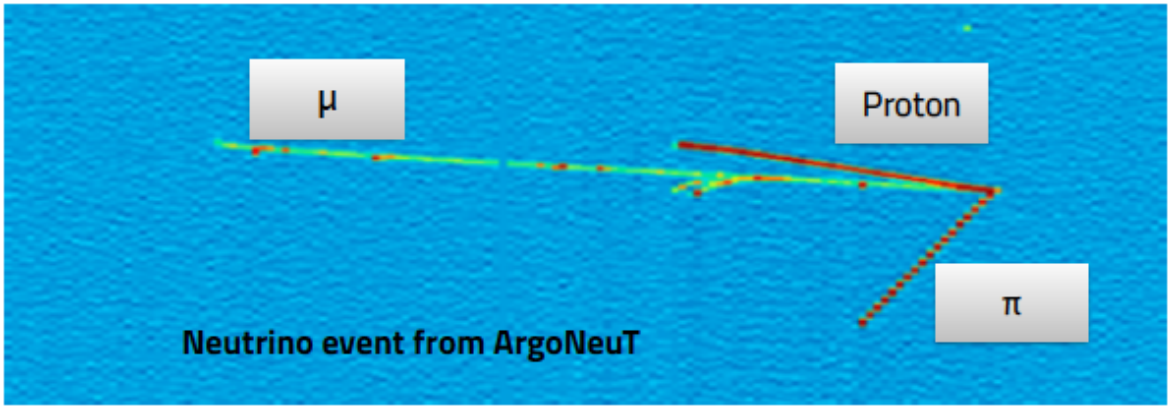
Differences between neutrino and antineutrino oscillations depend on mass ordering and CP violation!

Calibrating a LAr TPC

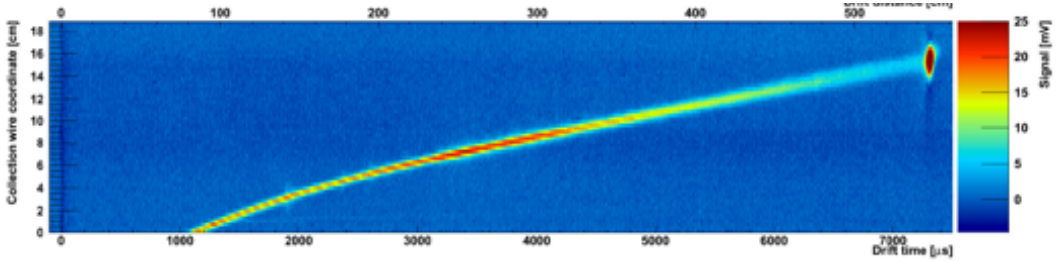
- Looking for distortions in oscillated neutrinos energy spectrum
- Good sensitivity to CP violation requires excellent detector response
- Use intense UV laser beams and neutron sources to calibrate detector



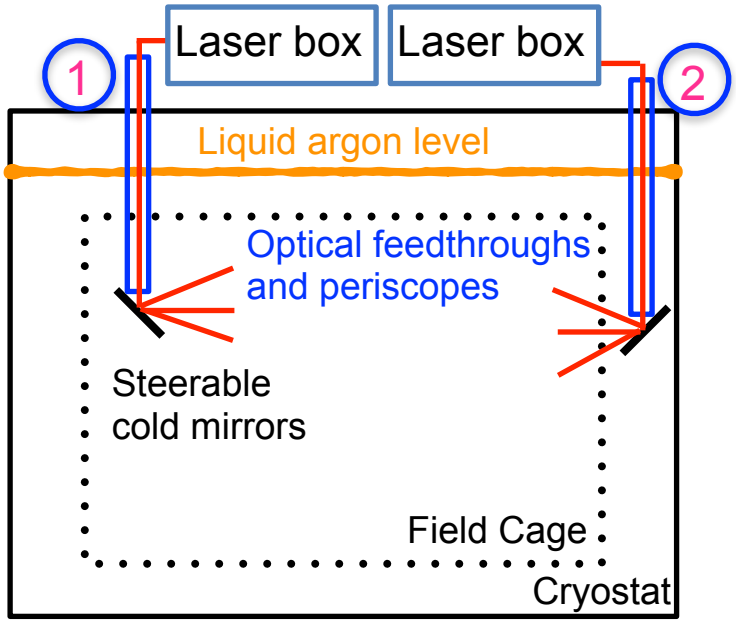
Neutrino event

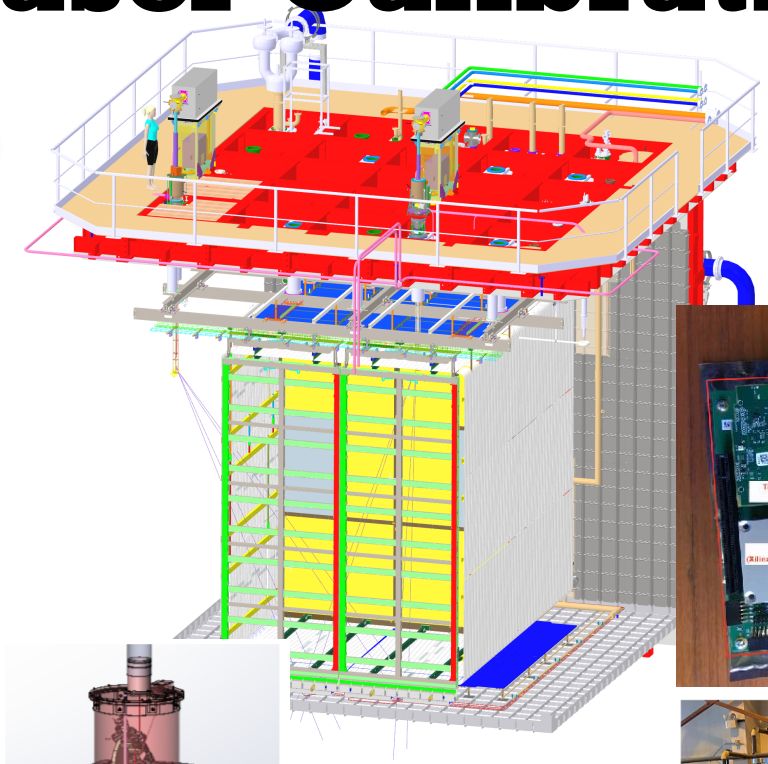


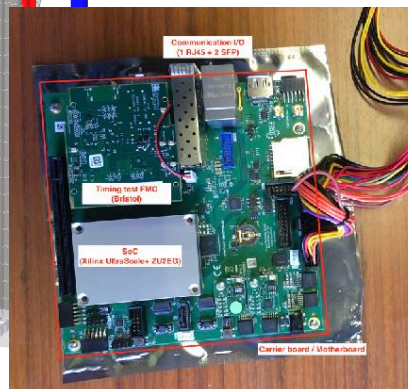
Laser tracks

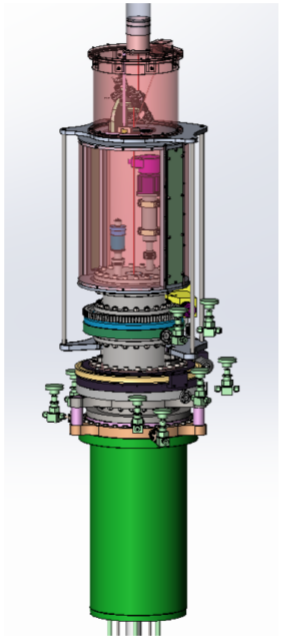


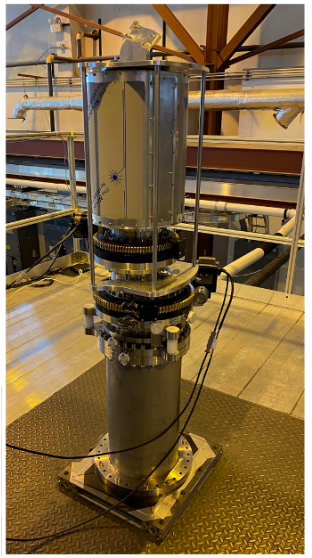
ProtoDUNE Laser Calibration











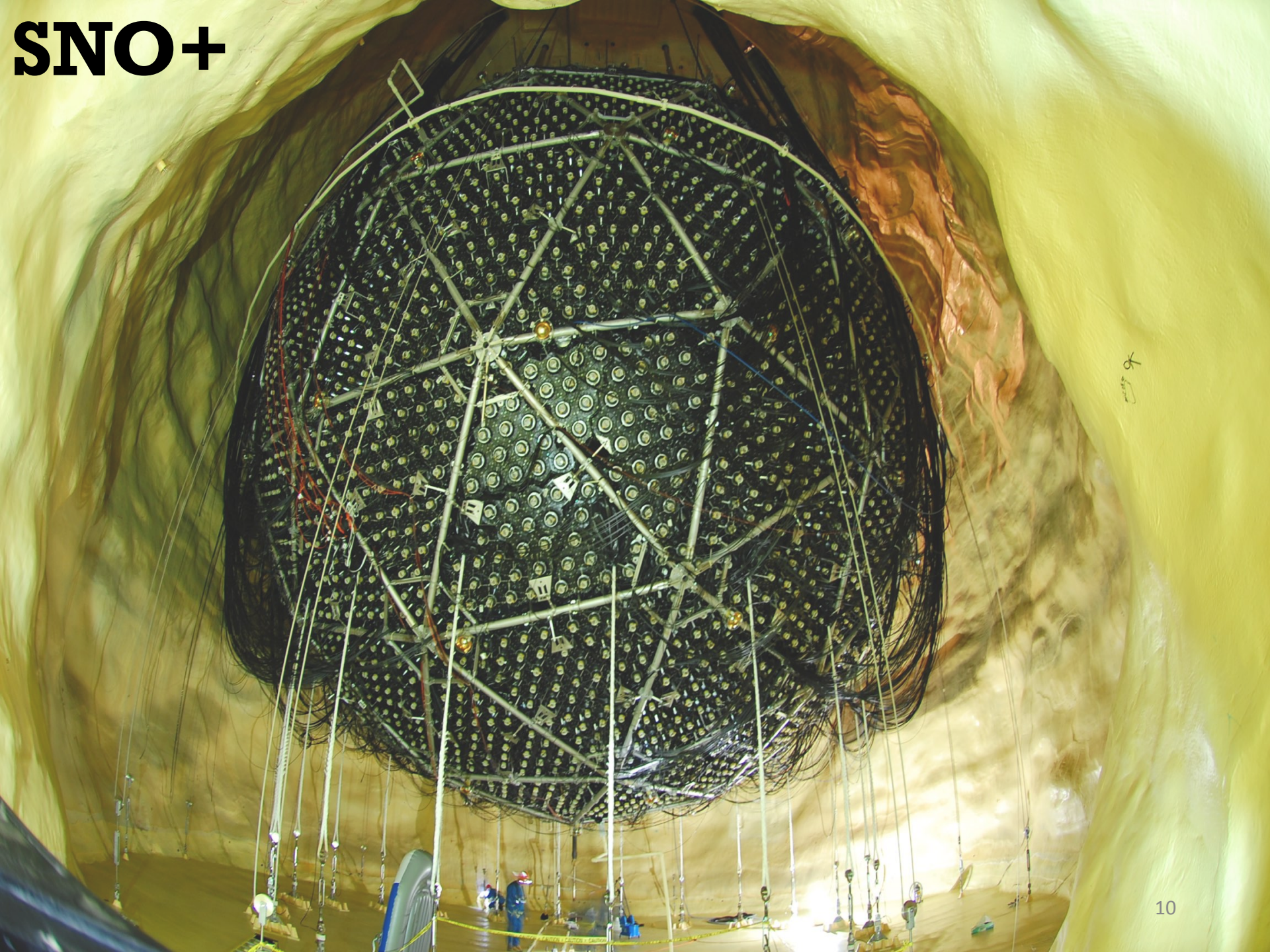
- ProtoDUNE@CERN
- Two periscopes+lasers
- Designed/built by LIP+LANL
- Installation August

Projects for students

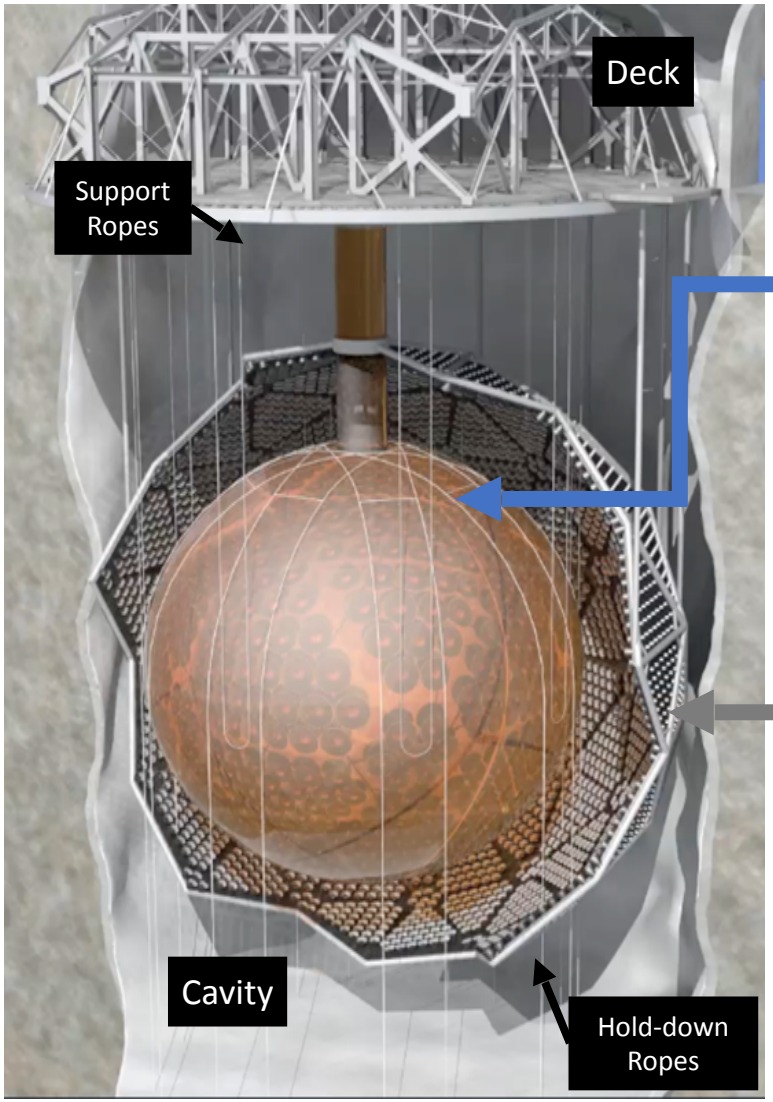
- Laser calibration simulation / analysis (Lis./Coimb.)
  - ionization of liquid argon by laser beams
  - Develop analysis methods to measure detector performance: electron lifetime, recombination…
- Electronics/control/DAQ interface (Coimbra)
  - Interface with DUNE DAQ, automatize calibration data taking, provide precise alignment data
- Neutron response simulations (Lis.)
  - Simulate response of DUNE/ProtoDUNE to external neutron sources

Contact: maneira@lip.pt

SNO+



The SNO+ Detector



At a depth of 2km (rock, ~5900 mwe, ~63 cosmic muons/ day)

Acrylic Vessel
6 m radius, 5 cm thickness

905 tonnes of ultra-pure water

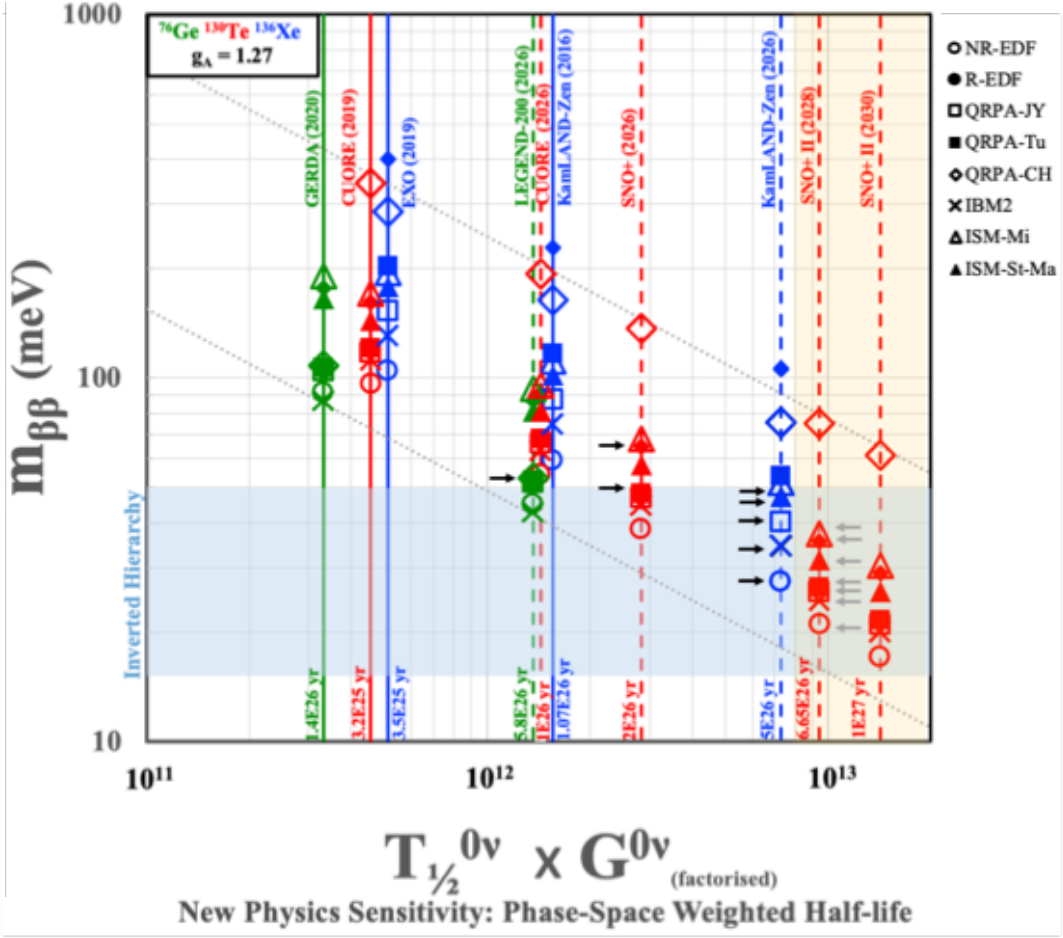
780 tonnes of Liquid Scintillator

+ 3.9 tonnes of natural Tellurium

Now fully filled

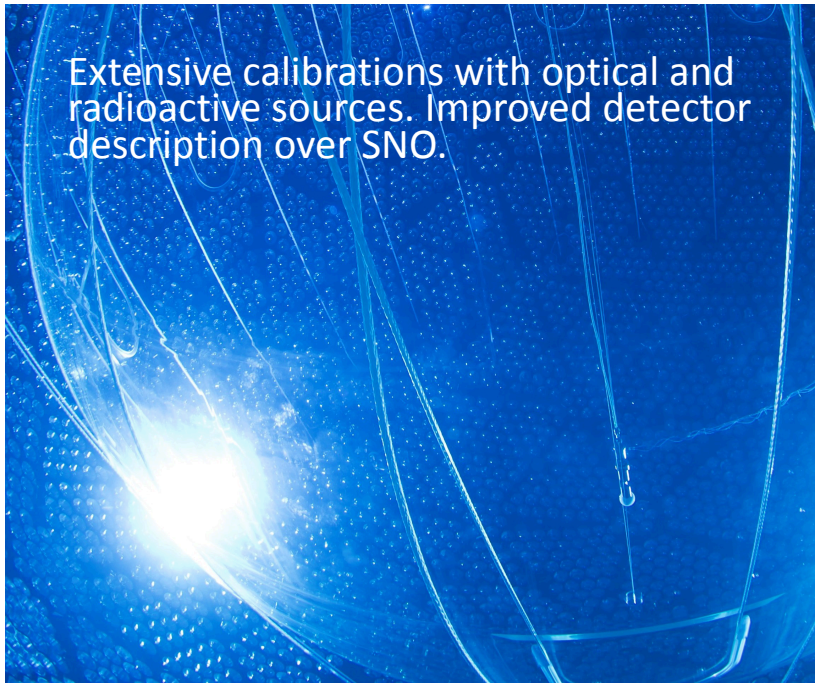
PMT Support Structure
8.9 m radius, holds 9400 PMTs + Concentrators

Double-beta decay sensitivity

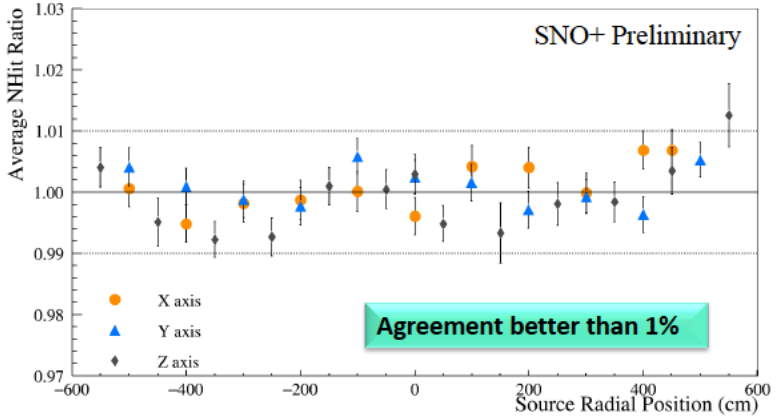


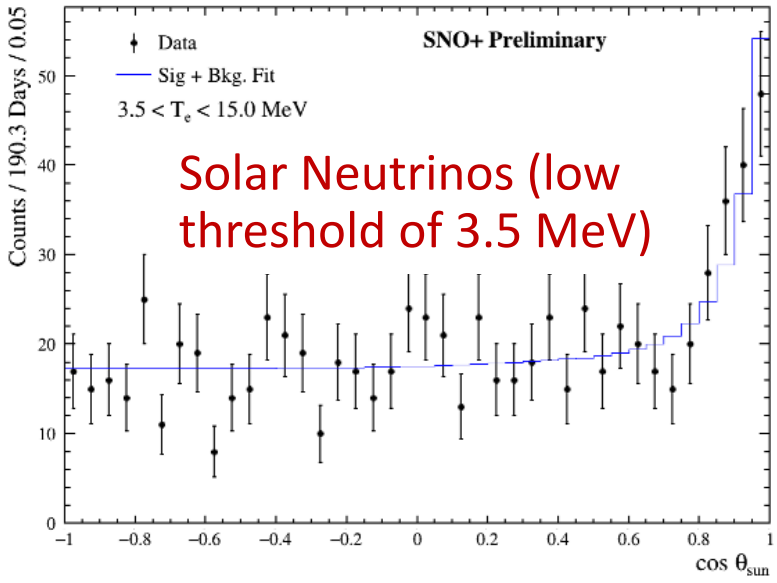
- Depending on nuclear models, SNO+ can have leading sensitivity
- Possible to increase loading from 0.5% to 3% and do even better

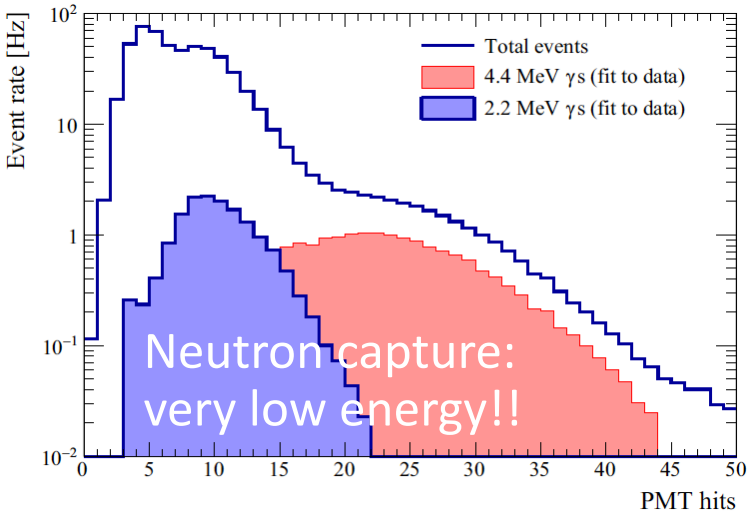
Water Phase



Ratio between data and MC



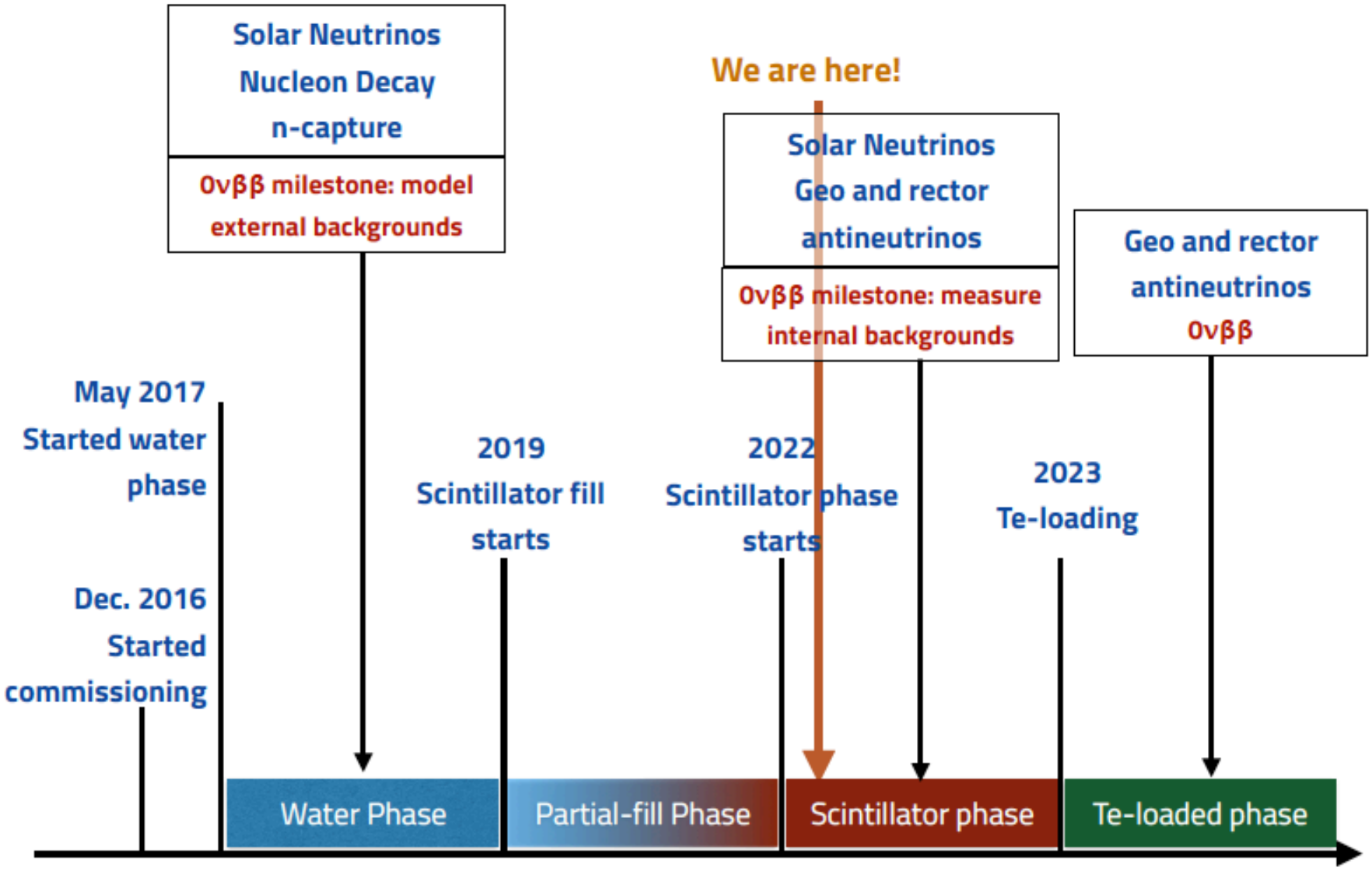




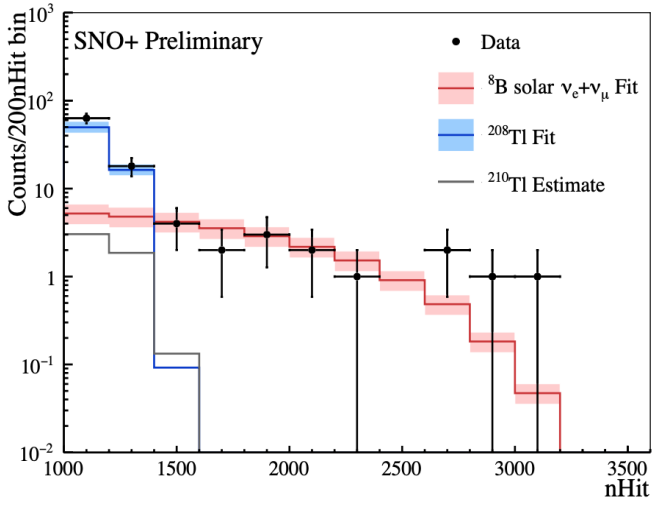
Best neutron response of any H_2O Cherenkov detectors (crucial to anti-neutrino signal)

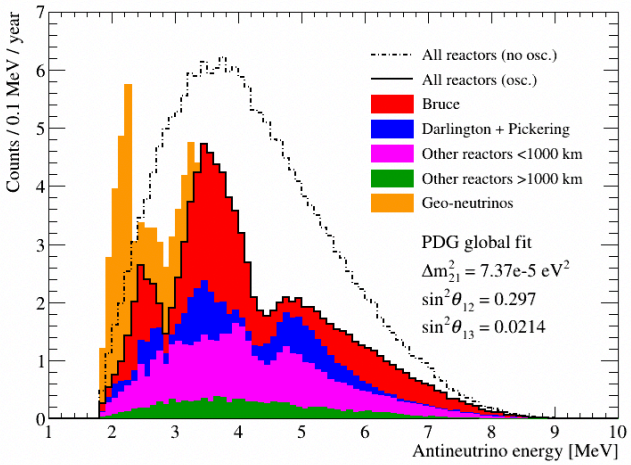
SNO+ timeline

Detector now filled with scintillator and full PPO concentration: prospect of ~year of stable data!



Projects for students 1: full scintillator data





- Measure B8 solar neutrino flux
  - Good prospects for a low energy threshold measurement
  - First measurement in partial fill done@ LIP
- Measure reactor antineutrino oscillations
  - Coincidence tagging
  - Help clarify current ambiguity KamLAND/ solar
  - Possibly detect first geo-neutrinos in North America?

Contact: maneira@lip.pt

SNO+ Projects for students 1: Preparation for DBD analysis

- Tellurium data starting late 2023. Use simulations and pure scintillator data until then
- Develop improvements to analysis
  - Event reconstruction
  - Background tagging techniques
- Analyse scintillator data, measure backgrounds that will be needed for DBD analysis

Lisbon and Coimbra

Contact: maneira@lip.pt