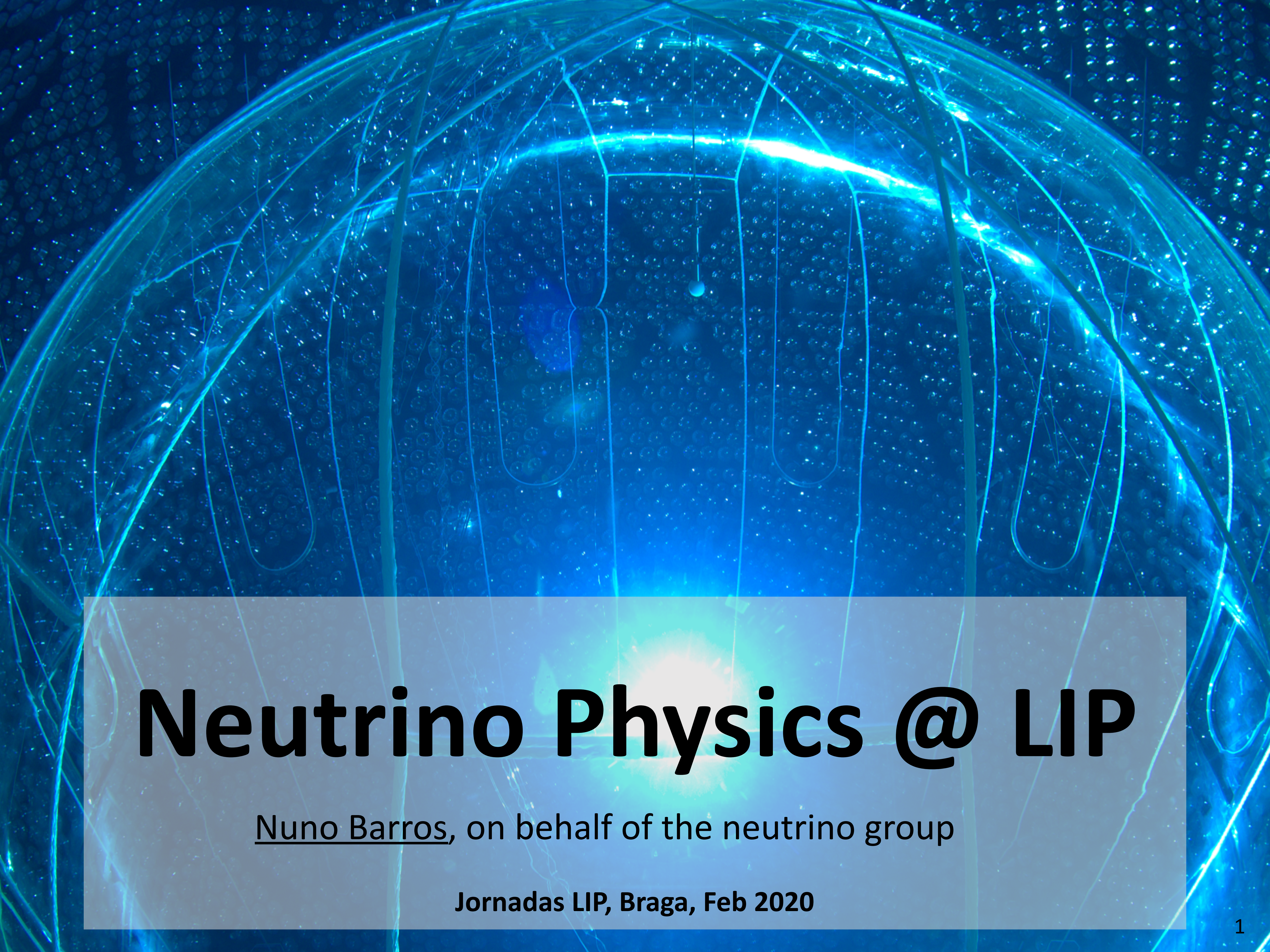


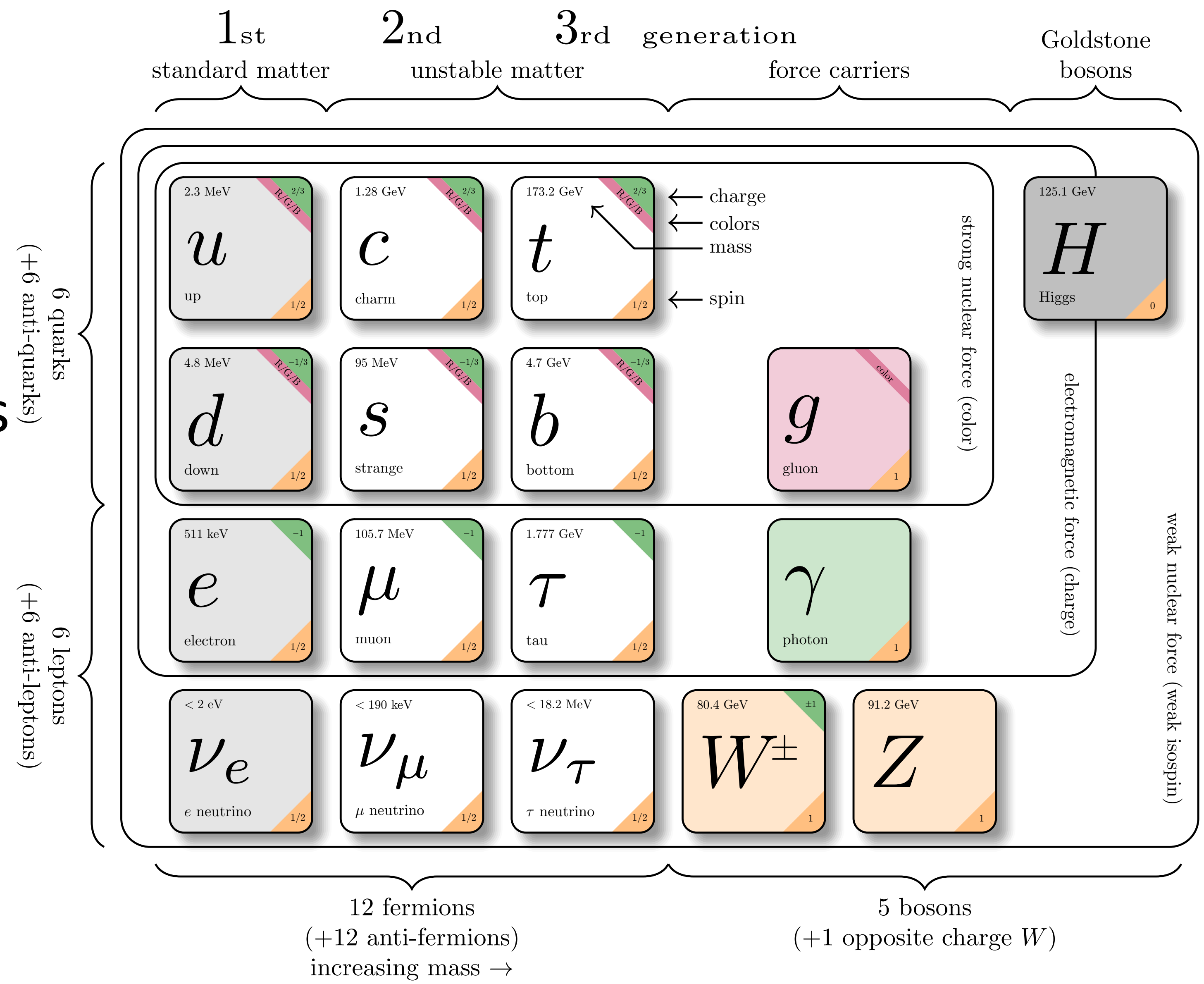
Neutrino Physics @ LIP

Nuno Barros, on behalf of the neutrino group

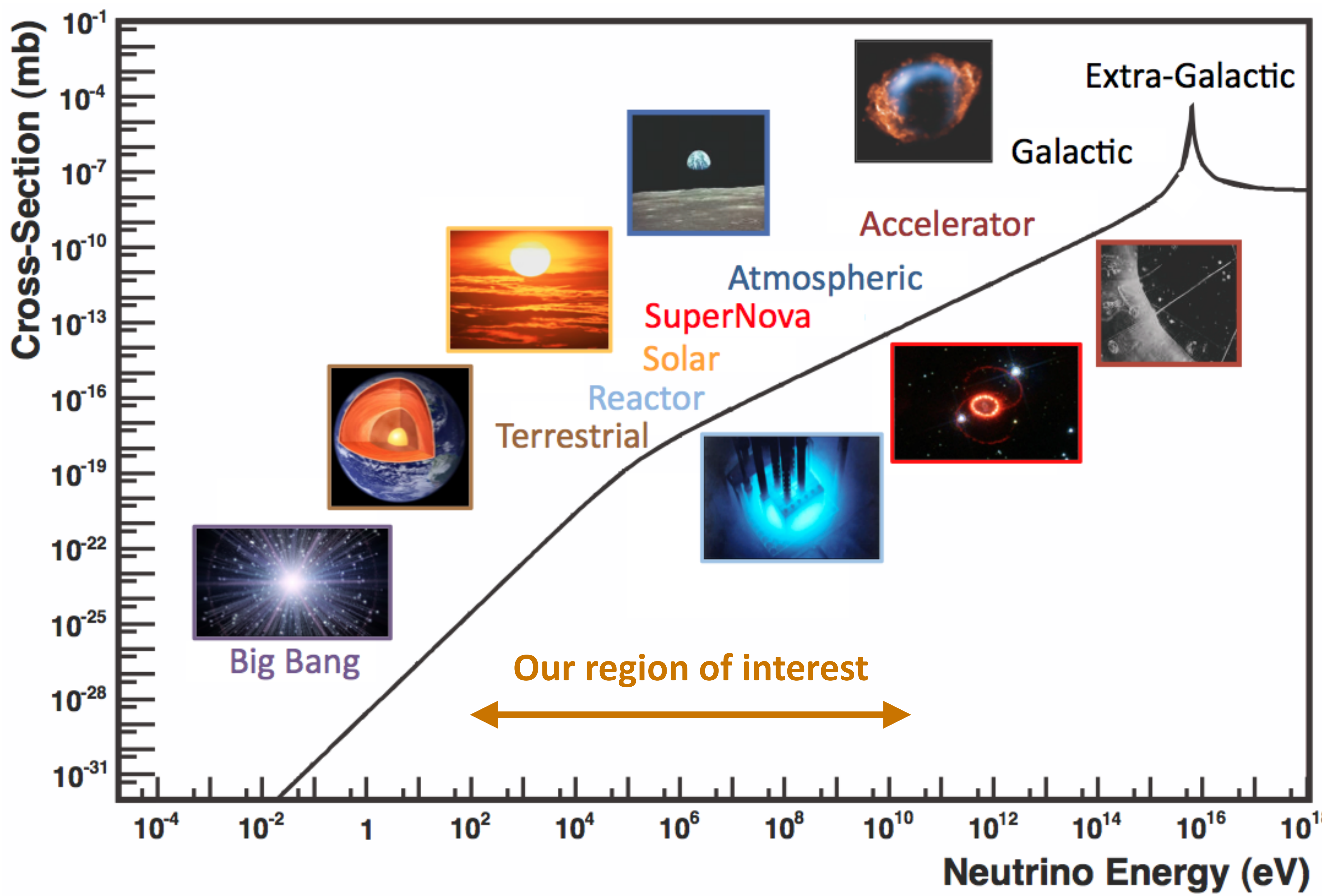
Jornadas LIP, Braga, Feb 2020

What do we know about neutrinos?

- Have no charge - do not participate in electromagnetism
  - Could be their own anti-particles
- Come in three flavors
- Are very light
  - Thought to be massless
  - Neutrino oscillations imply massive neutrinos
- Interact very weakly

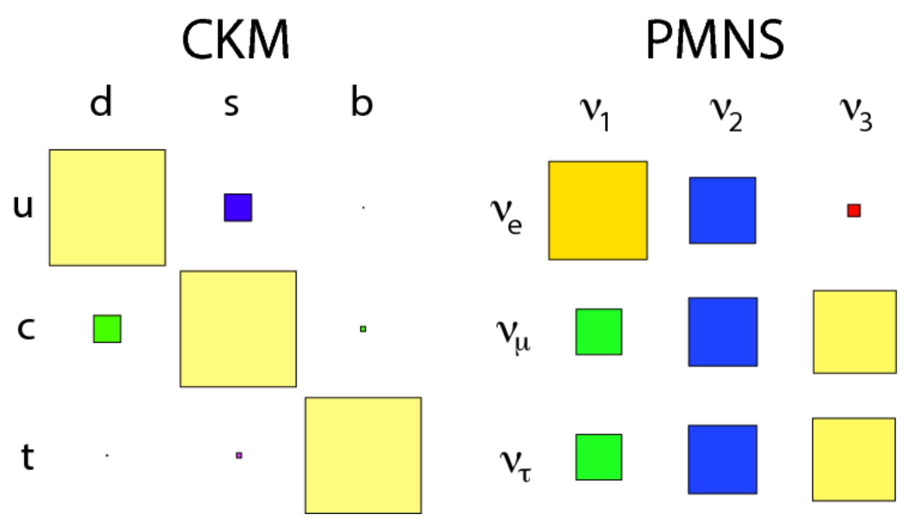


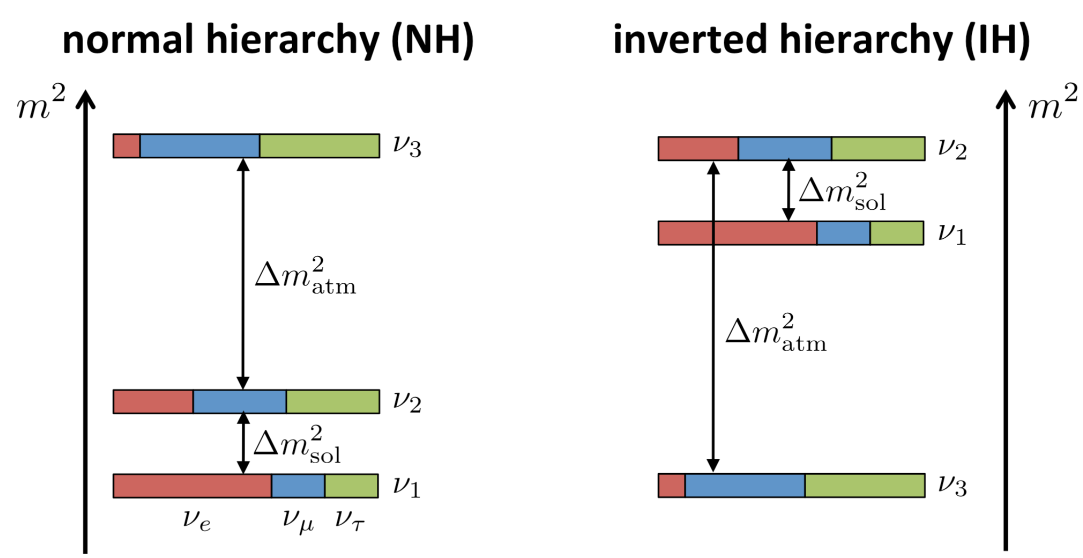
Where neutrinos come from?



What haven't we learned yet about neutrinos

- **Is there CP violation in the lepton sector?**
- Which mass hierarchy is correct?
- What are the precise values of the neutrino mixing parameters?





- What is the absolute mass scale?
- **Are neutrinos Majorana or Dirac particles?**

DUNE

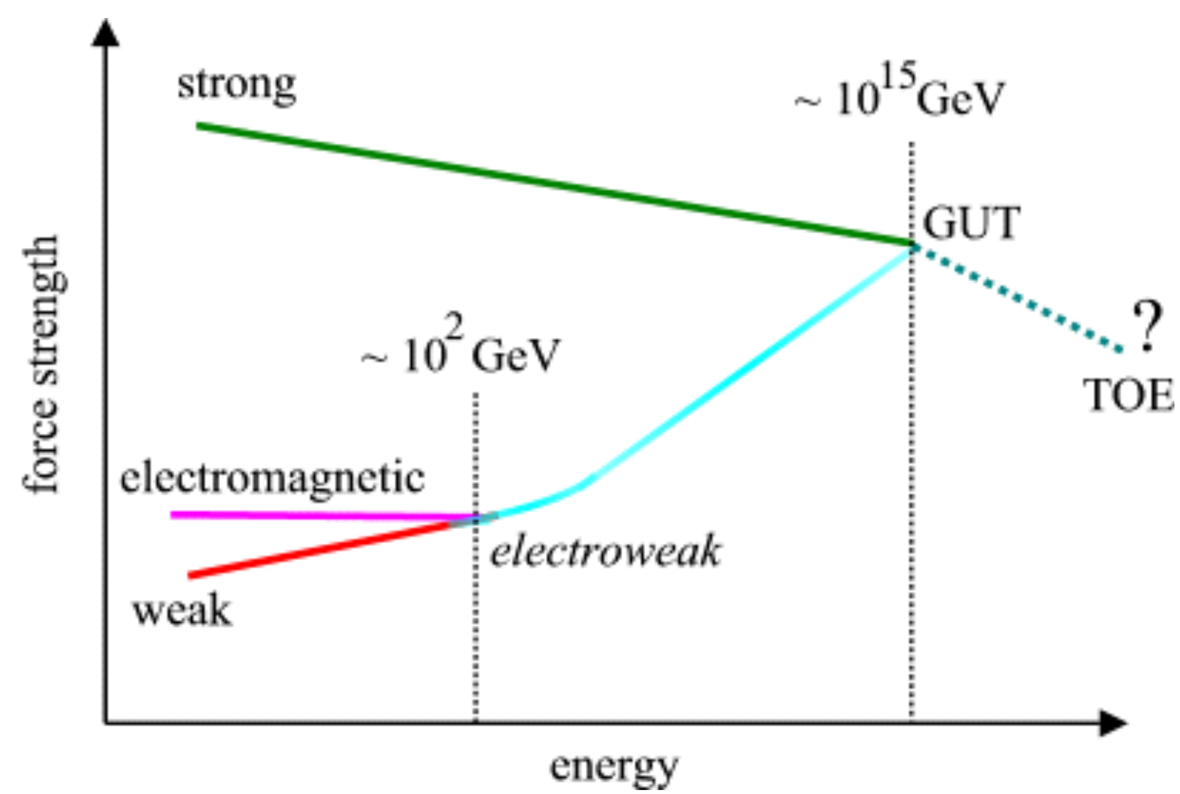
SNO+

Massive Majorana neutrinos

$m_\nu \cdot m_N \approx m_D^2$

- Neutrinos could their own antiparticles, with only chirality/helicity distinguishing them (Majorana)

- **IF** Heavy Majorana neutrinos exist, a "see-saw" mechanism can explain the smallness of masses
  - Dirac term m_D ~ 100 GeV (scale of W, Z, Higgs bosons)
  - If m_N ~10^{14} – 10^{15} GeV (GUT scale)
  - Then m_ν ~ 0.01 - 0.1 eV (expected from oscillations/limits)
    - **Coincidence?**



- **IF** neutrinos are Majorana fermions **AND** they violate CP they could help explain matter-antimatter asymmetry in the Universe —> **leptogenesis**

The neutrino group@LIP

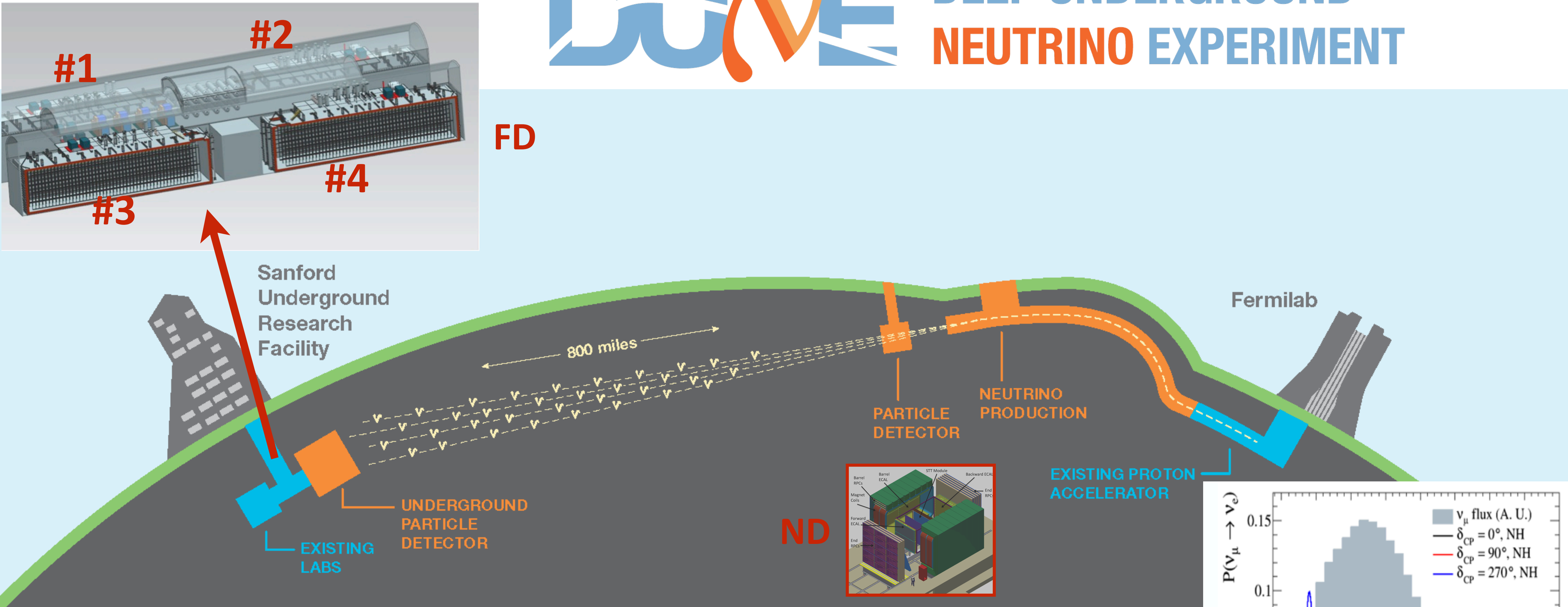
SNO+ DUNE

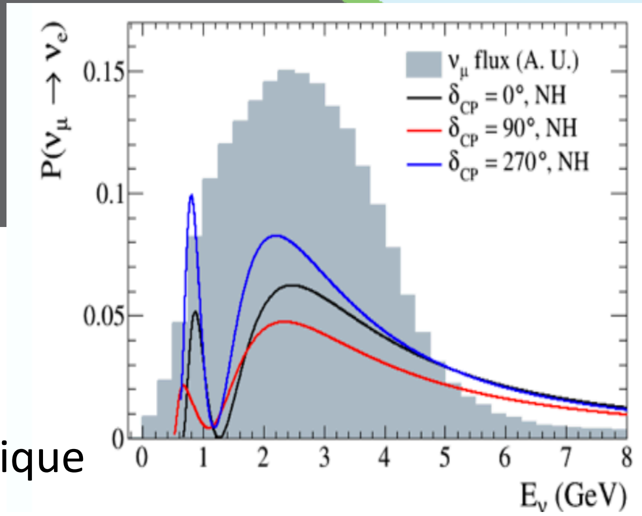
LIP Responsibilities

- **SNO+**
  - Optical Calibration Conveners (N. Barros, J. Maneira)
  - Water-phase Analysis Coordinator (N. Barros)
  - Backgrounds WG Coordinator (V. Lozza)
  - Partial-Fill Analysis Coordinator (V. Lozza)
  - Anti-neutrino WG Coordinator (S. Andringa)
- **DUNE/ProtoDUNE**
  - ProtoDUNE Trigger Coordinator (N. Barros)
  - Calibration & Cryo-Instrumentation Consortium Convener (J. Maneira)

DUNE

DEEP UNDERGROUND NEUTRINO EXPERIMENT



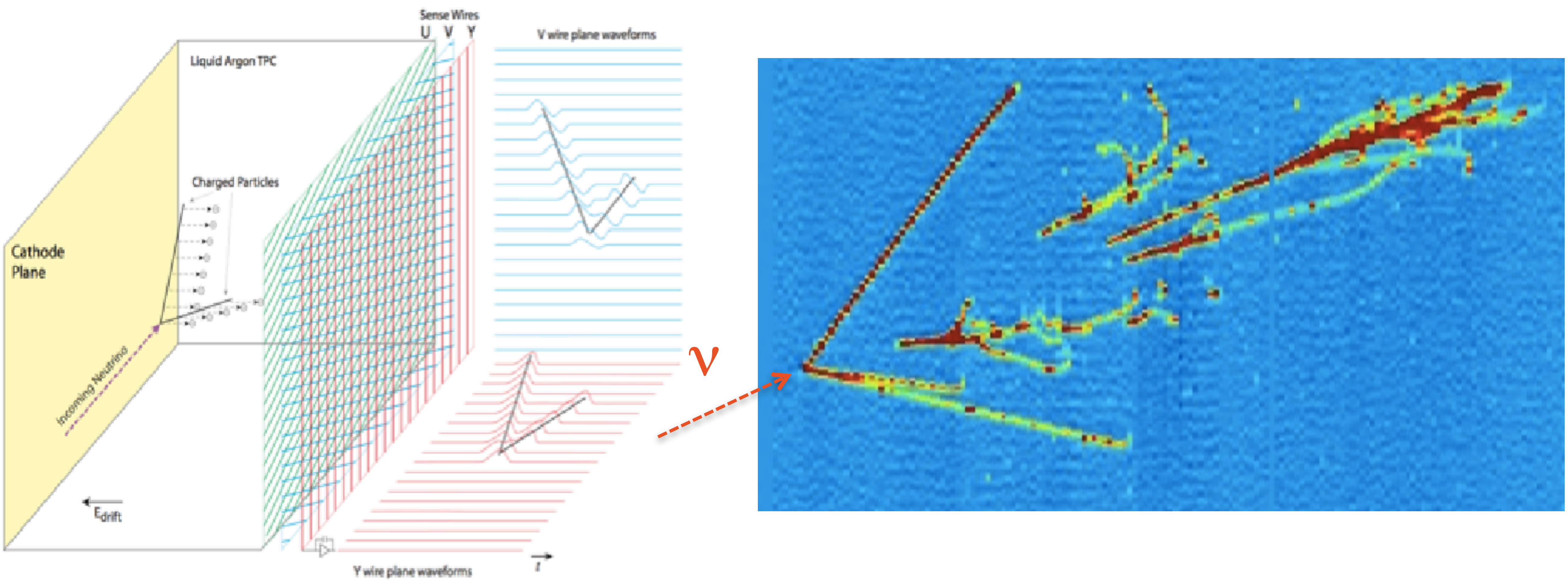


- **Neutrino Oscillation Physics**
  - High sensitivity potential for leptonic CP violation
  - Identify the neutrino mass hierarchy
  - Precision oscillation physics and test of 3-flavor oscillations
- **Proton Decay**
  - Target SUSY-favored mode $p \rightarrow K^+ \nu$
- **SN burst physics and astrophysics**
  - Galactic core collapse supernova, unique sensitivity to ν_e
- **Atmospheric Neutrinos**
- **Solar neutrinos (similar approach as SN)**
- **Neutrino Interaction Physics (Near Detector)**

E~O(few GeV) ⟷ E~O(10 MeV)

DUNE Far Detector: LAr TPCs

- Major Challenges:
  - Event reconstruction (monolithic detector)
  - Scaling of technology
- Technology advantages:
  - 3D imaging (use image processing technology for event classification)
  - Full event topology

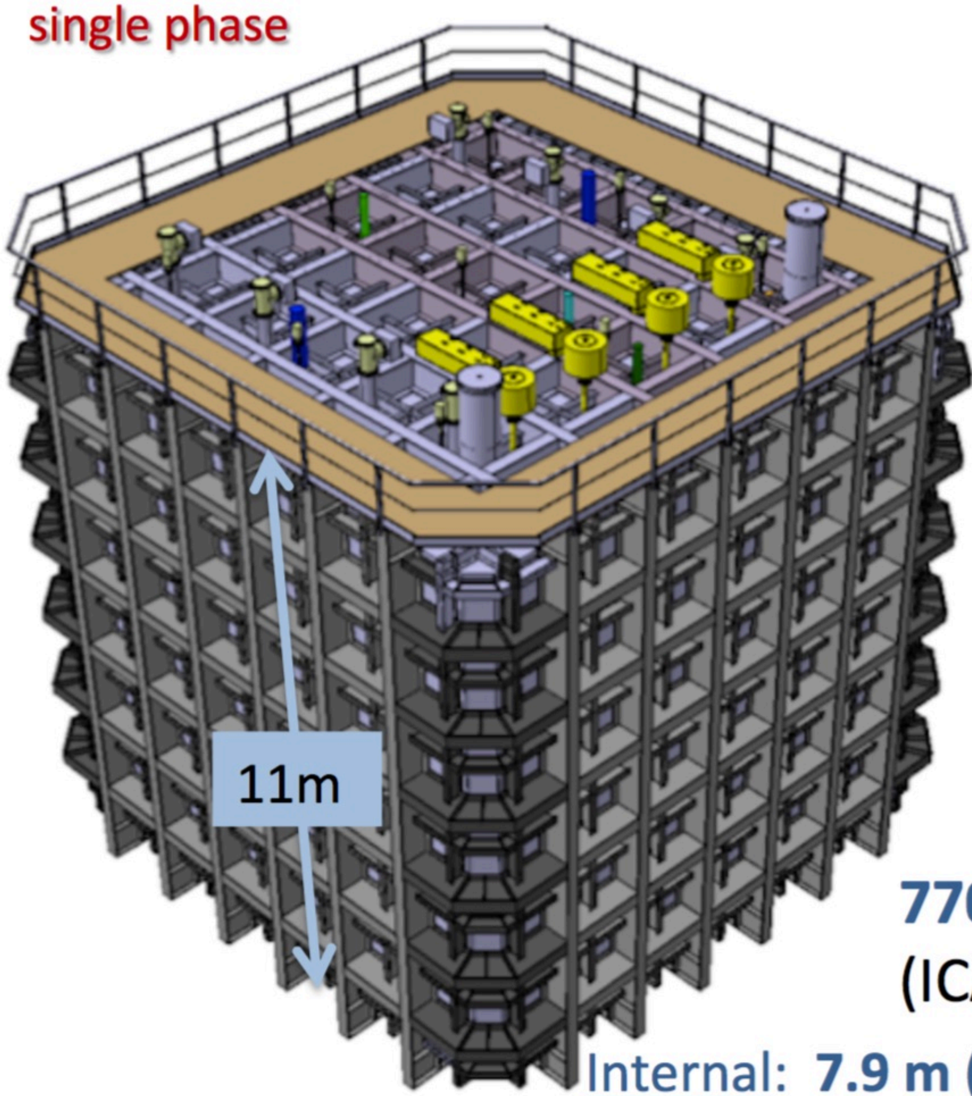


ProtoDUNE cryostats @ CERN

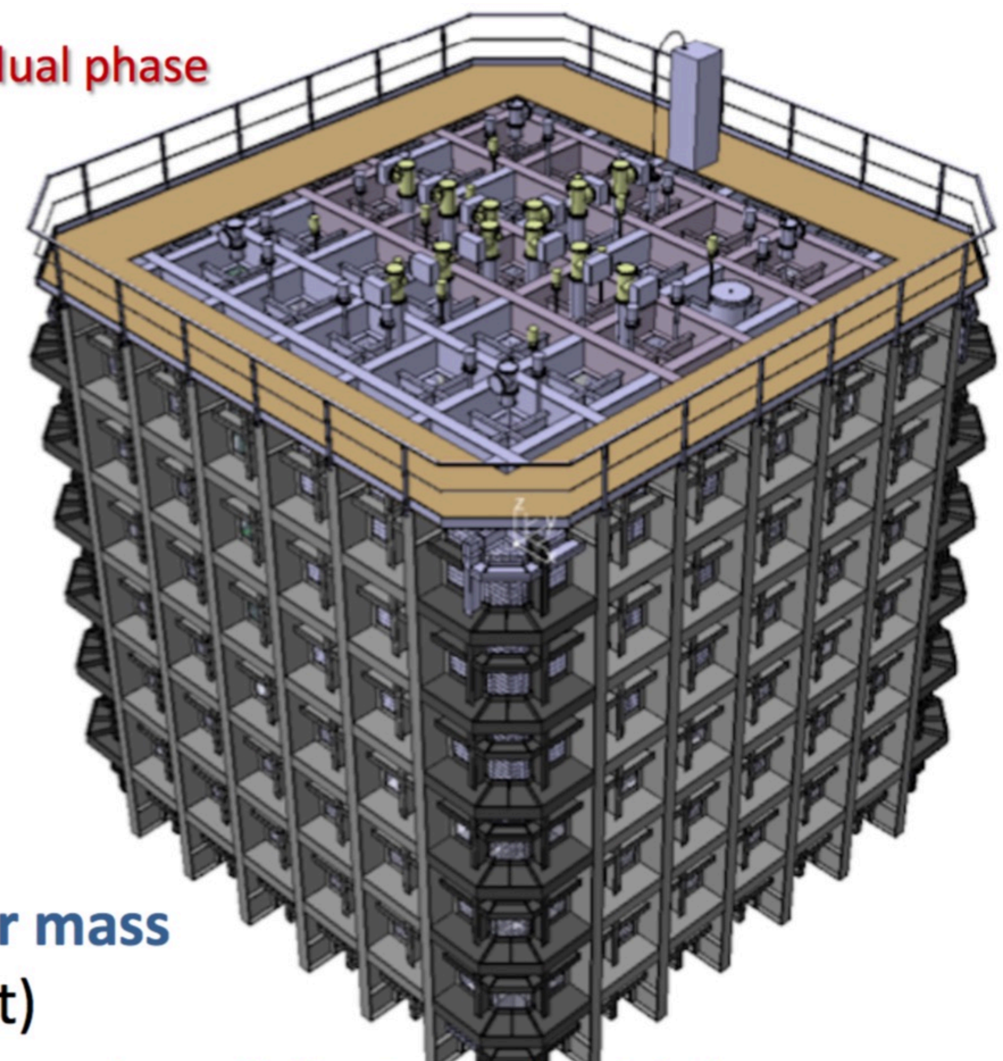
- Use nearly identical cryostats for single and dual phase protoDUNE
  - Serve as prototype for the 10kt cryostats
  - First run about to complete
  - Second (last) run planned for late 2021

Sandbox to test all components of the DUNE far detectors

single phase



dual phase

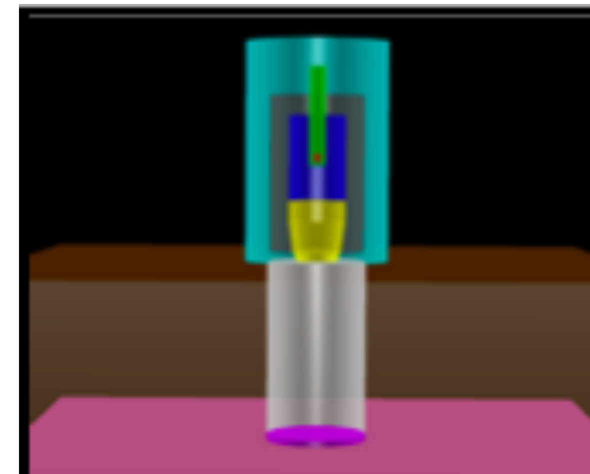


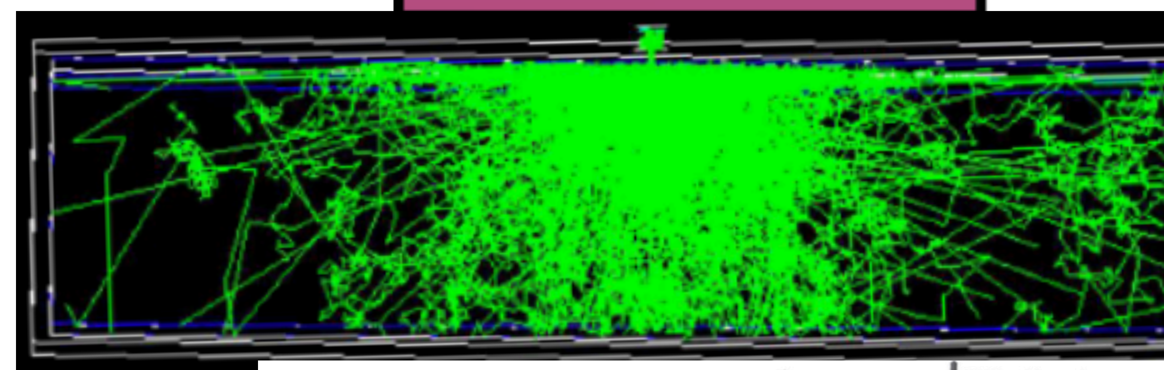
770 t total LAr mass
(ICARUS: 600 t)

Internal: **7.9 m (Transv) x 8.5 m (Parallel) x 8.1 m (Height)**
External: **10.8m (Transv) x 11.4 m (Parallel) x 11.0 m (Height).**

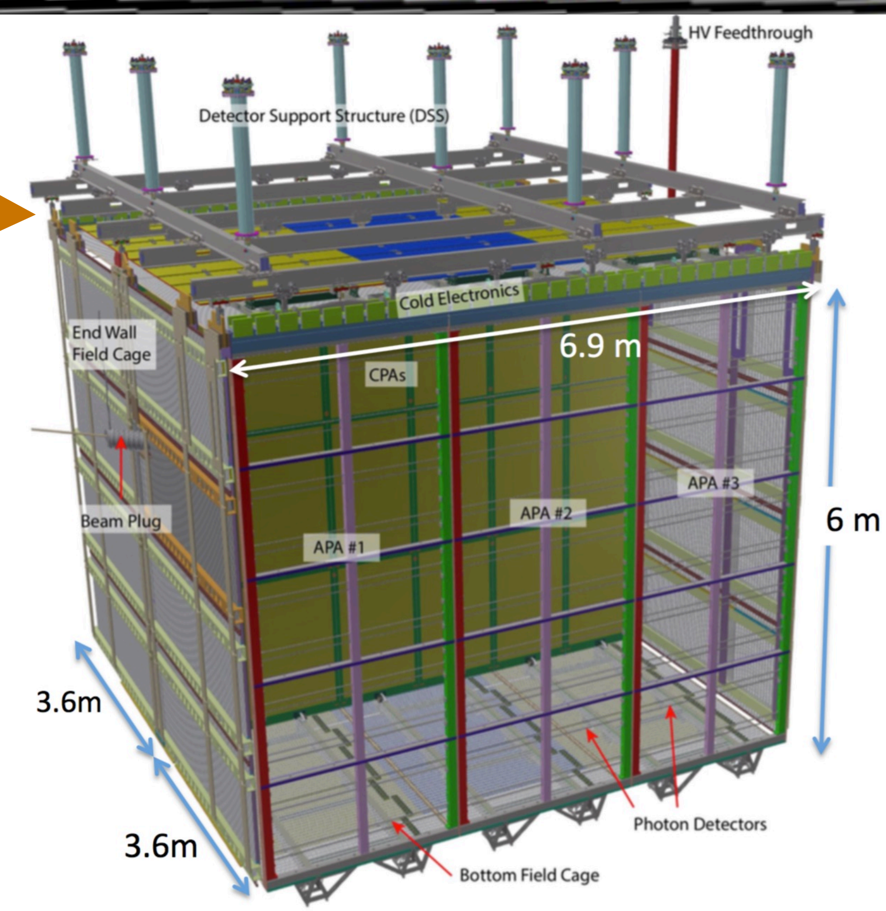
DUNE Activities at LIP

- **<u>Detector Calibration (DUNE and ProtoDUNE)</u>**
  - Ionisation laser system
  - Pulsed Neutron Source

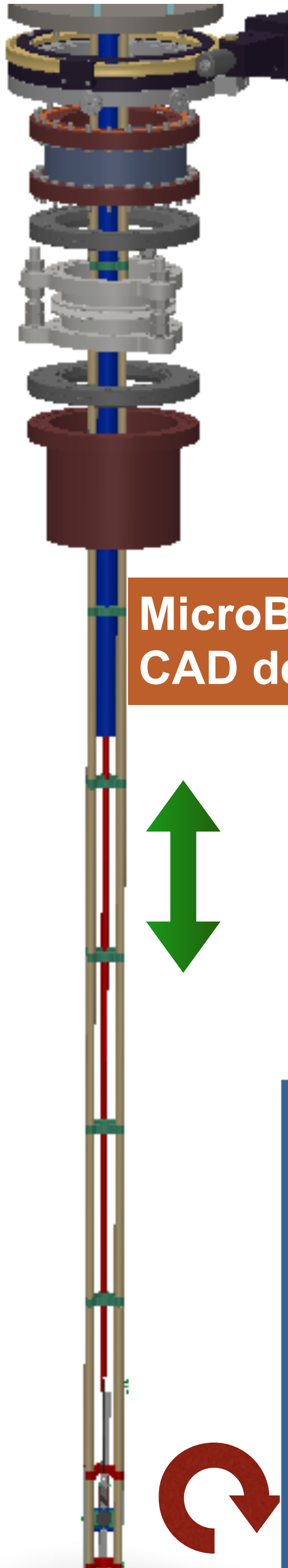




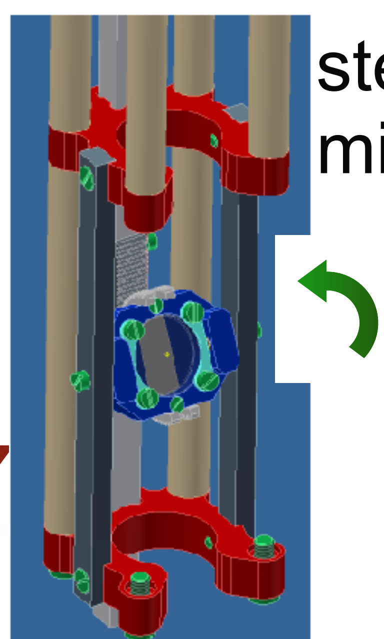
- **<u>ProtoDUNE</u>**
  - Trigger/DAQ
  - Electron Lifetime Measurements



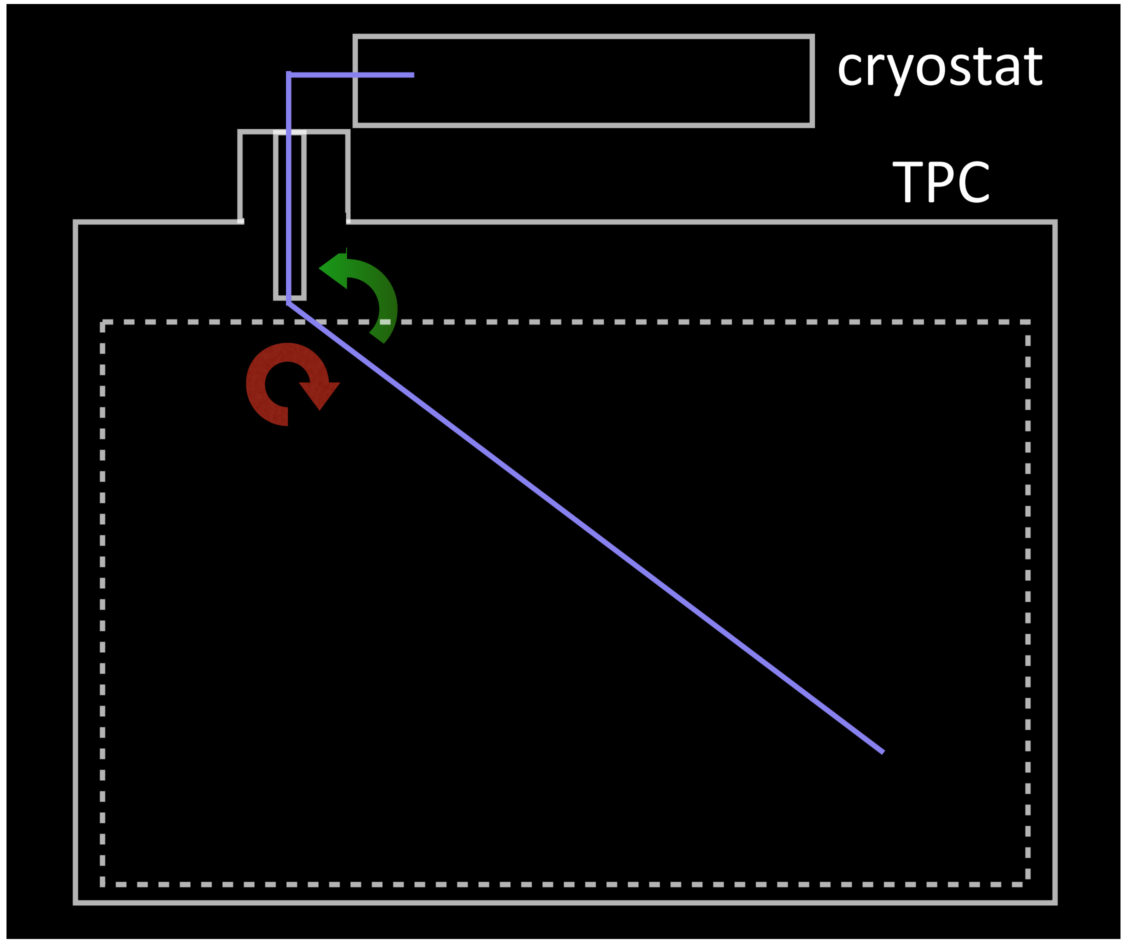
Ionisation laser



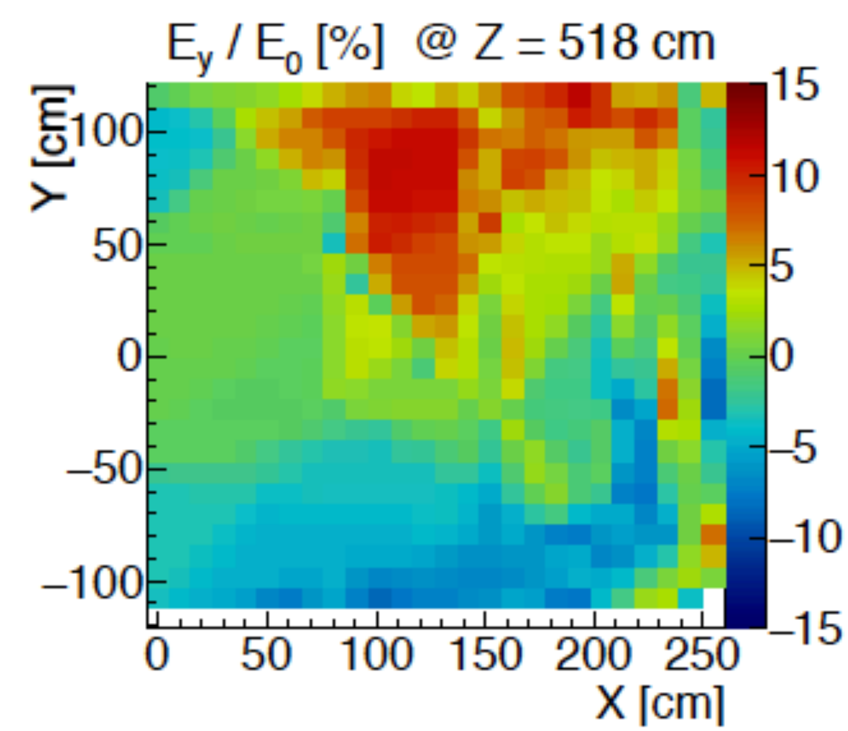
MicroBoone CAD design



steerable mirror



266 nm Nd:Yag laser

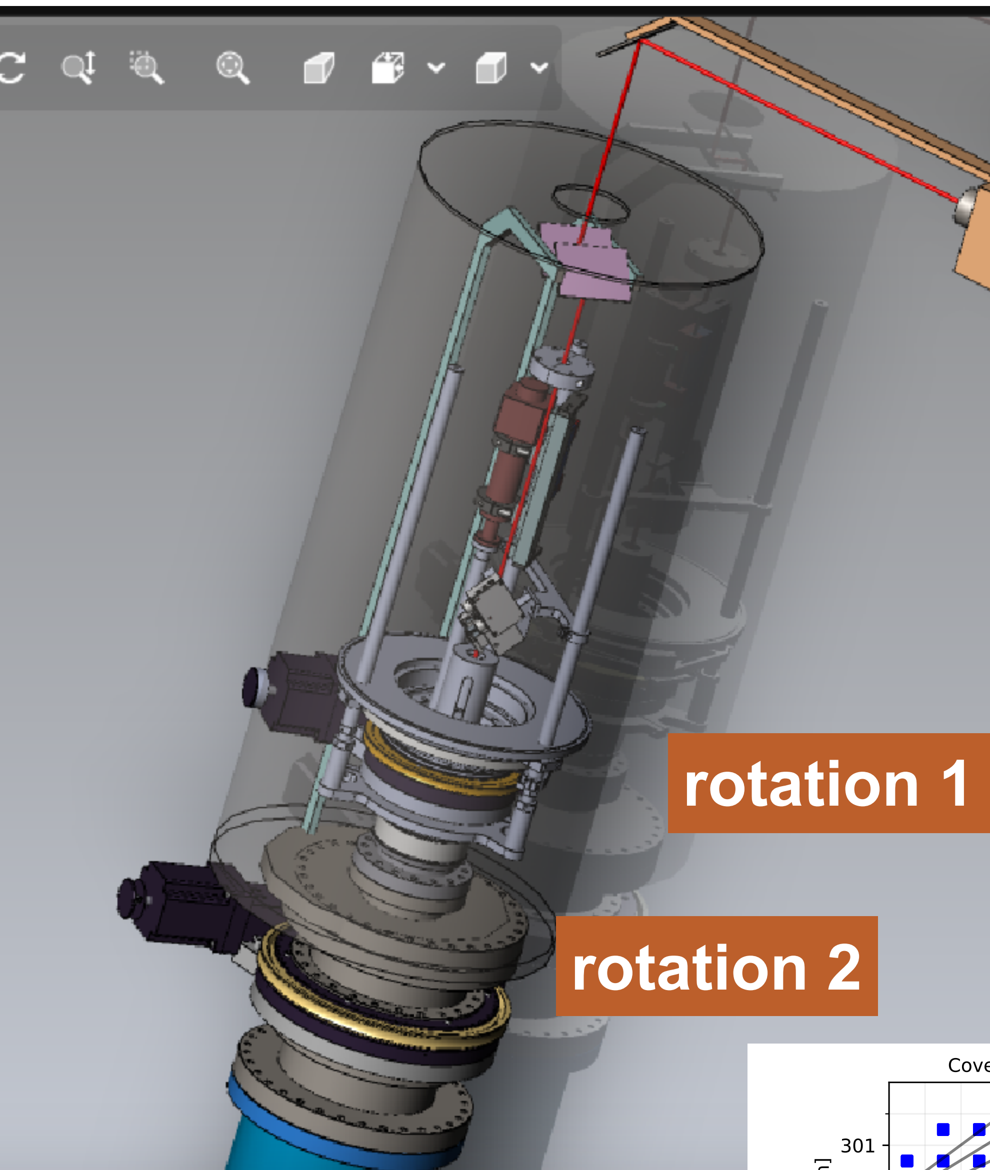


Major goals:

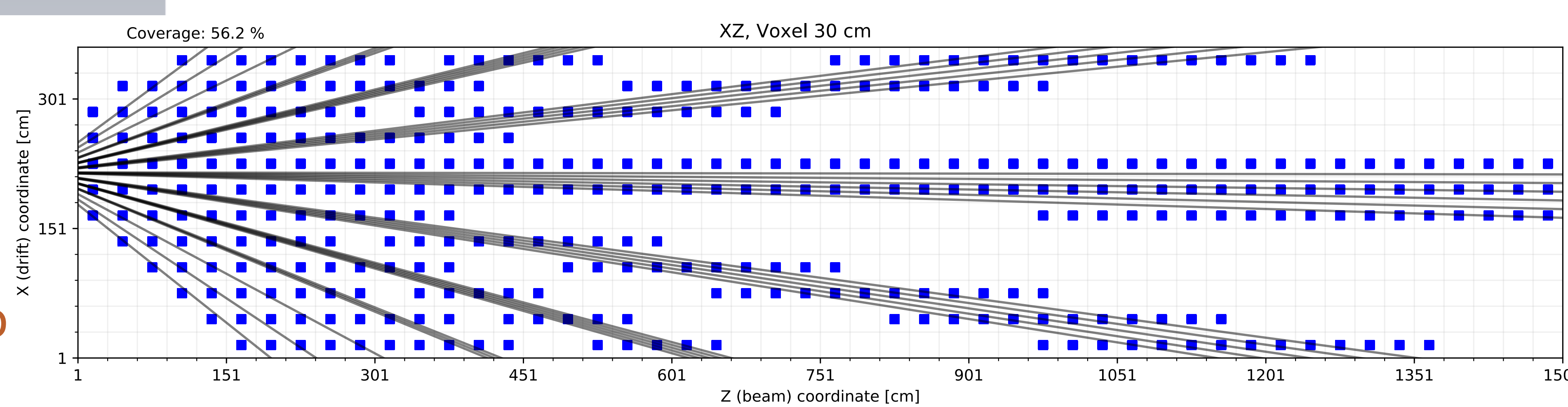
- Map electric field distortions in drift volume to < 1%
- Measure electron lifetime in whole drift volume

LIP activities in laser calibration

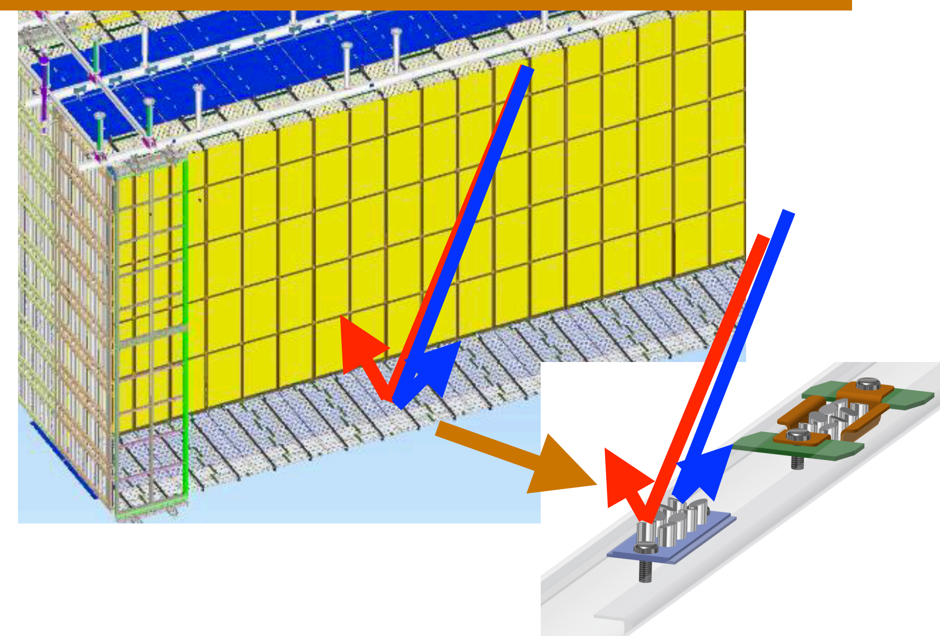
Alternative laser periscope



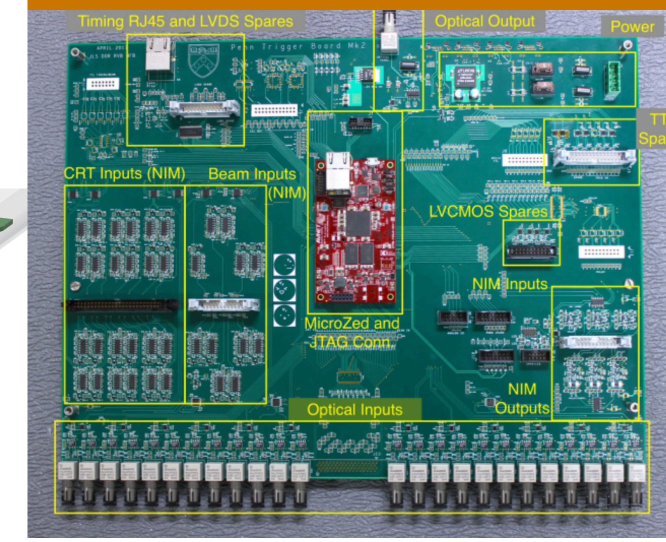
Dual rotary system adds a degree of freedom and solves low coverage due to FC shadows.



Laser position calibration



Cal/DAQ interface



Calibration/Analysis Software

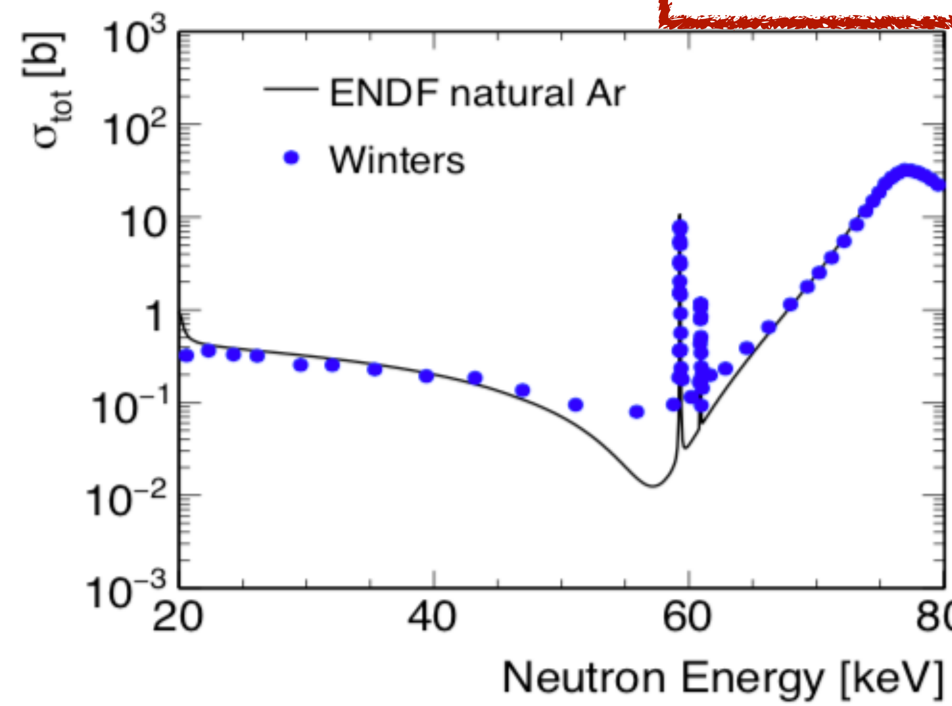
- DAQ data reduction
- Run control interface
- Data Quality

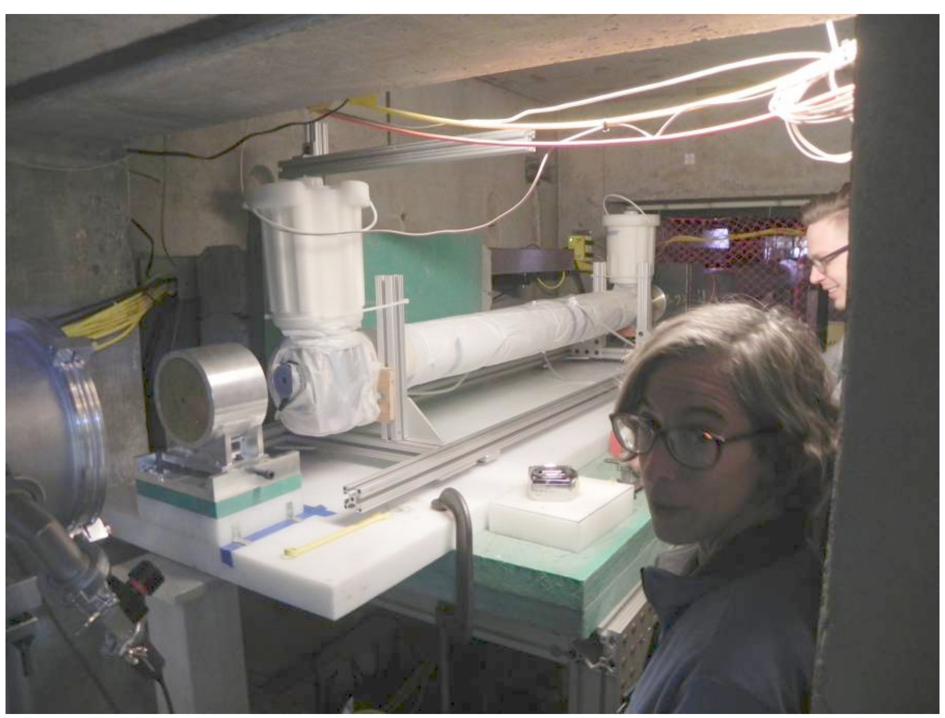
J. Maneira, F. Neves, N. Barros, R. Alves

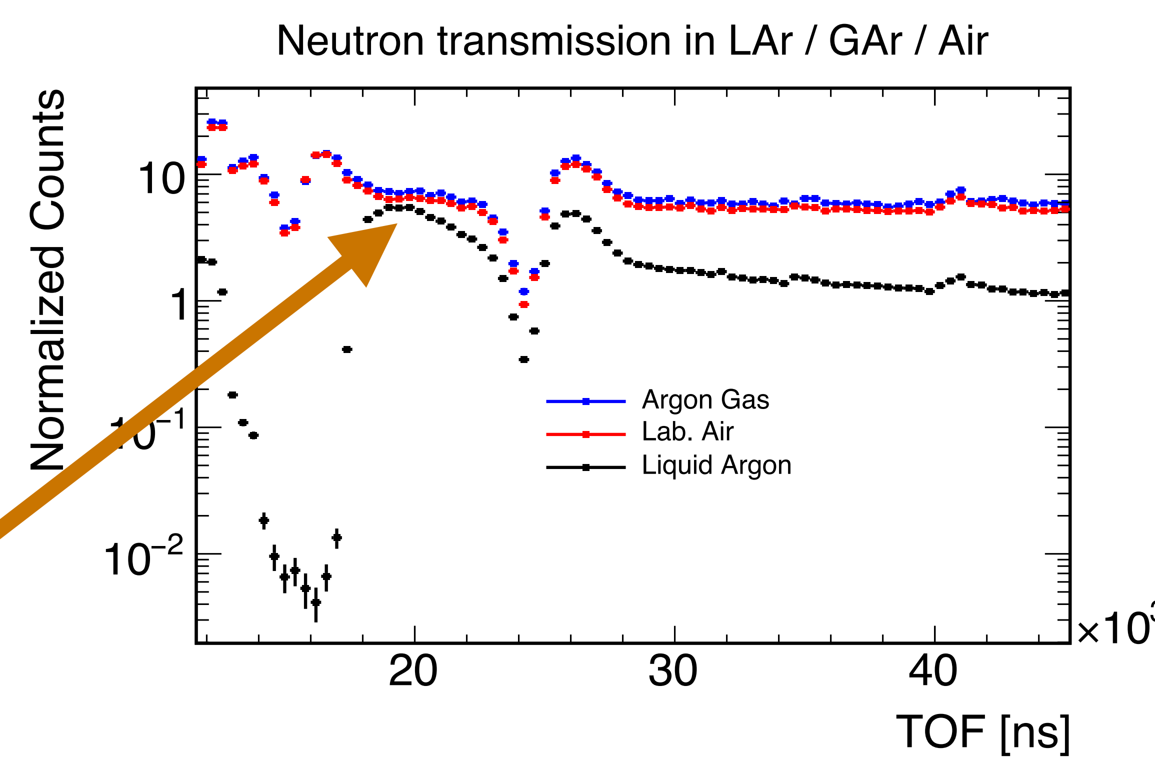
ARTIE : Argon Resonance Transmission Interaction Experiment

S. Andringa

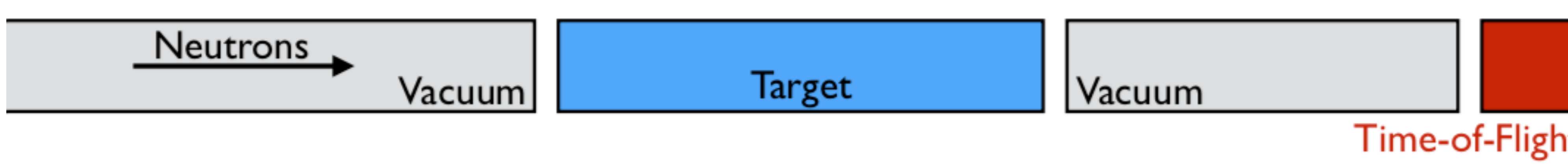
- Searching for an anti-resonance in the n+40Ar cross section using a neutron beam at LANL
  - Critical for assessment of n-backgrounds
    - **Dominant background for low energy program (solar, SN)**
  - Necessary measurement to validate need for external neutron calibration source







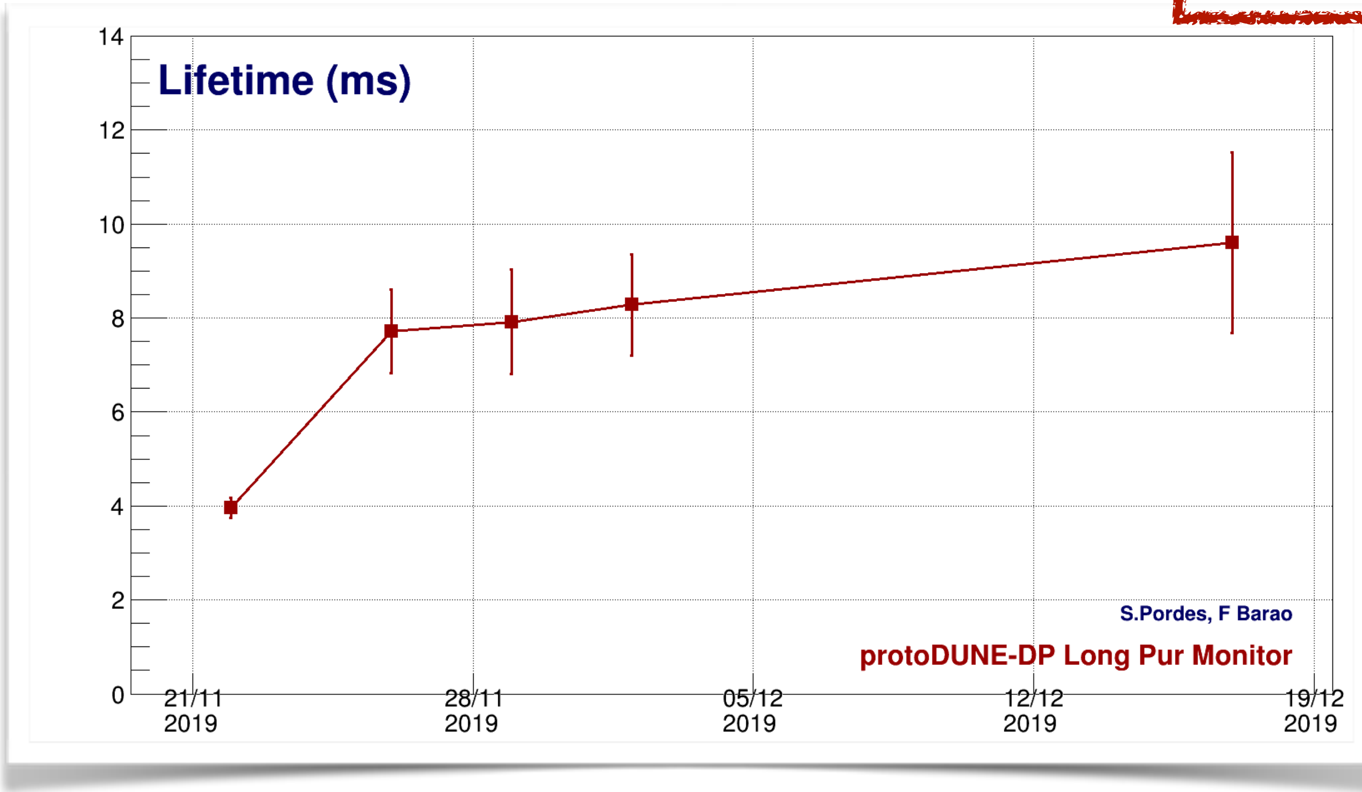
Anti-resonance

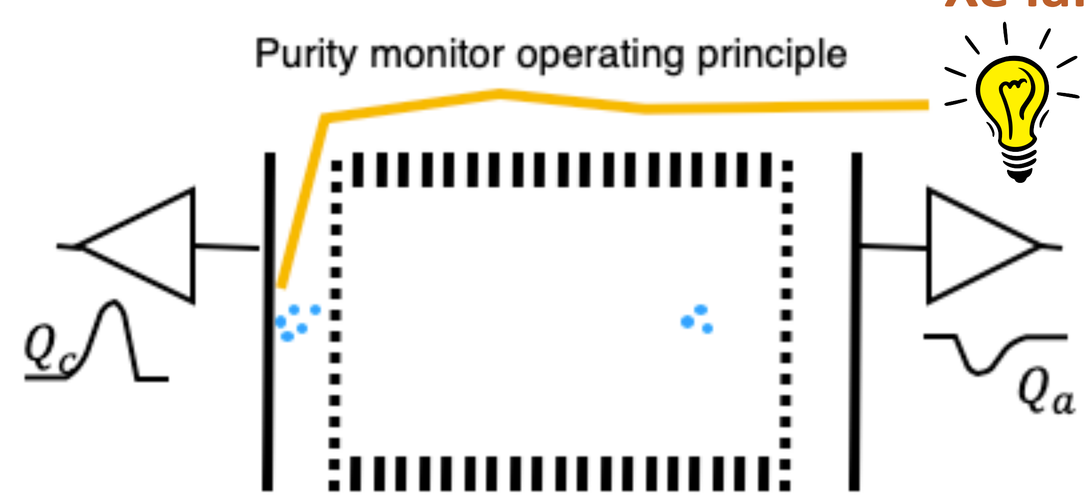


protoDUNE-DP argon purity

F. Barão

- Periodic measurement of argon purity using internal monitor
  - Electron lifetime proportional to ratio of anode and cathode charge amplitude
- Very important assessment of detector state while filling
- Electron lifetime has been consistently above 7 ms and slowly increasing
  - ~2x full volume drift time





$$\tau_e = -T_d/\ln\left(\frac{Q_a^*}{Q_c}\right)$$

*corrected

Plans over next year

- Test run of DD neutron generator in protoDUNE-SP
- Complete design of laser calibration system to deploy in protoDUNE-SP
  - Collaborate with LANL in construction of first prototypes
- Design DAQ and SC interface for calibration in PD-SP
- Increase analysis efforts in PD data
  - Analysis of cosmic ray data
    - Understand the detector response with well known event topologies
  - Characterisation of K events from beam
    - Trademark signal for DUNE nucleon decay searches
  - Sensitivity studies and calibration MC
    - Optimisation of calibration analyses, improve sensitivity

SNO+

(partially filled with scintillator)

SNO+ detector

780 tons of **liquid scintillator**

new calibration systems

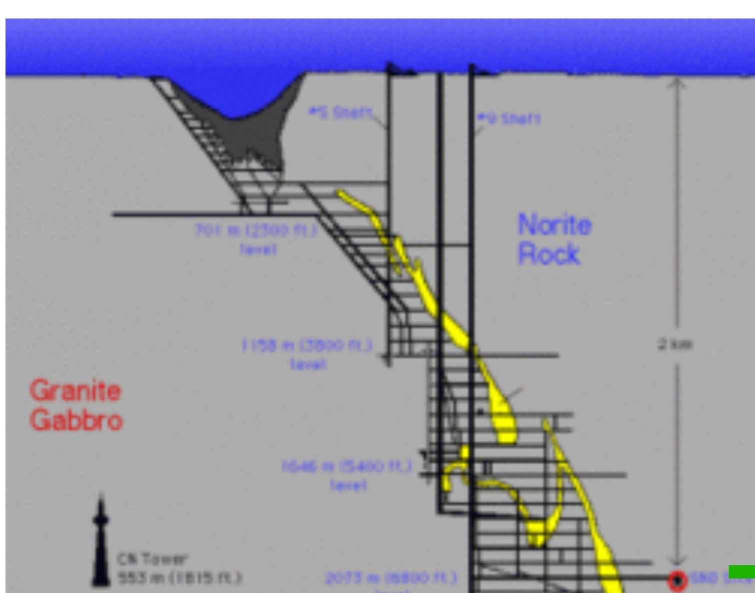
new DAQ and readout cards

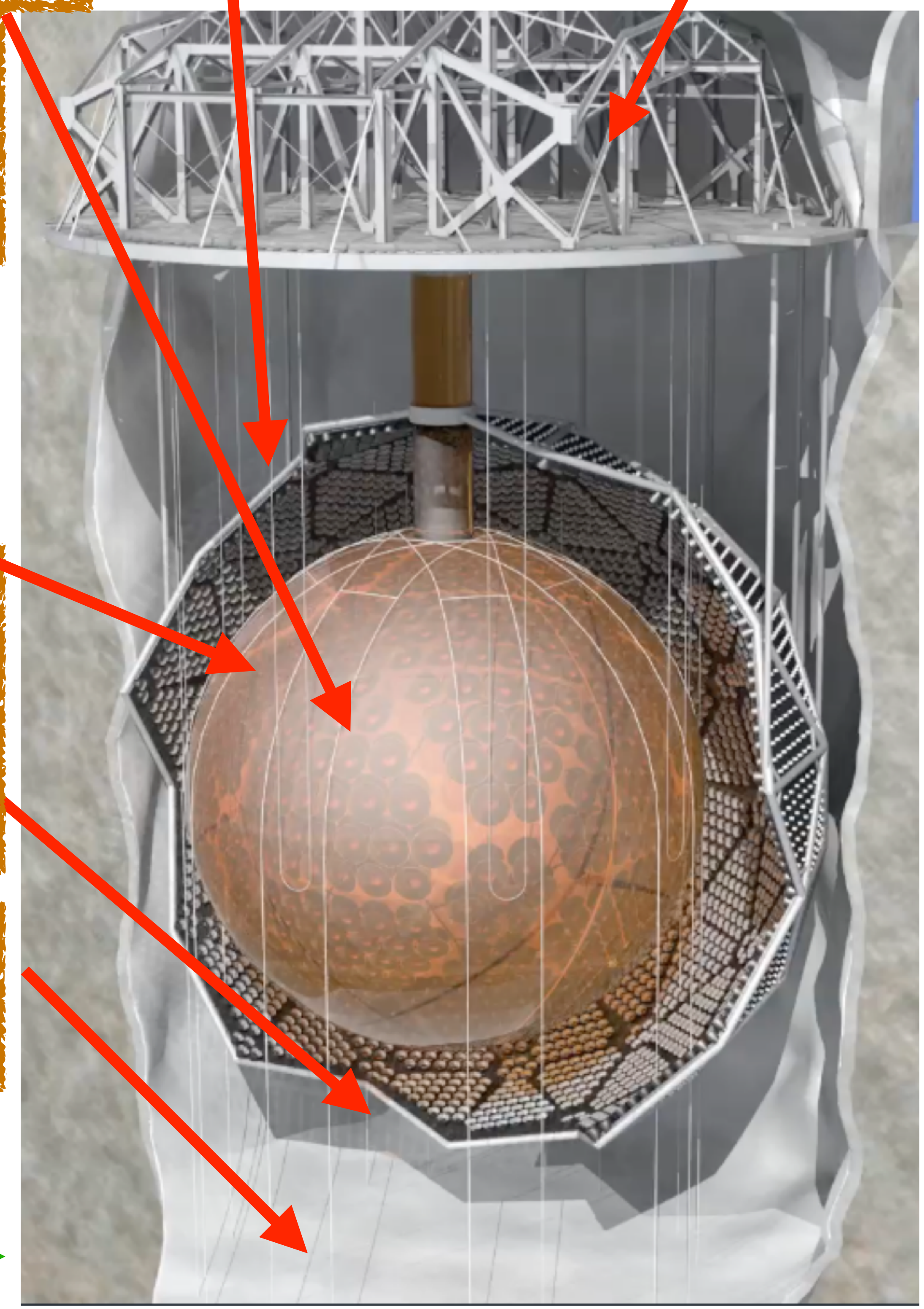
loaded with **double-beta decay isotope** (^{130}Te)

contained in an acrylic vessel (AV) 12 m diameter

viewed by ~ 9300 PMTs (8'') mounted on 17 m diam. structure

shielded by 7 kt ultra-pure water

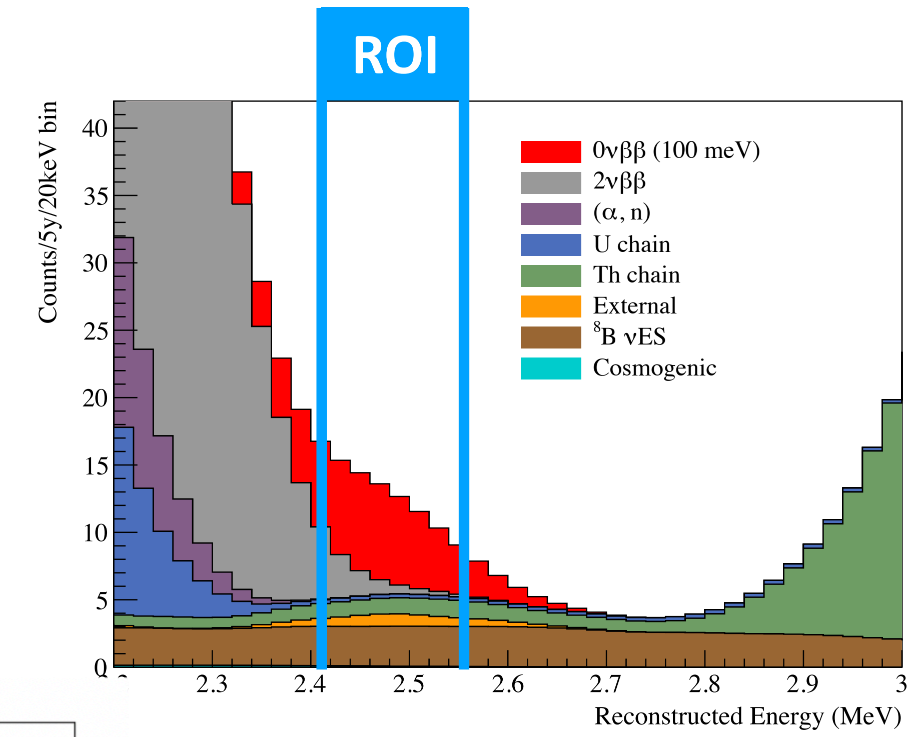




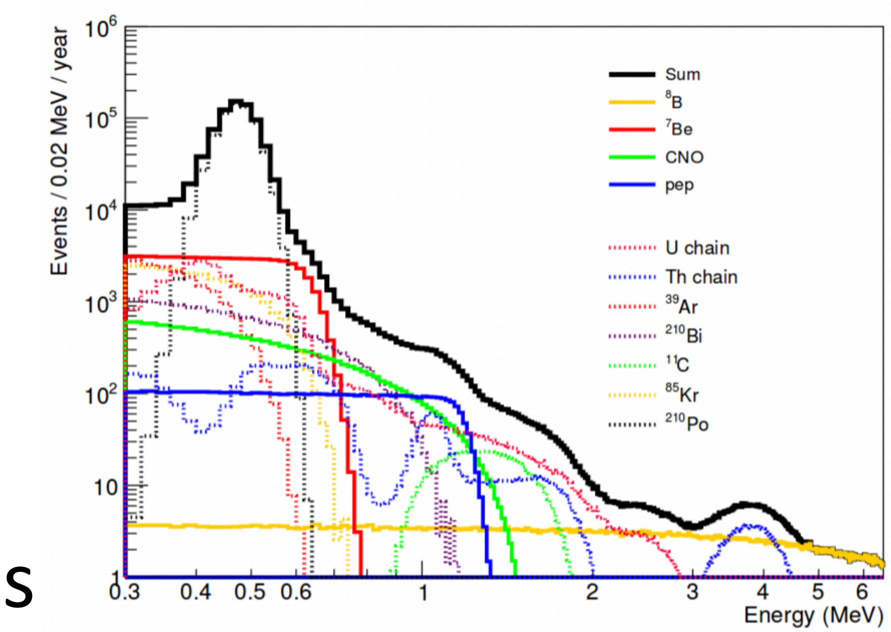
SNO+ physics program

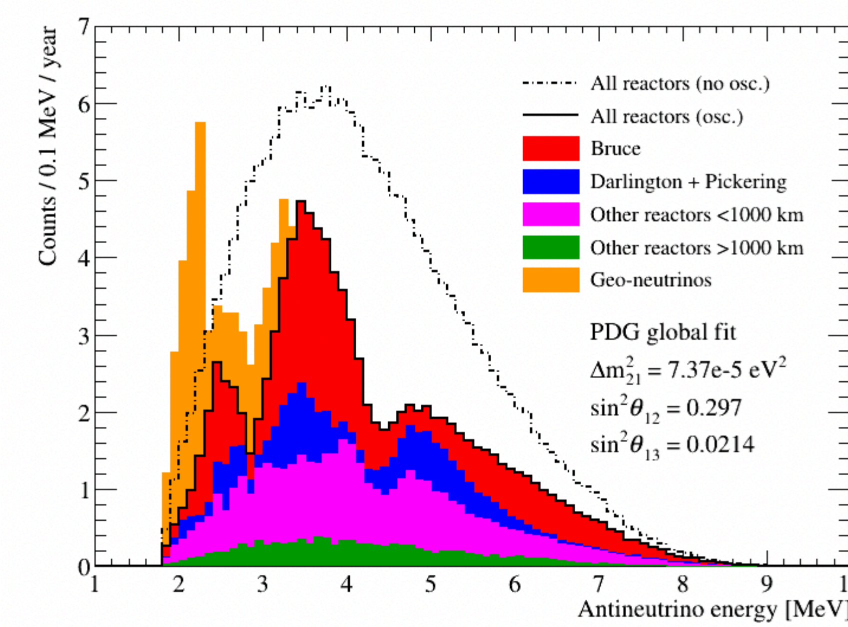
…780 ton scale low background calorimeter

- Main objective:
  - **Search for 0νββ in ^{130}Te**



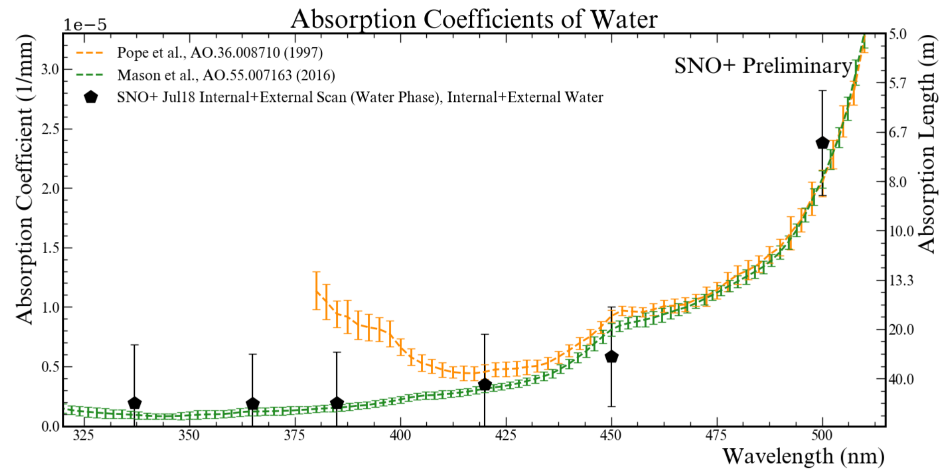
- Other topics of interest
  - **Solar neutrinos**
  - Nucleon decay
  - Supernova neutrinos
  - **Reactor and geo-antineutrinos**

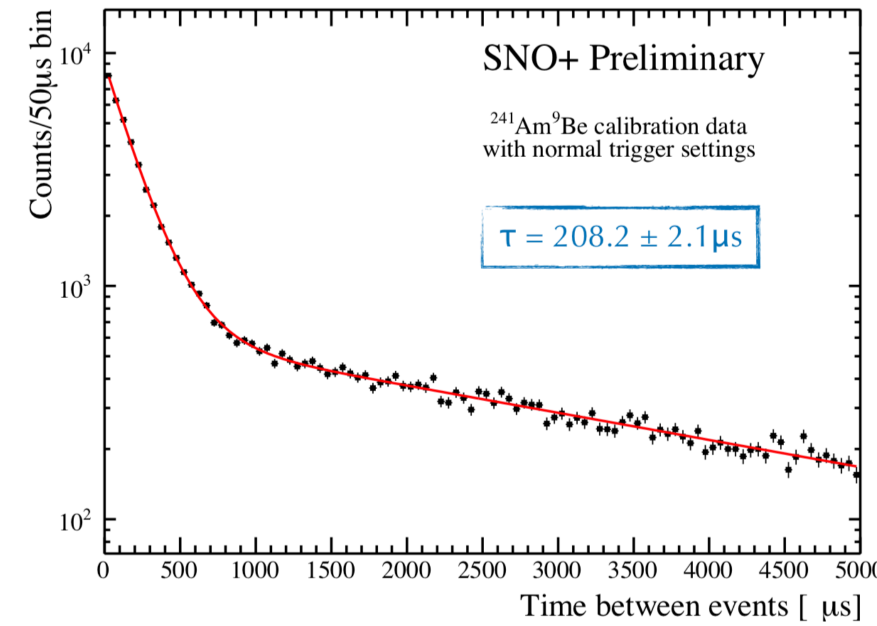


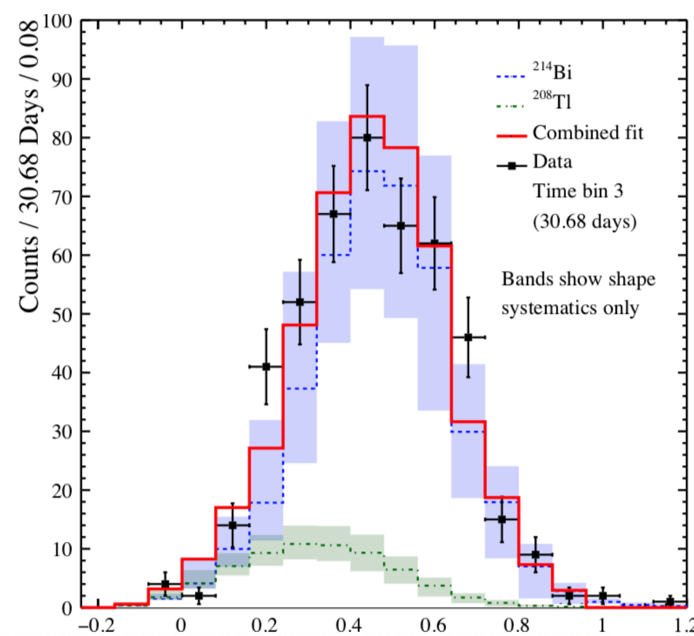


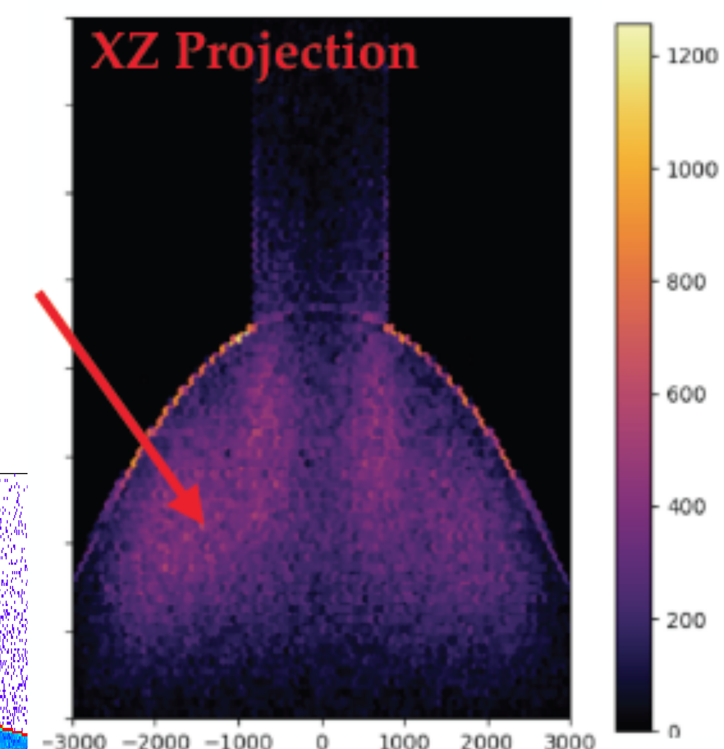
SNO+ Activities at LIP

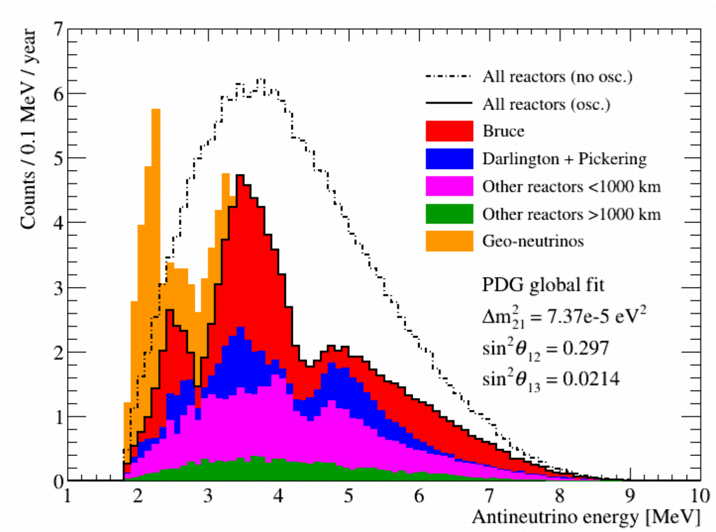
- **Detector Calibration**
  - Optical Calibration
  - AmBe
  - Low energy gamma
- Data Quality
- **Backgrounds**
  - Water phase
  - Partial fill
- **Physics Analyses**
  - Anti-neutrinos
  - Solar neutrinos
  - ββ0ν decay

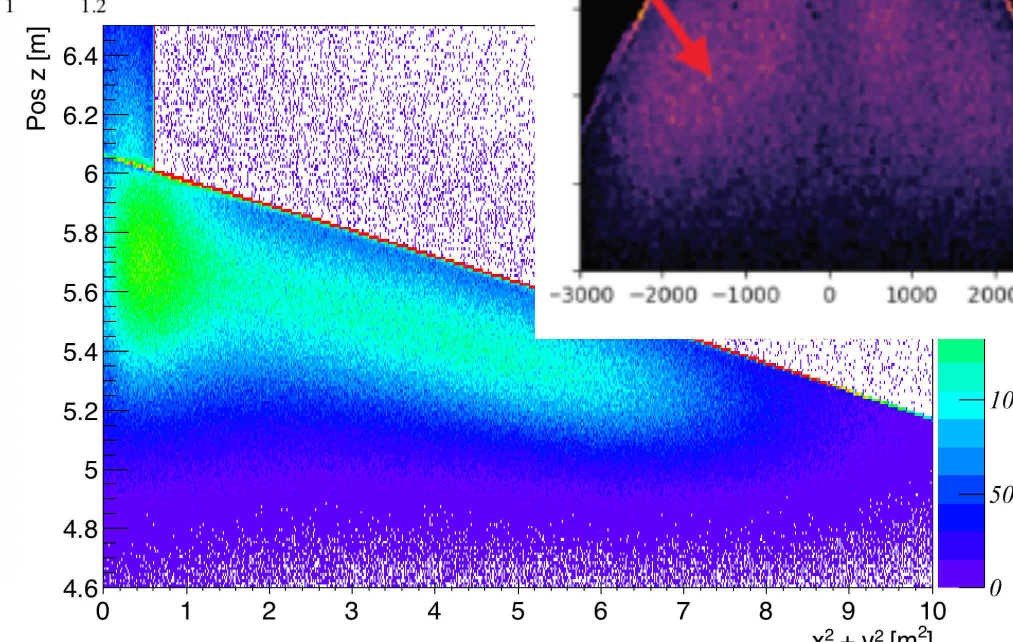








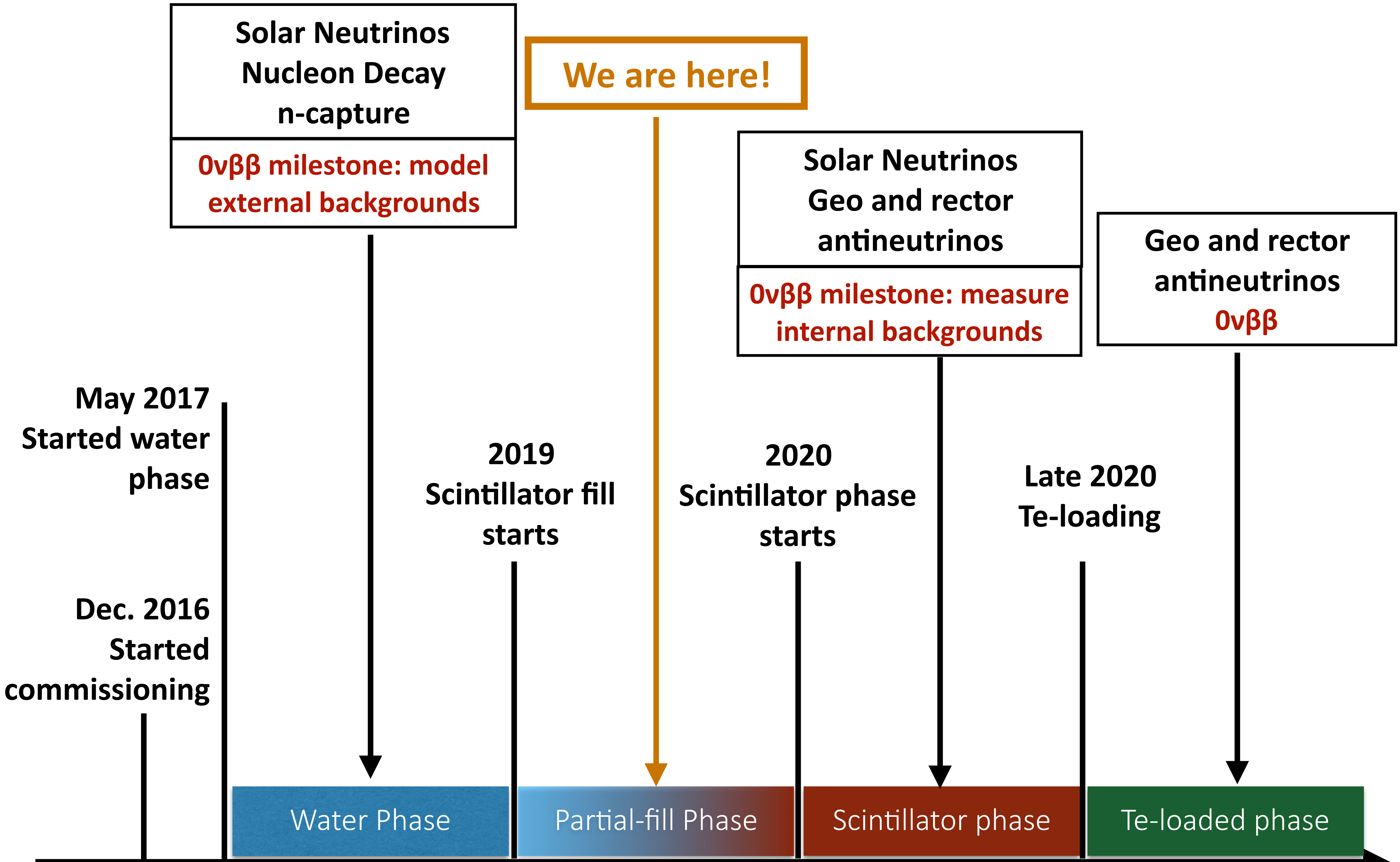


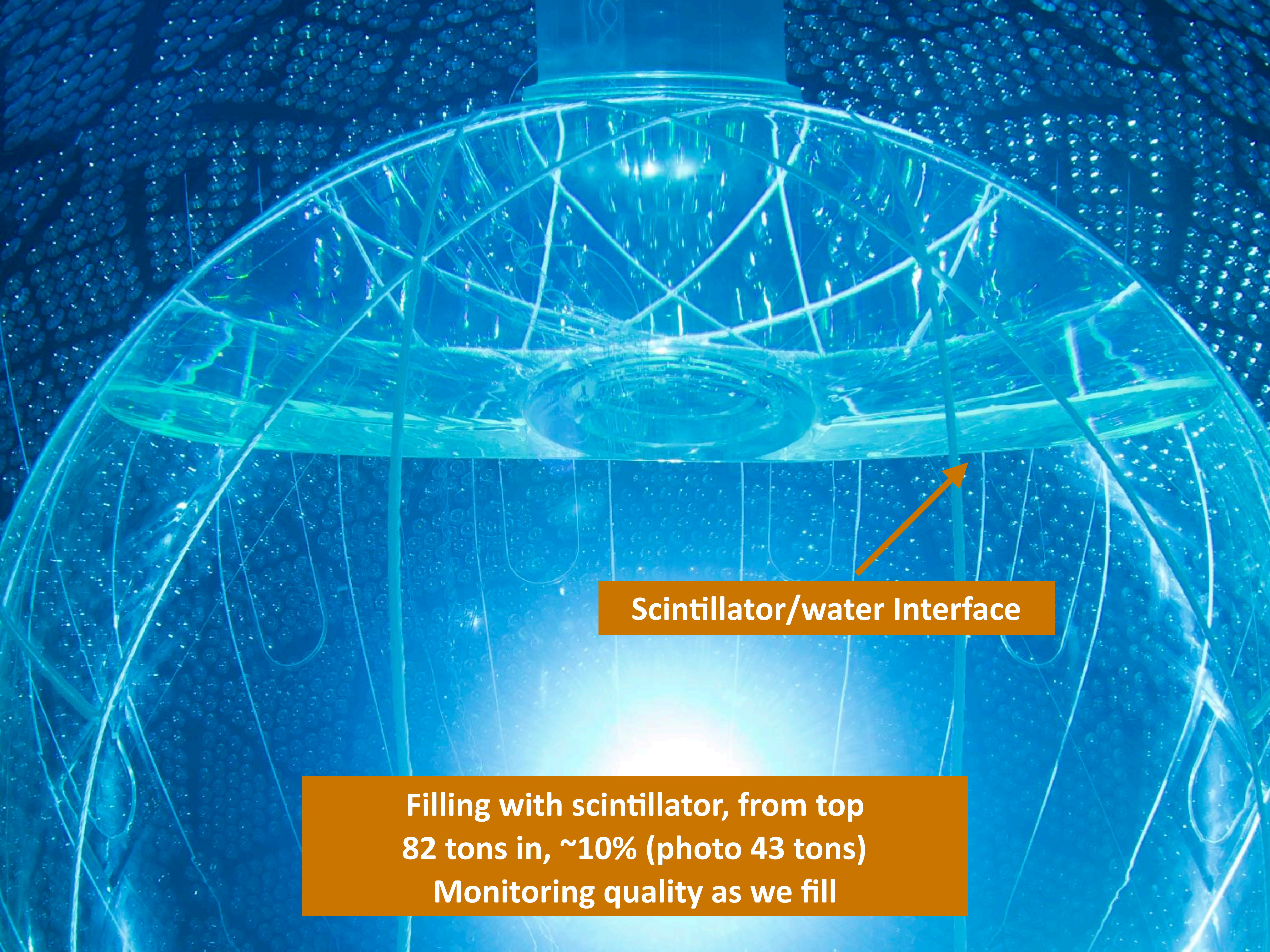


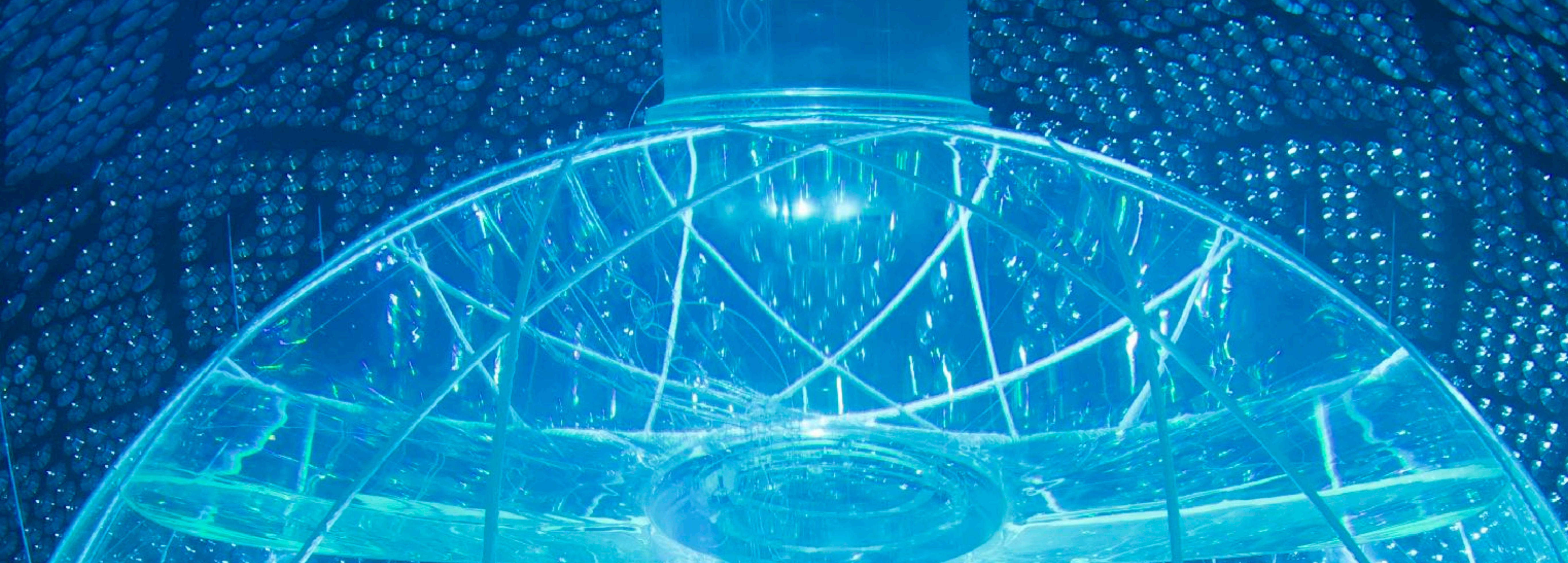
SNO+ calibration hardware@SNOLAB

- Mechanism to deploy sources in scintillator
- 2 units built at LIP-Coimbra, now at SNOLAB
- 1st one now cleaned and sent underground (Stefan Nae and Ana Sofia Inácio worked on this)

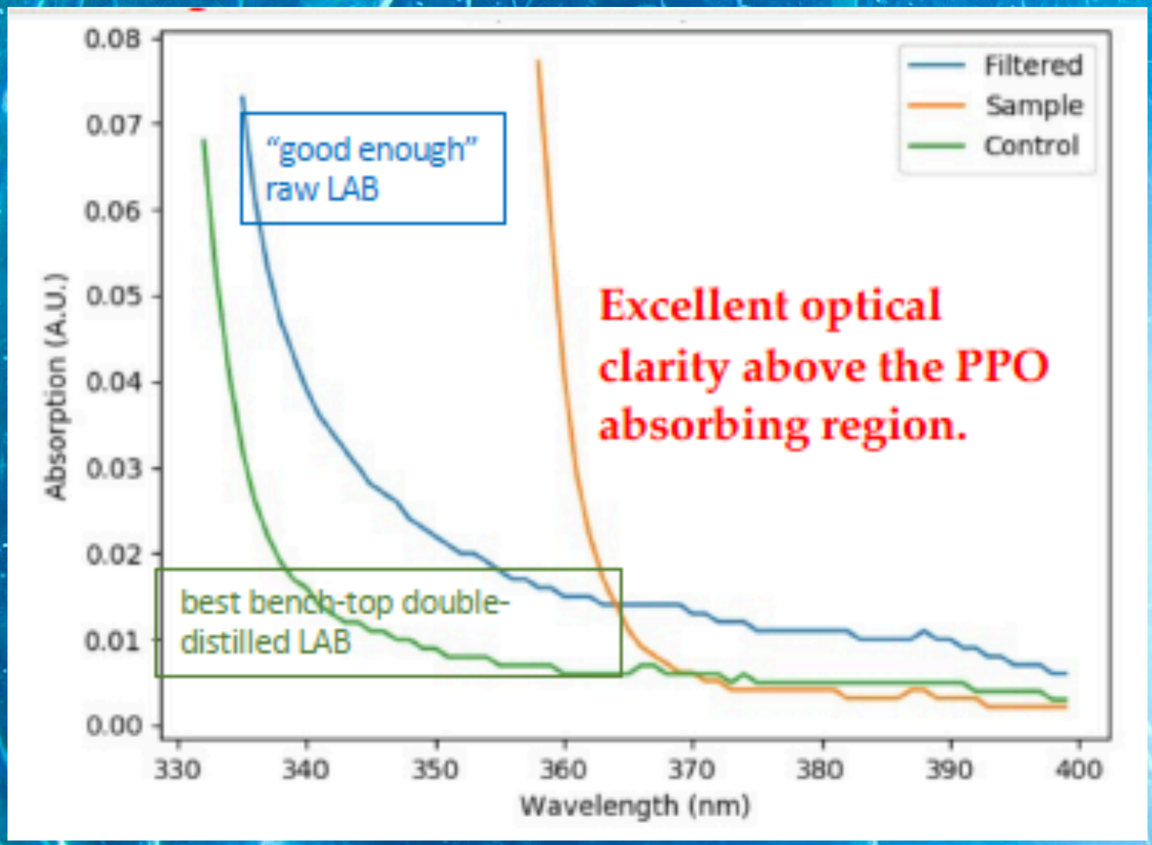
SNO+ timeline

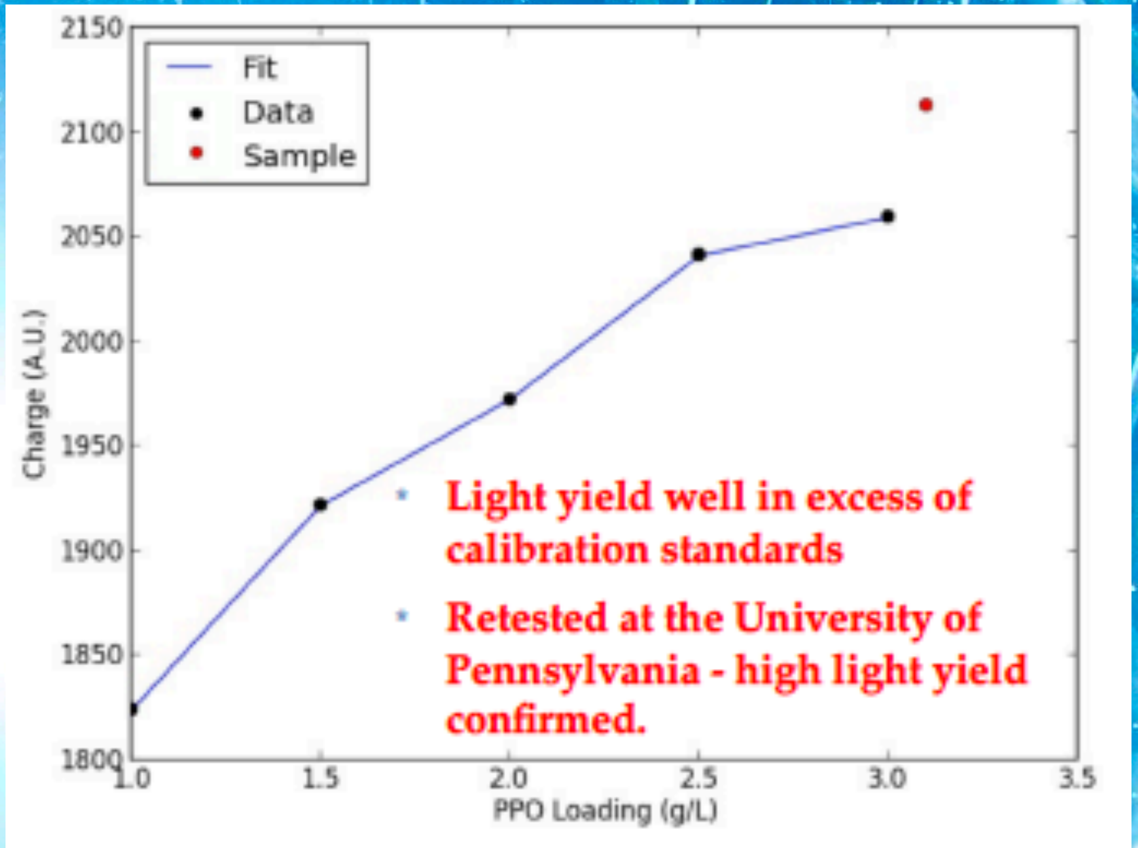



Scintillator/water Interface
Filling with scintillator, from top
82 tons in, ~10% (photo 43 tons)
Monitoring quality as we fill

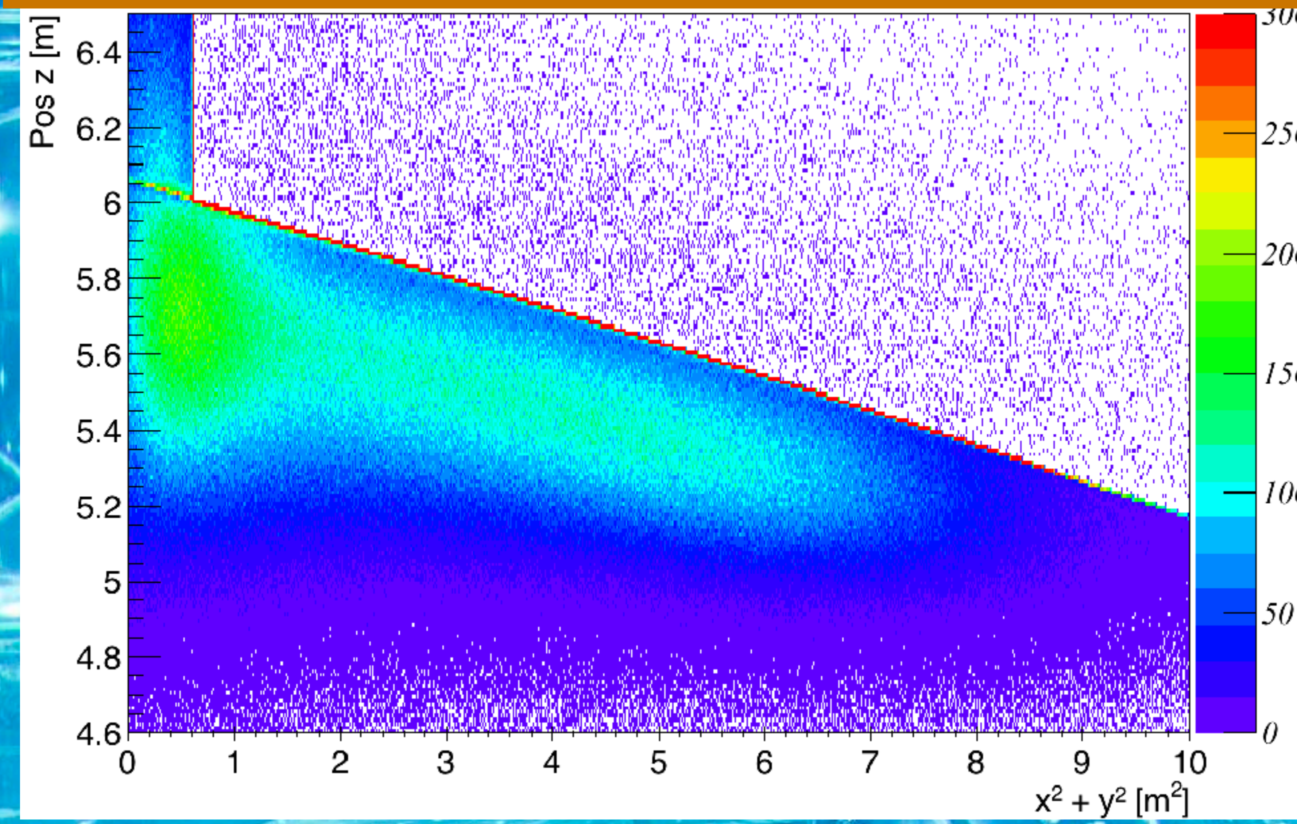


Scintillator Optical Properties within objectives





Interface visible in event reconstruction

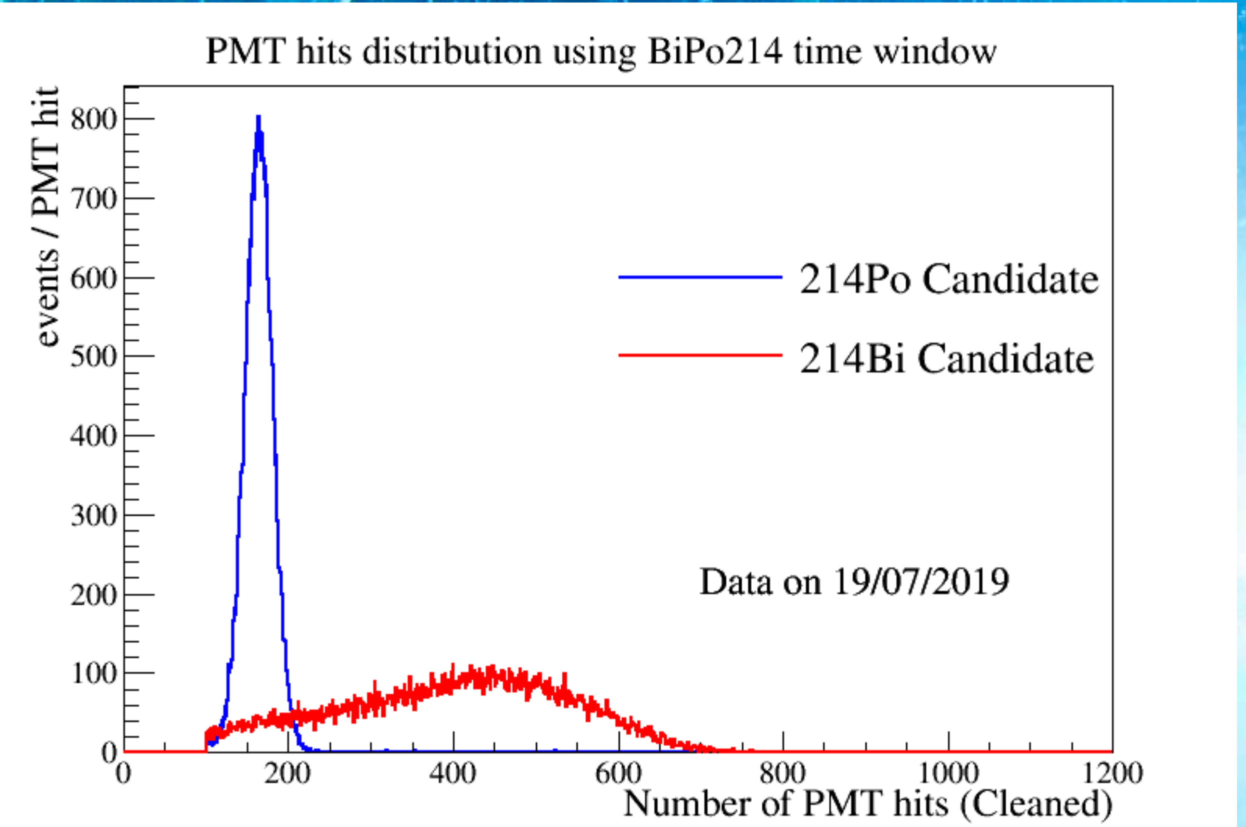


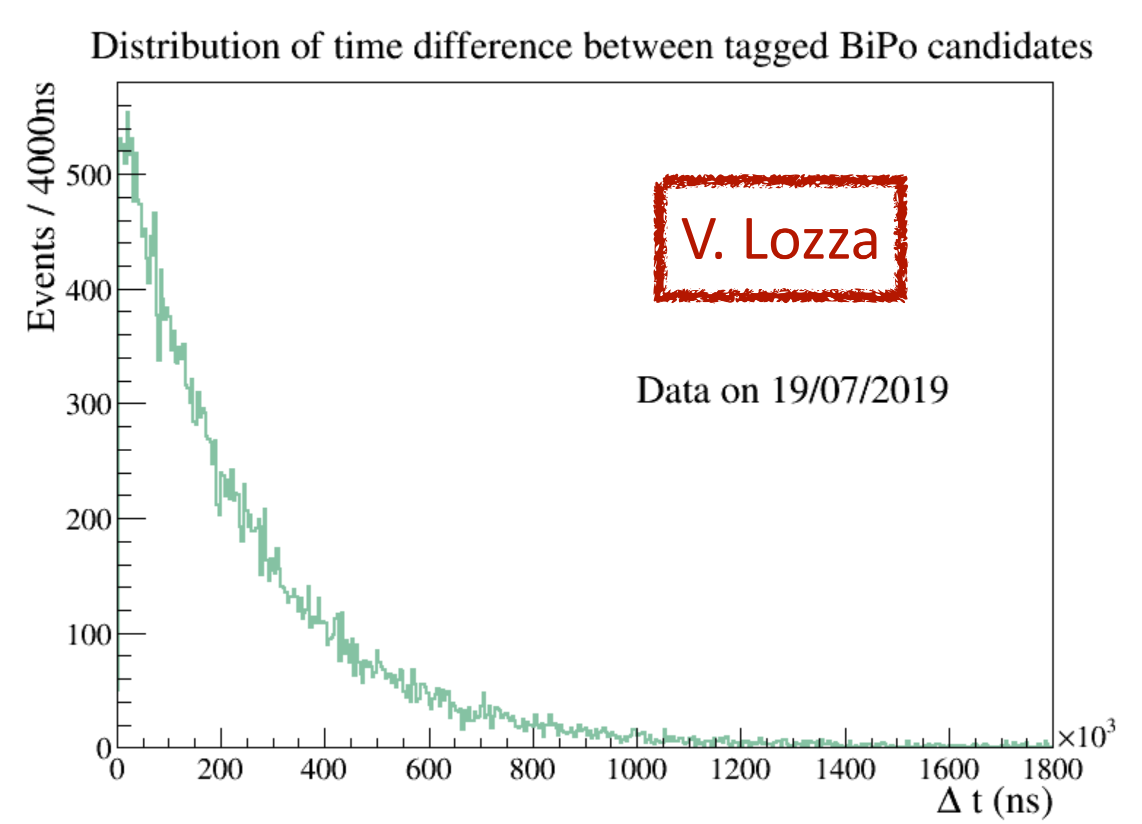
Continuous monitoring of internal backgrounds

High levels of radon (as expected)

No visible Th chains

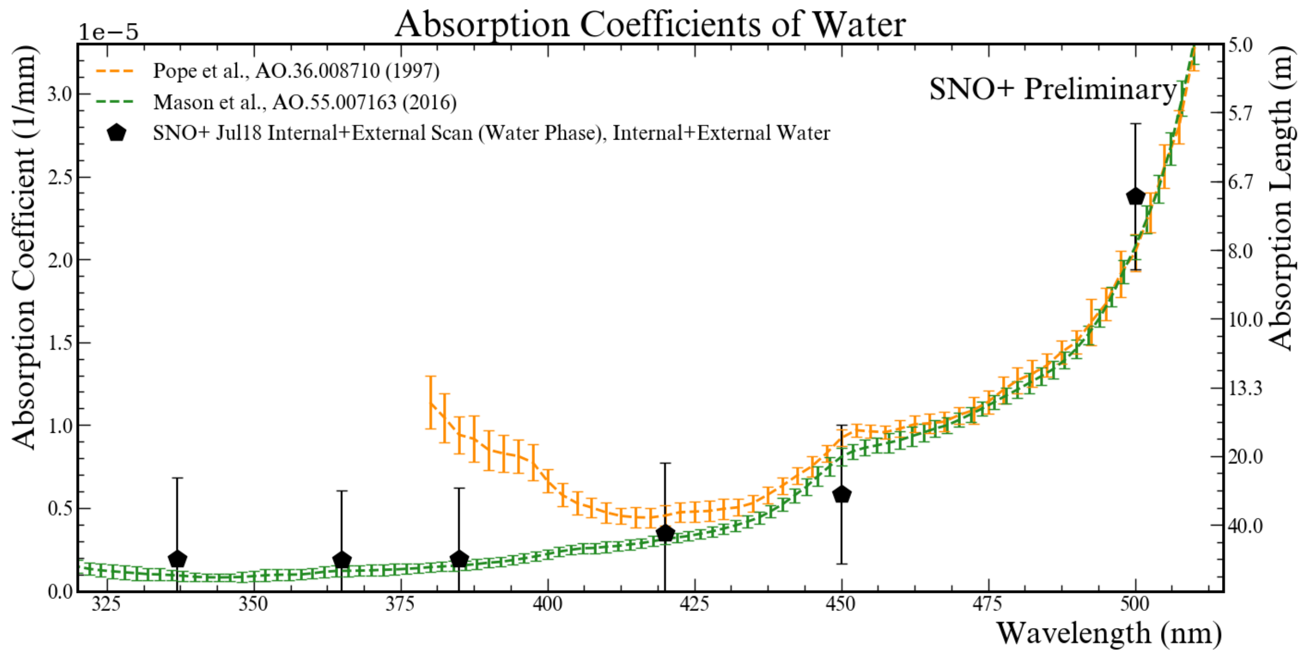
Internal backgrounds in DBD ROI below expectation



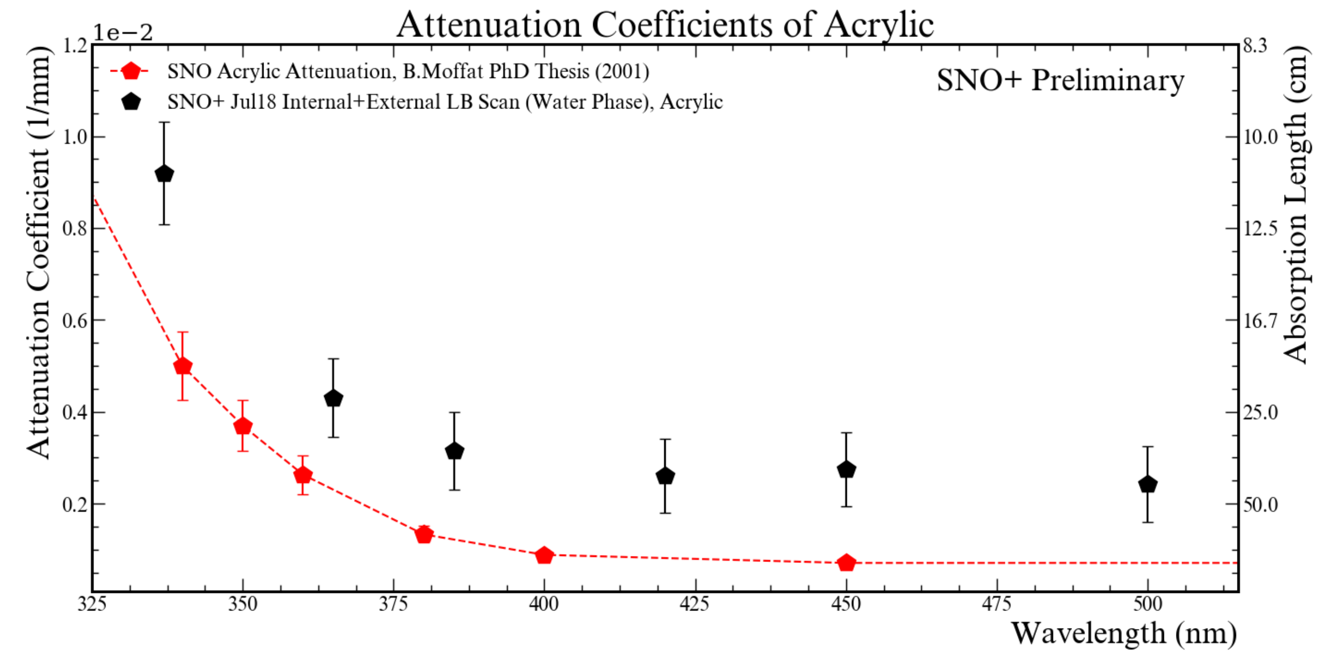


Results from the optical calibration

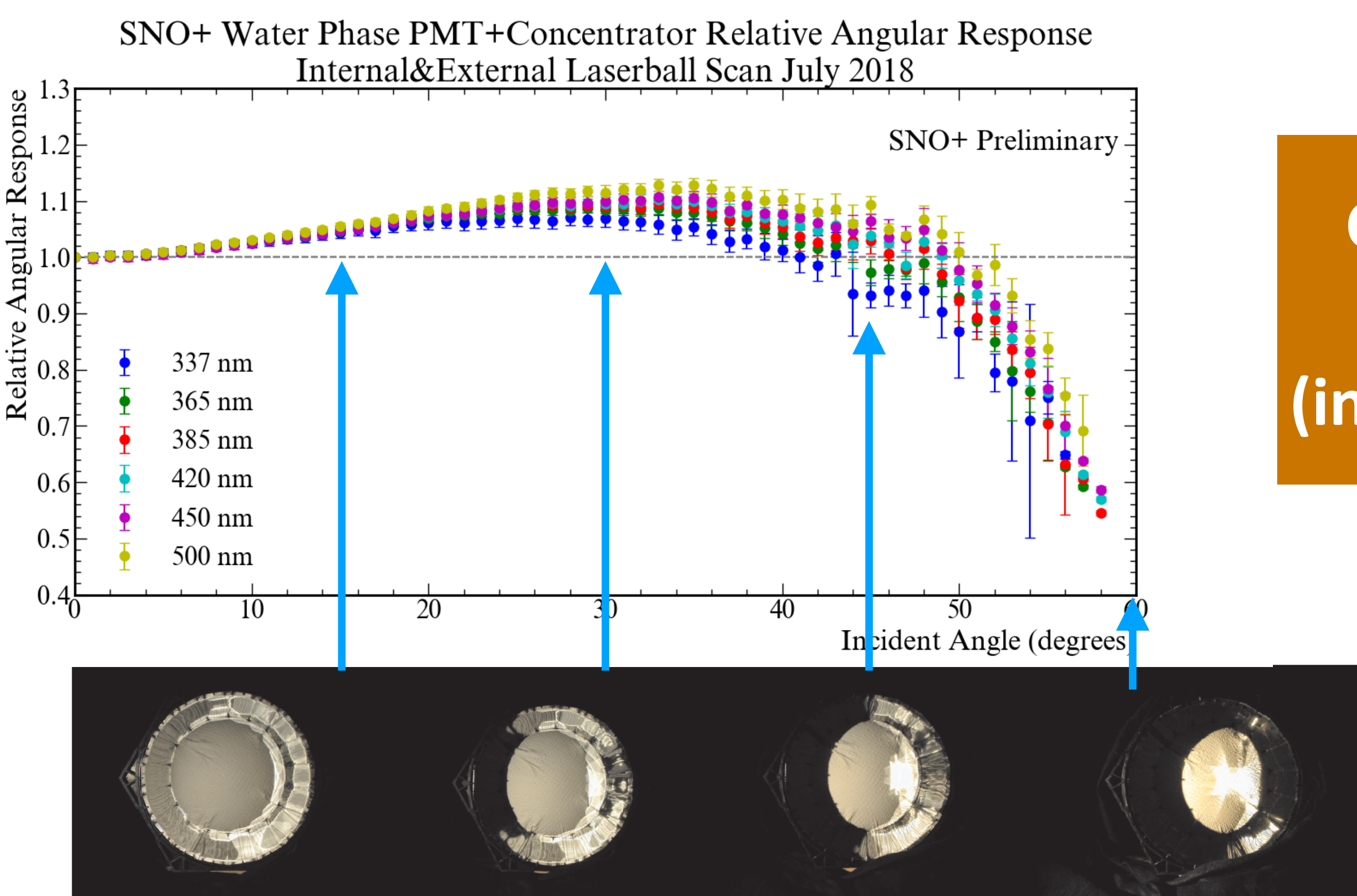
More accurate water attenuation



More accurate water attenuation



A. Inácio



Characterization of the PMTs to high angles of incidence (in SNO only able up to 45 degrees)

See poster by A. Inácio for more details

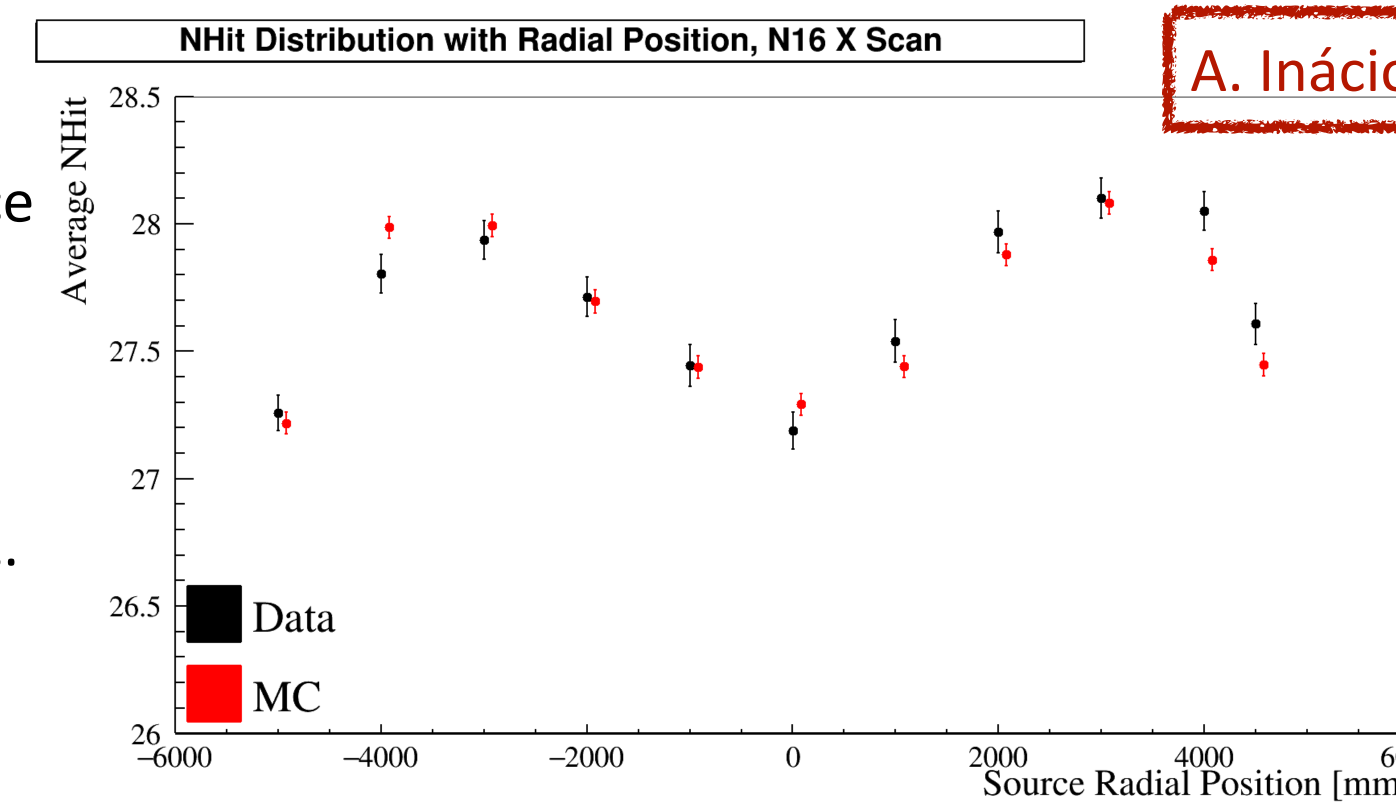
The best understood detector response (so far)

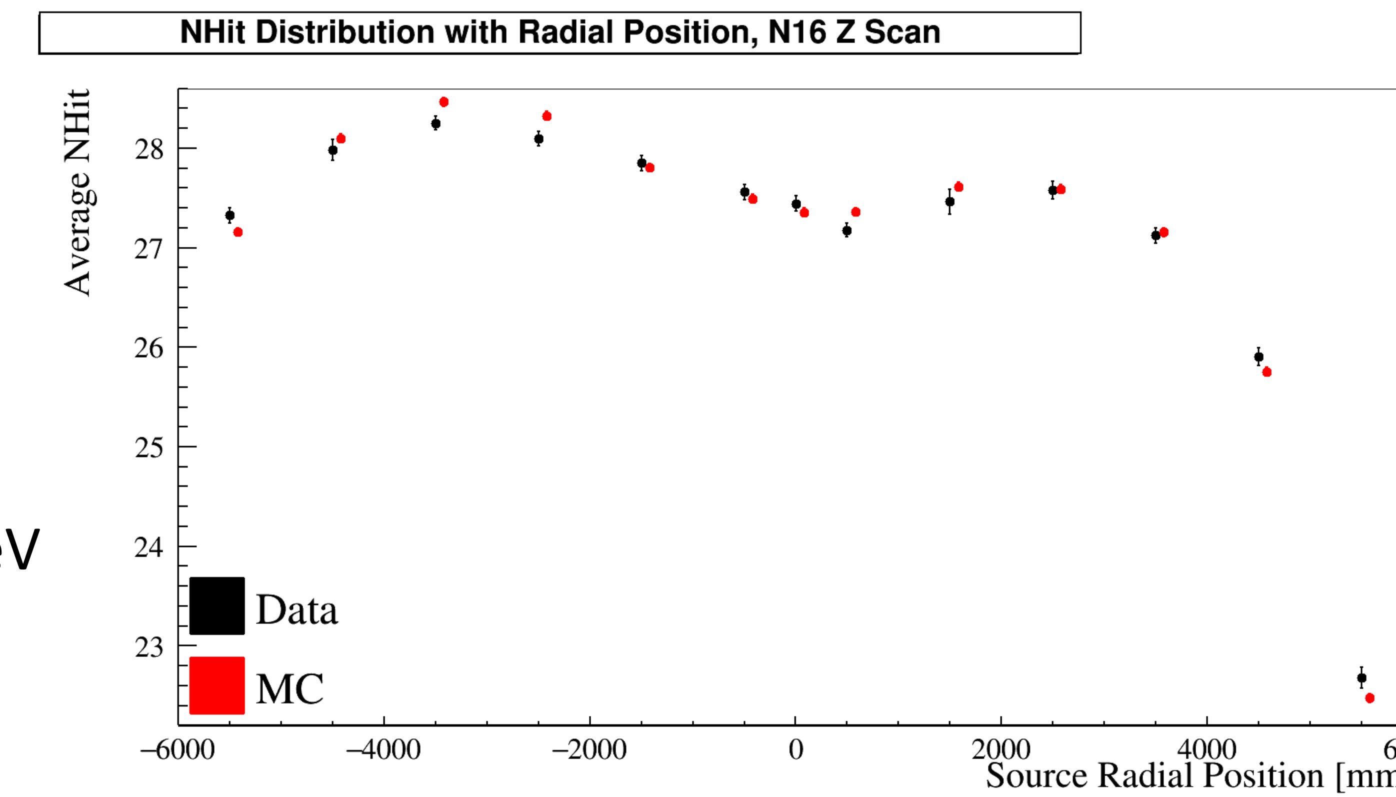
A. Inácio

- Cross-check with another calibration source (^{16}N)
- Other work behind the scenes: scattering measurements, PMT collection efficiency,…

^{16}N source:

- β-decay to $^{16}O^*$: 6.1 MeV gamma
- Tagged using the β
- Tune reconstruction
- Estimate energy systematics

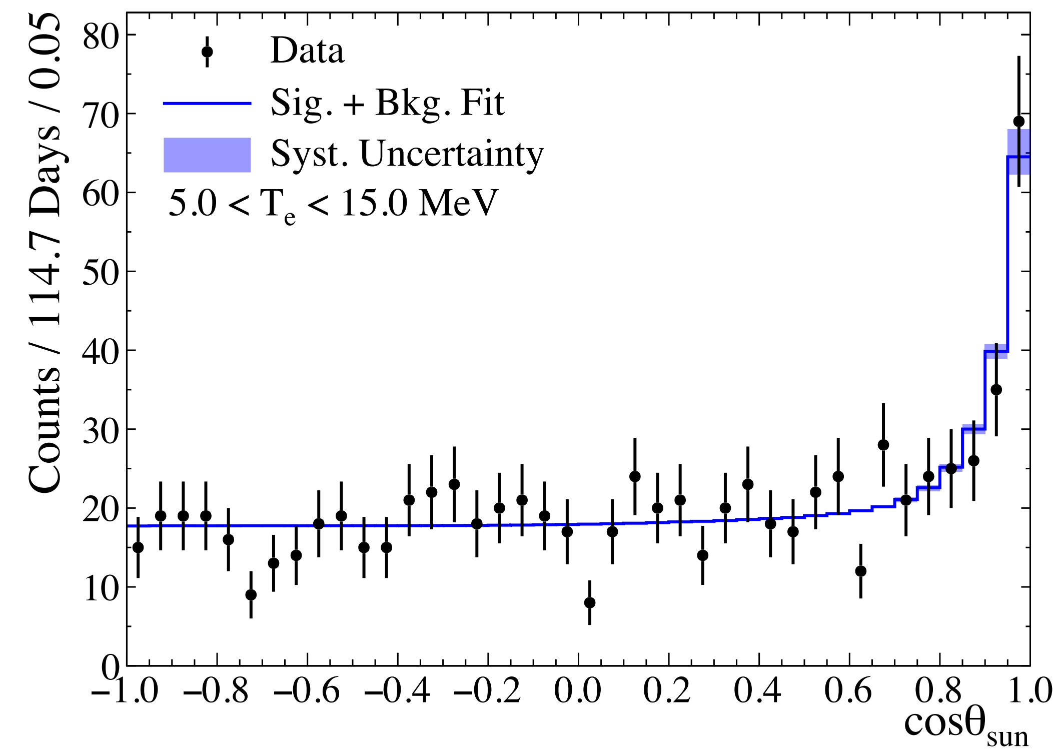




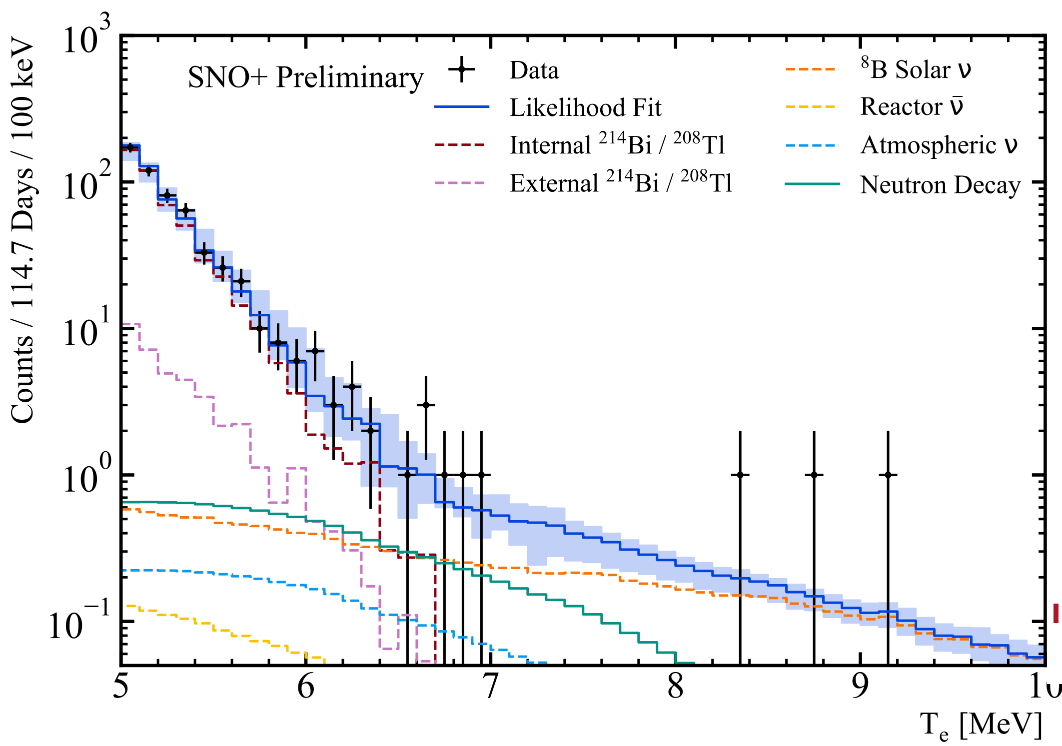
Data/MC agreement to better than 1%

Water-phase results

- Solar neutrino analysis **Phys. Rev. D 99, 012012 (2019)**
  - Use only direction to Sun (no energy)
- Invisible nucleon decay **Phys. Rev D 99, 032008 (2019)**
- Re-analysis with extended **low background** dataset ongoing (doubling the statistics)



N. Barros, V. Lozza



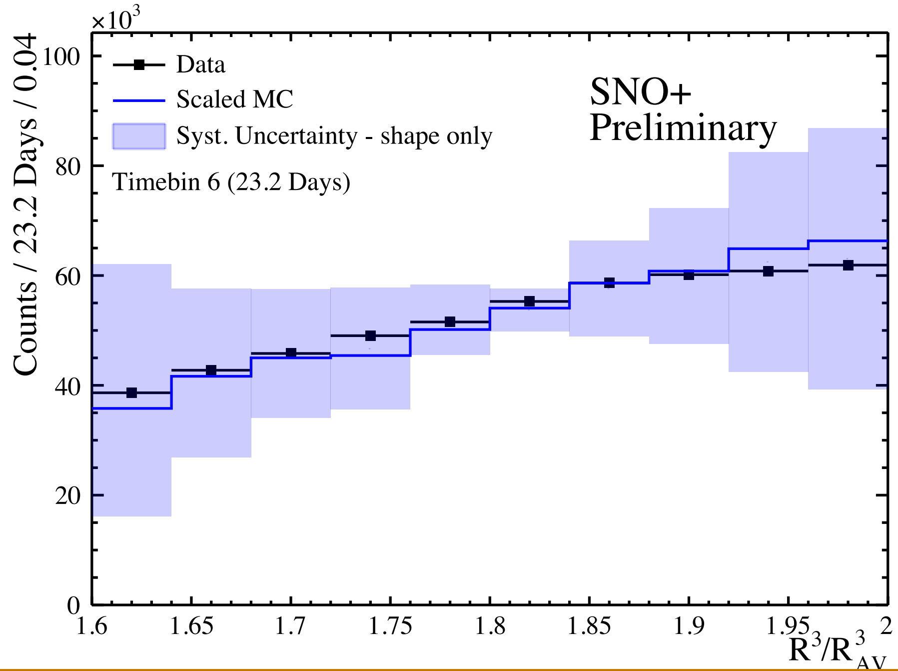
Improved limits

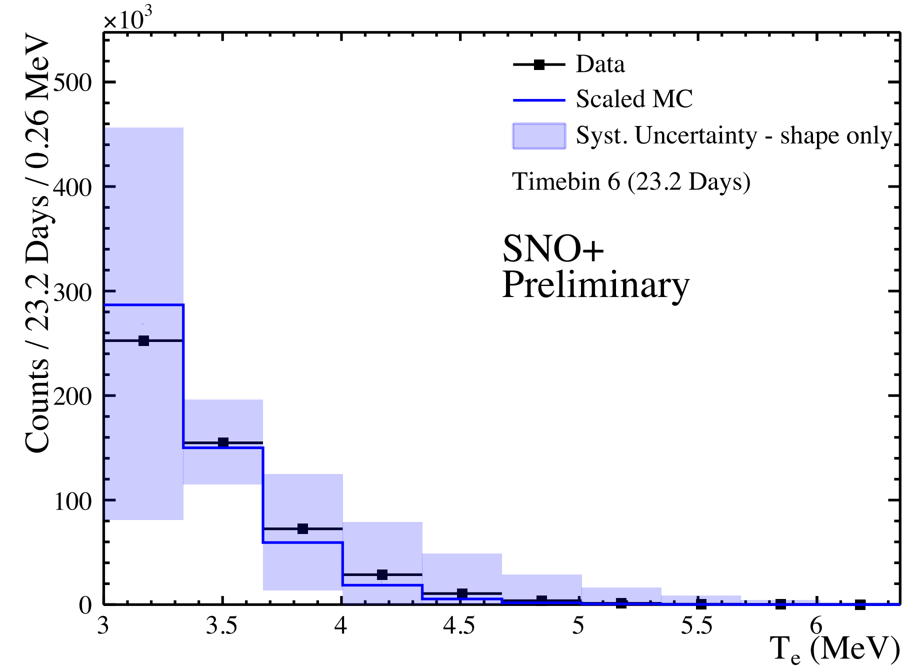
	Spectral analysis	Counting analysis	Existing limits
n	2.5×10^{29} y	2.6×10^{29} y	5.8×10^{29} y [Kamland]
p	3.6×10^{29} y	3.4×10^{29} y	2.1×10^{29} y [SNO]
pp	4.7×10^{28} y	4.1×10^{28} y	5.0×10^{25} y [Borexino]
pn	2.6×10^{28} y	2.3×10^{28} y	2.1×10^{25} y [*]
nn	1.3×10^{28} y	0.6×10^{28} y	1.4×10^{30} y [Kamland]

External backgrounds

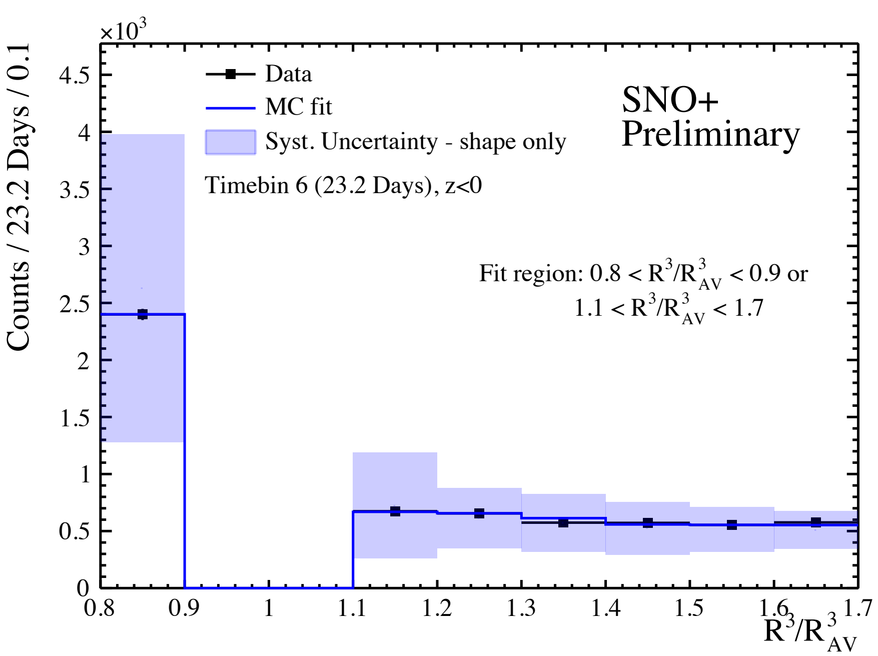
V. Lozza

Gamma background from PMTs





Gamma background from water buffer, AV and PMTs



Measurement/Expectation Ratio		
	Above equator	Below equator
AV+Ropes	$2.2 \pm 0.08^{+2.4}_{-1.9}$	$1.3 \pm 0.08^{+1.0}_{-0.9}$
Water buffer	$0.6 \pm 0.06^{+1.9}_{-0.6}$	$1.0 \pm 0.07^{+3.3}_{-1.0}$
PMT	$1.2 \pm 0.02^{+1.1}_{-0.5}$	$1.2 \pm 0.02^{+1.1}_{-0.5}$

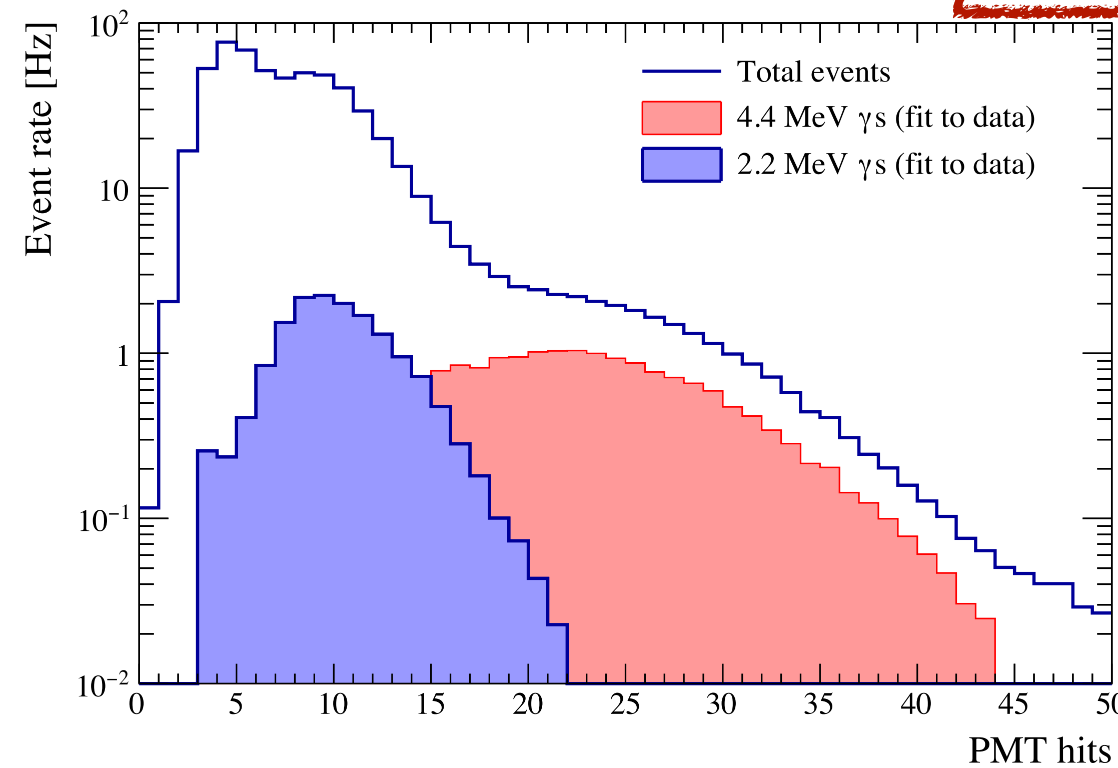
Major milestone for 0νββ search

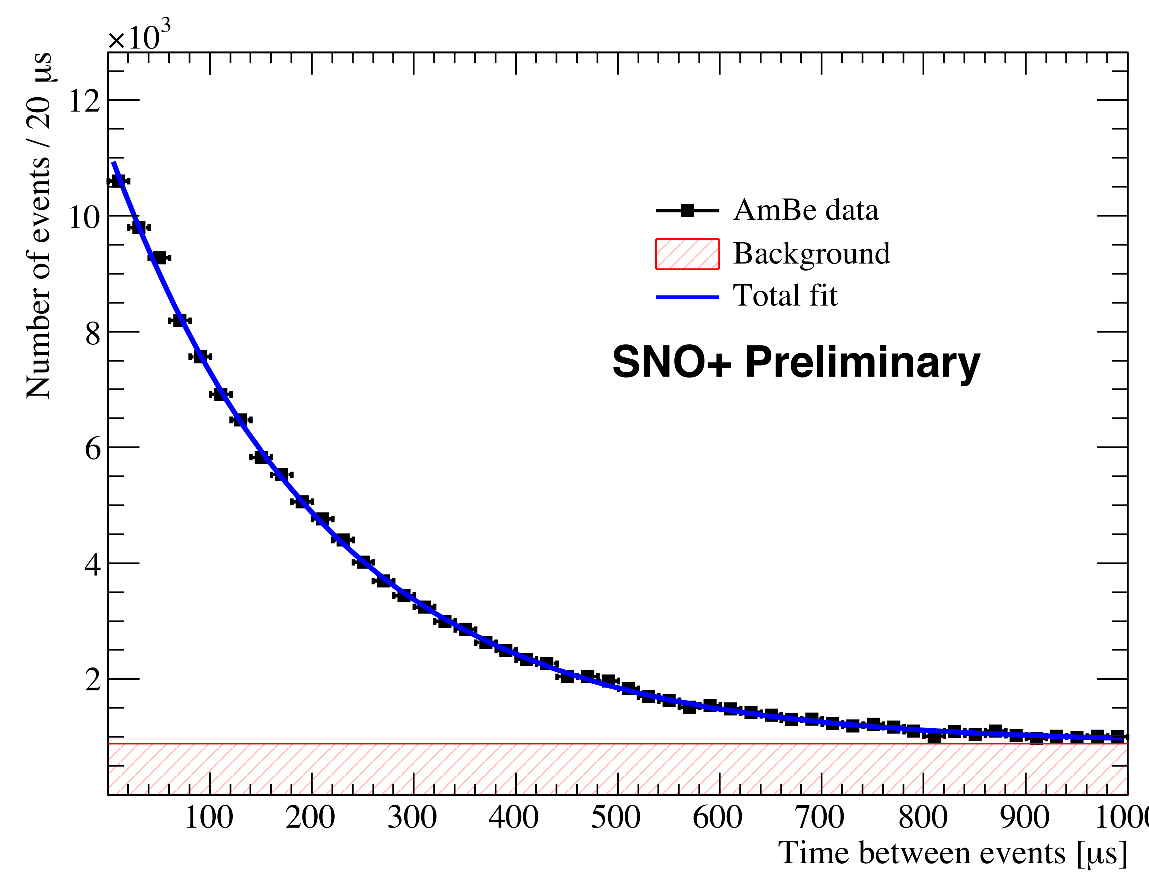
Neutron capture in water

S. Andringa

- Use $^{241}Am^{9}Be$ source (untagged)
    - Coincidence of 4.4 MeV gamma and neutron (emission of 2.2 MeV gamma upon capture)
- Calibrate lower energies
- Opens the door to search for reactor neutrinos in water (ongoing analysis)

n capture time : ~0.2 ms

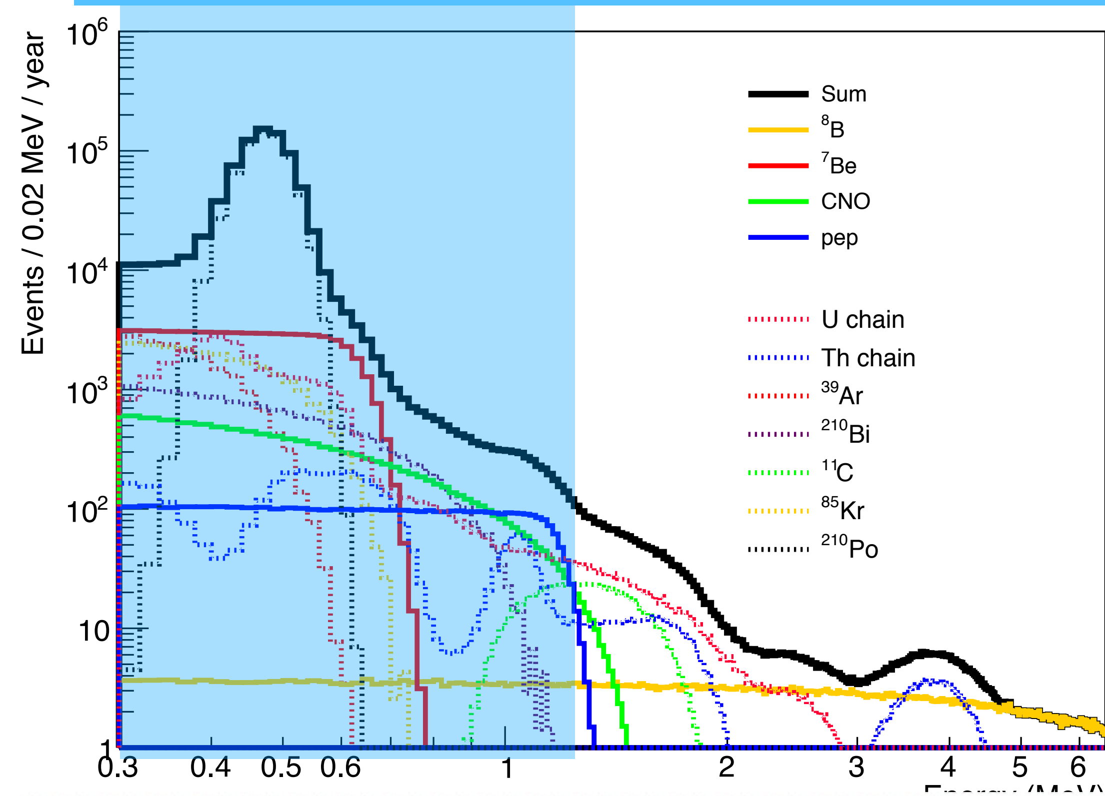


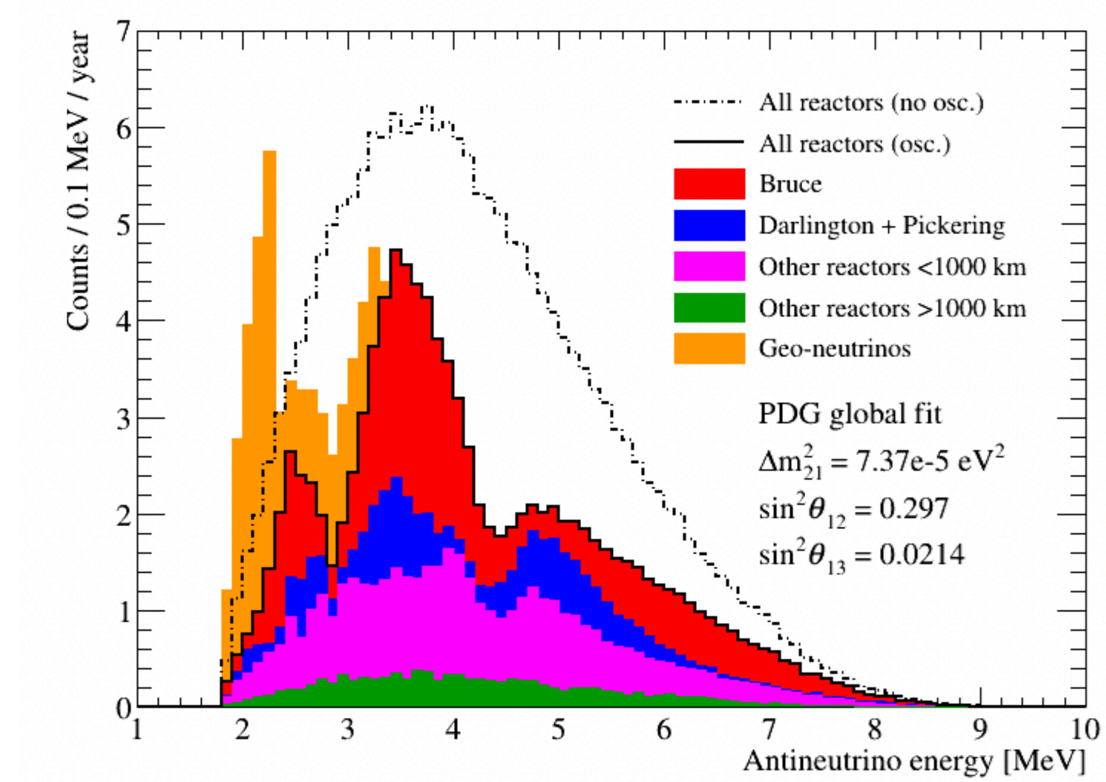


What comes next?

- **Short commissioning run with pure scintillator (mid-2020)**
  - **Characterize internal backgrounds**
  - Commission calibrations
  - Test of calibration and reconstruction tools
  - Physics searches:
    - **Low energy solar neutrinos (lowest ^{11}C background)**
    - Geo- and **reactor antineutrinos**
      - Could check discrepancy reactor/solar with short running time
- **Load with Te**
  - 3 ton of natural Te : 0.5% loading (~1330 kg ^{130}Te)
  - **ton-scale experiment**

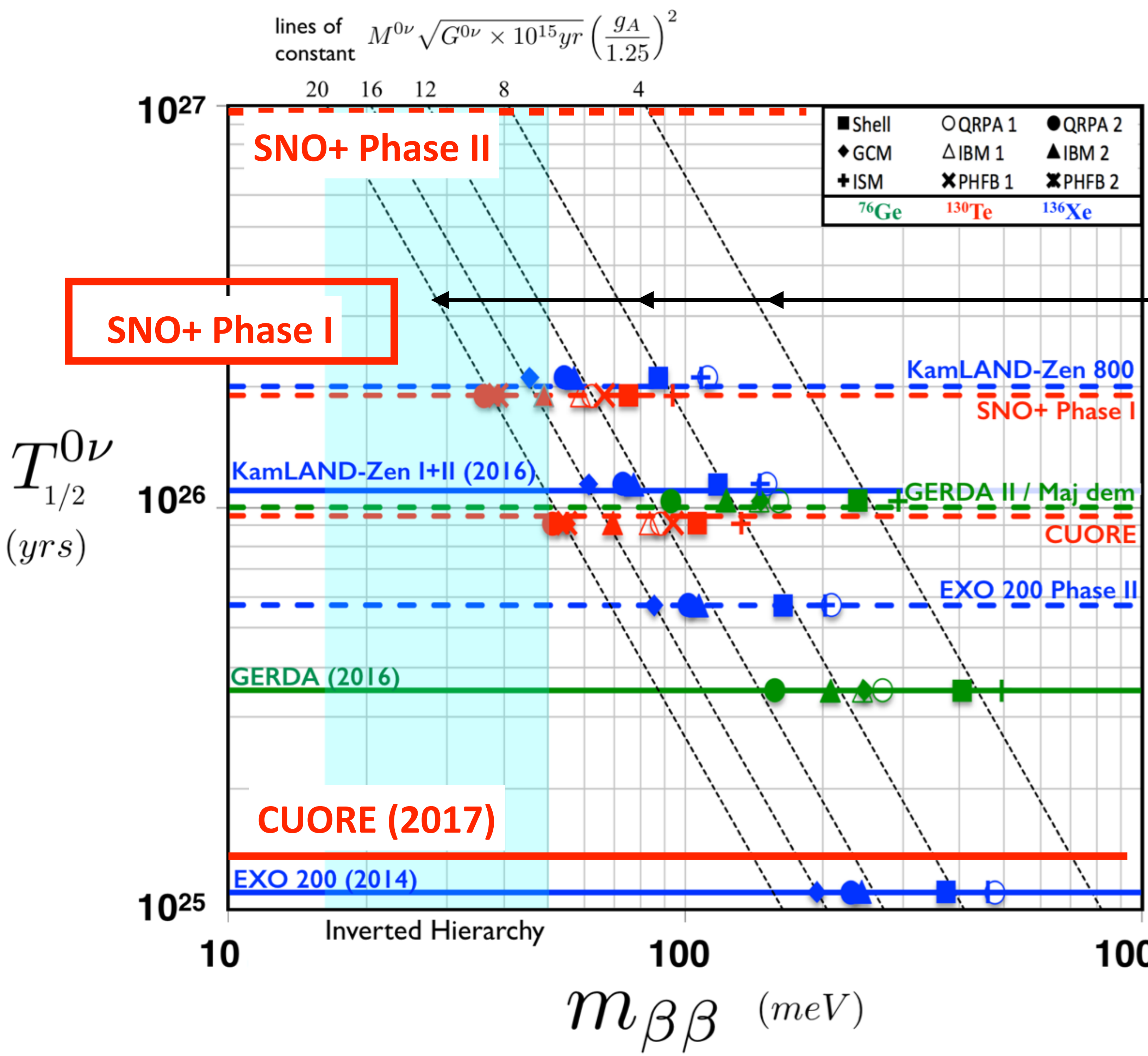
Region may be dominated by ^{210}Bi from leaching. To be checked.





Comparison with other experiments

Higher $T_{1/2}$ is better



Lower $m_{\beta\beta}$ is better

We don't know which of the nuclear models (diagonal lines) is best.

Large uncertainties.

Need experiments with different isotopes!

Summary

- **After decades of interesting discoveries, neutrinos remain one of the least understood elementary particles**
    - They oscillate (and we know how)
    - They are massive (but we don’t know how much)
- **The LIP group is heavily involved in key experiments to answer all these questions**
    - CP violation with **DUNE**
    - $0\nu\beta\beta$ with **SNO+**
- **The group is involved in various aspects of the experiments:**
    - Calibration (DUNE & SNO+)
    - DAQ (DUNE)
    - Backgrounds (SNO+)
    - Data Analysis (DUNE & SNO+)