UPDATES ON THE SNO+ EXPERIMENT

Gersende Prior

on behalf of the SNO+ LIP group

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTICULAS

INVESTIGADOR FCT

20th February 2016 Jornadas Científicas do LIP Braga, Portugal

OUTLINE

- the SNO+ LIP group
- detector overview
- physics
- calibration systems
- group activities
- status & future plans

Current students

Former members

Coimbra worshop team

Current staff

THE SNO+ LIP GROUP

Amélia Maio

Joaquim Oliveira

Xavier Rodrigues

Rui Alves

Gersende Prior

Gonçalo Lemos

José Maneira (PI)

Pedro Jorge

Stefan Nae

Nuno Dias

Fernando Barão

Carlos Silva

Sofia Andringa

Orlando Cunha

Ana Sofia Inácio

Evangelia Samara

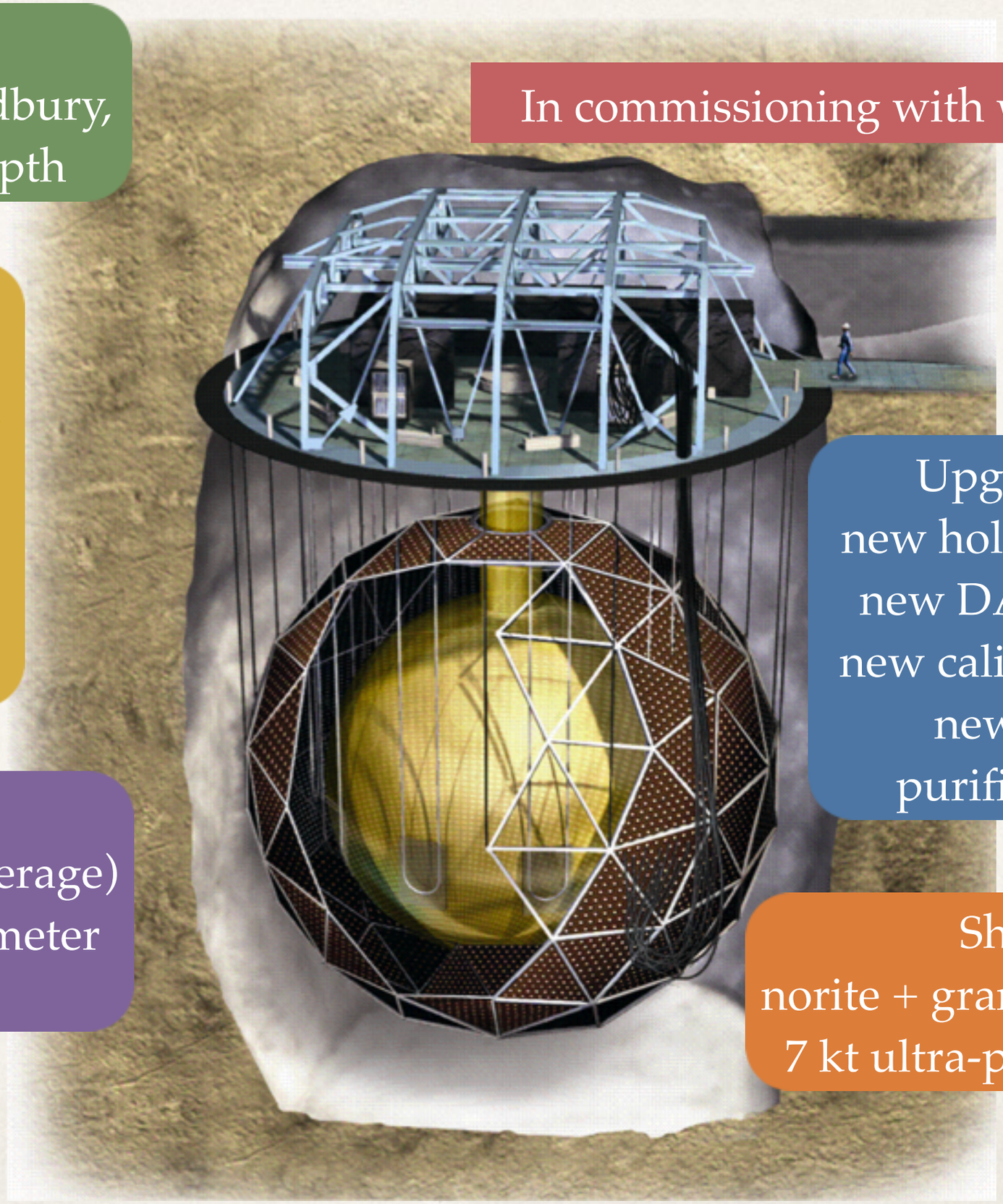
Naima Zahar

Américo Pereira

THE SNO+ DETECTOR

Where:
located in a mine (Sudbury, Canada) at 2 km depth

In commissioning with water at present



Target:
liquid scintillator loaded with different amounts of ^{130}Te contained in a 12 m diameter and 5 cm thick acrylic vessel

Upgrade of SNO:
new hold-down rope net
new DAQ and readout
new calibrations systems
new scintillator purification system

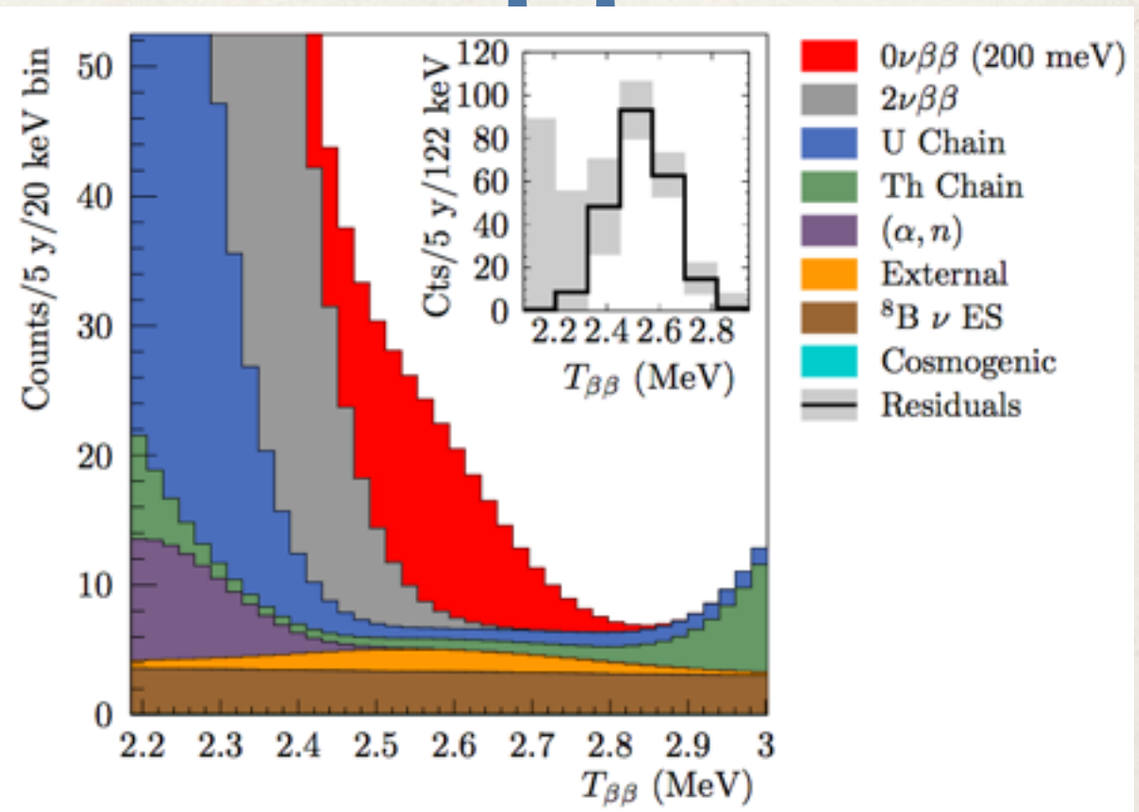
Detector:
~9300 PMTs (54% coverage) sitting on a 17 m diameter support

Shielding:
norite + granite / gabbro rocks
7 kt ultra-pure water shield

SNO+ PHYSICS: 0νββ

Search for Majorana neutrinos

0νββ decay:
- ν are Majorana particles
- ν mass is not zero
- lepton number violated



Decay rate:

$\Gamma^{0\nu\beta\beta} \sim (T^{0\nu\beta\beta}_{1/2})^{-1} \sim m_{\beta\beta}^2 / m_e^2$

number of isotope nuclei

energy window acceptance fraction

background counts (keV.yr)$^{-1}$

$$T^{0\nu\beta\beta}_{1/2} = \frac{N \cdot \ln(2)}{n_\sigma} \cdot \sqrt{\frac{f(\delta\epsilon) \cdot t}{(b \cdot M + c) \cdot \delta E \cdot t}}$$

energy window (keV)

number of standard deviation

isotope mass (kg)

background counts (keV.kg.yr)$^{-1}$

5 years data - 0.3% ^{nat}Te loading:

- $T^{0\nu\beta\beta}_{1/2} > 9\times10^{25}$ yr, $m_{\beta\beta} \sim$ 55-133 meV

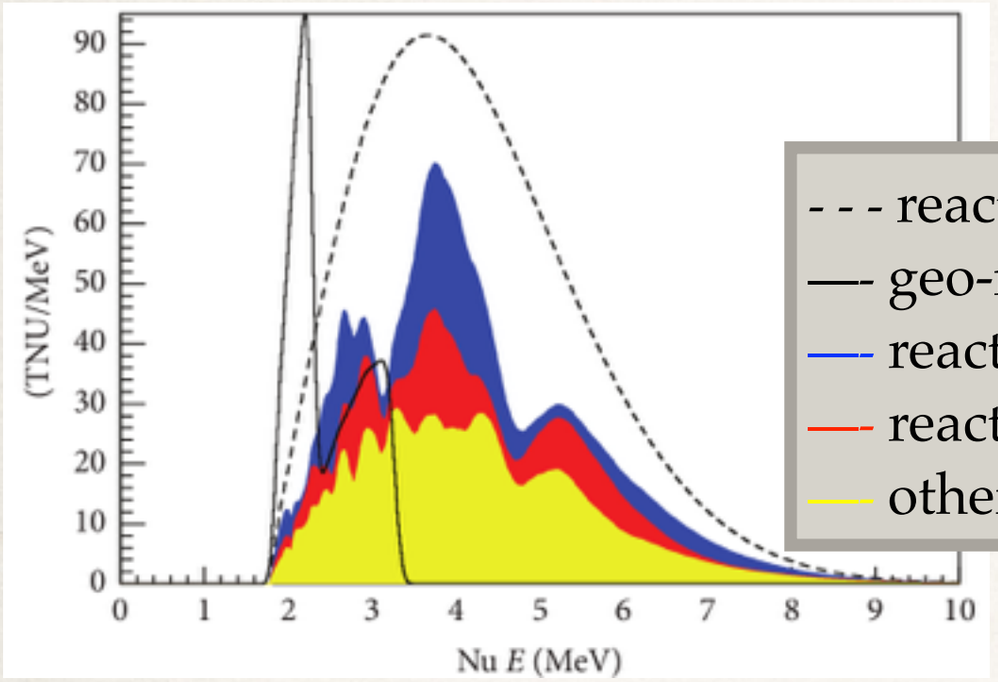
Backgrounds:
- 2νββ irreducible (asymmetric energy window)
- ^{8}B solar ν irreducible ("flat" and known)
- internal U/Th rejection via coincidence cuts
- (α,n) rejection via coincidence cuts
- external γ's rejected via fiducial volumes cuts
- cosmogenics lowered w. purification/storage

SNO+ data-taking phases

- Water
- Liquid scintillator
- LS + 0.3% ^{nat}Te
- LS with higher loading

SNO+ PHYSICS: others

Reactor anti-neutrinos & geo-neutrinos

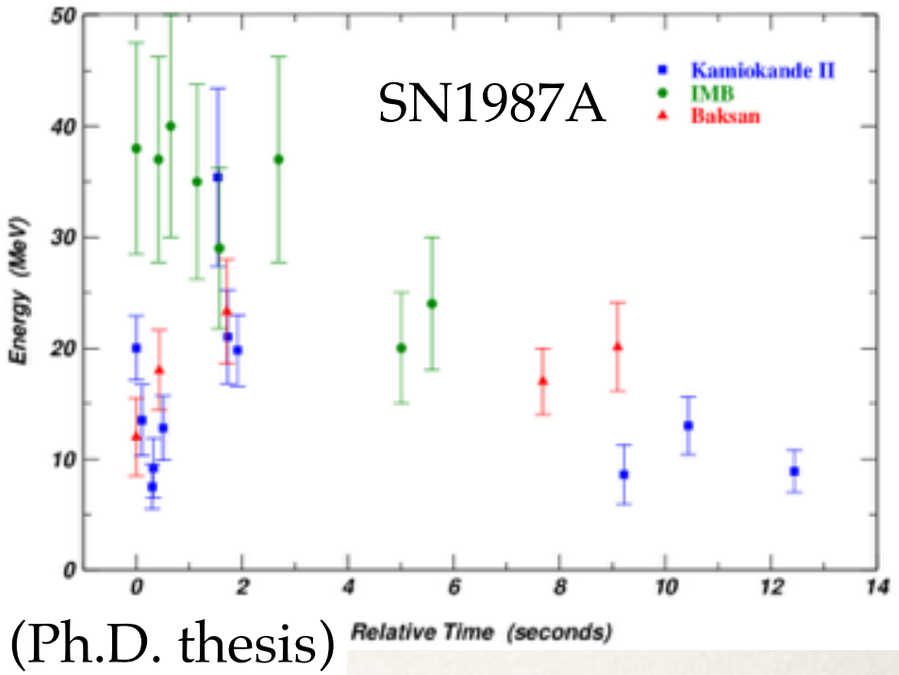


reactor

reactor + geo

- - - reactors (no oscillation)
—- geo-neutrinos
—- reactors at 240 km
—- reactors at 350 km
—- other reactors

Supernova neutrinos (SNEWS)



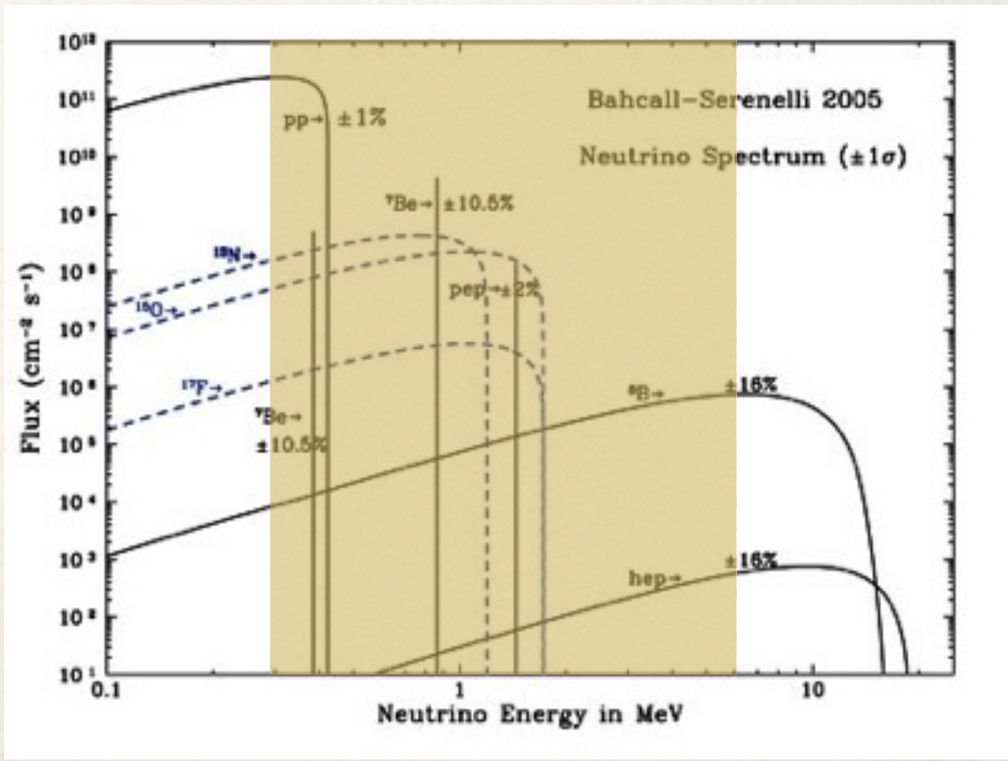
J. Heise (Ph.D. thesis)

Exotics:
invisible nucleon decay (IND), axion-like particles (ALP), dark matter (DM)

IND, ALP, DM

DM

Solar neutrinos: pep, CNO, low-E ^{8}B



SNO+ data-taking phases

Water

Liquid scintillator

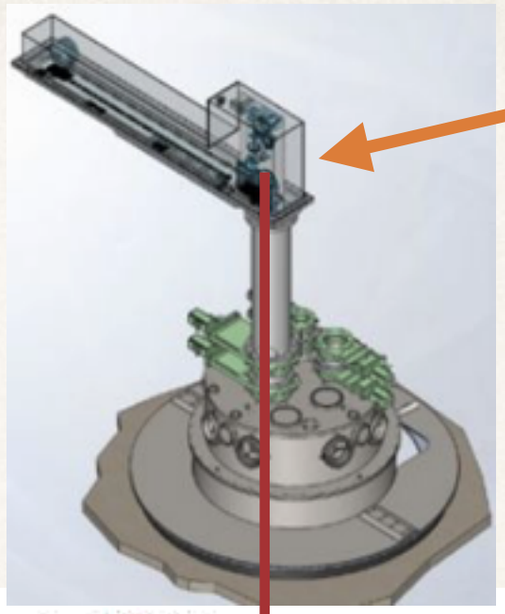
LS + 0.3% ^{nat}Te

LS with higher loading

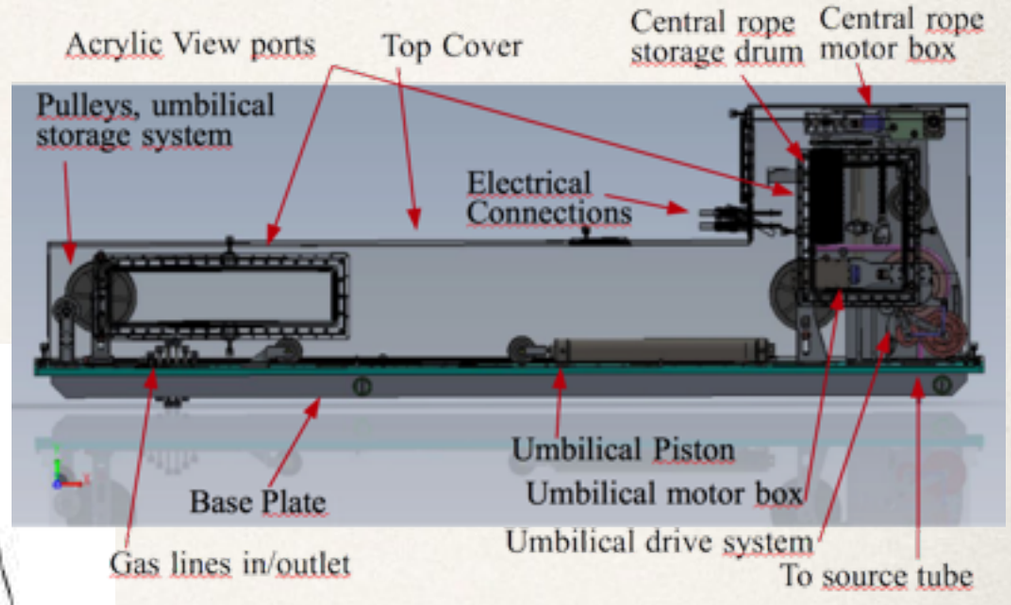
CALIBRATION OVERVIEW

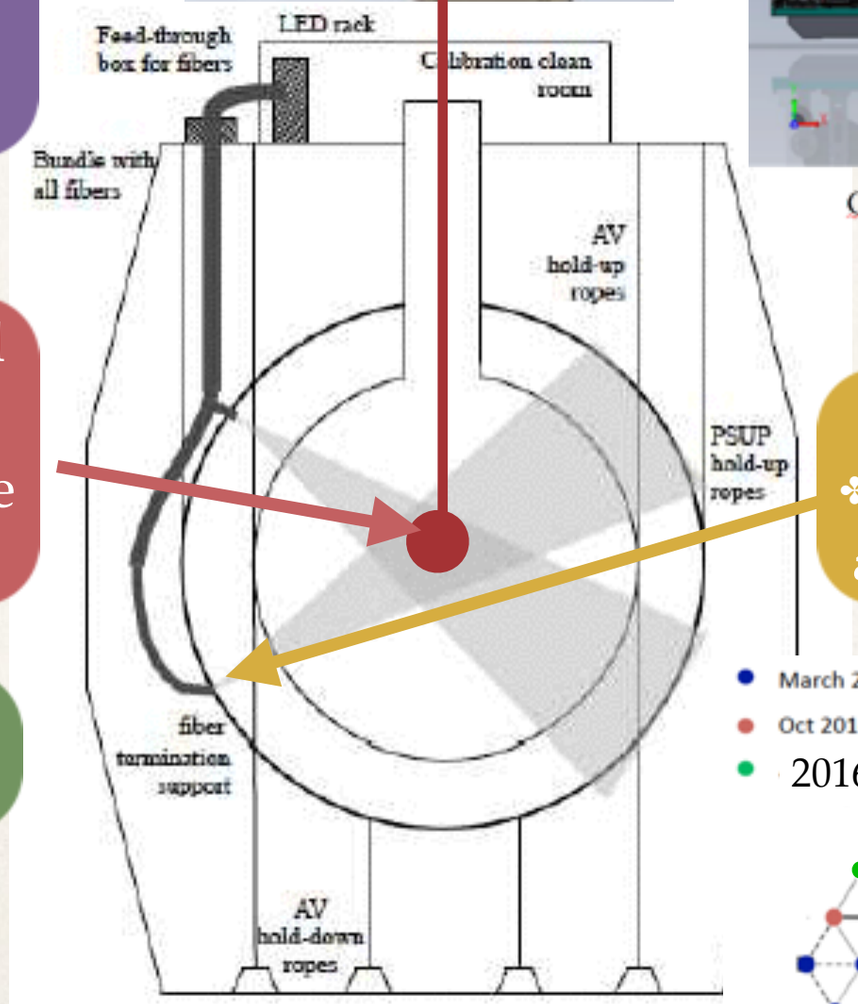
Radioactive sources:
- reconstruction
- particle ID systematics

Optical sources:
- measure in-situ scintillator
- measure PMT parameters
- internal (laserball)
- external (fibers)



Umbilical Retrieval Mechanism (URM):
- deploy and store long "hose" with no twisting and sealed from lab air

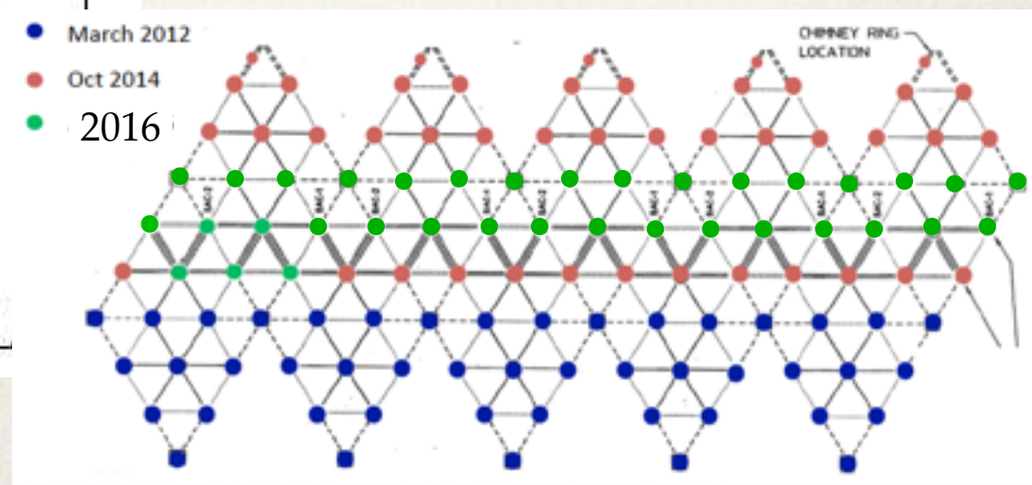




Internal optical source: laserball
- new design under prototyping
- will use the SNO laserball in the water phase

External optical source: fibers
- fibers installation to be completed as the water level raises

Internal sources <u>umbilical:</u>
- carry fibers, wires, gas tubing

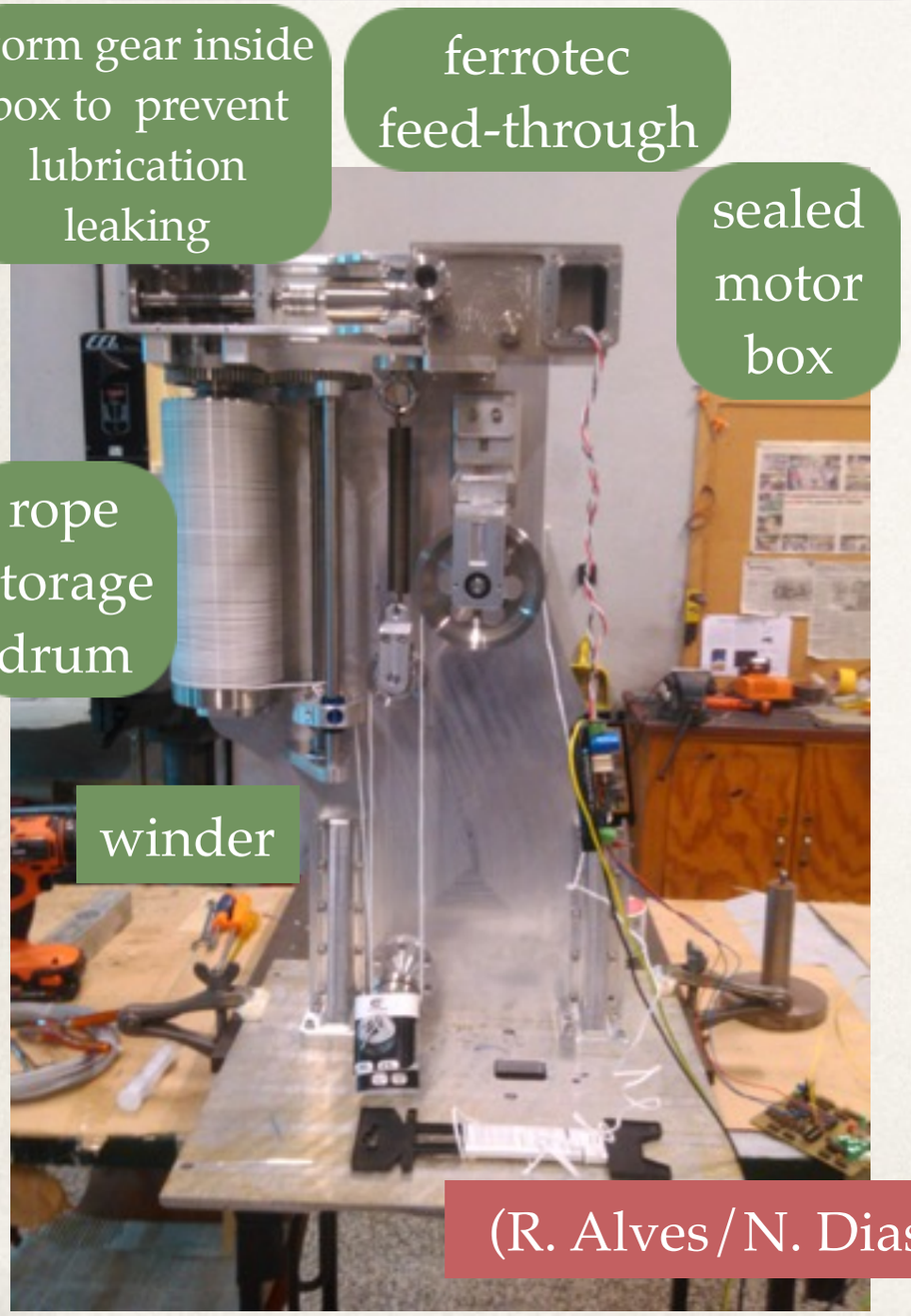


Group activities: URM fabrication 1/2

URM design adapted from SNO:
- enclosed motor, much better sealing

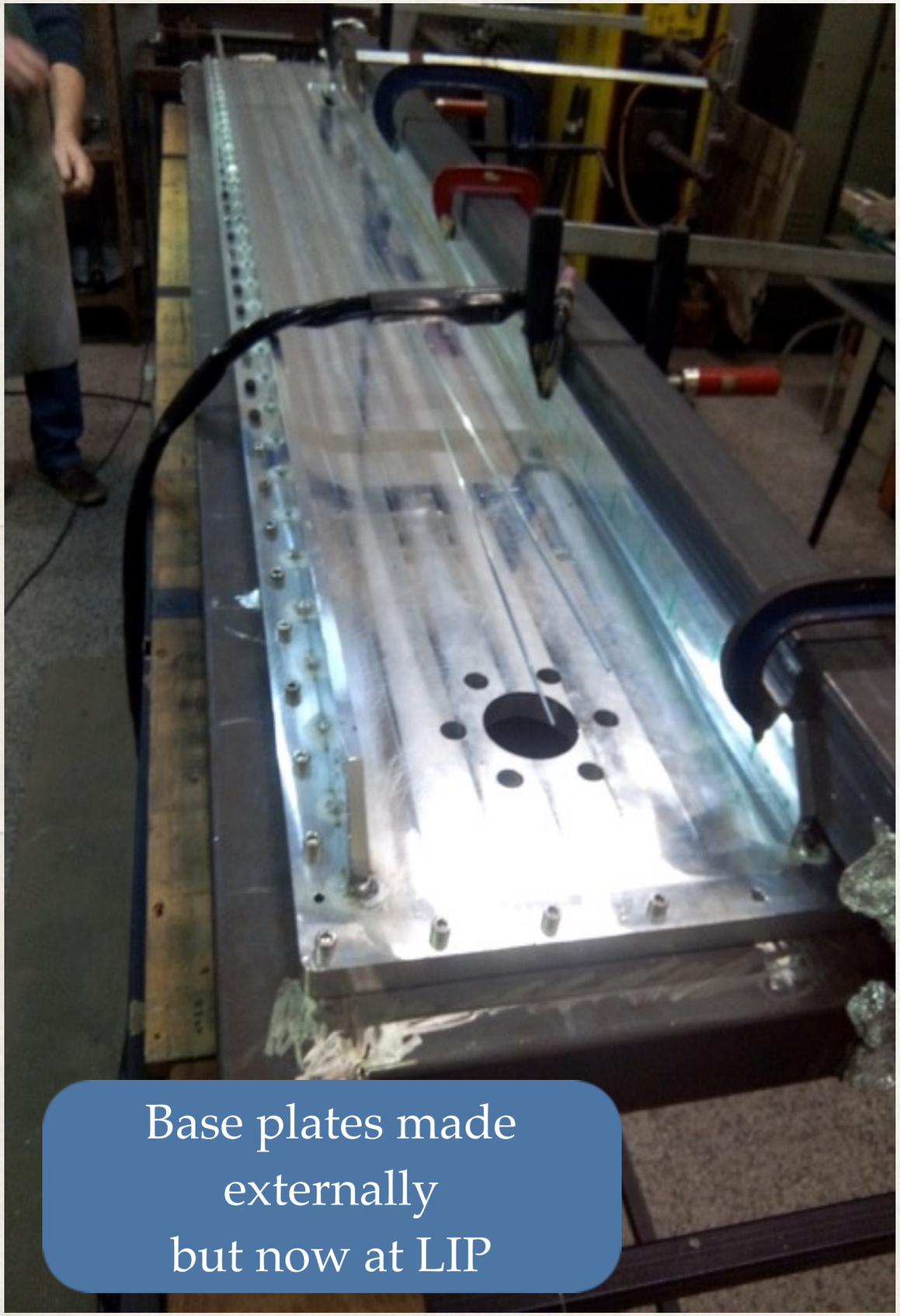
Central rope mechanism:
- almost completed
- tested at Coimbra stairwell

URM welding steps:
1. fabricate a test box before the welding of large parts
2. optimize welding procedure
3. perform vacuum and helium checks
4. weld window flanges on large box walls

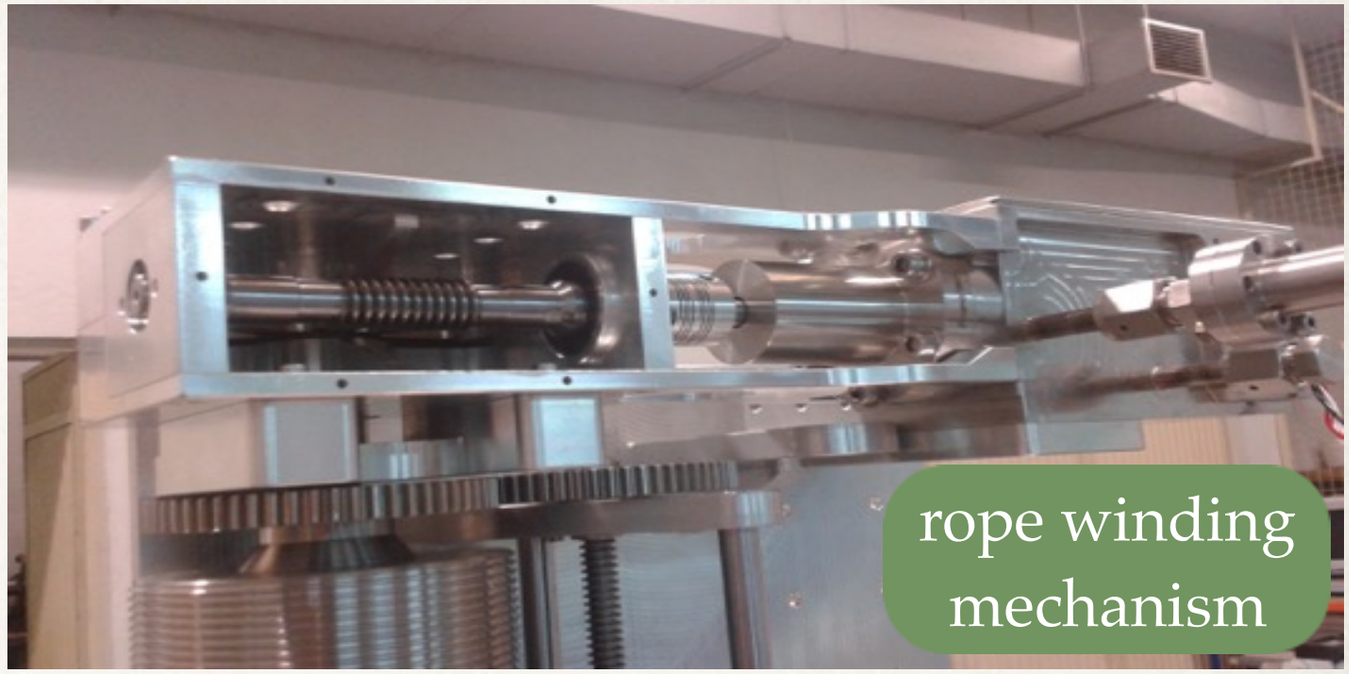


(R. Alves / N. Dias / C. Silva / A. Pereira / O. Cunha / J. Oliveira)

Group activities: URM fabrication 2/2



Base plates made externally but now at LIP



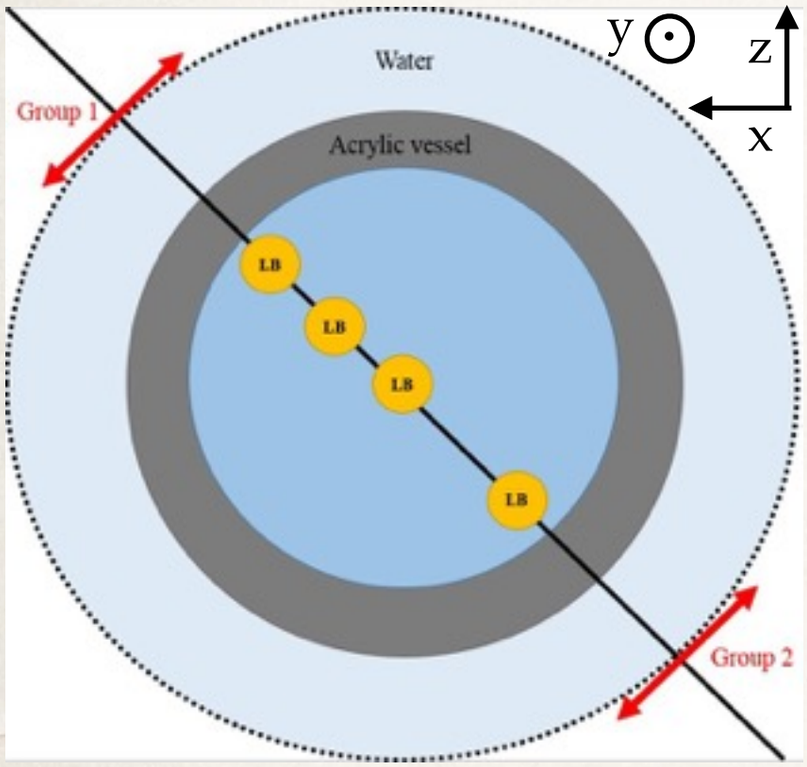
rope winding mechanism

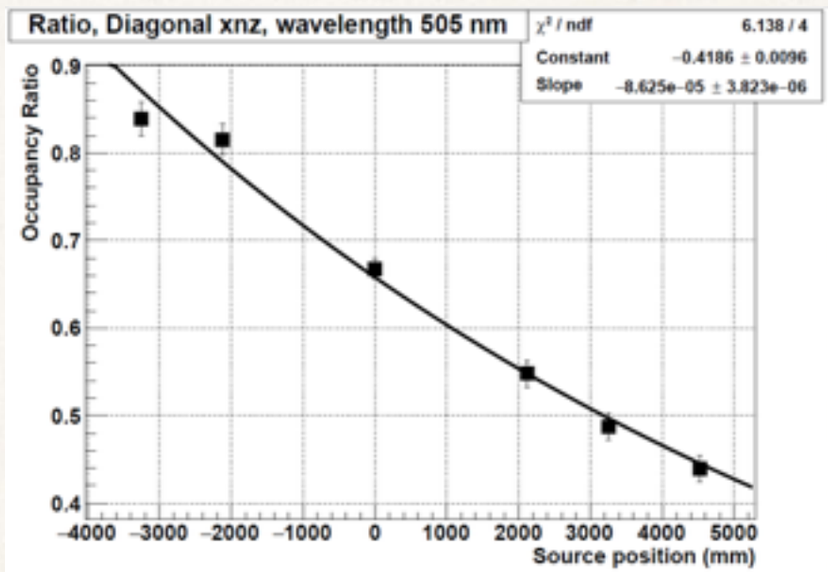
Prepared semi-clean assembly area

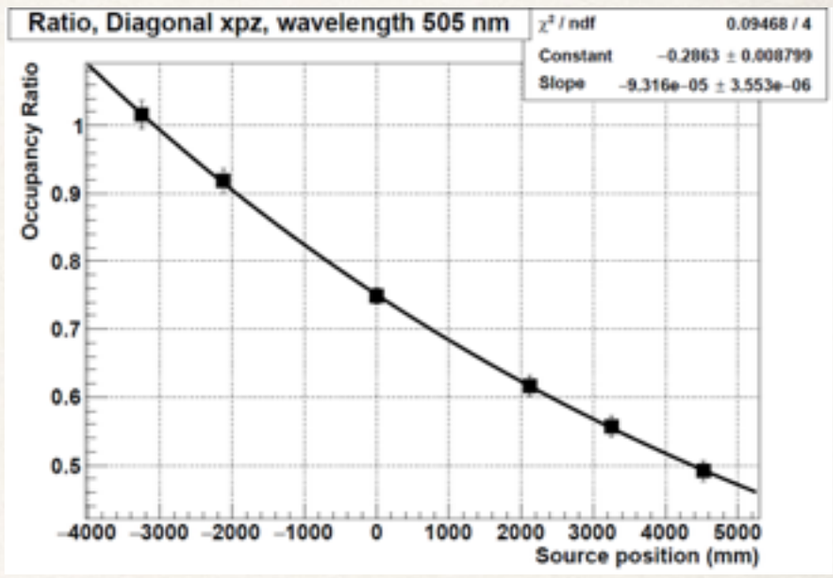
Group activities: laserball

Diagonal scans analysis (A.S. Inácio):

- aims is to measure the attenuation coefficients from water/liquid scintillator
- 2 diagonals (x=±z and y=±z) and 5 positions per diagonal for 5 different wavelengths simulated
- y=±z diagonal preliminary analysis show that statistics too limited by shadowing

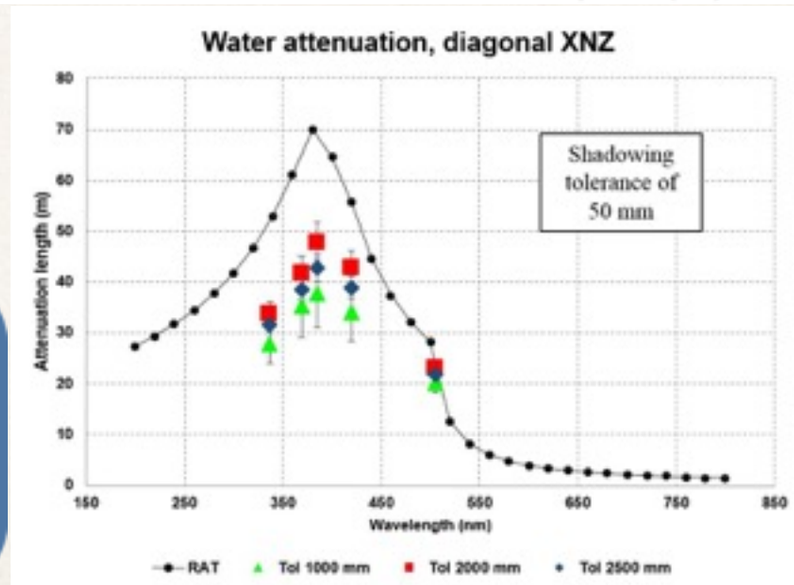


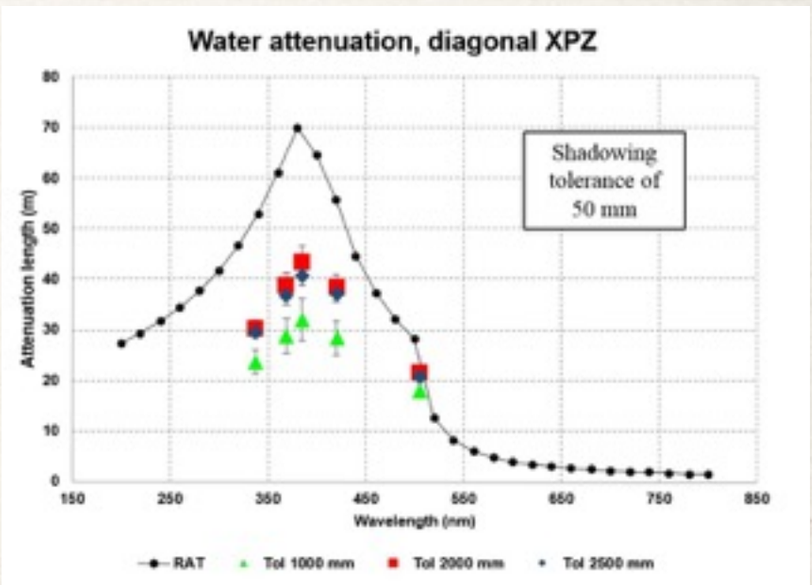




Code (J. Maneira/G. Prior):

- simulation (generator, production)
- optics parameters
- database insertion





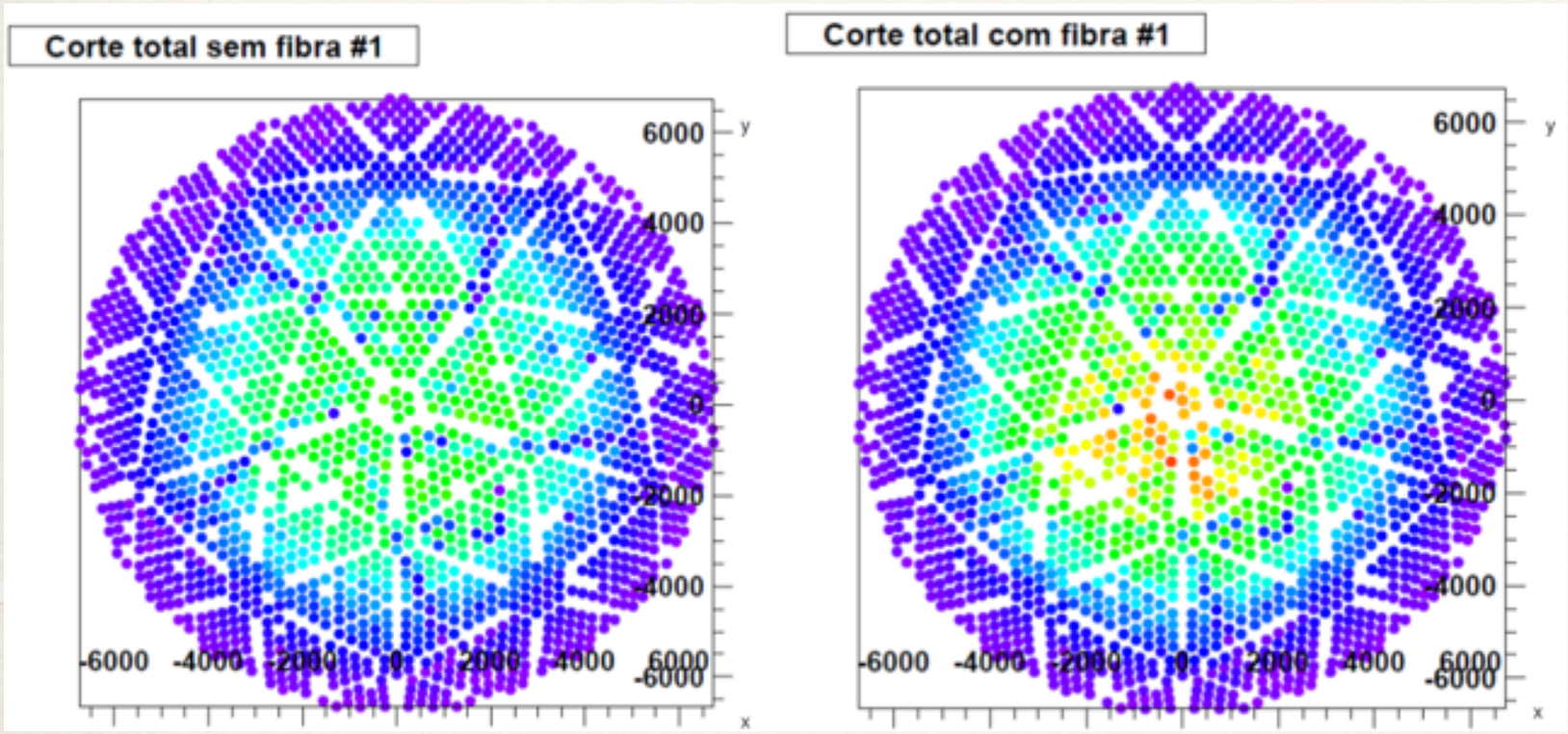
Water attenuation from simulation:

- tuning shadowing and PMT-diagonal distance cuts
- + solid angle correction…

Group activities: Fibers

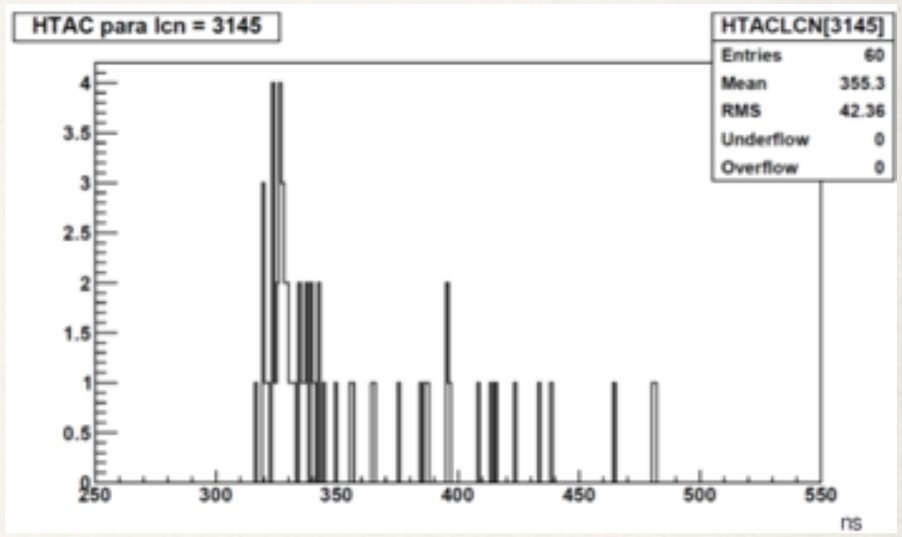
Study of additional top fibers positions (G. Lemos):

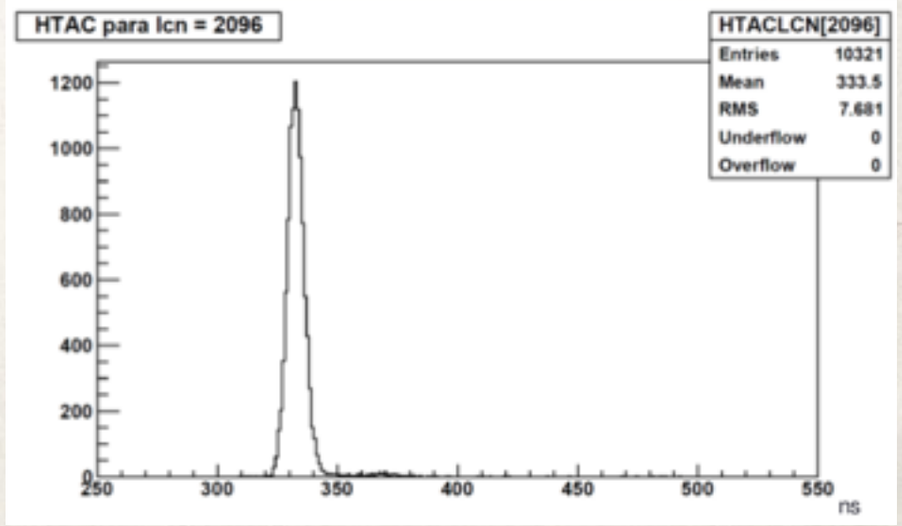
- very important to have each PMT seen by at least one fiber
- cannot put fibers on the very top of the detector (due to the detector access chimney)
- shadow from the ropes may prevent the illumination of some bottom PMTs
- simulated 5 top fibers positions + one additional location



Low occupancy PMTs study:

- shadowing
- PMT gain /calibration



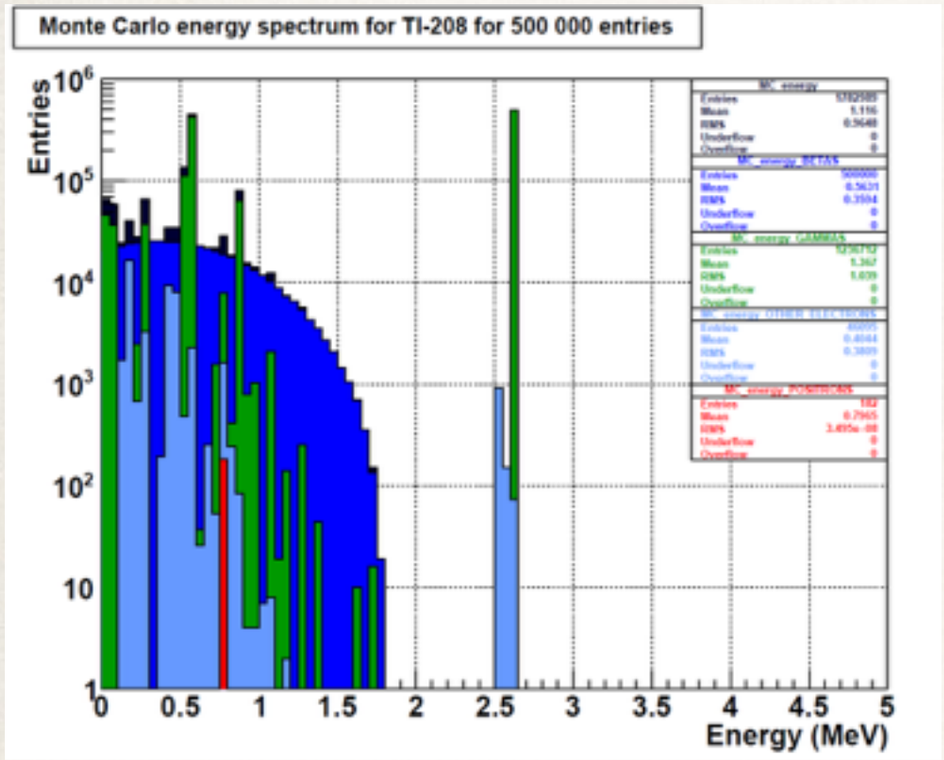


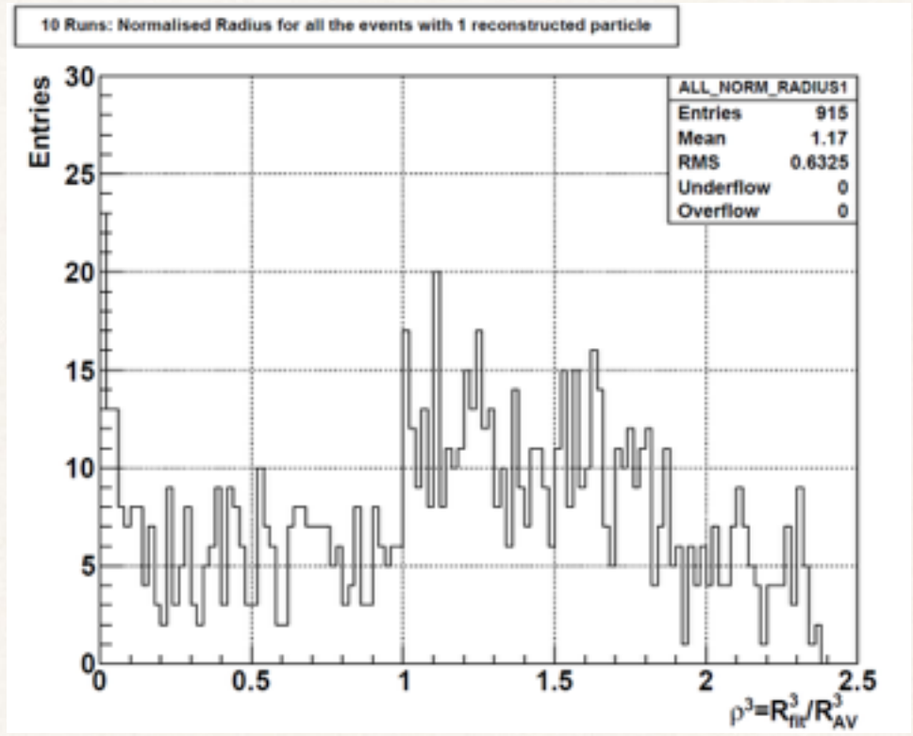
- calculated hit probability for each PMT by a given fiber
- applied Poisson correction to the raw occupancy
- identified low occupancy PMTs

Group activities: backgrounds

PMTs background study in the water phase (E. Samara):

- simulated 5 million ^{208}Tl events created in the PMTs glass
- reconstructing 915 events in the detector water (one trigger, fitter output all valid)
- identified some re-triggers (events in consecutive windows, very few PMTs hits)





Position fit performance:

- too high number of events at (0,0,0)
- need to understand the effect of the acrylic vessel

^{214}BiPo and ^{212}BiPo coincidence backgrounds (G. Prior):

- tested cuts (time separation only) on pure ^{214}BiPo/^{212}BiPo dataset - 100% tagging efficiencies
- tested cuts (time + position separation) on a mixed (signal + background) dataset
- compared the cuts efficiency with three concurrent algorithms

Mixed data set ^{214}BiPo tagging:

- 99.8 ± 3.2 % tagging efficiency
- signal sacrifice from 3.38 ± 0.22% to 1.83 ± 0.16% (with cut on #PMTs hit)

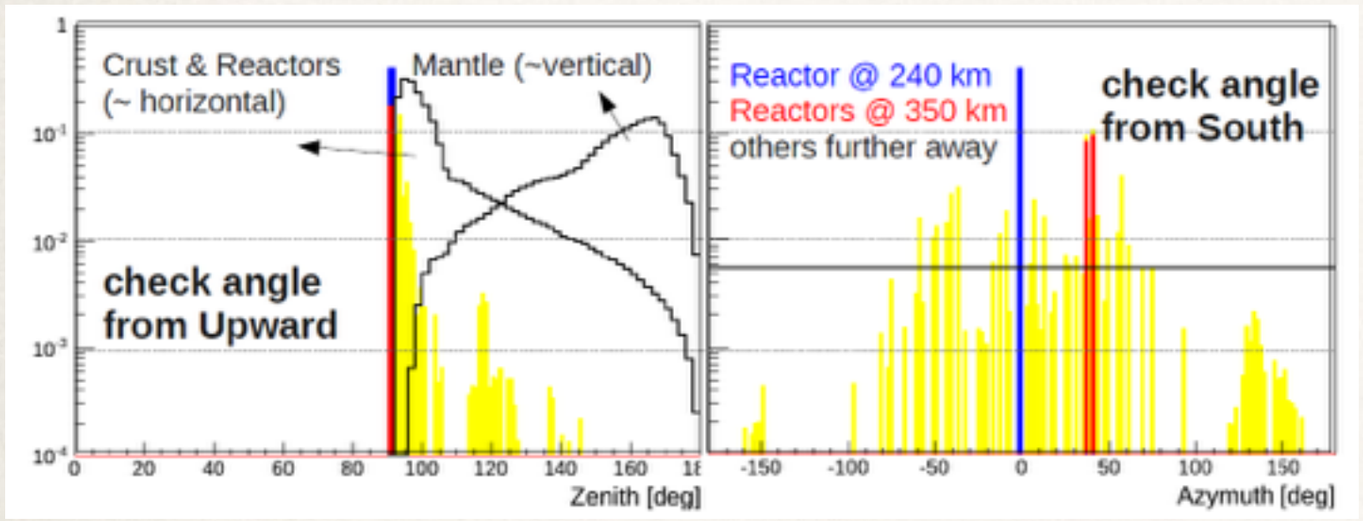
New mixed data set:

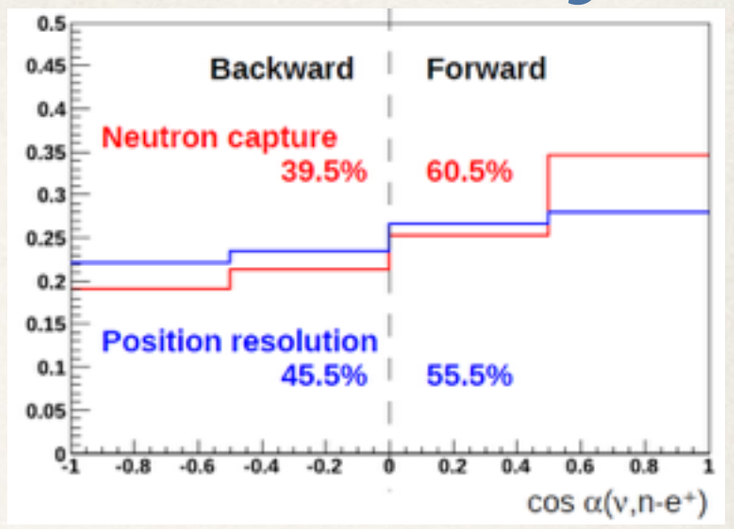
- add ^{212}BiPo in separate windows
- add ^{8}B signal

Group activities: anti-ν directionality

Exploring geo/reactor anti-ν separation with directionality (S. Andringa):

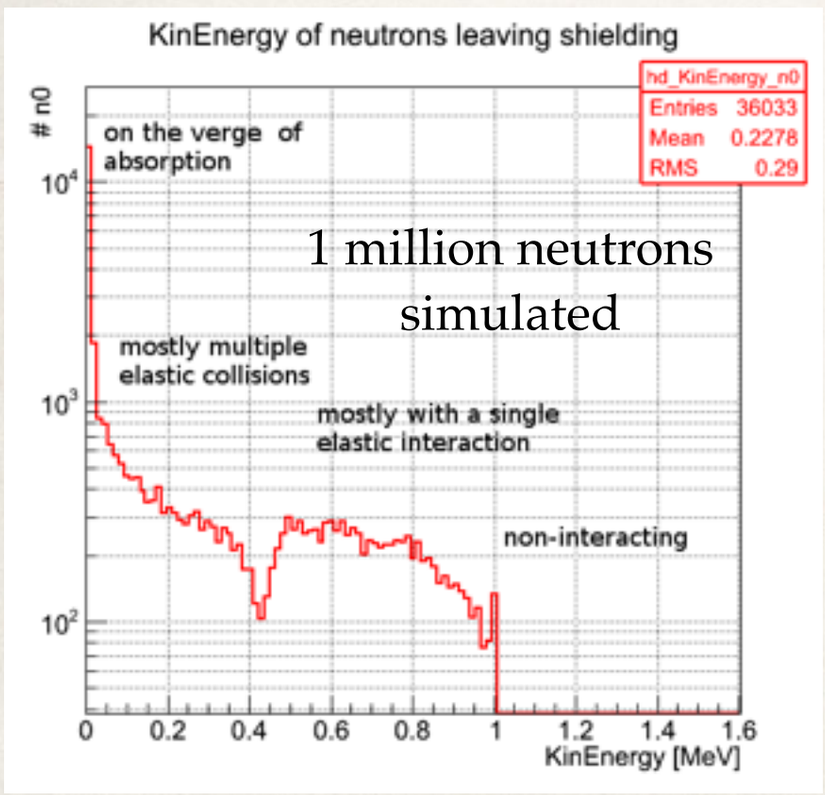
- ✤ tagged by delayed coincidence (e+,n)
- ✤ energy from the positron and direction from the neutron
- ✤ geo-neutrinos come from the earth center
- ✤ most reactors located in the South region of SNO+





- ✤ neutron capture is slow (distort direction)
- ✤ ~10% North/South asymmetry
- ✤ expect 2σ sensitivity after 5 years of scintillator

S. Nae joined recently the group



Directional neutron source (N. Zahar/P.Jorge/A.Maio):

- ✤ SNO+ isotropic AmBe source neutron spectrum up to 12 MeV
- ✤ also emits 4.4 MeV γ´s (used for event timing)
- ✤ studied material shieldings that blocks neutrons in all but one direction

Borax extremely effective at blocking more than 96% of 1 MeV neutrons

optimizing the "hole collimator"

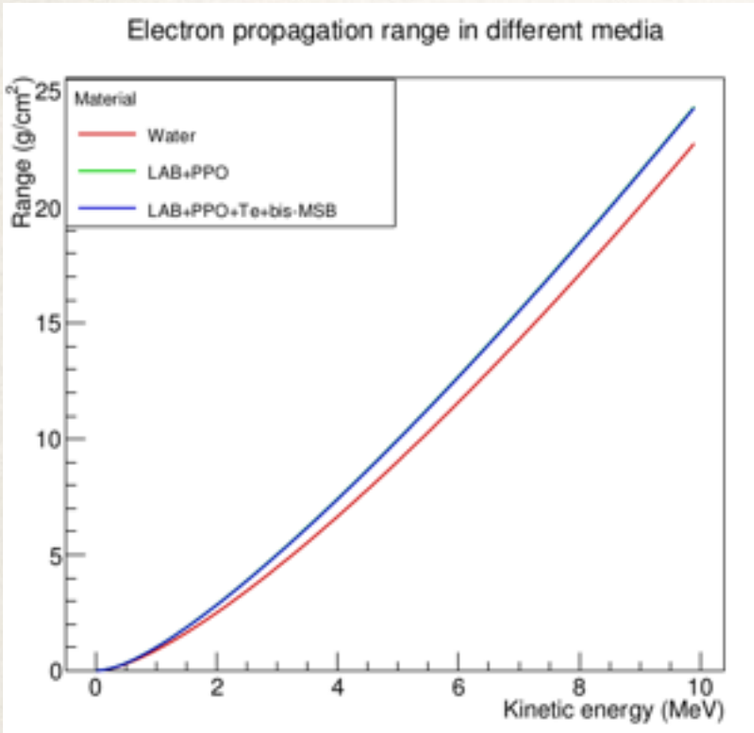
- ✤ dedicated 1.5 year exploratory project ended in October 2015
- ✤ final results presented at the IDPASC "Space, Particle & Earth" workshop
- ✤ established contacts with the geo-chemistry group of Lisbon U.

Group activities: detector response

detector response framework (F. Barão/X. Rodrigues):

✤ directionality very important to some physics topics (exotics, backgrounds, anti-ν…)

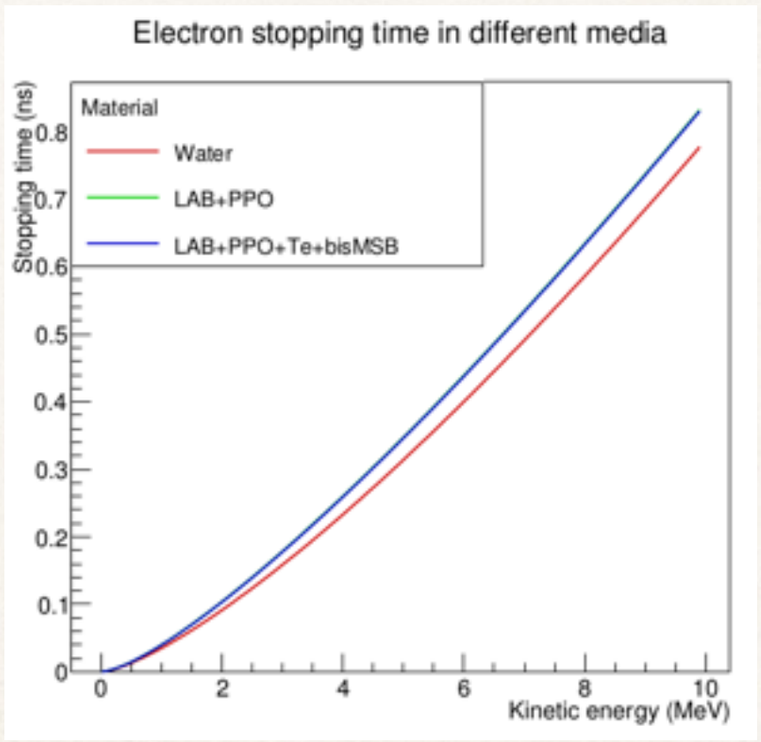
✤ looking into ways to separate Cherenkov light from scintillation light

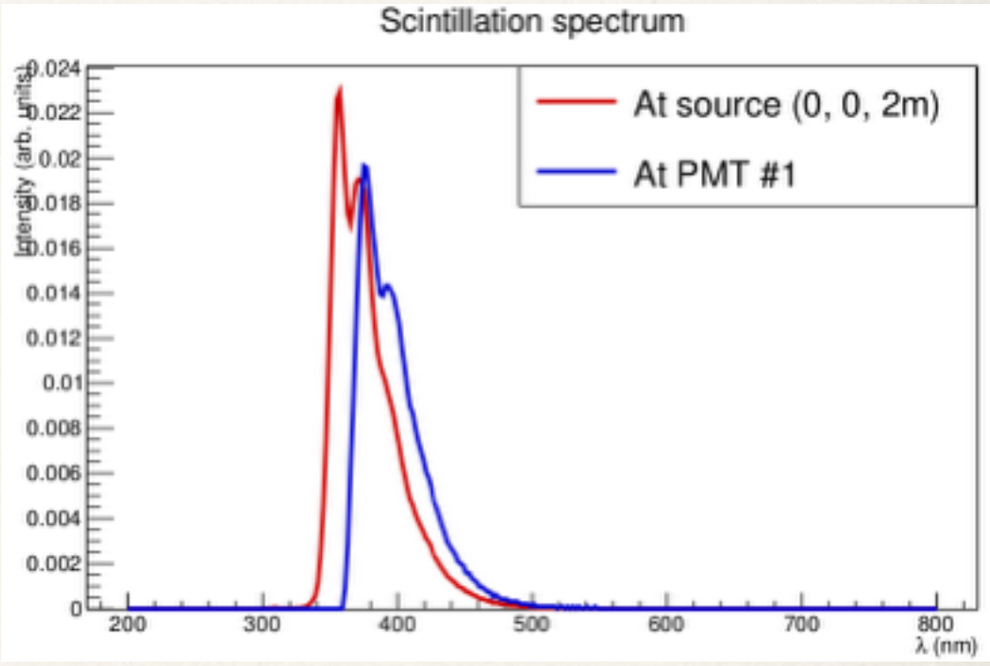


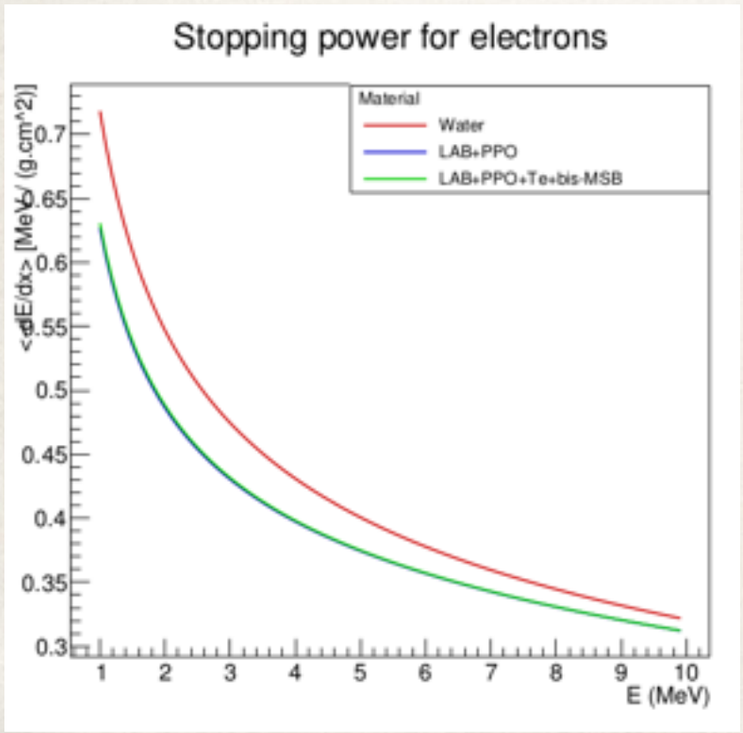
✤ independent tool able to reproduce the light propagation in the detector

✤ optics included: Rayleigh scattering length, absorption length, scintillation spectrum, light yield

✤ geometry included PMTs position, pipes, ropes







estimation of the photon signal in every detector cell:

✤ add PMTs dimension

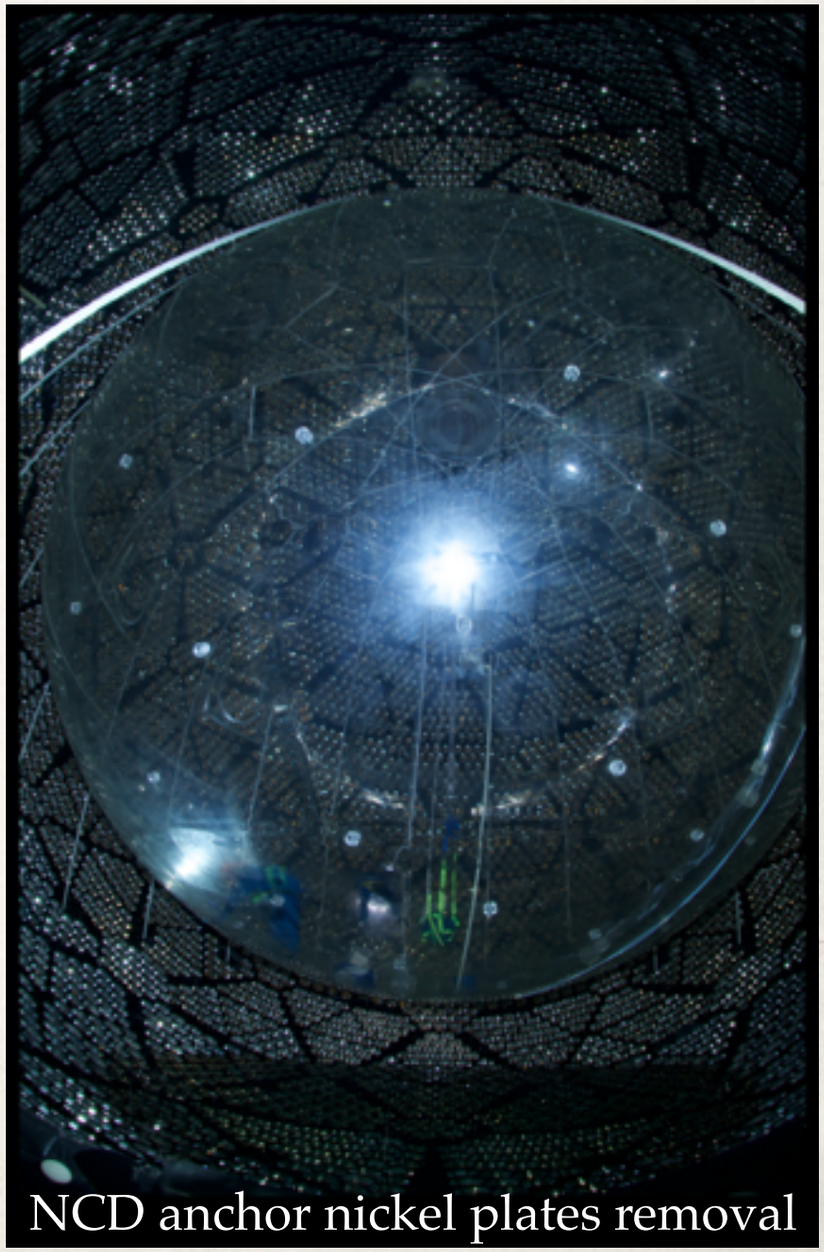
✤ PMT quantum efficiency

✤ PMTs angular efficiency

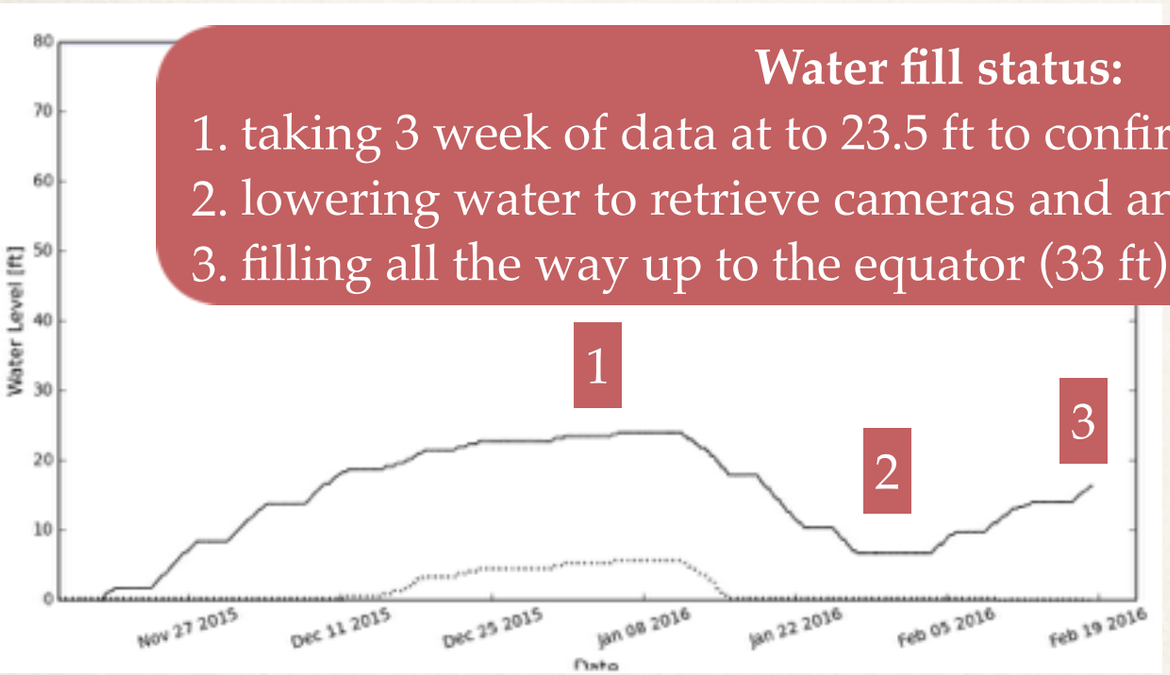
Status of the SNO+ experiment

Experiment delayed by over a year since summer 2014 due to a leak:

- ✤ 10/2014 - discover water loss from cavity
- ✤ 11-12/2014 filling up to 30 ft , understand data/leak models
- ✤ 01-02/2015 searching for leak from boat, testing various methods
- ✤ 02-03/2015 discovered 1 hole in liner at 20.5 ft, repair from boat
- ✤ 04/2015 fill again but water leak still present
- ✤ 05-07/2015 develop/test scanning device, systematic inspection
- ✤ 08-09/2015 draining cavity all the way down, perform inspection
- ✤ 10/2015 discovery 2 other leak candidates at 4 ft
- ✤ 11-12/2015 repair the leaks, filling again all the way up to 23.5 ft
- ✤ 12/2015 patched another hole at 21 ft found on the way up
- ✤ 01/2016 confirmed that the cavity liner was successfully repaired



NCD anchor nickel plates removal



Water fill status:

1. taking 3 week of data at to 23.5 ft to confirm leak repair
2. lowering water to retrieve cameras and anchors nickel plates
3. filling all the way up to the equator (33 ft) for float-the-boat test

As of Feb. 18, 2016, 10:27 a.m. UTC, the water level in the cavity is 16.319 ft

- ✤ 2016 water commissioning phase (expected this summer)
- ✤ 2017 scintillator phase
- ✤ 2017-2018 (Te-loaded phase)

THANKS !

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- IF/00863/2013
- IF/00863/2013/CP1172/CT2006
- EXPL/FIS-NUC/1557/2013