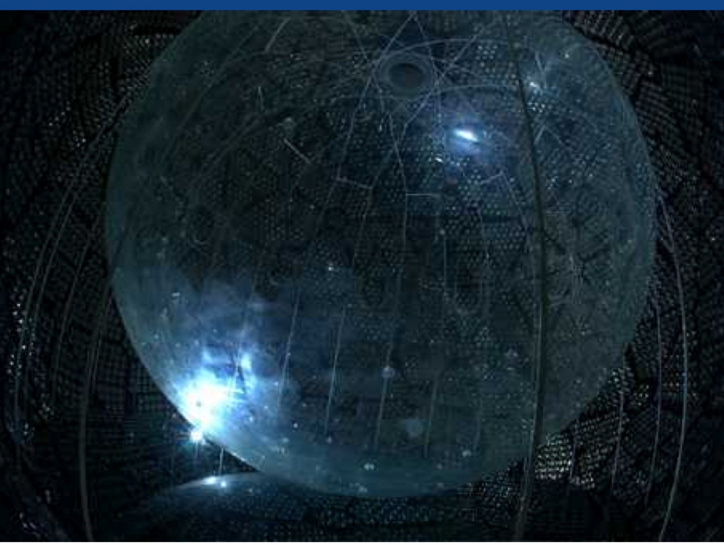
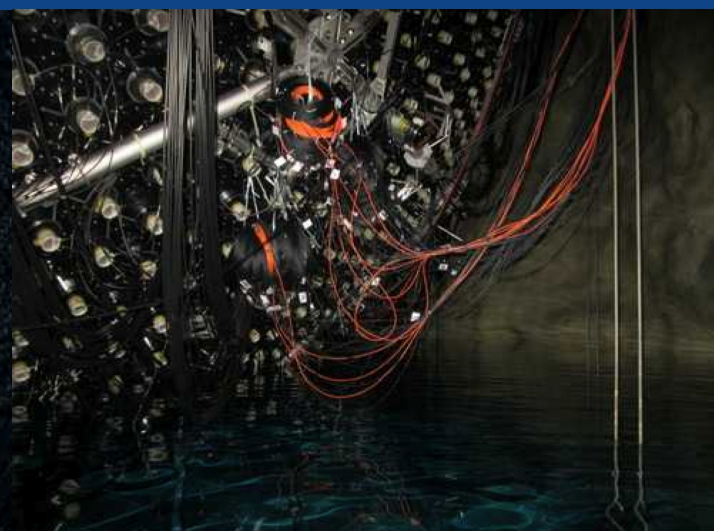
Neutrinoless double beta decays with SNO+

Gersende Prior (LIP)
on behalf of the SNO+ Collaboration

LIP seminar – July 3rd 2014





LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTICULAS

LIP

SNO+

IF INVESTIGADOR FCT

Outline

1. Introduction: neutrino properties and today's questions

2. Neutrinoless double beta decay

3. The SNO+ experiment

- physics goals
- detector description
- calibration and deployment systems
- backgrounds and sensitivity to neutrinoless double beta decay

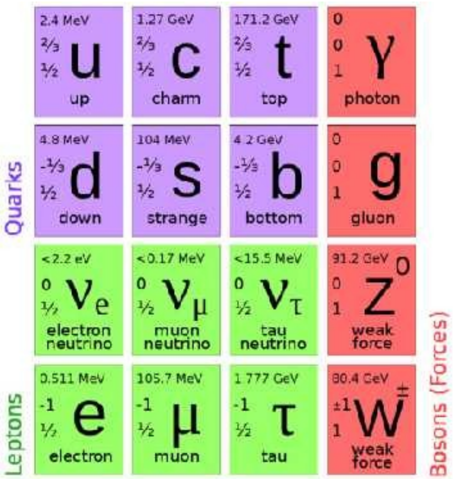
4. Status

- LIP activities and experiment status
- run plan

Recent SNO+ presentations by LIP members:
- J. Maneira (IDPASC2014)
- S. Andringa (Jornadas do LIP 2014)
- A. Maio (CALOR2014)
- L. Seabra (CALOR2014)

Introduction: neutrino properties and today's questions

- Neutrinos in the Standard Model are
  - neutral leptons present in three flavours (ν_e, ν_μ, ν_τ)
  - with no charge and no mass
  - interacting via the weak interactions



- Results (among the many) from solar ν experiments
  - Y. Fukuda et al., Phys. Rev. Lett. 81 Number 6 page 1158 (1998)

The first results of the solar neutrino flux measurement from Super-Kamiokande are presented. The results shown here are obtained from data taken between 31 May 1996, and 23 June 1997. Using our measurement of recoil electrons with energies above 6.5 MeV, we infer the total flux of ^{8}B solar neutrinos to be $2.42 \pm 0.06(\text{stat})^{+0.10}_{-0.07}(\text{syst}) \times 10^6\ \text{cm}^{-2}\,\text{s}^{-1}$. This result is consistent with the Kamiokande measurement and is 36% of the flux predicted by the BP95 solar model. The flux is also measured in 1.5 month subsets and shown to be consistent with a constant rate. [S0031-9007(98)06804-5]

Less solar (ν_e) neutrinos measured than predicted by the Standard Solar Model (SSM)

  - Q.R. Ahmad et al. (SNO), Phys. Rev. Lett. 89 011301 (2001)

Observations of neutral-current ν interactions on deuterium in the Sudbury Neutrino Observatory are reported. Using the neutral current (NC), elastic scattering, and charged current reactions and assuming the standard ^{8}B shape, the ν_e component of the ^{8}B solar flux is $\varphi_e = 1.76^{+0.05}_{-0.05}(\text{stat})^{+0.09}_{-0.09}(\text{syst}) \times 10^6\text{cm}^{-2}\text{s}^{-1}$ for a kinetic energy threshold of 5 MeV. The non-ν_e component is $\varphi_{\mu\tau} = 3.41^{+0.45}_{-0.45}(\text{stat})^{+0.48}_{-0.45}(\text{syst}) \times 10^6\text{cm}^{-2}\text{s}^{-1}$, 5.3$\sigma$ greater than zero, providing strong evidence for solar ν_e flavor transformation. The total flux measured with the NC reaction is $\varphi_{NC} = 5.09^{+0.44}_{-0.43}(\text{stat})^{+0.46}_{-0.43}(\text{syst}) \times 10^6\text{cm}^{-2}\text{s}^{-1}$, consistent with solar models.

Total ν flux (all flavours) consistent with the SSM

Neutrinos change flavour on their way from Sun to Earth and therefore have a mass !

Introduction: neutrino properties and today's questions

- Weak eigenstates versus mass eigenstates (PMNS matrix)

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \times \begin{pmatrix} e^{i\alpha 1/2} & 0 & 0 \\ 0 & e^{i\alpha 2/2} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

with $c_{ij} = \cos(\theta_{ij})$ and $s_{ij} = \sin(\theta_{ij})$

CP violation occurs in the quark sector, it is natural to expect a similar situation in the lepton sector

3 mixing angles θ_{ij}, 1 CP violation phase δ, 2 Majorana phases α_1 and α_2

- Oscillation probability (in vacuum)

$$P(\nu_\alpha \rightarrow \nu_\beta) = \delta_{\alpha\beta} - 4\sum \Re(W^{ij}_{\alpha\beta}) \cdot \sin^2(\Delta m^2_{ij} \cdot L/4E) + 2\sum \Im W^{ij}_{\alpha\beta} \cdot \sin^2(\Delta m^2_{ij} \cdot L/2E)$$

with $\Delta m^2_{ij} = m^2_i - m^2_j$ and $W^{ij}_{\alpha\beta} = U^*_{\alpha i} U_{\beta i} U_{\alpha j} U_{\beta j}^*$

($\delta_{\alpha\beta}$ Kronecker symbol)

2 squared mass difference $\Delta^2 m_{ij}$

Oscillation probability depends on the neutrino travel length (L) and energy (E)

Introduction: neutrino properties and today's questions

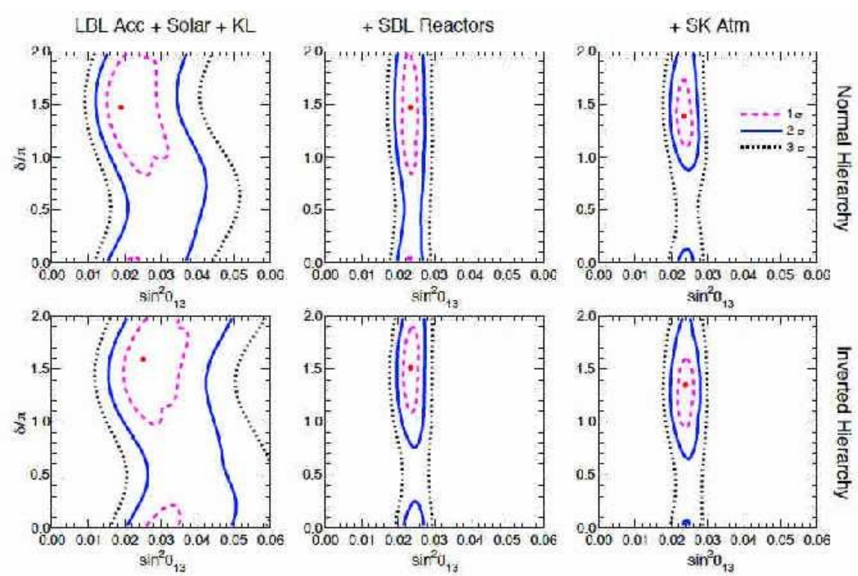
- Mixing angles
  - $\theta_{12} \sim 34°$ (solar)
  - $\theta_{23} \sim 40°$ (atmospherics)
  - $\theta_{13} \sim 9°$ (short baseline reactors)
- Squared mass differences
  - $|\Delta m^2_{23}| \sim 2.4 \times 10^{-3}\ eV^2$ (accelerators)
  - $\Delta m^2_{12} \sim 7.5 \times 10^{-5}\ eV^2$ (long baseline reactors)
- First hints on δ_{CP} (F. Capozzi et al. arXiv:1312.2878)

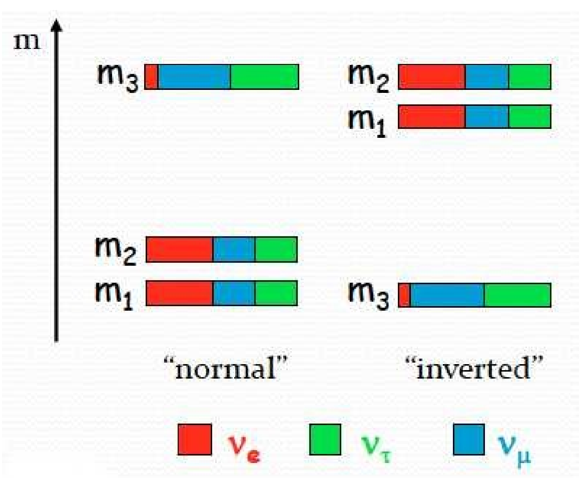
Neutrinos are Majorana (being equal to its own anti-particle) or Dirac particles ?

What is the neutrino absolute mass ?

$0\nu\beta\beta$ experiments will explore those three questions

Mass hierarchy: Normal or Inverted ?





Neutrinoless double beta decay

- Double-beta decays ($2\nu\beta\beta$)

$\beta^-\beta^-$: $X(A,Z) \rightarrow Y(A,Z+2) + e^- + e^- + \overline{\nu}_e + \overline{\nu}_e$

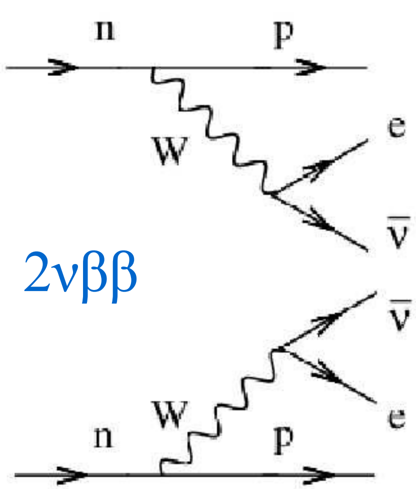
usually even-Z, even-A nuclei for which the single beta decay is forbidden or highly suppressed

35 naturally occuring isotopes can decay via $\beta^-\beta^-$ emission
Observed in 11

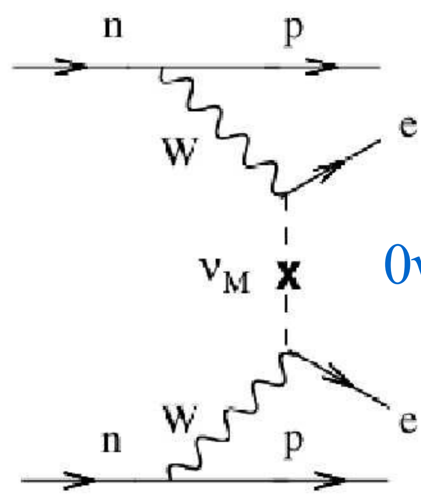
$\beta^+\beta^+$: $X(A,Z) \rightarrow Y(A,Z-2) + \nu_e + \nu_e +$
- $2e^-$ capture
- e^- capture + e^+ emission
- $2e^+$ emission

$\beta+\beta+$ theoretically predicted but not yet observed

- Neutrinoless double-beta decays ($0\nu\beta\beta$)



$2\nu\beta\beta$



$0\nu\beta\beta$

If the neutrino is a Majorana particle and one of the neutrinos has a non-zero mass then $0\nu\beta\beta$ can exist.
In that case the lepton number is violated

Neutrinoless double beta decay

- Decay rate

Nuclear matrix elements (NME)

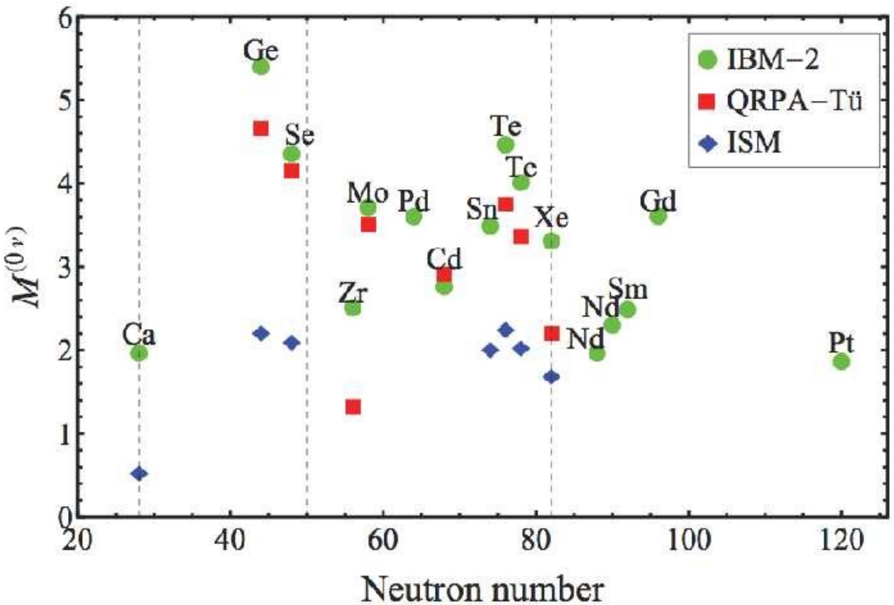
$\langle m_{\beta\beta}\rangle = \Sigma m_i.U_{ei}^2$
effective Majorana mass

Phase space factor

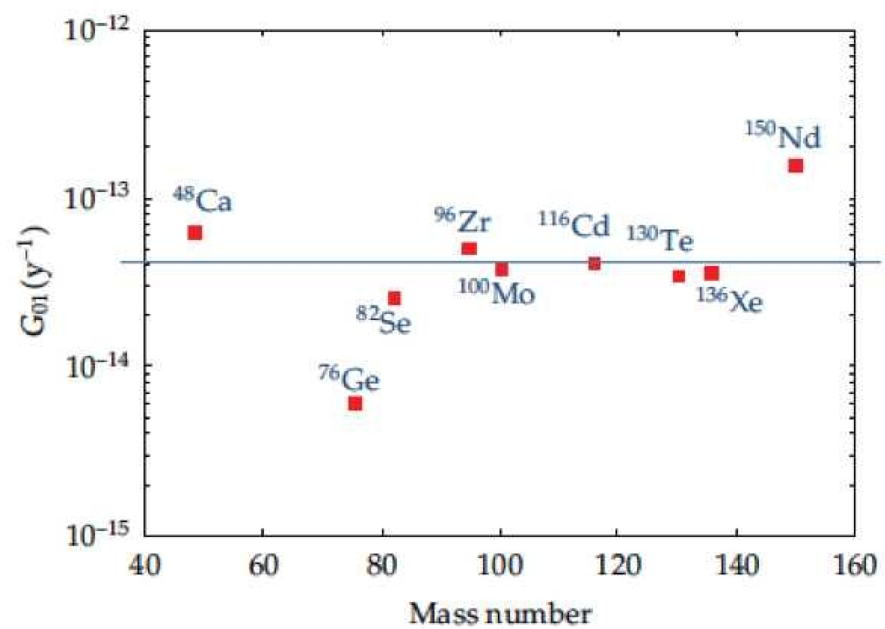
  - $\Gamma^{0\nu} = (T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z).|M_{0\nu}|^2 .\langle m_{\beta\beta}\rangle^2/m_e^2$

$0\nu\beta\beta$ experiments measure or set a limit to $T^{0\nu\beta\beta}_{1/2} \sim 10^{25}$ yr

- NME calculations
  - J. Barea et al. Phys. Rev. C 87 014315, (2013)

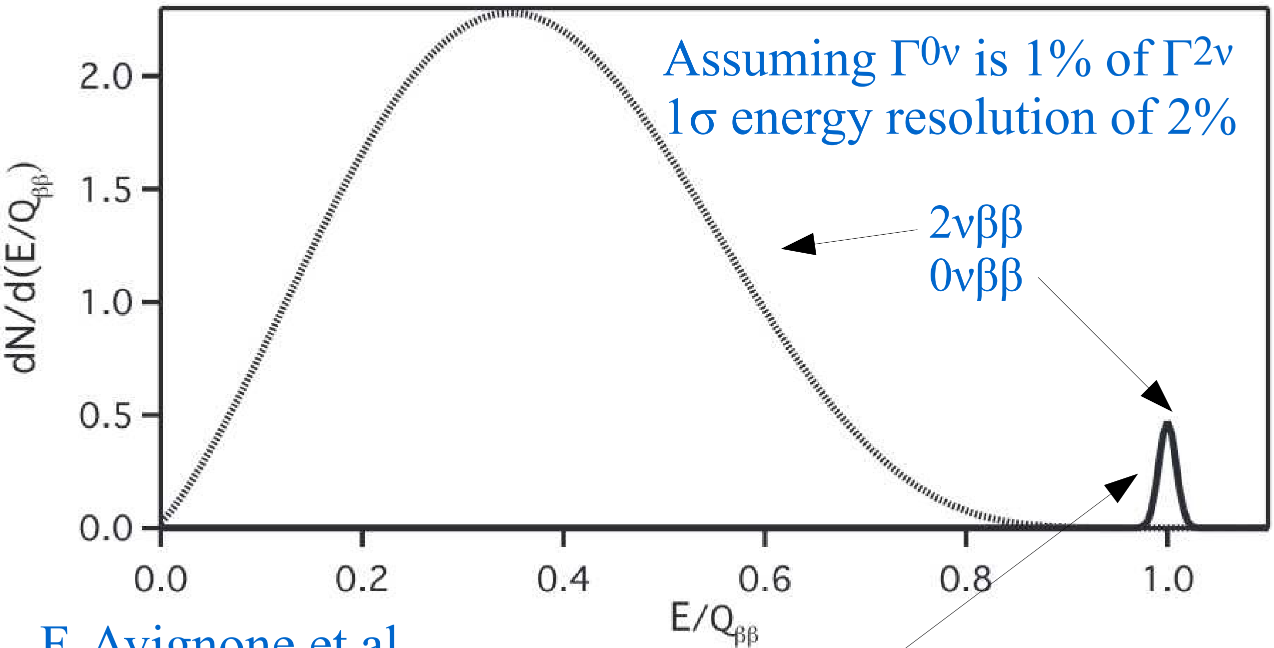


IBM-2 microscopic interacting boson model
QPRA-Tü quasi-particle random phase approximation
ISM interacting shell model



NME models calculations not always in agreement or, for some nucleus, not calculated by all models.

Neutrinoless double beta decay



F. Avignone et al.,
Rev. Mod. Phys. 80 p 481 (2008)

$$T_{1/2}^{0\nu} \propto \frac{1}{n_\sigma} \cdot \left(\frac{\epsilon \cdot a}{W} \right) \sqrt{\left(\frac{M \cdot t}{b \cdot \Delta(E)} \right)}$$

n_σ number of standard deviation
ε detection efficiency
a isotopic abundance
W molecular weight of the material
M total mass of the source
Δ(E) spectral width of the energy
b background rate in count/(keV.kg.yr)

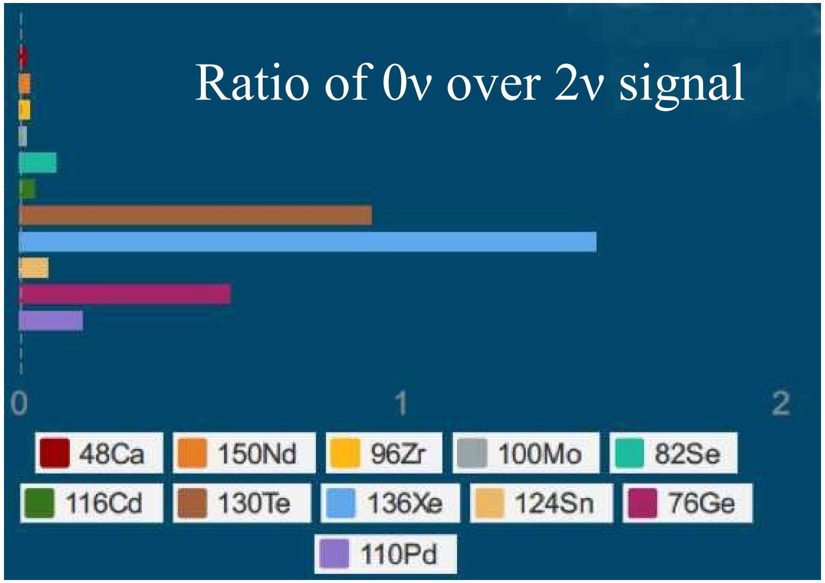
Where to look...

What reality is more likely to look like

The Telegraph,
animal camouflage gallery

Neutrinoless double beta decay

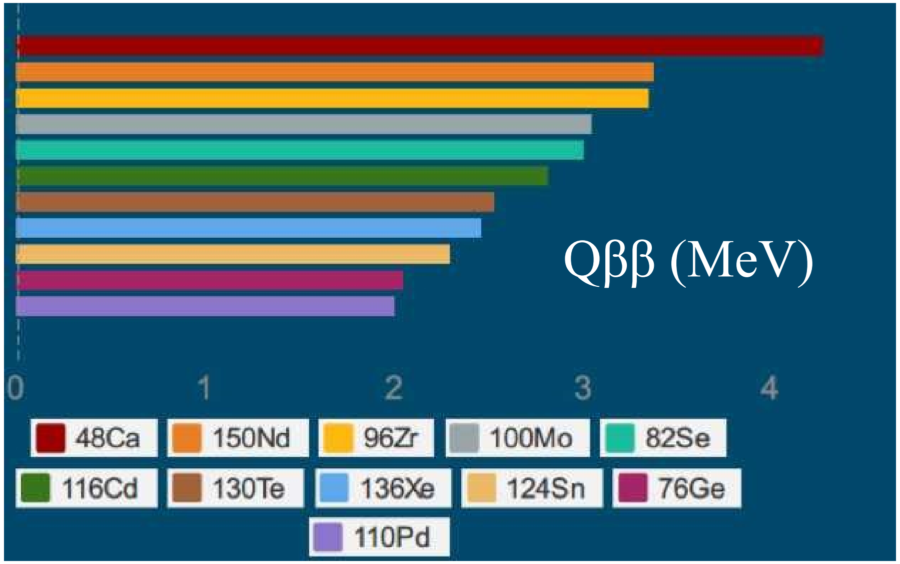
- The choice of the isotope depends on
  - NME knowledge/accuracy
  - $Q_{\beta\beta}$
  - Isotope natural abundance (small detectors or less enrichment)
  - World availability (production and costs)
  - Ratio to the "irreducible" ($2\nu\beta\beta$) background
  - Other backgrounds presents in the ROI (Region of Interest) such as U/Th, solar neutrinos,...

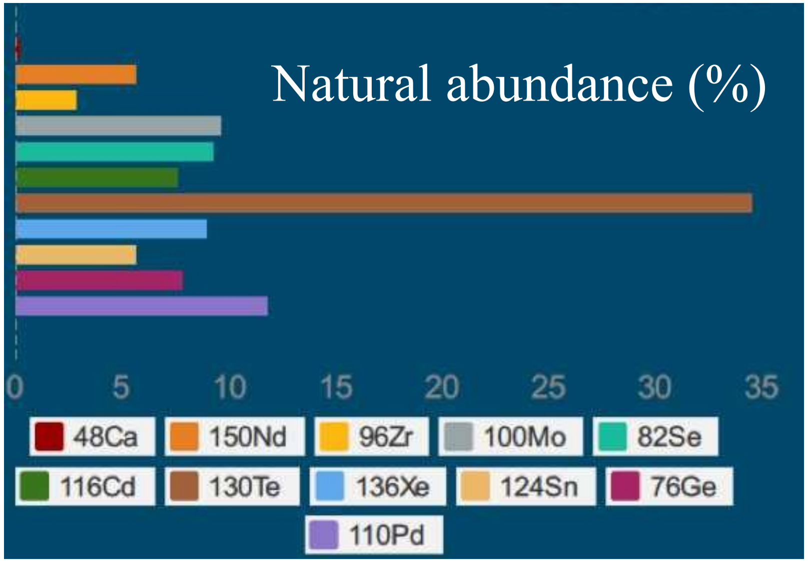


World production rates/cost

^{130}Te - 150 tons/year - 1000 \$/kg

^{136}Xe - 50 tons/year – 360 \$/kg

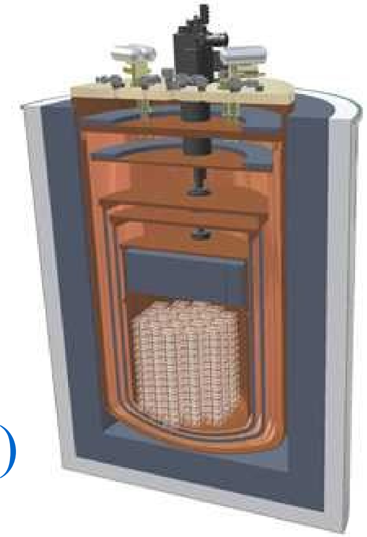




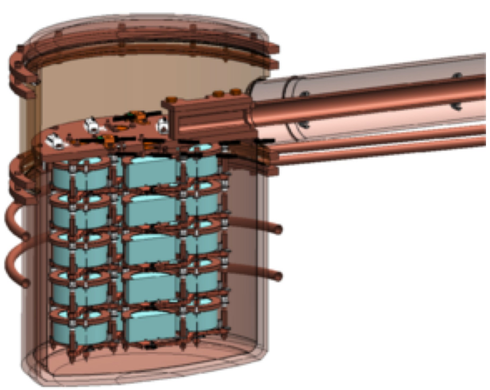
Courtesy:
L. Winslow
Neutrino2014

Neutrinoless double beta decay

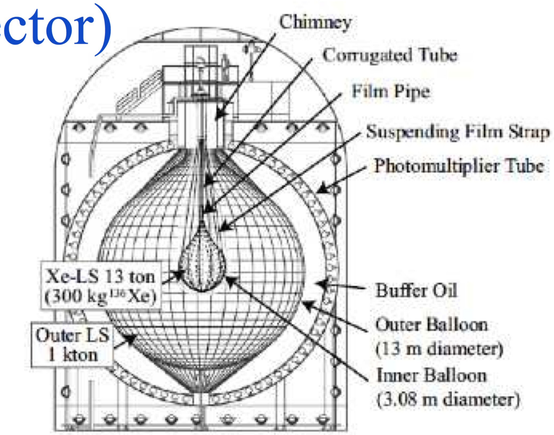
- The choice of detector technology depends on:
  - detector material cleaniness and shielding requirements
  - achievable energy resolution in the ROI
  - ability to scale the detector up
  - choice of isotope (crystal arrays versus HPG or liquids)
  - ability to change isotope
  - tracking ability (if source ≠ detector)



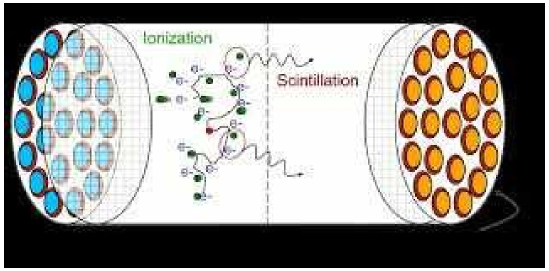
Bolometers: CUORE
TeO_2 array
~700 kg isotope mass



Semi-conductors: MAJORANA/GERDA
HP ^{76}Ge modules
~30 kg isotope mass



Liquid scintillators:
KamLAND-Zen/SNO+
^{136}Xe ~300 kg isotope mass
^{130}Te ~800 kg isotope mass



TPC: EXO-200
^{136}Xe
~ 200 kg isotope mass

Neutrinoless double beta decay: liquid scintillator

- Large mass
  - large volume detectors, so large mass possible even at small loading
- Low background
  - intrinsic radiopurity very good
  - rejection of external background via fiducial volume cuts
  - purification of cosmogenically activated contaminants
  - for $Q_{\beta\beta} > 2$ MeV many backgrounds can be identified with delayed coincidence tagging
- Poor energy resolution
  - harder to distinguish background γ lines
  - higher background from $2\nu\beta\beta$ spectrum
- Background from solar neutrinos
  - detector mass larger than isotope mass

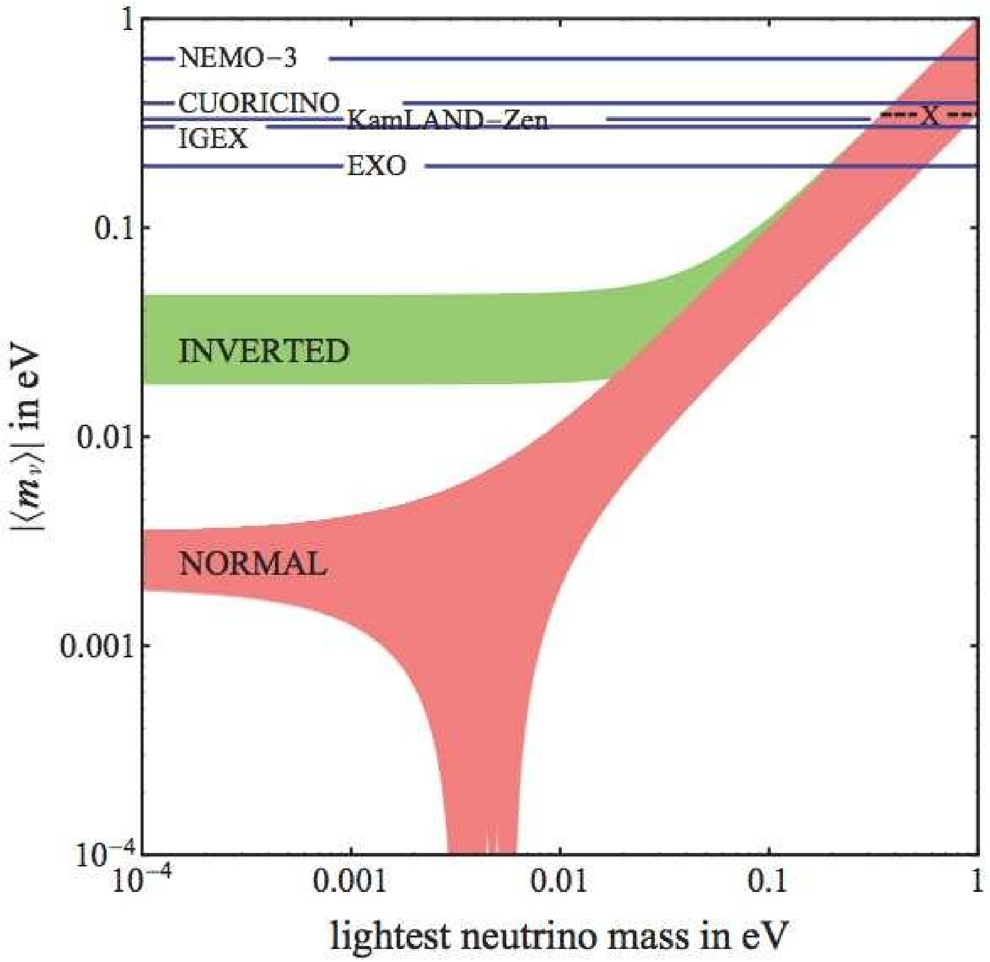
SNO+ has the highest isotope mass (ton-scale)

^{130}Te highest $0\nu\beta\beta/2\nu\beta\beta$ ratio

R. Raghavan, Borexino yellow book (1991), PRL72, 10 (1994)

Neutrinoless double beta decay

- Where do we stand



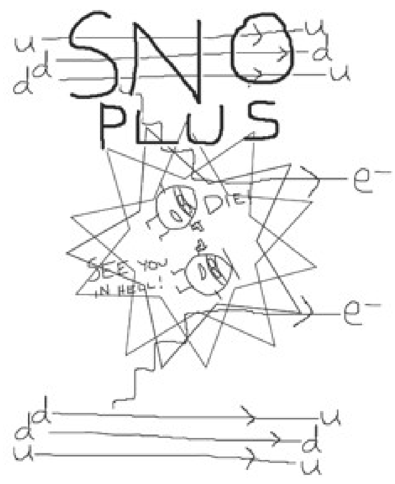
Claim (--X--) from part of the Heidelberg-Moscow Collaboration:
$T^{0\nu}_{1/2}$ (^{76}Ge) = 2.23 x 10^{25} yr
Corresponds to $m_{\beta\beta}$ ~ 0.32 eV
[H.V. Klapdor-Kleingrothaus et al. Mod. Phys. Lett. A 21 **20** p 1547 (2006)]

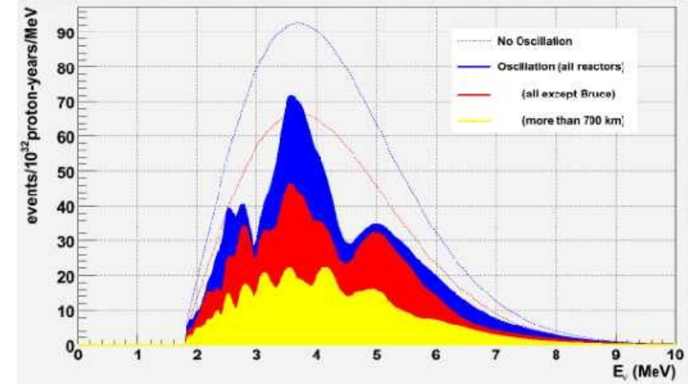
Lower limit from ^{136}Xe (EXO-200):
$T^{0\nu}_{1/2}$ (^{136}Xe) > 1.6 x 10^{25} yr
Corresponds to $m_{\beta\beta}$ < 140-380 meV
[M. Auger et al. PRL 109 032505 (2012)]

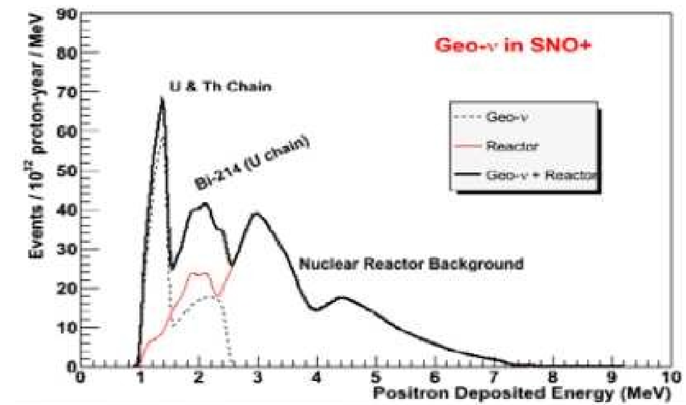
Experiments expect to reach the top of the inverted mass region by ~2018

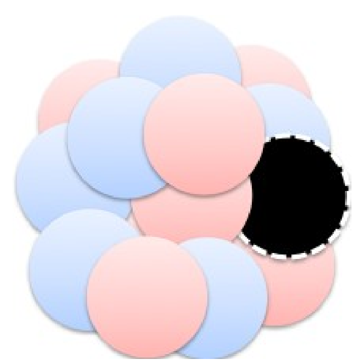
The SNO+ experiment: purpose and phases

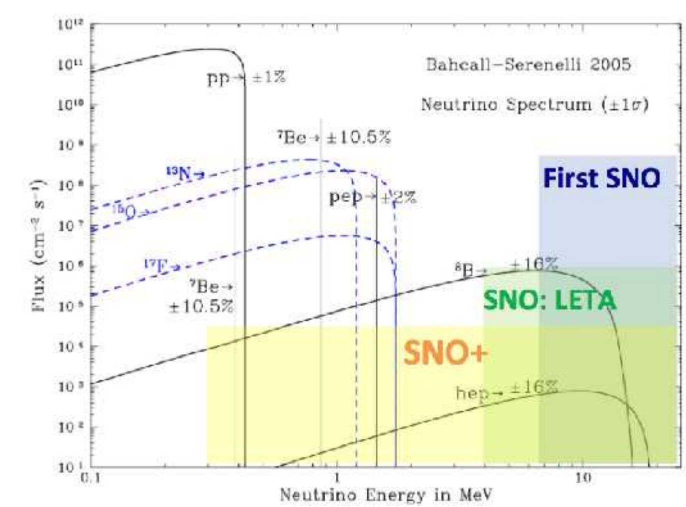
- SNO+ physics goals
  - search for Majorana neutrinos
  - anti-ν from reactors
    (3 nuclear plants @240-350 km)
  - geoneutrinos
  - solar ν (pep,CNO, low-E ^{8}B)
  - supernova neutrinos (SNEWS)
  - exotics (e.g. nucleon decay)
- SNO+ phases
  - water phase
  - liquid scintillator phase (LS)
  - isotope loaded liquid scintillator phases at different loading concentrations (starting at 0.3%)











The SNO+ experiment: detector

- The SNO+ detector

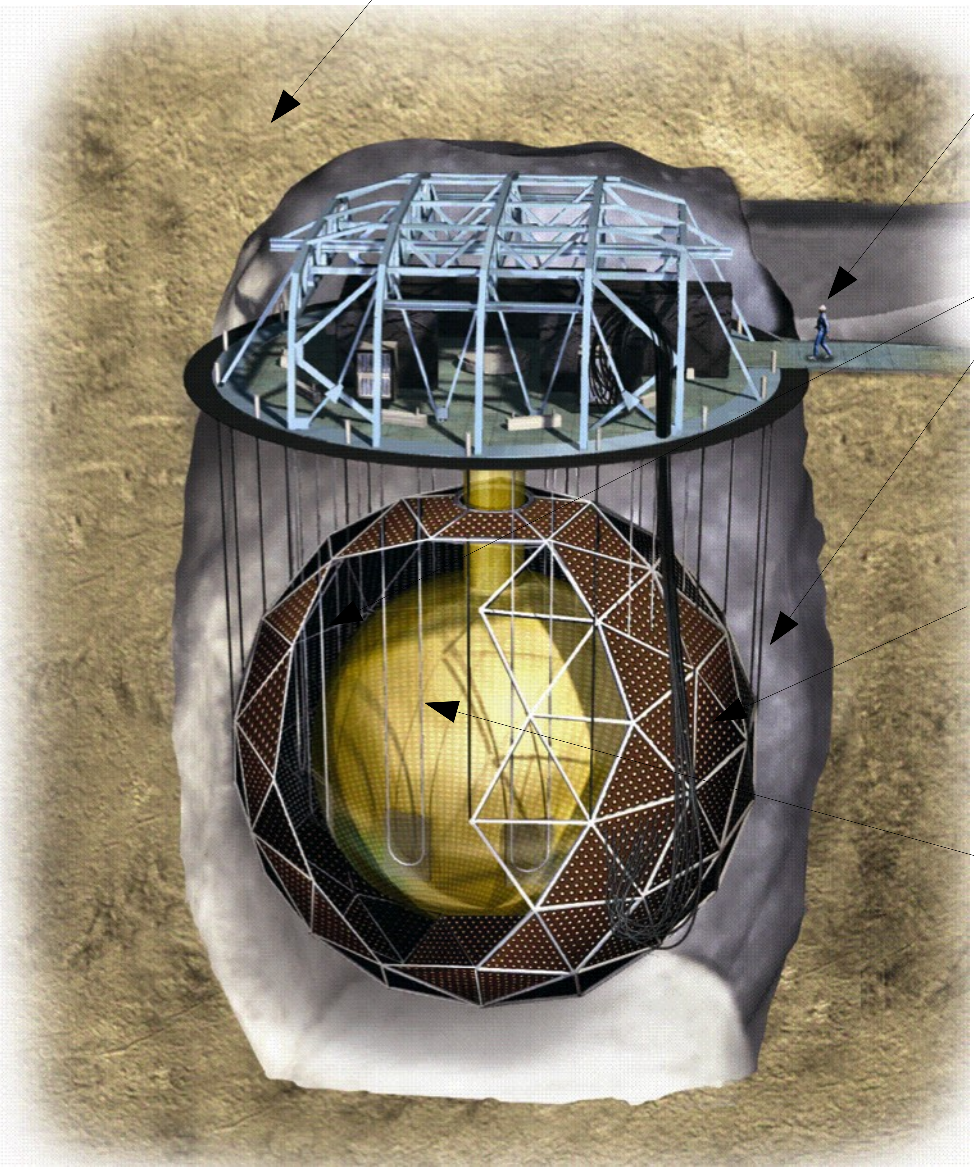
SNO heavy water replaced by 780 tons of LS

New readout cards

New hold-down rope system

New DAQ system

New calibration systems

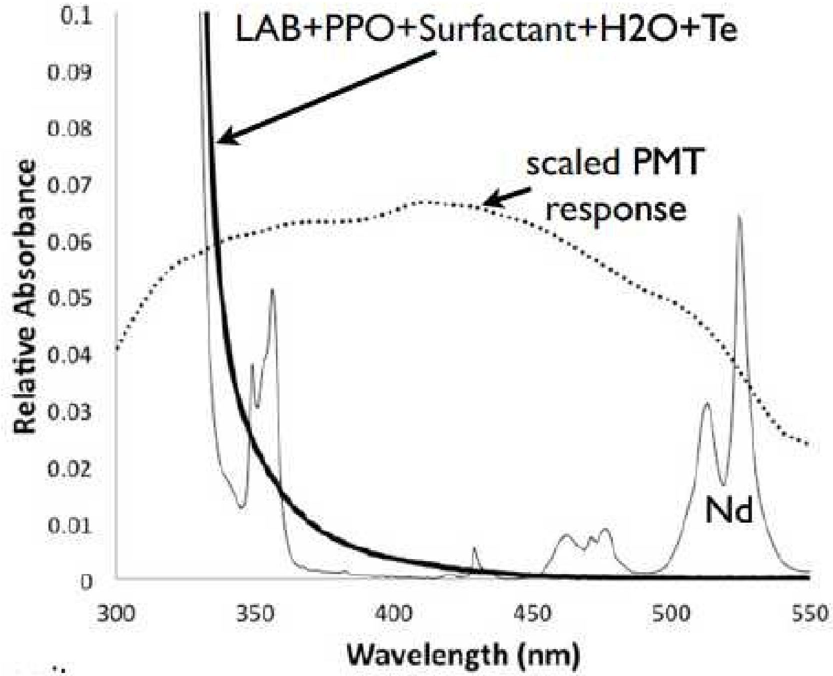


Creighton mine, Sudbury, ON (Canada), 2 km (6000 m.w.e) depth

The SNO+ experiment: isotope loading options

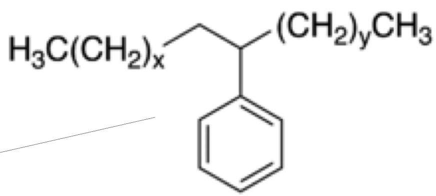
- Initially explored ^{150}Nd
  - natural abundance 5.6%
  - $T^{2\nu\beta\beta}_{1/2} = 6.7\text{x}10^{18}$ yr
  - $Q_{\beta\beta} = 3.37$ MeV
  - light yield ~8400 γ/MeV (0.5% Nd)
- New isotope ^{130}Te: advantages
  - higher natural abundance (34.08 %)
  - higher half-life $T^{2\nu\beta\beta}_{1/2} = 7.9\text{x}10^{20}$ yr
  - higher light yield ~9400 γ/MeV (0.5% Te)
  - $2\nu\beta\beta$ rate ~100 lower than of ^{150}Nd
  - no inherent optical absorption lines
- New isotope ^{130}Te: constraints
  - lower end-point ($Q_{\beta\beta} = 2.53$ MeV)

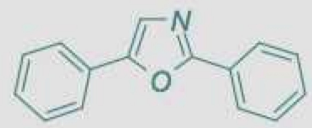
R&D on water-based
liquid scintillators led
to the choice of ^{130}Te (2013)



The SNO+ experiment: liquid scintillator + ^{130}Te

- Liquid Scintillator
  - solvent Linear Alkylbenzene (LAB)
  - fluor 2 g/l 2,5 diphenyloxazole (PPO)





2,5-diphenyloxazole (PPO)

- ^{130}Te loading
  - new technique by dissolving telluric acid (H_6O_6Te) in water
  - combine with LAB with the help of a surfactant
  - attenuation length changing as the concentration increases (will be measured)

M. Yeh et al. (BNL)

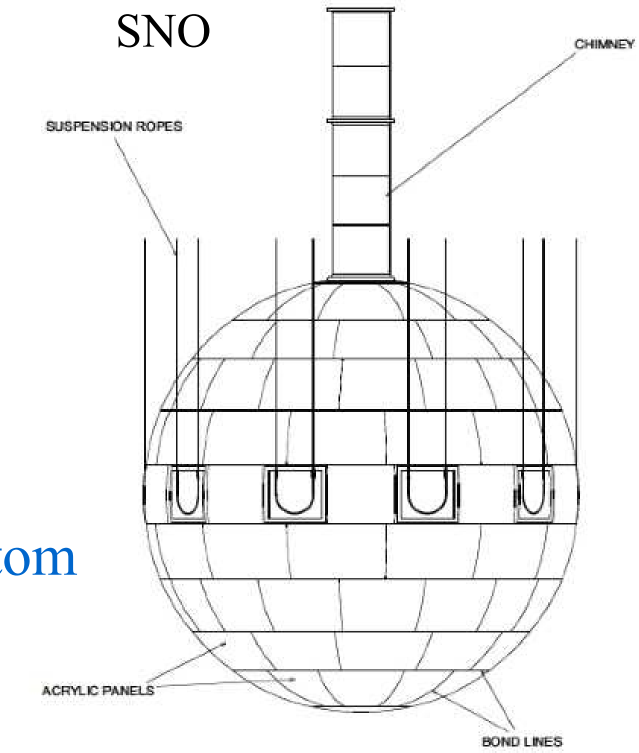

Old loading technique

☼ Chemically compatible with acrylic
☼ High radiopurity
☼ Good optical properties (attenuation length > 10 m at 0.3%)
☼ Safe: low toxicity and high flashpoint (140°C)
☼ Stability > 1 yr explicitely demonstrated at 0.3% loading.

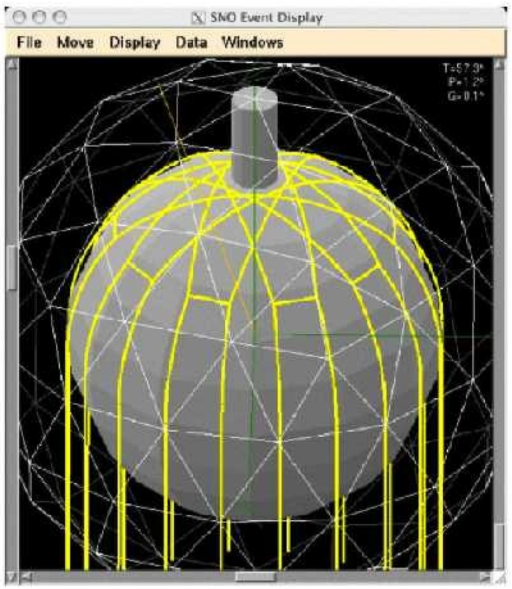
Higher loading (~3%) under study

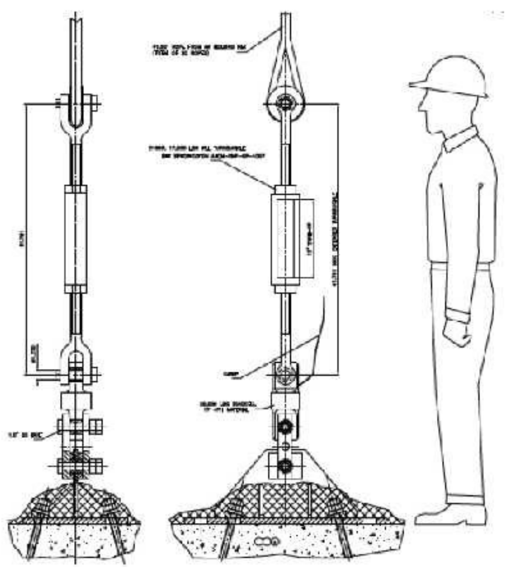
The SNO+ experiment: AV and rope system

- SNO rope system (hold-up)
  - during SNO the AV was negatively buoyant
  - suspension ropes were enough to “hang” the AV



- SNO+ rope system (hold-down net)
  - 130 T added buoyancy due to LS
  - installation of an hold-down rope net
  - turnbuckle/loadcell anchors installed at the cavity bottom



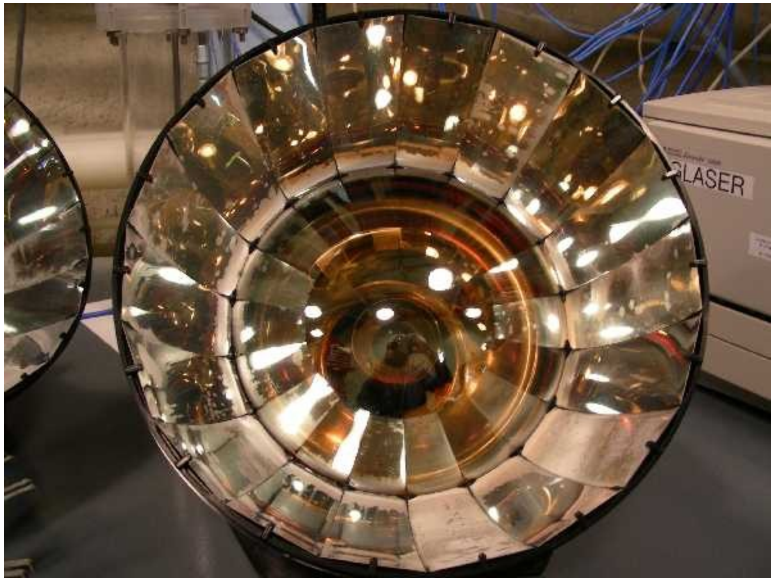


Float-the-boat: tension the hold-down net to 284,000 lb (total load LS) by floating the AV filled to the equator in cavity water, and to hold the tension there for ~2 weeks. A “partial float-the-boat" will occur at the AV bottom (applying a 80,000 lb load to the rope net) to confirms the hold-down turnbuckles adjustment. The rope tension will be monitored during the procedure.

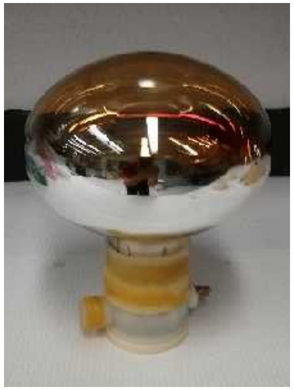
Float-the-boat procedure under final review

The SNO+ experiment: detection system

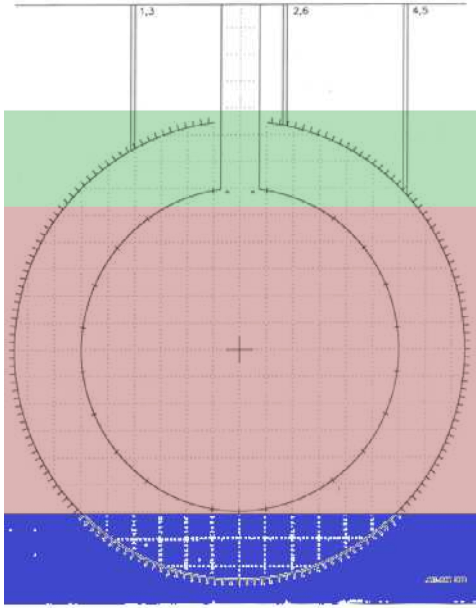
- SNO+ Photomultipliers
  - 9522 20 cm (8") PMTs (Hamamatsu R1408) operating at ~ 2000 V
  - 850 PMTs with short circuits in the base electronics or other failures
- Repair campaign
  - dark box tests: resistance+capacitance, signal quality at operational voltage, monitoring of breakdown while ramping voltage up
  - base dis-assembly and circuit board replacement
  - base re-assembly and test in dark box
  - PMT cleanup rinsing and bagging



PMT + concentrator (damaged petals)



150 PMT removed for repair (top)
480 PMT remaining to be replaced
220 PMT repaired and replaced (bottom)
Failures: 10% tubes
90% base electronics



The SNO+ experiment: DAQ and software

- System overview
  - 9728 channels (19 crates, 16 Front End Cards per crate, 32 Channels per FEC)
  - Data for each event (trigger types, trigger ID number, clocks, digitized trigger pulses, hit information)
  - Data for each hit (integrated charges, hit times, status tags)

- Upgrades
  - need to accommodate for the increased data rate
    - SNO solar neutrino average ~ 40 PMTs illuminated
    - SNO+ $2\nu\beta\beta$ average ~1500 PMTs illuminated
    - backgrounds rate of several Hz
  - SNO software aging or incompatible with SNO+ needs
    - new DAQ software (SHaRC became ORCA)
    - new database (old SNO was based on HEPDB)
    - new monitoring tools (couchDB and webpage)
    - new slow-control/alarm vizualization tools

SNO "polling" system:
reads one crate at a time
2-250 kB/s bandwidth
SNO+ "pushing" system:
sending data in parallel
nominal data rate **~2.5 MB/s**

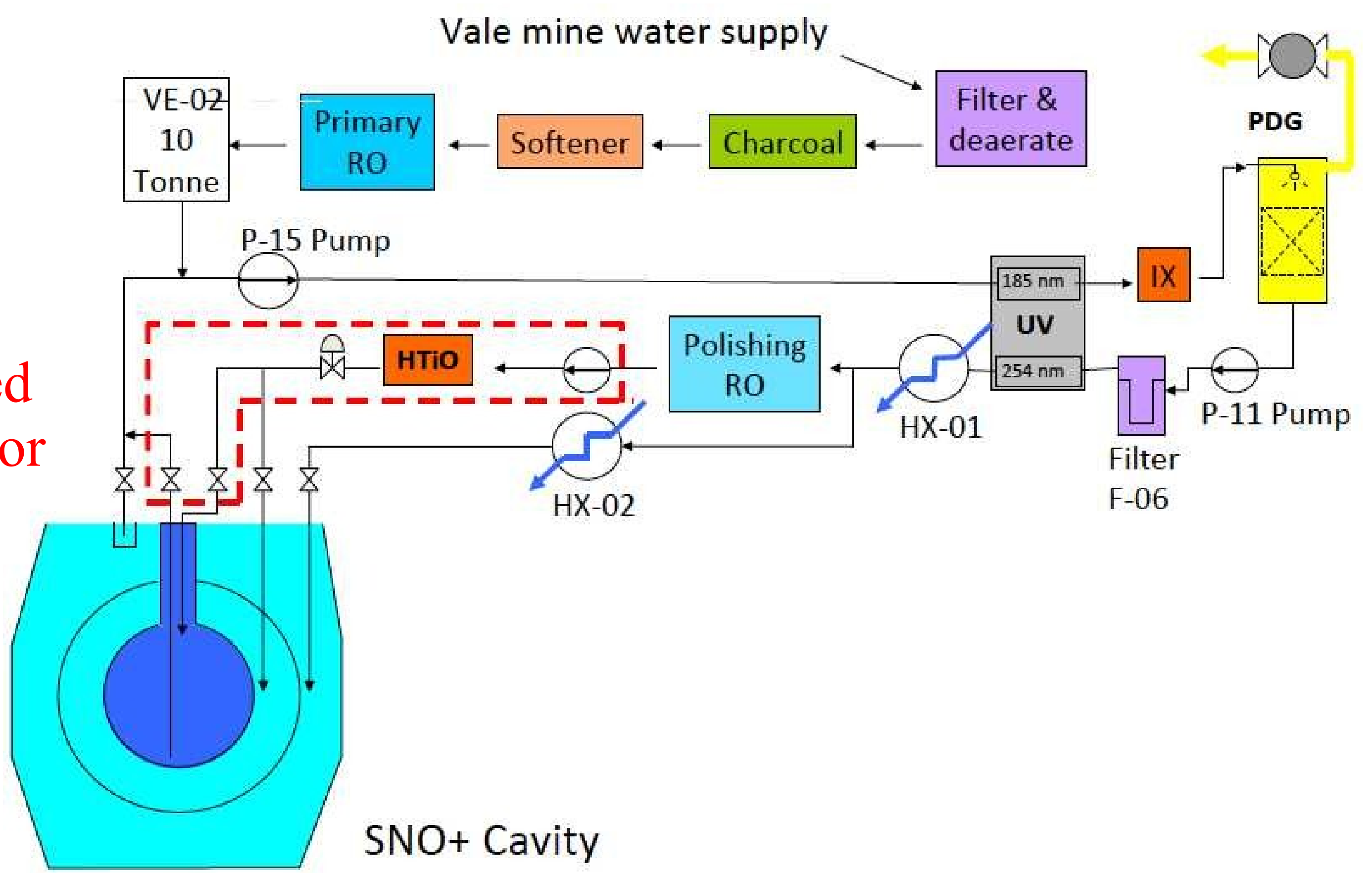
Airfill runs and water commissioning runs to tests the full system

The SNO+ experiment: water system

- Water system
  - water provides initial leach/wash of the AV
  - SNO experiment water system reconditioned
  - new configuration to supply water inside the AV

Achieved water purity is comparable to SNO

Water replacement by scintillator will be performed by adding purified scintillator to the top of the neck while water is withdrawn from the bottom of the AV

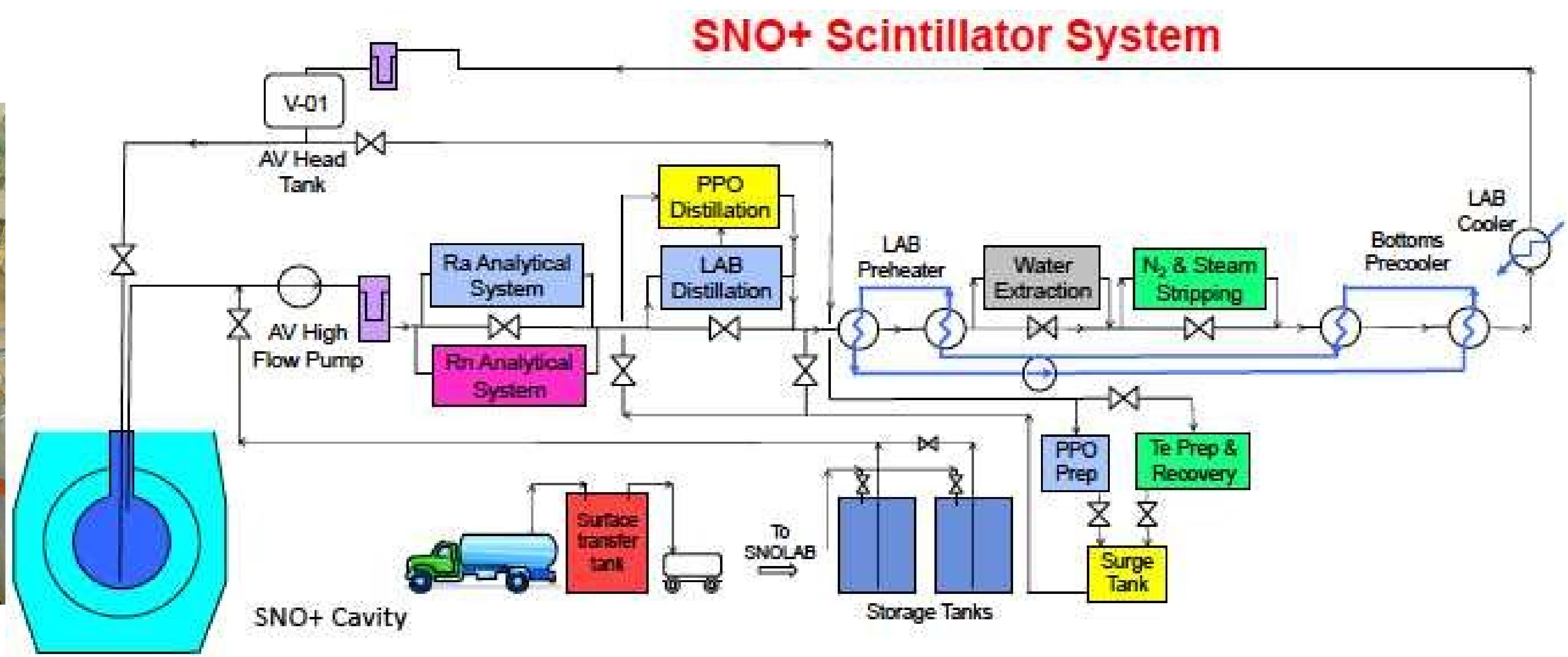


The SNO+ experiment: scintillator system

- Scintillator plant system
  - stainless steel transport and circulation system
  - 15 L/min LAB distillation improves optical path length, removes ^{7}Be, Pb, Th, U with > 90% efficiency
  - N_2/steam stripping columns remove Rn, O_2, Kr and Ar
  - Rn analysis facility (cryo trapping + Lucas cell)
  - 150 L/min water Scheibel extraction column remove ^{40}K, Ra and ^{210}Pb

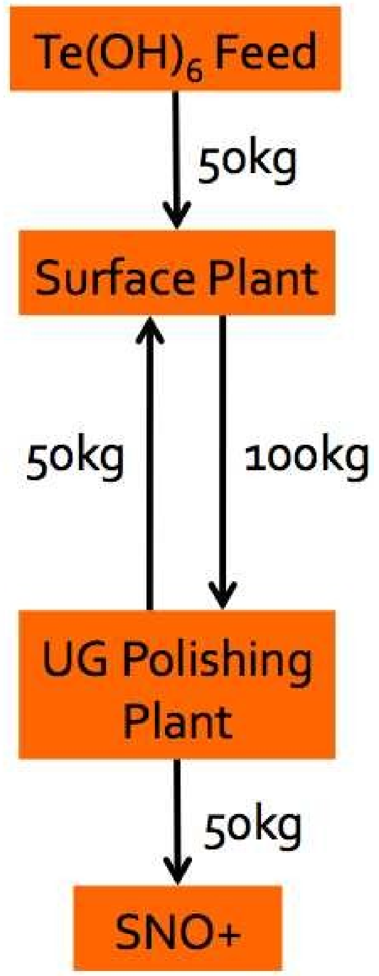
Solar phase:
more constraints on radio-purity requirements


distillation columns



The SNO+ experiment: ^{130}Te purification

- $Te(OH)_6$ crystals ethanol rinsing
  - purification technique factor reduction of 10^3 (one pass) to 10^5 (after second pass) demonstrated by spike tests
  - technique to purify large quantities of ethanol under development
- Purification in a nutshell
  - need to accommodate ~4.5 tons of $Te(OH)_6$ for 0.3% loading
  - main purification to be done on surface due to SNOLAB restrictions on ethanol
  - transporting material rapidly underground (< ~5 hrs)
  - cosmogenic re-growth still requires "polishing" purification underground with lower yield (no ethanol used)



Bottom line: 45 days purification time

Metal scavenger columns to purify surfactant

The SNO+ experiment: calibration systems

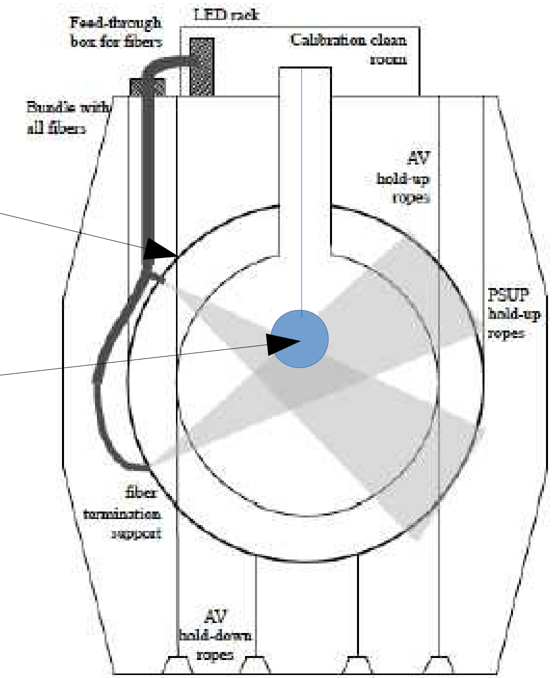
- Calibration purpose
  - measurements and validation of the detector parameters
- Simulation: need to validate models of
  - light production
  - light transport
  - light detection
- Reconstruction: measurements and algorithms cross-check of
  - energy
  - position
  - particle ID

Light yield from different particles across the detector energy range with radioactive sources

Optical calibration for light transport models through different media (LS, H_2O)

PMT timing calibration for light detection

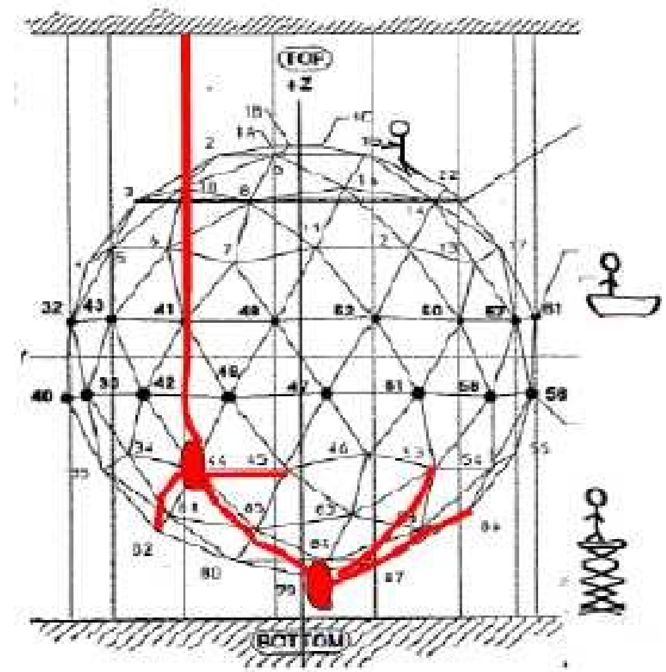
The SNO+ experiment: calibration systems



- Optical calibration
  - embedded (fixed) fiber-based system
    - laser/LED based light injection system installed on the PMT array
  - deployed light source (laserball)
  - deployed cherenkov light source
- Radioactive (deployed) sources
  - several (β,γ) radioactive sources being developed
- Sources deployment system
  - deploy several type of sources from the top of the AV
  - off-axis deployment
  - avoid scintillation contamination
  - radon tight: fully sealed system

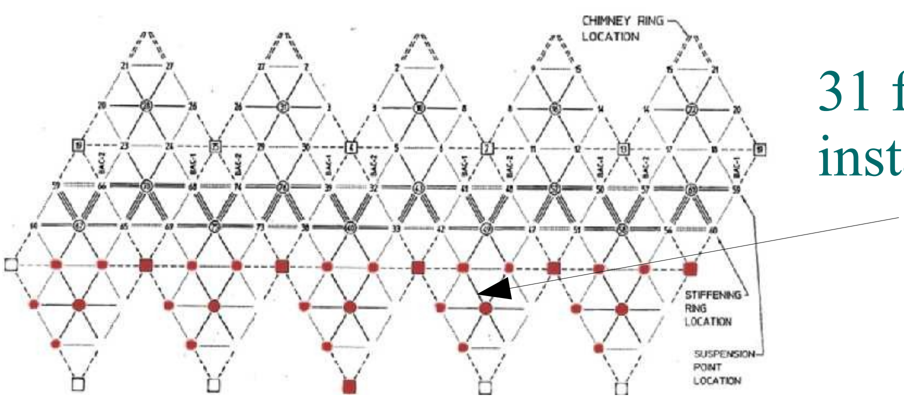
The SNO+ experiment: calibration systems

- Fiber-based optical system
  - LEDs pulses (510 nm) in 92 points
    - PMTs timing and gain calibration,
    - scintillator transparency monitoring
  - laser pulses (4 wavelengths, 3 angles) in 4 points
    - measure scattering properties of the medium
  - LEDs pulses (≠ wavelengths, 2 angles) in 4 points
    - monitor the optical attenuation length

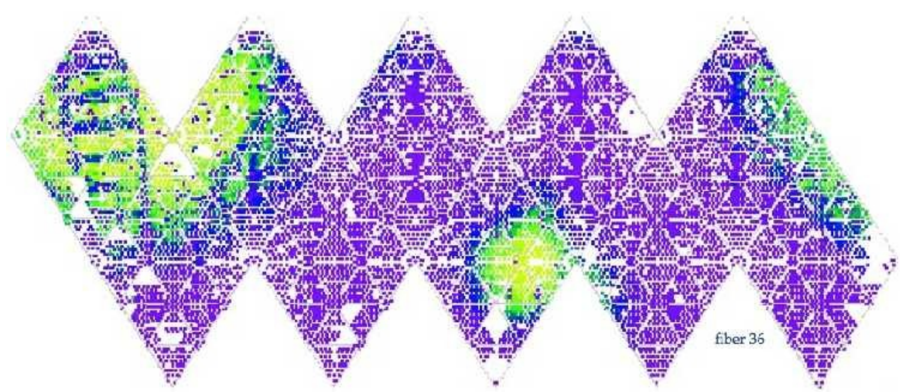


Courtesy: S. Andringa (LIP Jornadas)

Fiber-based system advantages:
- constant calibration permitted
- dead-time reduced



31 fibers installed



LIP design and construction (with Sussex for LED/electronics, Oxford for laser/quartz fibers)

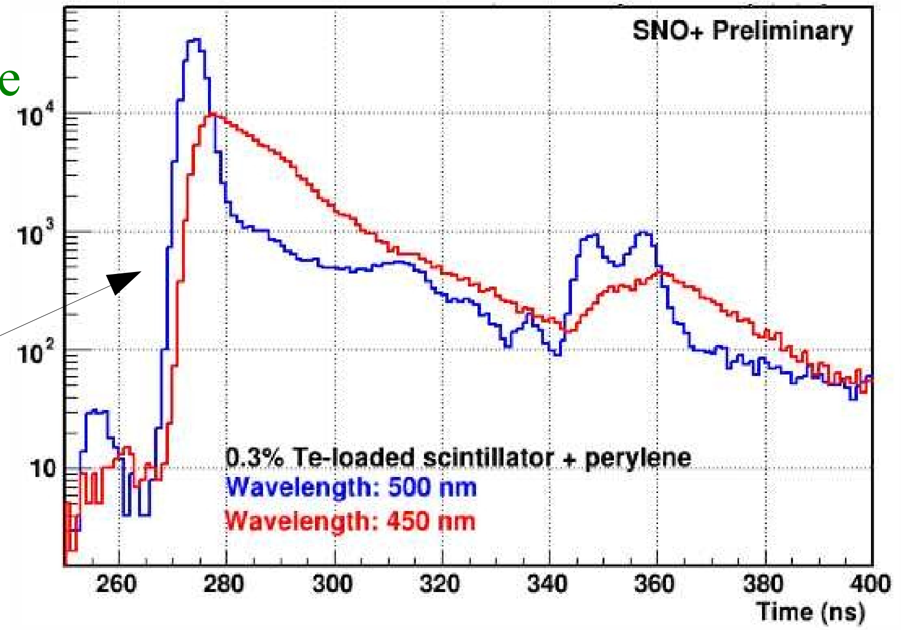
The SNO+ experiment: calibration systems

- Deployed optical systems
  - Laserball
    - 10 cm diameter quartz flask + nitrogen laser
    - use of dyes to change wavelengths
    - very low radon emanation (< 30 atoms per day)
    - neck diameter reduced (minimise shadowing)
    - PMTs angular response (and light concentrators) calibration
    - liquid scintillator monitoring (extinction length)
    - relative PMT efficiency
    - position dependence of the optical response

New laserball design
based on SNO experience

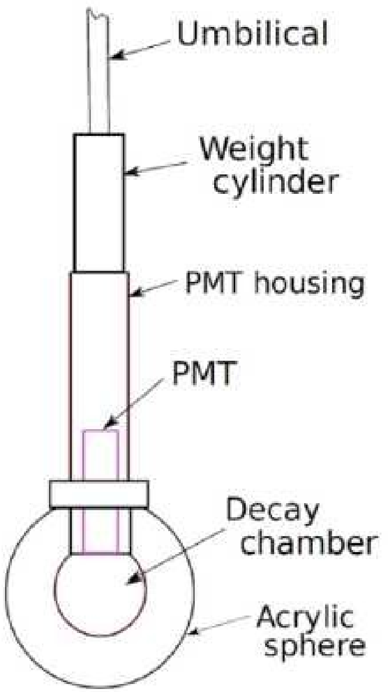
Strong LIP participation
in analysis

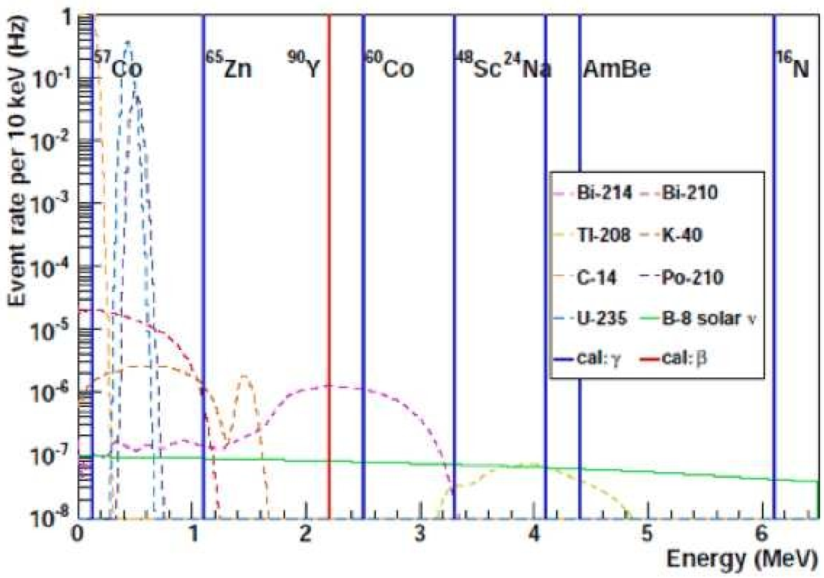
PMT hits time for
laserball pulses
at two wavelengths



The SNO+ experiment: calibration systems

- Optical calibration: Cherenkov source
  - ^{8}Li source hosted in a hollow acrylic sphere
  - PMT to tag the ^{8}Li decays by the scintillation light from the 2-α emitted.
  - high energy e- from the ^{8}Li decay enters the acrylic wall and produce Cherenkov γ
  - PMT efficiency calibration
- Radioactive sources

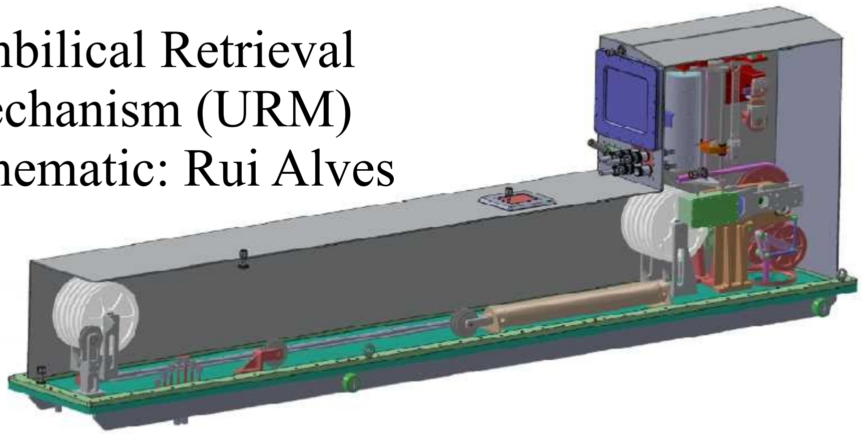


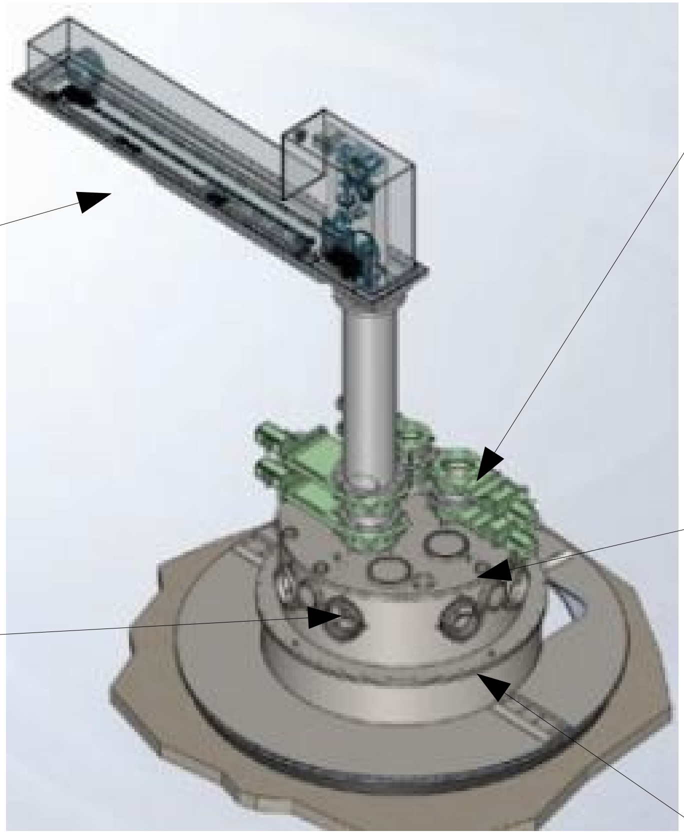


The SNO+ experiment: deployment systems

- Umbilical Retrieval Mechanism (URM) and Universal Interface (UI)

Umbilical Retrieval
Mechanism (URM)
Schematic: Rui Alves



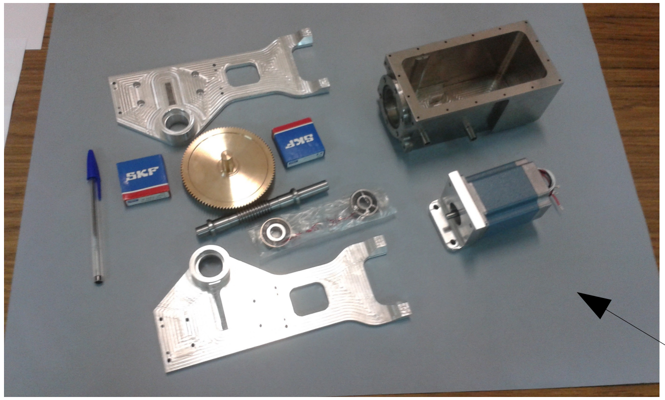


Sealing system
with gate valves

side rope motors
plugging holes

glove box
ports

calibration sources interface (UI)



Production work
started at
LIP Coimbra

Design and construction at LIP Coimbra

The SNO+ detector: backgrounds

- Backgrounds zoo

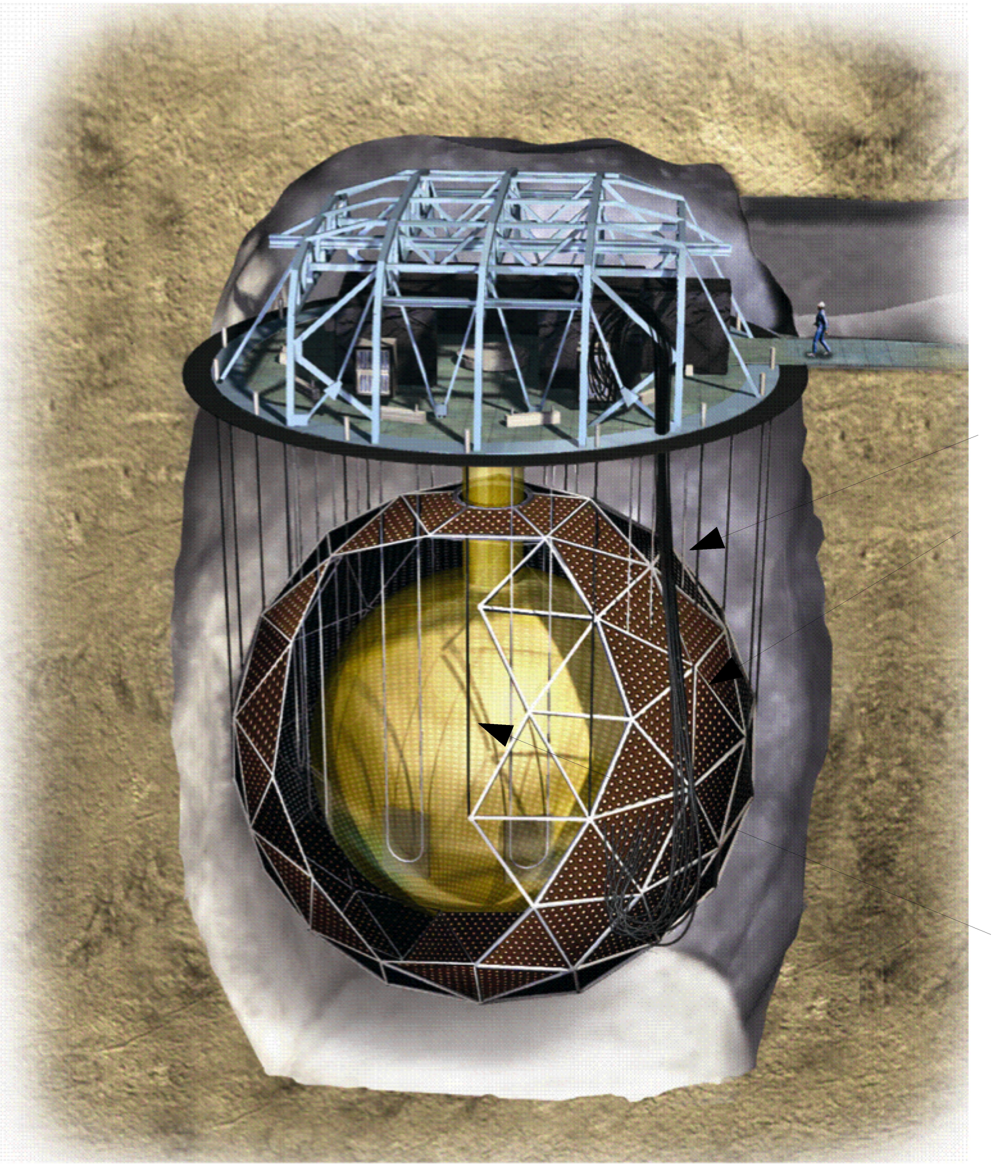
Cosmogenics
- ^{11}C
- ^{39}Ar
- ^{14}C
- ^{13}C
- Te activated isotopes (e.g. ^{60}Co)

Natural sources
- U/Th chains
- ^{40}K
- ^{85}Kr

(α,n) γ

2νββ decay

Solar ^{8}B



External radioactivity (in regions outside the scintillator volume but propagate into it)
- AV
- PMTs
- H2O
- ropes

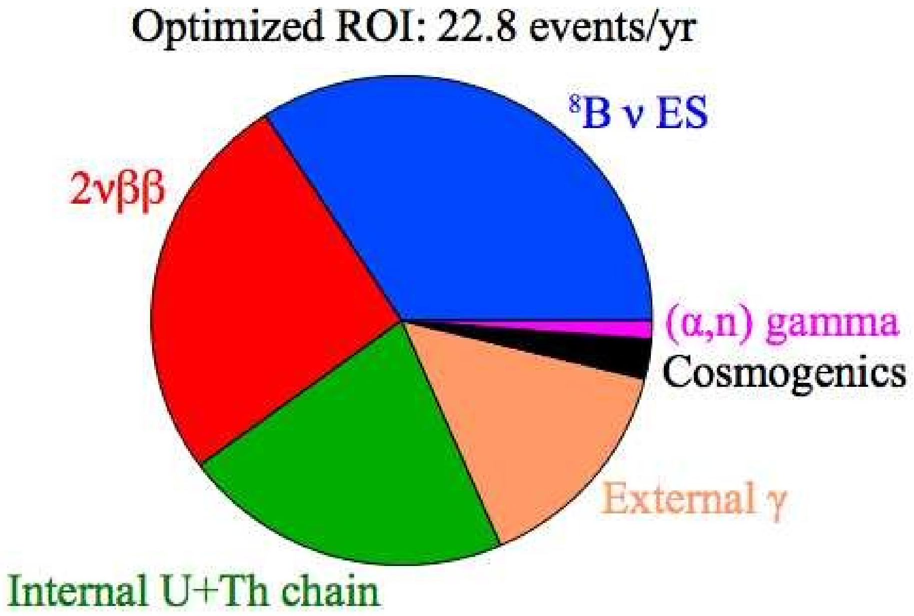
Internal radioactivity (scintillator volume)
- scintillator
- AV leaching
- ropes/pipes inside the AV

The SNO+ detector: backgrounds

- Backgrounds mitigation

2νββ (irreducible)
Energy resolution fundamental
(separation between the two decays)

^{8}B ν ES (irreducible)
Flux well known
Can use high energy tail to estimate background in ROI

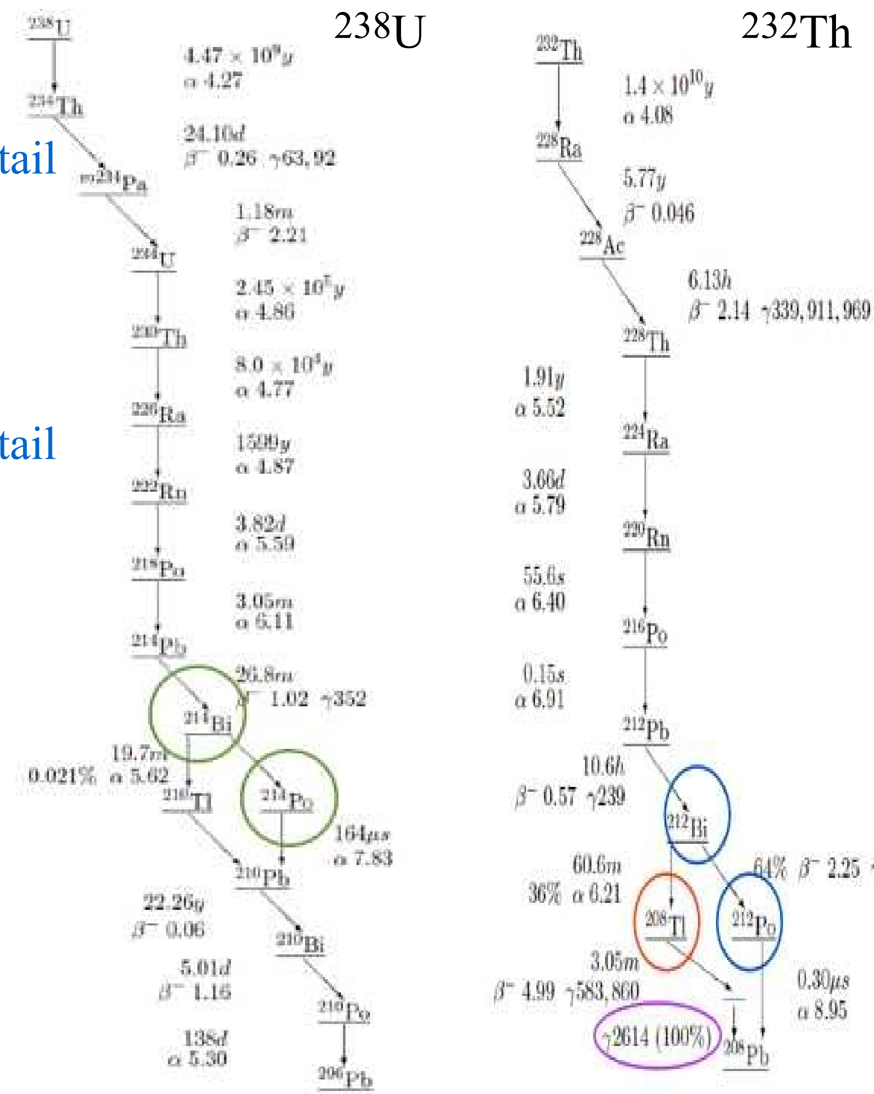


Cosmogenics
Removal via multi-stage distillation of the LS, re-crystallisation of the telluric acid using nitric acid, rinsing with ethanol

Constant monitoring of the water/LS radiopurity with ex-situ measurements

The SNO+ detector: backgrounds

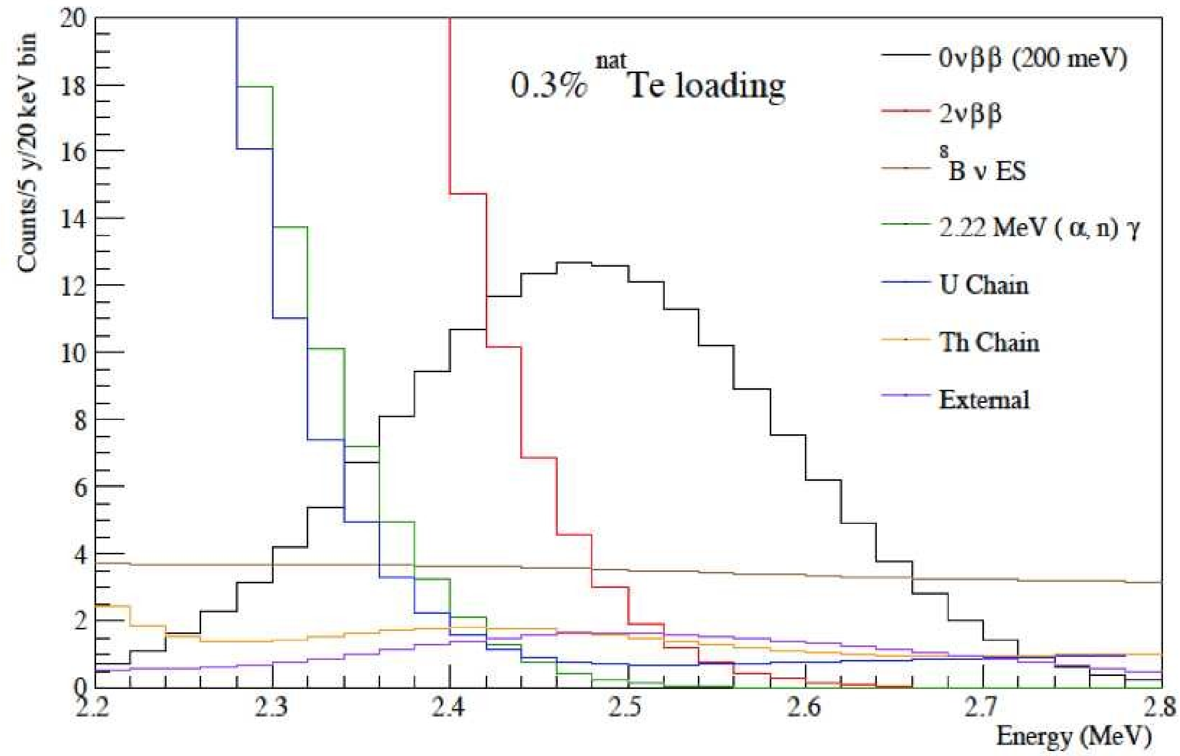
- Internal U/Th decay chains
  - ^{238}U chain target level ~2.5x10^{-15} $g_U/g_{cocktail}$
    - β-α delayed coincidence technique to tag ^{214}Bi-^{214}Po ($\tau^{1/2}$ = 164 μs)
  - ^{232}Th chain target level ~3x10^{-16} $g_{Th}/g_{cocktail}$
    - β-α delayed coincidence technique to tag ^{212}Bi-^{212}Po ($\tau^{1/2}$ = 299 ns)
    - α-β delayed coincidence technique to tag ^{212}Bi-^{208}Tl ($\tau^{1/2}$ = 3.05 min)



- External gammas
  - 2.6 MeV γs from external ^{208}Tl
    - suppressed with fiducial volume cut
    - from AV can be removed via PMT time residuals analysis
- (α,n) gammas
  - delayed neutron capture tagging

The SNO+ experiment: sensitivity

- SNO+ sensitivity 0.3 % ^{130}Te loading
  - R < 3.5 m (20%) fiducial volume cut
  - 5 years of data-taking
  - > 99.99% efficiency ^{214}Bi tag
  - 98% efficiency internal ^{208}Tl tag
  - factor 50 reduction ^{214}BiPo (pile-up)
  - negligible cosmogenics
  - $m_{0\nu\beta\beta}$ = 200 meV
    [J. Barea et al. Phys. Rev. C 87 (2013) 014315]
    [J. Kotila, F. Iachello Phys. Rev. C 85 (2012) 034316]



Can reach mass sensitivity of 80-100 meV
after 5 years of data taking at 0.3% ^{130}Te loading

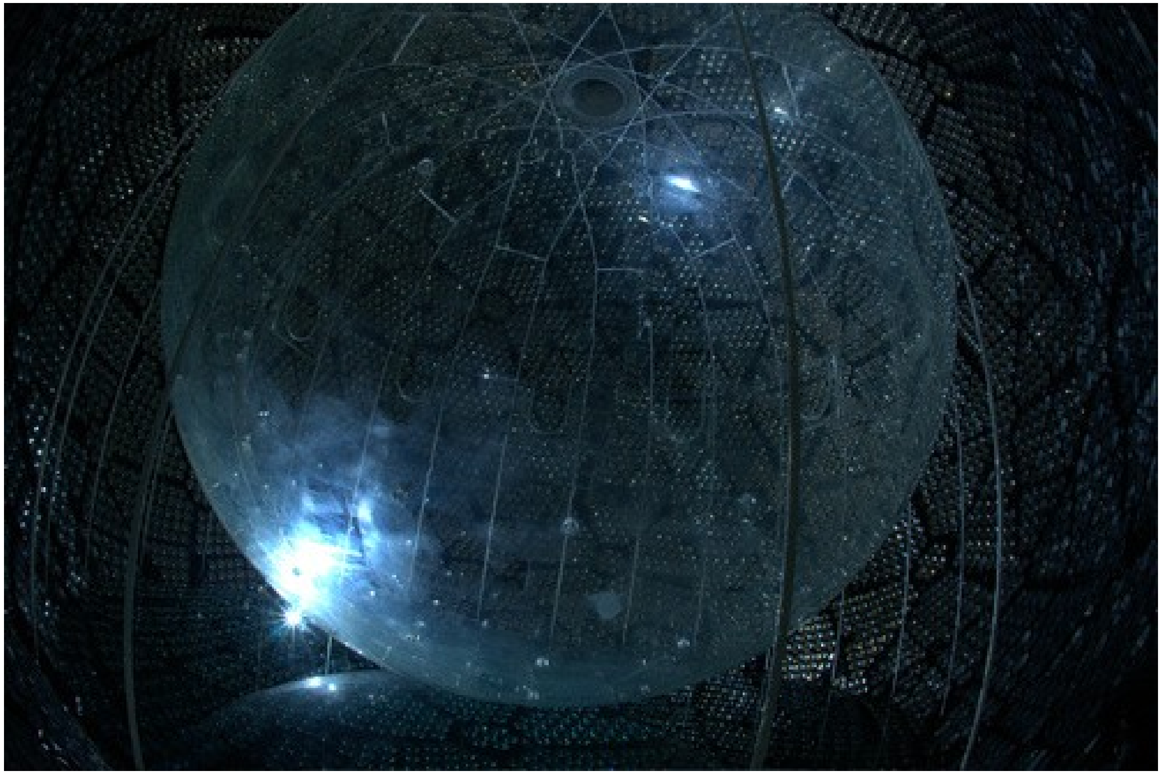
The SNO+ experiment: LIP activities

- Calibration
  - design, construction, installation of the PMTs calibration system
  - design and construction of the URM (source deployment system)
  - leadership and strong participation in optical calibration analysis

- Physics data-taking and analysis
  - DAQ and data-quality checks
  - backgrounds for double beta decay
  - leadership and strong participation in the anti-neutrinos physics

The SNO+ experiment: status

- Status
  - on-going installation of the scintillator plant
  - on-going construction of the calibration systems
  - efforts also on-going in the DAQ/database/monitoring software
  - water plant is now operational
  - water level reached ~18 ft (just below the AV)



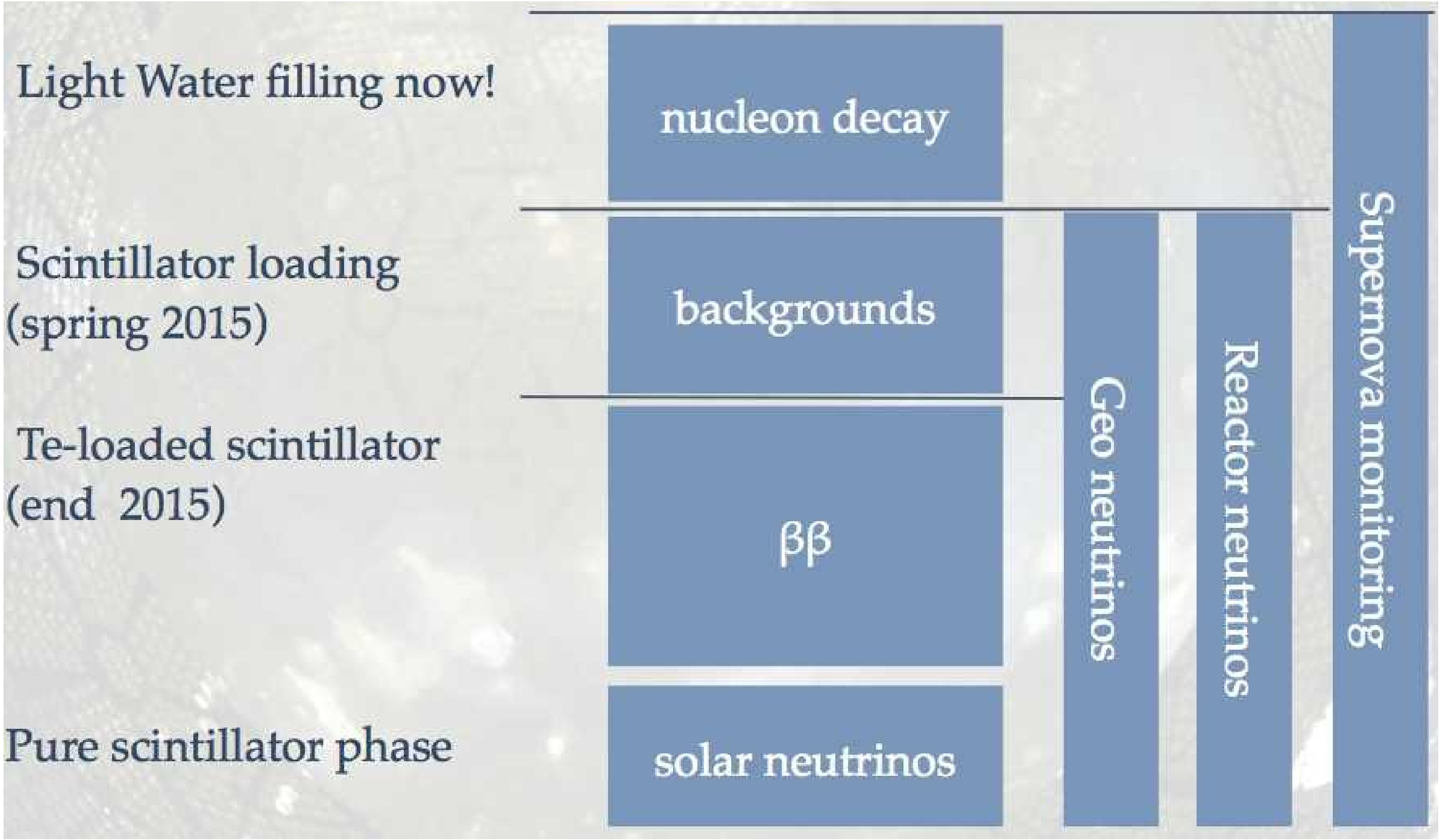
Validation of the detector stability ("float the boat") in presence of water both in and out the acrylic vessel to come

SNO+ collaboration is preparing for the water-phase: exciting times !

The SNO+ experiment: run plan

- Run plan

Courtesy
F. Descamps
Jinping Workshop
(June 2014)



SNO+ neutrinoless double-beta decay physics program will be to probe the neutrino mass in the top of the inverted hierarchy mass region (80-100 meV) starting with 0.3% ^{130}Te loading in the first phase.

Acknowledgments

This work was partially funded by Fundação para a Ciência e a Tecnologia (FCT, Portugal) through project grant PTDC/FIS/115281/2009

BACKUP SLIDES

Backup slides

- Radioactive sources

AmBe (n,γ) - 2.2-4.4 MeV for detector's energy scale, resolution, vertex reconstruction

^{16}N (γ) 6.1 MeV for energy scale

^{24}Na (γ) 2.754 MeV + 1.386 MeV detected at 4.12 MeV for linearity of the energy range

^{48}Sc(γ) (1.037 – 1.312 - 0.983) MeV measures the energy dependence of the scintillator energy response

^{57}Co(γ) very low energy calibration source (122 – 136) keV

^{60}Co(γ) calibration of the energy near the endpoint of ^{130}Te

^{90}Y (β) 2.2 MeV to understand difference in quenching and spatial distribution between

α and γ

Internal background radiation will also be used as sources.