Status of the SNO+ Experiment

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on behalf of the SNO+ Collaboration

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LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTICULAS
LIP

SNO+

IF INVESTIGADOR FCT

Outline

I - The SNO+ experiment:

- ✳ collaboration
- ✳ detector
- ✳ physics goals and phases
- ✳ scintillator & isotope selection

II - SNO+ Status:

- ✳ ropes tensioning, water level
- ✳ PMTs and DAQ systems
- ✳ water/scintillation systems & isotope purification
- ✳ calibration systems

III - 0νββ physics sensitivity:

- ✳ neutrino masses current limits
- ✳ background mitigation
- ✳ phase I & higher loading sensitivity

IV - Conclusion & outlook

Collaboration

- Armstrong Atlantic State University
- Brookhaven National Laboratory
- Lancaster University
- Laurentian University
- Lawrence Berkeley National Laboratory
- LIP Coimbra
- LIP Lisboa
- Oxford University
- Queen Mary, University of London
- Queen's University
- SNOLAB
- Technical University of Dresden
- TRIUMF
- Universidad Nacional Autonoma de Mexico
- University of Alberta
- University of California - Berkeley
- University of California - Davis
- University of Chicago
- University of Liverpool
- University of North Carolina at Chapel Hill
- University of Pennsylvania
- University of Sussex
- University of Washington

23 Institutes
6 countries
90 members

Detector

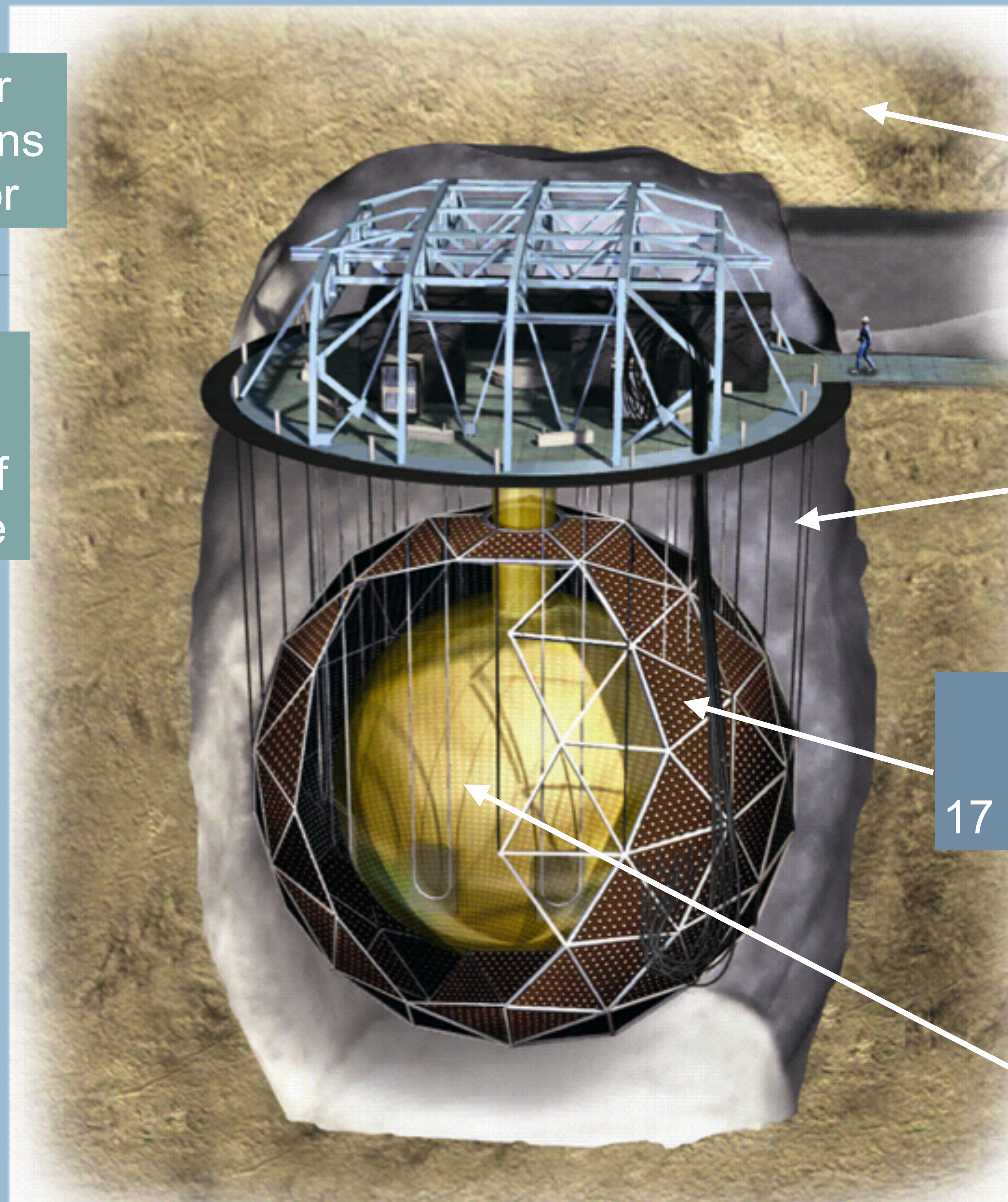
SNO heavy water replaced by 780 tons of liquid scintillator

Liquid scintillator will be loaded with different amounts of double-beta isotope

New hold-down rope system

New DAQ system and readout cards

New calibration systems



norite + granite/gabbro

7kt ultra pure water shield

~9300 PMTs (54% coverage) 17 m diameter structure

12 m diameter 5 cm thickness acrylic vessel (AV)

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

Physics goals & phases

- ✳ search for Majorana neutrinos
- ✳ solar neutrinos (pep,CNO, low energy ^{8}B)
- ✳ reactor anti-neutrinos (3 nuclear plants @240-350 km)
- ✳ geo-neutrinos
- ✳ supernovae neutrinos (SNEWS)
- ✳ exotics (e.g. nucleon decay)

See "Anti-neutrino measurements in SNO+" poster by S. Andringa.

water → unloaded liquid scintillator 1 → 0.3% ^{nat}Te loading → unloaded liquid scintillator 2 → higher loading 1 → higher loading 2

Scintillator mixture & isotope selection

Liquid scintillator: **solvent:** linear alkylbenzene (LAB) + **fluor:** 2,5 diphenyloxazole (PPO)

LAB choice motivated by:

- ✴ its long time stability
- ✴ its compatibility with acrylic
- ✴ can be produced with high radio purity
- ✴ good optical properties (high attenuation length)
- ✴ its linear response in energy
- ✴ high flash point and low toxicity

^{130}Te isotope choice motivated by:

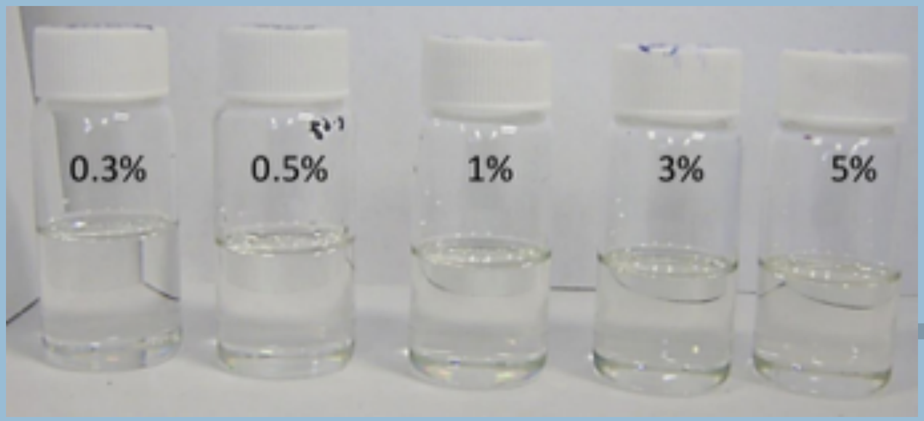
- ✴ its high natural abundance (34.08%)
- ✴ its high half-life $T^{2\nu\beta\beta}_{1/2} = 7.0 \times 10^{20}$ yr
- ✴ no inherent optical absorption lines
- ✴ ~300 detected photo-electron hits/MeV (0.3% ^{nat}Te)

But low end-point ($Q_{\beta\beta}$ = 2.53 MeV)

Loading technique:

- ✴ dissolve telluric acid $Te(OH)_6$ in water
- ✴ combine with LAB with the help of a surfactant

0.3% of ^{nat}Te loading (by weight) = 800 kg of ^{130}Te



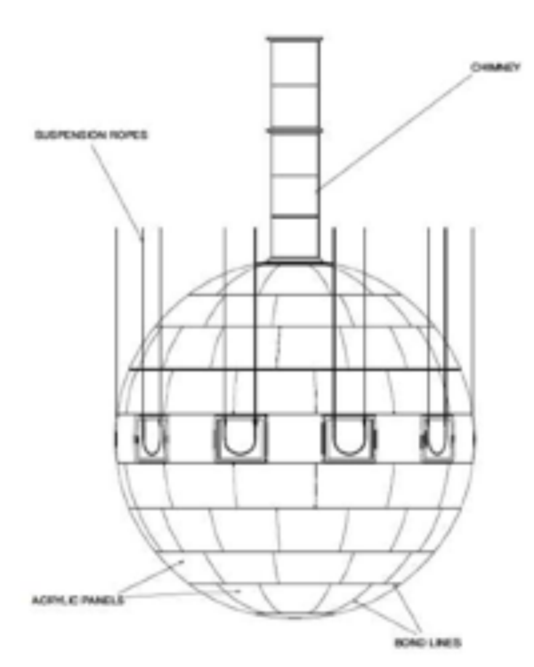
← Higher loading (3%) under study

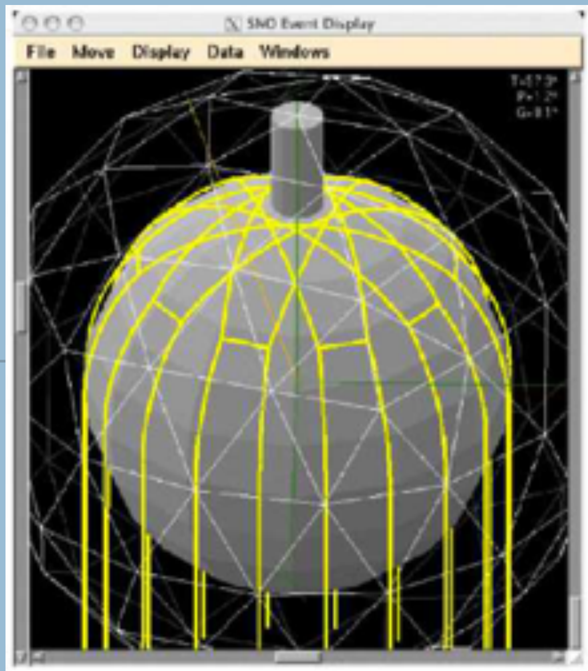
Rope tensioning & water level

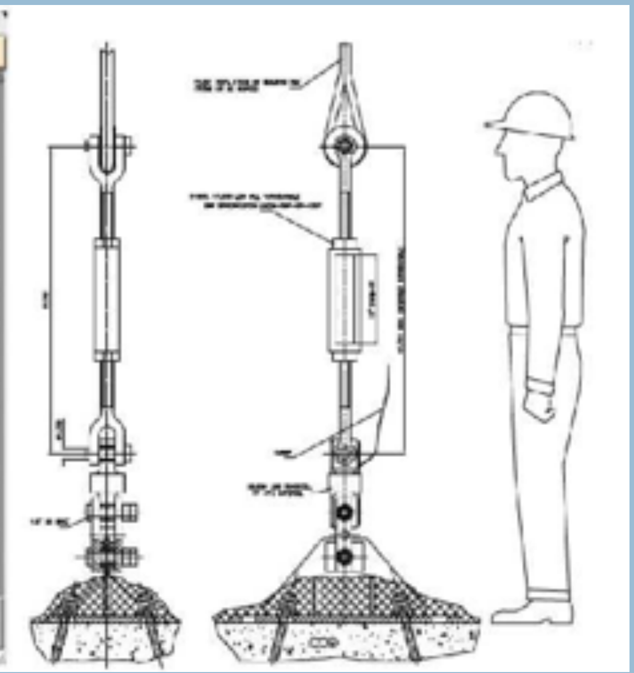
Hold-up (SNO) rope system

+

hold-down net

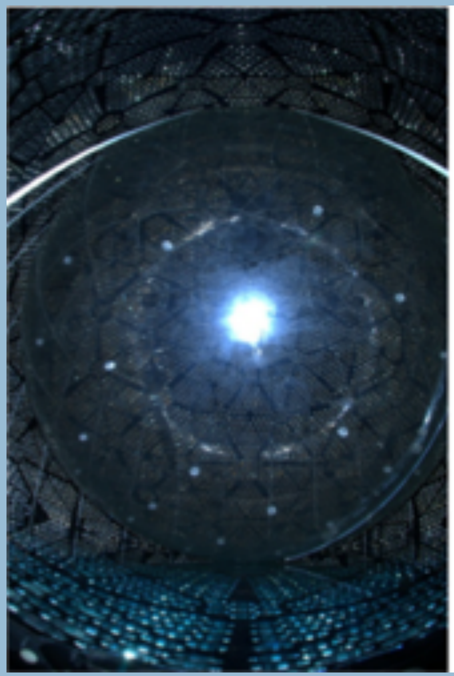


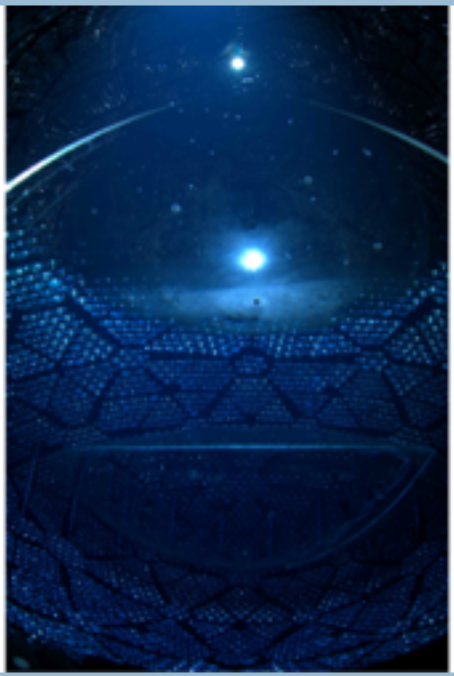


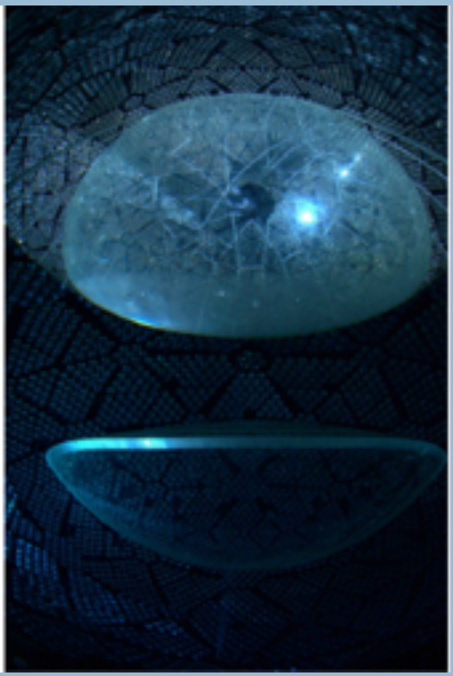


Rope tensioning (float-the-boat):
tension the hold-down net to 284,000 lb (total load of liquid scintillator) by floating the AV filled to the equator in cavity water and hold the tension for 2 weeks.

Liquid scintillator adding ~130 T of buoyancy







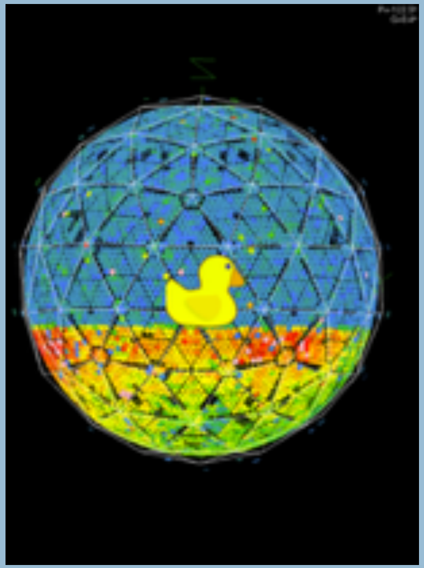
Partial float-the-boat:
when cavity water level was at the AV bottom, a 80,000 lb load was applied to the rope net. Successful & confirmed the anchor adjustment.

Current water level 20 ft (18 ft below equator)
water fill to resume after cavity liner inspection

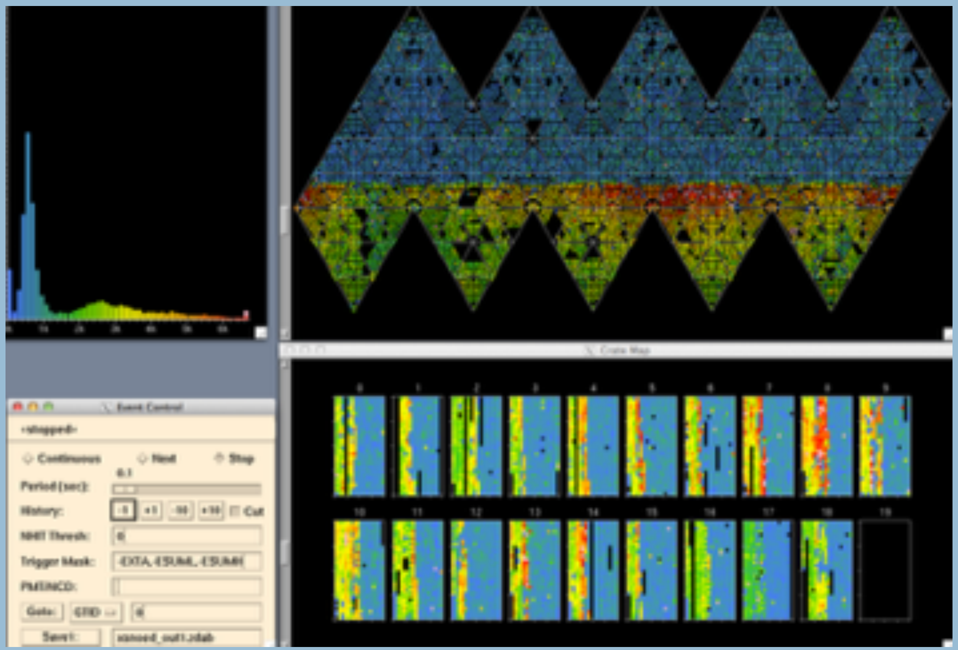
PMTs and DAQ systems

SNO+ photomultipliers (PMTs):
- ✳ 9522 PMTs [20 cm (8´´) Hamamatsu R1408]
- ✳ 850 PMTs with base short circuits (90%) or tube failure (10%)
- ✳ 391 PMTs repaired and replaced (1/2)

New requirements:
- ✳ transition from reading one crate at a time at 2-250 kB/s bandwidth (SNO) to sending data in parallel at 2.5 MB/s.
- ✳ event size increasing from 40 PMTs (SNO solar ν) to 1500 PMTs (SNO+ 2νββ).



Upgrades:
- ✳ new DAQ software (ORCA @UNC)
- ✳ new databases (couchDB, Redis)
- ✳ new visualization tools (D3/Cubism)
- ✳ new monitoring & slow-control systems



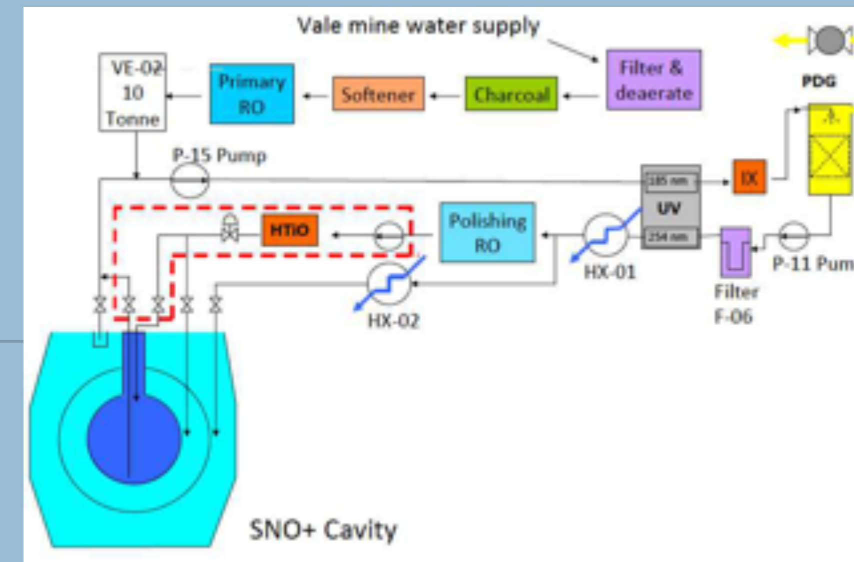
First Mock Data challenge:
successful test of near-line framework

Airfill and water commissioning runs used to test the full system.

Water/Scintillation systems & isotope purification

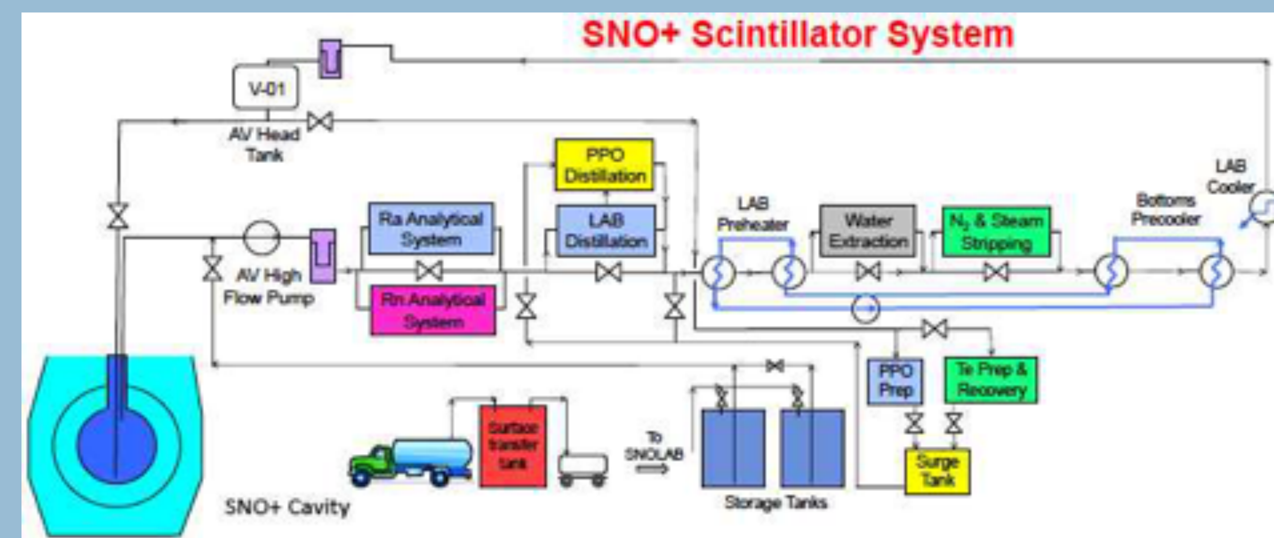
Water system:

- ✳ reconditioned to supply water inside the AV
- ✳ initial leach/wash of the AV
- ✳ achievable purity comparable to that of SNO
- ✳ also for scintillator mixing and purification
- ✳ complete and in operation



Scintillator system:

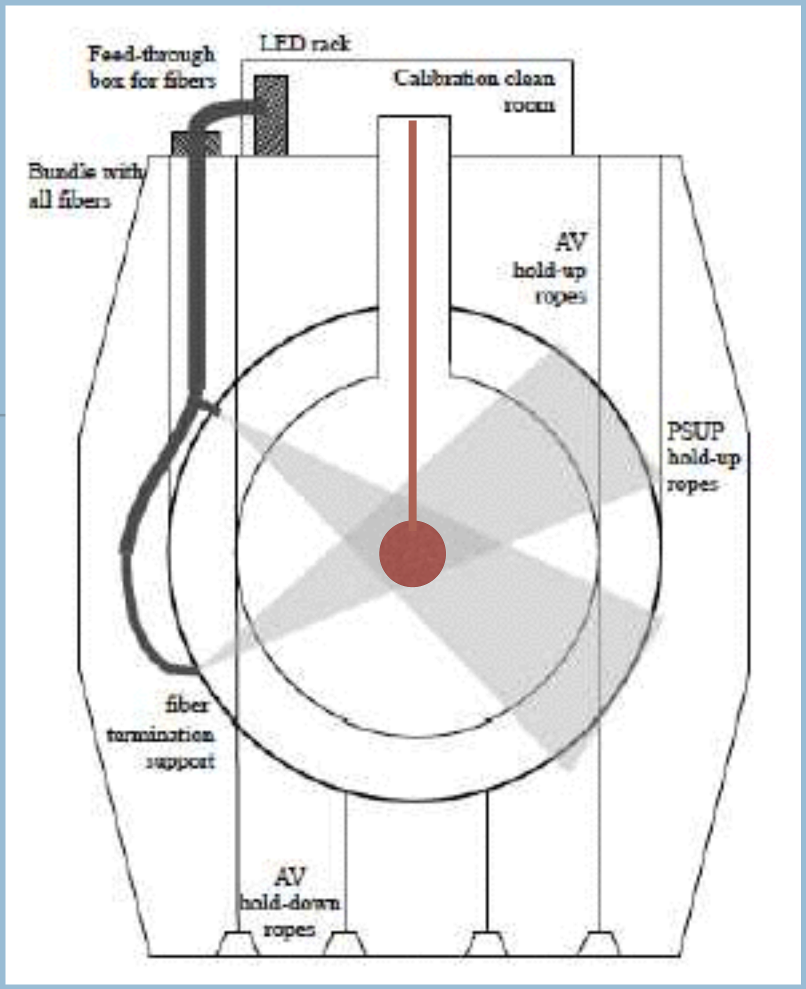
- ✳ provide multistage LAB/PPO distillation
- ✳ high temperature vacuum distillation
- ✳ water extraction (remove ^{40}K, Ra, ^{210}Pb)
- ✳ N_2/steam stripping (remove Rn, O_2, Kr, Ar)
- ✳ major piping/vessel installation done
- ✳ working on leak checking
- ✳ then cleaning and passivation



Isotope purification:

- ✳ double-pass (with ethanol rinsing) purification on surface (purification factor 10^4)
- ✳ purification underground (no ethanol) additional factor 100
- ✳ investigating the possibility to move the surface purification system underground

Optical calibration systems



Purposes:

- ✳ measure the PMTs response
- ✳ measure in-situ the optical properties of the media

Systems:

- ✳ fixed fiber-based system using LEDs/laser light injection placed on the PMTs array
- ✳ deployed light (laser with dyes) source (laserball)
- ✳ deployed cherenkov light source

Calibration:

- ✳ validation of light transport models in different media
- ✳ PMT angular response, timing and gain calibration
- ✳ attenuation length, scattering properties of the media
- ✳ monitoring transparency of the media
- ✳ PMTs efficiency

Deployment system:

- ✳ deploy several types of sources from the top of the AV
- ✳ off-axis (in two planes) source location achievable
- ✳ radon-tight and fully sealed system

Fibers system:

- ✳ LEDs or laser pulses
- ✳ different wavelengths
- ✳ different fibres angles
- ✳ 106 different location points

New laserball under construction

69 fibers installed and tested

Cherenkov source prototype ready

Radioactive sources

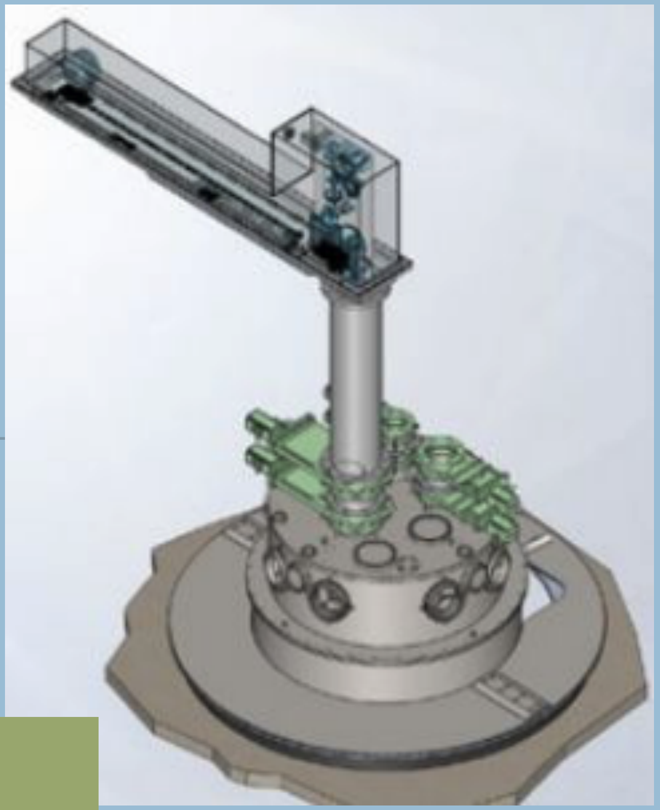
Purposes:

✳ measure efficiency and systematic uncertainties of event reconstruction (energy, position, particle id)

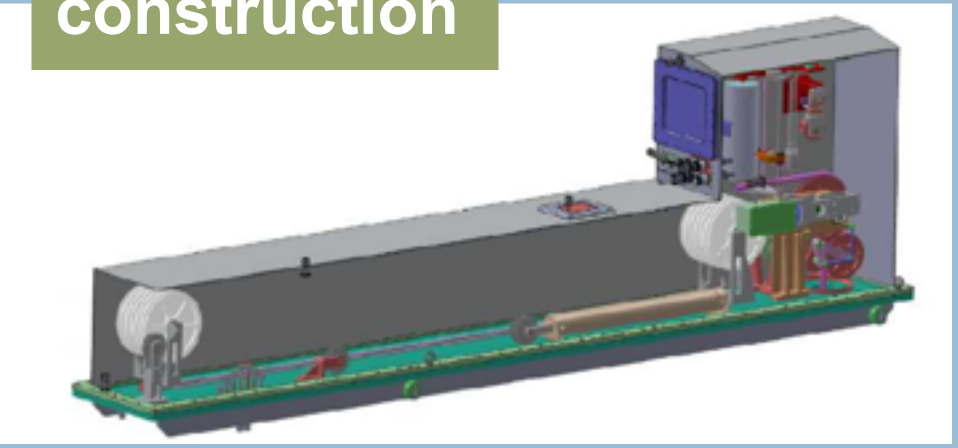
Systems:

✳ several (β,γ) radioactive sources under study

✳ will be deployed in the detector from top of AV



Under construction



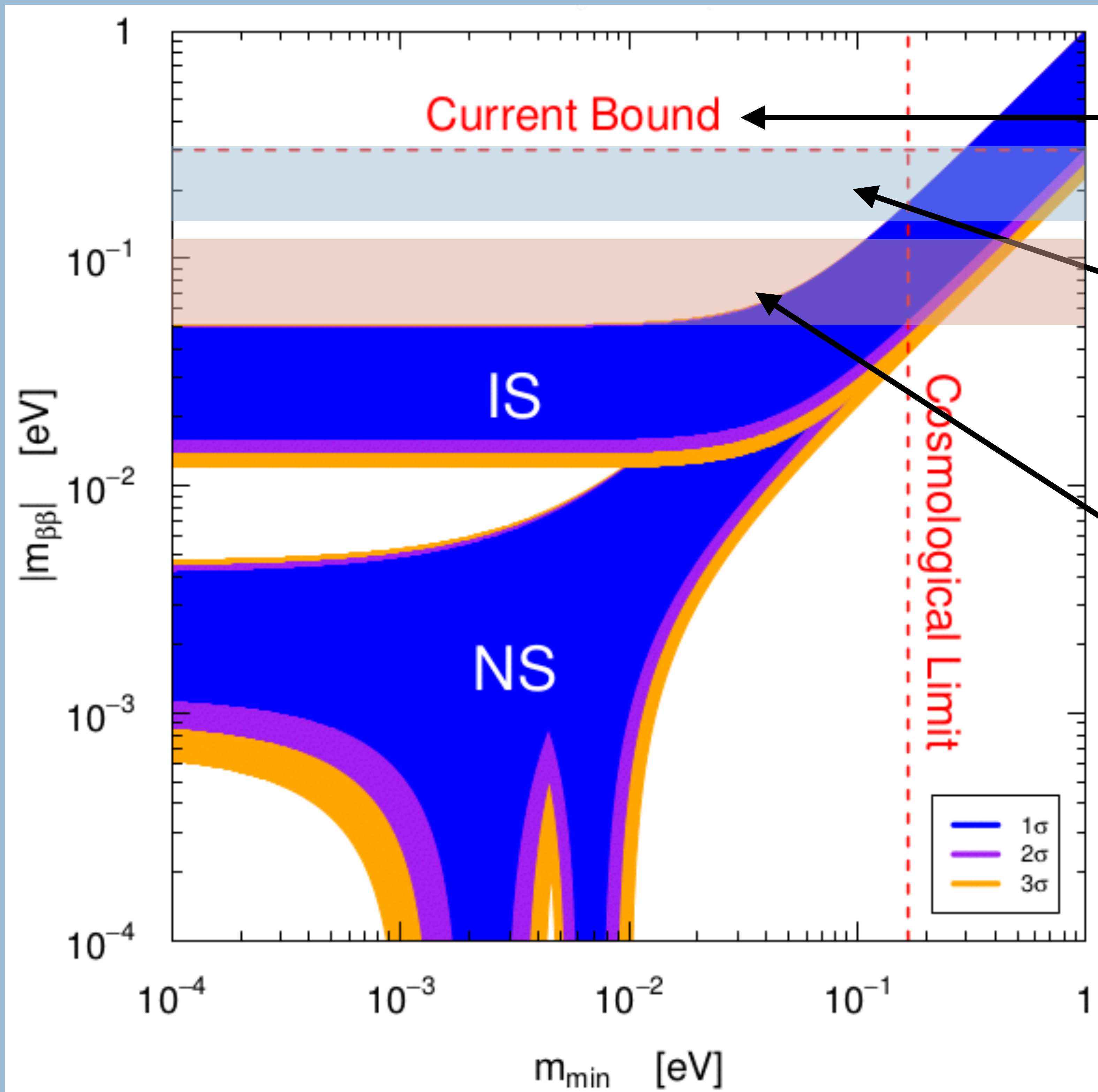
Source	Radiation	Energy [MeV]
AmBe	n, γ	2.2, 4.4 (γ)
^{60}Co	γ	2.5 (sum)
^{57}Co	γ	0.122
^{24}Na	γ	4.1 (sum)
^{48}Sc	γ	3.3 (sum)
^{16}N	γ	6.1
^{220}Rn/^{222}Rn	α, β, γ	various

Universal deployment/interface:

✳ mechanism able to deploy sources, voltages, gas, ropes…

✳ sealed interface with glove box, view ports, gate valves..

Neutrino mass current limit



From IGEX, Heidelberg-Moscow, Cuoricino and NEMO-3

From KamLAND-Zen, EXO-200 and GERDA I

SNO+ sensitivity to an effective Majorana mass $m_{\beta\beta}$ = 55-133 meV with 0.3% ^{nat}Te

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

S. M. Bilenky and C. Giunti, Modern Physics Letters A 71, Number 13 (2012) 1230015

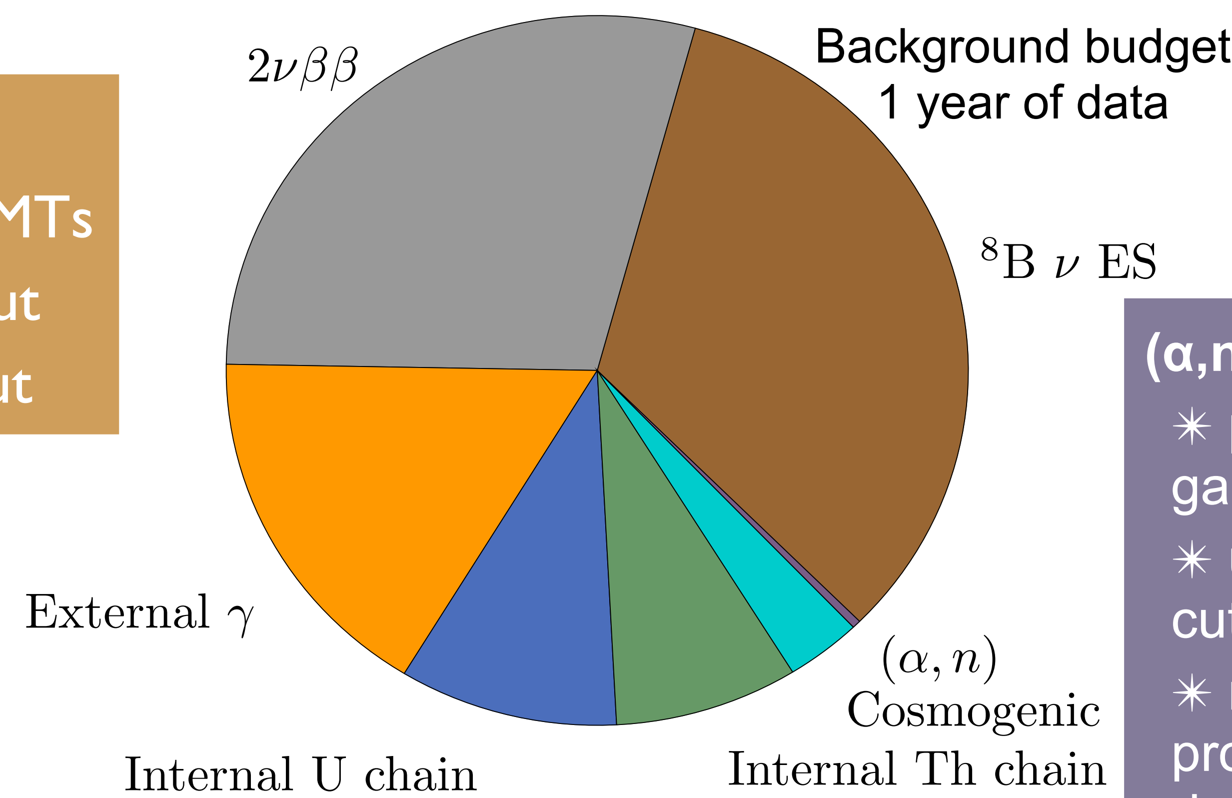
Background mitigation

$2\nu\beta\beta$ (irreducible):

- ✳ use asymetric ROI around the $0\nu\beta\beta$ signal
- ✳ energy resolution limited

^{8}B solar neutrinos (irreducible):

- ✳ “flat” continuous background from elastically-scattered electrons
- ✳ normalized using published flux data and solar mixing parameters



External γ:

- ✳ AV, ropes, water shielding, PMTs
- ✳ use a fiducial volume (FV) cut
- ✳ PMT hit time distribution cut

(α,n) backgrounds:

- ✳ prompt signal & delayed gamma can leak in FV & ROI
- ✳ use coincidence-based cuts
- ✳ remove > 99.6 % of the prompt signal and 90% of the delayed events

Internal U/Th chain:

- ✳ dominant background from ^{214}BiPo and ^{212}BiPo decays
- ✳ coincidence-based cuts developed
- ✳ 100% rejection for events in separate trigger windows
- ✳ factor of rejection 50 (events in same trigger window) based on PMT hit timing

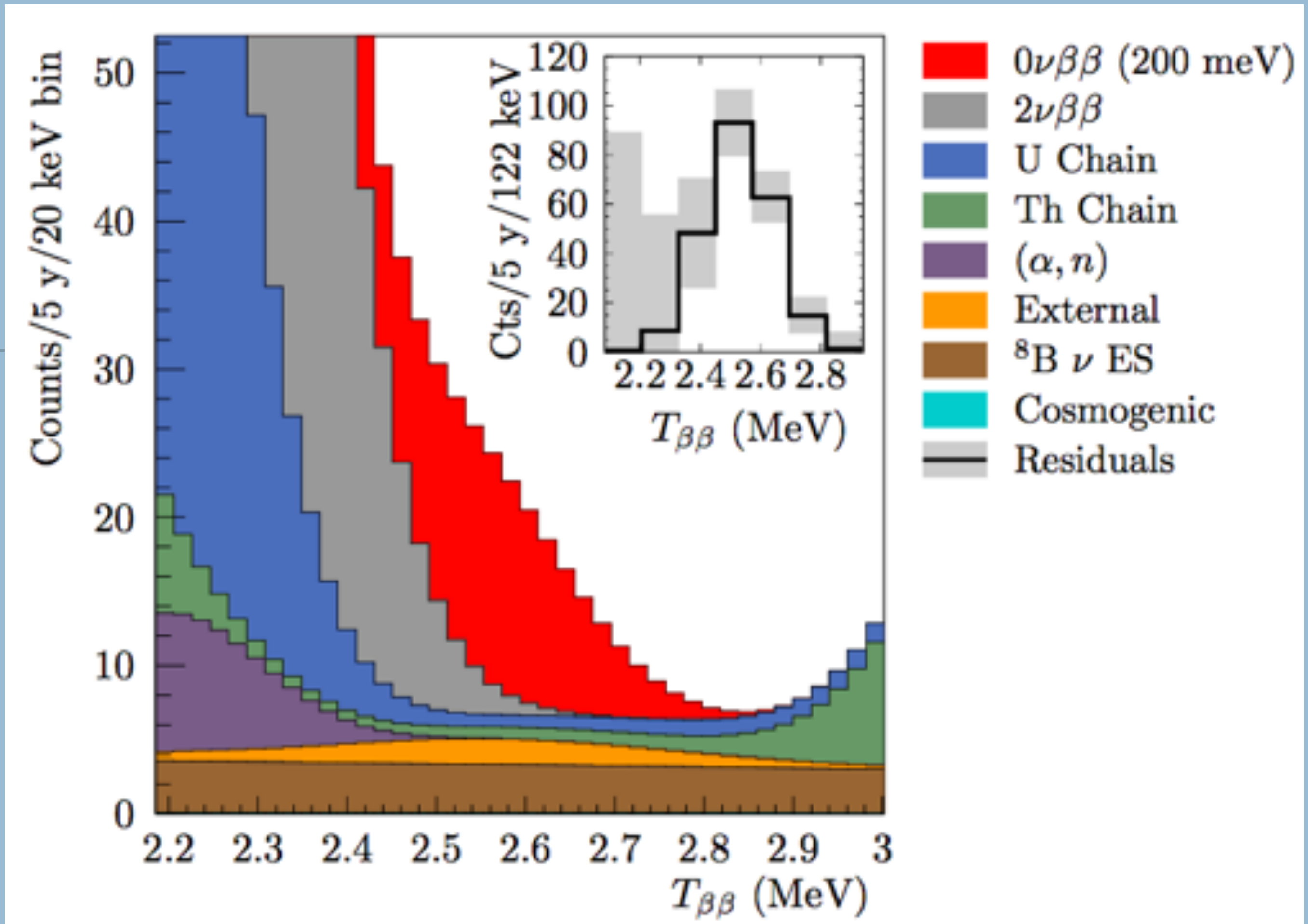
Cosmogenics:

- ✳ purification techniques
- ✳ long term underground storage
- ✳ less than one event per year in FV and ROI

Phase I & higher loading sensitivity

SNO+ sensitivity at 0.3% ^{nat}Te loading:

- fiducial volume cut R < 3.5 m (20%)
- > 99.99% rejection for ^{214}BiPo assumed
- > 98% rejection for ^{212}BiPo assumed
- 200 Nhits/MeV light yield
- phase space factor G = 3.69×10^{-14} yr^{-1}
- $g_A = 1.269$
- $M_{0\nu\beta\beta} = 4.03$ (IBM-2)



1 year data:

- $T^{0\nu\beta\beta}_{1/2} = 3.9 \times 10^{25}$ yr
- $m_{\beta\beta} \sim 105$ meV

5 years data:

- $T^{0\nu\beta\beta}_{1/2} = 9.4 \times 10^{25}$ yr
- $m_{\beta\beta} \sim 68$ meV

Summary plot of all background and a hypothetical 0νββ signal corresponding to a mass mββ = 200 meV for 5 years of data-taking.

Higher loading sensitivity:

- R&D efforts show that at 3% ^{nat}Te loading a light yield of 150 Nhit/MeV can be achieved with perylene as second wavelength shifter
- loss of light yield can be compensated by HQE PMTs/PMTs concentrator improvements
- could set a lower limit on $T^{0\nu\beta\beta}_{1/2} = 7 \times 10^{26}$ yr (mass range of 19 - 46 meV)

Conclusion & outlook

SNO+ main physics goal is the search for 0νββ for a mass range in the top of the IH mass region

Multi-purpose detector able to study also:

- ✳ solar neutrinos
- ✳ reactor and geo-neutrinos (see S. Andringa poster)
- ✳ supernova neutrinos
- ✳ nucleon decay

- ✳ water plant finished and under operation
- ✳ scintillator plant undergoing final cleaning and passivation work
- ✳ source insertion and deployment mechanisms under construction
- ✳ DAQ / dataflow / monitoring / nearline tools in benchmarking
- ✳ detector ready to take data

2015-2016 water commissioning phase

2016 scintillator phase

2017 Te loading phase I

Acknowledgements

LIP

COMPETE
PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE

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QREN
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PORTUGAL 2007.2013

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- **IF/00863/2013**
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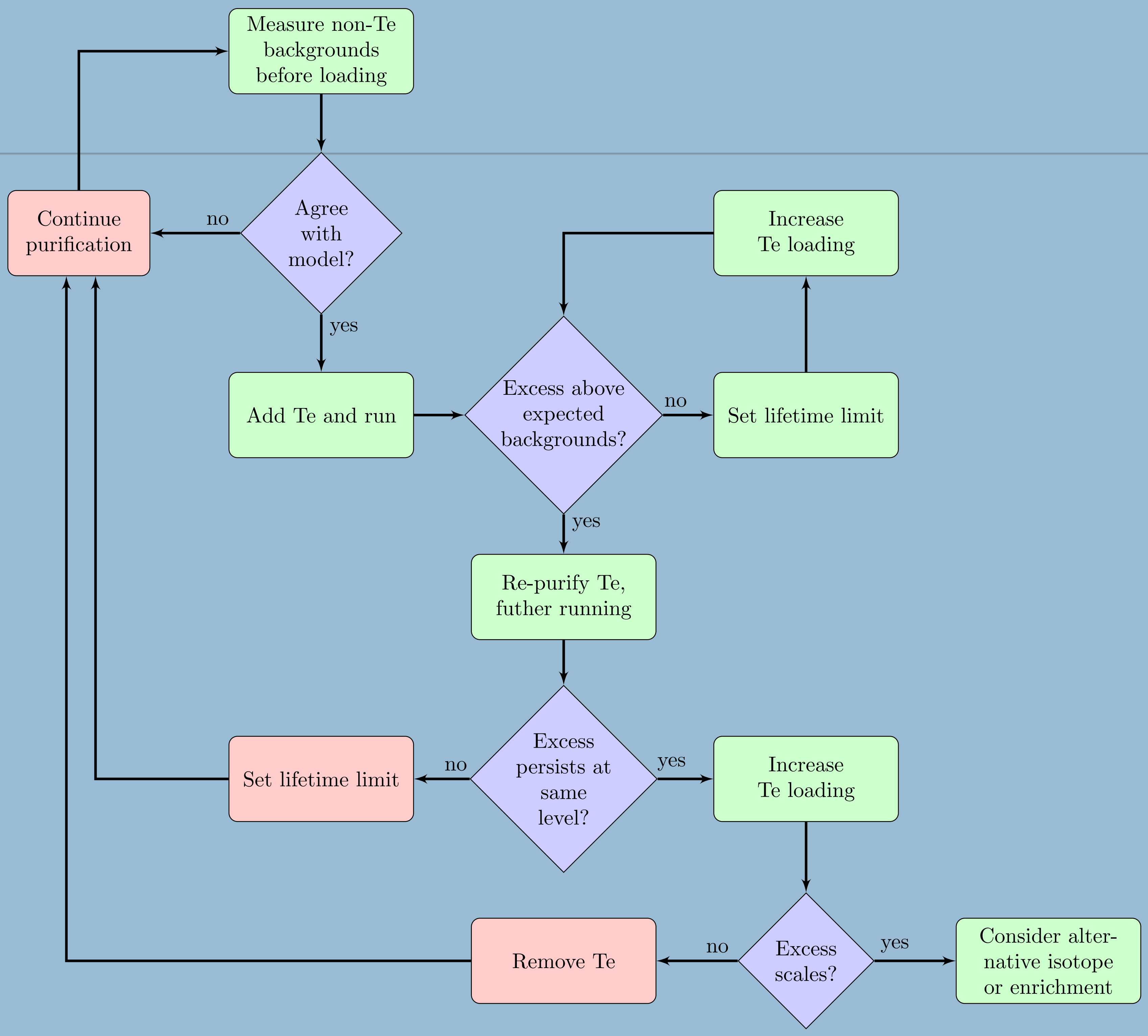
- **EXPL/FIS-NUC/1557/2013**

BACKUP

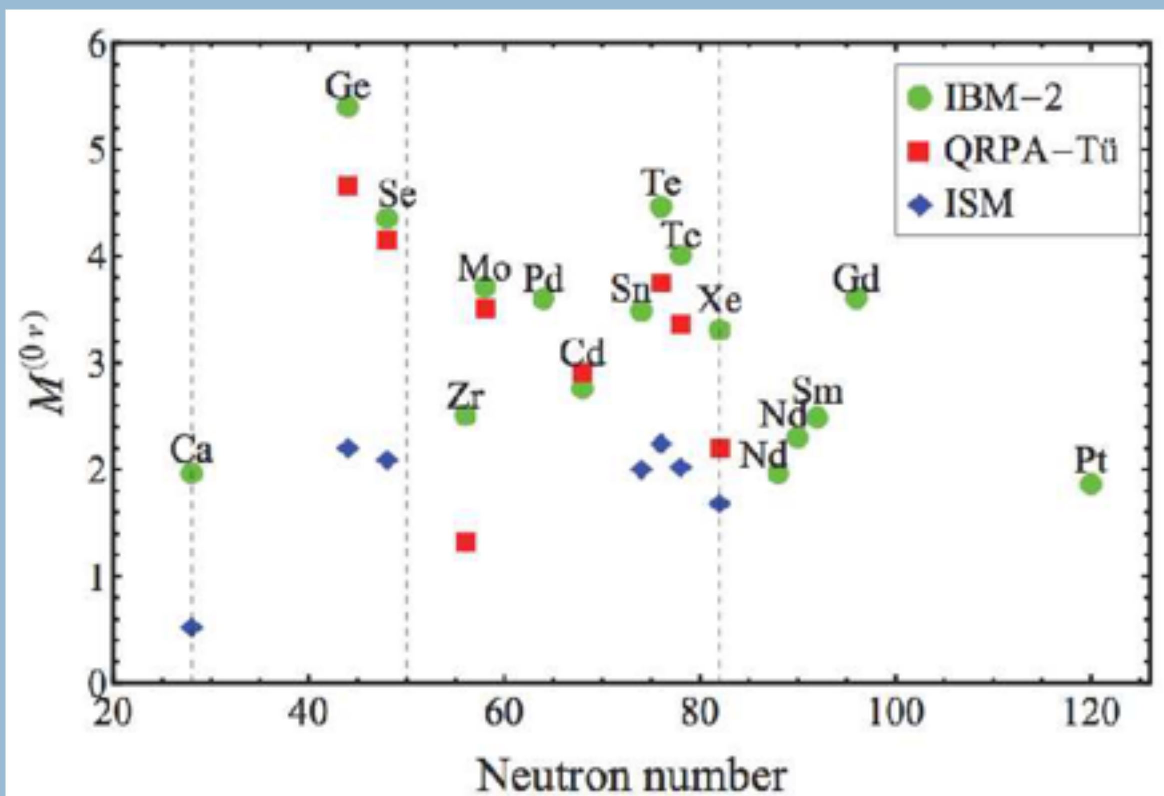
What do we do if we see a bump ?

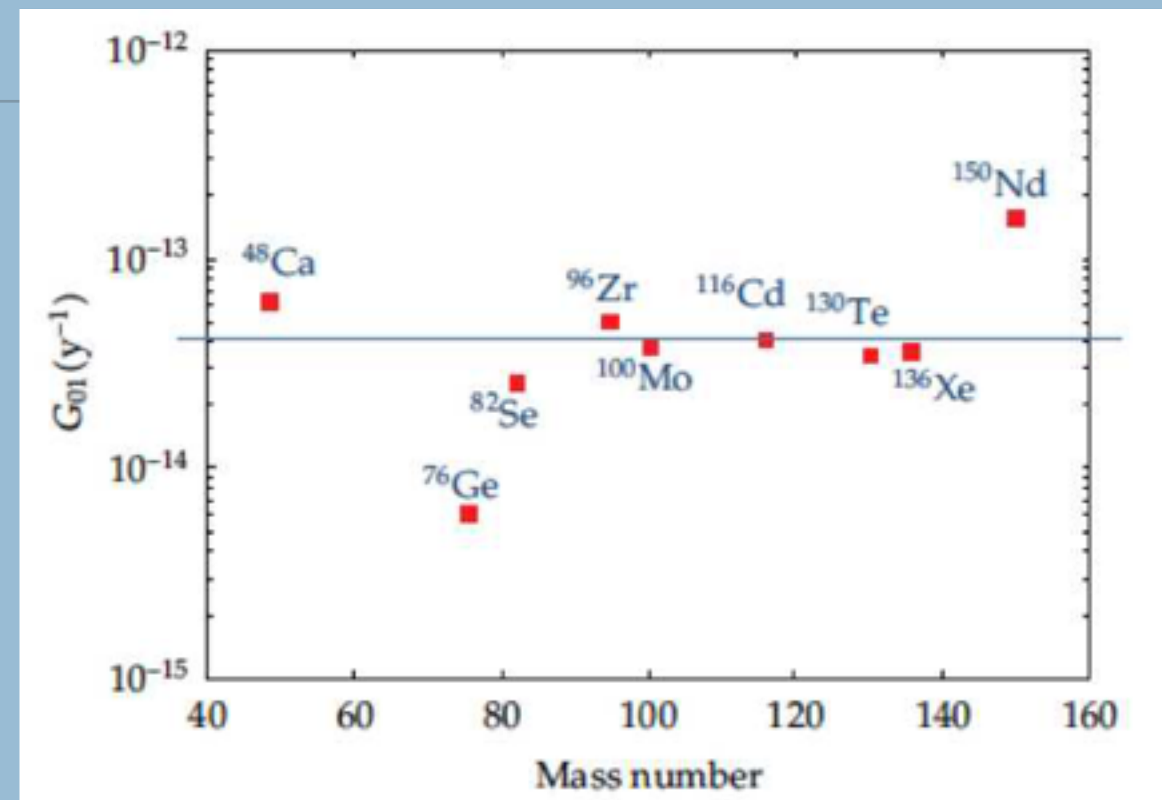


Neutrinoless double beta decay

Decay rate
$\Gamma^{0\nu\beta\beta} = \ln(2) \,.\, (T^{0\nu\beta\beta}_{1/2})^{-1} = \ln(2) .\, G^{0\nu\beta\beta}(Q_{\beta\beta},Z) \,.\, |\, M^{0\nu\beta\beta}\,|^{2} \,.\, < m_{\beta\beta} >^2 / m_e^2$

$< m_{\beta\beta} > = \Sigma m_i \times U_{ei}^2$
effective
Majorana mass





J. Barea et al Phys. Rev. C 87 014315 (2013)

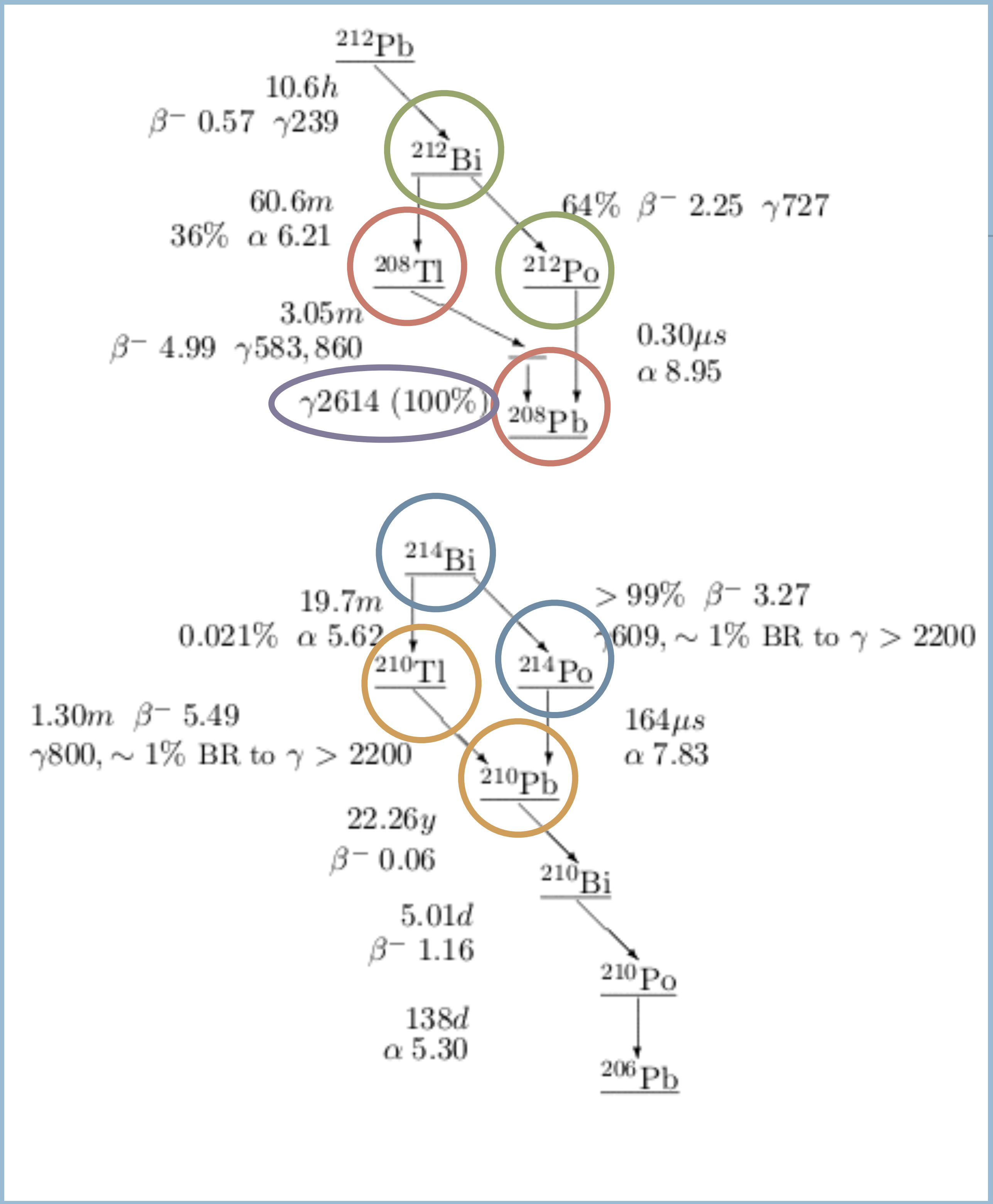
$$T_{1/2}^{0\nu\beta\beta} = \frac{N \cdot ln(2)}{n_\sigma} \cdot \frac{f(\delta\epsilon)\cdot t}{\sqrt{(b\cdot M + c)\cdot \delta E \cdot t}}$$

scaling with isotope quantity (e.g. internal U/Th)

independant of isotope quantity (e.g. solar ^{8}B)

N total number of isotope nuclei
n_σ number of standard deviation
$f(\delta\varepsilon)$ energy window acceptance fraction
M isotope mass in kg
δE energy window in keV
b background counts in $(\mathrm{keV.kg.yr})^{-1}$
c background count in $(\mathrm{keV.yr})^{-1}$

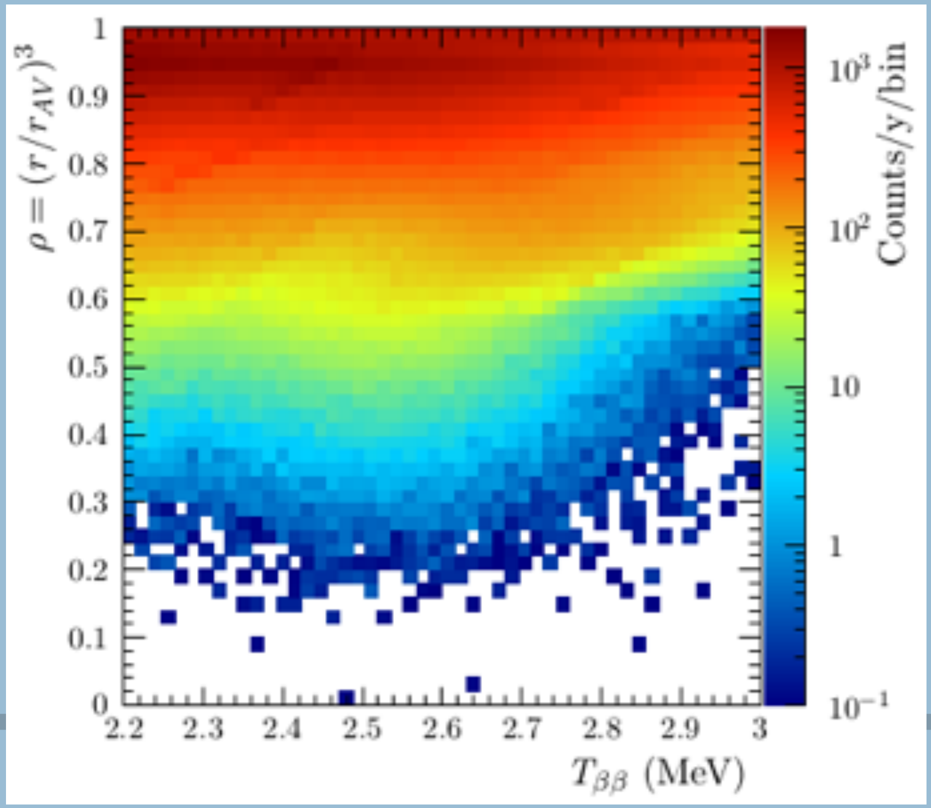
Backgrounds from the natural 238U and 232Th chains



✳ β - α coincidence tagging for events in different trigger windows
✳ PMTs hit time analysis for events in same trigger window

✳ α - β coincidence tagging for events in different trigger windows
✳ PMTs hit time analysis for events in same trigger window

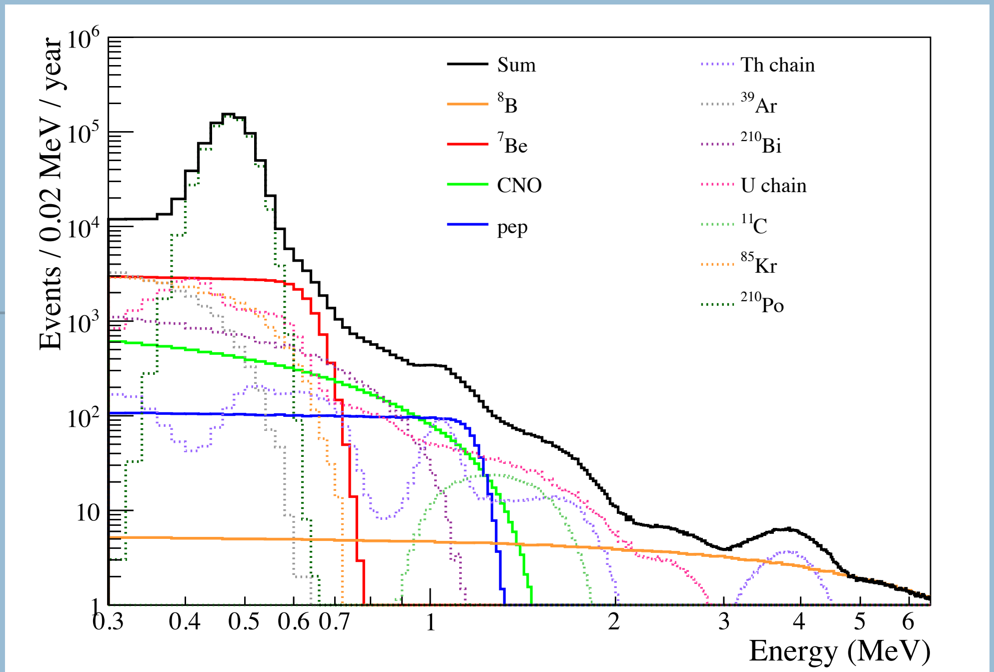
2.6 MeV γs from external ^{208}Tl
✳ can be suppressed with FV cut
✳ from AV can be removed via PMT hit time analysis



Other physics in SNO+

Solar neutrinos:

✳ with scintillator purity at Borexino level, sensitivity to CNO, *pep* and low-energy ^{8}B with unloaded scintillator
✳ if can source scintillator with reduced (one order magnitude) ^{14}C level can also measure *pp*
✳ ^{8}B with energy above the ^{130}Te end-point can be measured in the scintillator loaded phases



Anti-neutrinos from reactors and the Earth (see poster by S. Andringa)

Supernova neutrinos:

✳ measurements of Core Collapse supernovae neutrinos can shed light on explosion mechanism
✳ member of the Supernova Early Watching System (SNEWS)

Exotics physics:

✳ search for invisible nucleon decay mode signature in the water phase
✳ axion-like particle search in all SNO+ phases