Queen Mary University of London

SNO+

European Research Council
Established by the European Commission

Jeanne Wilson

19-8-2014

IPA, QMUL

SNO+ Collaboration

Queen's
Alberta
Laurentian
SNOLAB
TRIUMF

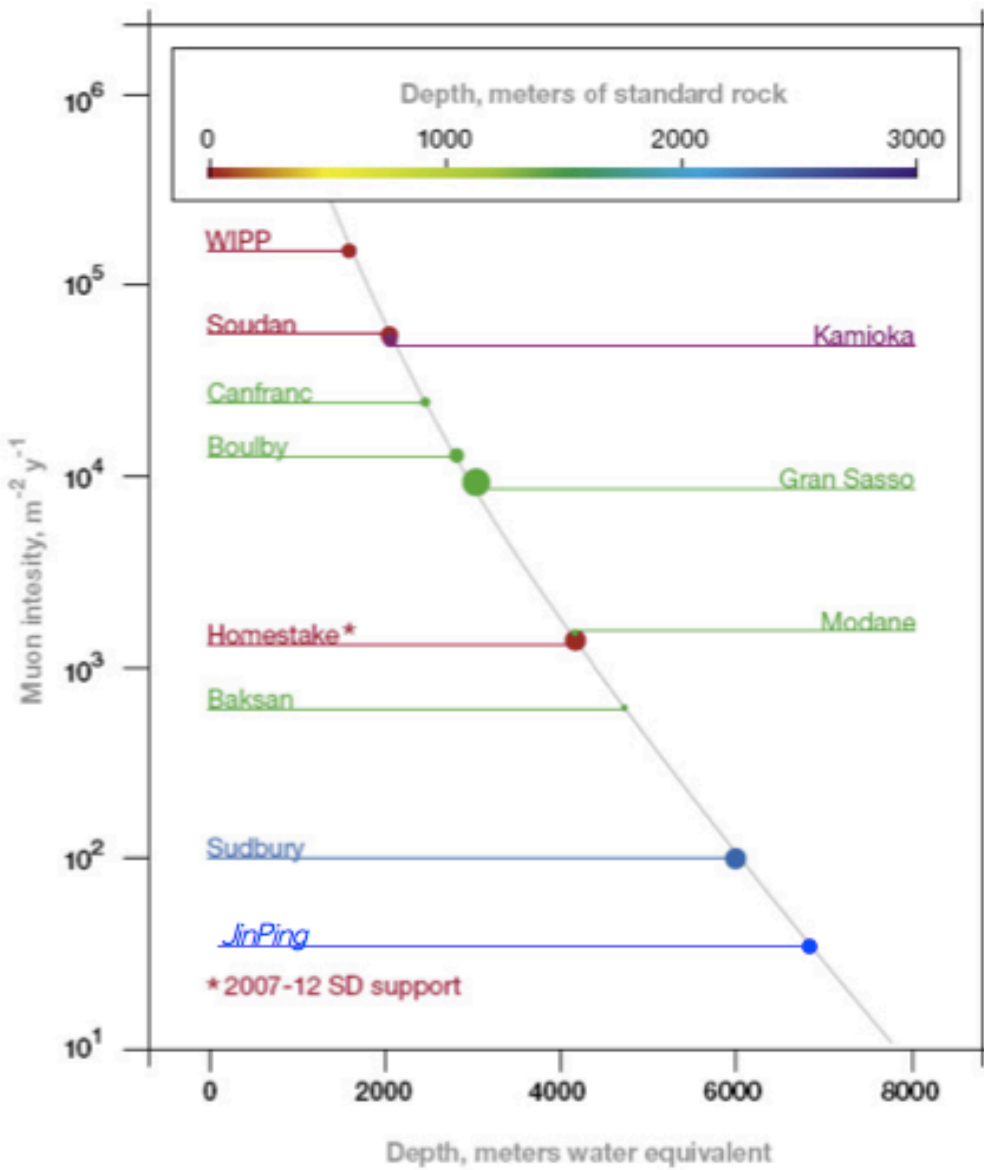
BNL, AASU
U Penn, UNC
U Washington
UC Berkeley/LBNL
Chicago, UC Davis

Oxford
Sussex
QMUL
Liverpool
Lancaster

LIP Lisboa
LIP Coimbra

TU Dresden

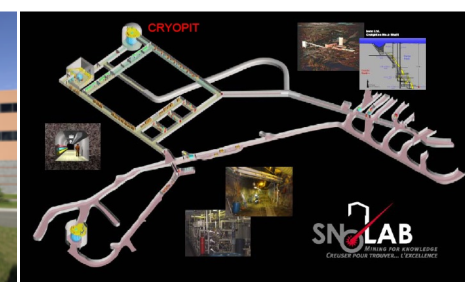
Location



Adapted from http://www.deepscience.org/contents/underground_universe_popup03.shtml

Muon flux = 70 muons/day

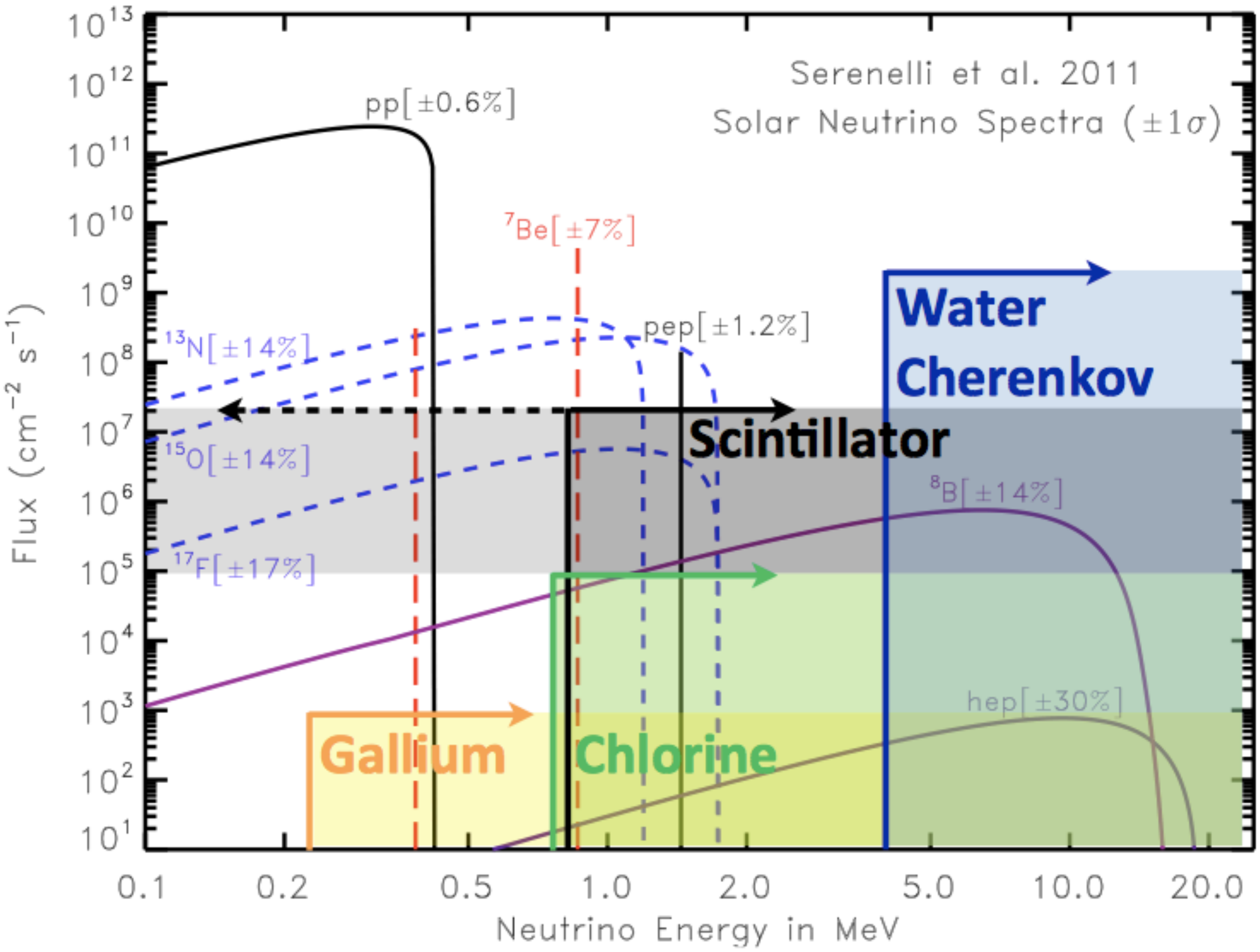
Class-2000 clean room lab



SNO+ Physics Program

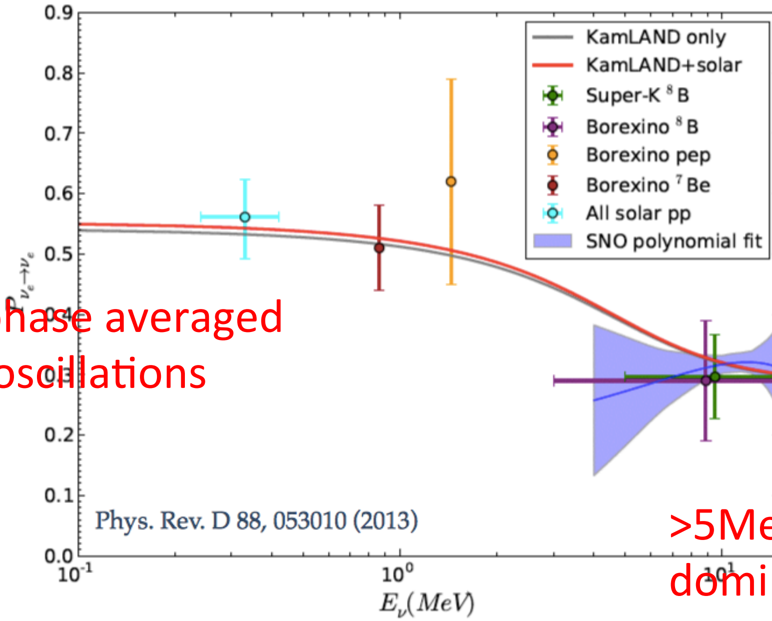
- Low Energy Solar Neutrinos
- Neutrinoless double beta decay search
- Supernovae sensitivity
- Reactor Neutrinos
- Geoneutrinos
- Invisible Nucleon Decay (water phase)

Solar Neutrinos



Solar Neutrino Physics

- What can the Sun tell us about neutrinos?
  - Precision pep flux
  - Low energy ^{8}B spectrum
  - Day/night asymmetry?



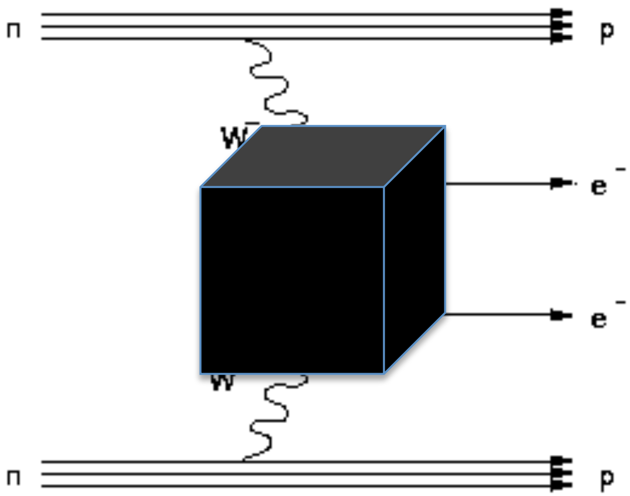
<1MeV phase averaged vacuum oscillations

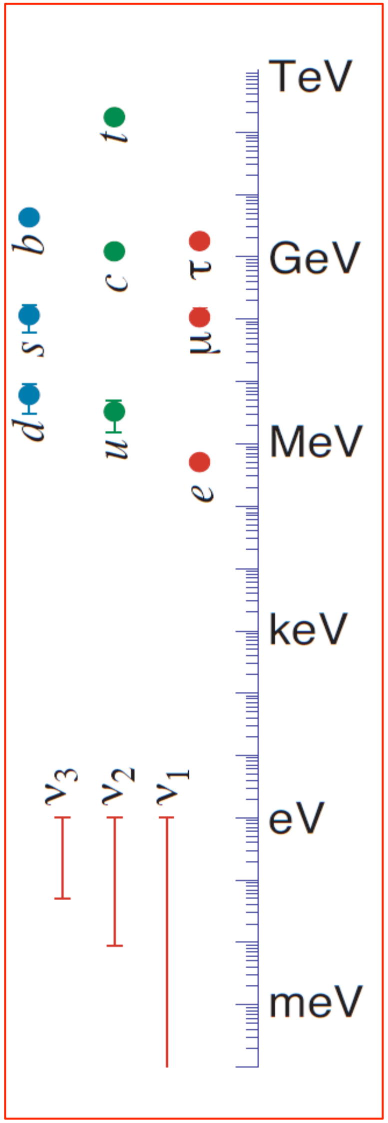
>5MeV Matter dominated resonant conversion

- What can neutrinos tell us about the Sun?
  - CNO flux -> Resolve solar metallicity problem
  - Direct pp measurement -> Luminosity constraint

Double Beta Decay

- Hard to explain smallness of neutrino masses with Higgs mechanism
- Most favoured alternative = See-saw mechanism
  - Majorana neutrinos
  - Leptogenesis





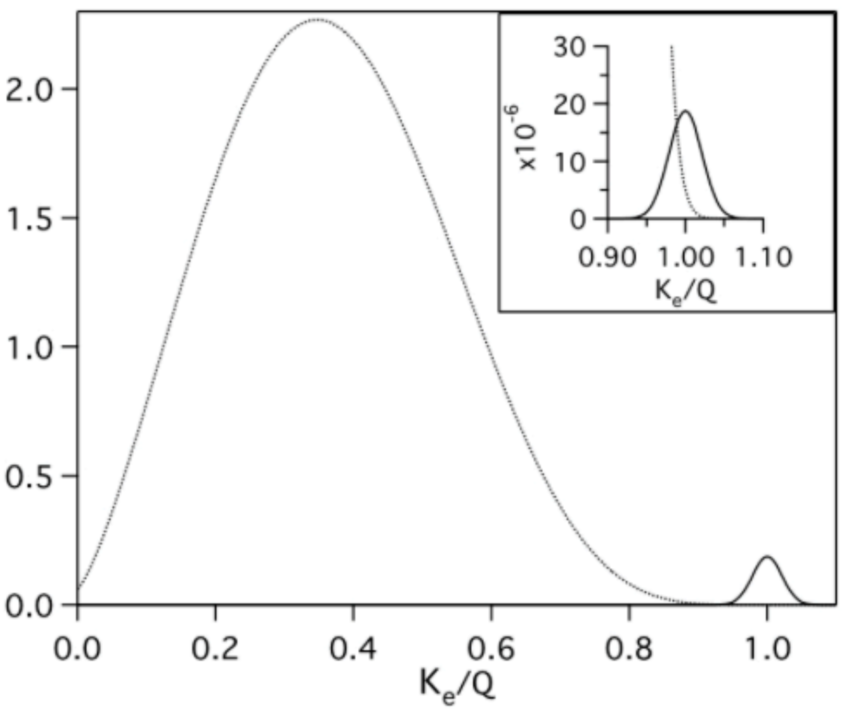
Neutrinoless Double Beta Decay

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu} \cdot \left|M^{0\nu}\right|^2 \cdot \langle m_{\beta\beta} \rangle^2$$

Phase space   Nuclear Matrix Element

$$\langle m_{\beta\beta} \rangle^2 = |\sum_i U_{ei}^2 m_{\nu_i}|^2$$

Sum of the electron kinetic energies, normalized to the endpoint Q.



Experiment options

- Select isotopes with favourable phase space
- Select isotopes with favourable matrix elements
  - Beware large uncertainty / differences between models
- Good energy resolution
- Low Backgrounds in region of interest (ROI)

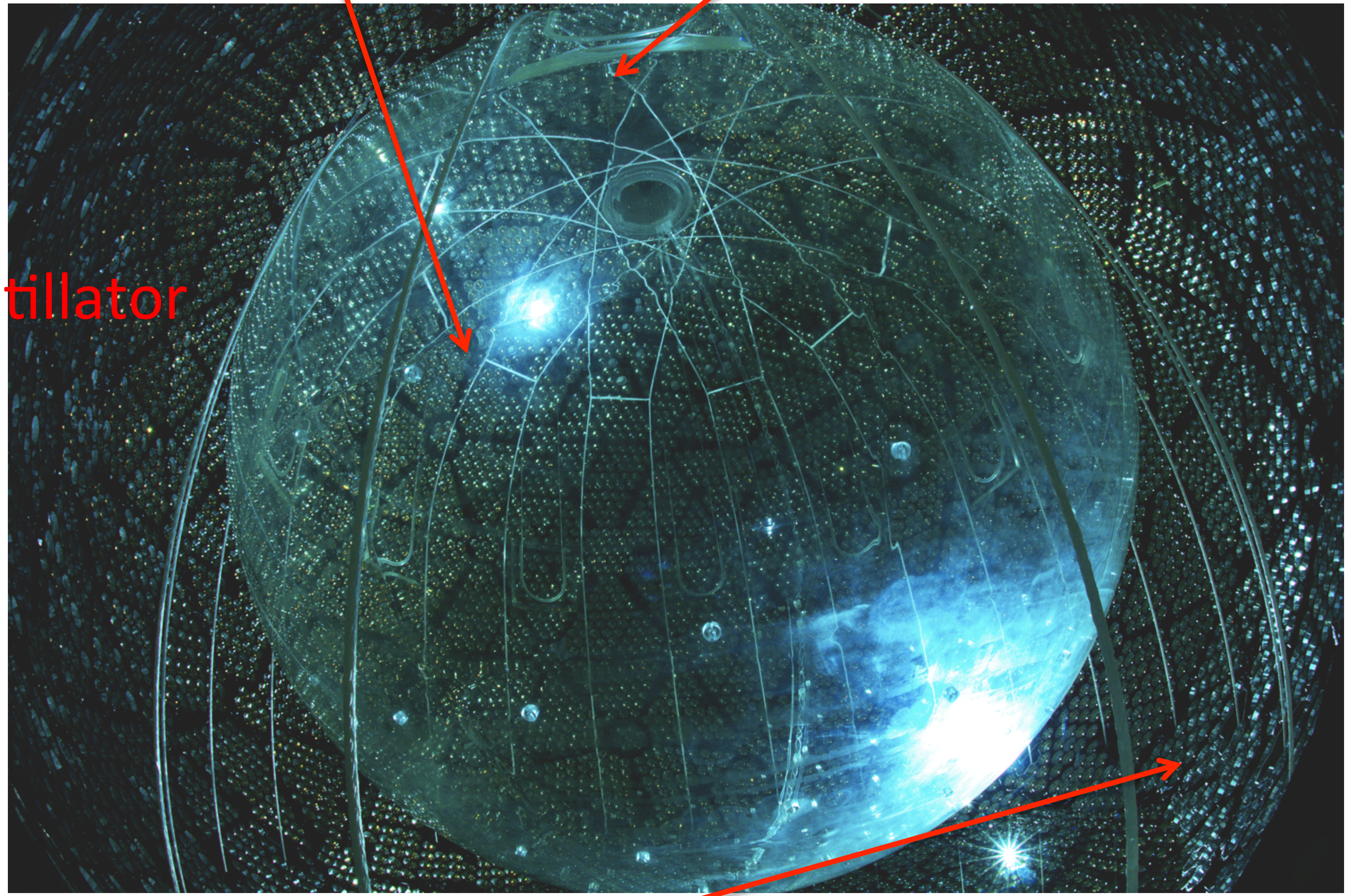
0νββ search – SNO+ approach

- Statistics over energy resolution
- Tellurium – 130
  - Favourable 0νββ : 2νββ phase space ($T_{1/2}^{2\nu\beta\beta} = 7\times10^{20}$ years)
  - 34% natural abundance
  - 2.53MeV endpoint energy
- Large amount of isotope
  - 0.3% loading (by weight) = 2.34tonnes ^{nat}Te = 800kg ^{130}Te = $1.5million
  - Towards tonne-scale 0νββ search at relatively low cost
- Large homogeneous detector, well defined background model
  - Aim to be dominated by solar neutrino background
- Isotope In/Out capability

SNO+ Detector

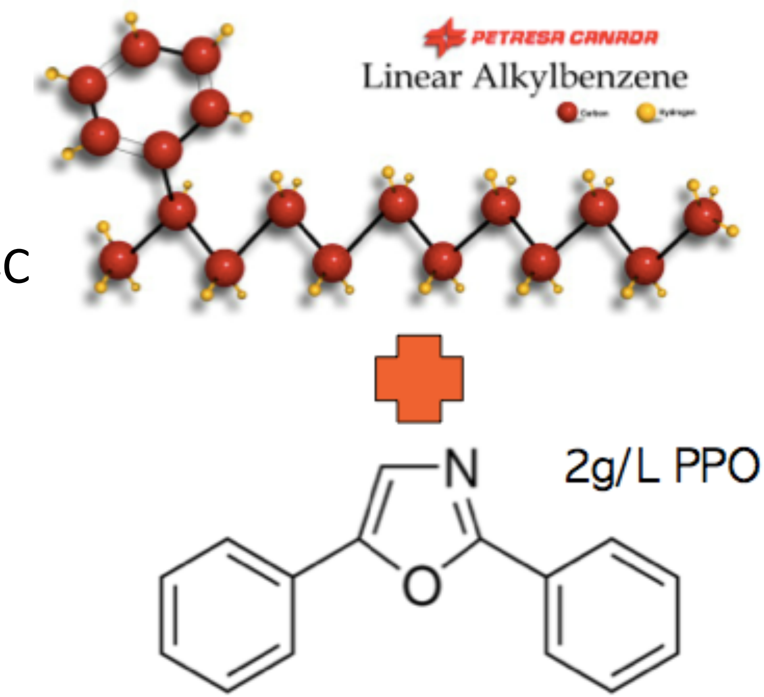
- 12m diameter Acrylic Vessel
- 780 tonnes scintillator
- 7ktonnes water shielding
- ~9500 8inch PMT array

Hold down rope net

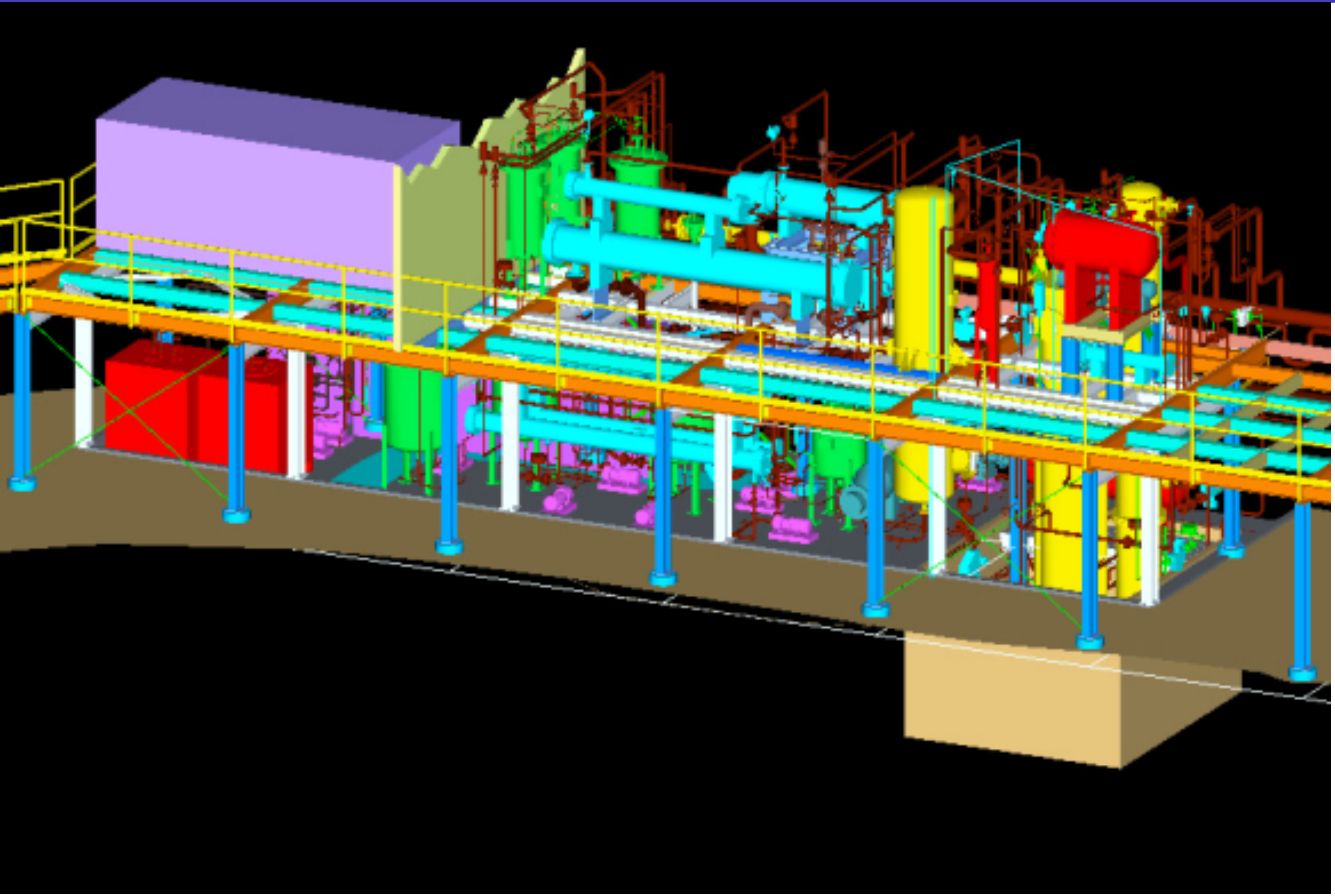


Liquid Scintillator

- Linear alkylbenzene (LAB) + 2g/L fluor 2,5 diphenyloxazole (PPO)
  - Chemical compatibility with acrylic
  - High light yield, high purity
  - Good optical transparency, low scattering
  - Fast decay – β - α separation
  - Low toxicity, environmentally safe
  - High flash point, 140C, boiling point 278-314C
  - Low solubility in water, 0.041 mg/L



Scintillator purification plant



Purification Plant - LABPPO

- Multi-stage distillation
  - Remove heavy metals, improve UV transparency
- Pre-purification of PPO concentrated solution
- Steam/N_2 stripping under vacuum
  - Remove Rn, Kr, Ar, O_2
- Water extraction
  - Remove Ra, K, Bi
- Metal scavengers
  - Remove Bi, Pb
- Microfiltration
  - Remove dust

<u>Target levels:</u>

- ^{85}Kr: 10^{-25} g/g
- ^{40}K: 10^{-18} g/g
- ^{39}Ar: 10^{-24} g/g
- U: 10^{-17} g/g
- Th: 10^{-18} g/g

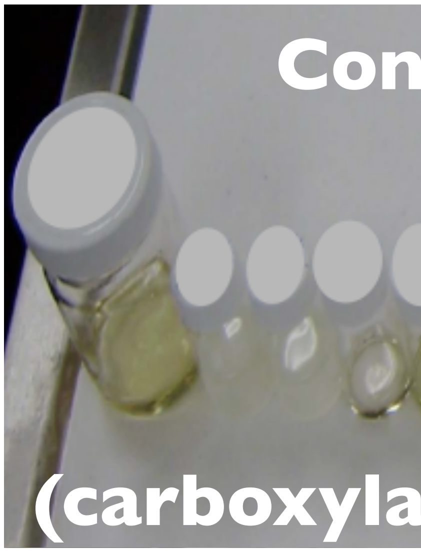
Space is limited underground!

First Attempts at Te-Loaded Scintillator

First Attempts at Te-Loaded Scintillator

- …then, breakthrough new approach was developed at BNL, works for loading Te in liquid scintillator

First Attempts at Te-Loaded Scintillator



- …then, br ach was developed ding Te in liquid scin

pH Selective Telluric Acid Recrystallisation

- Telluric acid obeys the following equilibrium:

$$Te(OH)_6 \leftrightarrow Te(OH)_5O^- + H^+$$

Insoluble ($Te(OH)_6$) Soluble ($Te(OH)_5O^-$)

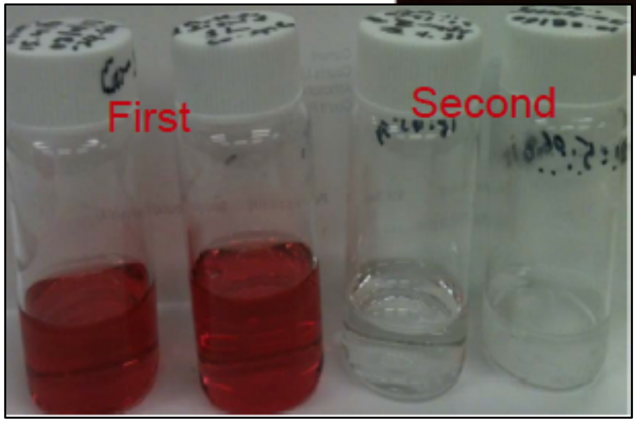
  - pH determines the equilibrium state

1. Dissolve telluric acid in water and filter it
   - Removes insoluble impurities

2. Add nitric acid to force the telluric acid to recrystallize/precipitate, pump away the liquid, rinse with ethanol
   - Removes soluble impurities

- By "tuning" the pH at each step, the process can be quite selective – most elements are removed with high efficiency

Cobalt removal by multi-pass purification



See S. Hans et. al. *Purification of Telluric Acid for SNO+ Neutrinoless Double Beta Decay Search*. In preparation.

Measured Single Pass Reduction Factors

Element	Reduction Factors From Spike Tests	Non-spiked, before purification	Non-spiked, after purification
Sn	$>1.67\times10^{2}$	20	<20
Zr	$>2.78\times10^{2}$	70	<10
Ti		40	<10
Al		<30	<30
Co	$(1.62\pm0.34)\times10^{3}$	<10	<10
Mn		150	<5
Fe		40	<30
Ag	$>2.78\times10^{2}$	<10	<10
Y	$>2.78\times10^{2}$	<10	<10
Sc	$>1.65\times10^{2}$	<10	<10
Sb	$>2.43\times10^{2}$	30	<20
^{228}Th	$(3.90\pm0.19)\times10^{2}$	<0.02	<0.02
^{224}Ra	$(3.97\pm0.20)\times10^{2}$	1400	<5
^{212}Pb	$(2.99\pm0.22)\times10^{2}$	440	<3
^{212}Bi	$(3.48\pm0.81)\times10^{2}$	300	<10
^{238}U	$(3.90\pm0.19)\times10^{2}$	<0.02	<0.02

Two-pass purification should meet our purity goals.

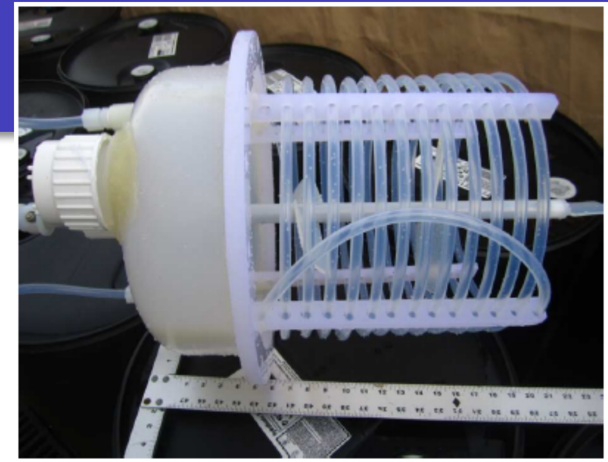
Cosmogenics

- Nitric acid recrystallisation process performed on surface for safety
- Cosmogenic isotopes re-develop between the end of purification and moving the Te underground
  - Goal = 5 hour transit time
  - Additional underground polishing step
    - Dissolve in warm water
    - Thermal recrystallisation

	No purification	Purification + 5 hrs re-activation + "polishing" & 6 month cool-down
^{22}Na	15309	0.0947
^{26}Al	0.048	5.724E-7
^{42}K	565	0.0044
^{44}Sc	102	0.0004
^{46}Sc	43568	0.1993
^{56}Co	2629	0.0099
^{58}Co	25194	0.0888
^{60}Co	6906	0.0396
^{68}Ga	37343	0.2201
^{82}Rb	18047	0.0071
^{84}Rb	11850	0.0113
^{88}Y	390620	2.3079
^{90}Y	823	0.0019
^{102}Rh	276189	1.8389
^{102m}Rh	133848	1.0438
^{106}Rh	1534	0.0111
^{110m}Ag	69643	0.4184
^{110}Ag	939	0.0056
^{124}Sb	3101138	9.7353
^{126m}Sb	240	1.205E-5
^{126}Sb	358996	0.0015

Lozza & Petzoldt, Cosmogenic activation of a natural tellurium target, Astroparticle Physics. DOI: 10.1016/j.astropartphys.2014.06.008

Scale-Up



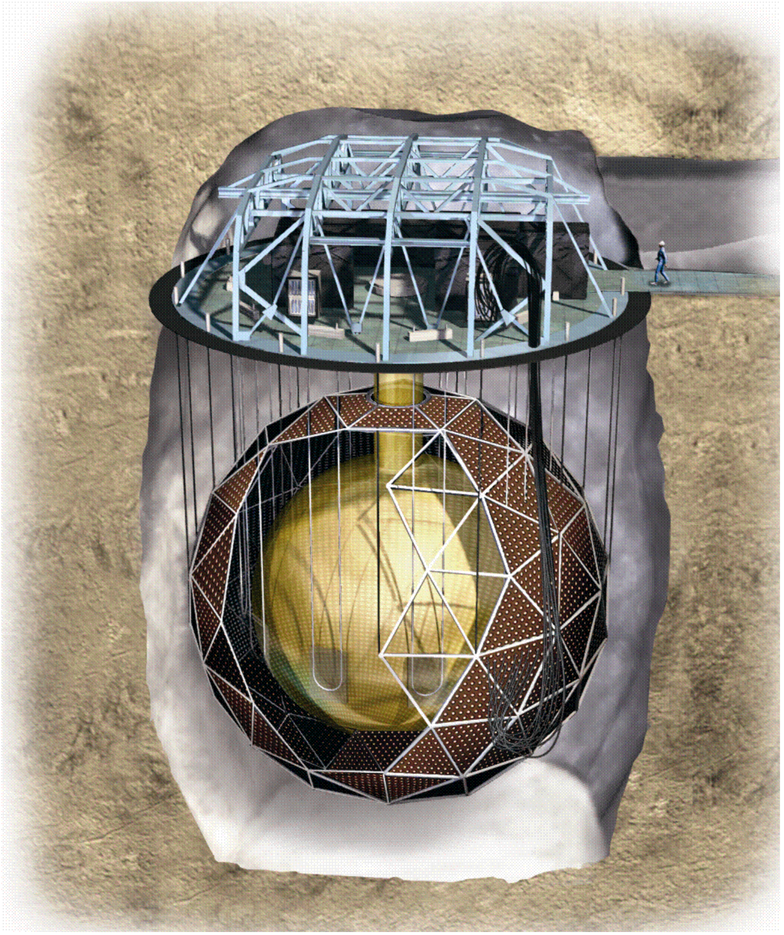
- Working with an industrial partner (SeaStar Chemicals, Sydney, BC) to scale processes up to ~200kg batch size
  - A few months to process the 4 tonnes of telluric acid for 0.3% loading
- Currently operating a 10kg pilot-scale plant
- Plan to have the full-scale system at SNOLAB this winter

Backgrounds

LAB-PPO : ^{238}U, ^{232}Th, ^{14}C

Externals:

^{214}Bi, ^{208}Tl ϒ from PMTs, AV, Ropes, H_2O



Implanted Radon daughters in AV:

^{210}Pb, ^{210}Bi, ^{210}Po

Thermal neutrons:

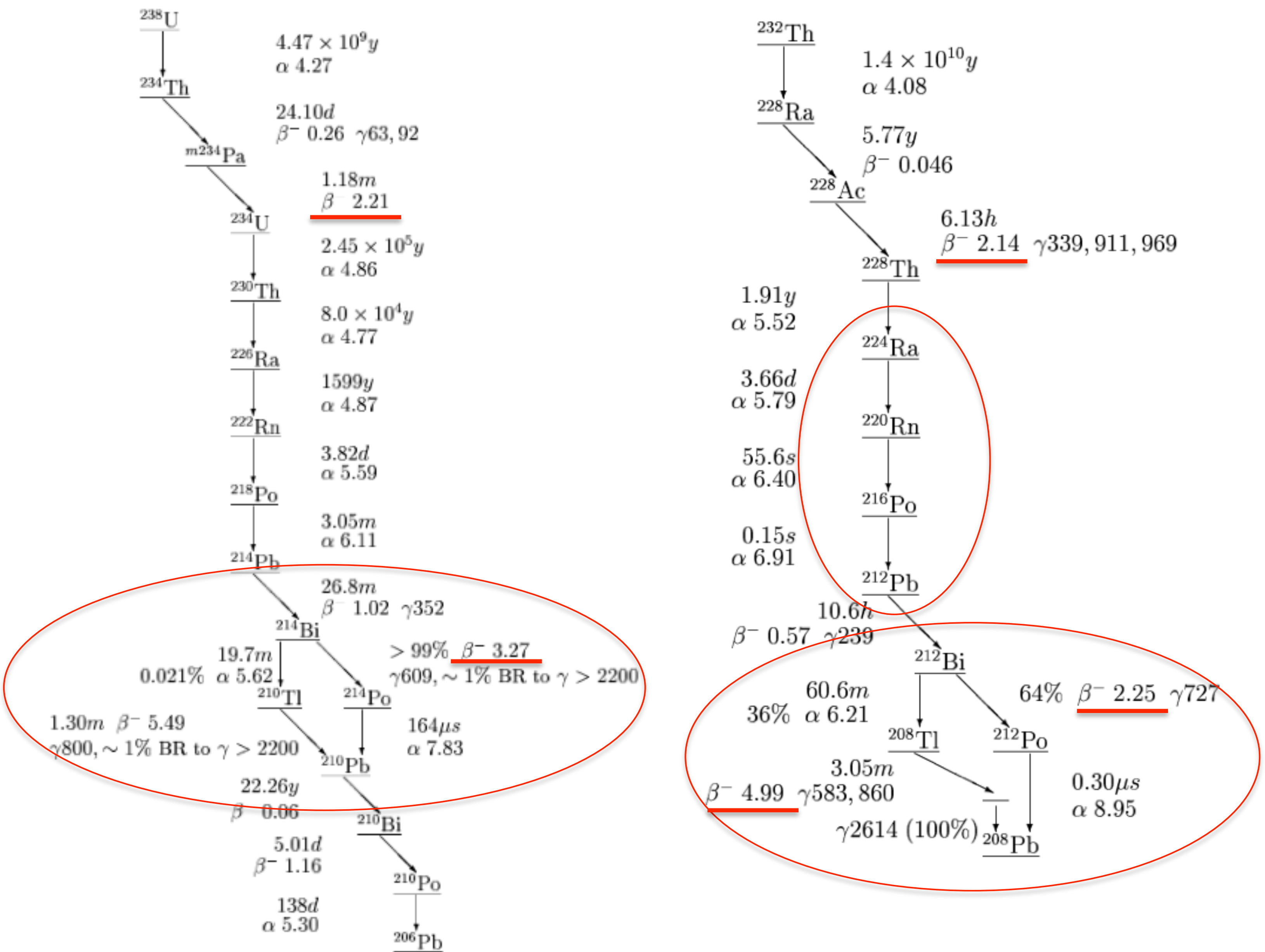
capture on H to 2.2MeV ϒ:

Muon induced neutrons, (α,n)

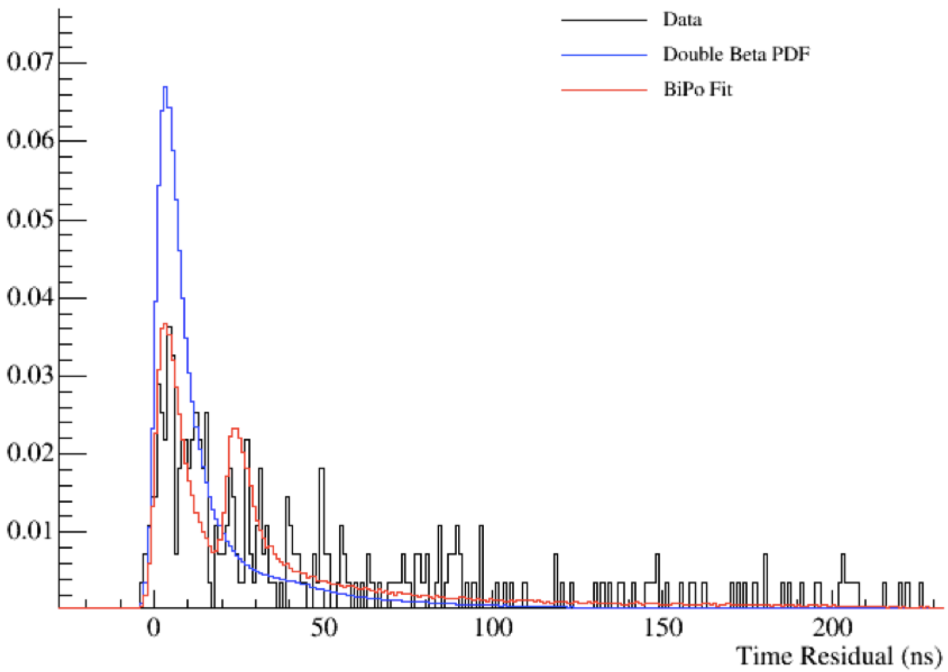
Tellurium : ^{238}U, ^{232}Th, ^{210}Po

Residual cosmogenically activated isotopes: ^{60}Co, ^{131}I

Uranium and Thorium Chain



BiPo rejection

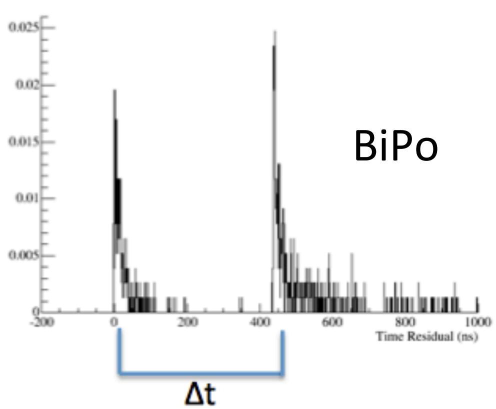


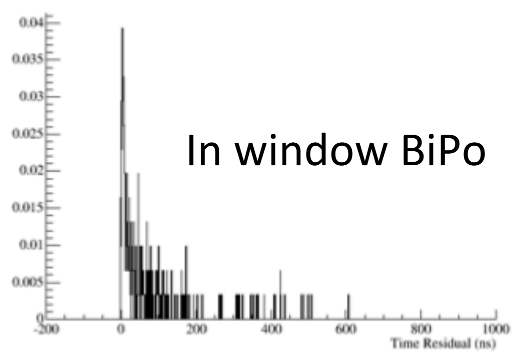
Likelihood ratio cuts to reject in-window BiPo

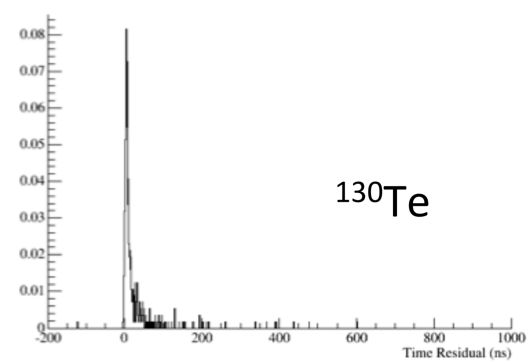
- Timing Residuals
- Beta and alpha energies

Overall
214BiPo factor > 25000 rejection
212BiPo factor > 70 rejection

SNO+ 'RAT' Simulations

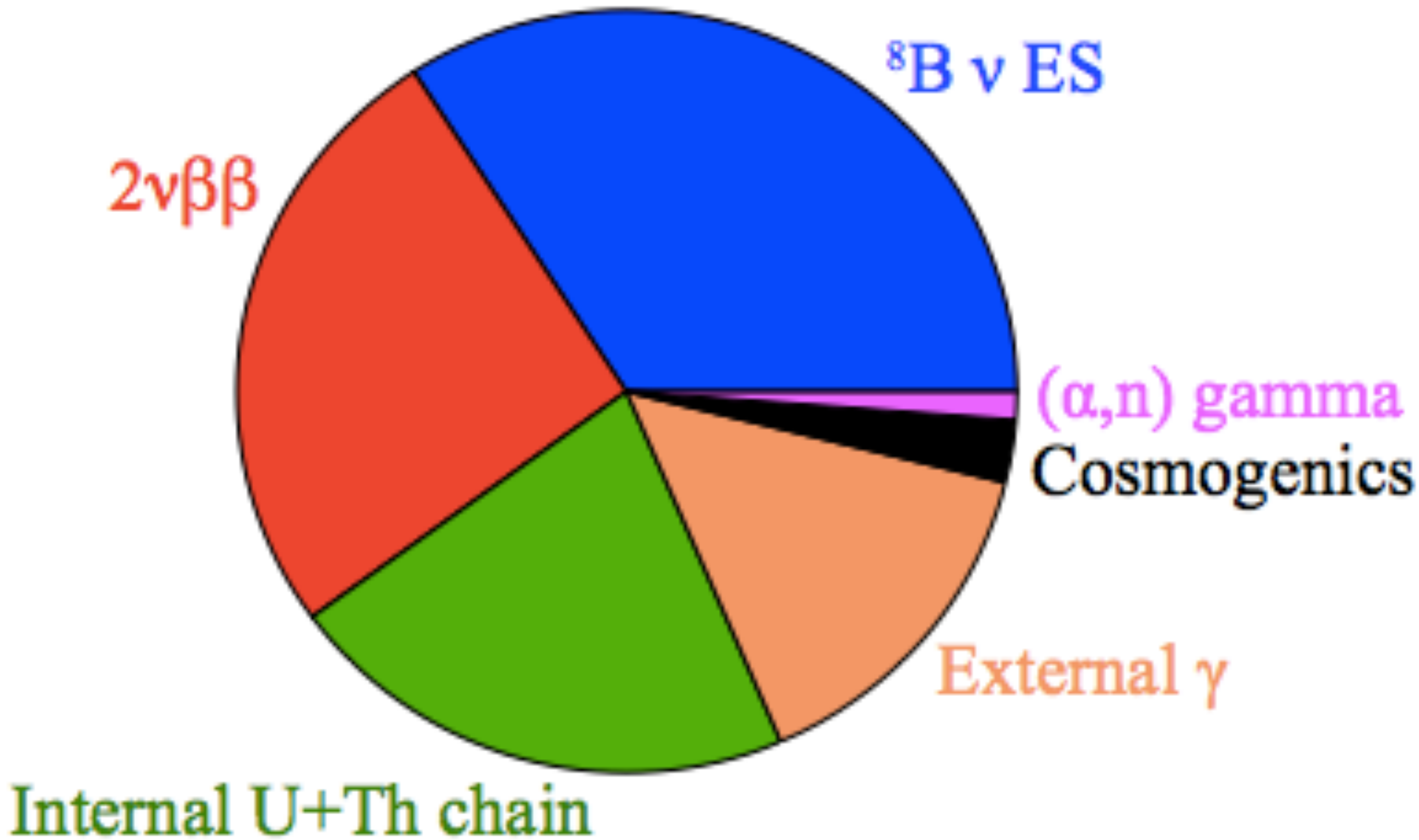






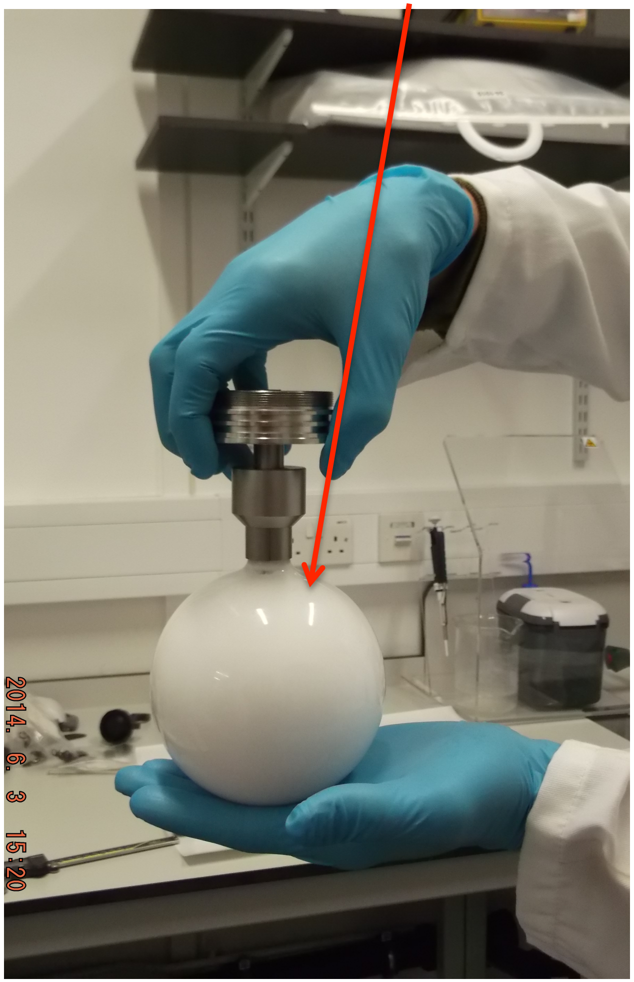
Backgrounds

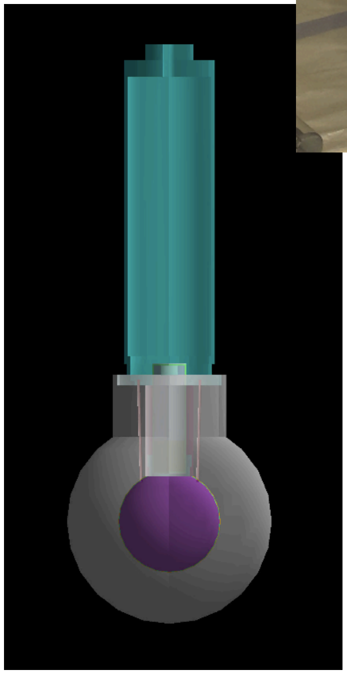
Optimized ROI: -0.5σ – 1.5σ ~25 events

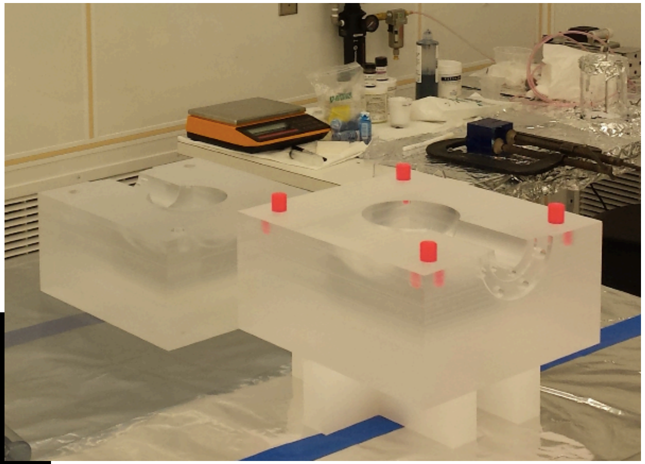


Calibration

- Deployed sources:
  - Laserball (optics), Cerenkov source

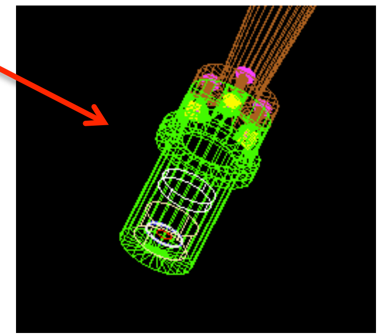


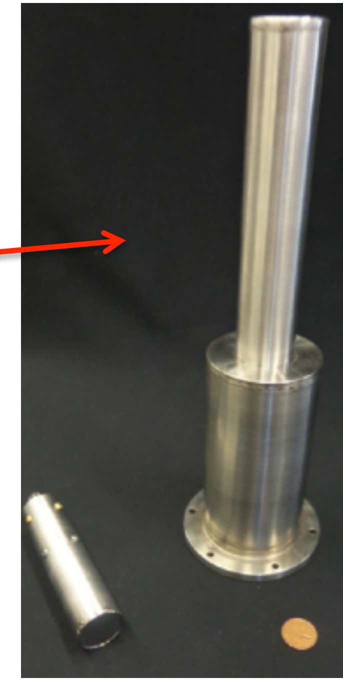


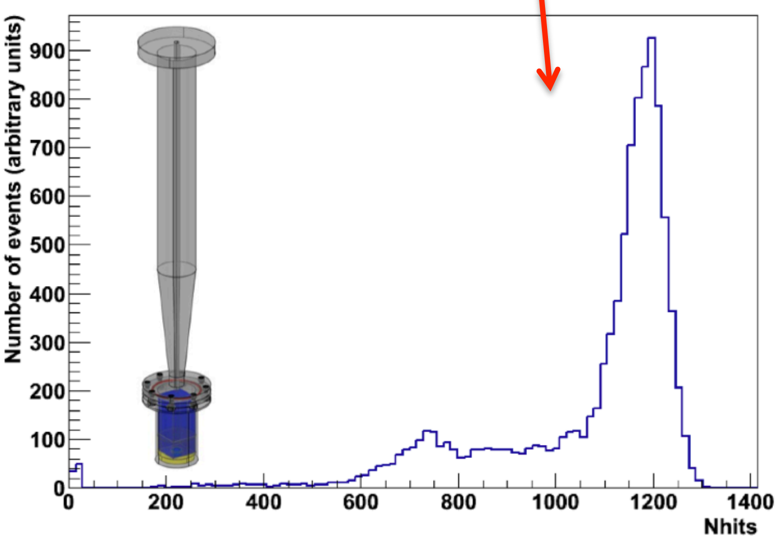


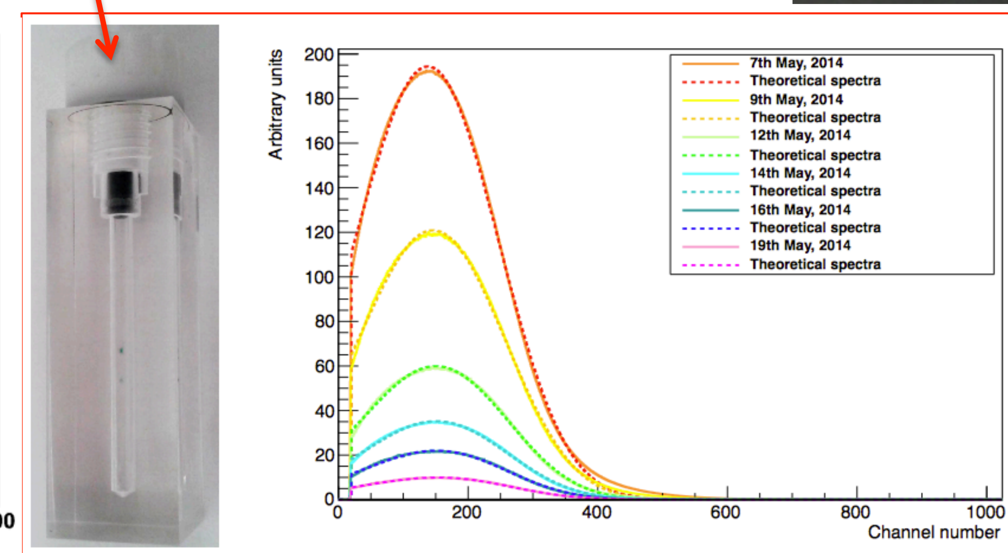
Calibration

- Deployed sources:
  - Laserball (optics), Cerenkov source
  - ^{48}Sc, ^{60}Co, ^{90}Y (beta), ^{57}Co, ^{24}Na



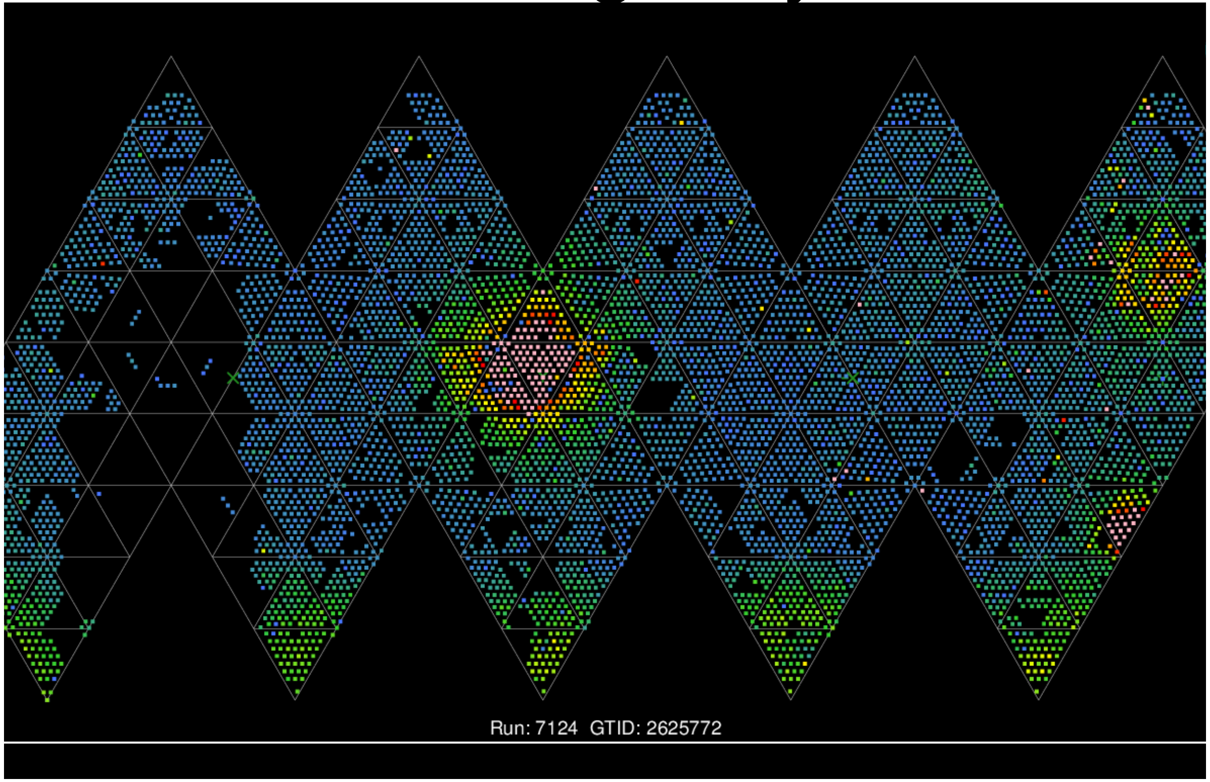






Calibration

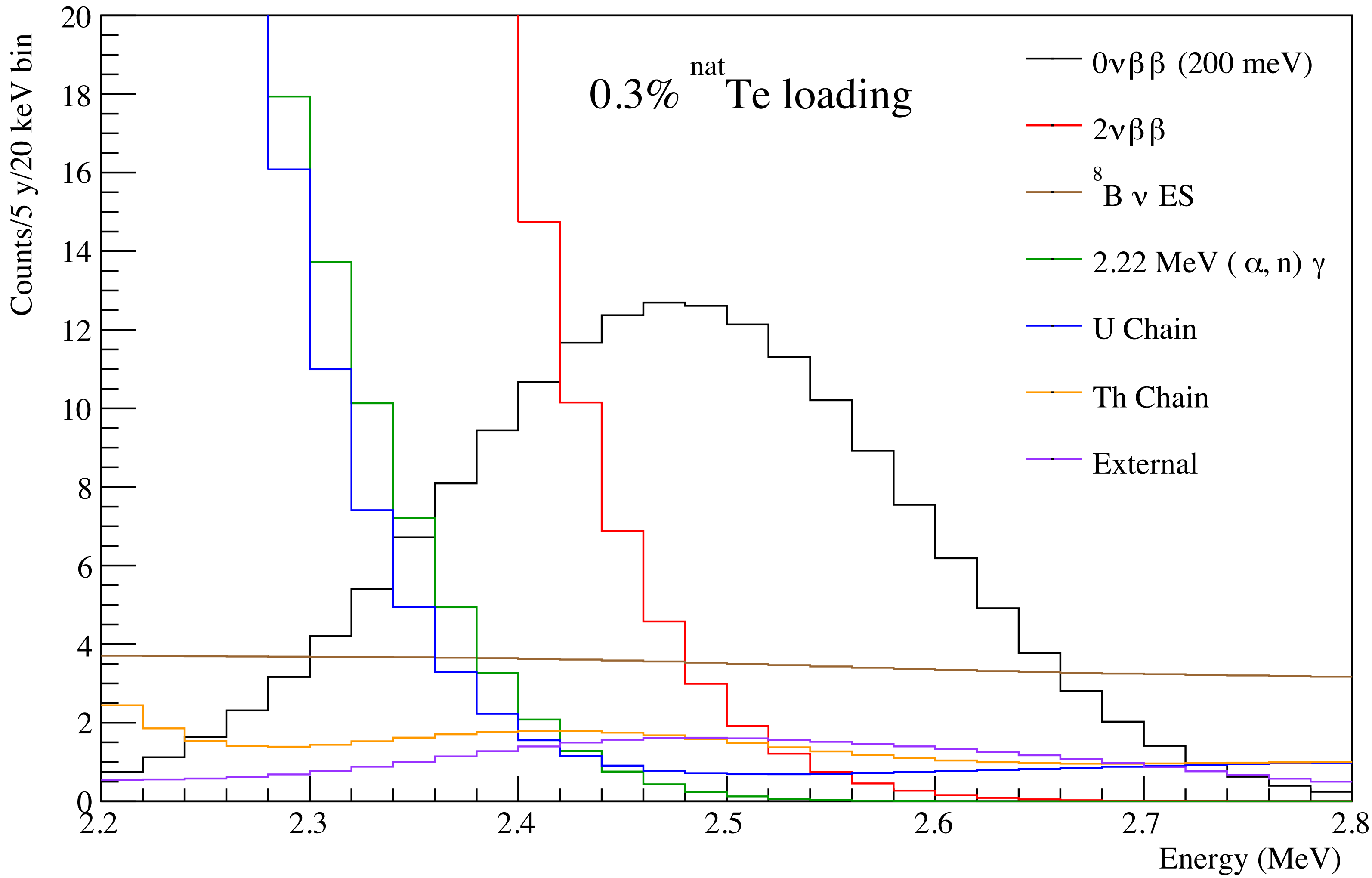
- Deployed sources:
  - Laserball (optics), Cerenkov source
  - ^{48}Sc, ^{60}Co, ^{90}Y (beta), ^{57}Co, ^{24}Na
- Embedded light injection fibres



Calibration

- Deployed sources:
  - Laserball (optics), Cerenkov source
  - ^{48}Sc, ^{60}Co, ^{90}Y (beta), ^{57}Co, ^{24}Na
- Embedded light injection fibres
- Internal sources
  - ^{14}C, ^{210}Bi, ^{210}Po, ^{214}Bi-Po, ^{212}Bi-Po

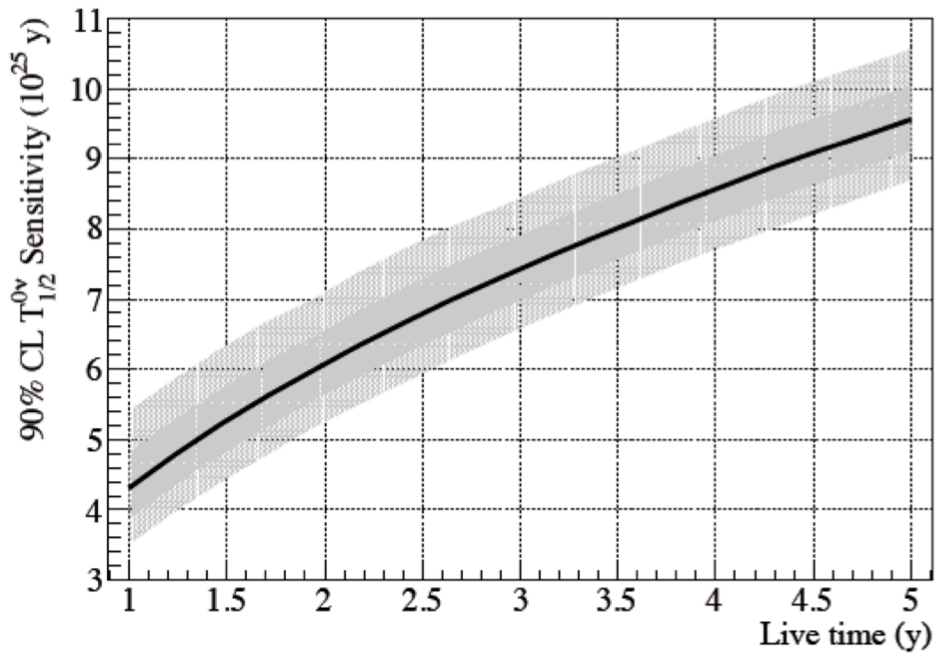
Spectrum Plot



Spectrum inputs

- 3.5m (20%) fiducial volume cut
- 5 years data taking
- >99.99% efficient ^{214}Bi tag
- 98% efficient internal ^{208}Tl tag
- Factor 50 reduction in $^{212}BiPo$ (pileup)
- Negligible cosmogenics
- $m_{\beta\beta}$ = 200meV

Sensitivity 0.3% loading



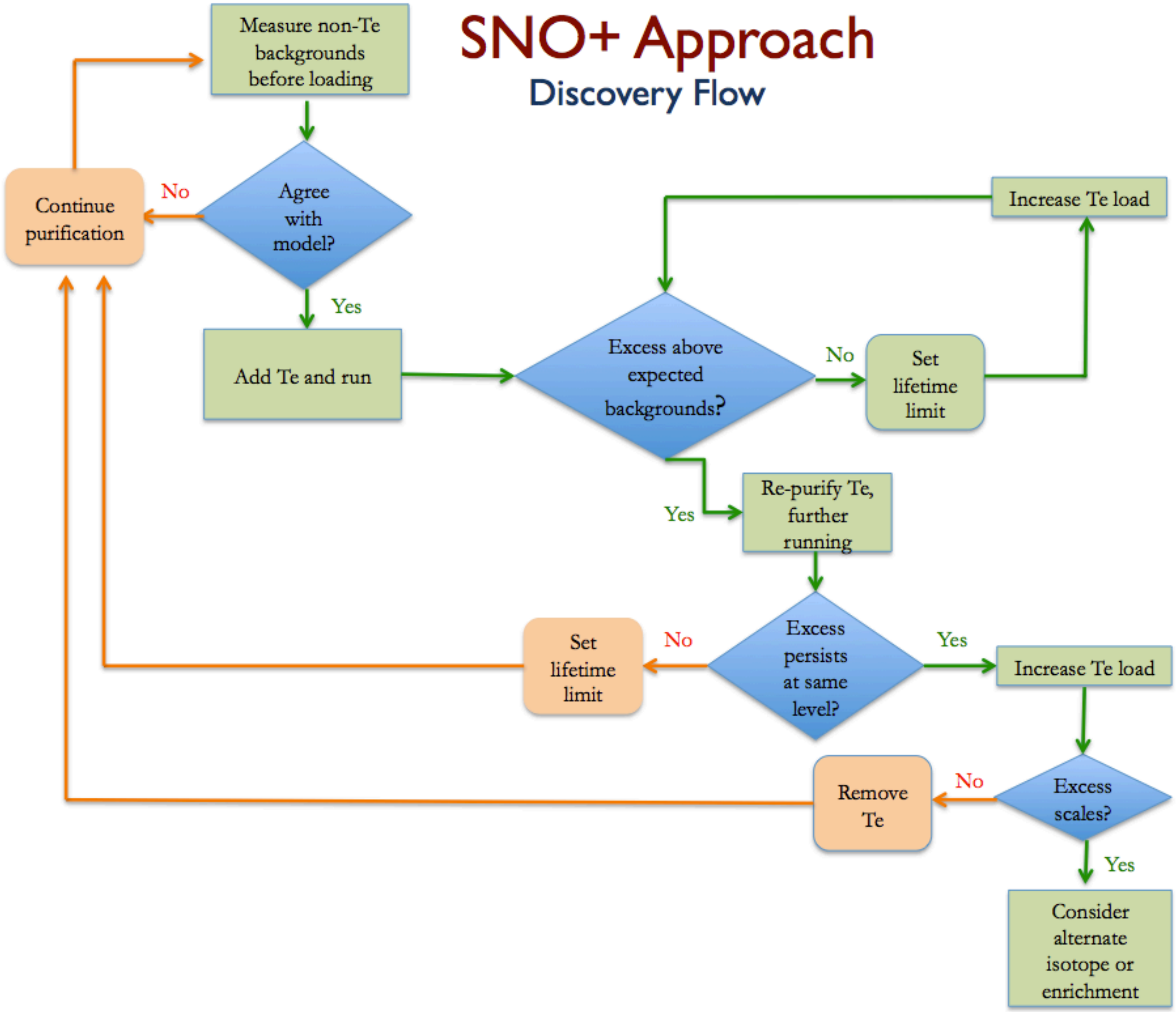
3 years at 0.3% loading -> ~7.5×10^{25} years

5 years at 0.3% loading -> ~9.5×10^{25} years

Cuoricino $T_{1/2} > 2.8 \times 10^{24}$ years at 90% C.L -> <300-710meV, depending on the adopted nuclear matrix element evaluation

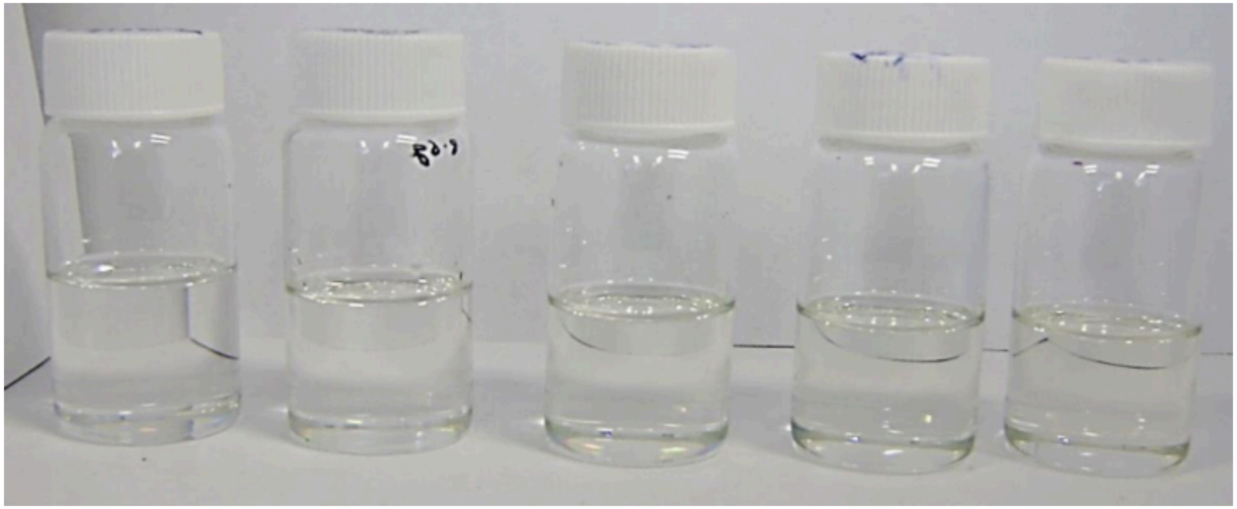
arXiv:1012.3266 [nucl-ex]

What if we see a bump?



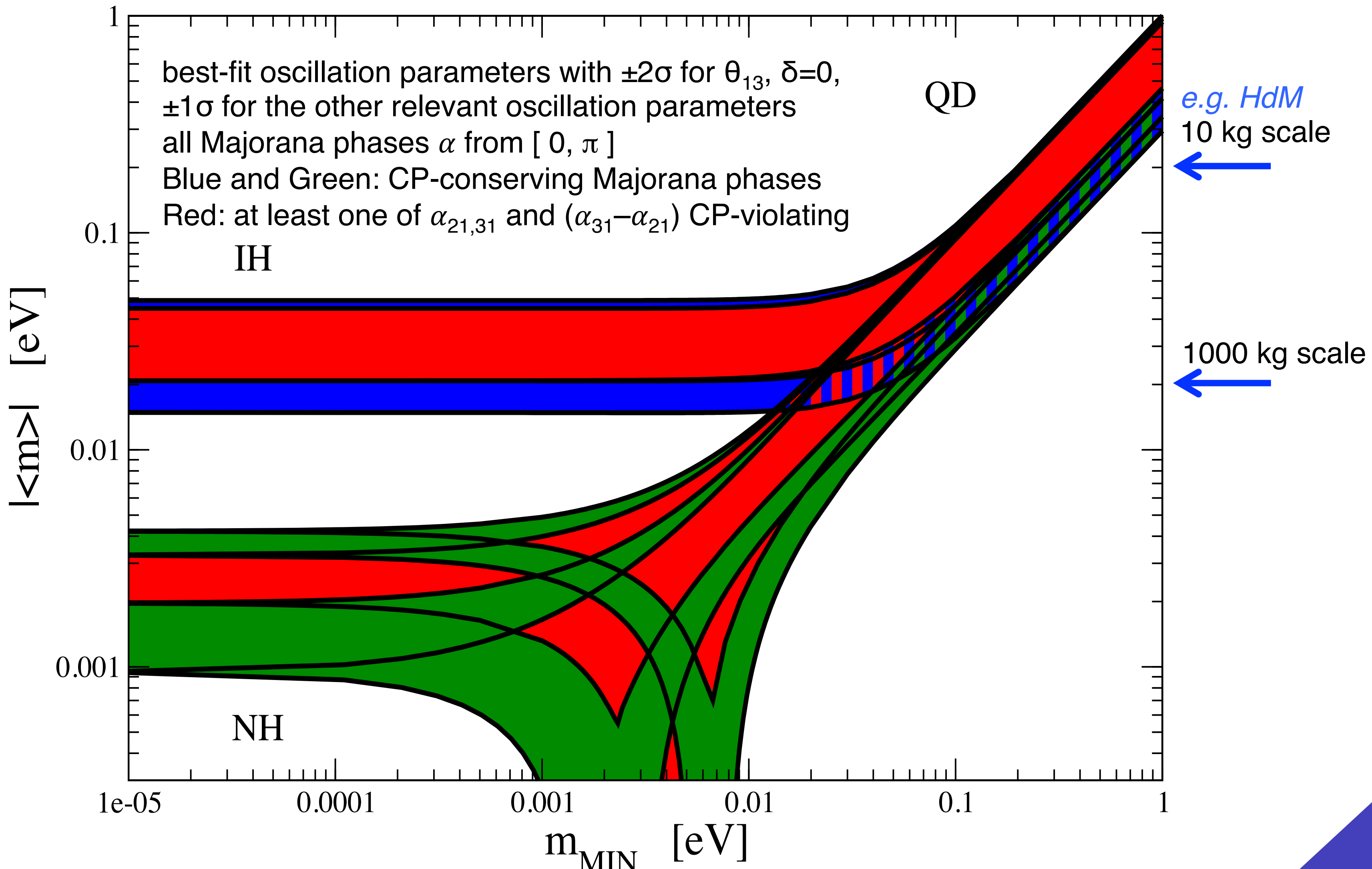
Percent Loading of Tellurium is Feasible

- 0.3%, 0.5%, 1%, 3%, 5% (from left to right)

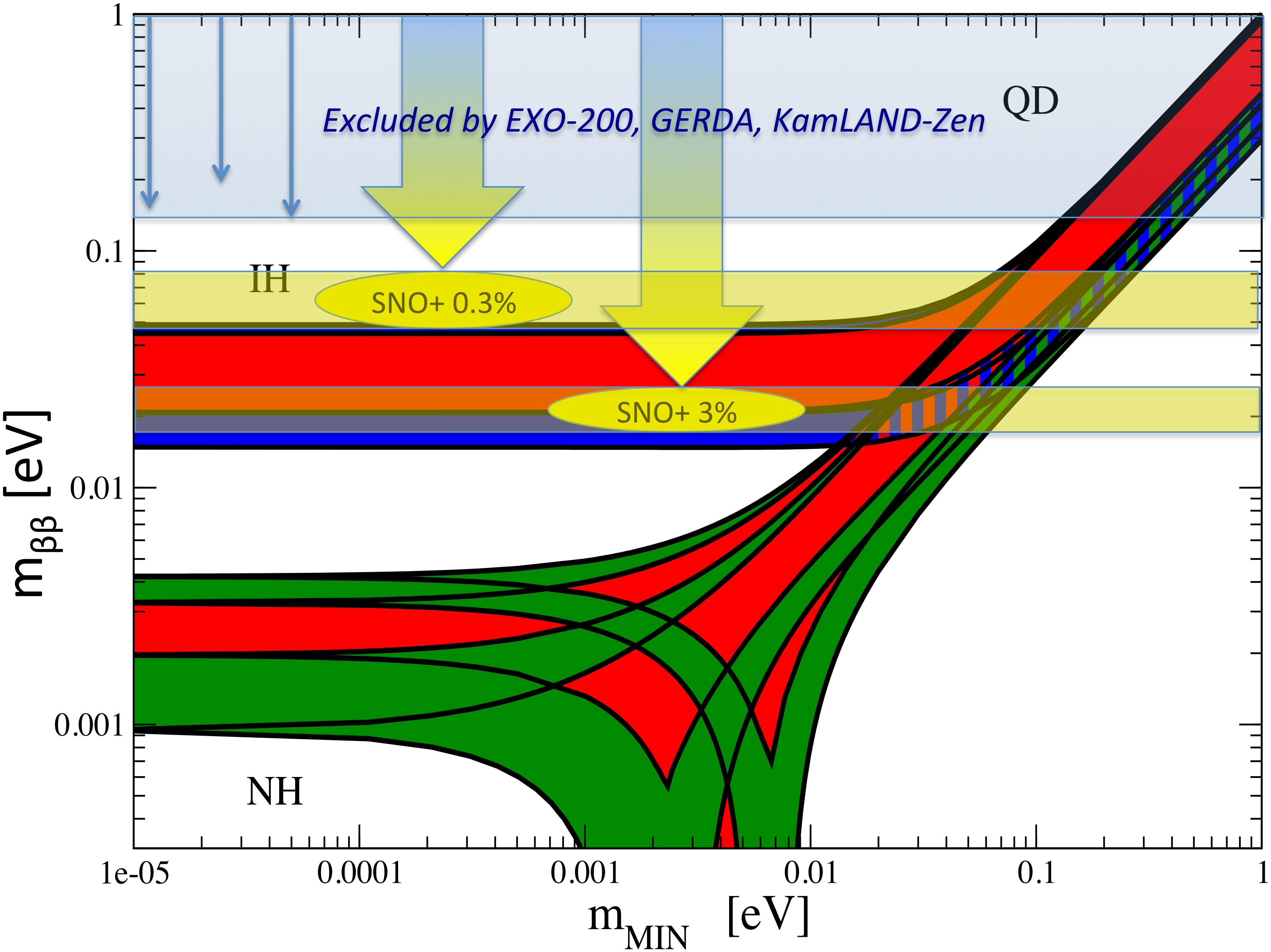


- 3% Te in SNO+ Phase II DBD corresponds to 8 tonnes of ^{130}Te *isotope* (cost for this much tellurium is only ~ $15M)
- Contain isotope within a bag (KamLAND-Zen style)?
- Upgrade SNO+ PMT array – High QE PMTs?

$\langle m_{\beta\beta} \rangle$ and the Neutrino Mass Hierarchy



updated figure by S. Pascoli in RPP 2013 "Neutrino Mass, Mixing and Oscillations", originally in S. Pascoli and S. Petcov, PRD 77, 113003 (2008)



Excluded by EXO-200, GERDA, KamLAND-Zen
QD
IH
SNO+ 0.3%
SNO+ 3%
NH
1
0.1
0.01
0.001
1e-05
0.0001
0.001
0.01
0.1
1
$m_{\beta\beta}$ [eV]
m_{MIN} [eV]


Thank you for listening!

Backup slides

Status

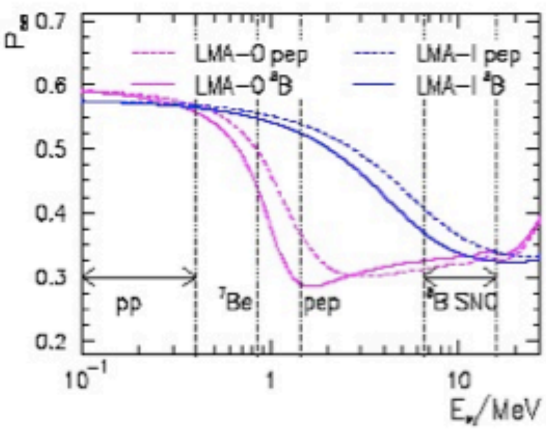
- now filling the SNO+ detector with water
- water-filled data taking starts in 2014
  - to study external backgrounds and detector optics
- float-the-boat test in the next few months
  - to demonstrate hold-down rope system operation at full buoyant load
- now installing scintillator purification plant process piping
- liquid scintillator fill to start in 2015
- installation of tellurium purification skid and Te purification in late 2015
- addition of Te to SNO+ liquid scintillator and DBD run in 2016

TimeScale

- 2014: water fill and water commissioning
  - nucleon decay physics
  - Backgrounds analysis
  - Supernovae neutrinos
- 2015: start liquid scintillator fill
  - background analysis
  - reactor- and geo- antineutrinos
  - Supernovae neutrinos
  - low energy solar neutrinos
- 2016: 0.3% Te loading
  - neutrinoless double beta decay
  - reactor- and geo- antineutrinos
  - Supernovae neutrinos

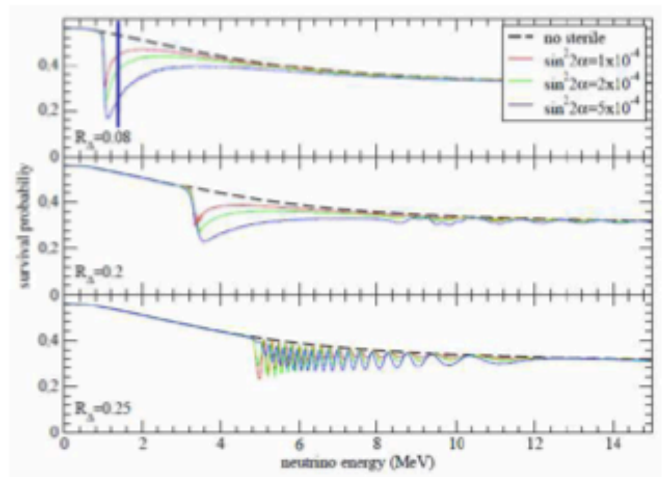
Pep neutrinos – test for new Physics

Non-standard interactions (flavour changing NC)



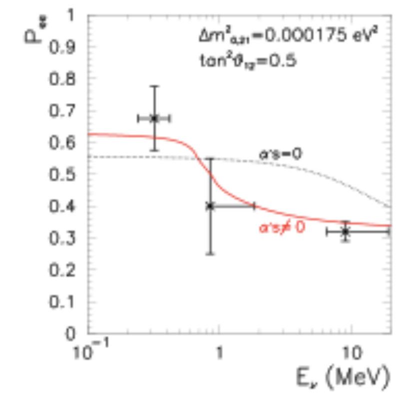
Friedland, Lunardini, Peña-Garay, PLB 594, (2004)

Sterile Neutrinos



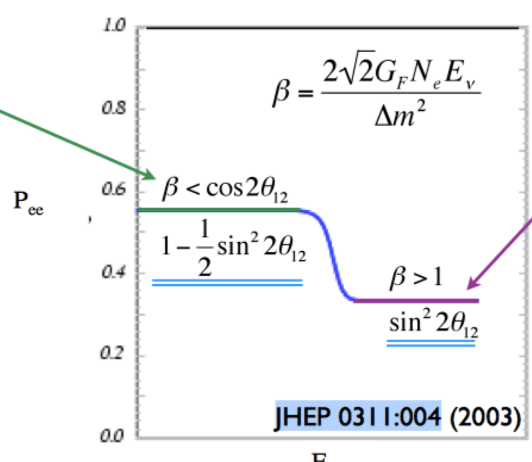
Holanda & Smirnov PRD 83 (2011) 113011

Mass varying neutrinos (MaVaNs)



M.C. Gonzalez-Garcia, M. Maltoni
Phys Rept 460:1-129 (2008)

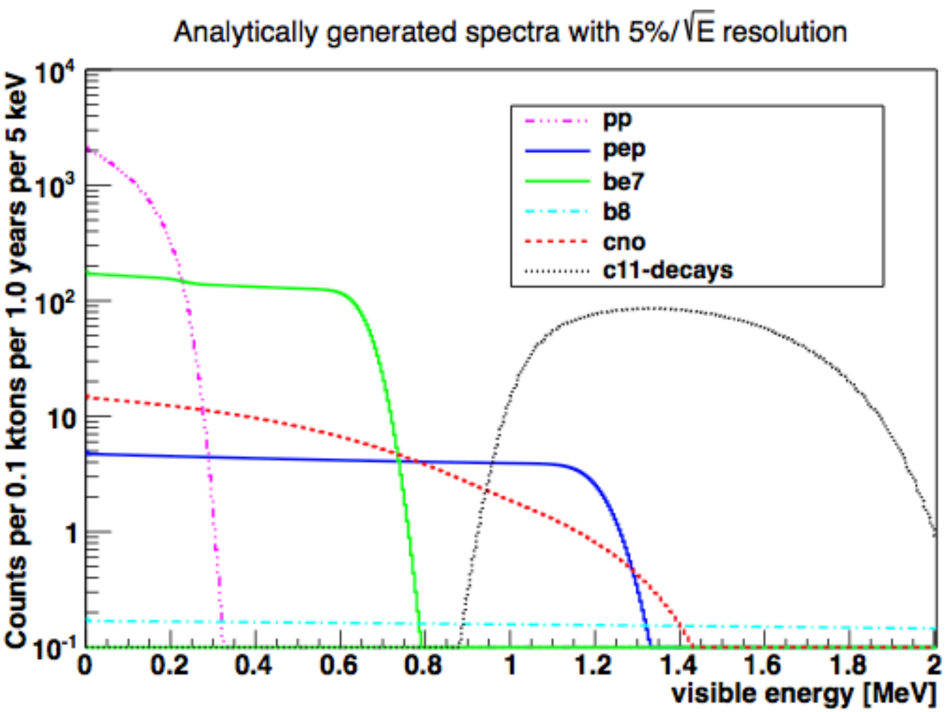
Low energy (<1MeV):
Phase-averaged vacuum oscillations



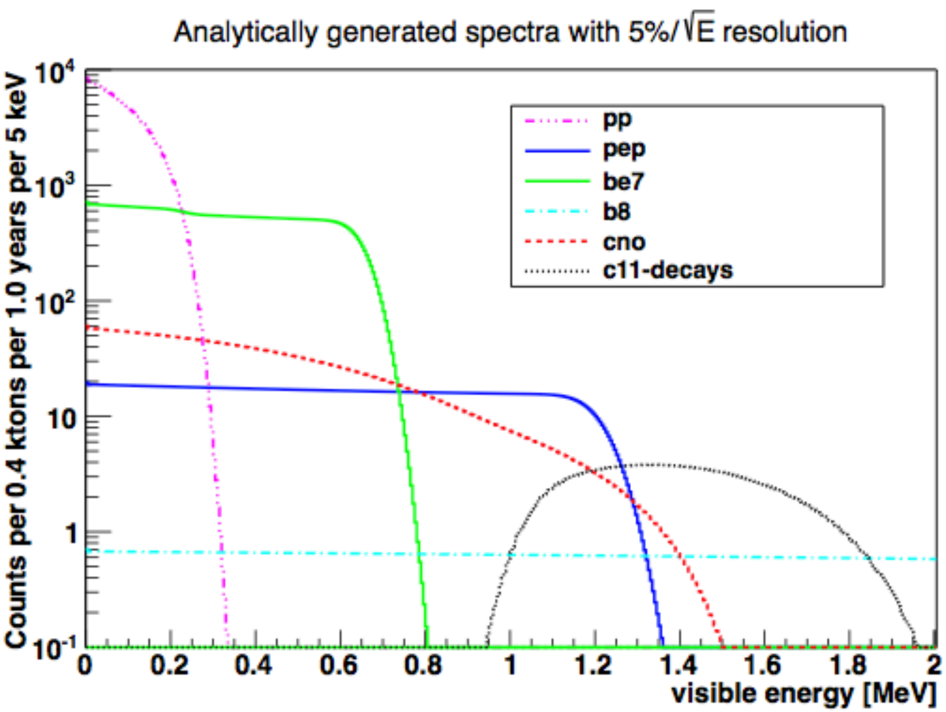
'High' energy (>5MeV):
Matter-dominated resonant conversion

A matter of depth

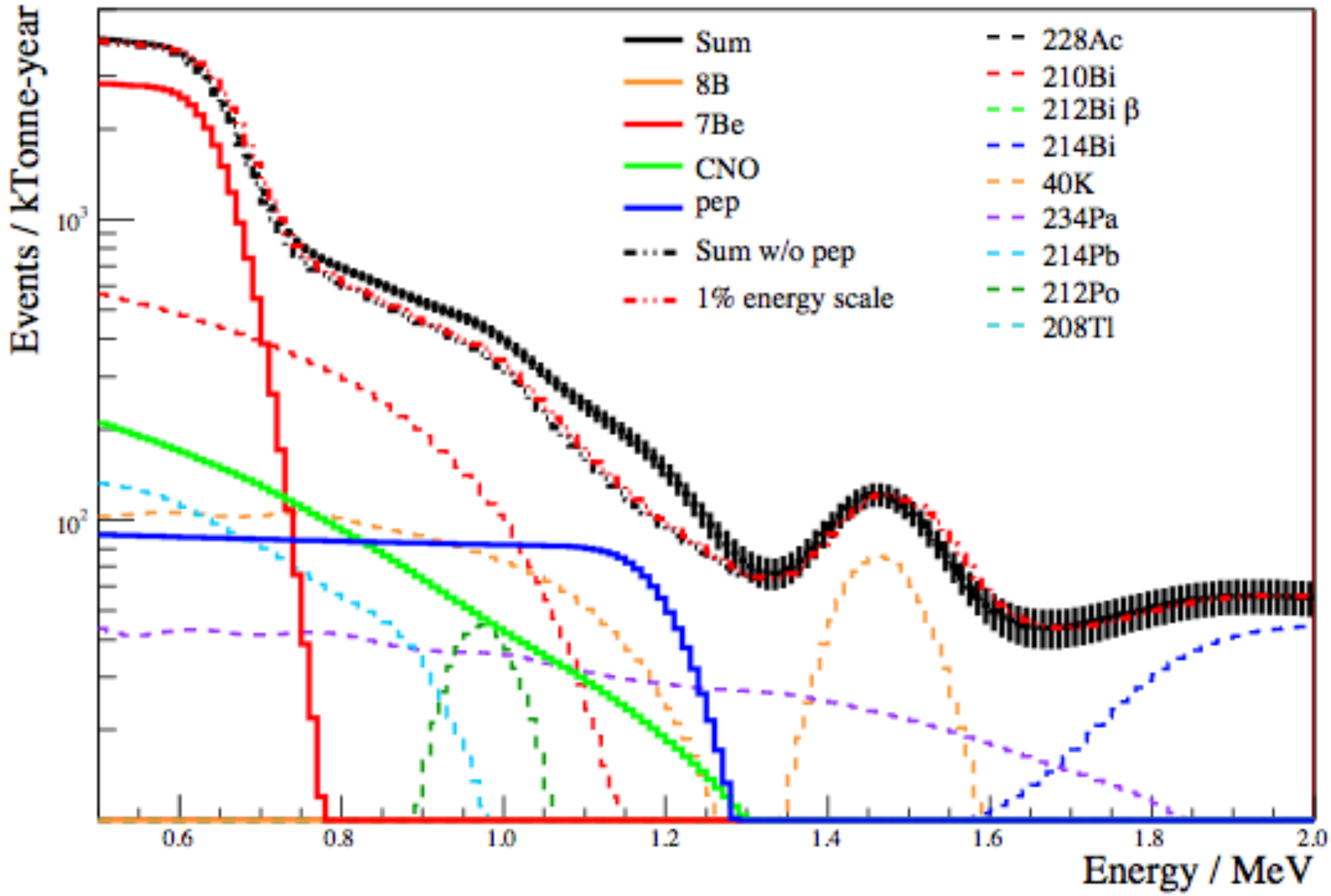
Borexino



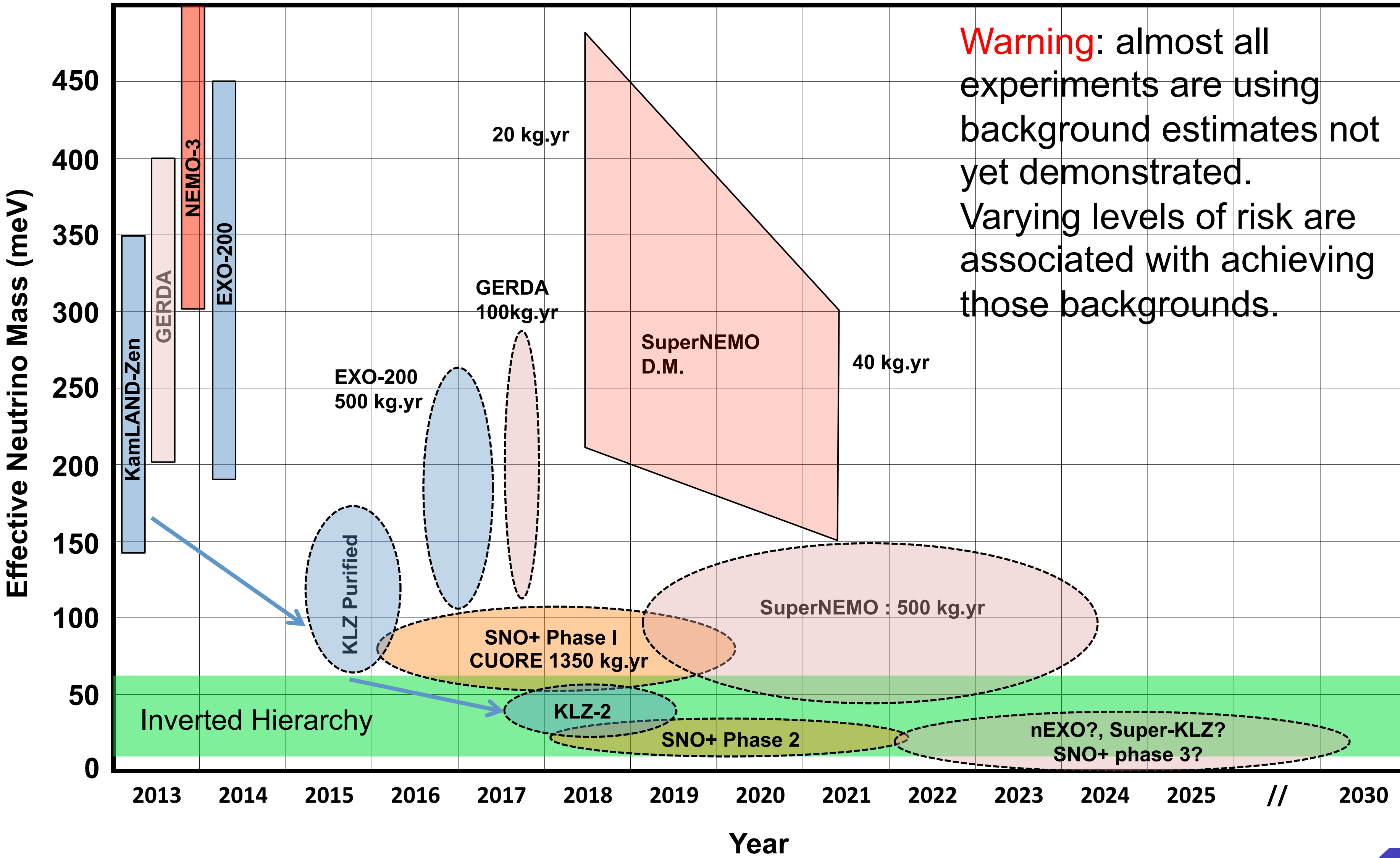
SNO+



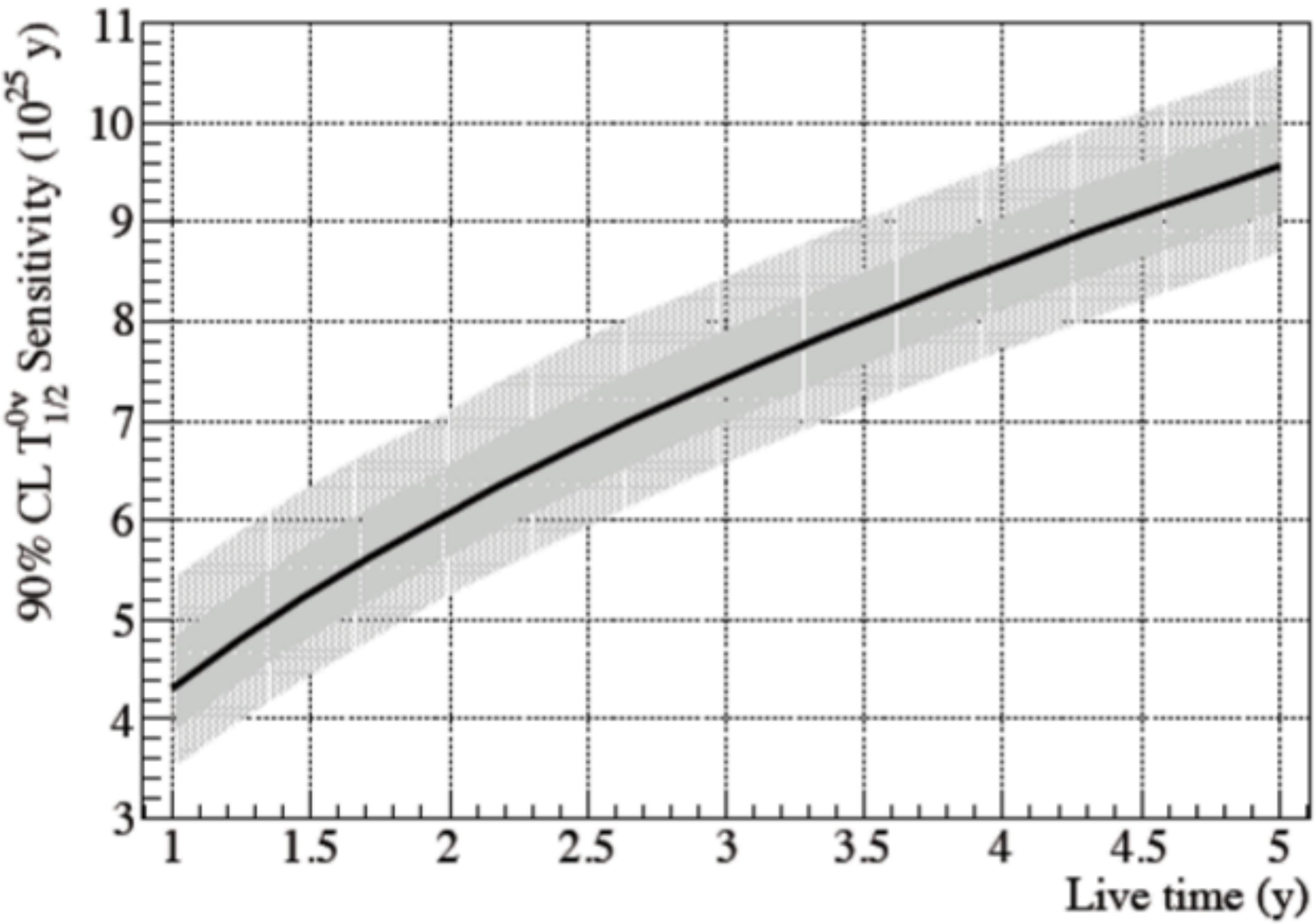
SNO+ solar signals



Comparing Sensitivities



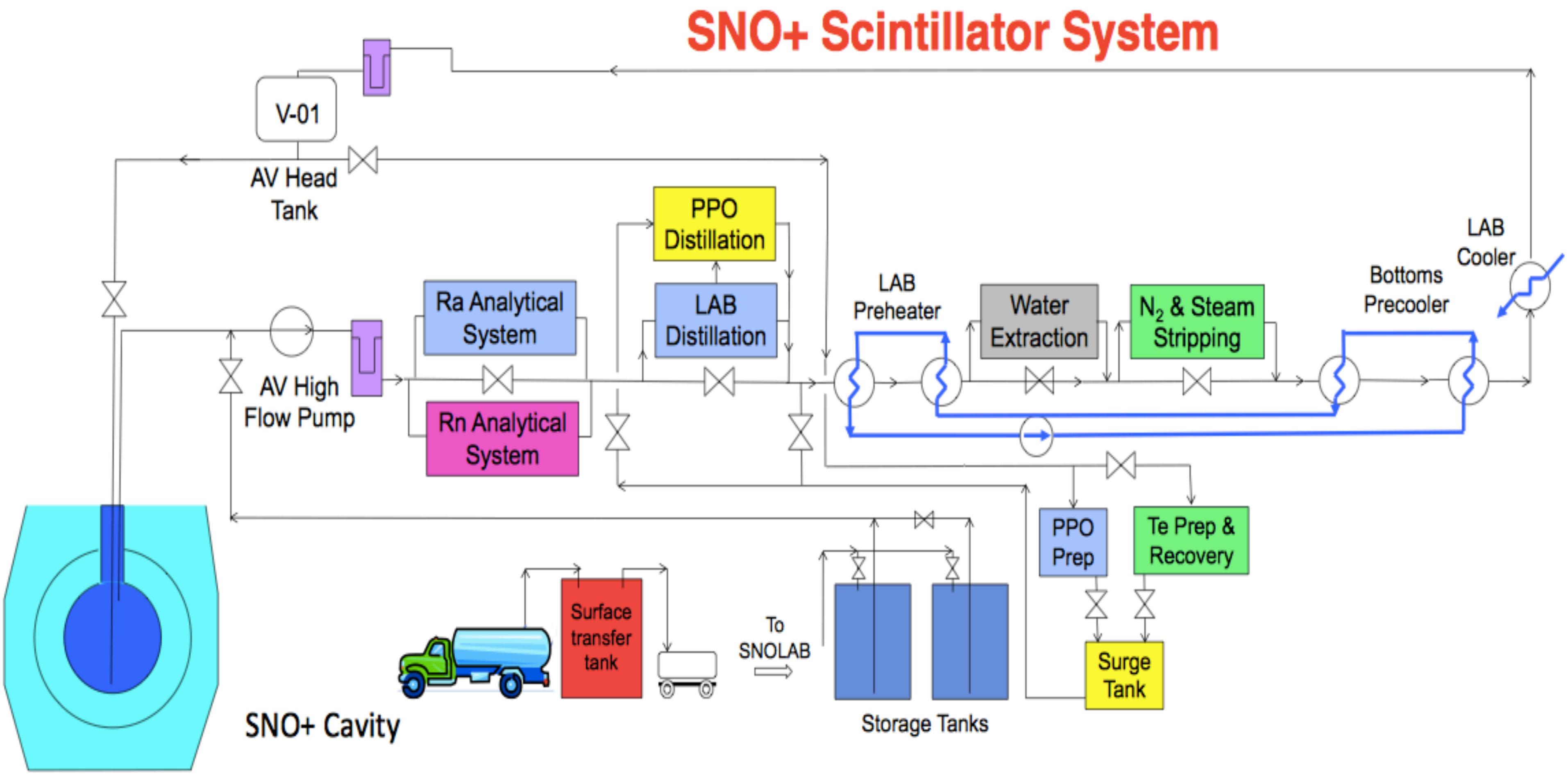
Sensitivity 0.3% loading



Half-life sensitivity @90%CL

Solar Neutrinos

- SNO+ has decided to prioritise $0\nu\beta\beta$
- Radon daughters have accumulated on the surface of the AV over the last few years in a significant way. If these leach into the scintillator, the purification system has the capability to remove them.
- However, depending on the actual leach rate, that removal might be inefficient and the ^{210}Bi levels in the scintillator too high for a pep/CNO solar neutrino measurement without further mitigation.
- Mitigation could include enhancing online scintillator purification, draining the detector and sanding the AV surface to remove radon daughters, or deploying a bag.
- $0\nu\beta\beta$ and low-energy ^{8}B solar neutrino measurements are not affected by these backgrounds


SNO+ Scintillator System
V-01
AV Head Tank
PPO Distillation
LAB Distillation
Ra Analytical System
Rn Analytical System
AV High Flow Pump
LAB Preheater
Water Extraction
N2 & Steam Stripping
Bottoms Precooler
LAB Cooler
PPO Prep
Te Prep & Recovery
Surge Tank
Surface transfer tank
To SNOLAB
Storage Tanks
SNO+ Cavity