The SNO+ Experiment

Overview and status

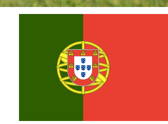
P G Jones – On behalf of the SNO+ collaboration

Collaboration

Queen's
Alberta
Laurentain
SNOLAB
TRIUMF

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

Oxford,
Sussex
QMUL
Liverpool
Lancaster



LIP Lisboa
LIP Coimbra

TU Dresden

SNO to SNO+

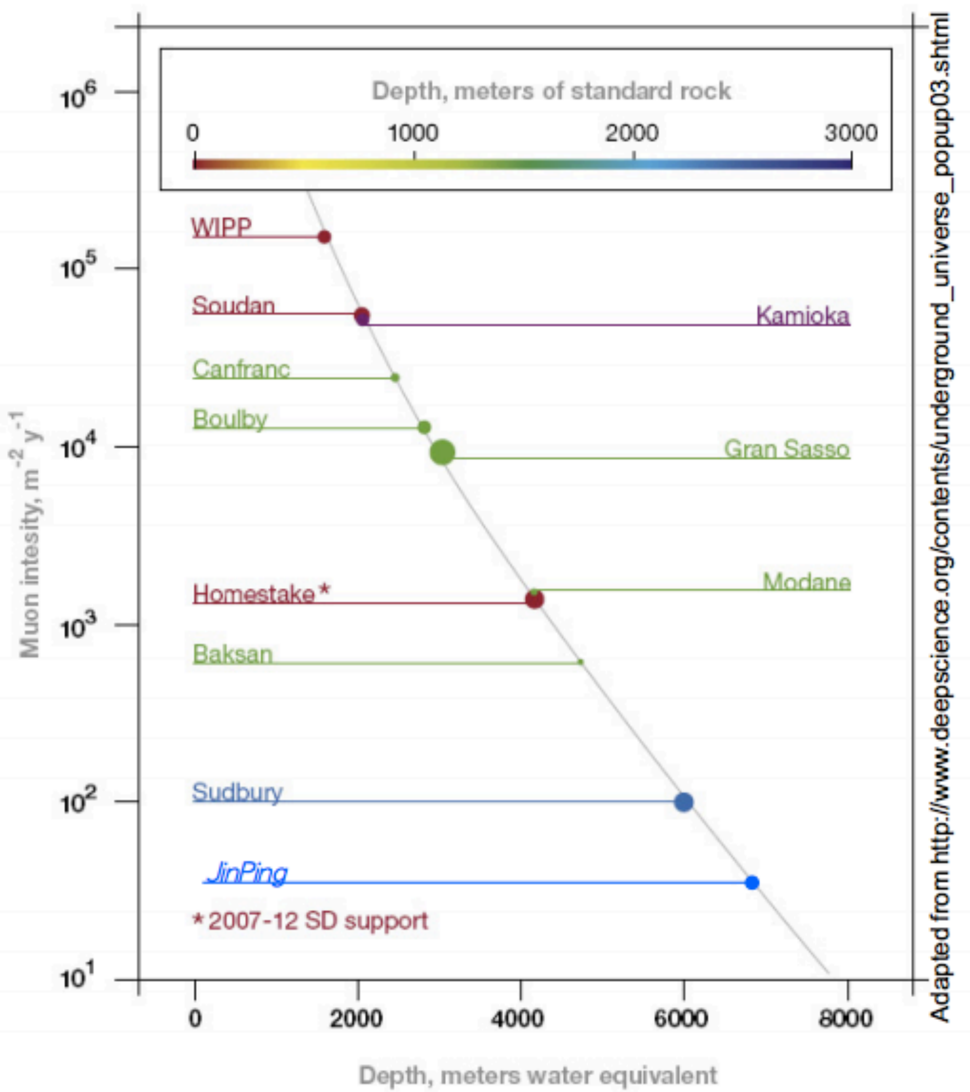
- D_2O -> Liquid Scintillator
- Upgrade and repair the SNO detector

SNO+ Aims

Water phase	Te loaded phase	Scintillator phase
Nucleon decay	$0\nu\beta\beta$	Solar neutrinos
Reactor neutrinos	Reactor neutrinos	Reactor neutrinos
Supernova	Geo neutrinos	Geo neutrinos
	Supernova	Supernova

Time →

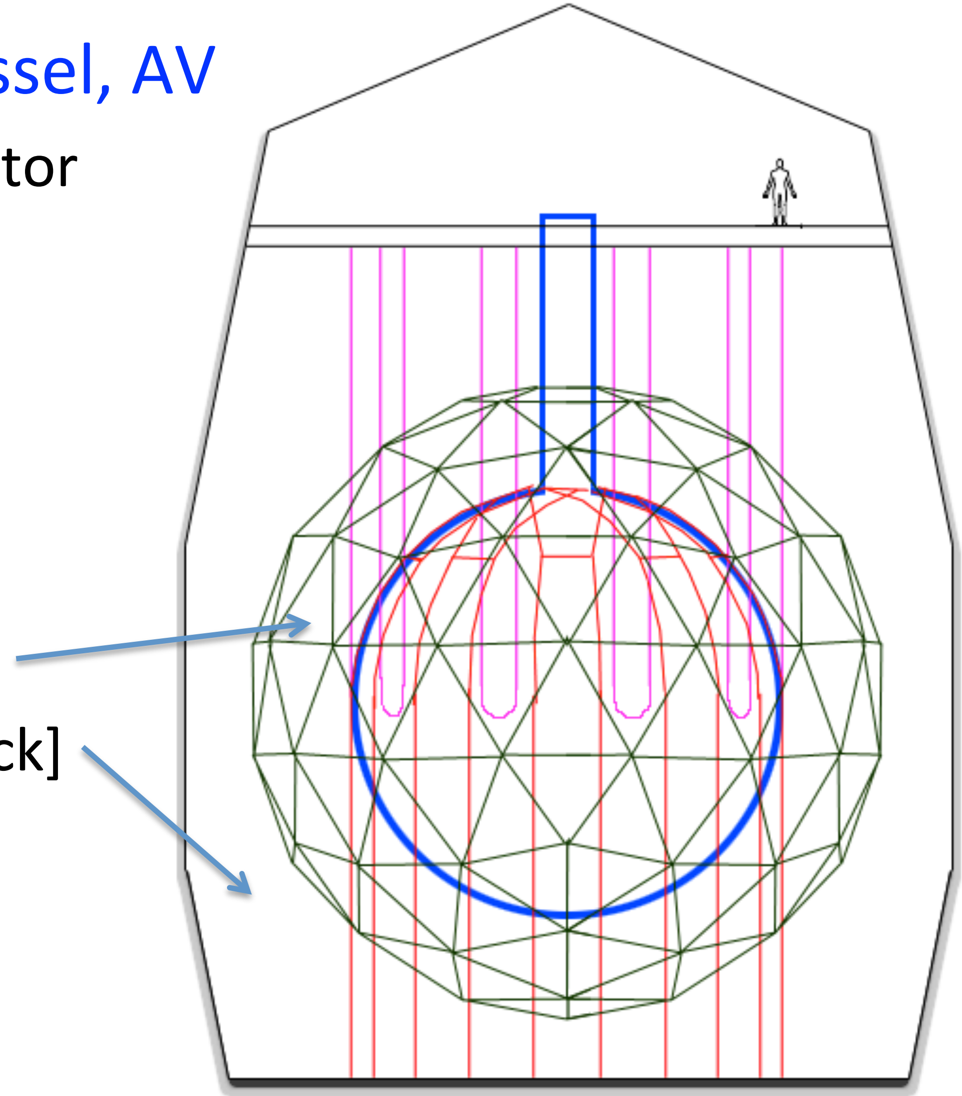
SNOLAB



- 6070mwe
- ~70 muons/day
- Class-2000 clean room

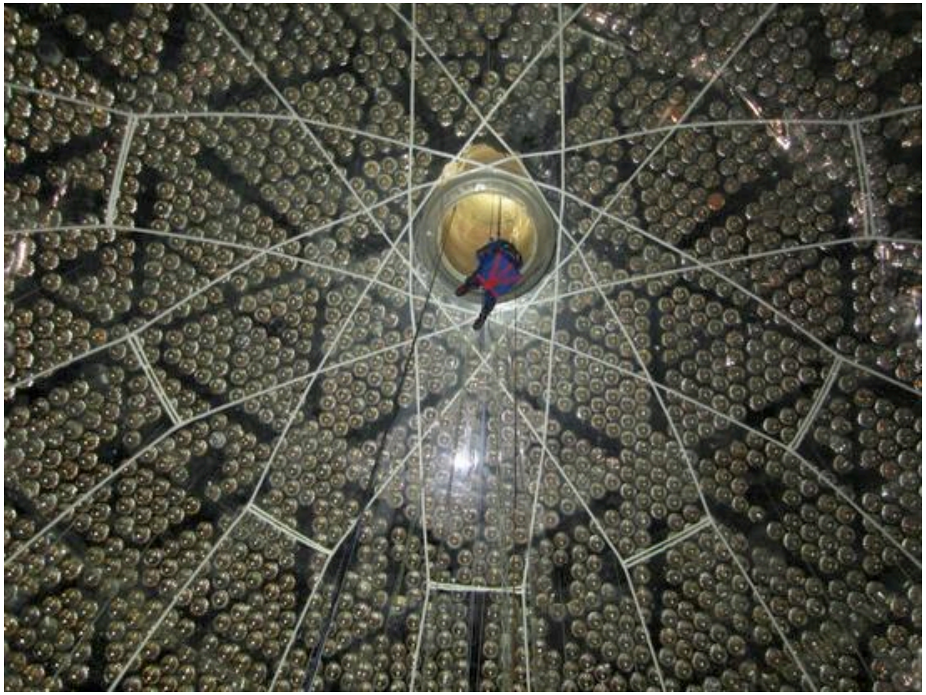
Detector

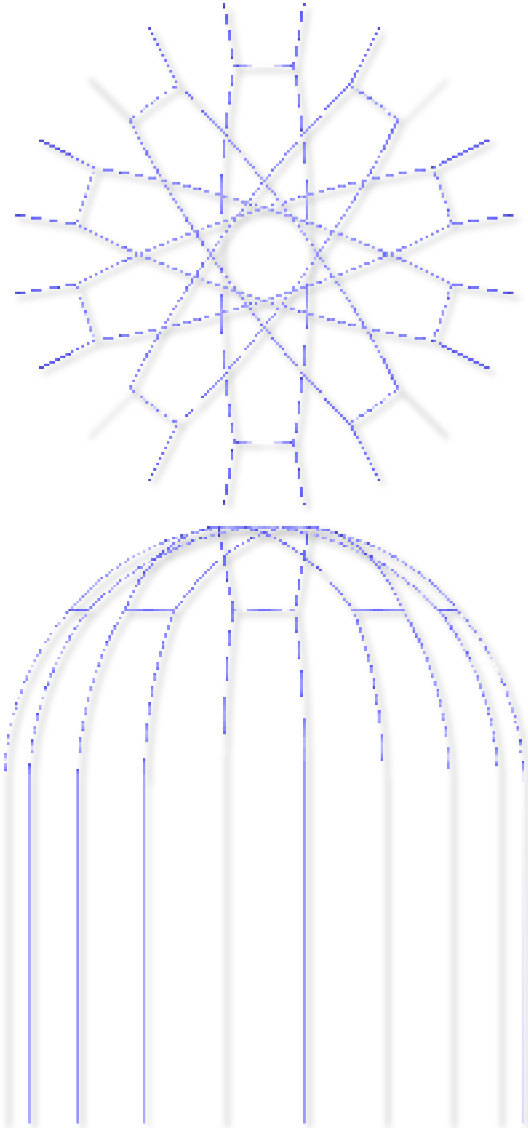
- 12m diameter acrylic vessel, AV
  - 780 tonnes liquid scintillator
- ~9500 PMTs
  - 8” Hamamatsu R1408
  - 54% coverage
- H_2O shielding
  - 1.7 Kt internal [AV, PSUP]
  - 5.3 Kt external [PSUP, Rock]
- Hold up ropes
- Hold down ropes



Ropes

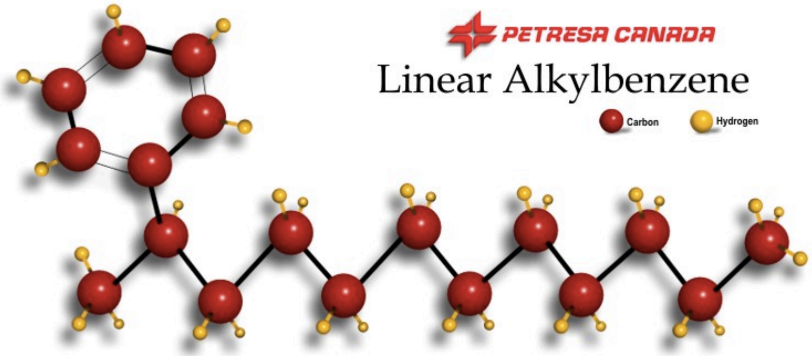
- New hold down (pictured)
  - ø ~40mm Tensylon
- Replaced hold up
  - ø ~20mm Tensylon





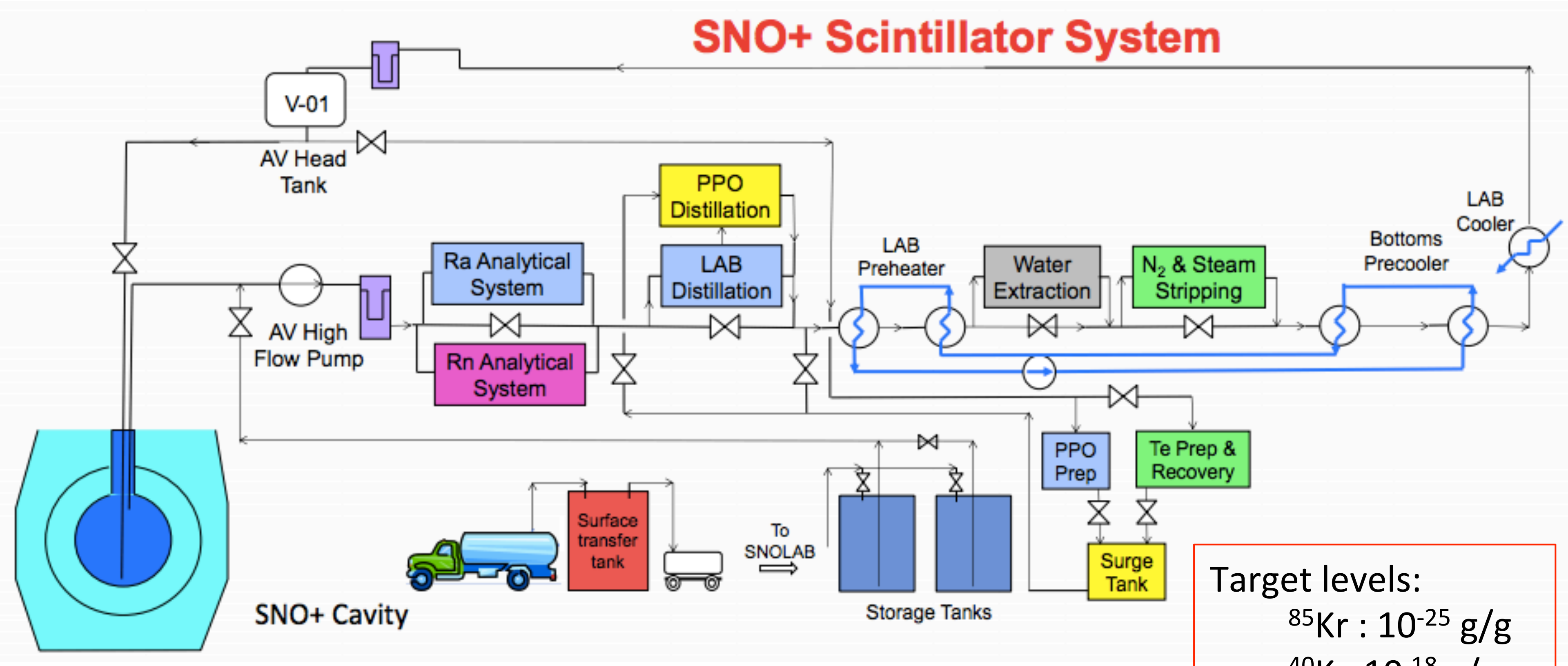
Scintillator

- Linear alkylbenzene, LAB
  - + 2g/L fluor 2,5-diphenyloxazole, PPO



- Chemical compatibility with acrylic
- High light yield (~10,000 optical photons/MeV)
- Low scattering, Good optical transparency
- Fast decay (different for betas and alphas)
- High flash point 140°C, Boiling point 278-314°C
- Low toxicity
- Environmentally safe, Inexpensive
- Low solubility in water 0.041 mg/L

Scintillator purification

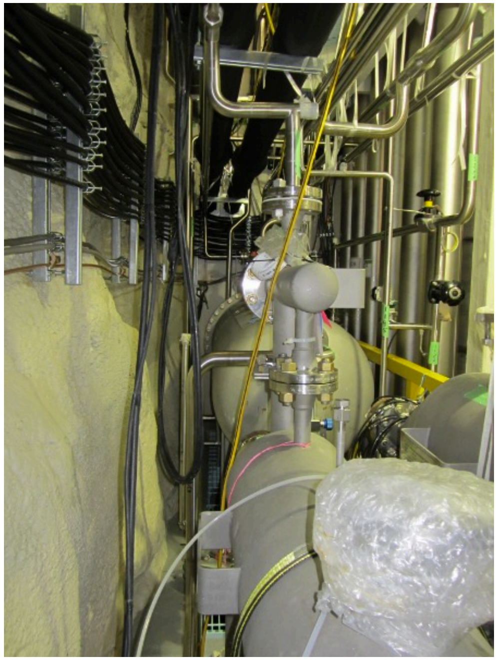


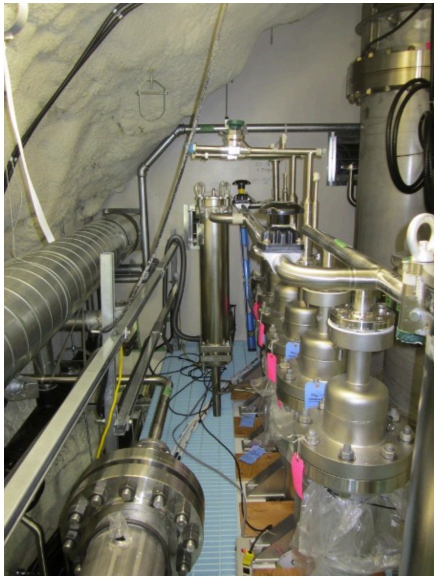
Target levels:

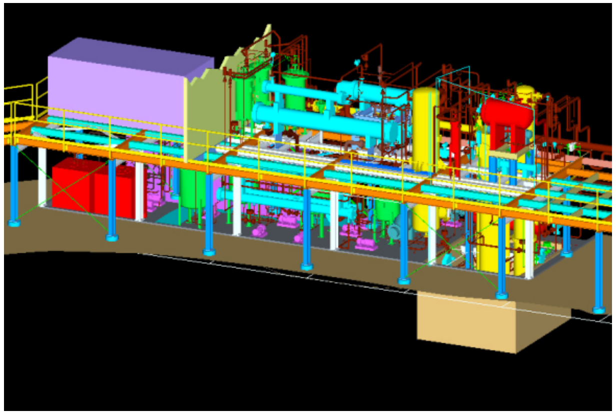
- ^{85}Kr : 10^{-25} g/g
- ^{40}K : 10^{-18} g/g
- ^{39}Ar : 10^{-24} g/g
- U : 10^{-17} g/g
- Th : 10^{-18} g/g

Scintillator plant

- Completion estimated fall 2015

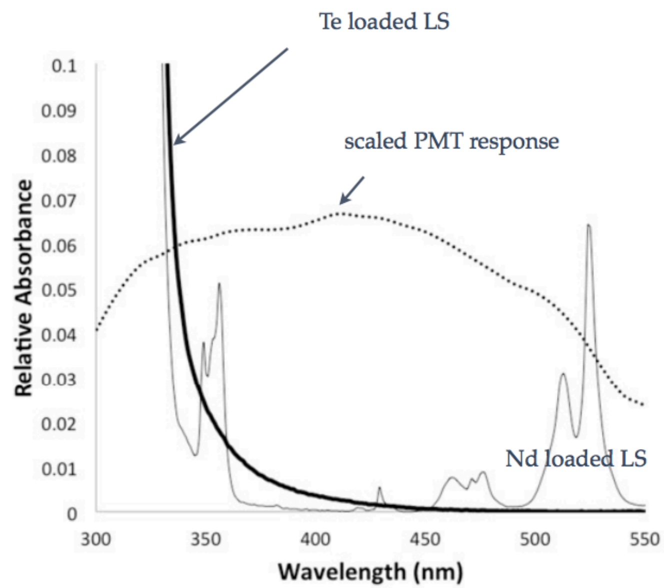


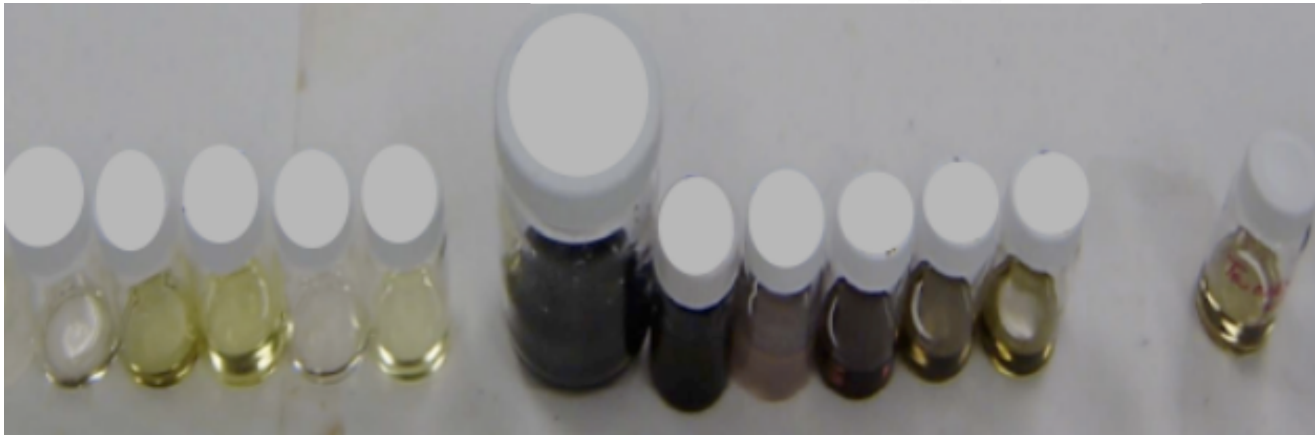


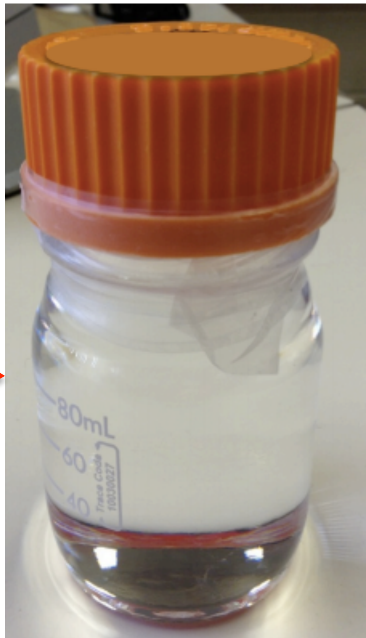


Isotope

Te







Carboxylate-based organometallic complex

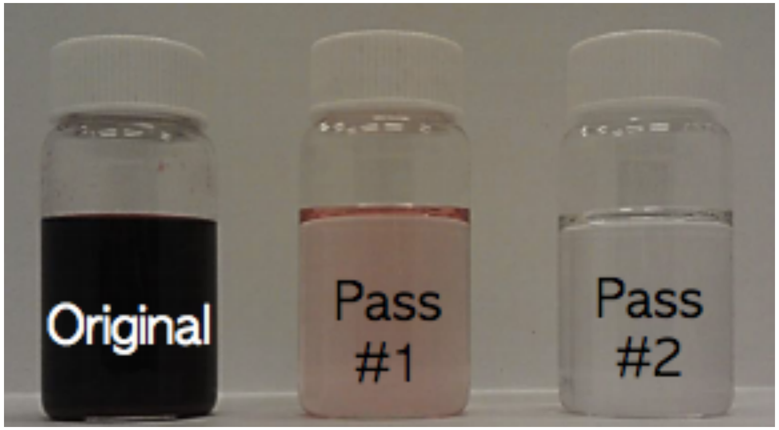
Isotope purification

- Above ground
  - Dissolve $Te(OH)_6$ in water
  - Re-crystalize using nitric acid
  - Rinse with ethanol

  10^4 reduction

- Below ground
  - Dissolve in 80˚C water
  - Thermally re-crystalize
  - 50% yield

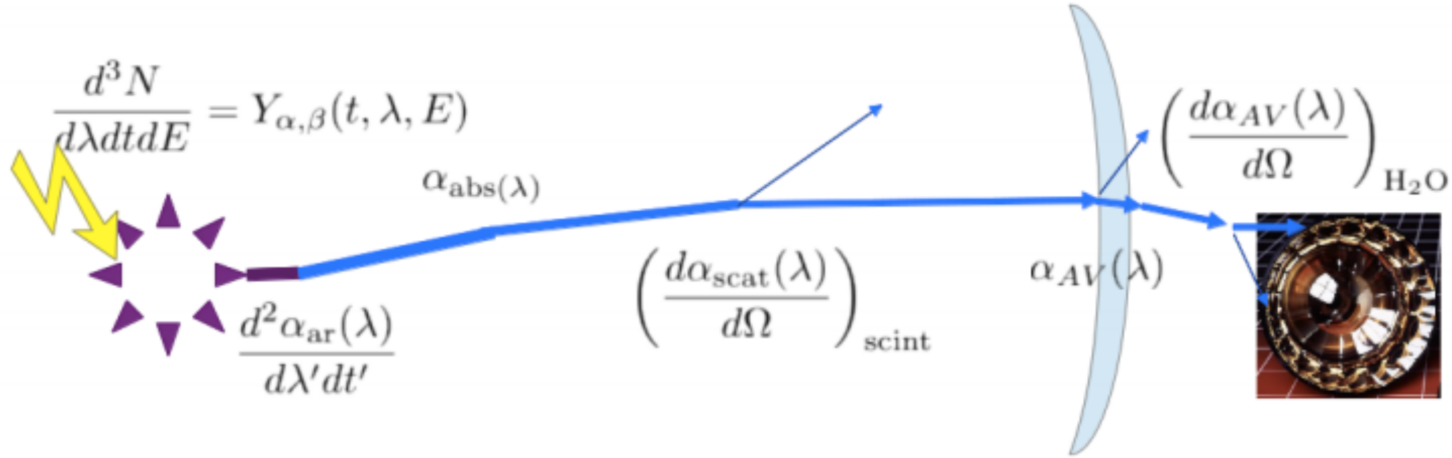
  10^2

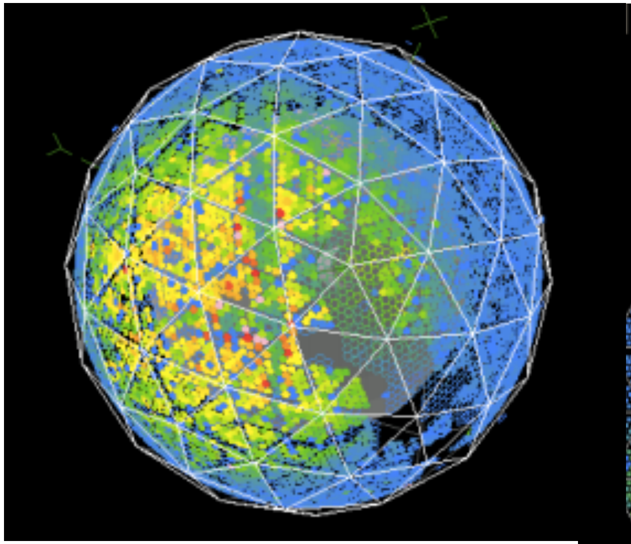


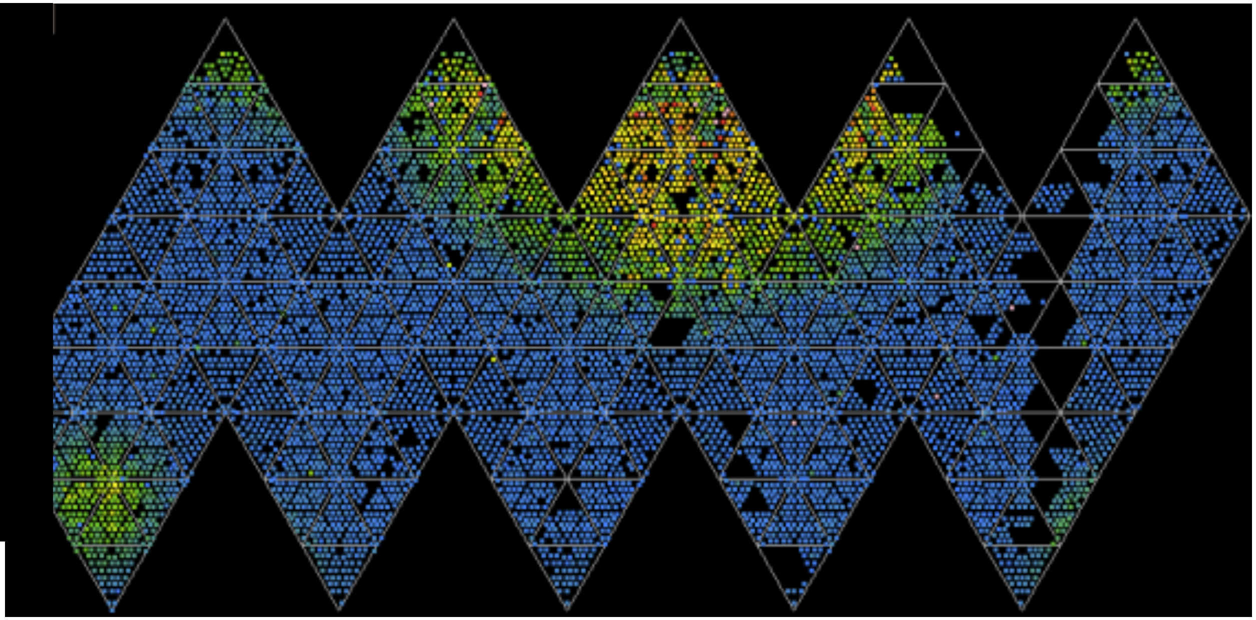
^{60}Co spike test

Calibration

Brief overview



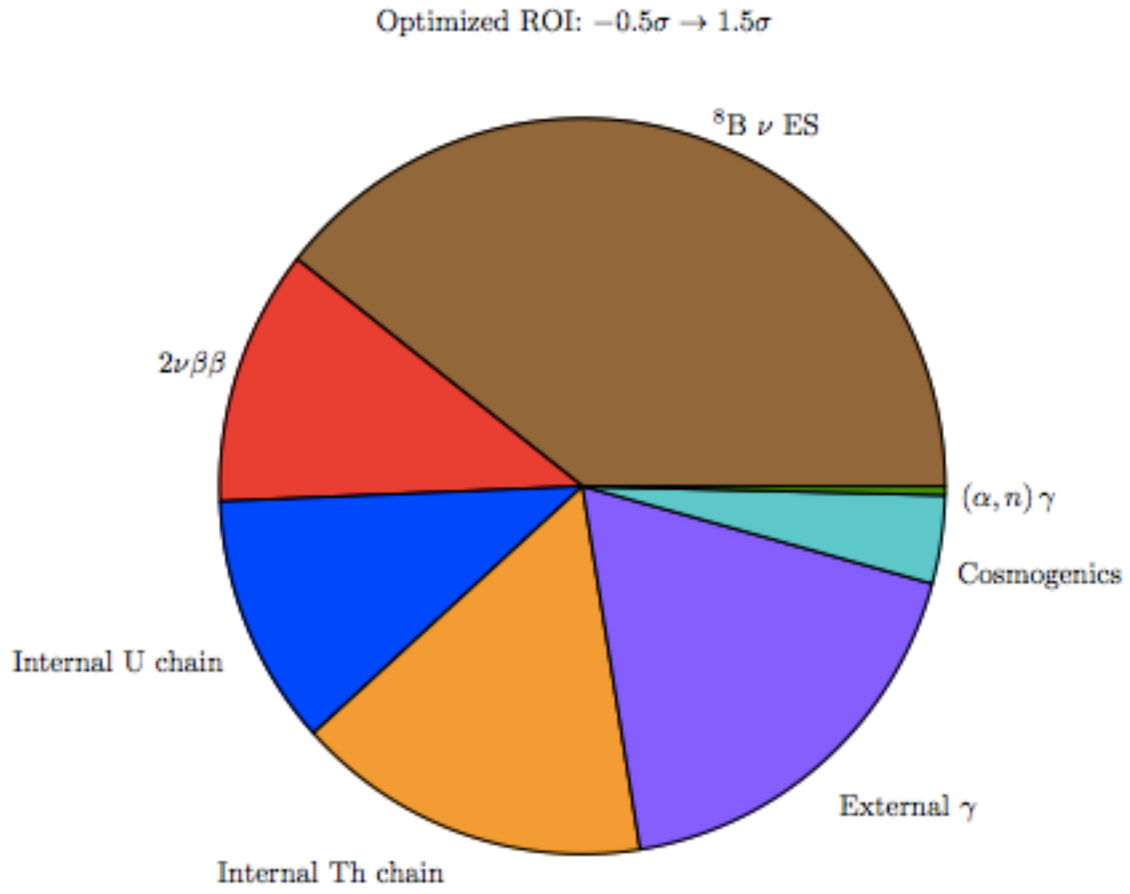




Backgrounds

As predicted using the SNO+ Monte Carlo

- 18.6 events/year



Backgrounds

Cosmogenic

- Cosmogenic activation ^{nat}Te
  - At sea level
- Purification reduction ~ 10^4
- Expect negligible background
  - In ROI

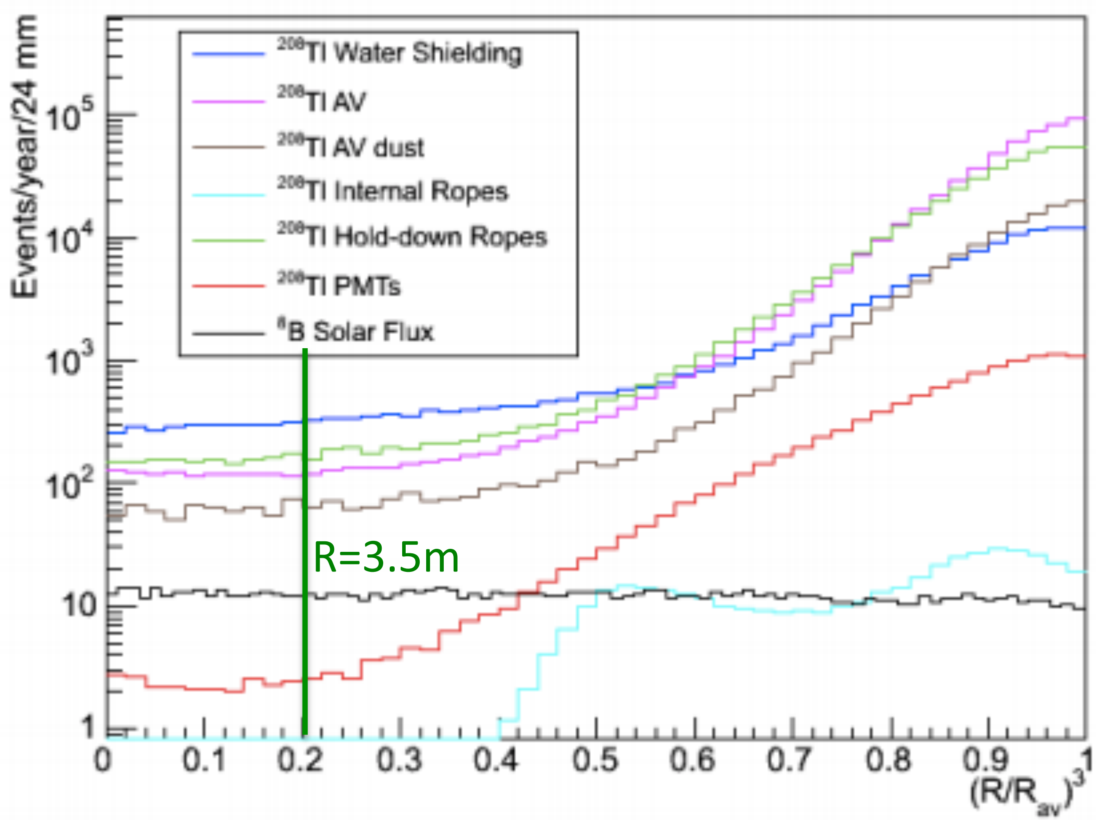
Element	Reduction Factor	Assay Technique
Stage 1 Te purification, single-pass spike test		
Co	1492 ± 326	X-ray fluorescence
Sb	>243	
Sn	> 167	Auto-titration
Fe	> 100	X-ray fluorescence
Na	346	Auto-titration
Sc	> 165	X-ray fluorescence
Ge	> 333	X-ray fluorescence
Y	> 278	X-ray fluorescence
Zr	> 278	Auto-titration
Ag	> 278	X-ray fluorescence
Bi	348 ± 81	Th-228 tracer
Ra	397 ± 20	Th-228 tracer
Th	390 ± 19	Th-228 tracer
Stage 1 Te purification, double-pass spike test		
Co	3.7×10^5	X-ray fluorescence
Th		
Stage 2 (UG) Te purification, single-pass spike test		
Co	12	
Ag	> 20	
Zr	17	

V. Lozza, J. Petzoldt "Comogenic activation of a natural Tellurium target", http://dx.doi.org/10.1016/j.astropartphys.2014.06.008

Backgrounds

External γ

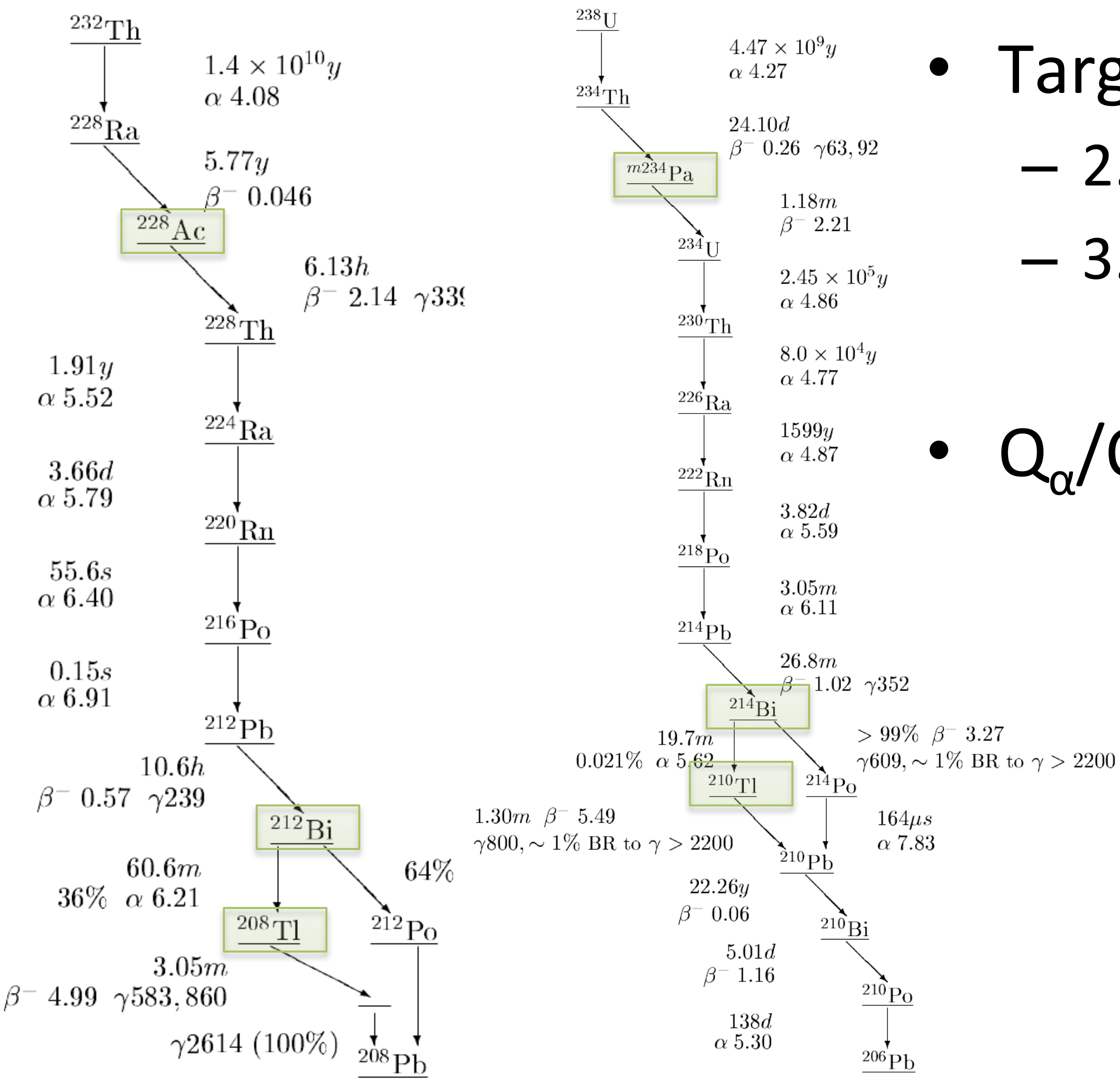
- 3.5m FV $(R/R_{AV})^3=0.2$
- 3.8 events/year predicted in ROI



^{208}Tl 2.6MeV γ example for full energy domain (no ROI cut)

Backgrounds

Internal ^{238}U and ^{232}Th

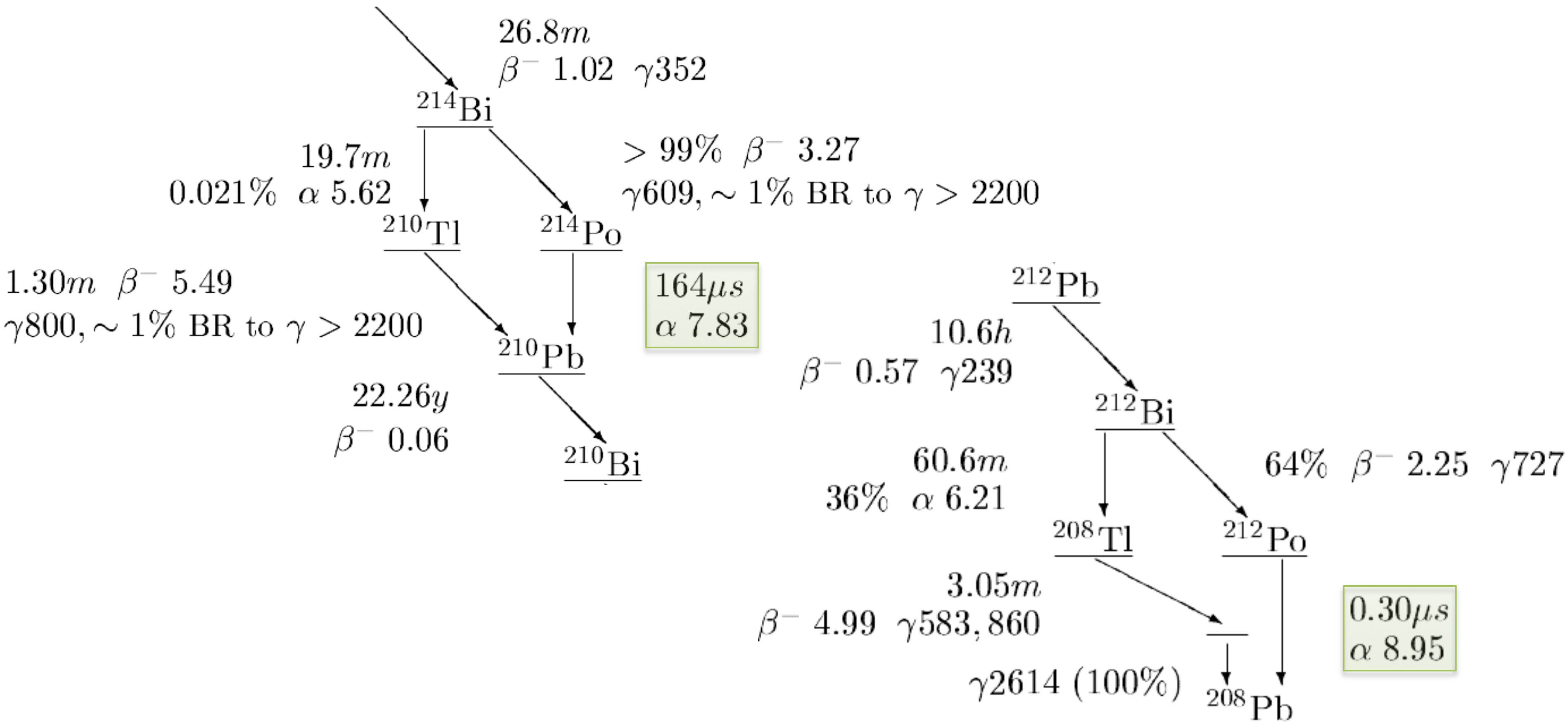


- Target levels
  - 2.5×10^{-15} g(^{238}U)/g(cocktail)
  - 3.0×10^{-16} g(^{232}Th)/g(cocktail)
- Q_α/Q_β ~ 1/10 (quenching)

Backgrounds

Bi -> Po

- Direct (in ROI) and pileup with Po (into ROI)

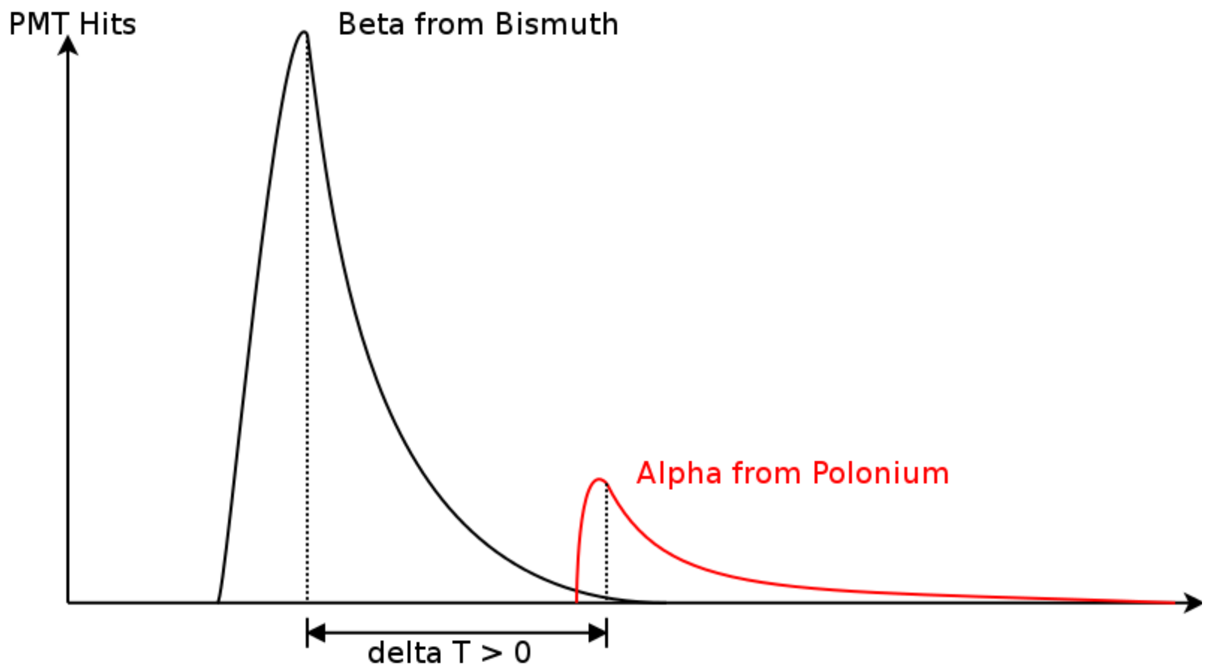


Background Rejection

Bi Po coincidence decays

- Tag Polonium alpha decay…

- …can then reject previous Bismuth events

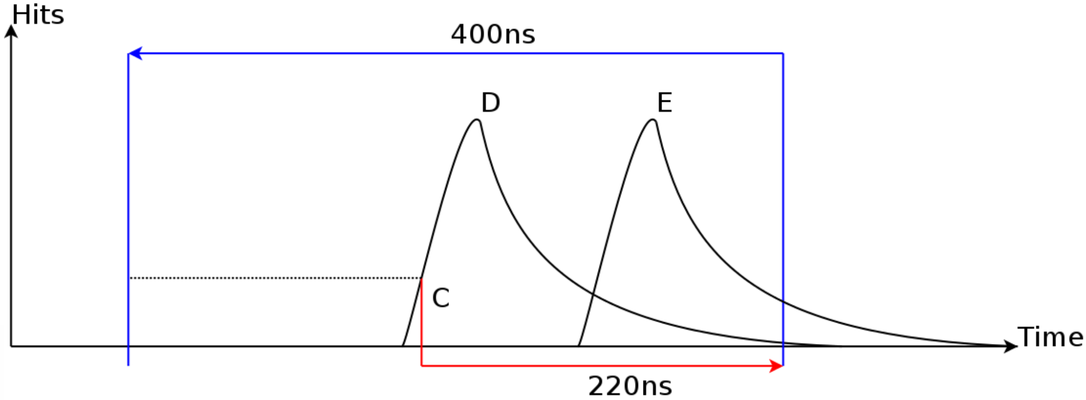


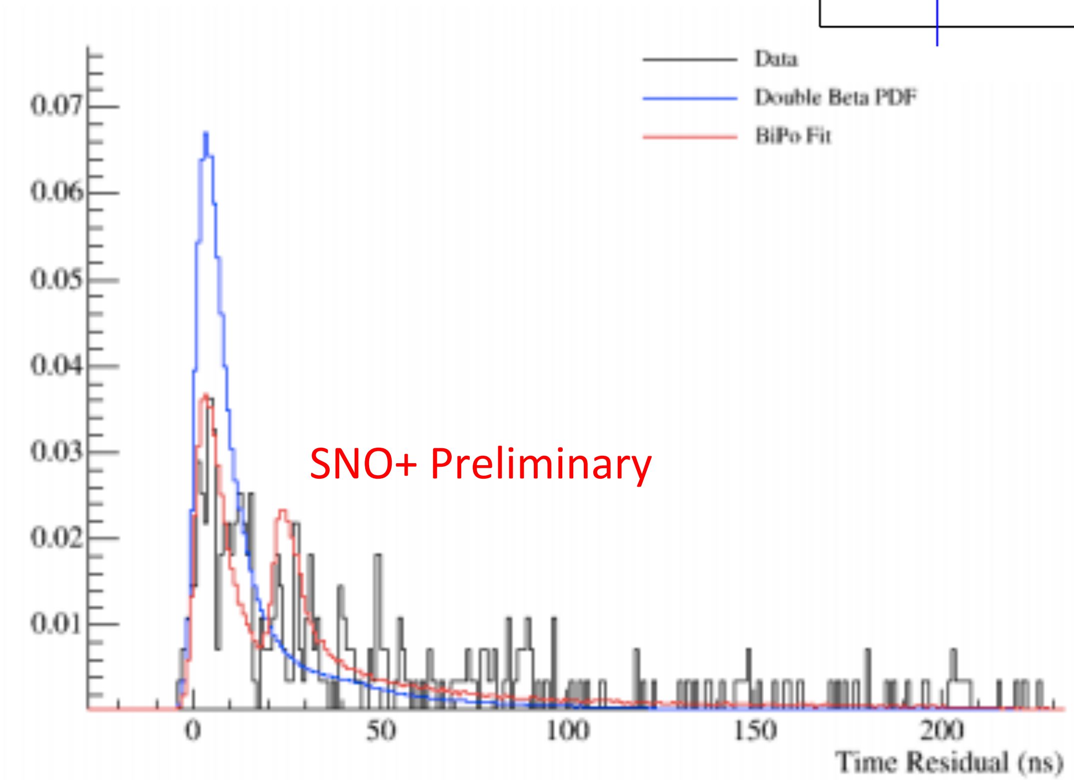
Hit time residuals

Backgrounds

Bi Po coincidence Pileup

Pileup and delayed coincidence-rejection factors:
214BiPo > 25000 rejection in ROI
212BiPo > 70 rejection in ROI

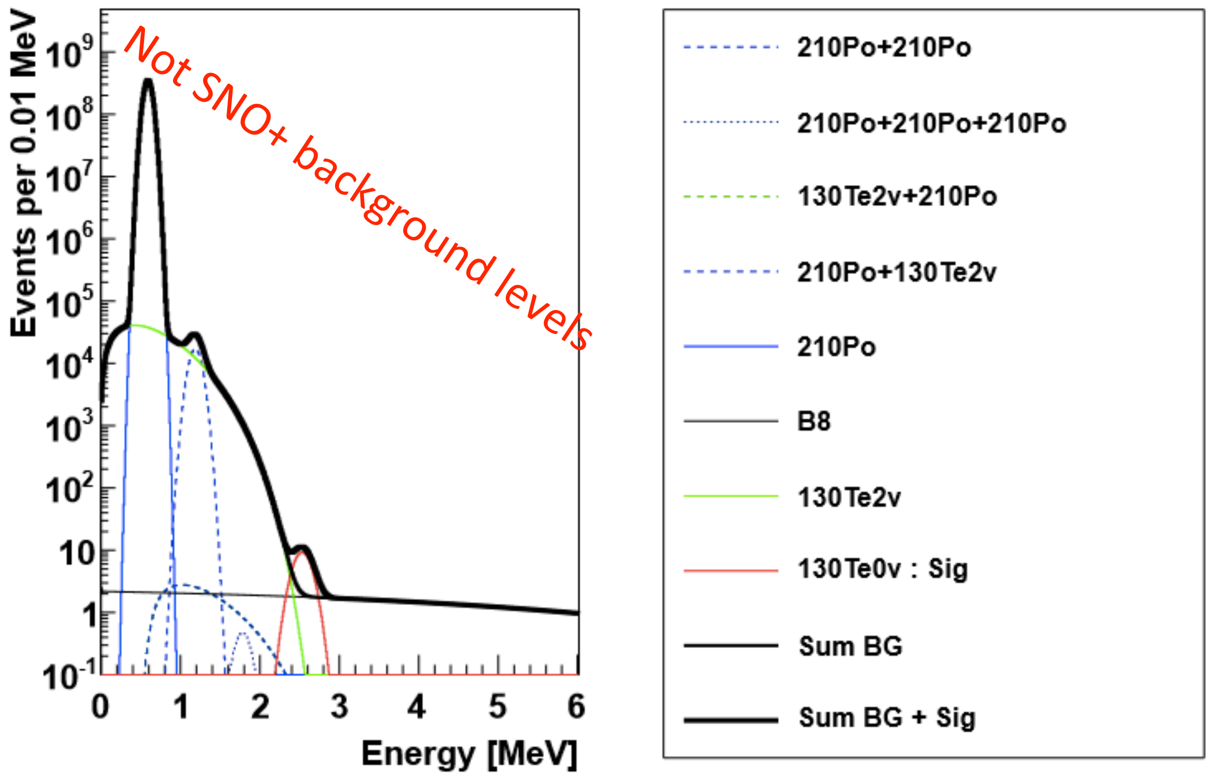




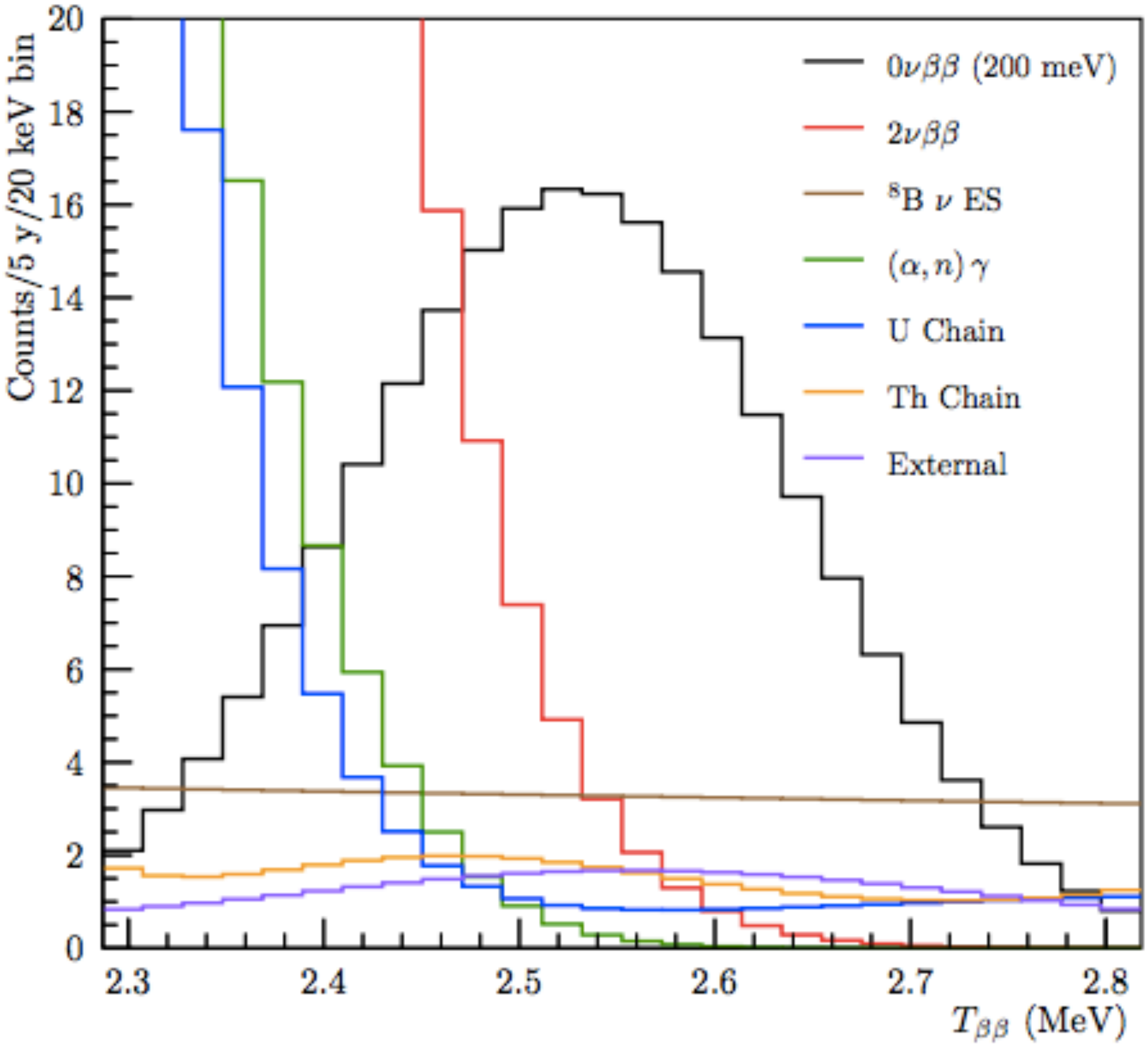
Background Rejection

Pileup

- Negligible pileup predicted
  - However, powerful techniques developed to reject
    - Isotropy and timing based

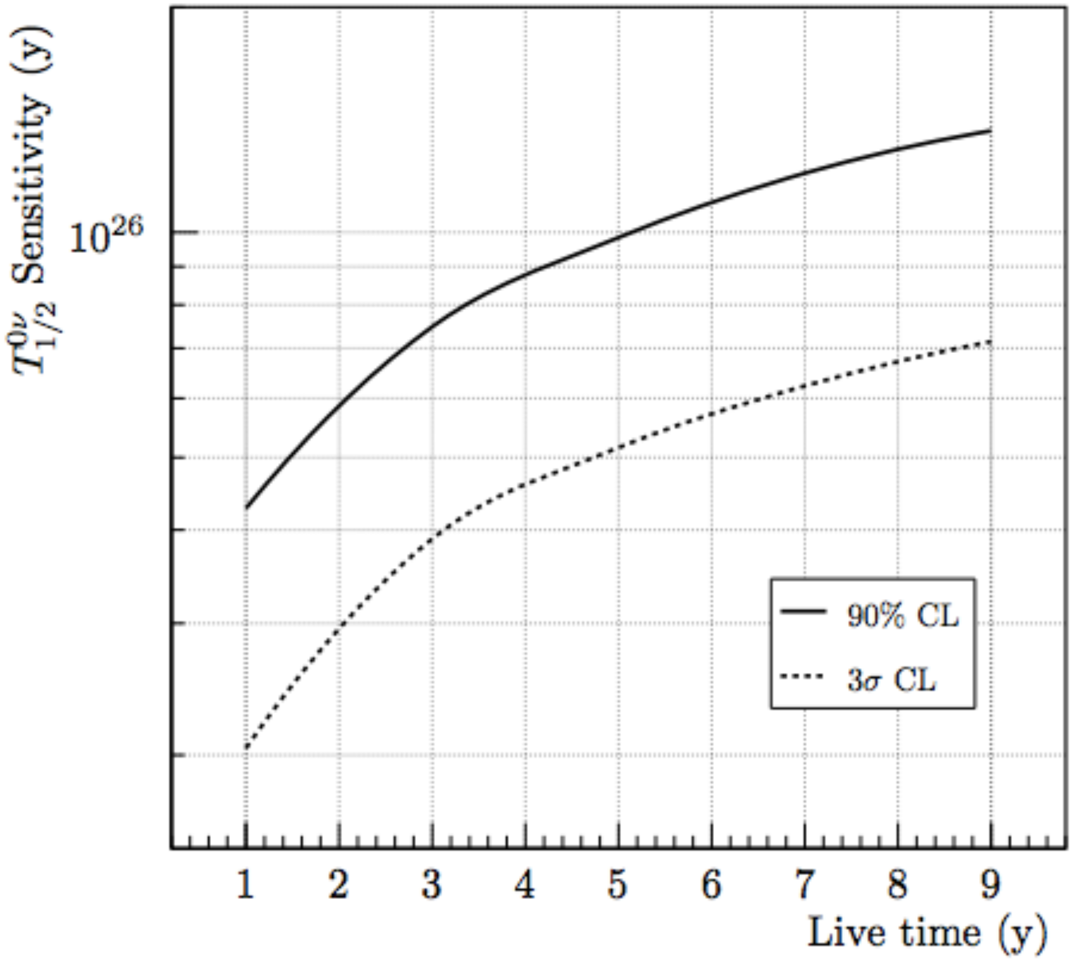


Spectrum



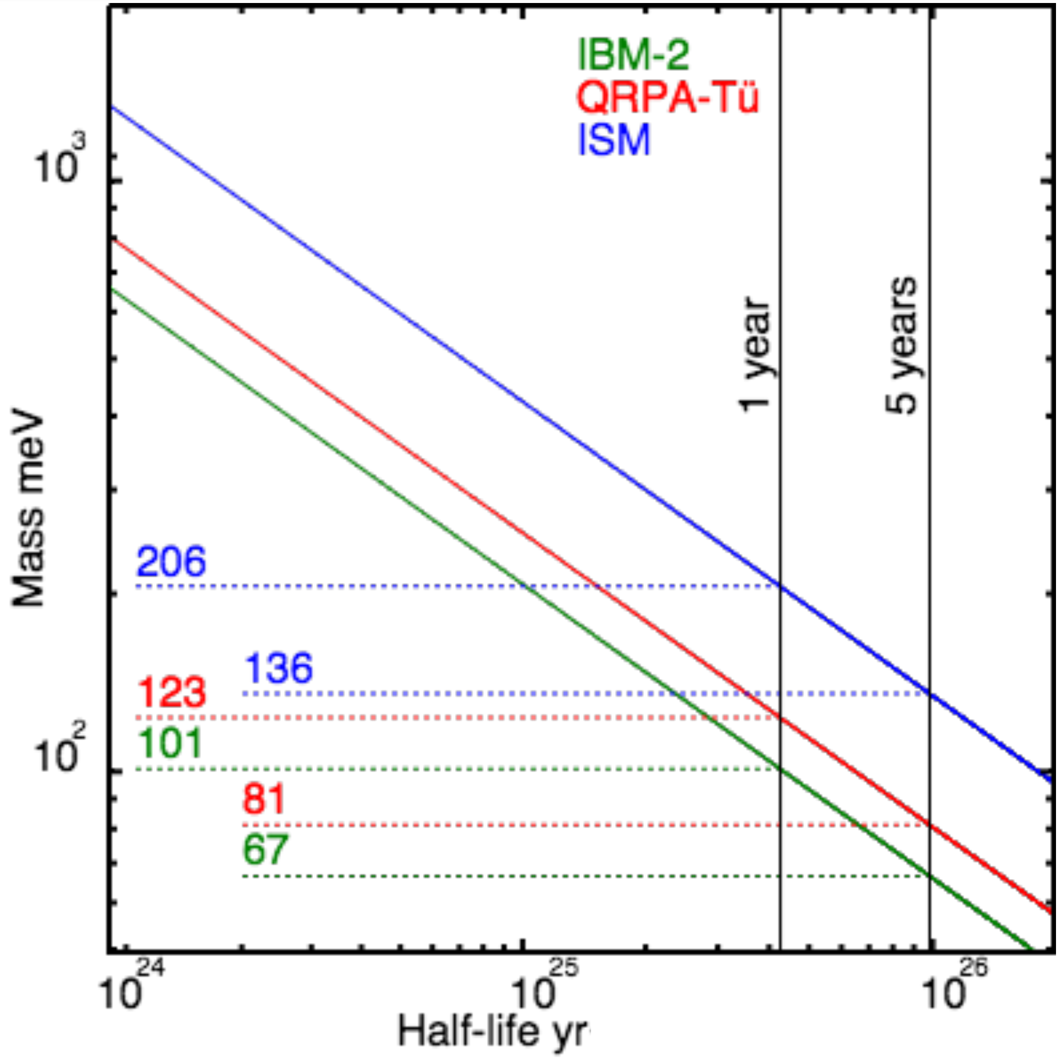
Counts/5 y/20 keV bin
0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
2.3, 2.4, 2.5, 2.6, 2.7, 2.8
$T_{\beta\beta}$ (MeV)
$0\nu\beta\beta$ (200 meV)
$2\nu\beta\beta$
^{8}B ν ES
$(\alpha, n)\,\gamma$
U Chain
Th Chain
External

Half-life limit



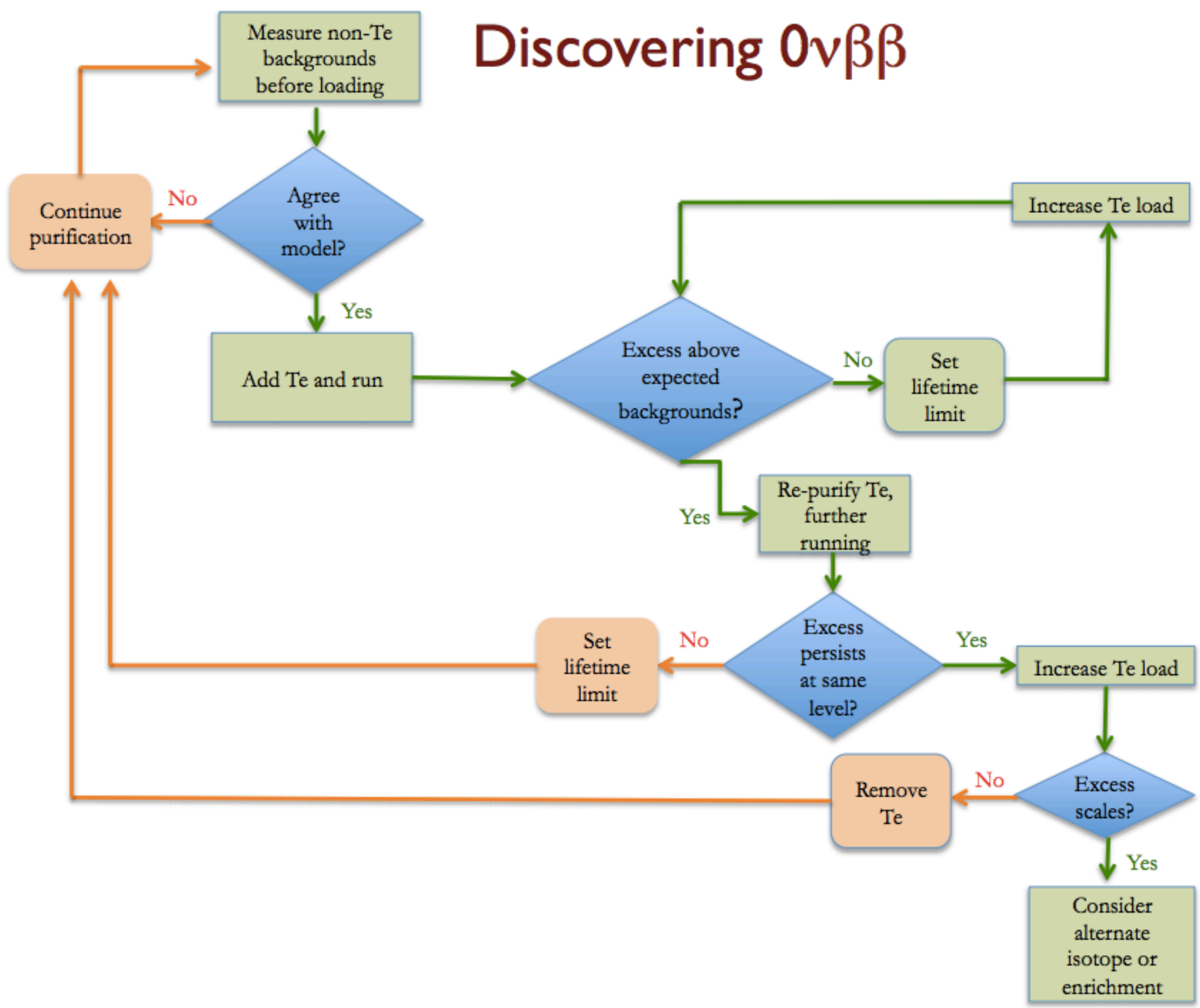
90% CL; $T_{1/2} = 4.27 \times 10^{25}$ yr : 1 year, $T_{1/2} = 9.84 \times 10^{25}$ yr : 5 years

Mass sensitivity

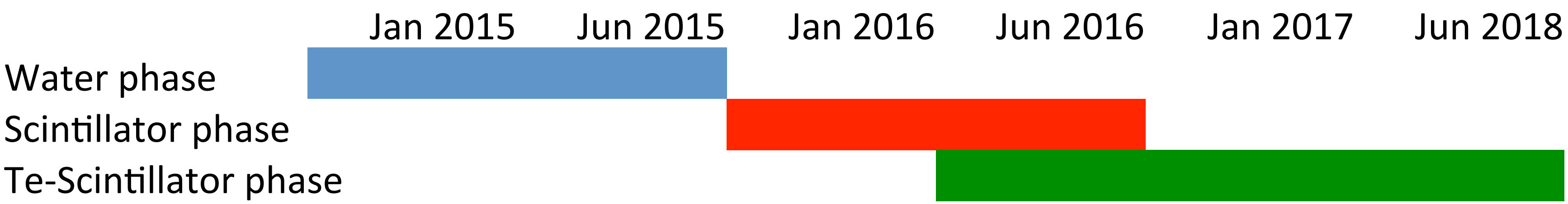


M and G from arXiv:1301.4203 [nucl-th] arXiv:1209.5722 [nucl-th]

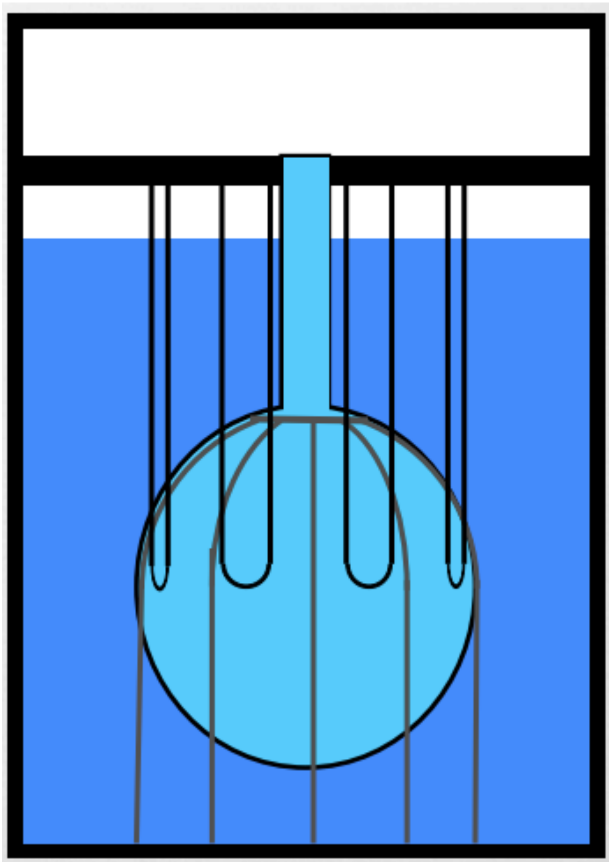
Discovering 0νββ



Schedule

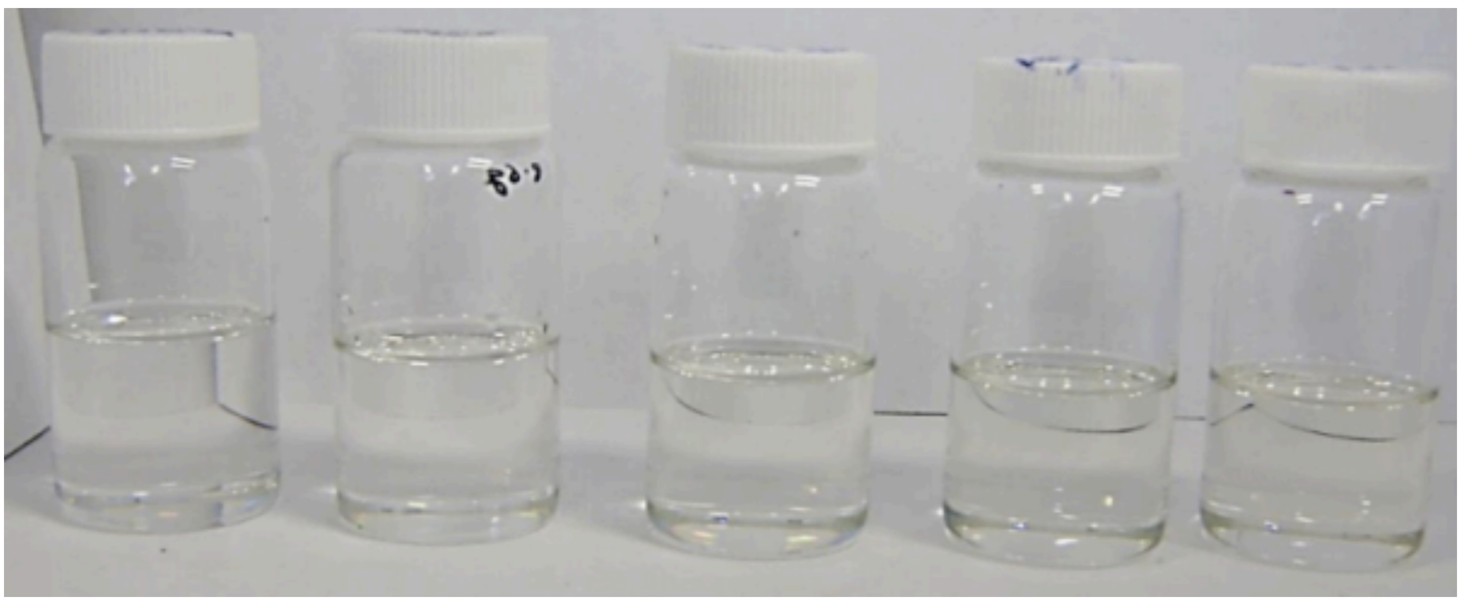


- Water phase
  - External background analysis
- Scintillator phase
  - Background analysis
- 0.3% Te-Scintillator phase
  - 0νββ physics



Higher loading

- SNO+ plans 0.3% Te loading (8 tonne of Te)
- Percent level loading feasible
  - Investigate smaller volume containment in a bag
  - Investigate upgrading PMTs to high QE



0.3%, 0.5%, 1%, 3%, 5% Te loading samples

Conclusion

- SNO+ at 0.3% ^{nat}Te loading will set competitive limits
  - $T_{1/2} = 9.84 \times 10^{25}$ yr at 90% CL after 5 years
- Possible to significantly increase loading
  - Potentially world leading sensitivity
- Water data early next year
- $0\nu\beta\beta$ data late 2016

Limit/Spectrum assumptions

- 1. 130Te undergoes double beta decay with nuclear matrix element
- M = 4.03 (IBM-2) [1] and phase space factor G = 3.69 x 10^-14 y^-1, based on
- the expression in [2] and g_A = 1.269 [1]
- 2. Scintillator loaded with 0.3% natTe by mass
- 3. Energy resolution is Gaussian with width sigma(E) = sqrt(E [MeV]/200)
- 4. 3.5 m (20%) fiducial volume cut
- 5. 100% efficiency of detection and analysis, including reconstruction
- 6. Tagging techniques which remove all 212BiPo and 214BiPo coincidences in
- separate trigger windows, and reduce in-window coincidences by a factor of 50
- 7. Backgrounds rates as given in SNO+-doc-507-v20

[1] J. Barea, J. Kotila, F. Iachello, Nuclear matrix elements for double-beta decay, Phys. Rev. C 87, 014315 (2013).

[2] J. Kotila, F. Iachello, Phase space factors for double-beta decay Phys, Rev. C 85, 034316 (2012).

[3] R. Bonventre, A. LaTorre, J.R. Klein, G.D. Orebi Gann, S. Seibert, O. Wasalski, Non-Standard Models, Solar Neutrinos, and Large theta13, Phys. Rev. D 88, 053010 (2013).

[4] SNO Collaboration, Combined Analysis of all Three Phases of Solar NeutrinoData from the Sudbury Neutrino Observatory, Phys. Rev. C 88, 025501 (2013).