0νββ in SNO+

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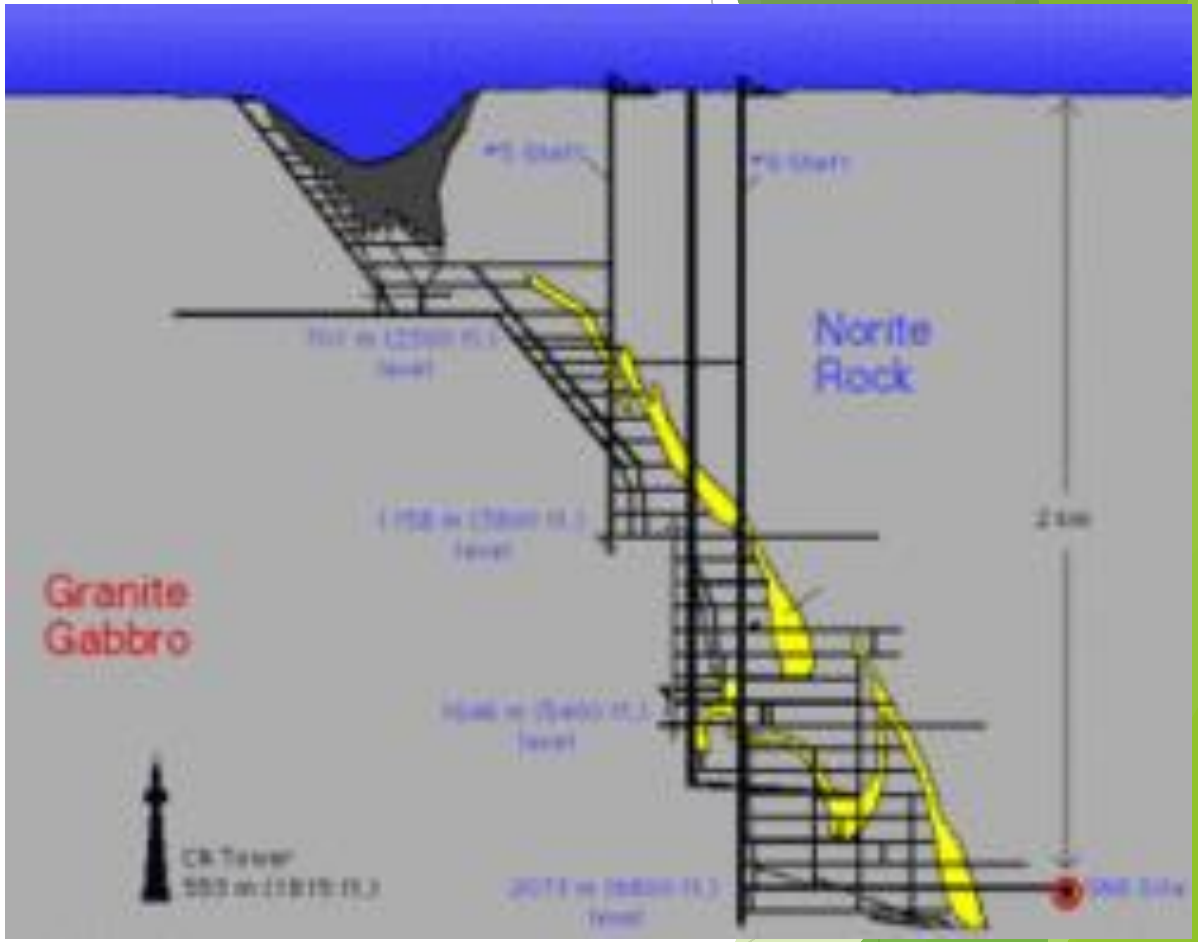
Detector: Part I

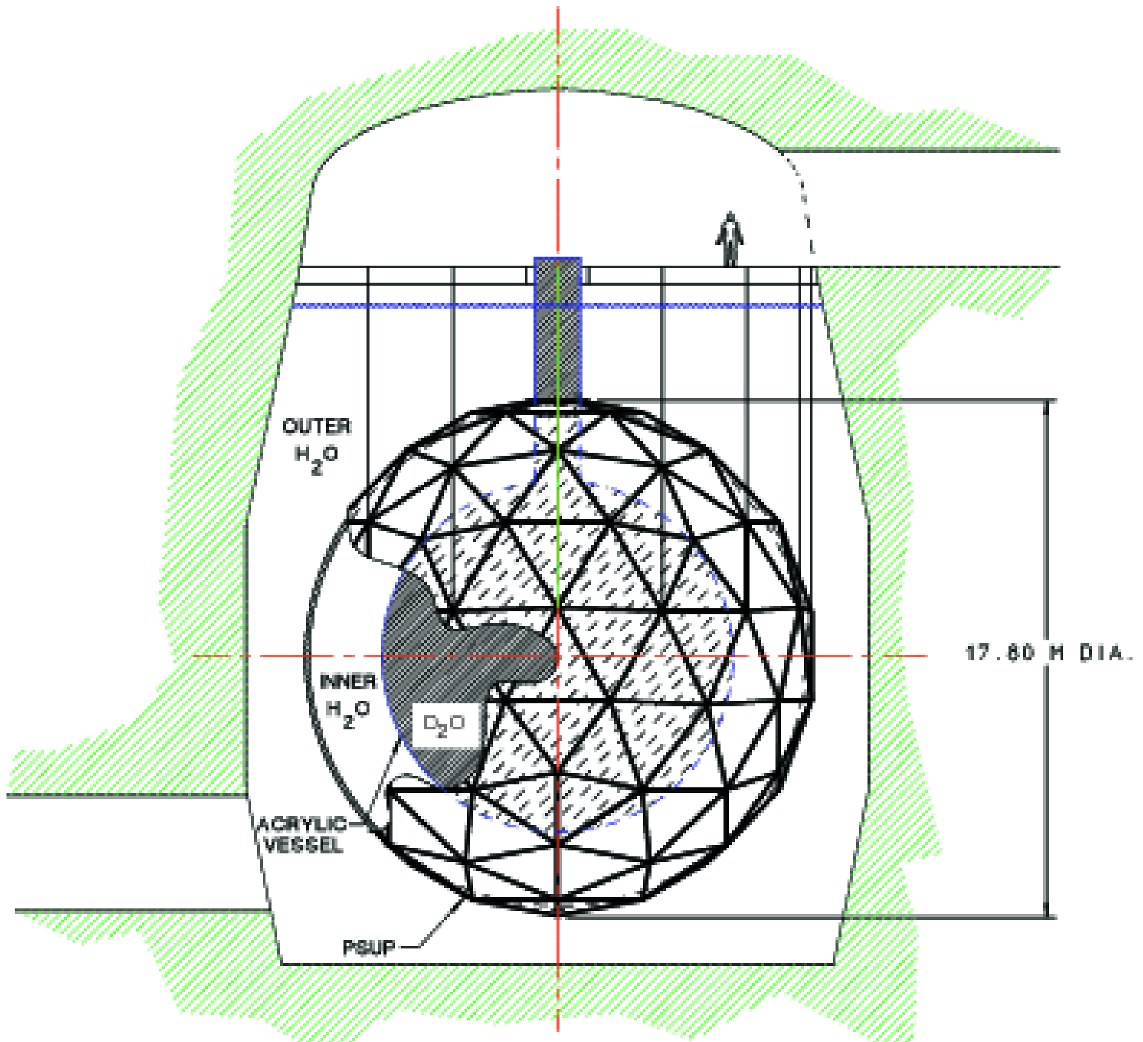
- Sudbury Neutrino Observatory (SNO), at SNOLAB
- SNO+ reuses infrastructure from the SNO experiment2 km underground, Vale’s Creighton nickel mine near Sudbury, Ontario, Canada.
- World’s deepest operating scientific laboratory



https://www.snolab.ca/science

Detector: Part II

- 34 m by 22 m barrel-shaped
- Ultra pure water
- 17.8 m diameter steel frame form the PSUP
- PSUP suspended from the cavity deck
- Holds ~9,500 8 in PMTs



https://inspirehep.net/record/509079/files/SNO-nim-2-PSUP-2.png

Detector: Part III

- 12 m diameter, 5.5 cm thick acrylic vass
- SNO→SNO+ :
- heavy water → linear alkyl benzene scintillator (LAB)
- LAB-PMT separation of 3 m

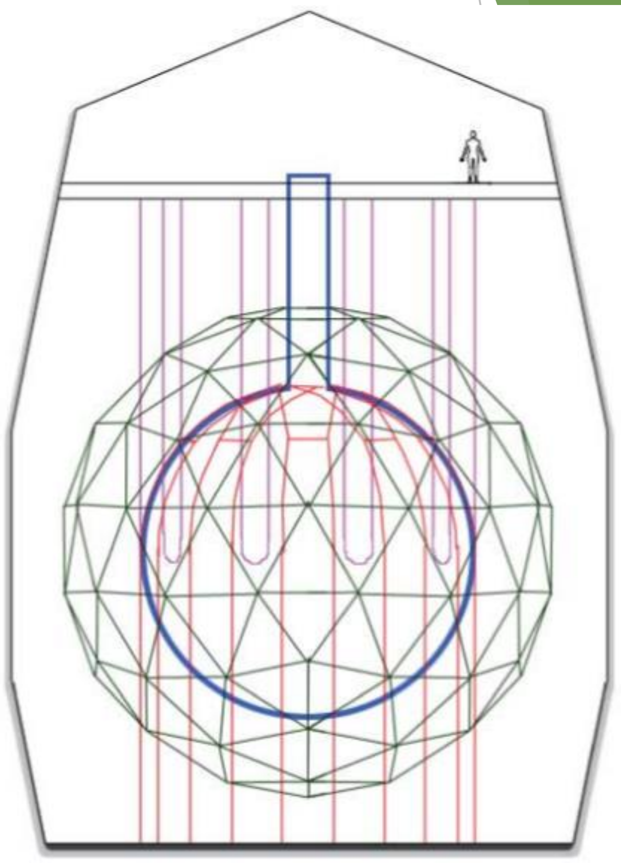
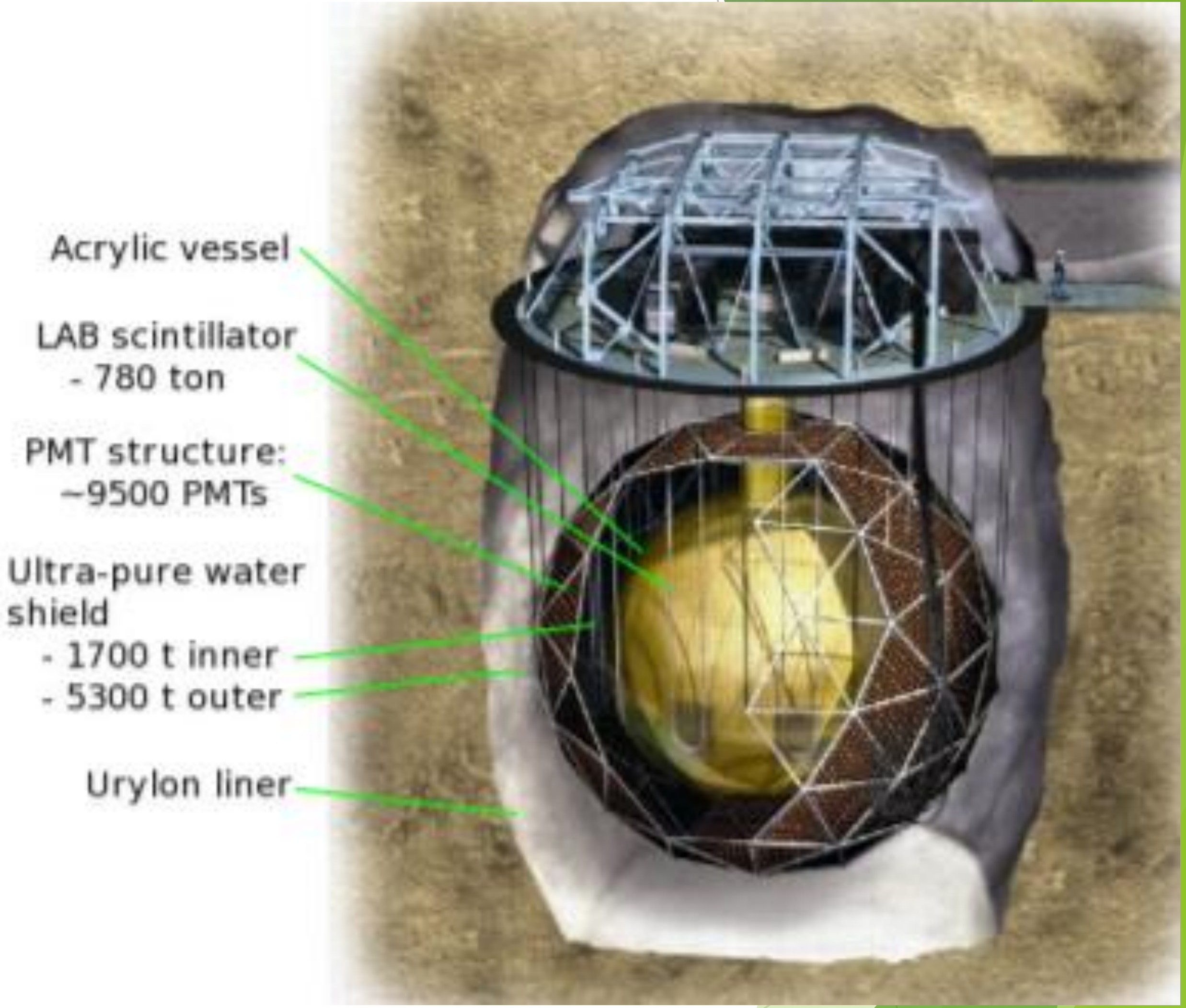


Figure 1: The SNO+ detector, figure from [9]. The 12 m diameter acrylic vessel (blue) is viewed by ~9300 PMTs supported by a ~18 m diameter geodesic structure (green) and is held by a system of high purity ropes (purple). The AV and the PSUP are within a volume of highly purified water. A rope net (red) will be used to offset the buoyancy of the liquid scintillator contained within the AV.

Detector Part IV

- Background reduction and shielding
  - Inner water provides 1700 tons of shielding.
  - Outer water → 5700 tons of shielding
- Radon protection
  - Cavity walls lined with Urylon
    - Attenuate radon from walls by 10^7
  - Radon tight universal interface and cover gas system



https://indico.cern.ch/event/175304/contributions/1439322/attachments/224999/314878/mottram_iop.pdf

Linear alkylbenzene (LAB)

- Long time stability
- Compatibility with the acrylic
- High purity levels from the manufacturer
- Long attenuation and scattering length
- High light yield
- Linear response in energy
- High flash point
- Environmental safe

- Production plant is nearby → Short transport time → reduce possibility of cosmogenic activation
- **Can dissolve heavy metals with long term stability and good optical properties**

Te-Loading

- Telluric acid is dissolved in water
- Add surfactant
- Load into the scintillator
- Wavelength shifters added to match the quantum efficiently of the PMTs

Why ^{130}Te for 0νββ?

- Large natural abundance → 34.08 %
- Lifetime for the 2νββ is 7.0 ± 0.9 (stat) ± 1.1 (sys) x 10^{20} yr, one of the longest of all the 0νββ isotopes
- Te+LAB mixture does not have inherent optical absorption lines
- Can move towards higher sensitivities by increasing the loading. A 150 Nhits/MeV light yield can be achived.

Electronics and Optical Properties

- Can reject >99.99% α while retaining >99.9% β
- The scintillation pulse timing differs for protons, α, and β, allowing particle ID
- Due to higher light yield of LAB compared to heavy water, allows lower energy measurements (e.g. pp solar neutrinos)
- Also means more background events
- Updated DAQ and readout boards with a higher bandwith.

Background in SNO+

- Internal background sources : all non-signal interactions within the Acrylic Vessel
  - ^{238}U chain
  - ^{232}Th chain
  - ^{40}K, ^{39}Ar, and ^{85}Kr decay
  - Cosmogenically Induced Background e.g. when LAB was above ground
  - (α, n) background
- External background sources: produced outside the target volume, but can propagate within
  - Holding rope
  - Radioactive decay outside the scintillator volume

Dealing with external background

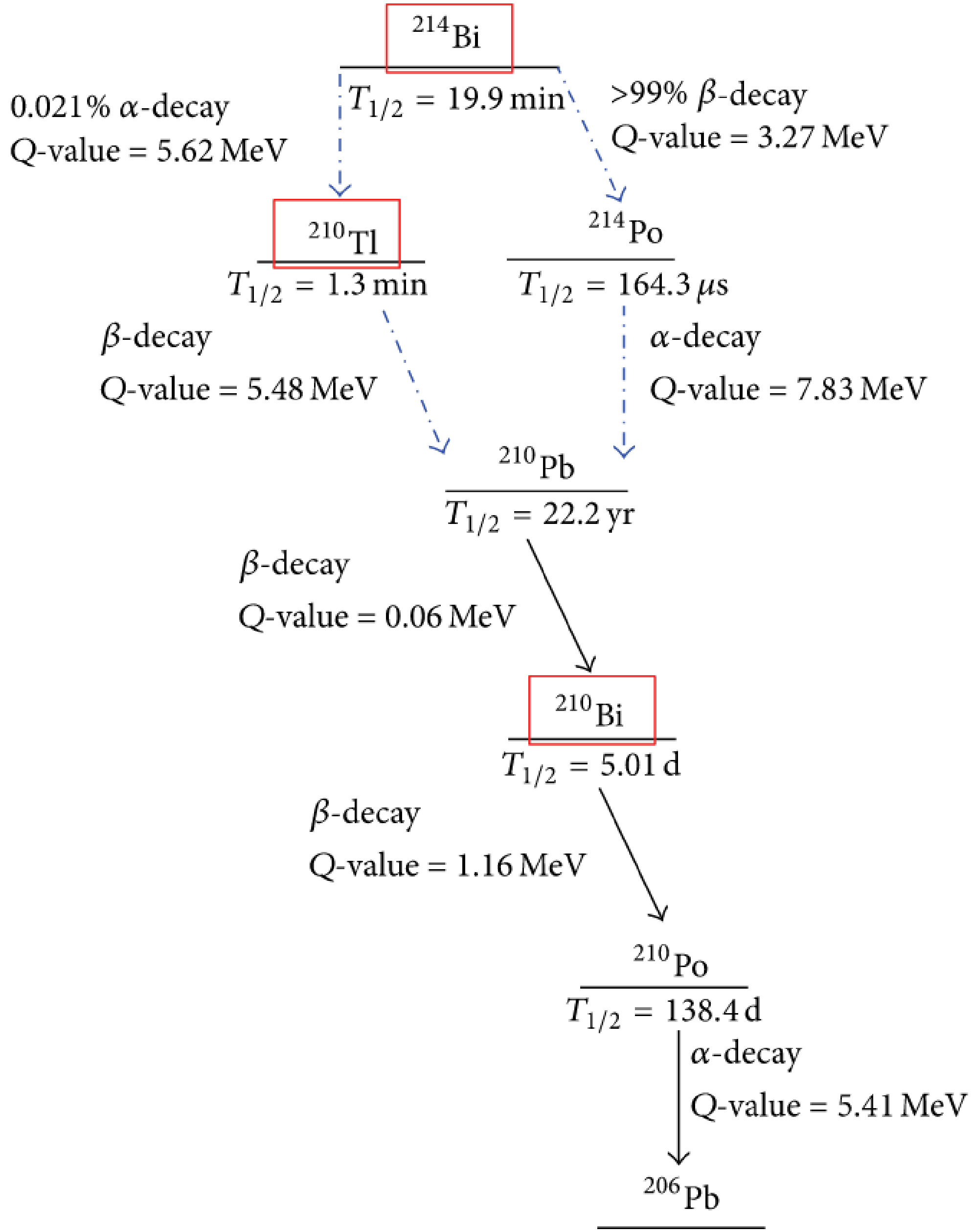
- Applying a fiducial volume cut
- Water phase and pure LAB phase data
  - The AV is only with ultra pure water or pure LAB, no Te at all, so background from external sources, external water, PMT array, ropes, and AW can be characterized.

Cosmogenic Backgrounds

- Purification techniques
- Long period of underground storage
- Less then 1 event/year in the fiducial volume

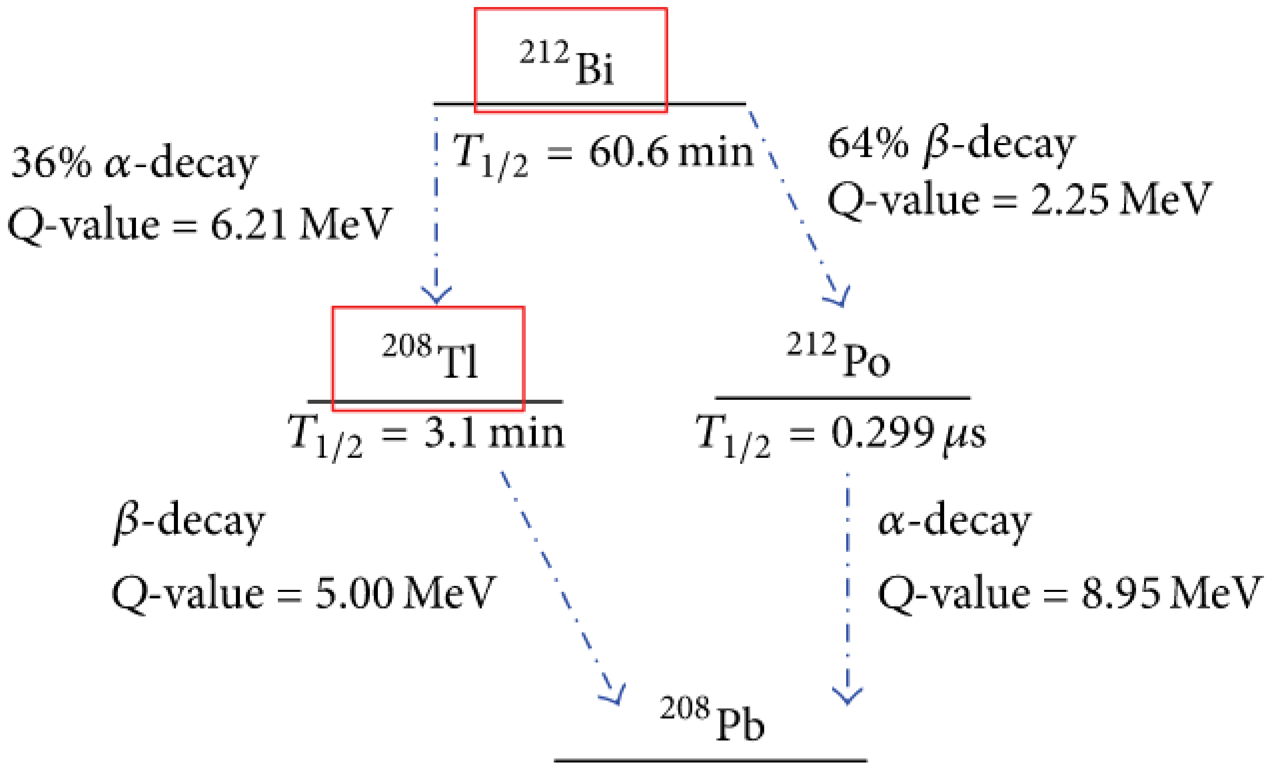
^{238}U chain

- Relevant part of the chain for SNO+ with Q-values (total kinetic energy released in the ground state-ground state transition), half-life, and decay modes.
- The red squares highlight the nuclides of most concern: Bi, Tl, and Bi.



^{232}Th Chain

- Same notion and color convention as before.
- Bi->Po decay falls in the same trigger window as the 0νββ



Accounting for decay background

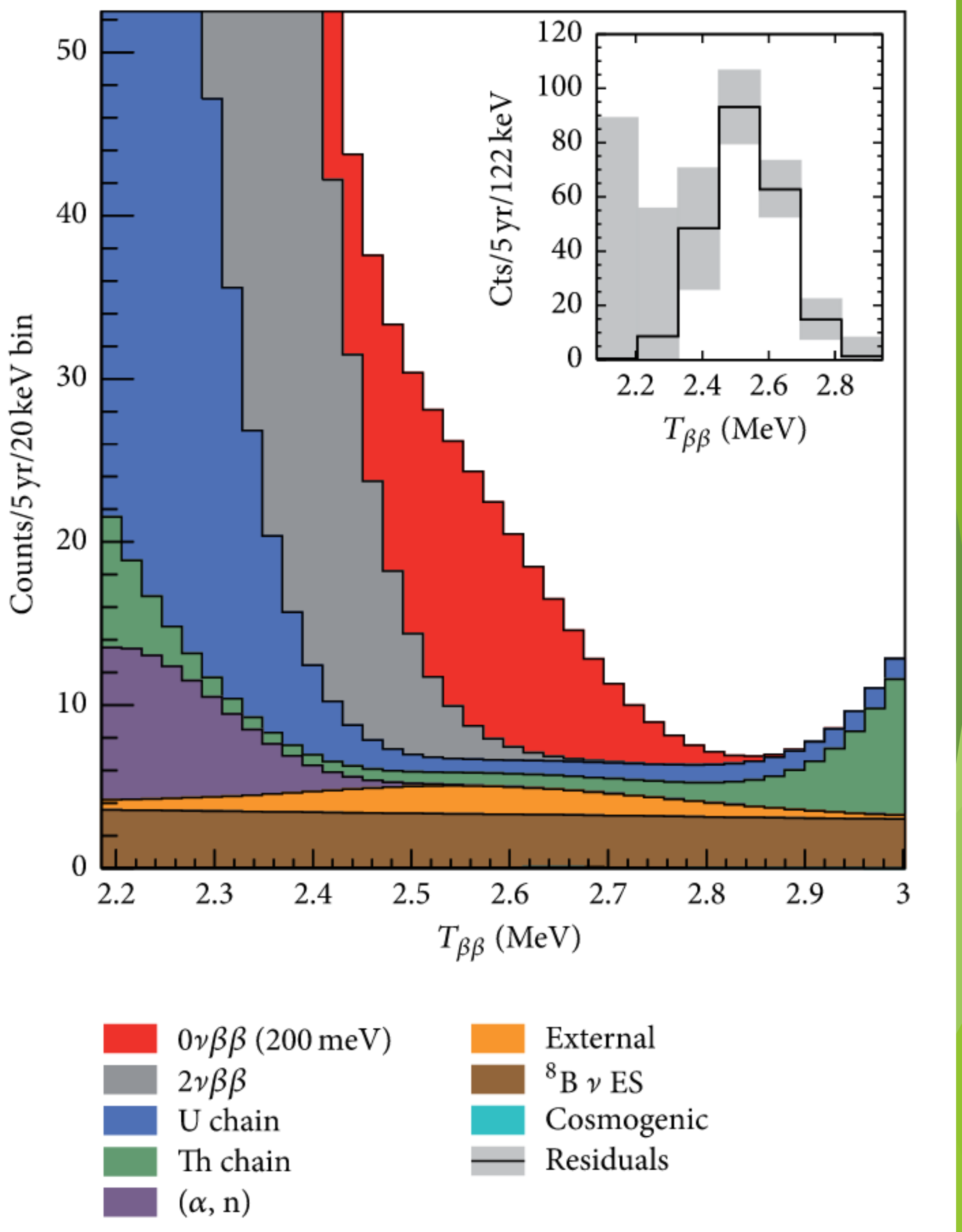
- Use coincidence between Bi-beta and Po-alpha reject to reject all Bi events that fall.
- α-β delayed coincidence can be used to extraction U-chain and Th-chain contaminants to reject events.
- Can be done in the LAB phase to see the chain background prior to the Te-loading.

Table 4: Expected background counts in the signal ROI and 3.5 m FV in SNO+ for the first year (year 1) and in 5 years of the 0.3% Te-loading phase. A light yield of 200 Nhits/MeV has been assumed. Cuts have been applied as described in the text.

Isotope	**1 year**	**5 years**
$2\nu\beta\beta$	6.3	31.6
^{8}B ν ES	7.3	36.3
Uranium chain	2.1	10.4
Thorium chain	1.7	8.7
External	3.6	18.1
(α, n)	0.1	0.8
Cosmogenics	0.7	0.8
Total	21.8	106.8

Projection signal to background

- Figure 6: Summary stacked plot of all backgrounds and 0νββ hypothetical signal corresponding to a mass $m_{\beta\beta}$ = 200 meV for 5-year data taking. Events are shown in the FV of 3.5 m, for 0.3% natural tellurium loading and 200 Nhits/MeV light yield. $T_{\beta\beta}$ is the effective kinetic energy.



Sensitivity

$$S = \epsilon \cdot N_{130} \cdot \ln 2 \cdot \frac{t}{T_{1/2}^{0\nu\beta\beta}},$$

- N_{130} is the number of ^{130}Te
- T is the live time
- $T^{0\nu\beta\beta}_{1/2}$ is the half life of ^{130}Te 0νββ
- ε is the signal detection efficiency

- Can use this and five years of measurements to set limits on the Majorana neutrino mass.

References

- S. Andringa, E. Arushanova, S. Asahi, et al., “Current Status and Future Prospects of the SNO+ Experiment,”Advances in High Energy Physics, vol. 2016, Article ID 6194250, 21 pages, 2016. doi:10.1155/2016/6194250
- E Arushanova and A R Back, “Probing neutrinoless double beta decay with SNO+”arXiv:1505.00247v1 [physics.ins-det] 1 May 2015
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- C. Zhang a D.-M. Mei a,b,∗ V. A. Kudryavtsev c S. Fiorucci , "Cosmogenic Activation of Materials Used in Rare Event Search Experiments", arXiv:1603.00098v4 [physics.ins-det] 31 Aug 2016