Background reduction in the **SNO+** Experiment

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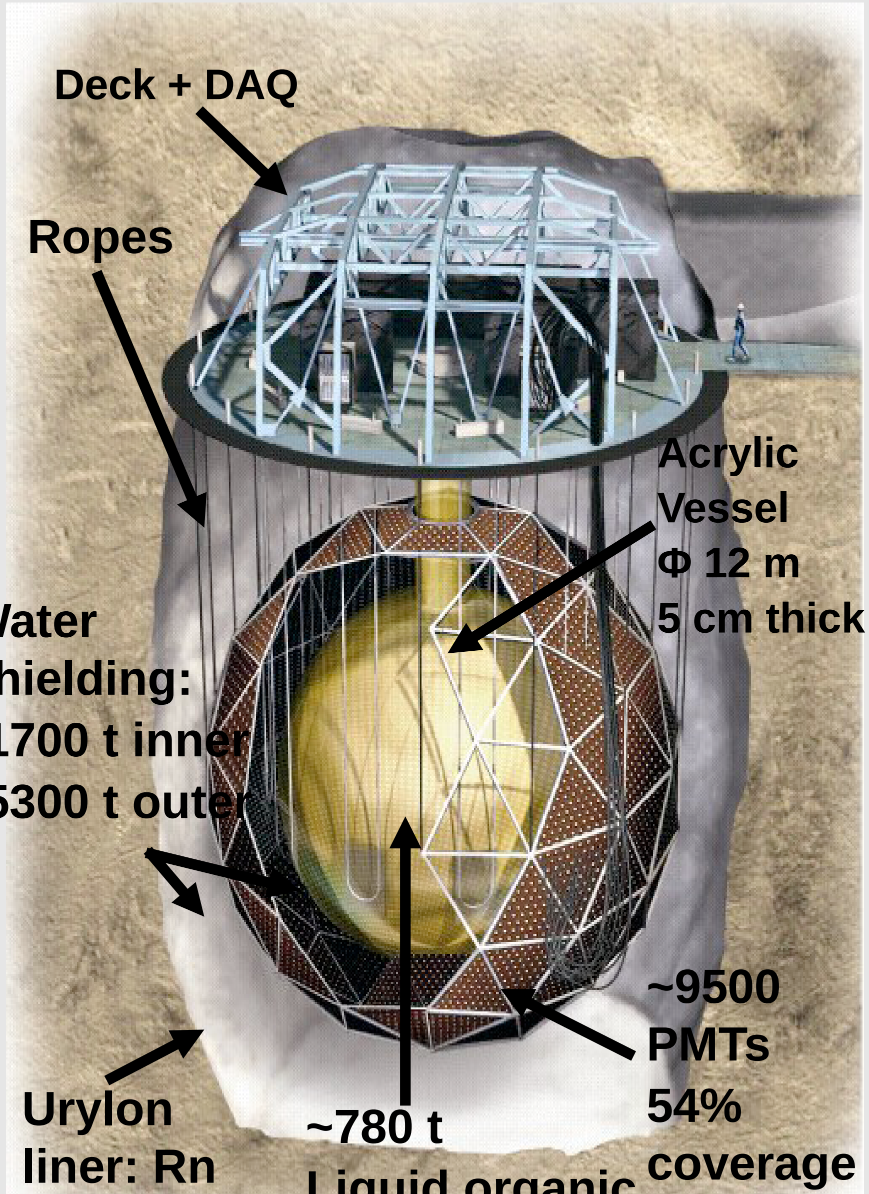
OUTLINE

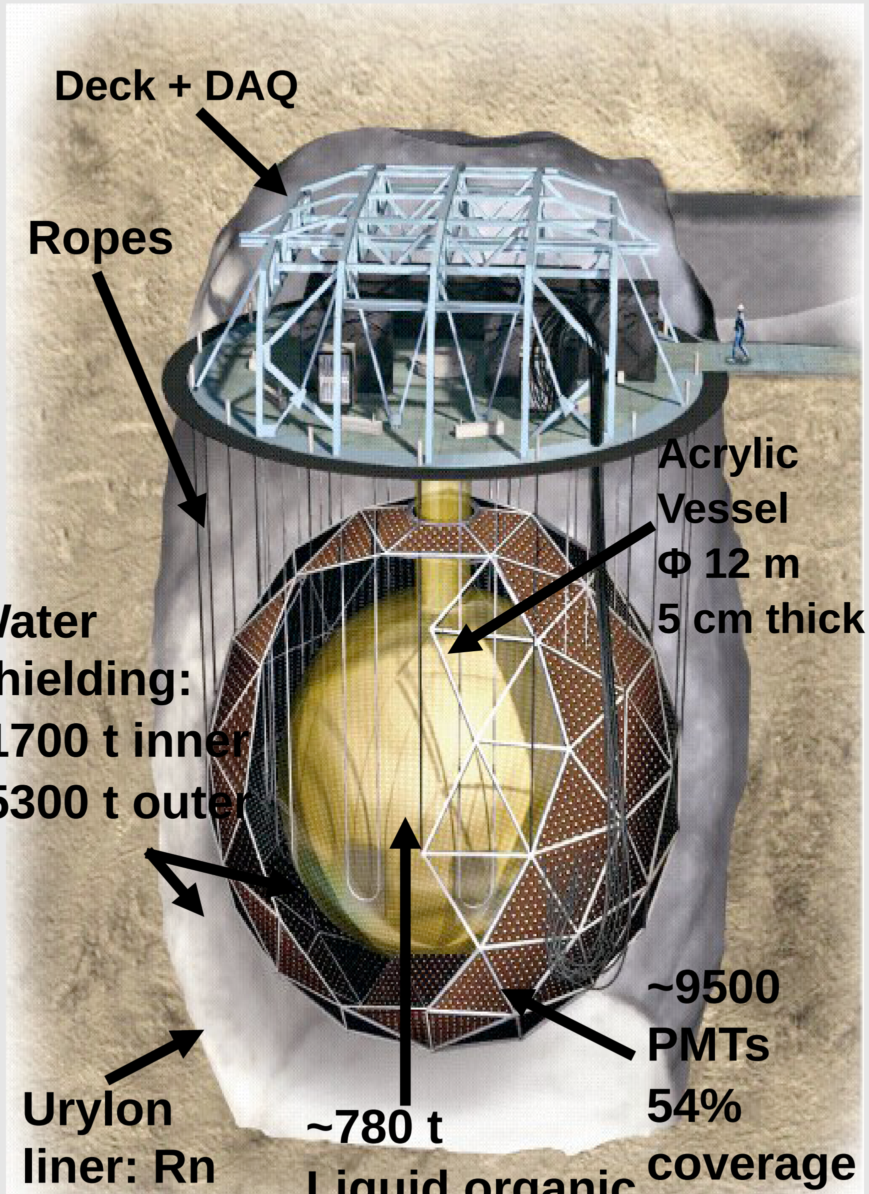
- General overview of the SNO+ experiment
- Brief double beta decay introduction
- Backgrounds in SNO+ and rejection techniques
  - Internal
  - Cosmogenics
  - Externals and others
- Total background and expected sensitivity
- Conclusions

The SNO+ Experiment



- SNO+: successor to Sudbury Neutrino Observatory (SNO)
- Located in SNOLAB inside the Creighton mine near Sudbury, Canada
  - Depth = 2070m (6000m.w.e)
  - ~70 muons/day in SNO+
  - Class-2000 clean room
- Broad neutrino physics program
  - Neutrinoless double beta decay (0νββ) of ^{130}Te
  - Reactor anti-neutrinos
  - Geo anti-neutrinos
  - Supernovae neutrinos
  - Nucleon decay
  - Solar neutrinos (pep, CNO, low energy ^{8}B)

The SNO+ Experiment



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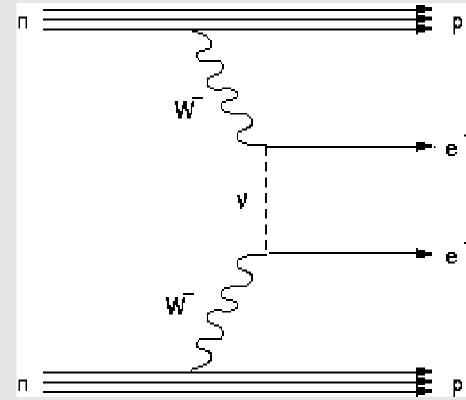
Double beta decay

$$(A,Z)\rightarrow(A,Z+2)+2e+2\bar{\nu}$$ (ΔL =0)

$$(A,Z)\rightarrow(A,Z+2)+2e$$ (ΔL =2)



Second process, theoretically possible → imply violation of lepton number:

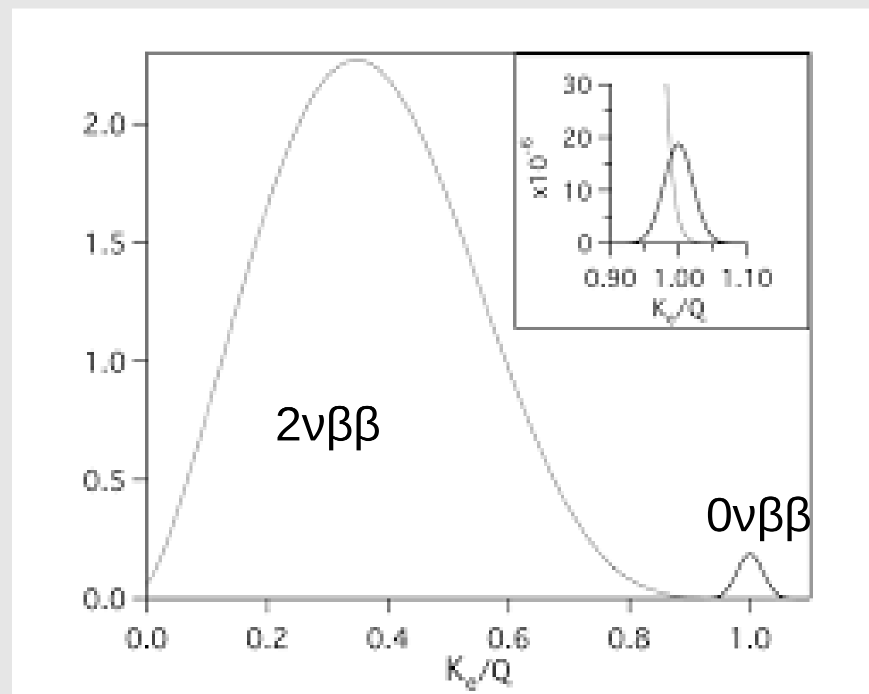
→ Neutrinos are Majorana particles (particle = antiparticle)

$$\left(T^{0\nu}_{1/2}\right)^{-1}=G_{0\nu}\left|M_{0\nu}\right|^{2}\left(\frac{\langle m_{\nu}\rangle}{m_{e}}\right)^{2}$$

→ Mass of neutrino can be obtained

- Typical half-life: ~ 10^{25}-10^{27} y → very low rate → control of backgrounds needed

  $Q_{\beta\beta}(^{130}Te)$ = 2527 keV



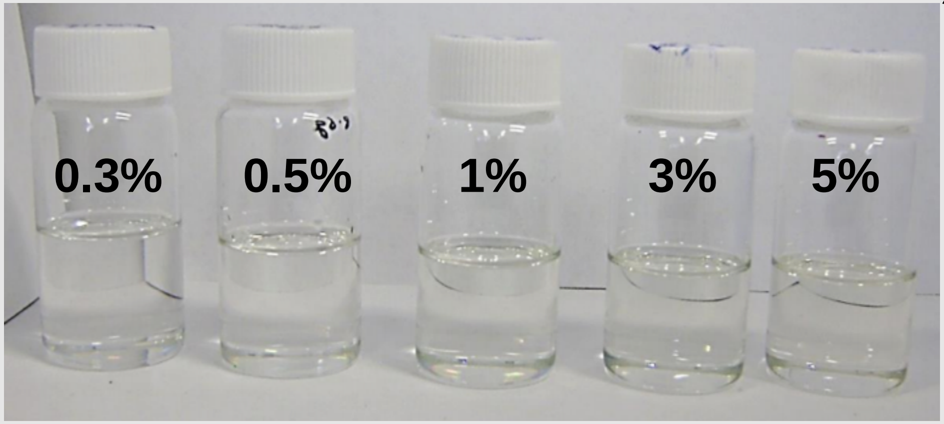
Double beta decay searches in SNO+

First phase 0.3% nat. Te =~ 800kg of ^{130}Te
Deployed into liquid scintillator
✔ The ββ isotope and the detector are distinct in SNO+: background runs before deployment

Scintillator cocktail
LAB + PPO (2g/L) + surfactant + H_2O + Te + wavelength shifter

^{130}Te

- ✔ High nat. abundance (34%)
- ✔ Slow 2νββ
- ✔ High light yield (~9,500 ph/MeV)
- ✔ α -β separation
- ✔ Successfully loaded in LAB



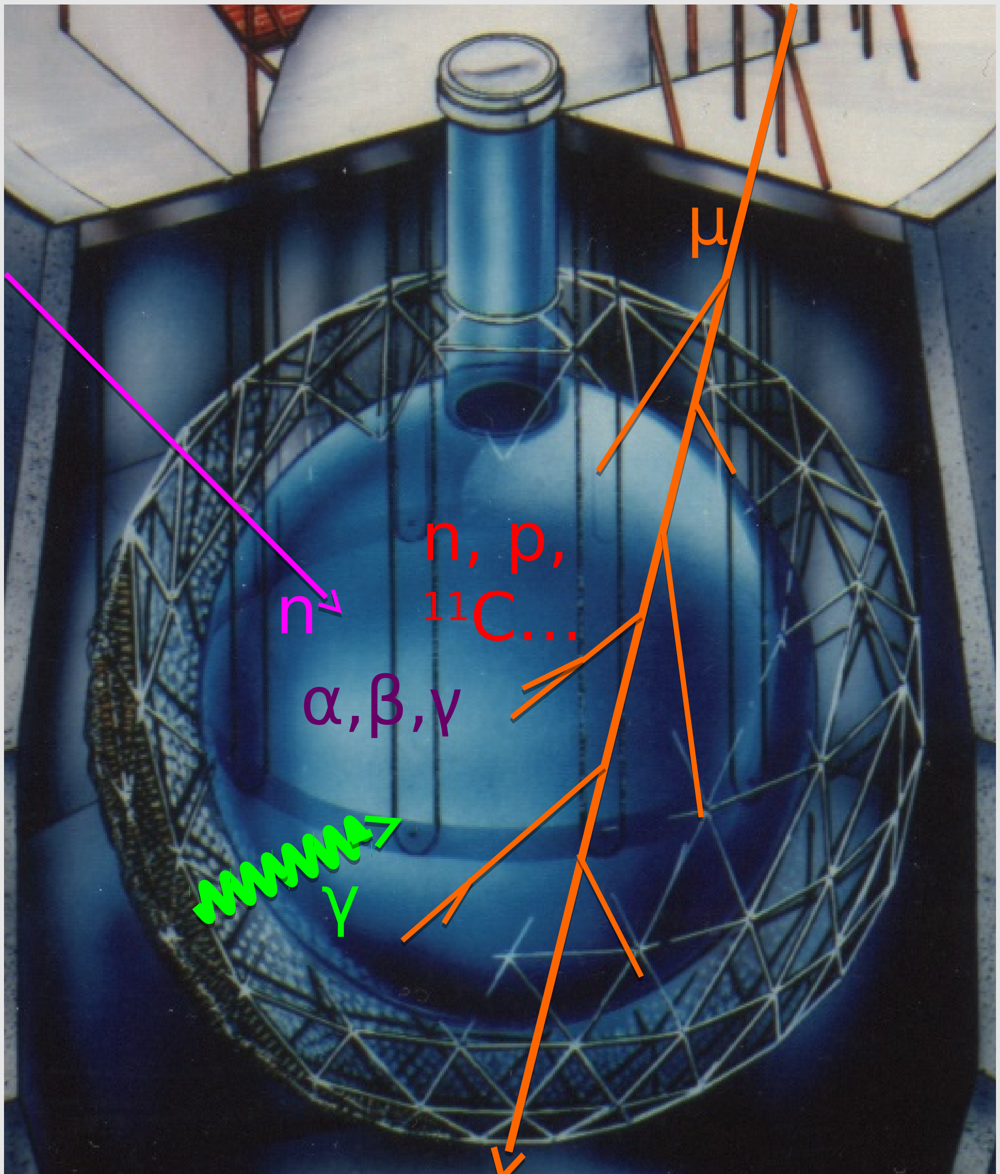
Different Te loadings in LAB

New loading technique (BNL) (Minfang's talk)

- Dissolve telluric acid ($Te(OH)_6$) in water
- Combine with LAB using a surfactant

➢ Good optical properties
➢ Stable > 1.5 year explicitly demonstrated for 0.3% loading

Backgrounds in SNO+



Internal (Scintillator + Te)
- U/Th chain, ^{40}K
- Neutron capture
- ^{14}C
- Te cosmogenics (^{60}Co, ^{88}Y, ^{110m}Ag, ^{124}Sb)

Externals
- ^{214}Bi and ^{208}Tl gammas from AV and PMT's mainly
- Radon (and radon daughters) from AV surface leaching into scintillator (^{210}Bi, ^{210}Po, ^{210}Pb)

Fast Neutrons

From external muons

Cosmic muons

^{11}C (solar phase), n capture 2.2MeV γ

^{8}B solar neutrinos

2νββ: slow rate isotope

Backgrounds in SNO+: Internals & cosmogenics

Purification for the internals backgrounds (Te and scintillator)

- Purification of **scintillator** (see Richard Ford talk this morning)
  - Target levels 6.8×10^{-18} g/g in ^{232}Th and 1.6×10^{-17} g/g in ^{238}U (~10^{-11} Bq/kg)

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- Purification of **Tellurium**
  - Te cosmogenics have long half-lives and decays that overlap the $0\nu\beta\beta$ energy region (main ones ^{60}Co, ^{110m}Ag, ^{126}Sn, ^{88}Zr, ^{88}Y, ^{124}Sb)
  - Rejection of cosmogenic isotopes needed 10^{4}-10^{5} (V. Lozza and J. Petzoldt, Astropart. Phys. 61, 62-71 (2015))
  - Target levels 2.5×10^{-15} g/g in ^{238}U (3×10^{-8} Bq/kg) and 3×10^{-16}g/g in ^{232}Th (1.2×10^{-9} Bq/kg) (raw Te ~ $x10^{-11}$ g/g U/Th, 10^{-4} Bq/kg)
  - Some of these cosmogenics are not soluble in water and can be removed (as U/Th) by the scavenging method.
  - But for others a different purification technique is required
  - New technique developed at BNL for Te-loaded scintillators (also details in Minfang Yeh talk).

Backgrounds in SNO+: Internals & cosmogenics

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

1. Surface passes (x2) (Acid-recrystallization):
   - Dissolve $Te(OH)_6$ in water
   - Recrystallize using nitric acid
   - Rinse with ethanol

     > 10^4 reduction

   + Improvement optical transmission blue region

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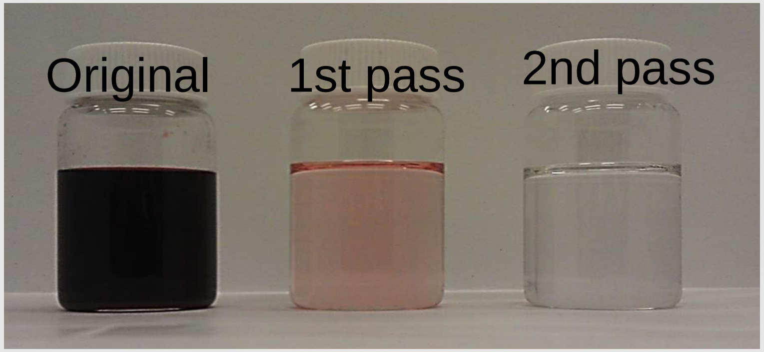

^{60}Co removed by a factor >10^4 after two passes

Transported Underground within 5h
Still can regenerate diminutive amount cosmogenic backgrounds

Currently operating a 10kg pilot-scale plant
Final design ~200 kg

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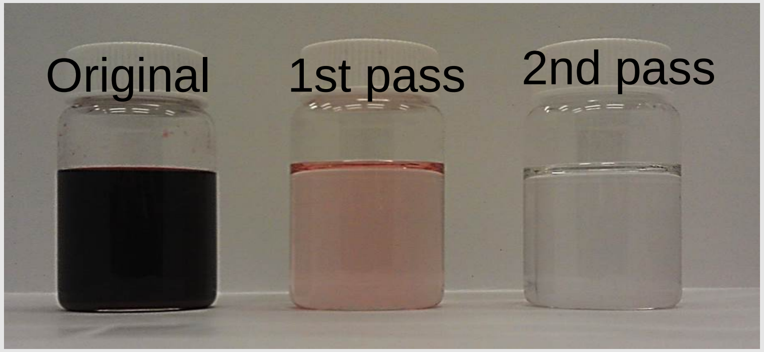


^{60}Co removed by a factor >10^4 after two passes

Transported Underground within 5h
Still can regenerate diminutive amount cosmogenic backgrounds

2. Underground passes (x1) (Thermal-recrystallization):
   - Dissolve purified $Te(OH)_6$ in warm water (80°C)
   - Cool to recrystallize thermally

   > 10^2 reduction

Approx. 70% of telluric acid crystal will be recovered.
The residual 30% will be transferred back to the surface.

Currently operating a 10kg pilot-scale plant
Final design ~200 kg

+ storage underground for 6 months →

→ **negligible contribution from cosmogenics**

Backgrounds in SNO+: Internals & Cosmogenics

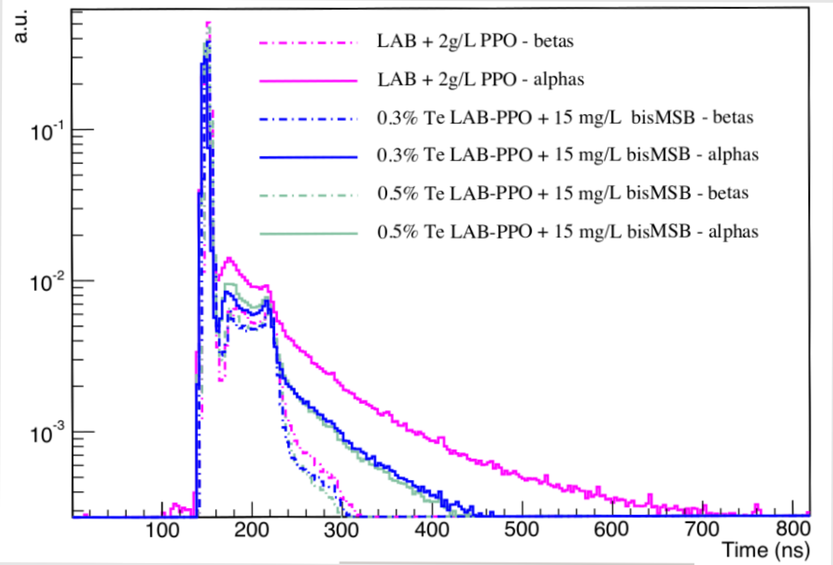
Further reduction of internals based on rejection techniques developed with MonteCarlo simulations.

β-α rejections(**delayed coincidence** and **pile-up**)

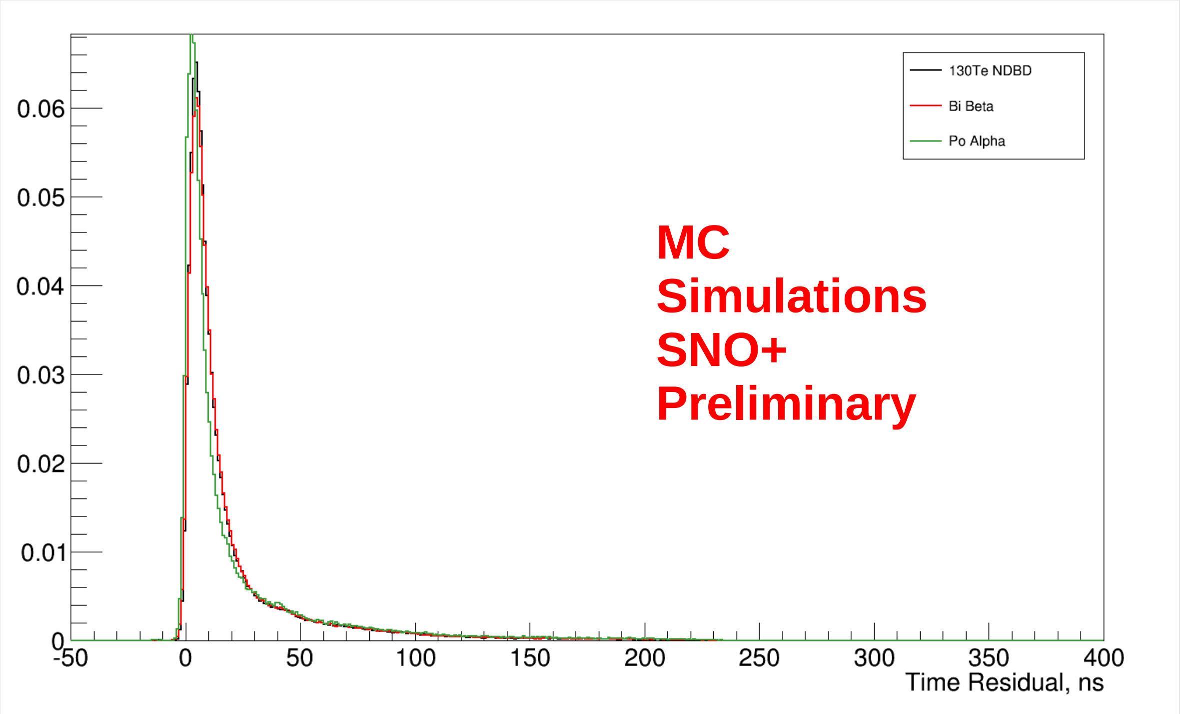
Measured time implemented in simulation framework

- Bi-Po α´s, expected 100% rejection if Bi-Po falls in separated trigger windows. Expected pile-up events in 500 ns time window:

- 0.2% pile up of ^{214}Bi-^{214}Po
- 69% pile-up of ^{212}Bi-^{212}Po



S. Grullon, Neutrino2014



K. Majumdar, Institute of Physics, Neutrino Physics 2013 Meeting

Likelihood ratio cuts based on time residuals differences and delay between β and α

→ extra 50 rejection factor for "pile-up" events

Overall

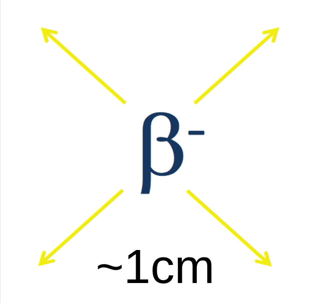
- ^{214}BiPo factor > 25k rejection
- ^{212}BiPo factor > 70 rejection

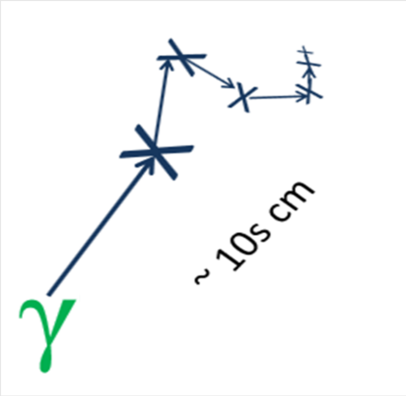
Backgrounds in SNO+: Internals & Cosmogenics

Further reduction of internals based on rejection techniques developed with MonteCarlo simulations.

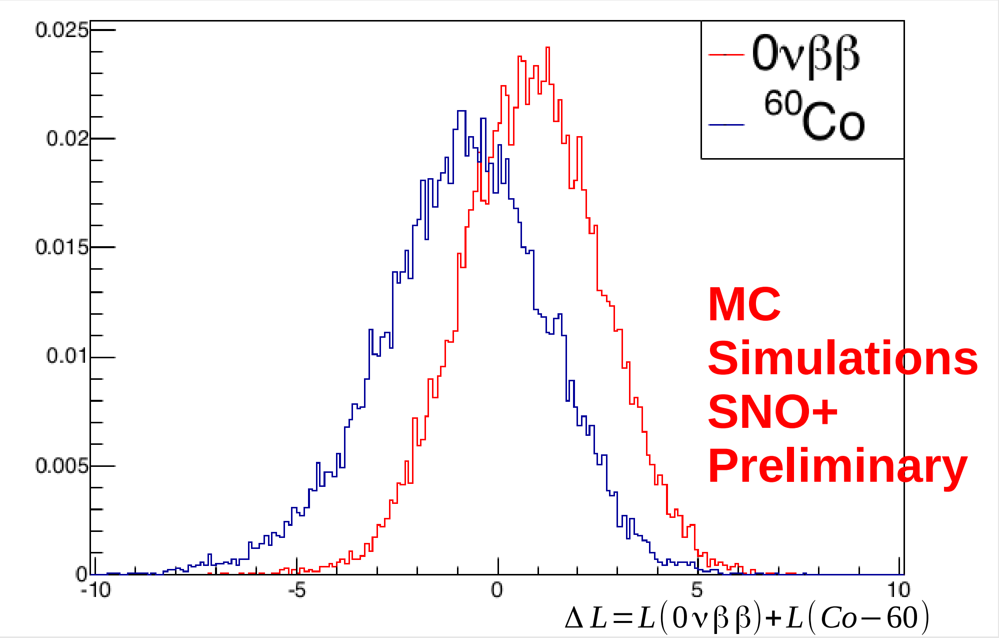
Cosmogenics **(Time residual likelihood cuts):** treating the PMT hit time residuals for diff. event as PDFs

- Compute the signal/backg likelihood difference
  → statistical separation between them using a likelihood analysis
- Time differences from how the charge is deposited: **pointike events (β) vs. non-pointlike (γ)**





- Improvements:
  - Defining a functional form PDF
  - Use of real data to constrain the PDF
    - Only need ~ 50 events to constrain PDF
    - 2σ separation with 20 events in RoI



J. Dunger, Institute of Physics, Neutrino Physics 2014 Meeting

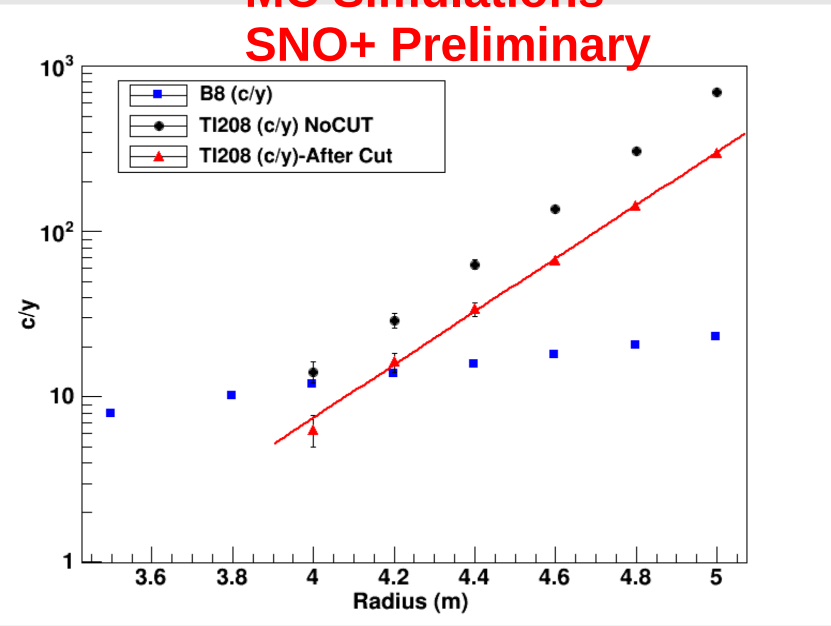
Backgrounds in SNO+: Externals and (α,n)γ

- **External background:** external gammas from U/Th chain (^{208}Tl and ^{214}Bi) from the AV, light water shield, rope net system and PMT
  → attenuated with fiducial volume (at 3.5m, 20% FV ~ 3.5 c/y)

- + 50% reduction with time likelihood cut (as for the cosmogenics)

  I. Coulter, Event reconstruction and background rejection in the SNO+ experiment, Institute of Physics 2013 Meeting (April 8–10 2013) Track 3/66

MC Simulations
SNO+ Preliminary



(α,n)γ

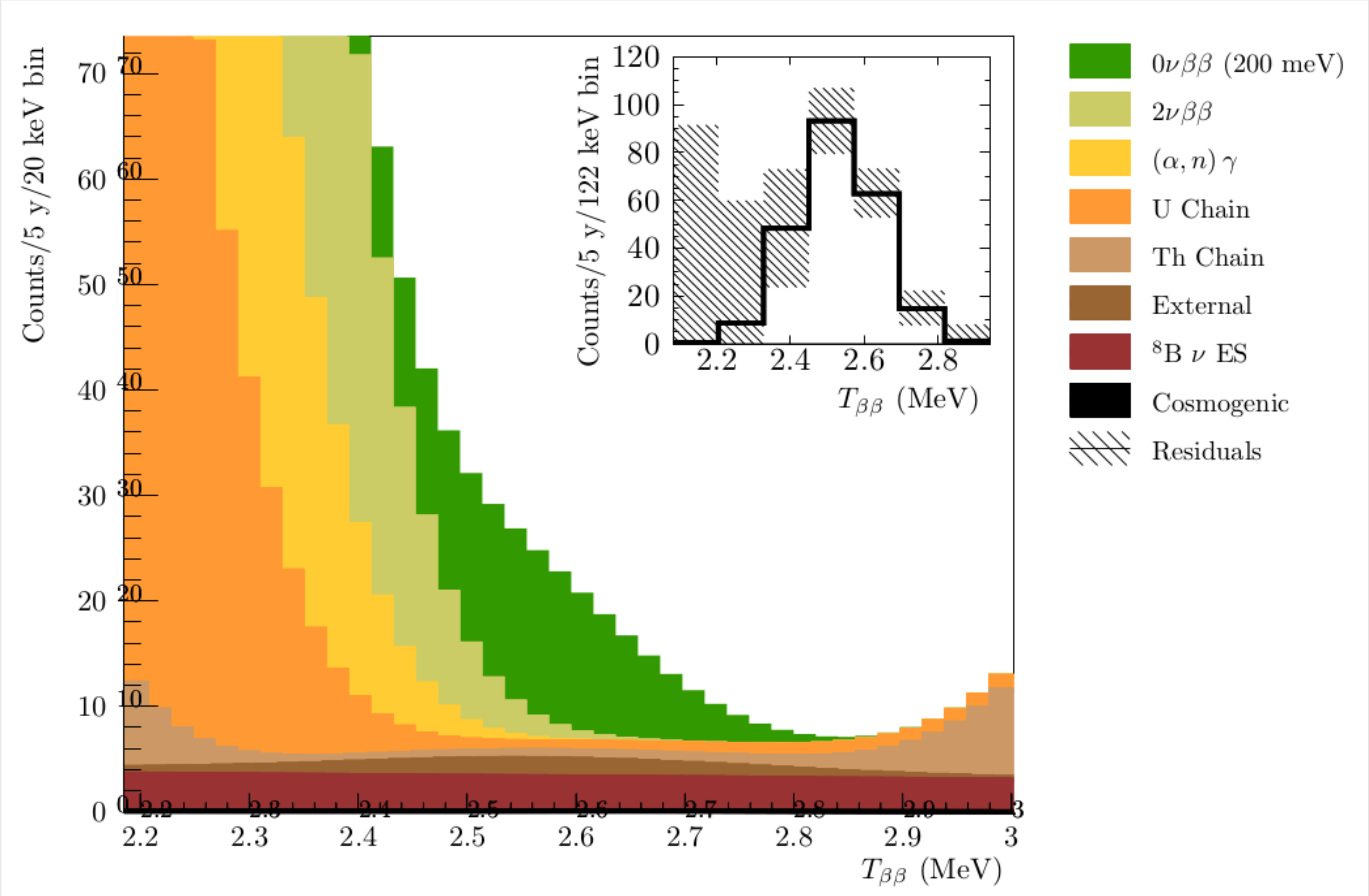
Main reaction: $\alpha + {}^{13}C \rightarrow {}^{16}O + n$ produce 2.2 MeV gammas

Can also produce a continuum from the collision of neutrons with protons (0.14 c/y)

Other backgrounds have been studied, as other sources of neutrons (from spontaneous fission, (n,n') reactions on Te), solar neutrino capture background for Te, external ^{222}Rn (new cover gas system), other pile-ups, etc...

With negligible or mitigable contributions to the RoI

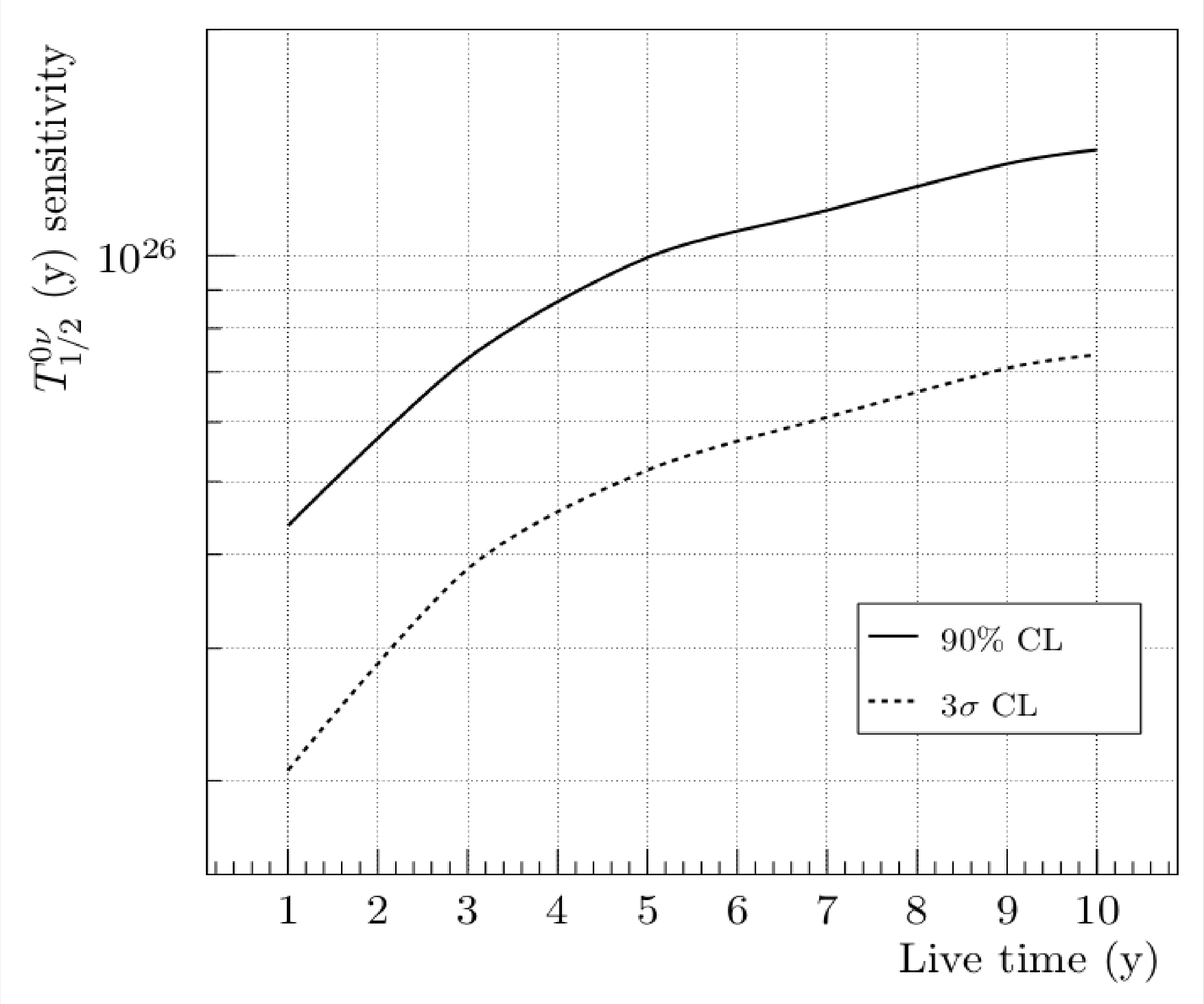
SNO+ Expected backgrounds



- 3.5 m (20%) fiducial volume cut
- 5 years
- RoI: −0.5σ → 1.5σ around $Q_{\beta\beta}$
- > 99.99% efficient ^{214}Bi tag
- 98% efficient internal ^{208}Tl tag
- Factor 50 reduction ^{212}BiPo (pile-up)
- Negligible cosmogenic isotopes
- $m_{0\nu\beta\beta}$ =200 meV*

*J. Barea et al. Phys. Rev. C87 (2013) 014315
J. Kotila, F.Iachello. Phys. Rev. C 85 (2012) 034316

SNO+ Sensitivity



The SNO+ sensitivity for a 0.3% loading as a function of lifetime, for both 90% CL limits and 3σ detection levels

- $T_{1/2}^{0\nu\beta\beta} > 10^{26}$ y (90% C.L.) for 5y lifetime

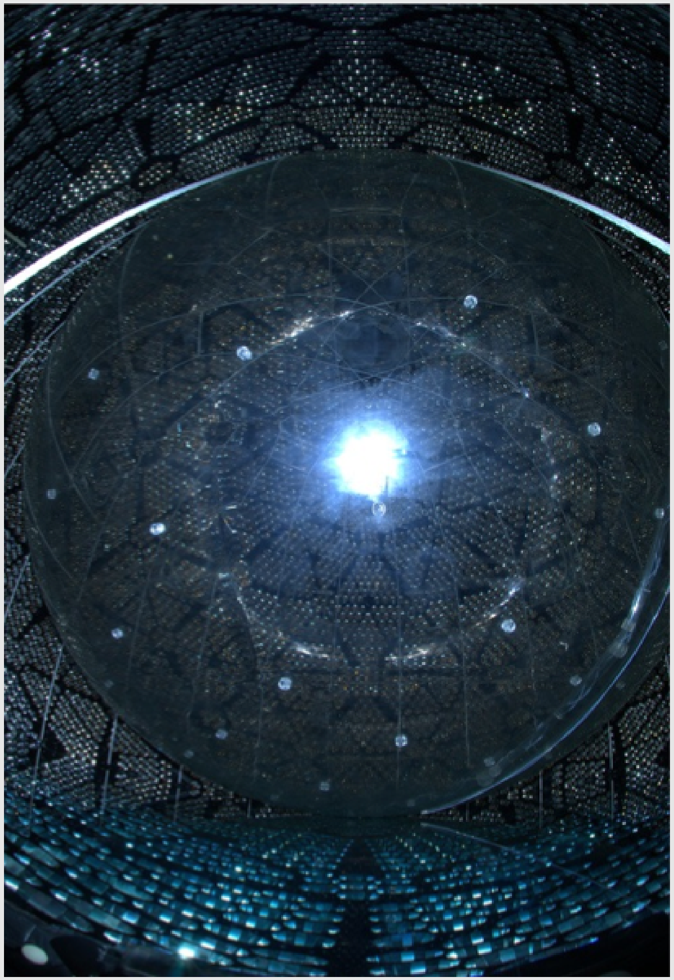
Conclusions

- SNO+ is a multi-purpose liquid scintillator detector
  - First aim is to detect the 0νββ of ^{130}Te
- In a neutrinoless double beta decay experiment it is mandatory the control and reduction of any source of background
- All the backgrounds impact in SNO+ have been evaluated through calculations and the full SNO+ Monte Carlo simulation (RAT)
- The main ones fall in the following categories: cosmogenics, external, Internal U/Th chain, 2νββ and ^{8}B neutrinos

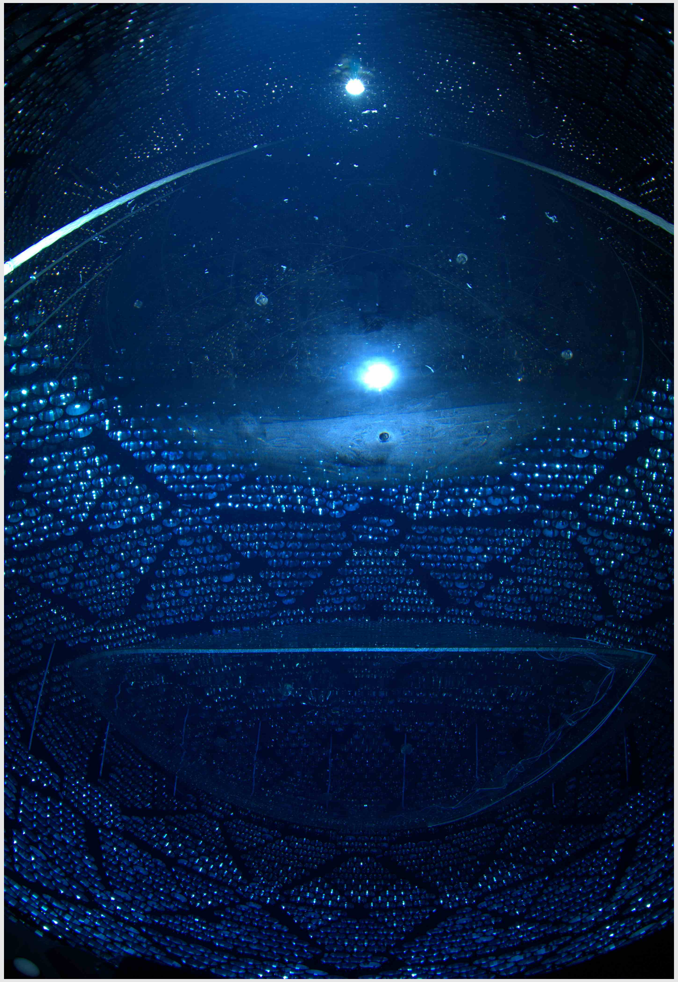
- Mitigation strategy:
  - Purification of all materials (in particular scintillator and Tellurium)
  - Energy RoI window
  - Fiducial volume restriction
  - Analysis techniques
    - Timing-based tags or cuts that exploit the β-α coincidences and the broadening of the PMTs hit time distributions for different types of events
- Applying the reconstruction and all the cuts to the simulated events, a total background of ~18 c/y is obtained
  - It gives a sensitivity of $T_{1/2}^{0\nu\beta\beta} > 10^{26}$ y (90% C.L.) for 5y lifetime

Thank you!

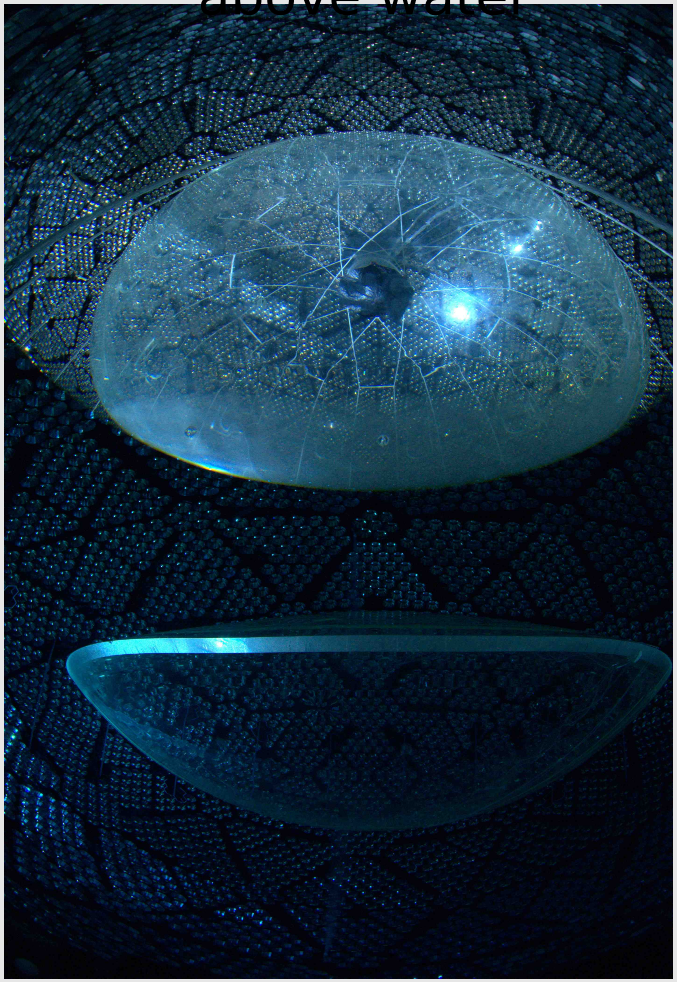
Camera above water



Camera and light underwater



Camera underwater, light above water



The detector and cavity are currently about half filled with water.

Backup

Cosmogenics

Short and long living isotopes can be produced by cosmogenic activation of natural Tellurium:

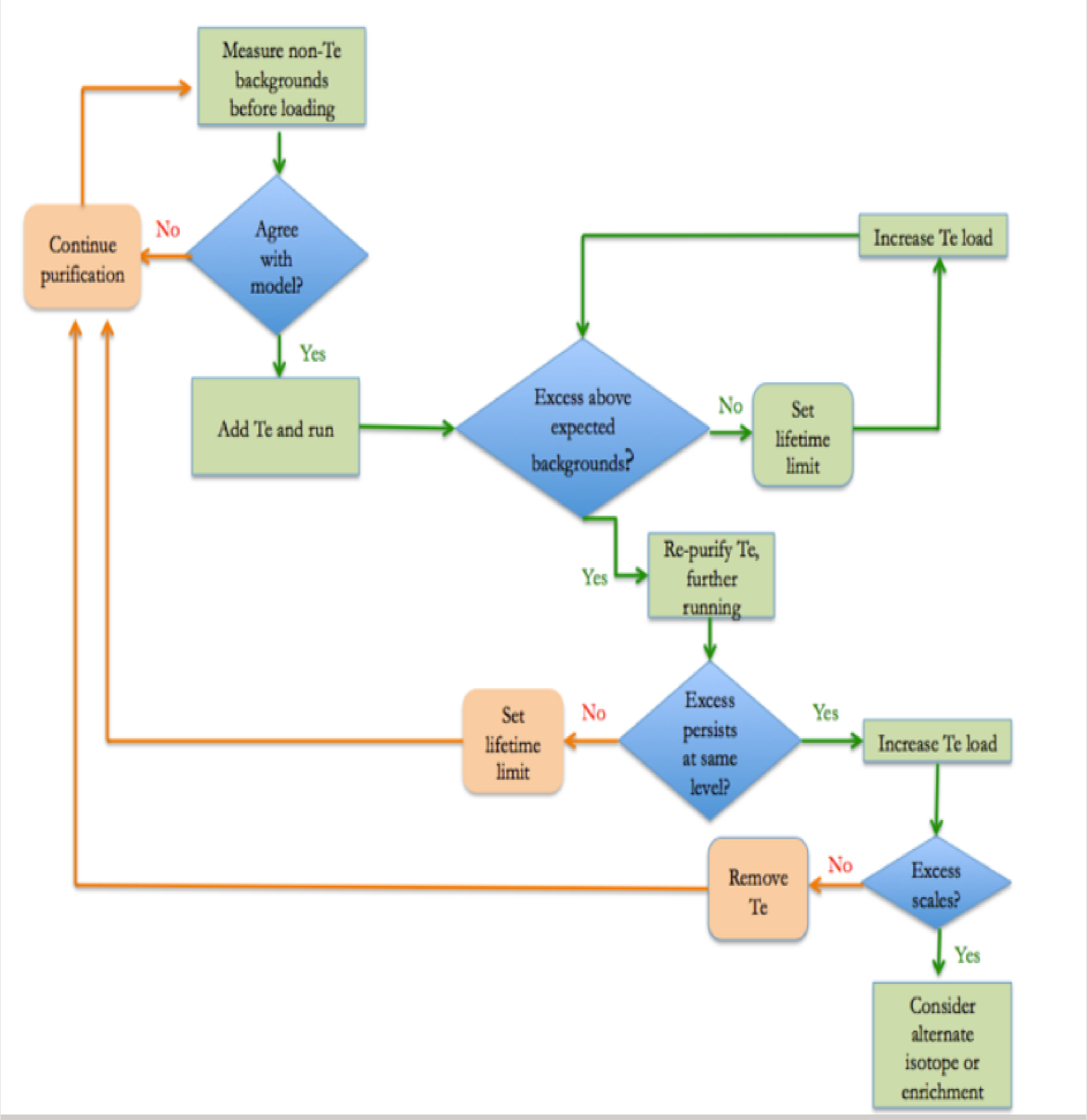
- Q-value > 2 MeV
- T1/2 longer than 20 days
- From spallation reaction on Te

- Production rates have been estimated using the program ACTIVIA (checked with YIELDX);
- neutron and proton flux parametrization at sea level from Armstrong and Gehrels;
- In the low energy range (E<200 MeV), when available, the TENDL library for cross sections has been used;
- 1 year sea level exposure;
- Purification on surface will be able to reduce the cosmogenic induced isotopes of a factor larger than 10^4;
- A further purification step UG and a cooling down of some months are additionally used to remove the isotopes that are reproduced after the transport UG (few hours)

→ Negligible cosmogenic isotopes

Isotope	Events Y1		
	t_{exp}=1 yr	PF stage 1 t_{exp}=5h surf	PF stage 2 t_{cool}=6 mo. UG
^{22}Na	765	0.54	0.0047
^{26}Al	0.000	0.000	0.0000
^{42}K	9	0.772	6.62e-5
^{44}Sc	6	1.84	1.938e-5
^{46}Sc	3	0.01	1.377e-5
^{56}Co	0.68	0.00132	2.57e-6
^{58}Co	0.008	1.60e-5	0.0000
^{60}Co	720	0.44	0.0041
^{68}Ga	209	0.43	0.001
^{82}Rb	399	2.33	0.0002
^{84}Rb	9	0.04	8.82E-6
^{88}Y	45927	48.19	0.271
^{90}Y	2.86E-4	1E-5	0.0000
^{102}Rh	2	0.002	1.24E-5
^{102m}Rh	3	0.02	2.49E-5
^{106}Rh	19	0.02	1.36E-4
^{110m}Ag	3811	3.80	0.0229
^{110}Ag	2.02	0.002	1.22E-5
^{124}Sb	132649	340.99	0.416
^{126m}Sb	8	8.41	0.0000
^{126}Sb	7827	93.12	3.29E-5

Strategy if we see a bump



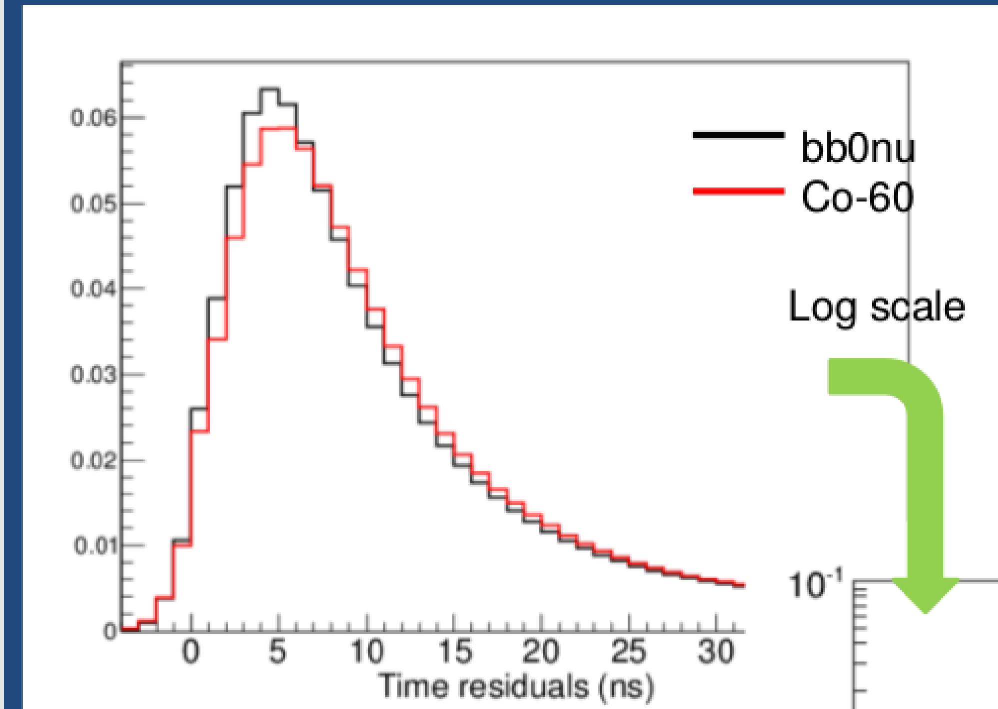
Huntig the isotope

- Initially explored ^{150}Nd
- Biller and Chen in Fall 2011 emphasized some advantages of Te for DBD
- New investigations by the collaboration were started.
- A new loading technique for Te in liquid scintillator was developed by Yeh et al. in early 2012
- Detailed studies of purification, scintillator optics and backgrounds were completed by the collaboration
- Verification of these studies was completed by the collaboration

→ The decision to pursue Te DBD was made by the SNO+ collaboration

Time Scale

- 2015: water fill and commissioning
  - nucleon decay physics
  - Backgrounds analysis
  - Supernovae neutrinos
- 2016: start liquid scintillator fill
  - background analysis
  - reactor- and geo- antineutrinos
  - Supernovae neutrinos
  - low energy solar neutrinos
- 2017: 0.3% Te loading
  - neutrinoless double beta decay
  - reactor- and geo- antineutrinos
  - Supernovae neutrinos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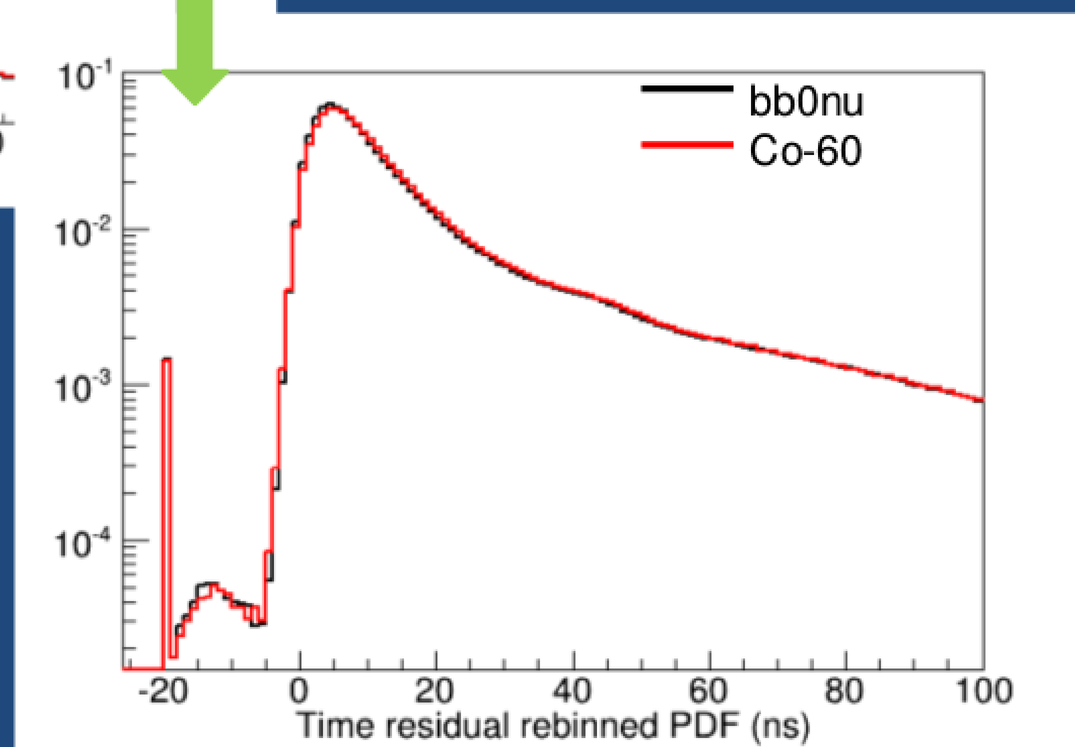
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