The AmBe source for the SNO+ detector calibration

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SNO+

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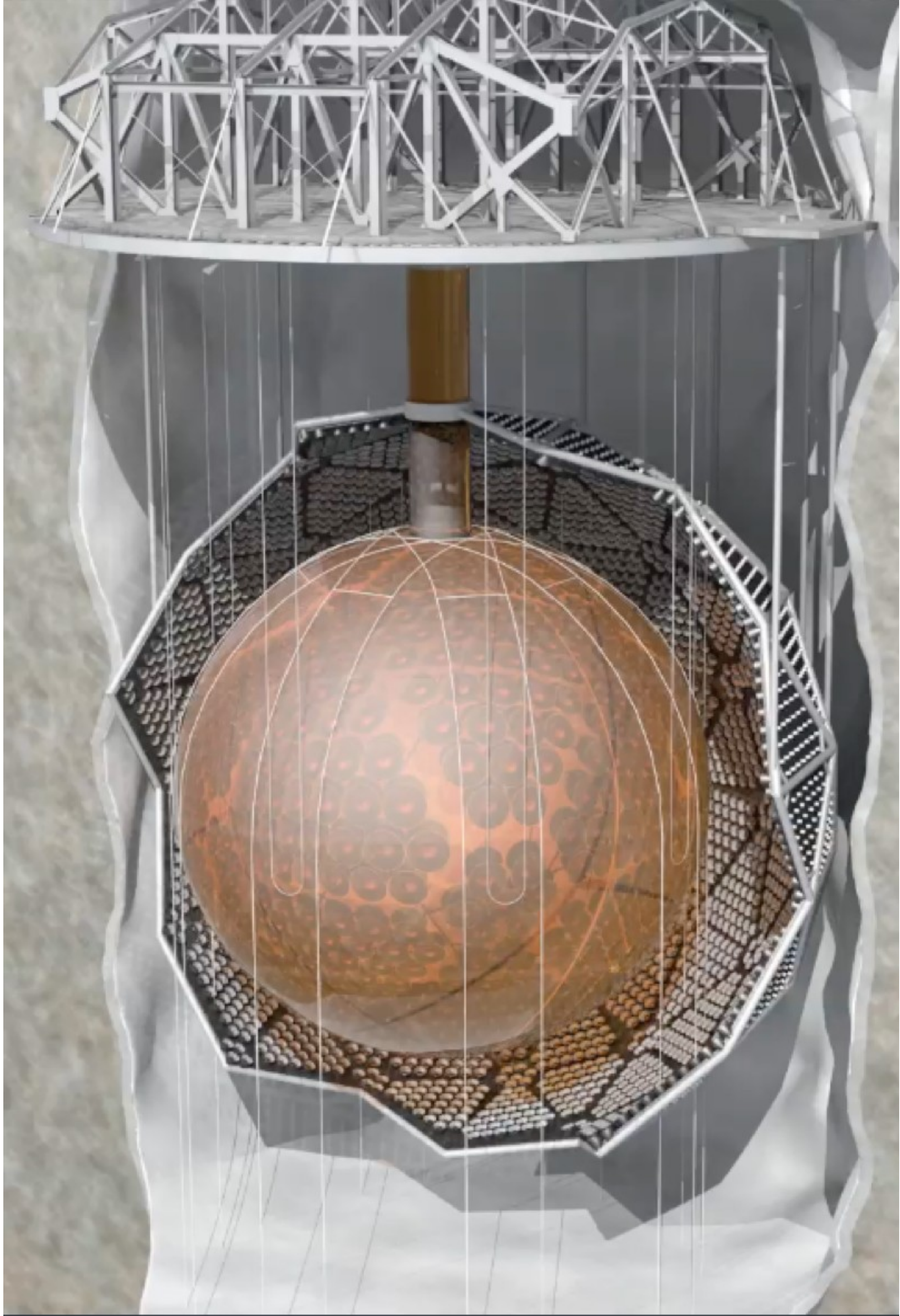
Overview

- SNO+
- Physics goals
- Physics motivation
- Calibration
- AmBe source
- AmBe shielding
- Conclusions

SNO+

- Successor experiment of SNO (Sudbury Neutrino Observatory)
- 6800 feet underground at SNOLAB facility
- 780 tons of liquid scintillator inside a 12 m diameter acrylic vessel (AV).
- New hold down rope system
- 7 kt ultra pure water shielding
- ~9400 PMTs
- Upgraded electronics



Physics Goals

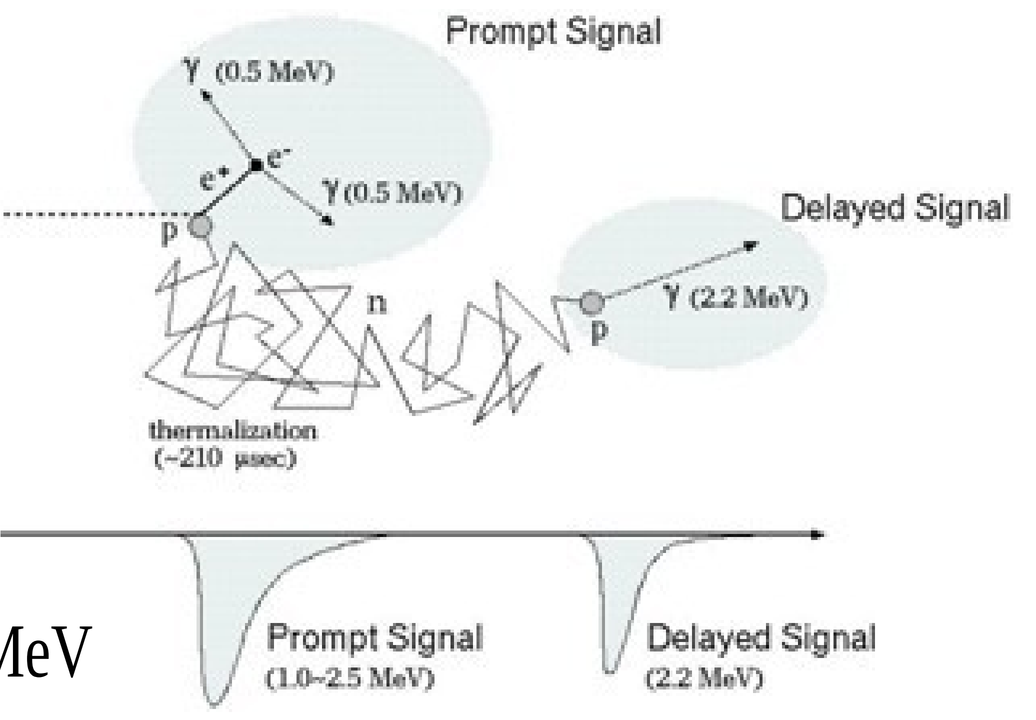
GOAL/PHASE	Water	Pure LAB	Te-loaded LAB
Neutrinoless double beta decay	-	-	✓
^{8}B solar neutrinos	-	✓	✓
CNO, pep solar neutrinos	-	✓	-
Reactor and Geo-neutrinos	-	✓	✓
Exotic searches	✓	✓	✓
Calibration goals	PMT response, electronics	Optical absoption, reemission, scattering	Optical parameters, detector response

Inverse Beta Decay

Inverse beta decay is a crucial reaction for the detection of reactor antineutrinos.

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

- High interaction probability and distinct signature
- Important to understand detectors response to neutron capture events



$$E_{\bar{\nu}_e} \simeq E_{prompt} + (M_n - M_p) - m_e \simeq E_{prompt} + 0.8\ \text{MeV}$$

Reactor - $\bar{\nu}_e$

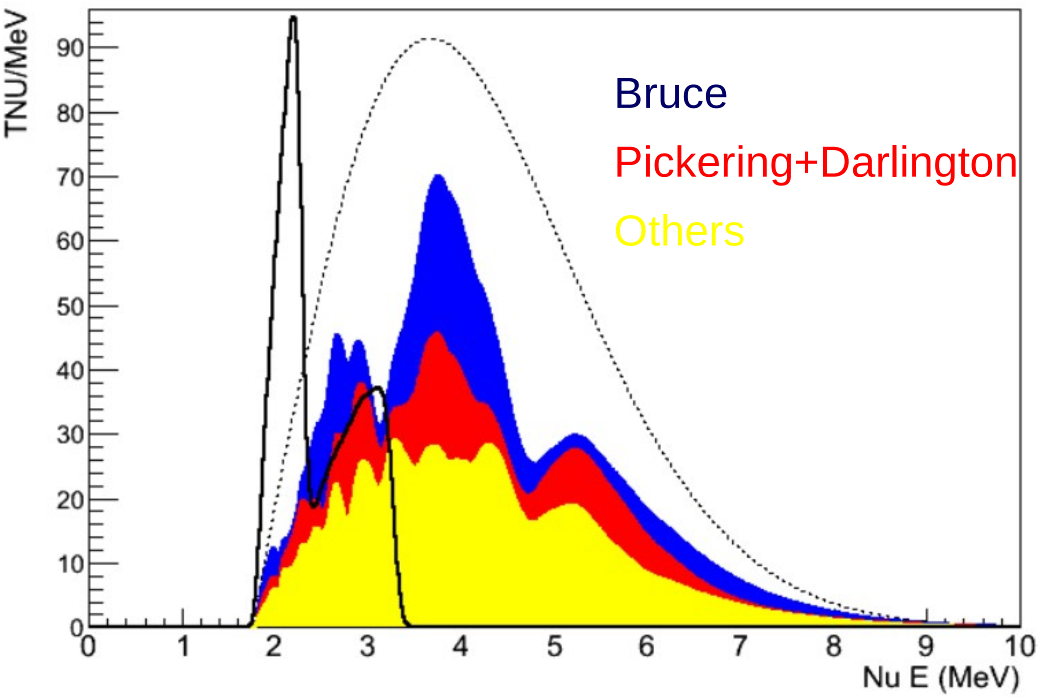
- Large fluxes from nuclear reactors
- Expect 100 interactions per year
- Constraints on neutrino oscillation parameters

Geo - $\bar{\nu}_e$

- Measuring contributions from Uranium and Thorium from the mantle and crust of the Earth
- Spectrum lies between 1.8-3.3 MeV

Supernova - $\bar{\nu}_e$

For reaction: $\bar{\nu}_e + p \rightarrow n + e^+$
expected number of events is: 194.7 ± 1.0
per entire reference SN (10kpc) for
780 tonnes of scintillator volume.

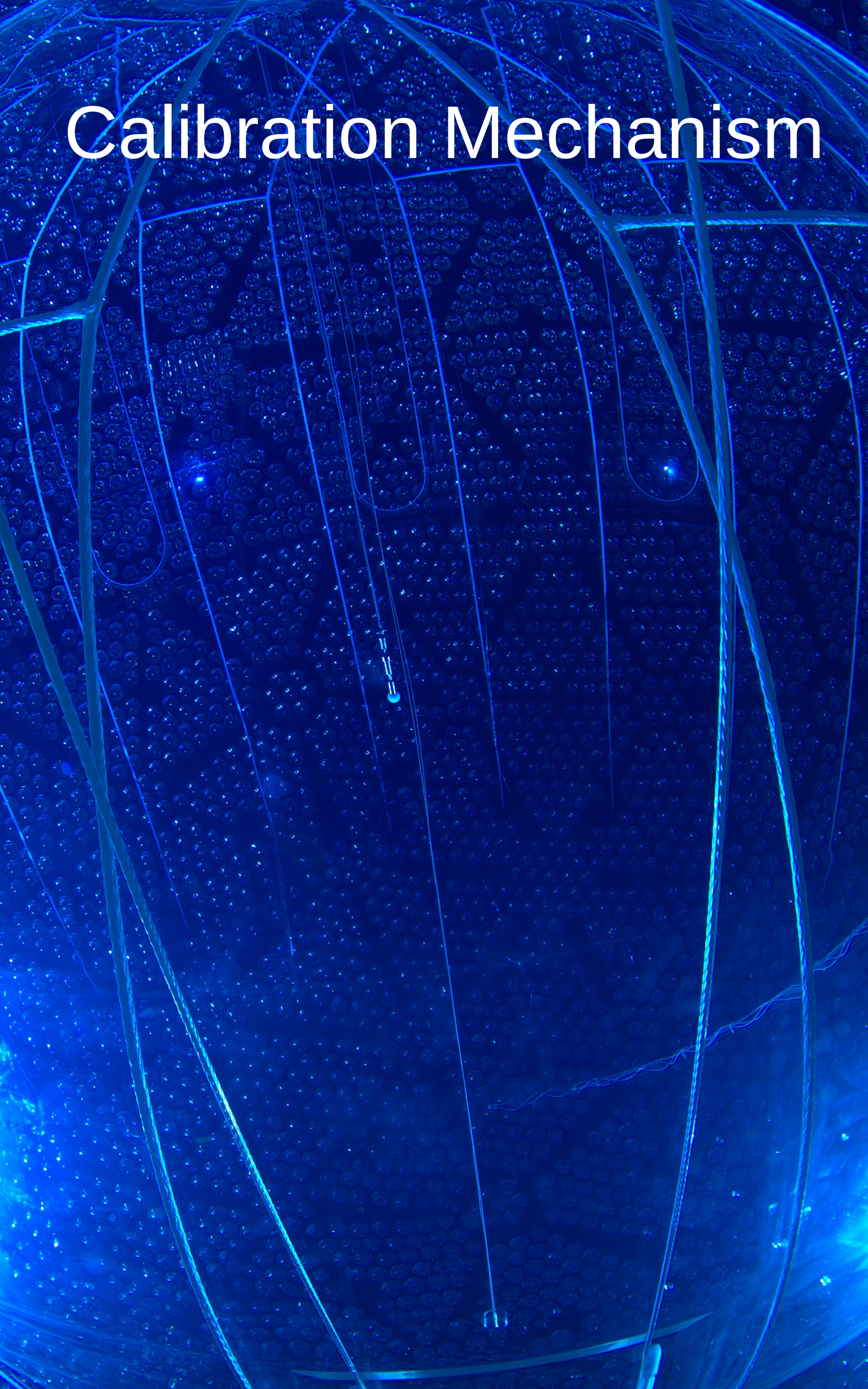


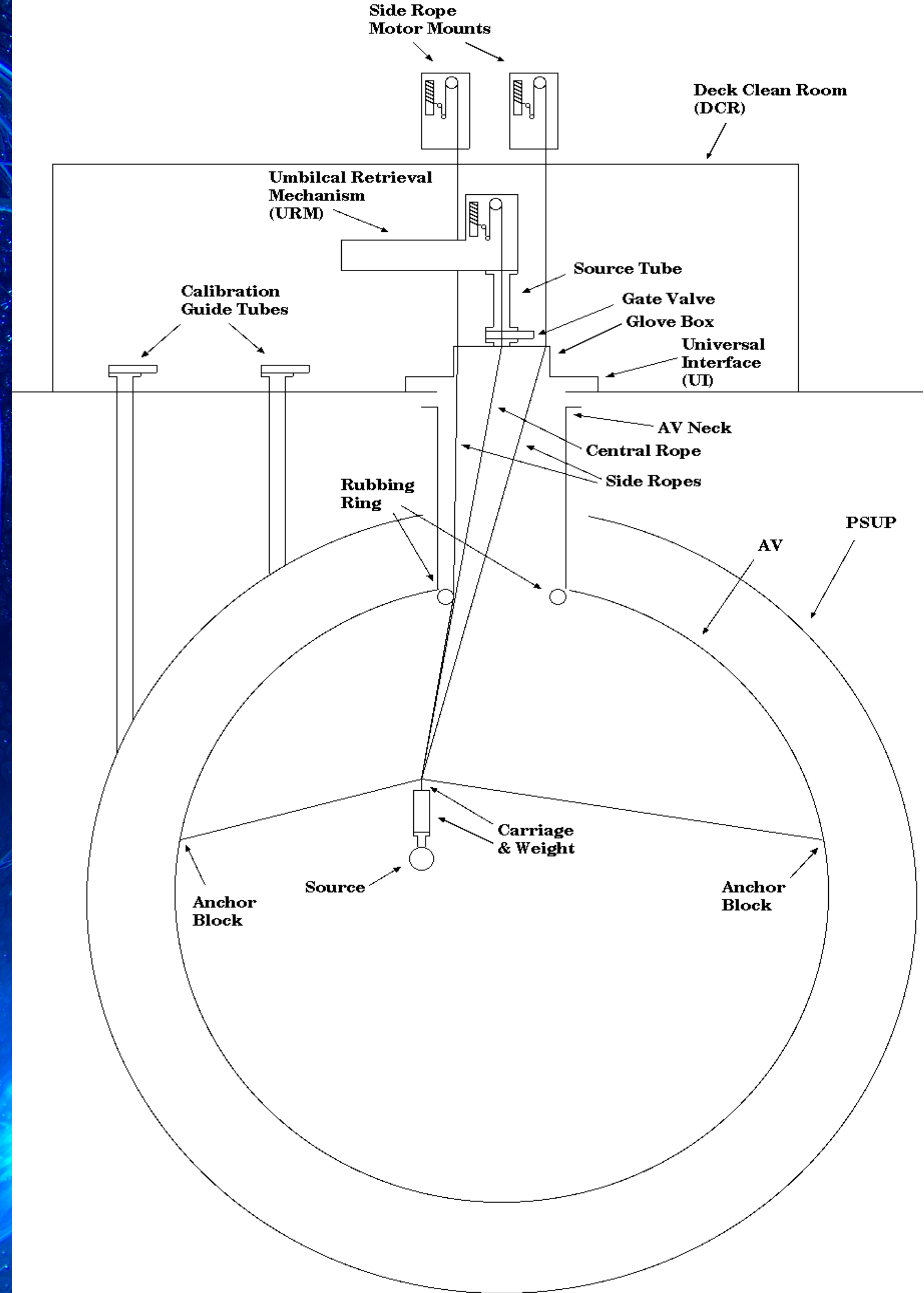
Calibration Sources

- Goal is to characterize the detector's response to different particles
- Various external optical and radioactive sources are deployed and produce β, γ , n particles

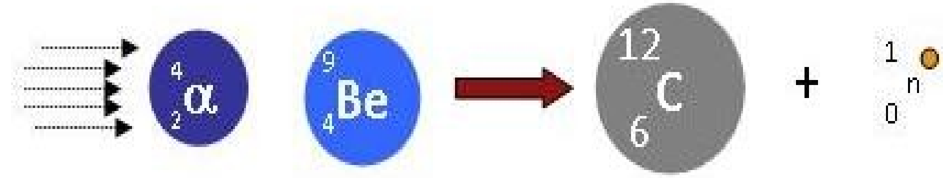
Source	Particle	Energy	Tag
AmBe	n, γ	2.2, 4.4 MeV	coinc
^{16}N	γ	6.1 MeV	yes
^{48}Sc	γ	1.0, 1.2, 1.3 MeV	no
^{57}Co	γ	122 keV	no
^{46}Sc	γ	0.89, 1.12 MeV	yes

Calibration Mechanism

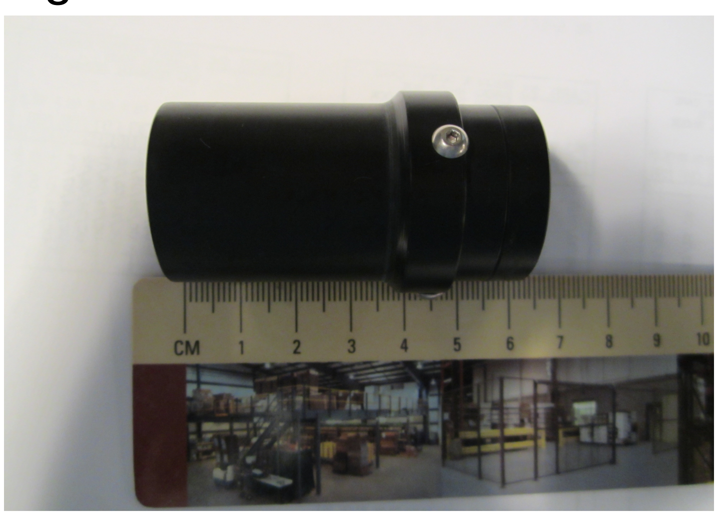


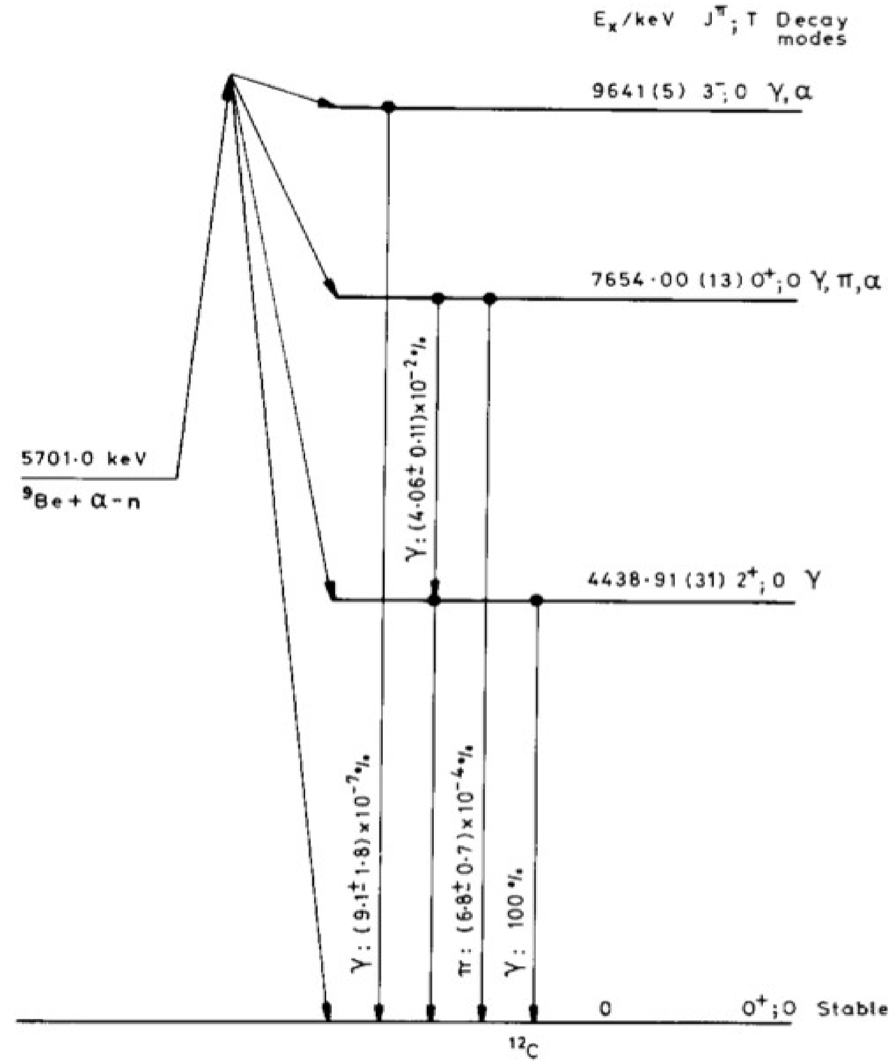


AmBe Source



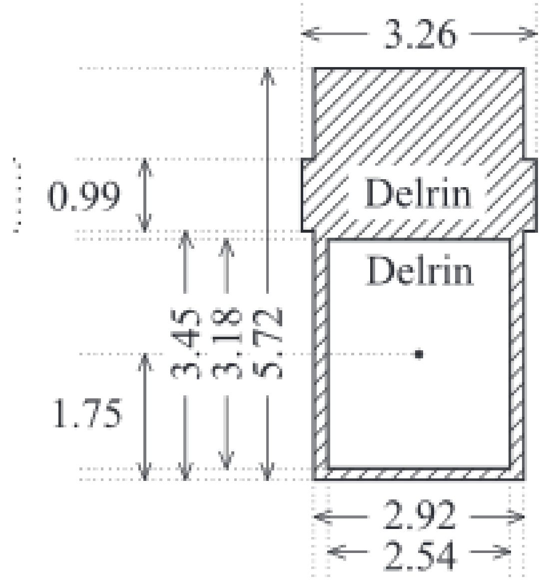
- Mixture of Americium and Beryllium powders
- ^{241}Am decays via α emission
- Induces ^{9}Be(α,n)^{12}C reaction
- 4.4 MeV gamma produced in 60% of ^{12}C de-excitations and used as a tag for neutrons

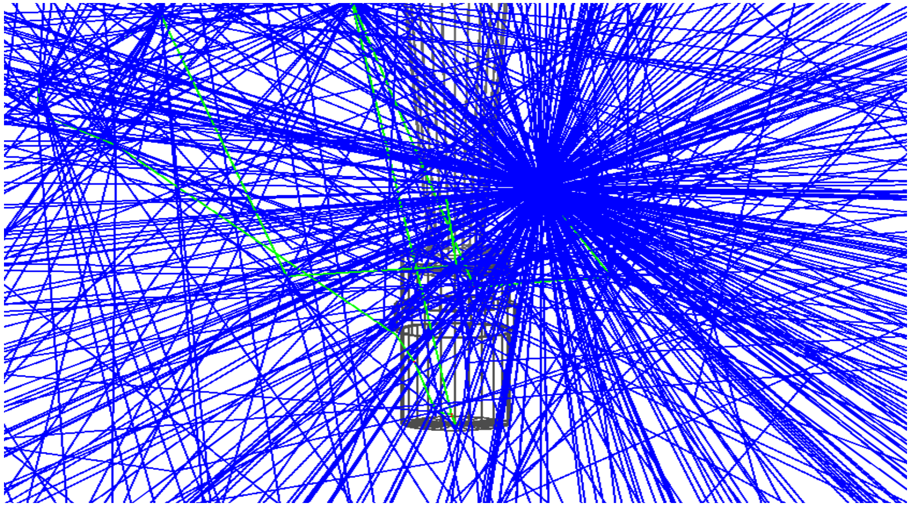




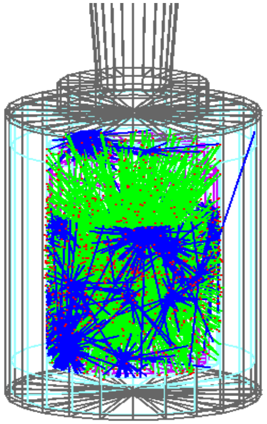
Shielding Motivation

- The source also produces ~10^6 low energy gammas (~59keV) per neutron
- This would “blind” the detector; therefore the source needs additional shielding





Am-Be high

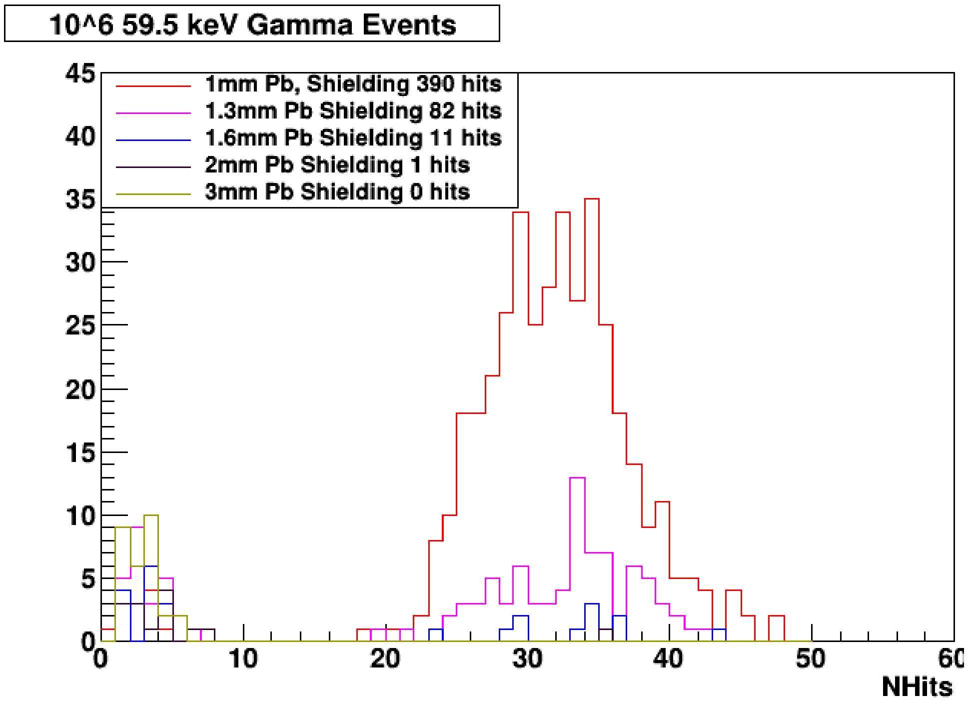


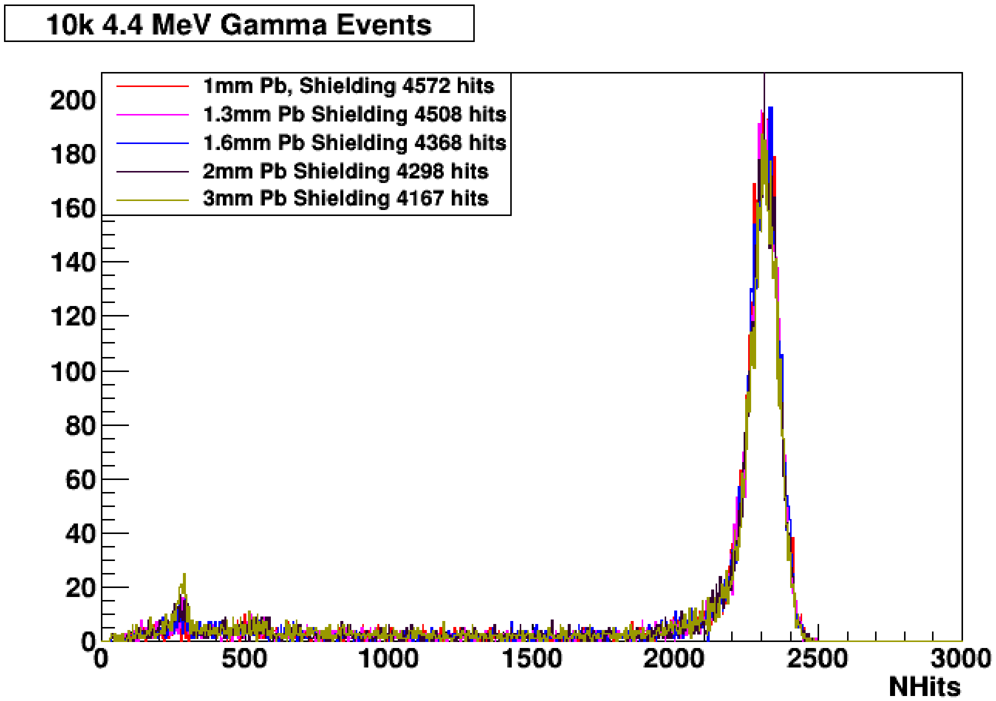
AmBe Shielding Materials

Material	Lead		Stainless Steel		Hevimet	
Thickness	59 keV	4.4 MeV	59 keV	4.4 MeV	59 keV	4.4 MeV
1 mm	0.03%	84.68%	6.25%	87.44%	0.06%	82.86%
2 mm	0%	80.34%	2.10%	84.74%	0%	75.22%
3 mm	0%	73.70%	0.69%	82.74%	0%	70.09%
5 mm	0%	71.63%	0.37%	80.51%	0%	62.68%
7 mm	0%	63.84%	0.06%	76.04%	0%	52.82%
8 mm	0%	60.81%	0.02%	74.78%	0%	49.21%

The % of gammas penetrating the different thicknesses of lead, stainless steel and hevimet.

Lead Shielding



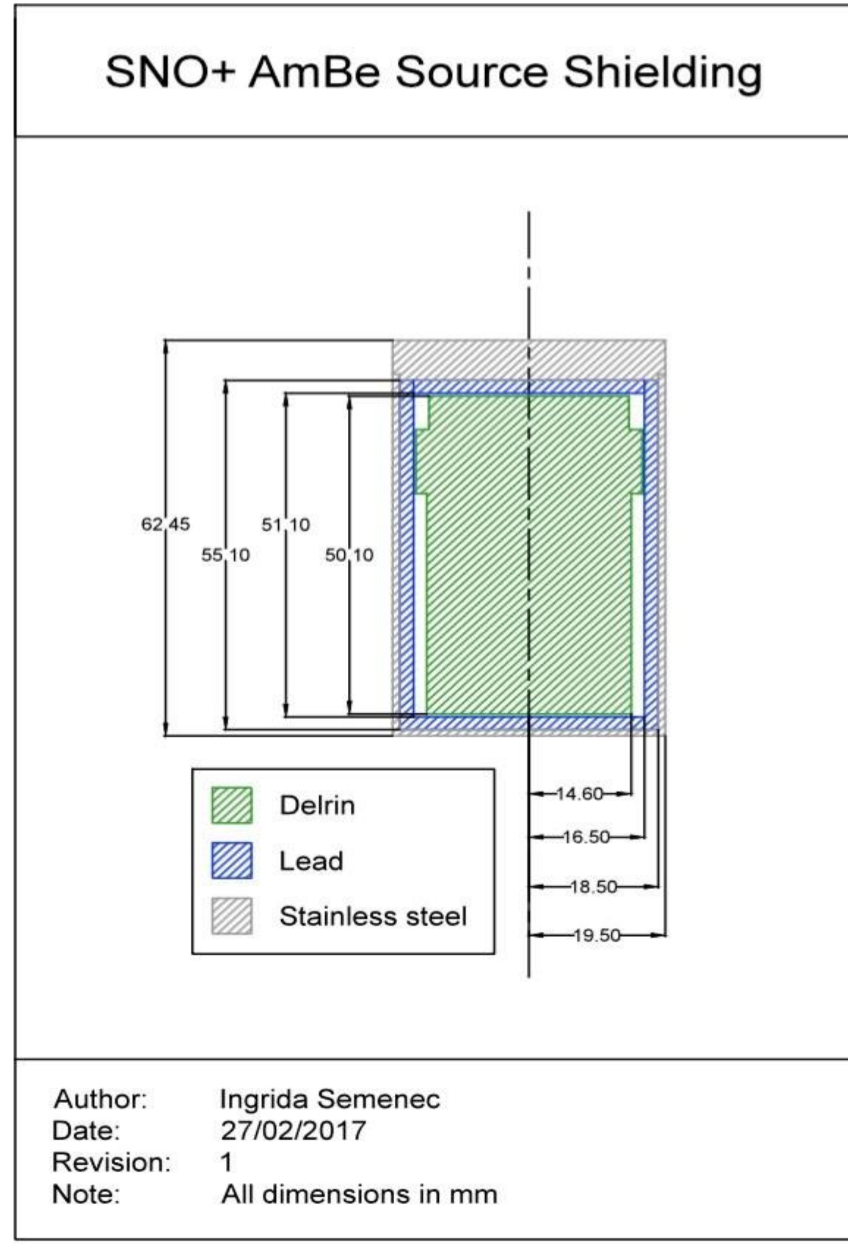


Nhit (number of PMT hits) distrinutions from the Monte Carlo simulations of 59.5 keV and 4.4 MeV γ particles inside the source capsule with varying shielding thicknesses.

AmBe Design

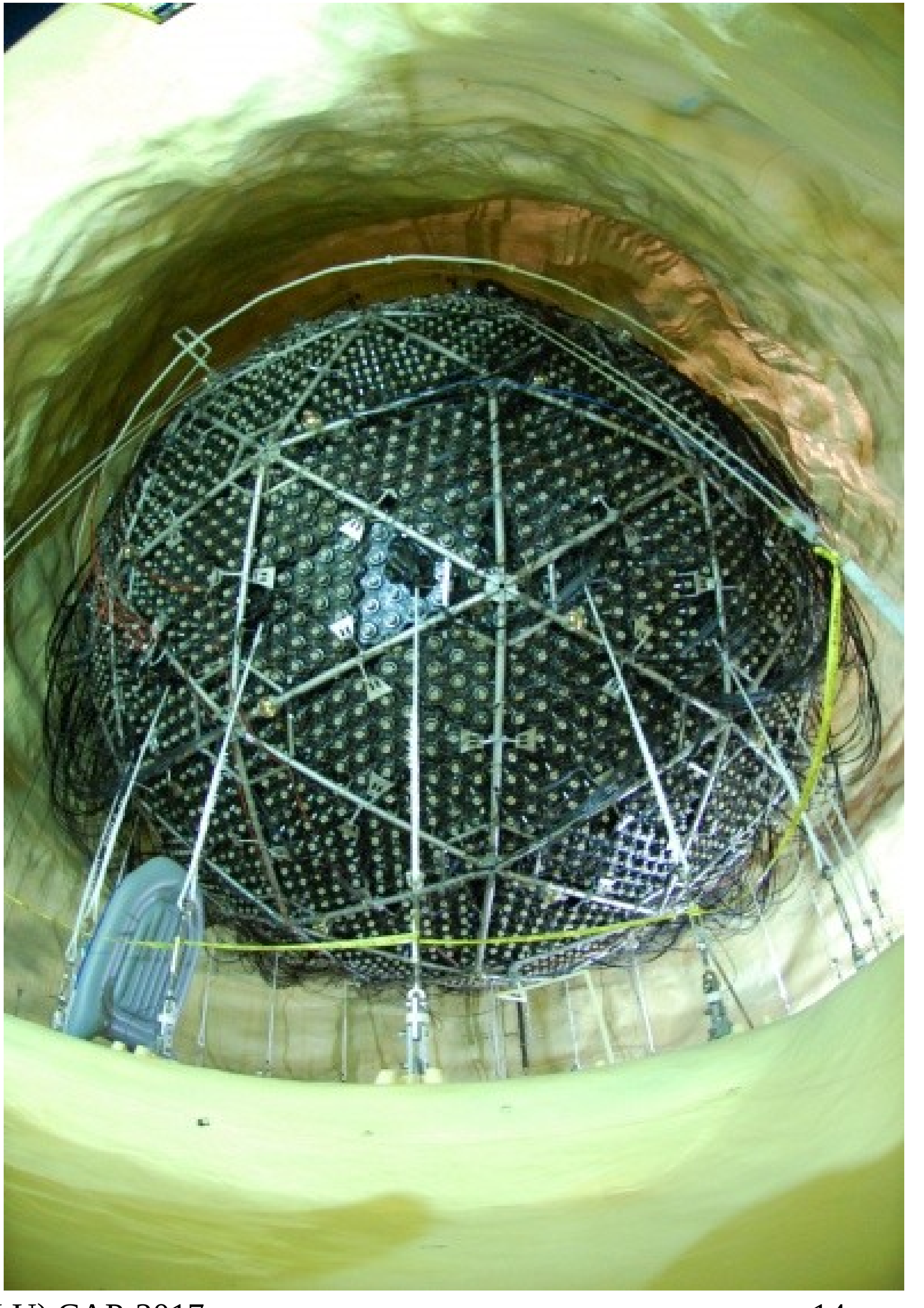
Thickness	59keV	4.4 MeV	Neutrons
1 mm	0.0390%	84.68%	88.15%
1.3 mm	0.0082%	83.87%	88.21%
1.6 mm	0.0011%	82.27%	88.21%
2 mm	0.0001%	80.34%	87.83%
3 mm	0.0000%	76.70%	87.37%

The % of gammas and neutrons penetrating the different thicknesses of lead.



Conclusions

- Calibration is essential for a successful experiment
- Neutron detection efficiency is critical input for antineutrino analysis
- AmBe source refurbishment for the scintillator phase is well underway
- 2 mm Lead + 1 mm Stainless steel provides sufficient shielding against low energy gamma rays
- Refurbished AmBe source will provide absolute neutron detection efficiency calibration for anti-neutrino analysis in SNO+

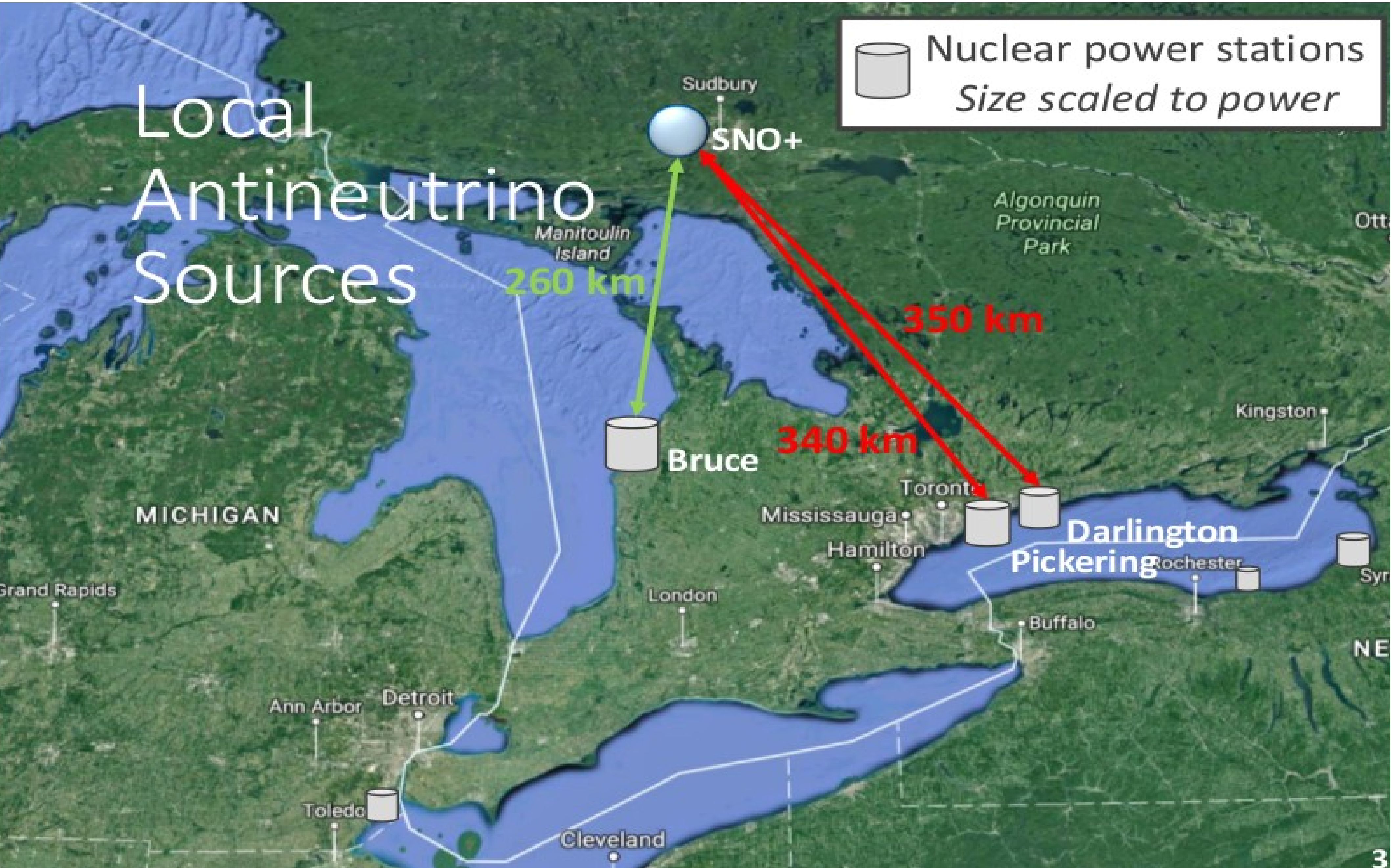


Thank you!

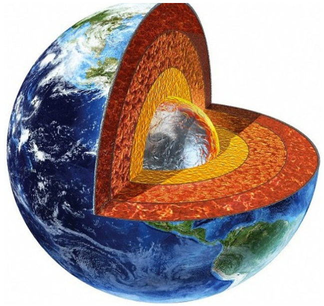
SNOLAB, University of Alberta, TRIUMF, Queens University, Laurentian University, LIP Coimbra, LIP Lisboa, TU Dresden, Oxford University, Queen Mary, University of London, University of Liverpool, University of Sussex, University of Lancaster, UNAM, Armstrong State University, Brookhaven National Lab, University of California Berkeley, Lawrence Berkeley National Laboratory, University of Chicago, University of Pennsylvania, University of Washington, UC Davis.

Backup Slides

Reactor - $\bar{\nu}_e$



Geo - $\bar{\nu}_e$

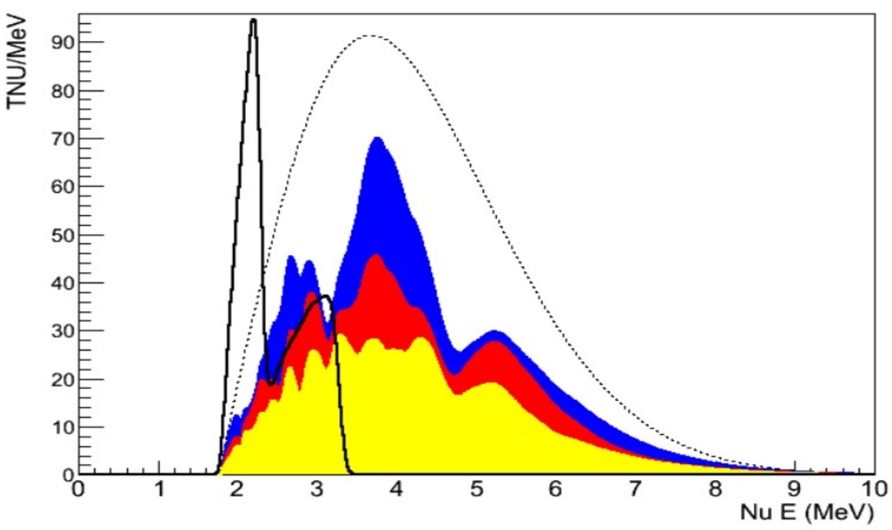


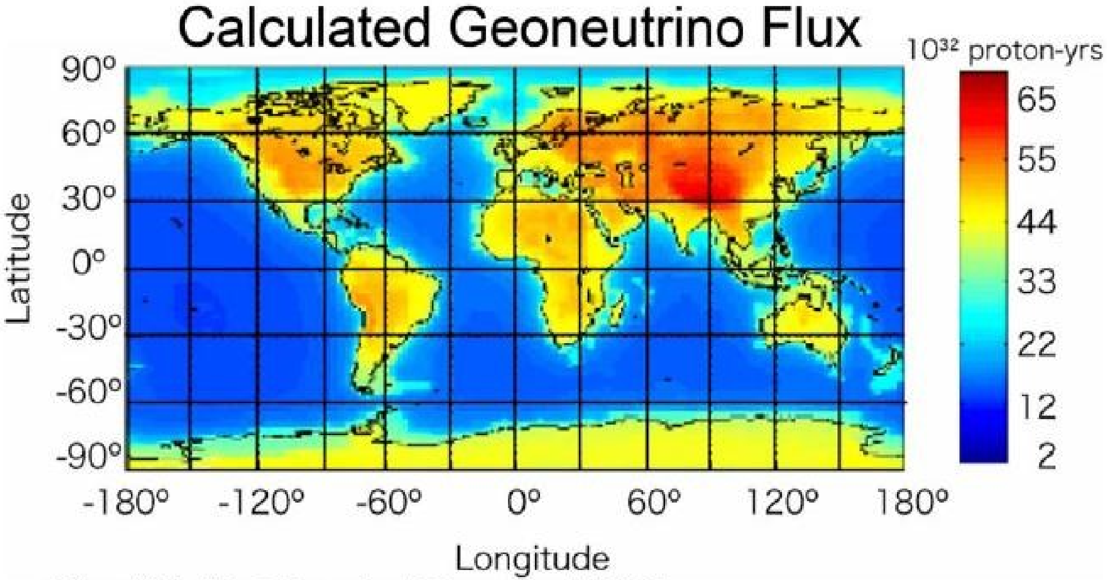
- Measuring contributions from Uranium and Thorium from the mantle and crust of the Earth.
- Measurements will be combined with KamLand and Borexino for global analysis.
- Region of interest: 1.8-3.3 MeV

$$^{238}U \rightarrow {}^{206}Pb + 8\,{}^{4}He + 6e^{-} + 6\bar{\nu}_e$$

$$^{232}Th \rightarrow {}^{208}Pb + 6\,{}^{4}He + 4e^{-} + 4\bar{\nu}_e$$

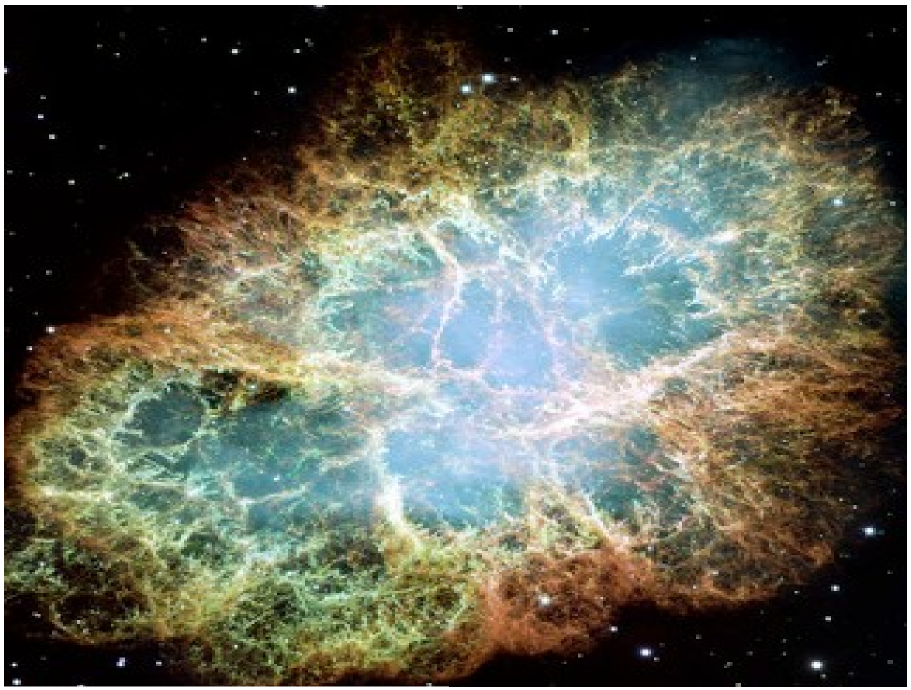
$$^{40}K \rightarrow {}^{40}Ca + e^{-} + \bar{\nu}_e$$





G. Fiorentini, M. Lissia, F. Mantovani, and R. Vannucci, hep-ph/0401085

Supernova - $\bar{\nu}_e$



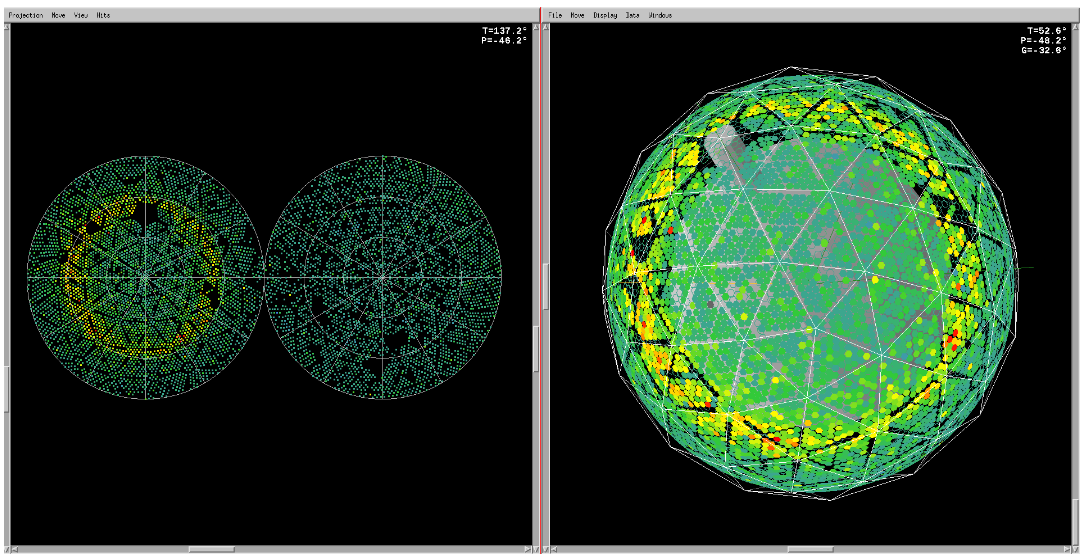
For reaction: $\bar{\nu}_e + p \rightarrow n + e^+$
expected number of events is: 194.7 ± 1.0
per entire reference SN (10kpc) for
780 tonnes of scintillator volume.

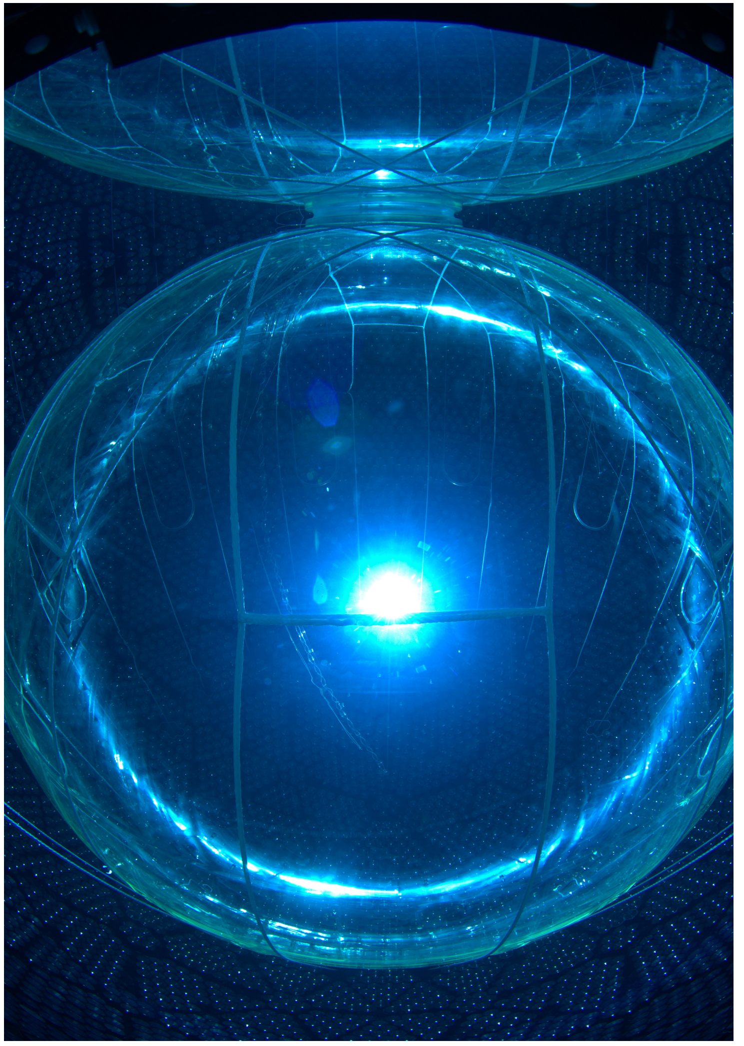
- Energy > 0.2 MeV. Mean energy for $\bar{\nu}_e$ is 15 MeV.
- ~ 99% of gravitational energy released is emitted in neutrinos (several 10^{53} erg).
- Core collapse (type II) supernovae occur in the Milky Way at a rate of about 3/century.

SNEWS = Super-K, IceCube, Borexino, KamLAND, Daya Bay, HALO, (SNO+).

Current Status

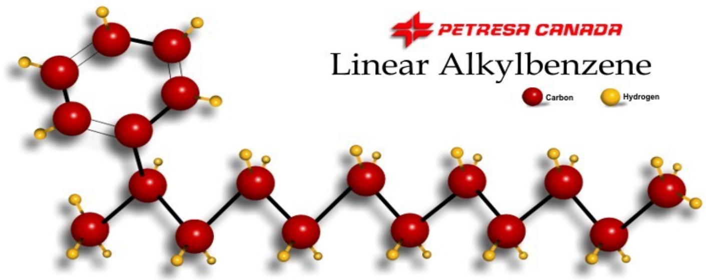
- Water Physics Now!
- 2017: Filling with scintillator
- 2018: Te-loaded scintillator

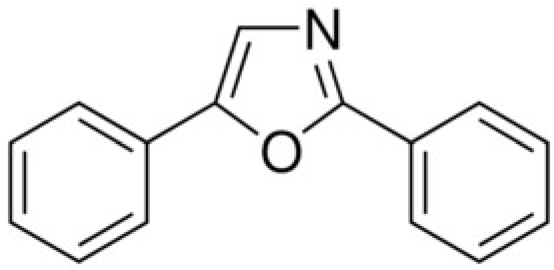




Scintillator Phase

- Organic scintillator- Linear alkylbenzene (LAB) + 2g/L fluor 2,5-diphenyloxazole (PPO)
- LAB gets excited by charged particles and produces light.
- Light yield is ~10,000 optical photons/MeV.

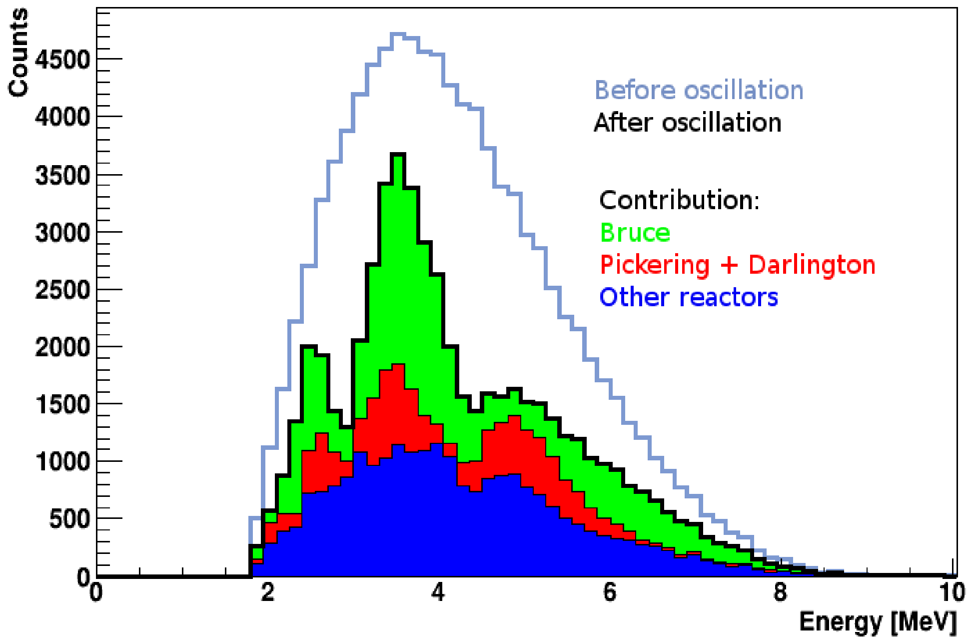




- High purity.
- Compatible with acrylic.
- Low scattering.
- Good optical transparency.
- Fast decay (different for β and α).

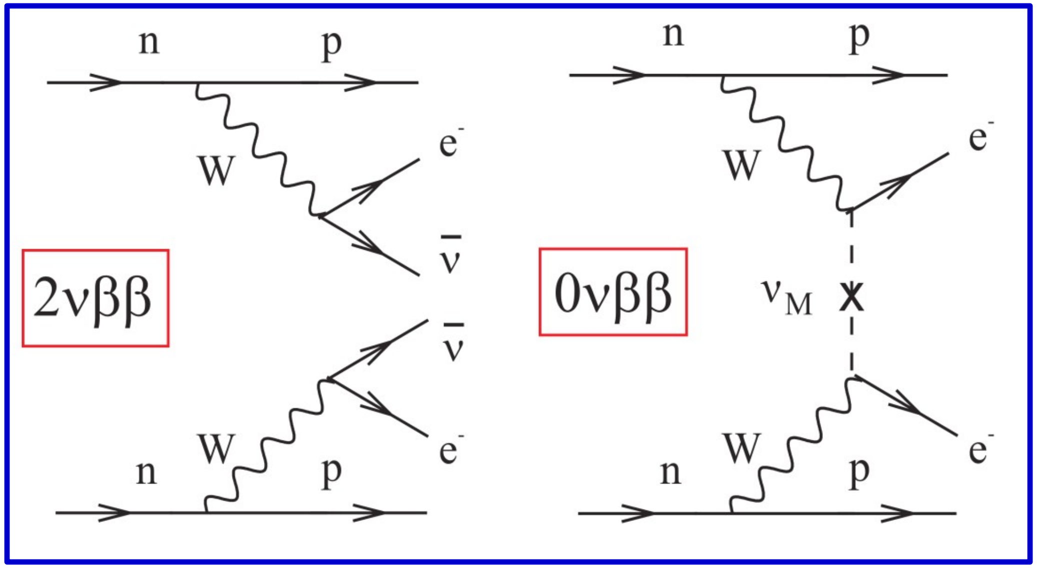
Reactor - $\bar{\nu}_e$

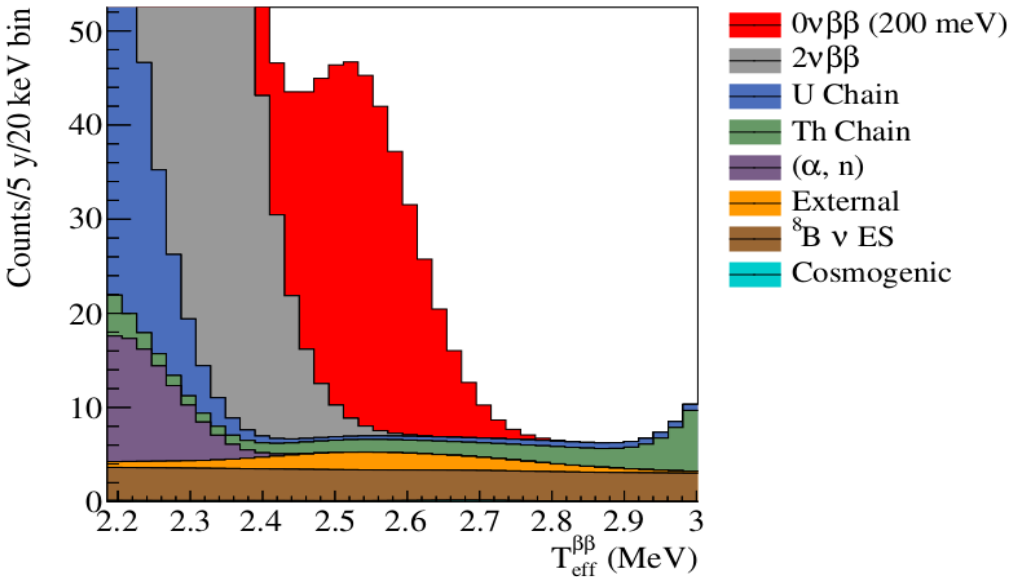
- Large fluxes from nuclear reactors
- Small fraction interacts inside the detector
- Expect 100 interactions per year
- Measurement gives constraints on neutrino oscillation parameters



Measure Δm^2_{12} to the precision of $0.2\times10^{-5}\,\mathrm{eV}^2$ with 7 years of data. The current best fit value: $(7.54+0.26/-0.22)\times10^{-5}\,\mathrm{eV}^2$.

Double Beta Decay



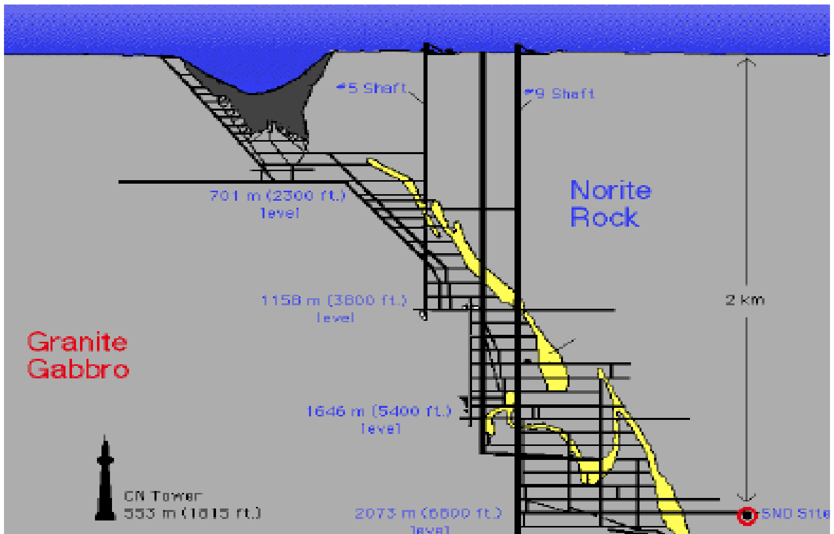


$$2\nu\beta\beta : (A,Z) \rightarrow (A,Z+2) + 2e^{-} + 2\nu \; ; \; \Delta L = 0$$

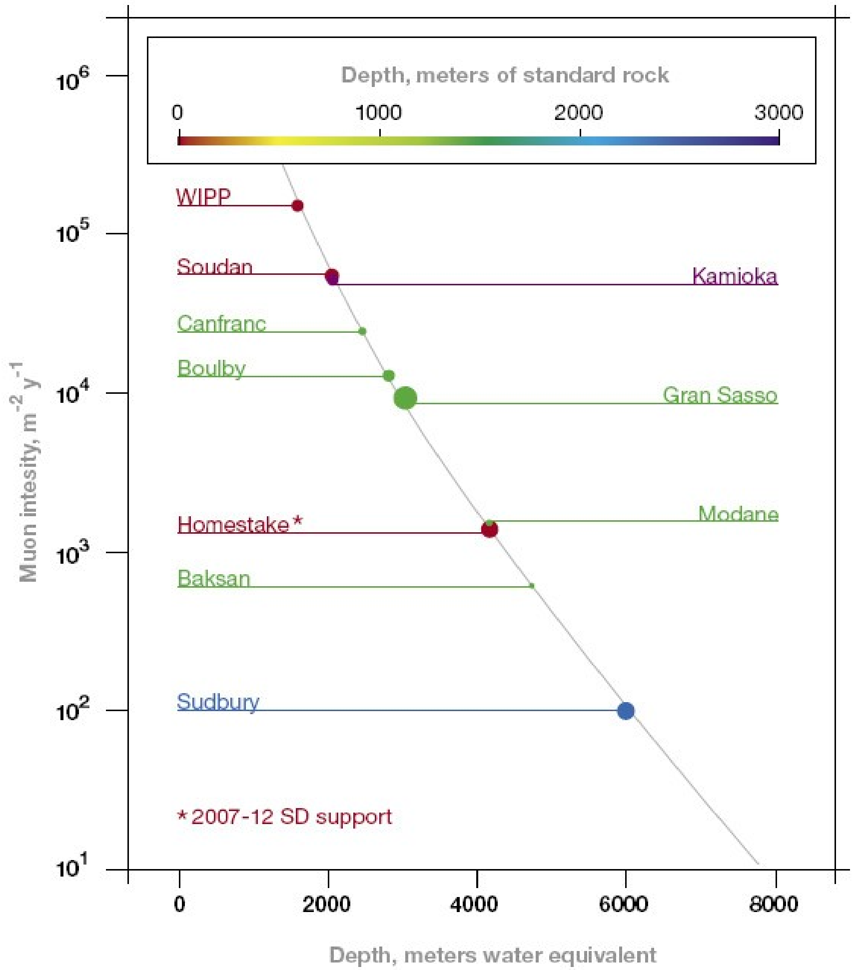
$$0\nu\beta\beta : (A,Z) \rightarrow (A,Z+2) + 2e^{-} \; ; \; \Delta L = 2 \rightarrow \nu = \bar{\nu}$$

- The expected internal backgrounds for the double beta decay phase
- 780 tonnes of LAB and 0.5% Te loading. Over 1 tonne of Te-130

Location


#5 Shaft
#9 Shaft
701 m (2300 ft.) level
Norite Rock
1158 m (3800 ft.) level
2 km
Granite Gabbro
1646 m (5400 ft.) level
CN Tower 553 m (1815 ft.)
2073 m (6800 ft.) level
SNO Site


SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE


Depth, meters of standard rock
0
1000
2000
3000
WIPP
Soudan
Kamioka
Canfranc
Boulby
Gran Sasso
Homestake*
Modane
Baksan
Sudbury
*2007-12 SD support
Muon intesity, m^-2 y^-1
10^6
10^5
10^4
10^3
10^2
10^1
0
2000
4000
6000
8000
Depth, meters water equivalent