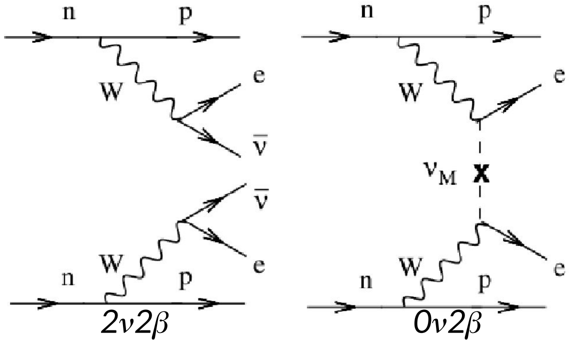
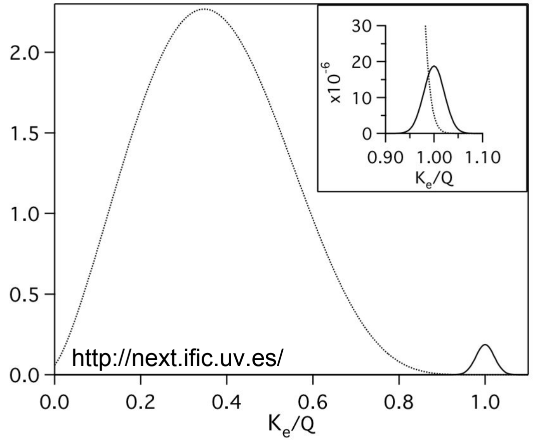
Status of SNO+

J. P. Yáñez for the **SNO+ Collaboration**
Lake Louise Winter Institute 2017

Bourses postdoctorales Banting Postdoctoral Fellowships
UNIVERSITY OF ALBERTA

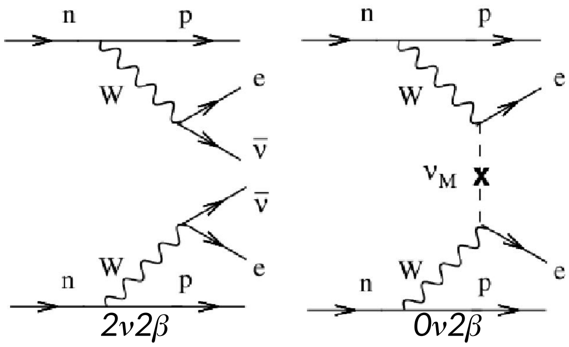
Neutrinoless double beta decay

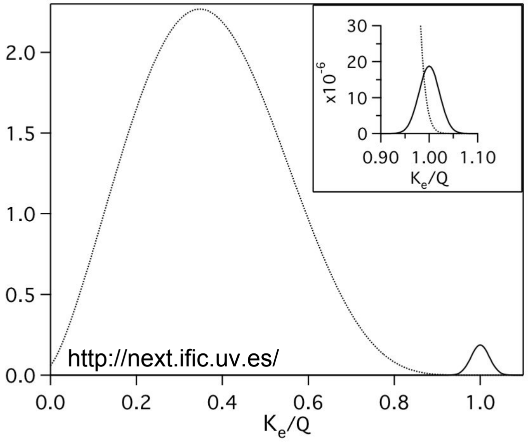




- The neutrino could be a Majorana fermion
  - Only possible for neutral particles
  - Be its own antiparticle
  - Possible to observe processes beyond the Standard Model
- Some isotopes undergo double beta decay
  - If the neutrino is Majorana, the decay can produce zero neutrinos
- *$2\nu2\beta$* is rare; *$0\nu2\beta$* would be even rarer - to detect it
  - Achieve (and understand) very low background
  - Accurately determine detector response
  - Consider scalability of the technique

Neutrinoless double beta decay





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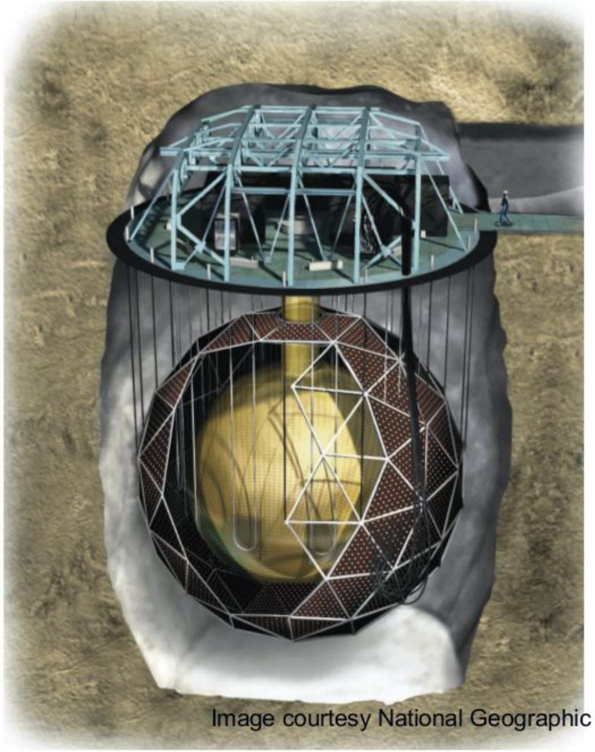
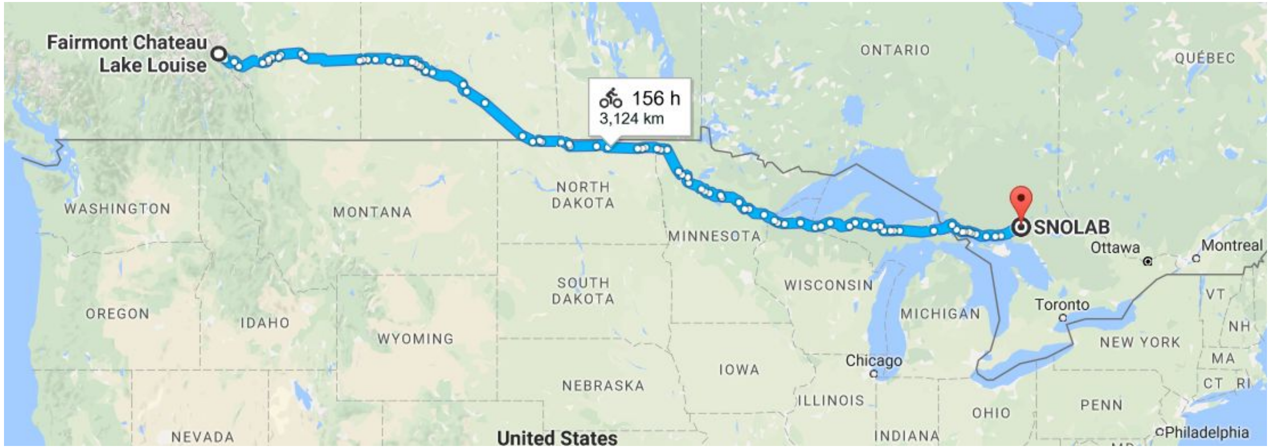
The SNO+ idea

- Refill the Sudbury Neutrino Observatory (SNO) with liquid scintillator (LAB) + a $\beta\beta$ isotope to search for neutrinoless double beta decay





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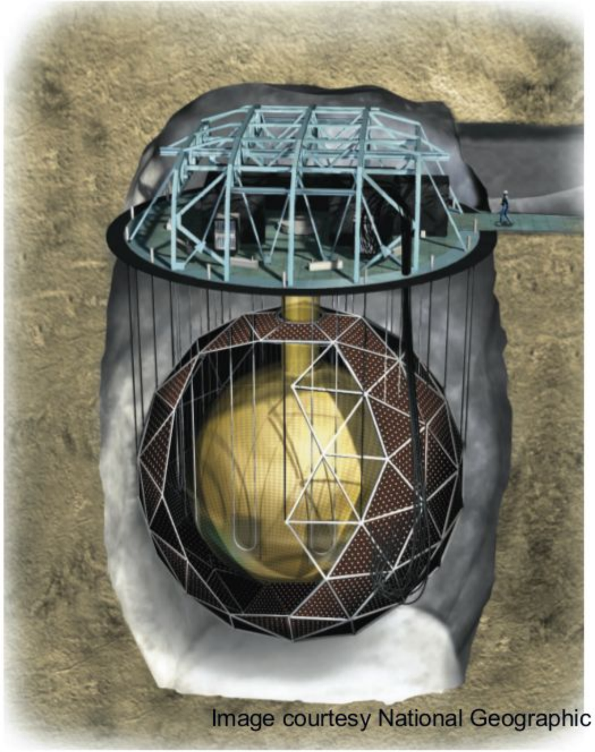

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- About SNO+
  - Low background neutrino detector in SNOLAB, ON, Canada
  - At a depth of 2km (rock, ~5900 mwe, ~63 cosmic muons/day)
  - Target volume: acrylic vessel, 6m in radius
  - Detection method: Cherenkov/scintillation light
    - ~9,300 PMTs mounted at ~8.9m radius (54% coverage)
  - Shielding & background suppression
    - Cavity filled with ultra pure water
    - Outward-looking PMTs
  - Isotope: ^{130}Te (Q-value 2.5 MeV)

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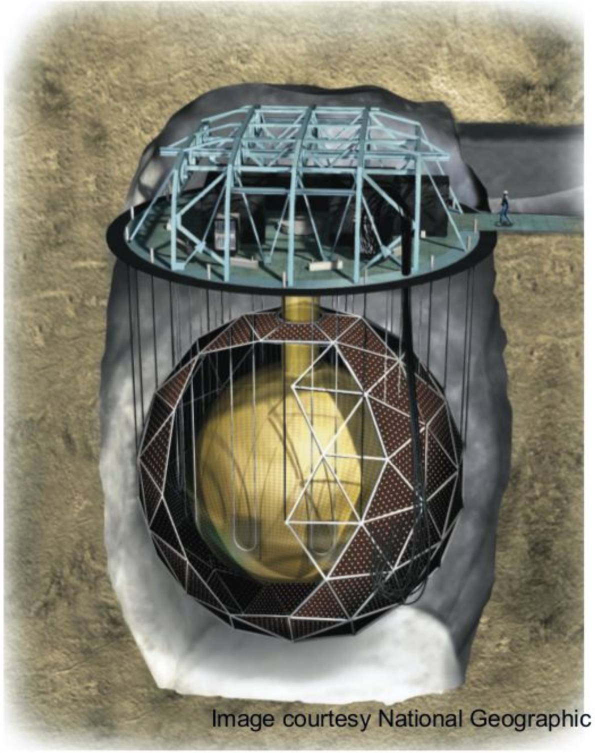
Image courtesy National Geographic

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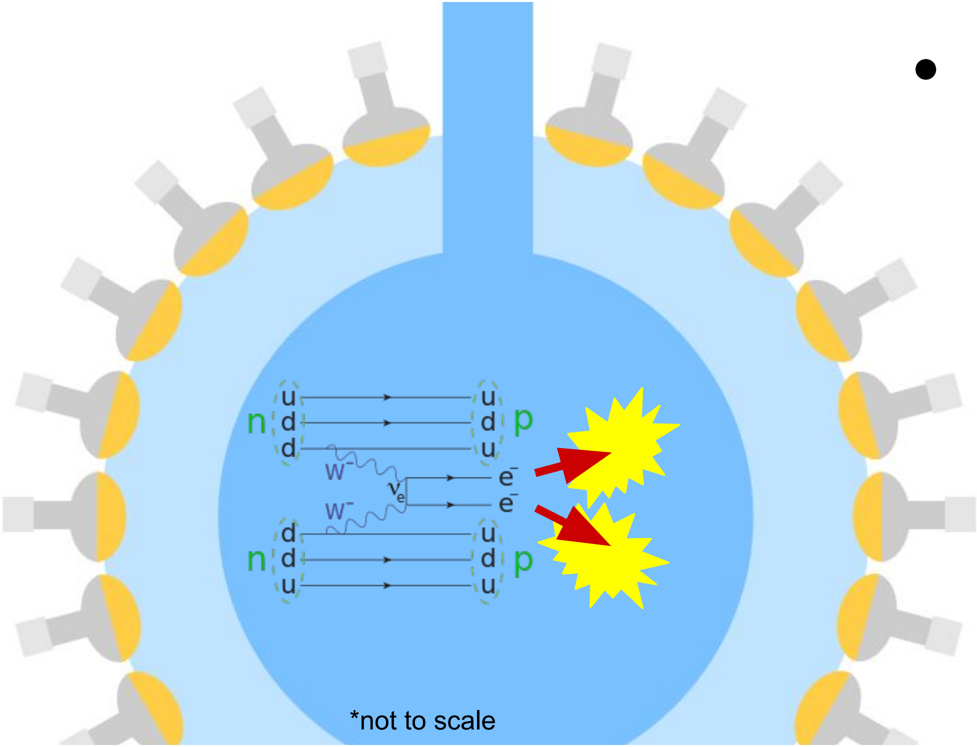
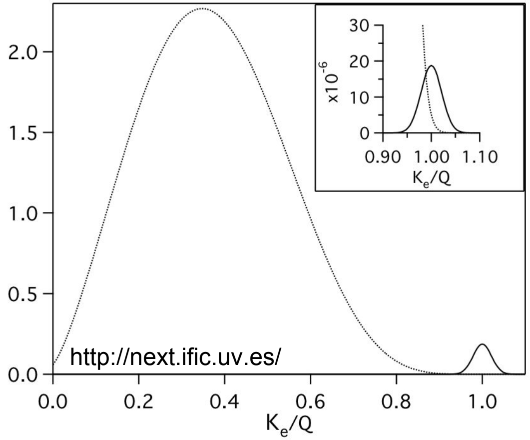
+REPAIRED PMTS, NEW DAQ AND CALIBRATION SYSTEMS

SNO+ *0ν2β* detection

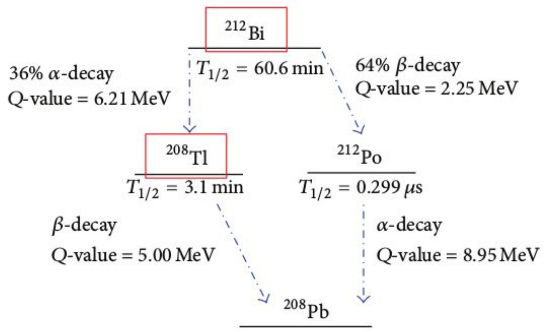


- *0ν2β* signal = 2 electrons
  - E total = Q value = 2527 keV
  - Uniform over volume
  - No directionality

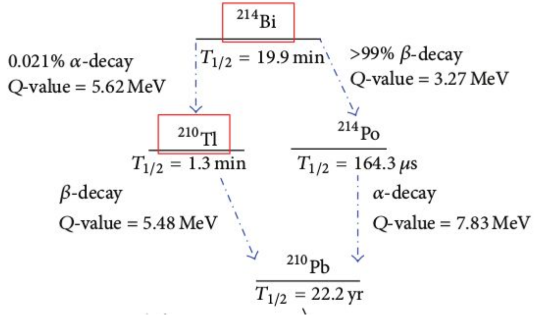


Backgrounds in *2β0ν* phase

^{238}U decay chain (relevant part)

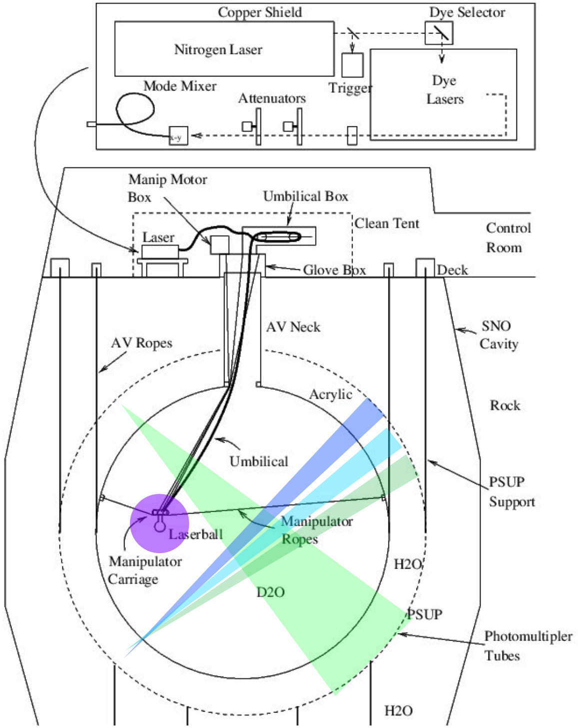


^{232}Th decay chain (relevant part)



- Products of ^{238}U and ^{232}Th decay chains
  - Naturally present in liquid scintillator
  - Events removed by coincidence tagging
- Cosmogenic induced backgrounds
  - Spallation reactions on tellurium while at the surface
  - Purification techniques in place, underground storage
- External backgrounds
  - Radioactive decays in ropes, PMT array, AV, water
  - Removed largely by fiducial volume cuts
- Solar neutrinos (^{8}B)
  - Independent flux constraints
- *2ν2β* decay - irreducible

Detector calibration

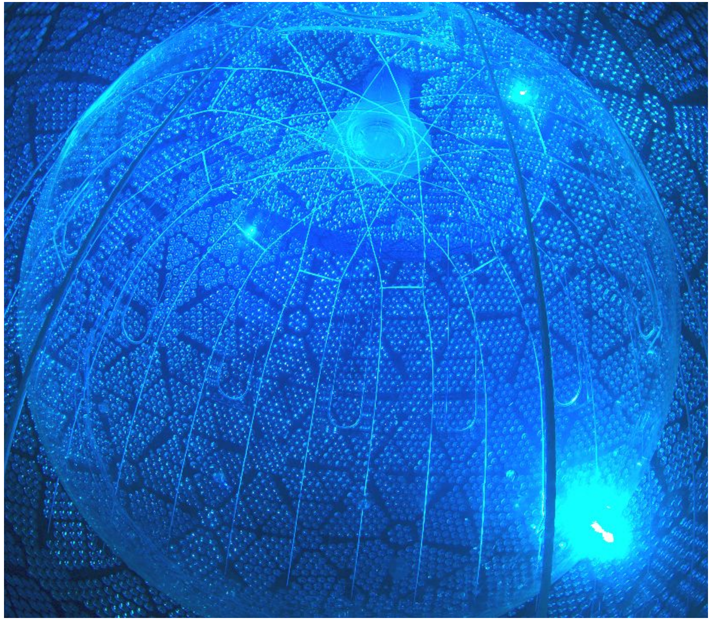


Multiple calibration systems in place

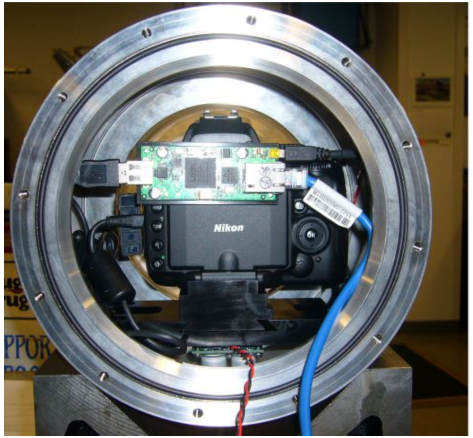
- Laserball - light diffusing sphere
  - Collection efficiency, reflections, attenuation
- Deployed radioactive sources
  - (Mostly) tagged gamma rays of known energy/energies
  - Energy scale and resolution
- Optical fibers mounted in PMT structure
  - Using fast LEDs/lasers, timing and gain measurements
  - Monitor stability, optical properties
  - No source insertion

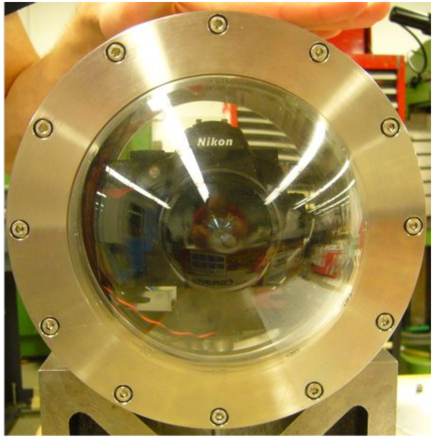
Detector calibration

- System of underwater cameras installed
  - Improve knowledge of calibration source location
  - Reduce uncertainties in analysis of calibration data

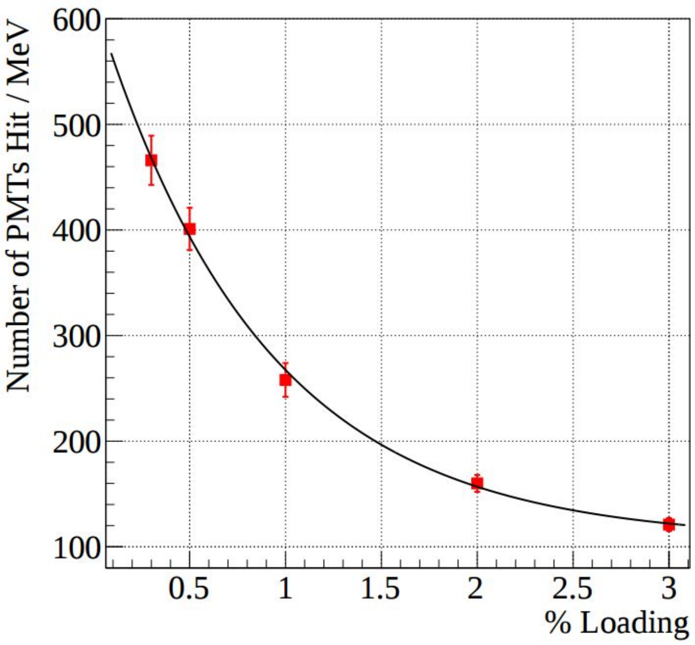


Taken Feb. 13, 2017



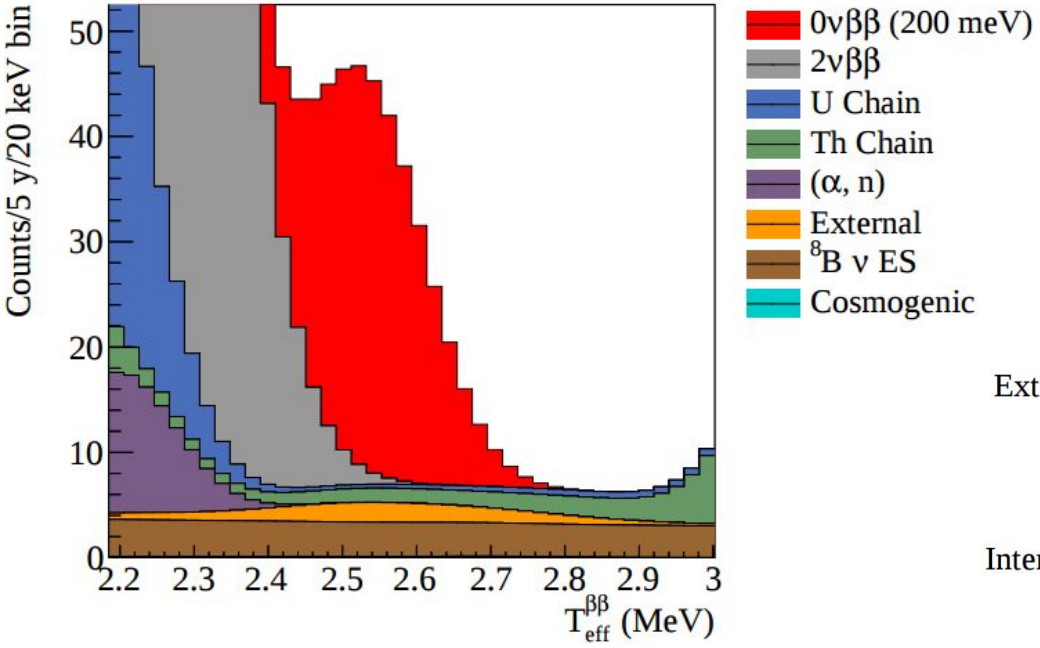


Liquid Scintillator + Tellurium

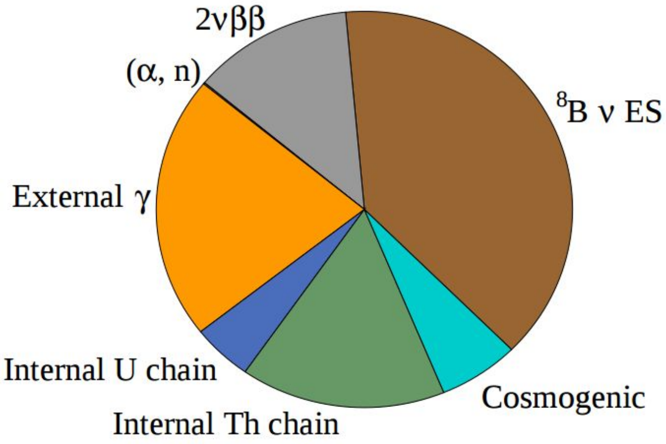


- LAB-PPO scintillator
  - Long time stability, acrylic compatible
  - High purity levels from manufacturer
  - High, linear light yield
- Natural tellurium
  - High natural abundance = scalability
  - Large $Q_{\beta\beta}$ of 2526.97 ± 0.23 keV
  - Stored, purified underground
- Loading Te in LAB-PPO
  - Planned to 0.5% (~ 1330 kg of ^{130}Te)
  - Loaded as Te acid + butanediol (TeBD)
  - TeBD is very transparent, some quenching
  - Backgrounds can be kept low

$2\beta0\nu$ signal in SNO+

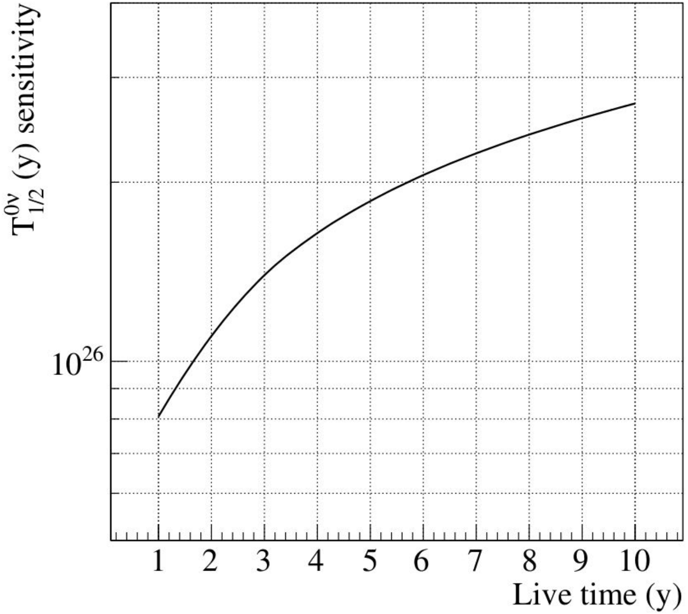


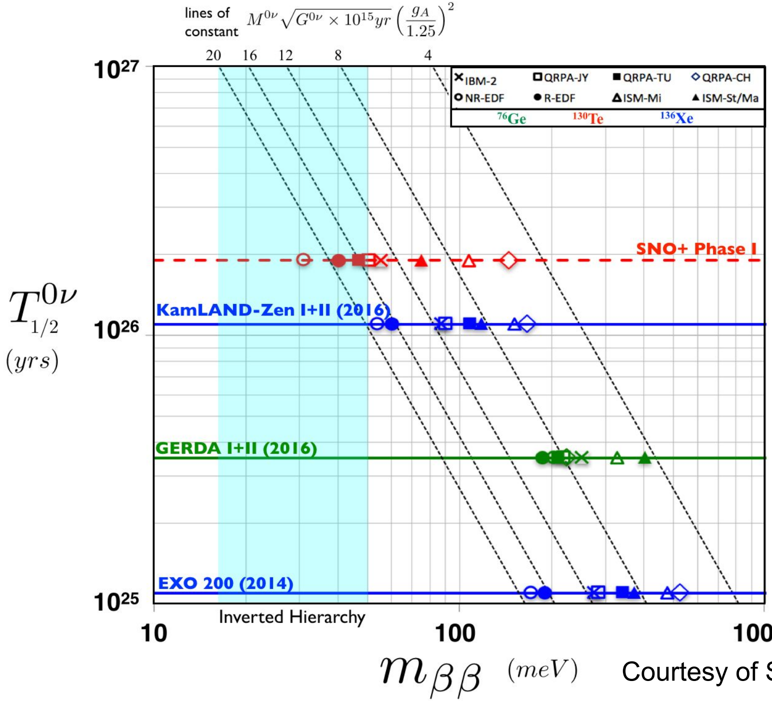
Backgrounds in ROI



SNO+ *2β0ν* sensitivity

$T_{1/2} \geq 1.96 \times 10^{26}$ yr (90% CL, 5 yr)

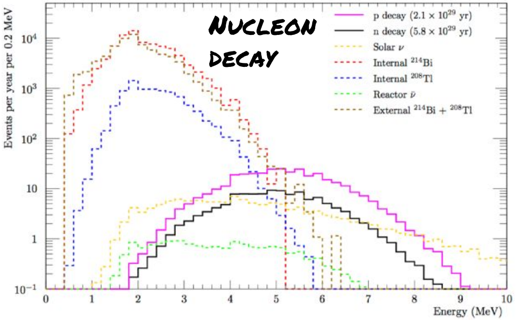




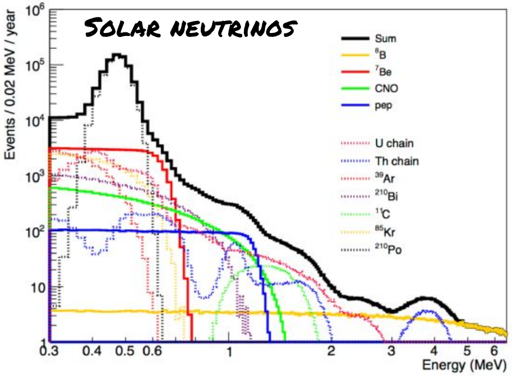
Courtesy of Steve Biller

Other physics potential

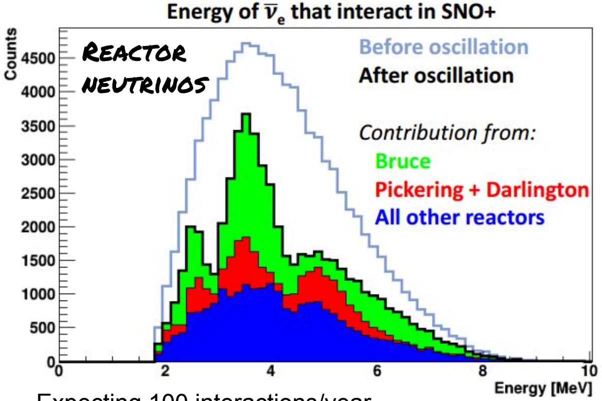
- Nucleon decay and exotic physics
- Solar neutrinos: ^{8}B, ^{7}Be, pep & CNO cycle
- Reactor and geo-neutrinos
- Supernovae neutrinos



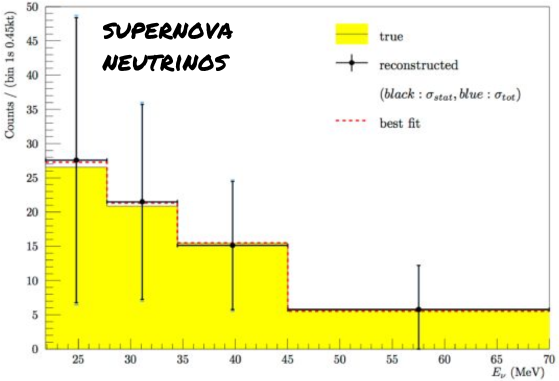
Expected background spectra for nucleon decay (eg. signals at KamLAND limits)



Expected fluxes for the 4 main solar neutrino signals and background (5.5m fiducial volume)



Expecting 100 interactions/year



True, reconstructed and best-fit supernova neutrino spectrum

Detector status

Scintillator purification plant underground

- Scintillator plant installed, in commissioning
- Tellurium purification comes next
- Water filled to neck level
- Electronics tested with high voltage
- DAQ system in place
- Calibration sources being commissioned
- Detector running and commissioning past 2 months

First delivery of 20 tonnes of LAB, Nov. 8 2016

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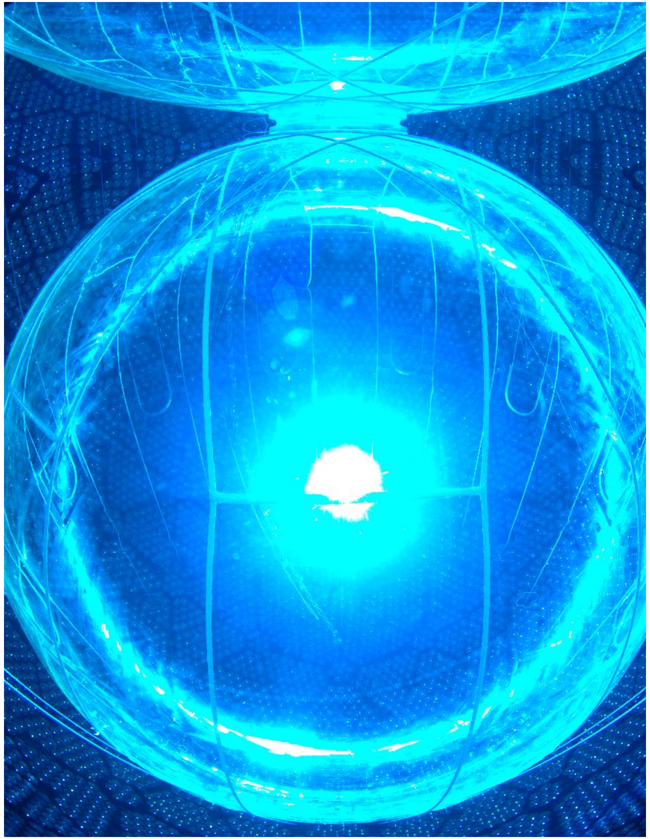

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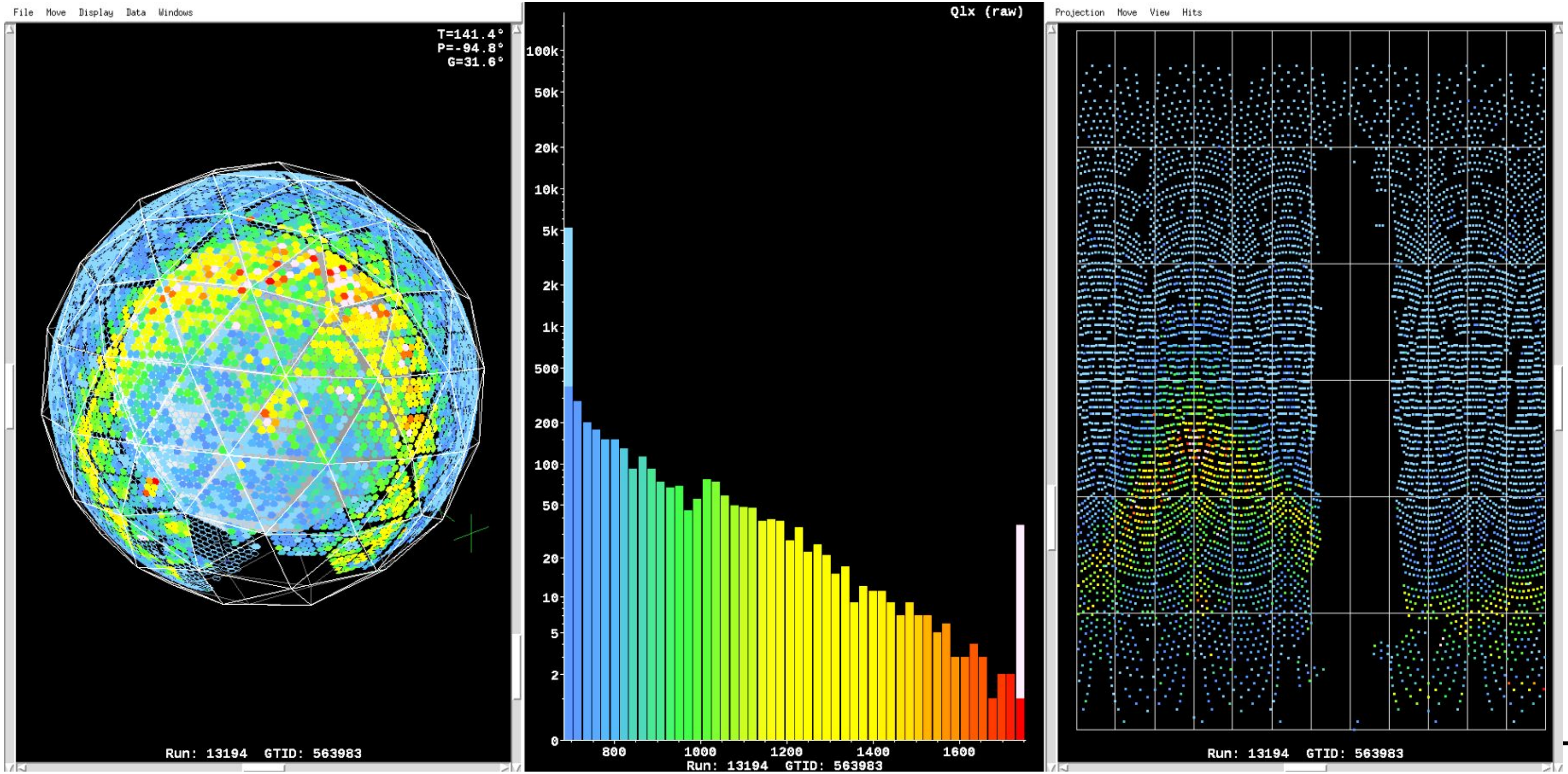
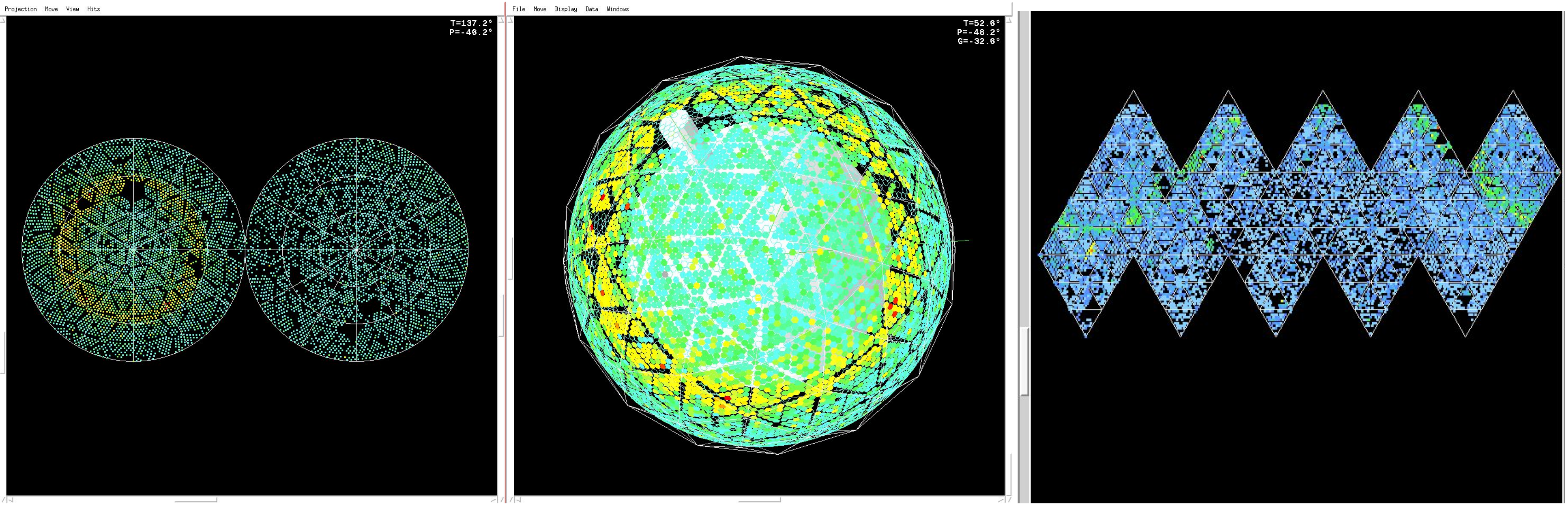
Muon candidate in SNO+



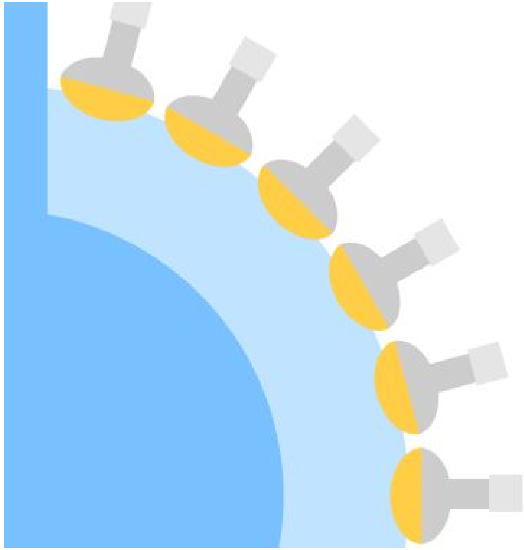
Down-going muon candidate

First neutrino candidate



Feb. 5th, 2017 - Appears to be going up, no outward looking PMTs triggered, spotted during monitoring

The SNO+ schedule

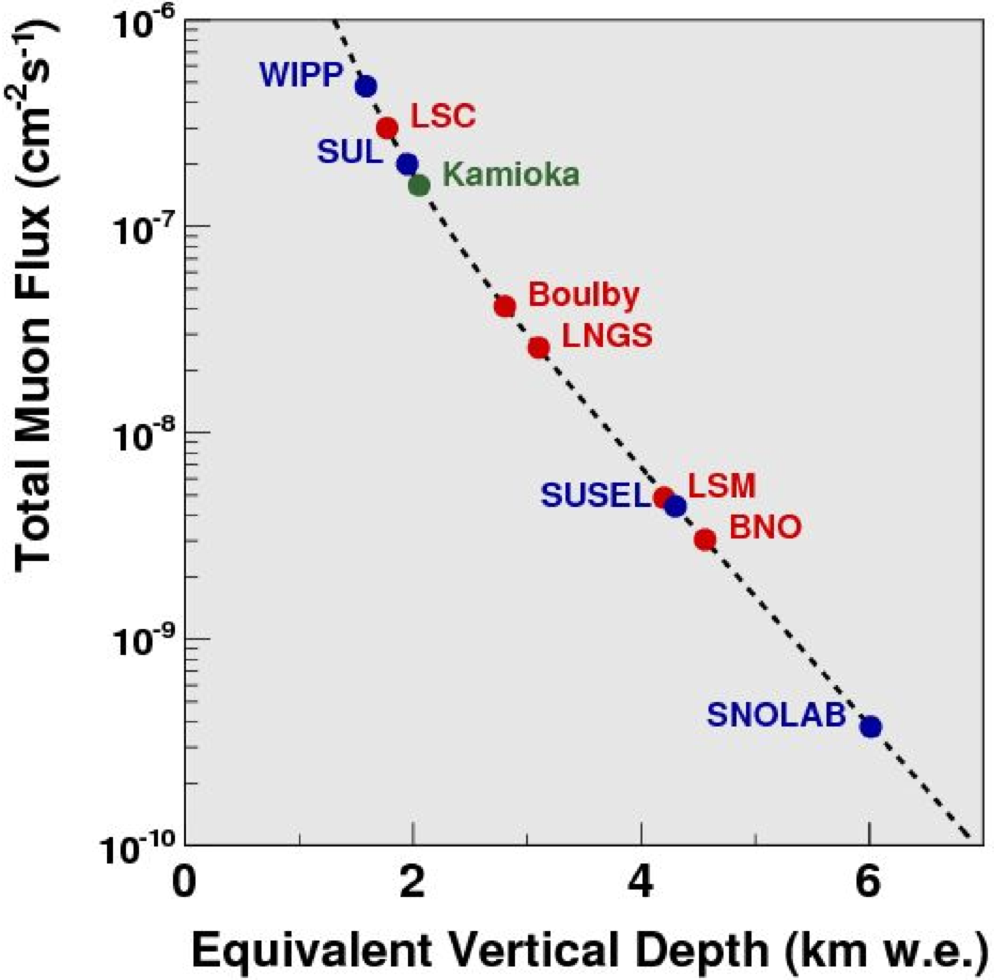


1. Ultra pure water phase - starting now
    - Recording ~10 hits/MeV deposited energy (Cherenkov light)
    - Invisible nucleon decay, exotic physics
    - Calibration
2. Scintillator phase
    - Estimated 500 hits/MeV deposited energy
    - Understanding of backgrounds
    - Solar neutrinos, geo+reactor neutrinos
3. **Tellurium-loaded scintillator phase**
    - Close to 400 hits/MeV deposited energy (0.5% loading)
    - **Neutrinoless double beta decay**

Summary & Outlook

- SNO+ will search for neutrinoless double beta decay
  - Down to $T_{1/2} \geq 1.96 \times 10^{26}$ yr, $m_{\beta\beta}$ ~ 36-90 meV (90% CL, 5 yr)
- Detector is ready for taking physics data
  - Cavity is close to full, electronics & DAQ are in place
  - Muons and first neutrino candidate already observed
- Calibration systems being commissioned
  - Mounted systems ready
  - Deployed sources for water phase are ready to go
- Water phase physics running soon

Backup slides

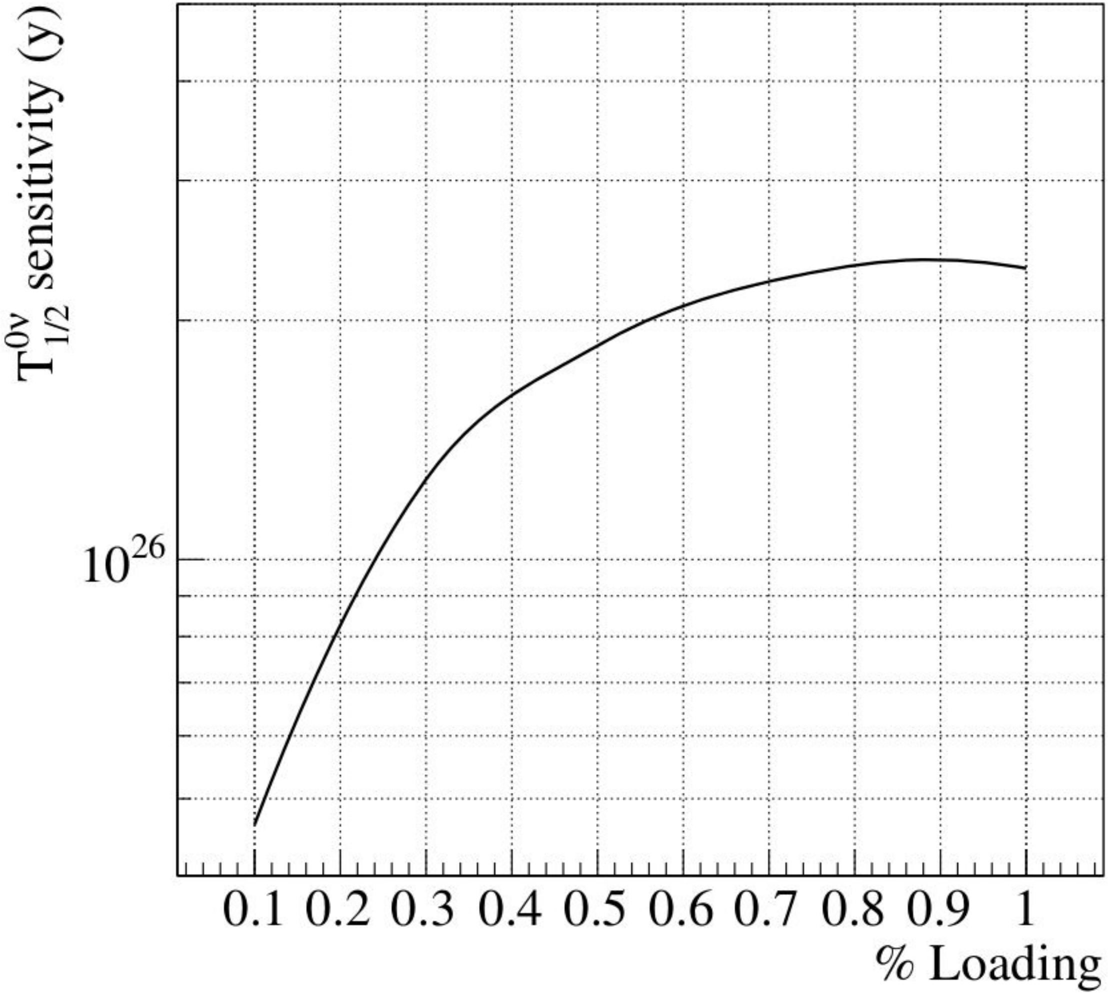


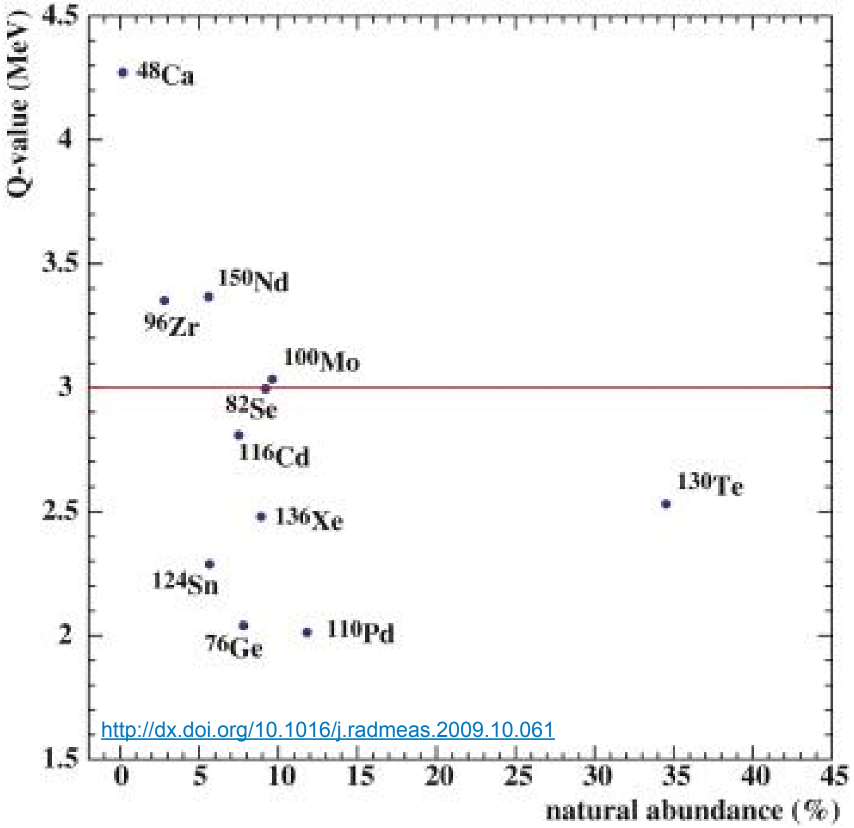
Total Muon Flux (cm-2s-1)
10-6
10-7
10-8
10-9
10-10
WIPP
LSC
SUL
Kamioka
Boulby
LNGS
SUSEL
LSM
BNO
SNOLAB
0
2
4
6
Equivalent Vertical Depth (km w.e.)

Deployed calibration sources

Source	Tagged?	Information
Laserball	Yes	Optical (quasi uniform diffuser)
Supernova source	Yes	Optical (fast pulsed generator for laserball)
Cherenkov	Yes	Optical (^{8}Li betas on acrylic)
^{16}N	Yes	Gammas (6.1 MeV)
^{46}Sc	Yes	Gamma (0.89, 1.12 MeV)
AmBe	Yes	Neutrons, gamma (2.2, 4.4 MeV)
^{57}Co	No	Gamma (122 keV)
^{48}Sc	No	Gamma (1.0, 1.1, 1.3 MeV)

^{130}Te (Q-value 2.5 MeV)

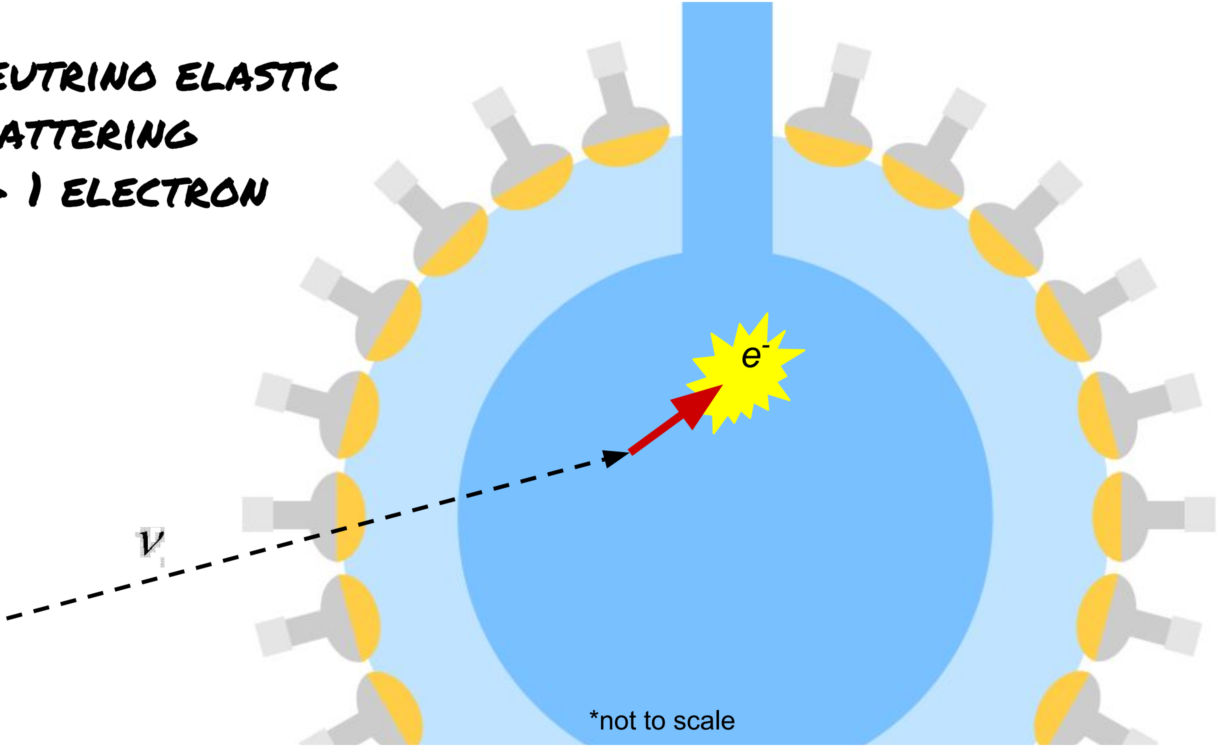

$T^{0\nu}_{1/2}$ sensitivity (y)
10^{26}
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
% Loading



http://dx.doi.org/10.1016/j.radmeas.2009.10.061

SNO+ detection principle

Neutrino elastic scattering
-> 1 electron



SNO+ detection principle

INVERSE BETA DECAY
-> 2 + 1 GAMMA RAYS

$p^+ + \bar{\nu}_e \rightarrow e^+ + n^0$