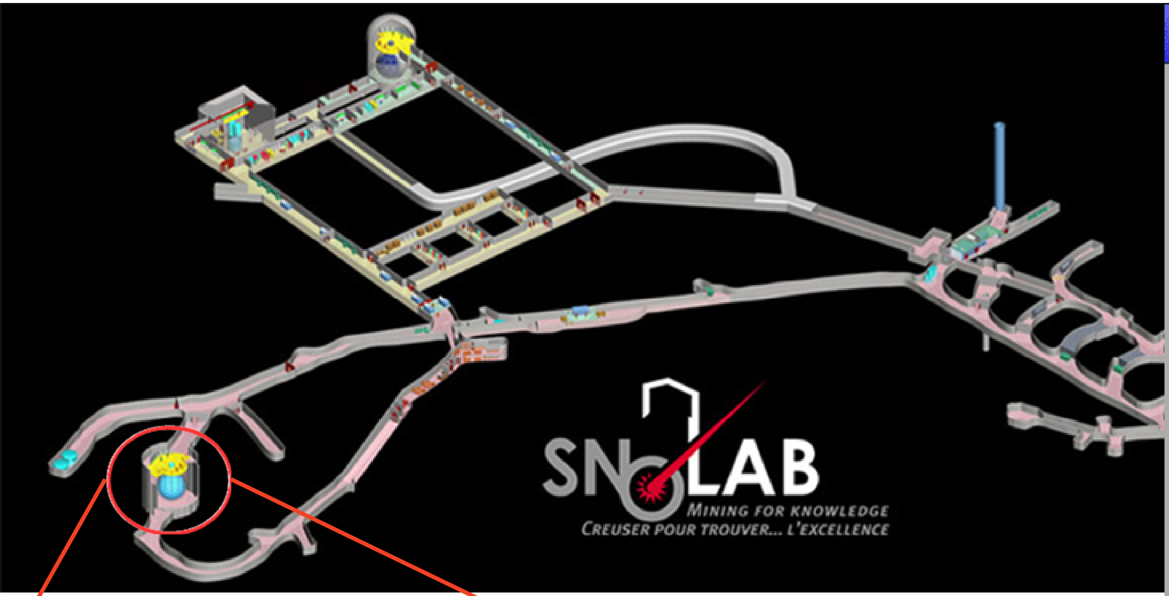
Status of the SNO+ experiment

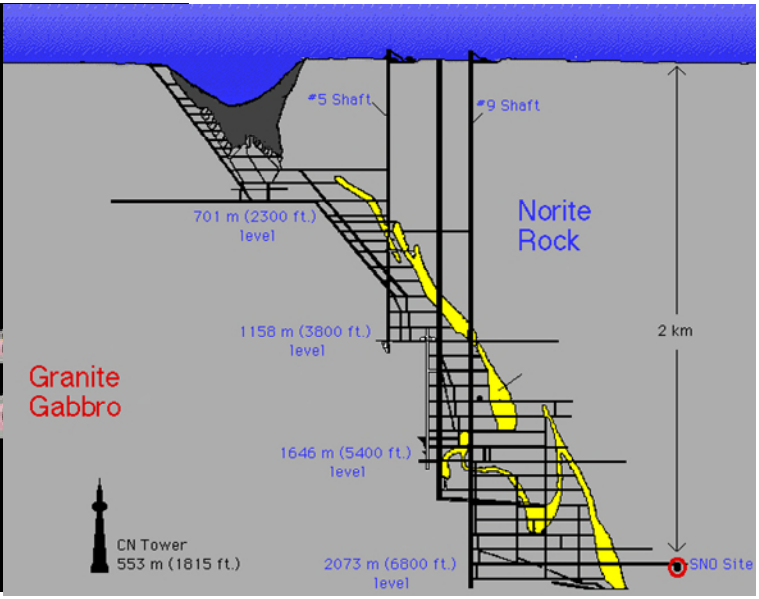
Aleksandra Bialek, SNOLAB

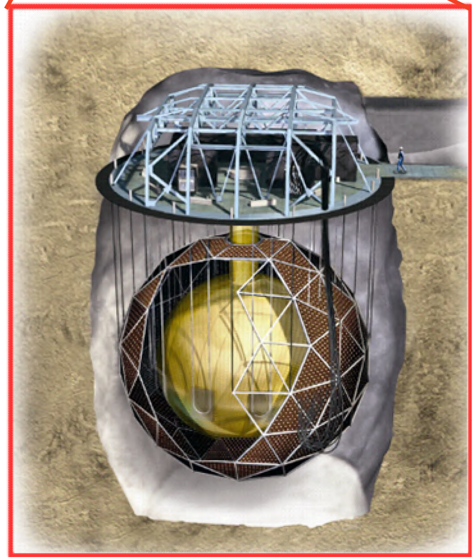
on behalf of the SNO+ collaboration

Canadian Association of Physicists Congress
June 3, 2019
Simon Fraser University, Burnaby

SNO+ @ SNOLAB







SNOLAB – underground laboratory:

- Creighton Mine, Sudbury, Canada
- Deep: 2km, 6000 mwe
  - ~ 70 muons /day in SNO+
- Clean : class 2000 clean room

Erica Caden's talk @ M2-3

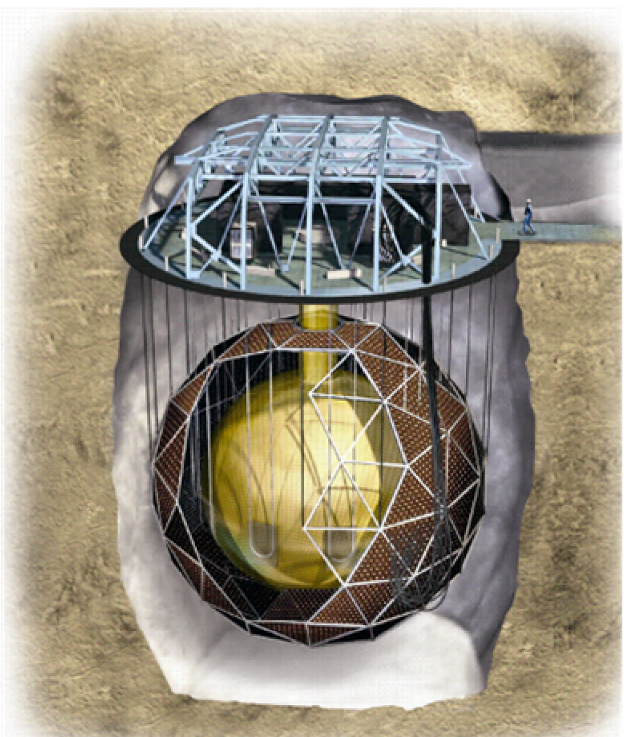
SNO+ Detector

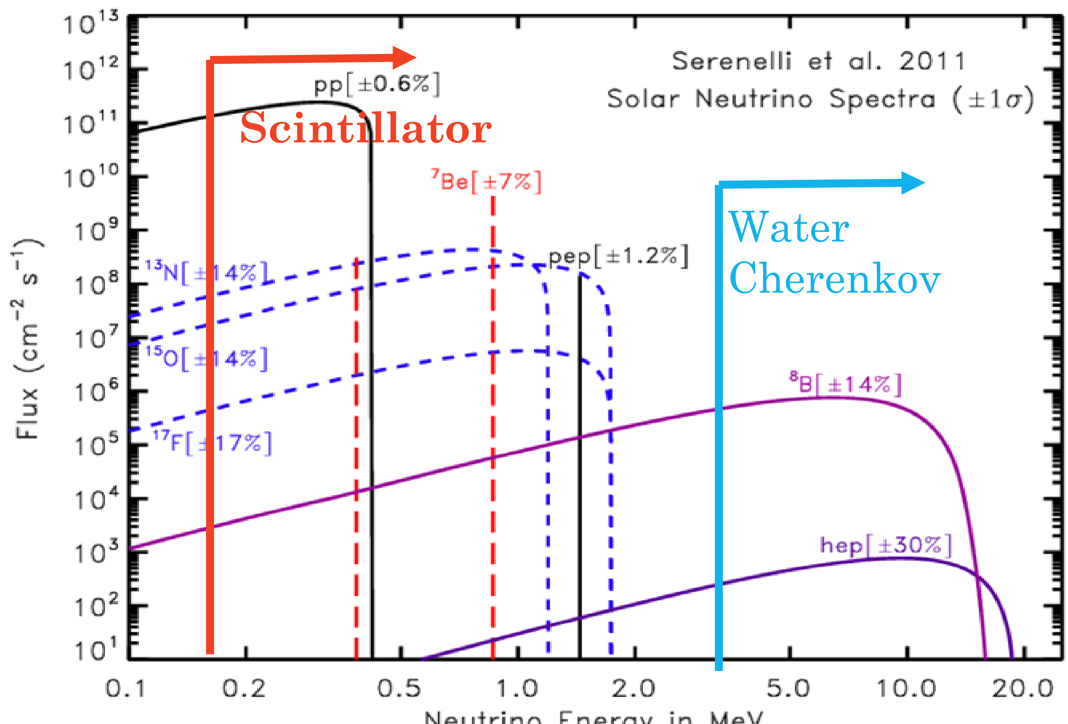
1984-2007

1 kt Heavy Water D_2O

2007-present

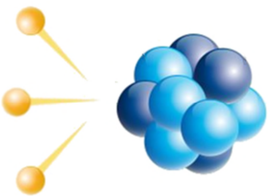
780 t Liquid Scintillator

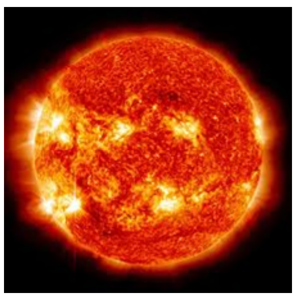




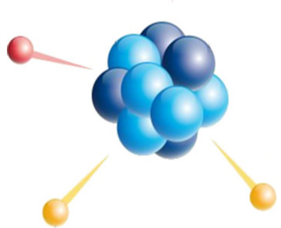
SNO+ Scientific Program

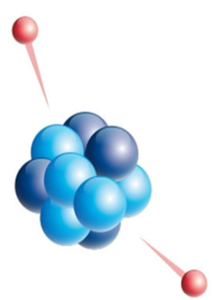
Nucleon decay and other exotic physics





Low energy solar neutrinos (pep, CNO)



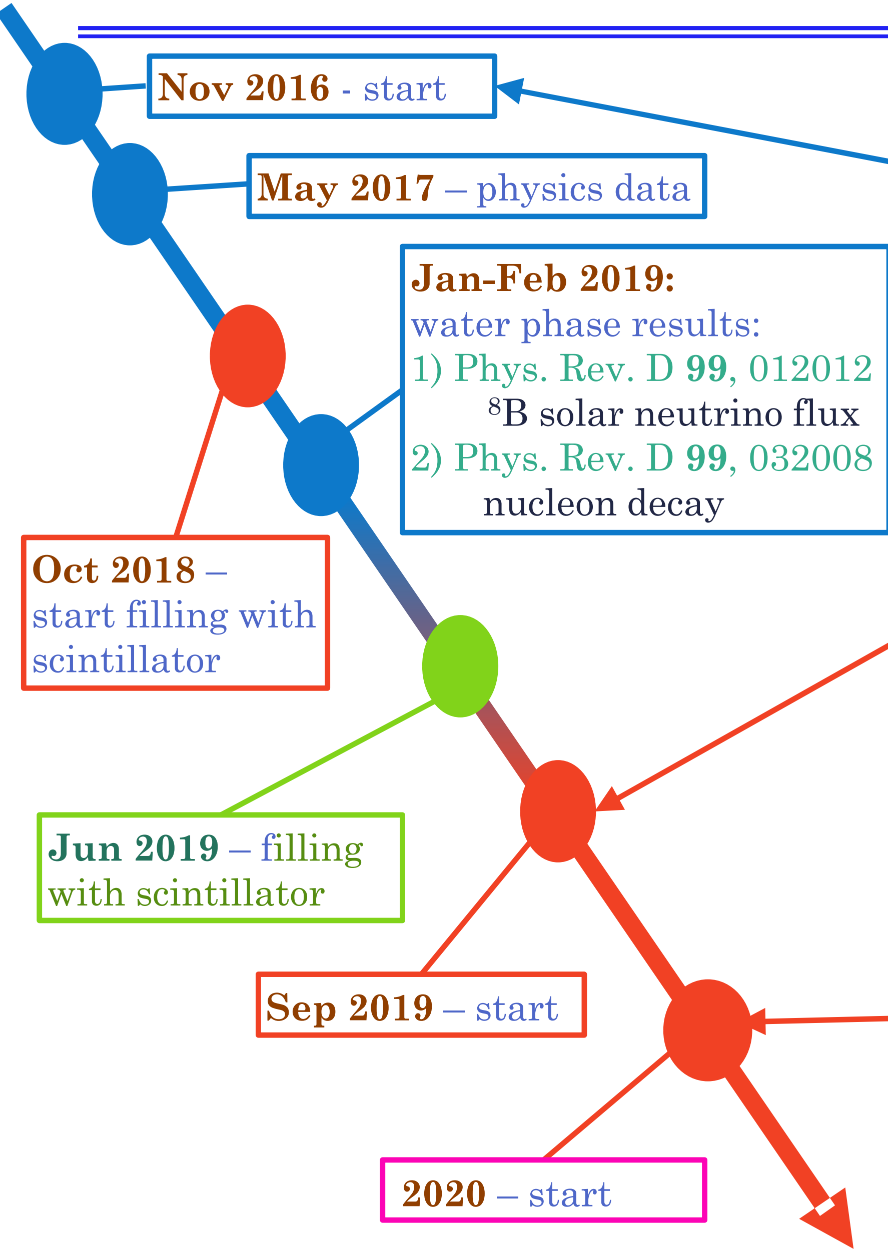


Neutrino-less double-beta decay

SNO+ phases:

- **Water phase:**
  - Detector calibration
  - Background measurements (external)
  - ^{8}B solar neutrinos flux measurement
  - Search for nucleon decay to invisible modes
- **Pure scintillator phase:**
  - Detector calibration
  - Background measurements (internal/external)
  - Low energy solar neutrinos
  - geo-, reactor, SN neutrinos physics
- **Te-loaded scintillator phase:**
  - double beta decay with ^{130}Te:
    - $2\nu\beta\beta$ decay lifetime
    - $0\nu\beta\beta$ decay search

SNO+ Timeline

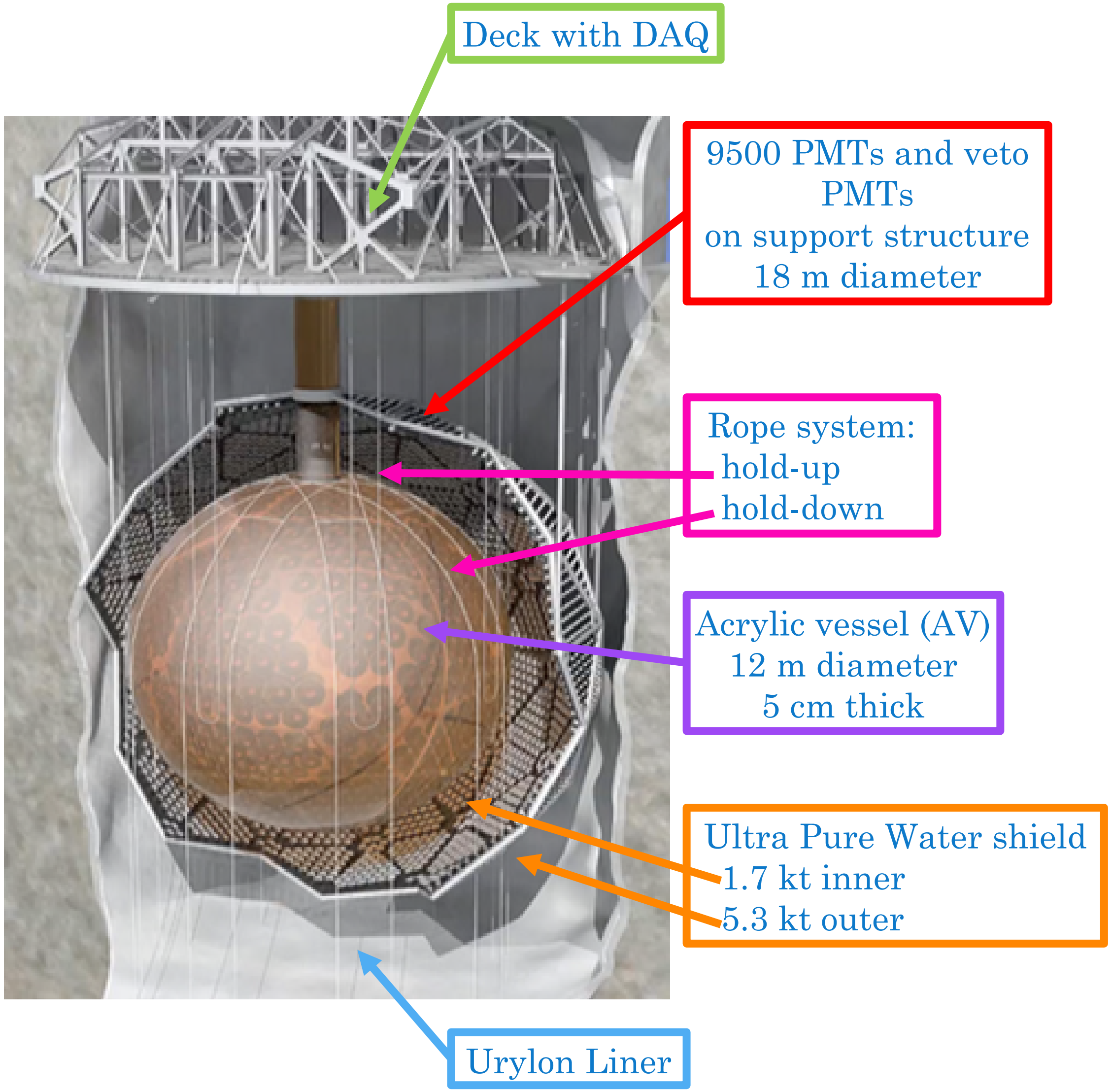


SNO+ phases:

- Water phase:
  - Detector calibration
  - Background measurements (external)
  - ^{8}B solar neutrinos flux measurement
  - Search for nucleon decay to invisible modes
- Pure scintillator phase:
  - Detector calibration
  - Background measurements (internal/external)
  - Low energy solar neutrinos
  - geo-, reactor, SN neutrinos physics
- Te-loaded scintillator phase:
  - double beta decay with ^{130}Te:
    - $2\nu\beta\beta$ decay lifetime
    - $0\nu\beta\beta$ decay search

SNO+ Detector

- ✓ New hold-down net
- ✓ Replace hold-up ropes
- ✓ New Purification Plants:
  - ✓ Scintillator, TeA, TeDiol
- ✓ New Cover Gas
- ✓ Repair and re-install the PMTs
- ✓ Seal the liner in the cavity
- ✓ Upgrade the DAQ
- ✓ New calibration system Internal and External

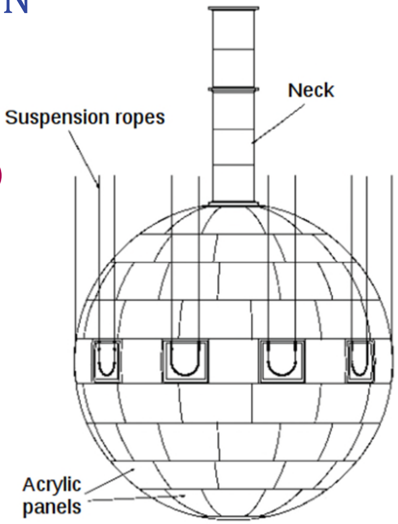


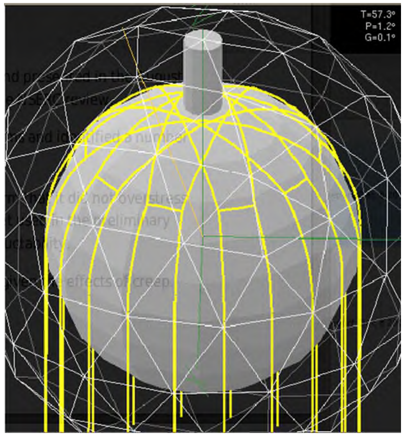
SNO+ Detector: Rope system

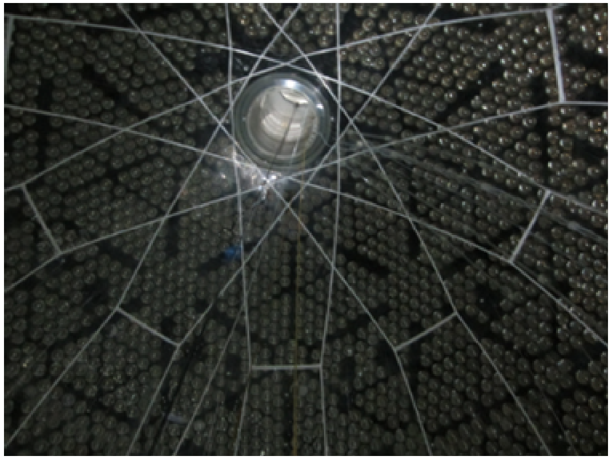
✓ New hold-down net
✓ Replace hold-up ropes

	Cavity	AV	AV hold-up	AV hold-down
SNO	UPW 999.7 kg/m^3	D2O 1106 kg/m^3	10 loops	-
SNO+		LAB 854.7 kg/m^3		10 ropes

- Designed to counteract the buoyant force of 1.25 MN
  - NIM A, 827 (2016), 152-160
- Ropes:
  - Tensylon (high-performance polyethylene fiber)
  - lower radioactivity
  - suitable mechanical properties







Status:

➢ Installed in 2012 and tested to its full capacity

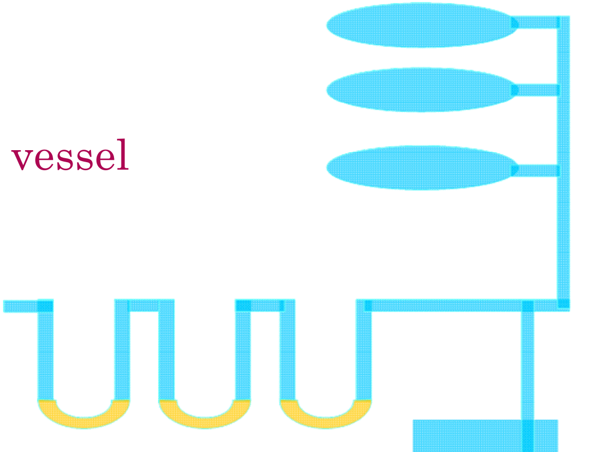
SNO+ Detector: Cover Gas

✓ New Cover Gas

Designed as a sealed system

- Reduce Rn gas level by 10^5 as compared to SNOLAB air
- Balance the pressure swings in the mine
  - mechanical constrains on the maximum dP across the vessel

- Buffer volumes (3 Bags)
  - for small external pressure changes
- Pressure relief system (3 U-traps)
  - for instant high pressure changes

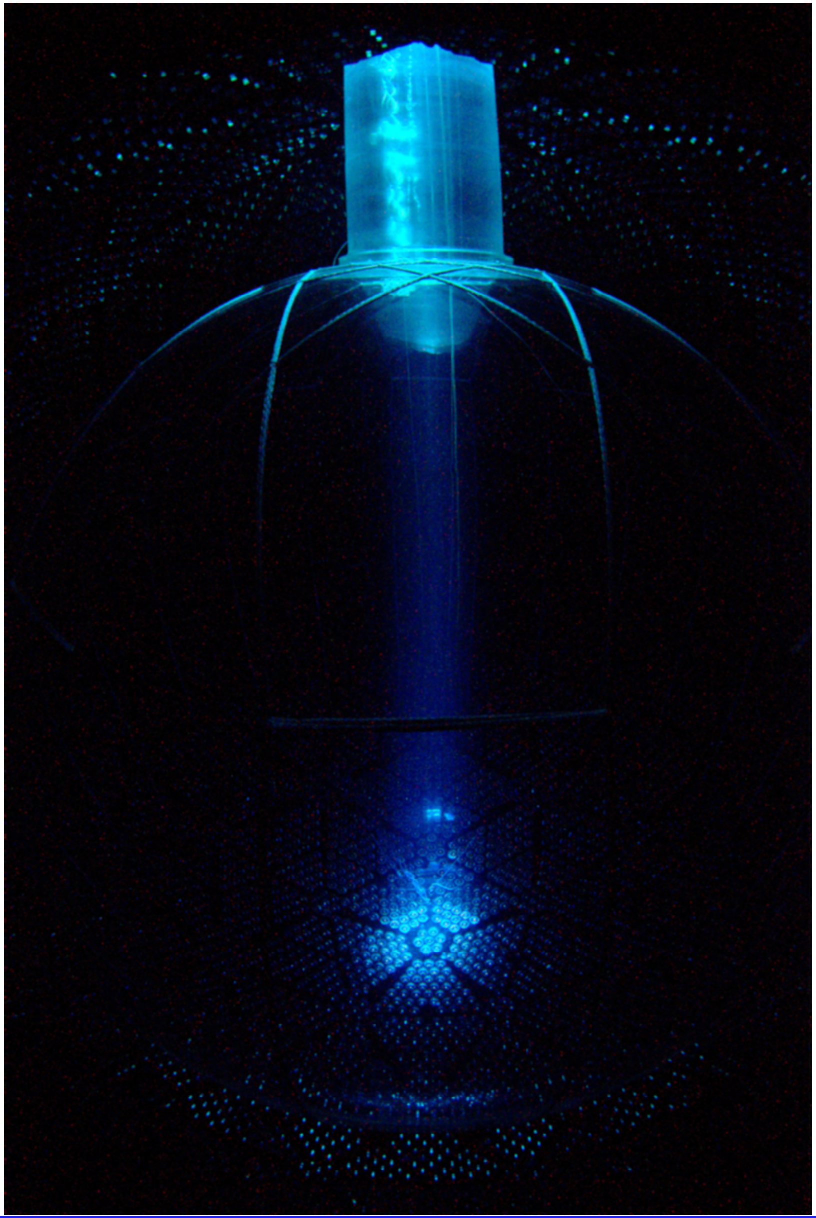


Status:

- Commissioned and operational since September 2018
- Reduction 10^5 in radon concentration (internal water)
  - Constant monitoring with radon monitor, RAD7 and data analysis

Water phase

- Commissioning of:
  - Water system and its purity (assays)
  - Electronics, DAQ,
    - Data taking, quality checks
  - Calibration systems
    - more in Ryan Bayes' & Janet Rumleskie's talks @ M2-3 and Jamie Grove's poster
- Detector response validation :
  - Optical properties
  - Compare data to the model (simulations):
    - energy scale, resolution
    - vertex position, angular resolution
  - Measure external backgrounds
    - consistent with expectations
- High purity water Cherenkov data
  - Search for nucleon decays
  - Measure ^{8}B solar neutrino flux



Water phase physics: Nucleon decay

- Baryon number violating process
  - Could explain matter-antimatter asymmetry in the universe
- Never been observed experimentally
- Decay through invisible modes (e.g. $n \rightarrow 3\nu$)
  - no visible energy directly deposited
  - produces an excited daughter that deexcites and emits gamma rays

Neutron decay:

$^{16}O \rightarrow {}^{15}N^* + inv$

$^{15}N^* \rightarrow {}^{15}N + \gamma$

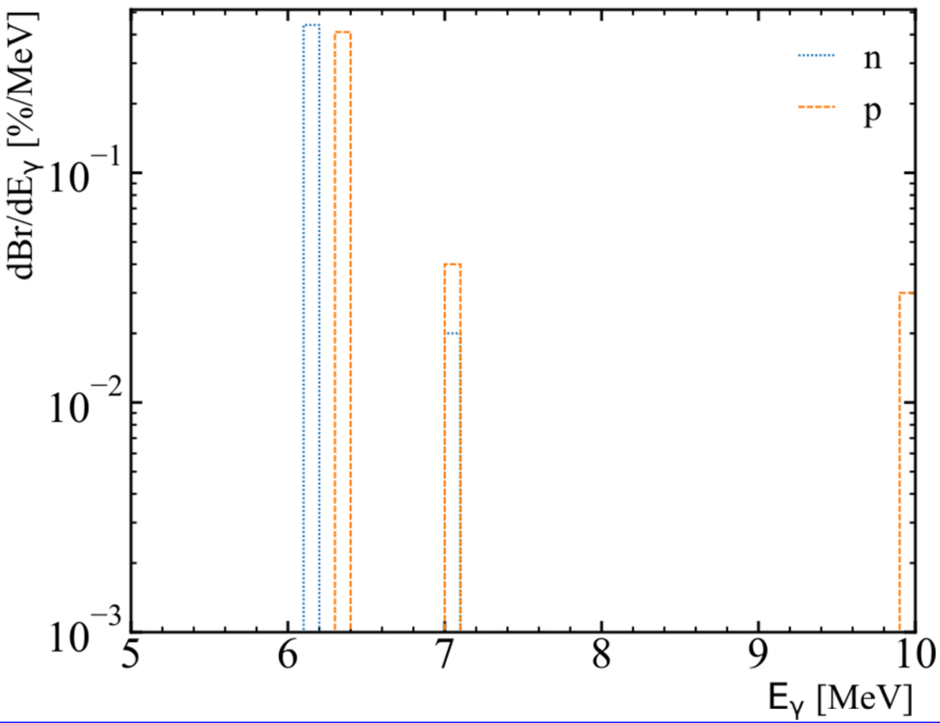
41%: 6.32 MeV
2%: 7.01 MeV
2%: 7.03 MeV
3%: 9.93 MeV

Proton decay:

$^{16}O \rightarrow {}^{15}O^* + inv$

$^{15}O^* \rightarrow {}^{15}O + \gamma$

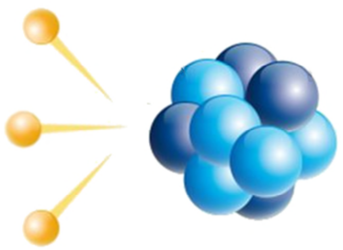
44%: 6.18 MeV
2%: 7.03 MeV

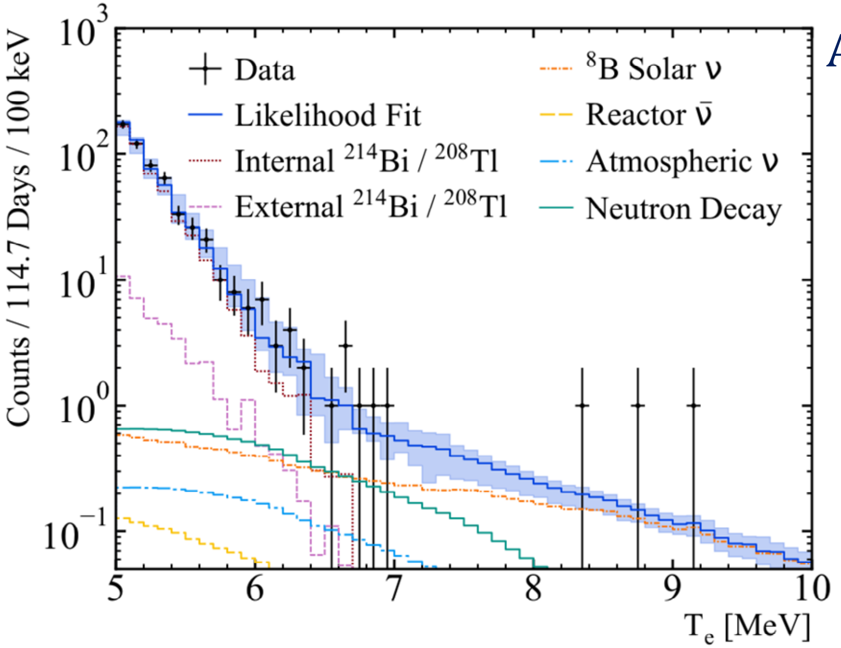


Water phase physics: Nucleon decay

Best limits so far for invisible mode:

- neutron decay lifetime: **5.8×10^{29} y**
  - ♦ Phys. Rev. Lett. **96**, 101802 (KamLAND)
- proton decays lifetime **2.1×10^{29} y**
  - ♦ Phys. Rev. Lett. **92**, 102004 (SNO)





Analysis of 235 days (May 4, 2017 - Dec 25, 2017)

- detector was live for 95% of the time
  - with 16.9% on calibration or maintenance
- Data quality checks to reduce instrumental backgrounds
- Cuts on energy, position, direction, isotropy to reduce backgrounds

➢ Final data set:

➢ 114.7 days with expected 17.65 events in ROI

➢ **SNO+ sets world-leading limit on invisible modes of proton decay:**

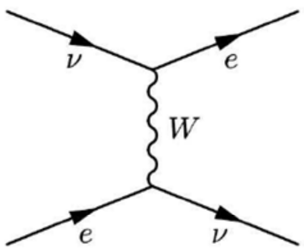
3.6×10^{29} years Phys. Rev. D **99**, 032008

Water phase physics: ^{8}B solar neutrinos

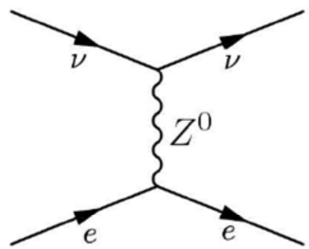
- Elastic scattering of electrons by neutrinos:

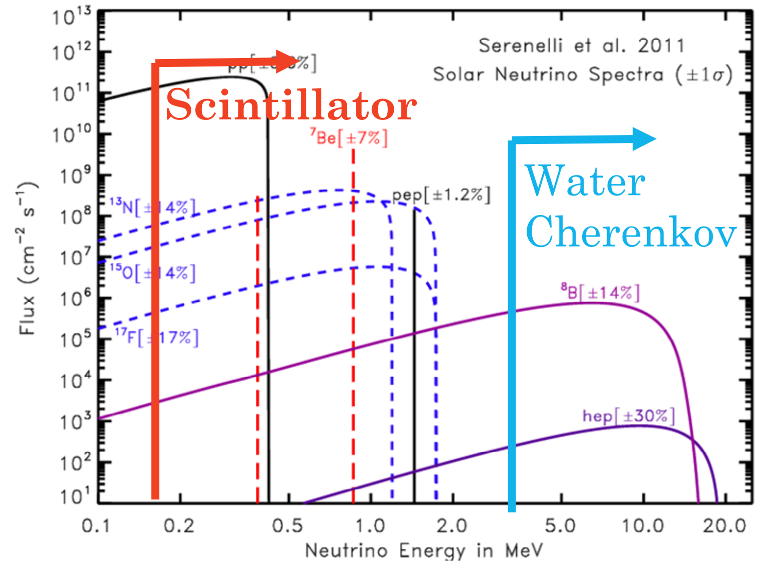
$$\nu_x + e^- \rightarrow \nu_x + e^- \quad (x=e, \mu, \tau)$$

CC interaction for x=e

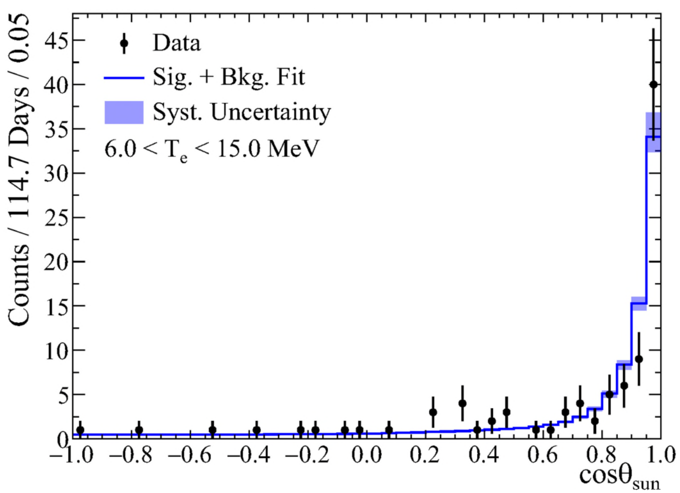


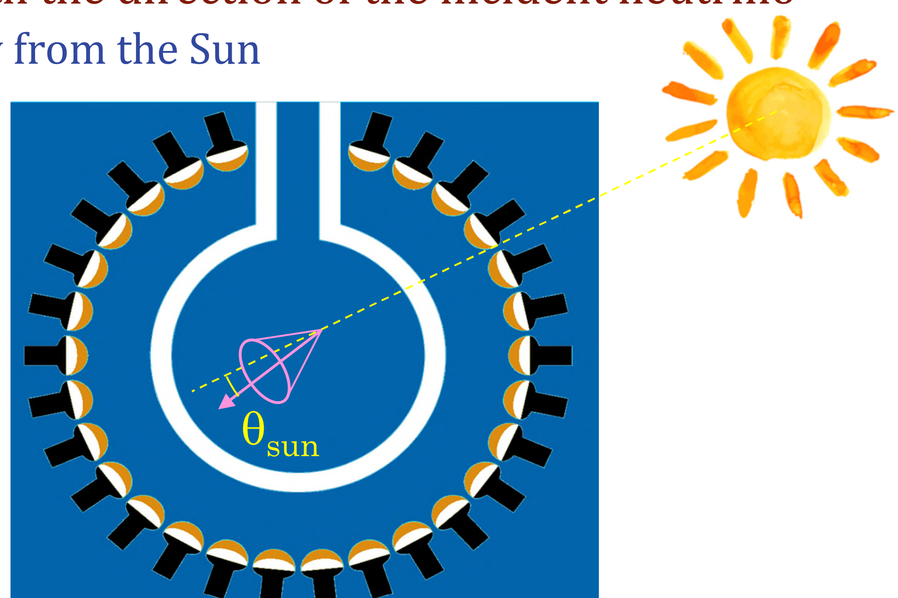
NC interaction for x=e, μ, τ





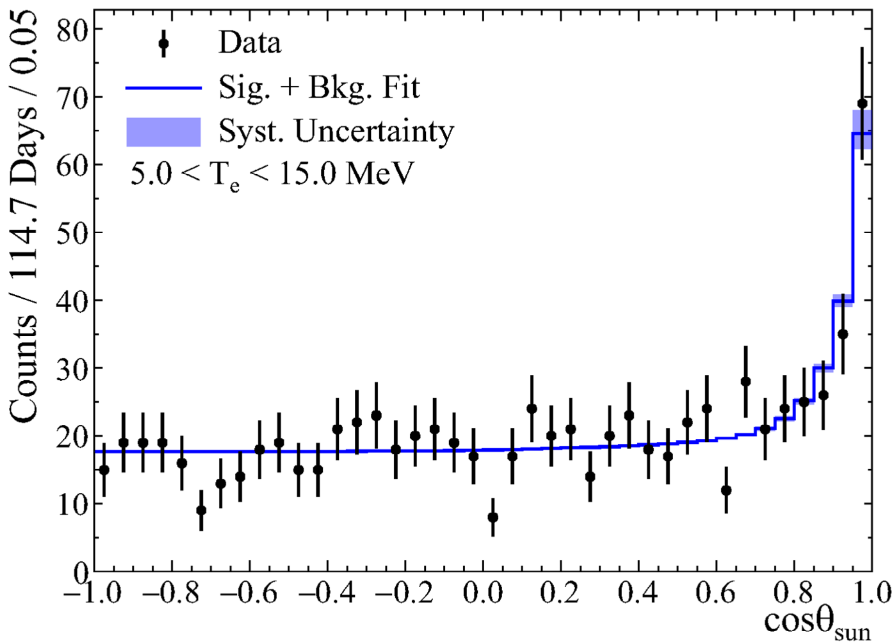
- scattered electrons direction correlated with the direction of the incident neutrino
  - produced Cherenkov radiation directed away from the Sun

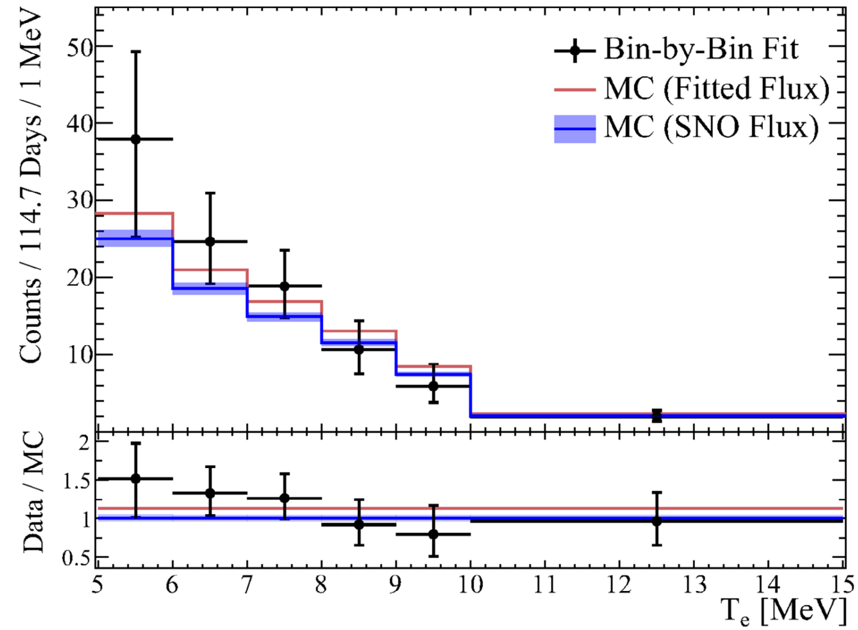




Water phase physics: ^{8}B solar neutrinos

- Analysis of data May- December 2017
  - Quality checks -> lifetime of 114.7 days





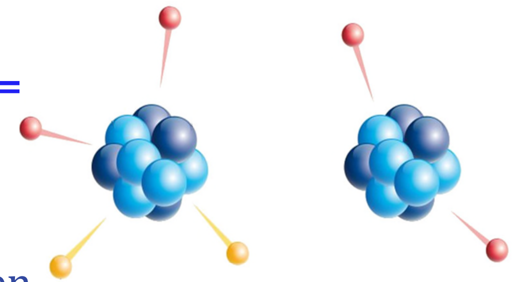
> **SNO+ mesures ^{8}B solar neutronos flux:**

$$\Phi_{^8\mathrm{B}} = 5.95^{+0.75}_{-0.71}(\mathrm{stat})^{+0.28}_{-0.30}(\mathrm{syst}) \times 10^{6}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$$

Phys. Rev. D **99**, 012012

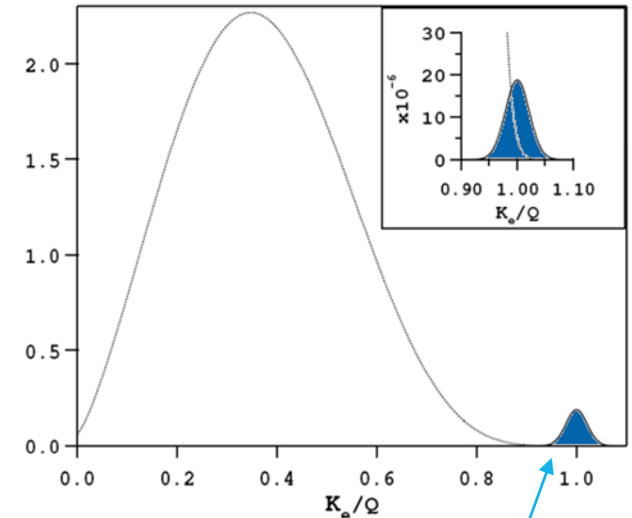
- Consistent with SNO results

Search for 0νββ with SNO+



- 2νββ
  - very rare nuclear decay allowed by Standard Model (SM)
  - occurs in nuclei where single beta decay is energetically forbidden
  - observed in 11 isotopes (half lives ~10^{18}-20^{24} y)

- 0νββ:
  - only happens if neutrinos are Majorana particles
  - lepton number violation
  - half-life depend on the effective neutrino mass squared
    - ♦ probes the absolute mass scale (currently not known)
    - ♦ may help determine the neutrino mass hierarchy



$$(T^{0\nu}_{1/2})^{-1} = G|M|^2 |m_{\beta\beta}|^2$$

Half-life:
10^{26} years ~ ν mass range 36–90 meV

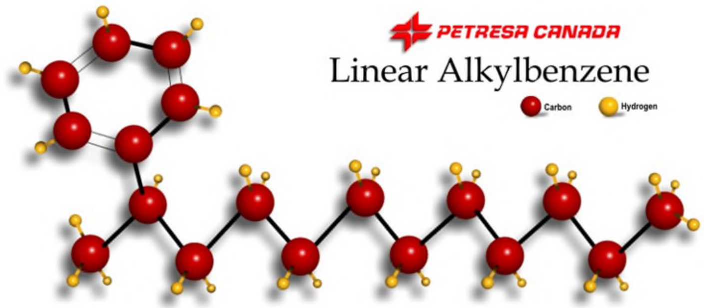
Nuclear physics term:
- phase space factor
- nuclear matrix element

Effective Majorana mass

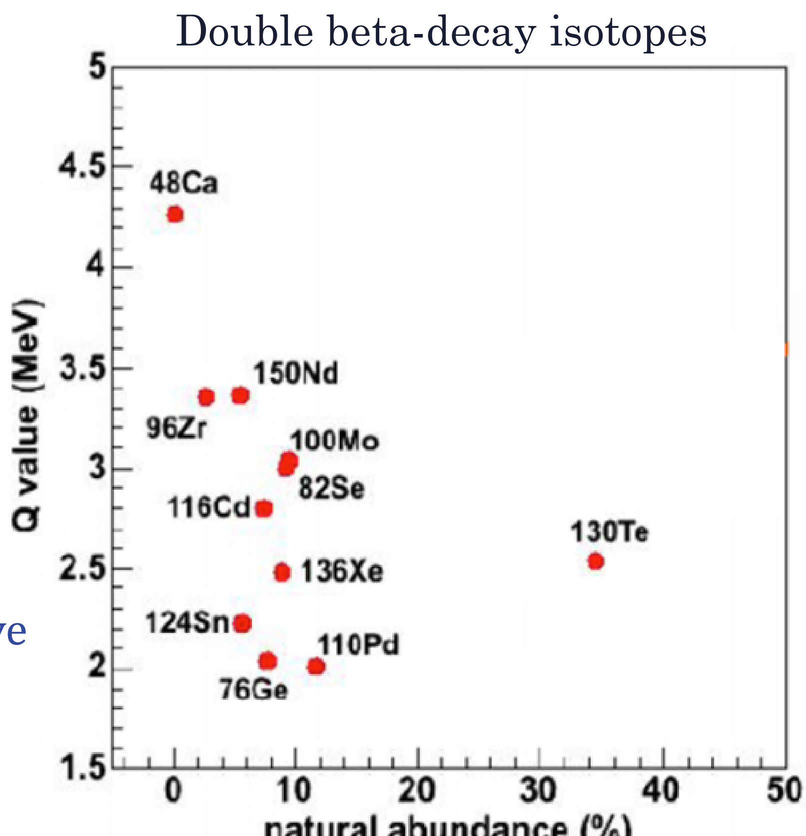
To observe peak at end-point of the 2νββ spectrum:
- ✓ Low background,
- ✓ Large detector
- o Good energy resolution,
- ✓ Signal above background from large quantity isotope

Search for 0νββ with SNO+

- Scintillator (LAB-PPO)
  - chemical compatibility with acrylic
  - stable with good light yield and optical transparency



- Tellurium 130
  - high natural abundance 34%
  - large Q-value: 2.52 MeV
    - ROI at lower background
  - $T_{1/2}^{2\nu\beta\beta} = 7.9 \times 10^{20}$ y
    - lower 2νββ background rate

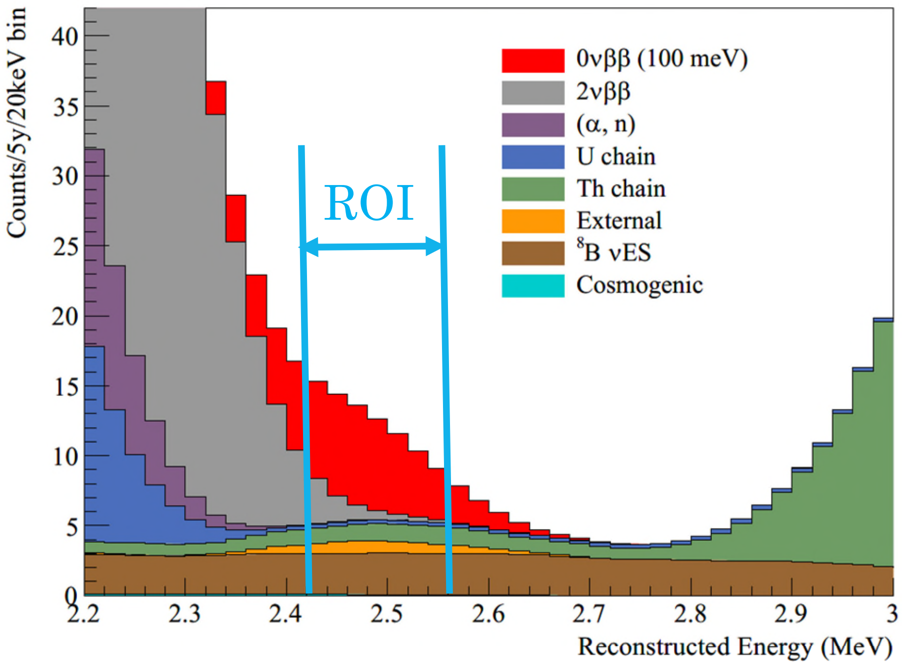


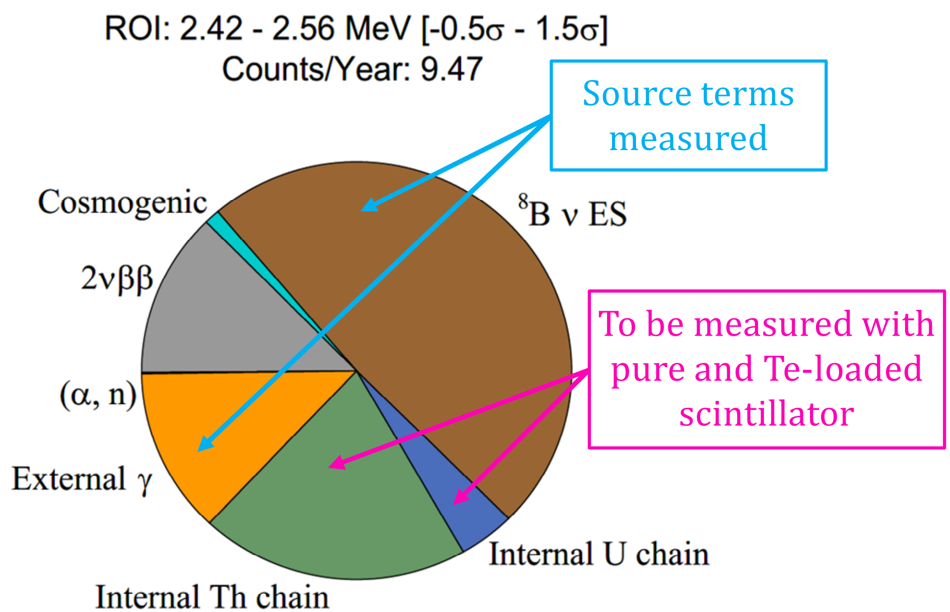
- Loading Te in Scintillator:
  - planned 0.5% ^{nat}Te = 1330 kg of ^{130}Te
  - easy to increase the isotope loading
  - loaded as telluric acid + butanediol derivative
  - stable cocktail

Search for 0νββ with SNO+

Simulations:

- 0.5% natural Te
- 5 years live time
- 3.3 m fiducial volume (17%)
- Light yield 460 Nhits/ MeV





Background reduction:

- Bi-Po coincidences (U/Th)
- developing method to reject γ + fiducialization
  - arXiv:1904.00440
- developing Cherenkov-scintillation separation (^{8}B ν)
- purification +storage U/G (cosmogenics)

Search for 0νββ with SNO+

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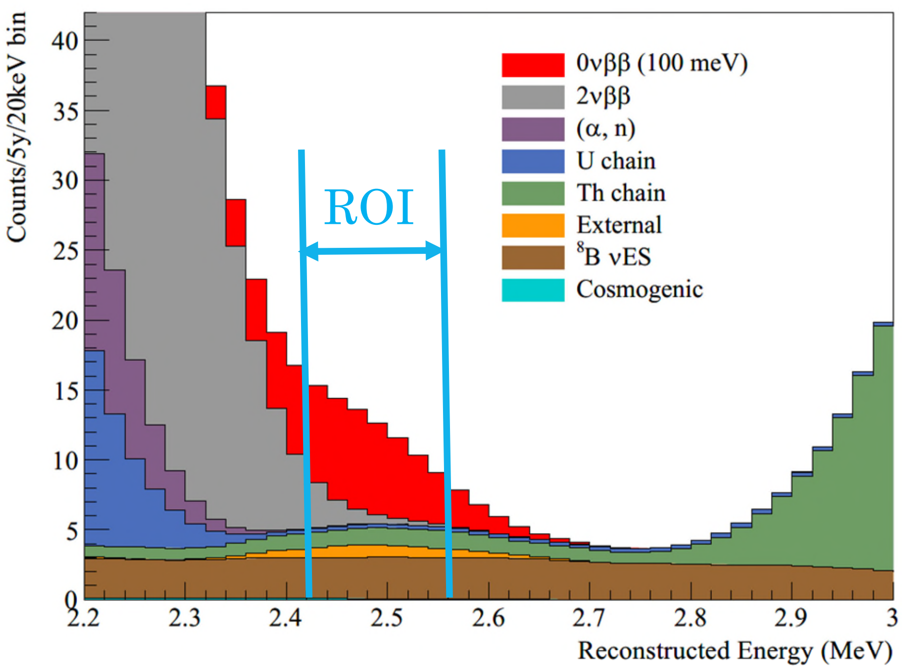
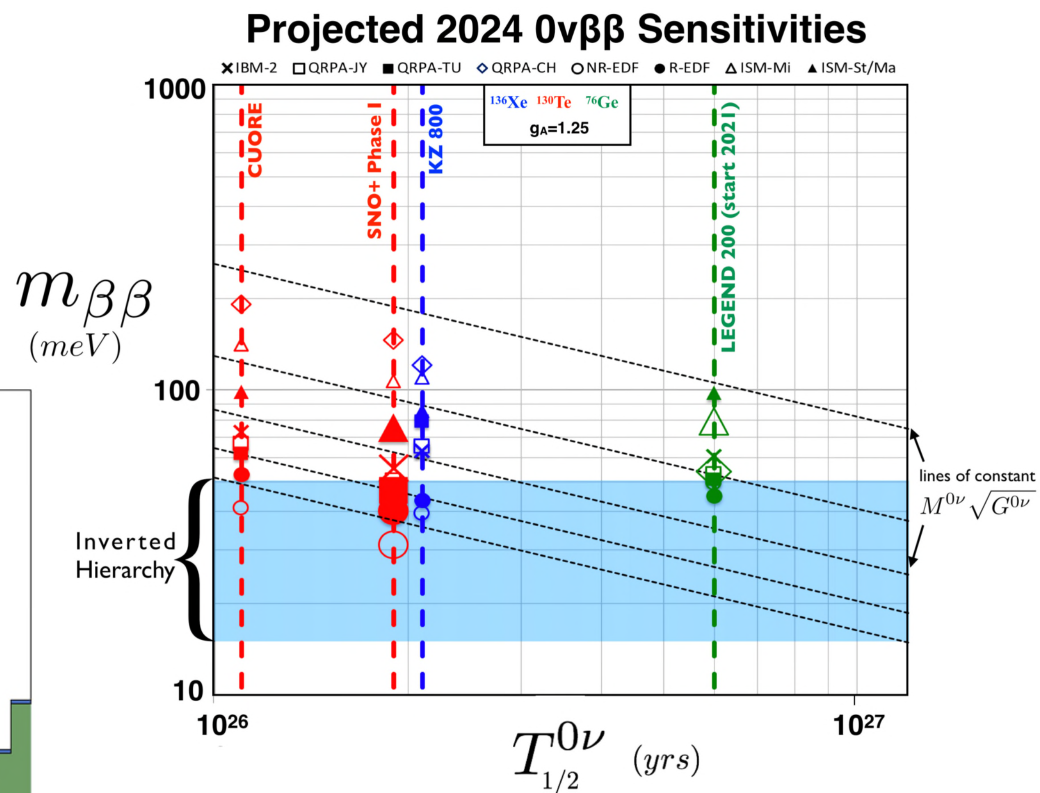




Large amounts of ^{130}Te and low backgrounds
→ excellent 0νββ sensitivity

In 5 years of runnning:

- Expected sensitivity:
  - 2.1 x 10^{26} years
- Effective mass:
  - 37 - 89 meV

Liquid Scintillator: Purification Plant

Target Levels:

$^{85}Kr < 10^{-25}$ g/g

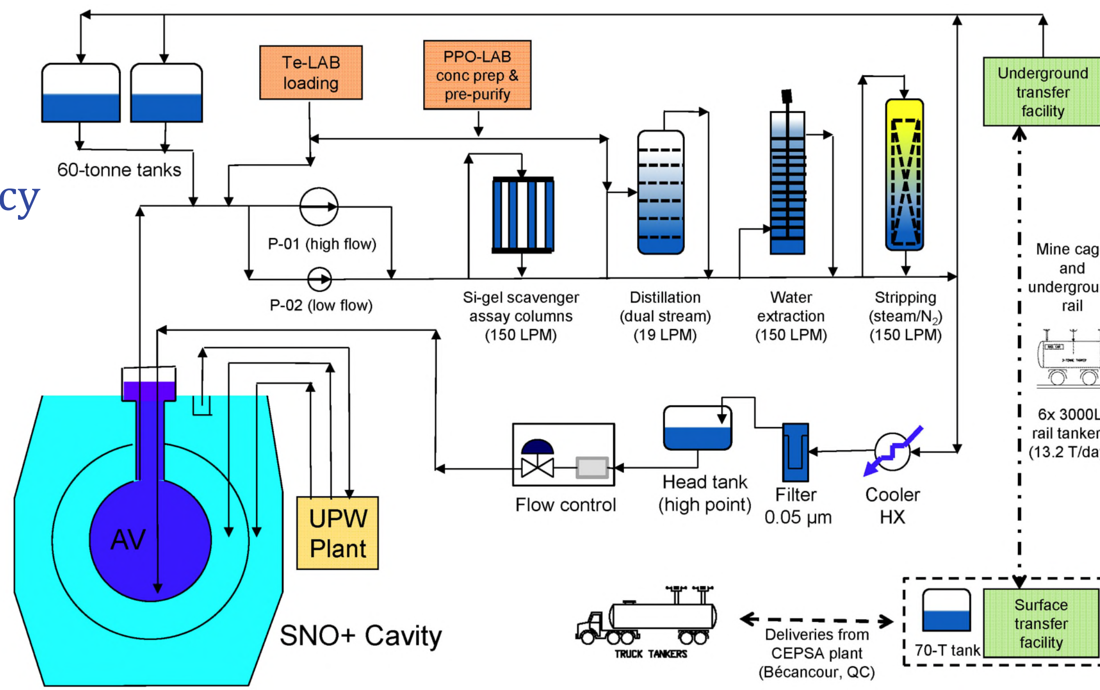
$^{40}K < 10^{-18}$ g/g

^{39}Ar: 10^{-24} g/g

^{238}U-chain: 10^{-17} g/g

^{232}Th-chain: 10^{-18} g/g

- Multi-stage distillation
  - Removes heavy metals
  - Improves UV optical transparency
- Water extraction (LAB-water)
  - Removes K, Ra, Bi and Po
- UPW Steam/N2 stripping
  - Removes gases Rn, Kr, Ar and O_2
- Metal scavengers
  - Removes Pb, Bi, Ra, Ac, Th
- Microfiltration



Liquid Scintillator: Purification Plant

QA/QC requirements:

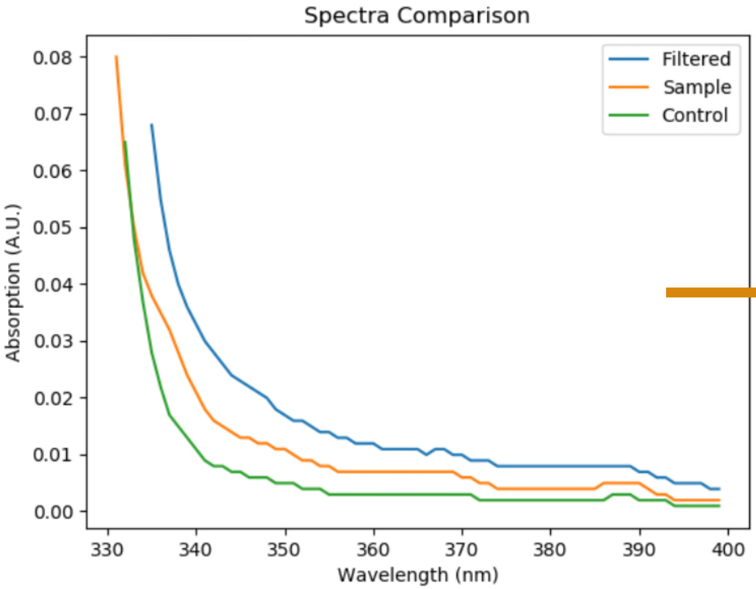
- Physical properties
  - Density, turbidity, temperature, humidity
- Optical properties
  - UV-Vis spectra, UV-Vis transparency,
  - Light Yield

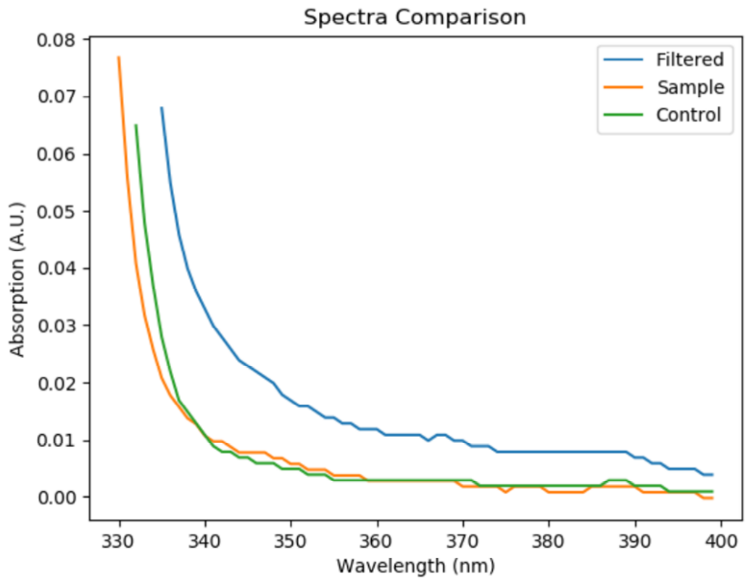
Status:

- Vacuum leak in the distillation column halted operations for several months. Repaired
- Scintillator purification and filling about to resume.
- Currently **~1.8 tonne** inside the AV

❑ Scintillator Plant produces **very good** quality product

- Distillation improves the optical quality





Telluric Acid: Purification Plant

0.5% Te-LS Target Levels:

^{238}U-chain: 1.3×10^{-15} g/g

^{232}Th-chain: 5.5×10^{-16} g/g

- Purchased TeA: ~ 10^{-11}g/g U/Th
  - Require purification factor ~ 10^4–10^5
- Activation of Tellurium by cosmic rays
  - Long-lived isotopes with decays in ROI
    ^{60}Co, ^{110m}Ag, ^{126}Sn, ^{88}Y, ^{124}Sb, ^{22}Na
    - stored underground since 2015

- Purification relies on:
  - solubility of TeA in water, based on pH:

$$\underset{\text{insoluble}}{Te(OH)_6} \leftrightarrow \underset{\text{soluble}}{Te(OH)_5O^-} + H^+$$

  - **insoluble** contamination:
    - dissolve TeA in hot UPW and filter it
  - **soluble** contamination:
    - force re-crystallization with cold nitric acid
    - pump away liquid and dry the crystals
    - rinse with UPW/nitric acid and purge

Status:

- Commissioning started

Tellurium Diol Production Plant

- Loading Te into scintillator
  - mix TeA and butanediol (BD) to produce organotellurate complex TeBD
  - TeBD can be mixed with LAB
- Materials prepurified: TeA, LAB, UPW, and BD

Status:

- Installation completed
- Commissioning has begun

Summary

- Well used time during Water Phase
  - Two physics papers published
  - Still collecting data with very low background
    - proved effectiveness of the cover gas
  - Measured external background
    - consistent with DBD target levels
  - Analysis ongoing and more papers in preparation

- Started filling detector with scintillator
  - In a few months, start taking data
    - measure the internal backgrounds

- All tellurium process systems installed and being commissioned
  - getting ready for loading tellurium and $0\nu\beta\beta$ data!

Thank you!