Status of the SNO+ Experiment

ERICA CADEN

FOR THE SNO+ COLLABORATION

15TH TOPICS IN ASTROPARTICLE AND UNDERGROUND PHYSICS

JULY 2017, SUDBURY, ONTARIO, CANADA

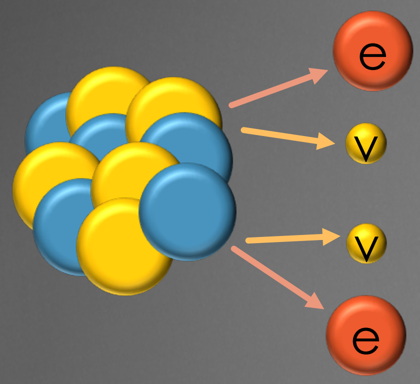
SNOLAB

Laurentian University
Université Laurentienne

Double Beta Decay

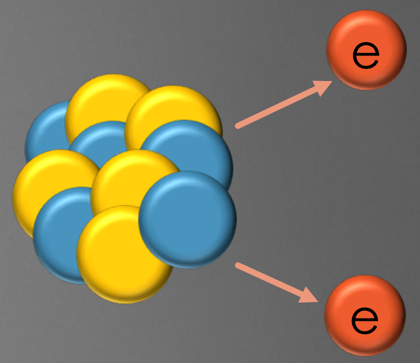
- Candidate isotopes: Even-even nuclei where single β decay is forbidden

2νββ



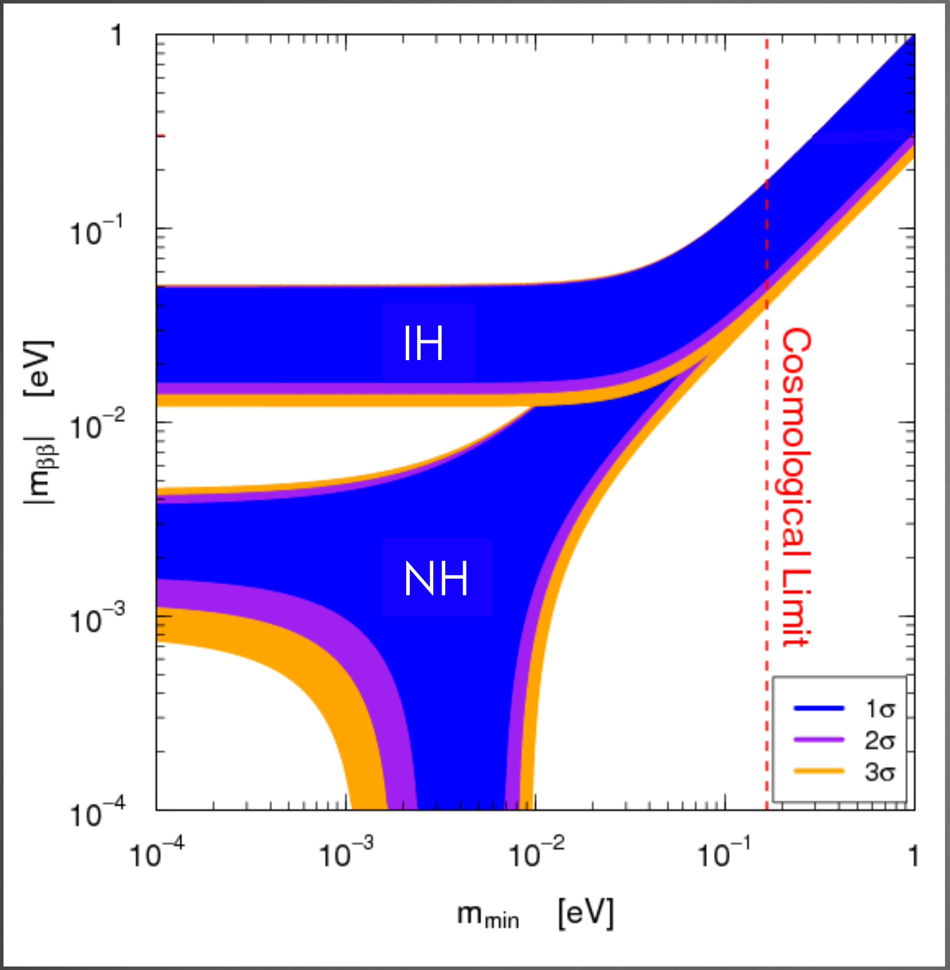
- Allowed in Standard Model
- Observed in 12 isotopes

0νββ



- Not yet observed
- Implies non-conservation of lepton number
- Implies neutrinos are Majorana particles

Double Beta Decay



Mod.Phys.Lett. A27 (2012) 1230015

- The rate of $0\nu\beta\beta$ is given by

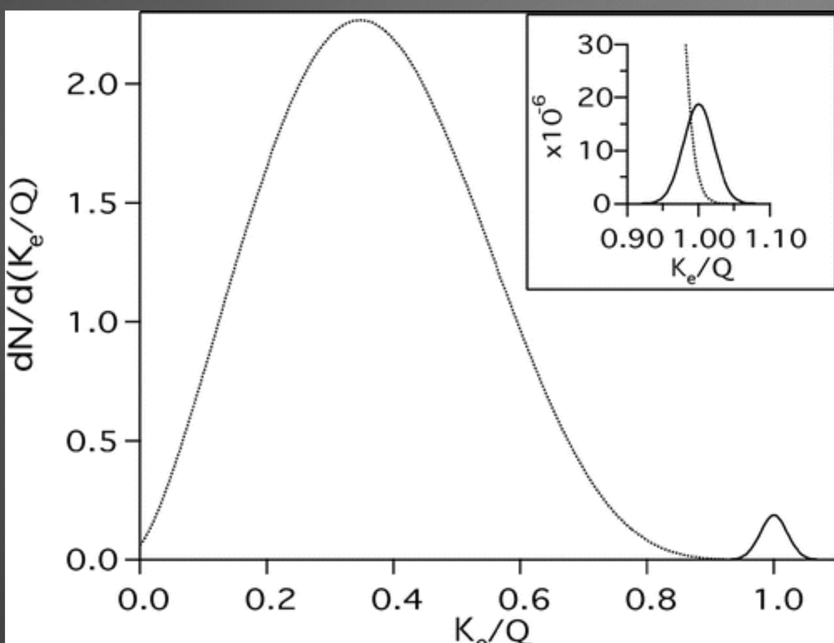
$$\left(T^{0v}_{1/2}\right)^{-1} = G^{0v}|M^{0v}|^2\langle m_{\beta\beta}\rangle^2$$

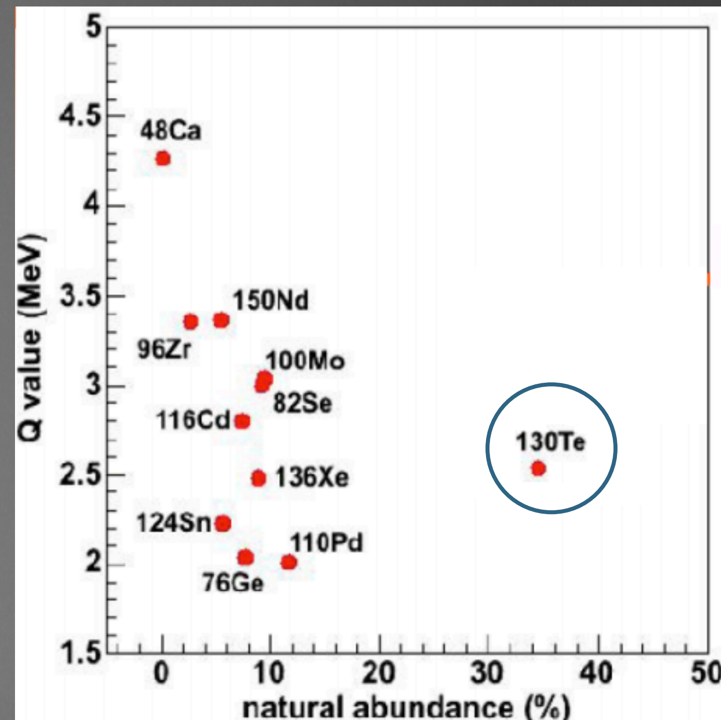
- $T_{1/2}$: half-life
- G: phase space factor
- M: nuclear matrix element
- $m_{\beta\beta:}$ effective neutrino mass

$$\langle m_{\beta\beta}\rangle = \left|\sum_i U^2_{ei} m_i\right|$$

Double Beta Decay

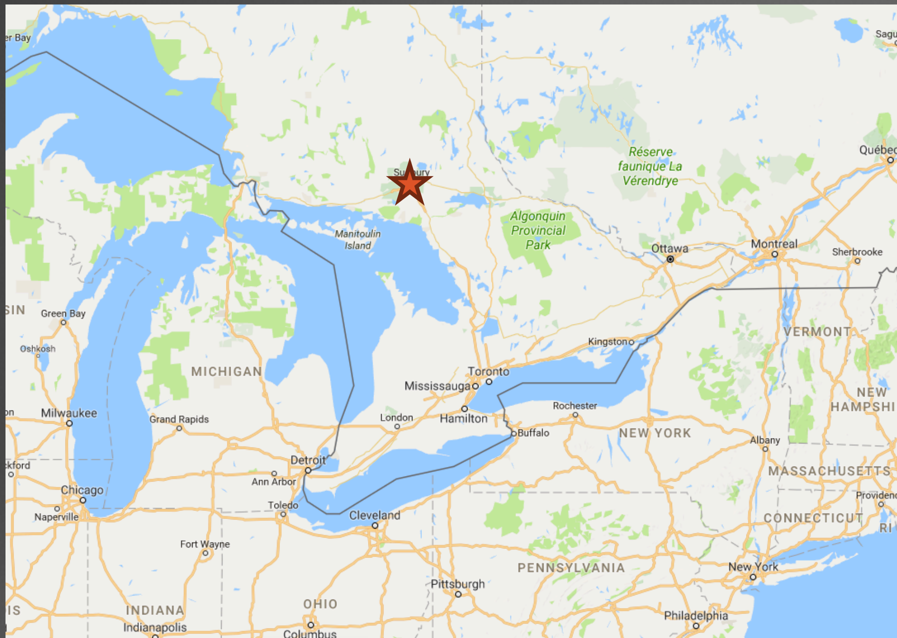
- Key experimental signature for 0νββ is a peak in visible energy at the Q-value of the nucleus, smeared by detector resolution.
- Requirements:
  - Large source mass
  - Low background
  - Good energy resolution

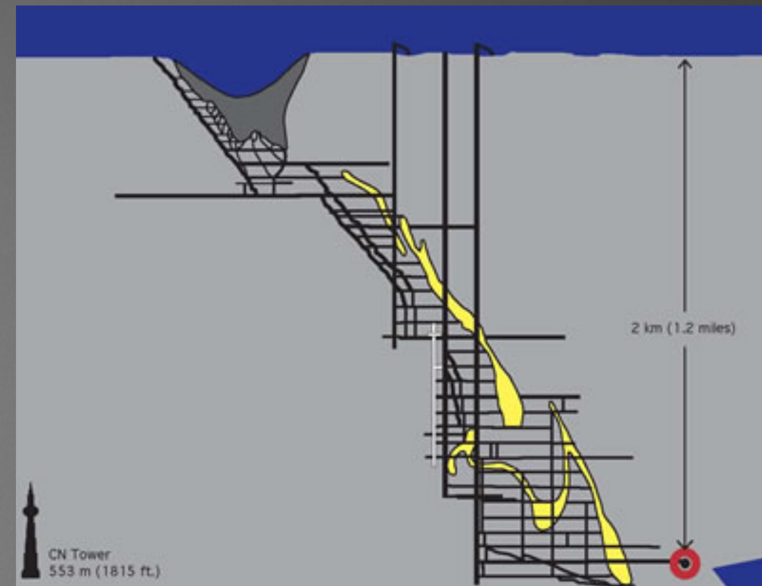


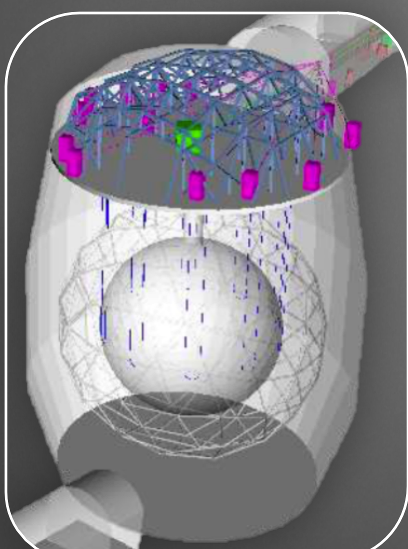


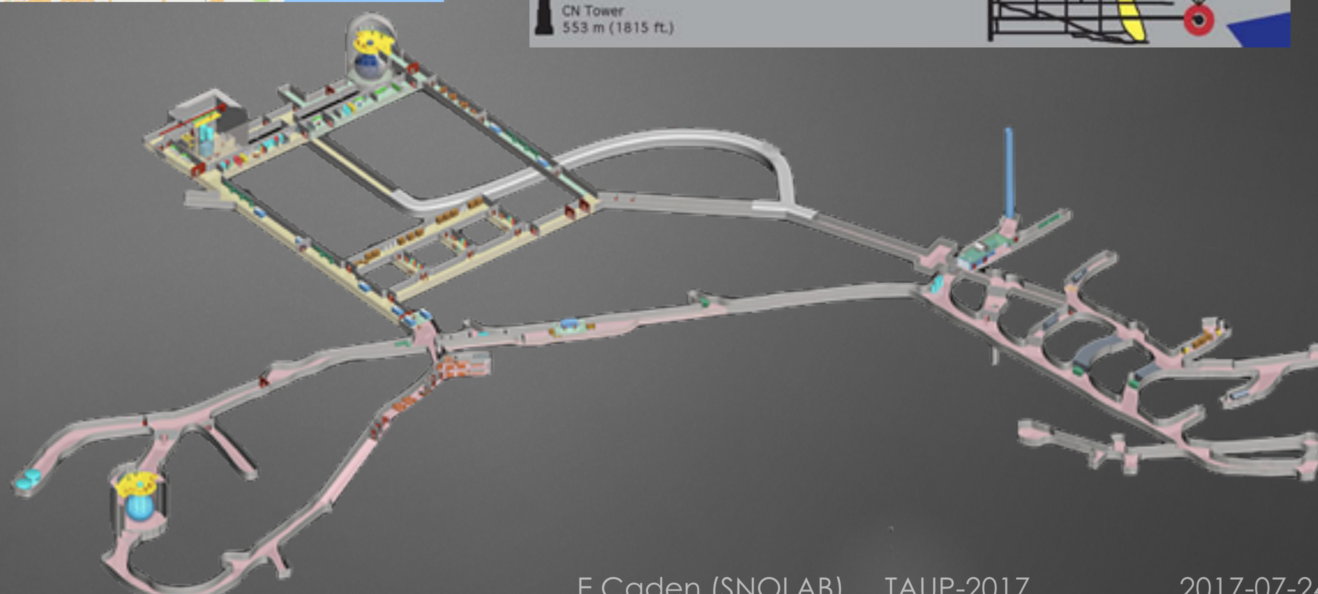
- Long 2νββ half-life: ~ 7×10^{20} years
- High Q-value : ~2.5 MeV
- High natural abundance: 34%

SNO+ @ SNOLAB

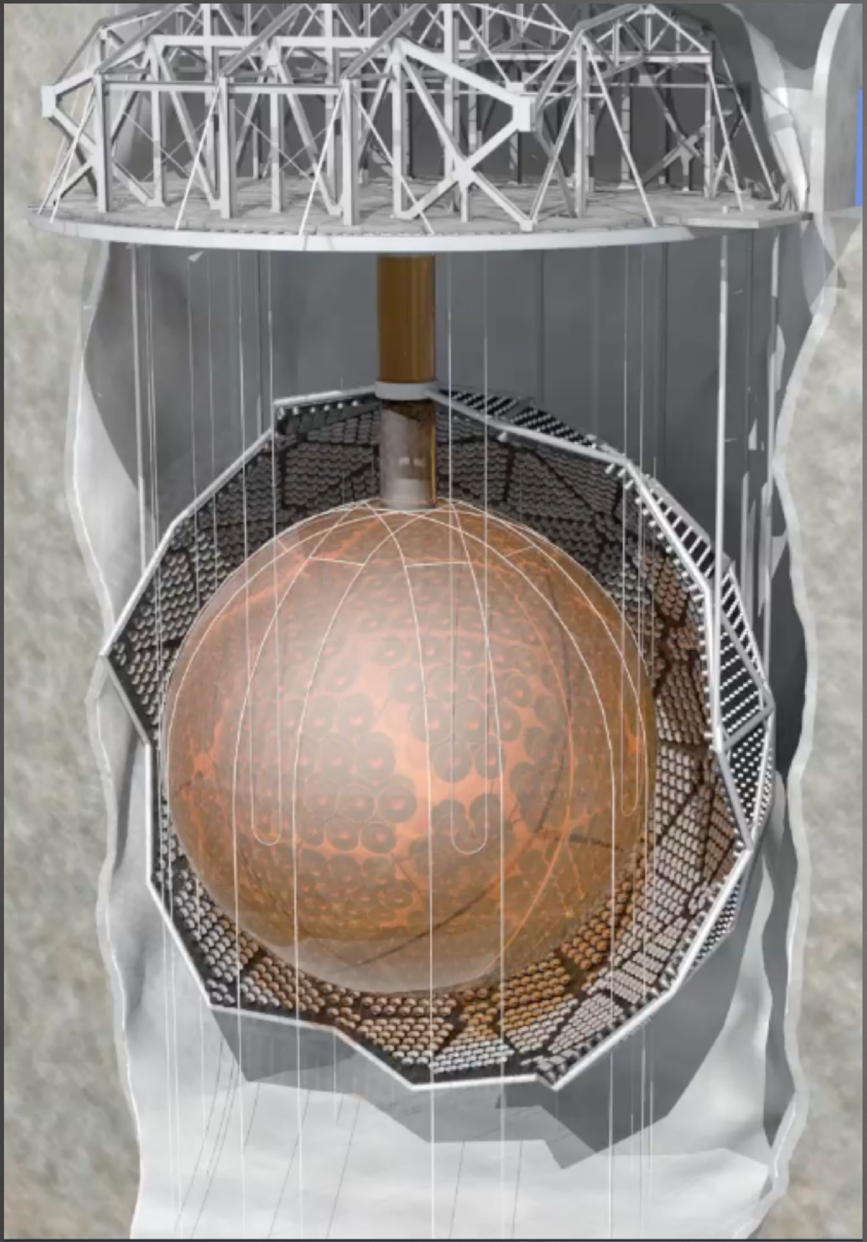

Sudbury
Réserve faunique La Vérendrye
Québec
Algonquin Provincial Park
Manitoulin Island
Ottawa
Montreal
Sherbrooke
Green Bay
Oshkosh
MICHIGAN
Milwaukee
Grand Rapids
Toronto
Mississauga
Kingston
VERMONT
NEW HAMPSHIRE
Rochester
London
Hamilton
Buffalo
NEW YORK
Albany
Detroit
Ann Arbor
MASSACHUSETTS
Providence
Chicago
Naperville
Toledo
Cleveland
CONNECTICUT
RI
Fort Wayne
PENNSYLVANIA
New York
Pittsburgh
INDIANA
Indianapolis
OHIO
Columbus
Philadelphia


2 km (1.2 miles)
CN Tower
553 m (1815 ft.)





SNO+ Detector



Deck with Upgraded DAQ and calibration system

Urylon liner: Rn seal

Replaced Hold Up Ropes

New Optical Monitoring System

Hold Down Rope Net

Acrylic Vessel
- Φ 12 m
- 5 cm thick

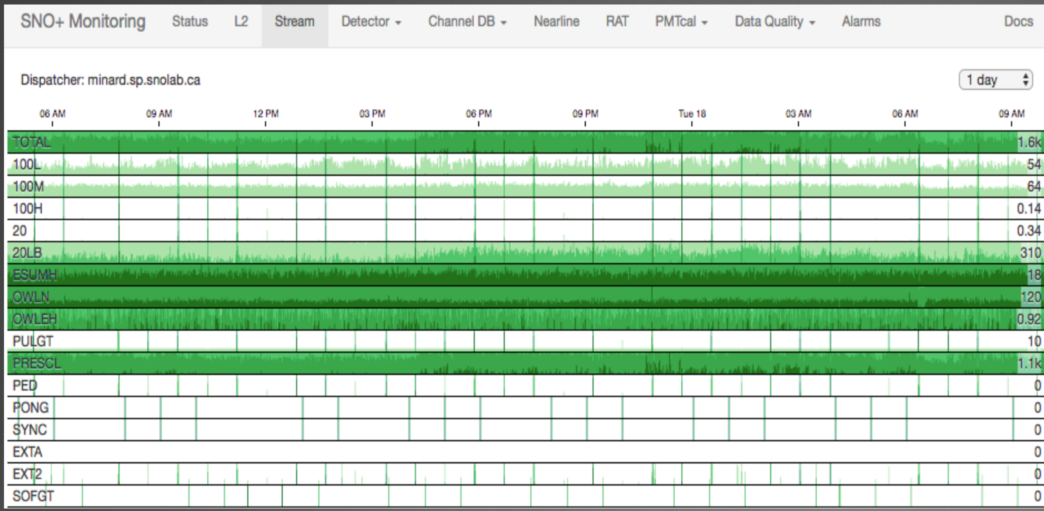
780 t Liquid scintillator + 3.9 t Tellurium

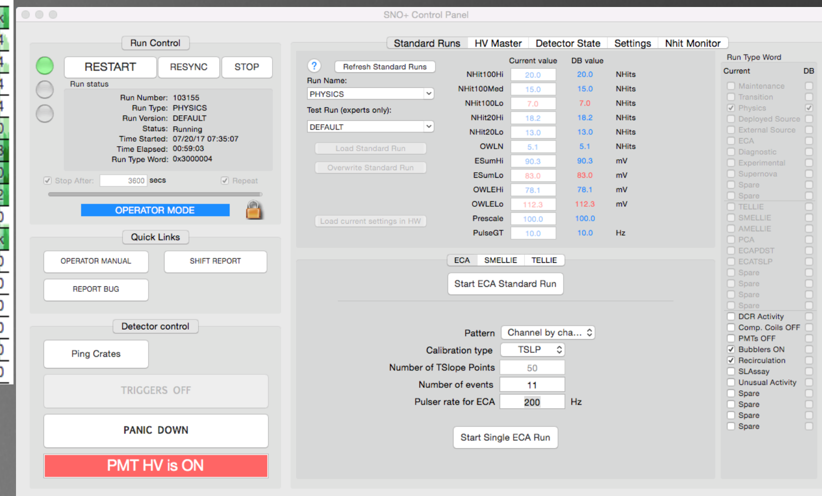
Water shielding
- 1700 t inner
- 5300 t outer

~9400 PMTs, 50% coverage

2070 km rock overburden @ SNOLAB

SNO+ Electronics Upgrades





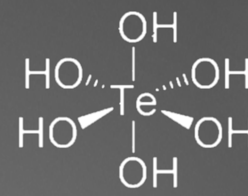
- SNO+ has improved upon the electronics of SNO in order to compensate for the higher data rates and light output expected by a scintillator experiment.
- New Read Out Cards, Analog Trigger boards, Waveform Digitizer, and Trigger Utility Board.
- A new DAQ system has been developed for SNO+. Using a modular approach decouples data flow from detector control (ORCA) and monitoring tools, providing more stability and increased control.
- Detector Commissioned: December 2016 – April 2017

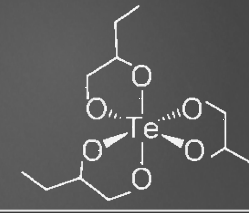
SNO+ LAB Process Plant

- Multi-stage distillation
  - Removes heavy metals
  - Improves UV transparency
  - Dual-stream PPO distillation
- N_2-Steam stripping: Removes Rn, Kr, Ar and O_2
- Water extraction: Removes Ra, K and Bi
- Metal scavengers: Removes Bi, Pb, Ra, Ac, Th (x 800 in single pass)

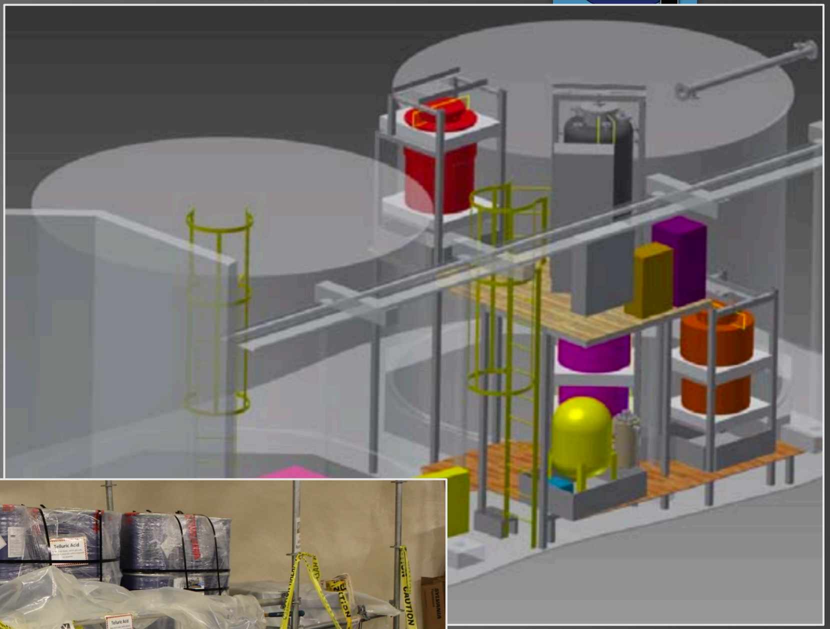
- While the detector is operational scintillator can be recirculated @ 150 LPM to provide re-purification as necessary.
- **Commissioning Ongoing**
- **Filling with Scintillator later this year**

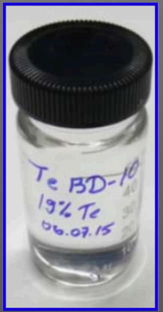
SNO+ Te
Purification & Loading





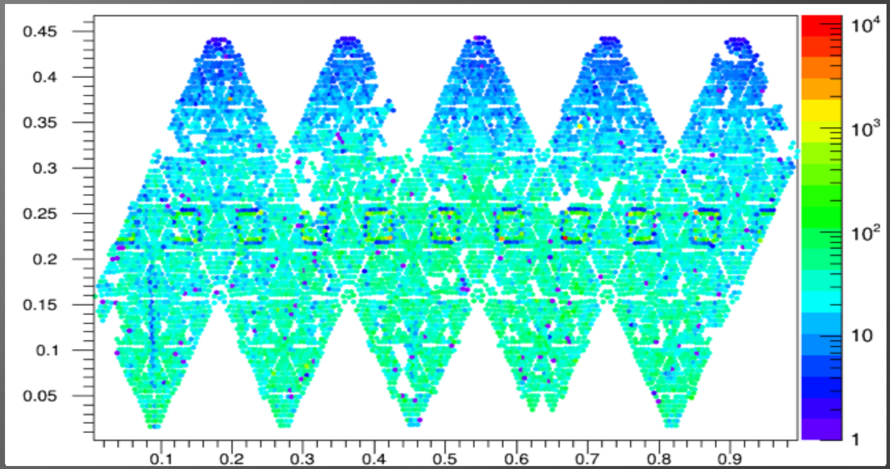
- Telluric Acid Underground "cooling" since 2015.
- Purified by multi-pass recrystallization based on solubility of TeA in water based on pH.
- Full scale plant now in construction underground.
- Cocktail: LAB+PPO+Te-ButaneDiol
- Initial phase: 0.5% Te (~1300 kg ^{130}Te)
- LAB Advantages:
  - Long attenuation length
  - No inherent optical absorption lines
  - High light yield
  - α-β separation decay time





SNO+ Calibration

- Original source deployment hardware refurbished and installed for SNO+
- **May '17:** Deployed Laserball - Light diffuser for studying detector's optical properties and PMT angular response
- **June '17:** Deployed ^{16}N - Energy scale and resolution studies



- In situ fibre systems inject light from the PMT array to the detector using optical fibres
- Measure PMT gain and timing, scattering properties of detector media
- New deployment hardware for scintillator/Te phase on site, commissioning ongoing

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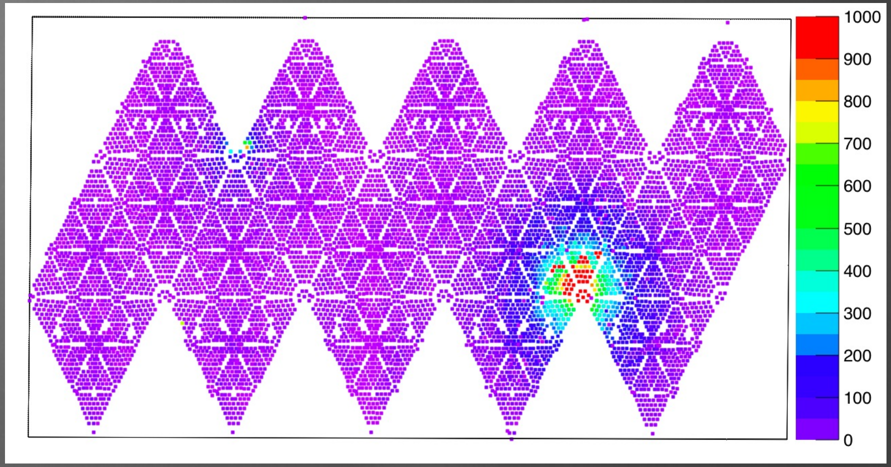
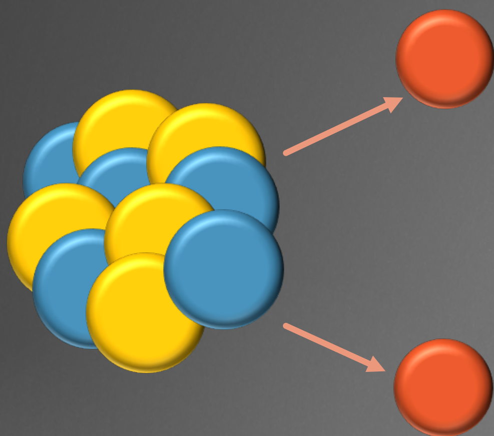
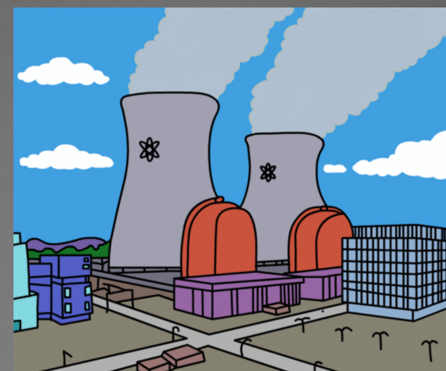


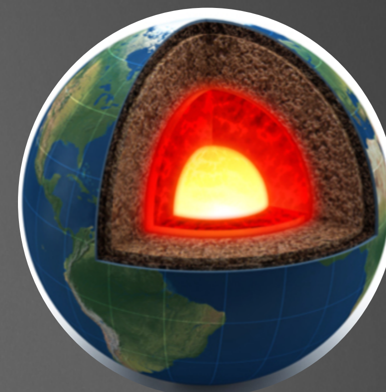
SNO+ Physics Program



Double Beta Decay

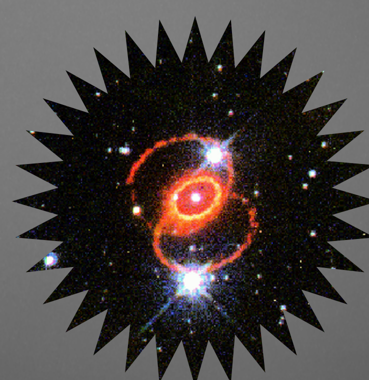


Reactor Antineutrinos

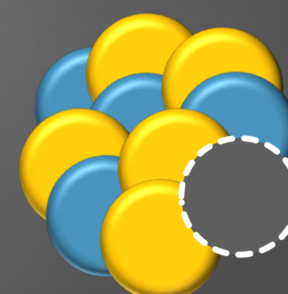


Geo Antineutrinos

Solar Neutrinos

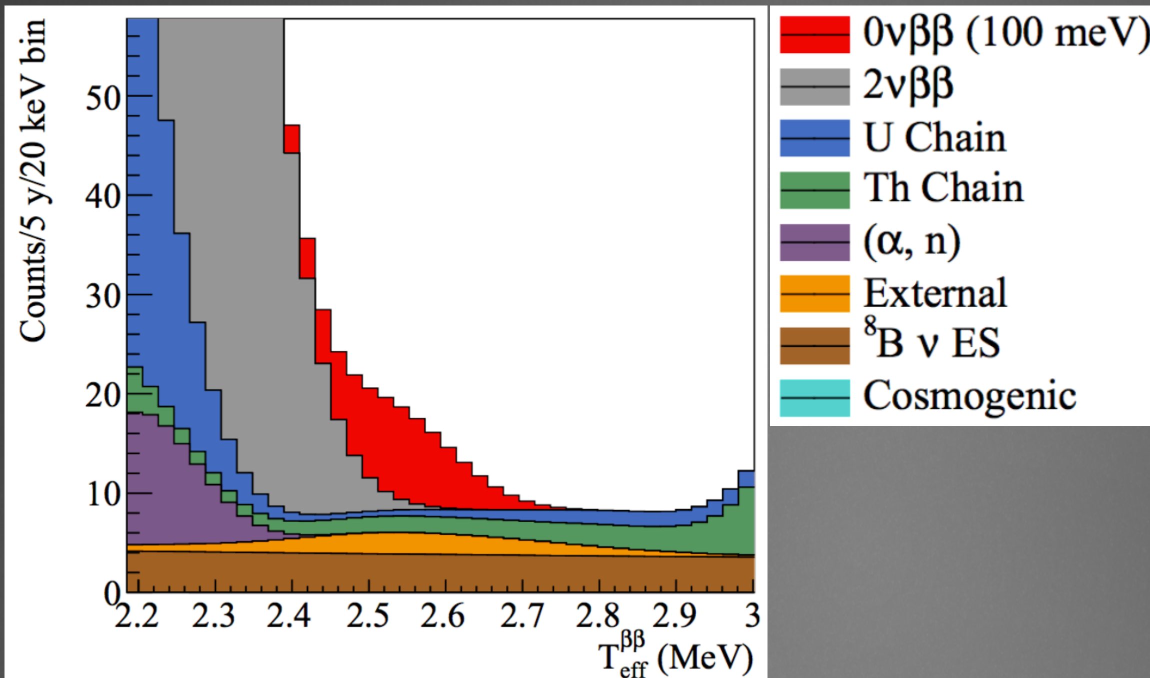


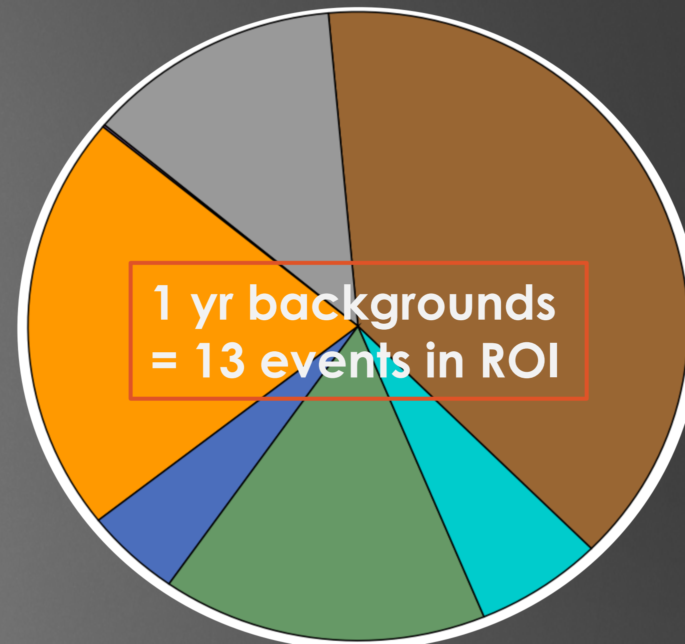
Supernovae



Nucleon Decay

SNO+ Sensitivity





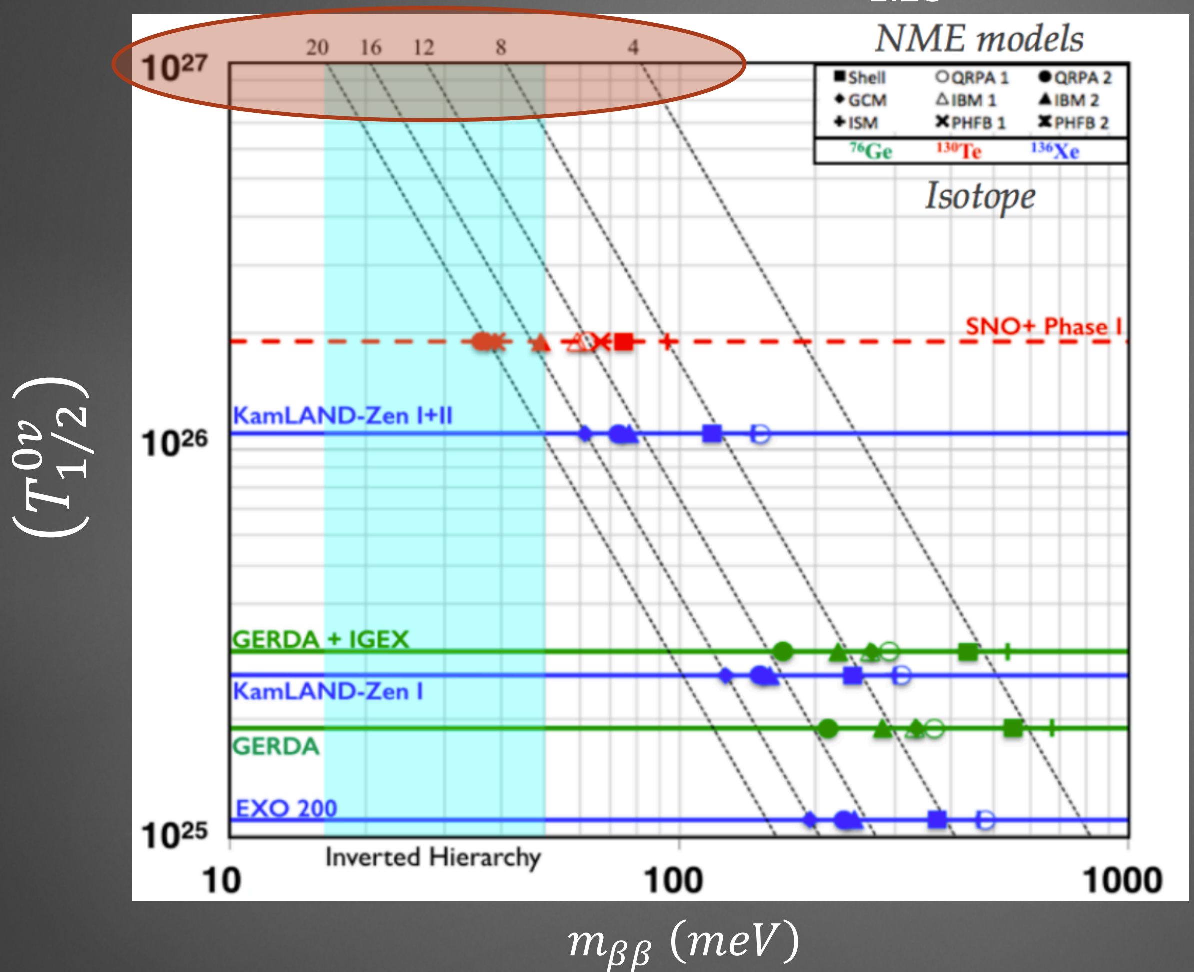
- LAB + PPO (2g/L) + bisMSB (15mg/L)
- 0.5% nat. Te (1330 kg ^{130}Te)
- FV = 3.5 m (20%)
- > 99.99% rejection ^{214}BiPo
- 98% rejection ^{212}BiPo
- 390 hits/MeV
- $m_{\beta\beta}$ =100 meV

After 5 yrs, 0.5% loading:
$T_{1/2} > 2 \times 10^{26}$ y, 90% CL
$m_{\beta\beta} \approx 40 - 90$ meV

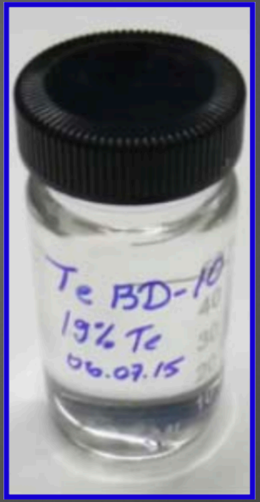
SNO+ Sensitivity

$$\left(T_{1/2}^{0\nu}\right)^{-1} = G^{0\nu}|M^{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

lines of constant $M^{0\nu}\sqrt{G^{0\nu}\times 10^{15} yr}\left(\frac{g_A}{1.25}\right)^2$

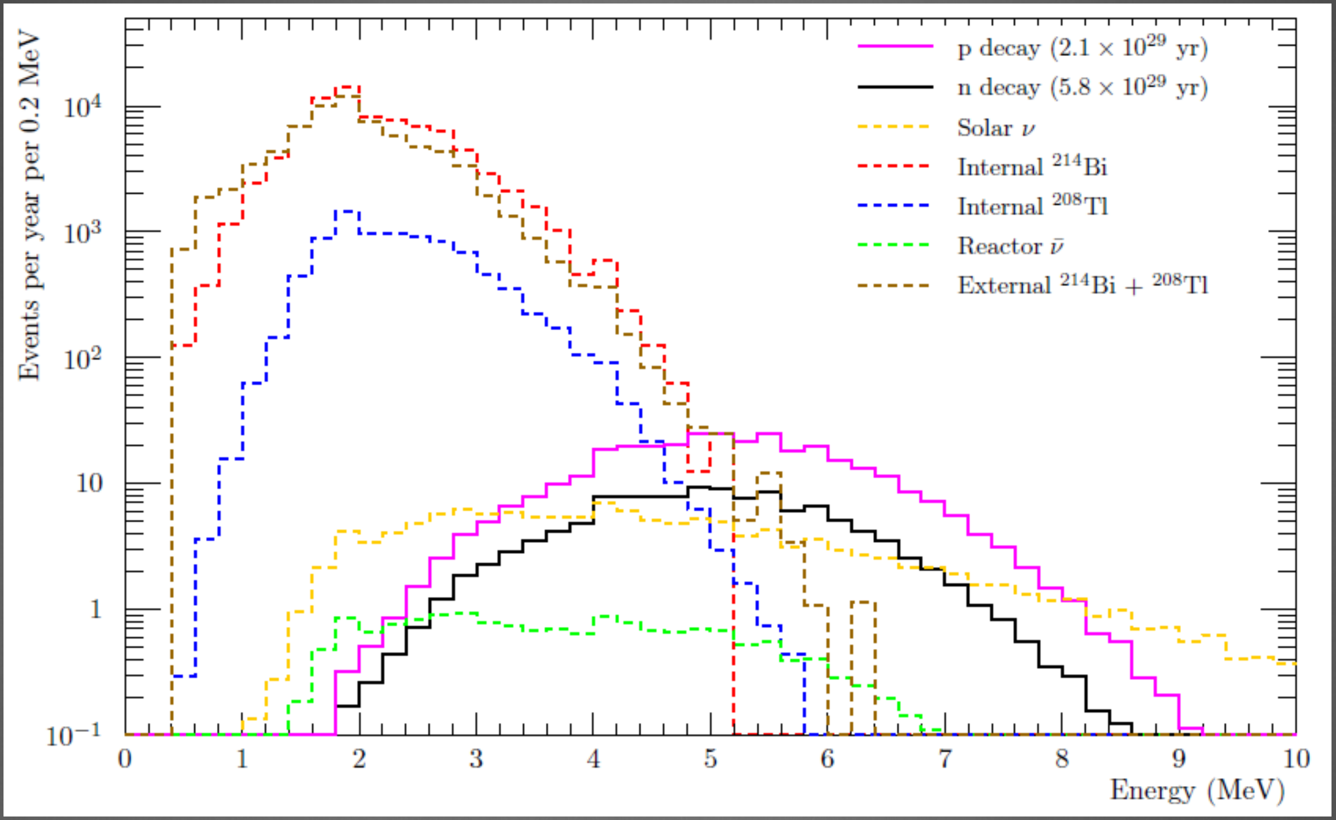


- **Phase II Sensitivity**
  - Higher Te Loading
  - Improved HQE PMTs



SNO+ Nucleon Decay

- Look for invisible decay modes
- $^{16}O \longrightarrow {}^{15}O^*$ or $^{15}N^* + \sim 5$ MeV γ



- 6 months of data → 30 background counts in ROI

90% CL:

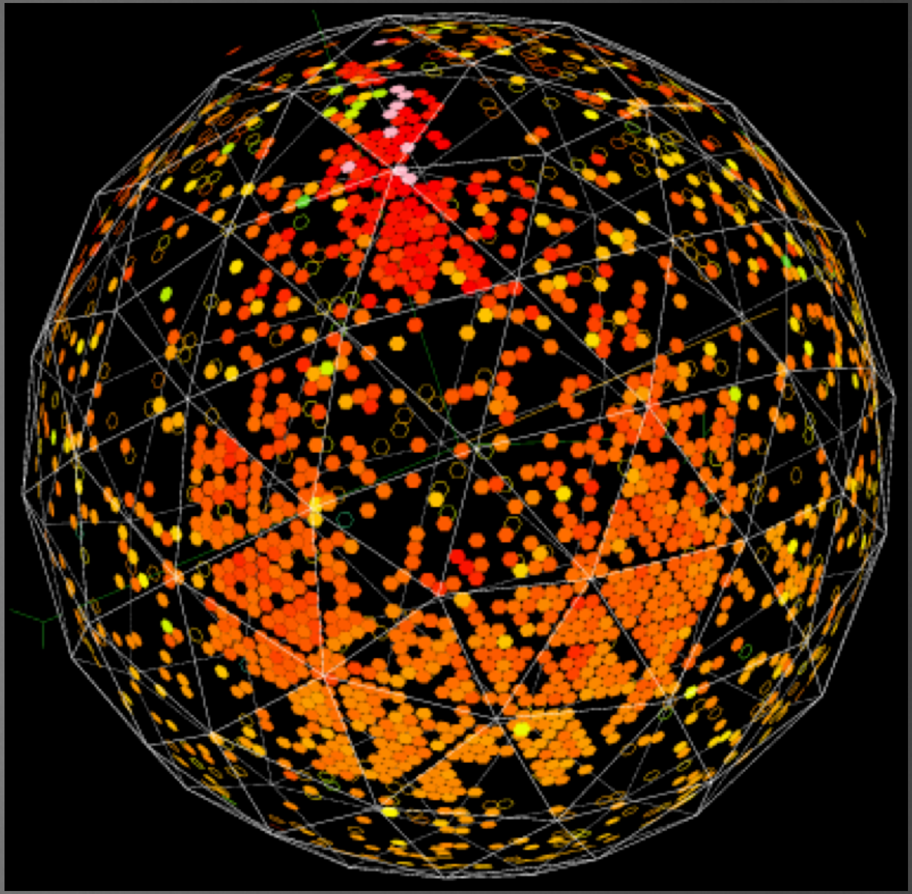
- τ_n**=1.2x10^{30} years** (current limit KamLAND: 5.8x10^{29} y)
- τ_p**=1.4x10^{30} years** (current limit SNO: 2.1x10^{29} y)

SNO+ Posters!

- **167. Data-Quality and Run Selection for the SNO+ experiment**
  - G. Prior, K. Singh
- **178. A Sensitive Assay Technique for ^{210}Pb In Water Developed For The SNO+ Experiment**
  - D. Chauhan, O. Chkvorets
- **179. Supernovae and SNO+**
  - J. Rumleskie, C. Virtue
- **180. SNO+ Calibration Hardware**
  - R. Bayes
- **189. Search for Invisible Nucleon Decay in the SNO+ Experiment**
  - I. Coulter, K. Labe
- **232. Underwater Photometry System of the SNO+ experiment**
  - K. Singh

Conclusions

- SNO+ is filled with light water and taking physics data
- In 6 months of running, SNO+ will set world leading limits on invisible nucleon decay
- Scintillator process plant is under commission
- Tellurium plant is under construction
- Neutrinoless Double Beta Decay phase will begin in late 2018
- SNO+ $0\nu\beta\beta$ sensitivity starts to explore the inverted hierarchy region



Muon Candidate, July 2017

SNO+ Collaboration

UNIVERSITY OF ALBERTA

THE UNIVERSITY OF CHICAGO

Universidad Nacional Autónoma de México
UNAM

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UNIVERSITY of PENNSYLVANIA

Queen's

BOSTON UNIVERSITY

TECHNISCHE UNIVERSITÄT DRESDEN

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UniversitéLaurentienne

NORWICH UNIVERSITY

Queen Mary
University of London

Lancaster University

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

BROOKHAVEN NATIONAL LABORATORY

BERKELEY LAB

UNIVERSITY OF LIVERPOOL

LIP

UNIVERSITY OF OXFORD

SNOLAB

US UNIVERSITY OF SUSSEX

TRIUMF