SNO+ Calibration with the ^{16}N Source

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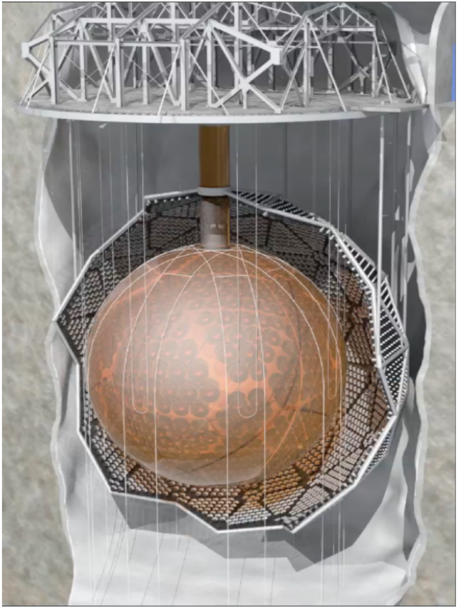
CAP-2018

June 13, 2018

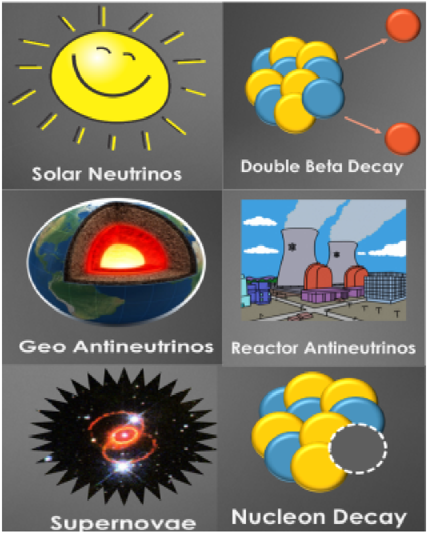
The SNO+ Experiment



- 6 km water equiv. overburden (2.0 km @ SNOLAB, ∼70/day)
- Acrylic vessel; 6m radius, 5cm thickness
- 9400 PMTs mounted on PSUP, ∼8m radius (∼54% coverage)
- 780 tonnes of liquid scintillator/ 905 tonnes of ultra-pure water
- Water shielding:
    - 1700 t inner
    - 5300 t outer

Physics Goals for SNO+

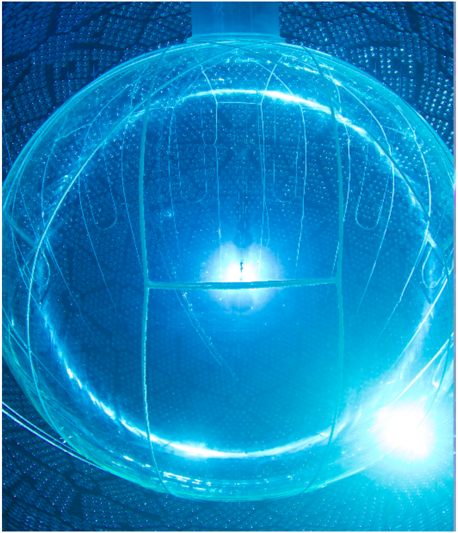
- Water Phase: Invisible nucleon decay
- Pure Scintillator Phase: Solar Neutrinos
- Tellurium-loaded Scintillator: **Neutrino-less double beta decay with** $^{130}\mathrm{Te}$
- All phases:
  - Supernova Neutrinos
  - Geo/Reactor anti-neutrinos



Current status of SNO+

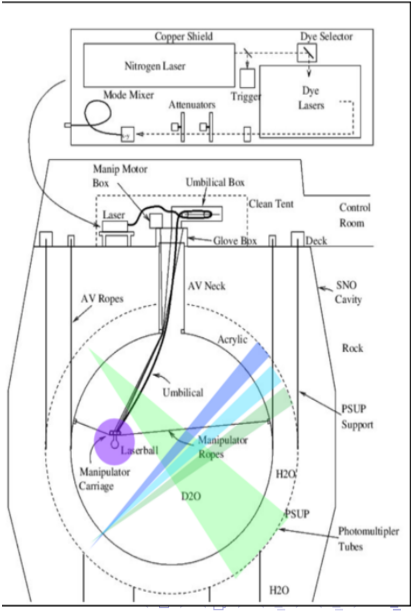
- **Water Phase started May 2017:**
- Detector Calibration with deployed and embedded sources.
- Understanding the backgrounds.
- Repairing the electronics and commissioning.

- Begin scintillator filling *summer 2018*

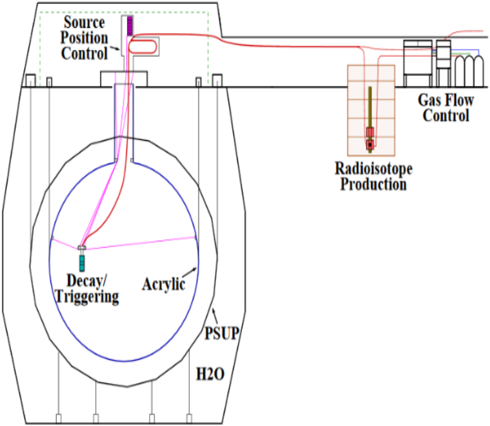


SNO+ Calibration during the Water Phase

- Deployed Sources:
  - ^{16}**N as the primary source** : calibrate the reconstructed energy and position and evaluate the associated bias and systematics.
  - The laser ball: the optical properties, PMT efficiency, angular response.
- Embedded Sources:
  - Embedded LED/Laser Light Injection Entity (ELLIE)
  - Timing, Attenuation, and Scattering



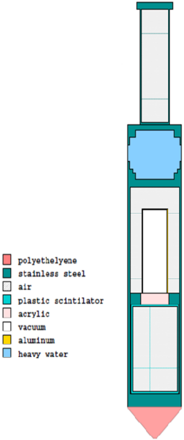
N16 Calibration Source for SNO+



- ^{16}N produced underground in DT generator underground.
- n+ ^{16}O $\rightarrow$ p + ^{16}N ($\tau_{1/2}$= 7.1 sec)
- Sent to the source container through the umbilical.

N16 Calibration Source for SNO+

- $^{16}N \rightarrow ^{16}O^{*} + \beta \quad Q$=10.4MeV
  ~70% $^{16}O^{*} \rightarrow \gamma$ (6.13MeV)
- Tagging by β: the source chamber has a dedicated PMT and plastic scintillator.
- γs are emitted through the cylinder, go through Compton scattering and produce Cherenkov radiation picked up by the detector.



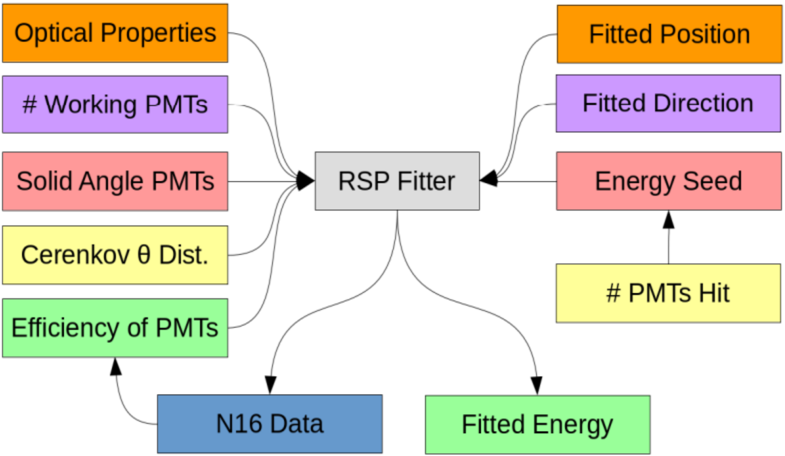
Umbilical Retrieval Mechanism (URM)

The URM along with side ropes enable positioning the source.

What do we calibrate with the ^{16}N source?

- Calibrate the global detection efficiency of the detector using the simulated prompt PMT hits spectrum to that from data.
- Calibrate the reconstructed energy, energy resolution and the relative energy scale.
- Calibrate the reconstructed position and evaluate the associated systematics and bias.

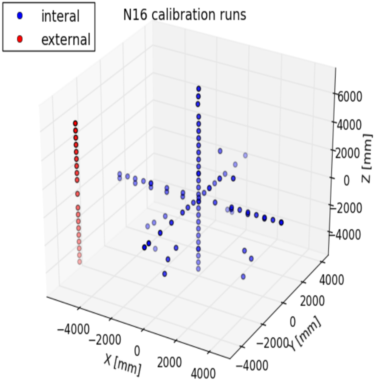
Response Processor Fitter (RSP)



[1] Taken from Z. Barnard

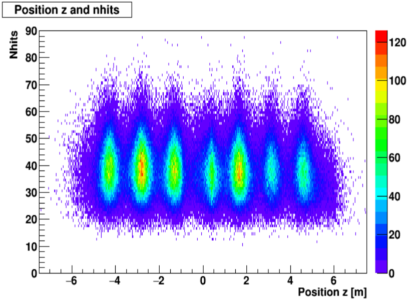
^{16}N calibration runs during the water phase

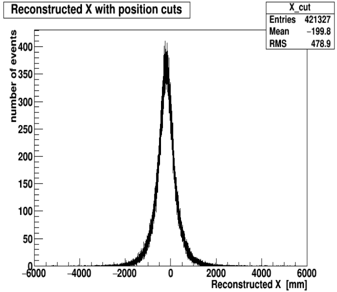
- May 2017: Internal vertical scan with 7 positions.
- Nov 2017: Internal full scan along x, y, z axis, over 90 positions.
- March 2018: External vertical scan, 19 positions.
- ^{16}N selection criteria:
  - Should be tagged by the source PMT.
  - Position and directionality cuts to avoid shadowing. Keep the events reconstructed more than 70cm away from the source.

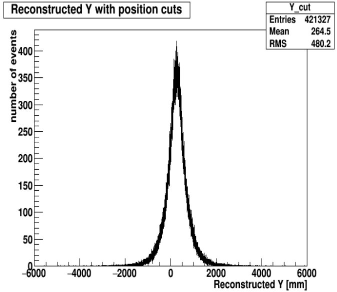


^{16}N Scan along the Z axis (May 2017)

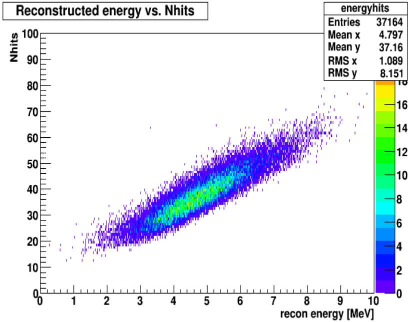
- X =-18.6 cm
- $Y = 25.6$ cm
- 7 different positions for Z

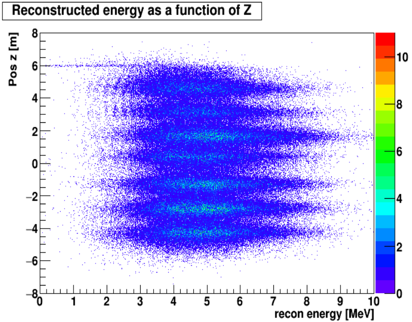






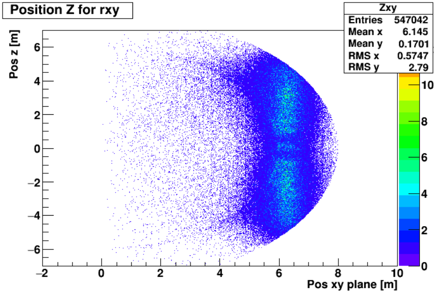
RSP reconstructed energy

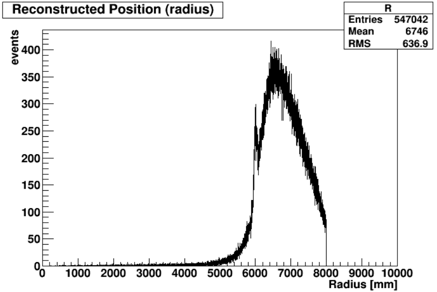




The external ^{16}N calibration

- Testing the reconstruction and understanding the background.
- The source is deployed through a vertical guide tube between the PSUP and the Acrylic vessel
- X =586.1 cm, Y =252.4 cm, 19 different positions for Z.





Summary

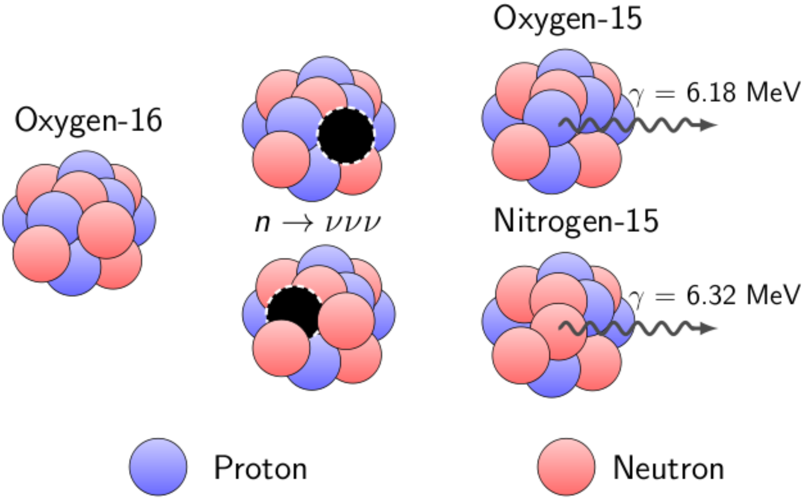
- ^{16}N calibration data has been taken for over 100 positions inside and outside of the AV.
  - Tuning the global detection efficiency.
  - Calibrating and testing the energy and position reconstruction and evaluating the associated bias and systematics.
- SNO+ has taken water data for over a year and is preparing to fill liquid scintillator this Summer.

Questions?

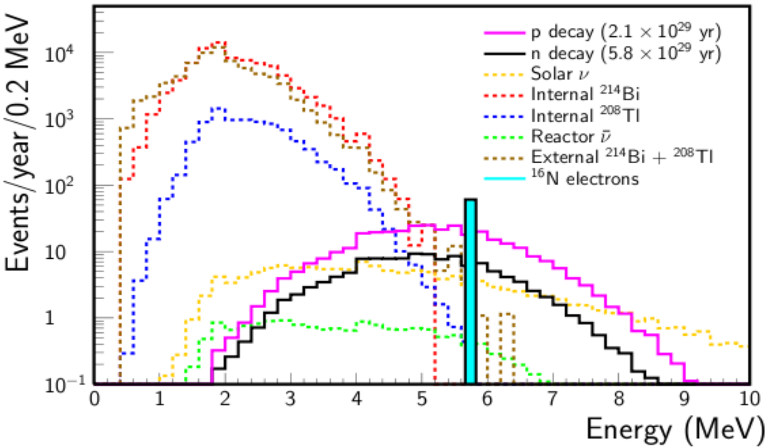
The SNO+ Collaboration

Univ. of Alberta • UC-Berkeley/Lawrence Berkeley National Lab. • Boston Univ. • Brookhaven National Lab. • Univ. of Chicago • UC-Davis • Tech. Univ. of Dresden • Lancaster Univ. • Laurentian Univ. • LIP Lisbon & Coimbra • Univ. of Liverpool • Univ. National Autonoma de Mexico • Univ. of North Carolina • Norwich Univ. • Univ. of Oxford • Univ. of Pennsylvania • Queen's Univ. • Queen Mary Univ. of London • SNOLAB • Univ. of Sussex • TRIUMF

Invisible Nucleon Decay (Backup)



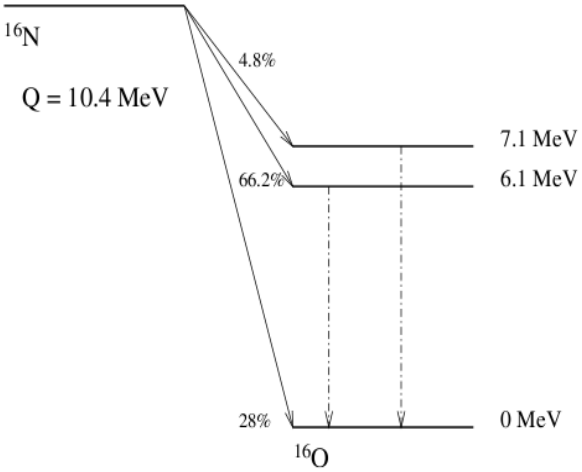
The expected signal for the invisible nucleon decay (MC)



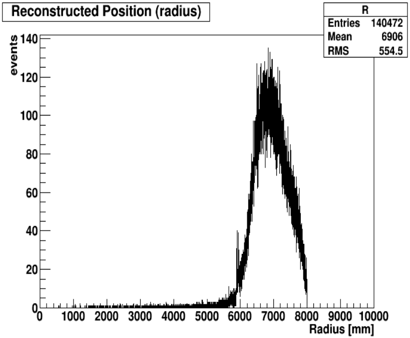
Understand Energy Scale with ^{16}N Calibration Source

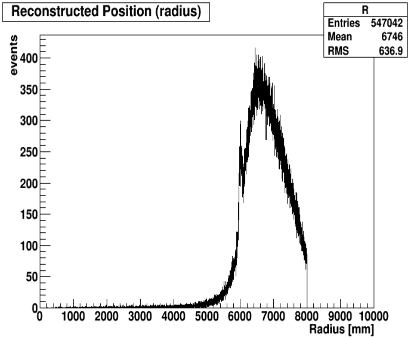
[1]I. Coulter, SNO+ Collaboration

N16 decay schematic

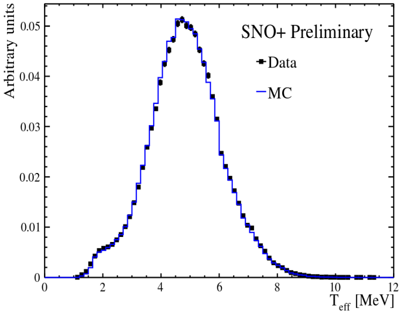


N16 external with the directionality cuts





Energy calibration



$$P(T_{\text{eff}}) = N \int P_{\text{source}}(T_e) \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{((1+\delta_E)T_{\text{eff}} - T_e)^2}{2\sigma^2} \right] dT_e$$