A Reconstruction Algorithm for SNO+

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SNO+

The successor of Sudbury Neutrino Observatory (SNO) experiment, which was awarded the 2015 Nobel Prize

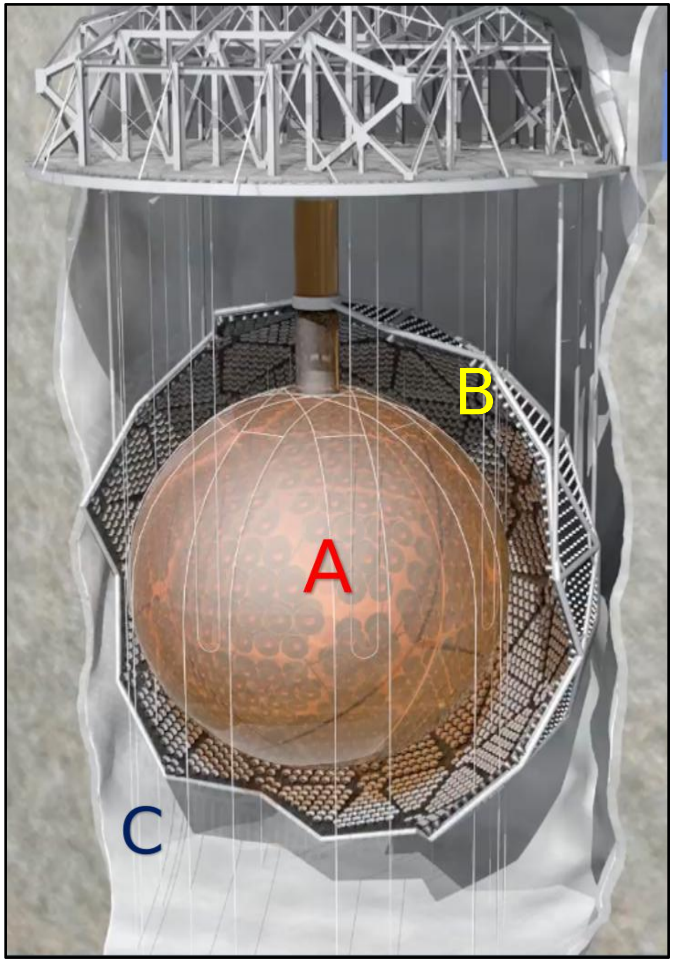
The SNO+ Detector

- Located 6800 ft underground in Creighton Mine
- **A**. 12 m diameter, 5 cm thick acrylic vessel
- **B**. ~9300 PMTs supported by ~18 m geodesic support structure
- **C**. Cavity filled with 7000 tons ultra pure water shield

Three physics phases

- **Water phase:** 905 tons of water (ongoing now)
- **Scintillator phase:** 780 tons of scintillator
- **Double beta decay phase:** loading 3.9 tons of natural tellurium into the scintillator
- **Main physics goal**

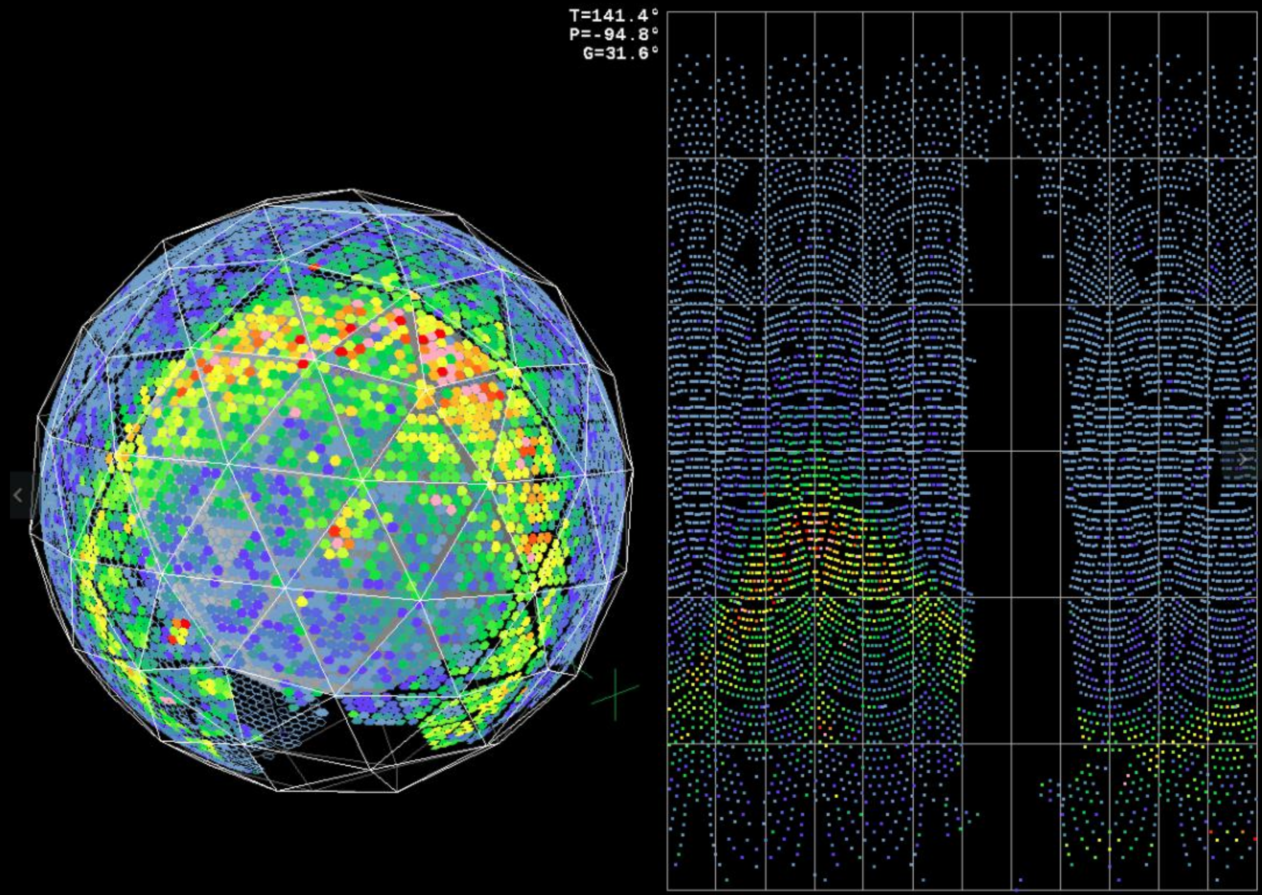
  - Searching for neutrinoless double beta decay in ^{130}Te



Current Status

NOW the detector is on STABLE water data taking

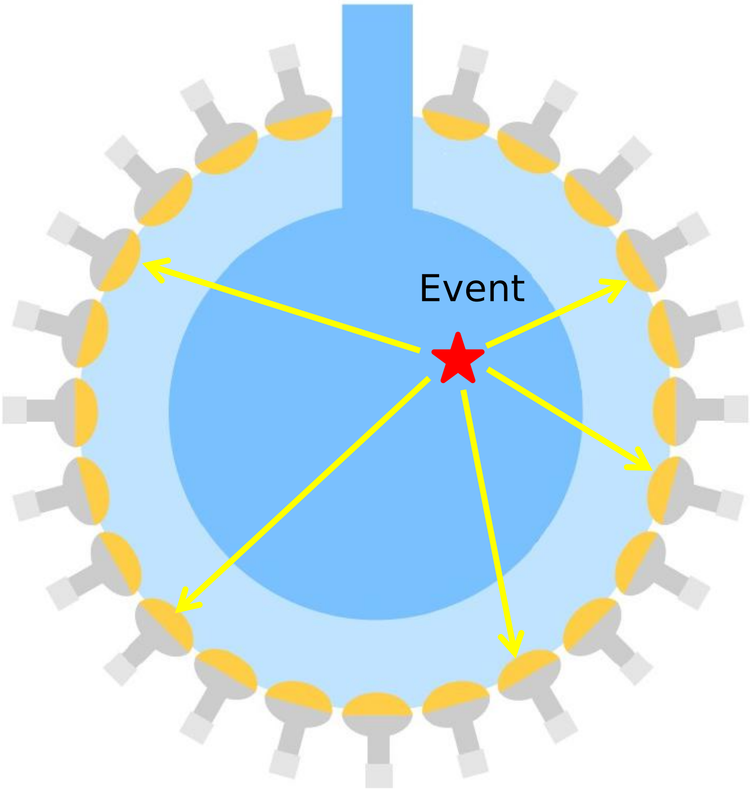
- PHYSICS data are being collected
- Data are being processed



A Muon candidate event

- PMTs in the detector record charge and time information
- Collected charge is used to extract the energy of an event in the detector and time information is useful to get the event position

Reconstruction Algorithm: Position

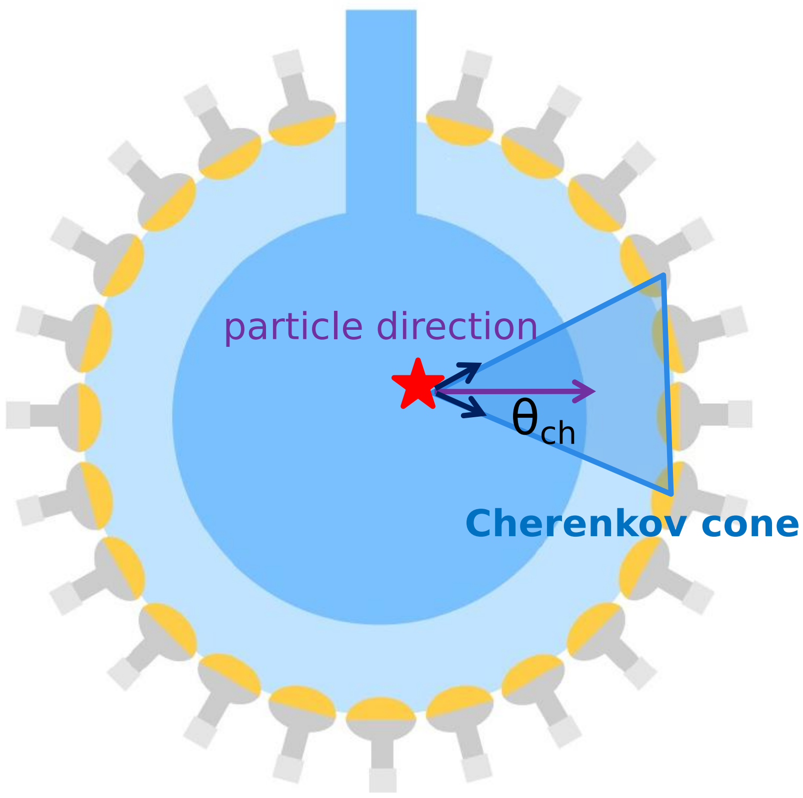


- An event is recorded every time when enough PMTs are triggered
- Hit time and charge are recorded every time in every event
- Position of the event is derived by minimizing the likelihood function using the hit time and positions of the PMTs

$$L = \prod_{i=0}^{\mathrm{Nhit}} P(T_i)$$

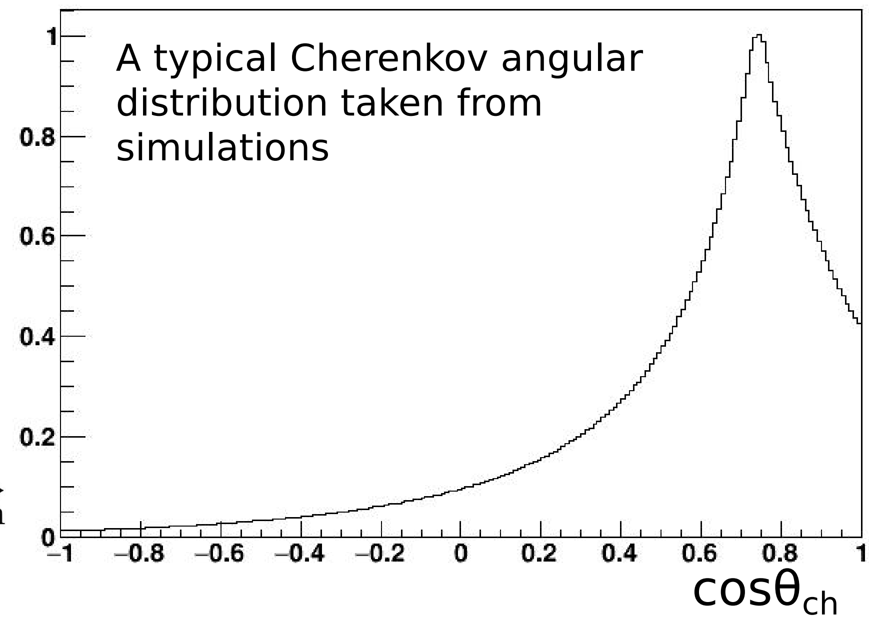
Nhit - the number of triggered PMTs
$\mathbf{T_i}$ - timing parameters for each triggered PMTs

Reconstruction Algorithm: Direction



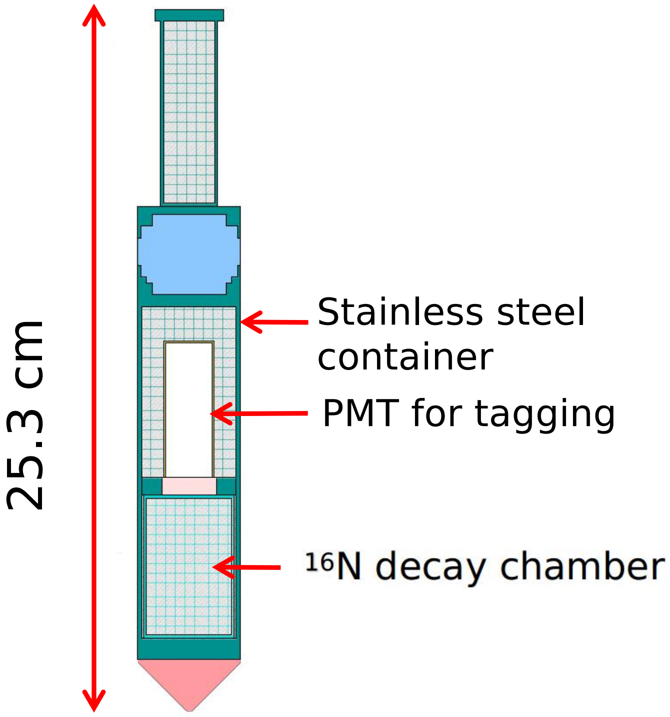
$$\cos\theta_{\mathrm{Ch}} = \overrightarrow{\text{event position} - \text{PMT position}} \cdot \overrightarrow{\text{particle direction}}$$

- In water, $\cos\theta_{ch} \approx 0.74$
- All the PMTs in the Cherenkov ring contribute to the peak of the probability density function

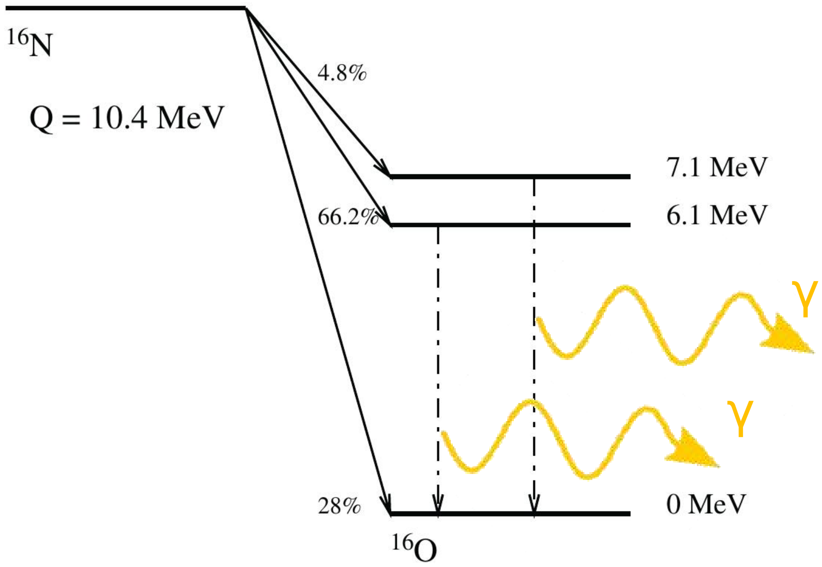


^{16}N Calibration Source

- Inherited from SNO
- Very well understood by SNO
- Using γ-rays from ^{16}N beta decay

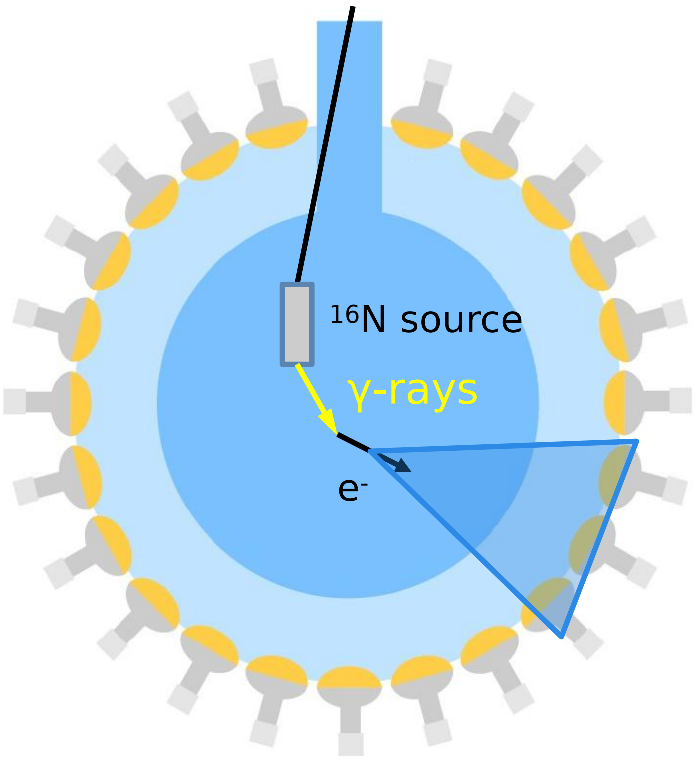


^{16}N beta decay scheme



- Emits **6.13 MeV** (**mostly**) and 7.12 MeV γ-rays
- γ-rays created in the decay chamber can be **tagged** by detecting the accompanied beta particles

^{16}N Source in the Detector

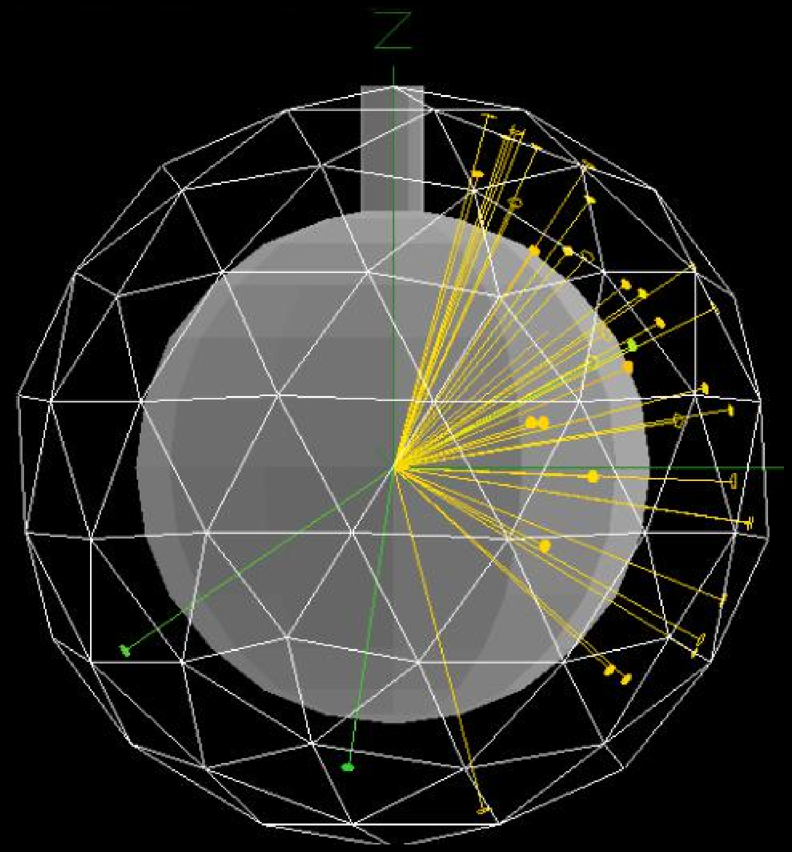


- The ^{16}N source deployed at **known** positions
- γ-rays emitted by the ^{16}N source scatter electrons in the water
- Electrons emit Cherenkov photons while traversing through water
- Photons reaching PMTs trigger the detector

Tagged events can be used to optimize the position and direction reconstruction algorithms

Utilizing SNO Data

- Running SNO+ reconstruction algorithms on SNO heavy water data to compare the performance and resolution with the SNO algorithms
- Using SNO heavy water setups implemented by the SNO+ software package

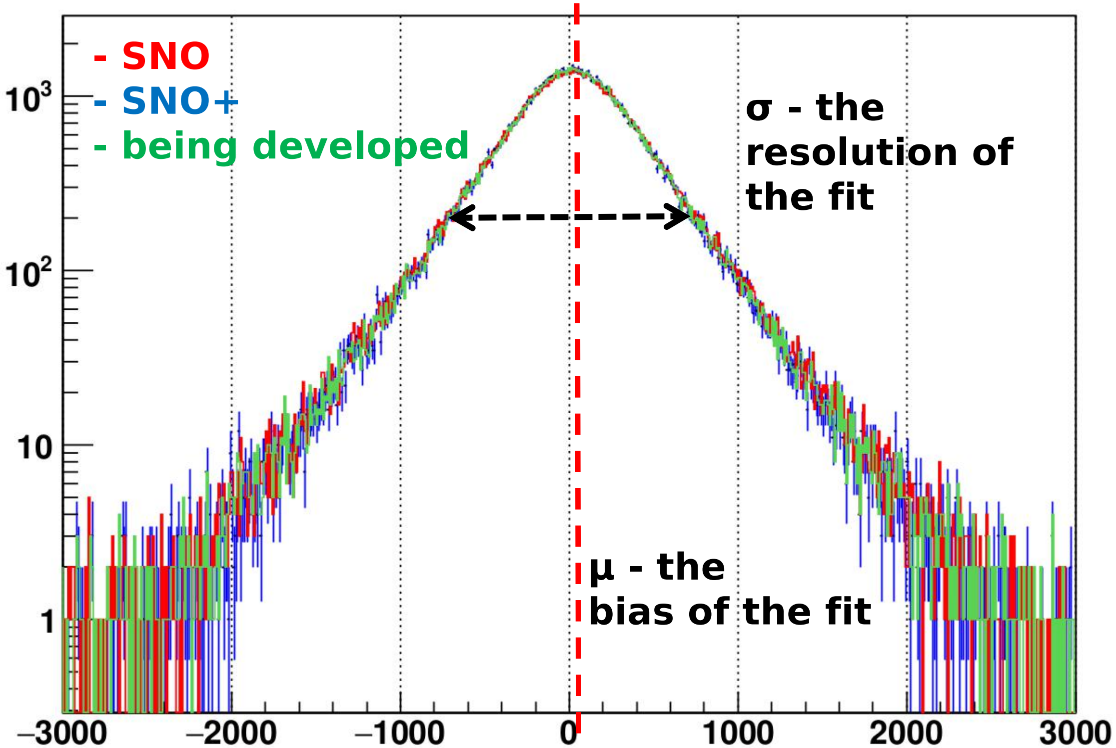


An ^{16}N event in the SNO detector

Position Reconstruction

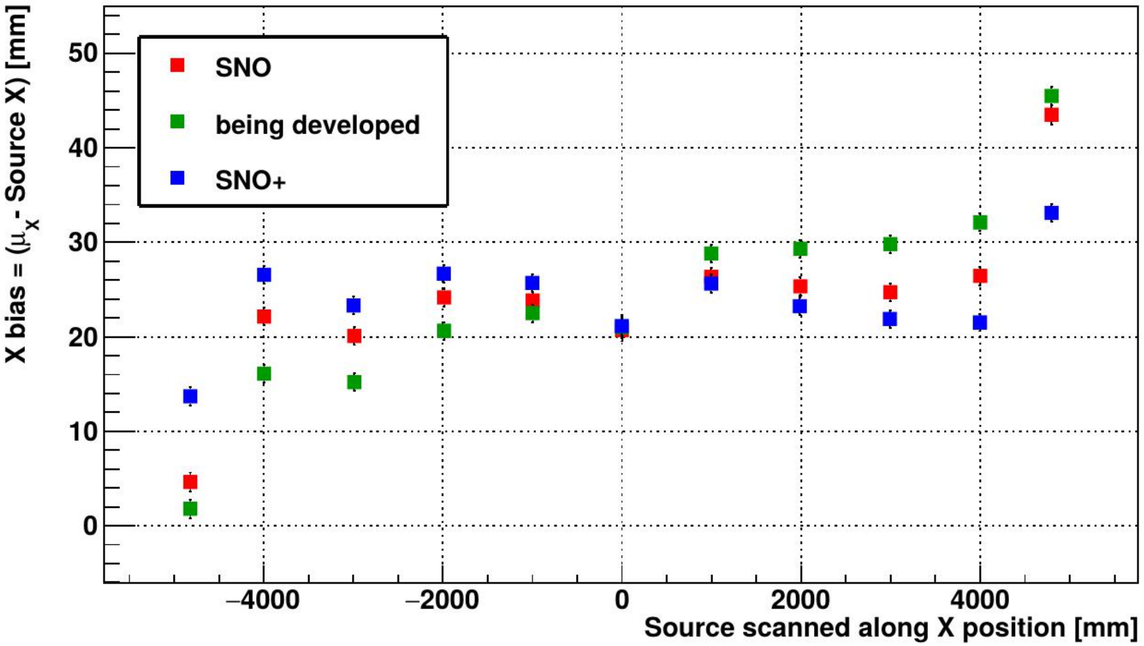
SNO+ algorithms for position and direction reconstruction are compared to the SNO algorithm, particularly in heavy water

- **SNO+ Algorithm** uses detailed light path calculations including refractions; reconstruction speed: ~0.3 s/event
- **New Algorithm (being developed)** similar to the SNO algorithm, uses the straight light path calculation; reconstruction speed: ~0.03 s/event

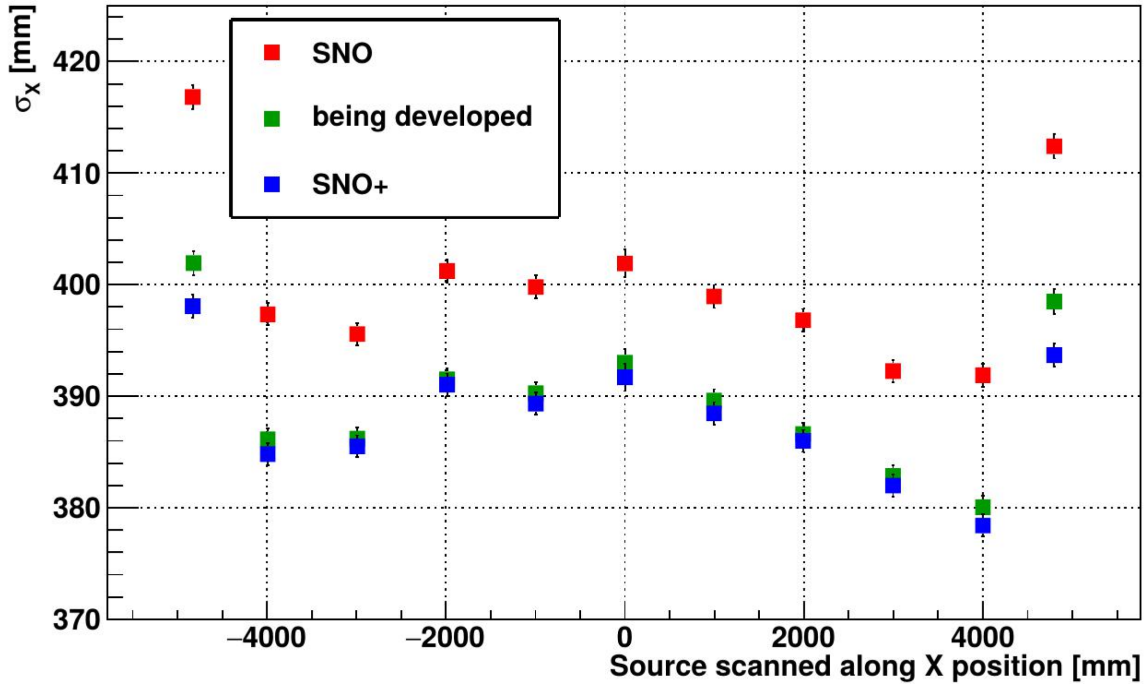


Reconstructed position when the source was deployed at the center

Take 11 runs of SNO data of the source scanned along X



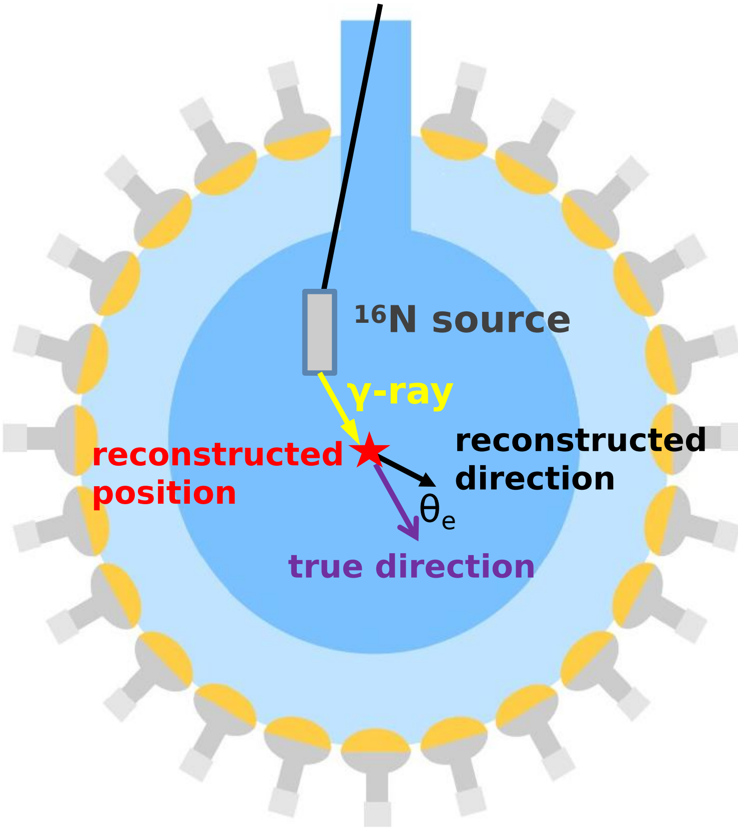
Biases of the reconstructed positions to the actual source deployed positions

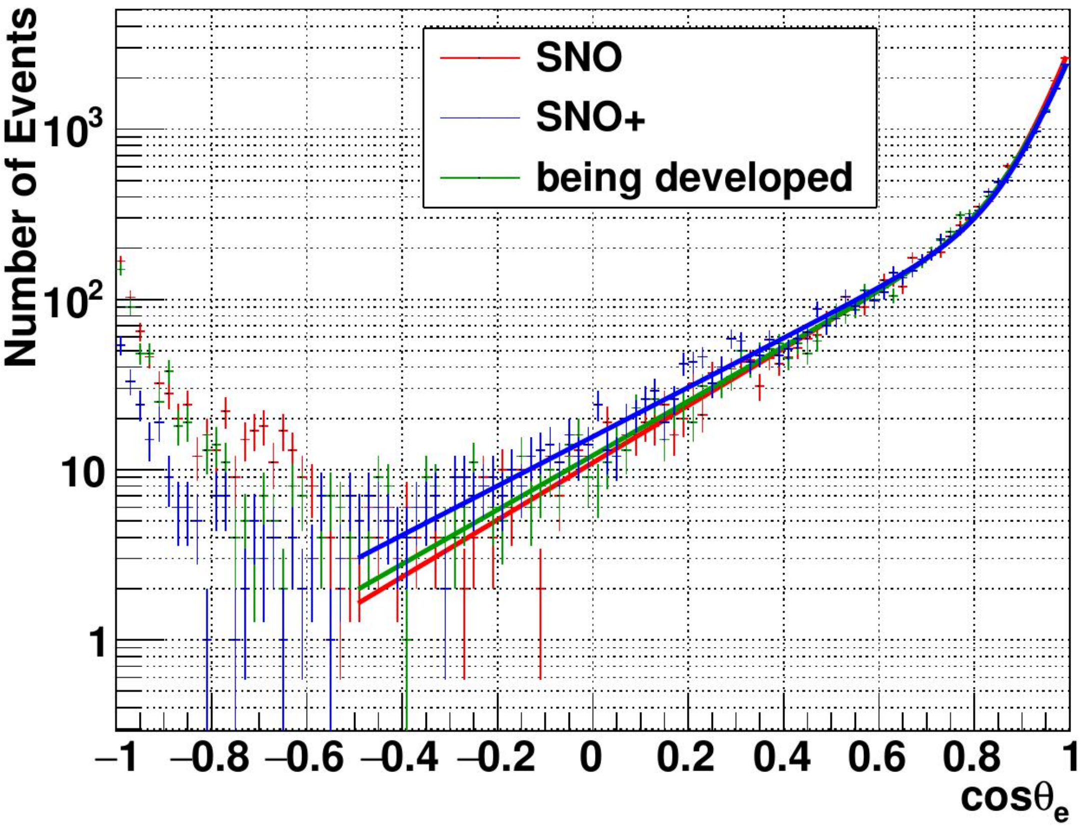


Resolutions of the reconstructed positions

Direction Resolution

Fit with a resolution function to quantify the direction resolution

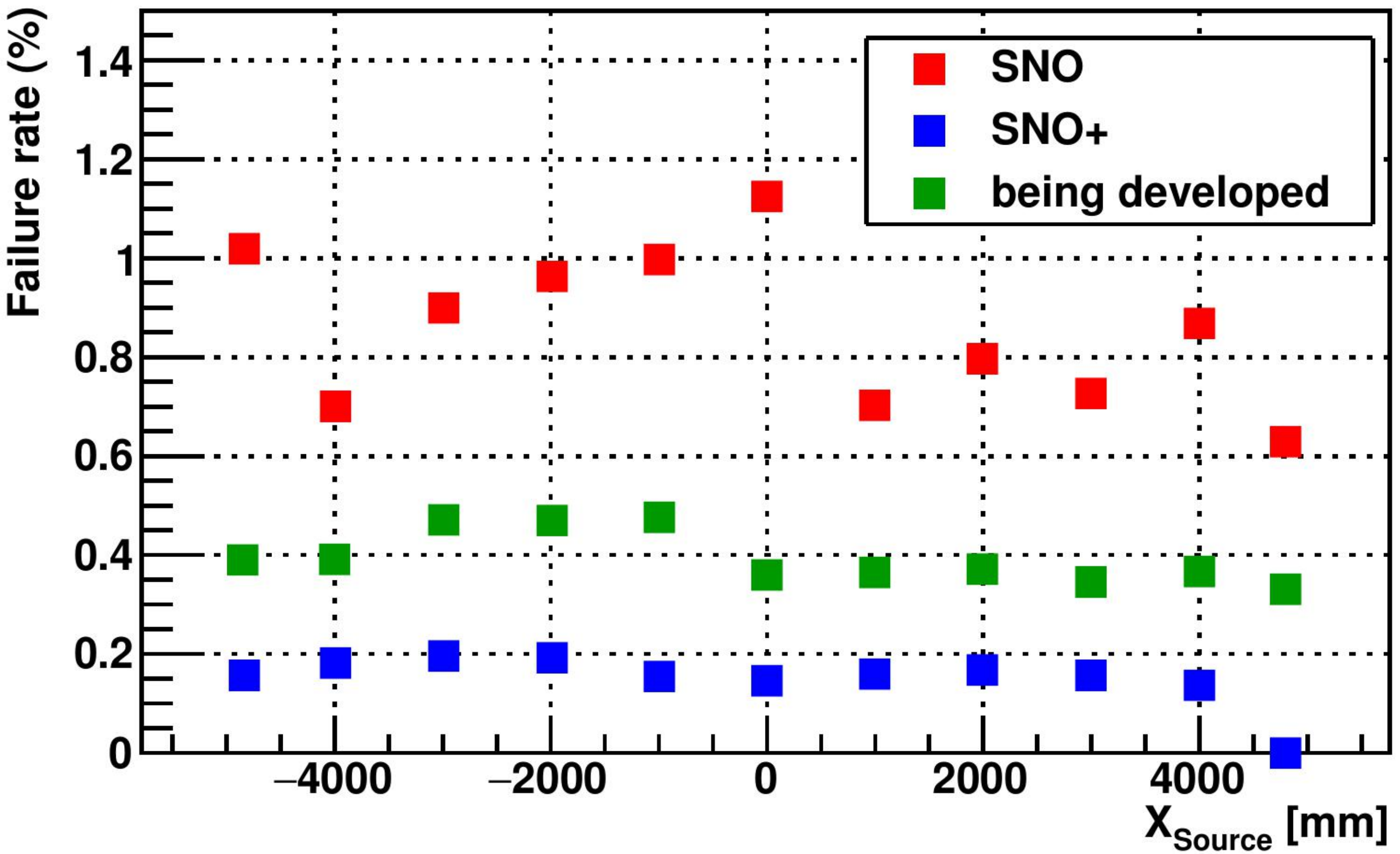




source position at center

Failure Rate of Reconstruction Algorithms

- The algorithms sometime fail to reconstruct events
- Failure rates of all the algorithms are below 2%



Summary

- **Position Reconstruction Algorithm**

  - the SNO+ algorithms have better position resolutions
  - the position biases are comparable to SNO

- **Direction Reconstruction Algorithm**

  - the direction resolutions of the SNO+ algorithms are comparable to SNO

- **Failure Rate**

  - the SNO+ algorithms have **lower** reconstruction failure rates than SNO

The new algorithm is also optimized for the SNO+ light water data.

By running the SNO+ algorithms on the SNO ^{16}N calibration data, the reconstruction performances of the SNO+ algorithms are examined and optimized.

These algorithms are being tested for the **recent** SNO+ ^{16}N calibration runs.

Thank you !

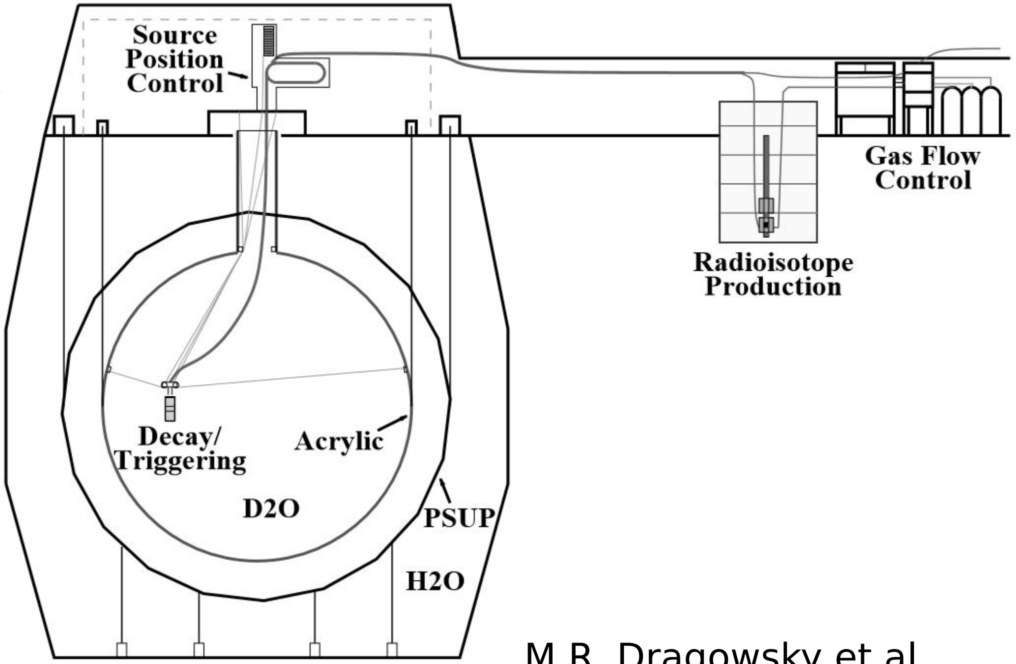
Backup slides

- Deployed in SNO heavy water successfully
- How the ^{16}N is created

DT generator:
deuterium + tritium $\rightarrow$ n + ^{4}He

Flow gas CO_2 stream

^{16}N production:
n + $^{16}O \rightarrow ^{16}N$ + p



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Calibration Sources for the Water-phase SNO+ Detector

- Calibration sources with **known** physics parameters: help to understand the detector response to the events and to make accurate measurements
- Two types of SNO+ calibration sources: optical sources and radioactive sources
- Optical sources: phototube response, optical properties of the detector media
- Radioactive source: energy scale, resolution, systematic uncertainties
- **^{16}N calibration source** is one of the **radioactive sources**