Low-Energy Calibration of the Hyper-Kamiokande Detector Utilizing a Deuterium Tritium Neutron Generator

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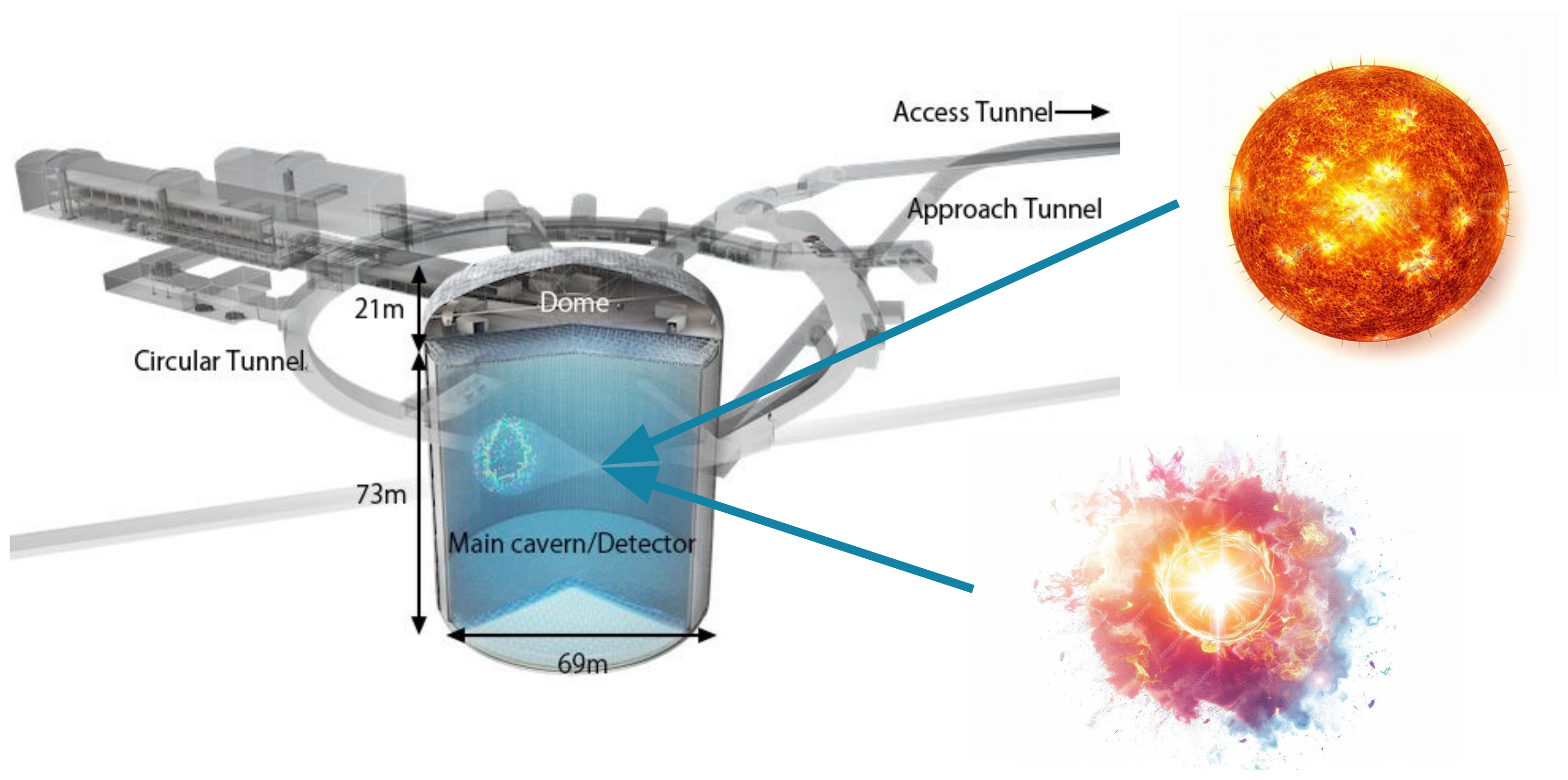
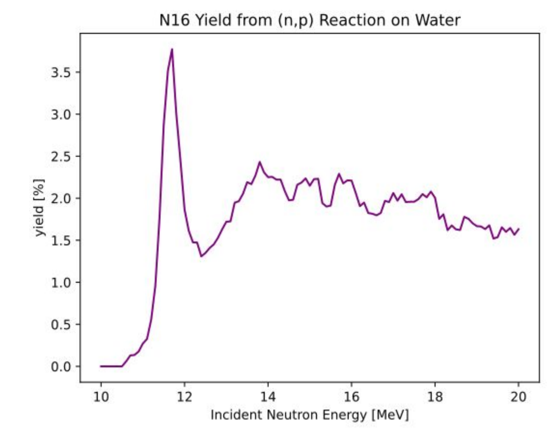
Hyper Kamiokande Experiment (HK)

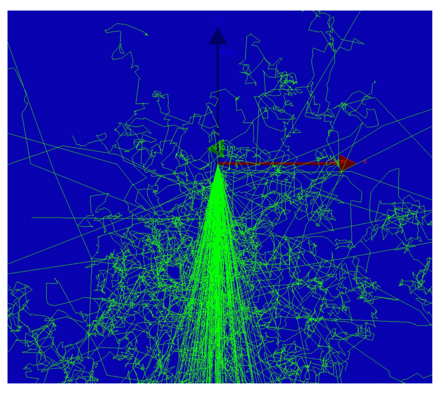


- **Hyper-Kamiokande (HK)** is a next-generation water Cherenkov neutrino detector currently under construction in Japan [1]. With a height of 73m and a diameter of 69m, the cylindrical detector will be the biggest detector of its kind in the world.
- **Broad Detection Range:** HK is designed to detect neutrinos across a broad energy spectrum, ranging from a few MeV to several GeV. This includes low-energy neutrinos such as those from solar and supernova sources, as well as high-energy neutrinos from atmospheric interactions and accelerators.
- **Detector Calibration:** Comprehensive calibration is crucial for the operational monitoring of the HK detector and to meet the systematic goals of the rich physics program.

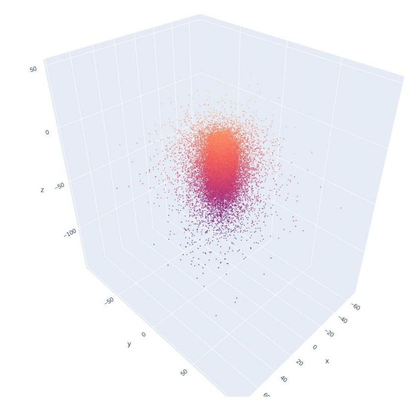
Water Activation Simulation

Water activation by a beam of 14.2MeV neutrons was simulated with GEANT4, and the properties of the generated N16 cloud, such as the yield the spatial distribution, were studied.



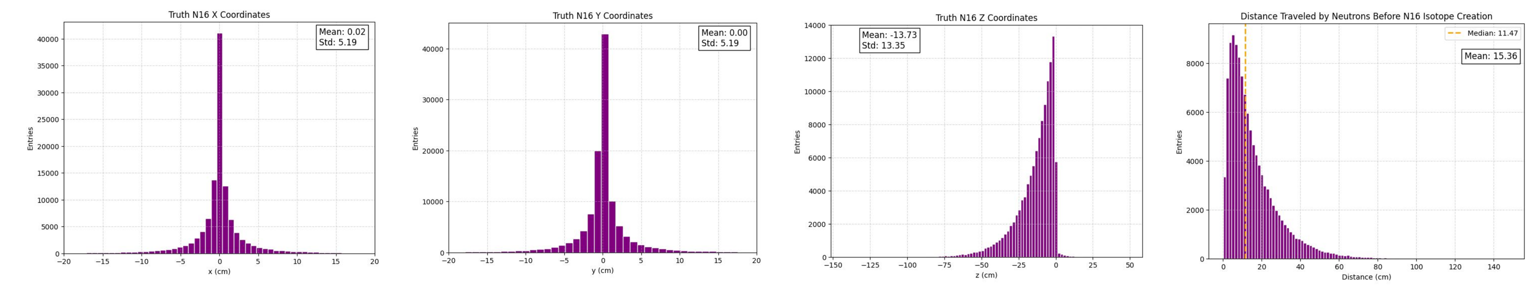


GEANT4 visualization of neutron tracks



visualization of the N16 cloud

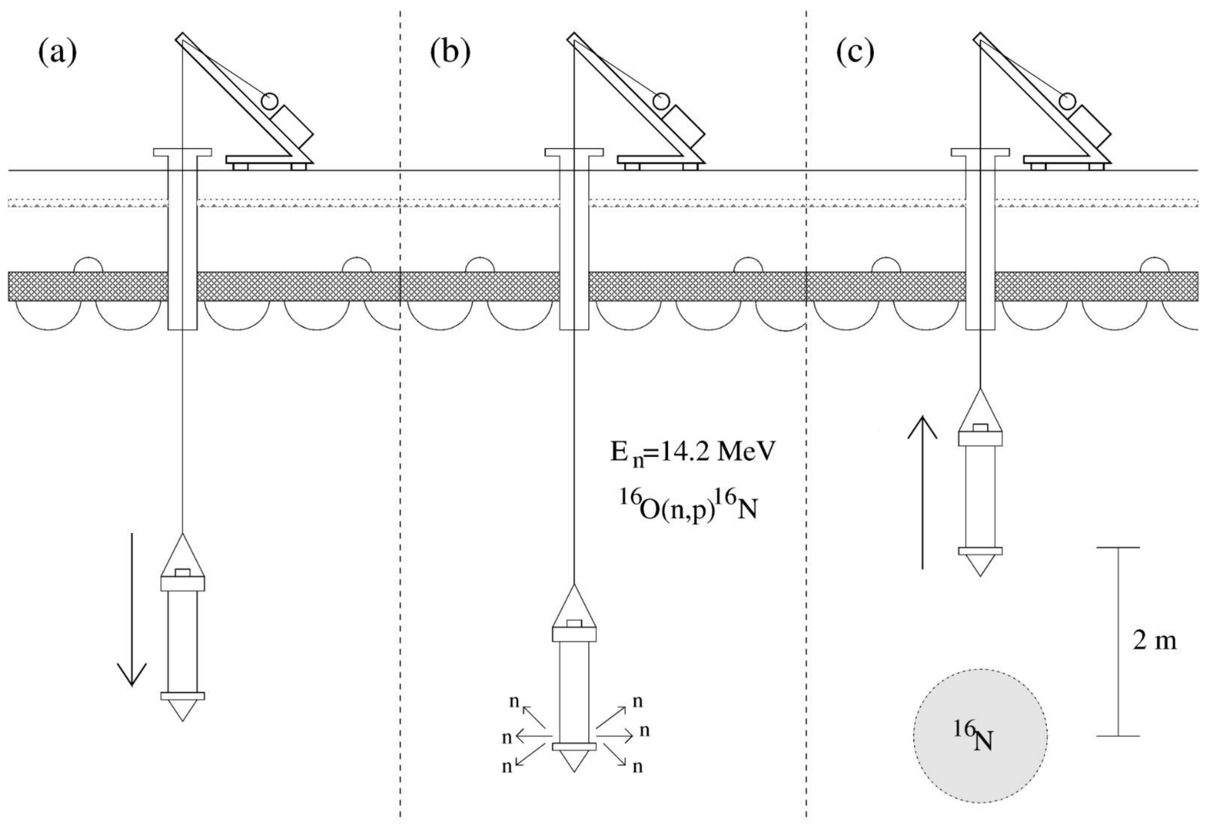
The neutrons beam was oriented downwards as the DT device will be deployed through calibration ports at the top of the water tank, introducing an expected asymmetry in the Z coordinates distribution.



Spatial distribution of the generated N16 isotopes. The mean distance traveled by neutrons before creating an N16 isotope is 15.36 cm, with half of them being created within 11.47 cm from the deployment point

Low-Energy Calibration

Multiple sources will be used periodically for calibrating the energy scale for low energy physics, one of them is Deuterium Tritium (DT) neutron Generator.



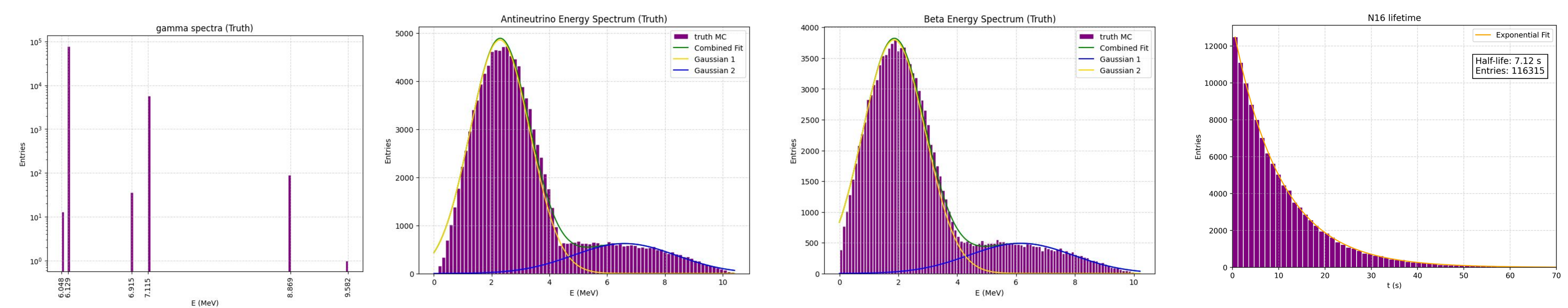
An overview of the DT data taking process [2]

The DT provides multiple advantages compared to the other calibration sources:

- Isotropy: the N16 isotopes beta-decay isotropically.
- Can be deployed closer to the walls.
- Device can be raised above the radioactive cloud before data taking to minimize the shadowing effect.
- Calibration process takes relatively shorter time.

N16 Decay Simulation

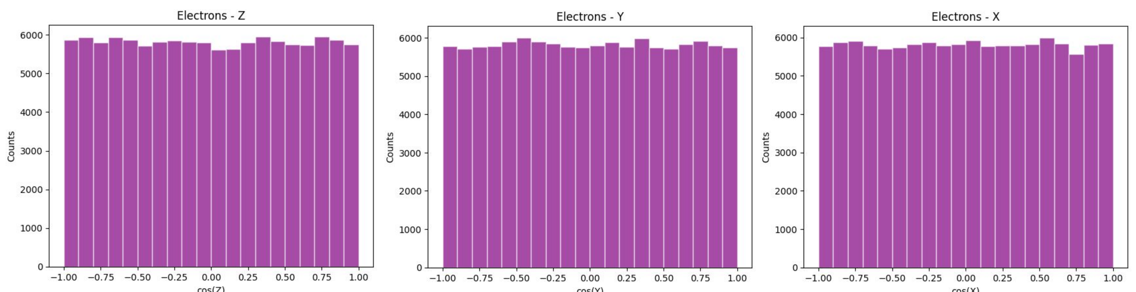
The decay of the N16 radioactive cloud was simulated with GEANT4, and the decay products were studied.



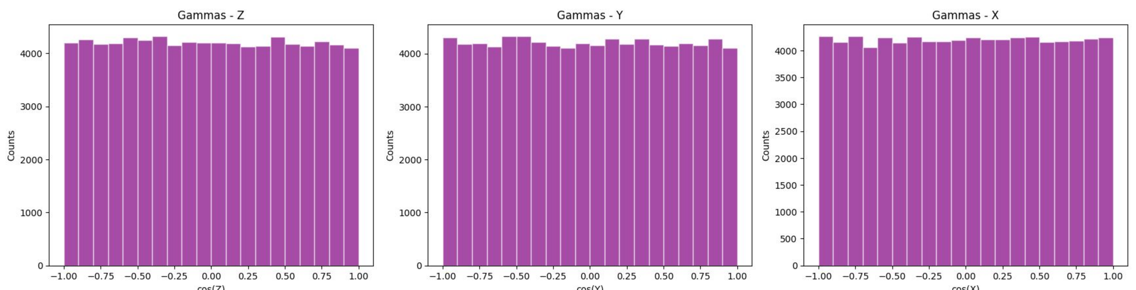
N16 half life, and daughters energy spectra

- N16 half-life and daughters' properties are consistent with literature.
- 67% of N16 will decay into a 6.13-MeV O16* which will be followed by the emission of a gamma.

The isotropy of the decay process was checked.



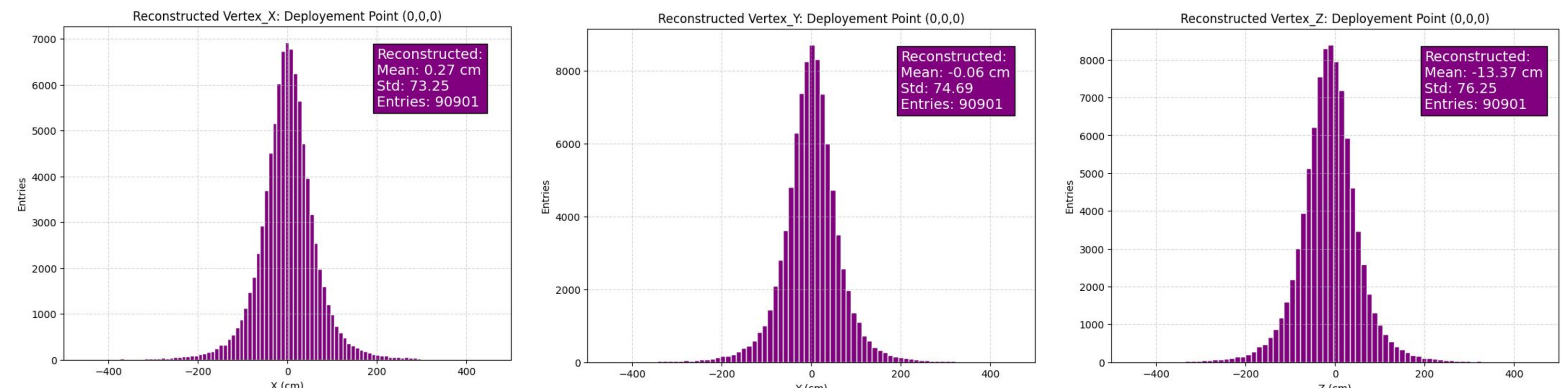
27% of N16 isotopes will decay directly into the ground state of O16, which explains why we have fewer gamma entries than electrons



Orientation of the electrons and gammas

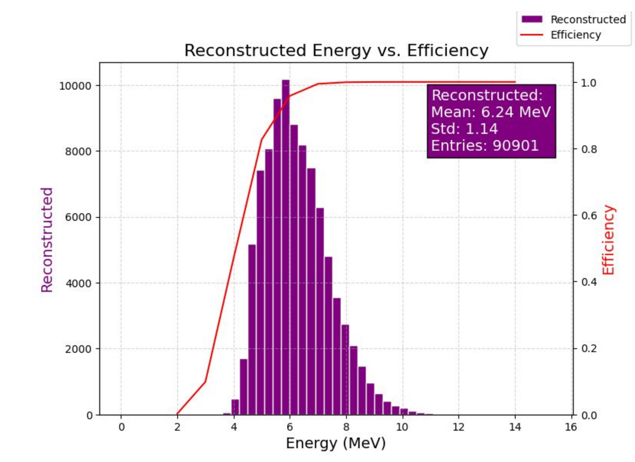
Detector Simulation and Event Reconstruction

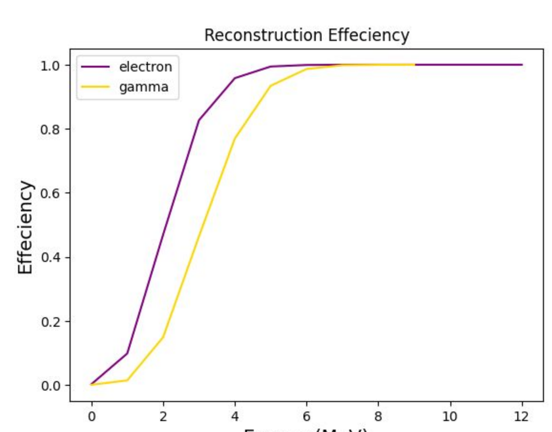
- WCSim is used to simulate events in HK.
- It takes text files in the NUANCE format as input, which include details about our daughter particles and initial conditions.
- WCSim simulates particle propagation and secondary particle production, including Cherenkov photons.
- It registers photon hits on photosensors and applies quantum and collection efficiency.



Reconstructed vertices for the scenario where the DT was deployed at the detector's center.

$$N_{\text{eff}} = \sum_{i}^{N_{50}} \left[(X_i + \varepsilon_{\text{tail}} - \varepsilon_{\text{dark}}) \times \frac{N_{\text{PMT}}}{N_{\text{alive}}} \times \frac{1}{S(\theta_i, \phi_i)} \times \exp\left(\frac{r_i}{\lambda_{\text{eff}}}\right) \times \frac{1}{\text{QE}_i} \right]$$





- Vertex reconstruction is done either by BONSAI or LEAF, depending on the PMT configuration of the detector.
- BONSAI and LEAF generates test vertices and then perform a maximum likelihood fit over all PMT hits in the event.
- BONSAI picks the vertex with four hits combination, while in LEAF it is set by a 3m/12ns grid in space-time [3]

- The energy is reconstructed using the reconstructed vertex and the number of Cherenkov photons produced N_{eff}.
- the relation between the energy and N_{eff} is determined using mono-energetic particles.
- This relation depends on the photo-coverage of the detector. [3]

References

[1] https://arxiv.org/abs/1805.04163 | [2] E. Blaufuss et al. (Super-Kamiokande), Nucl. Instrum. Meth. A458, 638 (2001)| [3] https://www-sk.icrr.u-tokyo.ac.jp/hk/doc/thesis/Jost-thesis.pdf