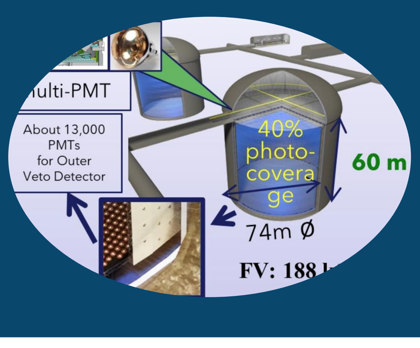
Energy scale cross-calibration of Hyper-Kamiokande detector using Deuterium-Tritium neutron generator



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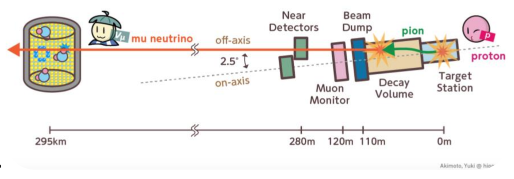
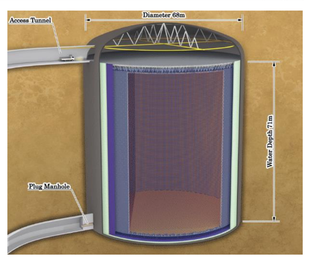
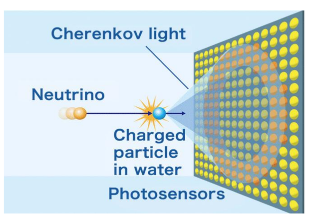
Hyper-K

- Hyper-Kamiokande detector is a next-generation long baseline neutrinos experiment expected to start taking data in 2027
- Deuterium-Tritium neutron generator is used to cross check the energy scale
- DTG overcome some limitations of LINAC, such as isotropy and lower dead time, and lower shadowing effect.





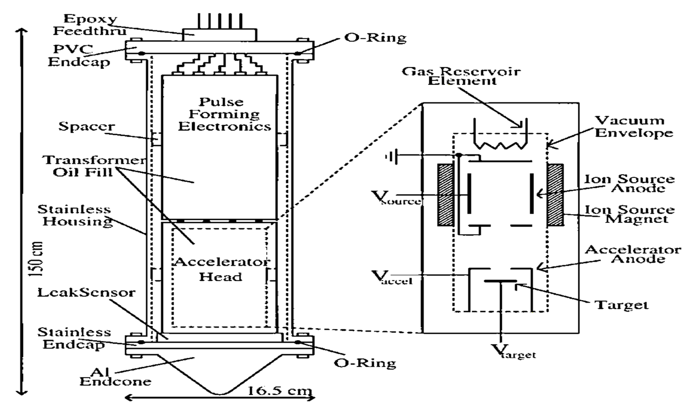


^{16}N is created by a neutron capture on ^{16}O, and used as a source of calibration[1] to be compared with LINAC calibration and combine both results to evaluate the total absolute energy scale.

Deuterium-Tritium neutron generator

The DTG generates neutrons by colliding deuterium and tritium ions with a fixed metal hydride target, containing equal parts of deuterium and tritium.

$$^{2}H + ^{3}H \rightarrow ^{4}He + n$$



The neutron generator can be pulsed at maximum rate of 100 Hz, with each pulse yielding approximately 10^6 neutrons.

DTG deployment

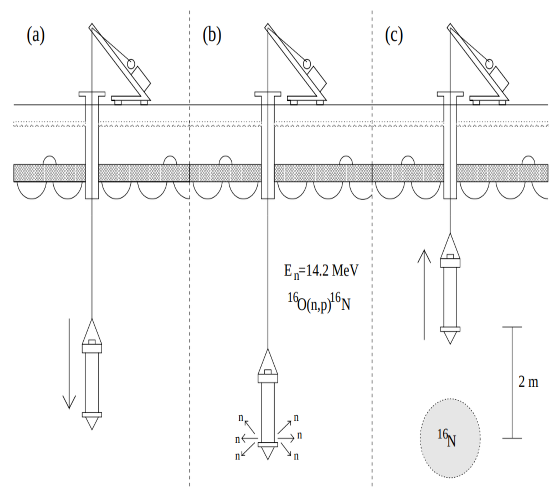
- DTG is a low energy cross calibration system.
- Used to generate an N16 cloud inside the inner detector:

$$^{16}_{8}O + ^{1}_{0}n \rightarrow ^{1}_{0}n + ^{16}_{7}N$$

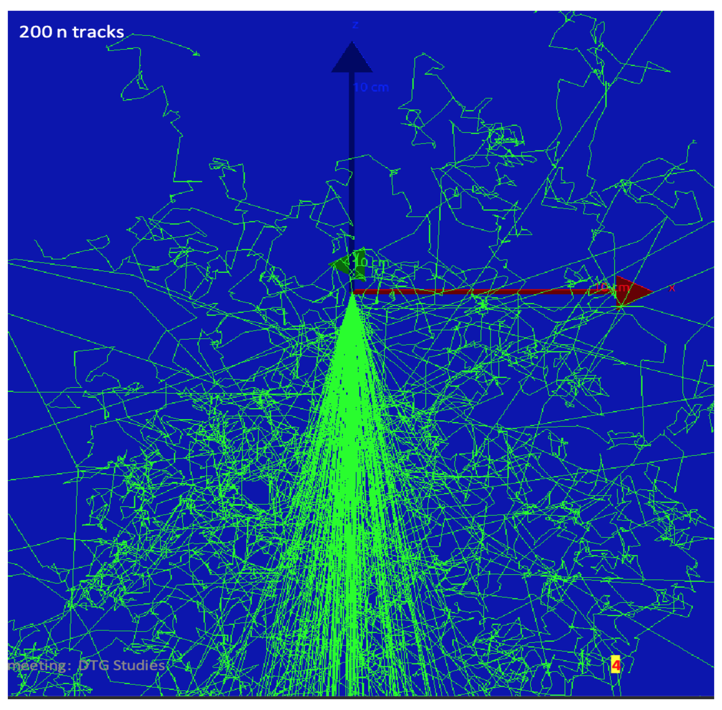
- This N16 cloud beta decays isotopically:

$$^{16}N \rightarrow ^{16}O^{*} + \overline{\nu} + e$$

- DTG device will be deployed through several calibration ports into different depths per port.
- After firing the neutrons, the device will be raised above the source before data taking to minimize shadowing effect.



Neutron activation simulation[1]



Visualization of generated neutron tracks in water

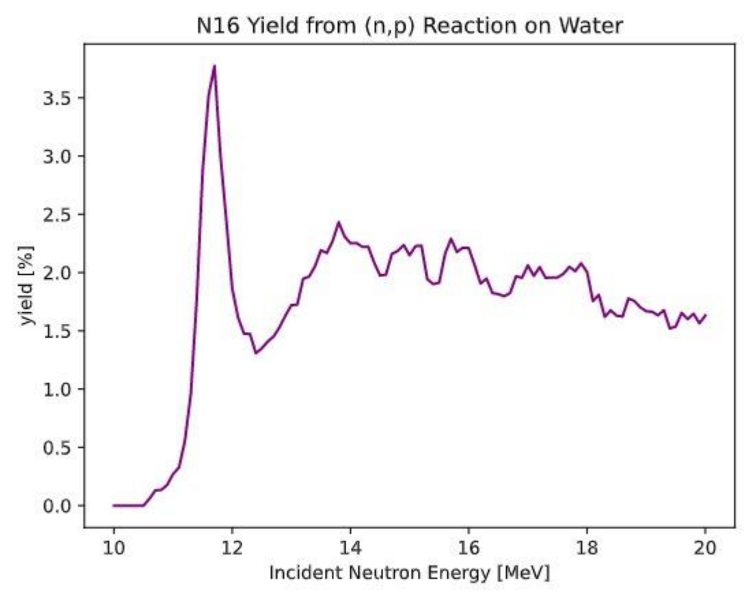
- GEANT4 simulation of a 4x4x4 m³ box of water
- Number of simulated neutrons: 5M
- Neutrons energy: 14.2 MeV
- Orientation: at the origin (0,0,0) directed towards -Z axis with an opening angle of 15 degrees.

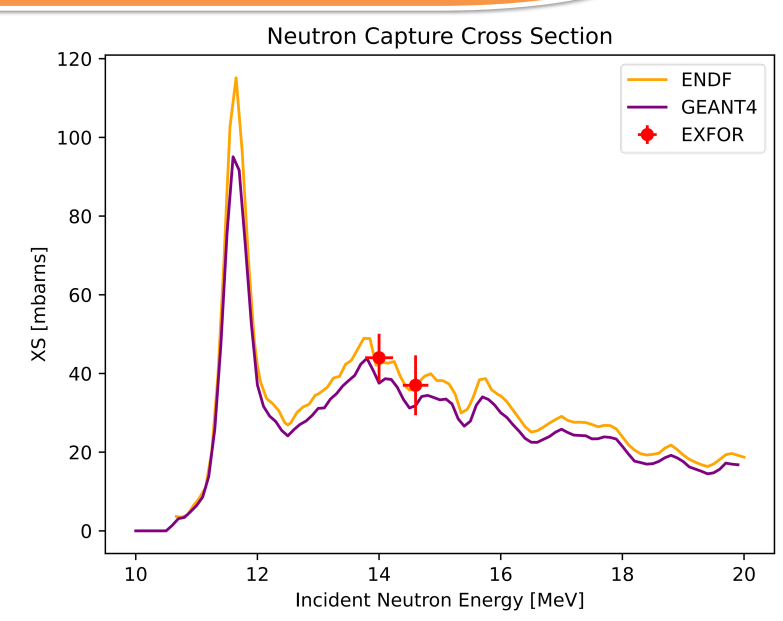
expected ^{16}N yield is 2.3%, while Super-K[1] results found 1.3% and 1% observed in their data.

$$\sigma_{tot} = \sigma_{inelastic} + \sigma_{elastic} + \sigma_{capture}$$

$$N^{16}{}_{yield}[\%] = \frac{n_{N16}}{n_{neutrons}} \times 100$$

^{16}N yield[%] and total cross section

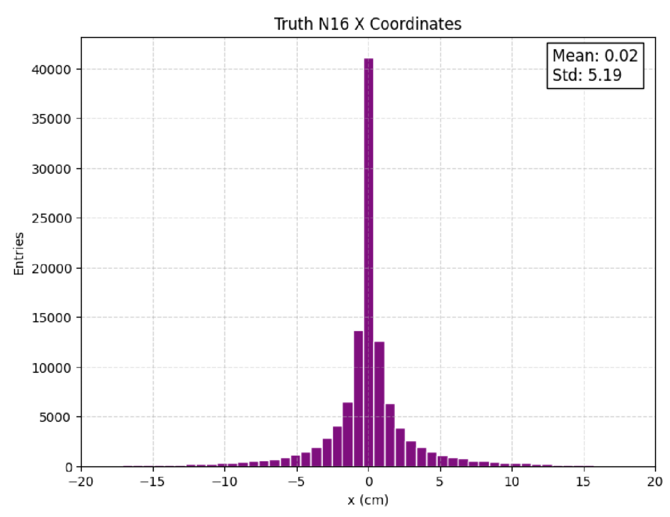


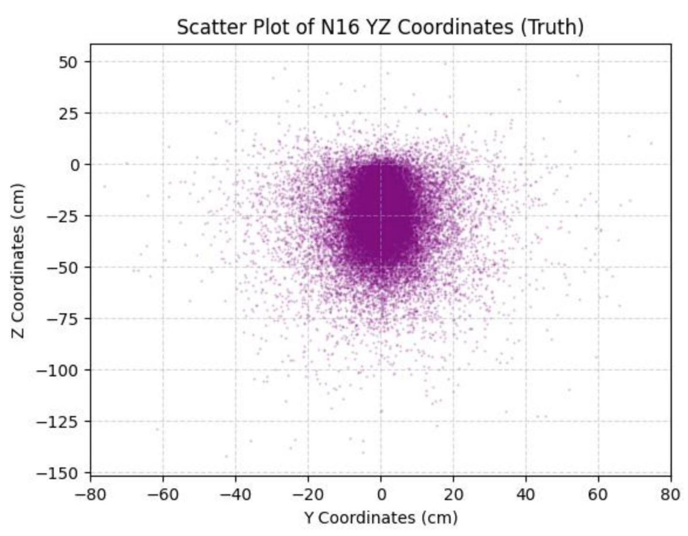


Capture cross section on ^{16}O on agreement with ITER measaurement[2]

Preliminary results: ^{16}N MC truth position

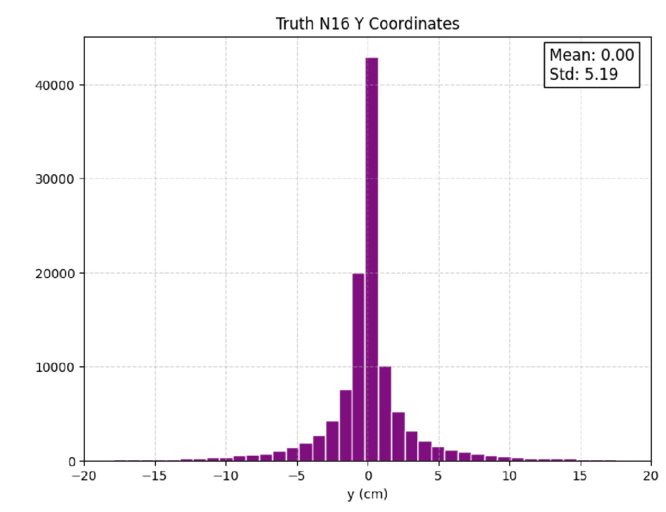
WCSim[4] :^{16}N x and y, z positions, the neutrons were directed towards –z

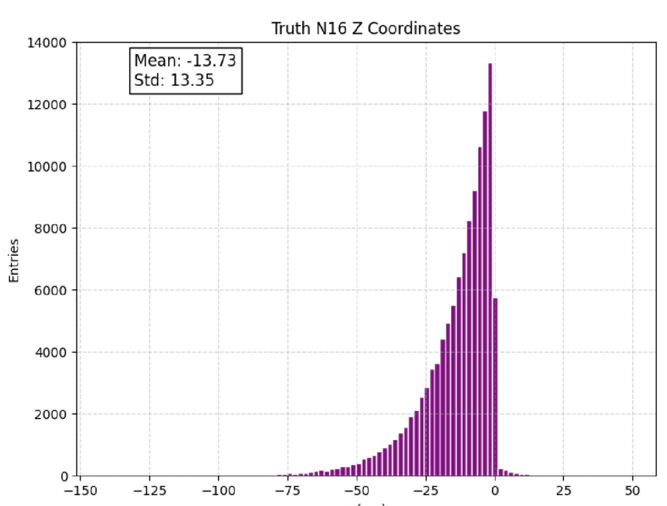




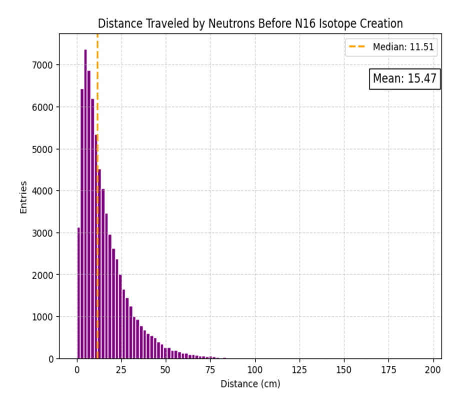
^{16}N samples are used as input for WCSim[4] toolkit

The decay product is propagated throughout the detector Volume



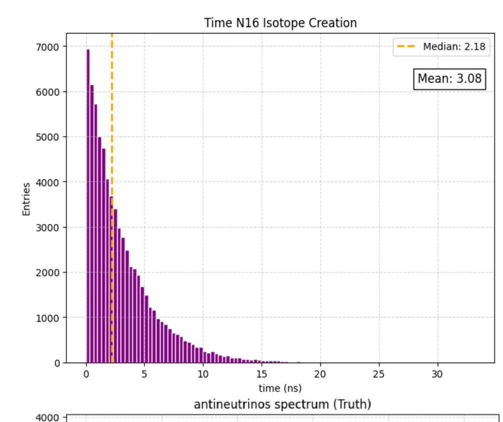


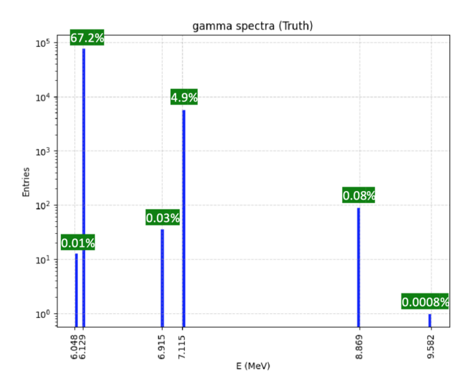
Preliminary results: ^{16}N properties



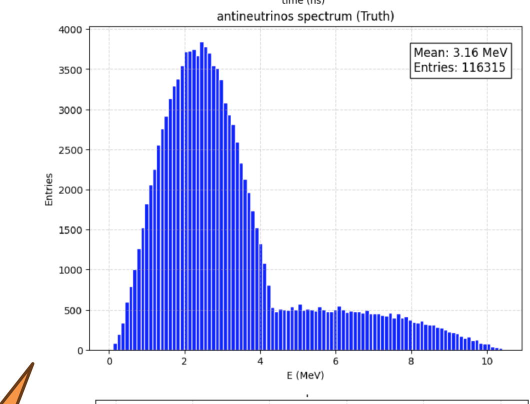
The mean distance traveled by neutrons before ^{16}N creation is 15.47 cm

Mean time before ^{16}N creation is 3.08 ns





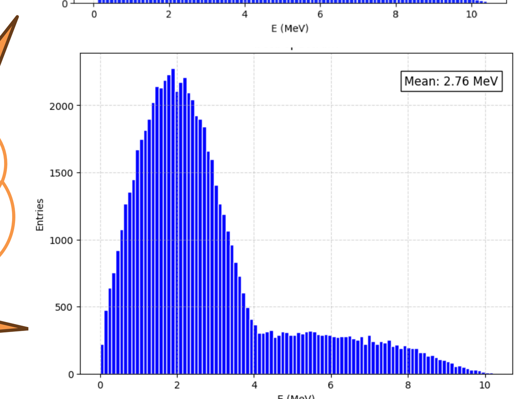
27.7% of ^{16}N will decay directly to the ground state of ^{16}O. The 6.129 MeV gamma ray is dominant with a fraction of 67.2%.



Fraction	$J_i^p \rightarrow J_f^p$	ΔI	Gamma Energy (MeV)
66.2%	$2^- \rightarrow 3^-$	+1	6.129
28.0%	$2^- \rightarrow 0^+$	-2	none
4.8%	$2^- \rightarrow 1^-$	+1	7.116
1.06%	$2^- \rightarrow 2^-$	+0	8.872
0.012%	$2^- \rightarrow 0^+$	-2	6.049
0.0012%	$2^- \rightarrow 1^-$	+1	9.585

Consistent with Super-K[1] results

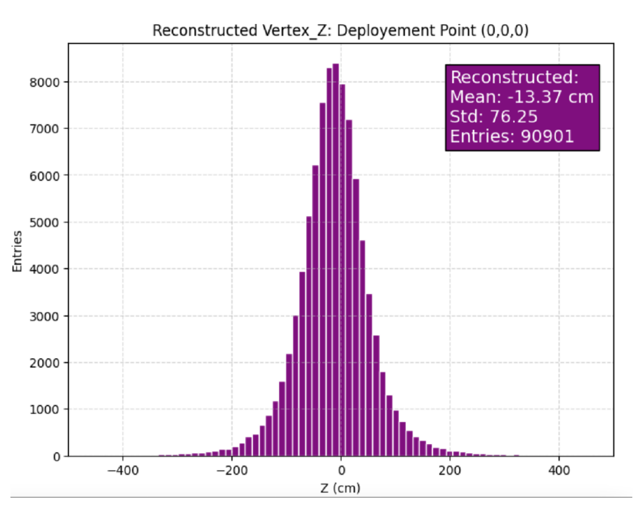
^{16}N beta decays plus a gamma particle coming from ^{16}O dexcitation
$^{16}N \rightarrow ^{16}O + e^- + \bar{\nu}_e + \gamma$

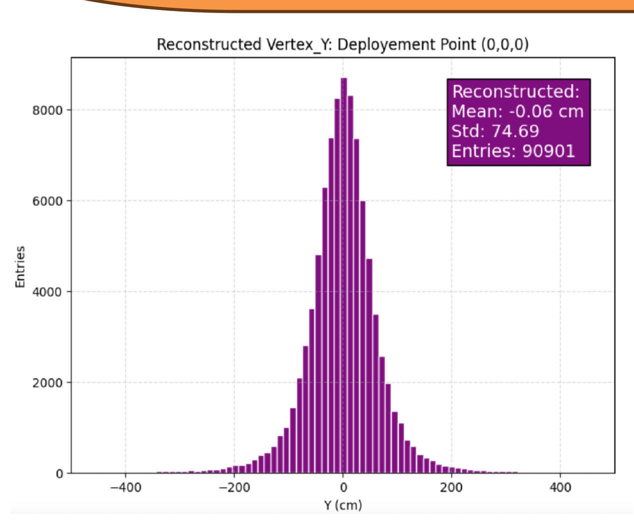


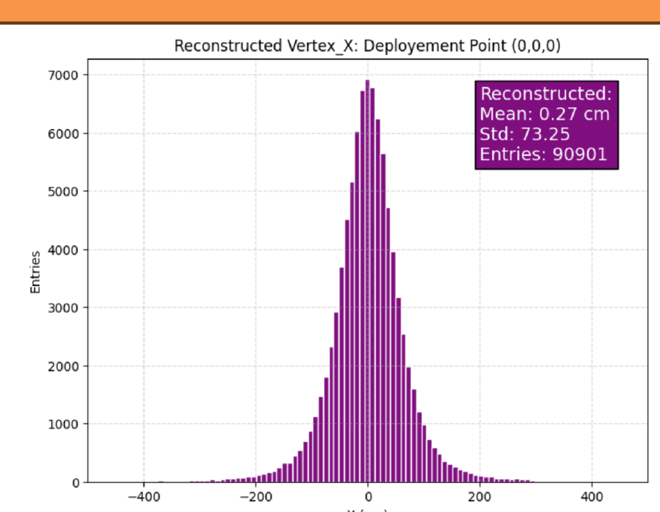
Electron energy is less than 4.3 MeV

Preliminary results: Reconstructed vertex and energy

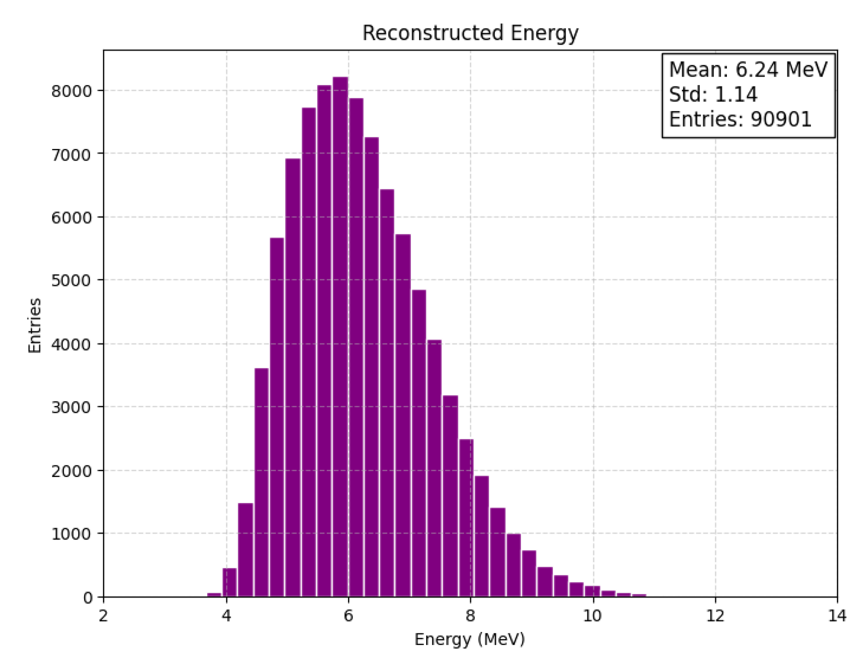
BONSAI[4] recconstruted vertex, and FLOWER[4] reconstructed energy







- The peak of energy is around 6 MeV which corresponds to the dominant gamma ray.
- Above a certain threshold (between 5 and 6 MeV), the shape of the energy spectrum can be fit with a Gaussian.
- At lower energies, the distribution appears to be affected by a cut in the shape due to detector's efficiency.



Reconstructed mean values are close to truth mean values, 0.02 cm, 0 cm, and −13.73 cm for truth mean vtx_x, vtx_y, and vtx_z respectively. However, a wider distribution spread due to the resolution of the detector is observed, where $\frac{\sigma_{reco}}{\sigma_{truth}}$ is around 14

Conclusions

- Preliminary results indicates that the water activation simulation and ^{16}N decay have been achieved, In particular, our ^{16}N yield appears to be higher when compared to previous Super-K[1] result.
- The reconstructed energy is dominated by 6.1 MeV gammas in coincidence with 4.3 MeV electron endpoint energy
- Next step is to reproduce the SK[1] results, adapt the simulation to HK environment, and identify a calibration strategy for deployment locations.

References

[1] Super-K collaboration: ^{16}N as a calibration source for Super-Kamiokande : https://doi.org/10.1016/S0168-9002(00)00900-1

[2] M.Pillon: Measurement of the $^{16,17}O(n,p)^{16,17}N$ cross sections for validating the water activation experiment for ITER at the Frascati neutron generator: https://doi.org/10.1016/j.nima.2021.165107

[3] J.k.Bienlein: the half life of ^{16}N: https://doi.org/10.1016/0029-5582(64)90202-0

[4] HK software: **W**ater **C**herenkov **S**imulation built on top of Geant4; BONSAI and FLOWER are reconstruction algorithms : https://github.com/WCSim/WCSim

higgstan.com: https://higgstan.com