

Neutrino reconstruction and oscillation analysis with neutron detection in SK-Gd

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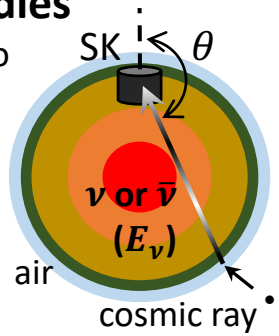
Abstract

We developed a new atmospheric neutrino reconstruction algorithm using the capture vertex information of the neutrons originating from neutrino reaction. Neutrino resolution is improved from 57.2° to 51.2° in direction and from 38% to 32% in energy. With the new method, expected event excess is now concentrated in fewer bins, and physics sensitivities are slightly improved.

1. Atmospheric Neutrino Studies

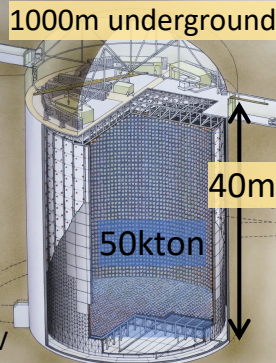
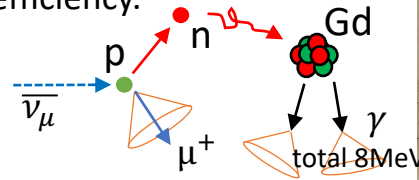
- Atmospheric neutrino is sensitive to mass ordering, δ_{CP} , and θ_{23} .
- Oscillation probability depends on E_ν and flying distance.

$\rightarrow E_\nu$ and \vec{d}_ν resolutions are important.



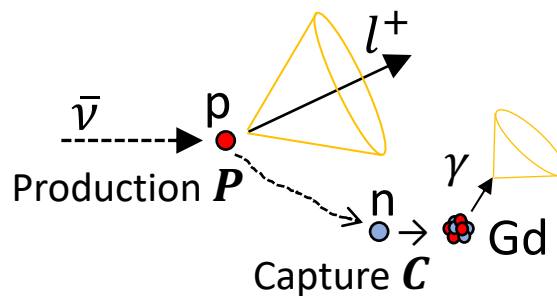
2. Super-Kamiokande(SK) and SK-Gd

- SK is a 50-kton water-Cherenkov detector.
- Doped with Gadolinium(Gd) since 2020 to enhance neutron efficiency.
- With 0.01% Gd in 2020-2022, neutron efficiency $\sim 50\%$.



3. Neutrino reconstruction with neutron vertex

- In previous oscillation analysis in SK, observed charged leptons are compared with MC.
- We aim to reconstruct E_ν and \vec{d}_ν by correcting neutron momentum estimated from its displacement.
- The algorithm is developed and tested only in MC for now.



$$\vec{p}_n \propto \vec{PC} ?$$

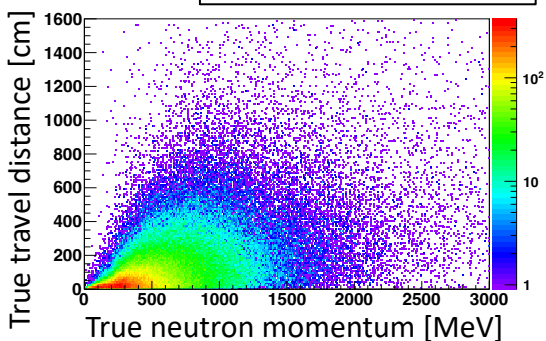
Capture vertex resolution got better with Gd!

Neutron momentum

- Estimate p_n from $|\vec{PC}|$.
- Model the correlation with liner function.

$$p_n = a \times |\vec{PC}|$$

if $p_n > u$, $p_n = u$

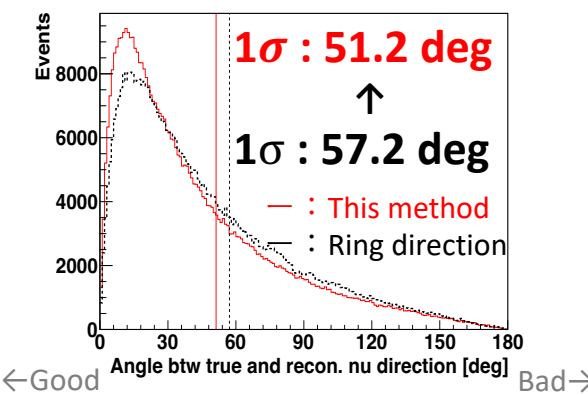


Neutrino reconstruction

- Parameters a, u are optimized to get best ν resolution in atmospheric 1-ring events.

Direction

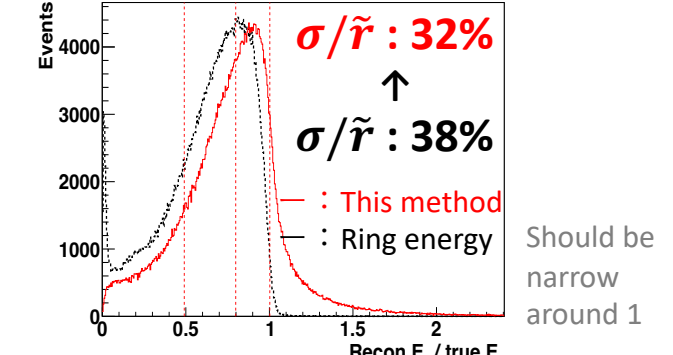
Reconstruct as $\vec{p}_\nu = \vec{p}_l + \vec{p}_n$ and minimize σ (=width of opening angle)



Energy

Reconstruct as $E_\nu = E_l + K_n$ (\vec{d}_n not used) and minimize σ/\tilde{r}

(\tilde{r} : median, σ : 68% width of E_{recon}/E_{true}).

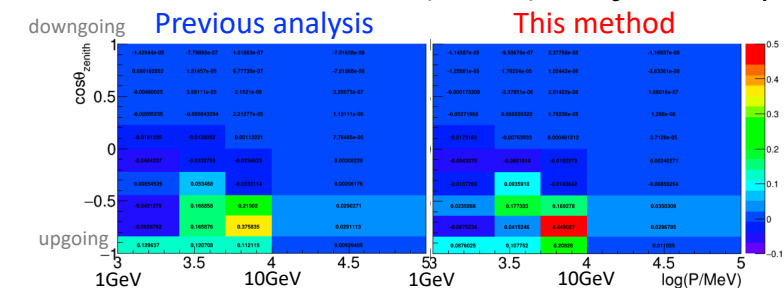


Should be narrow around 1

4. Effect on physics sensitivity

- In oscillation analysis in SK, # of observed events are compared with MC in 16 samples, divided in momentum, cos zenith bins.

Difference in # of events (IO-NO) in $\bar{\nu}_e$ -like sample



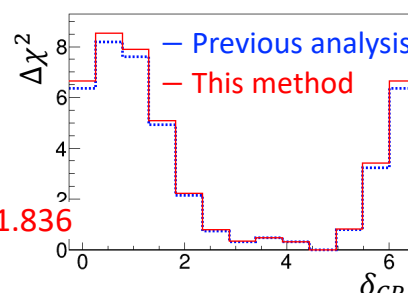
Expected event excess is now concentrated in fewer bins.

Sensitivity with 10-year SK-Gd:

- With Fully-contained events.
- No systematic errors.
- Assume 100% neutron efficiency + complete neutron vertex resolution in ν reconstruction.

Mass ordering determination $\Delta\chi^2 = 1.803$ vs 1.836

Effect on sensitivity is limited for now.



5. Summary and Prospects

- With a new neutrino reconstruction algorithm using neutron vertex, neutrino resolution is improved from 57.2° to 51.2° in direction and from 38% to 32% in energy in 1-ring events.
- # of events changed in an expected way, and physics sensitivities are slightly improved.
- Neutron vertex may also be useful in sample definition.
- T2K events can be used to test the algorithm.