Atmospheric neutrino oscillation analysis with neutron detection in SK-Gd

Shintaro Miki (Kamioka Obs., ICRR) smiki@km.icrr.u-tokyo.ac.jp

#112

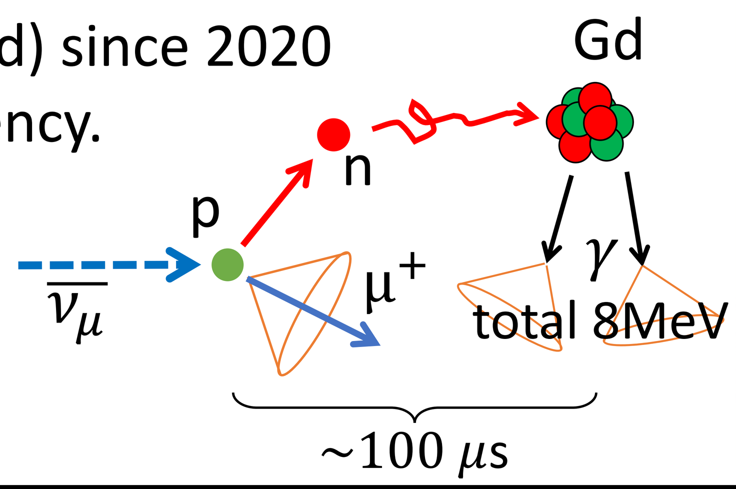
Abstract

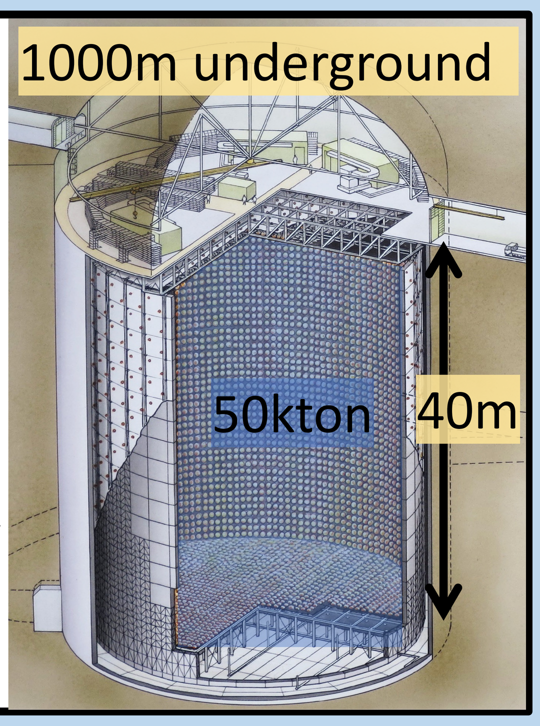
In atmospheric neutrino oscillation analysis, aiming mainly at mass ordering determination, neutron information available in SK-Gd improves $\nu/\bar{\nu}$ discrimination capability. Resolutions of energy and direction are also improved by accounting for more information carried by the hadronic system. Both improvements contribute to sensitivities to mass ordering. Data - MC consistency has been confirmed and data fit is ongoing.

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

- SK is a 50-kton water-Cherenkov detector.
- Doped with Gadolinium(Gd) since 2020 to enhance neutron efficiency.

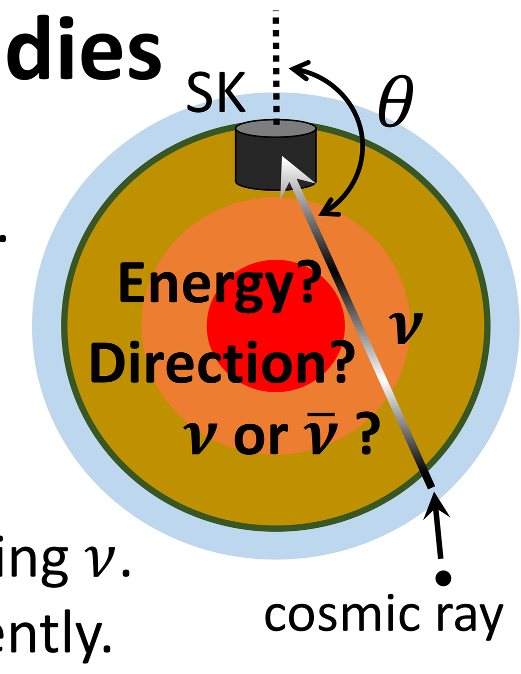
SK5: No Gd, ~25% eff. → (2020) SK6: 0.01% Gd, ~50% eff. → (2022) SK7: 0.03% Gd, ~65% eff.





2. Atmospheric neutrino studies

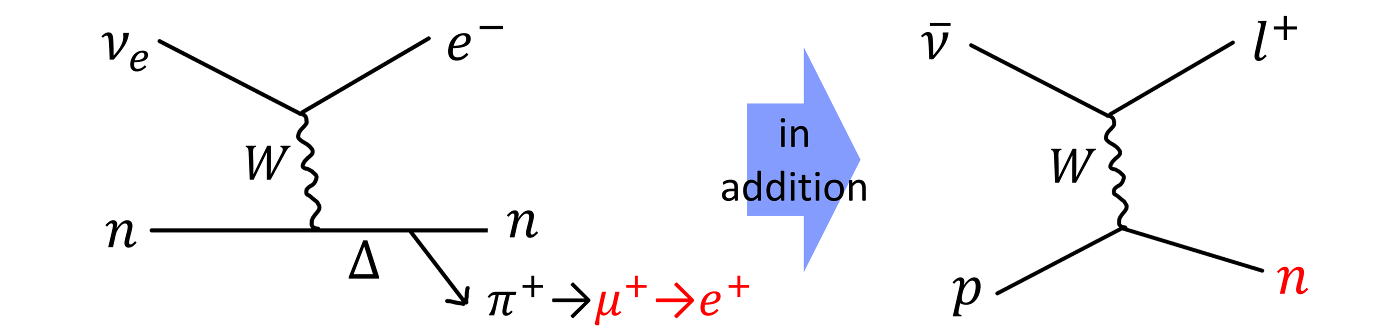
- Atmospheric neutrino is sensitive to mass ordering (MO), δ_{CP}, Δm^2_{32}, and θ_{23}. MO will limit lepton flavor mixing model.
- Observing how ν oscillates in earth core is important to determine MO.
- E_ν and $\vec{d_\nu}$ resolutions : To see core-crossing ν. $\nu/\bar{\nu}$ discrimination : They oscillate differently.



3. How are neutrons useful in atmospheric neutrino analysis?

① $\nu/\bar{\nu}$ discrimination

- Without neutron tag: ν-like if **decay-e** is tagged.
- With neutron tag : $\bar{\nu}$-like if **neutron** is tagged.

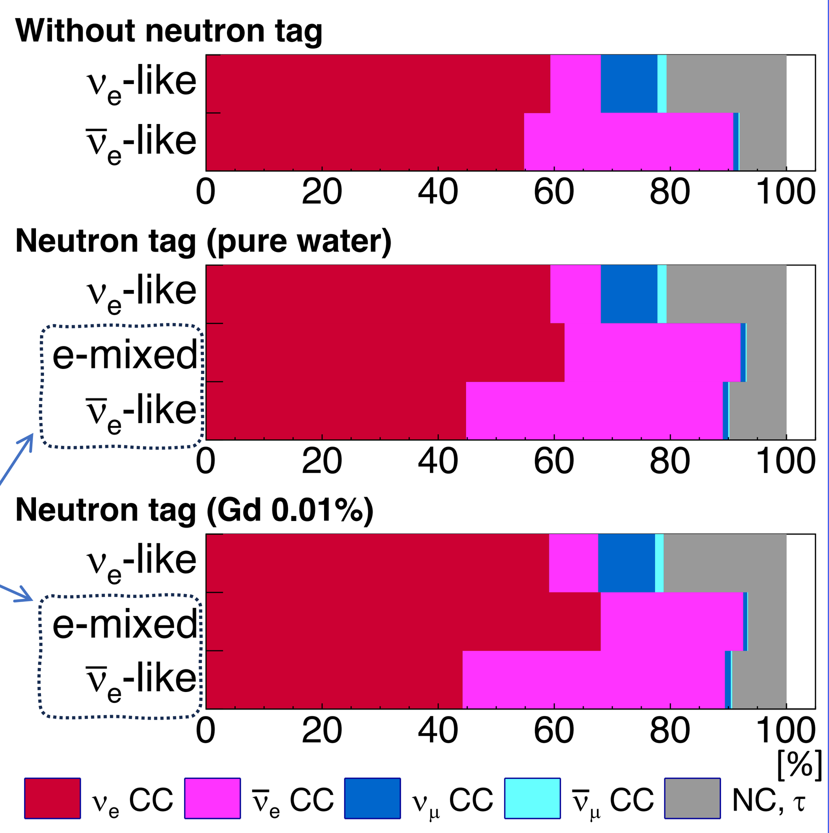


Valid only with π production mode. | Valid with most modes.

- Sample purity → (MC, Multi-GeV, e-like)

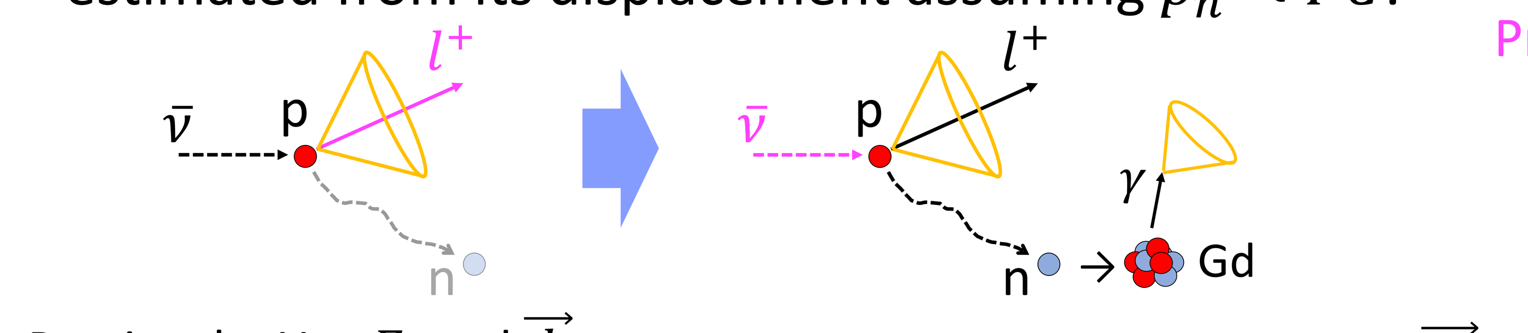
#decay-e > 0 → ν_e-like
else:
#neutron = 0 → e-mixed
#neutron > 0 → $\bar{\nu}_e$-like

Purity is improved by neutron tag.



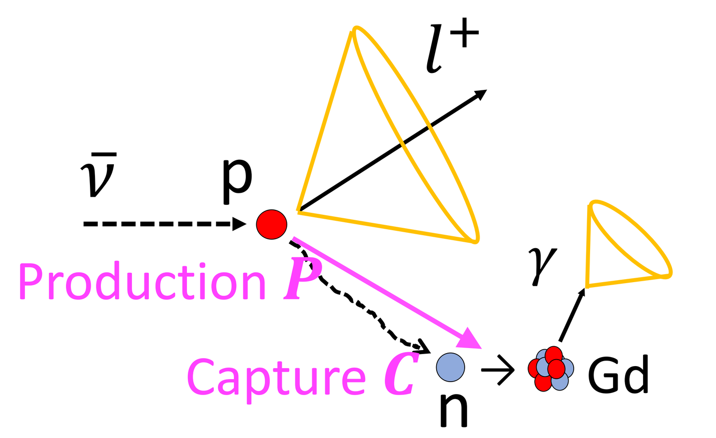
② Event reconstruction

- Reconstruct E_ν and $\vec{d_\nu}$ with neutron momentum estimated from its displacement assuming $\vec{p_n} \propto \vec{PC}$.



Previously: Use E_l and $\vec{d_l}$

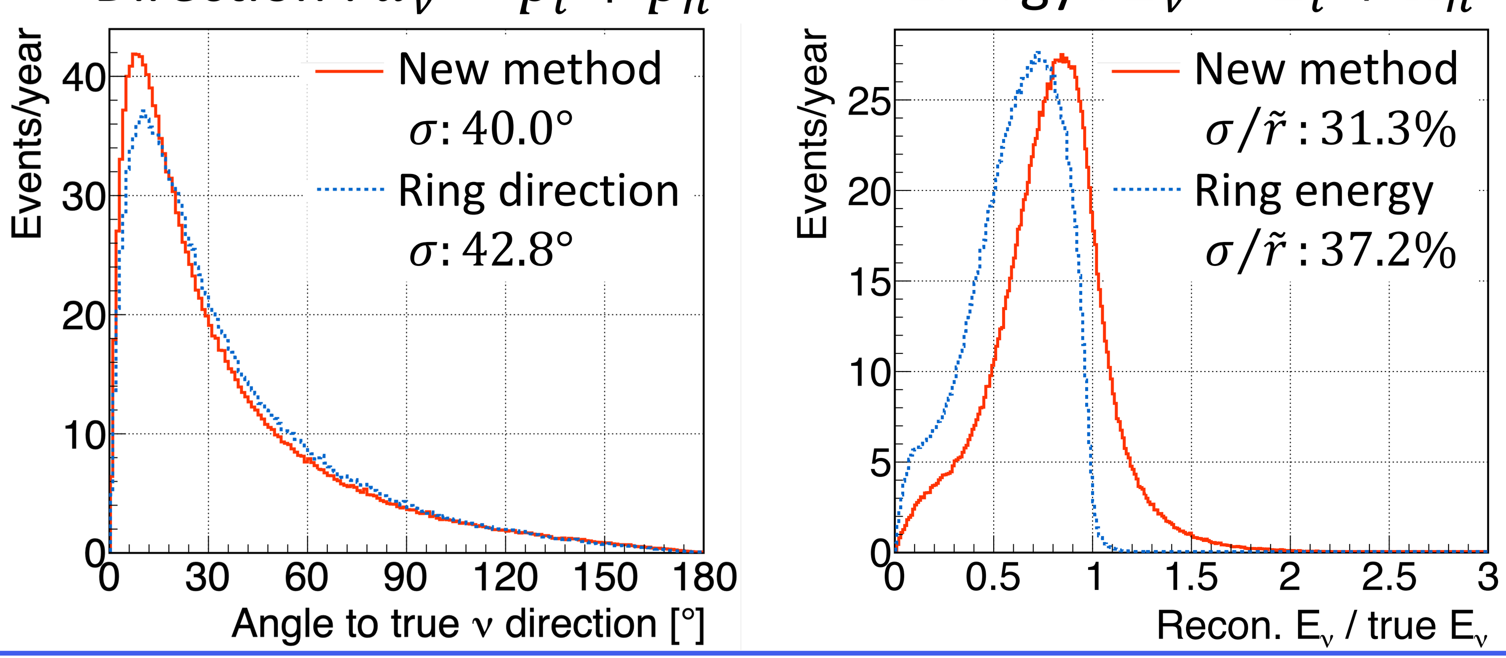
New method: Reconstruct E_ν and $\vec{d_\nu}$ → Better resolution for neutrinos



Neutrons are scattered before captured by Gd, but still we can assume $\vec{p_n} \propto \vec{PC}$.

- Resolution improvements in 0.01%Gd MC:

Direction : $\vec{d_\nu} \propto \vec{p_l} + \vec{p_n}$ | Energy : $E_\nu = E_l + K_n$



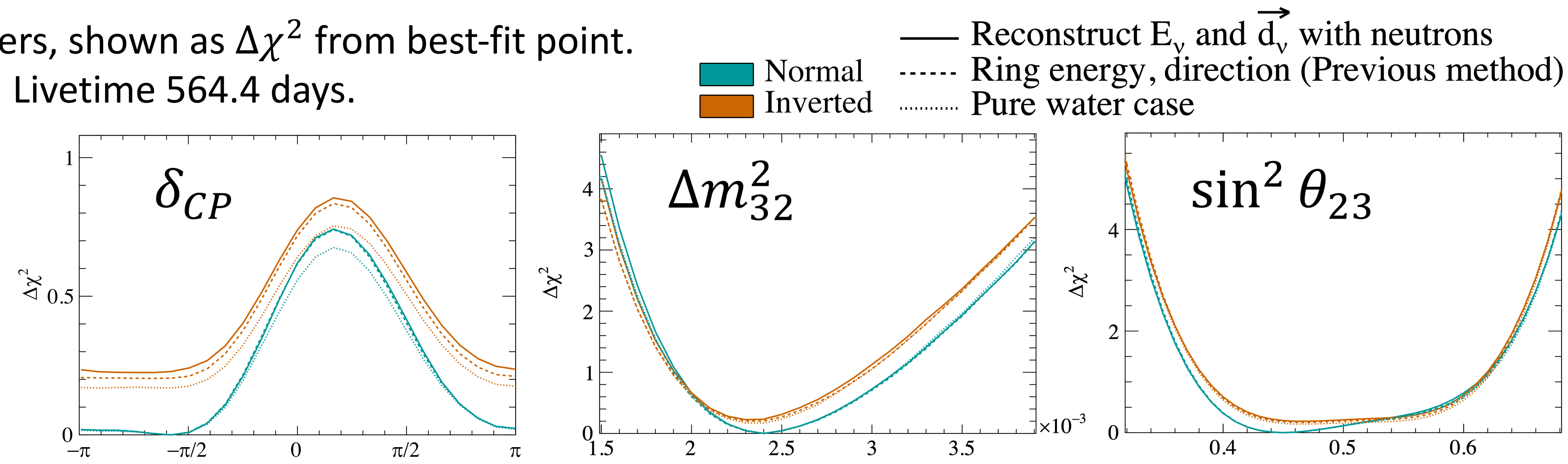
- Tested with atmospheric ν MC events with tagged neutrons.
- Energy resolution : $\sigma/\tilde{r}$ w/ $\tilde{r}$: median, σ : 68% width

Should be narrow around 1

4. Physics sensitivity

- Sensitivities to MO and other oscillation parameters, shown as $\Delta\chi^2$ from best-fit point.
- First ~2 years in SK-Gd (SK6 period) is considered: Livetime 564.4 days.
- Sensitivity to MO is improved by 21% with Gd, and by another 10% with new reconstruction.

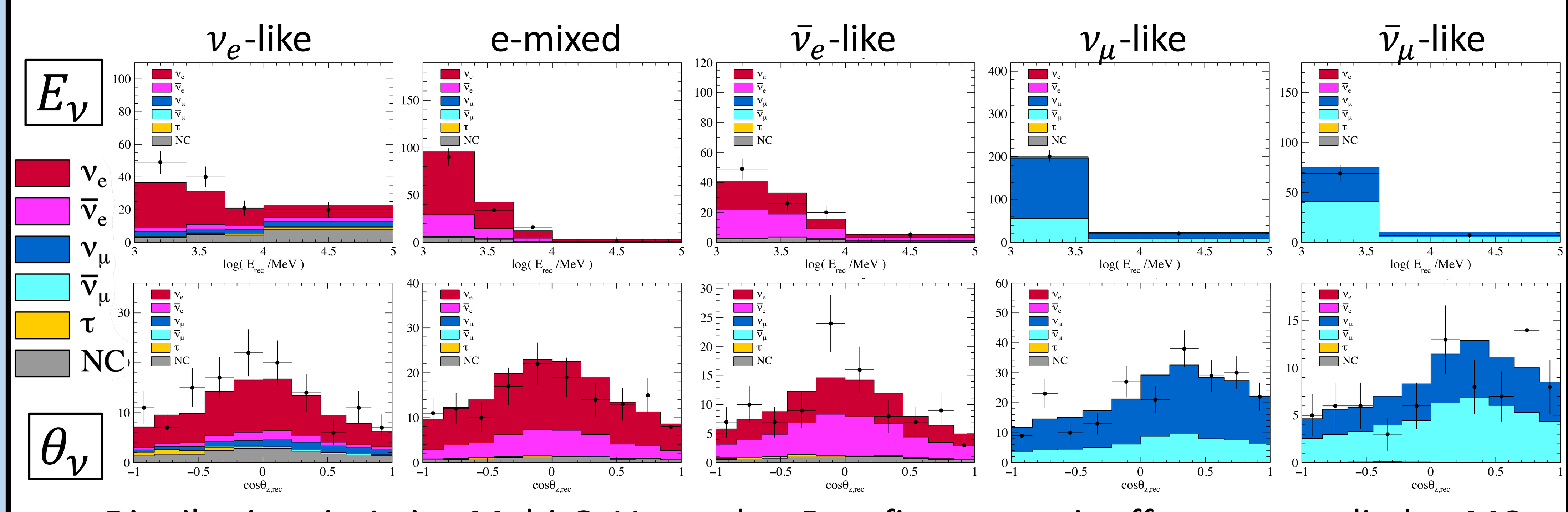
Sensitivity to mass ordering	$\Delta\chi^2$
Reconstruct E_ν and $\vec{d_\nu}$ with neutrons	0.225
Ring energy and direction (Previous method)	0.204
Pure water case	0.169



Assumed parameters:
Normal ordering, $\Delta m^2_{32} = 2.4\times10^{-3}$ eV^2, $\Delta m^2_{21} = 7.53\times10^{-5}$ eV^2, $\sin^2\theta_{23} = 0.45$, $\sin^2\theta_{12} = 0.307$, $\sin^2\theta_{13} = 0.022$, $\delta_{CP} = 4.45$

5. Data - MC comparison in SK-Gd

- Reconstructed E_ν and $\cos\theta_\nu$ distributions agree between data and MC. → Sample classification and new reconstruction work well.



Distributions in 1-ring Multi-GeV samples. Best-fit systematic effects are applied to MC.

6. Summary and Prospects

- In SK-Gd, neutron efficiency is enhanced, and atmospheric neutrino oscillation analysis will be improved in
  ① $\nu/\bar{\nu}$ discrimination,
  ② Energy and direction reconstruction by estimating hadron momentum from neutron displacement.
- Sensitivity to mass ordering is improved by 21% by ①, and 10% by ② with 0.01% Gd.
- Data - MC consistency is confirmed.

➢ Data fit to obtain oscillation parameters is ongoing.