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JUNO Atmospheric Neutrino Mass Ordering Sensitivity

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Jiangmen Underground Neutrino Observatory (JUNO)

Multi-purpose liquid scintillator experiment in China [1,3].

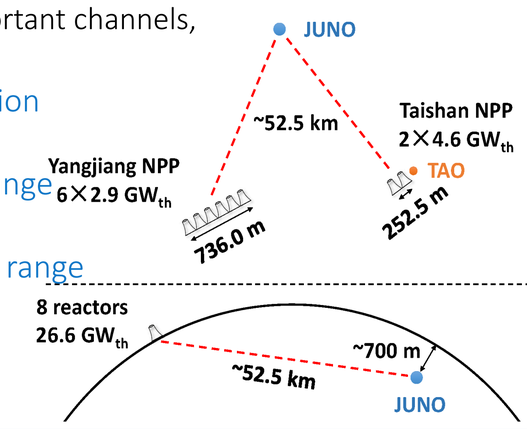
Optimized baseline for **neutrino mass ordering (NMO)** determination with reactor $\bar{\nu}_e$.

Atmospheric $\nu's$ also provide complementary and important channels,

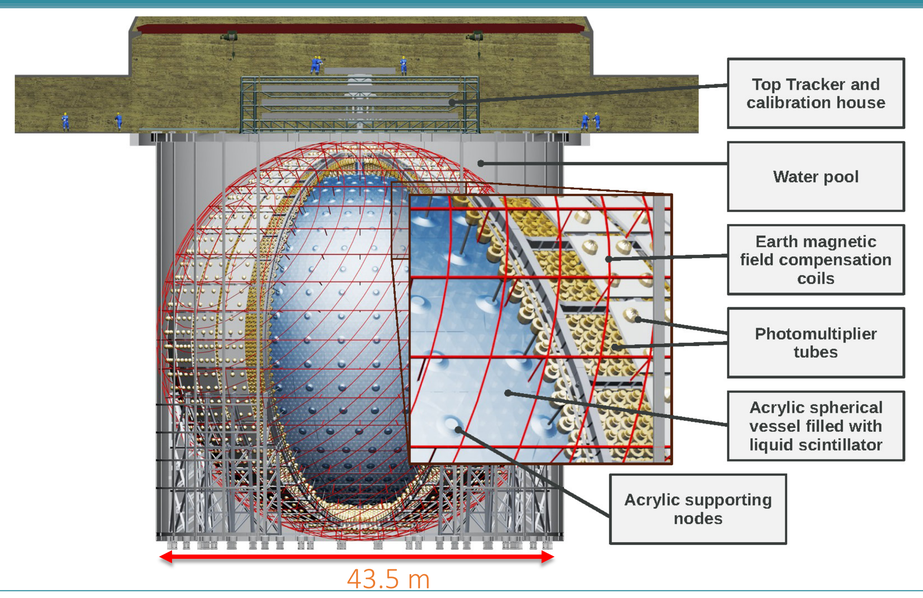
➢ ~78% optical coverage
- Great potential in track and direction reconstruction
- Energy resolution < 3%@1 MeV
- Anticipated good energy reconstruction in GeV range

➢ Delicate calibration [2]
- Energy scale uncertainty <1%@reactor $\bar{\nu}_e$ energy range

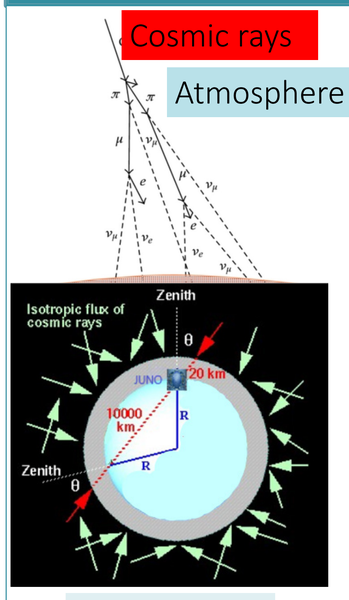
➢ 20-kton LAB-based liquid scintillator (LS)
- Large target volume for multiple sources of ν's
- Large statistics of atmospheric ν's



JUNO Detector

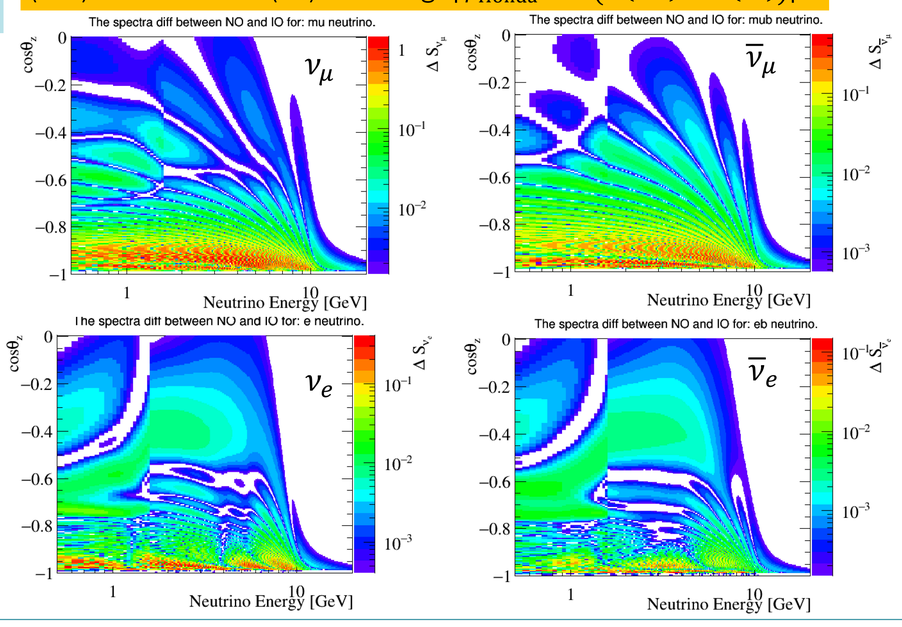


Atmospheric neutrinos @ JUNO



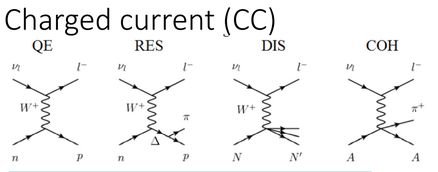
Major flavors: $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$

Charged current (CC) spectra difference between normal (NO) and inverted (IO) ordering: $|\phi_{\text{Honda}} \cdot \sigma \cdot (\mathcal{P}(\text{NO}) - \mathcal{P}(\text{IO}))|$



Signal detection channels:

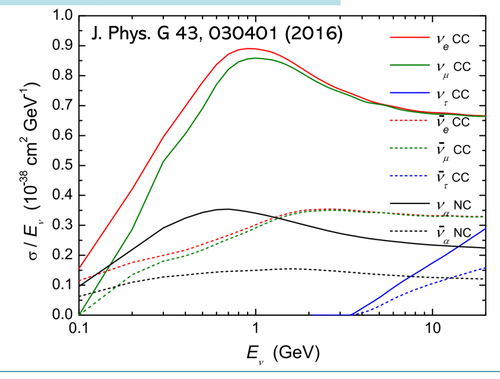
Charged current (CC)

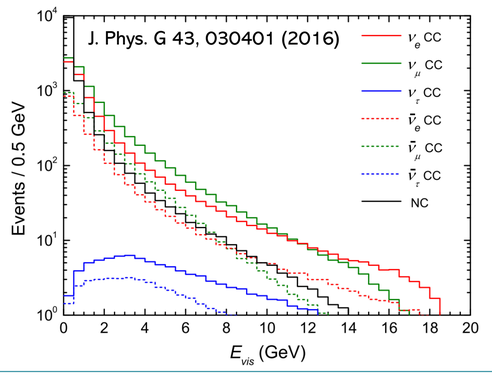


Most sensitive region: $E_\nu \in [0.5, 10]$ GeV, $\cos\theta_z \in [-0.8, -1]$

N/10 yrs	ν	$\bar{\nu}$	Total
$\nu_e/\bar{\nu}_e$ CC	6637	2221	8858
$\nu_\mu/\bar{\nu}_\mu$ CC	8662	3136	11798
$\nu_\tau/\bar{\nu}_\tau$ CC	90	44	133
Neutral Current (NC)	8558	3697	12255

Number of atmospheric ν interactions in JUNO





Classical event selection and classification

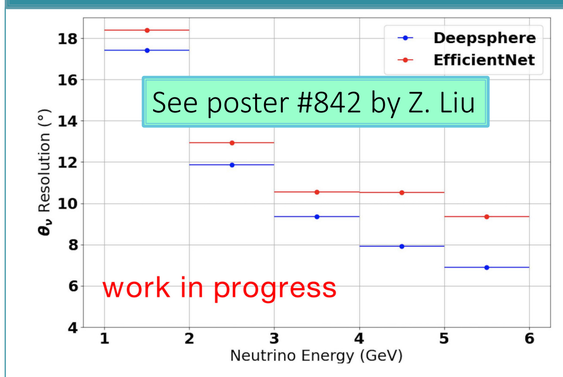
Optimistic case [3]:

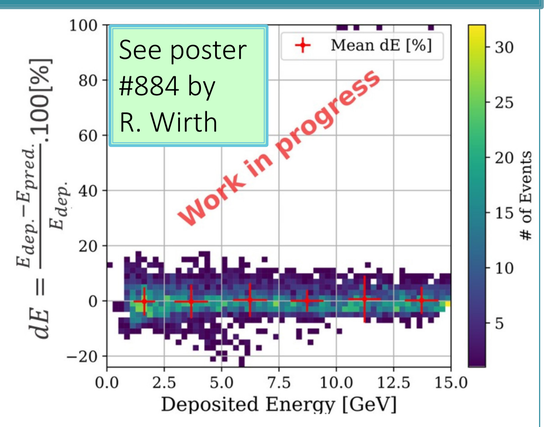
- $\nu_e/\bar{\nu}_e$ CC events: E_{electron} >1 GeV, efficiency: ~25%
  - Two samples: $\nu_e/\bar{\nu}_e$ like, based on number of Michel electrons
- $\nu_\mu/\bar{\nu}_\mu$ CC events: μ track in liquid scintillator L_μ >3 m, efficiency: ~44%
  - Four samples: fully contained (FC)/partially contained (PC) -- $\nu_\mu/\bar{\nu}_\mu$ like, based on μ^- capture, Michel electron number, and hadronic energy fraction.
- Neutrino direction θ_ν resolution $10°$, visible energy resolution 1%@1 GeV.

Pessimistic case [3]:

- **Track-like**: only $\nu_\mu/\bar{\nu}_\mu$ CC events with hadronic energy fraction< 65%
- **Point-like**: all other CC and NC events
- Neutrino direction θ_ν resolution $37.2°$, visible energy resolution 5%@1 GeV.
- Signal efficiency: 100%

Recent reconstruction progress





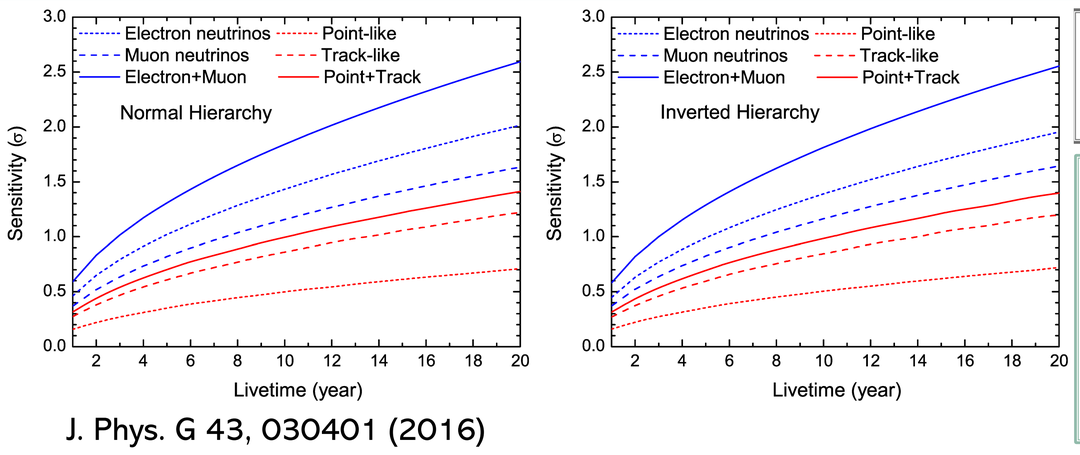
Neutrino direction and energy reconstruction in progress:

➢ Angular resolution: at a level of ~10°

➢ Energy resolution: ~6%

Particle identification (PID) studies are in progress.

NMO sensitivity and discussion



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➢ Median sensitivity discriminator by fitting to normal ordering Asimov data under both normal (NO) and inverted ordering (IO) hypotheses:

$$\Delta\chi^2_{\text{min}} \equiv \left|\chi^2_{\text{min}}(\text{NO}) - \chi^2_{\text{min}}(\text{IO})\right|,$$

- The JUNO atmospheric neutrino NMO sensitivity is dominated by statistics for livetime <10 years.
- The signal efficiency, PID, and angular resolution are the key factors for NMO determination.
- Complementary to NMO determination from reactor $\bar{\nu}_e$ @ JUNO (3σ in 6 years),
  - Combination expected to further improve the JUNO NMO sensitivity.
- Sensitivity with updated reconstruction performance is **in progress**.

References

[1] JUNO, A. Abusleme et al., JUNO physics and detector, Prog. Part. Nucl. Phys. 123, 103927(2022), arXiv:2104.02565.

[2] JUNO, A. Abusleme et al., Calibration Strategy of the JUNO Experiment, JHEP 03, 004 (2021), arXiv:2011.06405.

[3] JUNO, F. An et al., Neutrino Physics with JUNO, J. Phys. G 43, 030401 (2016), arXiv:1507.05613.