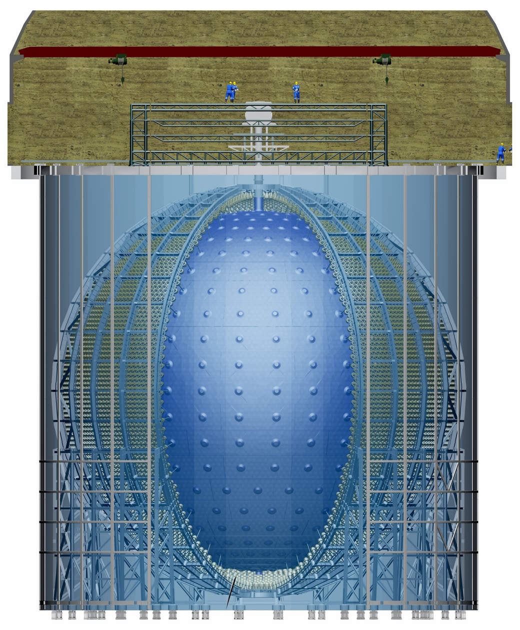
Atmospheric Tau Neutrino Interaction and its Identification at JUNO Experiment

Zhenning Qu[1,2] *on behalf of the JUNO collaboration*

1. Institute of High Energy Physics, Chinese Academy of Science
2. University of Chinese Academy of Science

I. Introduction

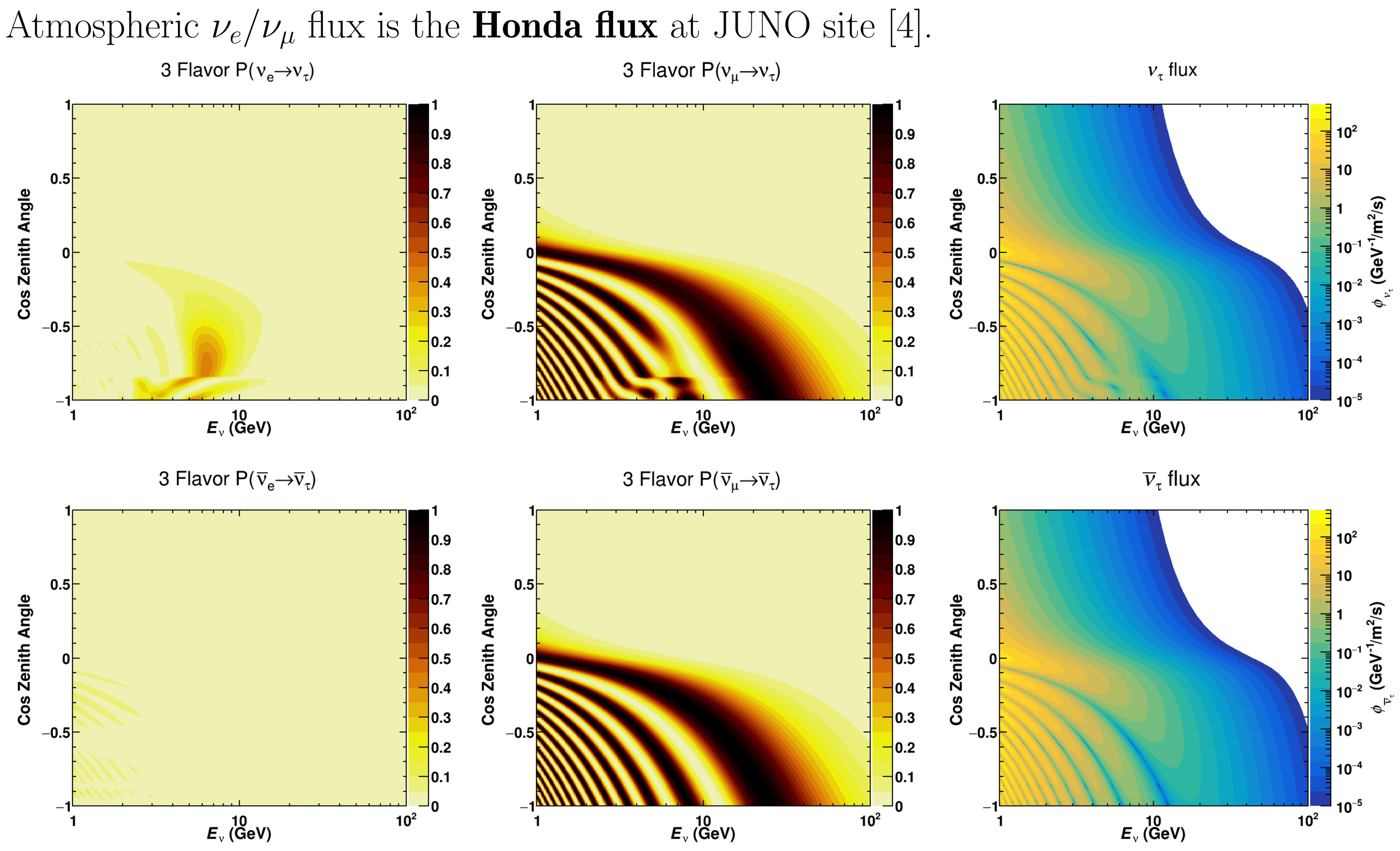


The Jiangmen Underground Neutrino Observatory (JUNO): a multipurpose neutrino observatory with the largest ever liquid scintillator (LS) detector [1]:

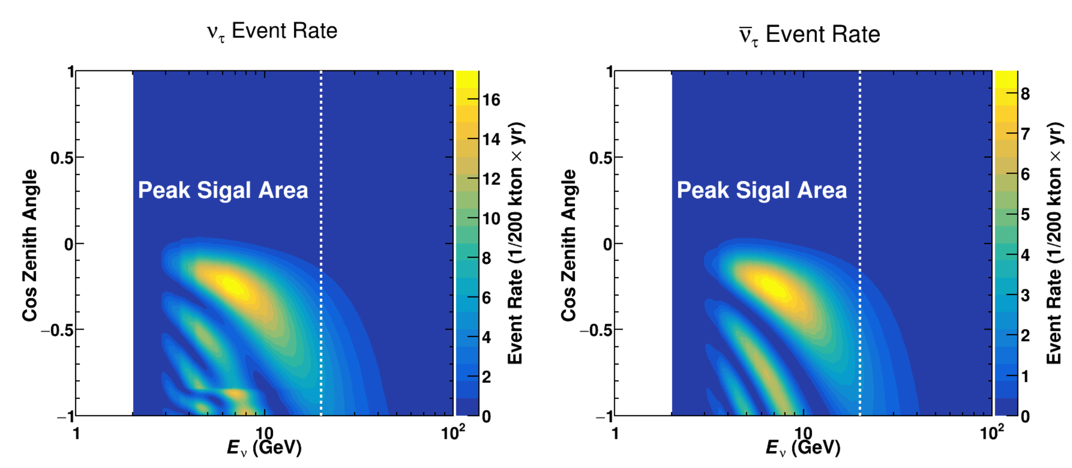
- Main goal: determine neutrino mass ordering
- Large target: 20 kton LS
- High photo-coverage: 78%

Motivation: 1. No $\geq 5\sigma$ results of atmospheric tau neutrino appearance from oscillations; 2. JUNO will be the first LS detector with the capability to measure it; 3. Constrain the Standard Model predictions

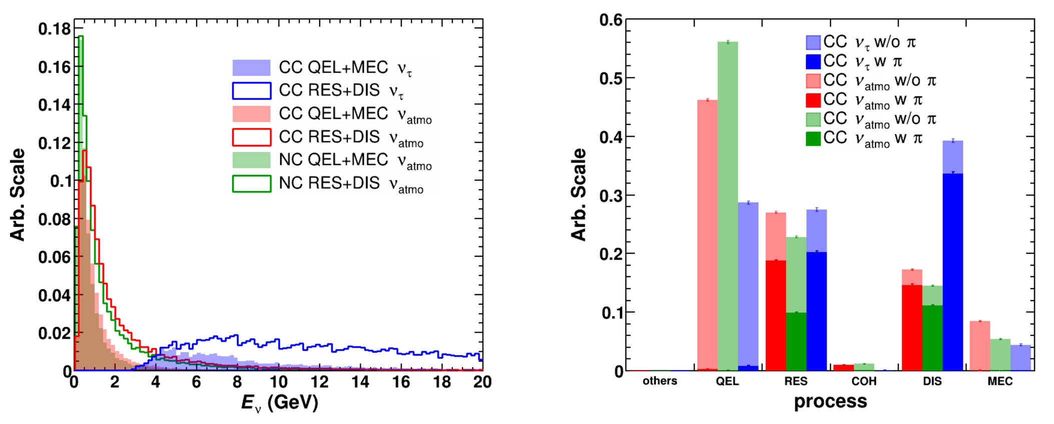
Oscillation probability and flux: use Prob3++ [2] with NO oscillation parameters [3]. Atmospheric ν_e/ν_μ flux is the **Honda flux** at JUNO site [4].



II. Neutrino interaction simulation



- **GENIE v3.02.00** [5]
- Targets: 88% ^{12}C, 12% ^{1}H
- E_ν: only analysis 0-20 GeV now
- Model: G18_10b_02_11b [6]
- Signal: charged current (CC) ν_τ
- Background: CC $\nu_e + \nu_\mu$, neutral current (NC) of all flavors



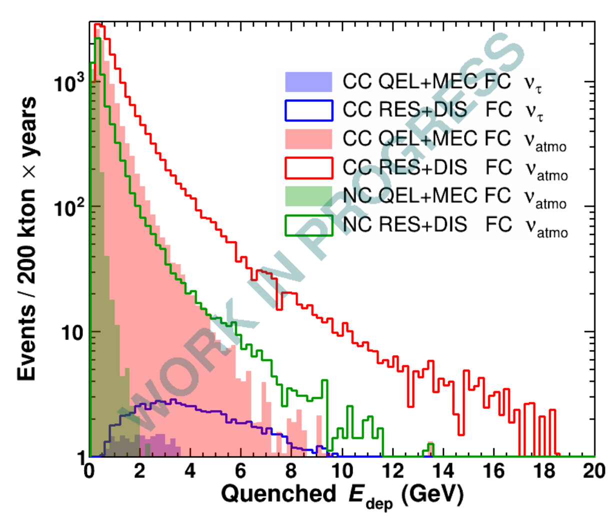
Interaction mode	RES + DIS ratio	Average number of produced $\pi^\pm$
CC ν_τ	66.8%	0.895
CC ν_{atmo}	44.8%	0.484
NC ν_{atmo}	37.9%	0.308

- Large lepton τ mass $\to$ high energy threshold $\sim$ 2.5 GeV (consider ^{12}C 2p2h effect)
- More high energy events $\to$ higher RES/DIS ratio $\to$ more hadrons (e.g. pion)

The high oscillation probability from ν_μ to ν_τ and the high energy threshold of CC ν_τ also mean suppression of low energy upward-going atmospheric neutrino event number.

III. Detector simulation

In this poster, the study is based on detector truth information from the detector simulation in the JUNO official simulation framework.



Selection:

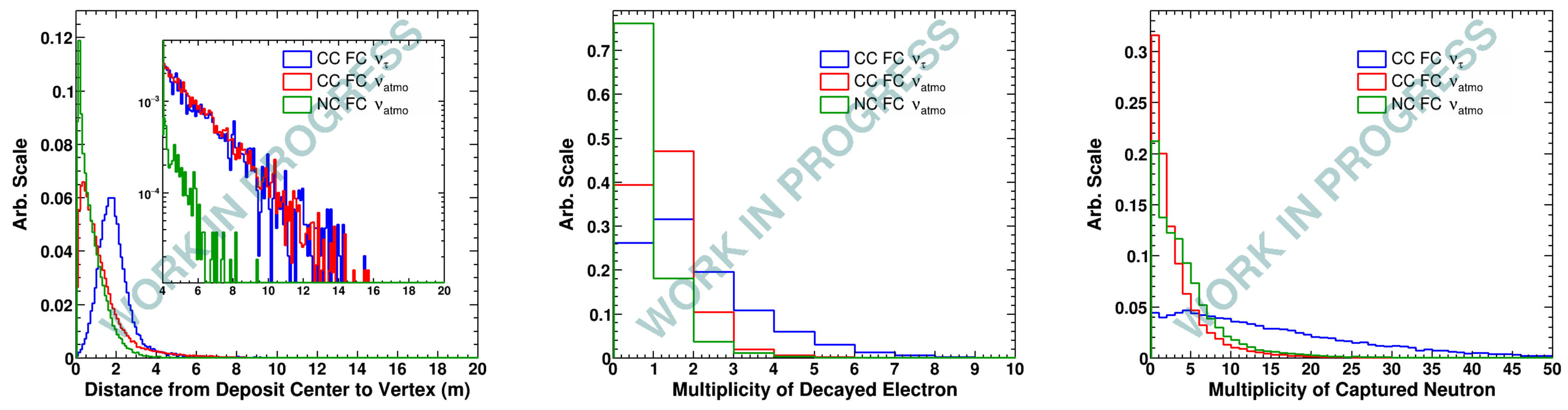
- Fully contained (FC): no hits from water pool PMTs
- Quenched deposit energy (QE_{dep}): 0.1 $\sim$ 20 GeV

Different energy spectrum expected for signal and background + JUNO fine energy resolution $\to$ good potential to distinguishing ν_τ events from primary atmospheric neutrinos.

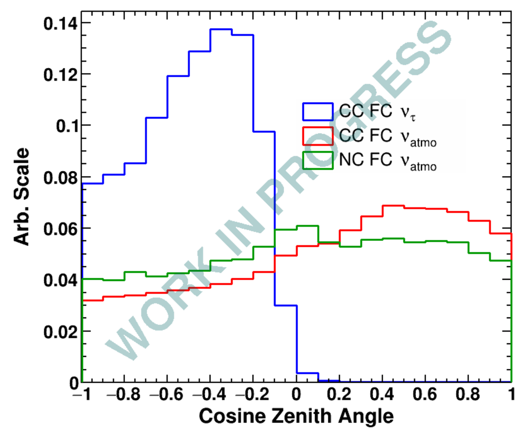
IV. Identification

1. **Tau decay:** τ (mean life $2.9\times10^{-13}s$) cannot be directly detected in JUNO. Instead, the decayed particles can help us to distinguish τ. Two decay modes of τ:

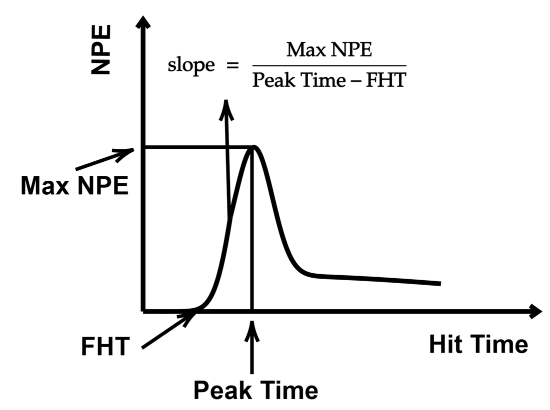
- Leptonic decay: $\tau \to e\nu\nu/\mu\nu\nu$ ($Br = 35.21\%$), similar to the atmospheric CC ν_e/ν_μ.
- **Hadronic decay**: $\tau \to \geq 1h\nu$, h stands for π (or K). **(1)** Different deposit energy for mesons and leptons $\to$ different **distances from the deposit energy center to the primary vertex**; **(2)** More **Michel electrons** from these charged meson decays; **(3)** Charged mesons are more likely to undergo inelastic scattering with nuclei in LS and produce more **neutrons** than leptons.

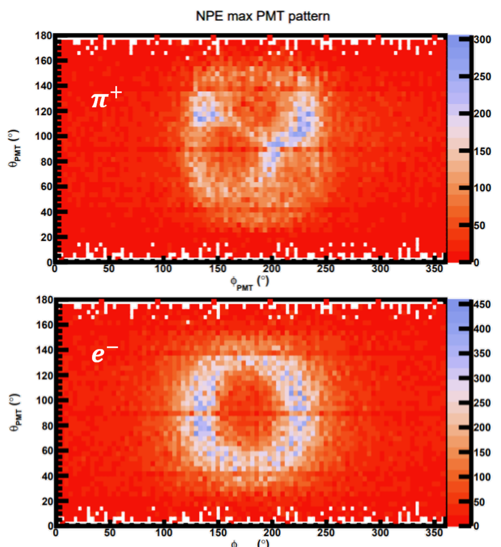


2. Neutrino direction: the oscillation length in excess of the tau threshold is at least 4,100 km $\to$ most ν_τ are upward-going.

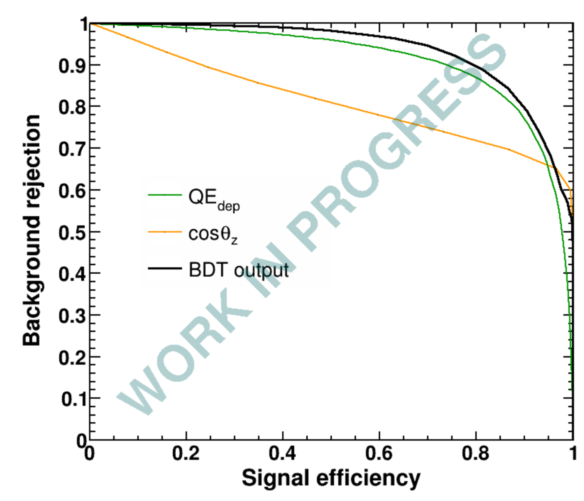


3. Spatial distributions of PMT's waveform features **(total PE, first hit time (FHT), peak time, max nPE)**. The statistical features of these 2-dimensional distributions contain both waveform shape and spatial information.





- Method: boosted decision trees (BDT) method in the ROOT-based TMVA [7] library
- Input: neutrino direction, distance, neutron multiplicity, and Michel electron multiplicity + PMT features (excluded high correlation ones)
- Samples: training and testing samples with energy spectrum weighted to a flat one, unweighted analysis sample



- Cutting on BDT output shows better efficiencies of signal selection and background rejection than just using neutrino direction.
- Preferred a 2D unbinned maximum likelihood fit with probability distribution functions (PDFs) of the BDT output and the QE_{dep}.

V. Summary and outlook

- Tau neutrinos can be separated from atmospheric neutrinos background thanks to:
  - different energy spectrum and neutrino direction distribution
  - special lepton tau decay topology
  - different PMT waveform shape and spatial distribution of hits
- A BDT method is processed and a good efficiency can be expected while the detector response and systematic errors should be further studied.
- The reconstruction of atmospheric neutrino is ongoing (see Poster 376 by Xinhai He).

References

[1] F. An and et. al, Journal of Physics G: Nuclear and Particle Physics **43**, 030401 (2016).
[2] *Prob3++*, `https://webhome.phy.duke.edu/~raw22/public/Prob3++/`.
[3] I. Esteban and et. al., Journal of High Energy Physics **2019**, 106 (2019).
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[6] J. Tena-Vidal and et. al. (GENIE Collaboration), Phys. Rev. D **104**, 072009 (2021).
[7] A. Hoecker and et. al., PoS **ACAT**, 040 (2009).