The methodology of atmospheric neutrino identification in JUNO

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Outline

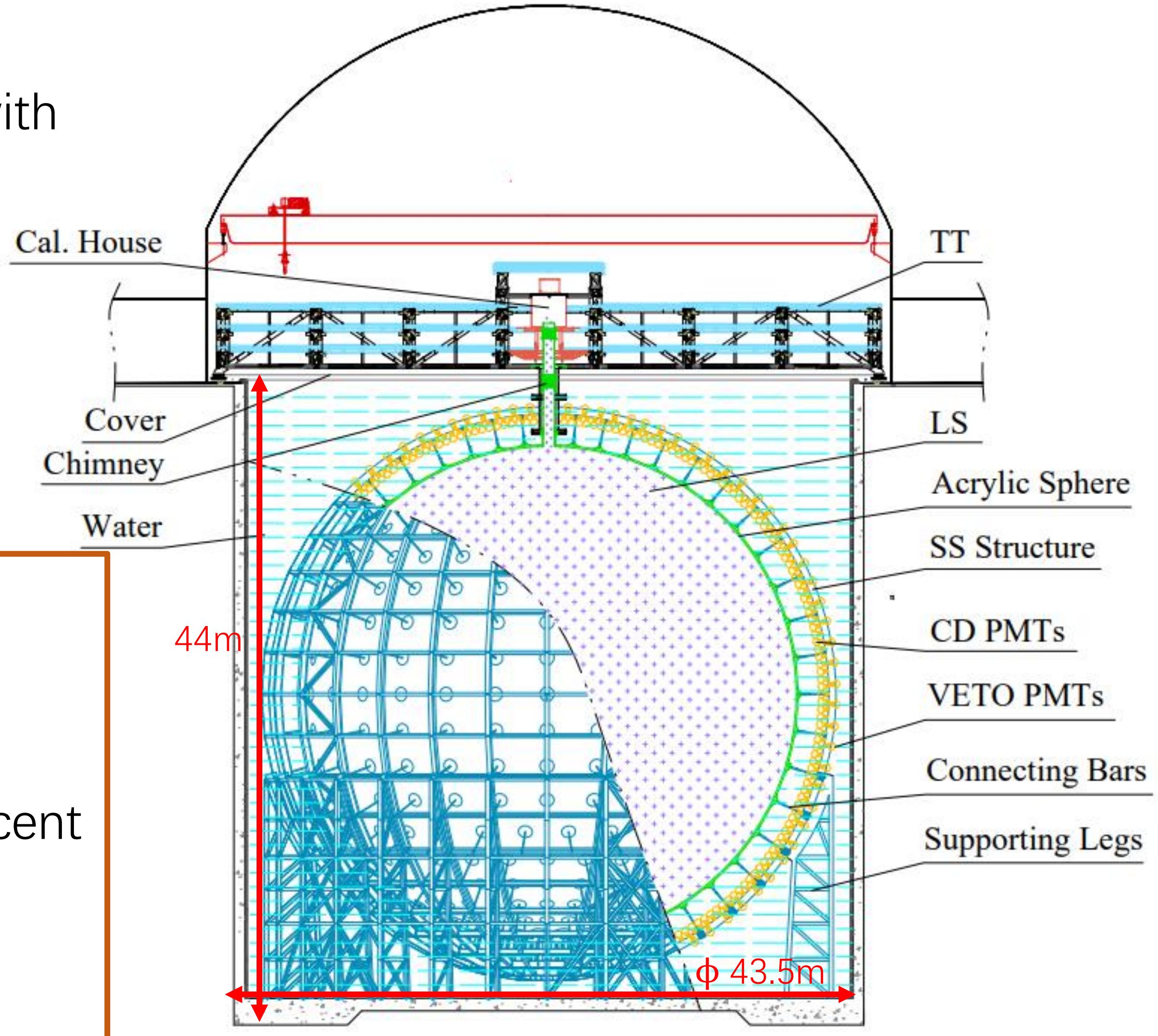
- Atmospheric neutrinos in JUNO
- Methodology of identification
- Preliminary performance of identification
- Summary and outlook

Jiangmen Underground Neutrino Observatory （JUNO）

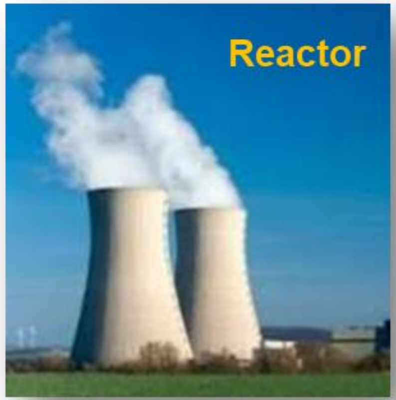
- ✓ JUNO will be the largest liquid scintillator detector with 20 kt LS, located in China
- ✓ ~78% photo coverage
  - 17612 20” PMTs + 25600 3” PMTs
- ✓ Energy resolution 3% @1MeV

Multi-purpose:

- Determine the neutrino mass ordering (NMO)
- Measure neutrino oscillation parameters to sub-percent level
- …



JUNO: A multi-purpose observatory

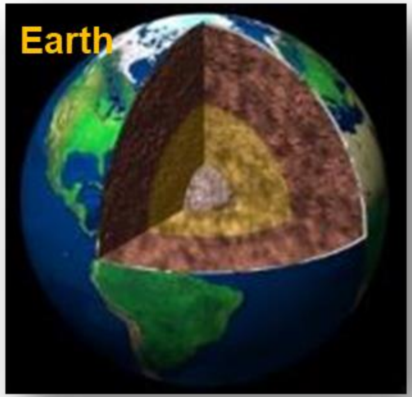


~60 IBDs per day

Several per day

Hundreds per day

~5000 IBDs for CCSN @10 kpc



Several IBDs per day

+ New physics

Neutrino oscillation & properties

Neutrinos as a probe

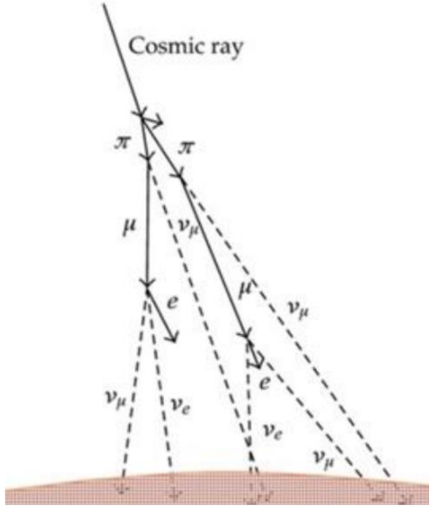
IBD: inverse beta decay $\bar{\nu}_e + p \rightarrow e^+ + n$

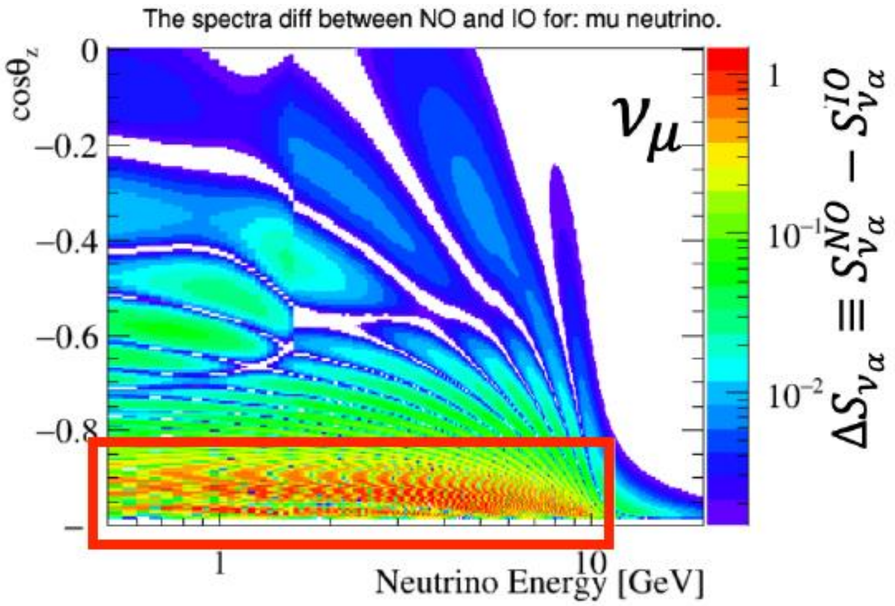
CCSN: core-collapse supernova

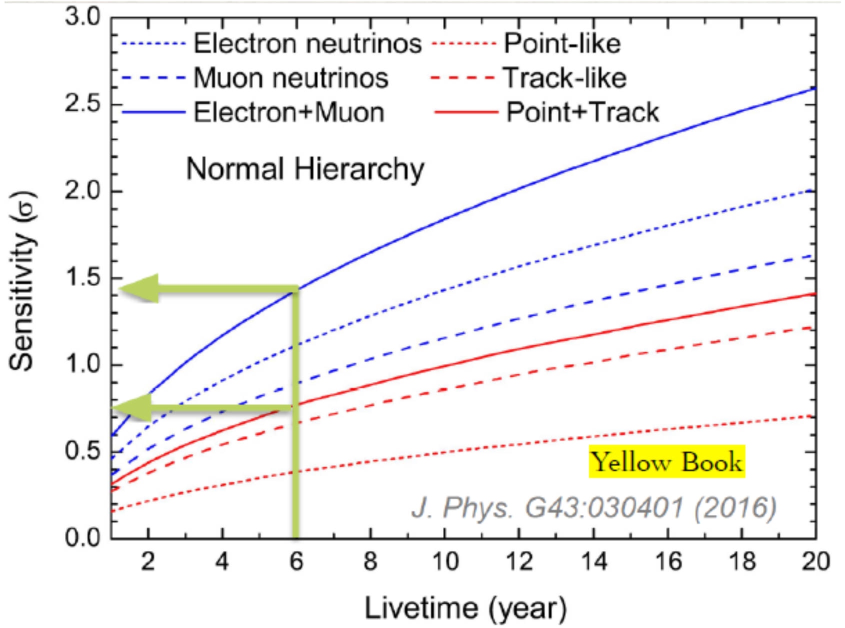
"Neutrino Physics with JUNO," J. Phys. G **43** (2016) no.3, 030401
"JUNO Physics and Detector," Prog. Part. Nucl. Phys. **123** (2022), 103927

Atmospheric neutrino in JUNO

- Atmospheric neutrinos originate from the decays of mesons (π and K) produced by the interaction of cosmic rays with the Earth's atmosphere
- The Mikheyev–Smirnov–Wolfenstein (MSW) matter effect acting on neutrinos passing through the Earth will play a key role in determining the NMO.







NMO sensitivity from JUNO Yellow Book: ~1.4σ@6years

- Combined with reactor neutrinos and atmospheric neutrinos can further enhance the NMO sensitivity of JUNO (analyses ongoing)

Atmospheric neutrino in JUNO

Crucial factors for atmospheric neutrino oscillation

- Directionality
- Energy
- Flavor

Challenges (Compare with LAr TPC or Water Cherenkov)

- No direct track of final states hadrons information;
- No Cherenkov rings;

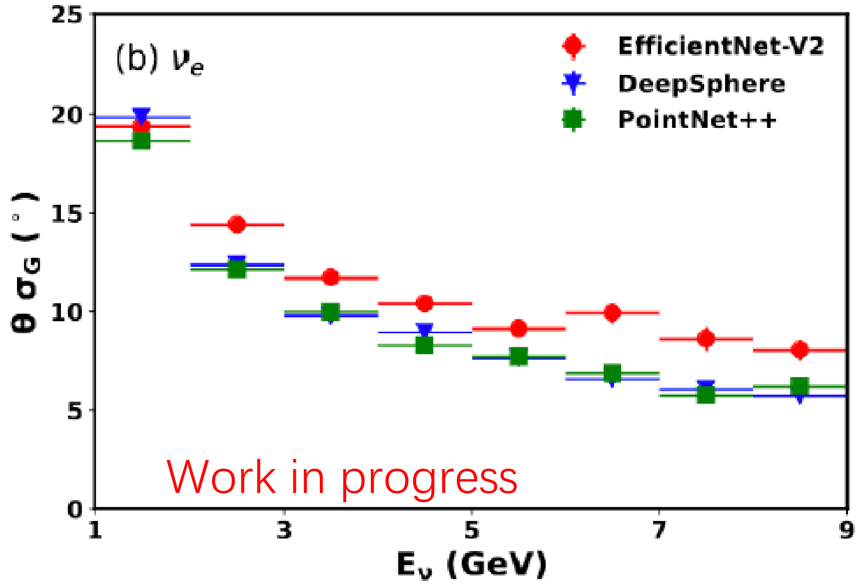
Advantages of JUNO

- Low energy threshold;
- Excellent neutron tagging;
- Hadronic component visible in LS;
- Can measure distinctive isotopes;

Direction and energy reconstruction:

- Develop a novel reconstruction method based on deep learning model

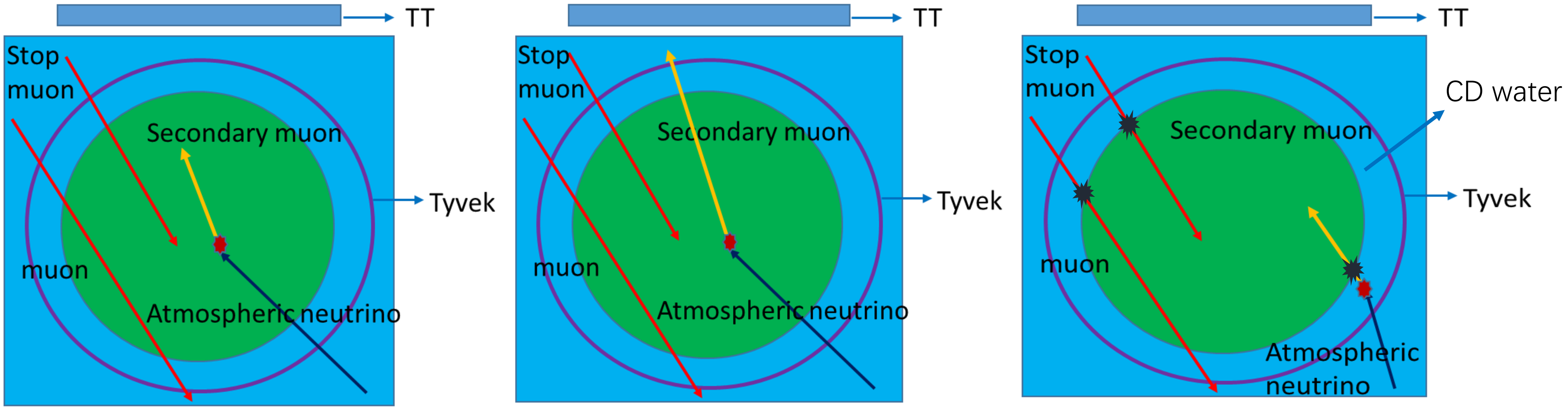
Duyang' talk: "JUNO's potential for GeV events"



- Methodology paper to be published soon

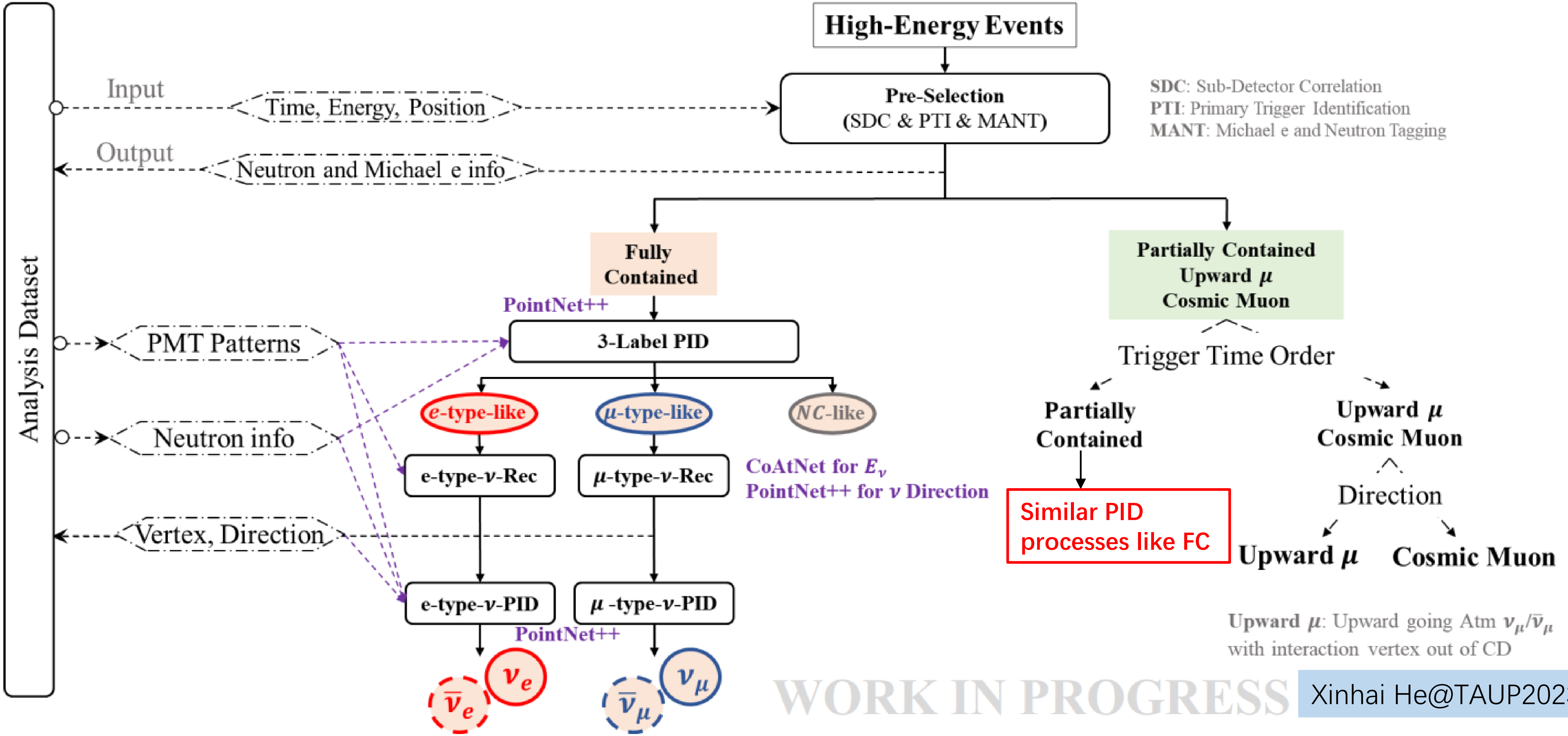
Atmospheric neutrino in JUNO

Category based on behavior of secondary particles



✓Fully contained (FC) ✓Partially contained (PC) ✓upward-going ν

Event selection flow



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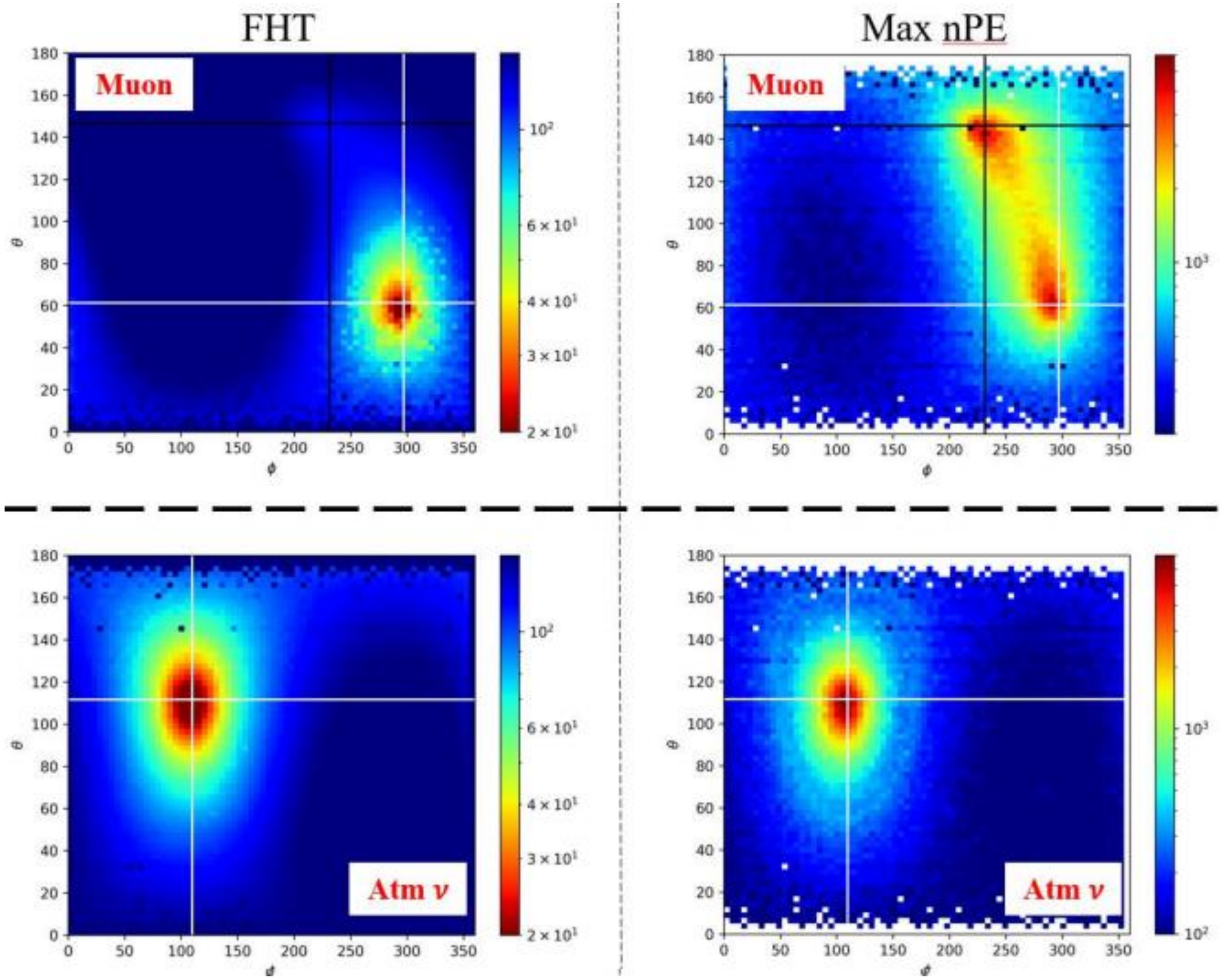
Muon background suppression



Classify FC/PC/Muon events:

Direction

- Cosmic Muon: Down-ward

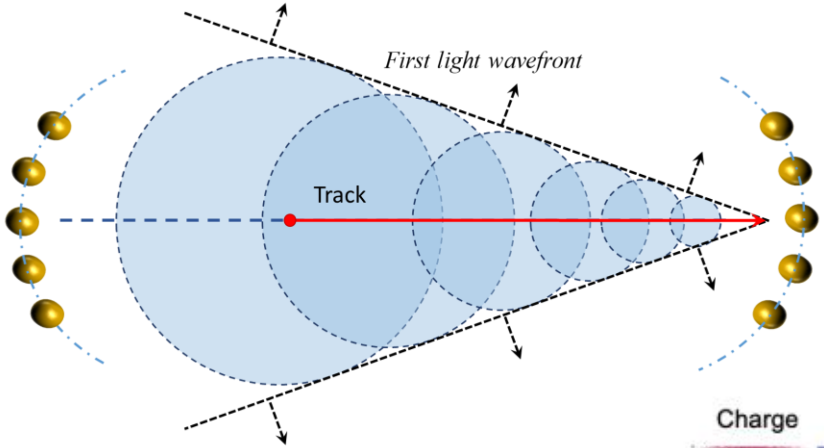
PMTs hit pattern

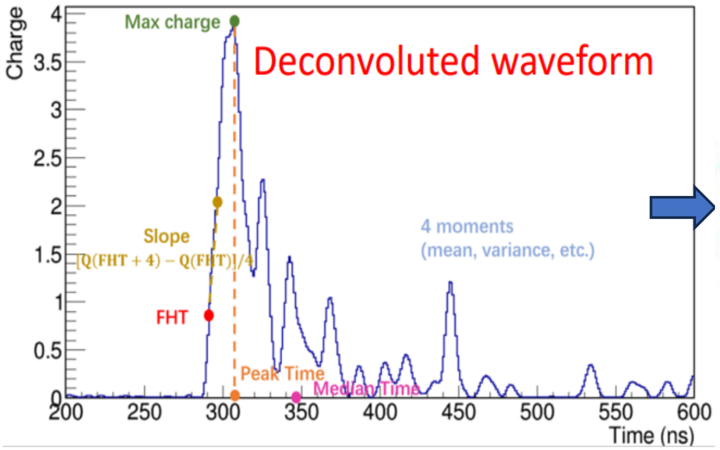
- Cosmic Muon: Multi Clusters
- Atm ν PC: Single Cluster

Analyses ongoing with great potential

Methodology of identification

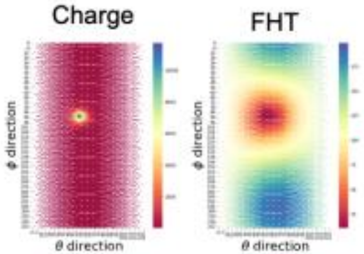
PMT's waveform reflect the event's topological structure and carry information about the event’s flavor, direction, energy, etc





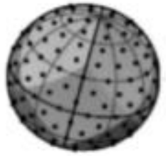
PMT features

Planar projection



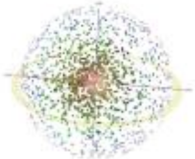
Planar models (EfficientNetV2)

Spherical projection



Spherical model (DeepSphere)

Point clouds, etc



3D Point cloud-based model (PointNet++)

Tasks:

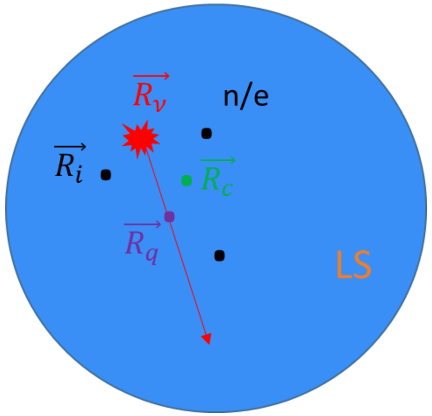
- Reconstruction (Direction, energy, vertex)
- Identification (Flavor)

- Different types of neural network models have been explored

Methodology of identification

Secondary particle information (event-level) are crucial for ν vs $\bar{\nu}$

- ✓ Neutron/Michel e multiplicity
- ✓ Neutron/Michel e position distribution
- ✓ Distance from the deposit center to vertex
- ✓ Lepton energy ratio for $\nu_u/\overline{\nu_u}$

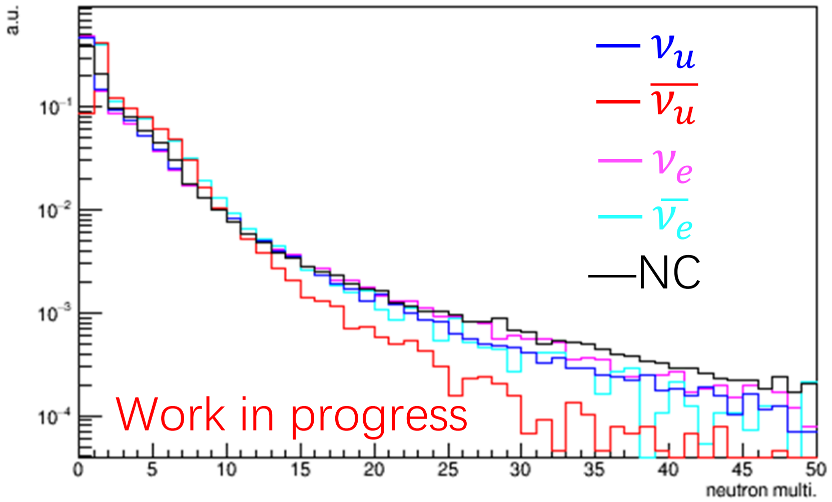


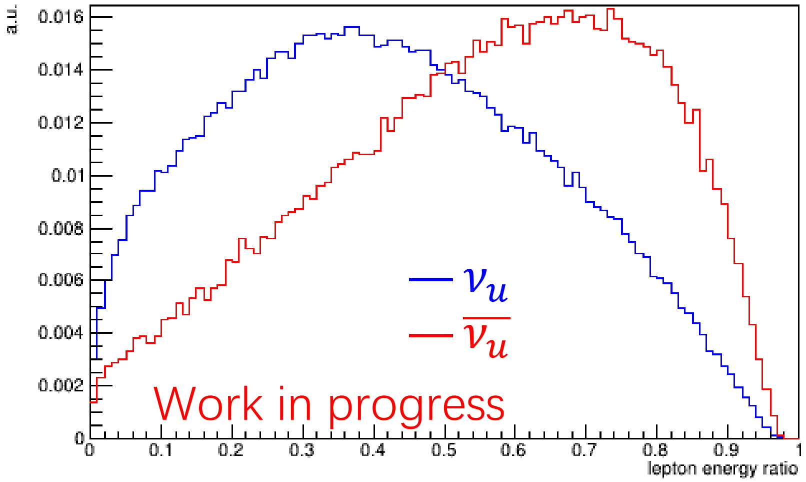
$\overrightarrow{R_i}$ is the neutron/Michel e position

$\overrightarrow{R_c}$ is the neutron/Michel e position center

$\overrightarrow{R_q}$ is the energy deposit center

$\overrightarrow{R_\nu}$ is the interaction vertex





- $\bar{\nu}$ tends to produce more neutrons than ν.
- The $\bar{\nu}$ channel tends to have larger values of lepton energy ratio compared to the ν.

Methodology of identification

- Only using event-level information based TMVA / Scikit-learn

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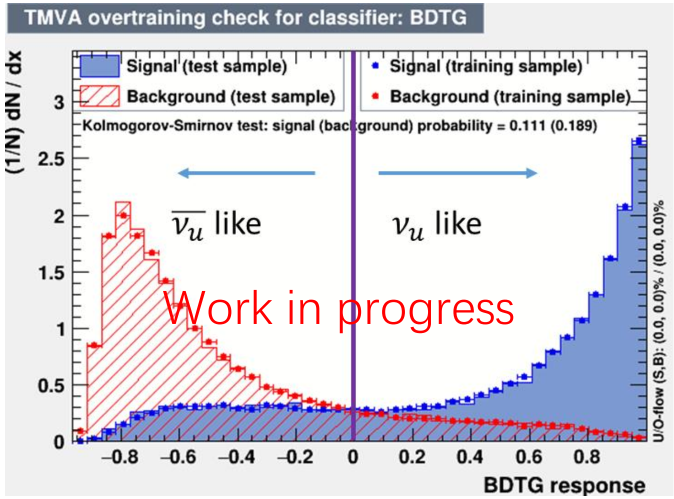
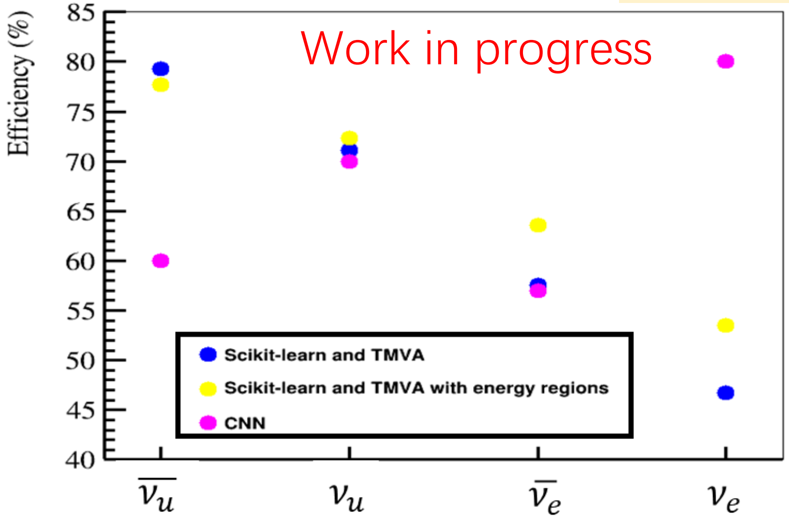
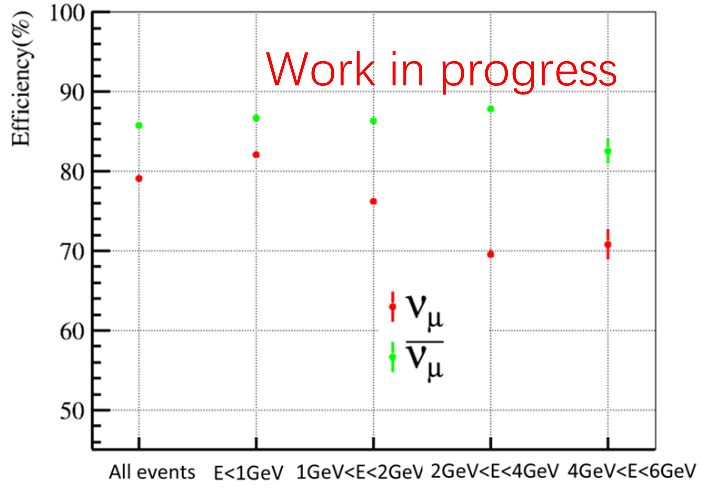
Strategy 1

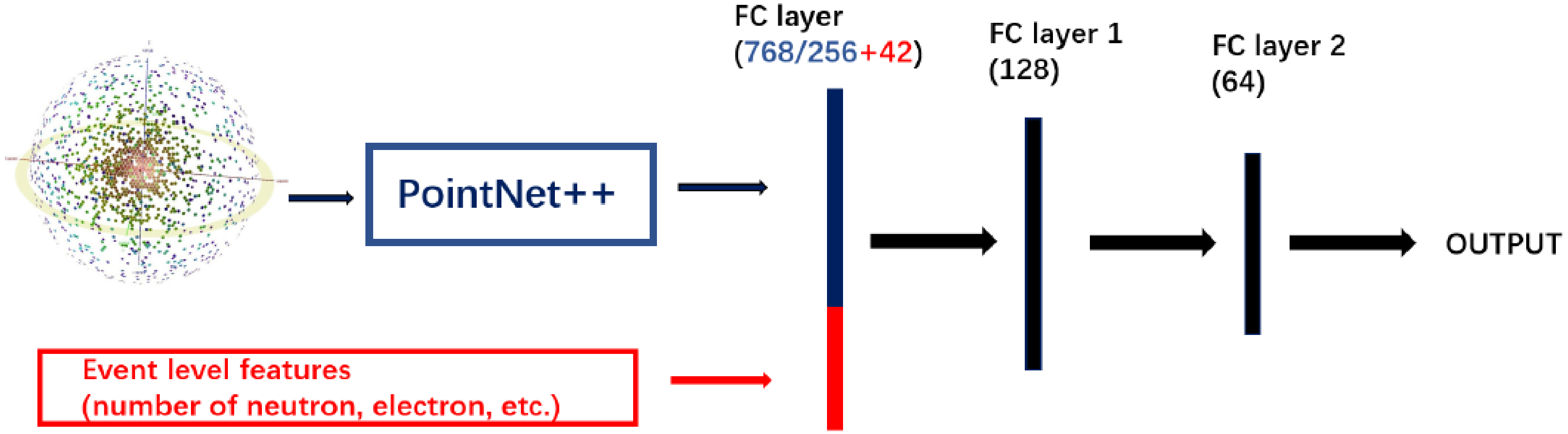






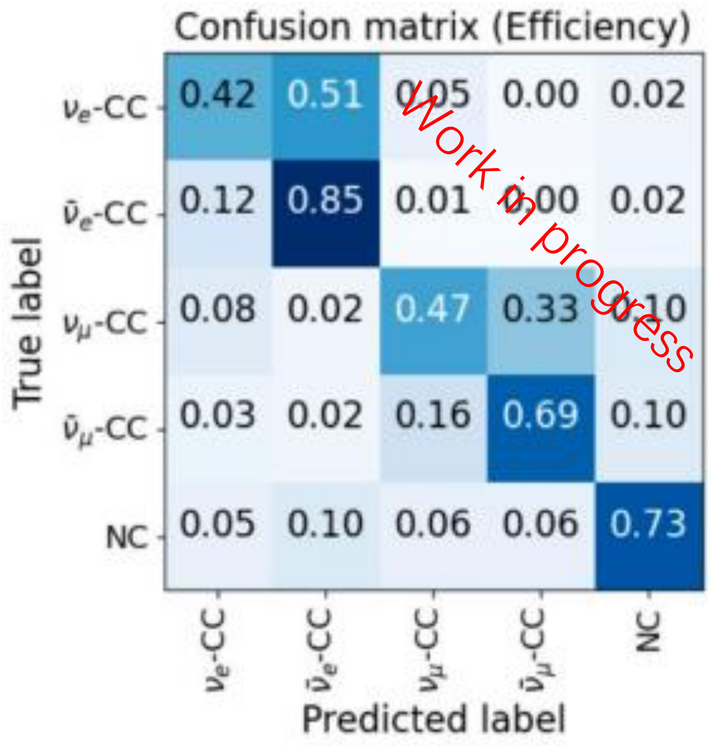
- Optimized flavor identification model by only using waveform or both waveform and event-level features

Strategy 2

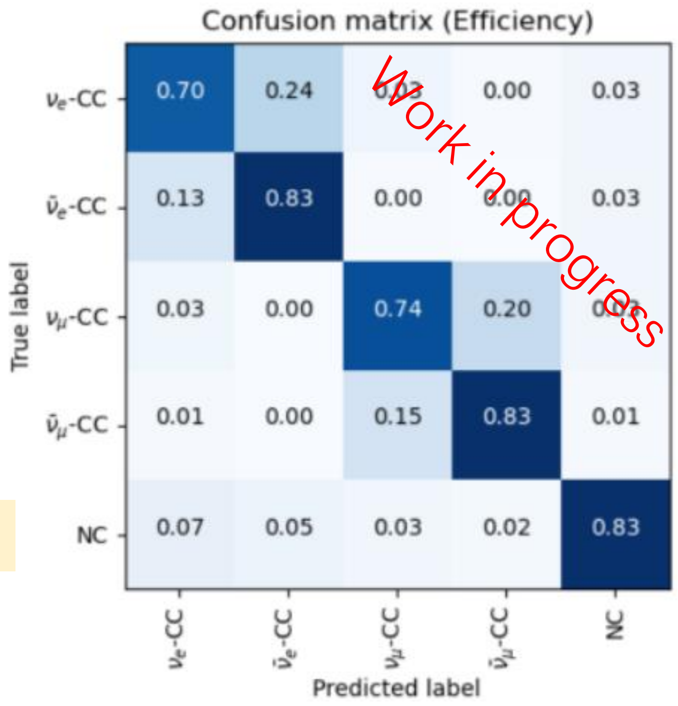


Flavor Identification Performance

- Only PMT waveform features as input



- Both waveform and event-level truth features as input



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- Neutron/Michel electron information are crucial for ν vs $\bar{\nu}$ separation

Summary and outlook

- The JUNO NMO sensitivity from atmospheric neutrinos is complementary to that from the JUNO reactor neutrino results.
- Atmospheric neutrinos identification in larger LS detector is carried out for the first time, and the preliminary results are promising.
- Various characteristic have been used to do PID including neutrons, Michel electrons and waveform features based on TMVA, Scikit-learn and various deep learning model.

THANK YOU!