PROCEEDINGS OF SCIENCE

Atmospheric neutrino event selection and classification for oscillation analysis at JUNO

PoS(TAUP2023)263

Xinhai He [a,*] on behalf of the JUNO Collaboration

[a] *Institute of High Energy Physics,*
19B Yuquan Road, Shijingshan District, Beijing, China

E-mail: xhhe@ihep.ac.cn

The Jiangmen Underground Neutrino Observatory (JUNO) is a multipurpose neutrino experiment that aims to determine the neutrino mass ordering (NMO) and measure the neutrino oscillation parameters with sub-percent precision. Atmospheric neutrinos can also contribute to the NMO sensitivity with a complementary approach: using the matter effects on neutrino oscillations. This work contains the recent Monte Carlo studies of atmospheric neutrino event selection and classification at JUNO, which will enhance the oscillation sensitivity by using novel data analysis techniques. Specifically, the PMT charge and time information from both the Central Detector and the Water Pool Veto detector will be used to suppress cosmic muon backgrounds and identify the different flavors. The multiplicity of spallation neutrons associated with the primary atmospheric neutrino interactions is expected to help separate neutrinos from antineutrinos.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08.-01.09.2023
University of Vienna

1. Introduction

JUNO is a multi-purpose liquid-scintillator experiment in China that aims to determine the Neutrinio Mass Ordering (NMO) [1, 2]. It consists of a Central Detector (CD), a water Cherenkov detector and a Top Tracker (TT). The CD contains 20 kton of Liquid Scintillator (LS), which acts as a target for the interaction of atmospheric neutrinos.

The atmospheric neutrinos are generated through the decay of particles produced by the interaction of cosmic rays with the Earth's atmosphere. Thanks to matter effect, atmospheric neutrinos can also contribute to the NMO sensitivity.

In this study, atmospheric neutrino events are simulated with GENIE as generator and Geant4 for detector simulation.

2. Atmospheric neutrino selection at JUNO

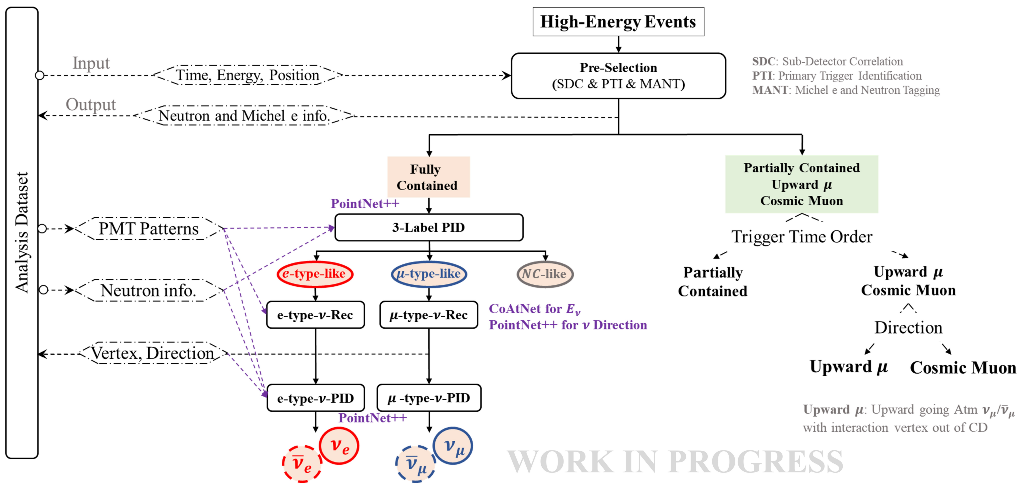

Figure 1: Strategy of atmospheric neutrino event selection at JUNO.

The strategy of atmospheric neutrino event selection at JUNO is depicted in figure 1. First, for high-energy events with reconstructed energy exceeding 500 MeV, Sub-Detectors Correlation (SDC), Primary Trigger Identification (PTI), and Michel electron And Neutron Tagging (MANT) are employed to facilitate the classification of fully-contained events and others. For the remaining events, further classification is made using time and direction information. For fully-contained events, their flavor can be identified, and energy and direction can be reconstructed using different machine learning models. Subsequently, Particle Identification (PID) is performed based on the flavor identification and reconstruction to distinguish between neutrinos and antineutrinos.

2.1 Cosmic muon suppression

Based on the different energy deposition positions of atmospheric neutrinos in the JUNO detector, they can be categorized into two groups: Fully-Contained (FC) and Partially-Contained (PC) events. An FC event is characterized by the atmospheric neutrino interaction vertex being

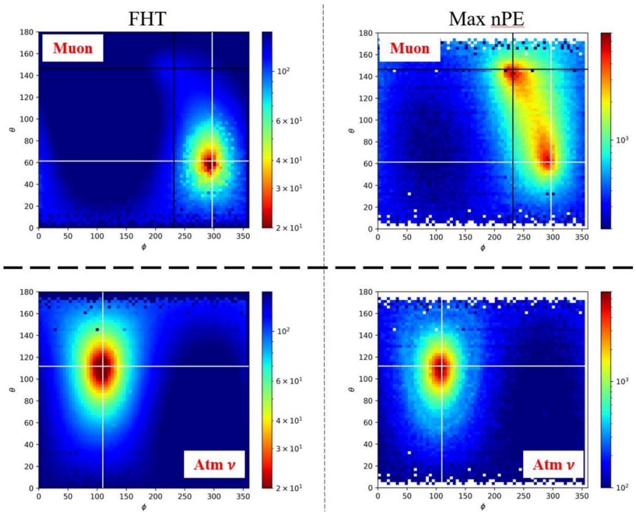

Figure 2: The PMTs patterns of First Hit Time (FHT) and maximum number of photoelectrons (Max nPE) from muon and atmospheric neutrino PC event.

within the Central Detector (CD) and the absence of any Water Pool (WP) triggers, making it distinguishable from cosmic muons. In contrast, PC events also have their interaction vertex within the CD, but they can deposit energy in the WP, leading to WP triggers. The main difference between muon and PC events is the location of light emission. In the case of a PC event, light emission begins inside the CD, typically resulting in a single cluster of large PMT hits, as depicted in figure 2. On the contrary, cosmic muons generally produce two clusters as they traverse the detector from the exterior. Consequently, PMT hit patterns can be used to discriminate between PC and cosmic muons events. Moreover, the direction and temporal sequence of triggers in the CD and WP differ, which further helps in the identification and suppression of cosmic muons for PC event classification.

2.2 Flavor identification

Atmospheric neutrino information such as flavor and incident direction are embedded in the PMTs waveforms. For example, as shown in figure 3, charged leptons and hadrons from the charged current interaction of atmospheric neutrino in LS can cause different FHT patterns of large PMTs. At the same time, the topology is also different between the track of muon and shower from electron.

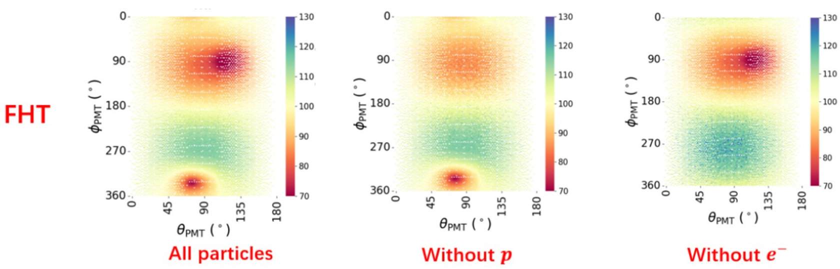

Figure 3: The FHT pattern of large PMTs from an interaction exemplar of ν_e : $^{12}\mathrm{C} + \nu_\mathrm{e} \to ^{11}\mathrm{C} + \mathrm{e}^- + \mathrm{p}^+$.

Therefore, we can extract the features from the PMT waveforms as input to machine learning models which can be used to perform flavor identification.

2.3 Neutrino and antineutrino discrimination

In addition to the PMTs hitting pattern, the multiplicity of captured neutrons can also differ for neutrinos and antineutrinos. According to the conservation of lepton number and charge, antineutrinos are inclined to produce more neutrons than neutrinos through charged current interactions. Moreover, the production of captured neutrons is influenced by final-state interactions (FSI) and secondary processes of final-state hadrons. In figure 4, the difference in multiplicity distribution between neutrinos and antineutrinos diminishes with FSI. Furthermore, final-state hadrons from neutrino can carry more kinetic energy than those from antineutrino, and captured neutrons are primarily produced by hadronic secondary processes in the case of high neutrino energy. Consequently, the difference in multiplicity distribution between neutrinos and antineutrinos can also diminish after detector simulation. However, the multiplicity of captured neutrons still retains the capability to distinguish between neutrinos and antineutrinos.

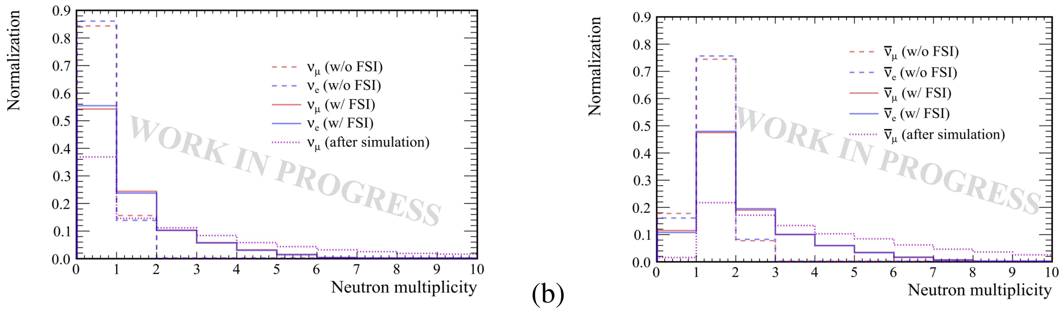

Figure 4: The multiplicity distribution of captured neutron from neutrino (a) and antineutrino (b).

3. Summary

Event selection plays a crucial role in the NMO analysis of atmospheric neutrino. In this study, we have developed a strategy for the event selection of atmospheric neutrinos at JUNO. Initially, we use triggers information from sub-detectors and PMTs hitting patterns to suppress cosmic muon events. Subsequently, for FC events, we extract the features of PMTs waveforms and put them into the machine learning models for flavor identification and reconstructing energy and direction. Finally, we perform a more precise particle identification to select candidates of all types of neutrinos.

References

[1] Angel Abusleme *et al.* [JUNO Collaboration], "JUNO physics and detector", Prog. Part. Nucl. Phys. 123, 103927 (2022).

[2] Fengpeng An *et al.* [JUNO Collaboration], "Neutrino Physics with JUNO", J. Phys. G. 43, 030401 (2016).