JUNO is a 20 kton multi-purpose underground neutrino detector, currently under construction in China, whose primary goal is the identification of the neutrino Mass Hierarchy. Large fiducial volume and excellent energy resolution allow also the study of sources like atmospheric neutrinos.

1. JUNO detector

JUNO main goal: determine neutrino Mass Hierarchy (MH)

- Different oscillation pattern in reactor \( \bar{\nu}_e \) spectrum, depending on the hierarchy
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  - Central detector: 20 kt liquid scintillator
  - 35,4 m diameter sphere
  - Double photosensors system 16,000 x 20” PMTs; 25,000 x 3” PMTs
  - Outer water pool Cherenkov veto, 2,400 x 20” PMTs
  - Top Tracker plastic scintillator stripes

2. Atmospheric neutrinos

- Produced in an air shower, initiated by a primary cosmic ray which hits the atmosphere.
- Almost entirely composed of \( \nu_e \) and \( \bar{\nu}_\mu \) (both \( \nu_e \) and \( \bar{\nu}_\mu \)).
- Main sources:
  - \( \nu_\pi \) and K decays
  - \( \nu_e \) : subsequent \( \mu \) decays \( \nu_\mu / \nu_e \approx -2 \), decreases as the \( \mu \) energy gets larger.
- Flux from \( \pi \rightarrow \mu \rightarrow \nu_\mu \cdot dN_\nu / dE_\nu \approx N_\nu (E_\nu) \cdot \frac{1-Z_{\nu\mu}}{1+B_{\nu e\nu}\cos^2 \theta_{\nu e}/E_\nu} + 0.635 \cdot \frac{1+B_{\nu e\nu}\cos^2 \theta_{\nu e}/E_\nu}{1+B_{\nu e\nu}\cos^2 \theta_{\nu e}/E_\nu} \)

3. MC simulation

The study is based on simulated Monte Carlo events, processed in 2 main steps:

Step 1:
Neutrino interaction generation in the detector:
- Max \( \nu_e \) energy: 20 GeV
- Total events: 500k \( \nu_e + \nu_\mu \) (and antineutrinos).
- Software: GENIE, Neutrino Monte Carlo Generator.

Step 2:
Propagation of secondary particles by a GEANT4-based simulation inside JUNO.

4. \( \nu_e - \nu_\mu \) discrimination

According to the \( \nu \) interaction, there are 3 classes of events:
- \( \nu_\mu \) CC interaction: \( \nu_\mu + \frac{1}{2} \bar{\nu}_e / p \rightarrow \mu^+ + X \), event elongated in time because of \( \mu \) ability to travel long distances and its late decay;
- \( \nu_e \) CC interaction: \( \nu_e + \frac{1}{2} \bar{\nu}_e / p \rightarrow e^- + X \), point-like event because of the short \( e^- \) track;
- NC interaction: \( \bar{\nu}_\mu + \frac{1}{2} \bar{\nu}_e / p \rightarrow \bar{\nu}_\mu + X \), geometry of event depends on the particles produced.

A time residual – based variable \( \tau_{res} \) is defined for each hit on the 3” PMT system (small time resolution): \( \tau_{hit} = \tau_{res} = \frac{t_{hit} - t_{hit0}}{t_{hit0}} \), where:
- \( \tau_{hit} \) = arrival time on the \( i \)-th PMT;
- \( t_{hit0} \) = speed of light inside the scintillator;
- \( R_{hit0} \) = distance of the \( i \)-th PMT from the vertex \( V \) of the event.

5. Cosmic \( \mu \) rejection

- Cosmic \( \mu \) can mimic the signal topology;
- Expected to produce an high amount of light both in the water cherenkov \( \mu \) veto (WV) and in the central detector (CD).
- \( \rightarrow \) Apply selection to \( \mu \) events not tagged by veto system: \( \text{NPE} < 60 \) in WV and \( \text{NPELPMT} > 100K \) in CD.
- Tested on 10000 cosmic \( \mu \) in JUNO with full sim., 0 passed the selection.

6. Spectrum reconstruction

The algorithm has been tested on an independent 10k \( \nu \) sample.

Work in progress:
- Study of residual contamination;
- Evaluation of systematic effects;
- Spectrum distortion introduced by flavor oscillations.