Realtime Multi-Messenger Program of KM3NeT

D. Dornic[1], F. Huang[2 *], M. Lincetto[1] on behalf of the KM3NeT collaboration
[1]Aix Marseille Univ, CNRS/IN2P3, CPPM, France; [2]Multidisciplinary Institute Hubert Curien, CNRS, France
* feifei.huang@iphc.cnrs.fr

Motivation

- Realtime neutrino analysis framework goals:
  - Receive external EM/GW/ν alerts; perform online neutrino correlation search
  - Send online (all flavor, all-sky) neutrino alerts (e.g. multiplets, HE) to external observatories for follow-up
- Requires: Fast online reconstruction & fast selection of high-purity neutrino sample (for further analysis)

KM3NeT Detector

- Two detectors ORCA and ARCA, target neutrino & science:
  - ORCA: (GeV - TeV) atmospheric ν, low energy astronomy, ...
  - ARCA: (TeV - 10 PeV) diffuse astrophysical ν, point source, ...
  - Both: MeV CCSN
- Current deployed: 2 lines of ARCA, 6 lines of ORCA

Online Analysis Framework

- All modules implemented except correlation, cross-match search and alert sending (all current under development)
  - cascade reconstruction turned off for now

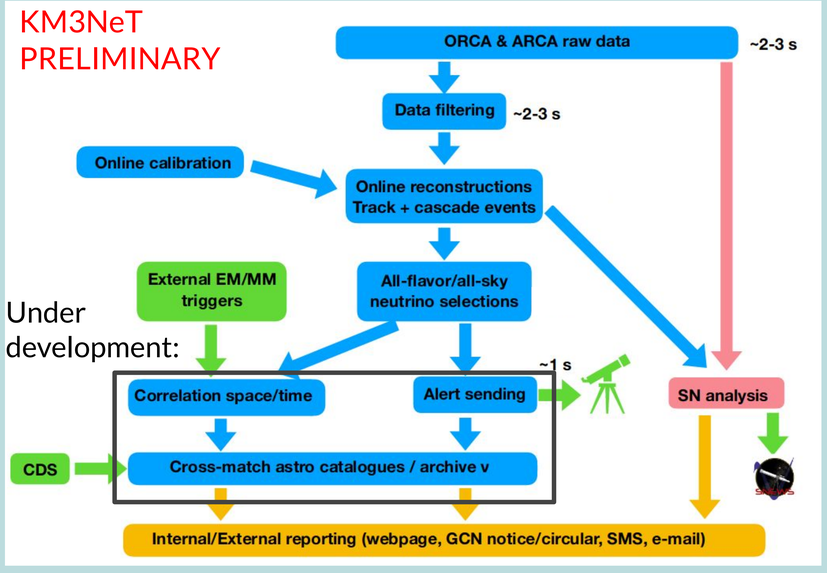

Fig. 1. Overview of the online analysis framework. CDS: Astronomical Data Center with catalogues of the astronomical objects outside the solar system.

Online Reconstruction

- Same fit algorithm as offline reconstruction
- Online track[1] + cascade reconstruction for 6-line ORCA is fast: ~1s (track: 0.1s, cascade: ~1s) /event
- 7-line ORCA's median track resolution at the online selection at 5% muon contamination:
  - ~ 1° at 1 TeV; 8° at 10 GeV

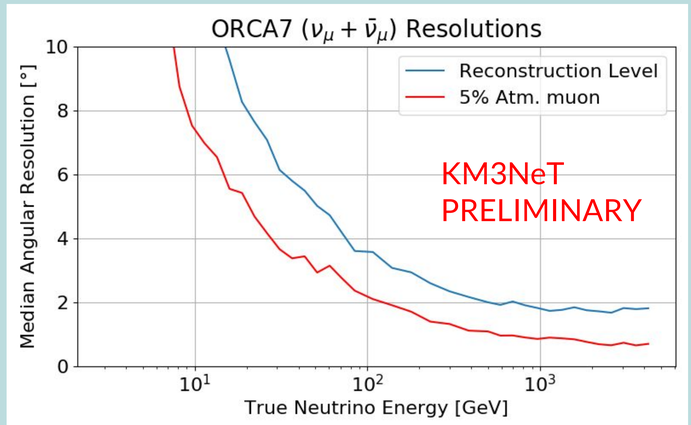

Fig. 2. Median angular resolution vs. true neutrino energy, where resolution is the angle difference between the direction of the reconstructed track and the true neutrino.

Time Performance

On average **4 seconds** from filtering raw PMT data to neutrino classification (current 6-line ORCA):

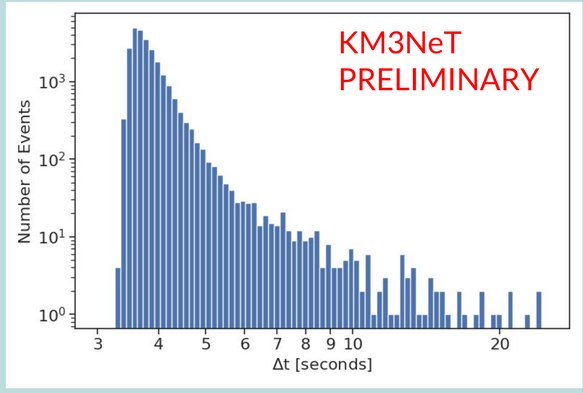

Fig. 4. The time it takes for raw PMT hits to go through data filtering, track reconstruction and event classification.

Online Neutrino Selection

- Goal: Fast online selection of a high-purity neutrino sample
- Method:
  - Train a classifier using Gradient Boosting Decision Tree (in LightGBM[2]) for seperating ν from cosmic muons
    - Trained with 7-line ORCA MC in 3 GeV - 5 TeV
  - Each reconstructed event is evaluated with a classification score indicating how likely it's a neutrino; time ~ 0.1s/event
- Preliminary selection by cutting above certain classification score
  - At 5% muon contamination rate (i.e. 95% purity), background muon reduced by 10^5 times while keeping over 30% of ν_μ CC
  - More classifier optimization possible

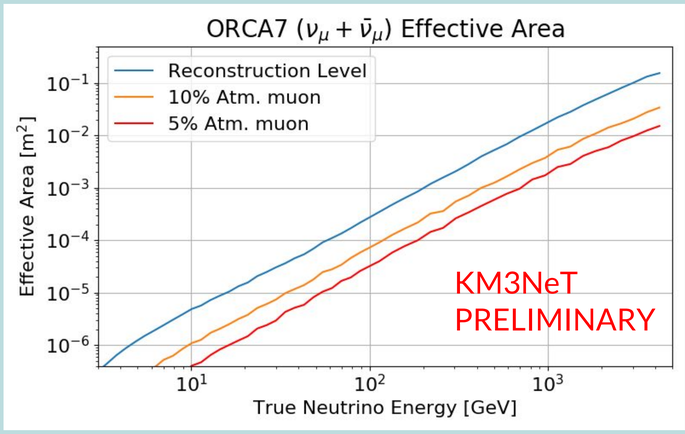

Fig.3. Effective Area vs. true neutrino energy at the reconstruction level, at neutrino selection with a 10% and 5% atmospheric muon contamination rate.

Summary & Outlook

- KM3NeT has fast online event reconstruction and neutrino classification
- Preliminary online selection using cuts on classification score can select high purity neutrino samples (~ 95% or even higher with stricter cuts)
- Alert receiving, sending and online correlation search modules are under development

References:
1. JGandalf track reconstruction: https://doi.org/10.22323/1.301.0950
2. https://lightgbm.readthedocs.io/en/latest/