Real-time Multi-Messenger Analysis Framework of KM3NeT

W. Assal[1], D. Dornic[1], F. Huang*[1], E. Le Guirriec[1], M. Lincetto[1,2], G. Vannoye[1,3] on behalf of the KM3NeT collaboration

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Motivation

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

Online Analysis Framework

- Response time ~ O(10 s)
- Event processing in the ORCA & ARCA shore station common analysis framework for data of both detectors
- Fully operational in ORCA6, in implementation in ARCA6
- Scalable with detector configuration
- For CCSN search, see dedicated poster by V. Kulikovskiy

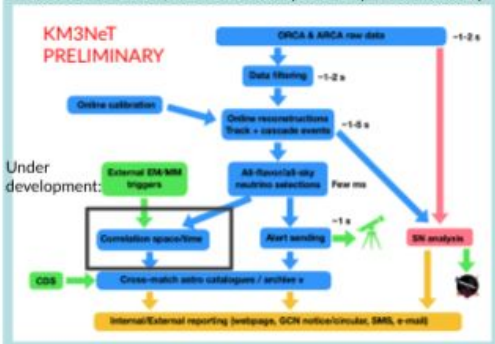

Fig. 1. Overview of the online analysis framework.
SNEWS: The SuperNova Early Warning System[1], CDS: Astronomical Data Center with catalogues of the astronomical objects outside the solar system.

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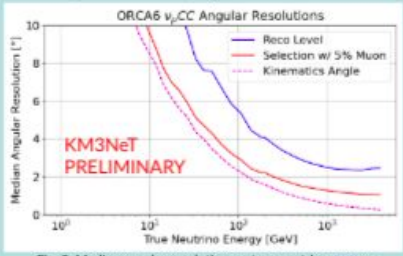

Fig. 2. Median angular resolution vs. true neutrino energy

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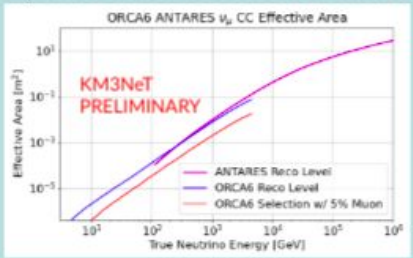

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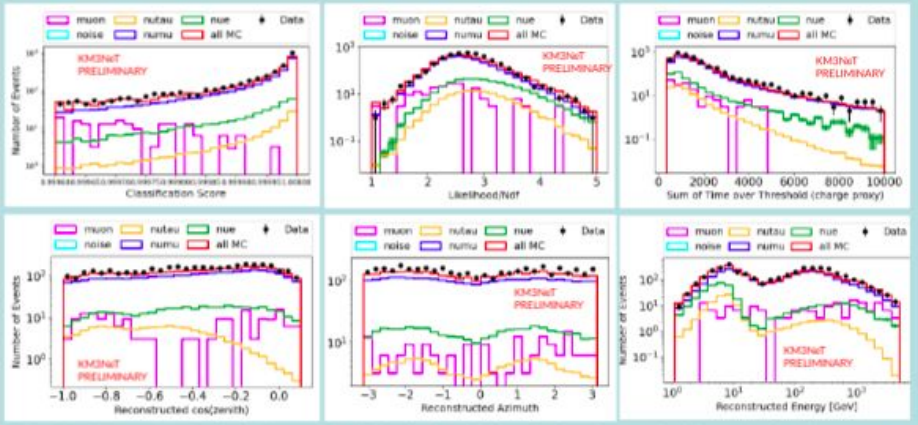

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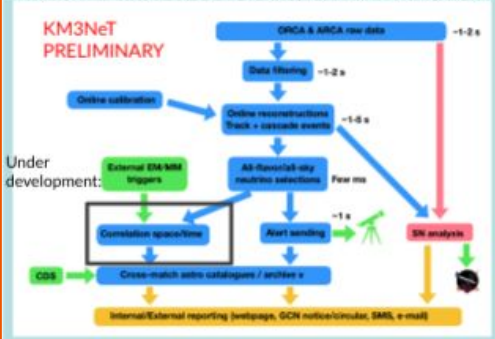

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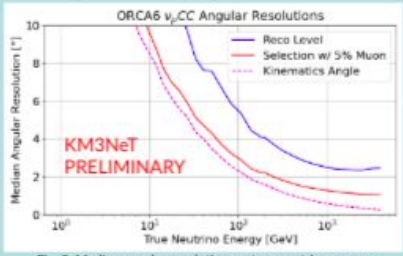

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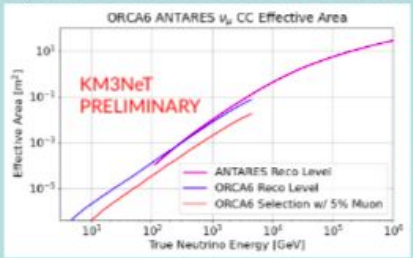

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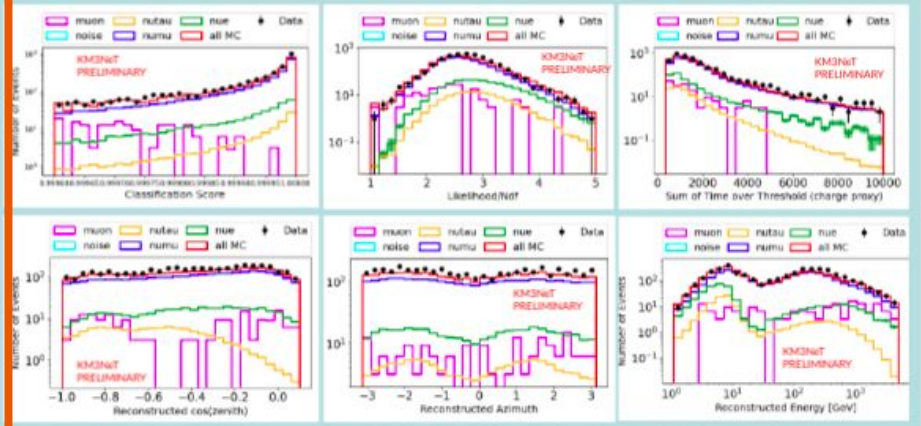

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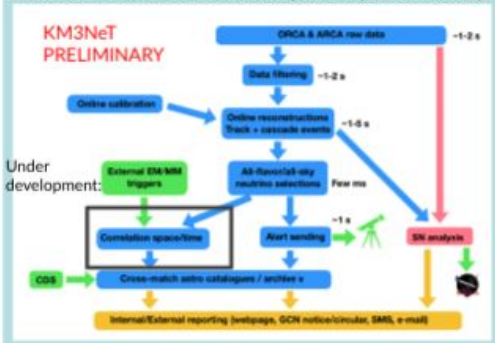

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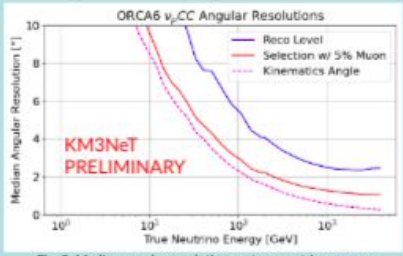

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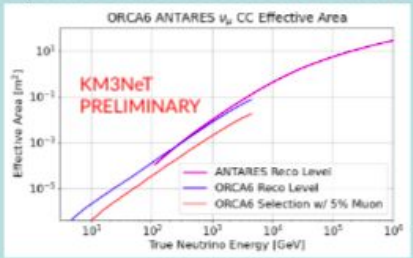

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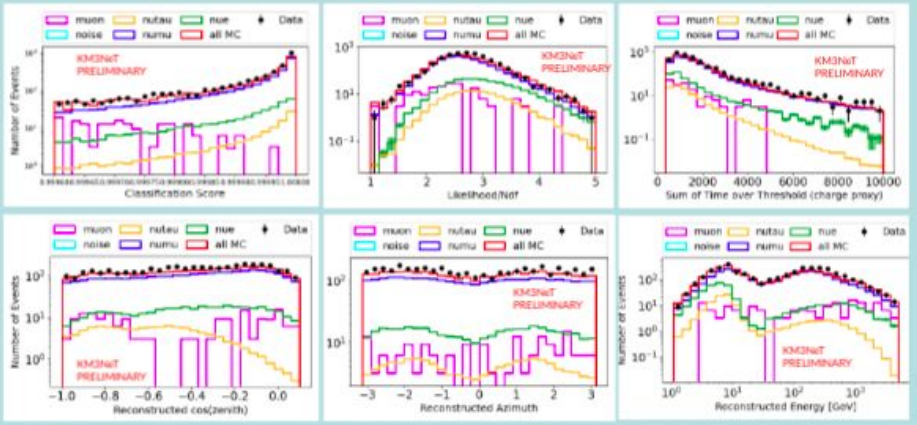

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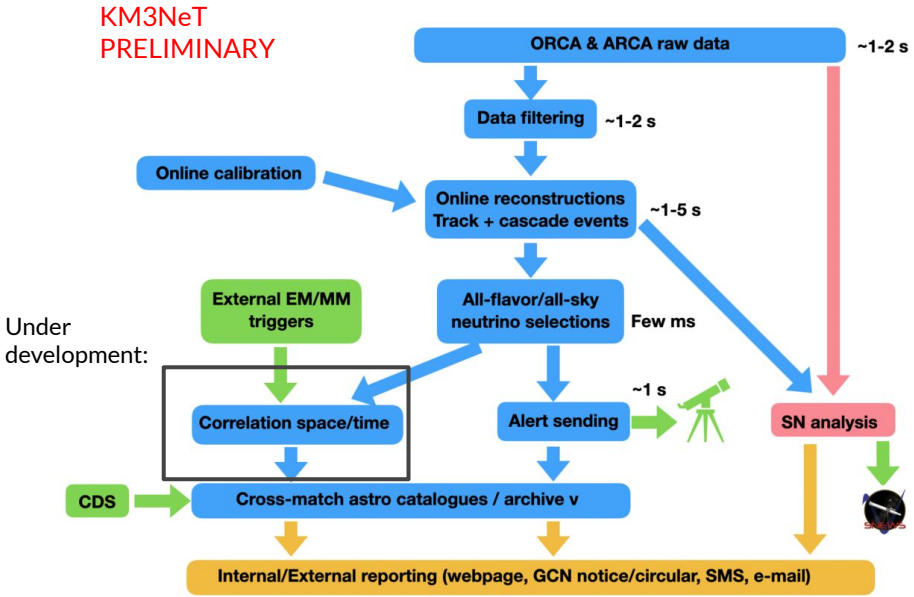

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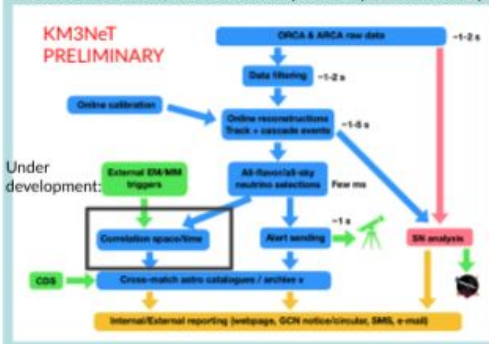

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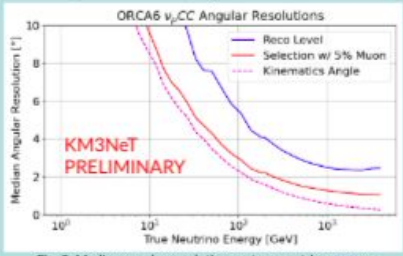

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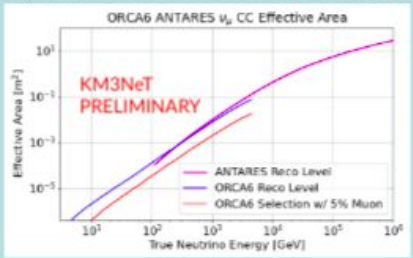

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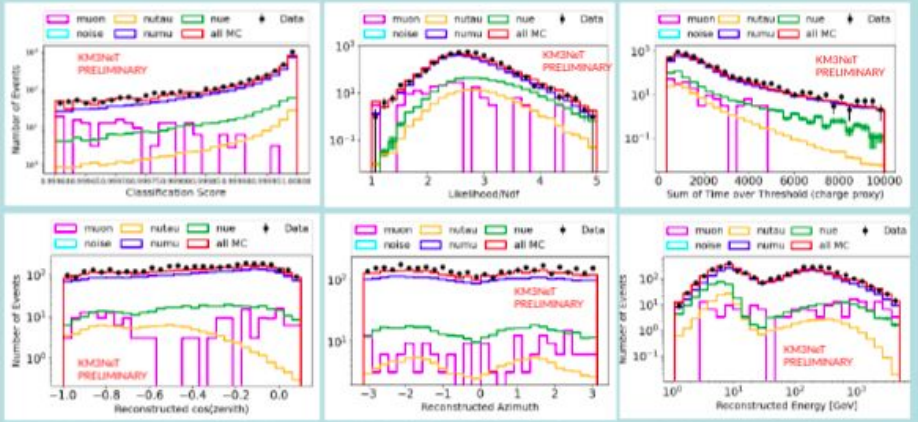

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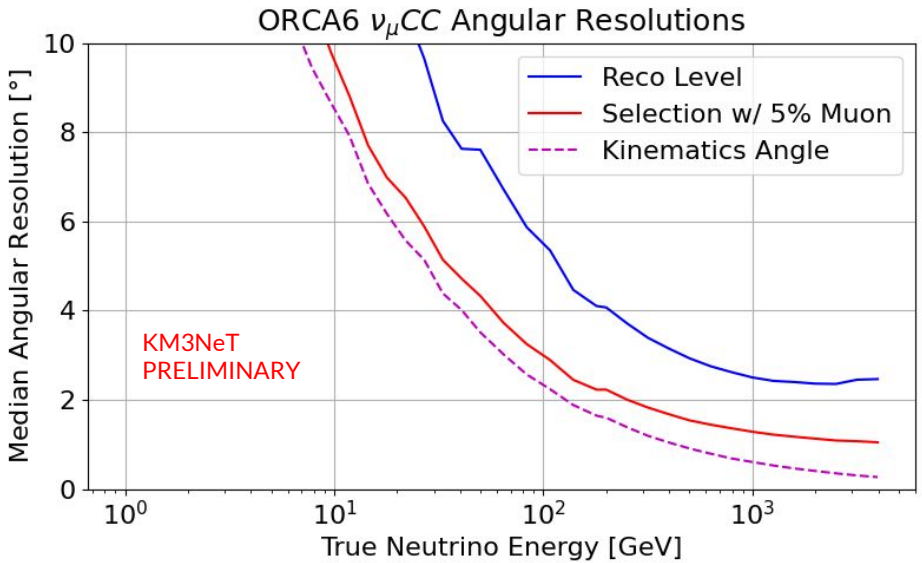

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- Preliminary track selection selects events with well reconstructed events:
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  - ~ 1° at TeV scale
- Resolution will further improve as we build more strings

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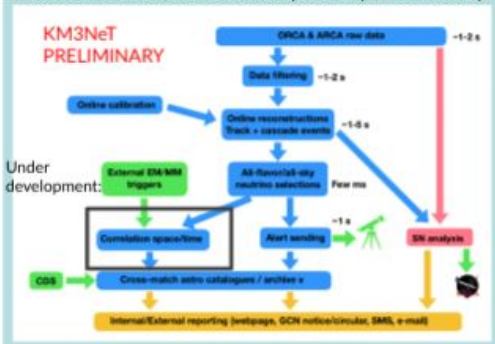

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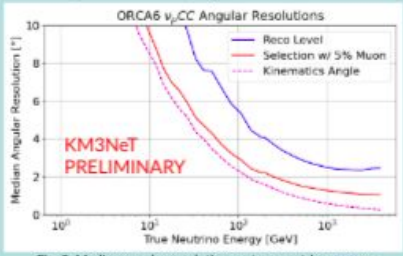

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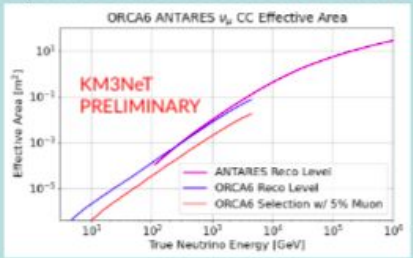

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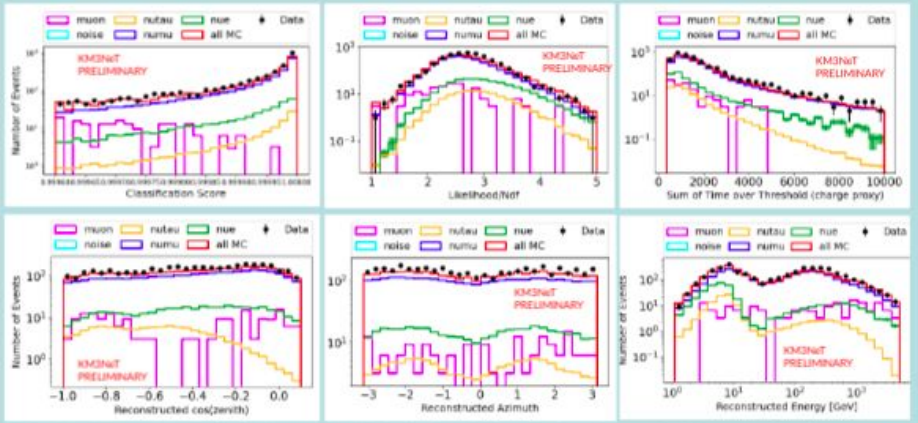

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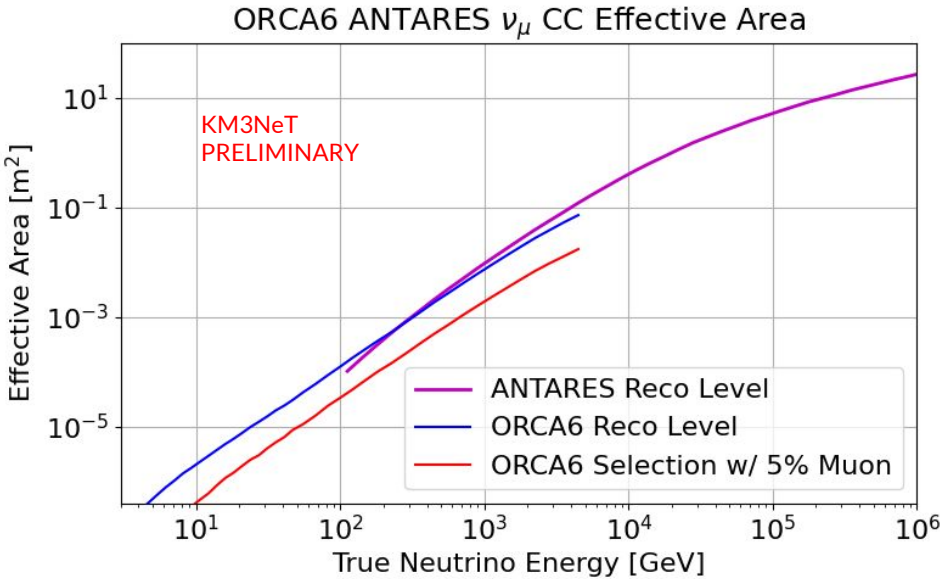

- Six lines of ORCA already has comparable performance as ANTARES
- The preliminary track selection based on online classification select a 95% pure sample

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  - Send online (all flavor, all-sky) neutrino alerts (e.g. multiplets, HE)
- Requires: Fast online reconstruction & fast selection of high-purity neutrino sample

Online Analysis Framework

- Response time ~ O(10 s)
- Event processing in the ORCA & ARCA shore station common analysis framework for data of both detectors
- Fully operational in ORCA6, in implementation in ARCA6
- Scalable with detector configuration
- For CCSN search, see dedicated poster by V. Kulikovskiy

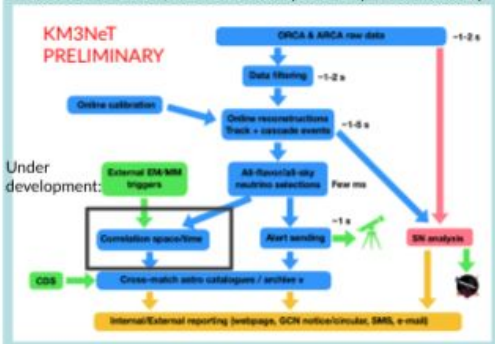


Fig. 1. Overview of the online analysis framework.
SNEWS: The SuperNova Early Warning System[1], CDS: Astronomical Data Center with catalogues of the astronomical objects outside the solar system.

Online Reconstruction

- Same fit algorithms as offline reconstruction
- Reconstruction of tracks[2] and cascades[3] separately
- Fast: ~1s (track: 0.1s, cascade: ~1s) /event ORCA6
- Median angular resolution at preliminary selection for numu CC events (limited by size of the detector): 9° at 10 GeV, up to 1° at TeV

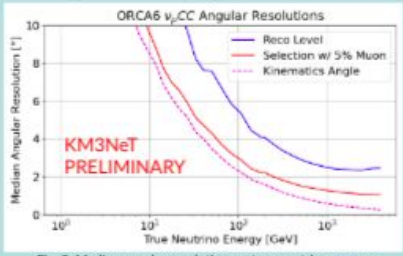


Fig. 2. Median angular resolution vs. true neutrino energy

Online Neutrino Selection

Comparable Effective Area of ORCA 6 & ANTARES:

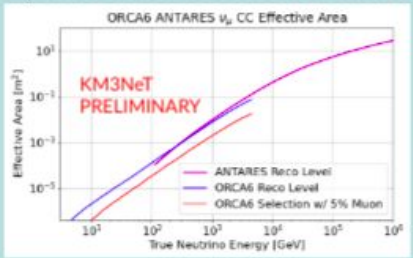


Fig.3. Effective Area vs. true neutrino energy at the reconstruction level, at neutrino selection with 5% atmospheric muon contamination rate.

Online Neutrino Selection

- Goal: Fast online selection of a high-purity neutrino sample
- Classification model trained with gradient boosting[4] decision tree
- Each event classified with a score indicating probability of neutrino; process time ~ 0.01s
- Preliminary selection at 5% muon contamination (not yet optimized for transient analysis), background muon reduced by 10^6 times & keeping 38% of the upgoing ν_μ CC signal. ~ 10 neutrinos (8.4 numu)/day in ORCA6
- First test on ORCA6 data:

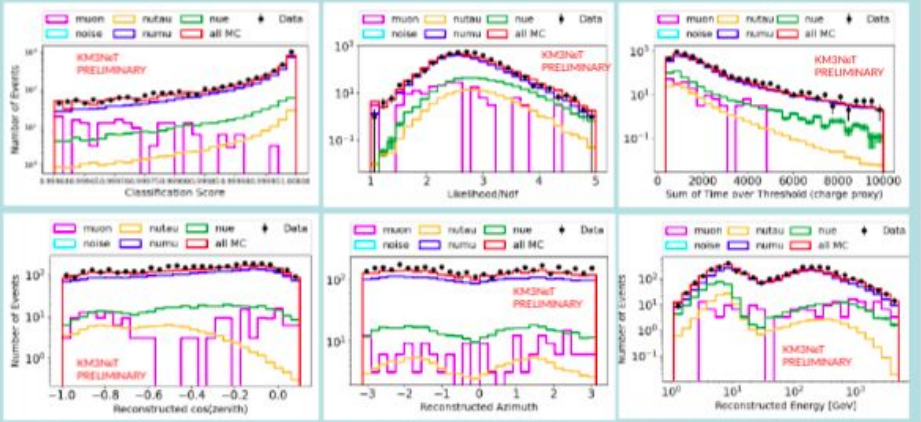


Fig.4. Data/MC comparisons for classification score, the likelihood/ndf, sum ToT (proxy for charge), reco. cos(zenith), reco. azimuth, and reco. energy

Summary & Outlook

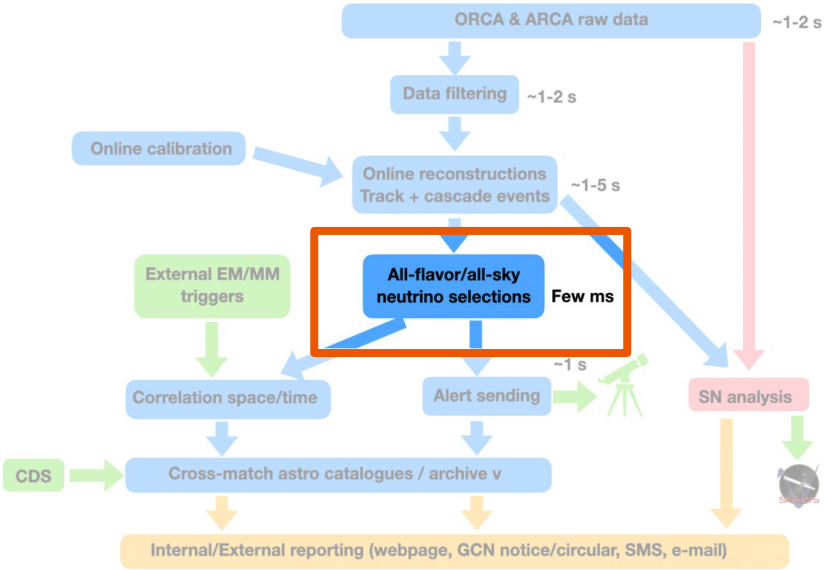
- Fast online event reconstruction and classification, framework response time O(10 s), alert receiving, sending ready
- Preliminary online selection in place with high purity neutrino sample
- Starting online analysis now & alert sending beginning in 2022

References

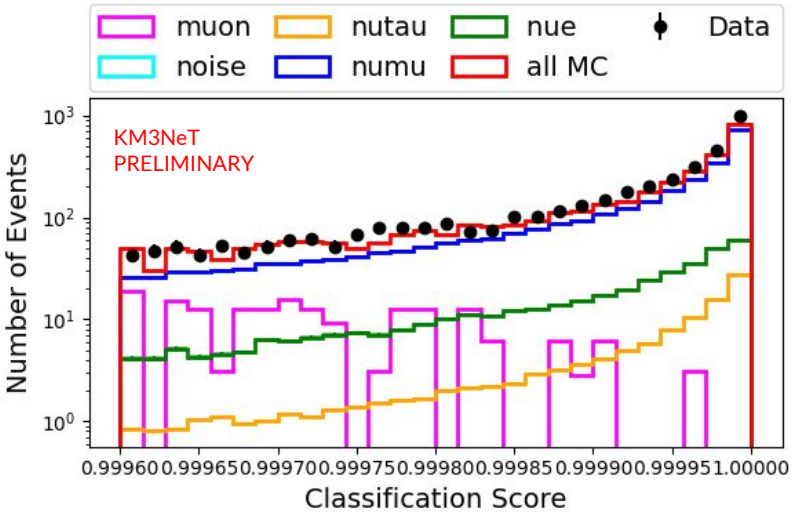
1. P. Antonioli, et al., New J. Phys. 6 pp. 114 (2004)
2. K. Melis, A. Heijboer, M. De Jong, (KM3NeT Coll.) PoS (ICRC2017) 950 (2018)
3. A. Domi, PhD thesis http://hdl.handle.net/11567/985989 (2019)
4. T. Chen, & C. Guestrin, Proceedings Of The 22nd ACM SIGKDD International Conference On Knowledge Discovery And Data Mining pp. 785-794 (2016)

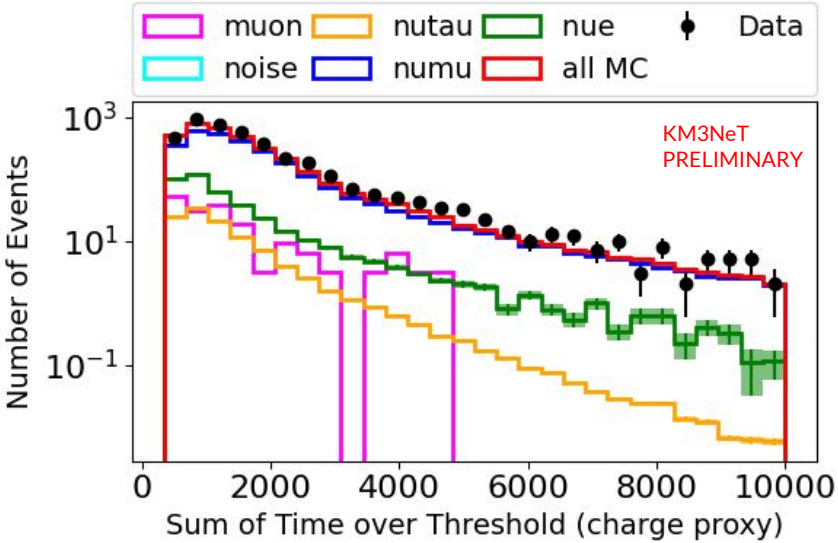
Event classification

- Goal: Fast online selection of a high-purity neutrino sample
- Classification model trained with gradient boosting[4] decision tree
- Each event classified with a score indicating probability of neutrino; process time ~ 0.01s
- Preliminary selection at 5% muon contamination (not yet optimized for transient analysis):
- ~ 10 neutrinos (8.4 numu)/day in ORCA6
    - background muon reduced by 10^6 times & keeping 38% of the upgoing ν_μ CC signal

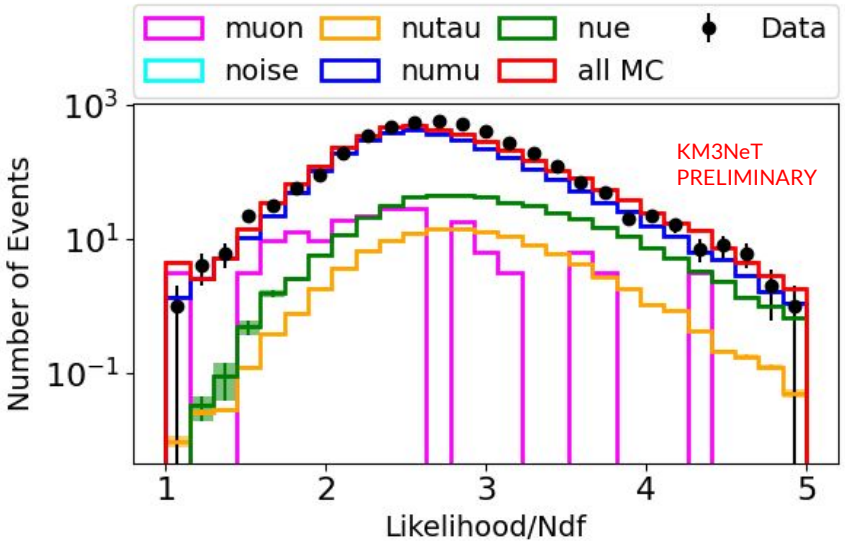


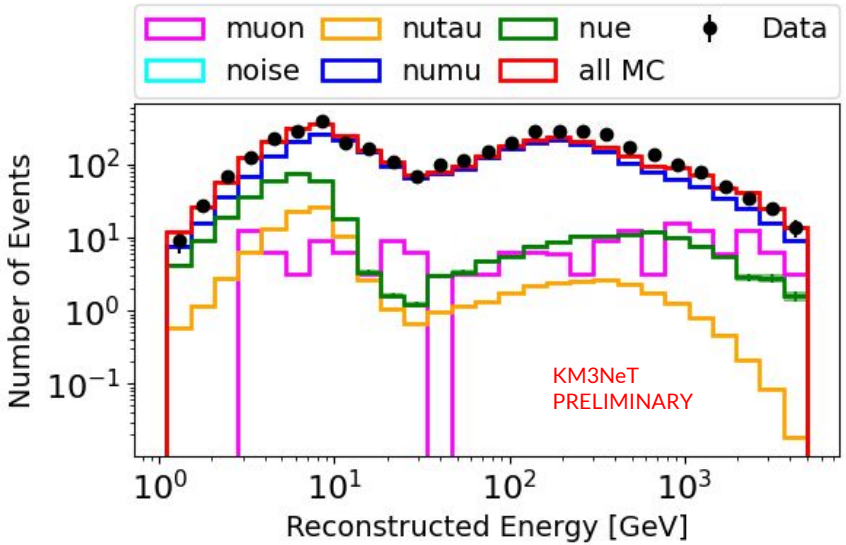
Event selection on 1-year ORCA6 Data





Event selection on 1-year ORCA6 Data





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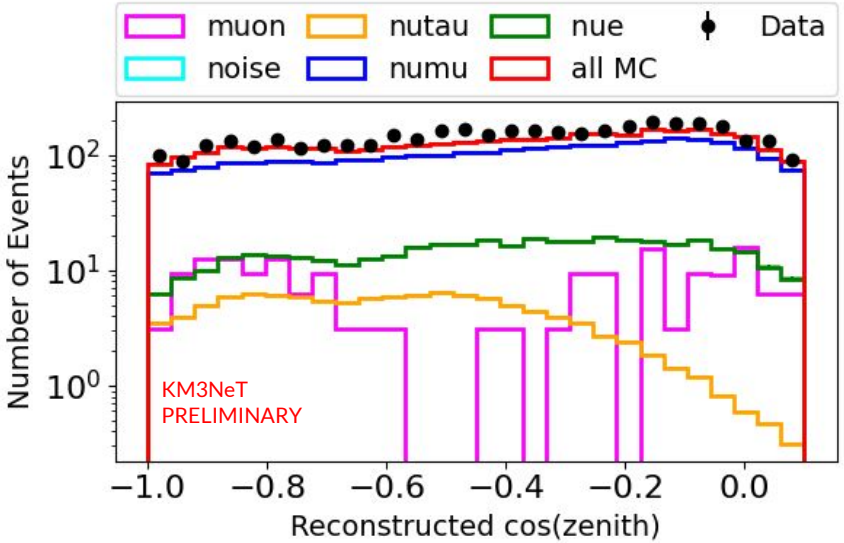

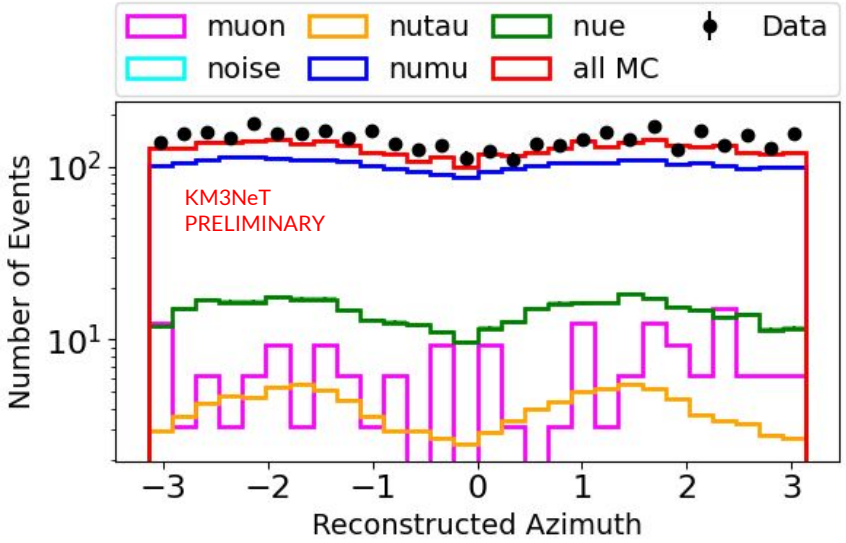

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