



Real-time Analysis in KM3NeT

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On behalf of the KM3NeT collaboration

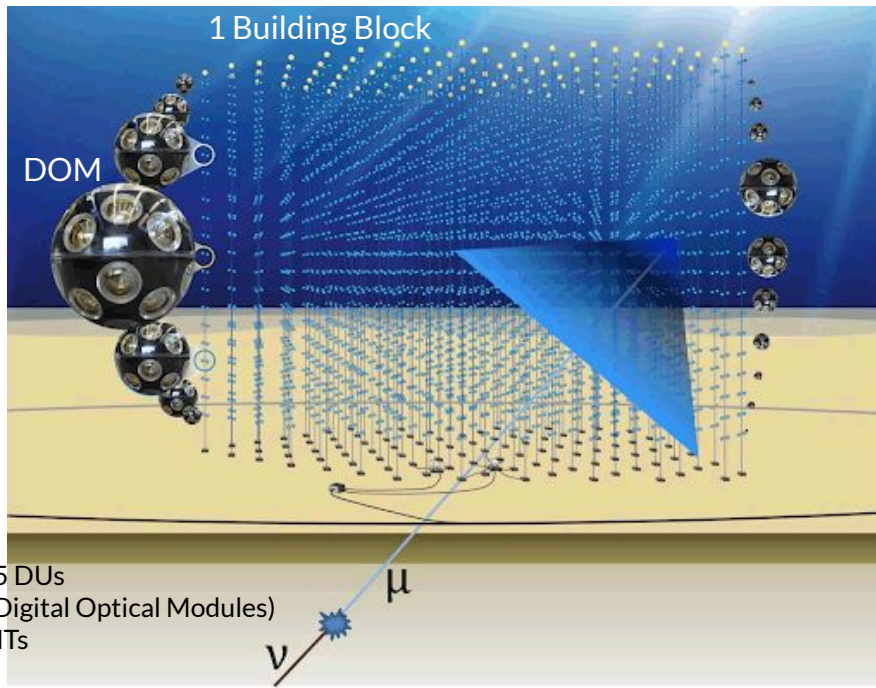
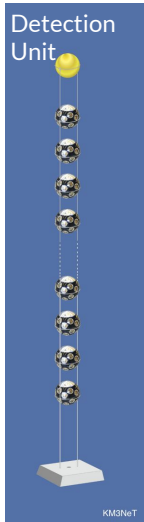




Outline

- Introduction to KM3NeT & science goals
- KM3NeT real-time analyses
- Summary

KM3NeT detector & science goals

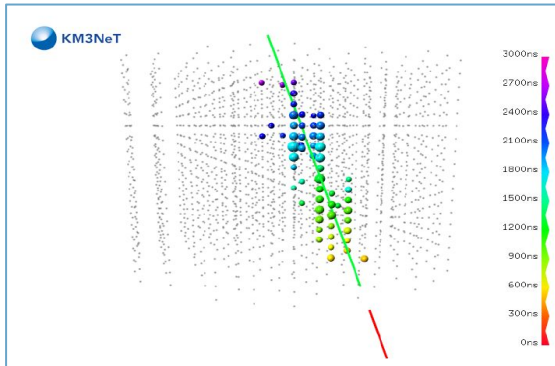


1 Building Block = 115 DUs
 1 String = 18 DOMs (Digital Optical Modules)
 1 DOM: 31 3-inch PMTs

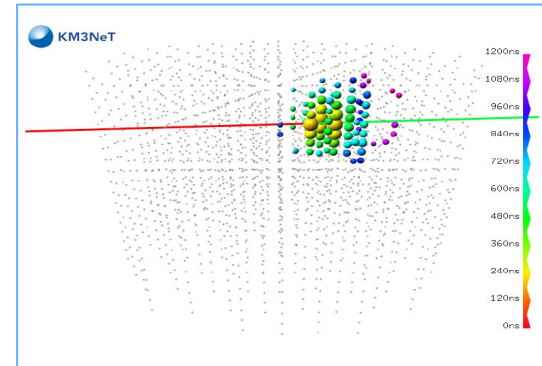
- ORCA: (GeV - TeV) goals:
 - Atmospheric neutrino oscillations, NMH, tau neutrino appearance, ...
 - Low energy astronomy for time/space clusters
 - e.g. winds of binaries, novae, choked GRBs, hidden jets in core-collapse supernova
- ARCA: (TeV - 10 PeV) goals in neutrino astronomy:
 - Neutrino search in galactic point-like sources
 - Diffuse neutrino flux,...
- Both ORCA & ARCA: MeV scale core-collapse supernova (CCSN) neutrinos

Neutrino Signatures

- **Track-like:** events with visible muon track, great pointing resolution for point-like neutrino source study
- **Shower-like:** events with no visible muon track.



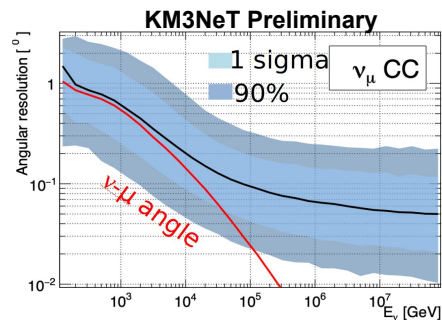
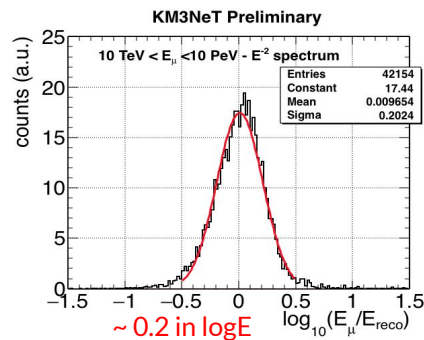
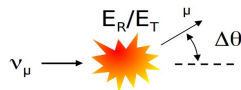
Simulated ν_μ CC track event



Simulated ν_μ NC shower event

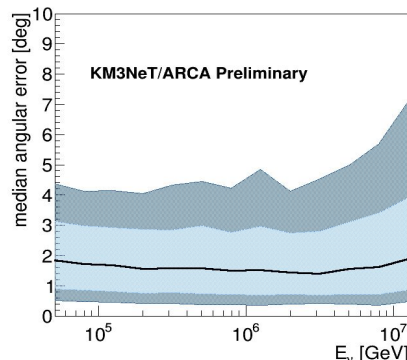
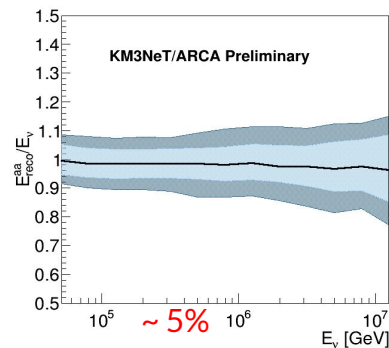
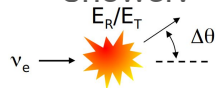
ARCA Reconstruction Resolutions

- Track:



Track median angular resolution < 0.1° at E > 100 TeV

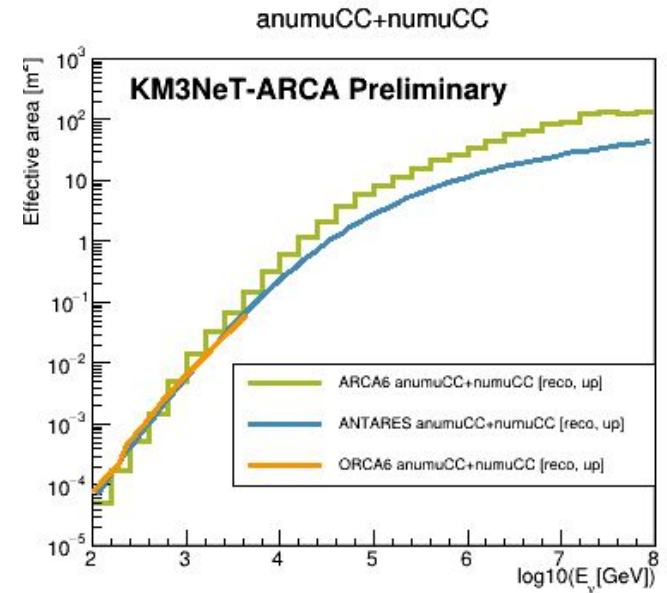
- Shower:



Shower median angular resolution < 2°

Detector Status

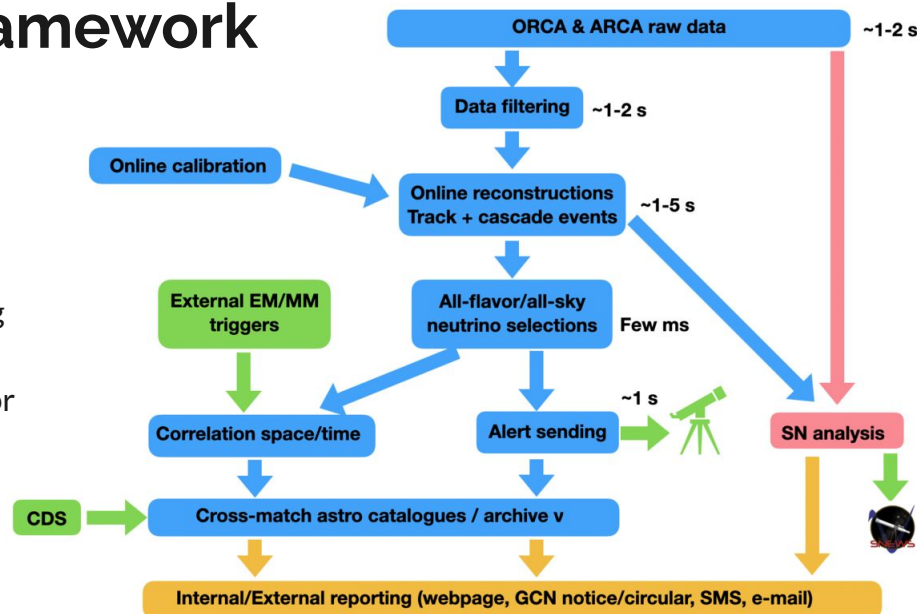
- ARCA: now have 8 DUs (ARCA8)
 - $E > 10$ TeV, ARCA6 already has significantly higher effective area than ANTARES
 - 15 more DUs in April 2022, and 12 more Autumn 2022
 - Full 223-DU expected ~ September 2026
- ORCA: 6 DUs since January 2020 (ORCA6)
 - ORCA6 already has similar effective area to ANTARES at TeV scale
 - Event display of ORCA6 neutrino candidates: [video link](#)
 - 7 additional DUs in November 2021, 10 additional DUs in 2022
 - Full 115-DU expected ~ October 2025



Effective area comparison of ARCA6, ORCA6, and ANTARES for reconstructed up-going $\nu_\mu CC + \bar{\nu}_\mu CC$ events (MC). Plot made by Rasa Muller

KM3NeT Real-time Alert Framework

- Two pipelines:
 - MeV supernova pipeline
 - GeV-PeV neutrino pipeline
- Goals:
 - Supernova (SN) monitoring for early warning
 - See Godefroy's talk
 - Receive external EM/GW/ ν alerts, search for correlated ν in KM3NeT
 - Send all flavor, all-sky neutrino alerts (e.g. multiplets, high energy) to external observatories for follow-up



Speed is essential for multi-messenger alert. We aim to be (nearly) real-time: Response $\sim O(10 \text{ seconds})$

* CDS: Astronomical Data Center with catalogues of the astronomical objects outside the solar system, SNEWS: SuperNova Early Warning System



Neutrino Alert Definitions

- **Current Alerts:** (Strict) Selection based only on neutrino event properties
- **Future Alerts:** Selection based on astrophysics properties



Current Alerts

- **(Strict) Selection based only on neutrino event properties**, e.g. classification scores, goodness of the fit, energy (“signalness”)
 - One alert stream by type of triggers (like HE/dir/VHE for ANTARES or bronze/gold for IceCube)
 - ORCA: mainly multiplet of events coming from the same direction in a given short time window
 - ARCA: mainly single VHE events
 - Typical alert rate: 1/month

* signalness: used by IceCube, probability of a neutrino candidate being of astrophysical origin



Future Alerts

- **Selection based on astrophysics properties**
 - Relax the neutrino alert selection and add cross-correlation with astro catalogues [x-match from the [CDS*](#)] + archive astro data point searches [[FINK](#) for ZTF/LSST + [astrogeo](#) for radio] ...
 - One alert stream by type of sources (like AGN/TDE/CCSN/GRB/Sun...)
 - Alert rate: 1 -2 /month

* CDS: Centre de Données astronomiques de Strasbourg

Alert Format

- Alert in [VO \(Virtual Observatory\) Event](#)
 - VOEvent is a standardized format to report observations of astronomical events
- Use [Comet broker](#) for alert distribution
- Status:
 - First Test of KM3NeT VOEvent with minimal content done, implementation of Comet broker and tests OK with dummy servers

VOEvent content:

- * ID
- * Detector (ARCA/ORCA)
- * Type of alert triggers
- * Multiplicity (i.e. number of events in given time and space windows)
- * Flavor
- * Energy
- * IsRealAlert
- * Time
- * RA, DEC, Longitude, Latitude
- * Error box 50%, 90% (TOC)
- * Reconstruction quality
- * Neutrino type (track / shower)
- * Probability of neutrino
- * Probability of astrophysical neutrino
- * Ranking



Alert Sending Plans

- Private internal alerts ~ Spring/Summer 2022
- Public alert sending expected around October 2022



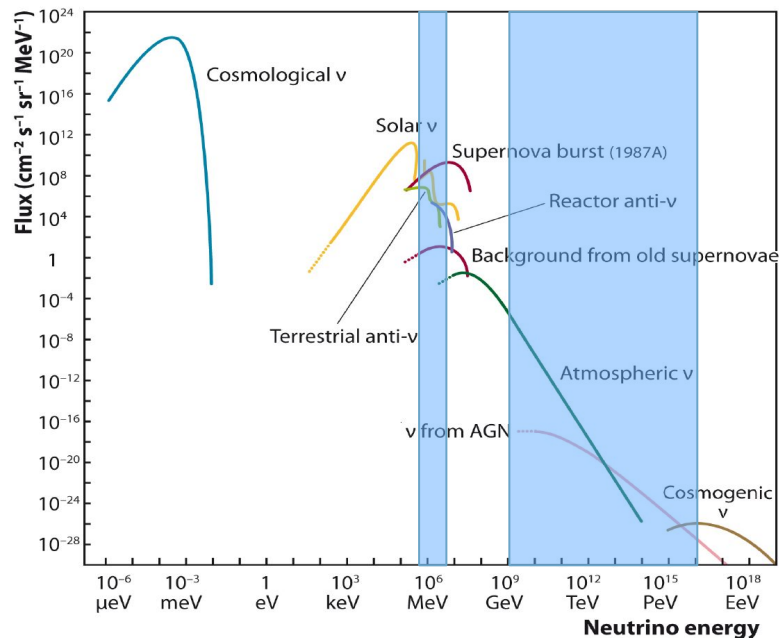
Summary

- KM3NeT is currently being constructed, will have excellent angular resolutions
- Real-time analysis in KM3NeT:
 - Fast online event processing ($< 10\text{s}$)
 - Alert Sender/Receiver mostly ready
 - Online analysis development underway
 - Alerts rate:
 - 1-2 /month for the physics triggers + 1/month on the neutrino triggers
 - Alerts plans:
 - Internal alerts ~ Spring/Summer 2022
 - Public alerts ~ October 2022



Backup

KM3NeT's energy of interest



[Fig. source link](#)

ORCA6 Track Resolutions

