KM3NeT Online Framework for Neutrino Alerts

Feifei Huang (IPHC, CNRS)
on behalf of the KM3NeT collaboration
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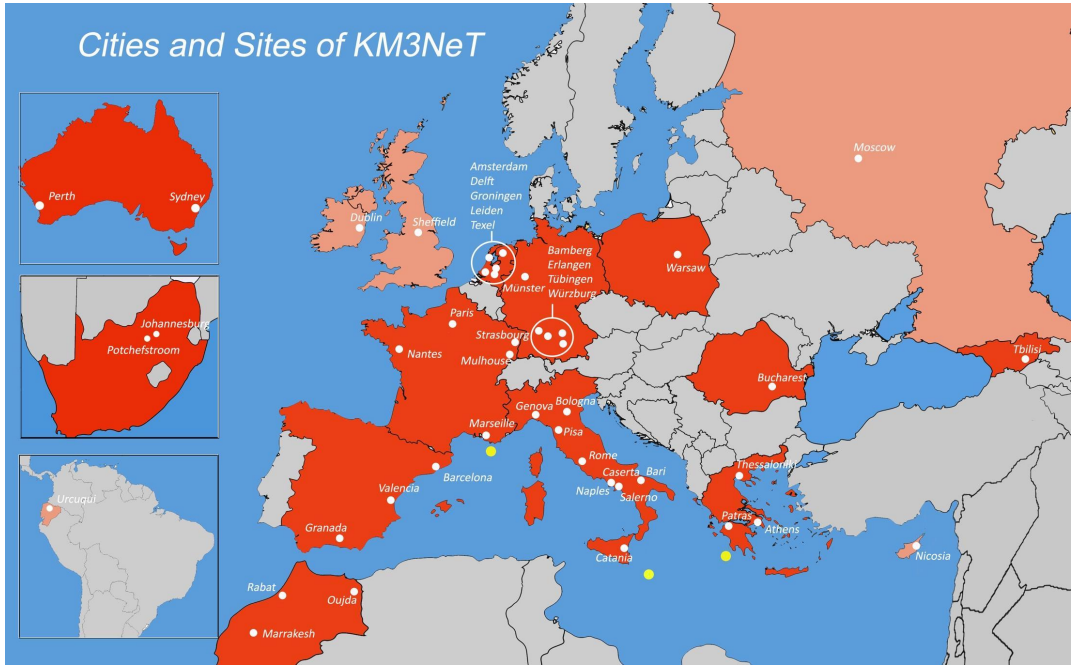
Outline

- Introduction to KM3NeT
- Neutrino Signatures
- Data Flow in KM3NeT
- Online Analysis Framework
  - Event Reconstruction
  - Event Classifier
  - Online Alert Sending and Reporting
- Summary & Outlook

The KM3NeT Collaboration



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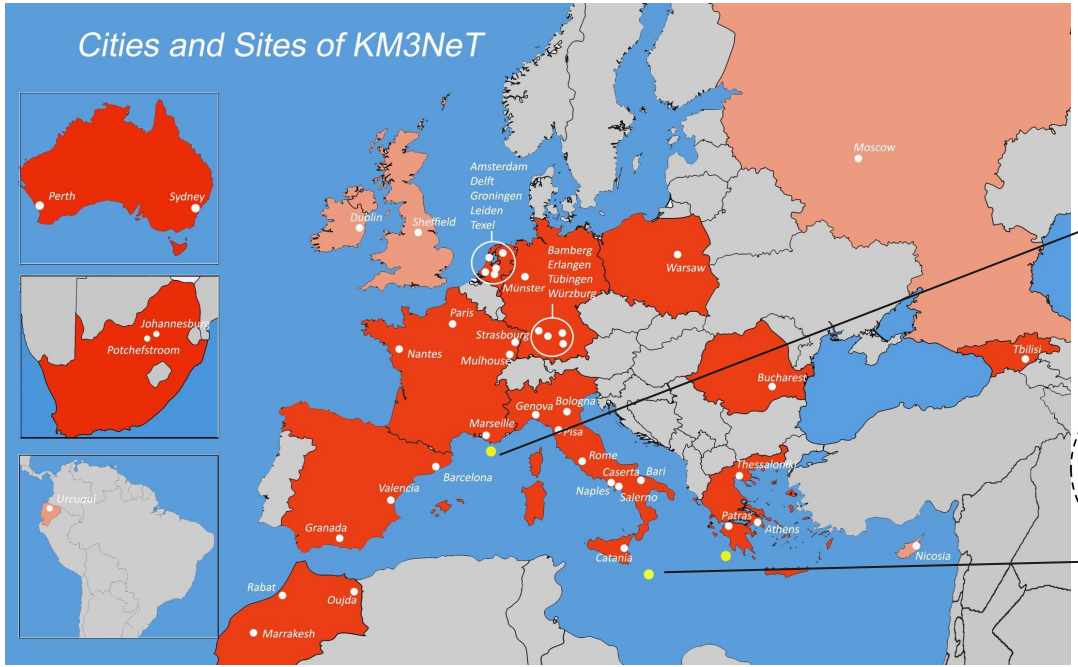
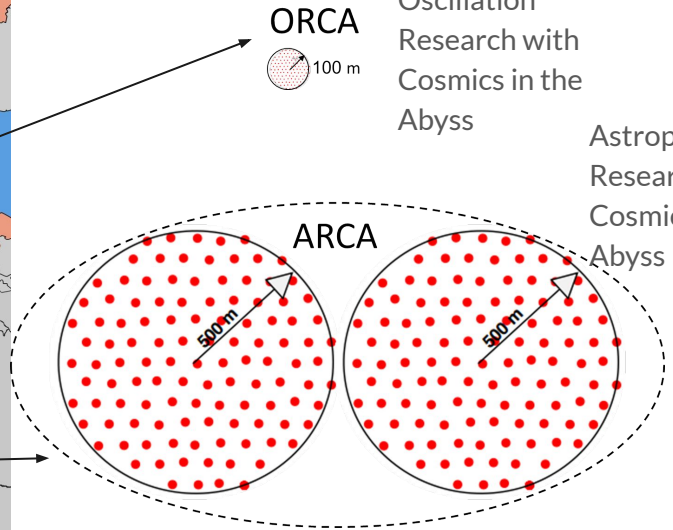
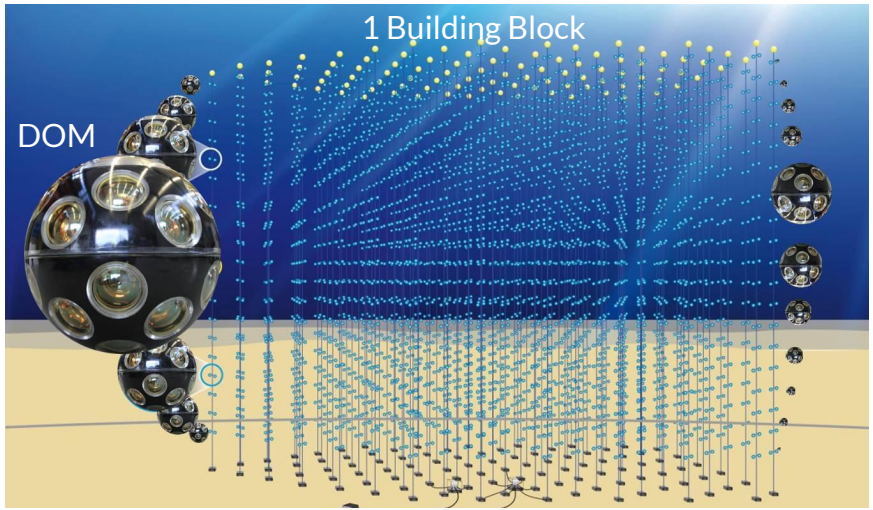




The KM3NeT Detector

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



- **ORCA**: low energy part
  - Full: 1 Building Block (115 strings) (LOI)
    - Phase-1: 6 strings
  - Spacing: 23 m (horizontal), 9 m (vertical)
  - Atmospheric neutrinos, 1 GeV ~ 1 TeV
  - Goals: neutrino mass hierarchy, oscillation parameters, tau neutrino appearance, supernova MeV neutrino, low energy astronomy, ...
- **ARCA**: high energy part, 2 building blocks
  - Full: 2 Building Blocks
    - Phase-1: 24 strings
  - Spacing: 90 m (horizontal), 36 m (vertical)
  - Astrophysical neutrinos, 1 TeV ~ 1 PeV
  - Goals: Point-like neutrino sources, diffuse flux...
- Currently deployed: 4 ORCA strings, 1 ARCA string

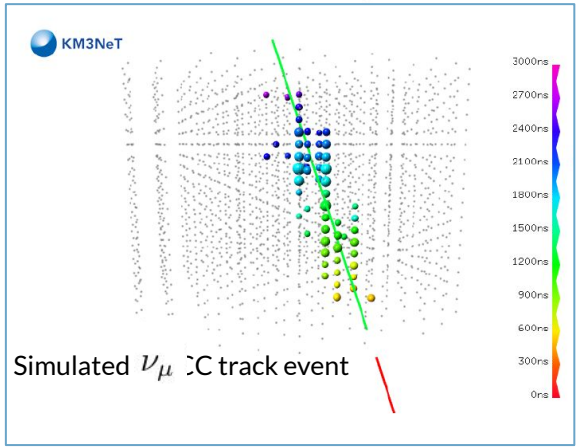
Neutrino Signatures

Track-like: events with visible muon track.

$$\nu_\mu + N \rightarrow \mu^- + X$$
$$\nu_\tau + N \rightarrow \tau^- + X$$

(N: nucleon
X: hadrons)

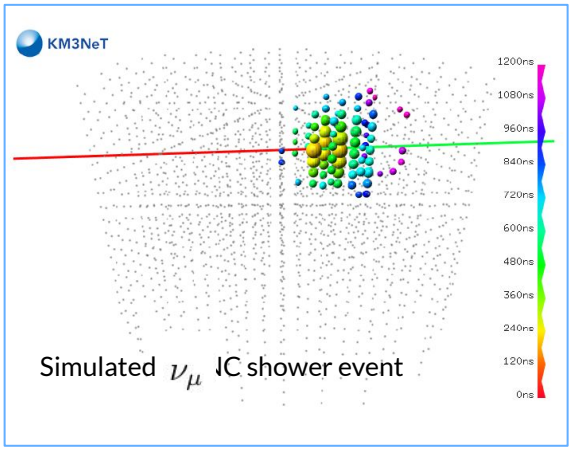
$$\tau^- \rightarrow \mu^- + \bar{\nu}_\mu + \nu_\tau$$



Simulated ν_μ CC track event

Shower-like: events with no visible muon track.

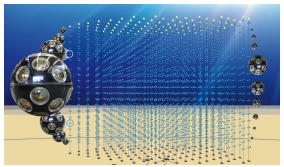
$$\nu_l + N \rightarrow \nu_l + X$$
$$\nu_e + N \rightarrow e^- + X$$
$$\nu_\tau + N \rightarrow \tau^- + X$$
$$\tau^- \rightarrow \pi^- + \pi^0 + \nu_\tau$$
$$\tau^- \rightarrow e^- + \bar{\nu}_e + \nu_\tau$$
...



Simulated ν_μ NC shower event

Data Flow

Acoustic and optical data taking



Off shore

All data to shore *

Data acquisition
Data filtering
Online analysis framework
Temporary local data storage

Shore station

Data transfer

Offline reconstruction,
Offline analysis
Long term data storage

Other remote repositories

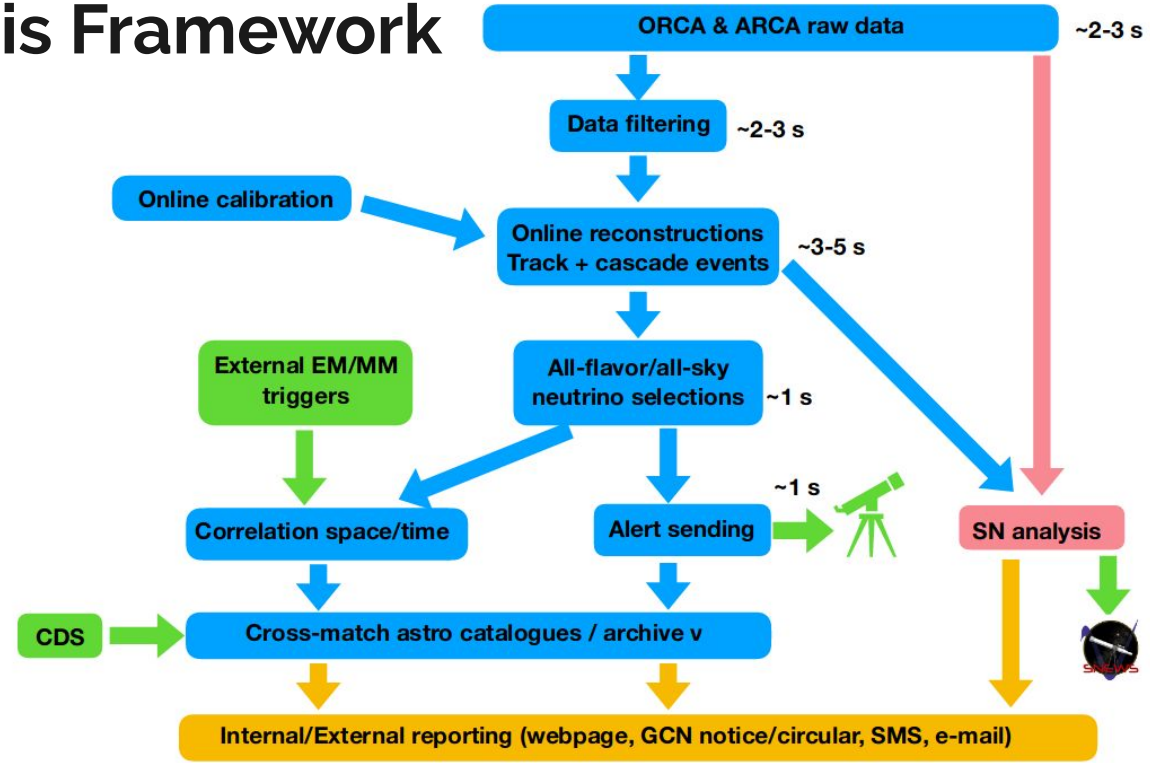
* All analog PMT pulses passing a preset threshold are time-stamped and sent to the shore station.

Online Analysis Framework

External EM/MM triggers: CTA, HAWC/LHAASO, Fermi, Swift, LIGO/Virgo, ELT...

CDS: Astronomical Data Center with catalogues of the astronomical objects outside the solar system

SNEWS: SuperNova Early Warning System



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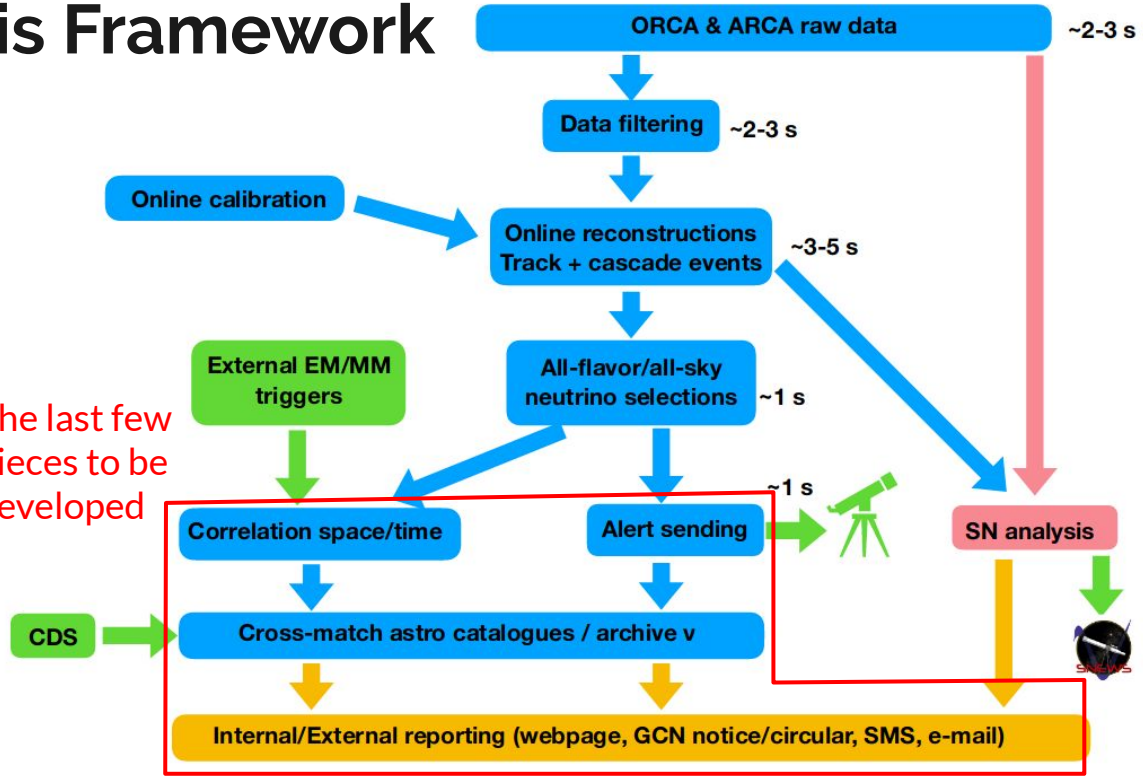
The last few pieces to be developed



Online Event Reconstruction

- Goal: To do energy and direction reconstruction of the incoming neutrinos
- Reconstruction process and time:
  - First guess track fit (potentially as a pre-selection criterion in the future) << 1s
  - Standard track direction reconstruction (used also in offline): ~ 1s
  - Shower reconstruction: 2 ~ 4 s /event (possible optimization)

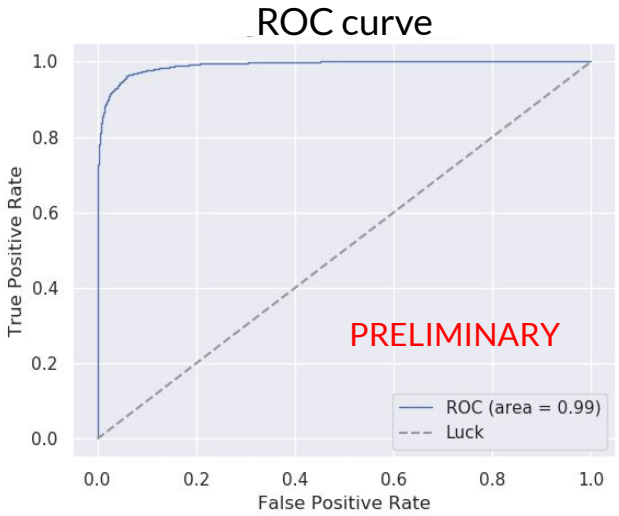
- Angular resolutions:

Tracks:
ARCA: < 0.1° (>10 TeV)
ORCA: 1 - 2° (100 GeV - 1 TeV)

Cascades:
ARCA: <1.5° (>10 TeV)
ORCA: ~4 - 5° (100 GeV - 1 TeV)

Online Event Classification

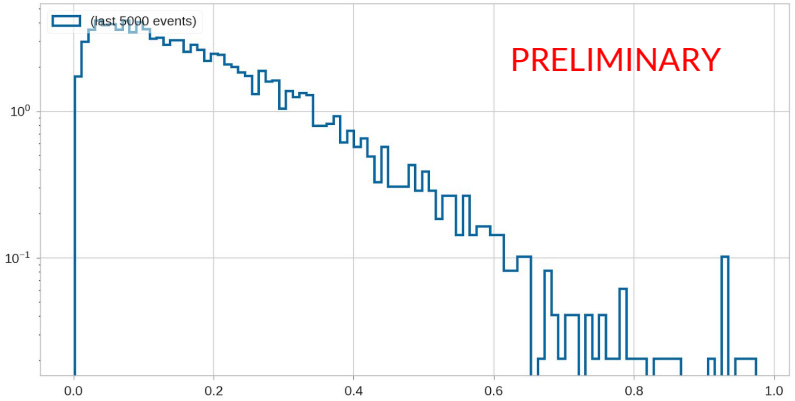
- Goal: Differentiate potential neutrinos from background
- Method: Use machine learning on MC
  - Obtain MC simulation tagged with signal and background.
  - Split MC into: training, validating and testing sets
    - Testing set: untouched until final evaluation
  - Develop training features, e.g. reconstructed track direction, charge-related parameters
  - Train and compare different classifiers - find the best one, e.g. compare ROC curve to evaluate classifier performance:
    - True positive rate: signal efficiency (i.e. ratio of correctly categorized signal to total true signal)
    - False positive rate: background efficiency (i.e. ratio of wrongly categorized background to total true background)
    - ROC curve the closer to the upper left (1, 0), the better. i.e value under the ROC curve closer to 1, the better



Online Event Classification

- Can tune the classifier's hyperparameters
- For evaluation, apply the final trained model on the testing set, apply proper weighting, plot signal and background rate vs. classification score
  -> Choose a classification score as selection criteria, depending on desired neutrino and background rate

- Current classifiers in ORCA:
  - Trained with 7-string ORCA MC high energy sample (50 GeV - 5 TeV), with LightGBM
  - If apply on the online ORCA 4 data (for testing), processing time: < 1s/ event (on 48 CPU cores)
- Work in progress:
  - Training for MC low energy sample; train for ARCA

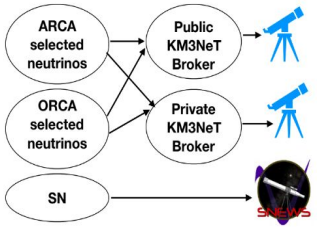


normalized classification score distribution of 4-string ORCA online data

Online Alert Sending and Reporting

- Alert sending policy:
  - Typical alert rate: few per month
  - Standard alerts will be distributed through private channel to observing teams upon MoU agreements like ANTARES.
  - After a commissioning phase, notable events will trigger alerts that will be distributed publicly to the astro community [Open Public Alert program]
- Alert distribution:
  - via the GCN network
  - Message: VO event (XML file)
  - Tool used: Comet
  - Open question: One or several brokers for public and private alerts for both KM3NeT detectors?

- Reporting:
  - SMS/email to alert KM3NeT shifters
  - Automatic GCN notices in case of very interesting neutrino signals
  - KM3NeT subgroup shifters (check detector stability, update reconstructions, etc)
  - GCN circular sent for refined information or identified counterpart (+ retraction).
  - Results displayed in public/internal web



KM3NeT VO Event format

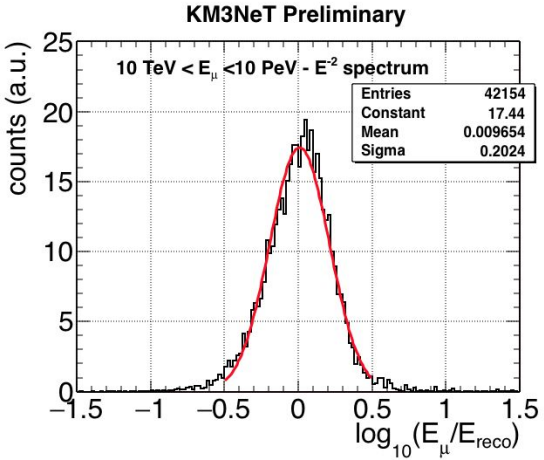
* ID
* Detector (ARCA/ORCA)
* Time
* RA, DEC
* Error box 50%, 90% (TOC)
* Energy estimator
* Reconstruction quality
* Neutrino type (track / shower)
* Probability of neutrino
* Type of alert triggers
* Multiplicity (i.e. number of events in given time and space windows)

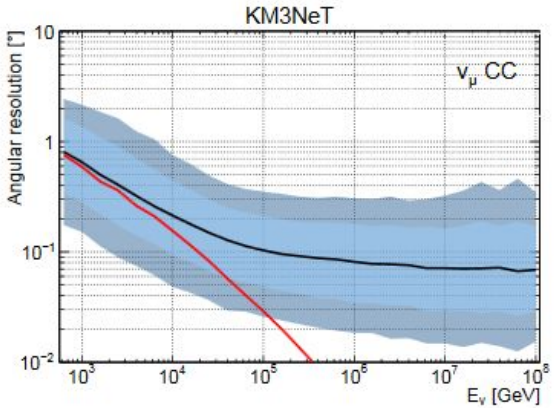
Summary & Outlook

- KM3NeT is being constructed.
  - Current running:
    - ORCA 4 strings
    - ARCA 1 string (temporarily shut down for maintenance at shore station)
  - Two new ORCA strings planned to be deployed during the week of November 25, 2019 or mid January, 2020 depending on the weather
- Having a great angular resolution, a large energy range and full sky coverage, KM3NeT will contribute enormously to the multi-messenger community.
- The KM3NeT online analysis framework is under development - we are working to make it ready in 2020

Backup

ARCA track resolutions





Online Architecture Overview