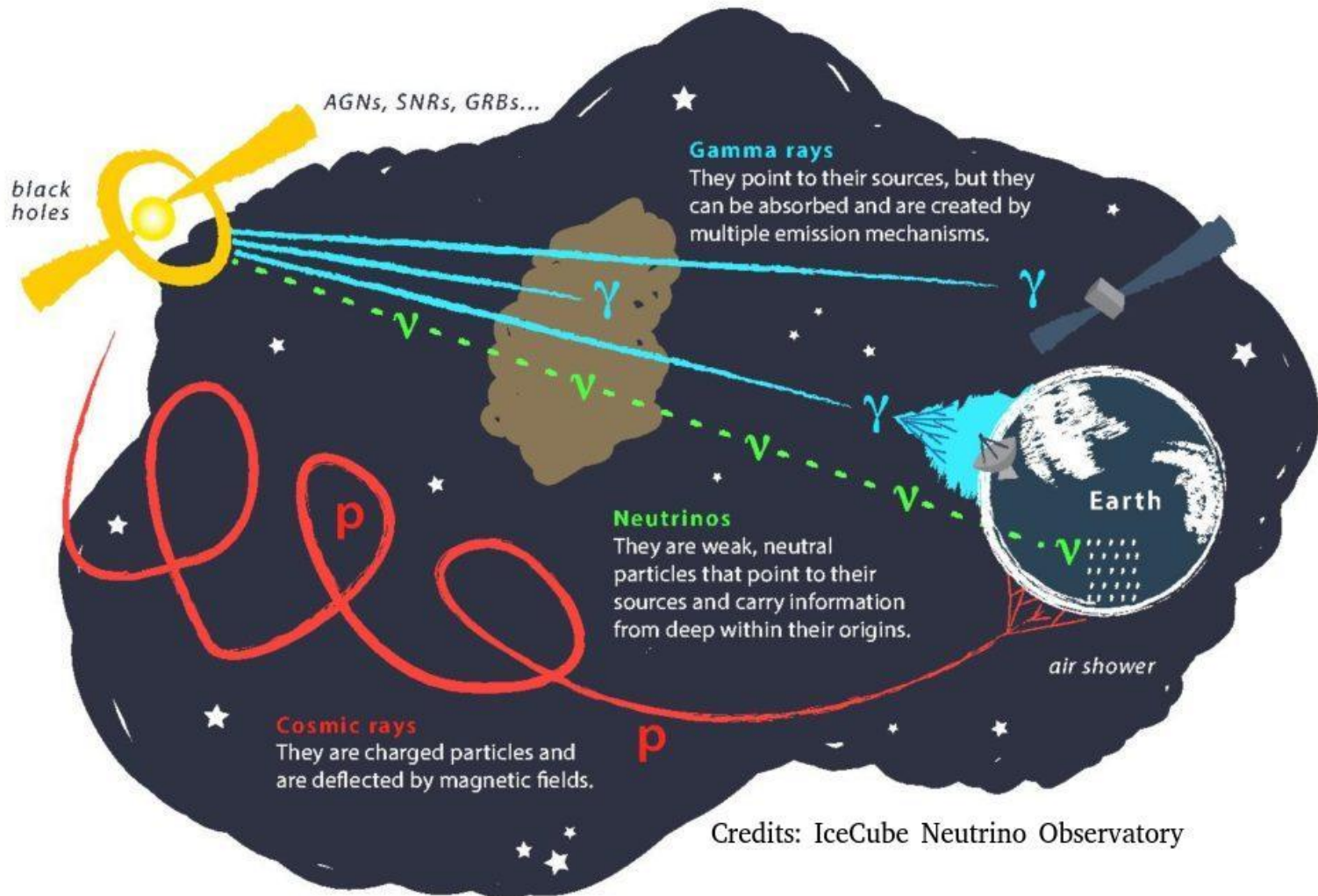




Status of the KM3NeT realtime astronomy program

Massimiliano Lincetto
for the KM3NeT collaboration

Neutrinos and multimessenger astronomy



The KM3NeT detectors

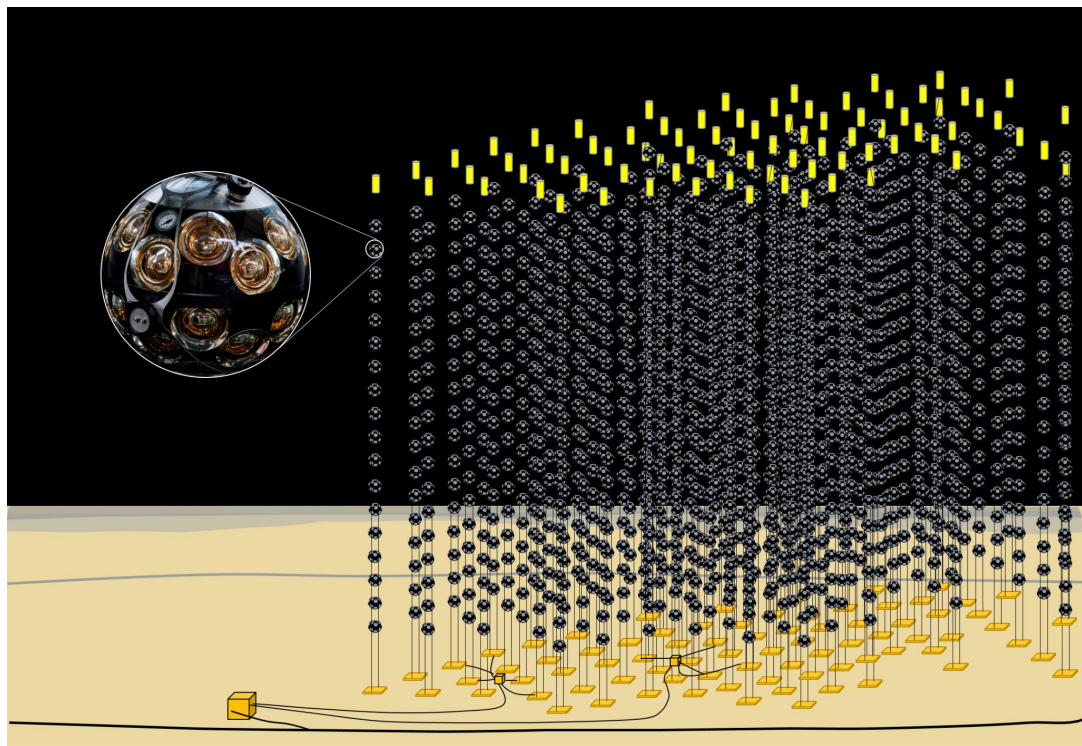
Digital Optical Modules (DOMs) with 31 PMTs each. Lines with 18 DOMs each.

Two instrumented sites:

ARCA (IT): km³ scale for astrophysics – 51/230 lines deployed.

ORCA (FR): 8 Mton scale for neutrino oscillations – **44**/108 lines deployed.

Joint multimessenger strategy.



Paradigms in neutrino astronomy

Neutrino-driven

All-sky (“neutrino sky maps”)

Single high-energy events

Multiplets

mostly
“offline”

Source-driven

Catalogue searches

Stacking searches

Single source or “trigger” follow-up

mostly
“online”

Paradigms in (realtime) neutrino astronomy

Neutrino-driven

All-sky (“neutrino sky maps”)

Single high-energy events

Multiplets

(1) ***promptly*** identify **spatial and temporal correlations** between neutrino data and multiwavelength / multimessenger data.

Source-driven

Catalogue searches

Stacking searches

Single source or “trigger” follow-up

(2) maximise the science potential by **facilitating coordinated observations**.

Challenges

Eddington bias: if neutrino sources are numerous and faint, individual high-energy events are just a sample of “lucky” rather than “special” objects (less chances for counterpart discovery, classification, characterisation).

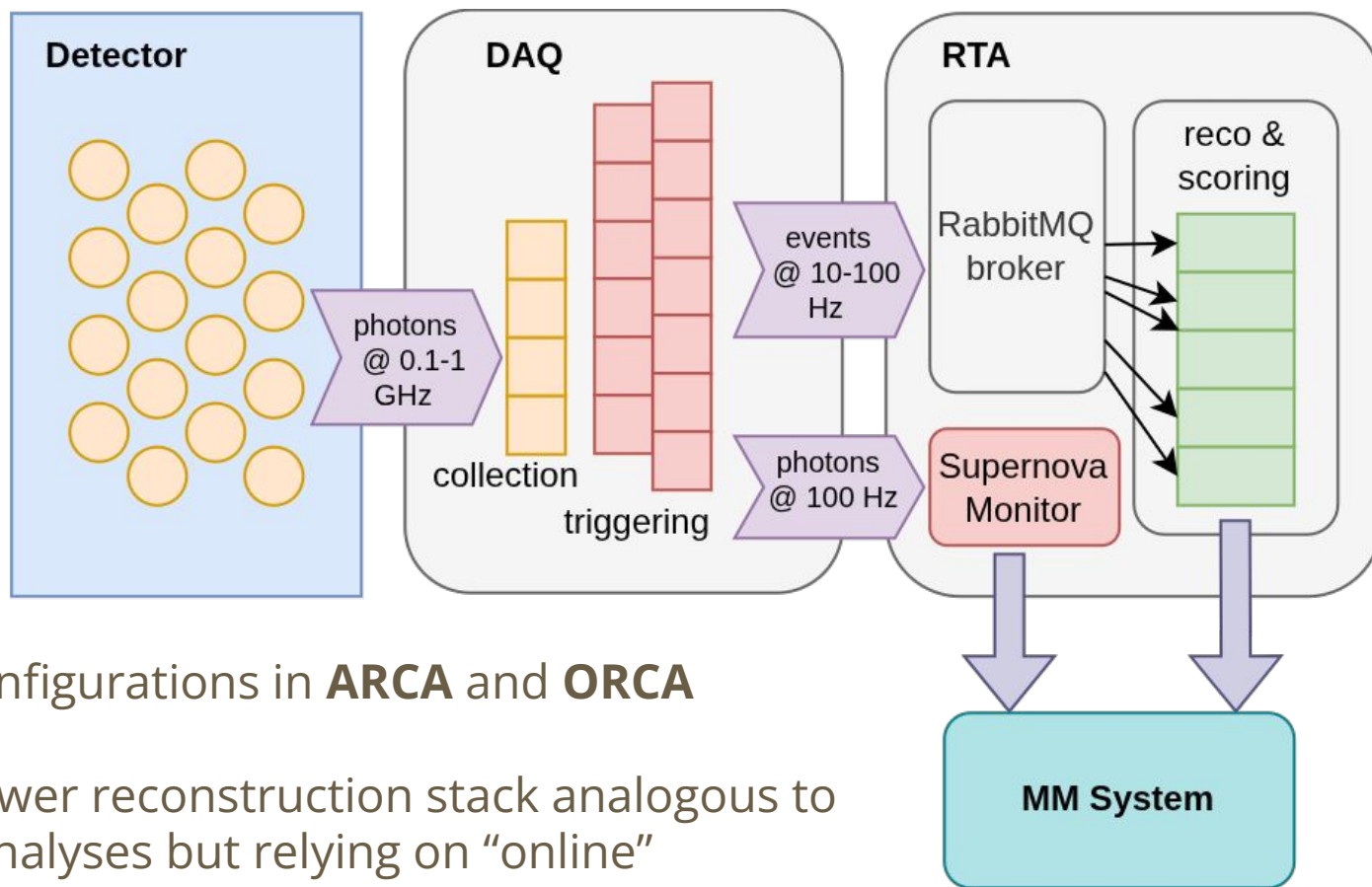
Choice of counterpart candidates: neutrino production in astrophysical sources yet not observationally characterised due to, e.g., low confidence neutrino “detections”, sparse multiwavelength coverage, high degeneracy of models...

Trial factor: many competing analyses with a continuously evolving sample -> **no good definition of post-trial p-value** (we rather deal with false alarm rates). **Often *a posteriori* choice of the test statistic.**

—

KM3NeT specifics: detector is under construction, quick-turnaround calibration is required after every deployment, selections may require re-optimisation

Infrastructure: real-time analysis

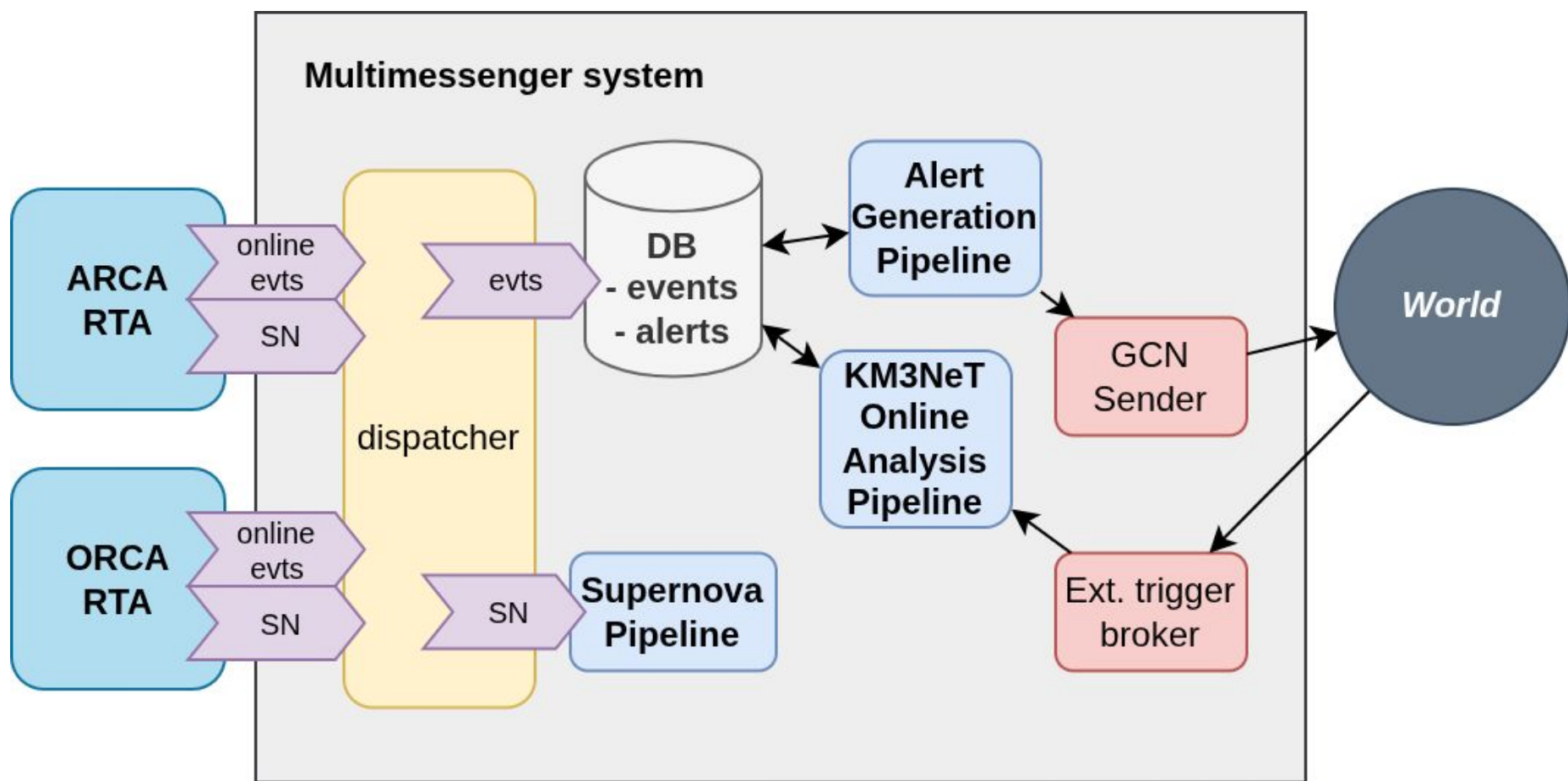


Similar configurations in **ARCA** and **ORCA**

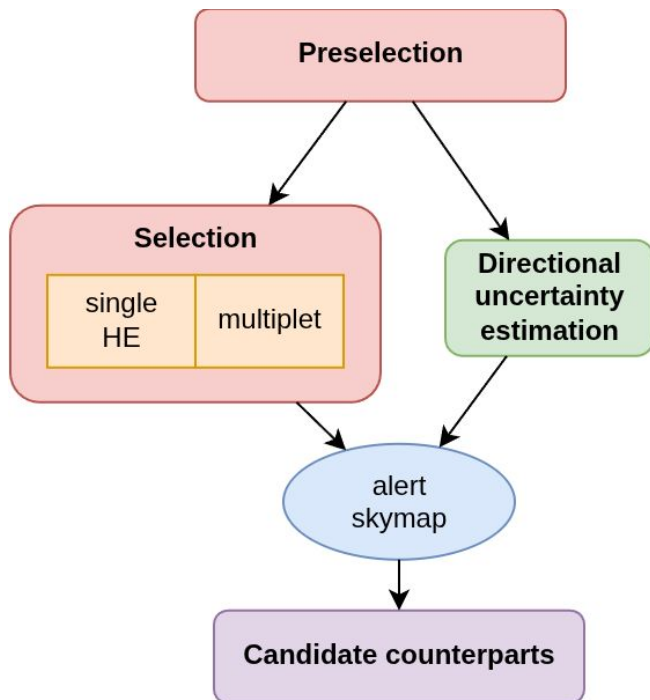
Track/shower reconstruction stack analogous to "offline" analyses but relying on "online" calibration.

Per-event processing time ~ 10-15 s

Infrastructure: multi-messenger system



Alert Formation



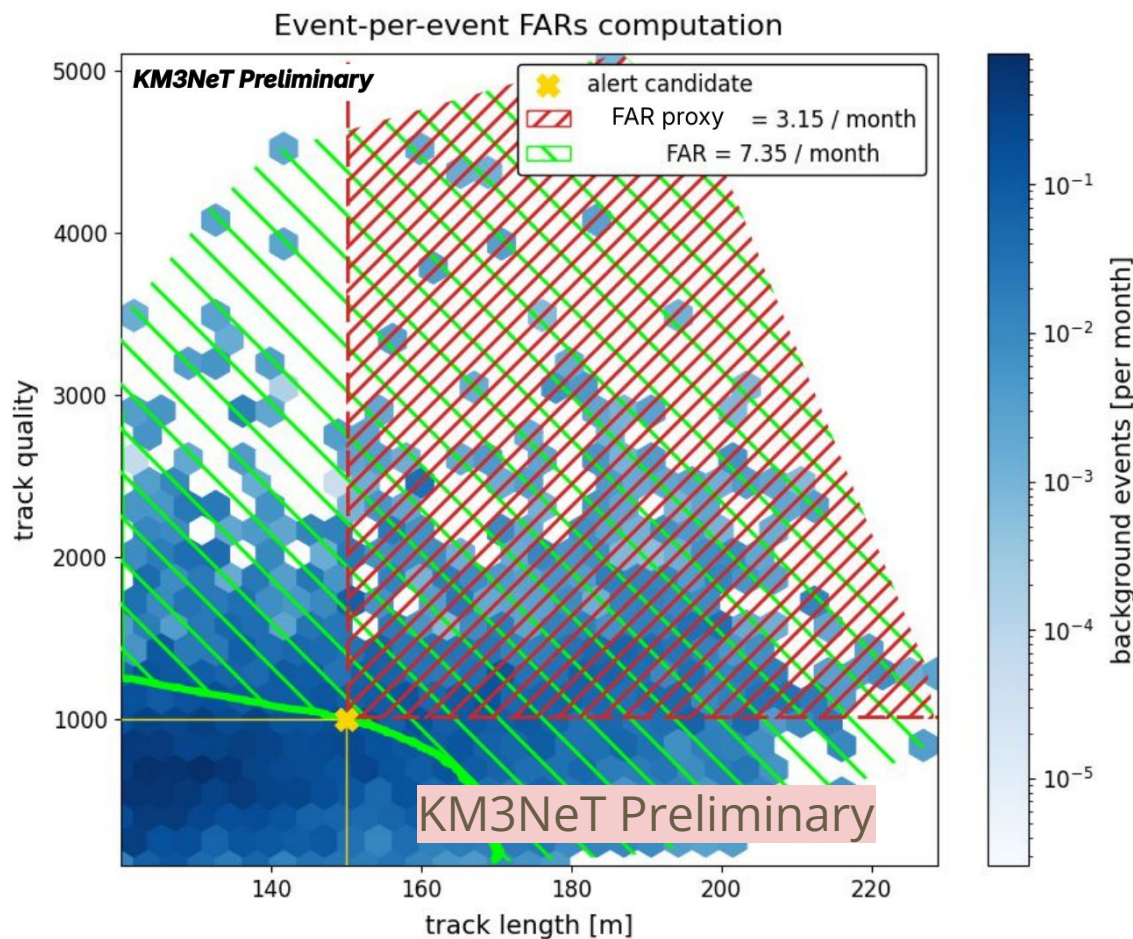
The **selection pipeline** is modular and supports multiple criteria.

The **directional uncertainty estimation** relies on on-the-fly simulations of “similar” events to estimate the **spatial probability distribution** of the alert origin (coded as multi-order HEALPIX map).

A search and ranking of **candidate counterparts** is performed (“astronomy module”).

Latency: ~ few minutes.

FAR-driven Event Selection



Track quality / track length / track energy as benchmark variables

Proxy for false alarm rate: **rate of events simultaneously above quality / length / energy** of the candidate.

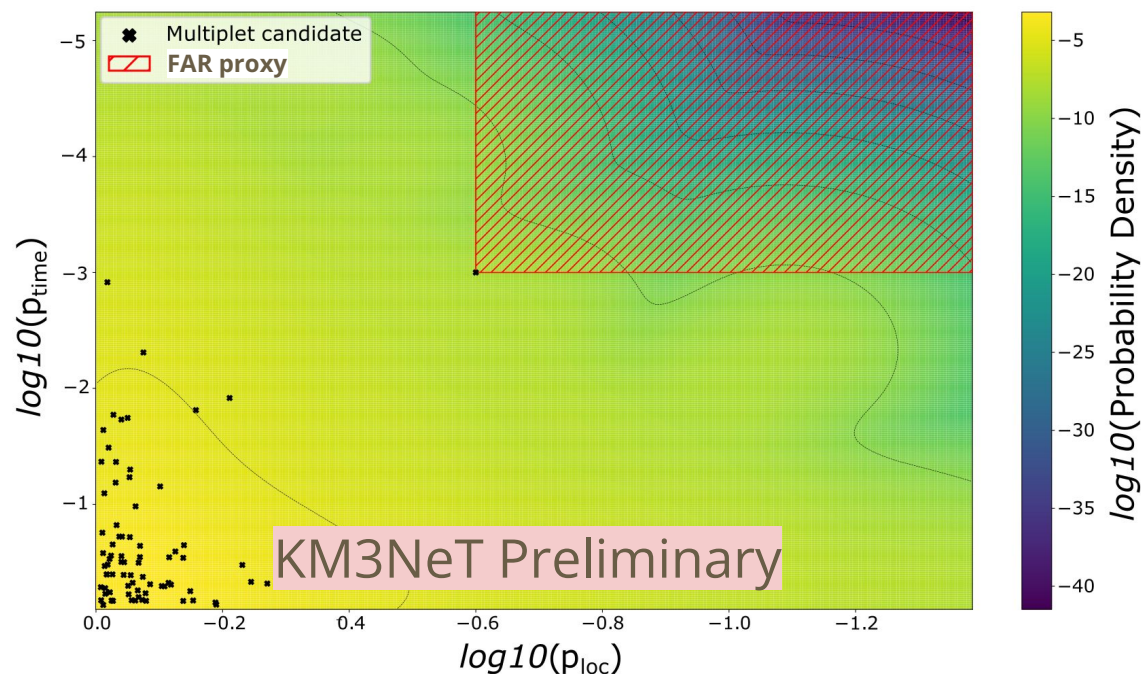
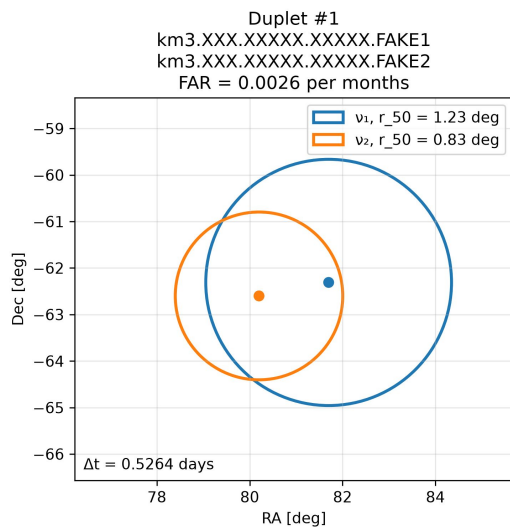
FAR: rate of events with FAR proxy above the candidate observed value.

Multiplet selection

Search for correlated events with sliding time window.

Scoring based on time difference and angular distance.

FAR determination similar to the single-event case.



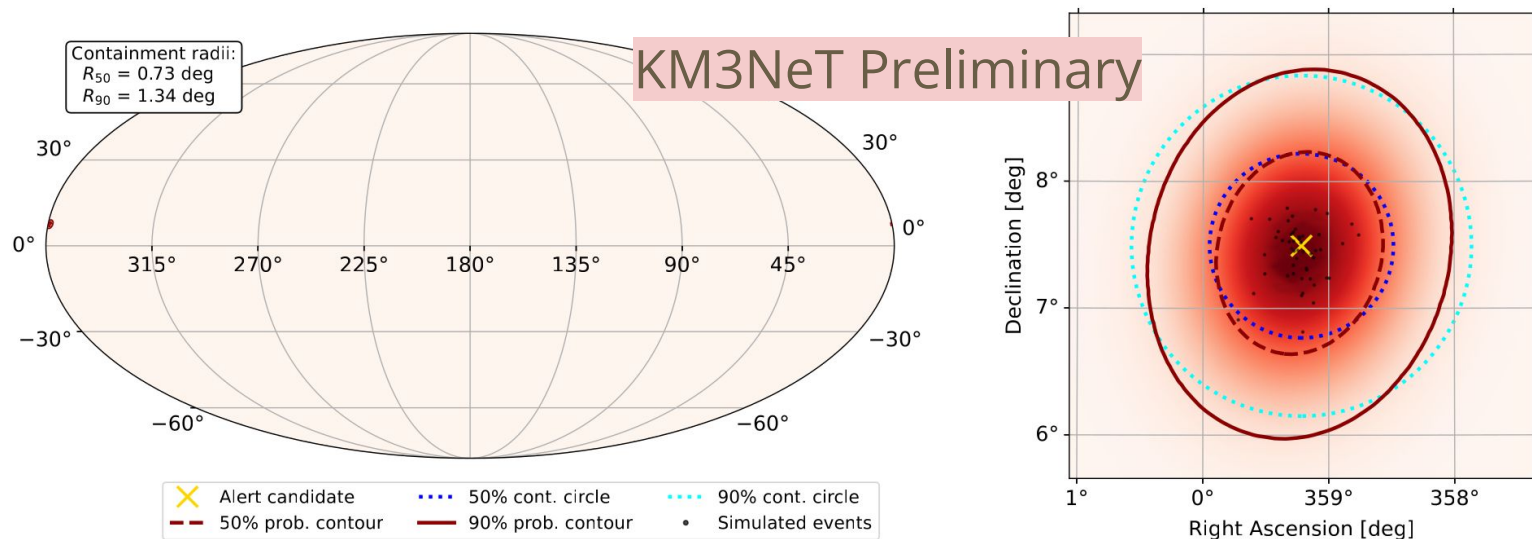
Angular Error Estimation

The **alert is simulated N times** accounting for fluctuations in the muon propagation & photon statistics + detector systematics.

Gaussian smearing to account for neutrino-muon kinematic angle.

Reconstructed directions are projected on a single reference frame to estimate spatial probability distribution (and containment contours).

KM3NeT/ORCA - km3.274.28311.93124.8796 error region



Counterpart search and ranking

Systematic search for counterparts performed in a set of catalogues:

- Radio VLBI (RFC) -> objects with compact radio emission (blazars)
- X-ray (ROSAT 2RXS)
- Gamma-ray (Fermi 4FGL)
- Transients: TNS

Ranking of sources based on positional association and relative source brightness.

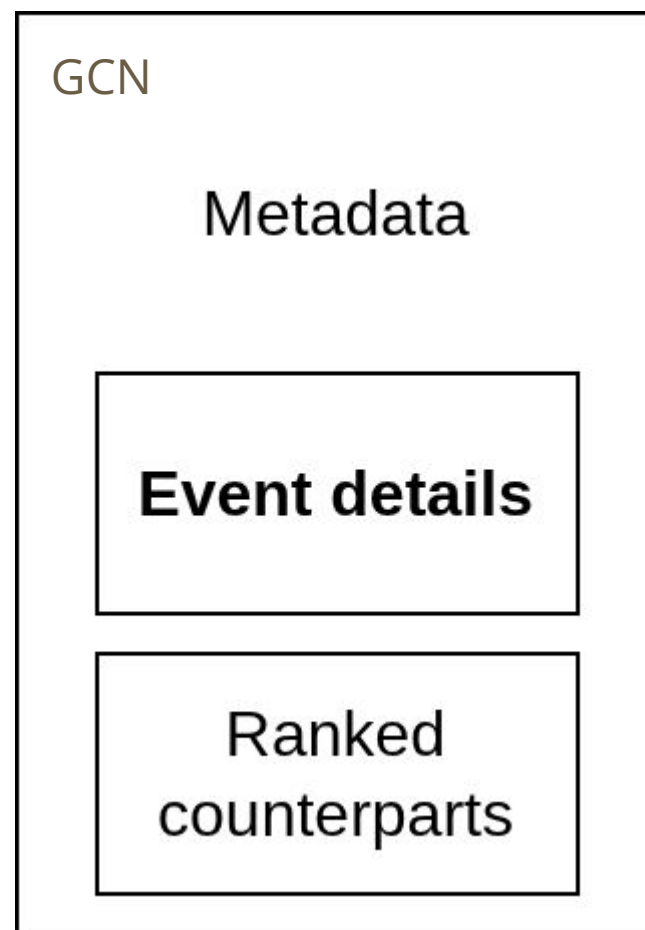
Variability of sources evaluated from gamma-rays (Fermi-LAT) and optical data (is the object flaring?)

Selection optimised differently for alerts on / off the Galactic Plane.

KM3NeT Alert Structure and Sending

Preliminary GCN schema has been [merged to the GCN codebase](#) .

A dedicated module is tasked with listening to the alert DB table and send the alert to GCN.



KM3NeT Online Analysis Pipeline (KOAP)

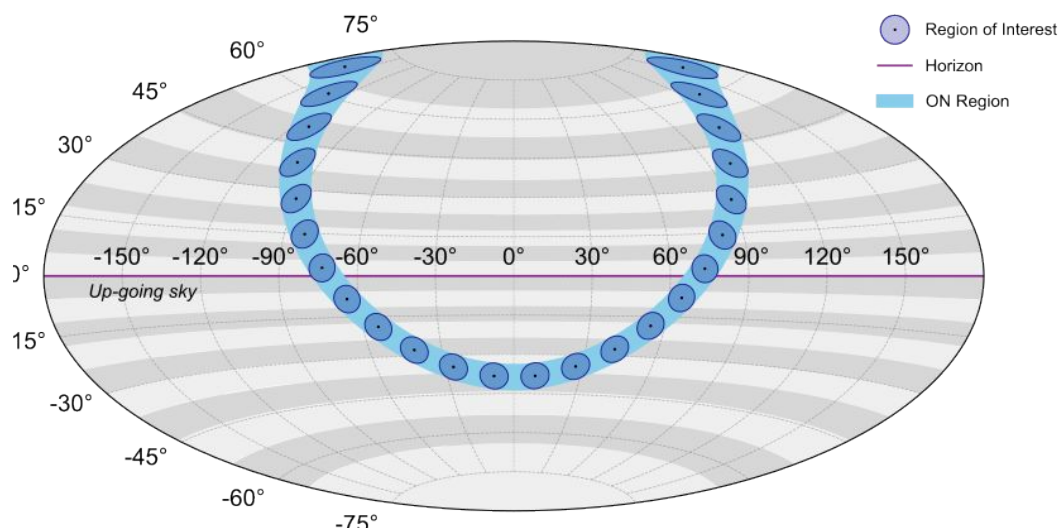
Automatic followup of selected external triggers.

ON-OFF analysis: background estimated from elevation bands with fixed cuts.

Based on N_{ON} and N_{OFF} estimates a **(pre-trial) p-value** and optionally **upper limits**.

Targets: FRBs, GRBs, microquasar flares, GW, optical transients collected by alert receiver (**KMMAR**).

Few thousands of triggers analysed so far.



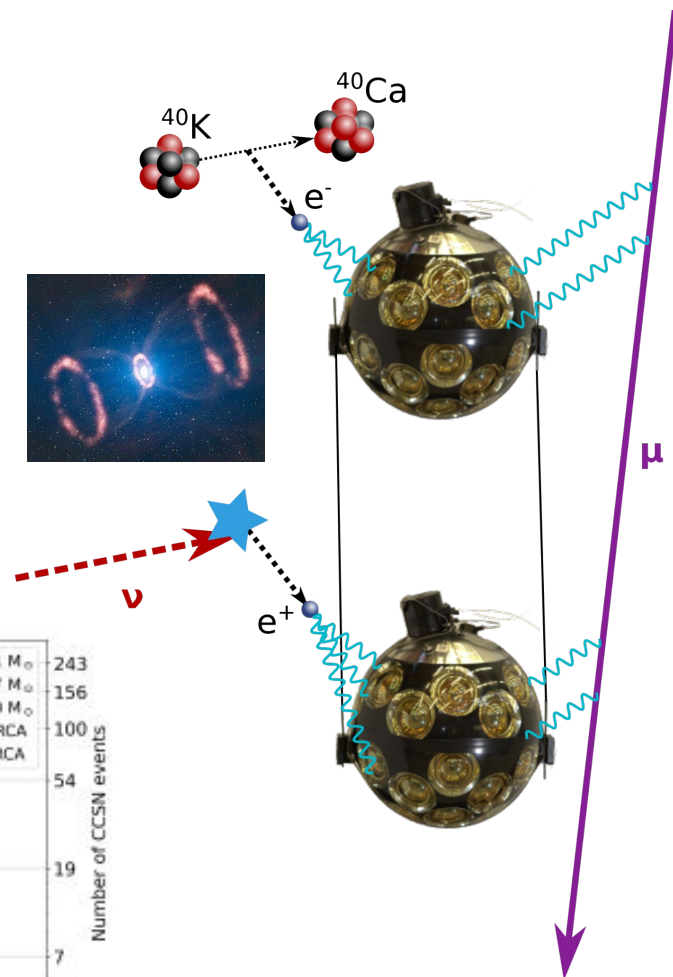
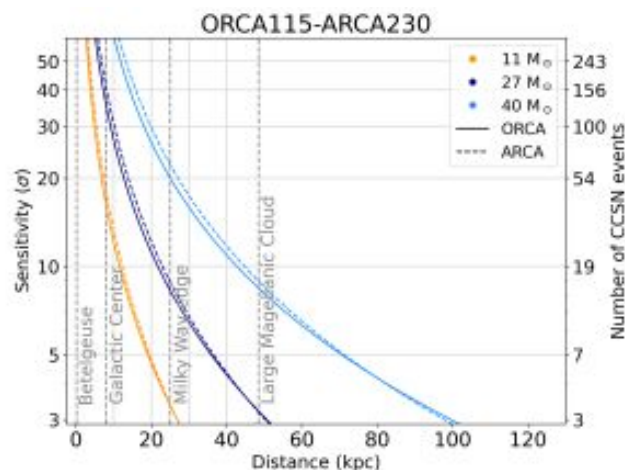
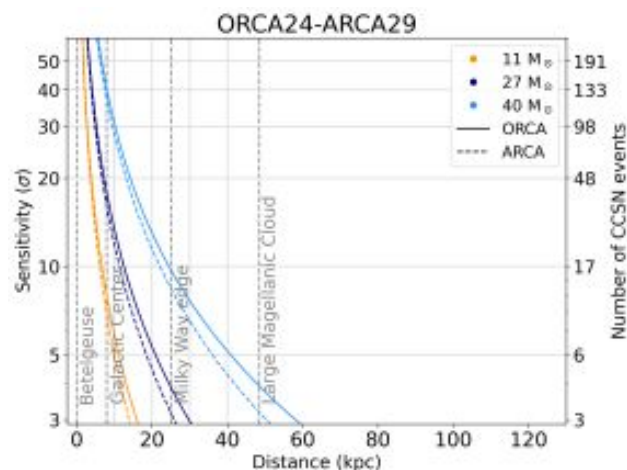
Credits: G. Pascua

Galactic core-collapse supernovae

O(10-20 MeV) neutrinos produced in a **(near-) galactic CCSN** produce a collective increase in the count/coincidence rate observed by KM3NeT.

Selection of multi-PMT coincidences, removal of muon-correlated hits, BDT for further discrimination -> sensitivity to CCSN in Galaxy and LMC.

Integration in SNEWS in progress.



Conclusion and outlook

KM3NeT is rapidly growing and its astronomy potential is increasing.

The KM3NeT realtime system has been under intense development and testing.

Current capabilities:

- single-event and multiplet alerts with real-time counterpart search
- automated, fast follow up of external triggers
- monitoring for nearby core-collapse supernova neutrinos (SNEWS integration in progress)

Current phase: **internal review and validation**

A **public alert program** will be operational *soon*.