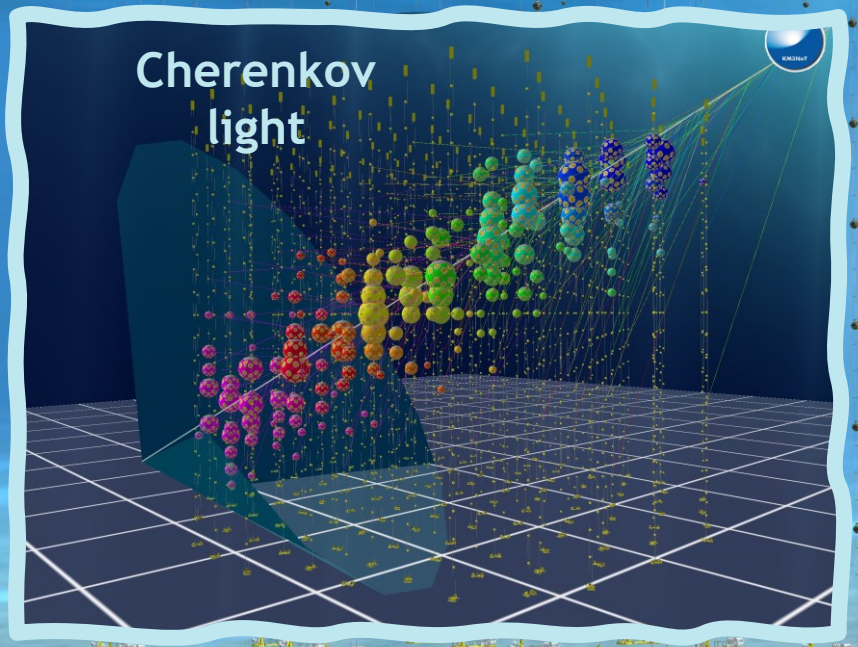
KM3NeT and Multi-messenger Astrophysics

Francesca Badaracco

On behalf of the **KM3NeT collaboration**

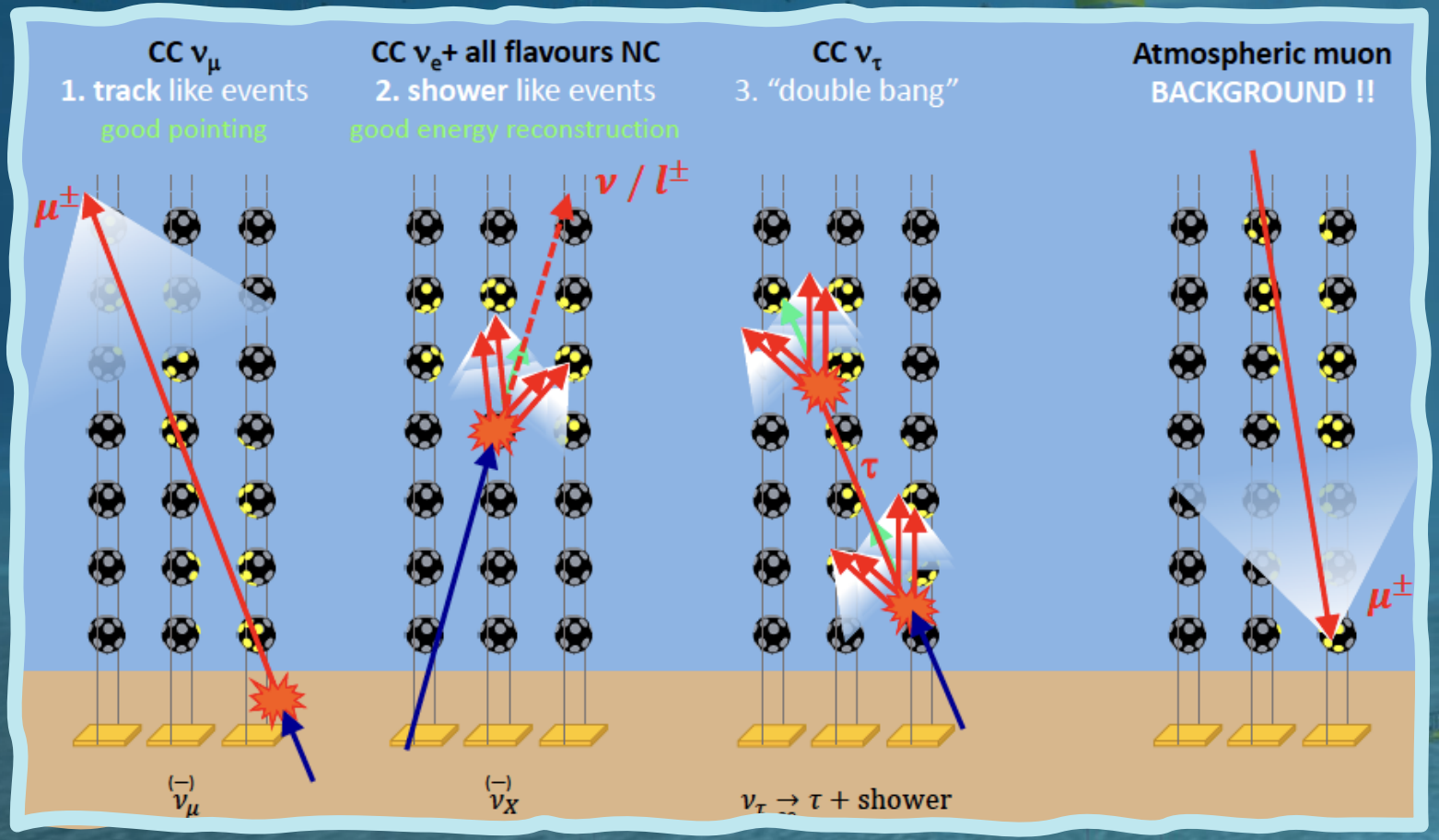
What is KM3NeT?



DOM
(Digital Optical Module)

DU
(Detection Unit)

What is KM3NeT?



ANGULAR RESOLUTION

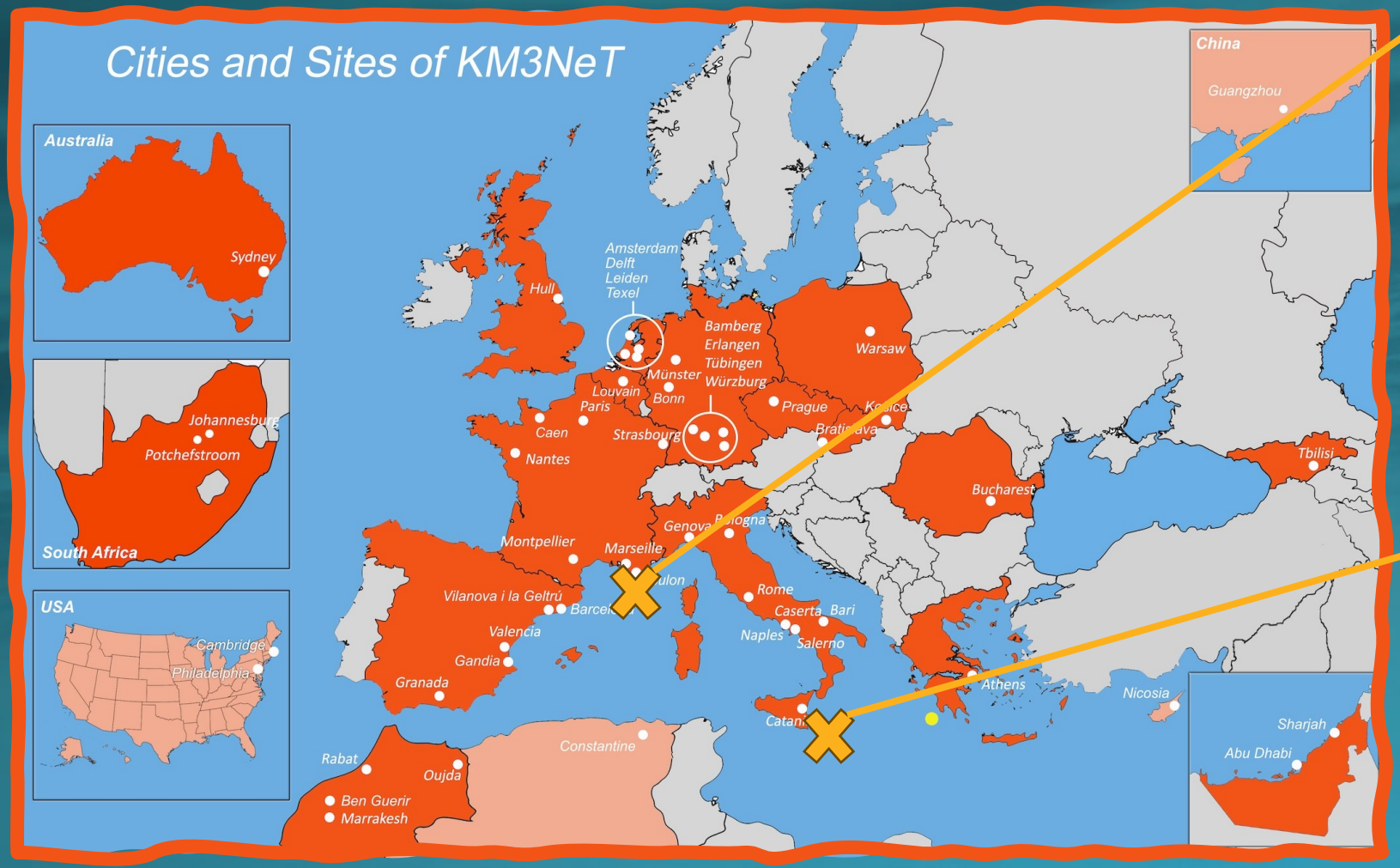
ARCA:
- Tracks 1 mrad
- Showers 1.5 degree

ORCA:
- Tracks 0.5 degree
- Showers 10-5 degrees

KM3NeT in numbers

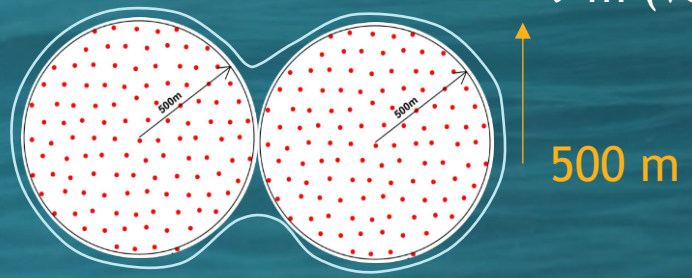
106 m

20 countries and 48 institutions



ORCA: **O**scillation **R**esearch with **C**osmics in the **A**byss

ORCA23 (20%)--> ORCA115
- Depth (max) = 2450 m
- DOM spacing: 20 m (horizontal); 9 m (vertical)

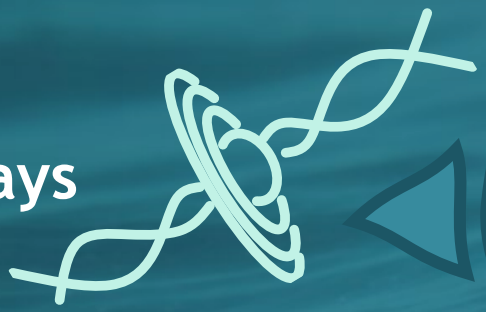


ARCA: **A**stroparticle **R**esearch with **C**osmics in the **A**byss

ARCA28 (12%)--> ARCA230
- Depth (max) = 3450 m
- DOM spacing: 90 m (horizontal); 36 m (vertical)

Cosmic Rays

Gamma Rays

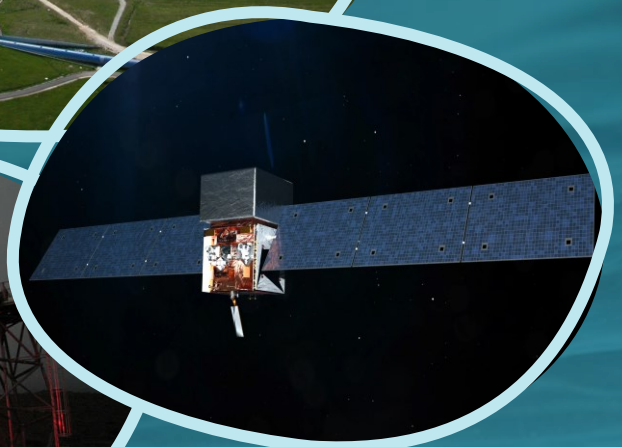


Multi-messenger with KM3NeT

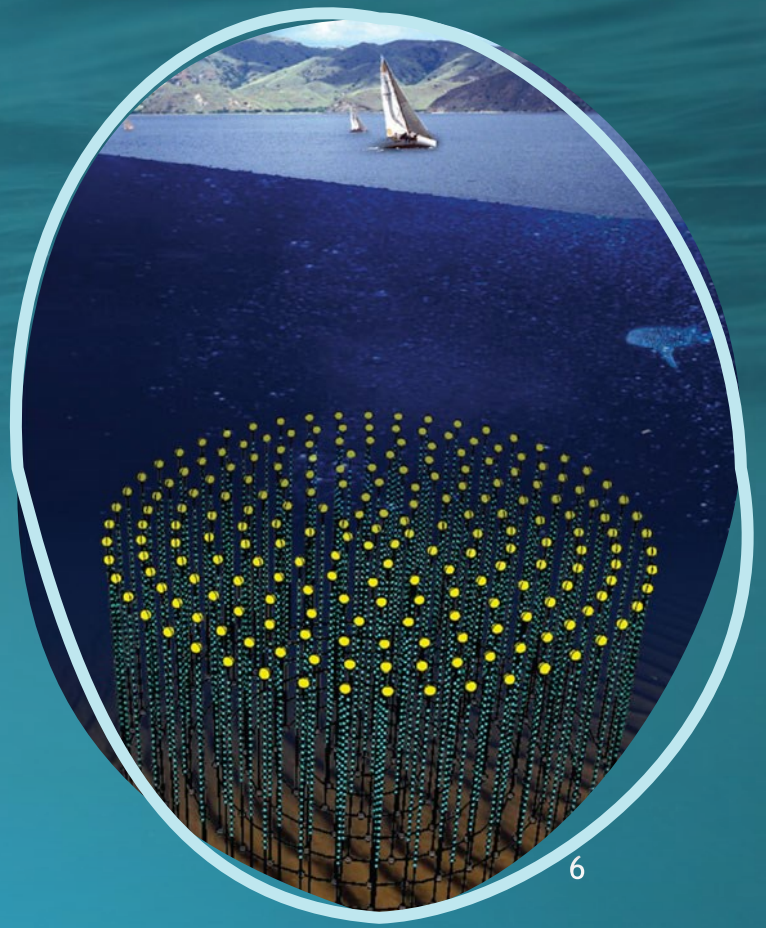
Gravitational Waves

Neutrinos $\nu_{e,\mu,\tau}$ $\overline{\nu}_{e,\mu,\tau}$

Multi-messenger with KM3NeT

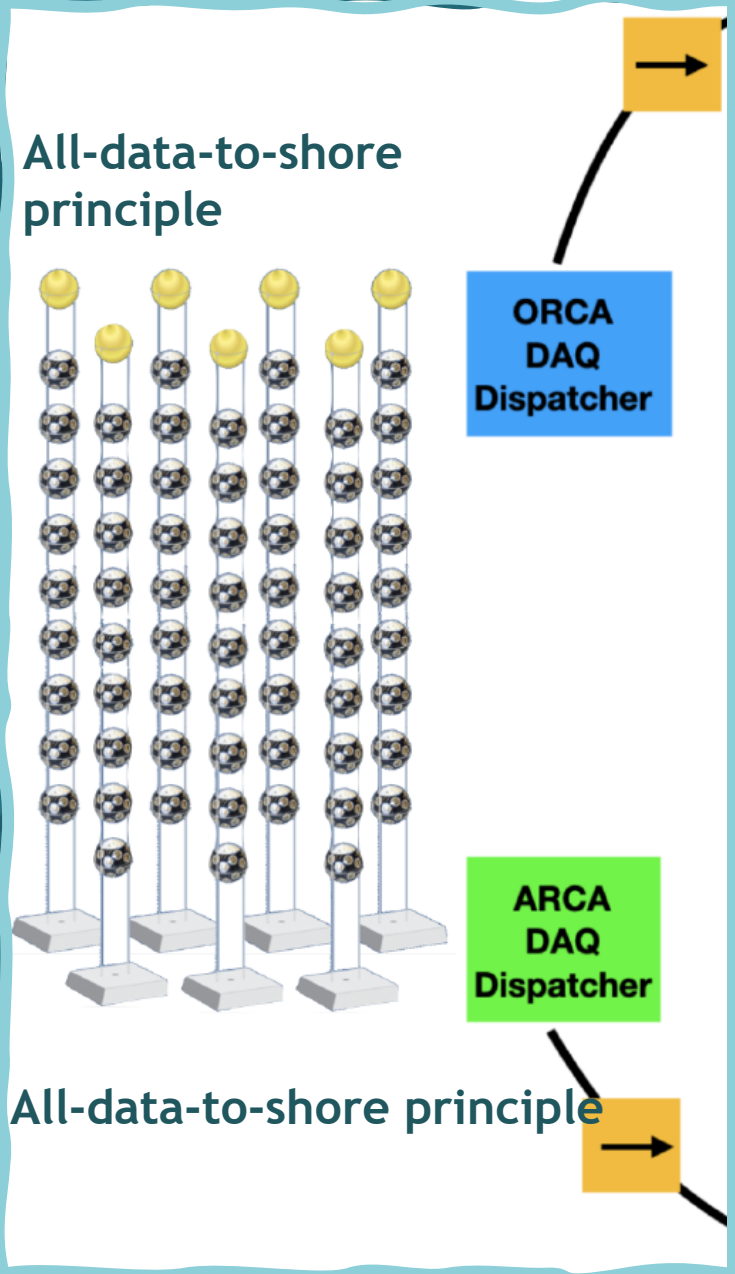


Sending out ν-alerts
Status: work in progress



Follow-up of external alerts.
Status: ongoing

KM3NeT Real Time Analysis



S. Celli et al. [KM3NeT], PoS(ICRC2023)1125

KM3NeT Real Time Analysis

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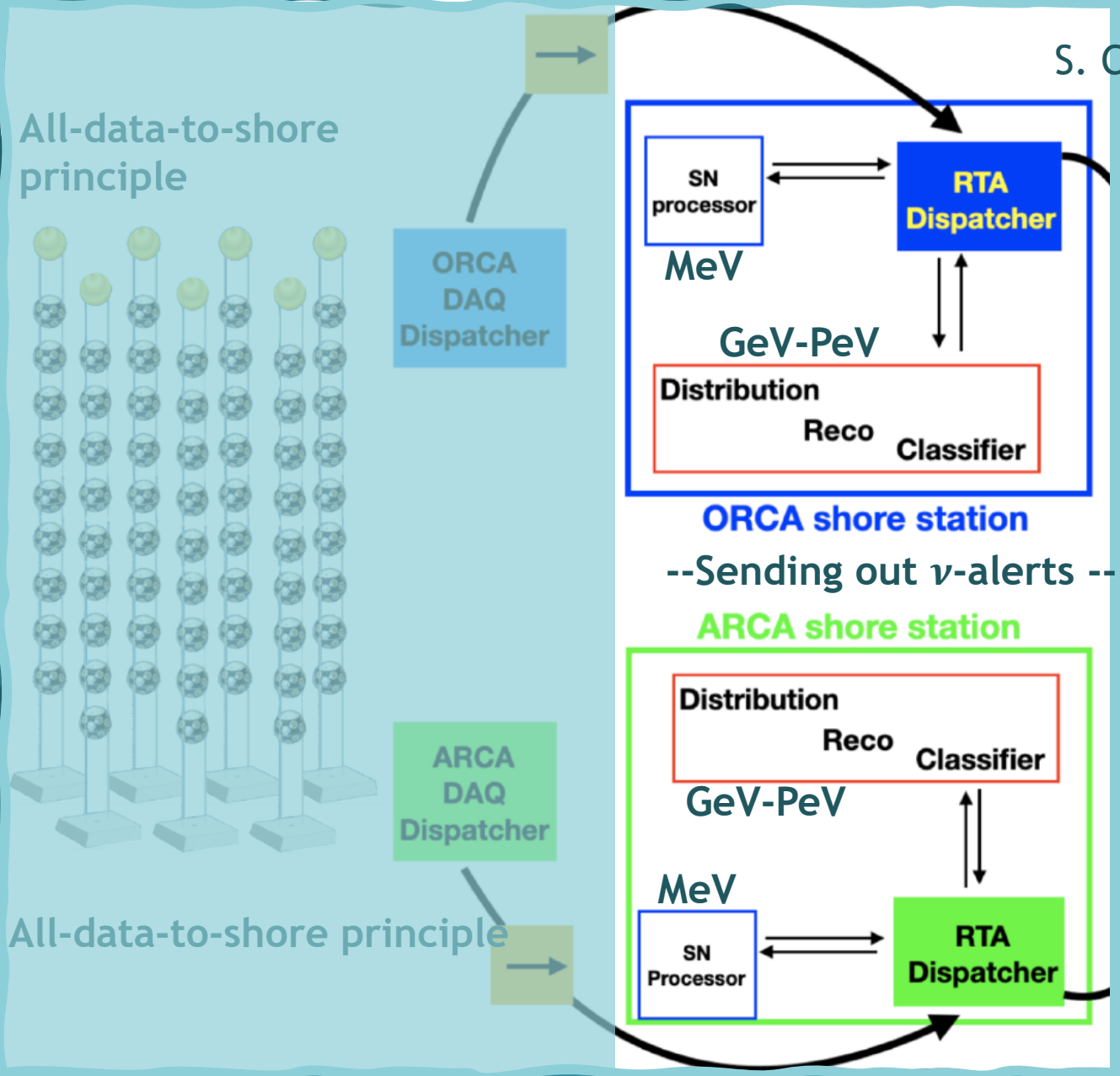
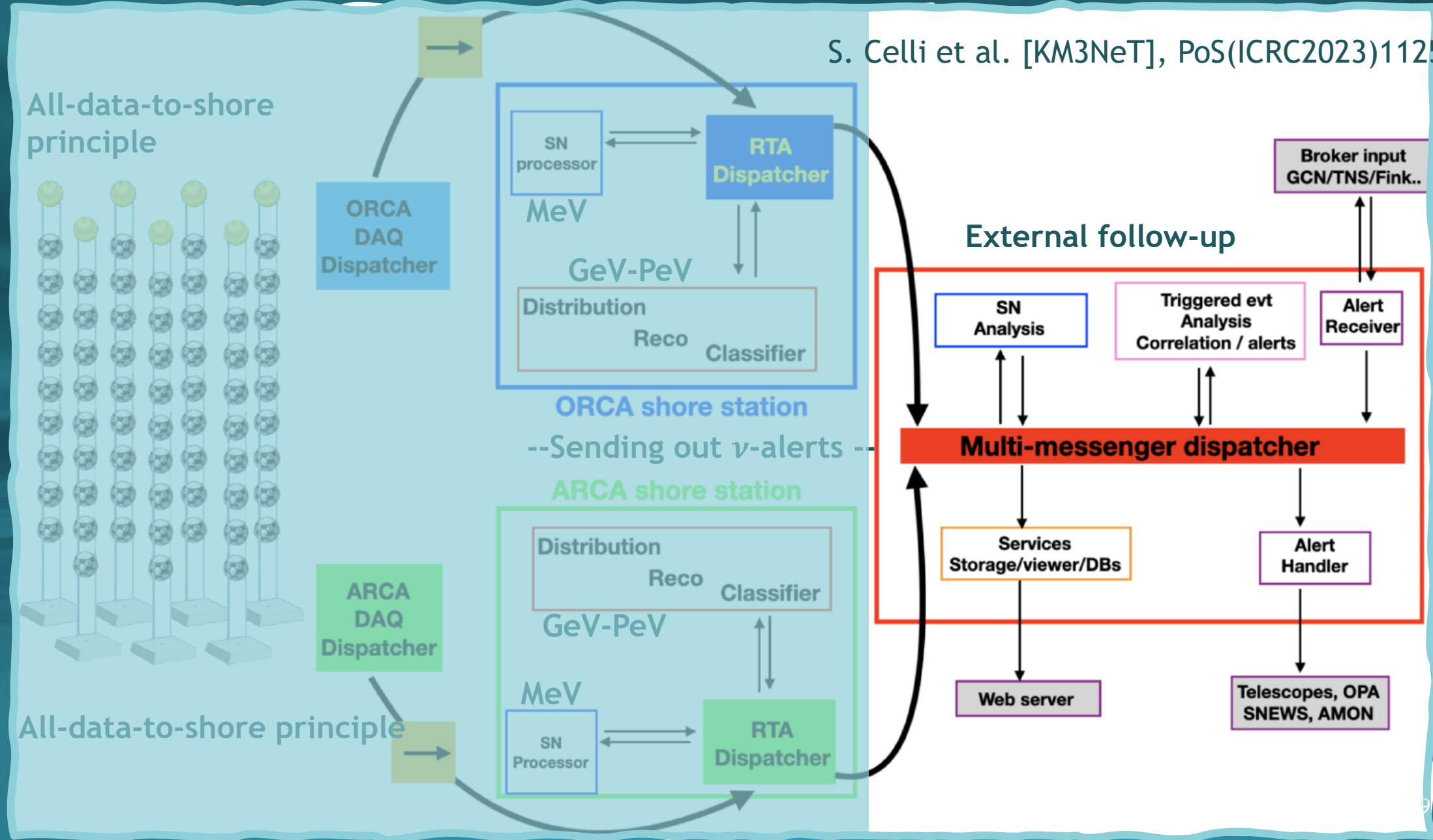
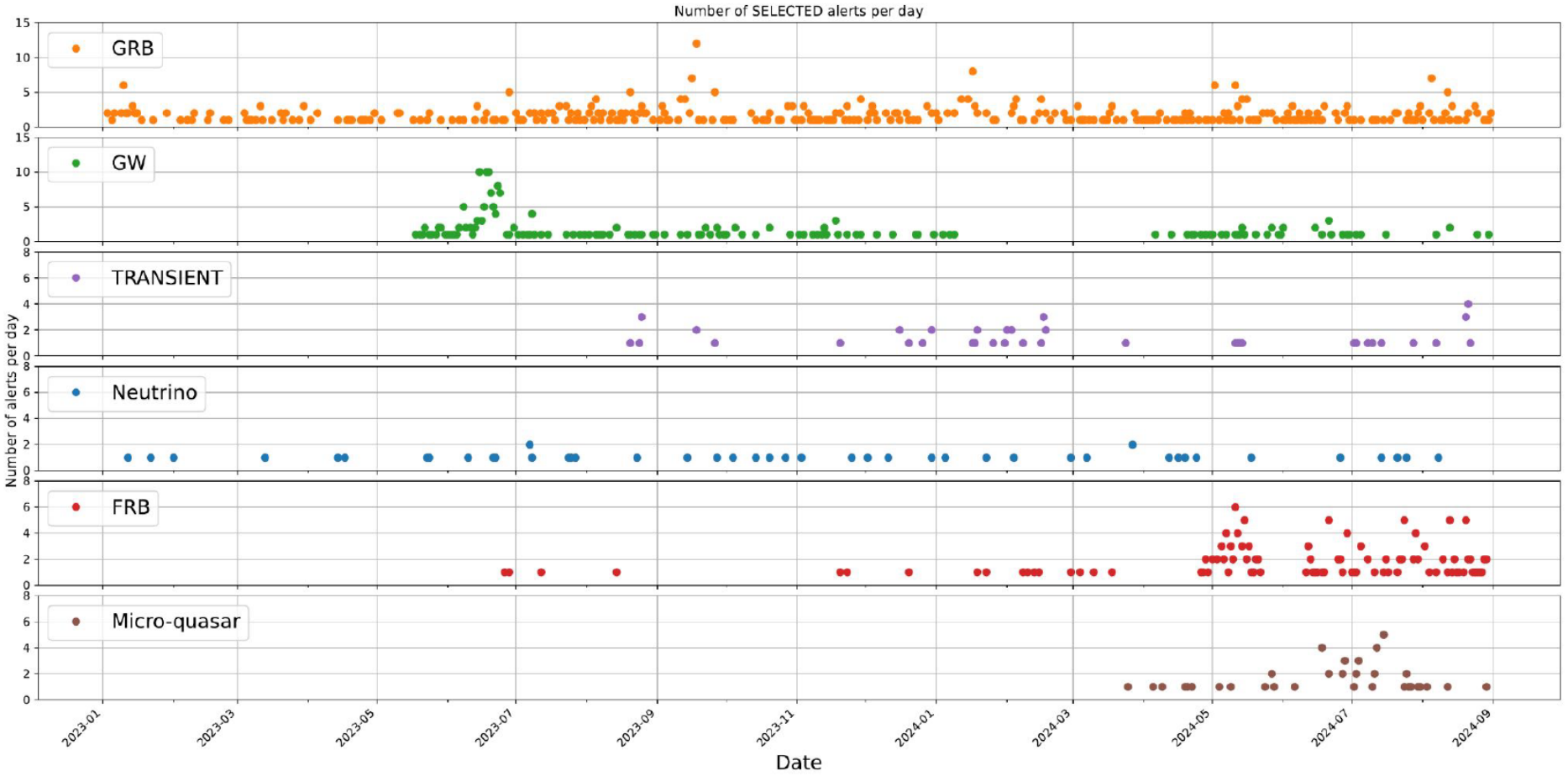


KM3NeT Real Time Analysis

S. Celli et al. [KM3NeT], PoS(ICRC2023)1125



Selected alerts

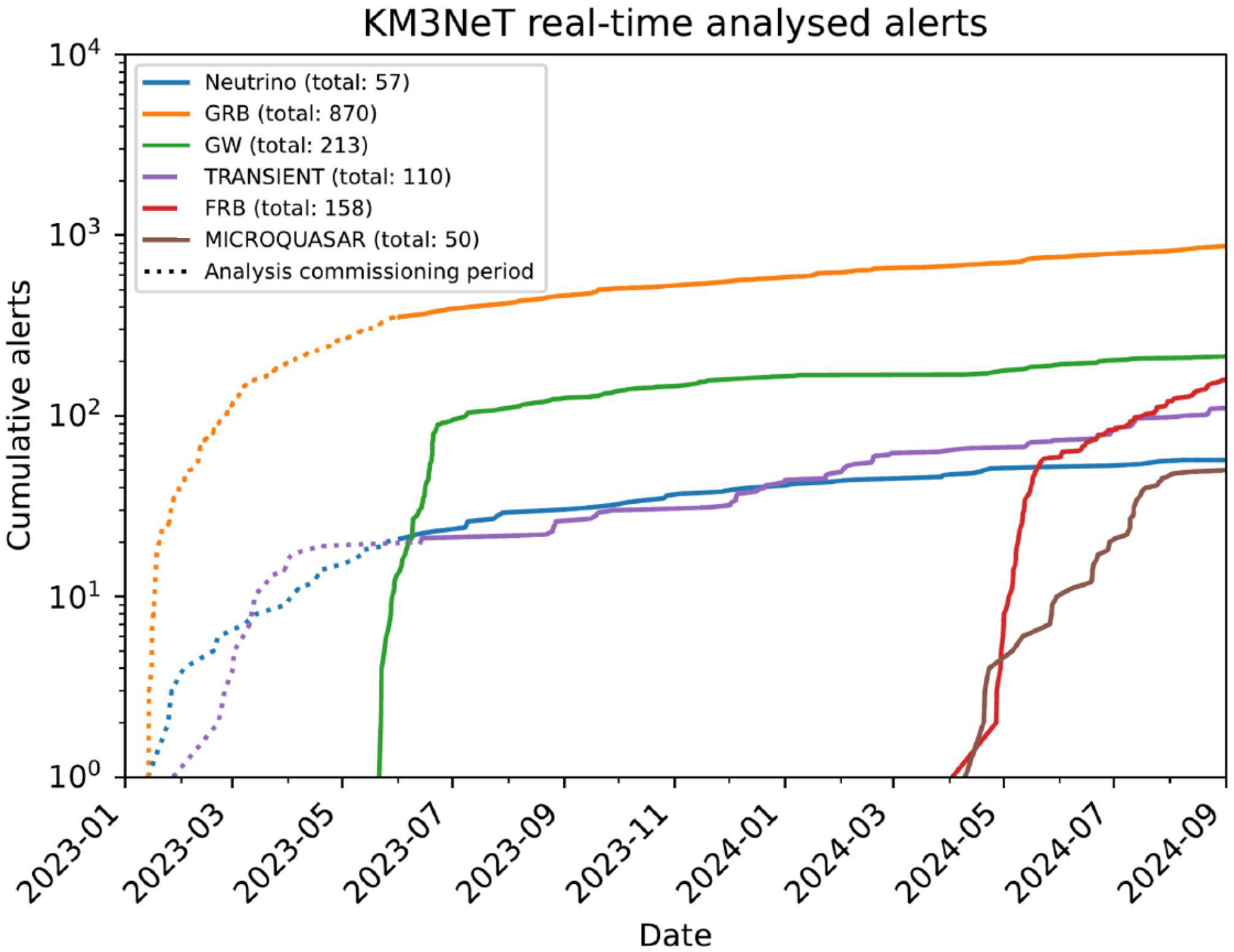


Median values:

- GRB: 1/day
- GW: 1/2 days
- Transient: 1/week
- Neutrino: 1/2 weeks
- FRB: 1/3 days
- Micro-Quasar: 1/3 days

Credits: J. Palacios González

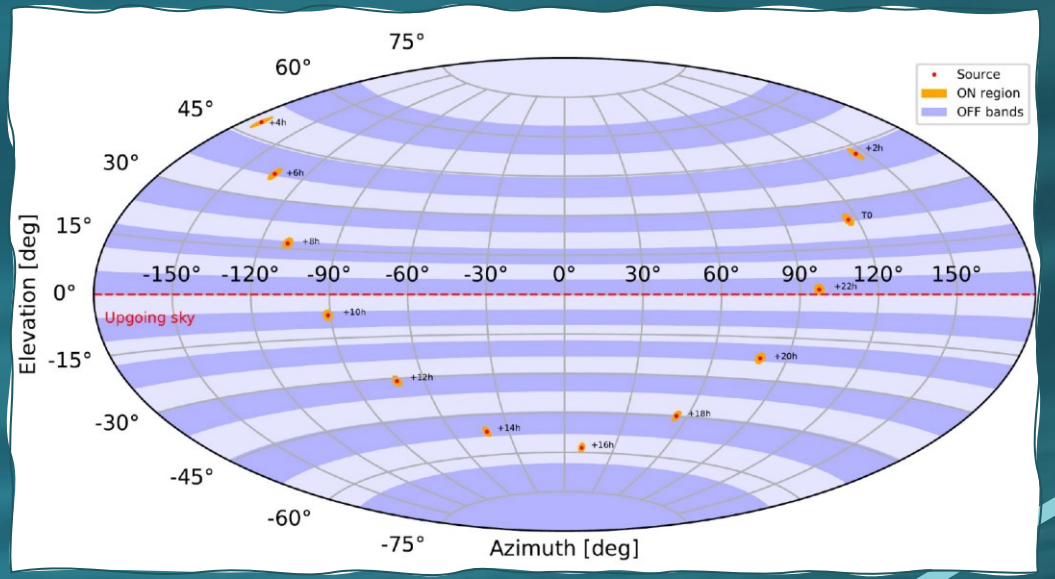
Analysed alerts



Credits: J. Palacios González

Follow-up

- Since **the beginning of 2023** we are continuously analysing incoming alerts in real-time.
- Only **track-like** events are used for follow-up (inclusion of shower-like events still in progress)
- **Binned ON/OFF** analysis technique: the observations in the signal time window in a given sky search region are compared to the background expectation estimated from a larger time window.
  - Event selection optimised to reduce the background to the level with the best achievable significance



ON: Region from where the signal comes from, considering the source error+KM3NeT angular error (4° for ORCA and 2° for ARCA)

OFF: 2 weeks before + bands at same elevation of source

Alert sending

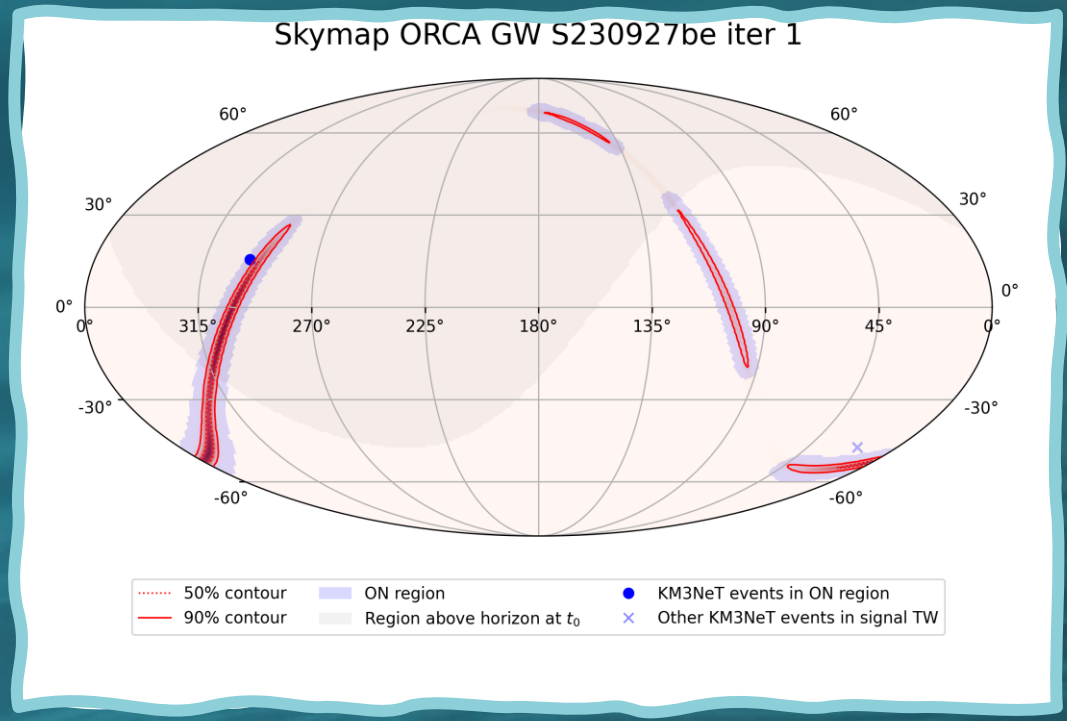
work in progress

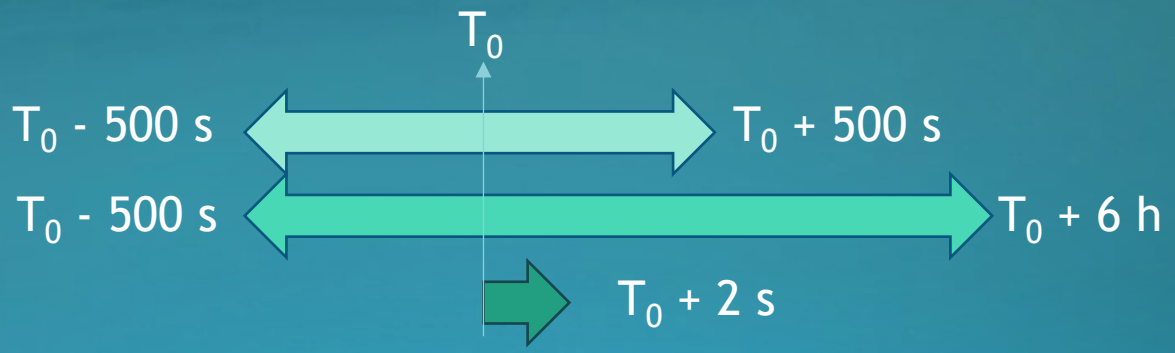
HE-ν candidate:
Cuts for proper event selection (work in progress)
→Send a notice (GCN / SNEWS2)

CCSN alerts:
Already working

GW Follow-up:

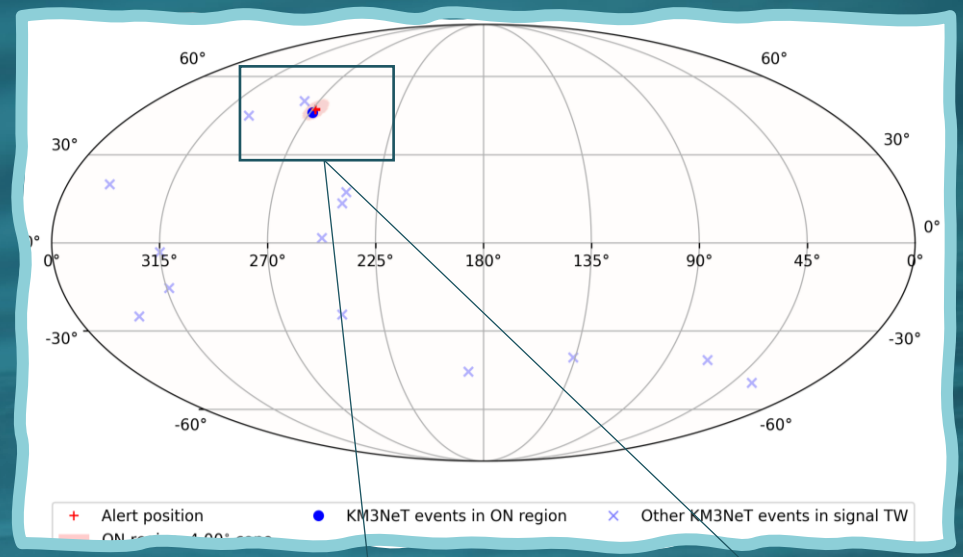
- **Alerts from: LVK (GCN)**
- **Period: Full run O4a covered.** The follow-up of run O4b is currently ongoing
- No **significant correlation** found.
- **Example: S230927be** (BBH merger)
  - Expected background: 0.018 events
  - 1 event in ON ⇒ p-value 0.019

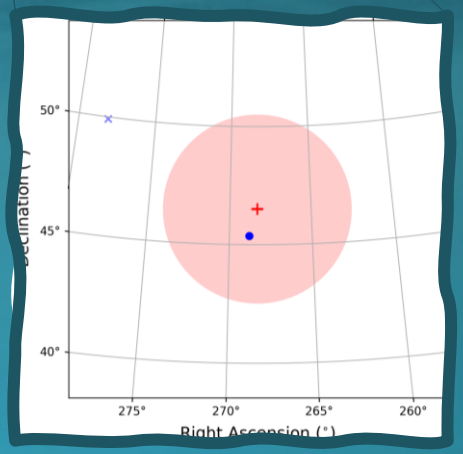


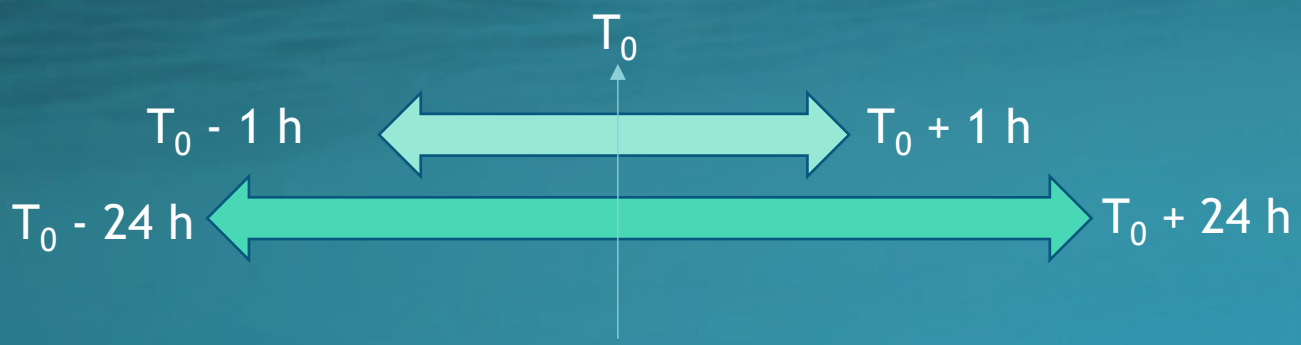


$\nu_{e,\mu,\tau}$ $\bar{\nu}_{e,\mu,\tau}$ HE Neutrino Follow-up:

- **Alerts from: IceCube** bronze and gold (GCN)
- No **significant correlation** found.
- **Example: IC 231027A** (Gold)
  - Expected background: 0.07 events
  - 1 event in ON ⇒ p-value 0.068

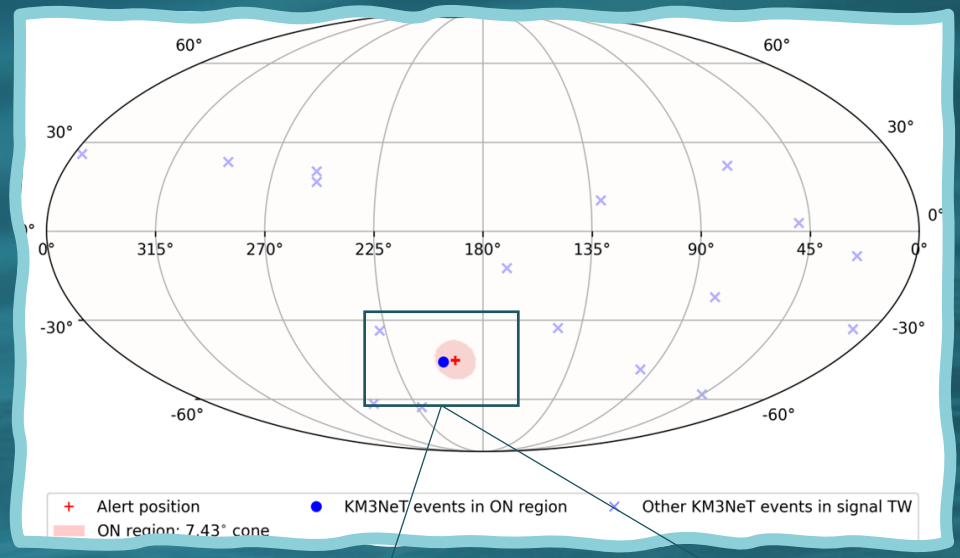


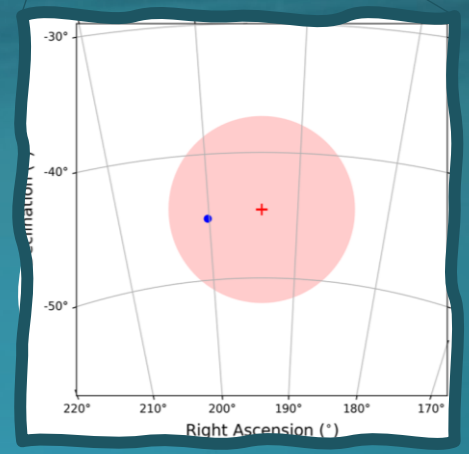


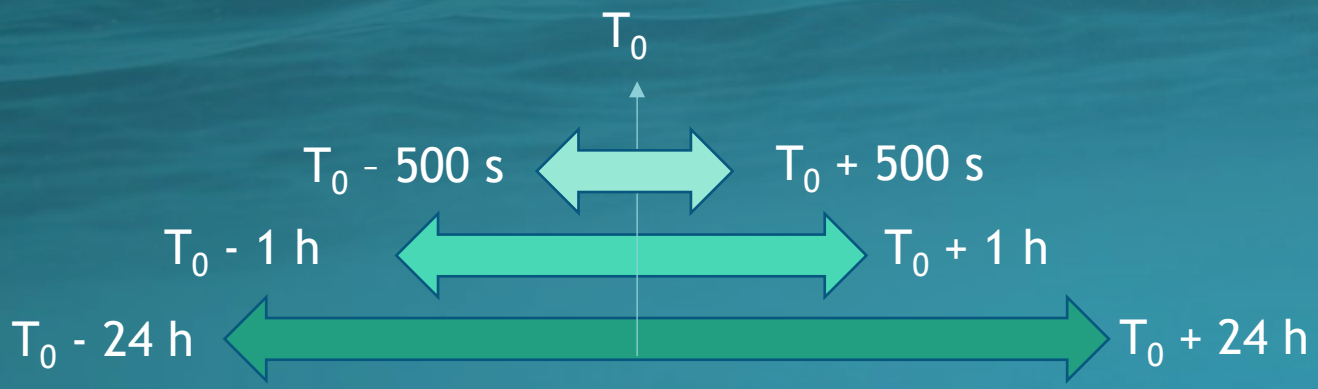


GRB Follow-up:

- **Alerts from:** Fermi, Swift & Integral (GCN)
- No **significant correlation** found.
- **Example:** 722864655 (Fermi)
  - Expected background: 0.13 events
  - 1 event in ON ⇒ p-value 0.12







FRB and μ-Quasars Follow-up:

Alerts from:

- **Chime VOEvent broker**
- **TNS** catalog (delayed by days to months)

No correlations up to now

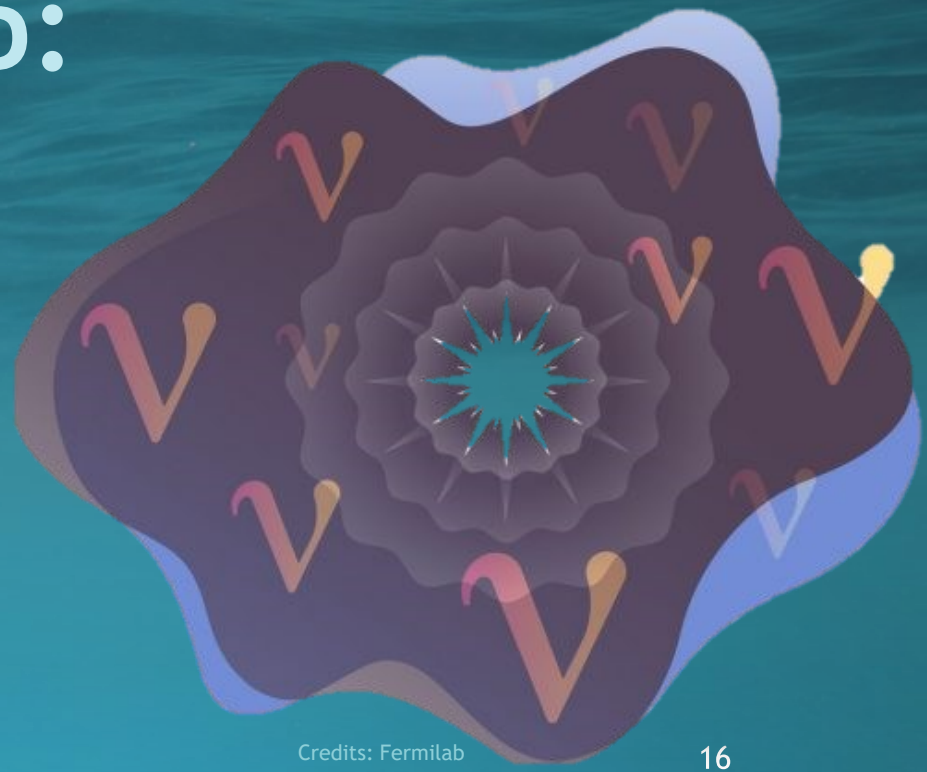
Transient sources selected from Fermi, Swift, Maxi, HAWC, EP_wxt (internal broker)

No correlations up to now

CCSN Follow-up:

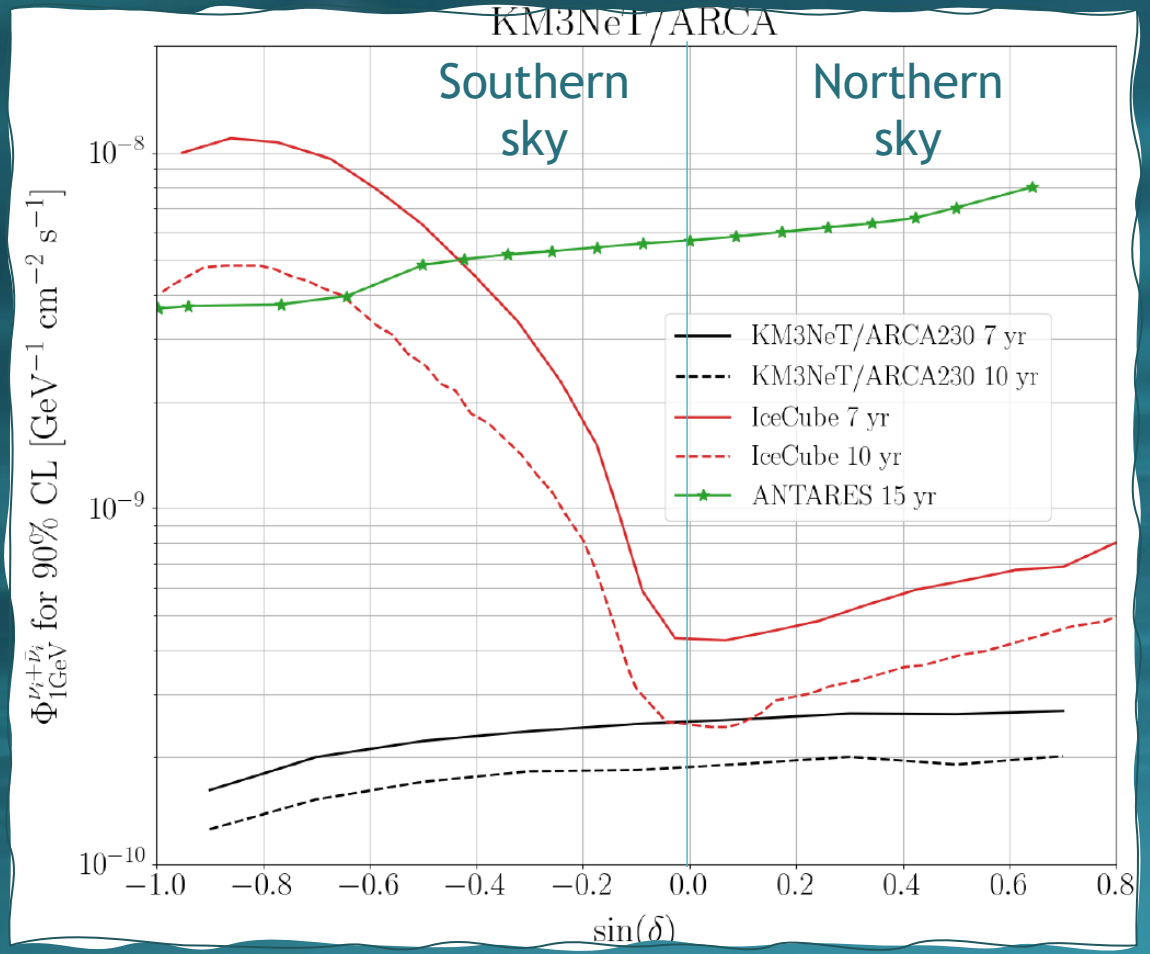
- Alert system: neutrinos arrive hours before EM radiation
- Main detection channel for CCSN neutrinos: inverse beta decay ($\bar{\nu}_e + p^+ \dashrightarrow e^+ + n$)
- Order of 10 MeV

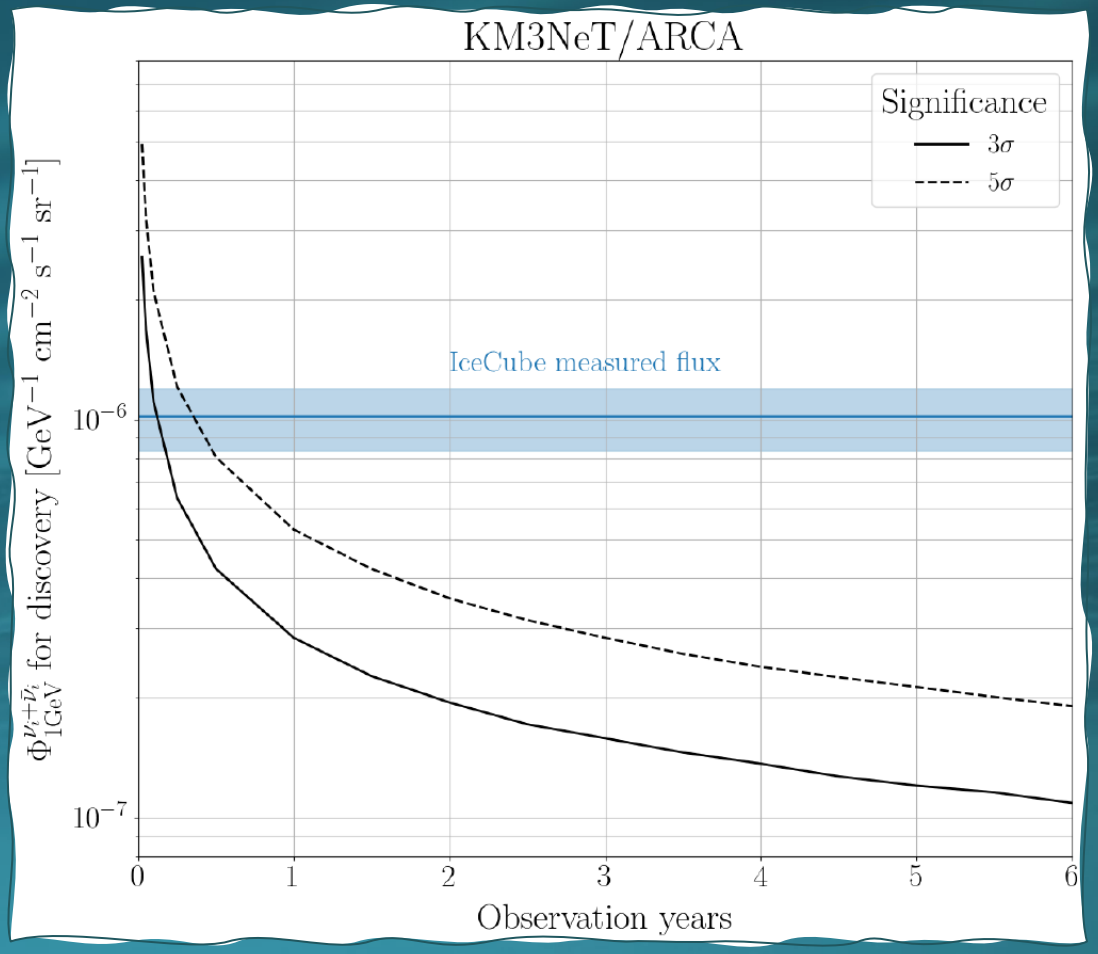
- Different strategy from the ON/OFF approach: KM3NeT is optimized for the detection of neutrinos >GeV --> individual positron trajectories cannot be reconstructed. --> **Search for an excess of coincidences** between PMTs in single DOMs above the expected background of the detector



Credits: Fermilab

Astronomy potential for KM3NeT/ARCA 230





Point-like source sensitivity as a function of the declination angle for a neutrino flux with spectral index γ = 2.

3σ and 5σ discovery flux for a **diffuse neutrino flux** with spectral index γ = 2.37 as a function of observation time.

Figures from: Eur. Phys. J. C 84, 885 (2024)

One more thing if tere is time…

KM3NeT is interdisciplinary and helps biologists to study cetaceans by recording their sounds

Conclusions

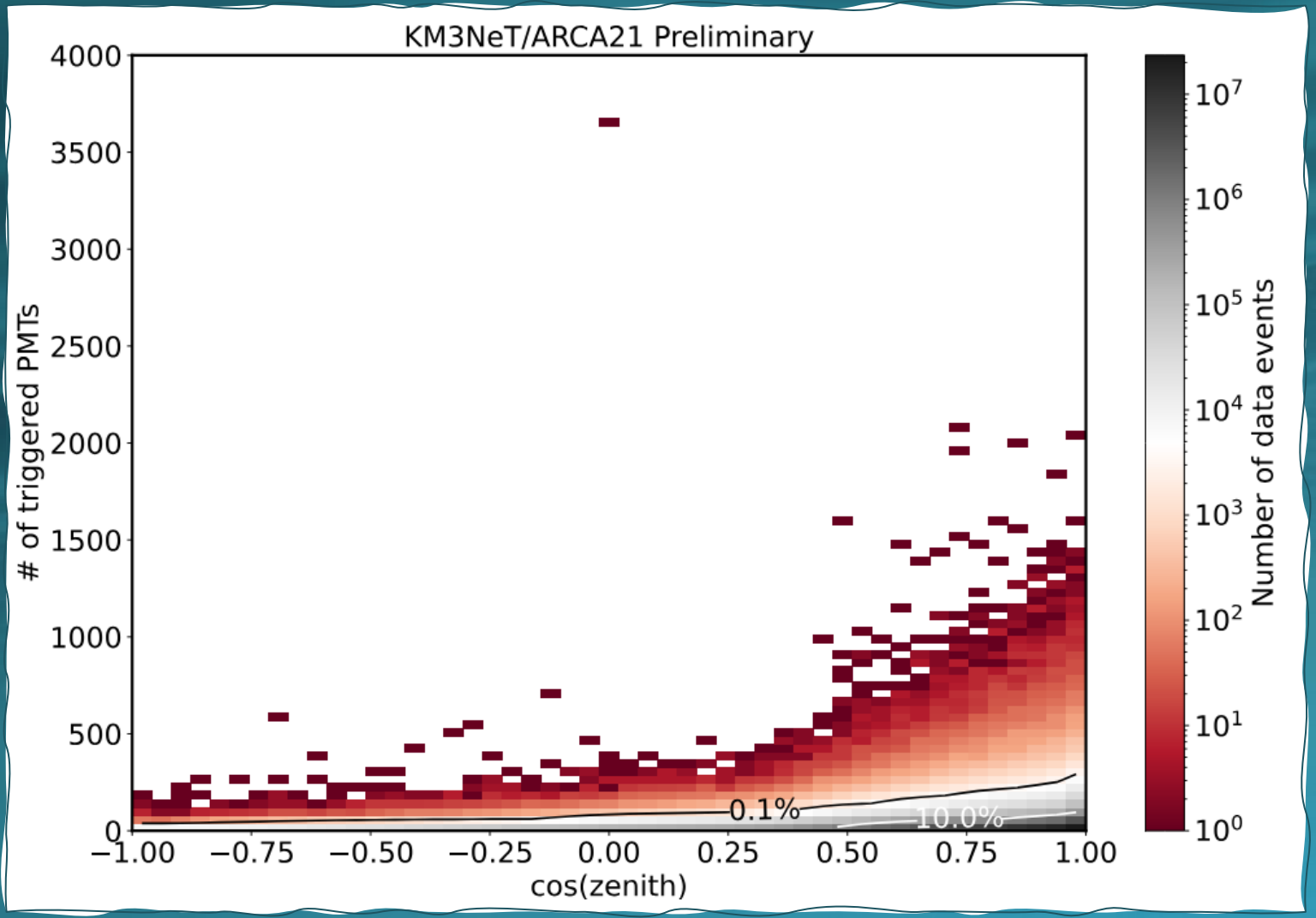
- KM3NeT is already in data taking mode even with a partial detector.
- Online analyses are ongoing:
  - Follow-up of external alerts
  - Work in progress regarding sending out alerts
- No significative spatial and temporal coincidences found up to now.
- VHE neutrino found! PAPER COMING SOON

BACK UP SLIDES

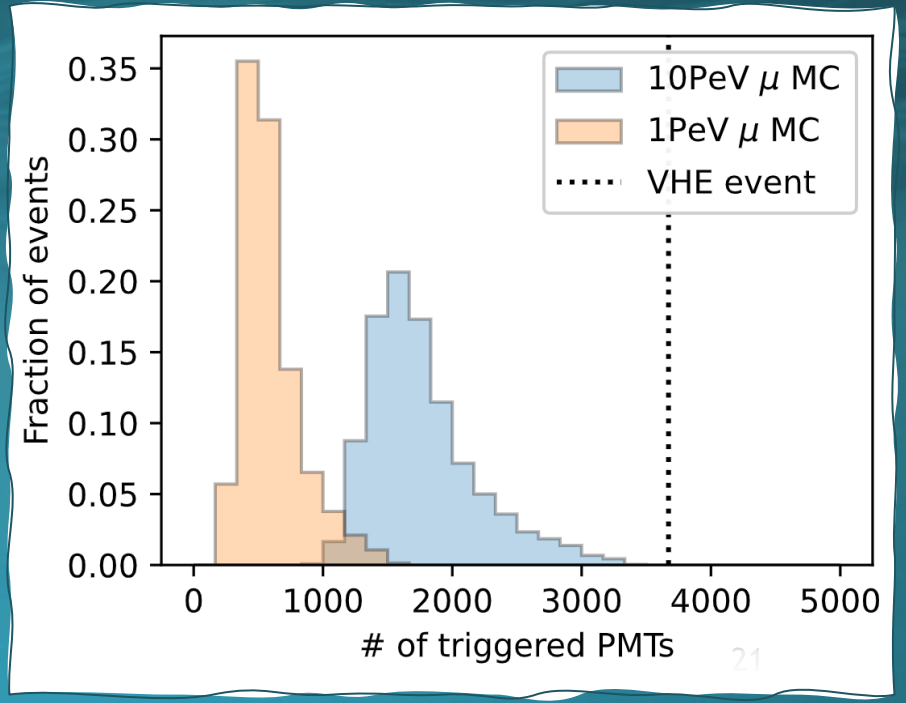
VHE event

well-reconstructed track, indicative of a highly-relativistic muon travelling several hundreds of metres through the detector.

#probability that the muon originated from a cosmic ray interacting in the atmosphere is negligible ($\ll 10^{-10}$) per year



Energy of some tens of PeV



Background sources in KM3NeT

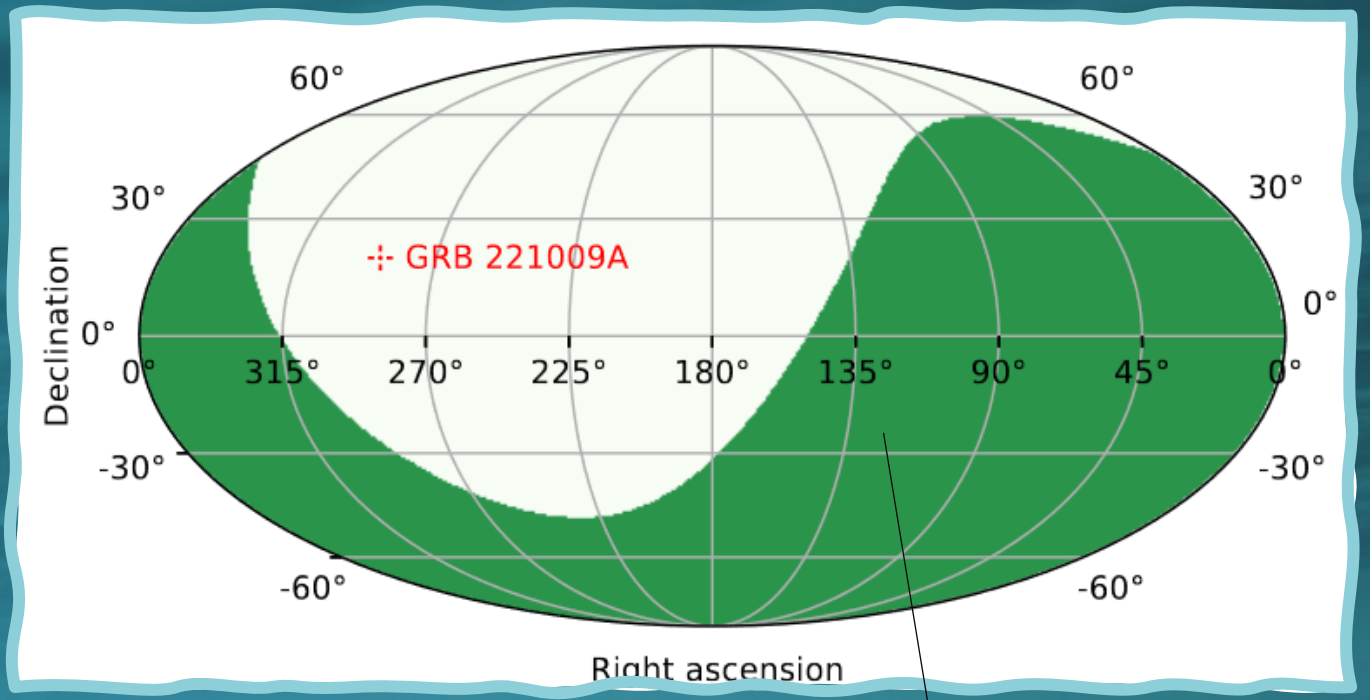
Bioluminescence

Atmospheric μ

Not bananas…
but ^{40}K

GRB 221009A :

- **Alerts from:** Fermi
- No **significant correlation** found.
- Above KM3NeT horizon --> larger background
- Multiple time windows tested
- See S. Aiello *et al* JCAP08(2024)006



Green --> Upgoing (equatorial coordinates at T_0)