KM3NeT physics results

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on behalf of the KM3NeT Collaboration
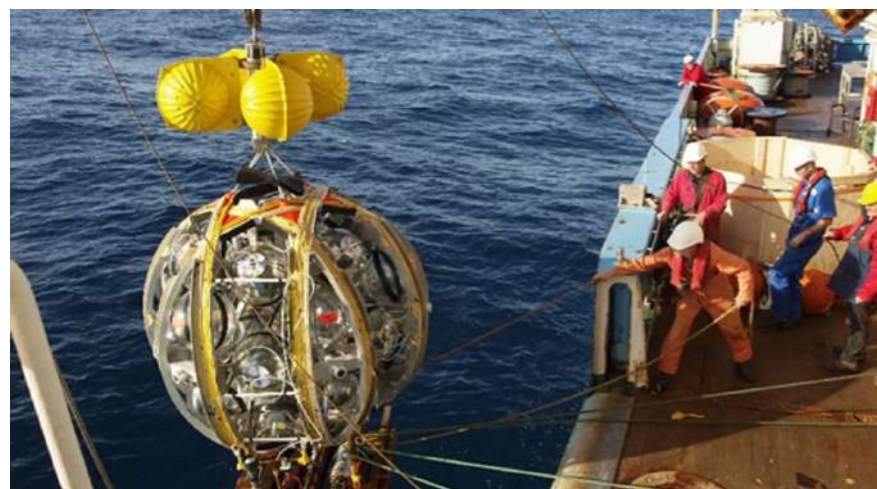silvia.celli@roma1.infn.it

KM3NeT at a glance

Main detector elements:
- Digital Optical Modules (DOMs)
- Detection Units (DUs)
- Seafloor network: Junction Boxes (JBs) and electro-optical cables

DOM:
17" glass sphere containing:
31x3" PMTs
LED and Piezo
Front end electronics

- Uniform coverage
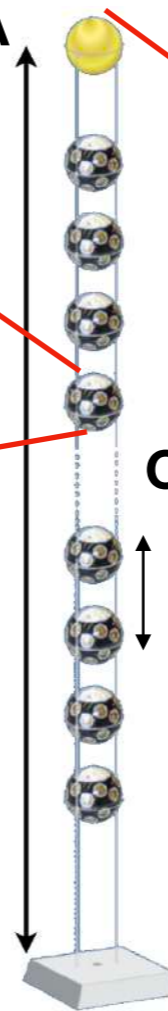- Directional information
- Digital photon counting
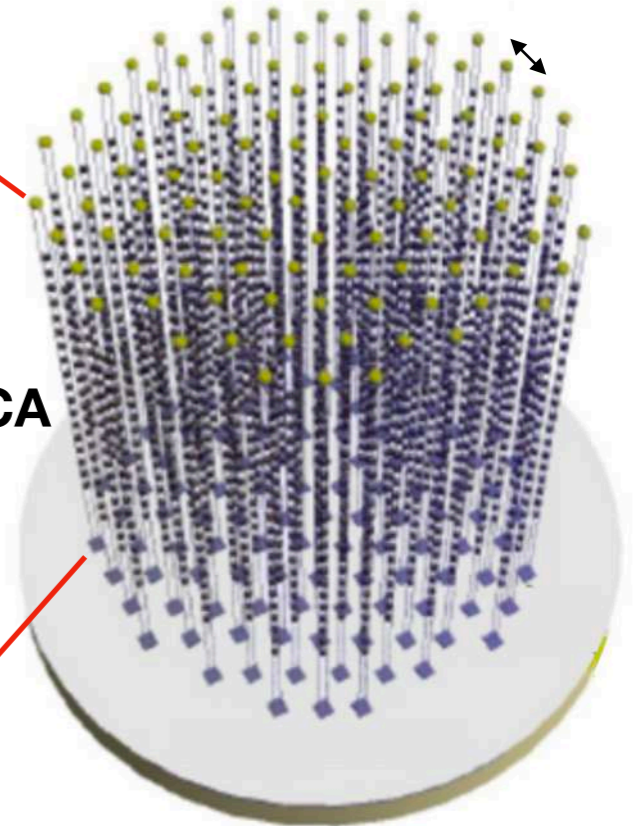- All data to shore

DOM

ORCA/ARCA
~200/700 m

ORCA/ARCA
~9/36 m

DU
18 DOMs+1base module/DU

LOM

ORCA/ARCA
~20/90 m

BUILDING BLOCK
115 DUs/building block

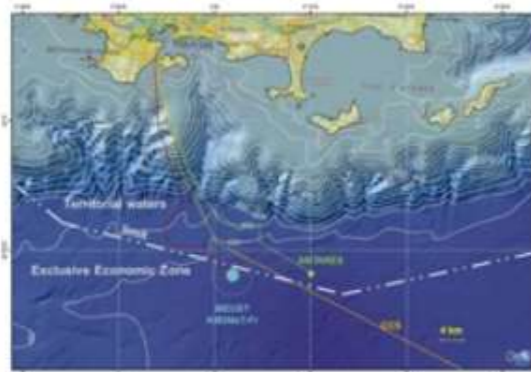# KM3NeT: a top view

ARCA (1 GTon)
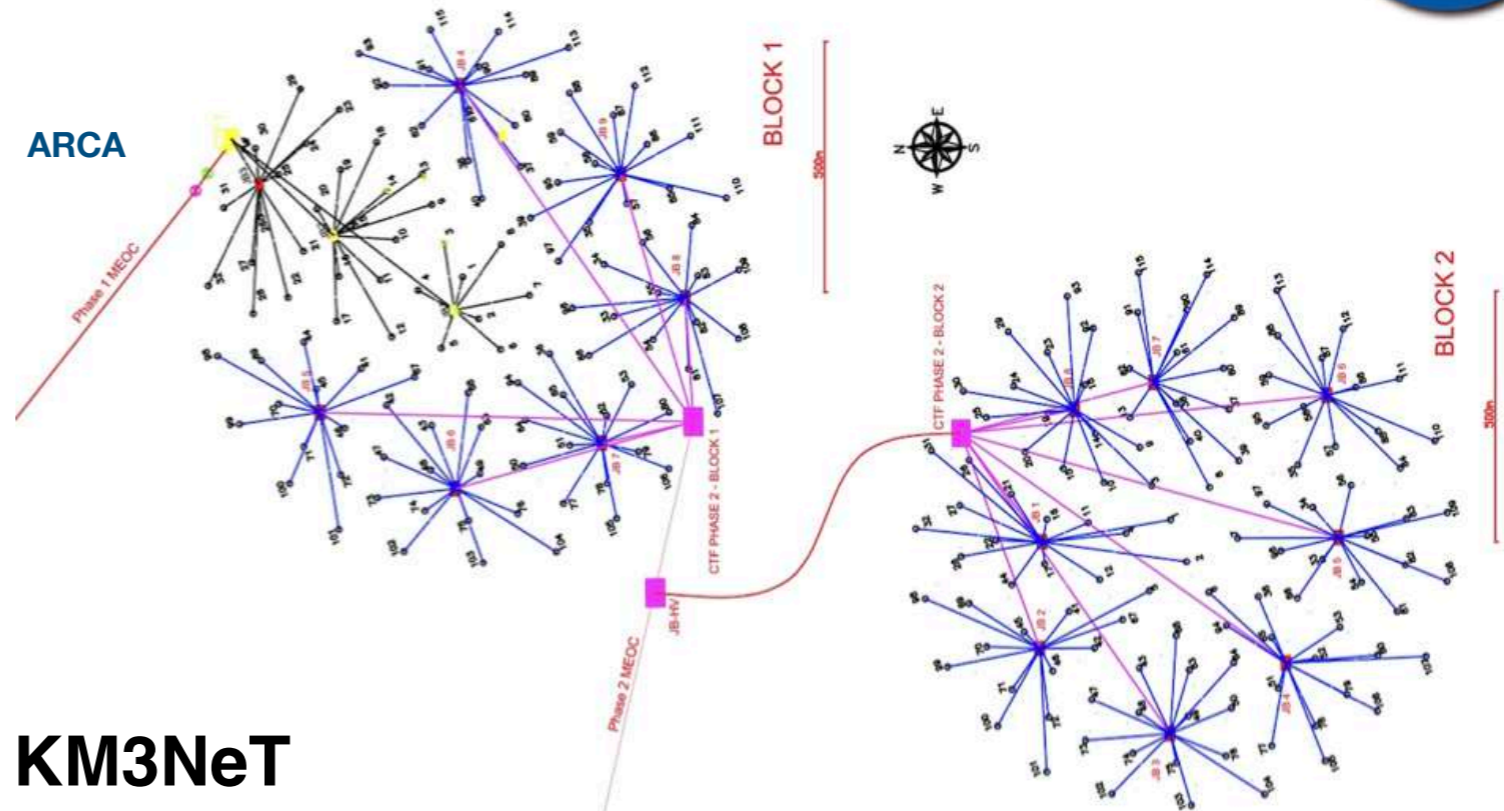Astroparticle Research
with Cosmics in the Abyss
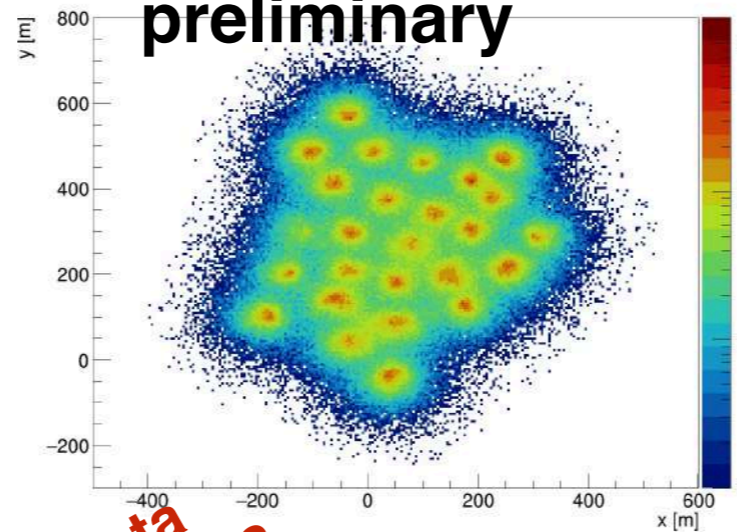
3500 m depth,
offshore Sicily

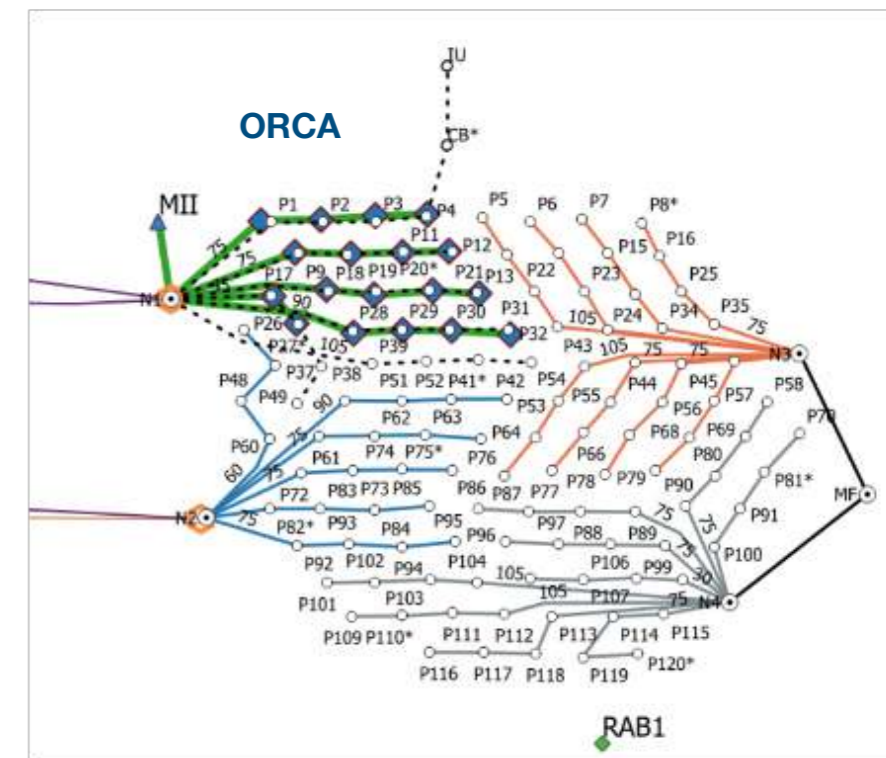## ORCA (6 MTon)
Oscillation Research
with Cosmics in the Abyss
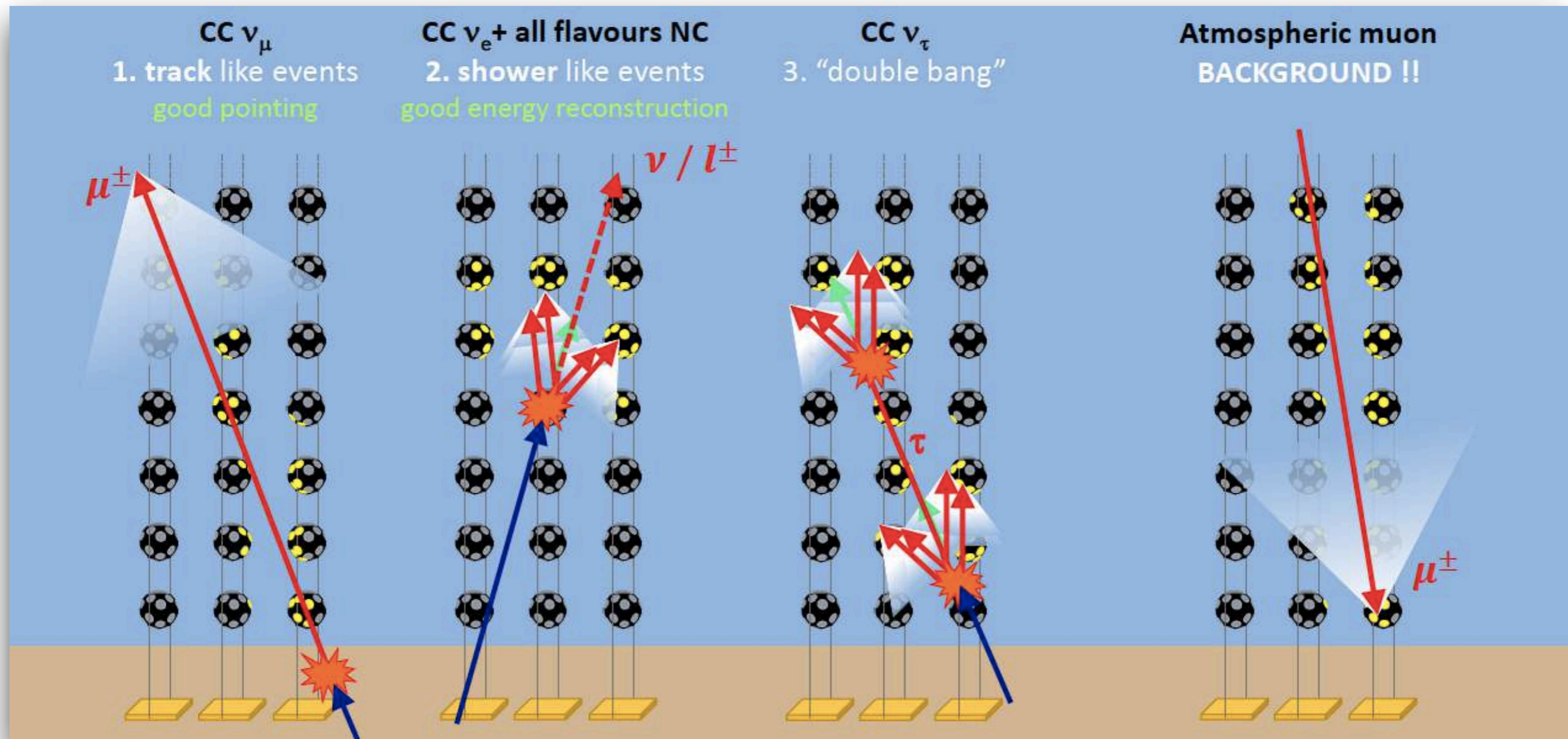
2500 m depth,
offshore Toulon

**KM3NeT
preliminary**

*real data
from ARCA28*

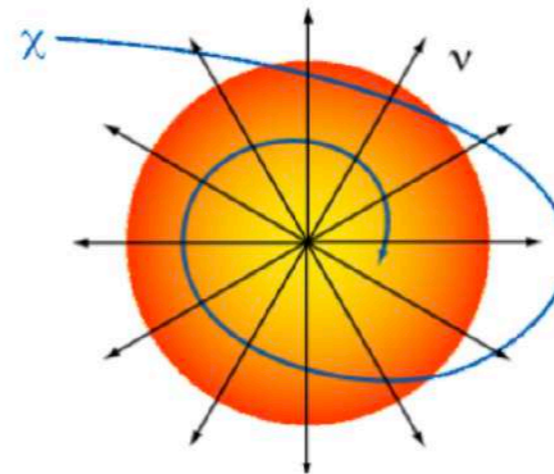# **Neutrino detection principle & event topologies**

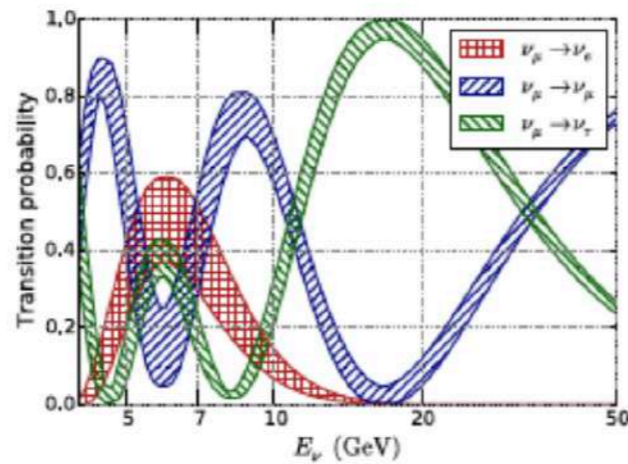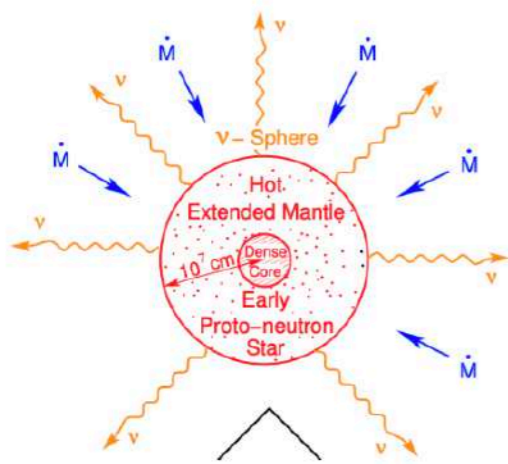- Track like events ⟶ golden astronomical channel
- Shower like events ⟶ calorimetric ⟶ diffuse analyses

Science with ν telescopes

NEUTRINO ENERGY FROM MeV TO PeV

| Super Novae explosion MeV | Neutrino oscillation GeV | Dark Matter (*) TeV | HE neutrinos Multi-messenger program PeV |

KM3NeT ORCA
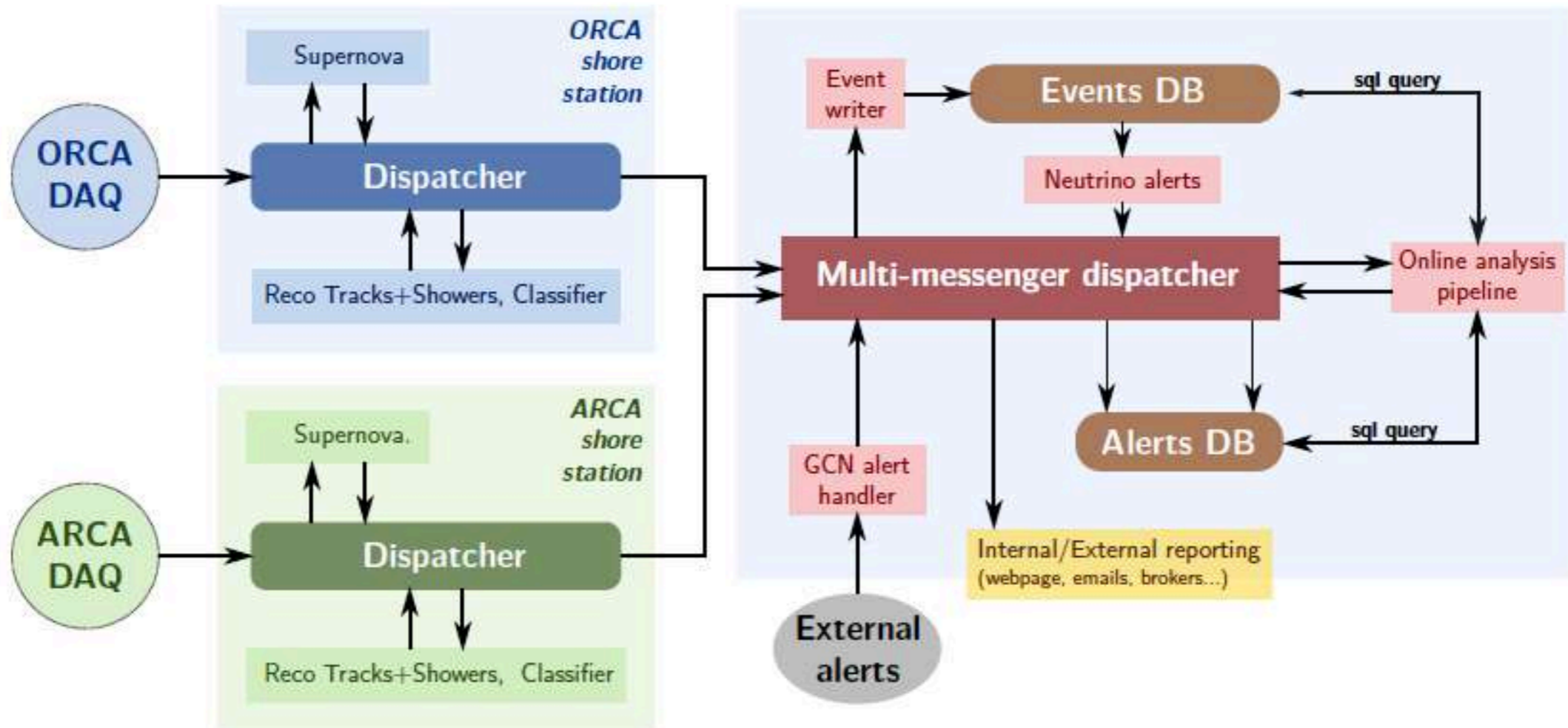
ARCA

KM3NeT ARCA

+ oceanography, biology, bioluminescence, …
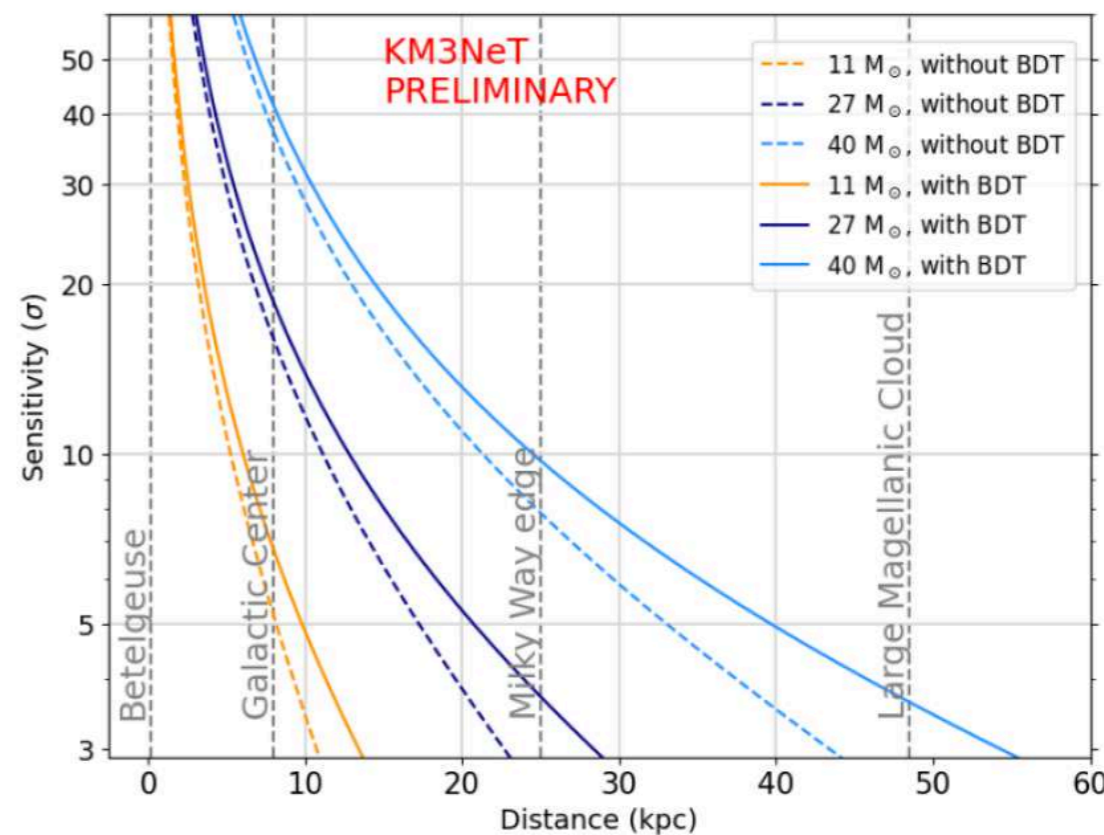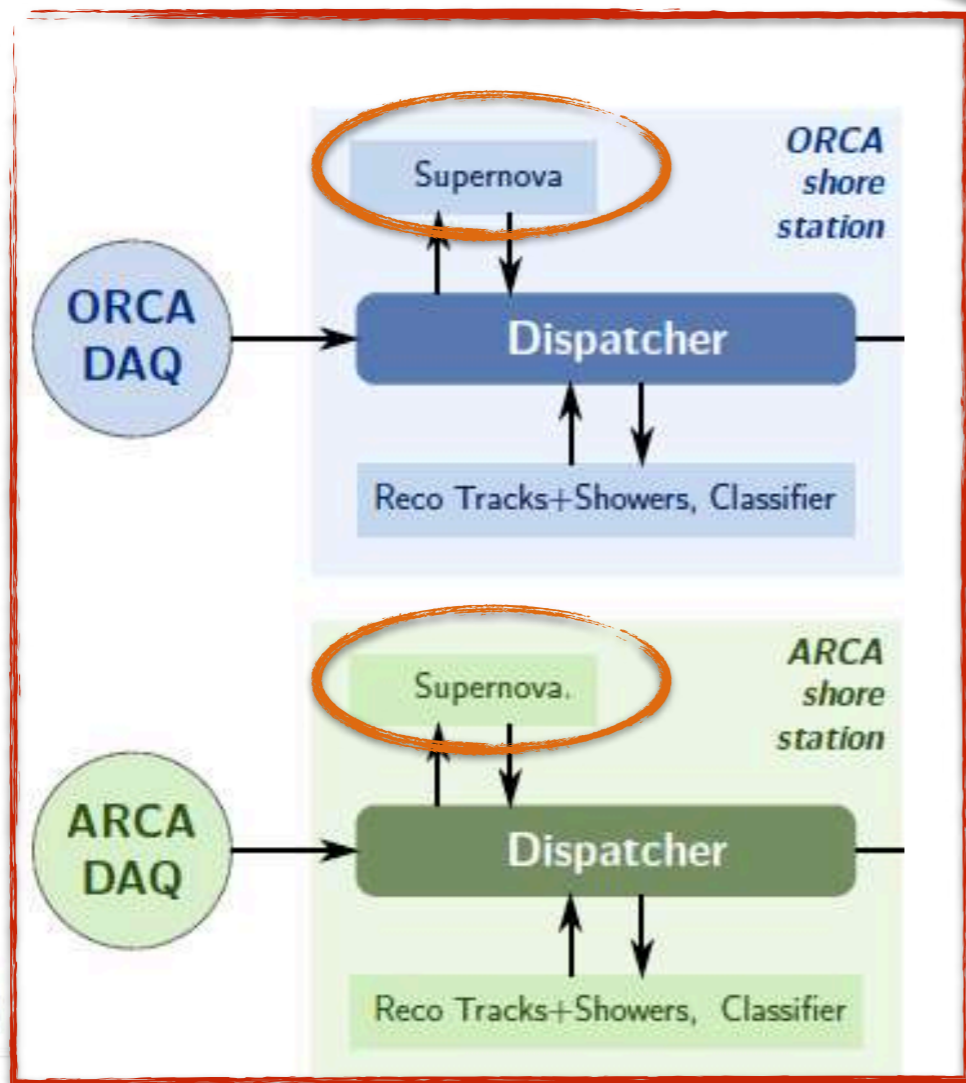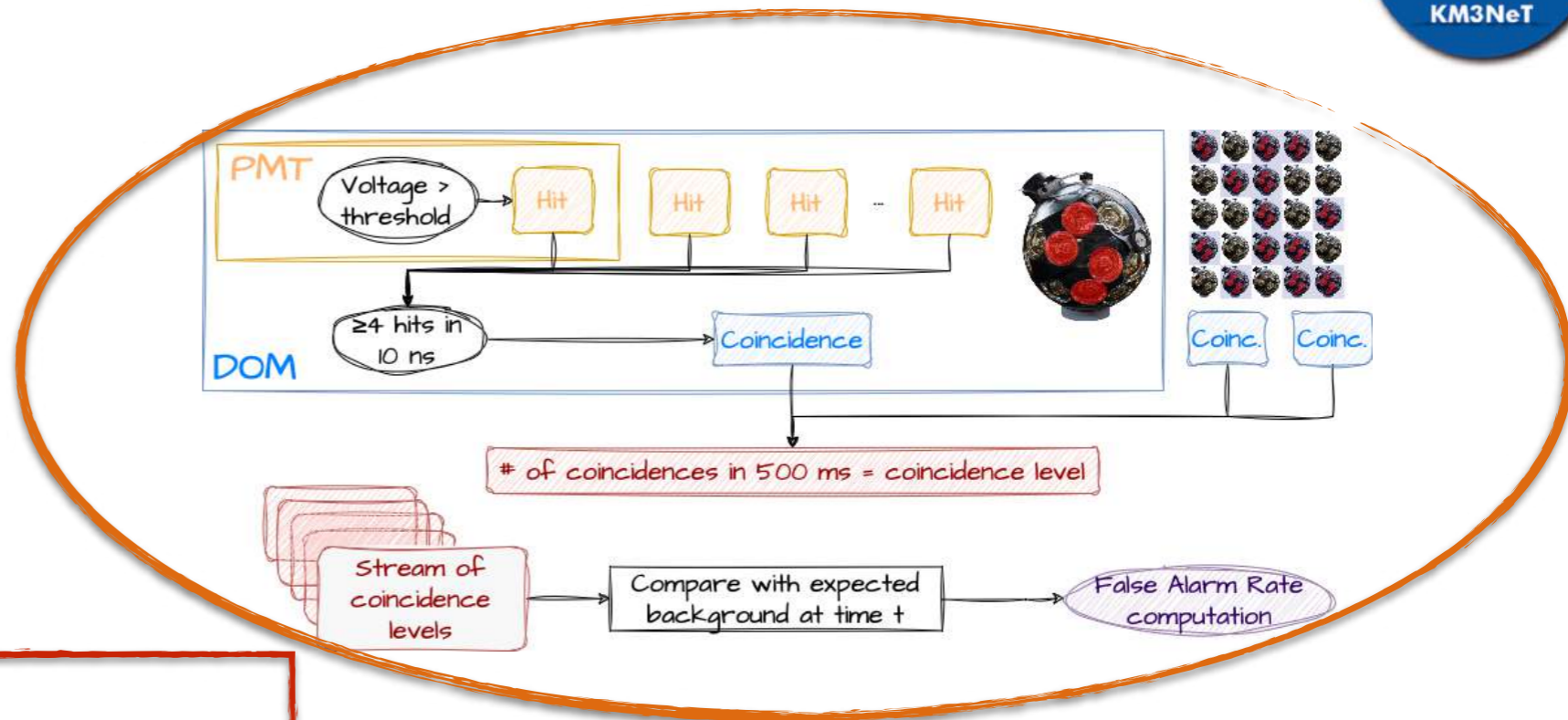
KM3NeT real time analysis system

In the view of searching for correlation among ν and MM signals (EM, GW), it is increasingly crucial to be able to identify (**reconstruct, classify & select)** cosmic neutrinos in real-time as to allow **fast follow up** for counterpart identification.

The **Real-Time Analysis (RTA)** program includes:
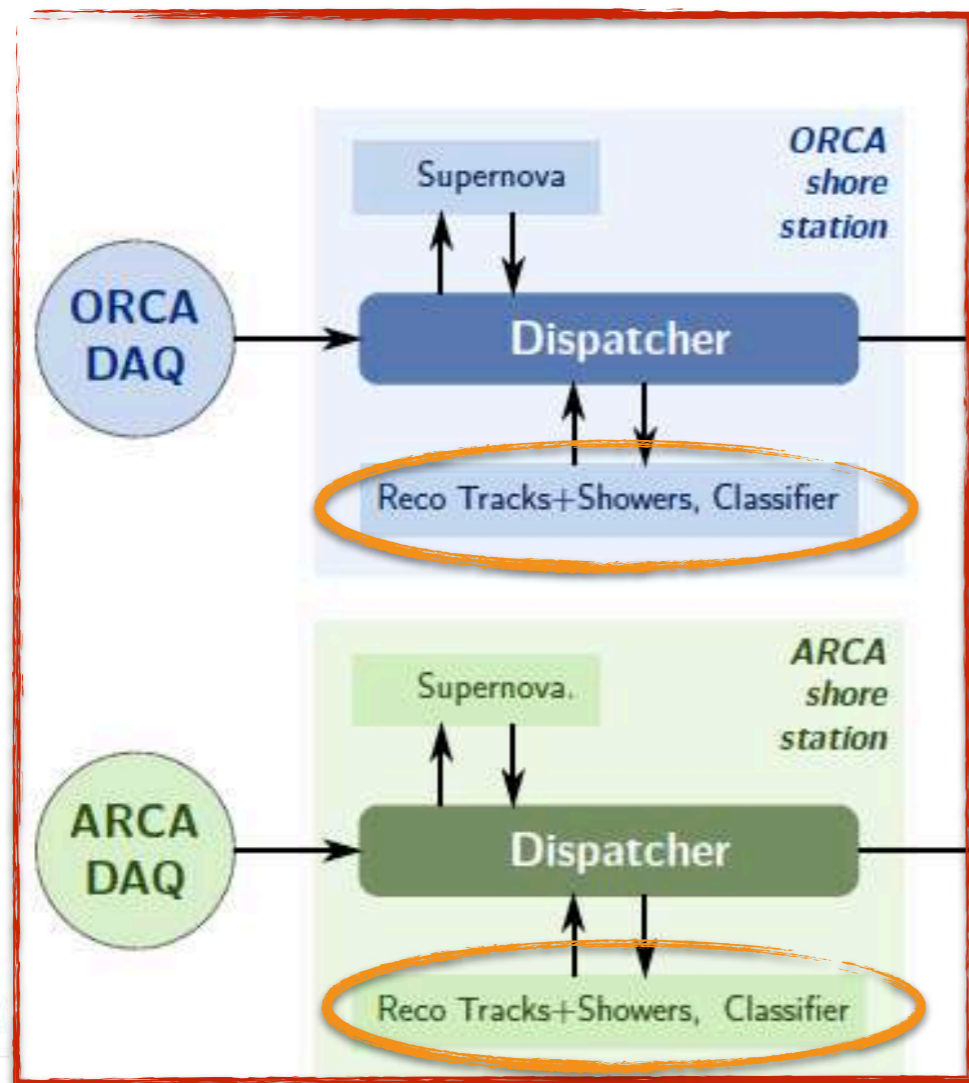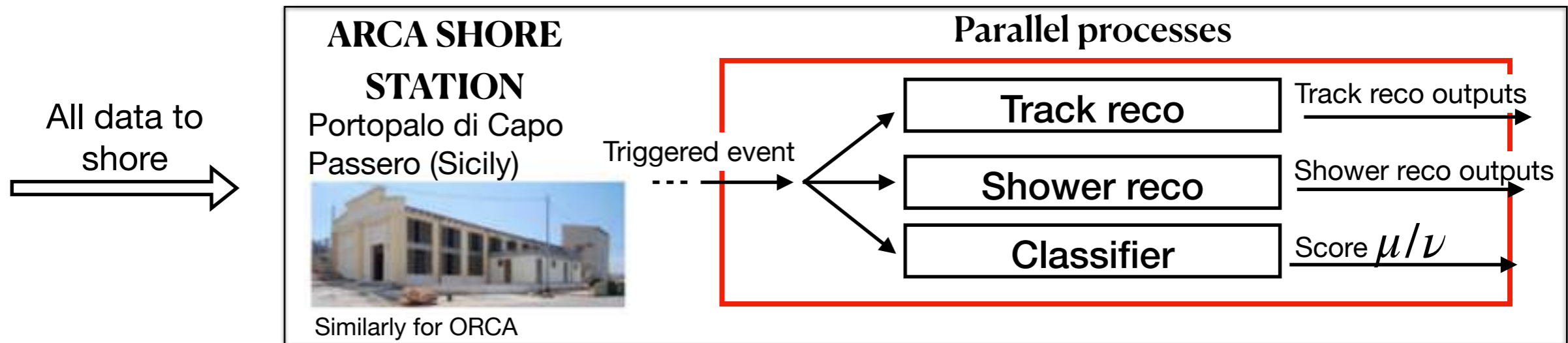1) Continuos **SN monitoring** (MeV)
2) **Follow-up of external triggers** (GW, IC, gamma) with high-energy neutrino data
3) **Neutrino alert** sending (HE, multiplets, …)

The online CCSN analysis

Goos et al. PoS (ICRC2023) 1160

Online reconstruction & classification

ARCA SHORE STATION
Portopalo di Capo Passero (Sicily)

Similarly for ORCA

All data to shore

Parallel processes

Triggered event

Track reco	Track reco outputs
Shower reco	Shower reco outputs
Classifier	Score μ/ν

ORCA shore station

Supernova

ORCA DAQ → Dispatcher

Reco Tracks+Showers, Classifier

ARCA shore station

Supernova.

ARCA DAQ → Dispatcher

Reco Tracks+Showers, Classifier

Current status of the detectors:

ORCA23

ARCA33

Tracks: Reco Level [Hz]
Tracks: Noise Cut [Hz]
Tracks: Noise Cut + coszen<0.1 [0.01 Hz]
Showers: Reco Level [Hz]
Classification level [Hz]
Classifier: score>=0.7 [Hz] [0.1 Hz]

ARCA28: KM3NeT preliminary
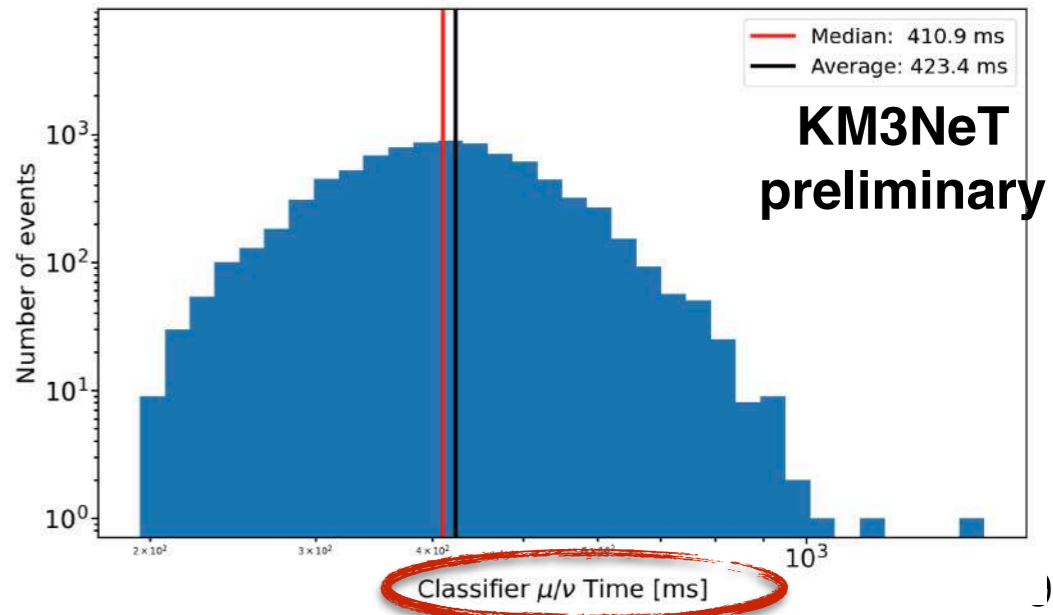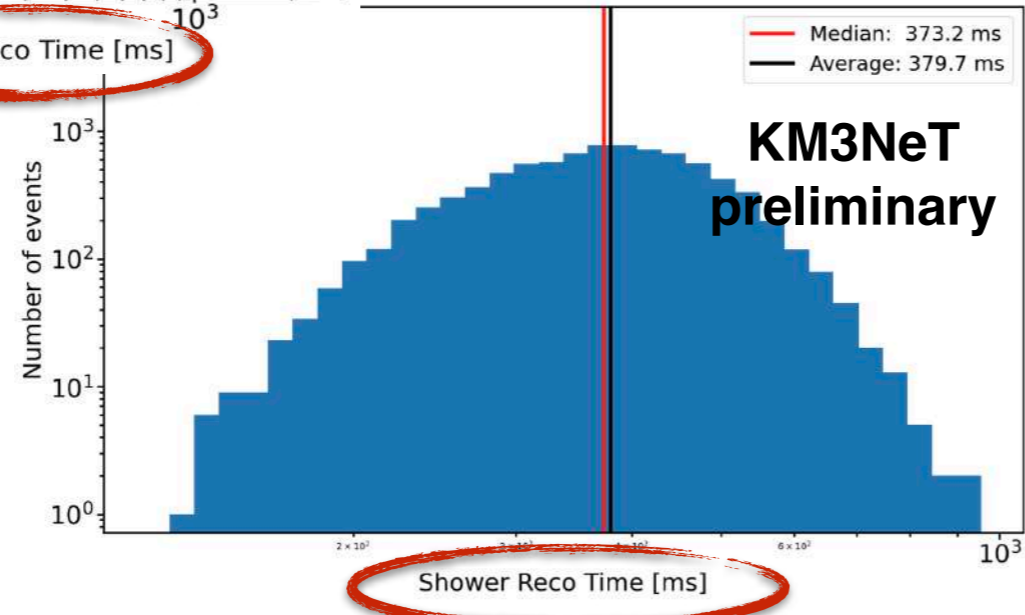
KM3NeT preliminary

Median: 264.7 ms
Average: 318.9 ms

Track Reco Time [ms]
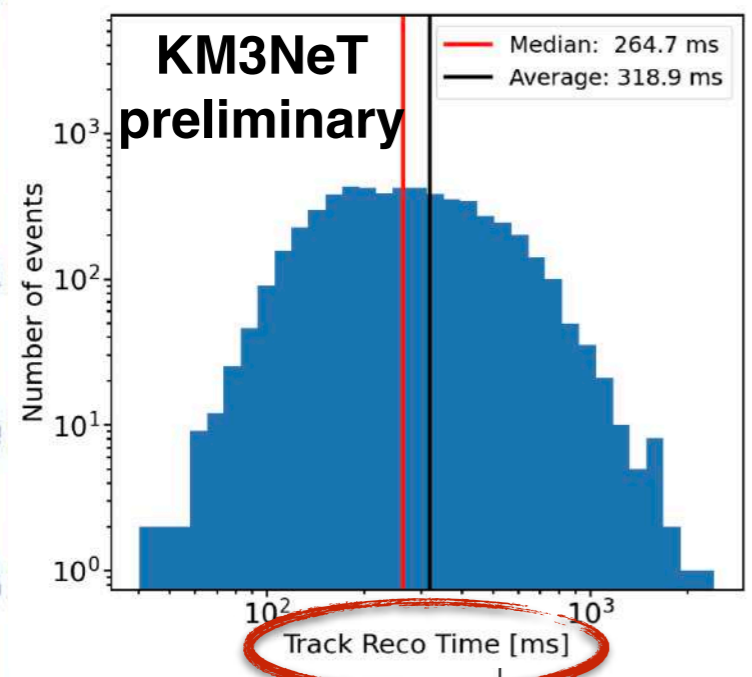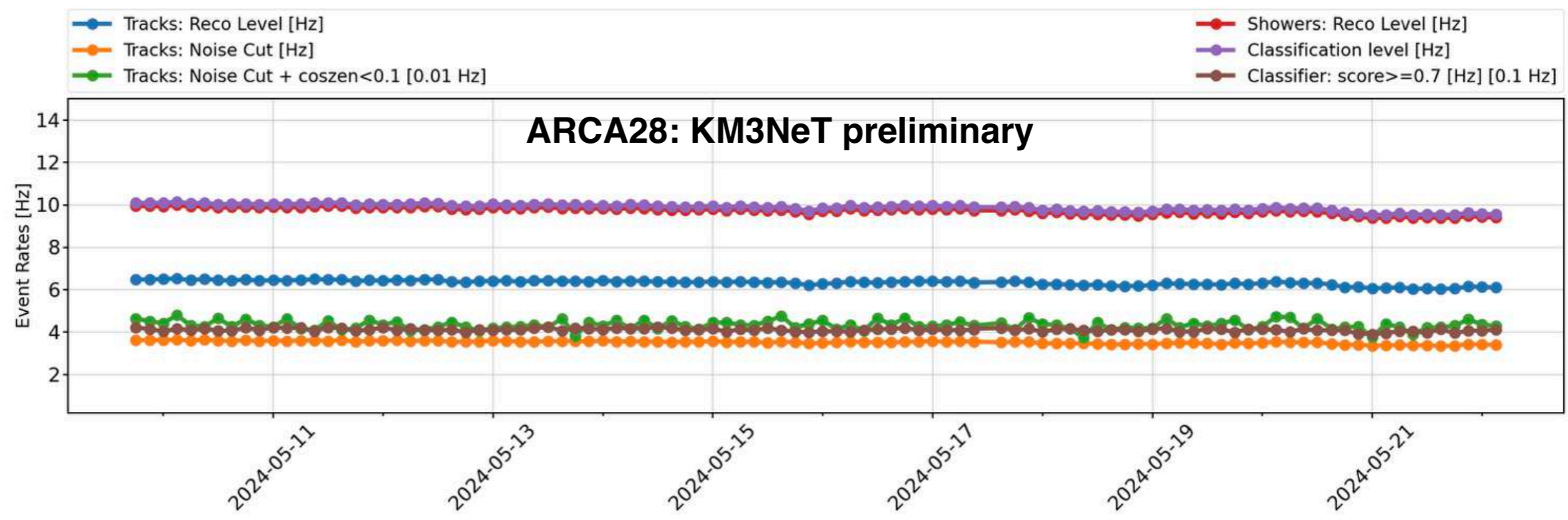
+ distribution & analysis time ⟶ KM3NeT can provide neutrino candidates within ~10 seconds!

Score μ/ν

KM3NeT preliminary

Neutrino score

Median: 373.2 ms
Average: 379.7 ms

KM3NeT preliminary

Shower Reco Time [ms]

Median: 410.9 ms
Average: 423.4 ms

KM3NeT preliminary

Classifier μ/ν Time [ms]
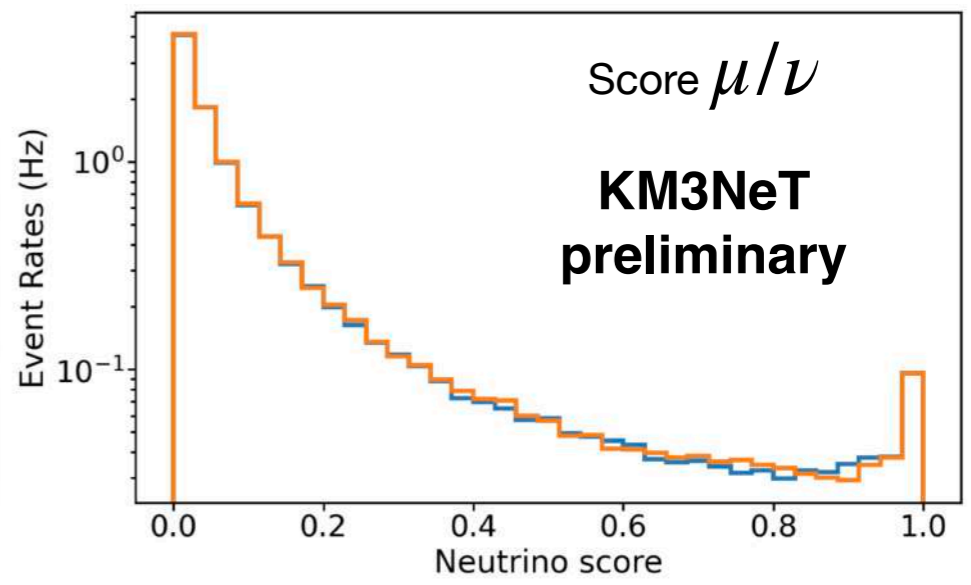
S. Celli et al. [KM3NeT], PoS 444 (ICRC2023) 1125

KM3NeT realtime follow-up of external triggers

- External triggers received from 3 external **brokers** (GCN, Chime, TNS), 1 internal broker (µQuasar), SNEWS and HyperK
- Each alert starts an **automated all-sky** analysis in **ARCA & ORCA**
- Only **track-like events** used so far in coincident search (showers inclusion in progress)
- **Iterative searches** in extended time windows, profiting of updated information from instruments

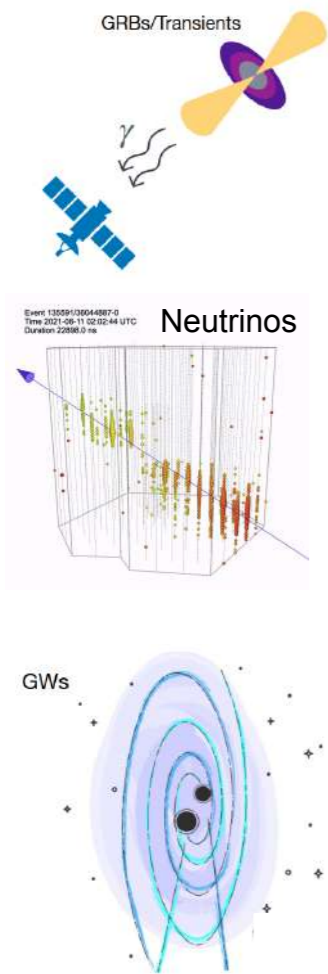

- **Binned ON/OFF analysis** method:
  - ➜ background estimation
  - ➜ cut optimization
  - ➜ flux limit computation

ORCA

ARCA

- **Pipelines** currently in place:
  - ➜ Gamma Ray Bursts (GRBs)
  - ➜ High-energy transients
  - ➜ IceCube (IC) neutrinos
  - ➜ Gravitational Waves (GWs)
  - ➜ Fast Radio Bursts (FRBs)
  - ➜ µQuasars
  - ➜ Core Collapse Supernovae (CCSNe)
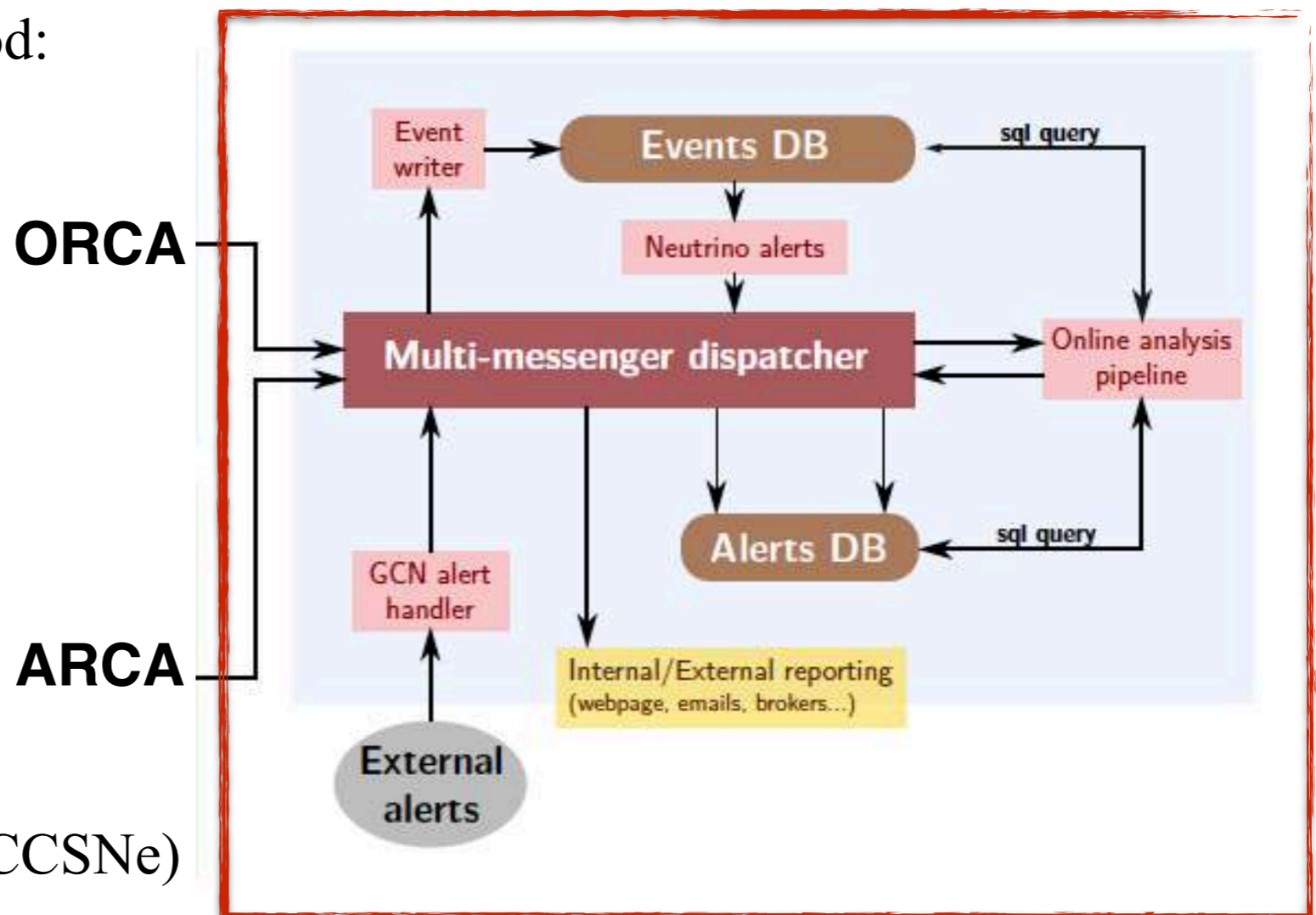
Spatial windows for realtime follow ups

GRBs

Transients

IC neutrinos

GWs
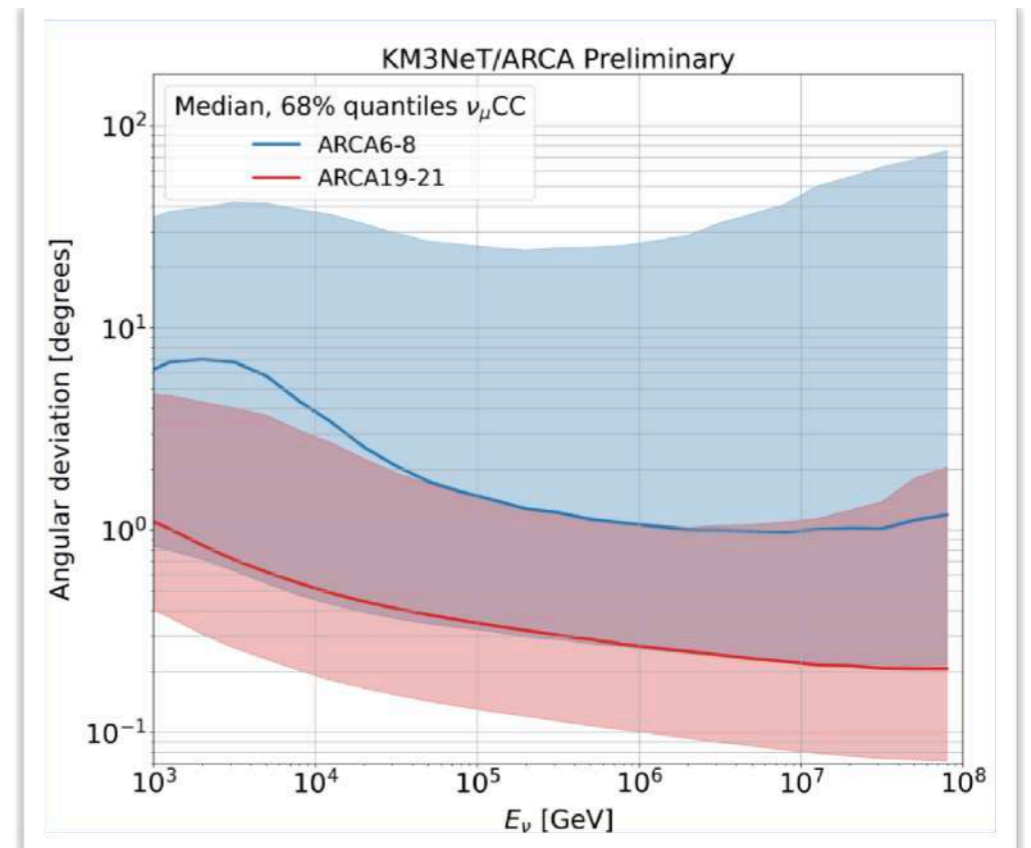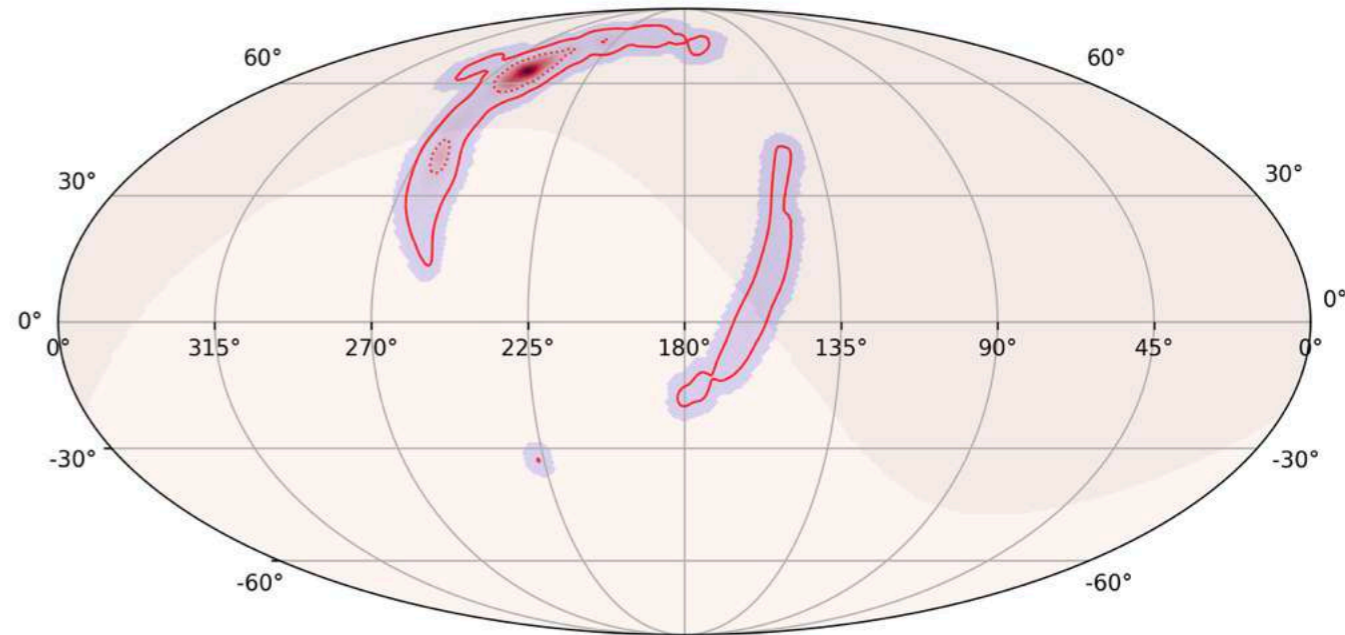
FRBs

μQuasars
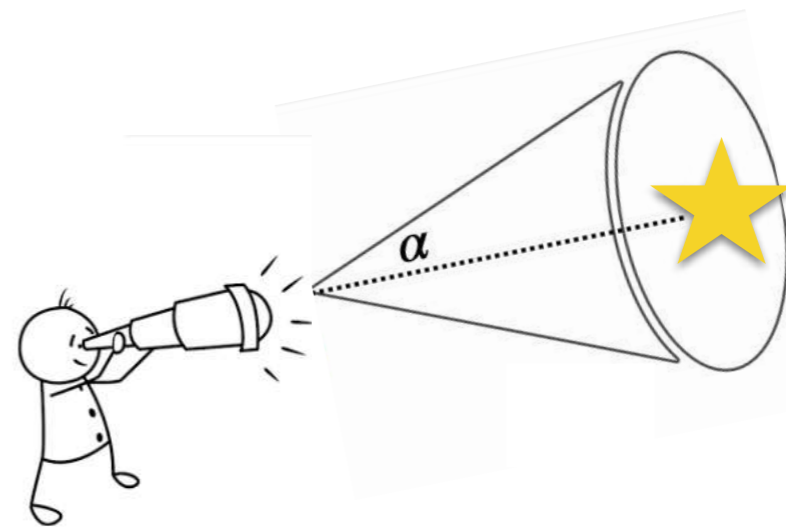
CCSNe

Neutrinos

GRBs/Transients

GWs

The angular search region is taken from the 90% GW probability map, extended for KM3NeT point spread function

Spatial windows for realtime follow ups

GRBs/Transients

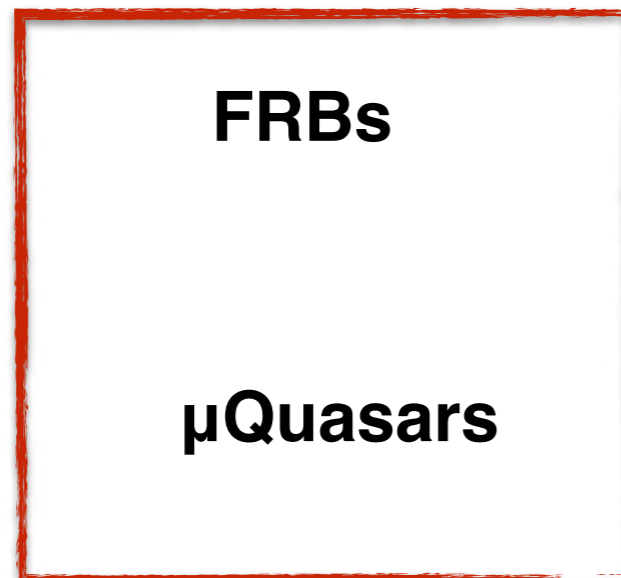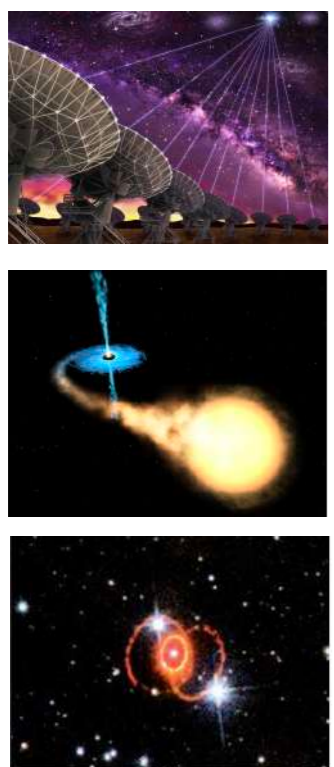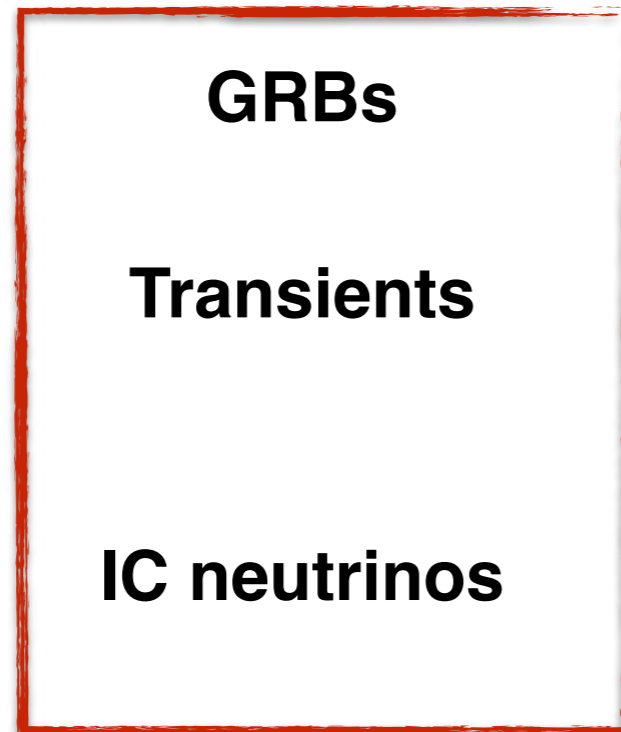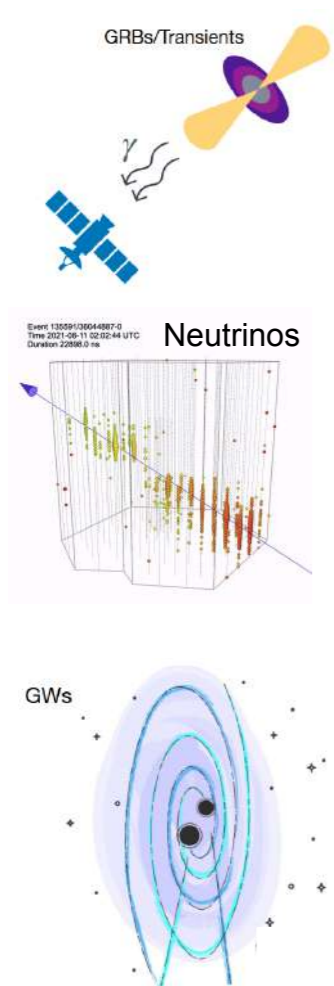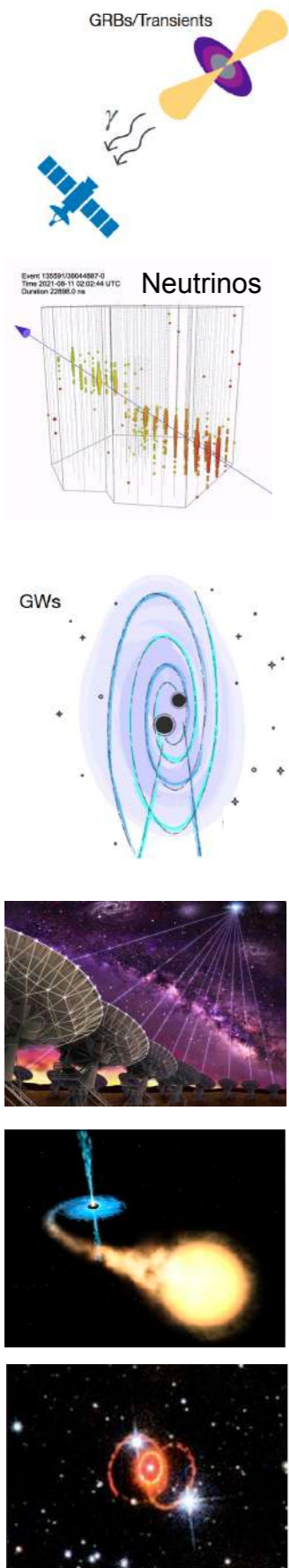Neutrinos

GWs

GRBs

Transients

IC neutrinos

GWs

FRBs

µQuasars

CCSNe

The angular search region is a cone, centered at the source position, whose extension α is

- **ARCA: max[2°,src_uncertainty]**
- **ORCA: max[4°,src_uncertainty]**

median angular error of online analyses in current partial detector configuration

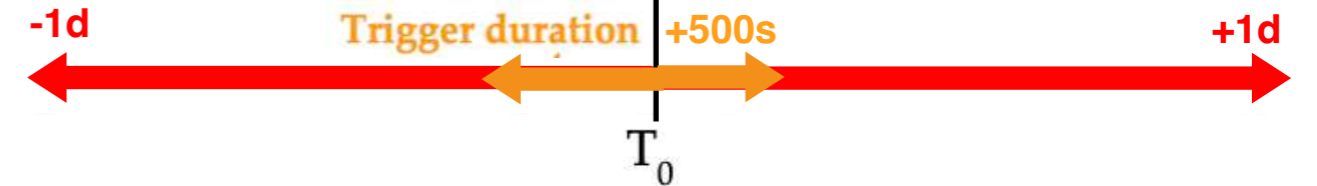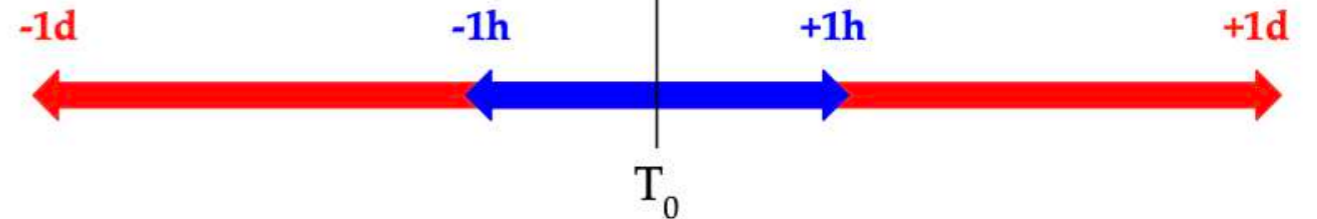# Temporal windows for realtime follow ups
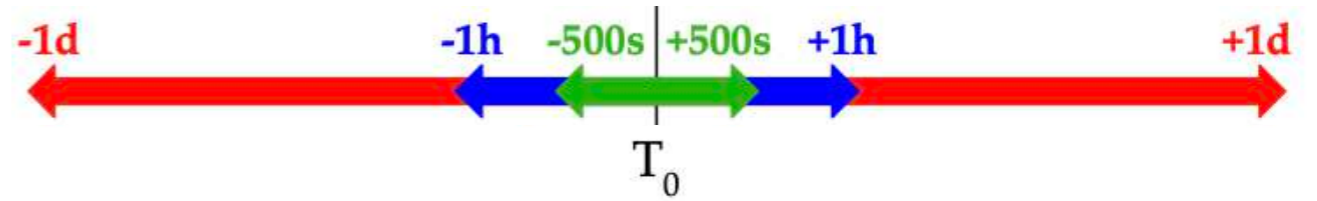
Selected alerts

Number of SELECTED alerts per day — KM3NeT Preliminary
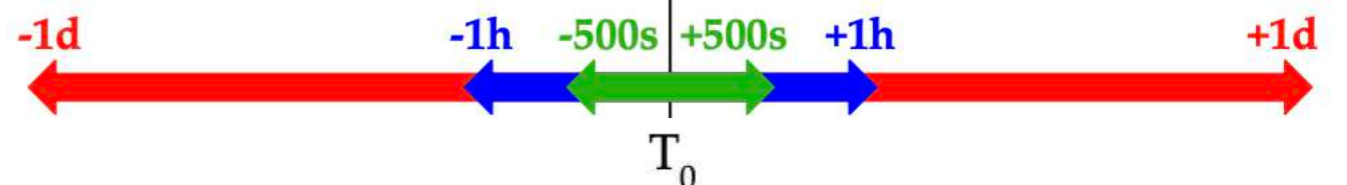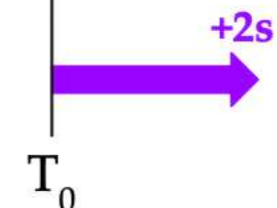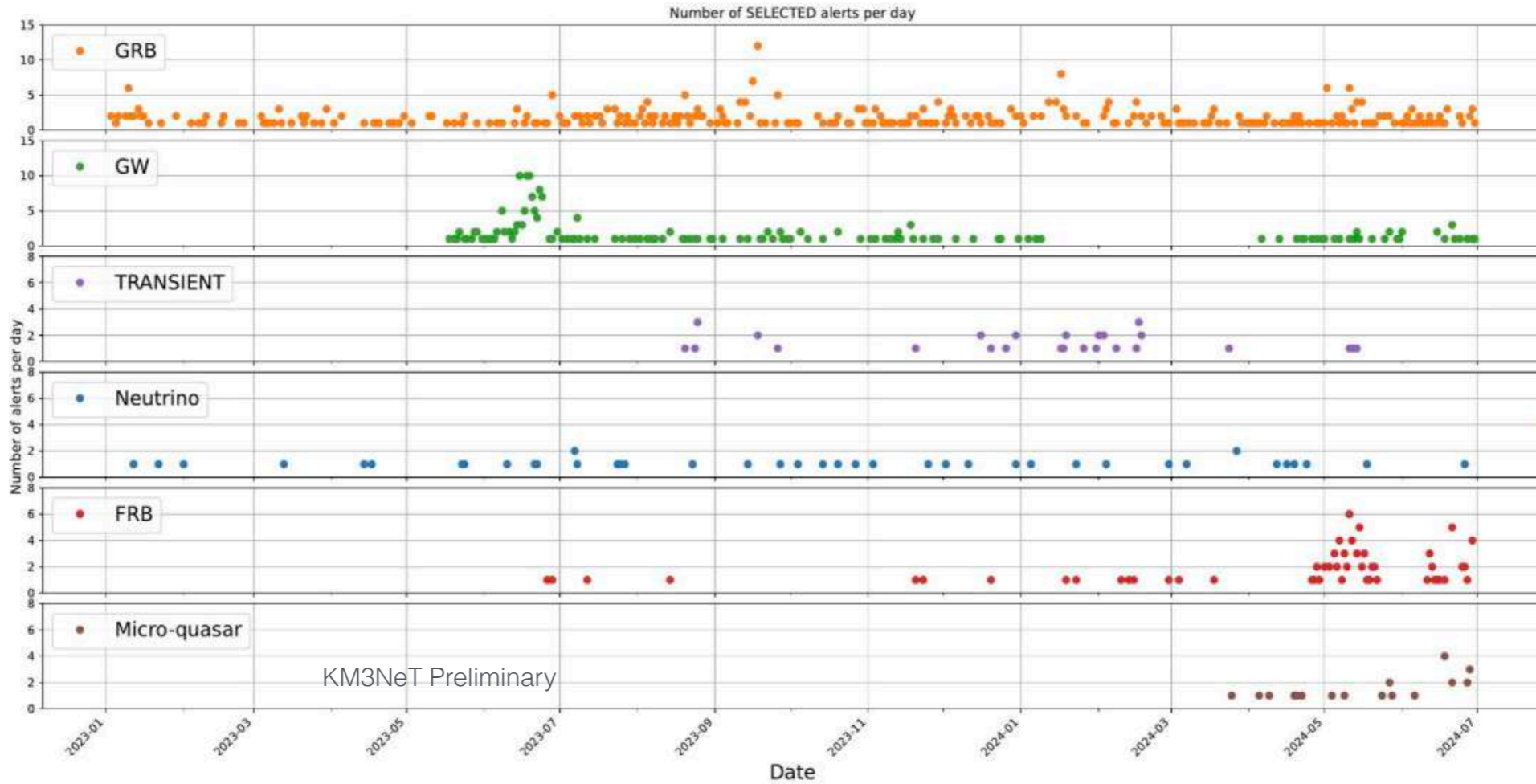
GRBs	~1 per day
IC neutrinos	~1 per 2 weeks
GWs	~1 per 2 days
Transients	~1 per week
FRBs	~1 per 3 days
μQuasars	~1 per 3 days

KM3NeT real-time analysed alerts — KM3NeT Preliminary

- Neutrino (total: 52)
- GRB (total: 755)
- GW (total: 192)
- TRANSIENT (total: 73)
- FRB (total: 58)
- MICROQUASAR (total: 10)
- Analysis validation

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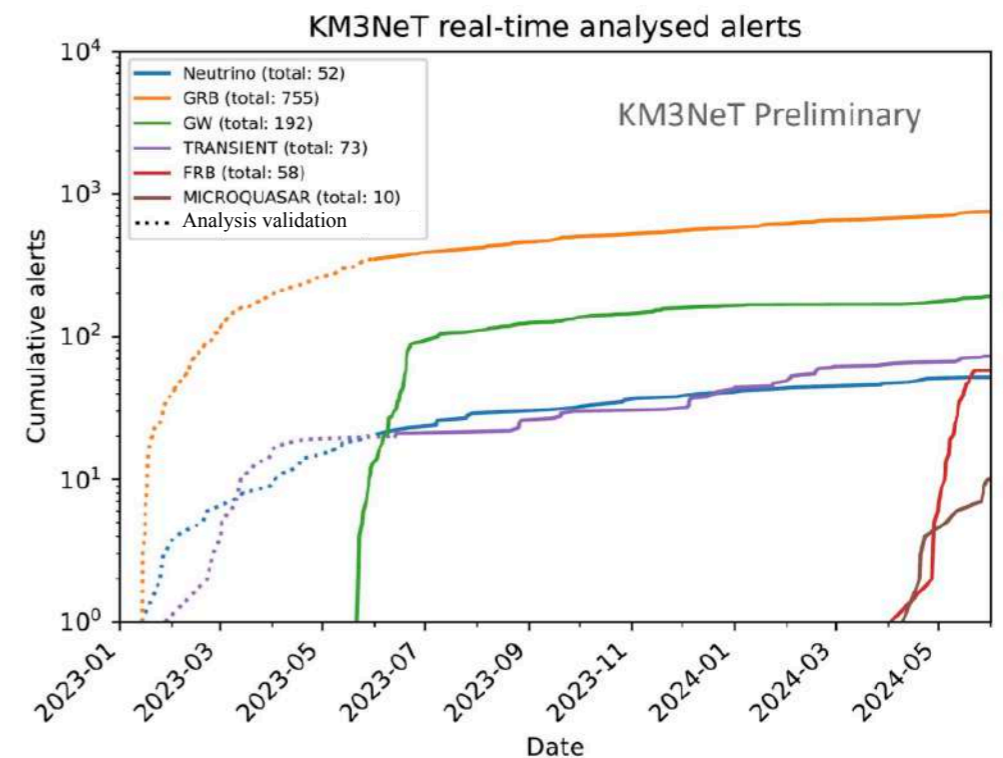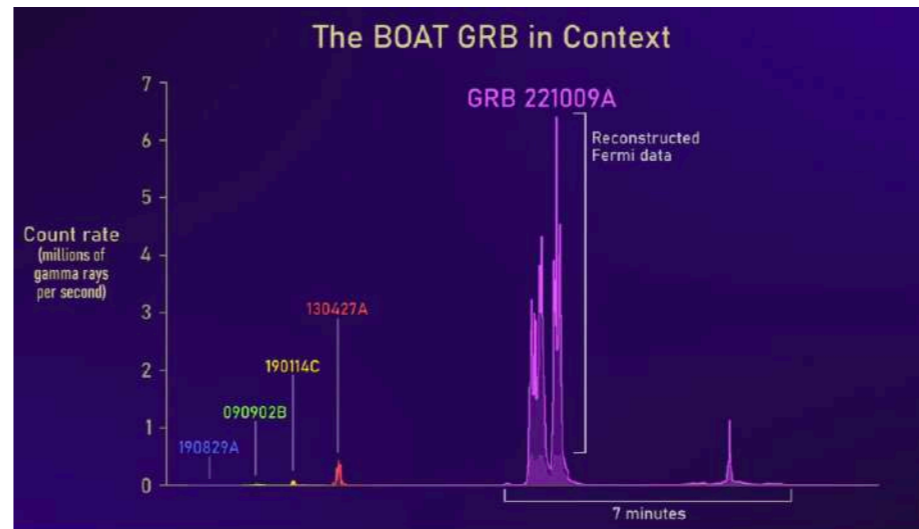
The BOAT GRB: search for neutrinos in KM3NeT data
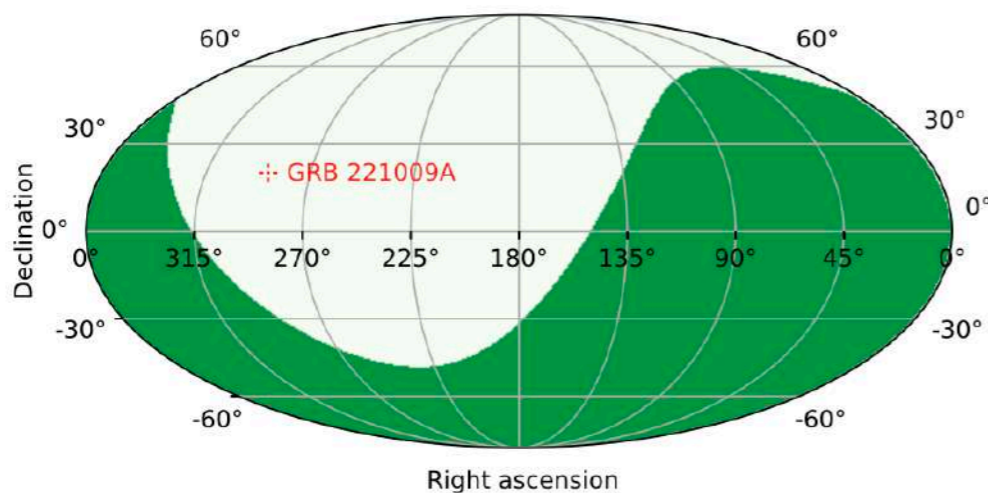
★ Highest fluence;
★ Nearby: z=0.152;
★ Highest Eiso~1x10^{55} erg;
★ Once in a 1000/10000 yr event.

Burns et al., ApJL 946 (2023) 31B

The BOAT GRB in Context
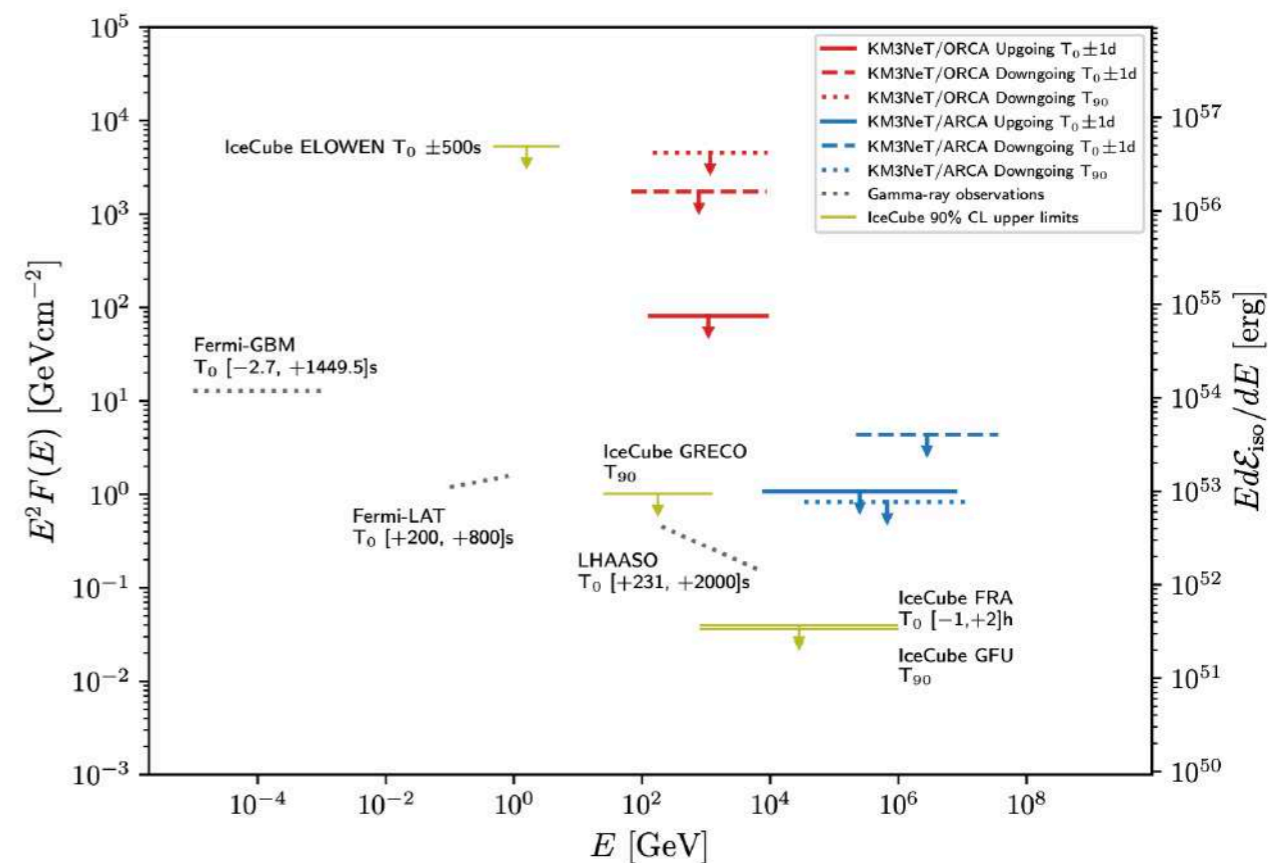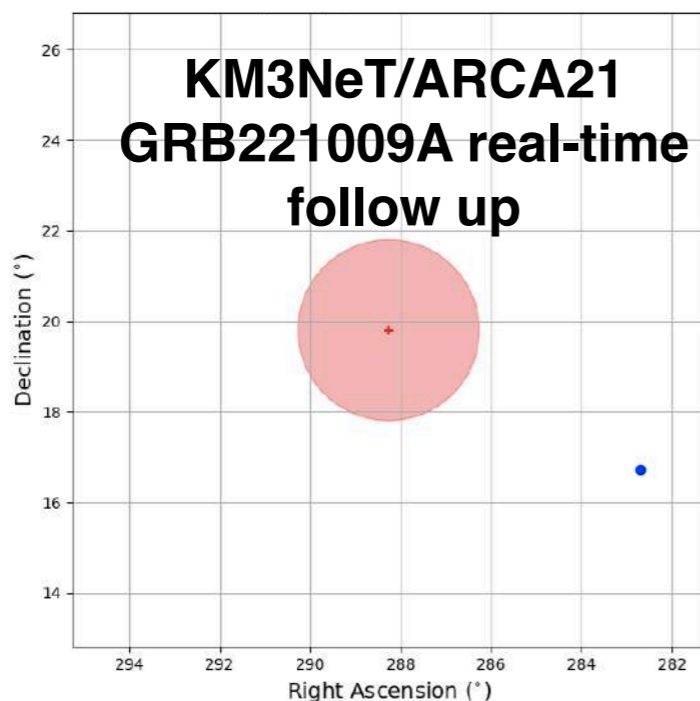
Cao et al. [LHAASO Coll.], Science 380 (2023) 1390

GCN 32677

- KM3NeT **real-time follow-up** in [-50;5000]s time window
- KM3NeT offline analysis

GCN 32741

Aiello et al. [KM3NeT] arXiv:2404.05354

KM3NeT/ARCA21 GRB221009A real-time follow up
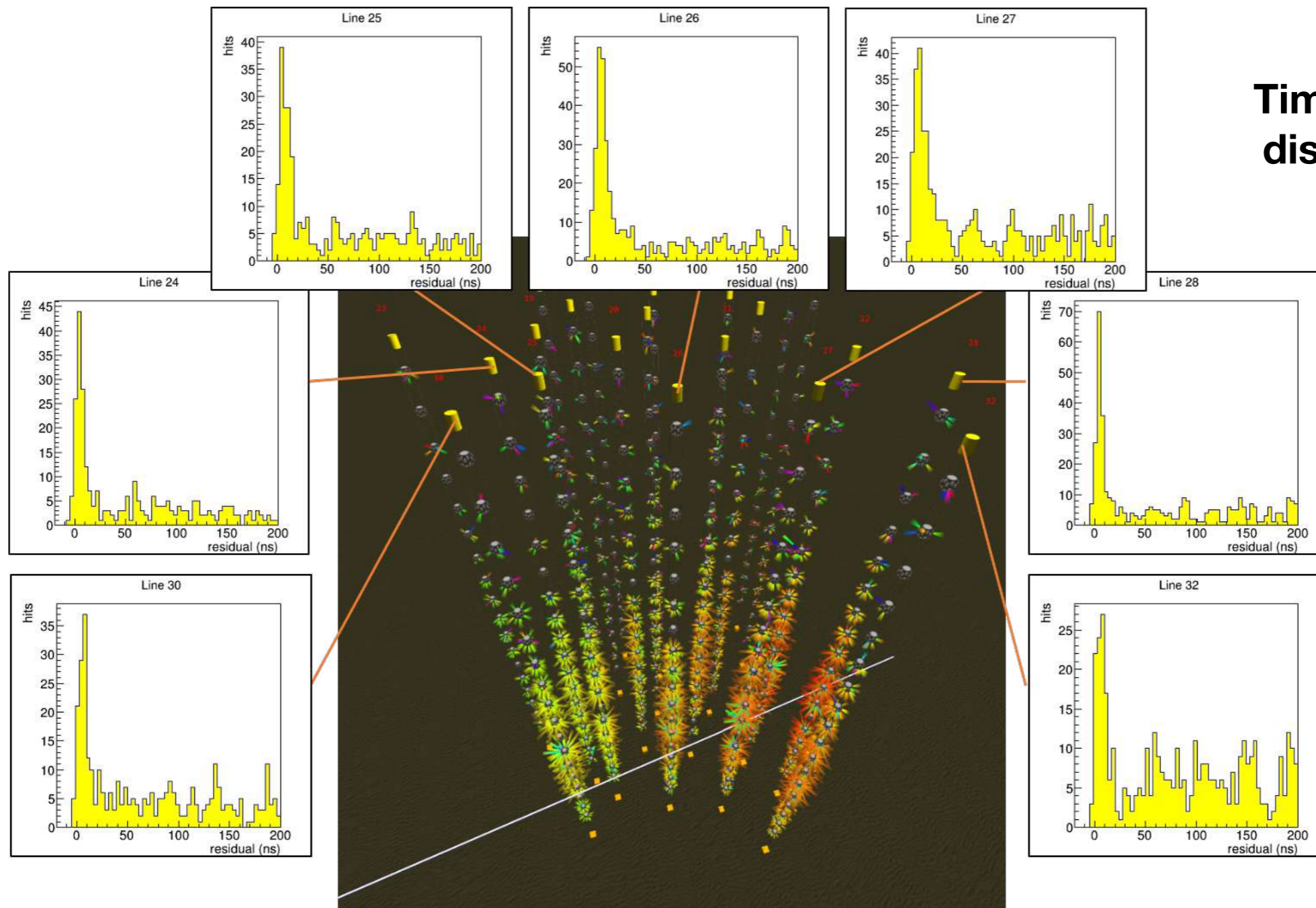

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Something unexpected…
A very energetic cosmic event detected!
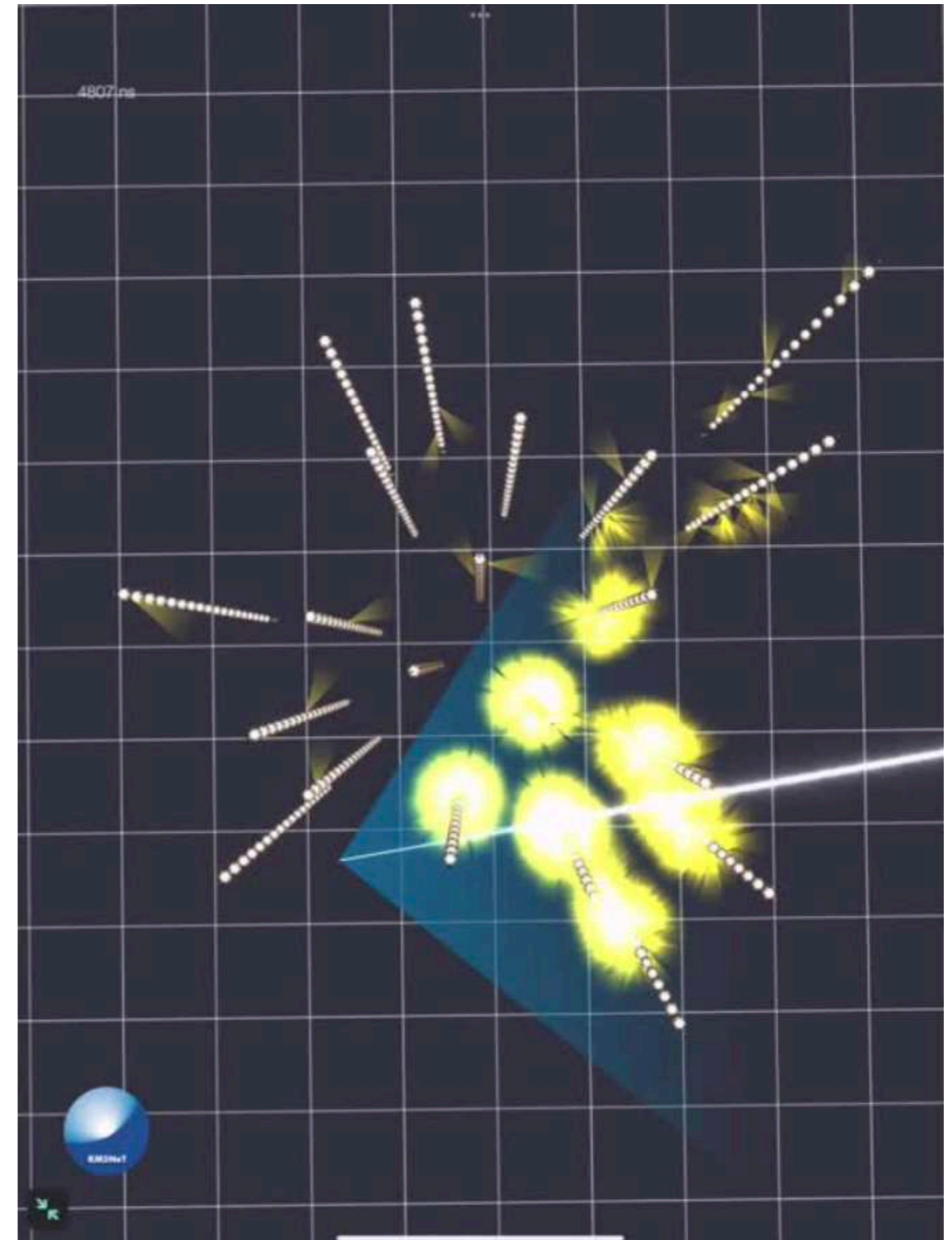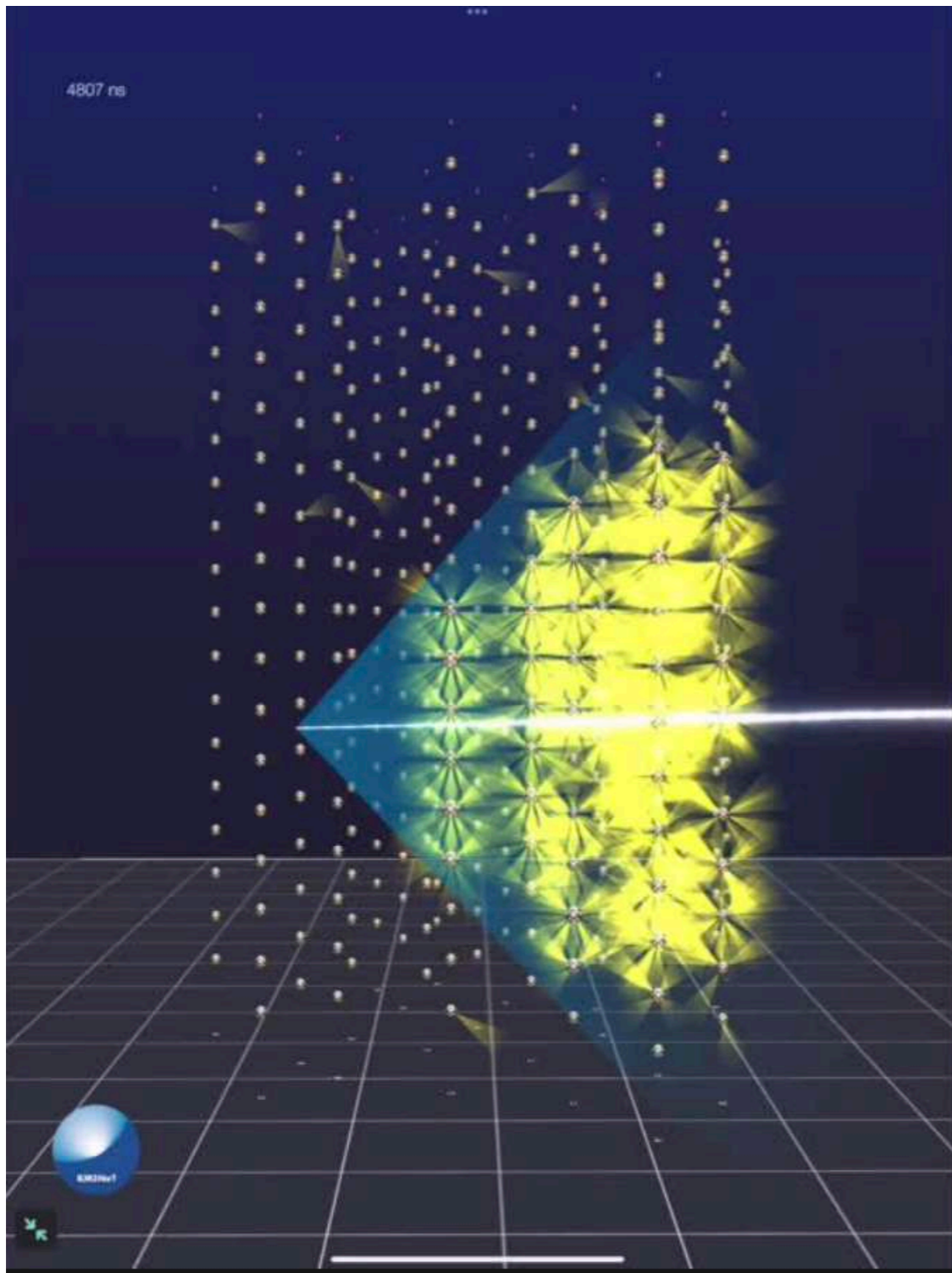
Something unexpected…
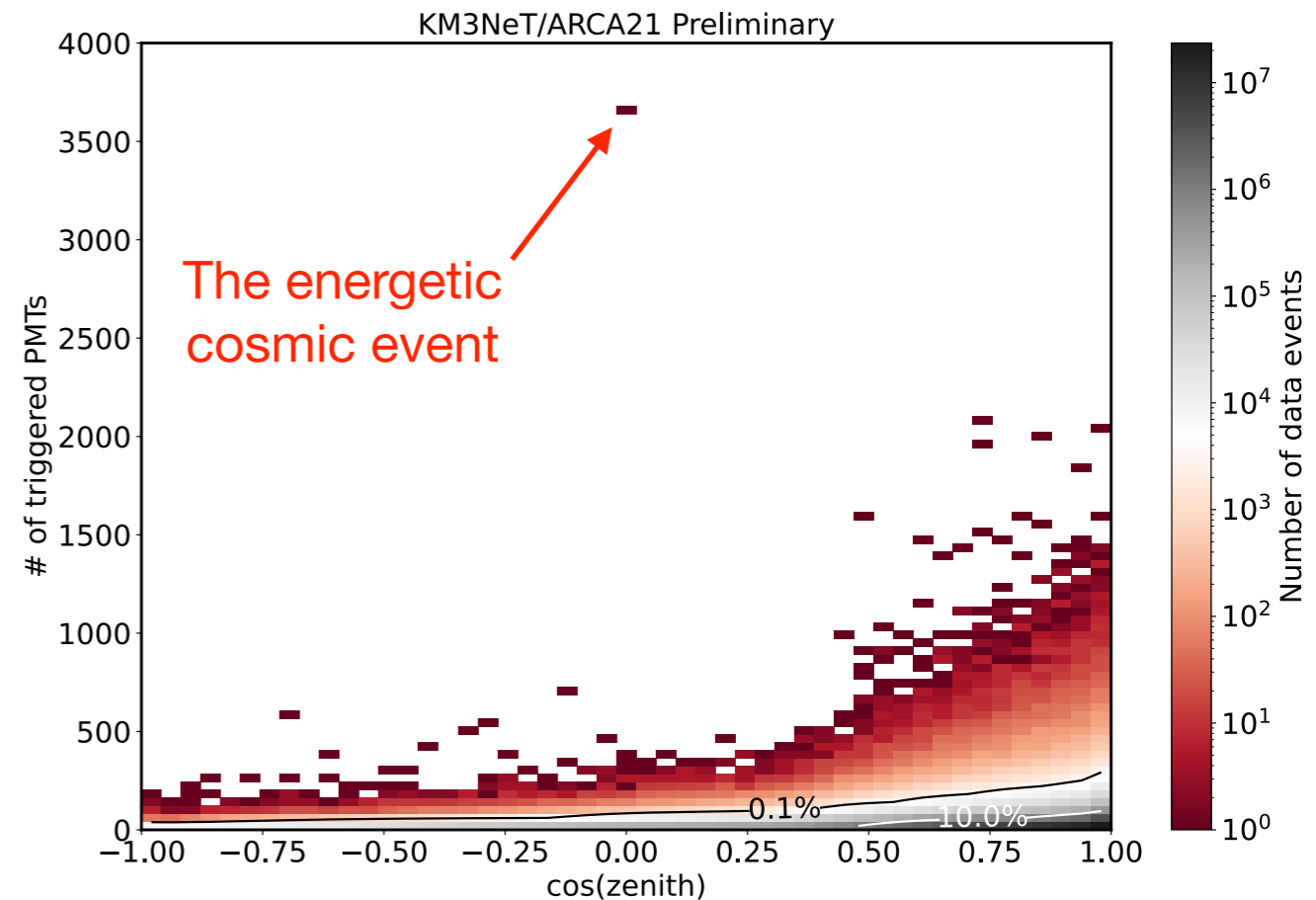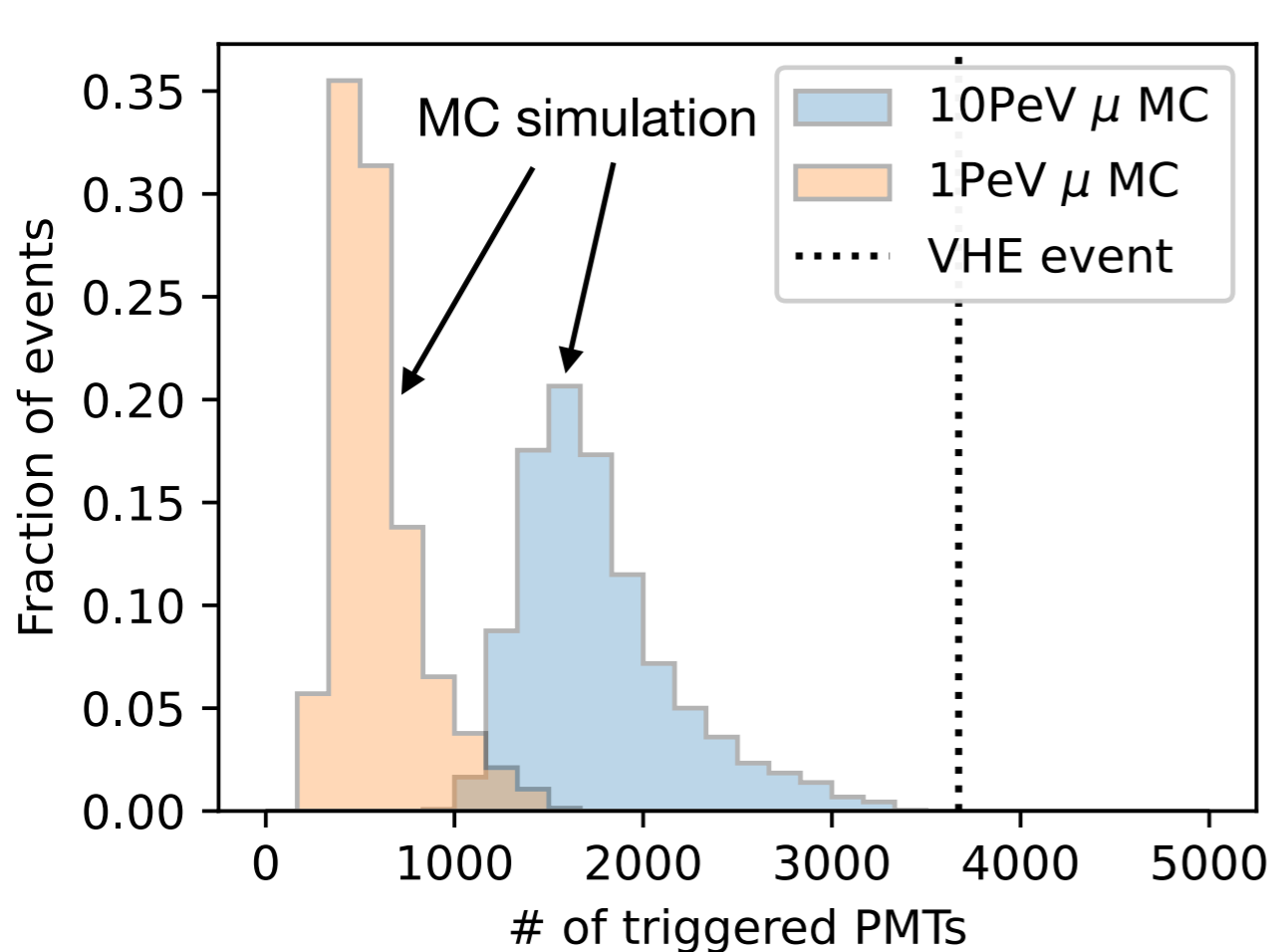
A very energetic cosmic event detected!

Time residual distributions

The event is well reconstructed as a track

Something unexpected...

A very energetic cosmic event detected!

The event is a horizontal event (1° above the horizon) with energy above 10 PeV

Huge amount of light detected ⇒ 35% of the total number of PMTs were triggered

Something unexpected…

A very energetic cosmic event detected!

Hit arrival time (ns)

Hit arrival time (ns)
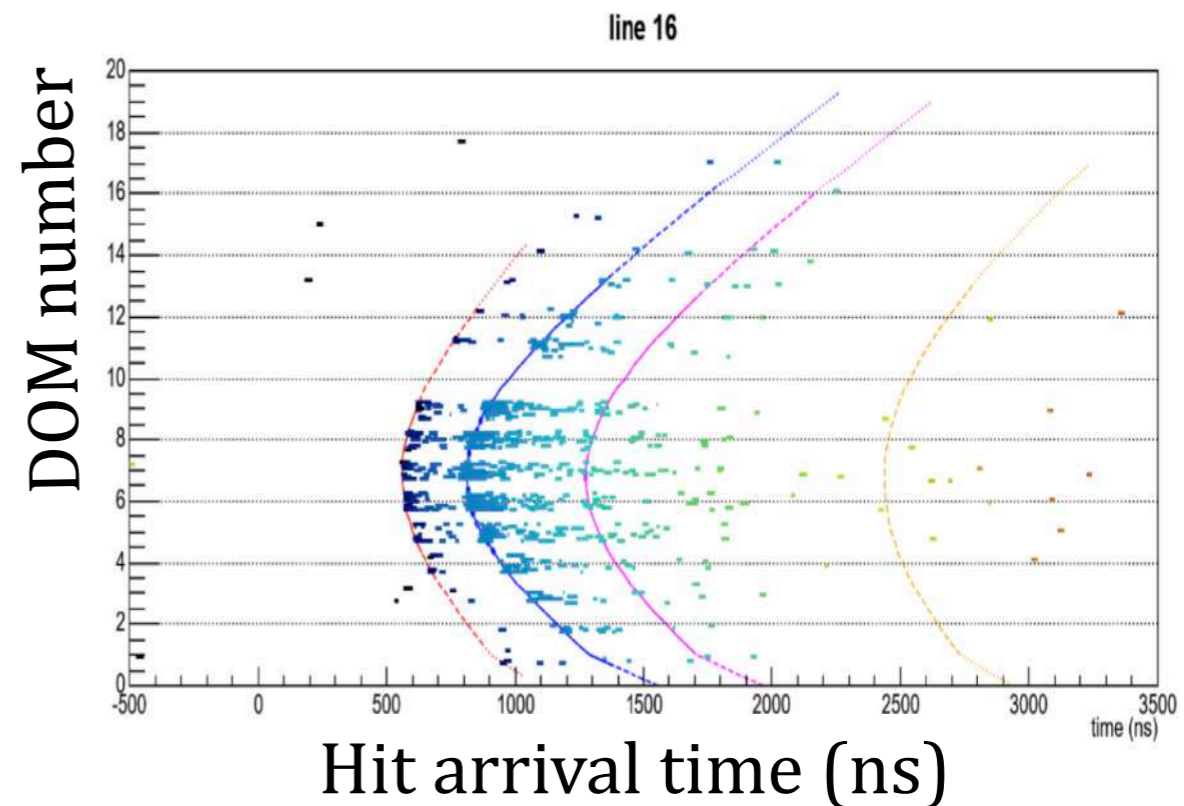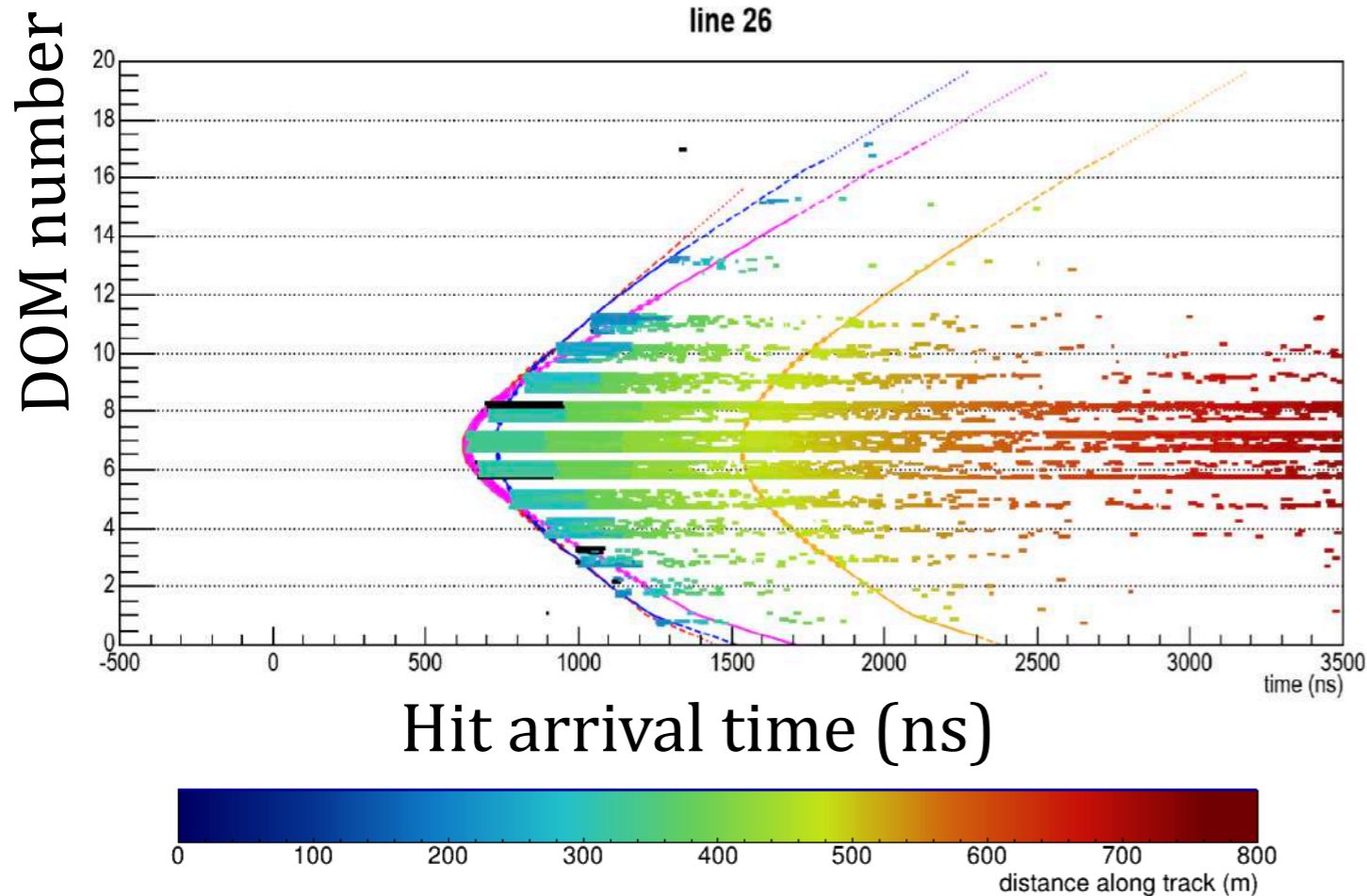
Hit times are fully consistent with photons from Cherenkov emission
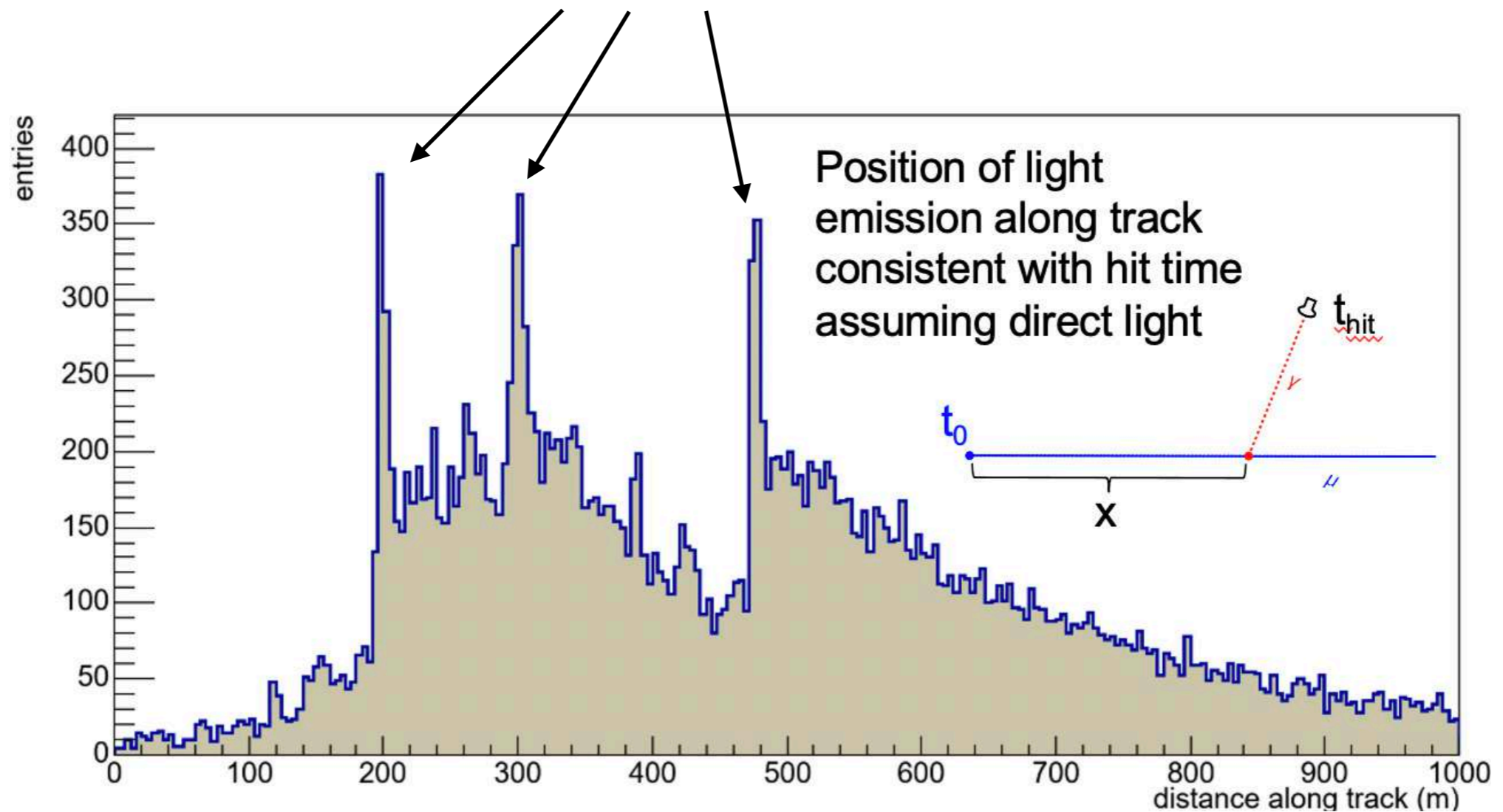
From the track and shower reconstructions

A muon track and three showers detected

Something unexpected…

A very energetic cosmic event detected!

Hit times consistent with the emission from three points along the track

Position of light emission along track consistent with hit time assuming direct light

t_{hit}

t_0

μ

X

Stochastic light emission

Conclusions

Water-based Cherenkov neutrino telescopes:
- **angular resolution** $\longrightarrow$ precision multi-flavor astronomy;
- location $\longrightarrow$ **privileged visibility of the Galaxy**;
- ARCA & ORCA $\longrightarrow$ **broad energy coverage**;
- marine observatory for environmental sciences.

KM3NeT is taking data and growing rapidly:
- **ARCA** is currently taking data with **33 DUs**, **ORCA** with **23 DUs**;
- More **sea campaigns** planned in next months!
- First circulars reporting the results of our **follow-up of external alerts**;
- Getting ready for releasing neutrino alerts to the community.

STAY TUNED FOR UPDATES!