

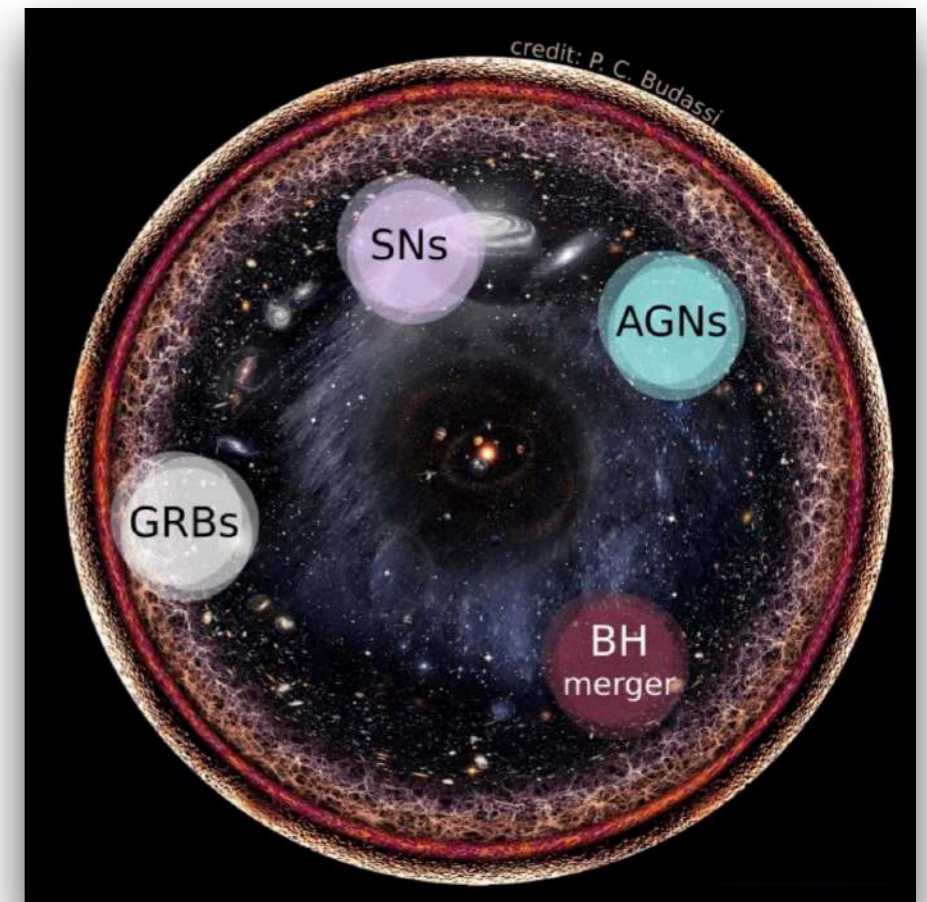
Realtime data processing with KM3NeT



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INFN - Sezione di Roma, Rome, Italy
on behalf of the KM3NeT Collaboration

silvia.celli@roma1.infn.it



KM3NeT at a glance



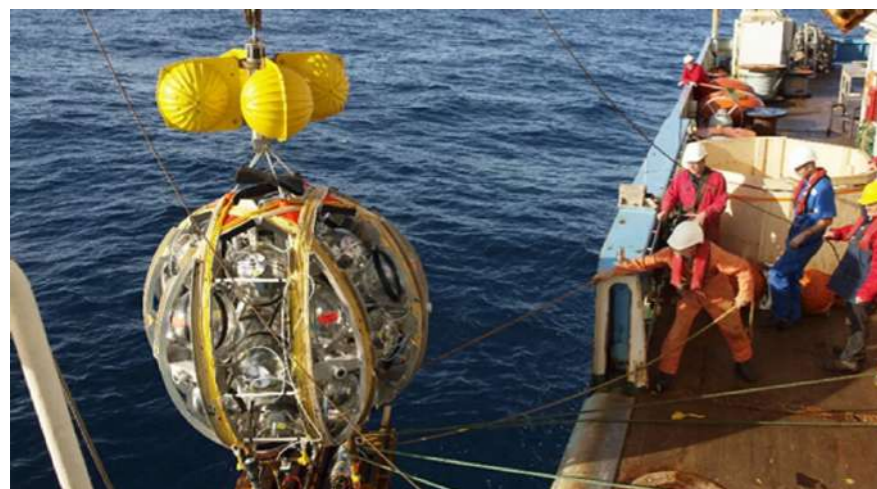
Main detector elements:

- 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

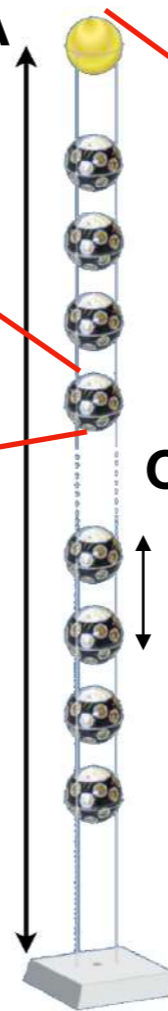
- Uniform coverage
- Directional information
- Digital photon counting
- All data to shore



DOM



ORCA/ARCA
~200/700 m



ORCA/ARCA
~9/36 m

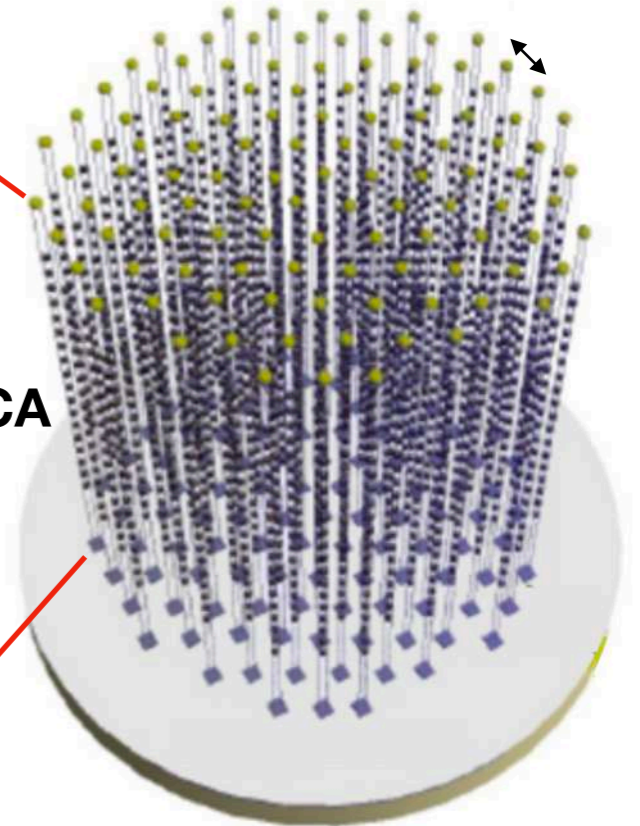
DU

18 DOMs+1base
module/DU



LOM

ORCA/ARCA
~20/90 m



BUILDING BLOCK
115 DUs/building block

KM3NeT: a top view



ARCA (1 GTon)

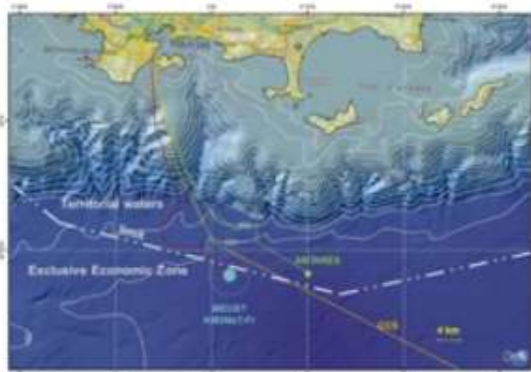
Astroparticle Research
with Cosmics in the Abyss



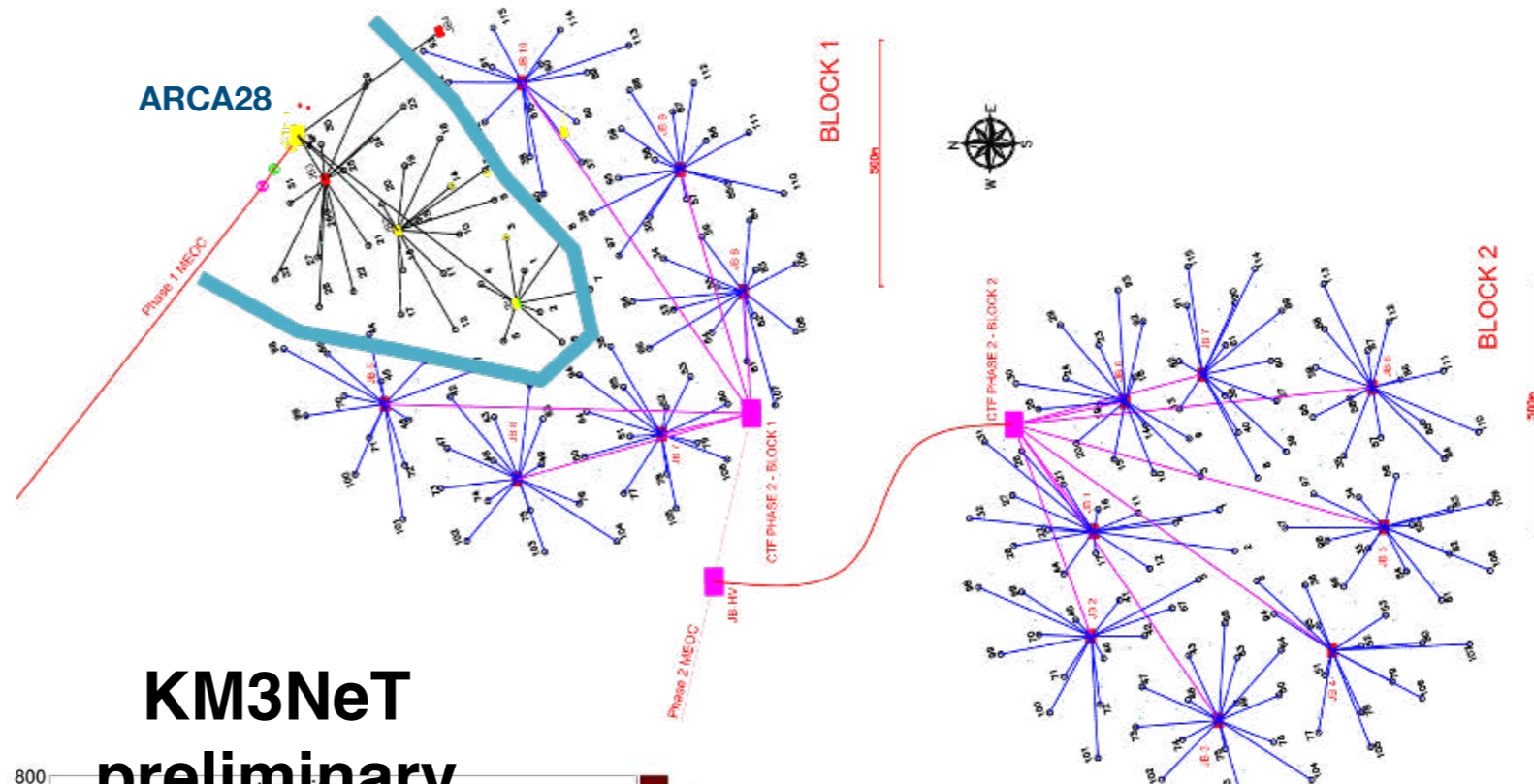
3500 m depth,
offshore Sicily

ORCA (6 MTon)

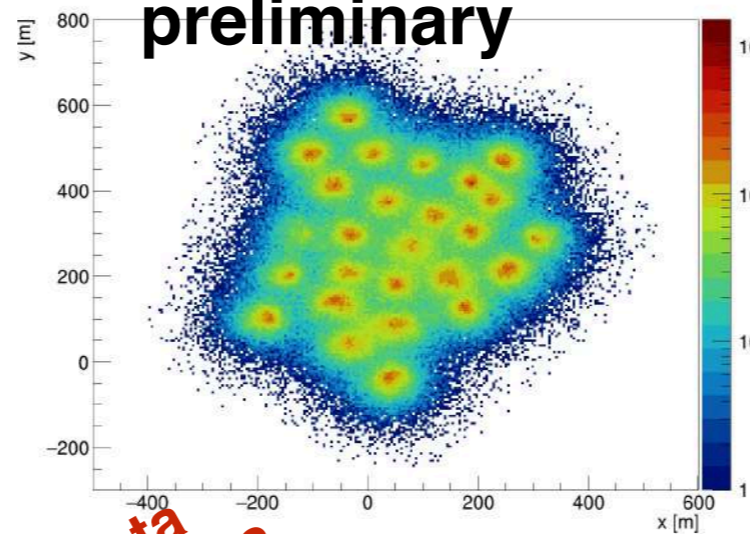
Oscillation Research
with Cosmics in the Abyss



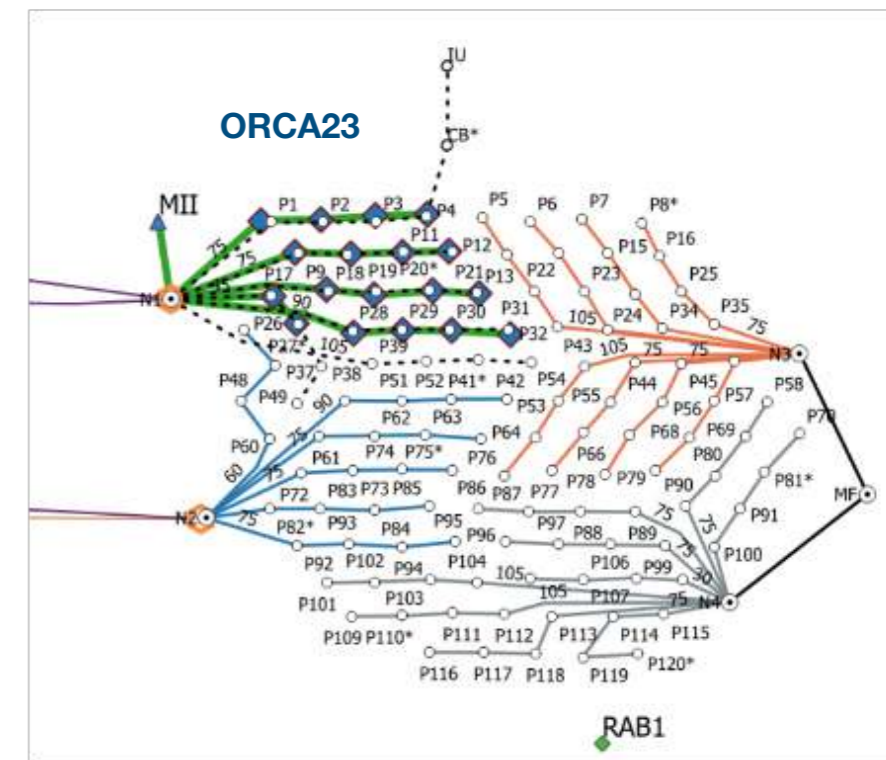
2500 m depth,
offshore Toulon



KM3NeT preliminary



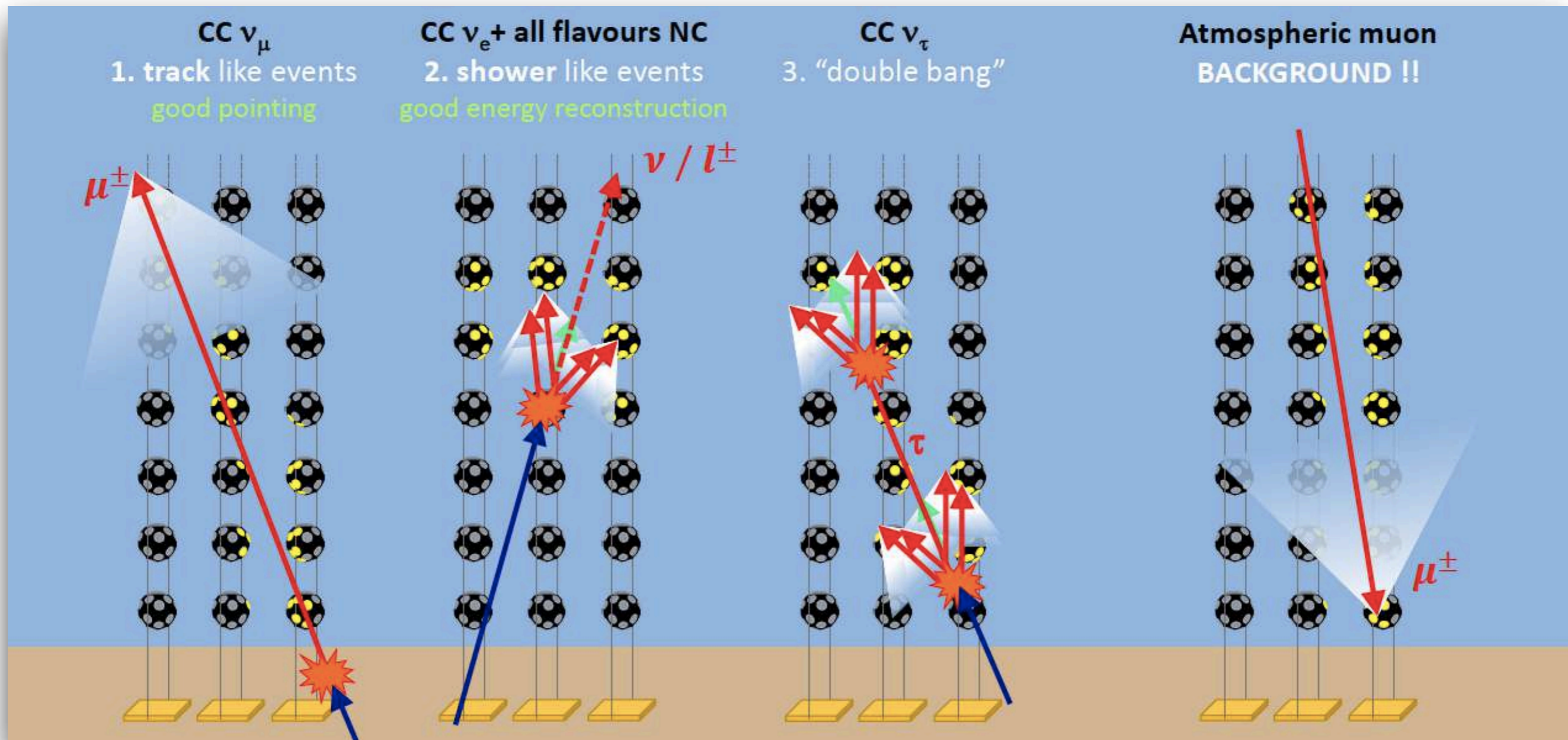
*real data
from ARCA28*



Neutrino detection principle & event topologies



- Track like events \longrightarrow golden astronomical channel
- Shower like events \longrightarrow calorimetric \longrightarrow diffuse analyses



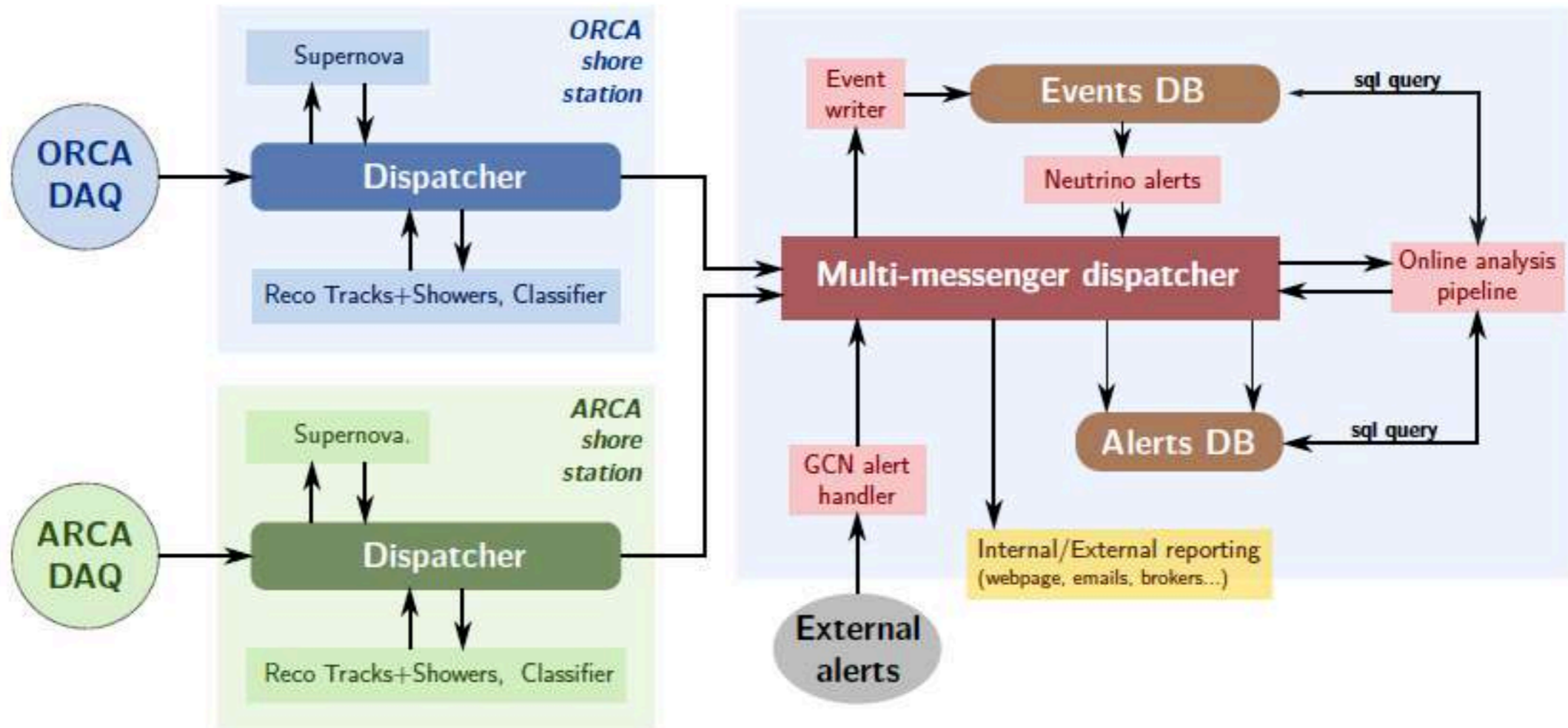
KM3NeT real time analysis system



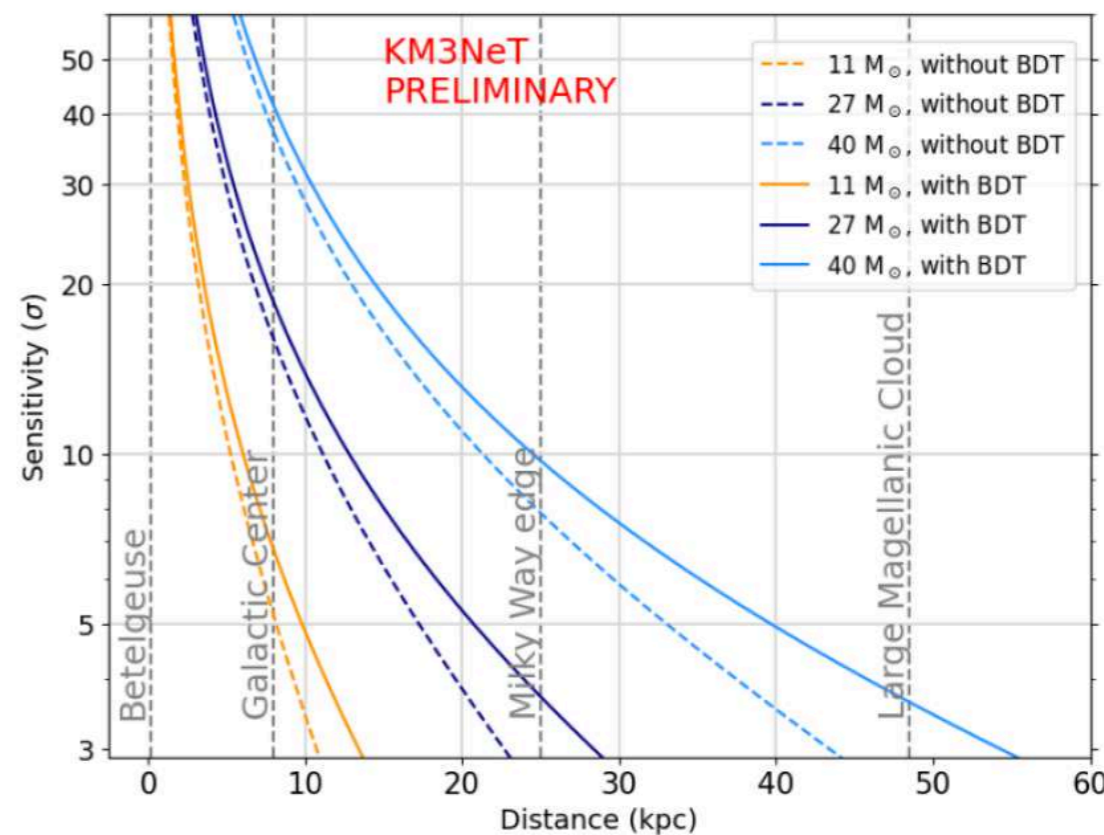
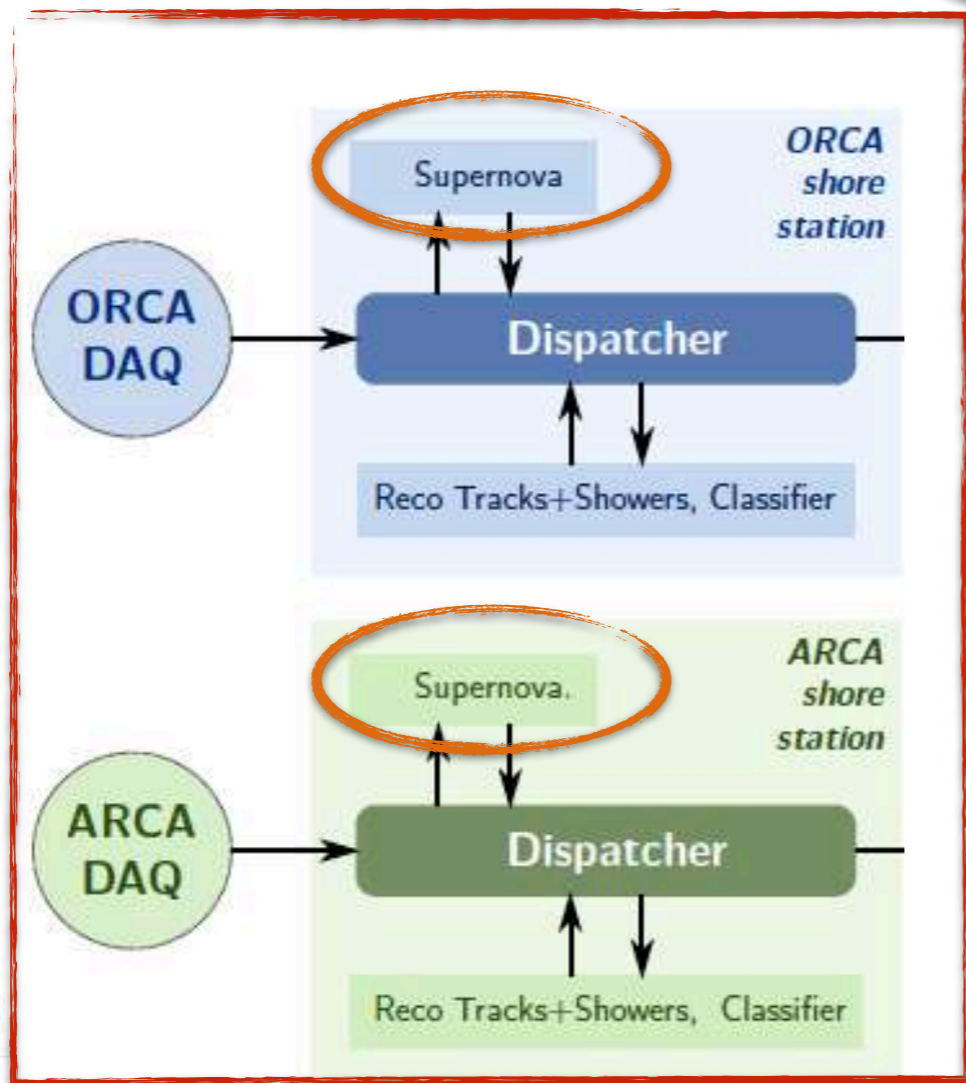
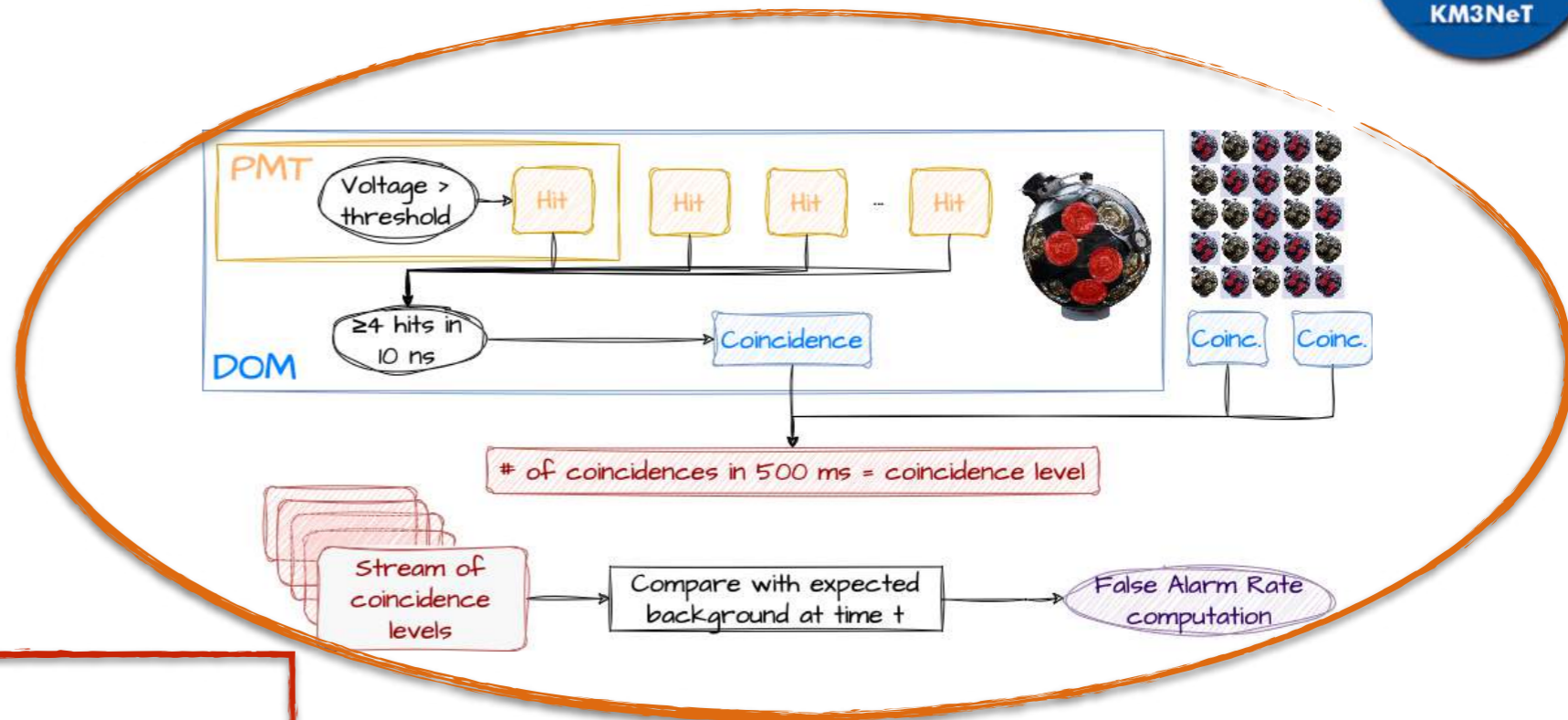
In the view of searching for correlation among ν and MM signals (EM, GW), it is increasingly crucial to be able to identify (**reconstruct, classify & select**) cosmic neutrinos in real-time as to allow **fast follow up** for counterpart identification.

The **Real-Time Analysis (RTA)** program includes:

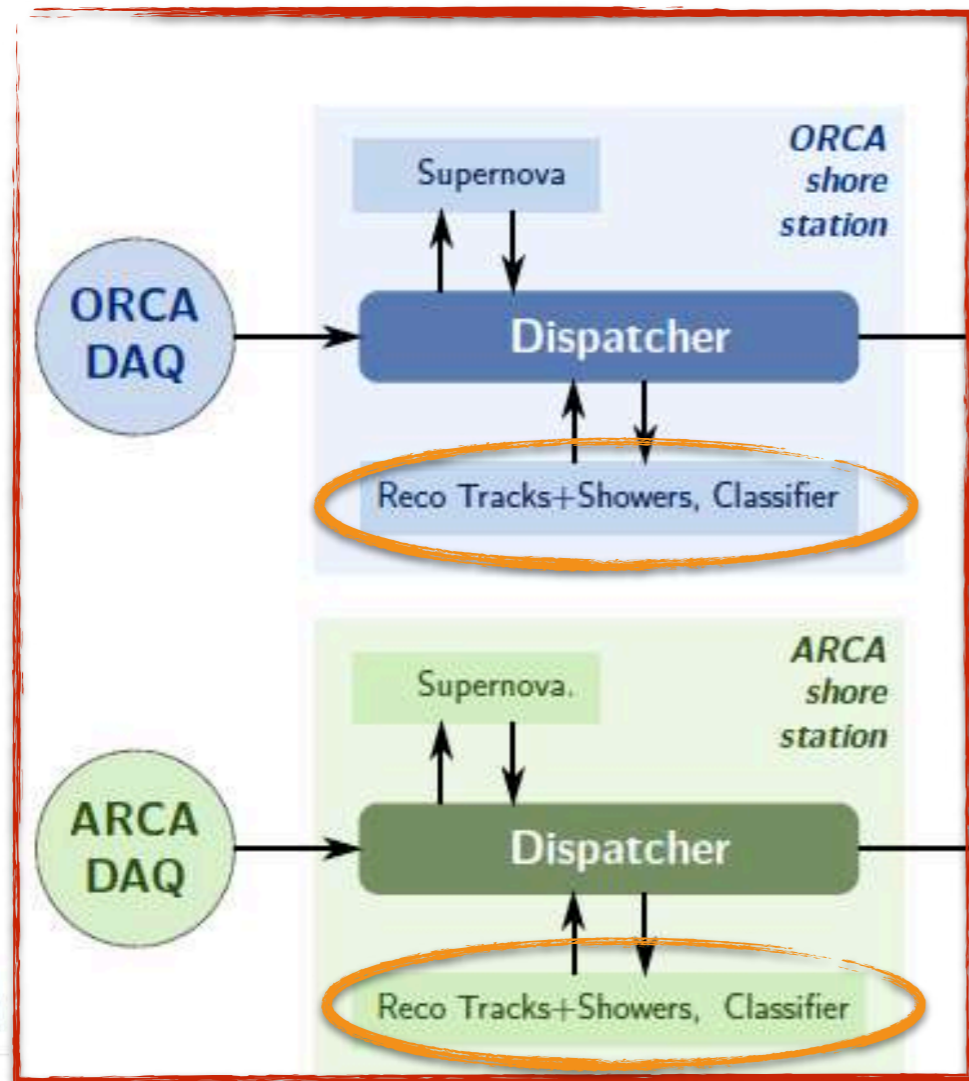
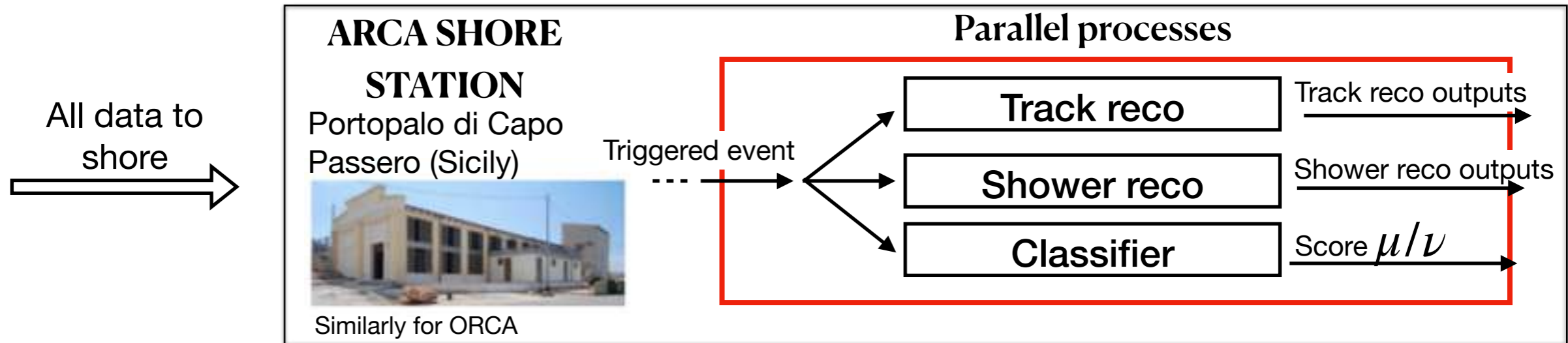
- 1) Continuous **SN monitoring** (MeV)
- 2) **External trigger** follow-up (GW, IC, gamma) with high-energy neutrino data
- 3) **Internal alert** sending (HE, multiplets, ...) —> **Jean Gregoire's talk**



The online CCSN analysis



Online reconstruction & classification



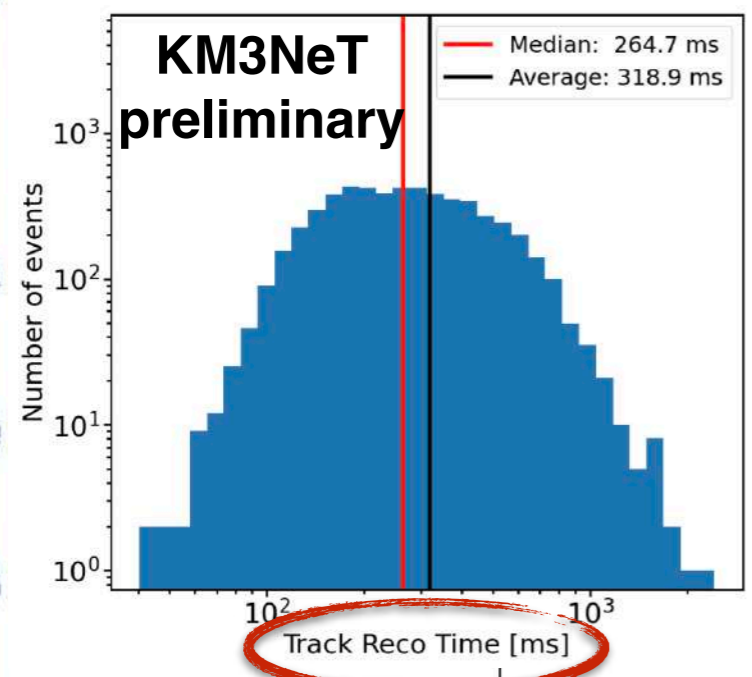
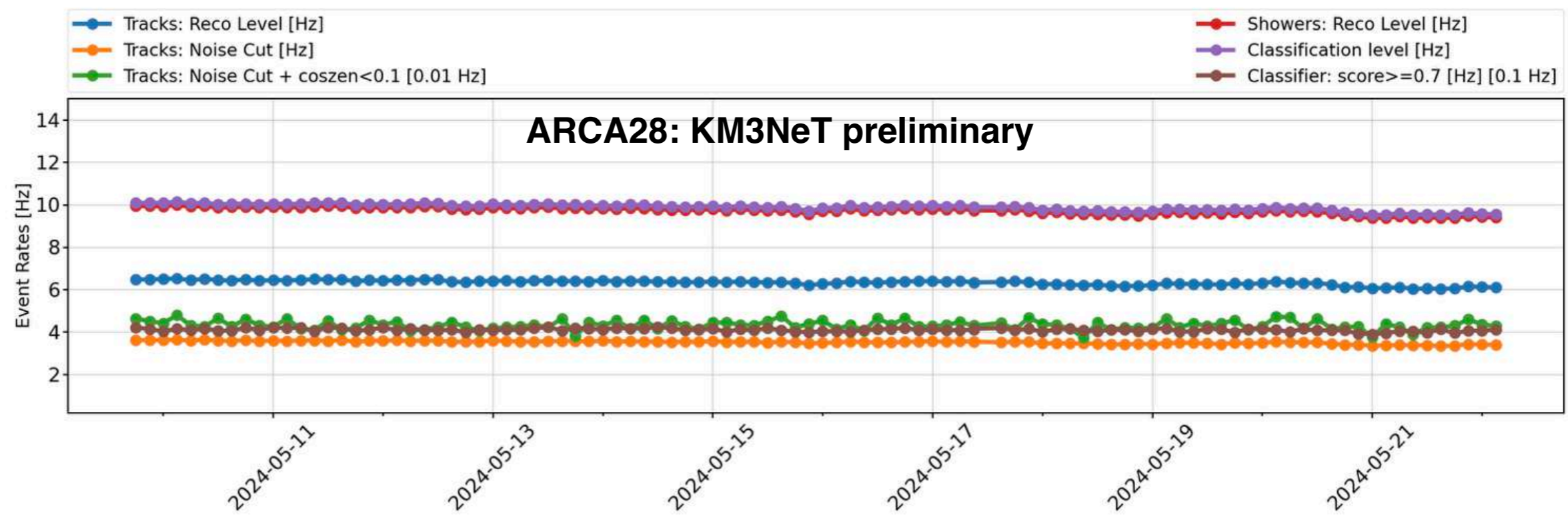
Current status of the detectors:

ORCA23

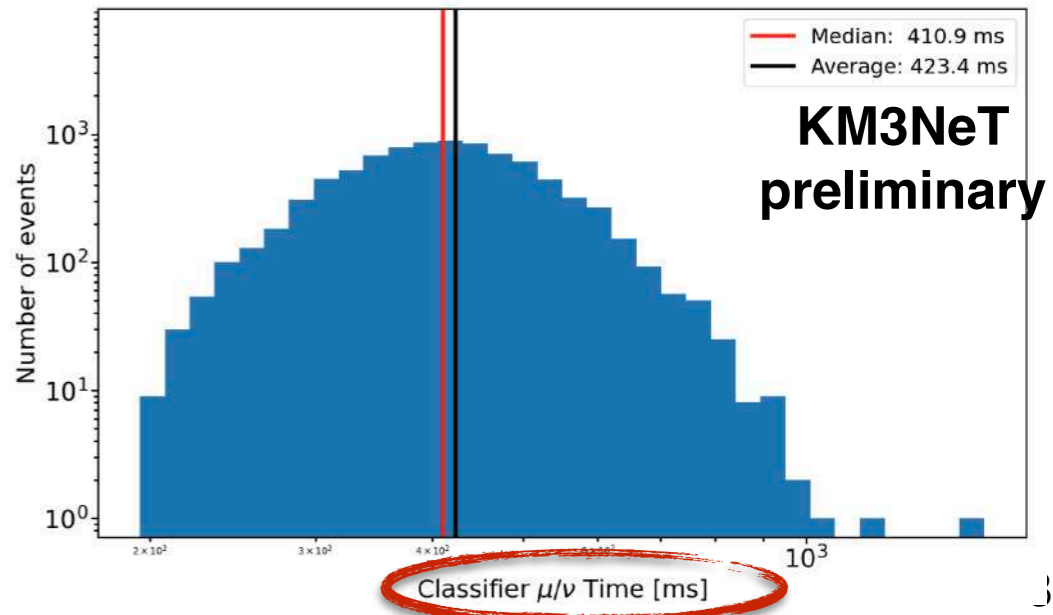
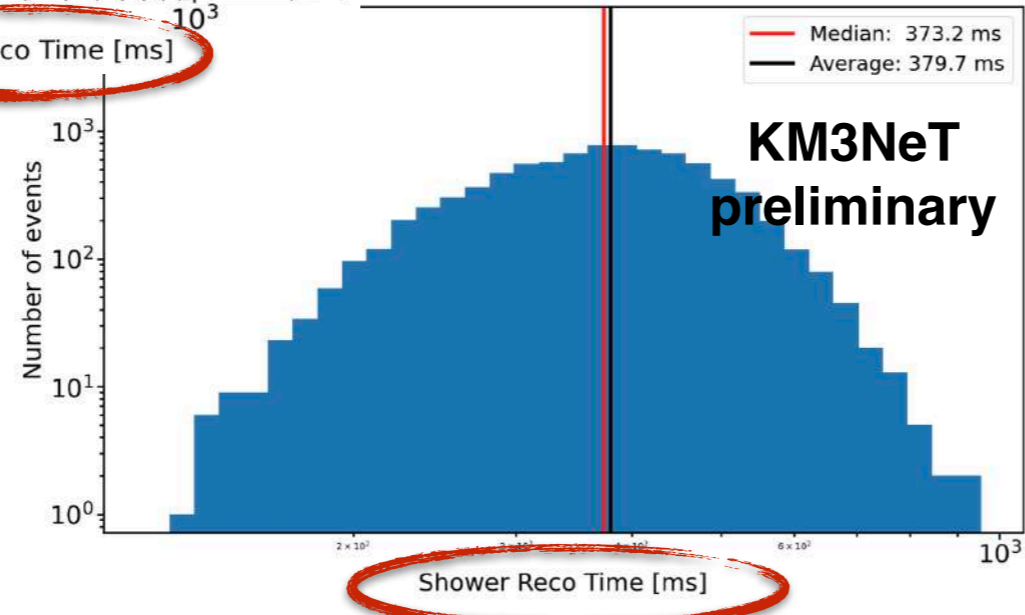
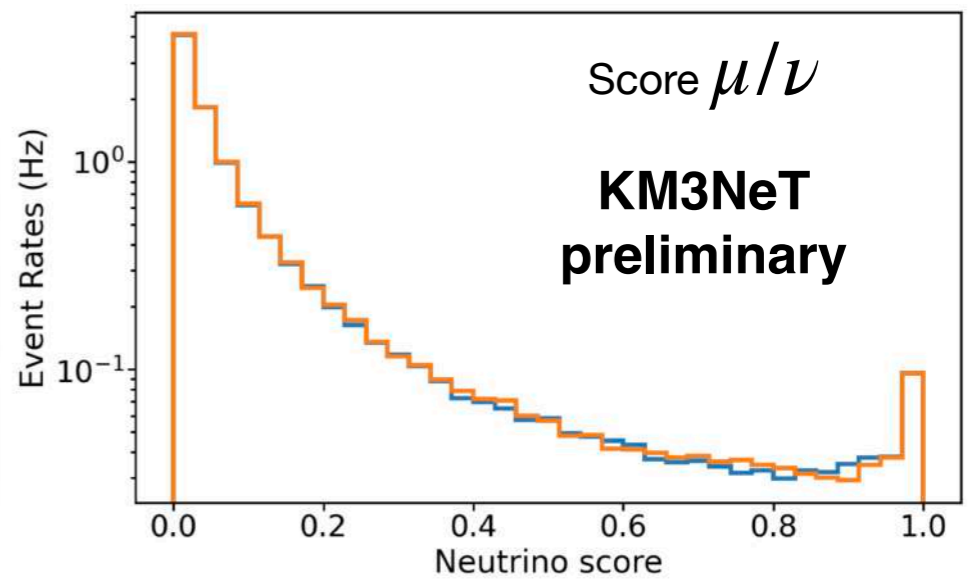



ARCA28





**+ distribution & analysis time →
KM3NeT can provide
neutrino candidates
within ~10 seconds!**



 S. Celli et al.
[KM3NeT],
PoS 444
(ICRC2023)
1125

KM3NeT realtime follow-up of external triggers

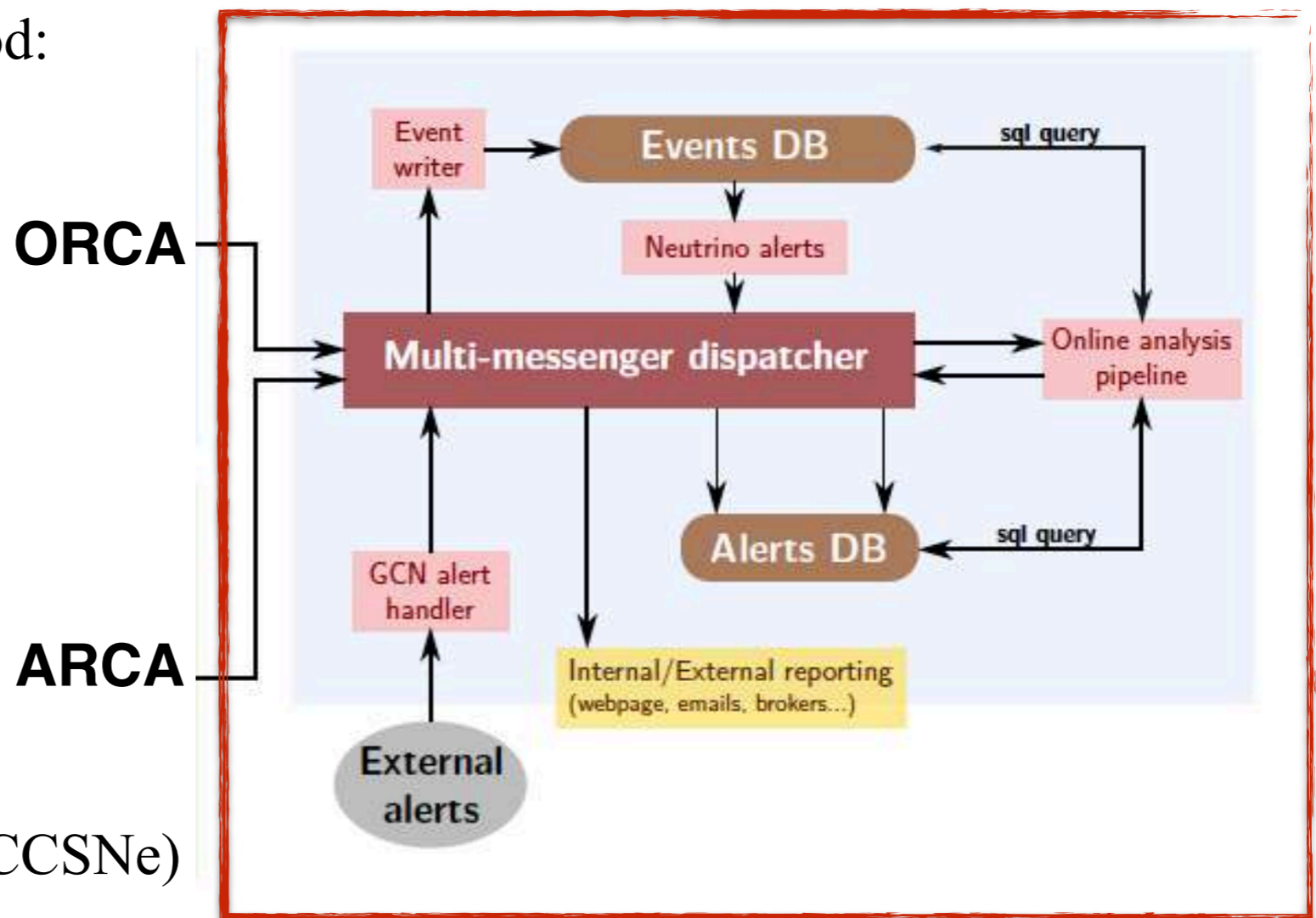
- External triggers received from 3 external **brokers** (GCN, Chime, TNS), 1 internal broker (μ Quasar), SNEWS and HyperK
- Each alert starts an **automated all-sky** analysis in **ARCA & ORCA**
- Only **track-like events** used so far in coincident search (showers inclusion in progress)
- **Iterative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

- **Binned ON/OFF analysis** method:

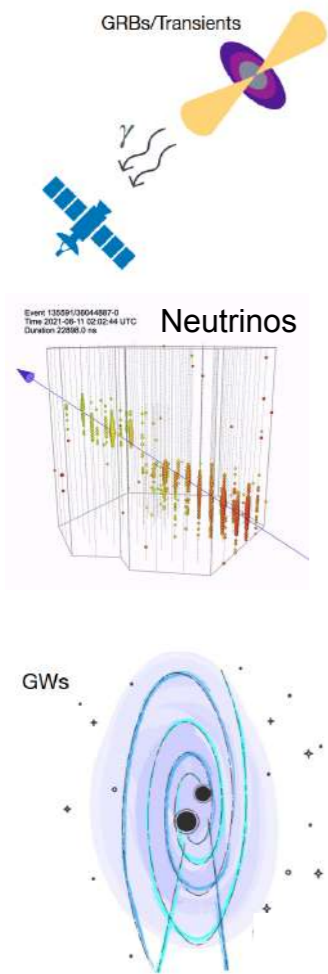
- background estimation
- cut optimization
- flux limit computation

- **Pipelines** currently in place:

- Gamma Ray Bursts (GRBs)
- High-energy transients
- IceCube (IC) neutrinos
- Gravitational Waves (GWs)
- Fast Radio Bursts (FRBs)
- μ Quasars
- Core Collapse Supernovae (CCSNe)



Spatial windows for realtime follow ups



GRBs

Transients

IC neutrinos

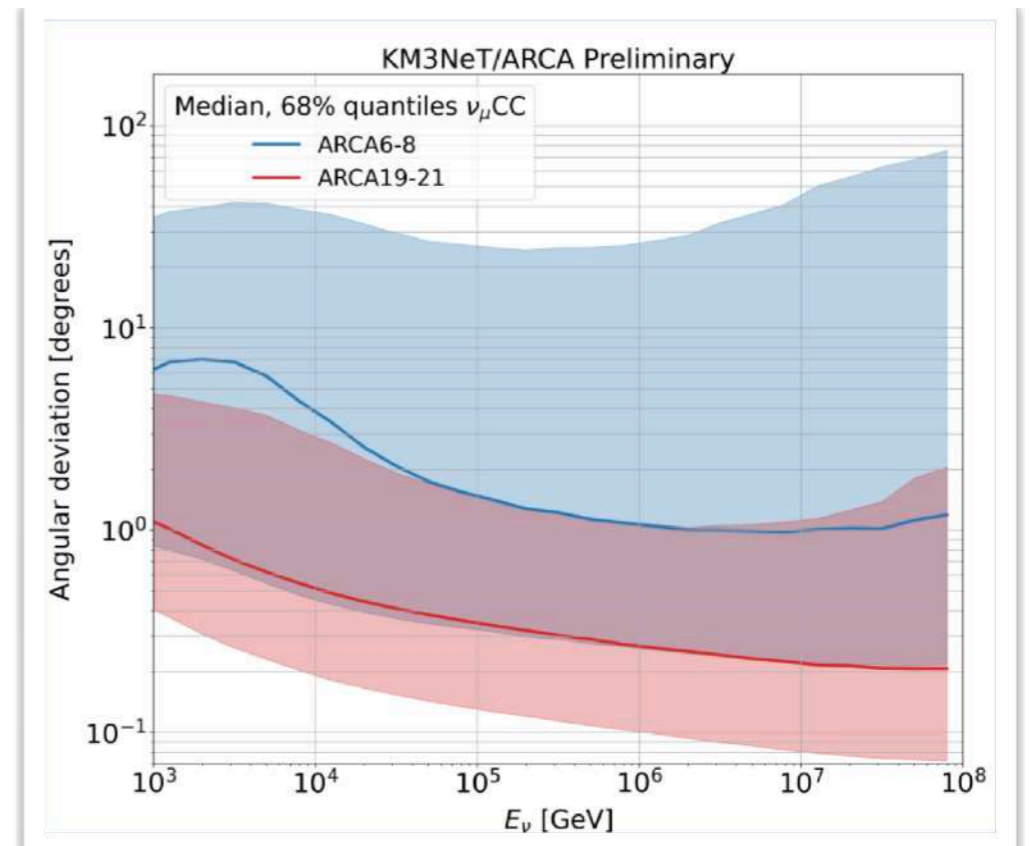
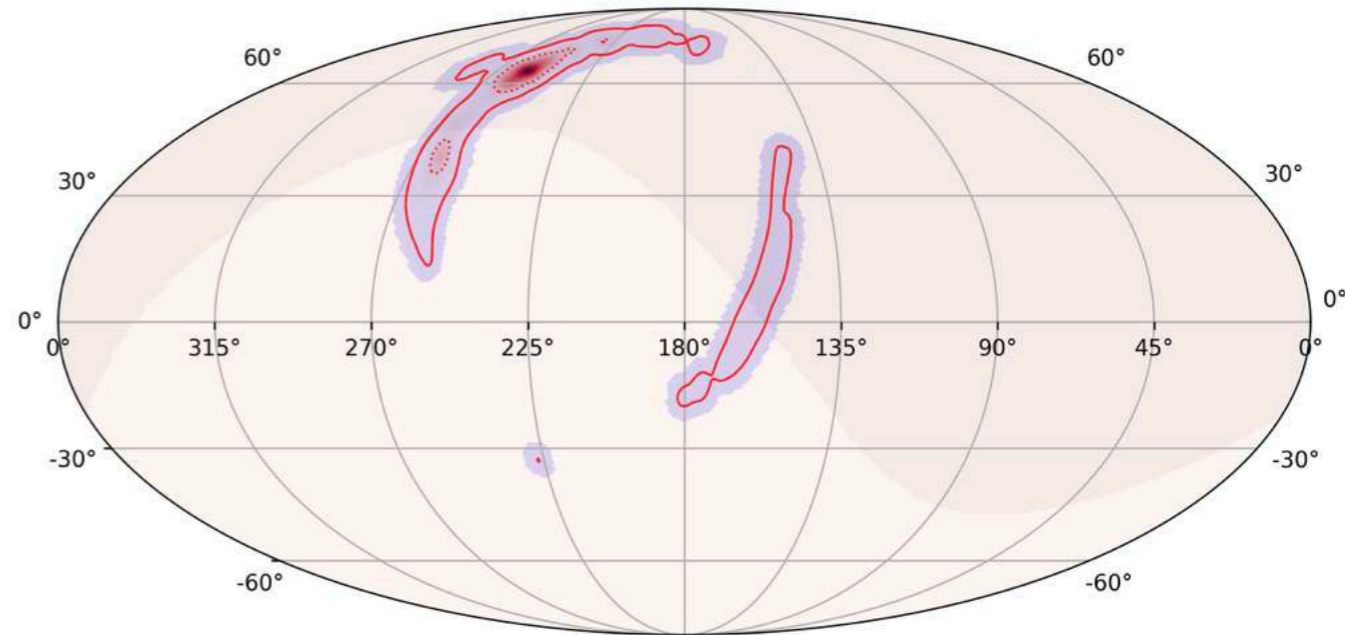
GWs

FRBs

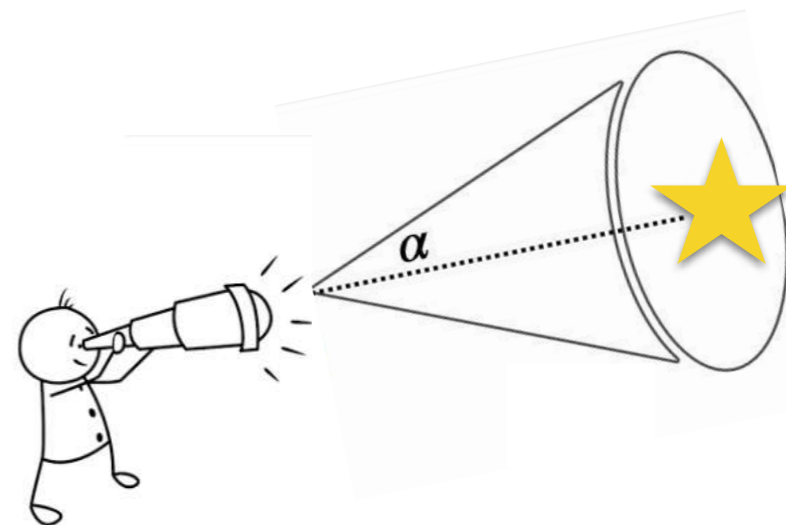
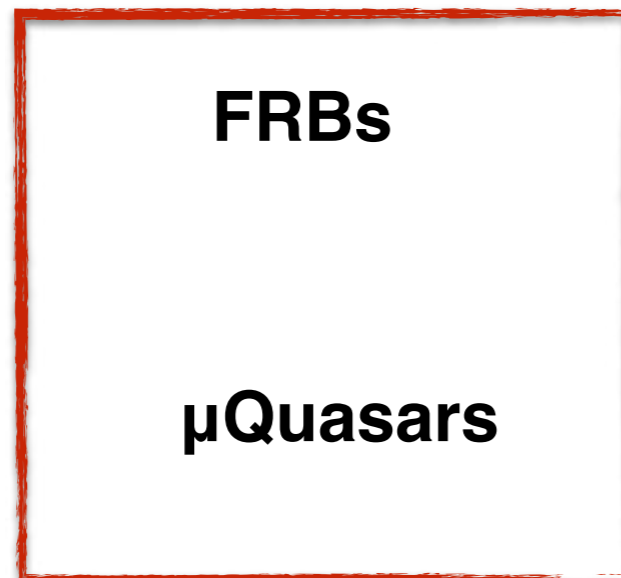
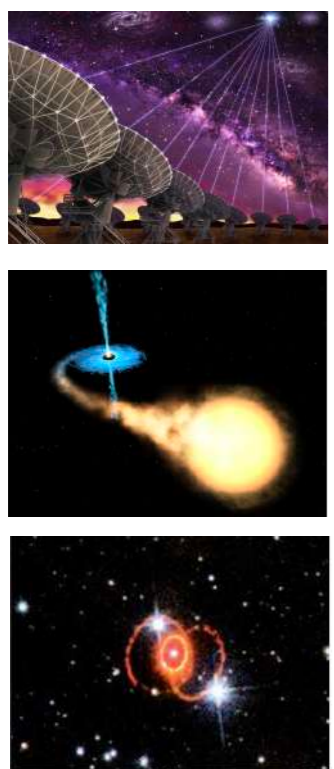
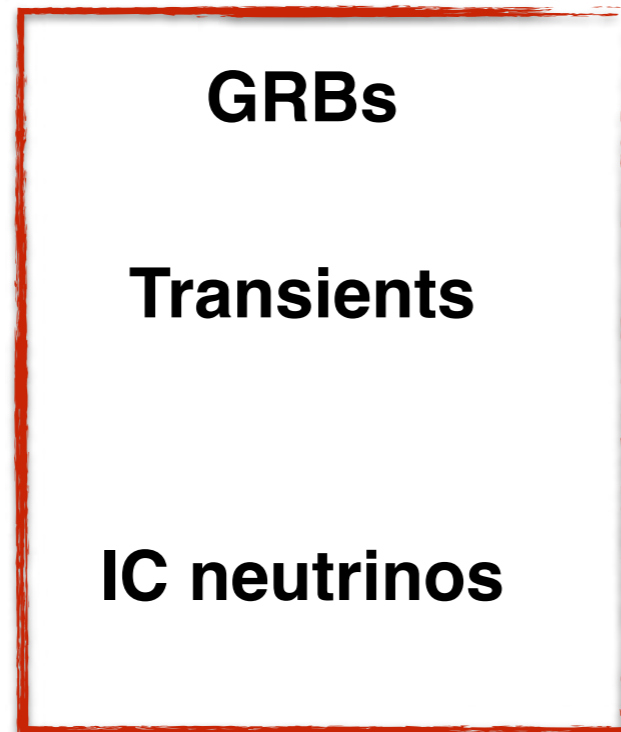
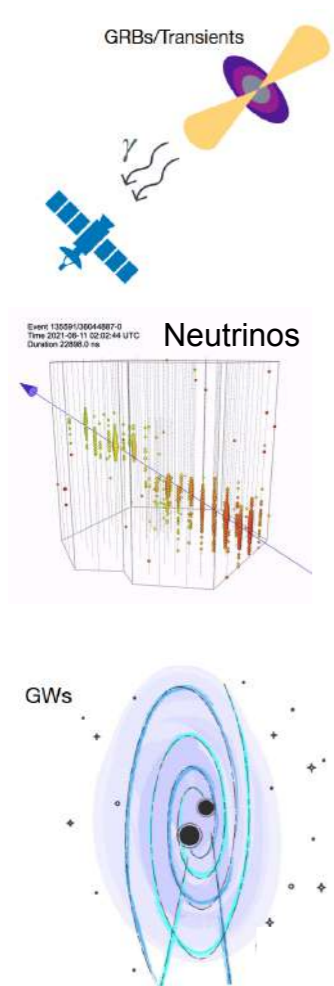
μ Quasars

CCSNe

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



Spatial windows for realtime follow ups

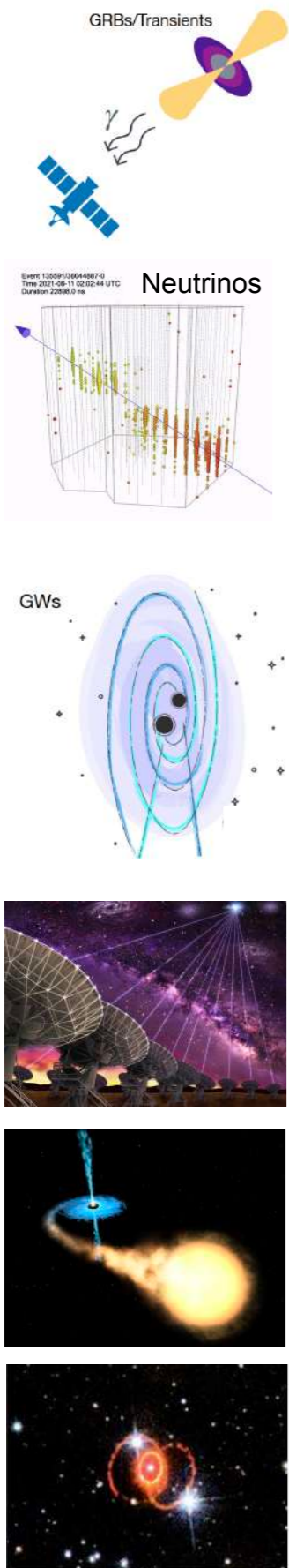


The angular search region is a cone, centered at the source position, whose extension α is

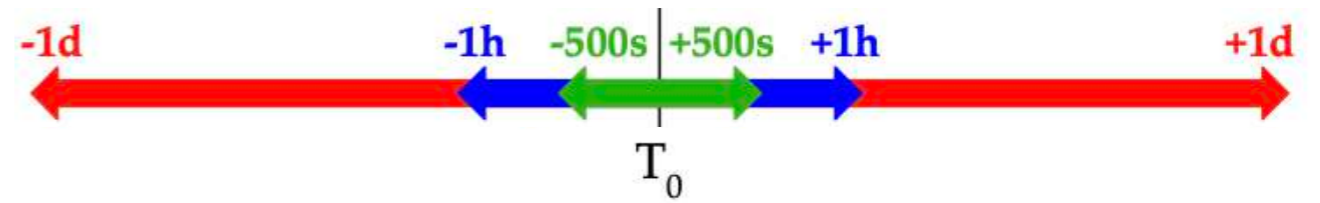
- **ARCA: $\max[2^\circ, \text{src_uncertainty}]$**
- **ORCA: $\max[4^\circ, \text{src_uncertainty}]$**

↑
median angular error of online analyses in current partial detector configuration

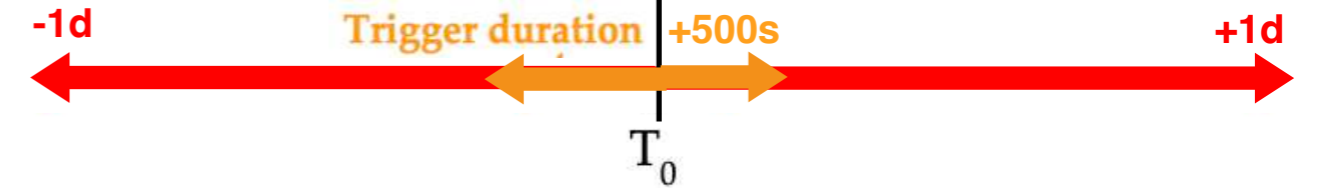
Temporal windows for realtime follow ups



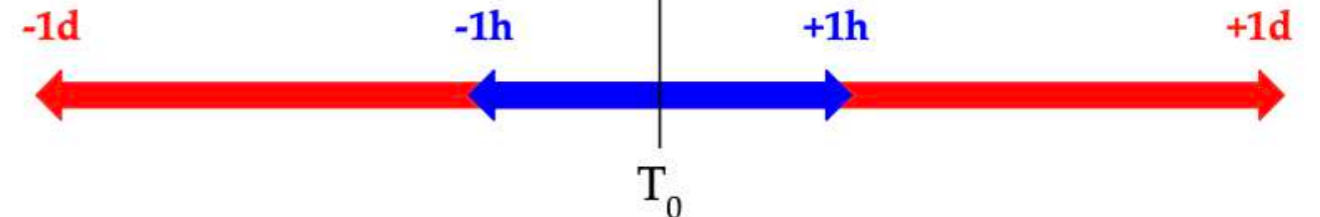
GRBs



Transients



IC neutrinos



GWs

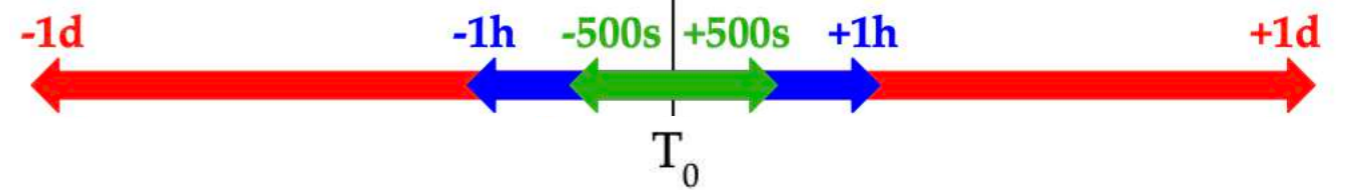
[HE analysis]



[MeV analysis]



FRBs

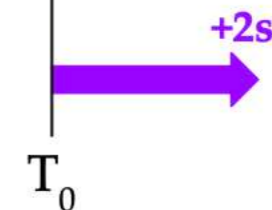


μQuasars

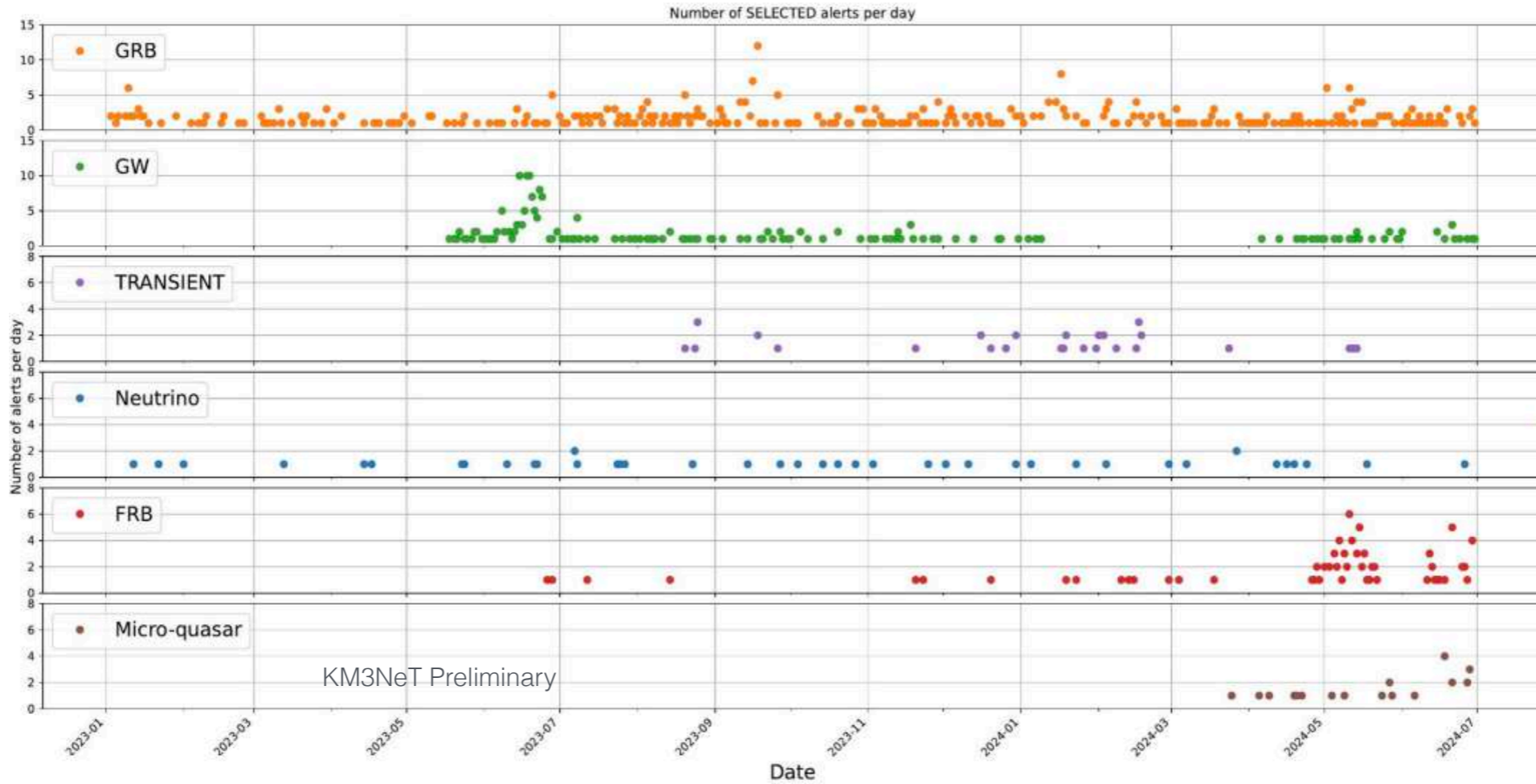


CCSNe

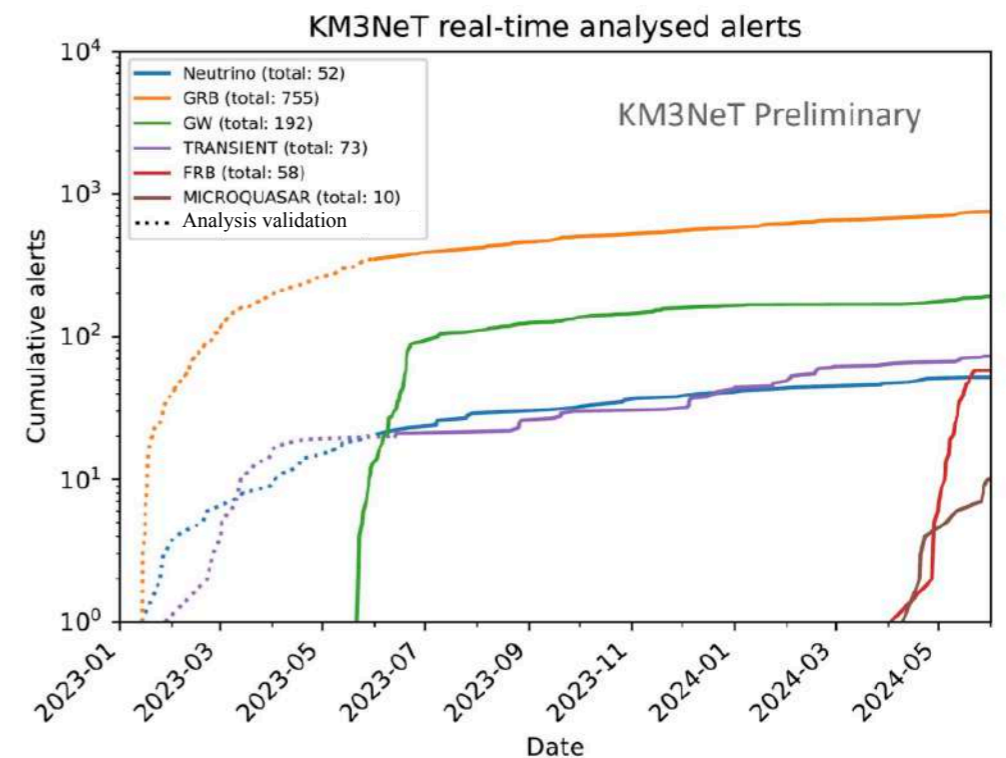
[MeV analysis]



Selected alerts



GRBs	~1 per day
IC neutrinos	~1 per 2 weeks
GWs	~1 per 2 days
Transients	~1 per week
FRBs	~1 per 3 days
μ Quasars	~1 per 3 days

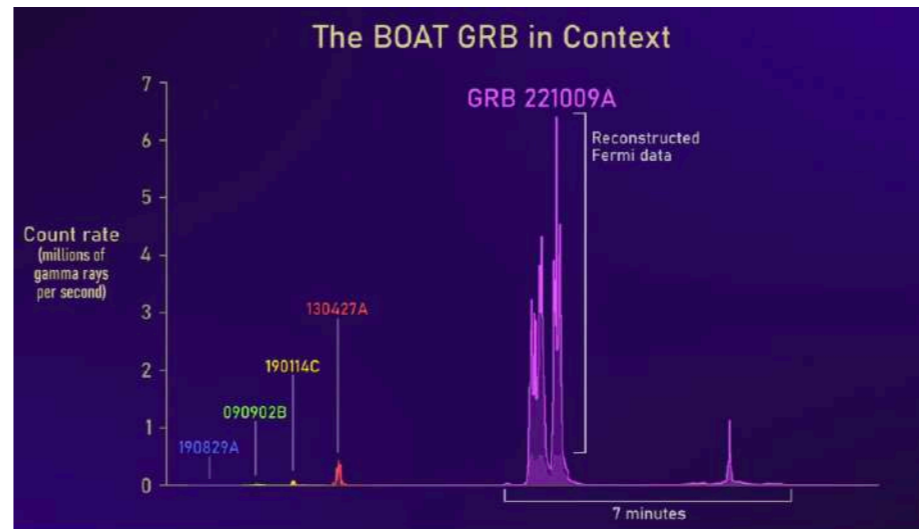


The BOAT GRB: search for neutrinos in KM3NeT data



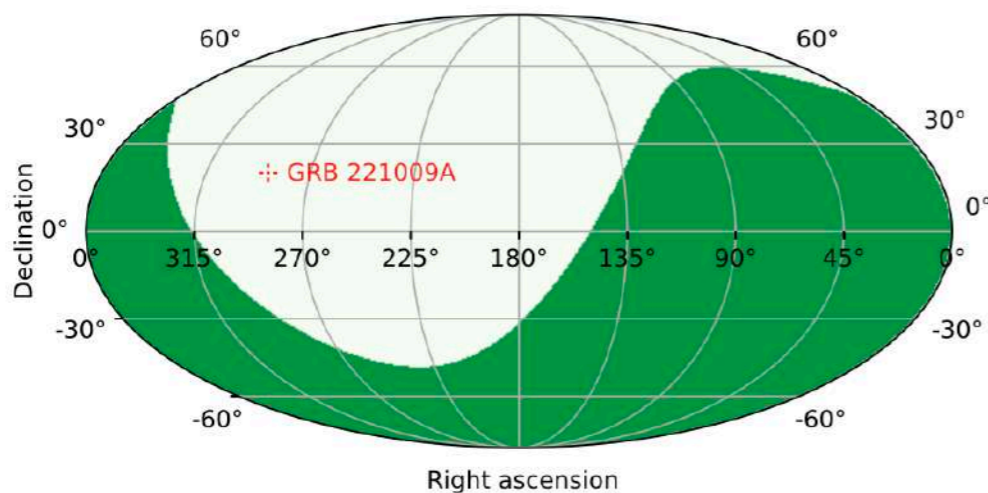
- ★ Highest fluence;
- ★ Nearby: $z=0.152$;
- ★ Highest Eiso $\sim 1 \times 10^{55}$ erg;
- ★ Once in a 1000/10000 yr event.

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



Cao et al. [LHAASO Coll.], Science 380 (2023) 1390

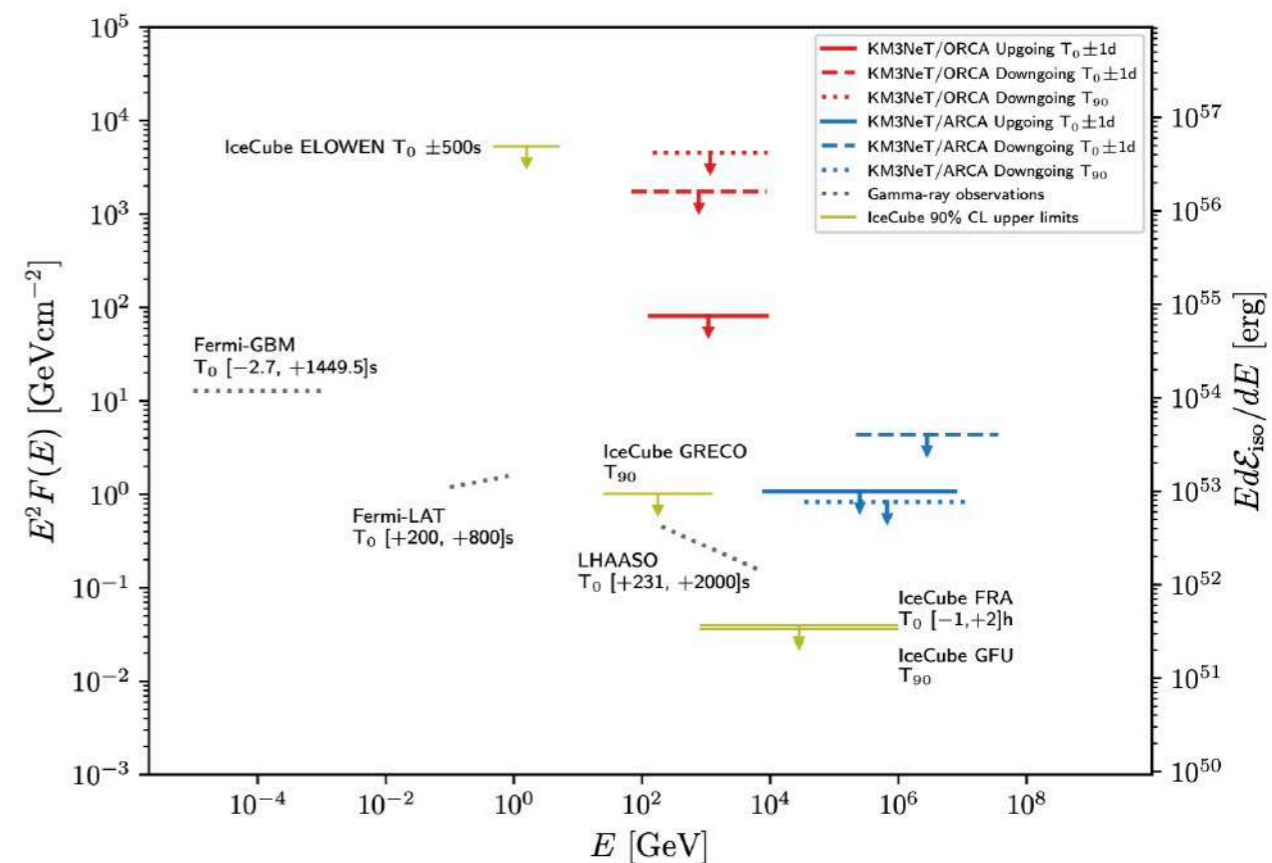
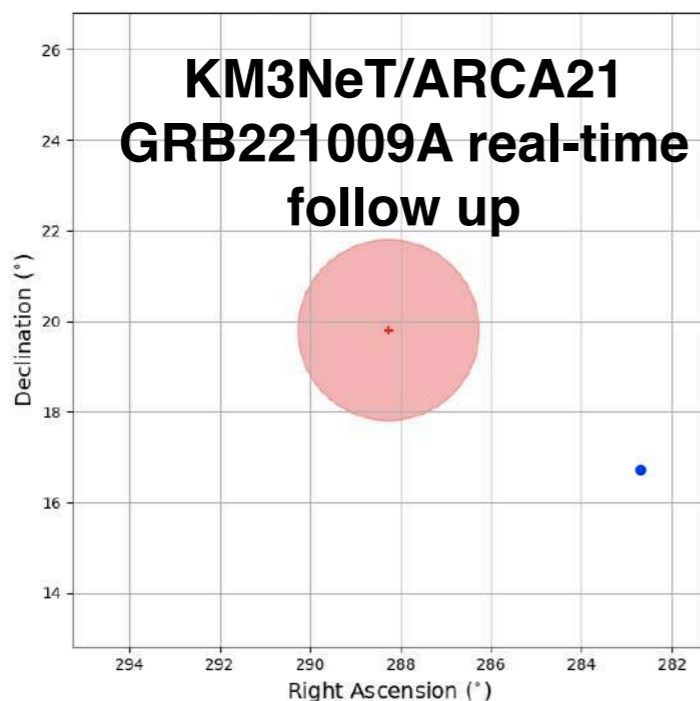
GCN 32677



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

GCN 32741

Aiello et al. [KM3NeT] arXiv:2404.05354



Conclusions

Water-based Cherenkov neutrino telescopes:

- **angular resolution** → precision multi-flavor astronomy;
- location → **privileged visibility of the Galaxy**;
- ARCA & ORCA → **broad energy coverage**;
- marine observatory for environmental sciences.

KM3NeT is taking data and growing rapidly:

- **ARCA** is currently taking data with **28 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 internal alerts.

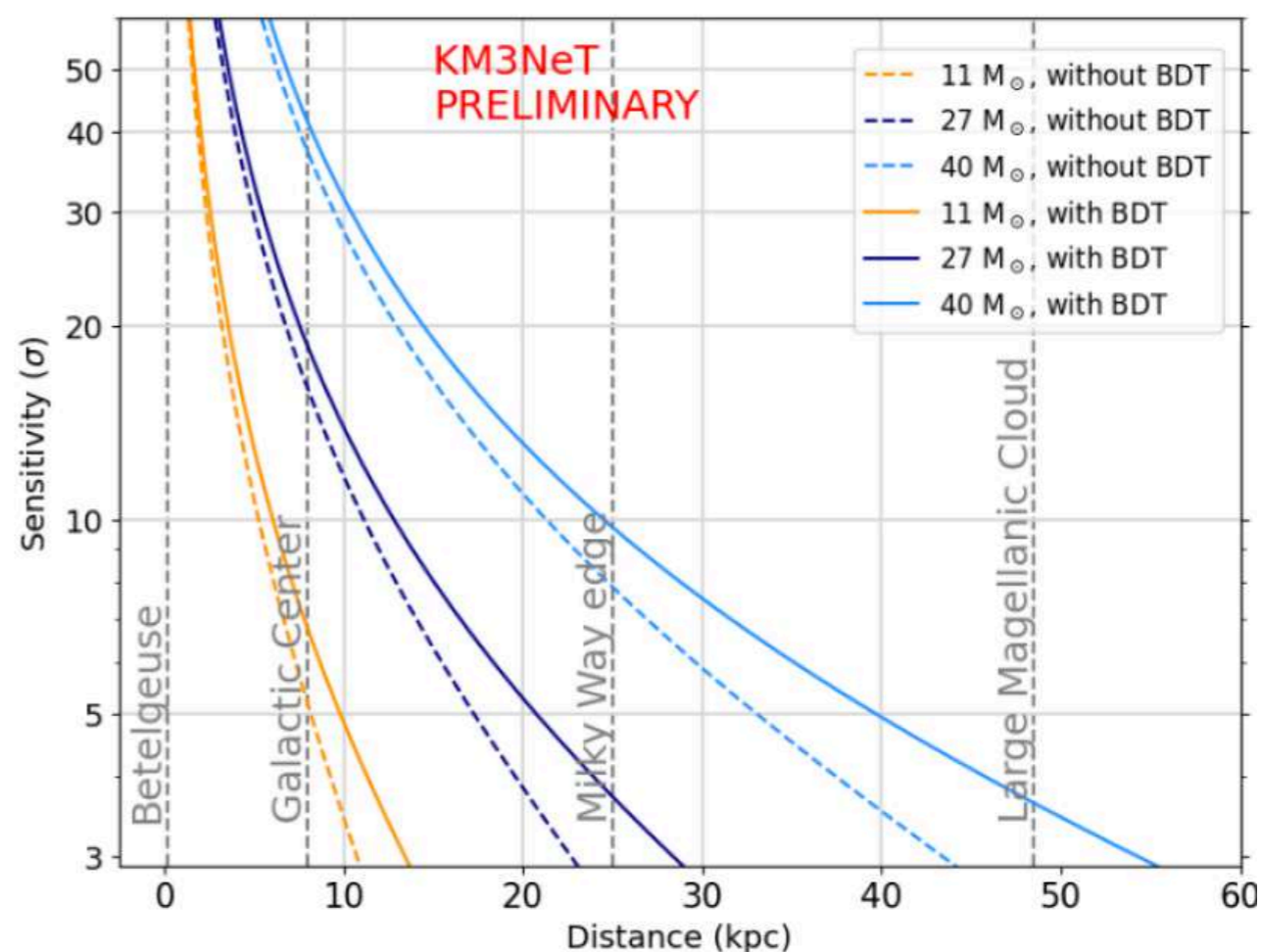
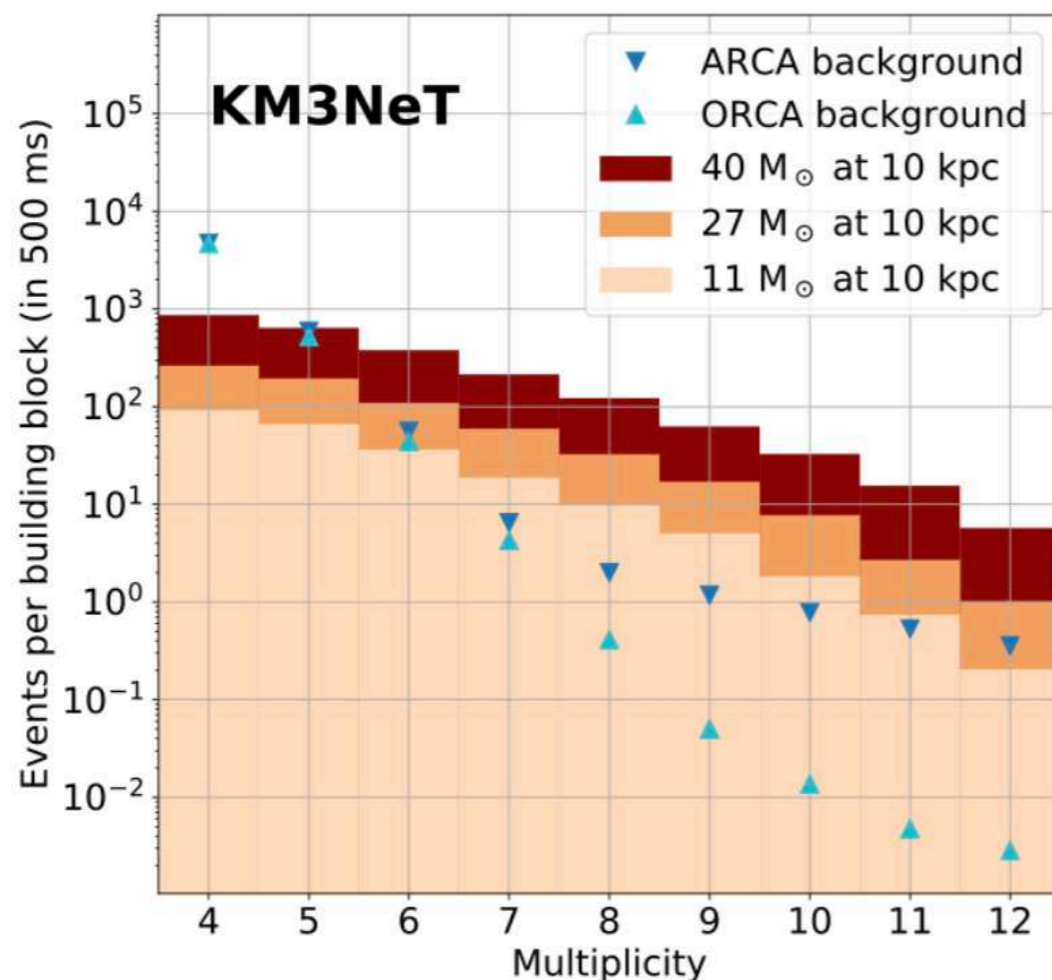
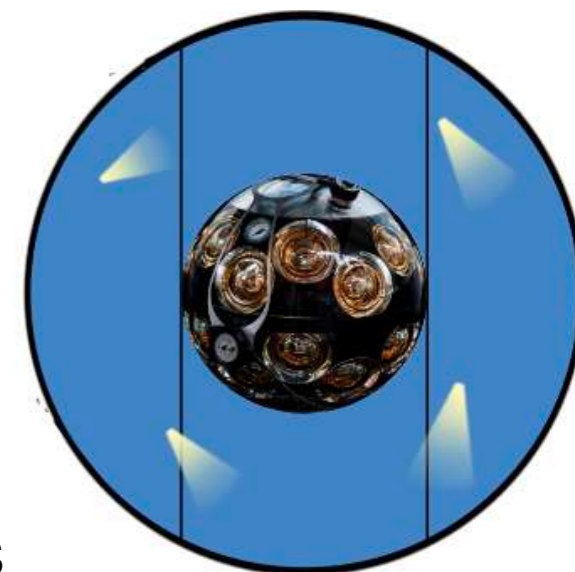
STAY TUNED FOR UPDATES!



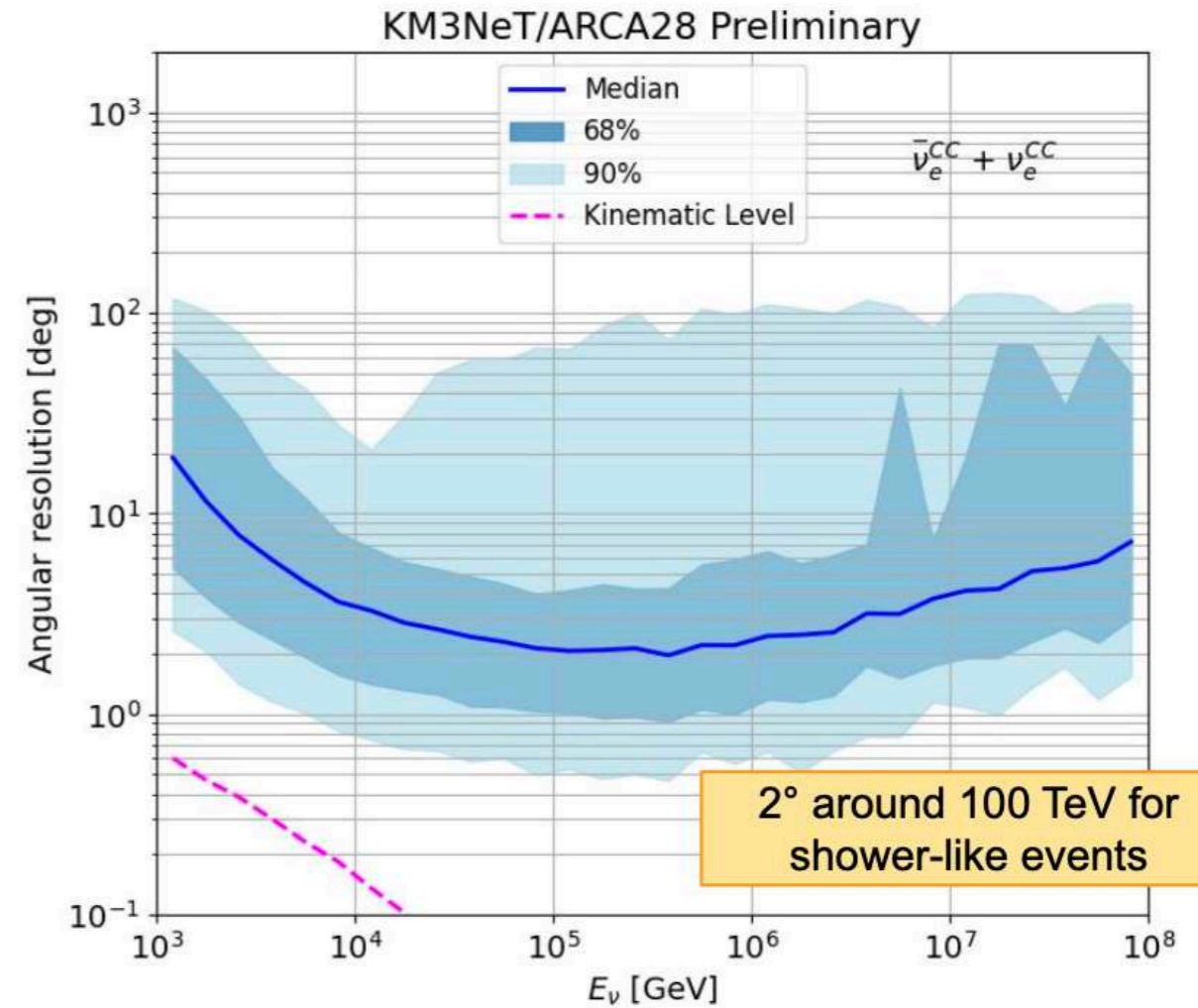
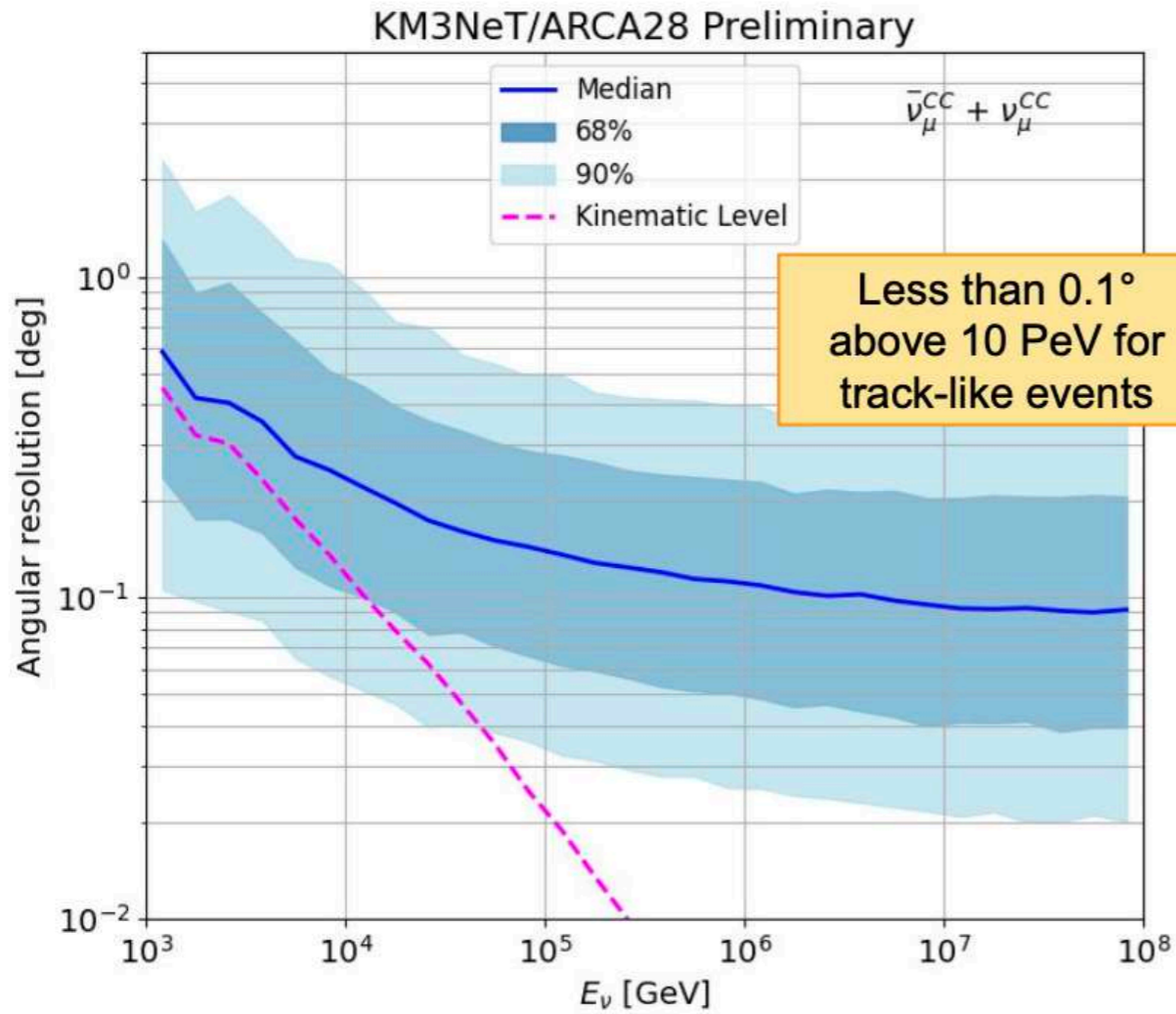
**THANKS FOR
YOUR KIND
ATTENTION!**

Search for MeV neutrinos from CCSNe

- Neutrinos < 100 MeV expected at massive stellar collapse
- Main interaction channels in water are IBD of electron antineutrinos with protons, ES on electrons and CC interaction with O nuclei
- Cherenkov signature detected as a population of coincidences in single DOMs = overall excess in detector
- K40, bioluminescence and atm. μ s are main backgrounds
- Alert sent in realtime through SNEWS



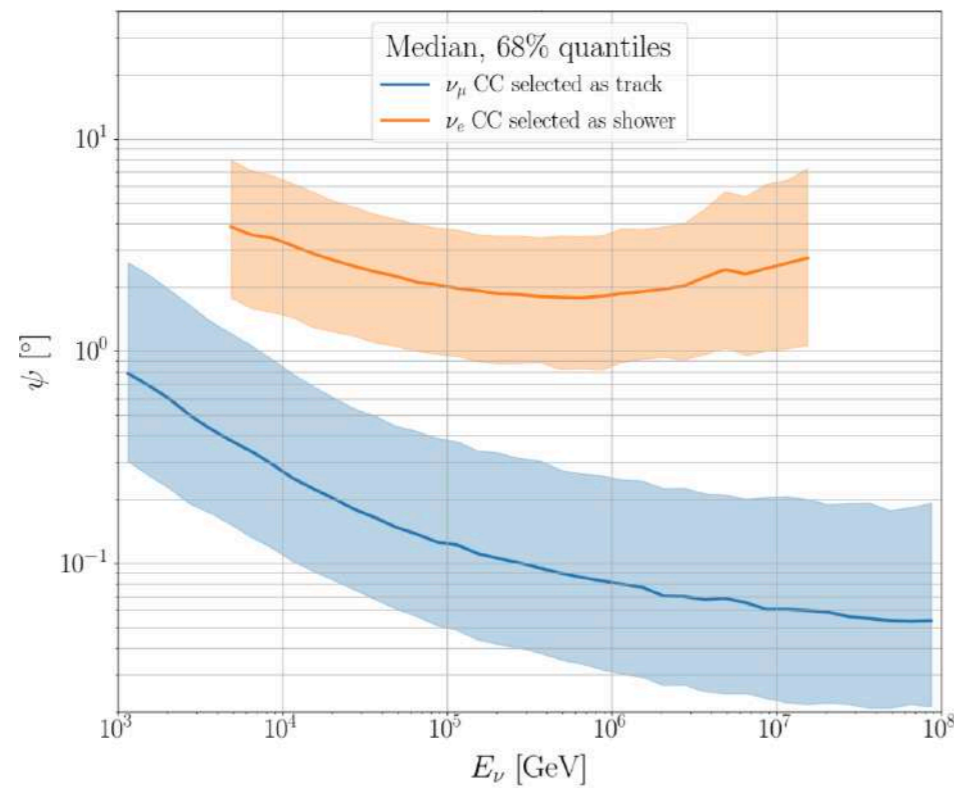
The KM3NeT/ARCA28 angular resolution



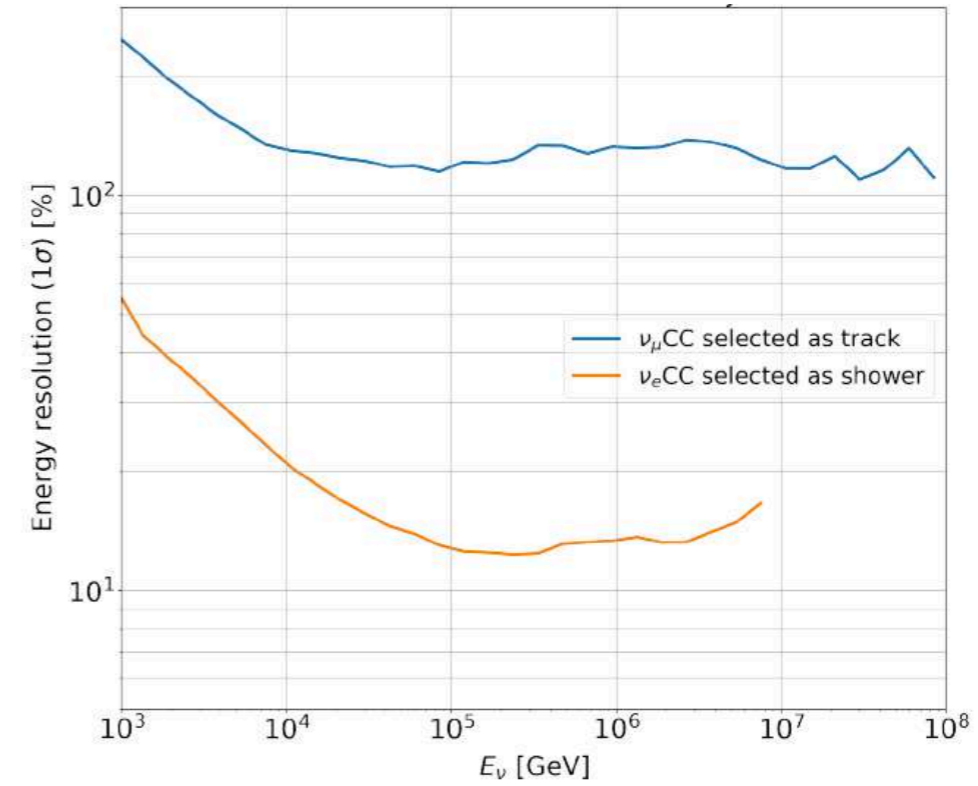
A. Veuro et al. [KM3NeT Coll.], MGXVII 2024

The KM3NeT/ARCA astronomical potential

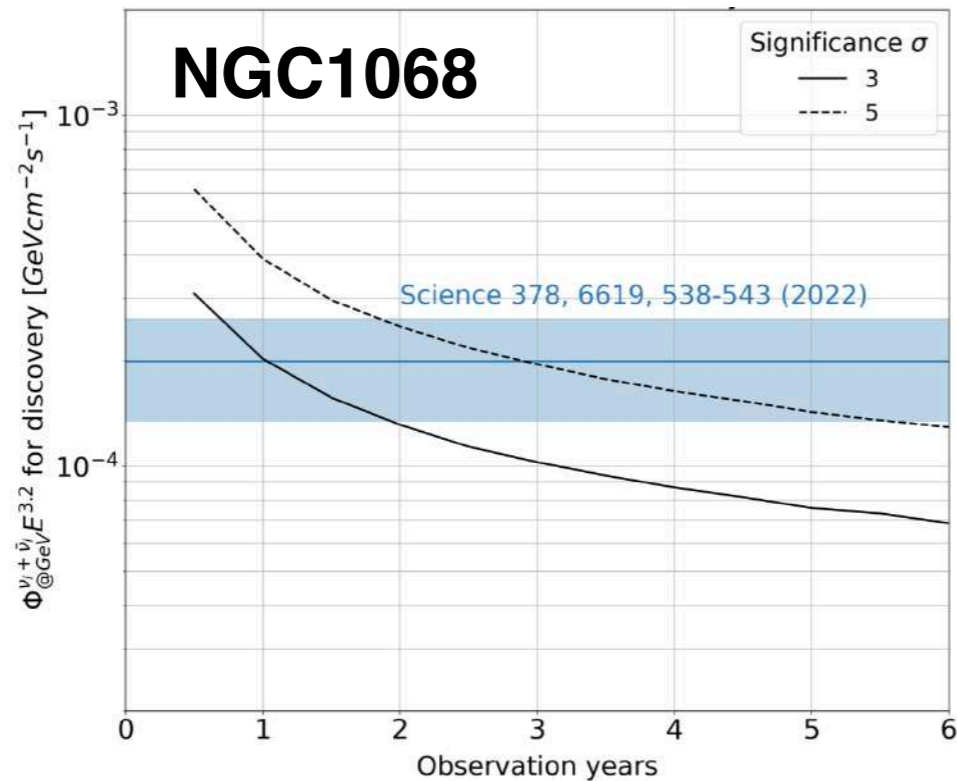
Angular resolution



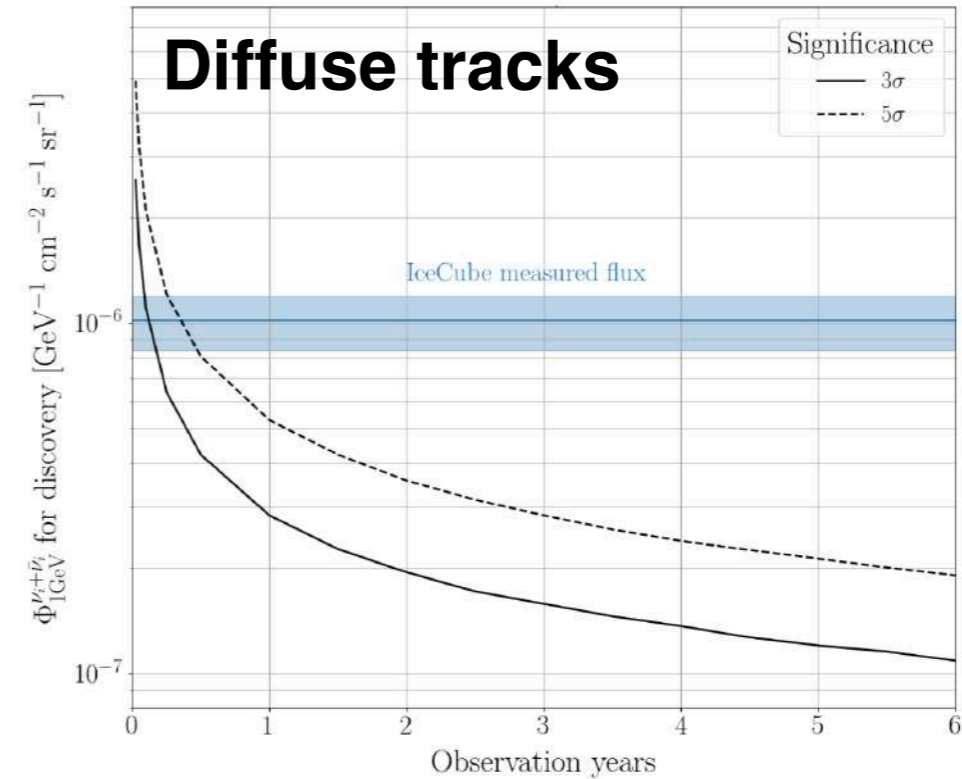
ARCA energy resolution



NGC1068



Diffuse tracks



On/off binned analysis



Signal in **on region**:

Search time window + Ω_{ON}

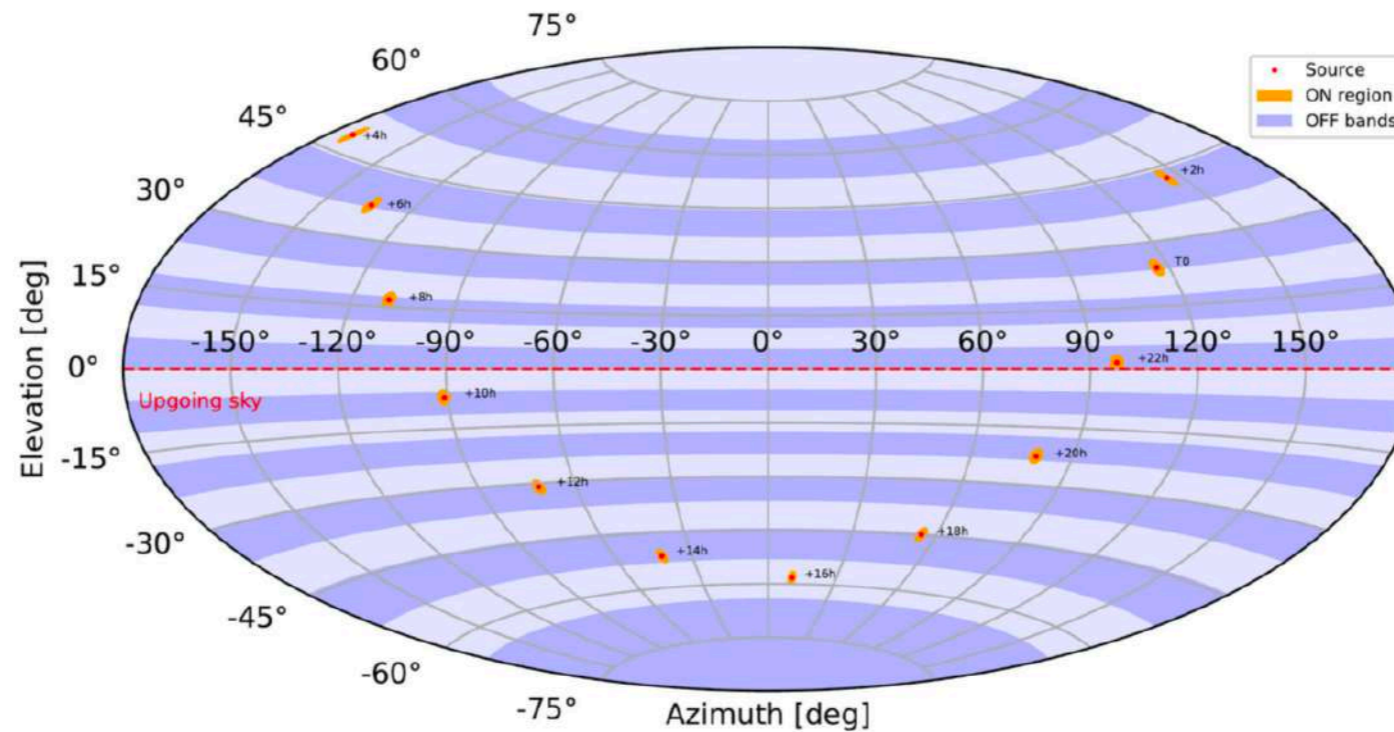
Background in **off region**:

2 weeks lifetime data before the alert

Bands at elevation of the source

$$n_{\text{bkg}} = \sum_{i \in \text{bands}} \frac{T_{\text{ON}} \Omega_{\text{ON}}^i}{T_{\text{OFF}} \Omega_{\text{OFF}}^i} N_{\text{OFF}}^i$$

T_{ON} : search time window, depending on the source type
 T_{OFF} : 2 weeks
 Ω_{ON}^i : overlap between ON region and OFF region band
 Ω_{OFF}^i : size of OFF region band
 N_{OFF}^i : number of events in OFF region band after selection

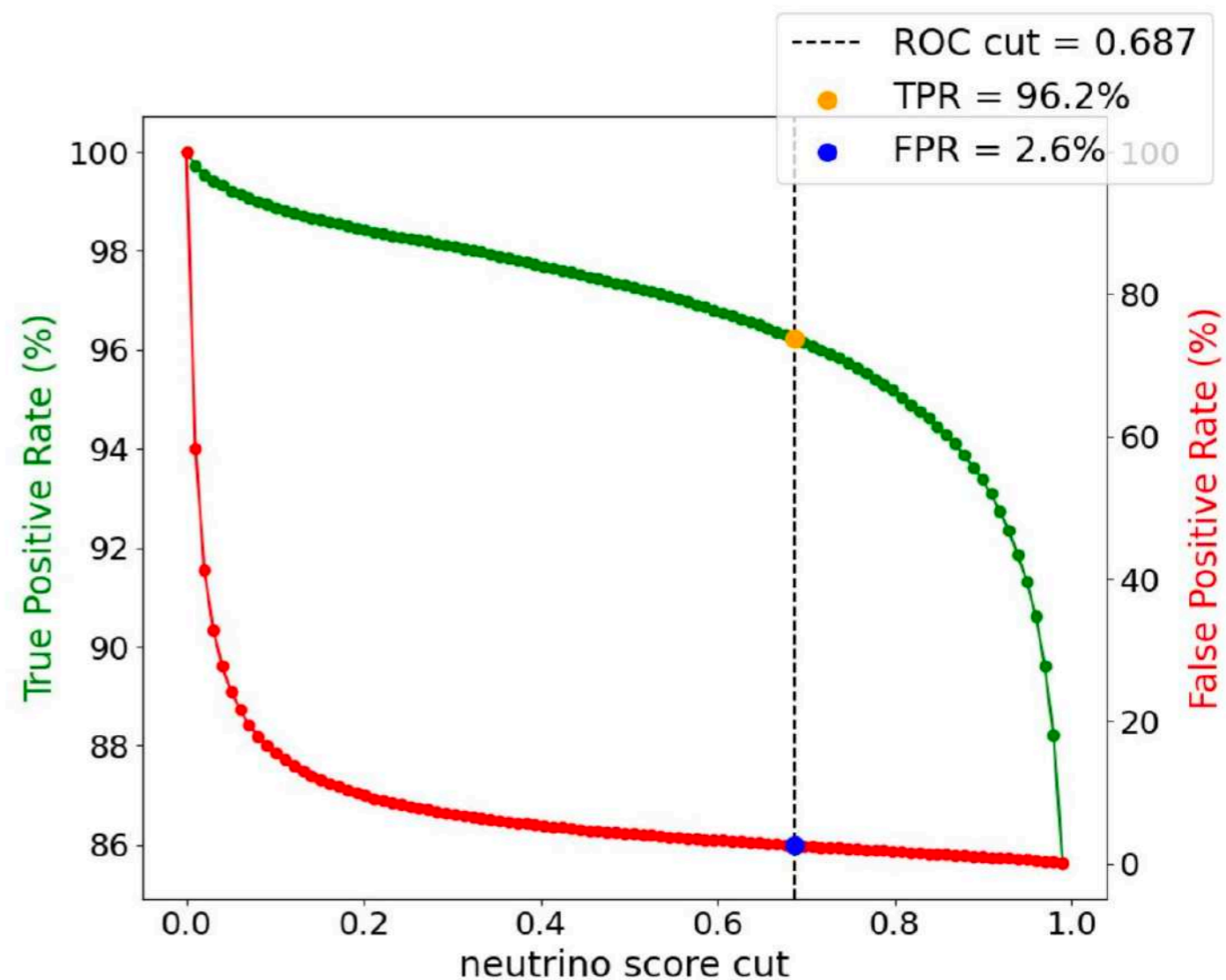
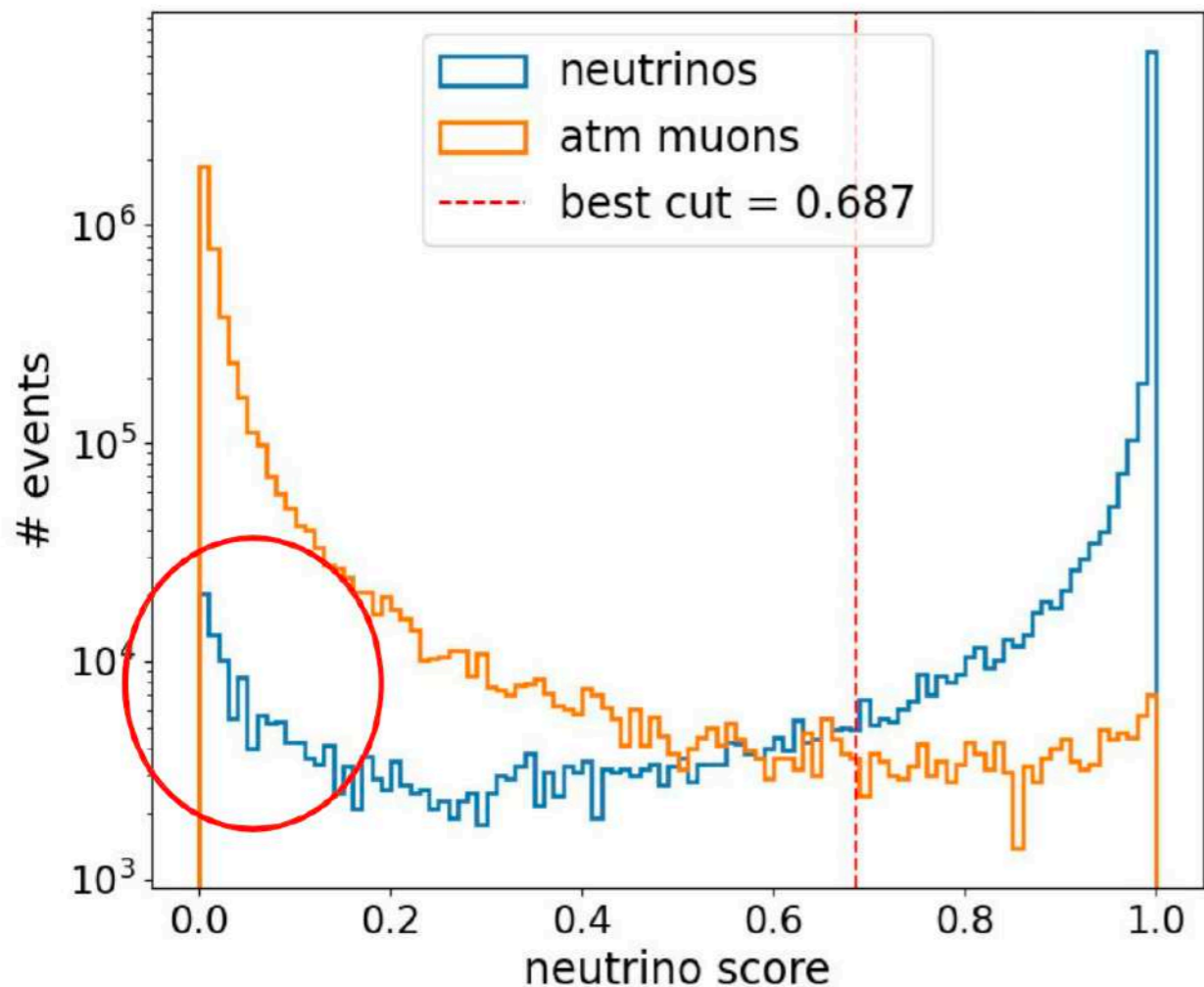


Selection cuts to achieve a target number of background events

Optimization criteria:

1. $n_{\text{BKG}} \leq \alpha$
2. $\sigma(n_{\text{BKG}})/n_{\text{BKG}} < 30\%$
3. $\sigma(n_{\text{OFF}}^i)/n_{\text{OFF}}^i < 50\%$

GNN performance for μ/ν identification

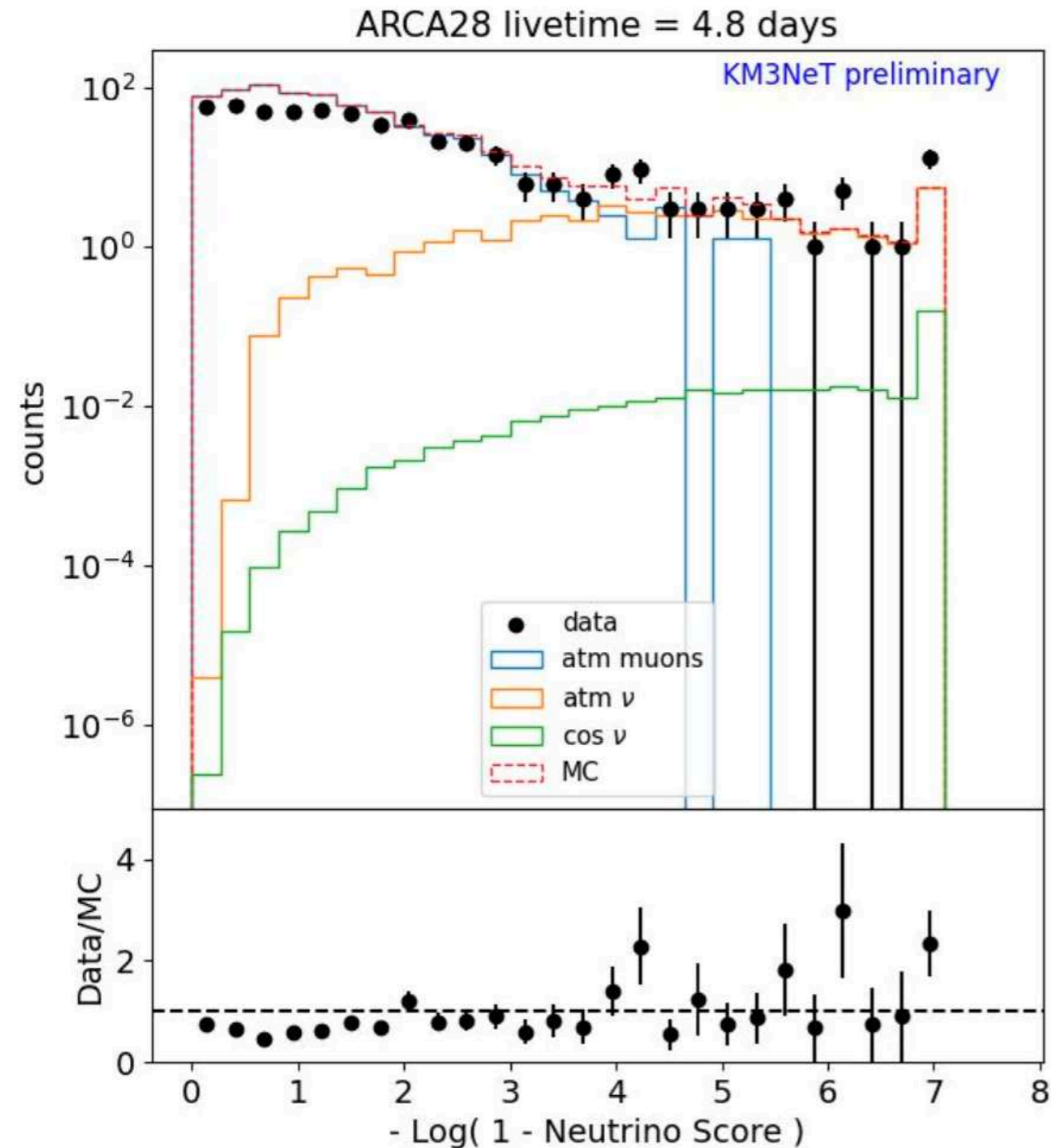


Machine learning in KM3NeT



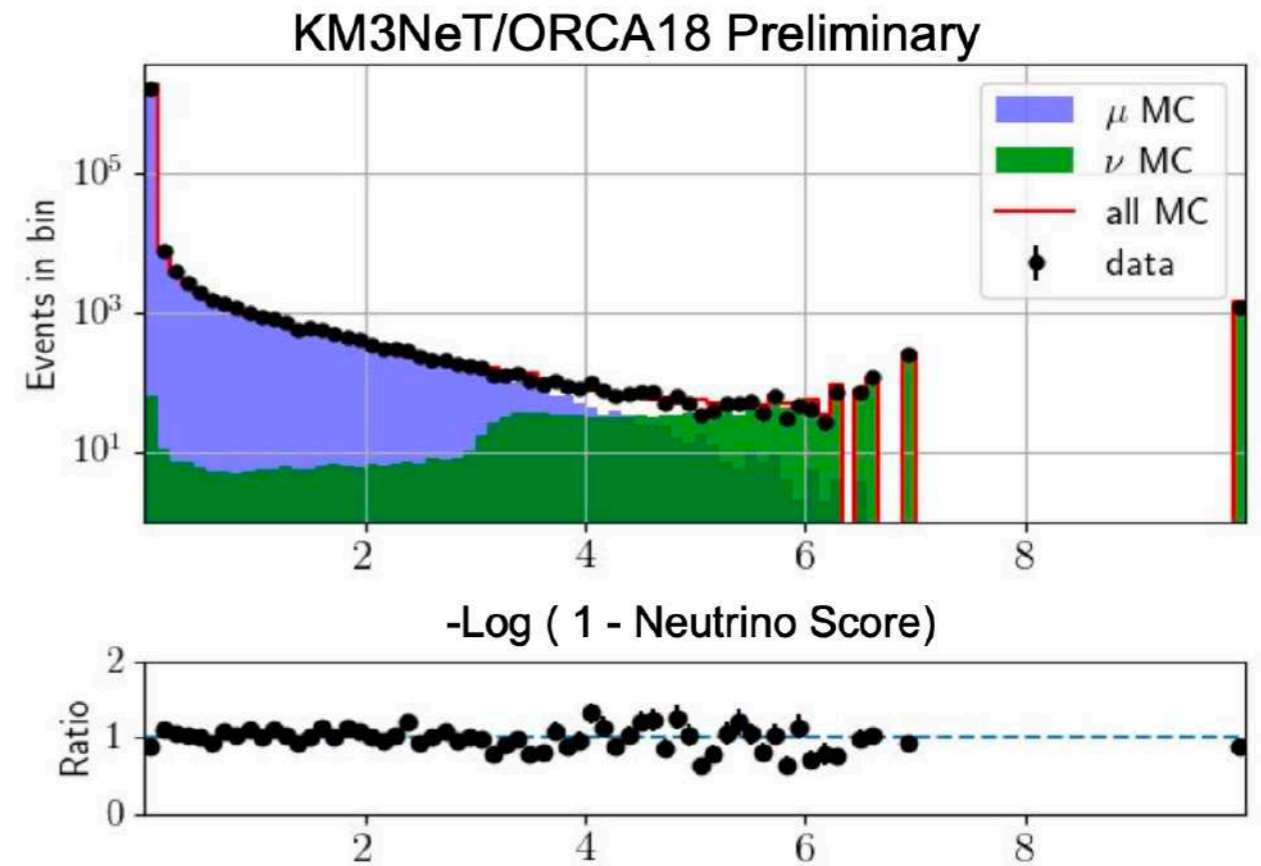
ARCA GNN

- does not require input features by the human side
- it acts as a black box

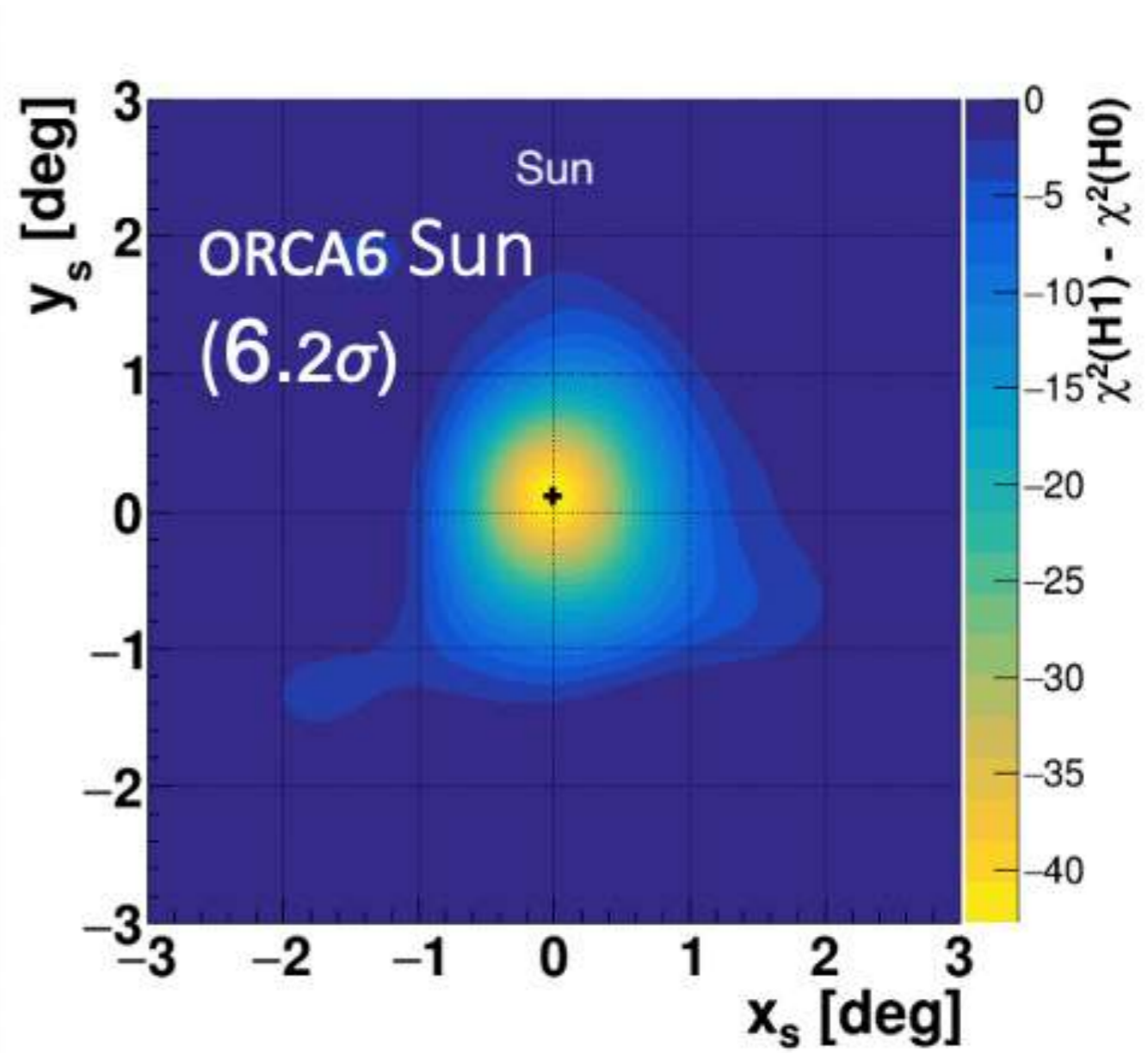
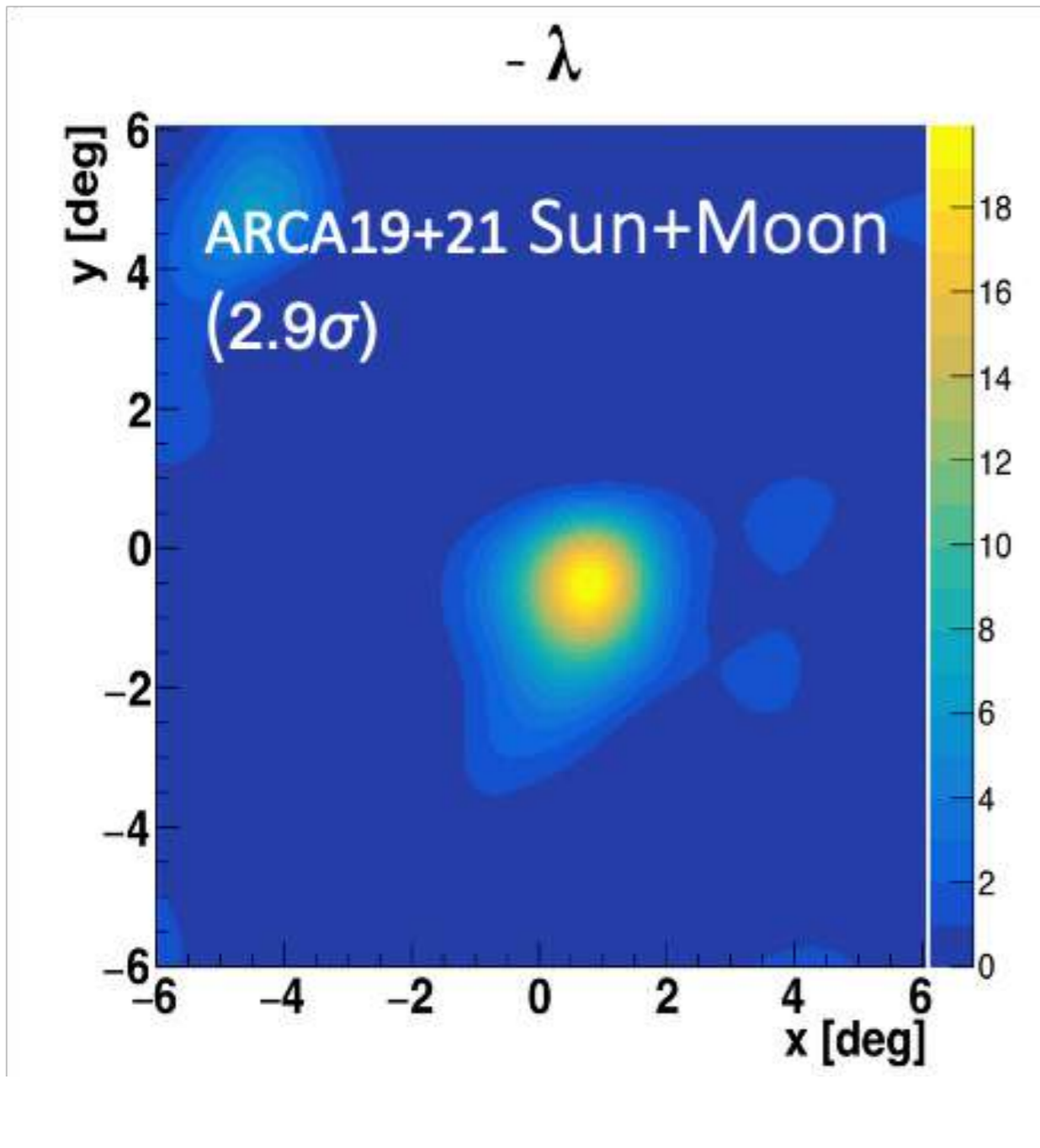


ORCA BDT

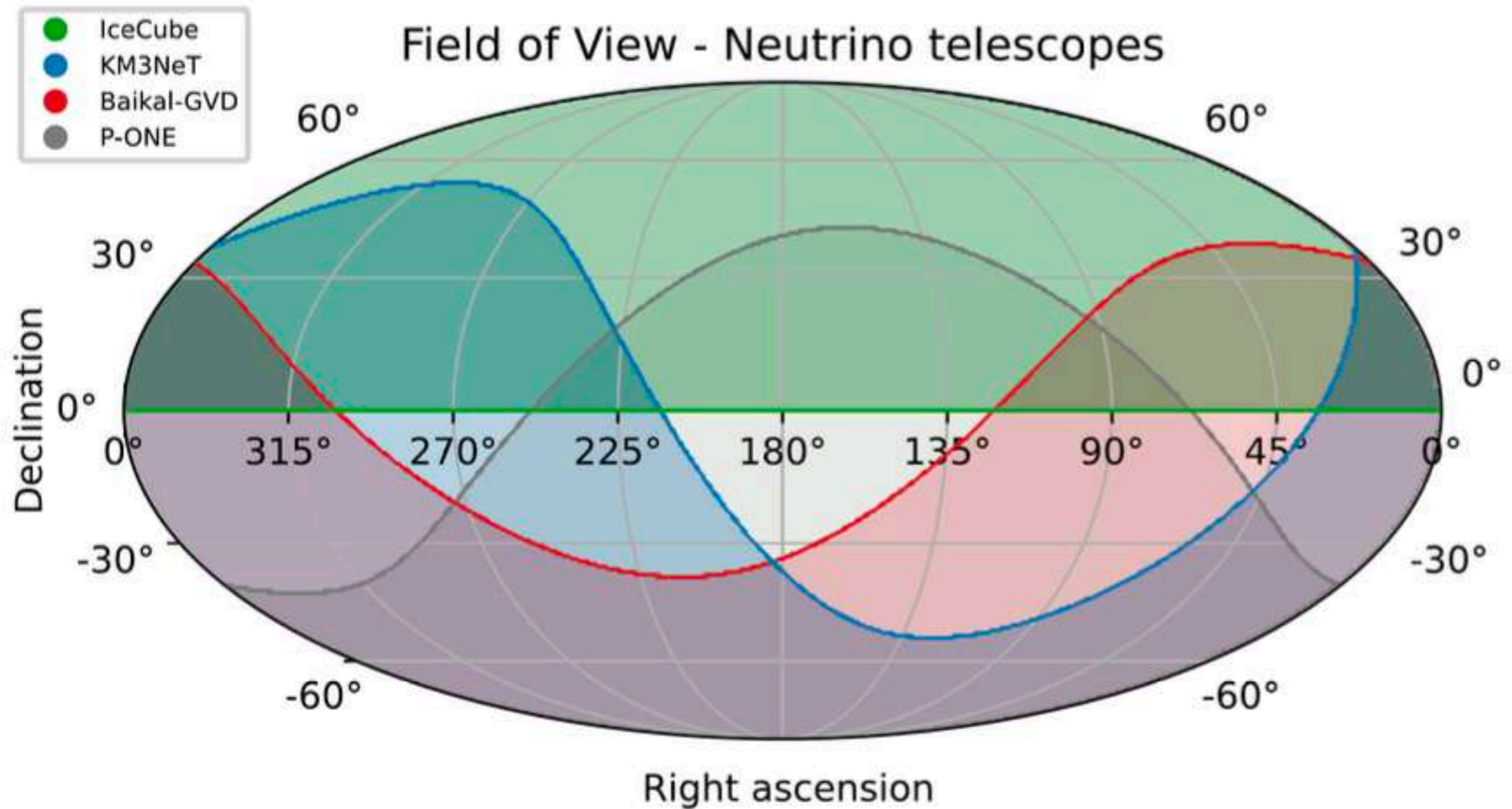
- transparent and easy to handle
- it requires human input (reco)



Pointing capabilities



Upgoing event selection



Point source searches with ARCA



Search for neutrinos from 101 candidate cosmic sources:

- 14 months of ARCA6+8+19+21
- upgoing track selection
- most significant p-value = 1%
- data from ARCA28 to be included
- ANTARES limits to be reached soon

