

First neutrino astronomy results with 6/8 lines of KM3NeT/ARCA

IRN Neutrino meeting,
IJCLab - Paris, 16-17/11/2022

Francesco Filippini

on behalf of the KM3NeT Collaboration

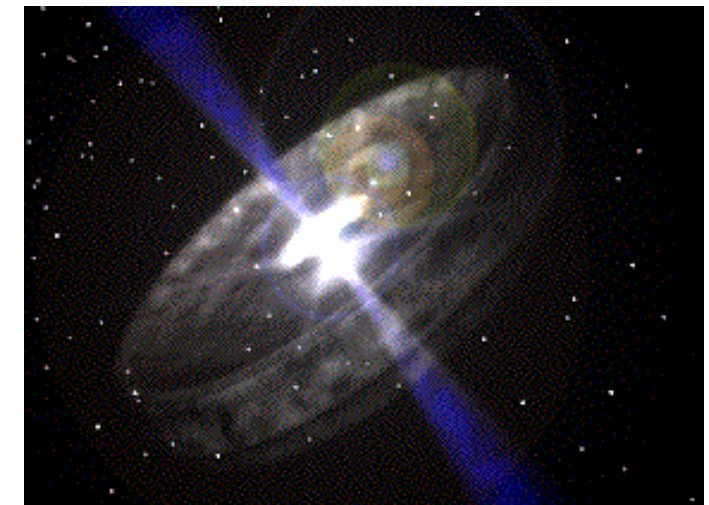
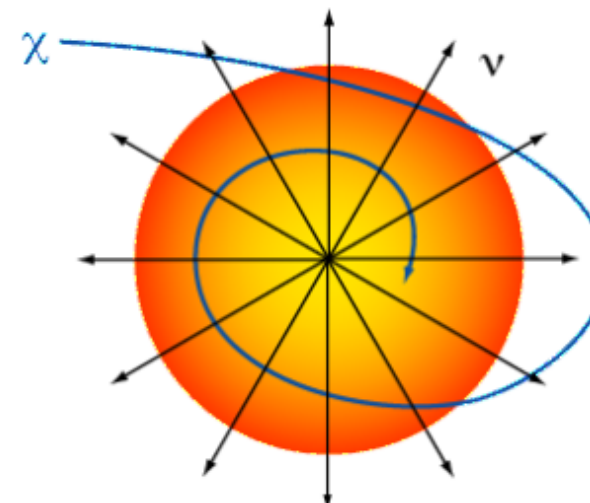
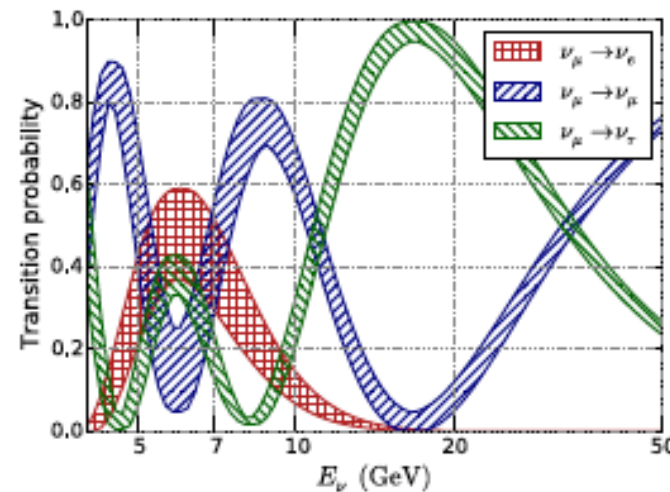
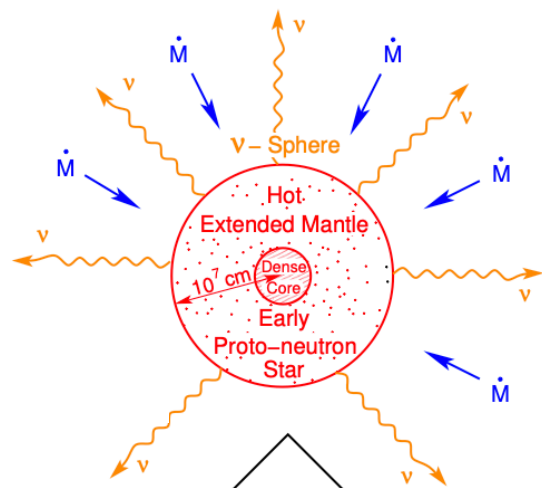
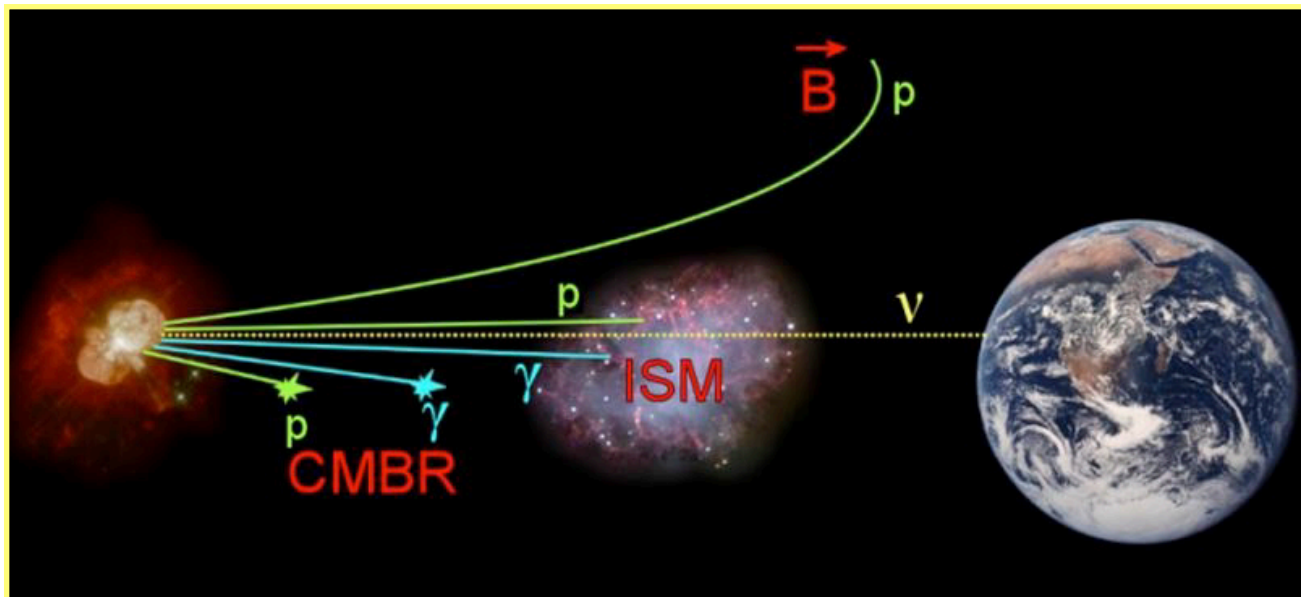
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KM3NeT

Astrophysics case

- Origin of Cosmic Rays
- Neutral messengers point back to their sources
 - Neutrons are short-lived, photons are likely to interact
 - ⇒ **Neutrinos as cosmic probe**
- Neutrinos are produced at sources via hadronic interactions
 - Cosmic diffuse flux
 - Point-like sources
 - Multi-messenger approach



Super Novae
explosion
MeV

Neutrino
oscillation
GeV

Dark Matter
GeV-TeV

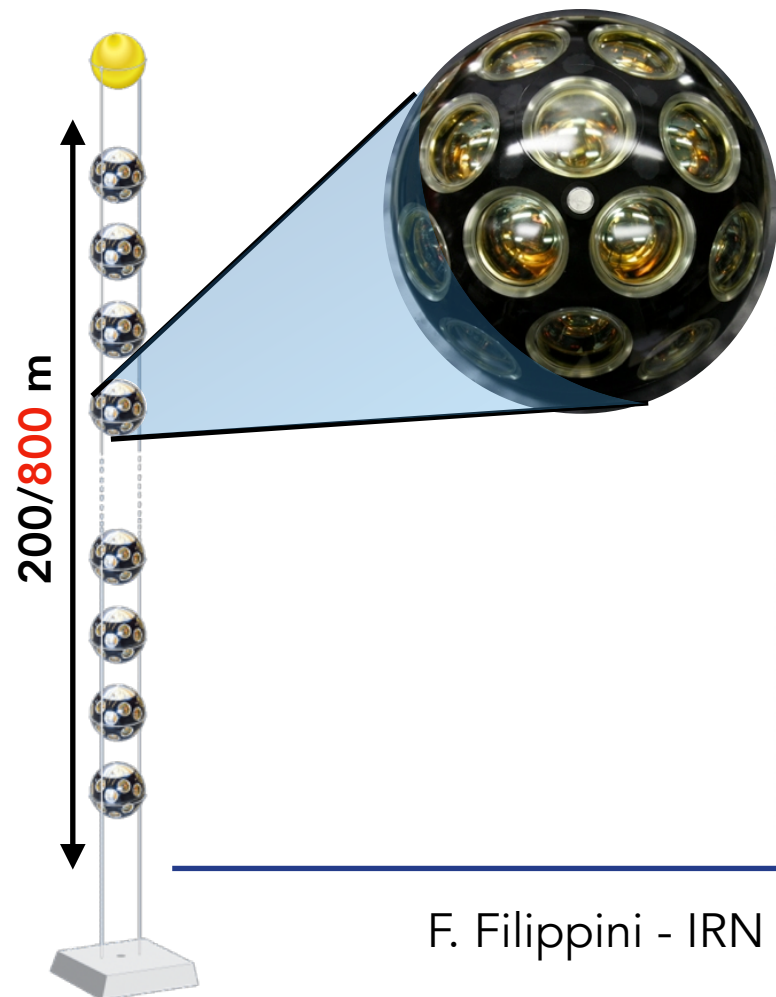
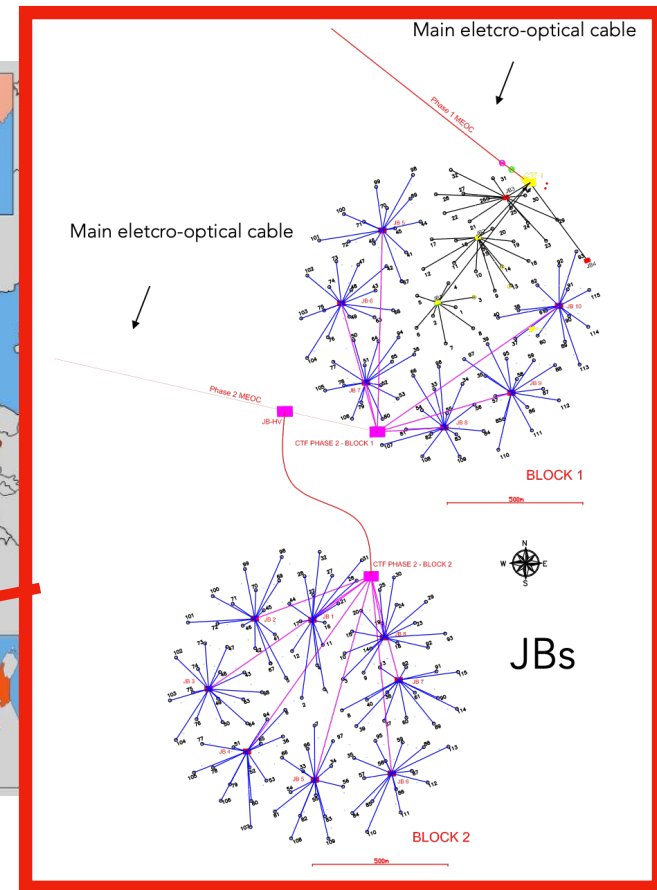
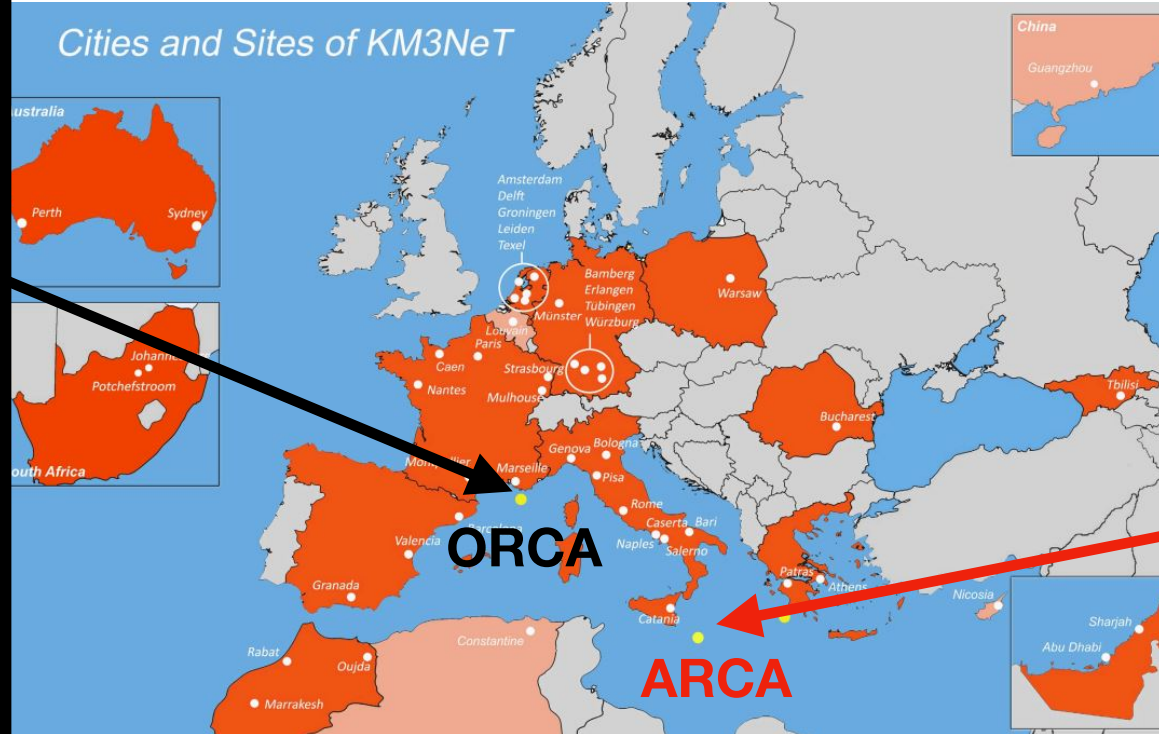
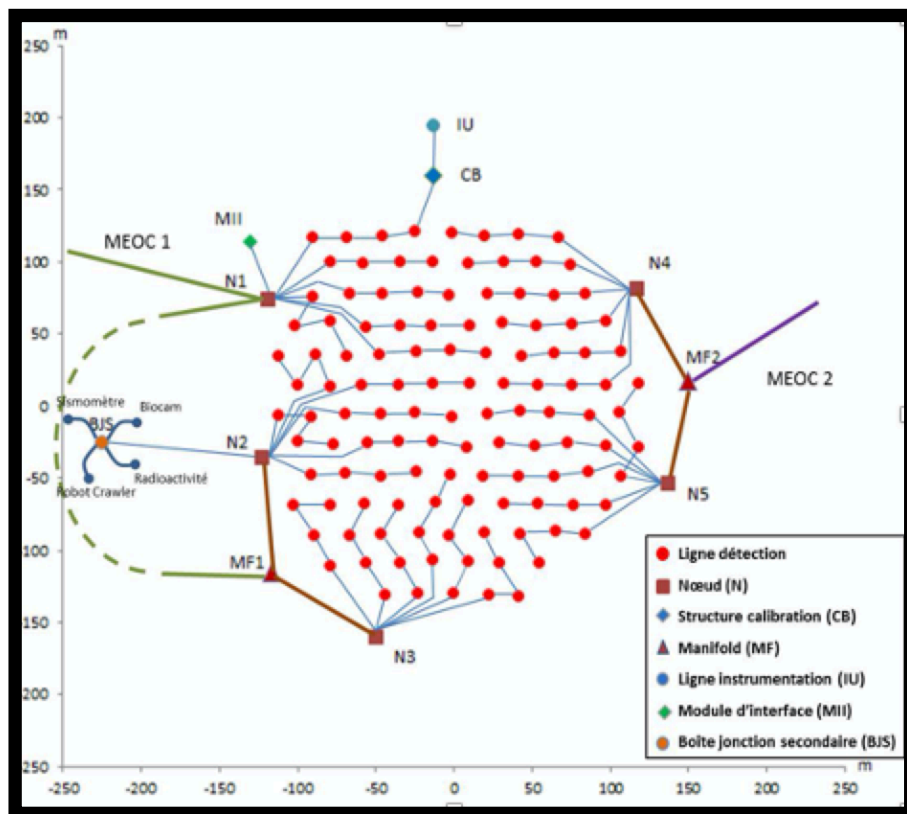
HE neutrinos, CRs
Multi-messenger
program
TeV-PeV

ARCA

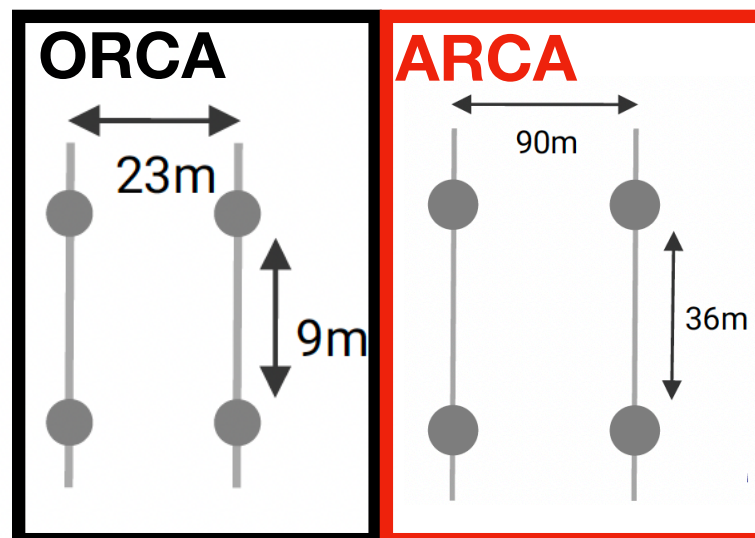
ORCA

ARCA

KM3NeT

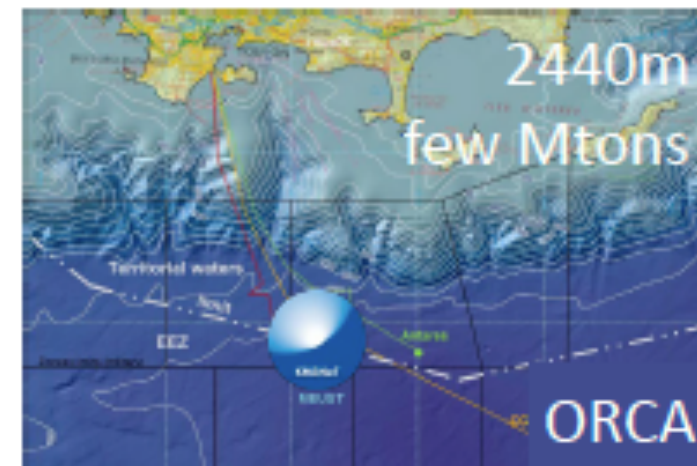
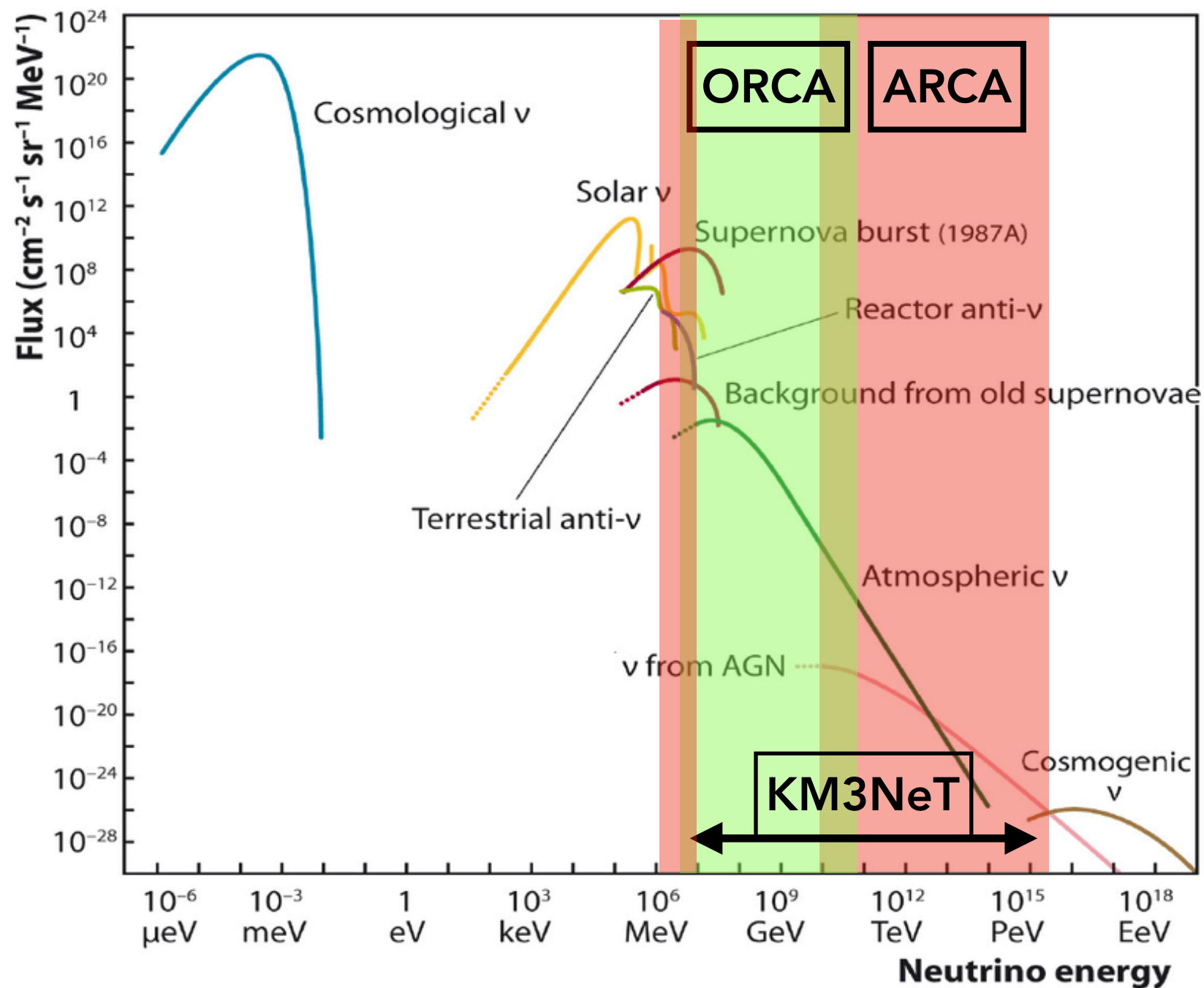


Two detectors, same technology, different layout and physics objectives



	ARCA	ORCA
Location	Italy	France
N. building blocks	2	1
N. DU per b.b.	115	115
DU distance	90 m	23 m
DOM spacing	36 m	9 m
DU height	~ 800 m	~ 200 m
Instrumented mass (Mton)	2* 650	7
Depth	3500 m	2500 m

Energy ranges



KM3NeT/ORCA

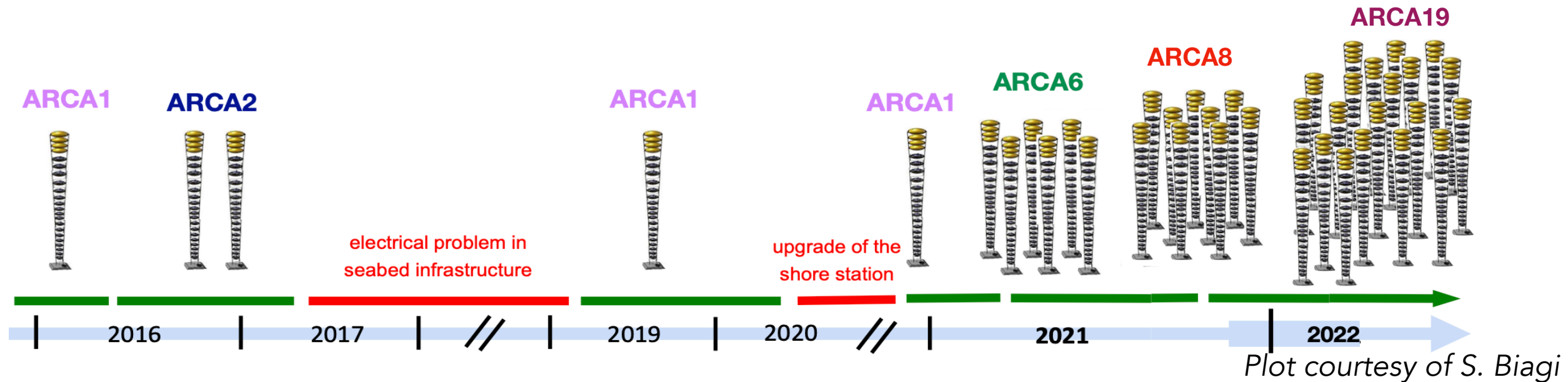
*Oscillation Research
with Cosmics in the Abyss*



KM3NeT/ARCA

*Astroparticle Research
with Cosmics in the Abyss*

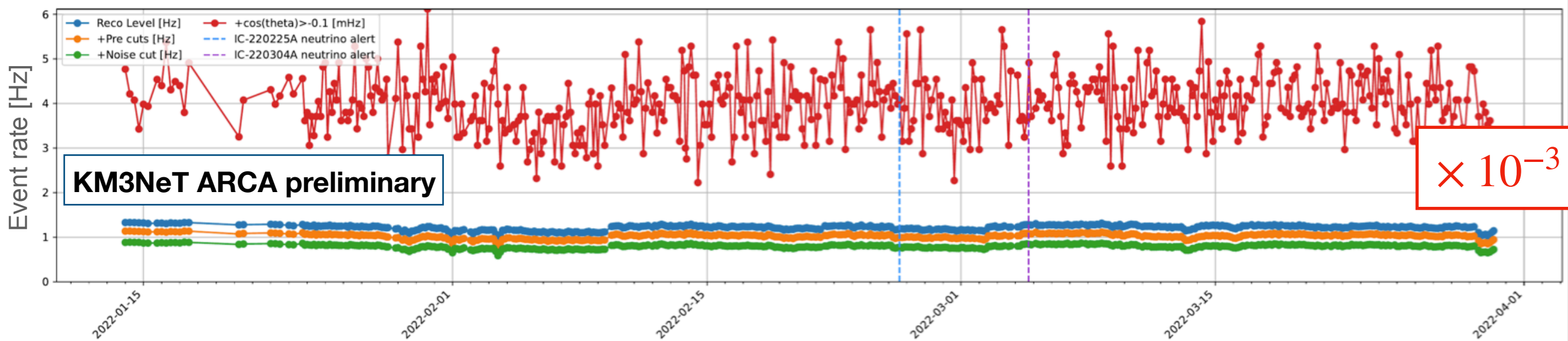
Data-taking period Arca6 - Arca8



Arca6 data-taking period : May 2021 - September 2021 (~100 days of livetime)

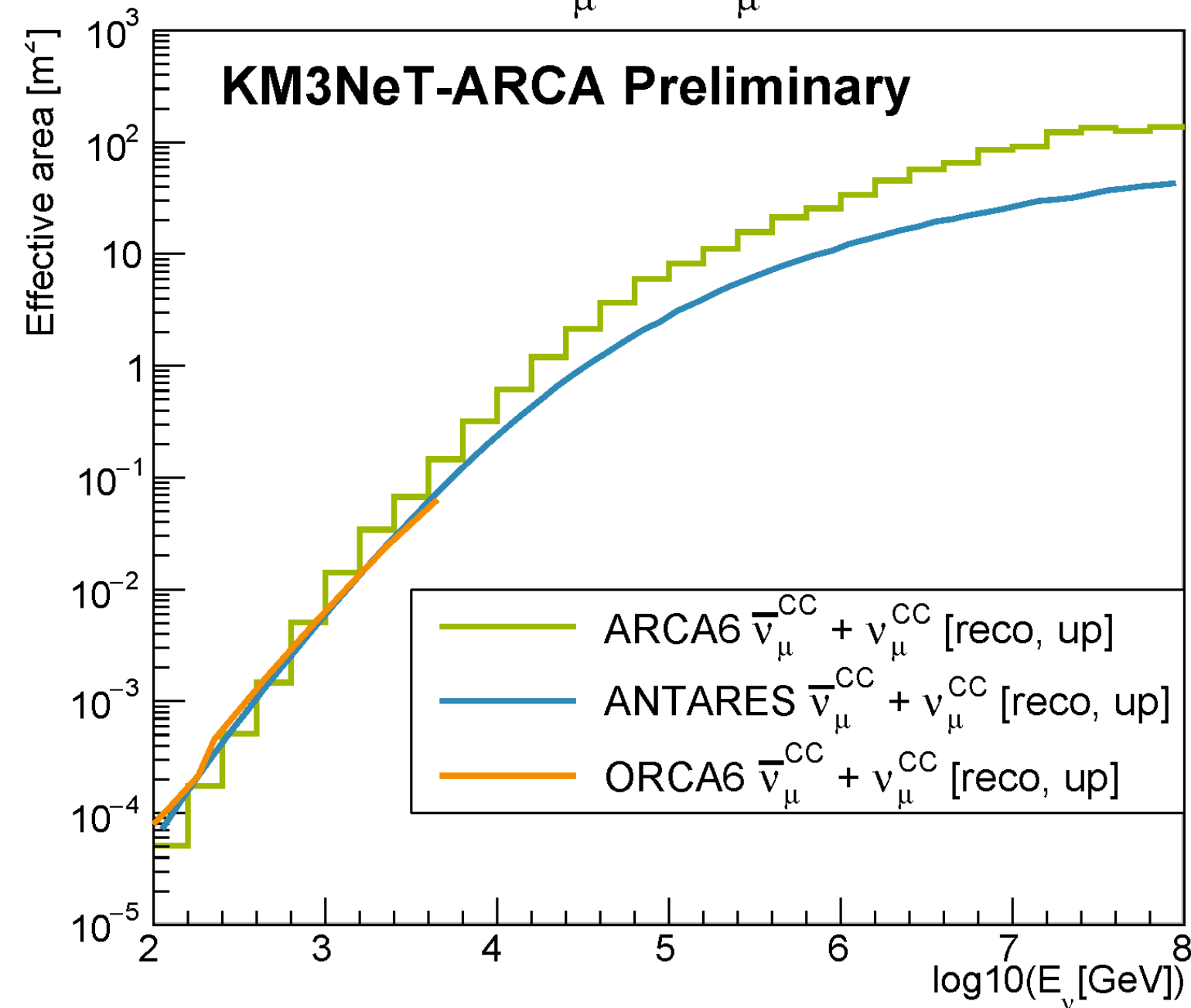
Arca8 data-taking period : September 2021 - end of May 2022 (~234 days of livetime)

Reconstructed event rate plot over 3 months of Arca8 data-taking



Effective Area

$$\bar{\nu}_{\mu}^{CC} + \nu_{\mu}^{CC}$$



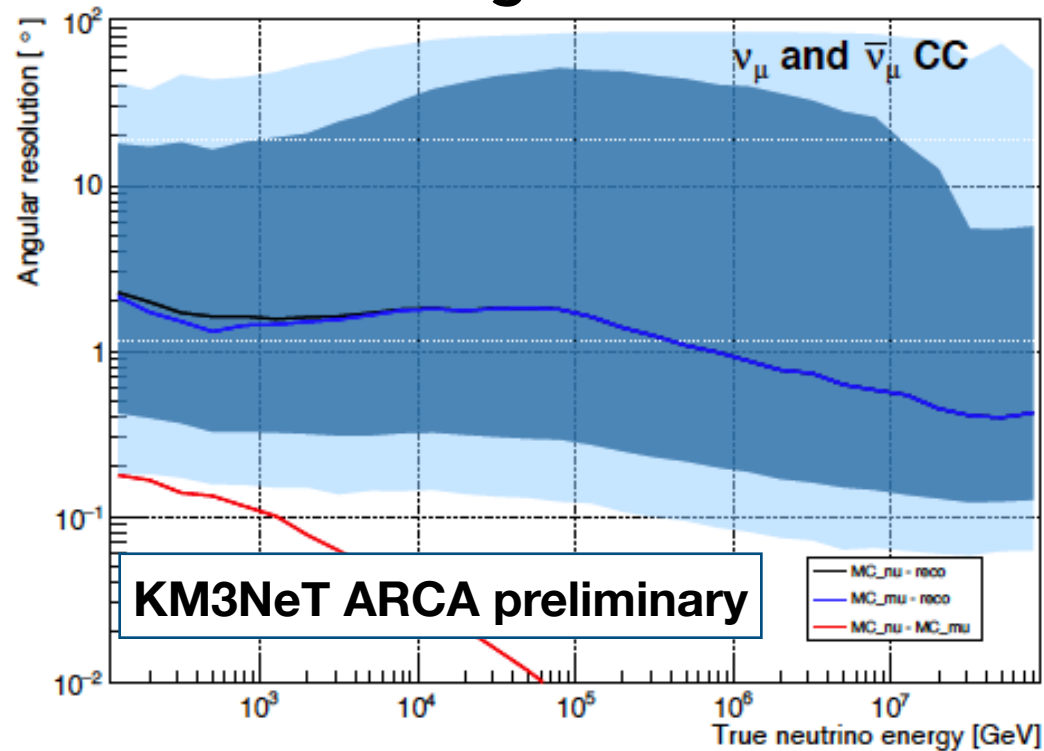
$A_{eff} \rightarrow$ Number of events per year
for a cosmic diffuse flux
 $\Phi = 10^{-8} E^{-2} GeV^{-1} cm^{-2} s^{-1} sr^{-1}$

PAST configuration KM3NeT/ARCA
and ORCA

**ARCA 6 effective Area,
comparable to ANTARES one**

Angular resolution track channel

Arca6 - angular resolution

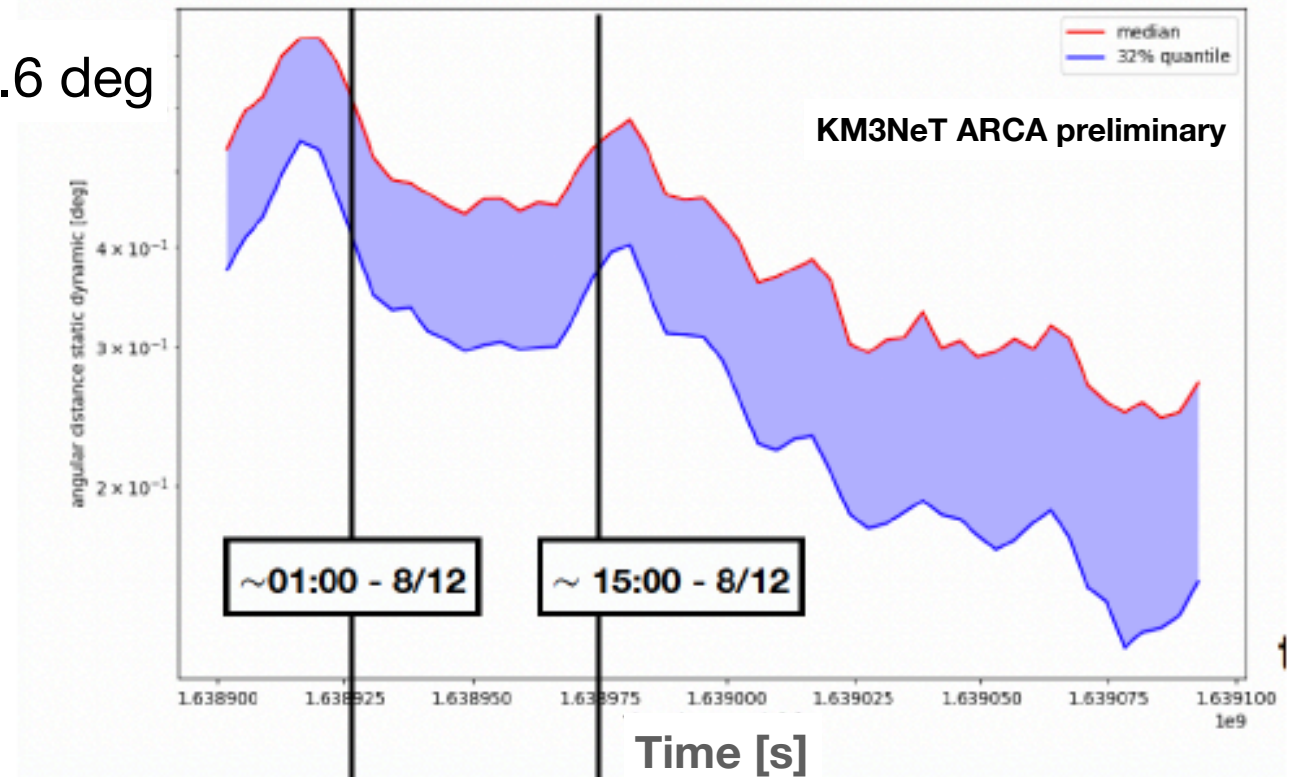


Angular resolution ARCA6 for track channel only (ν_μ , $\bar{\nu}_\mu$ CC)

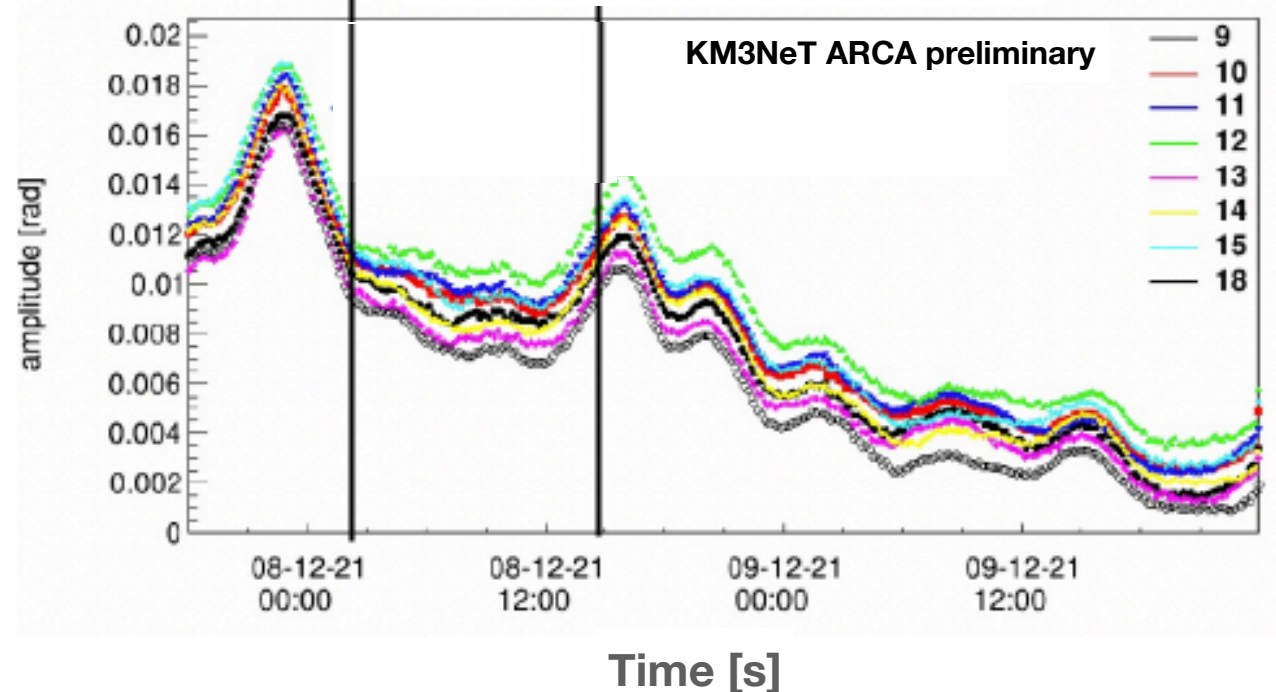
Important understanding of systematic effects:
dynamic calibration applied on data, updating position and orientation of the DOMs in function of time

Median angular distance reco tracks dynamic vs static calibration [deg]

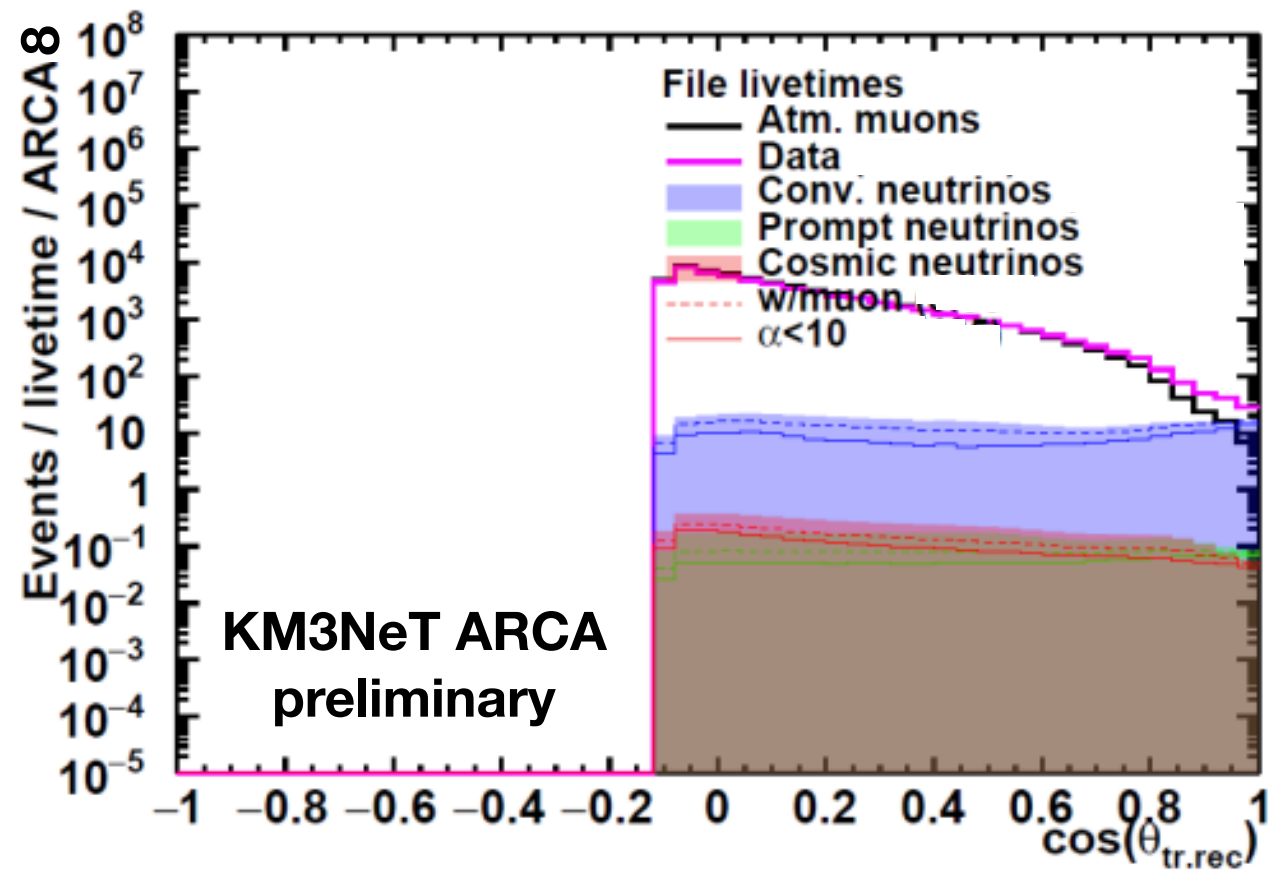
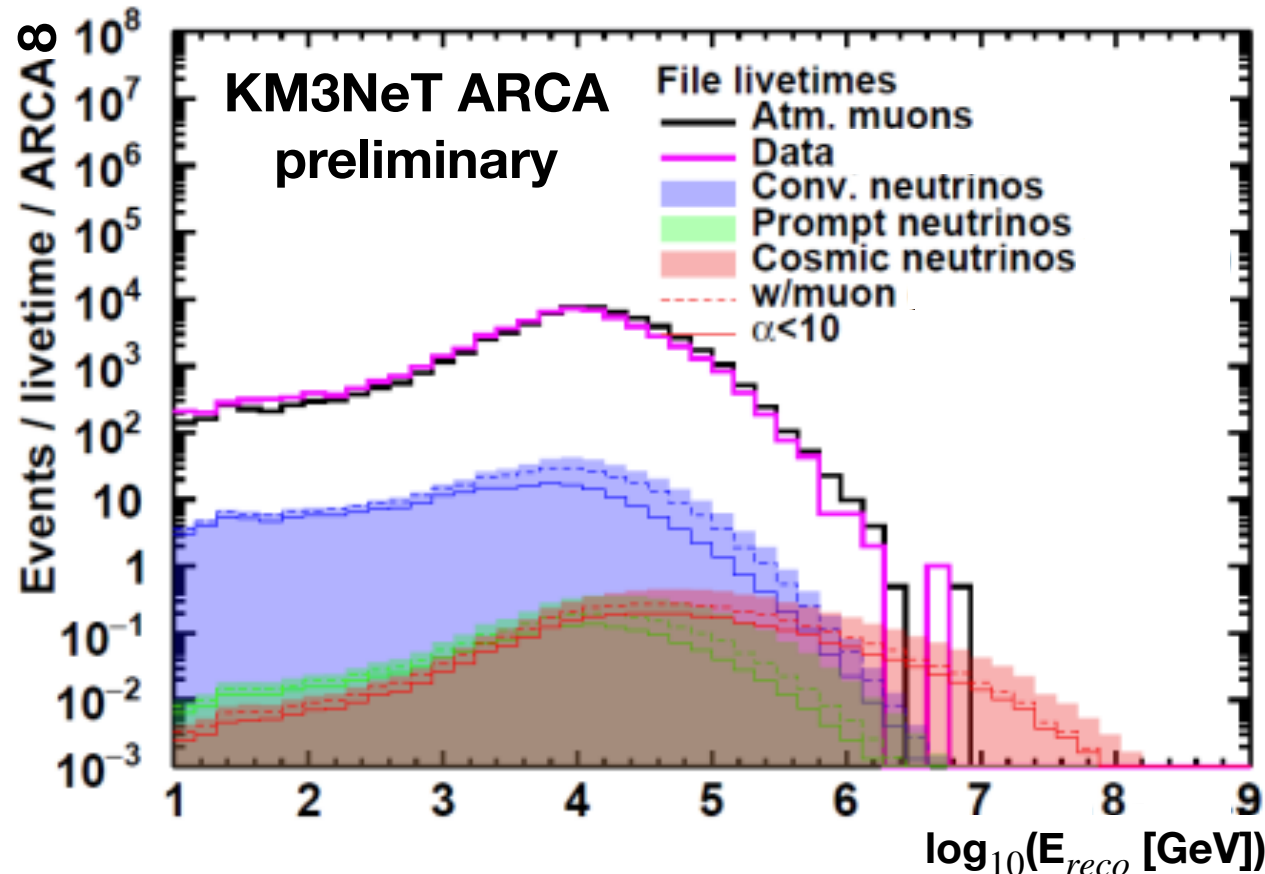
~ 0.6 deg



String tilt in function of time



Data-Monte Carlo comparison



Data and Monte Carlo in good agreement:

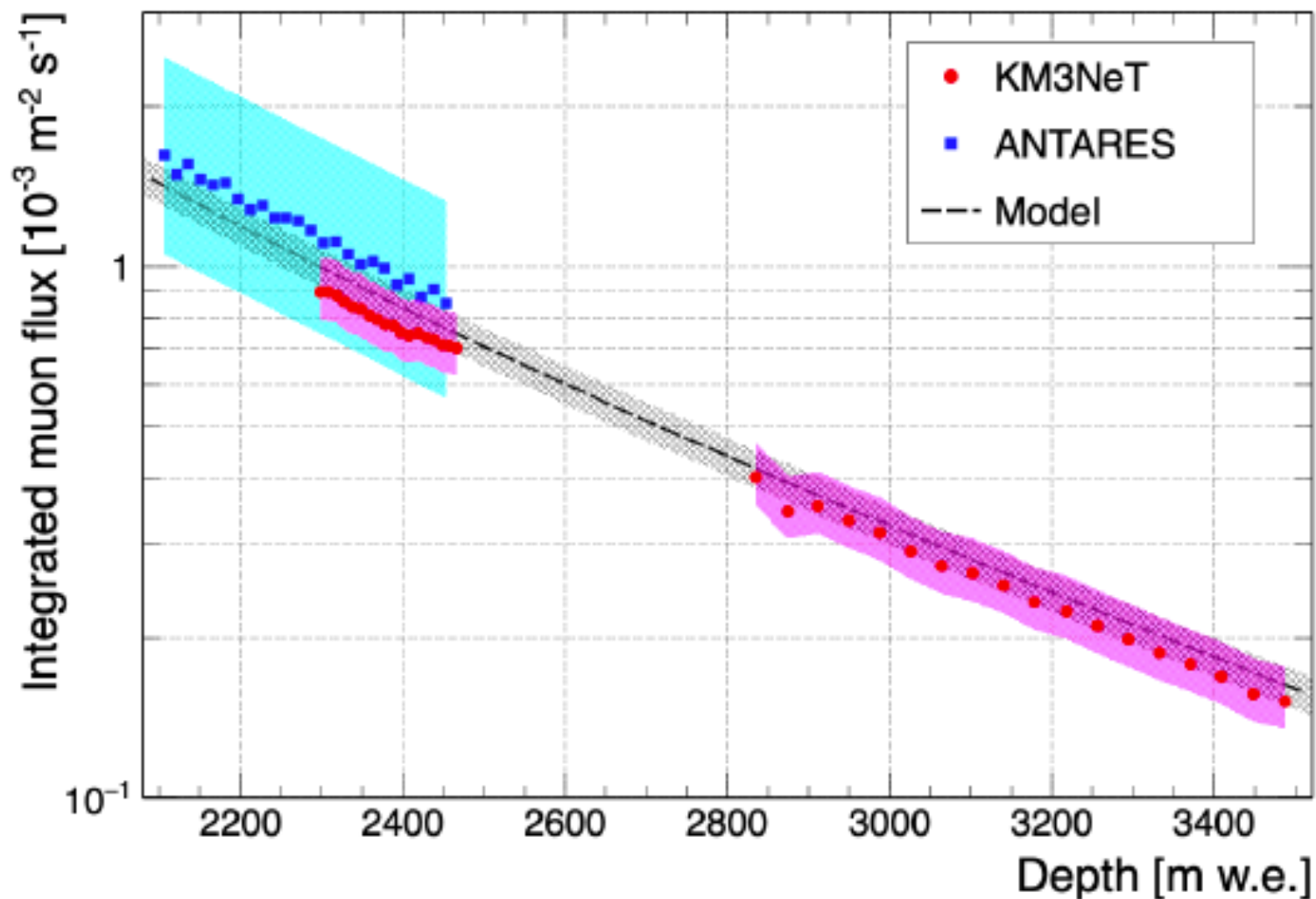
constant development and improves at each new production

Recent updates: mupage tuning, improved track_length determination, string stretching effects taken into account

Event rate for Arca8 after quality and up-going cut (day^{-1}):

- Atmospheric muons: 3.6×10^2
- Atmospheric neutrinos (Honda flux): 3
- E^{-2} cosmic neutrinos: 0.04

First data (Orca1 + Arca2)



First data used for
combined ARCA and ORCA
Depth intensity relation

Atmospheric muon flux
measurement
between 2232 – 3386 m
seawater depth

Data points (purple) in good agreement with the expected
Bugaev atmospheric muon flux (grey line)

[Bugaev et al. , Phys Rev D 58 1998 054001](https://arxiv.org/abs/1908.07401)

This work: <https://link.springer.com/article/10.1140/epjc/s10052-020-7629-z>

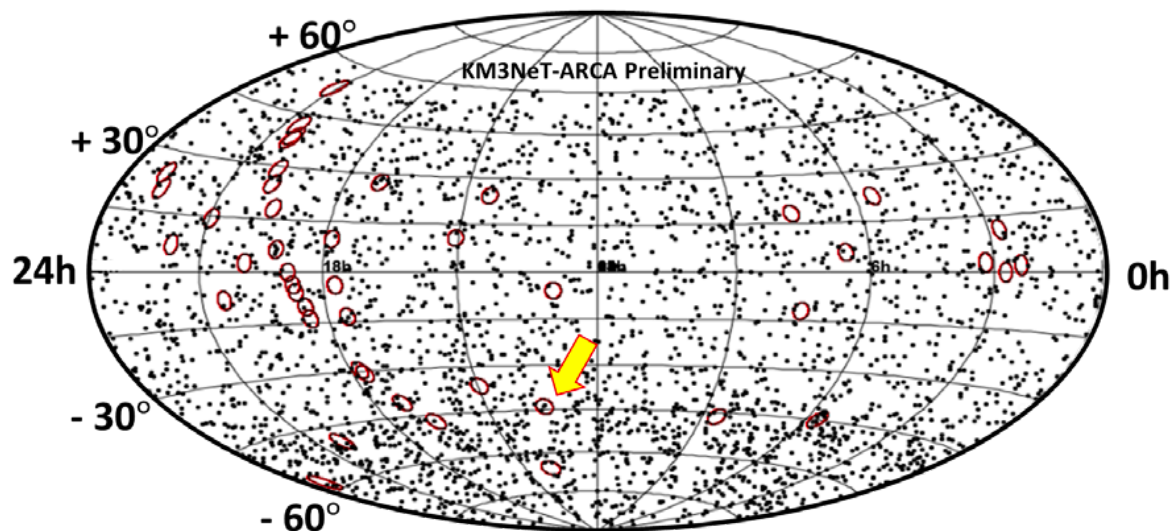
E^{-2} point source study ARCA6

92 days time integrated point like search
for neutrino excess
(May 2021 - September 2021)

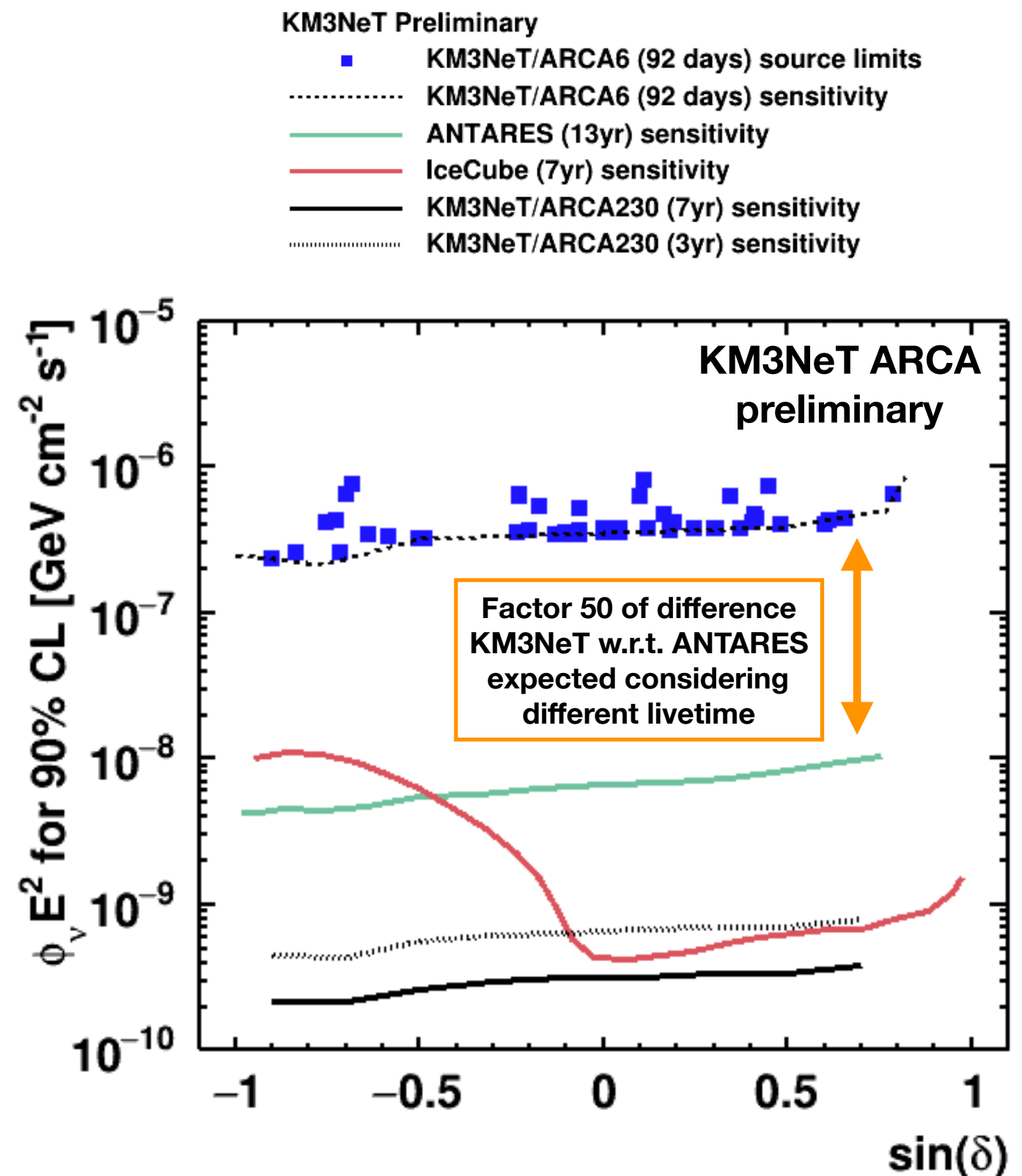
46 selected sources in the catalogue
 E^{-2} spectrum tested for each of them

No strong neutrino emission observed

Smallest p-value (0.02) found around
Centaurus A (yellow arrow in the sky map)
in line with the background expectation



[Poster P0745 @ Neutrino22](#)



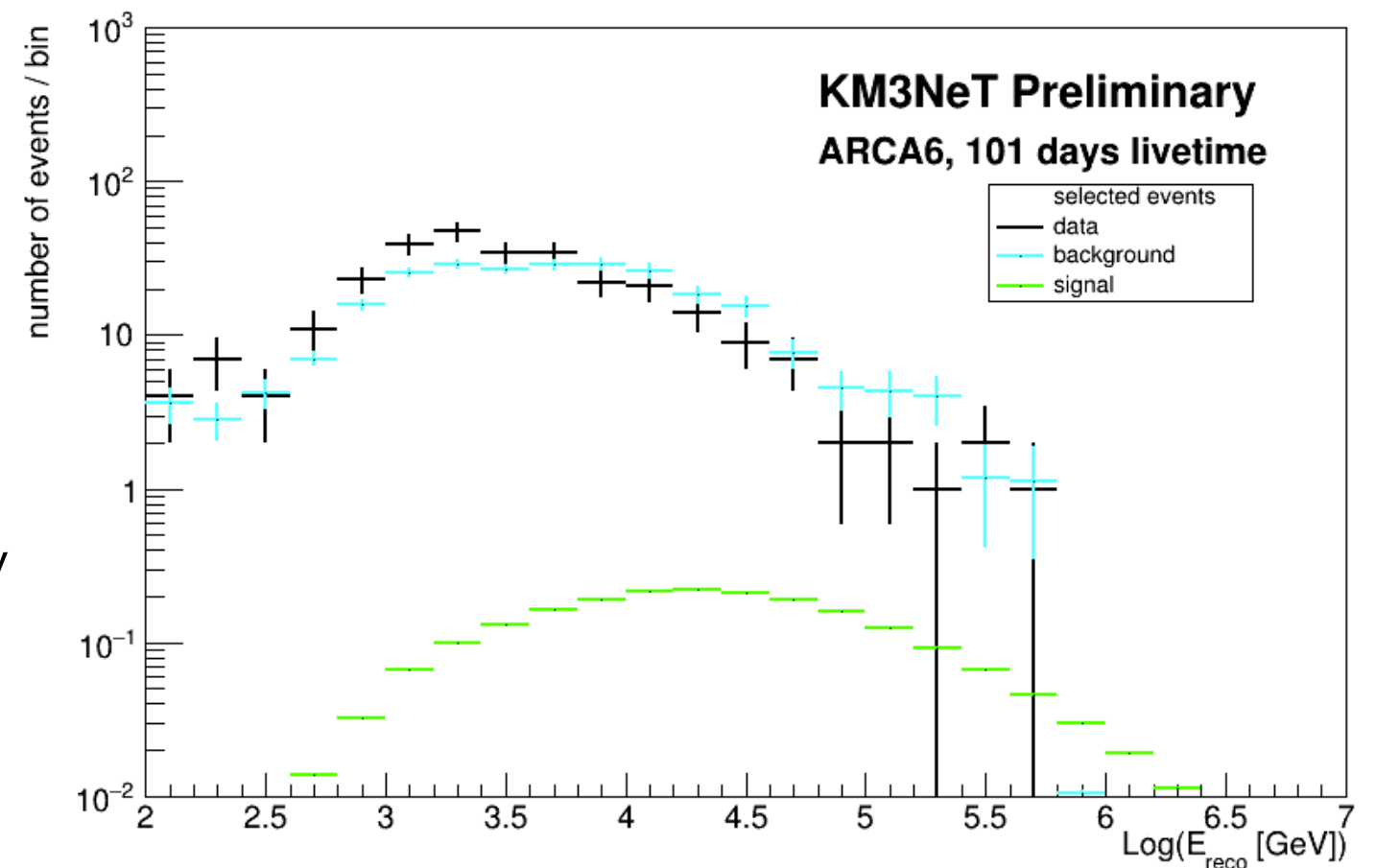
Diffuse ALL-SKY emission ARCA6

All sky search for a **diffuse emission** of astrophysical neutrinos.

Livetime of **101 days**

Multi-variate technique adopted to reduce the atmospheric muon contamination, keeping a high signal efficiency

Final energy distribution shown in the figure



Simulated signal flux taken from [1] :

$$1.44 \times 10^{-18} (E/100 \text{ TeV})^{-2.28} [\text{GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}]$$

Obtained sensitivity for the corresponding flux :

$$17.3 \times 10^{-18} [\text{GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}]$$

[Poster P0173 @ Neutrino22](#)

[1] ICRC 2019: [Measurement of the diffuse astrophysical muon-neutrino spectrum with ten years of IceCube data](#)

Galactic Ridge diffuse emission ARCA6

Search for a **diffuse emission** of astrophysical neutrinos from the **Galactic Ridge** region.

Privileged position of the KM3NeT detectors, looking at the Southern sky, and at the Galactic Centre

ON-OFF analysis performed with **101 days livetime**:

- ON region: $|L_{\text{gal}}| < 40^\circ$ and $|B_{\text{gal}}| < 3^\circ$
- OFF region: shift in time of the ON region, avoiding the Fermi Bubbles, as in [1]

Simulated signal flux:

$$1.2 \times 10^{-8} (E/1\text{GeV})^{-2.4} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$$

NO statistically significant excess found

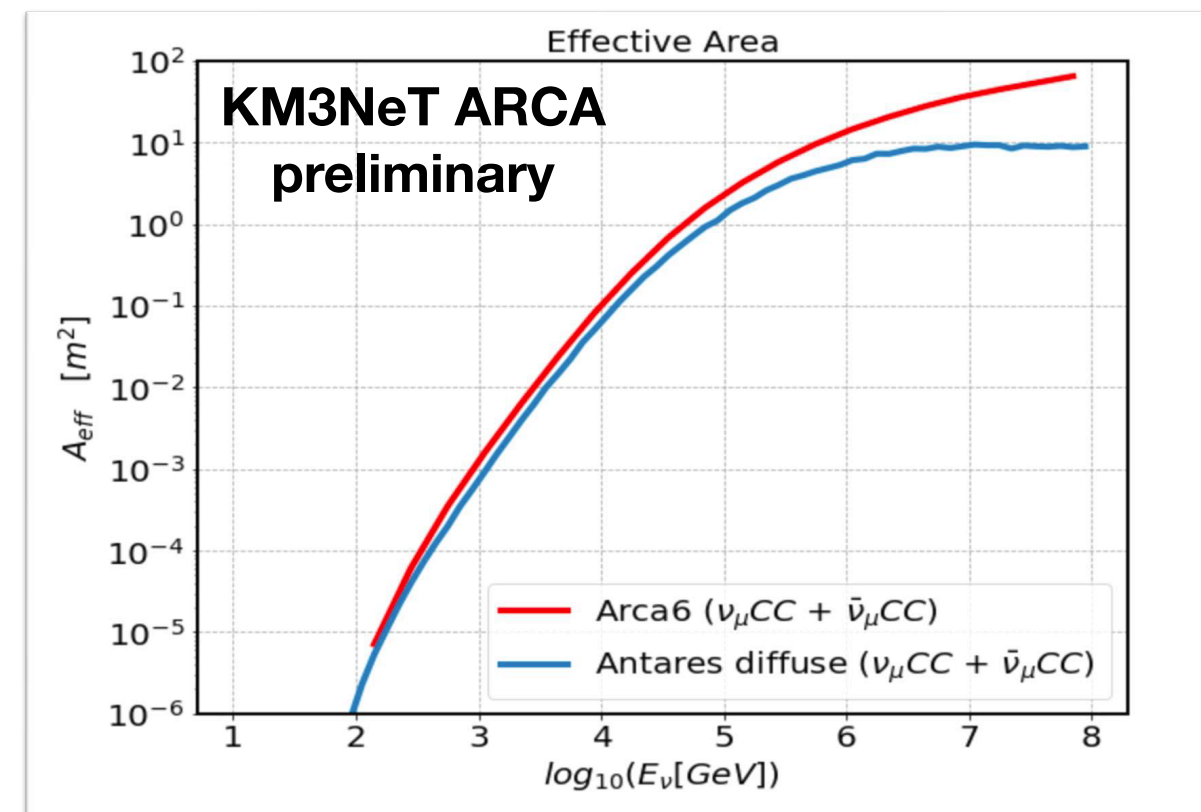
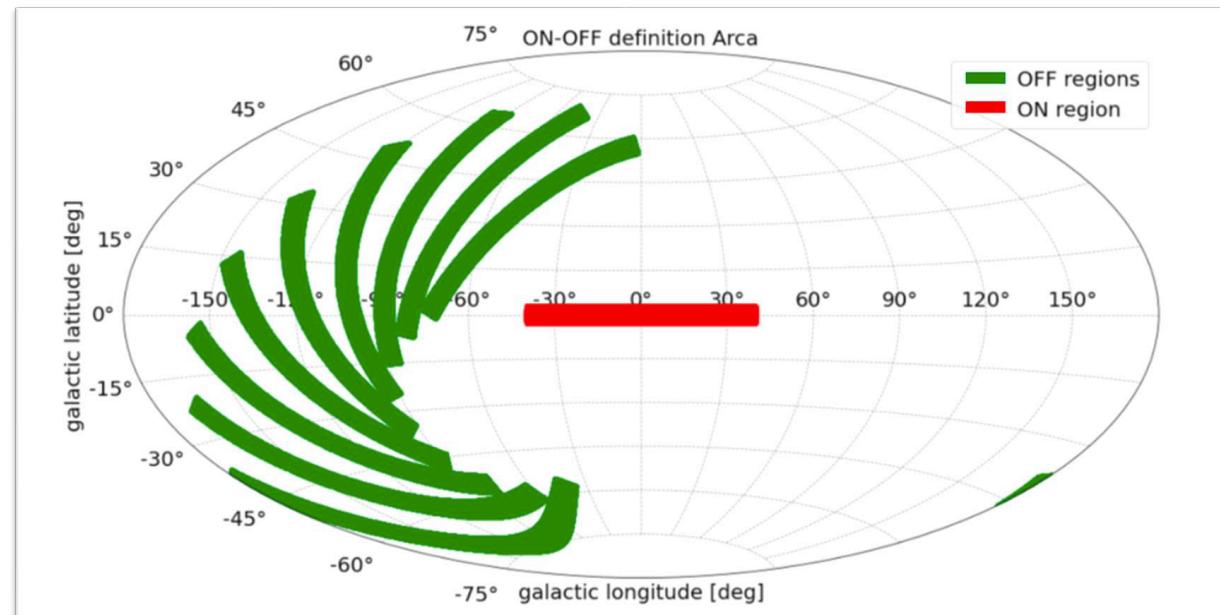
Upper limit (UL) : $6.2 \times 10^{-4} [\text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$

Higher UL respect to what is reported in [1], due to a smaller livetime.

Effective area comparable to ANTARES one

[Poster P0173 @ Neutrino22](#)

[\[1\] Antares ON-OFF galactic ridge analysis](#)



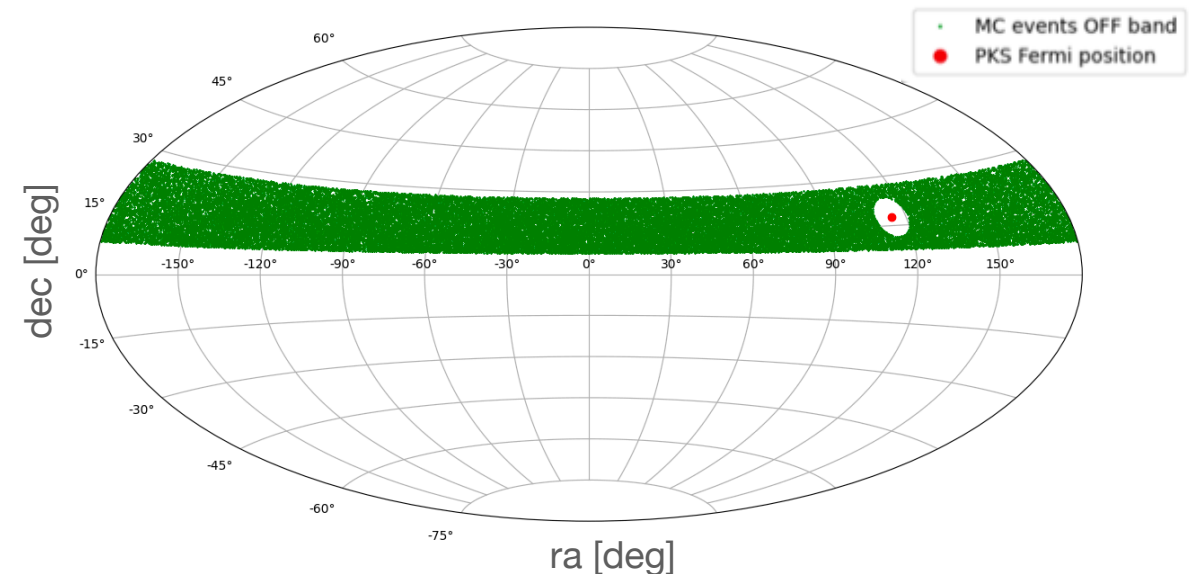
IceCube alert follow-ups (ARCA8 - ORCA 10)

ON - OFF technique used:

- ON region: circular region with optimized ROI
- OFF region: declination band of 10° standard time-window of ± 1 day.

E^{-2} spectrum assumed

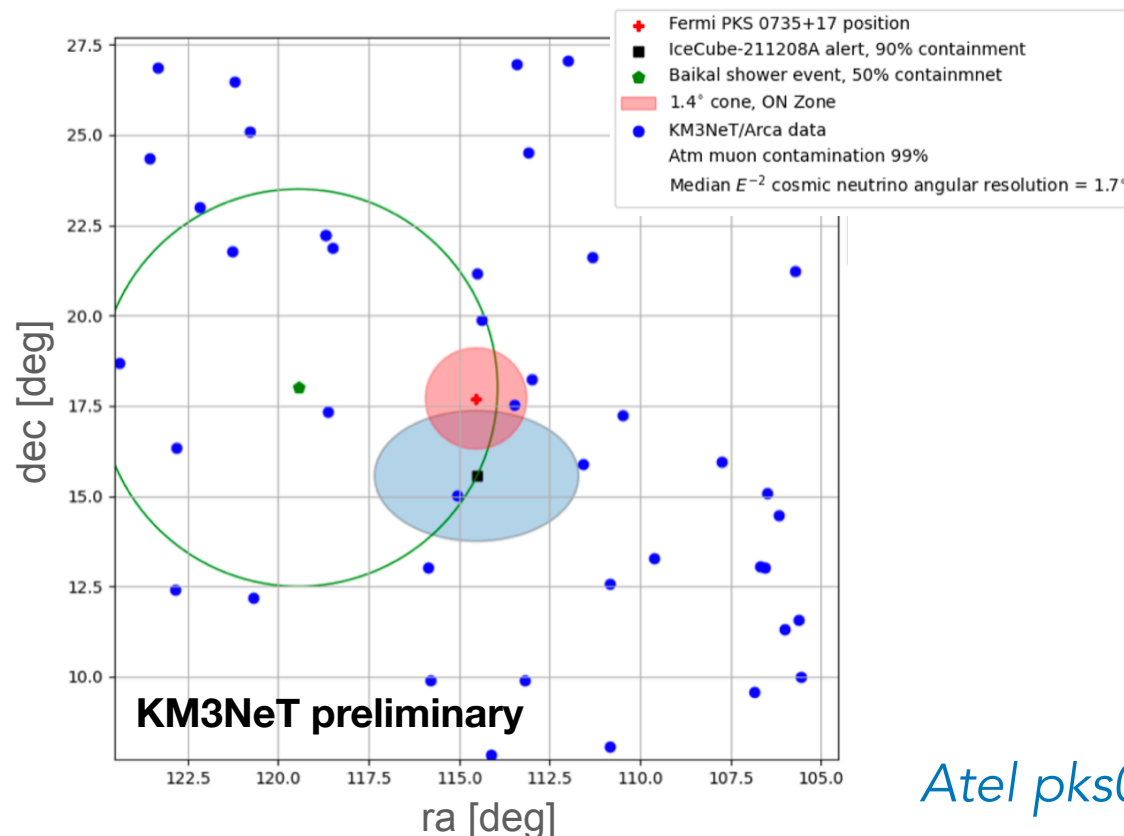
Selection of up-going events



Up to now followed-up IC alerts:

IC211208A (± 1 day), IC211208A (31 days), IC220205B (± 1 day), IC220225A (± 1 day), IC220304A (± 1 day)

Sky map PKS 0735+17 (31 days), 10° cone



For **PKS0735+17** also enlarged time window of 1 month

No significant discovery

Only 1 event found in the 1 month search for PKS0735+17
with $E \sim 18$ TeV
with associated p-value: 0.14

[Poster P0739 @ Neutrino22](#)

[Atel pks0735+17: https://www.astronomerstelegam.org/?read=15290](https://www.astronomerstelegam.org/?read=15290)

ARCA8 on-going analysis

Data analysis quite advanced right now

Arca8 Livetime available ~ 234 days

(End of September 2021 - End of May 2022)

Several new improvement introduced respect to Arca6 (dynamic calibration, mupage tuning, reconstruction improvements)

PLAN to updated Arca6 analysis:

- PS searches
- Diffuse all sky analysis
- Galactic ridge analysis

Ready soon

New analysis pipeline under development

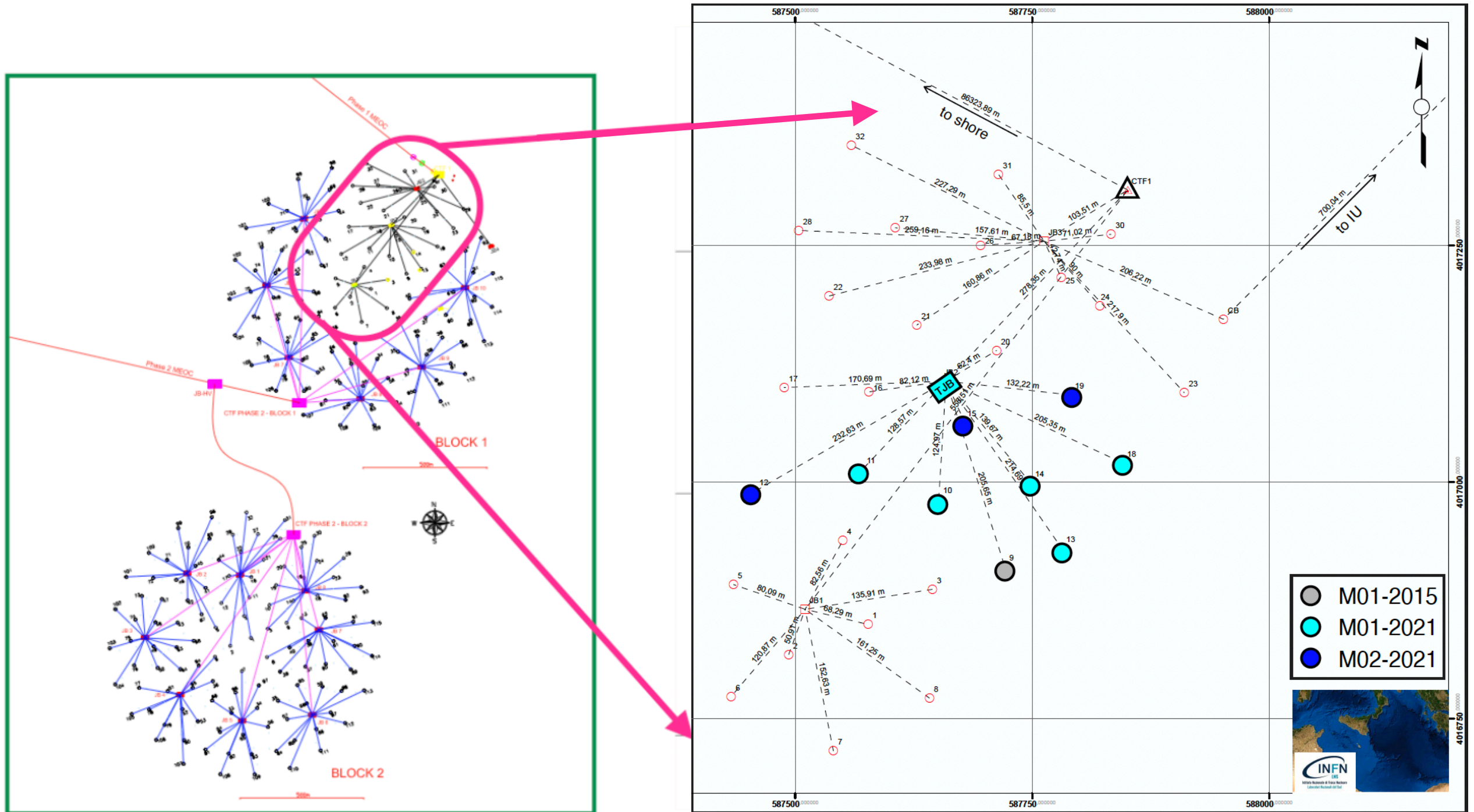
Stacking analysis

(Catalog used : Fermi 4LAC)

Transient likelihood analysis

From Arca8 to Arca19 and Arca21

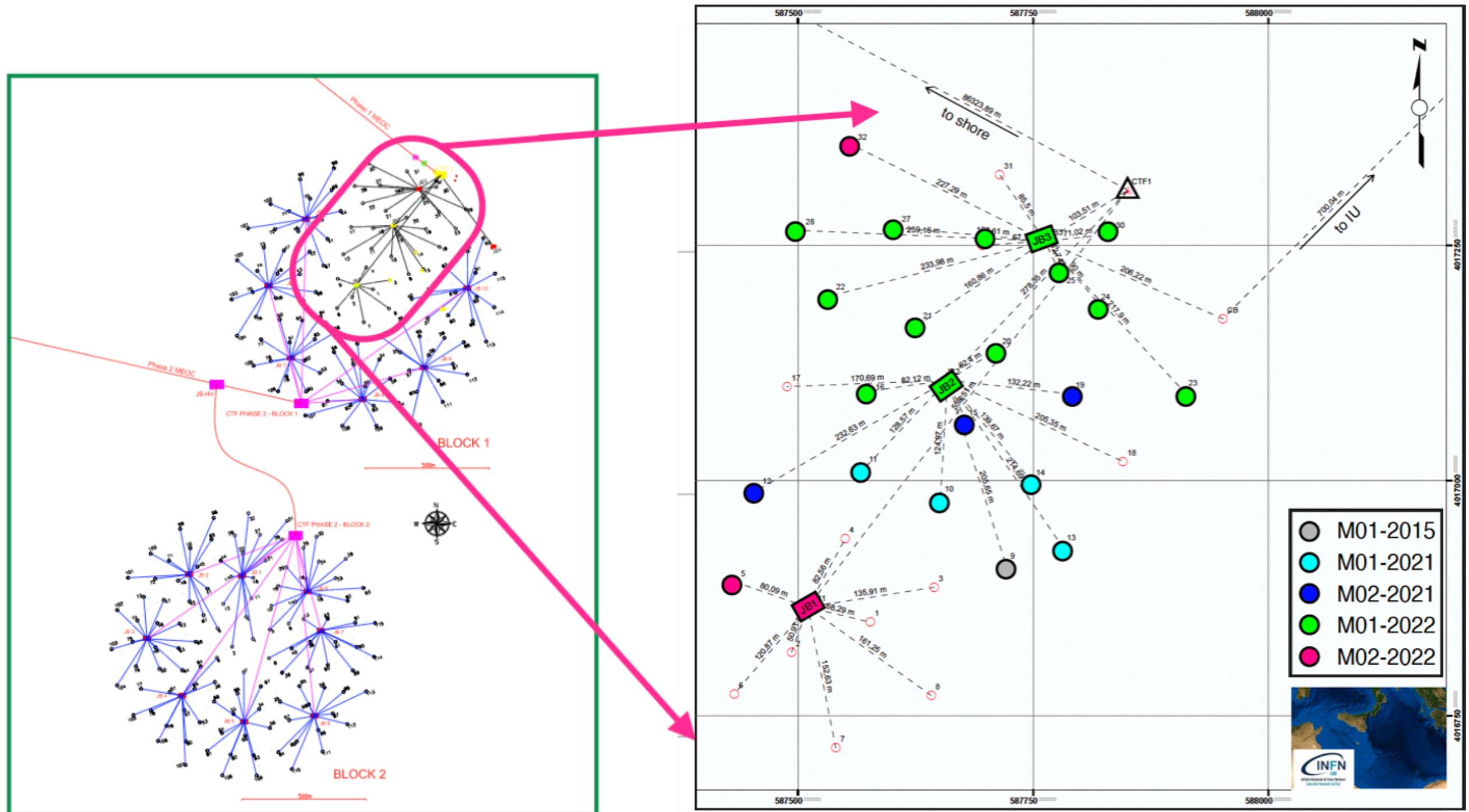
ARCA8 detector footprint



Phase-1 completion = 32 Detection Units

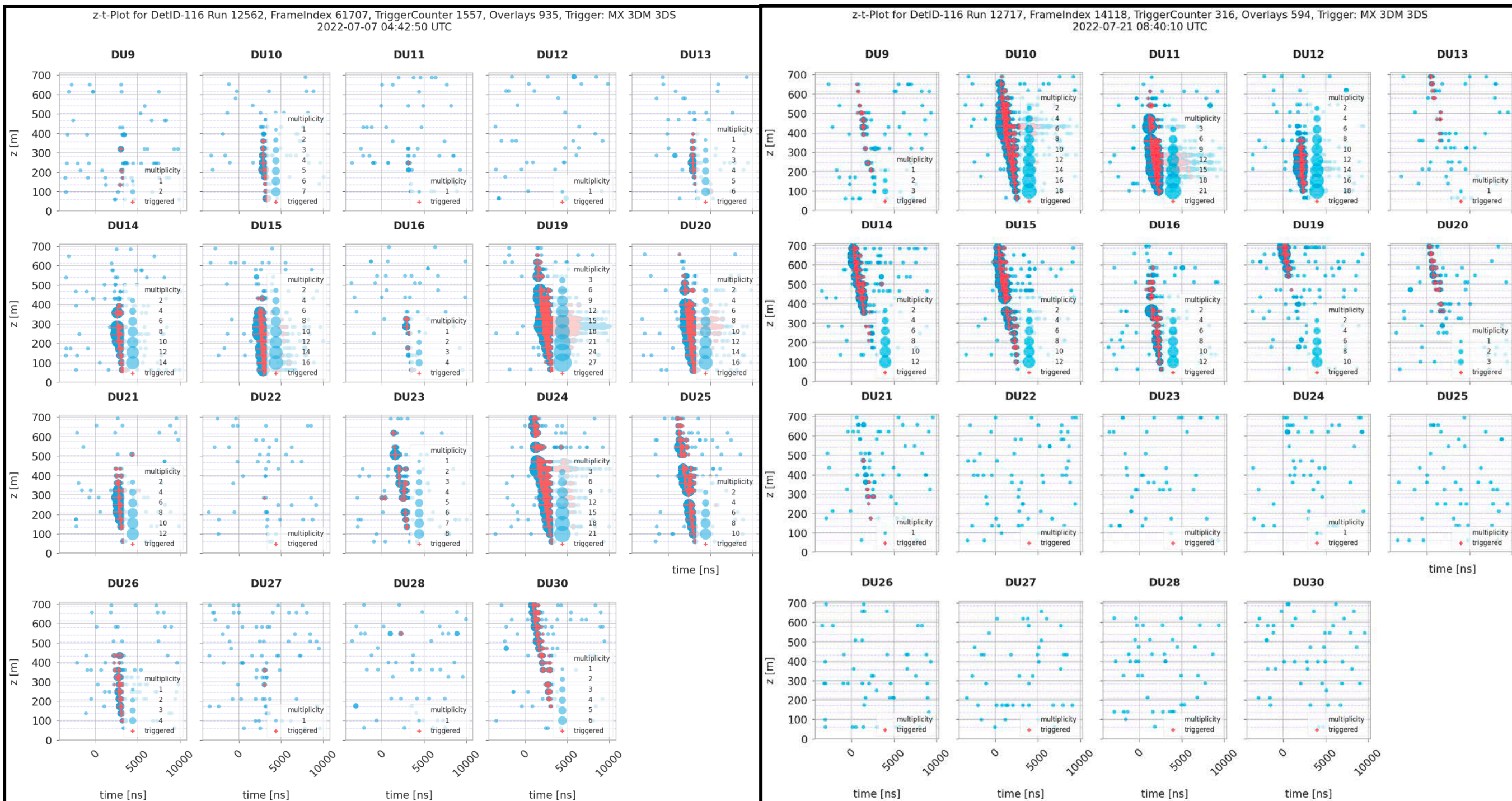
From Arca8 to Arca19 and Arca21

ARCA21 detector footprint



Selected triggered events

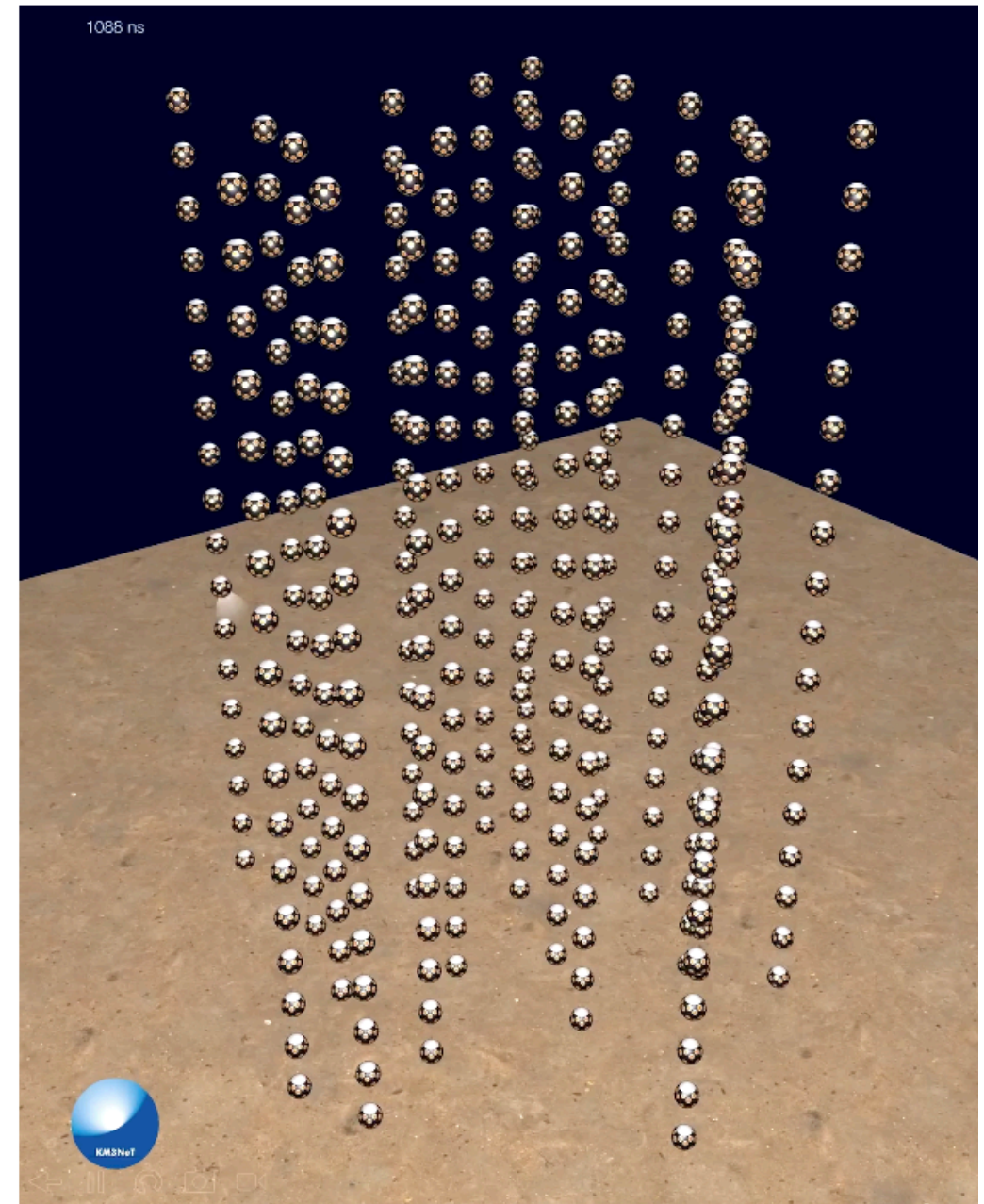
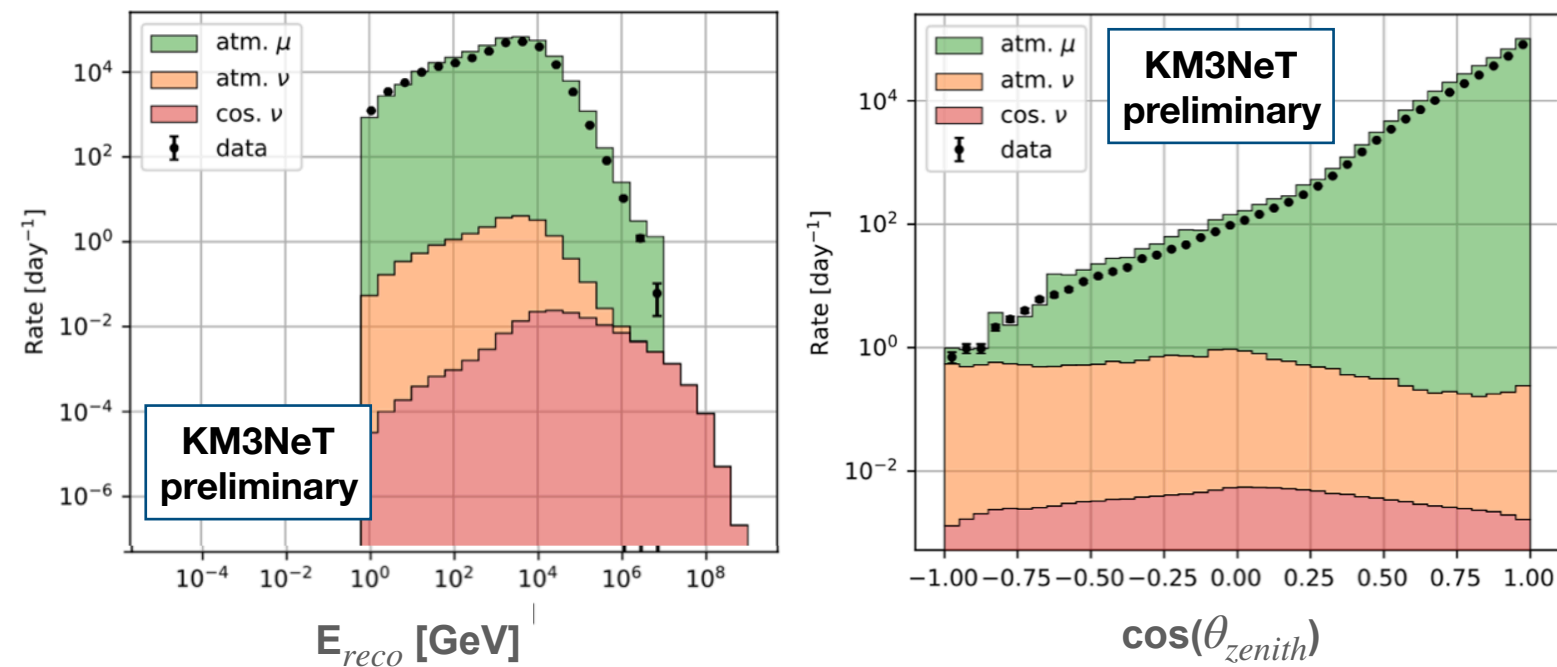
Selected triggered events for Arca19 detector:
height-time plot of hit distribution for each detection unit



ARCA19 data

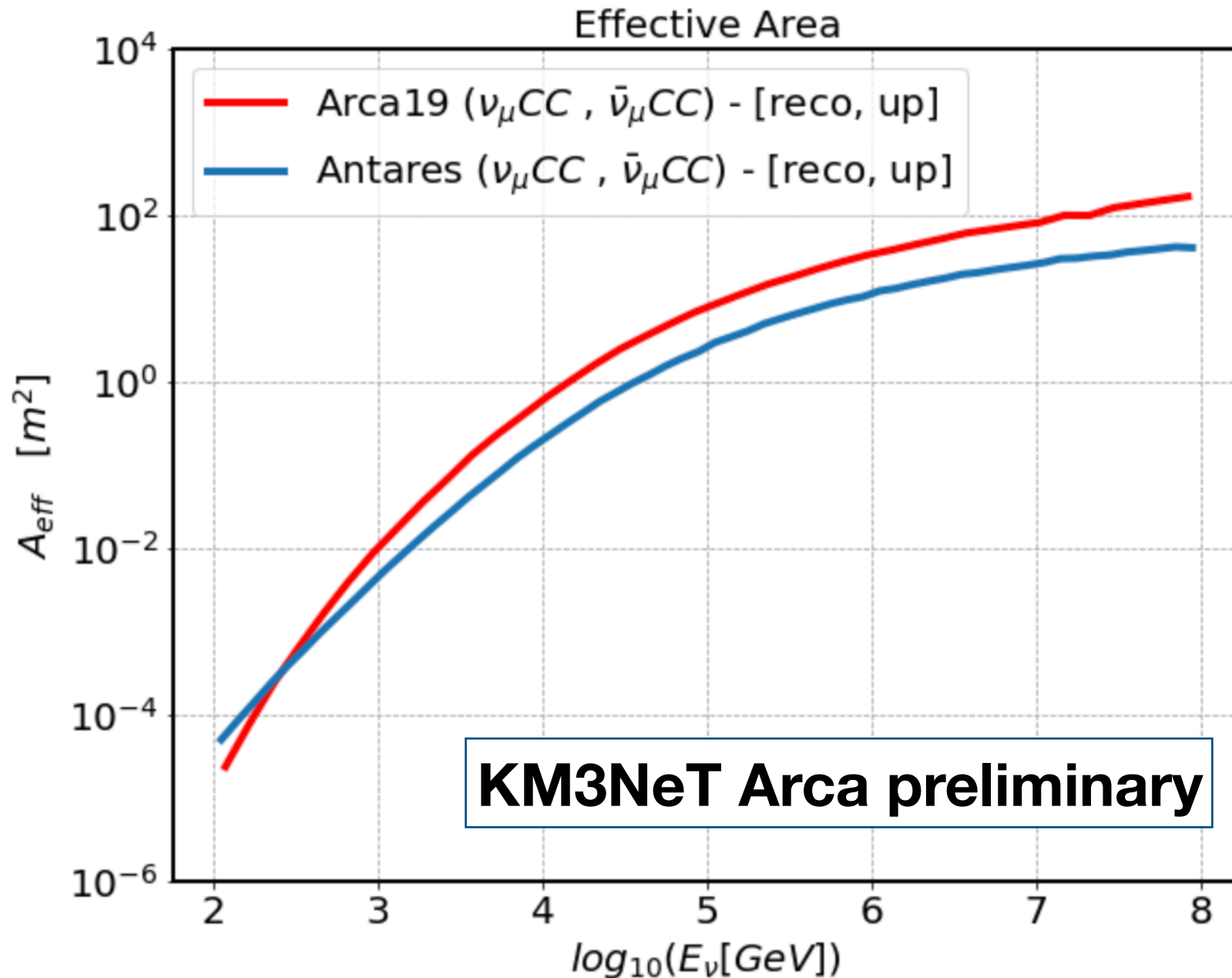
Since end of June, **Arca19 string configuration:**
great enlargement of instrumented volume

**Data have started to be analyzed
soon after the end of the commissioning phase**



New exciting results soon

ARCA19 effective area



PRESENT Arca19/21
effective Area
compared to Antares:
x3 time higher

Same selection applied:
reco, up-going cut

GRB 221009A follow-up (ARCA21 - ORCA 10)

Exceptional event:

- One of the brightest long GRB ever detected;
- GCN #32632: Swift-BAT detection. 14:10:17 UT. RA: 288.263° DEC: +19.803° (3-arcmin uncertainty);
- GCN #32636: Fermi-GBM detection. 13:16:59.0 UT. RA: 290.4° DEC: +22.3° (1-degree uncertainty);
- GCN #32677: LHAASO detected photons up to 18 TeV ~2000 s after the GRB trigger time (higher energy ever detected from a GRB);
- GRB ATel #15656: Fermi-LAT reports photons up to 99 GeV ~240 s after GBM time trigger (higher energy ever detected by Fermi-LAT);
- More than 40 GCN entries only in the 3 days after the alert.

1. Low energy (MeV) analysis KM3NeT/Arca and

Orca: considered as an unique detector

Post-trial: pvalue = 0.9

→ **NO SIGNIFICANT DETECTION**

KM3NeT GCN Circular 32741: <https://gcn.gsfc.nasa.gov/gcn/gcn3/32741.gcn3>

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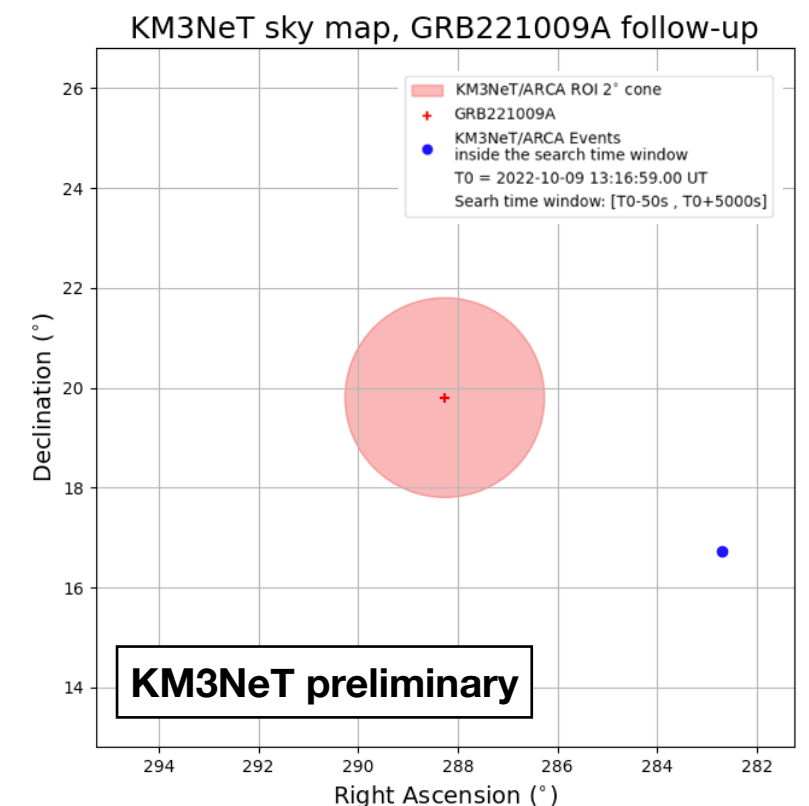
→ **NO SIGNIFICANT DETECTION**

2. Follow-up (GeV-PeV) KM3NeT/Arca - KM3NeT/Orca

Online processing makes use of preliminary calibrations and alignment

No events found in the signal region

More elaborated analysis on-going



KM3NeT GCN Circular 32741: <https://gcn.gsfc.nasa.gov/gcn/gcn3/32741.gcn3>

Conclusions and outlook

Analysis pipelines implemented and ready to be re-applied on new datasets;

Sensitivity and upper limits produced mainly affected by limited livetime;

Still some work to do, but learned a lot on detector, simulations, calibrations and on data;

Exciting and promising results we will be soon ready from Arca19 and Arca21 data

Thanks for your attention!

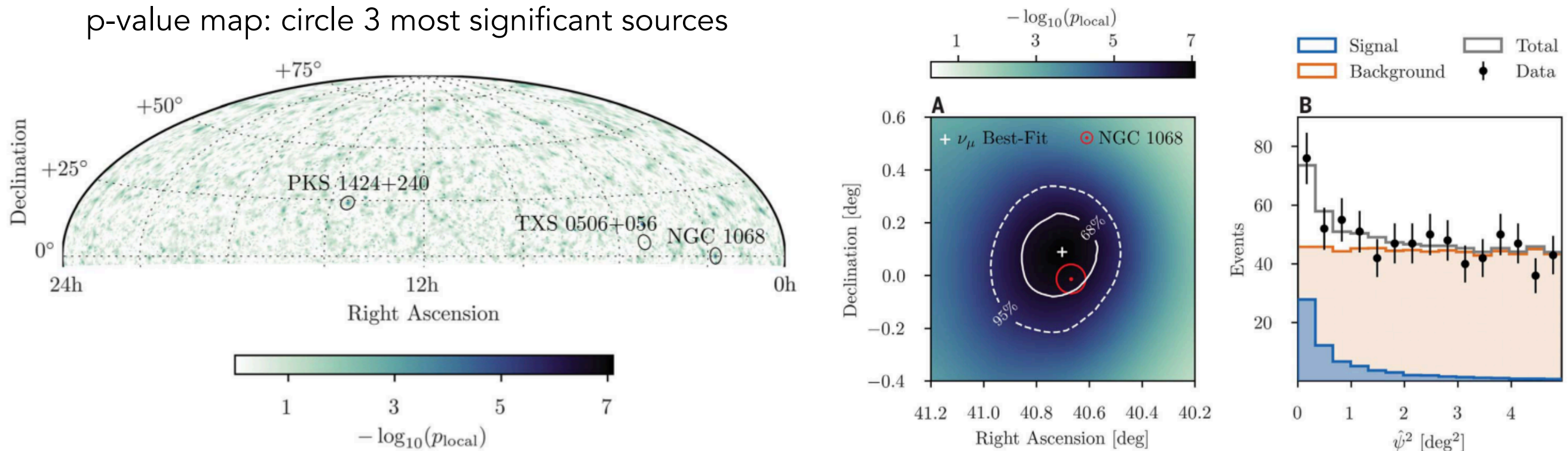
NGC 1068

Announced on a dedicated seminar by IceCube collaboration
(article available on Science: [here](#))

Evidence for neutrino emission from the nearby active galaxy NGC 1068

Excess of 79 events with a significance of 4.2σ

p-value map: circle 3 most significant sources

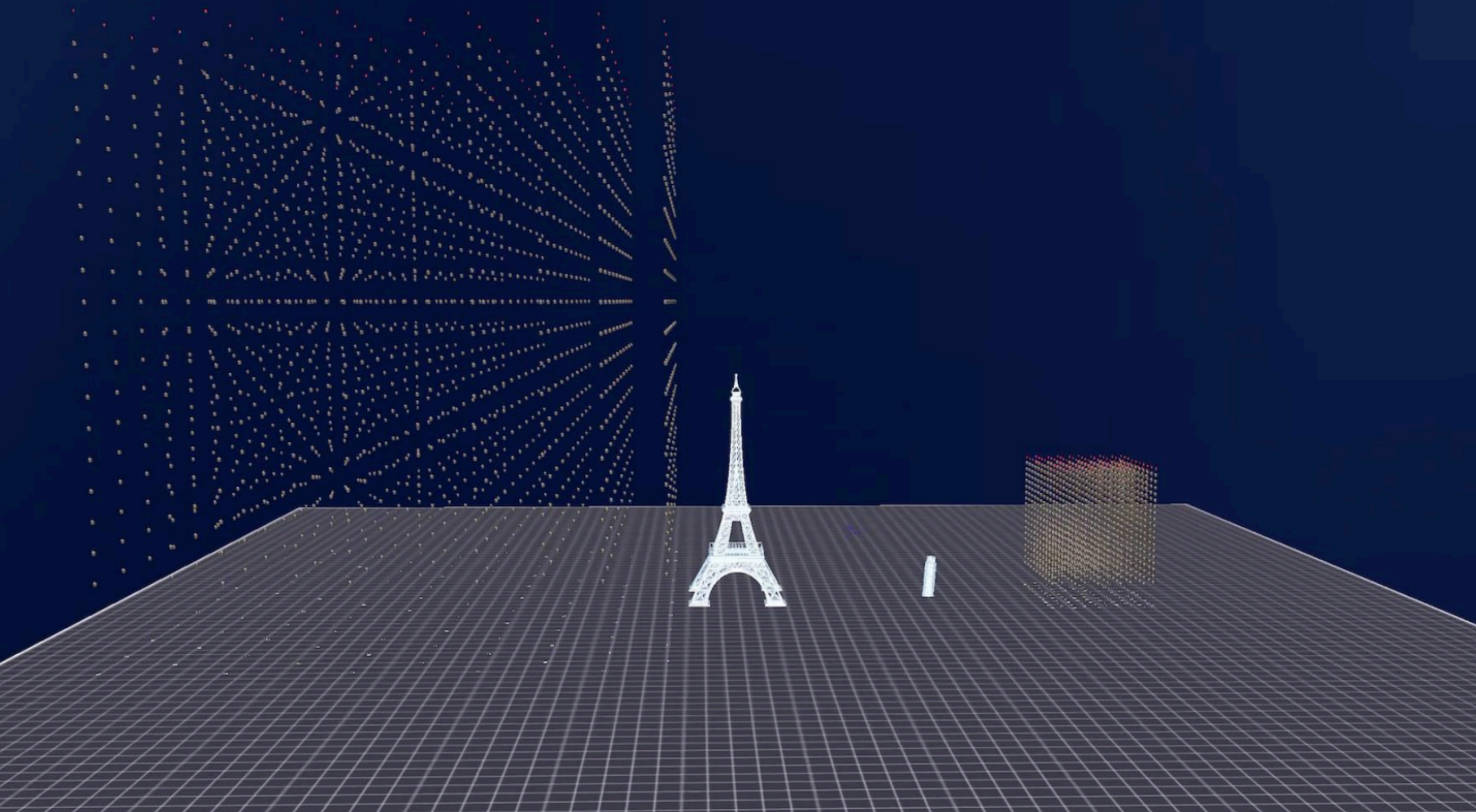


NGC1068 already included in the catalogue of point-like searches for **ANTARES** (latest limit [here](#)) and **KM3NeT/ARCA6** → **both analysis will be updated soon**

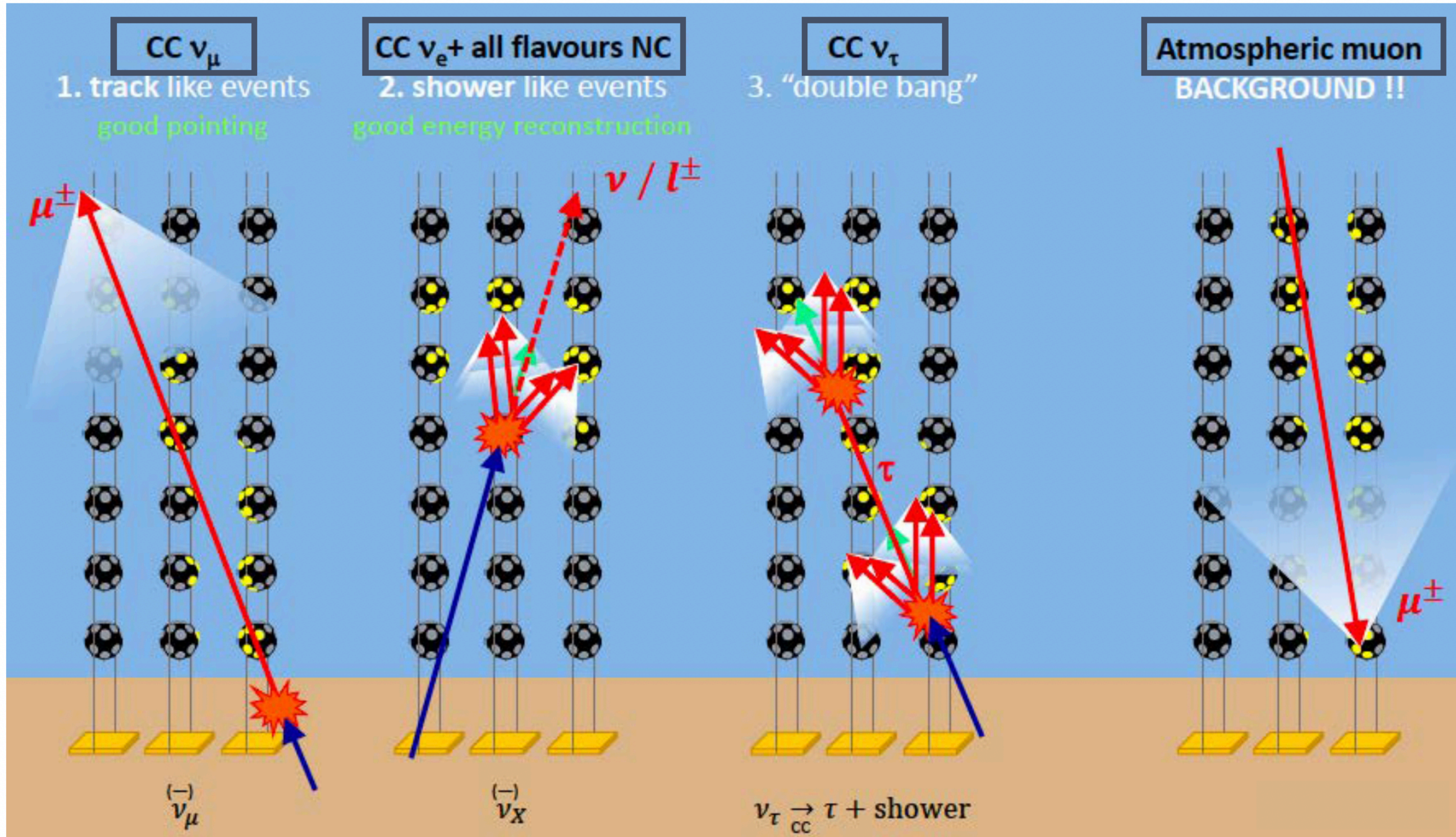
Promising and exciting future for neutrino astronomy!

Backup slides

KM3NeT: ARCA and ORCA



Neutrino event topologies

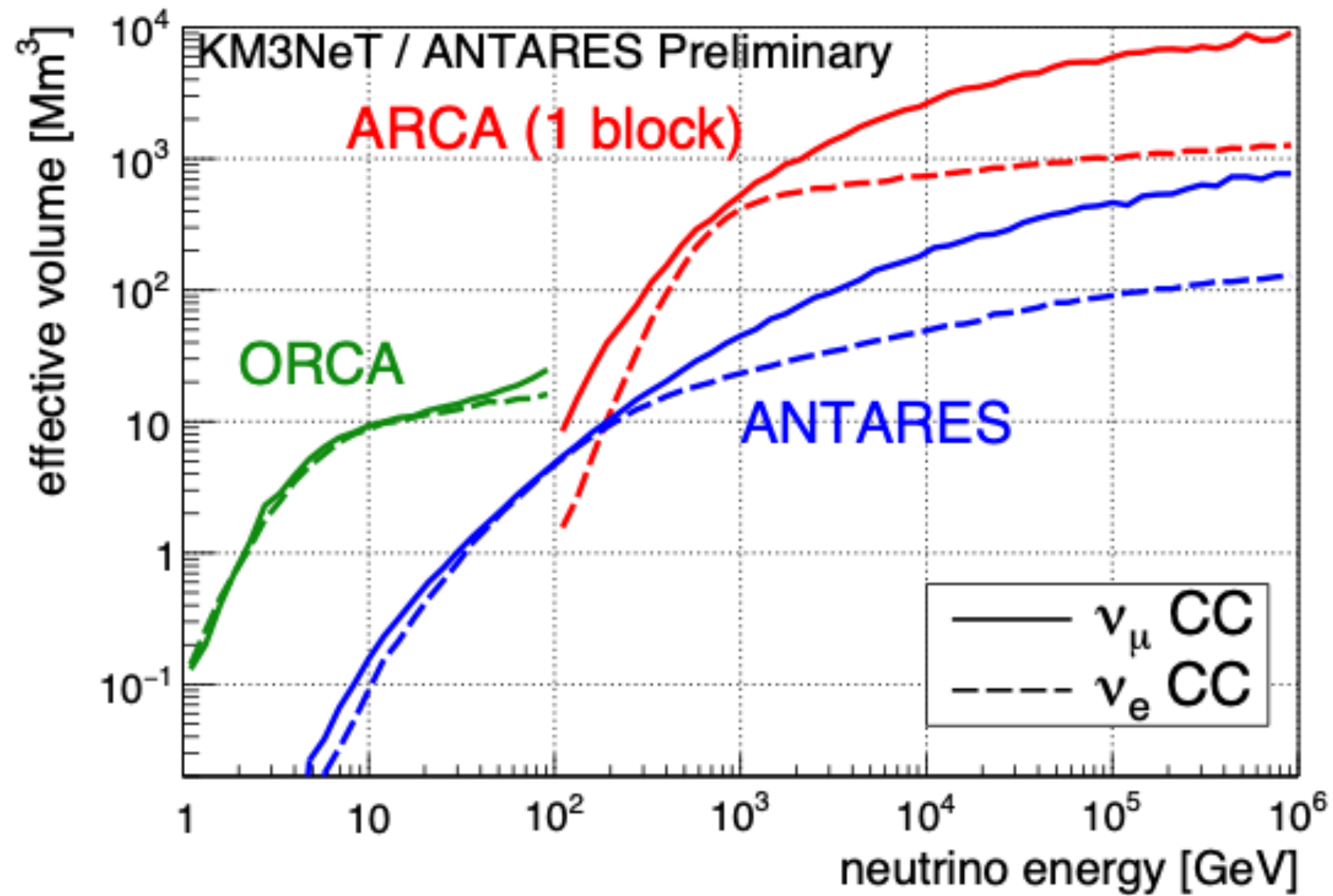


Tracks

Showers

Background

KM3NeT/ARCA and ORCA 1 block Effective Volume

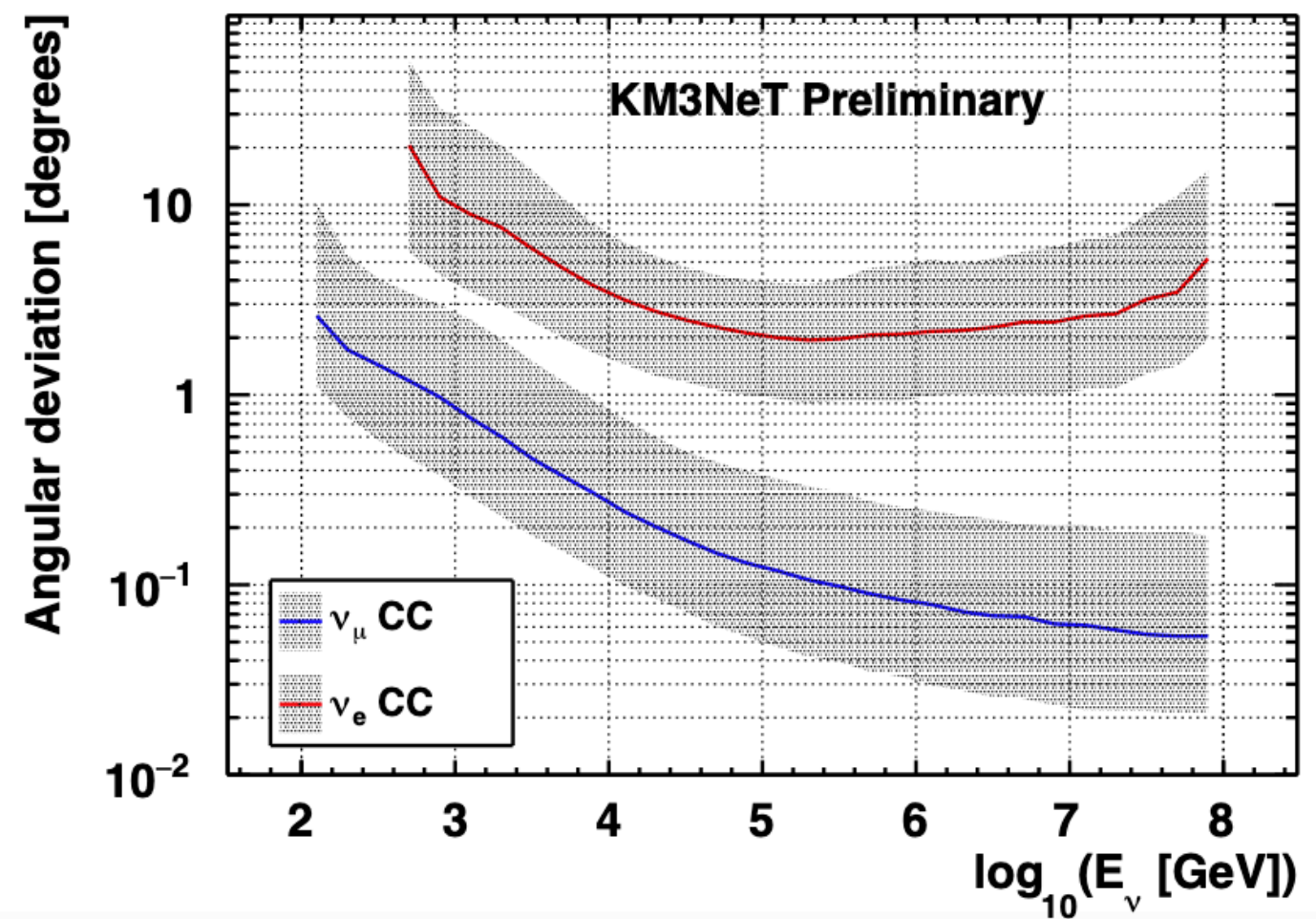


KM3NeT/ARCA

Angular Resolution

Taken from [Neutrino 2022](#)

- Median angular resolution reaches
 - 0.06° for tracks
 - 2° for cascades



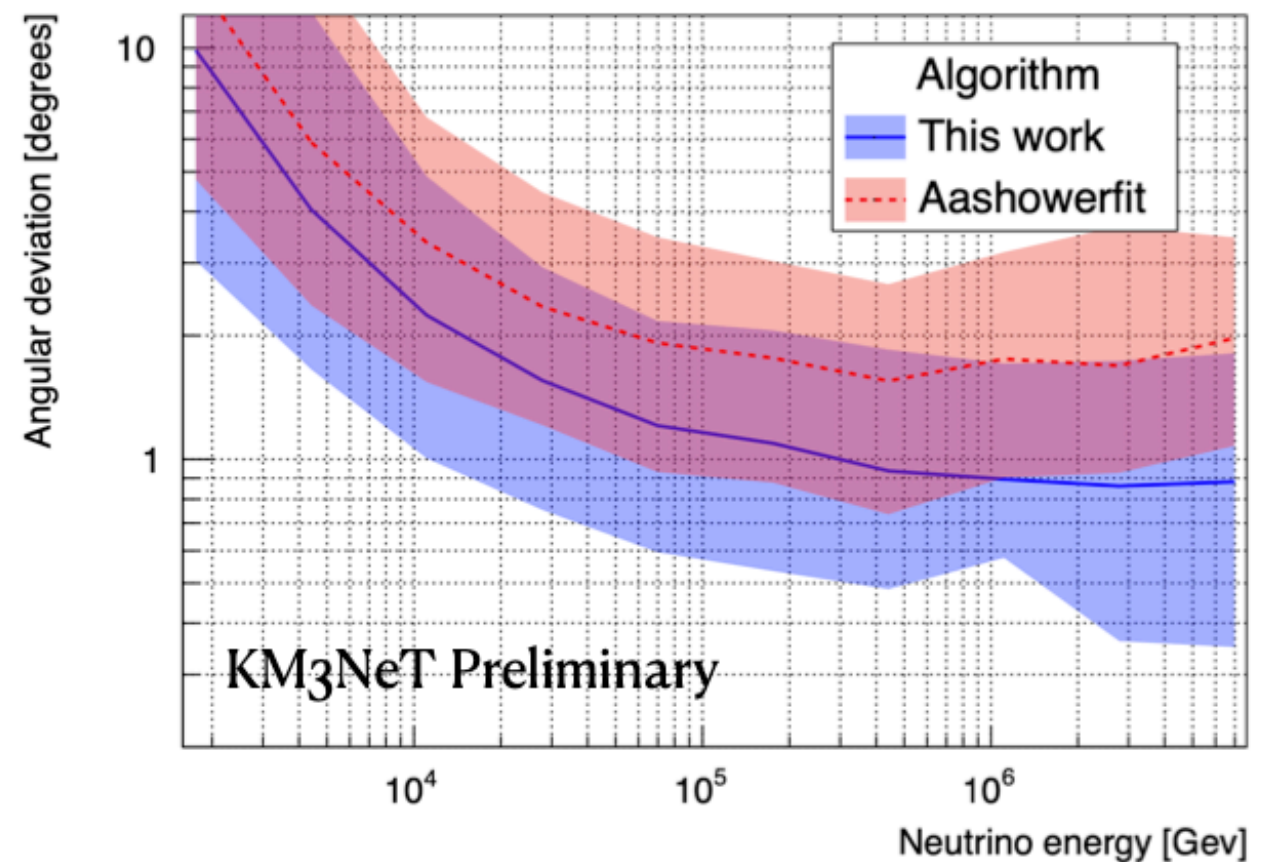
KM3NeT/ARCA

Improved cascade reconstruction

Aashowerfit: standard cascade reconstruction

- Elongated cascade model
 - Includes hit time information in direction reconstruction
 - Lever-arm effect
- Sub-degree resolution expected for the full detector

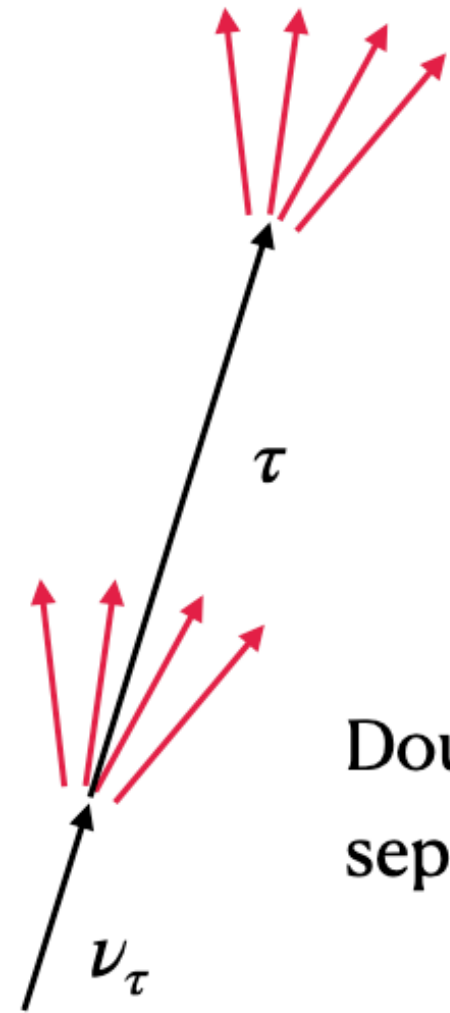
Taken from [arXiv:2205.02641](https://arxiv.org/abs/2205.02641)



KM3NeT/ARCA

Double cascade reconstruction

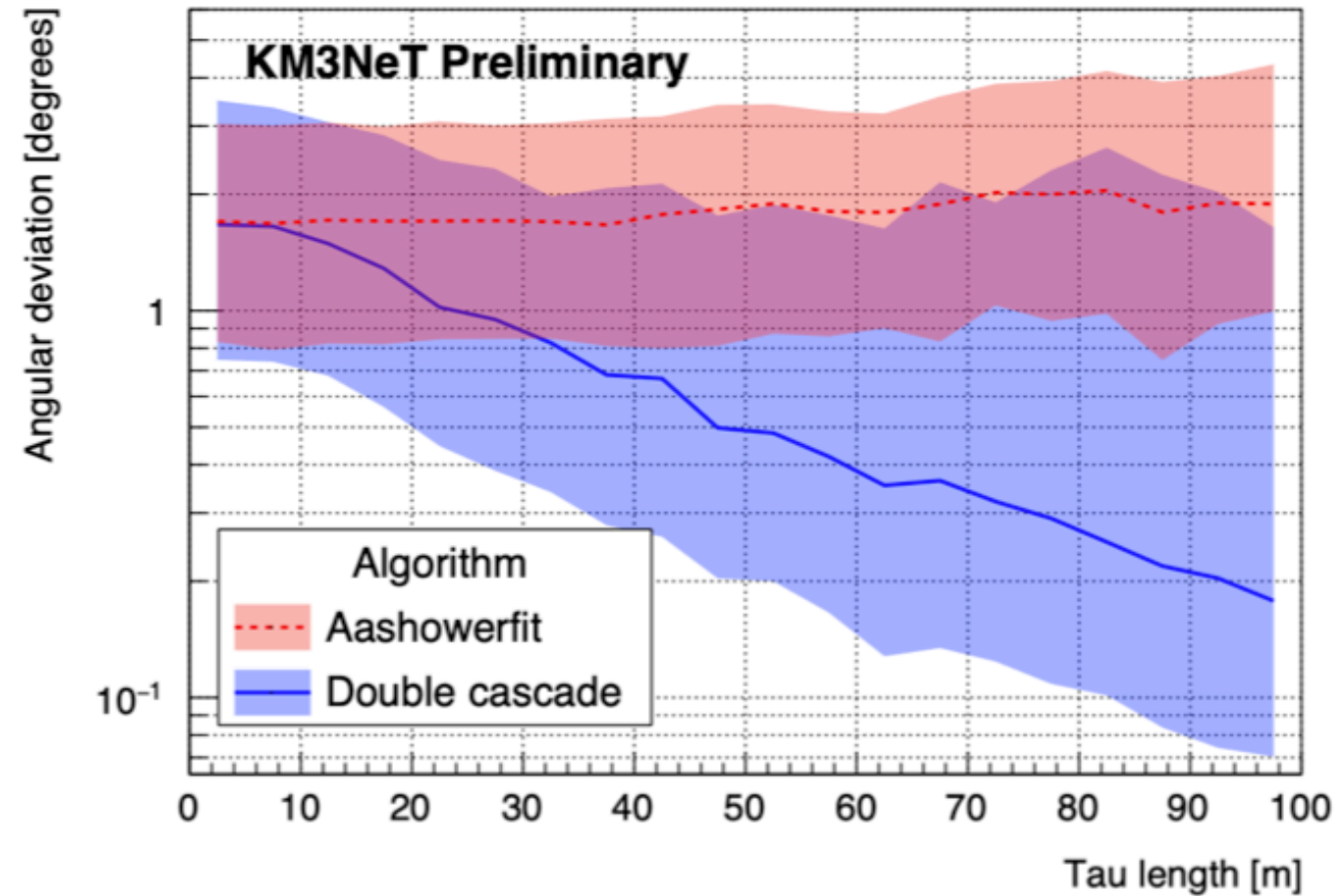
Aashowerfit: standard cascade reconstruction



Double cascade model separated by τ flight distance

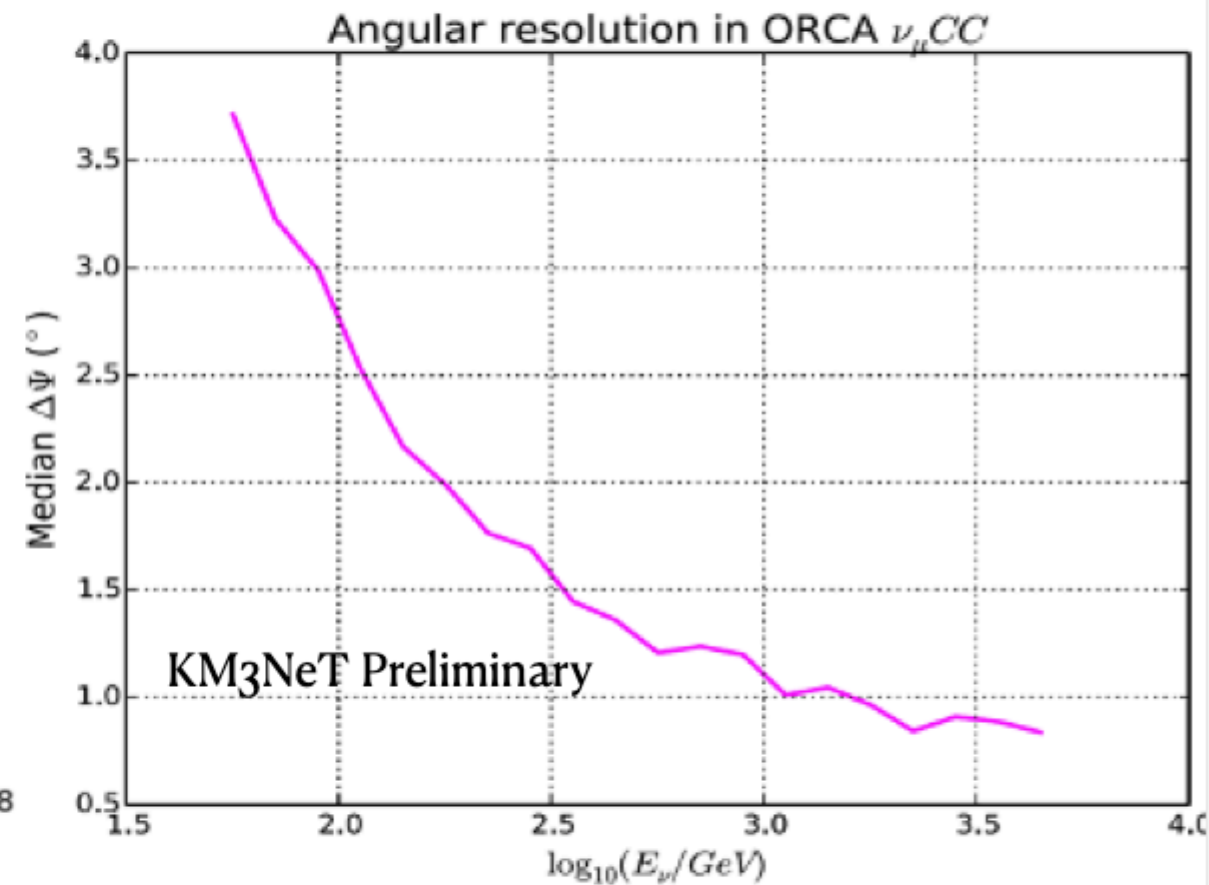
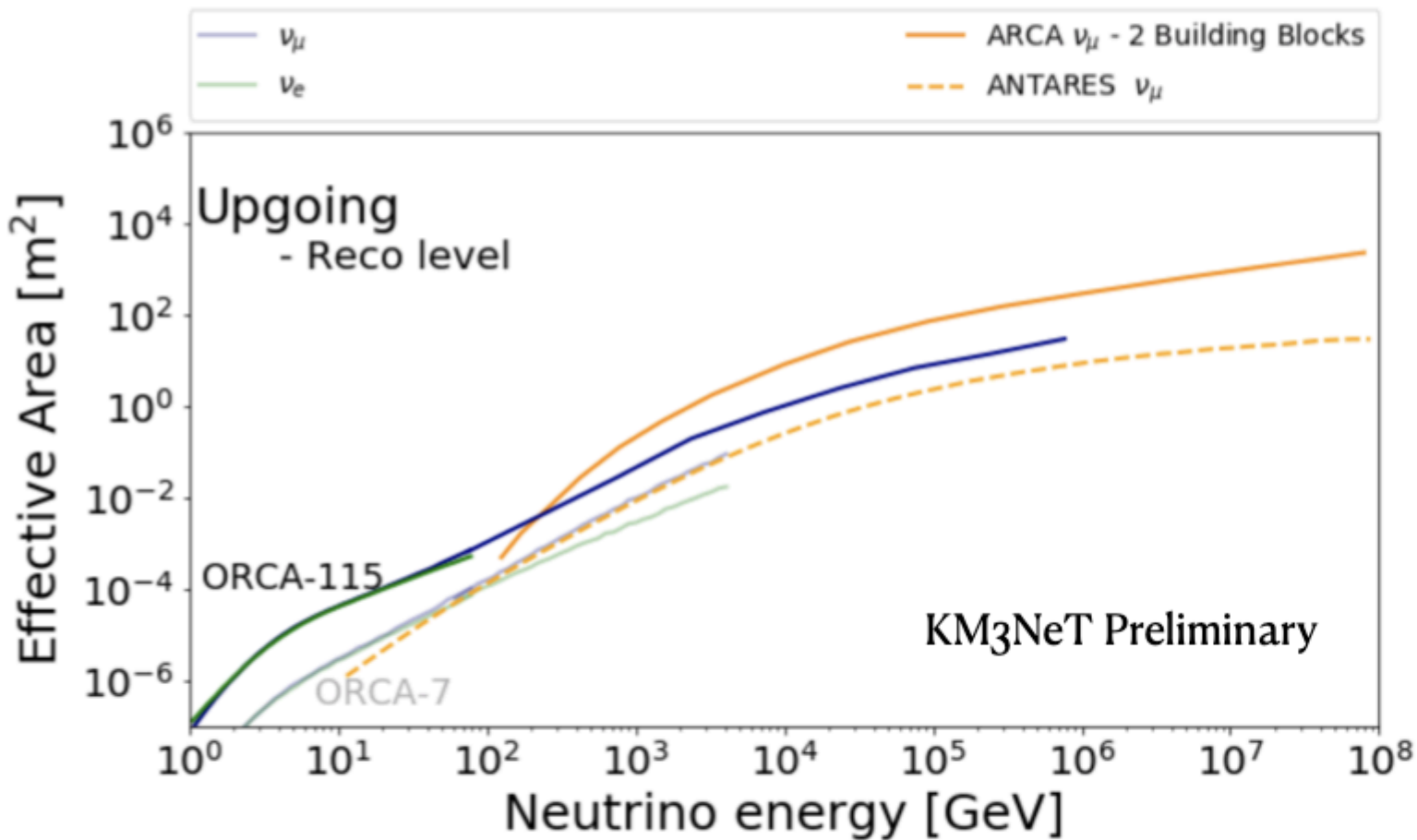
Separation between cascades provides extra lever arm effect

Taken from [arXiv:2205.02641](https://arxiv.org/abs/2205.02641)



KM3NeT/ORCA

Performance at high-energy

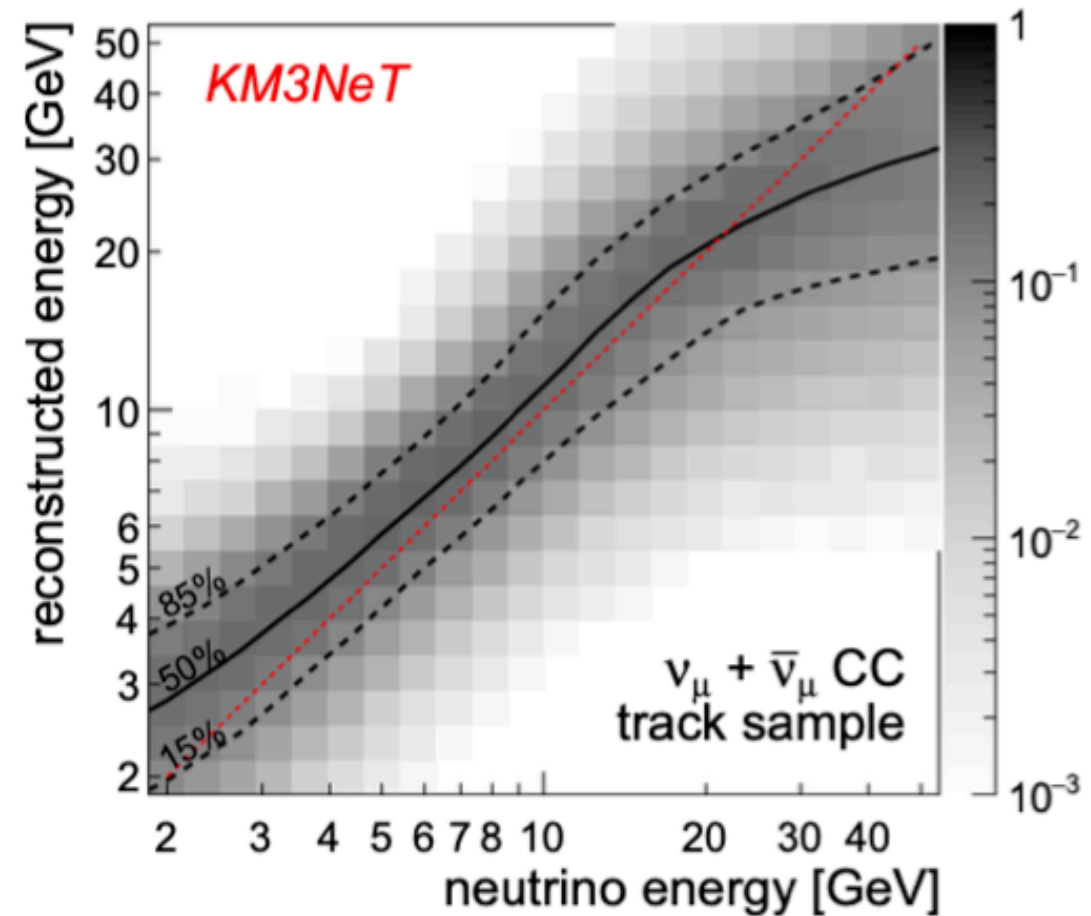
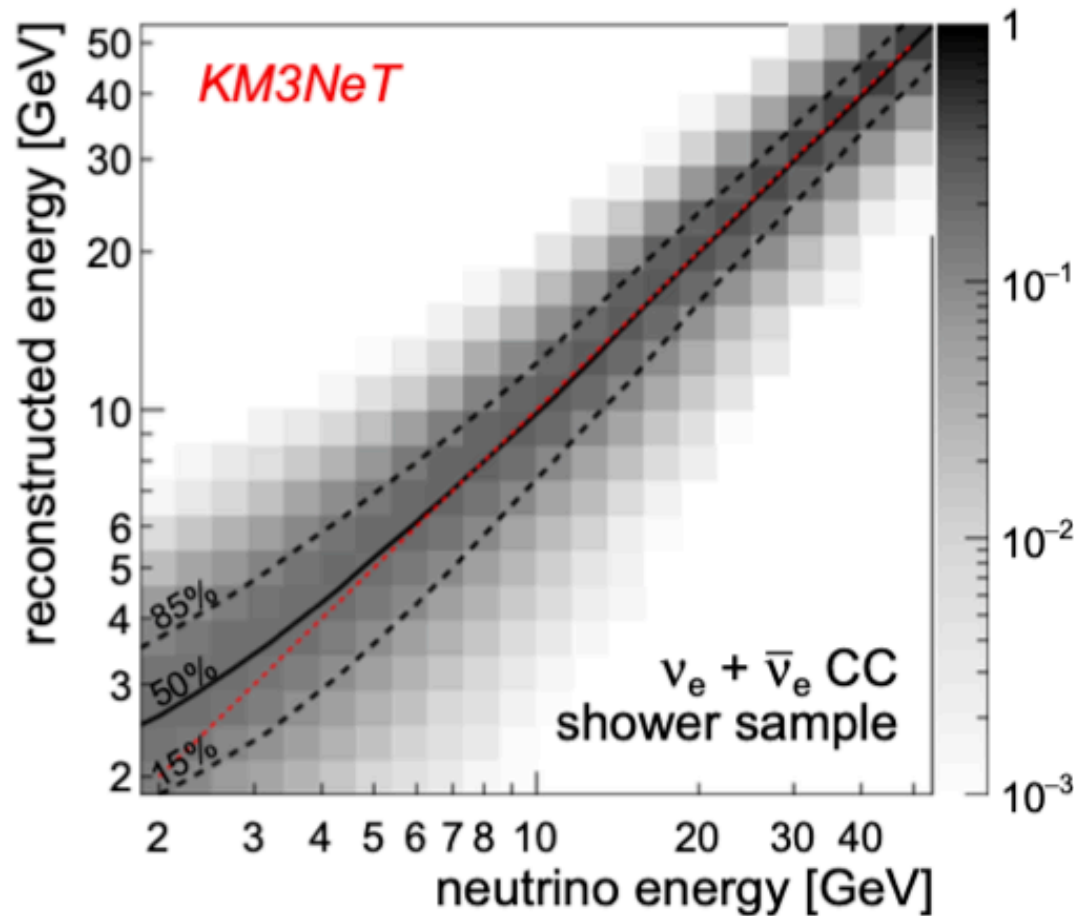


Current ORCA detector (11 lines) and 115 lines also sensitive at higher energies: follow ups!

KM3NeT/ORCA

Energy resolution

[The European Physical Journal C 82.1 \(2022\): 1-16](#)



$\Delta E/E$ at $E_\nu = 10$ GeV

$\nu_e/\bar{\nu}_e$ CC = 25 % , $\nu_\mu/\bar{\nu}_\mu$ CC = 35 %