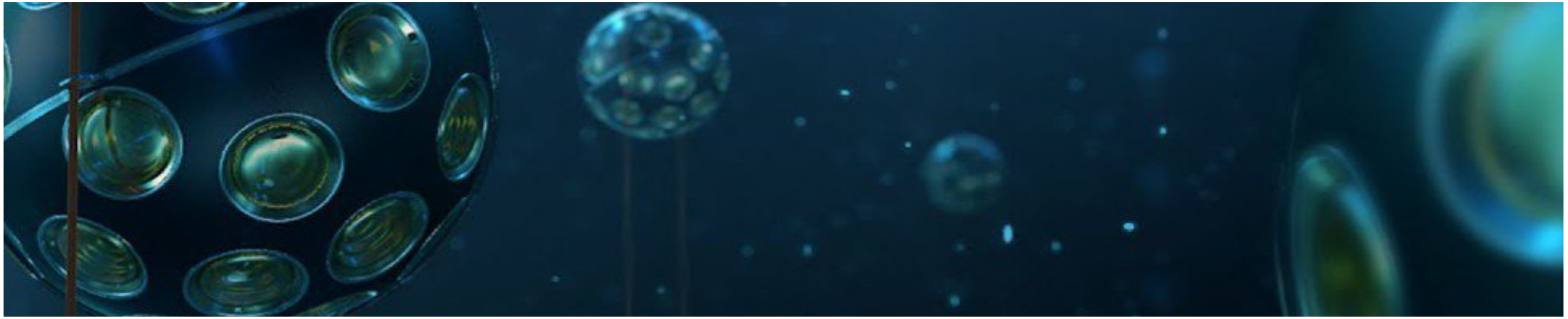


Very-High Energy event detected by KM3NeT/ARCA

Assemblea di sezione di fine anno - INFN Bologna

Francesco Filippini
on behalf of the KM3NeT/Bo team

INFN
Istituto Nazionale di Fisica Nucleare

francesco.filippini@bo.infn.it

ANTARES
KM3NeT

KM3NeT-Bo group presentation

Nome	Ruolo	Attività principale
F. Benfenati	Tecnologo TD PNRR PhD - 37° ciclo	DAQ - Laboratorio BLU Analisi dati
F. Carenini	PhD - 38° ciclo	Analisi dati - Calibrazioni temporali
P. Castaldi	PA UniBO - Ingegnere	Calibrazioni - posizionamento acustico
T. Chiarusi	Primo ric. INFN	**Coord. DAQ** - Analisi dati
F. Filippini	Post – doc INFN	RAMS (Reliability Availability Mantainability Security) Analisi dati
G. Illuminati	Ric. INFN	**Coord. Astronomy & MultiMessanger** Analisi dati
G. Levi	Ric. UniBO	KM3DIA – DAQ
A. Margiotta (Resp. Locale)	PA UniBO	**Chair PC KM3NeT; Chair IB ANTARES** Analisi dati Base Module ISR (Lab. BILBO)
R. Muller	Post-doc INFN	Analisi dati
M. Spurio	PO UniBO	**Dep. Spokesperson ANTARES** Analisi dati
I. Del Rosso	PhD - 38° ciclo	Analisi dati

KM3NeT/ARCA + PNRR = KM3NeT4RR ~ 67 Meuro
completamento "Building Block" 1 (115 DUs = 0.5 km^3) + 10 DUs del BB 2
Ringraziamento all'amministrazione per il supporto nella gestione del KM3NeT4RR

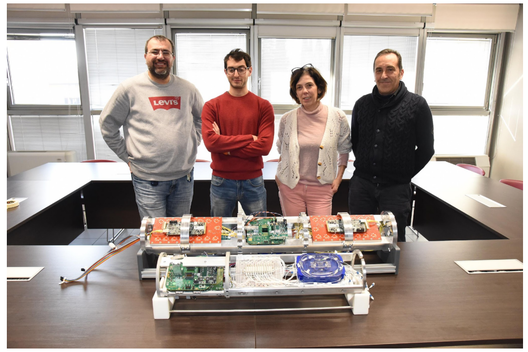
Integrazione e test moduli di base WWRS
F. Benfenati, A. Margiotta, G. Pellegrini, S. Ragonesi, C. Valieri

Finanziato dall'Unione europea NextGenerationEU · MUR · Italiadomani

BILBO
Bologna Integration Laboratory for Base-modules Objects

PIANO NAZIONALE RIPRESA E RESILIENZA (PNRR)
MISSIONE 4, "Istruzione e Ricerca"
COMPONENTE 2, "Dalla ricerca all'impresa"
INVESTIMENTO 3.1, "Fondo per la realizzazione di un sistema integrato di infrastrutture di ricerca e innovazione",
PROGETTO IR0000002 - KM3NeT4RR,
CUP: I57G21000040001

INFN



Riproduce il sistema DAQ/readout di KM3NeT
F. Benfenati, T. Chiarusi, L. Degli Esposti, F. Filippini, G. Pellegrini, S. Ragonesi

Finanziato dall'Unione europea NextGenerationEU · MUR · Italiadomani

BB-LAB
BCI - Bologna Common Infrastructure *BLU* - Bologna Laboratory for User-ports

PIANO NAZIONALE RIPRESA E RESILIENZA (PNRR)
MISSIONE 4, "Istruzione e Ricerca"
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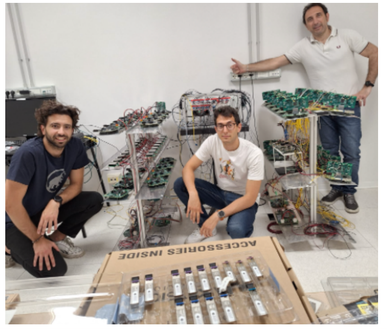
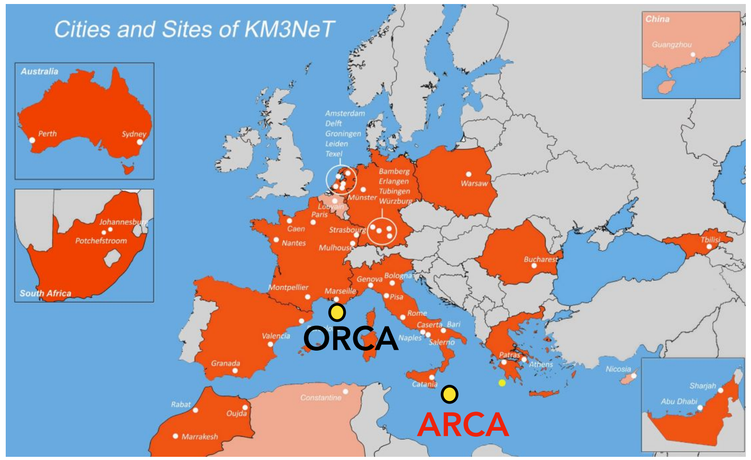
INVESTIMENTO 3.1, "Fondo per la realizzazione di un sistema integrato di infrastrutture di ricerca e innovazione",
PROGETTO IR0000002 - KM3NeT4RR,
CUP: I57G21000040001

INFN



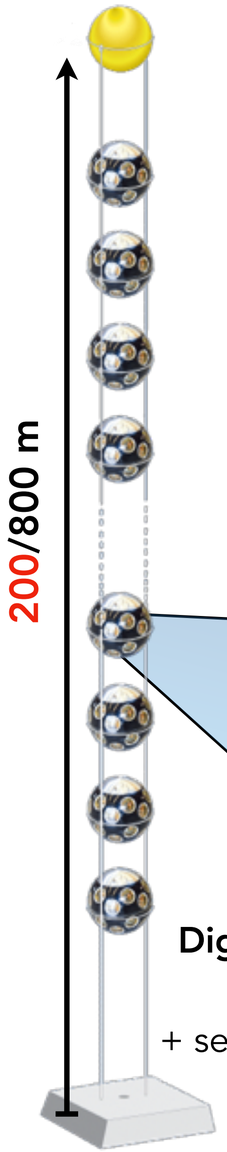
Tutti i fisici sono impegnati in INTENSA ATTIVITA' di analisi dei dati di KM3NeT
+ Completamento analisi dati ANTARES legacy papers
+ Analisi congiunte ANTARES-KM3NeT

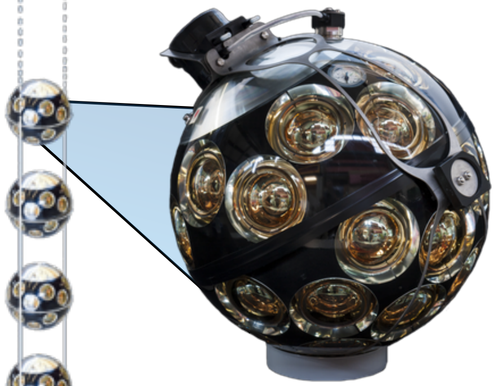
KM3NeT



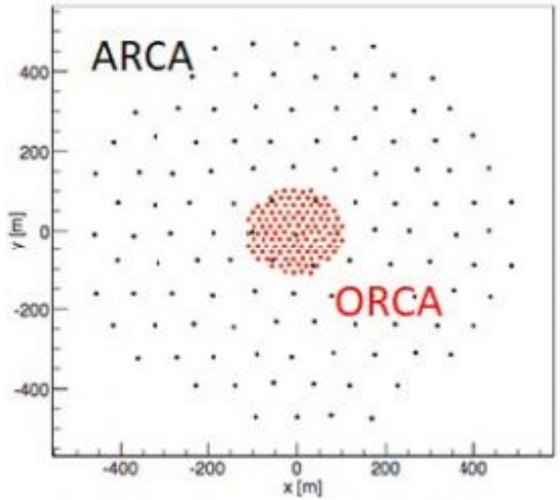
Two detectors, same technology, different layout and physics objectives.

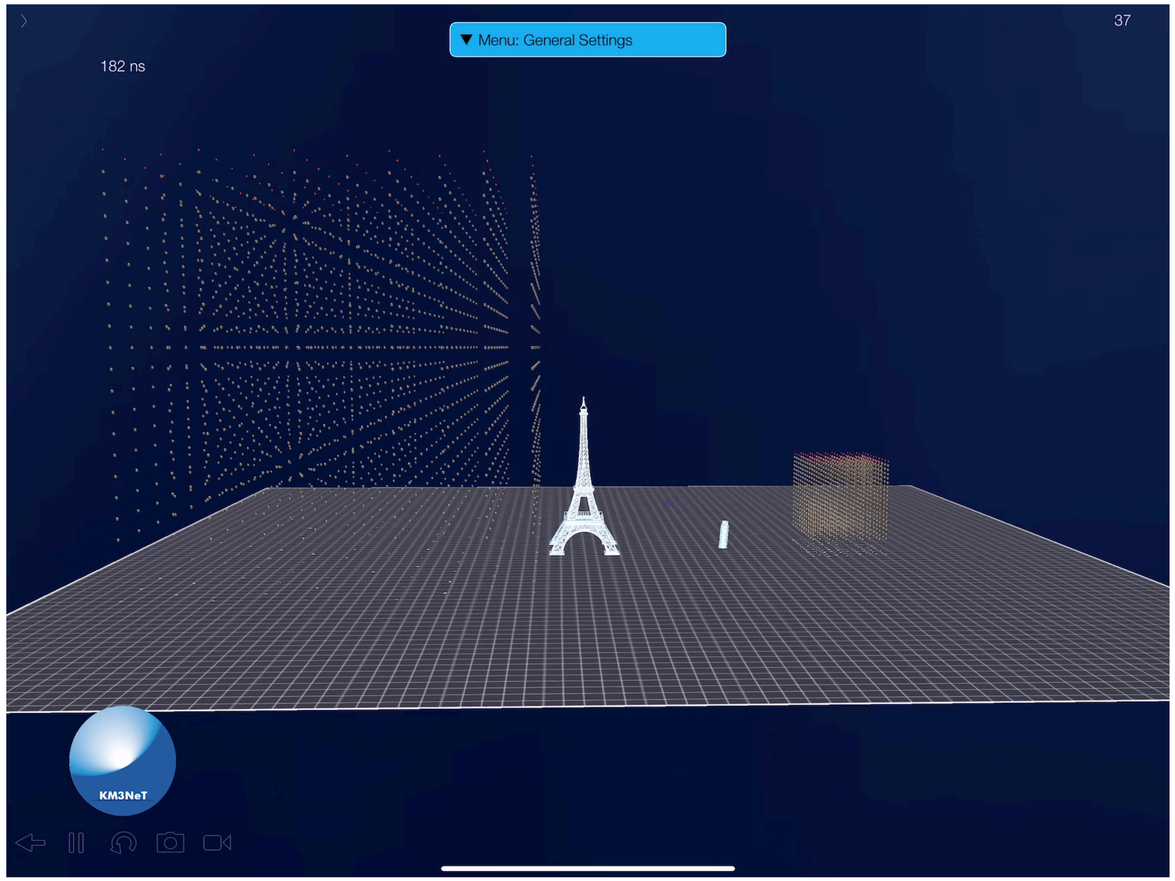
- **KM3NeT/ORCA:** ***O****scillation* ***R****esearch with* ***C****osmics in the* ***A****byss;*
- **KM3NeT/ARCA:** ***A****stroparticle* ***R****esearch with* ***C****osmics in the* ***A****byss.*





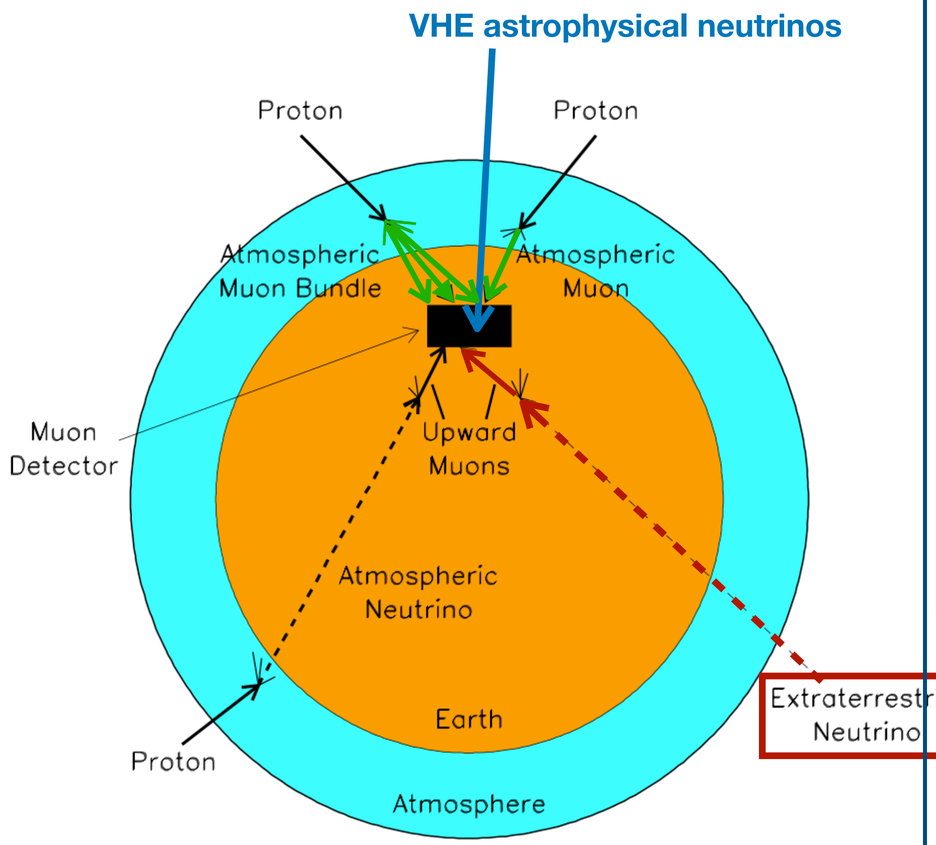
Digital Optical Module (DOM):
31 x 3’ PMTs
+ sensors for calibration porpoises





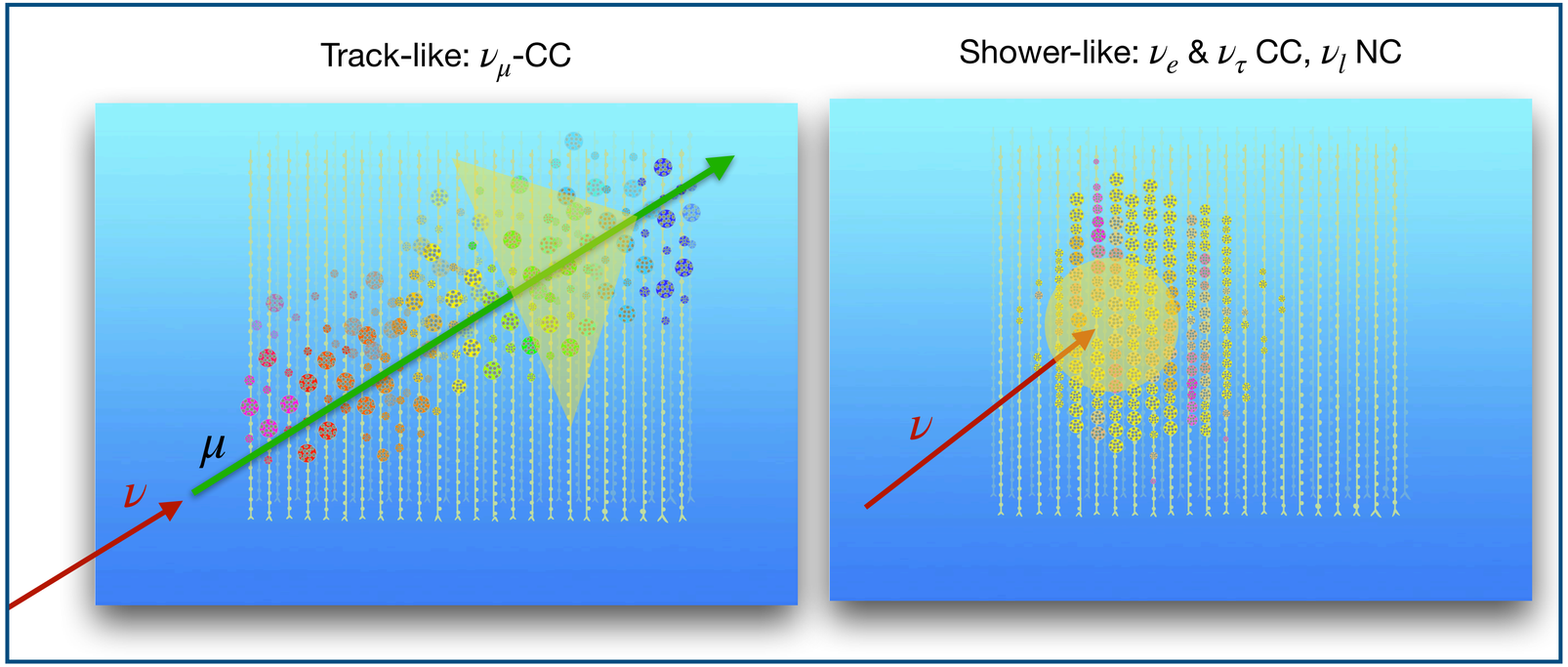
Detection principle and event topology

Detection principle



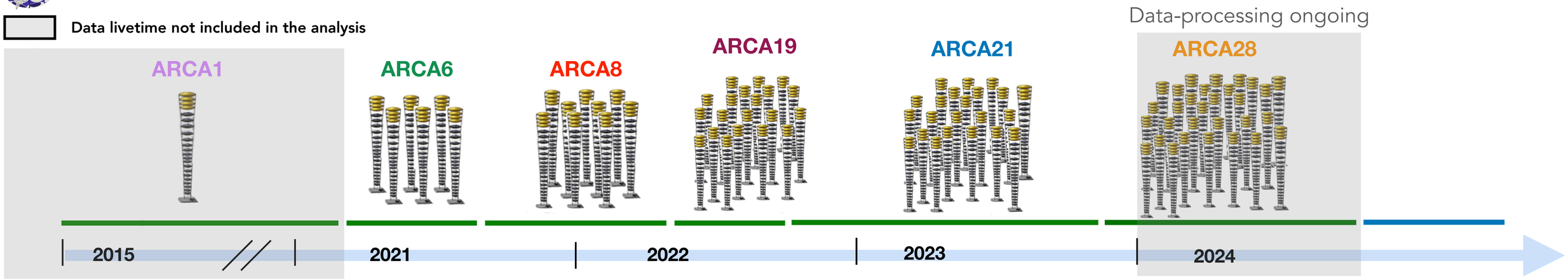
- Atmospheric muon flux $\sim 10^6$ bigger than neutrino flux;
- Earth becoming opaque for $E_\nu > 200\ TeV$.

Event topology



- ν_μ**-CC:** outgoing muon. Precise direction determination ($< 1^\circ$): **track-like events;**
- ν_e**-CC,** ν_l**-NC:** electromagnetic and hadronic showers. Precise energy determination. Poorer direction determination: **shower-like events;**
- ν_τ**-CC:** outgoing τ that decay. If both showers contained in the detector: **double-bang** topology.

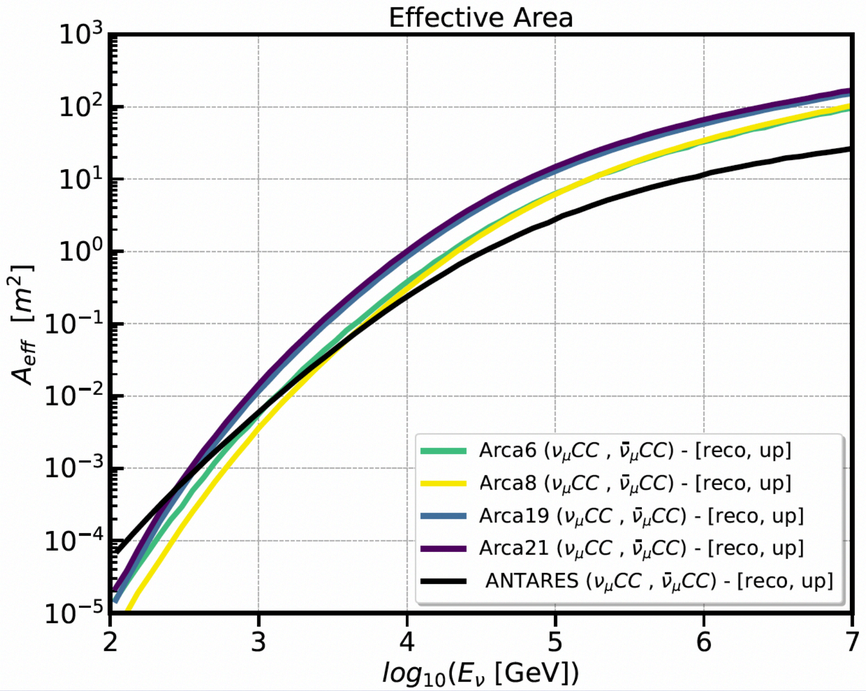
KM3NeT/ARCA data-taking



- **Arca6** data-taking period : May 2021 - September 2021 **(∼102 days);**
- **Arca8** data-taking period : September 2021 - end of May 2022 **(∼212 days);**
- **Arca19** data-taking period : May 2022 - September 2022 **(∼51 days);**
- **Arca21** data-taking period : September 2022 - September 2023 **(∼287 days).**

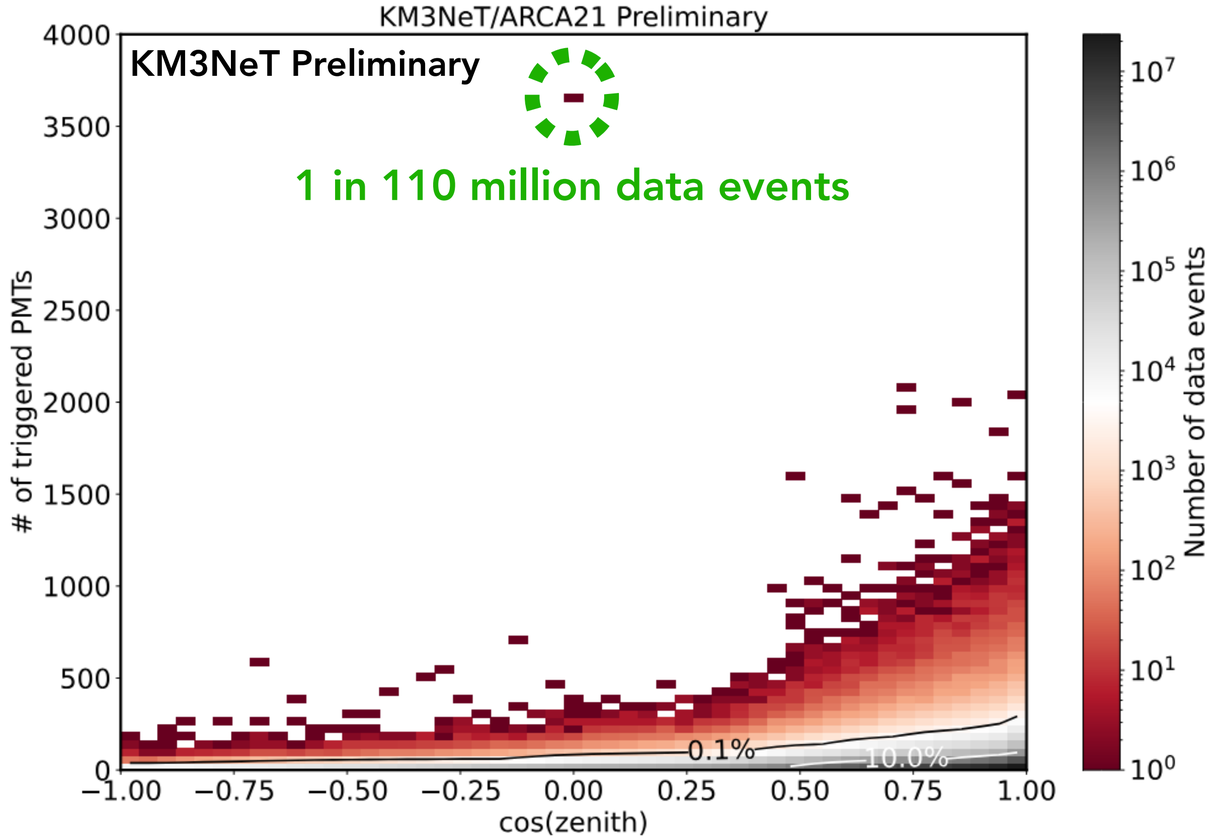
KM3NeT detectors: high duty cycle,
stable data-taking over long periods
(from December 2022 up to September 2023, efficiencies above 91%)

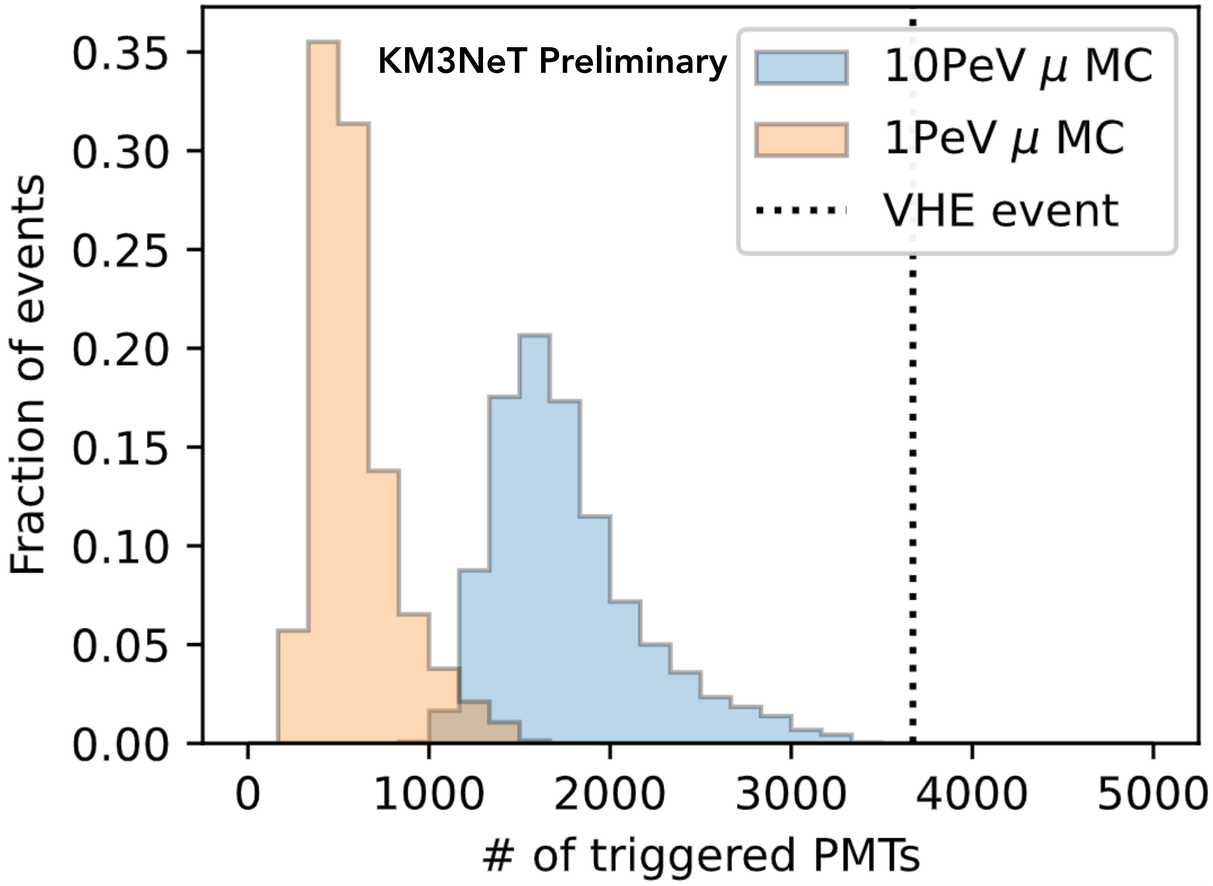
KM3NeT/ARCA21 × 3 effective area of KM3NeT/ARCA6



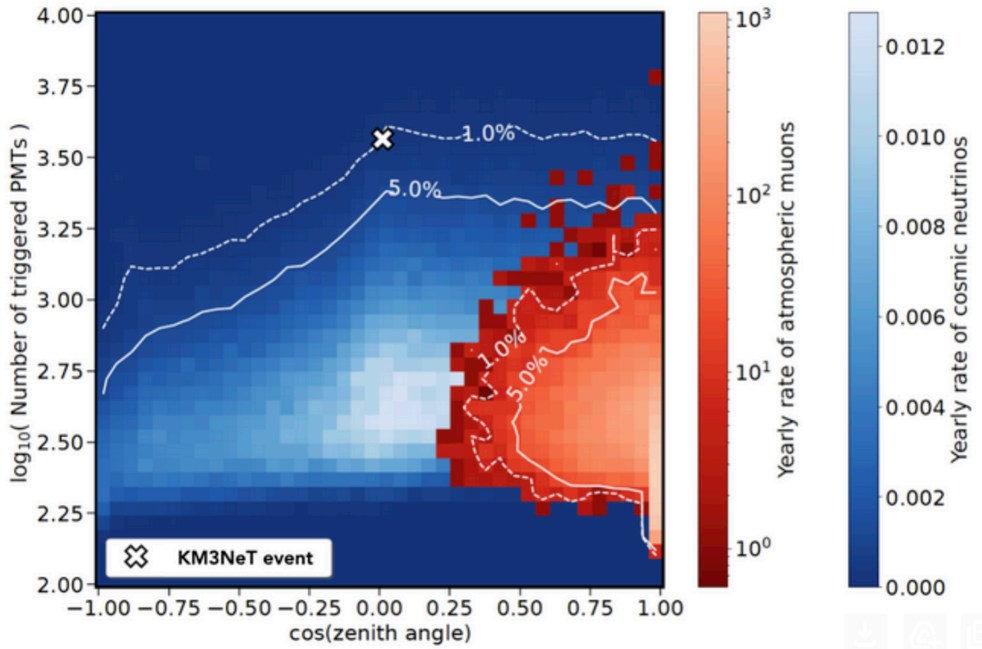
Very high energy event

- Significant event observed with huge amount of light;
- Horizontal event (1° above horizon) as expected since earth opaque to neutrinos at PeV scale;
- 3672 PMTs (35%) were triggered in the detector;
- Muons simulated at 10 PeV almost never generate this much light;
- Likely multiple 10's of PeV.





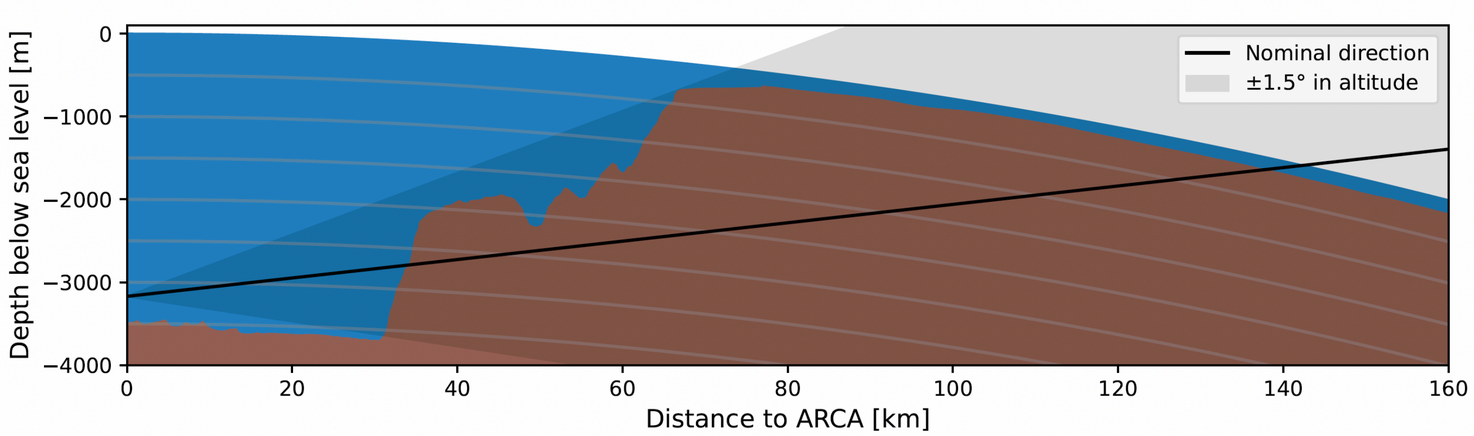
Background estimate

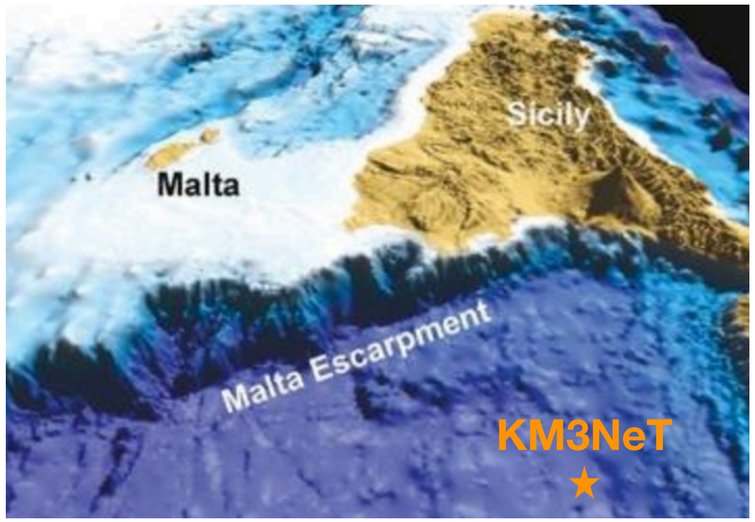


Event direction pointing back to Malta Escarpment.

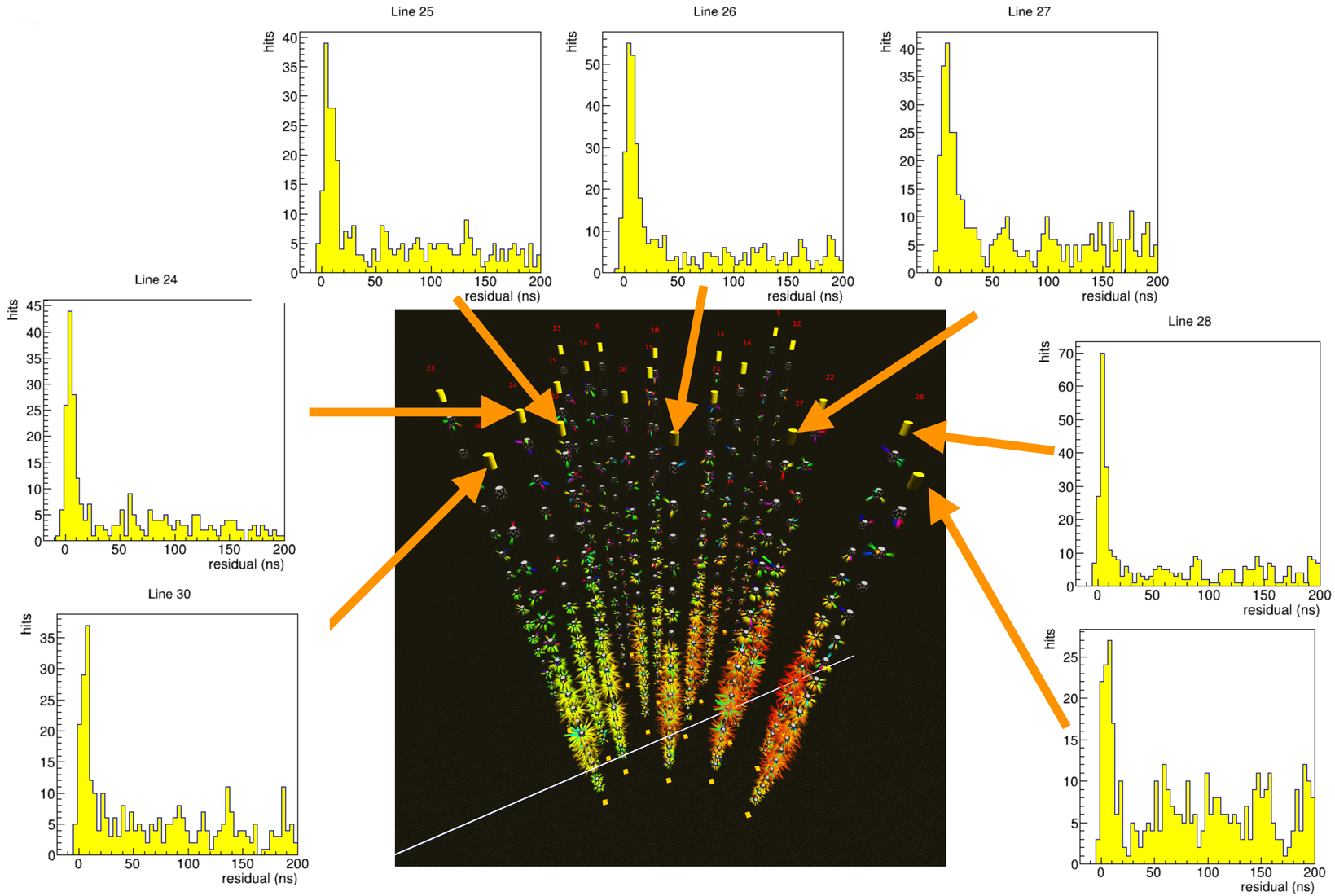
Total amount of matter = 140 km:

- contribution from atmospheric muons is therefore negligible;
- contribution from prompt atmospheric neutrinos is also tiny.





Reconstruction



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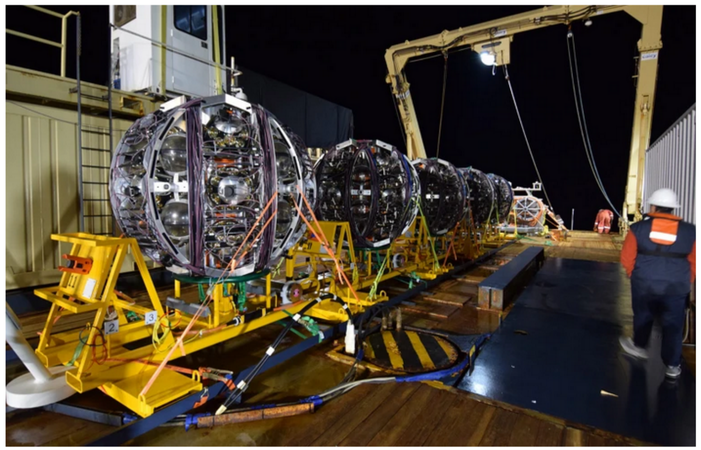
NEWS | 21 June 2024

‘Fantastic’ particle could be most energetic neutrino ever detected

The ultra-high-energy neutrino was spotted by deep-sea detectors and could point to a massive cosmic event.

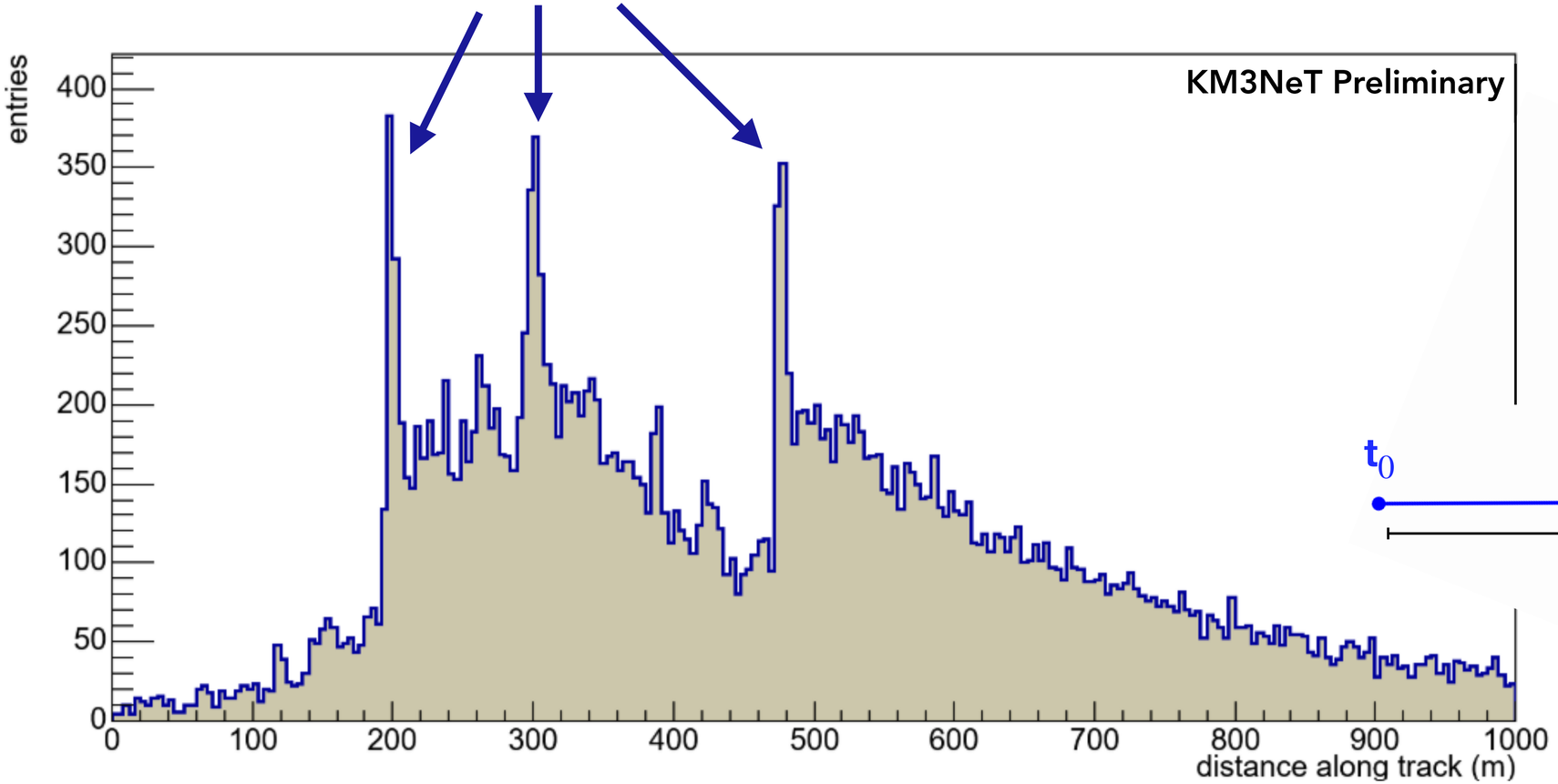
By Davide Castelvecchi

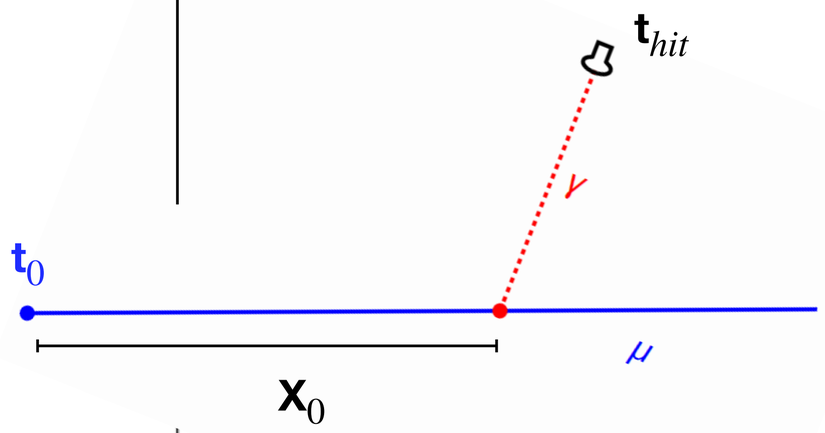


Five ARCA detectors on board a ship, ready for deployment. Credit: KM3NeT Collaboration

Stochastic losses

- Light profile consistent with **at least 3 large energy depositions** along the muon track;
- Characteristic of stochastic losses from very high energy muons.

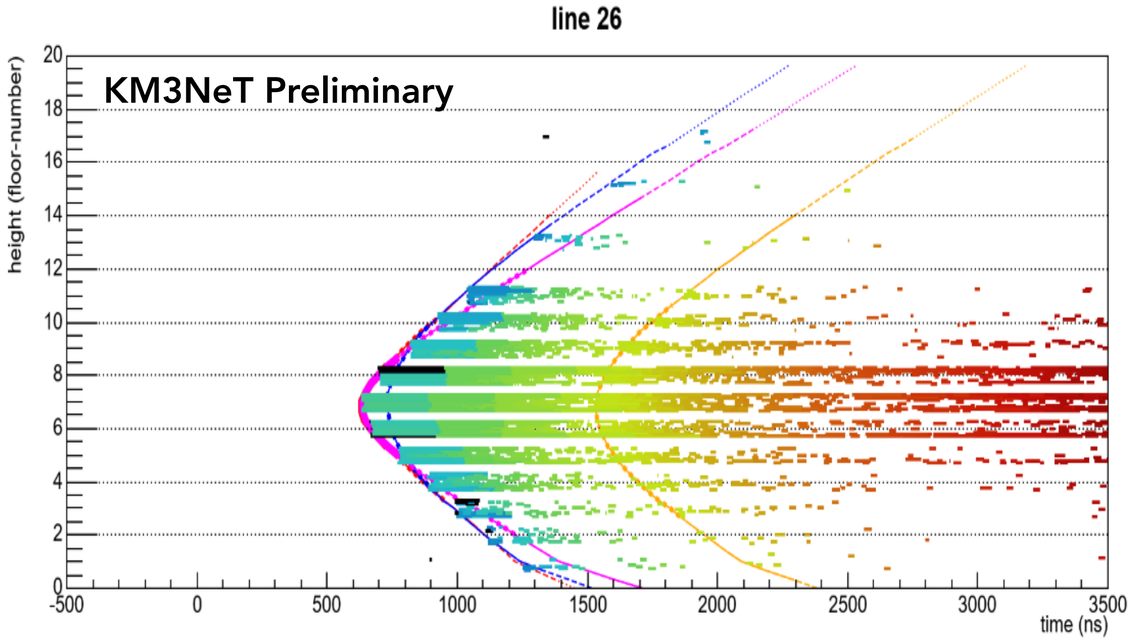


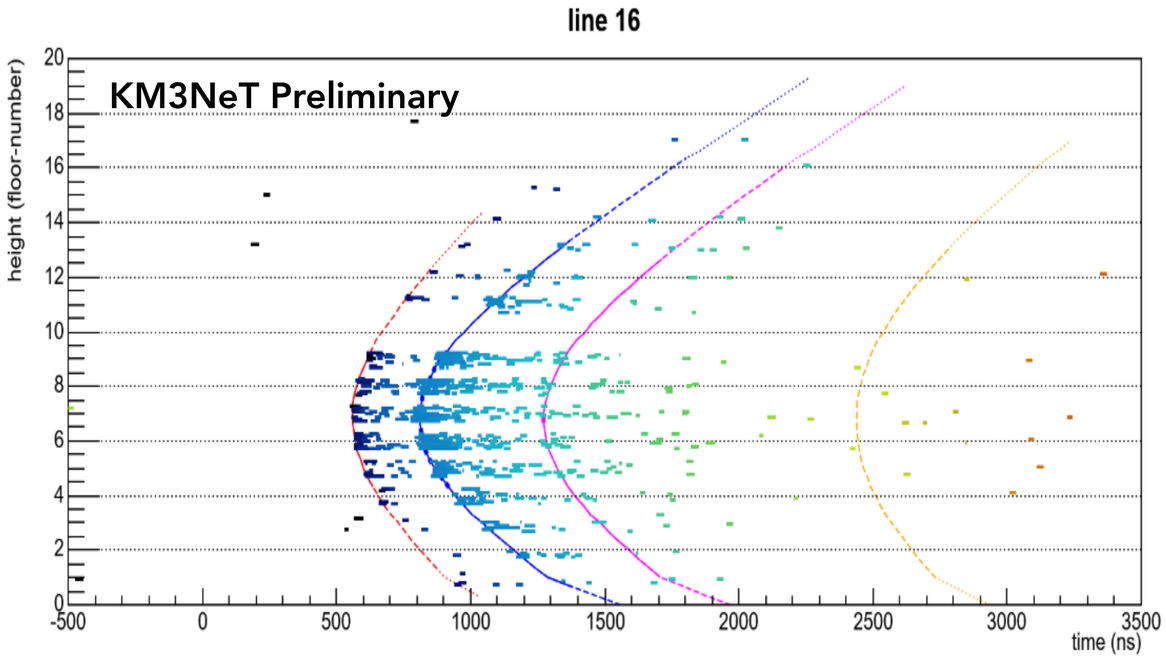


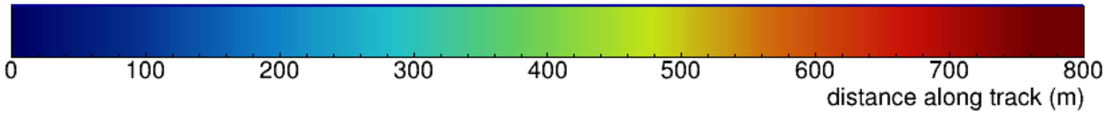
Position of light emission along track consistent with hit time assuming direct light

Height vs time distribution

- Light profile consistent with at least 3 large energy depositions along the muon track;
- Characteristic of stochastic losses from very high energy muons;
- Space-time distribution of light consistent with shower hypothesis associated with these energy depositions;
- Low scattering is key to observing this richness of detail.

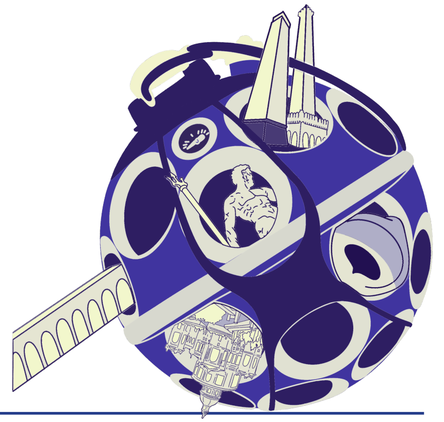




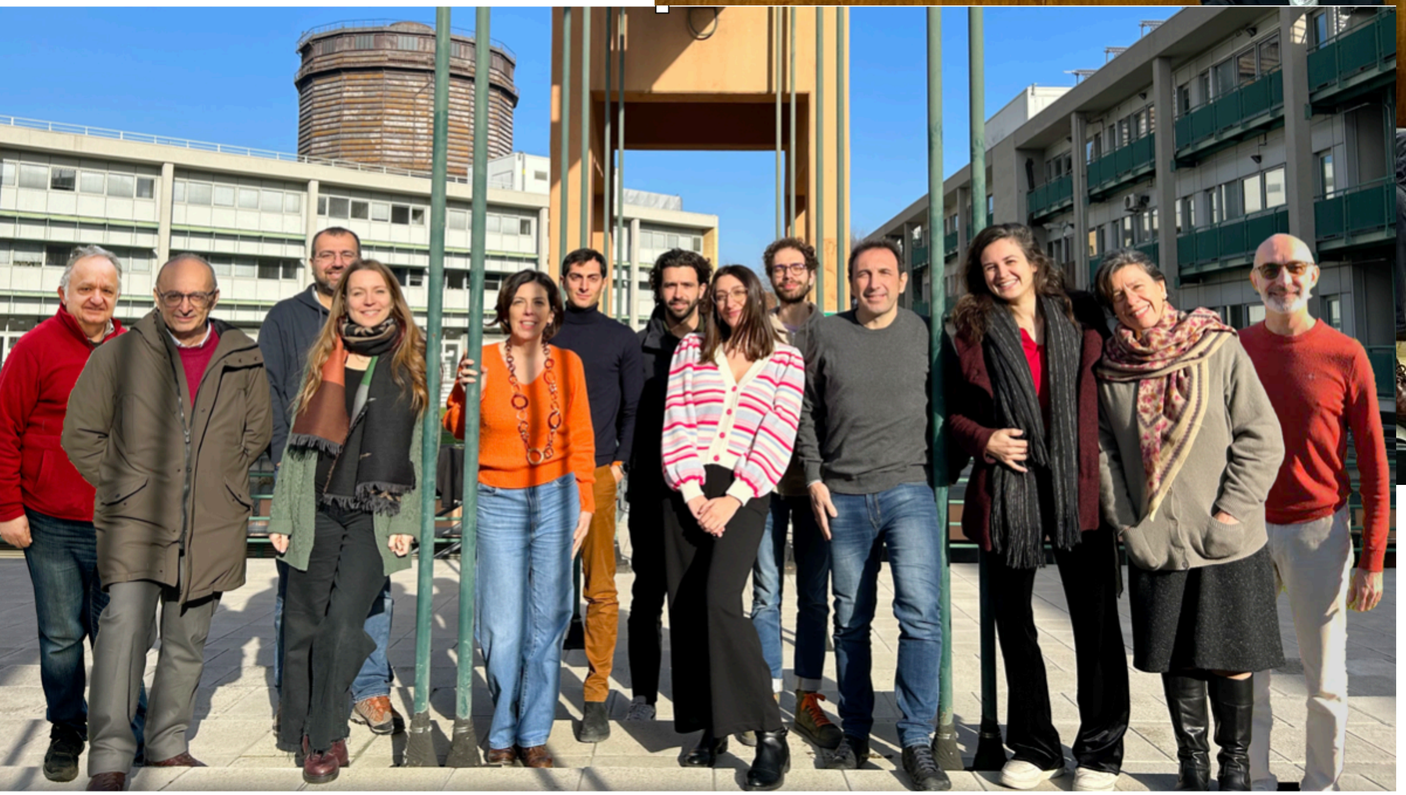


Conclusions and outlook

- KM3NeT has been taking high quality data during construction phase;
- The KM3NeT detectors explore the physics of multiple layers of light seen by the multi-PMT DOM design;
- Searches for astrophysical sources are under way;
- An unprecedented event was observed in rich detail;
- Likely multiple 10's of PeV;

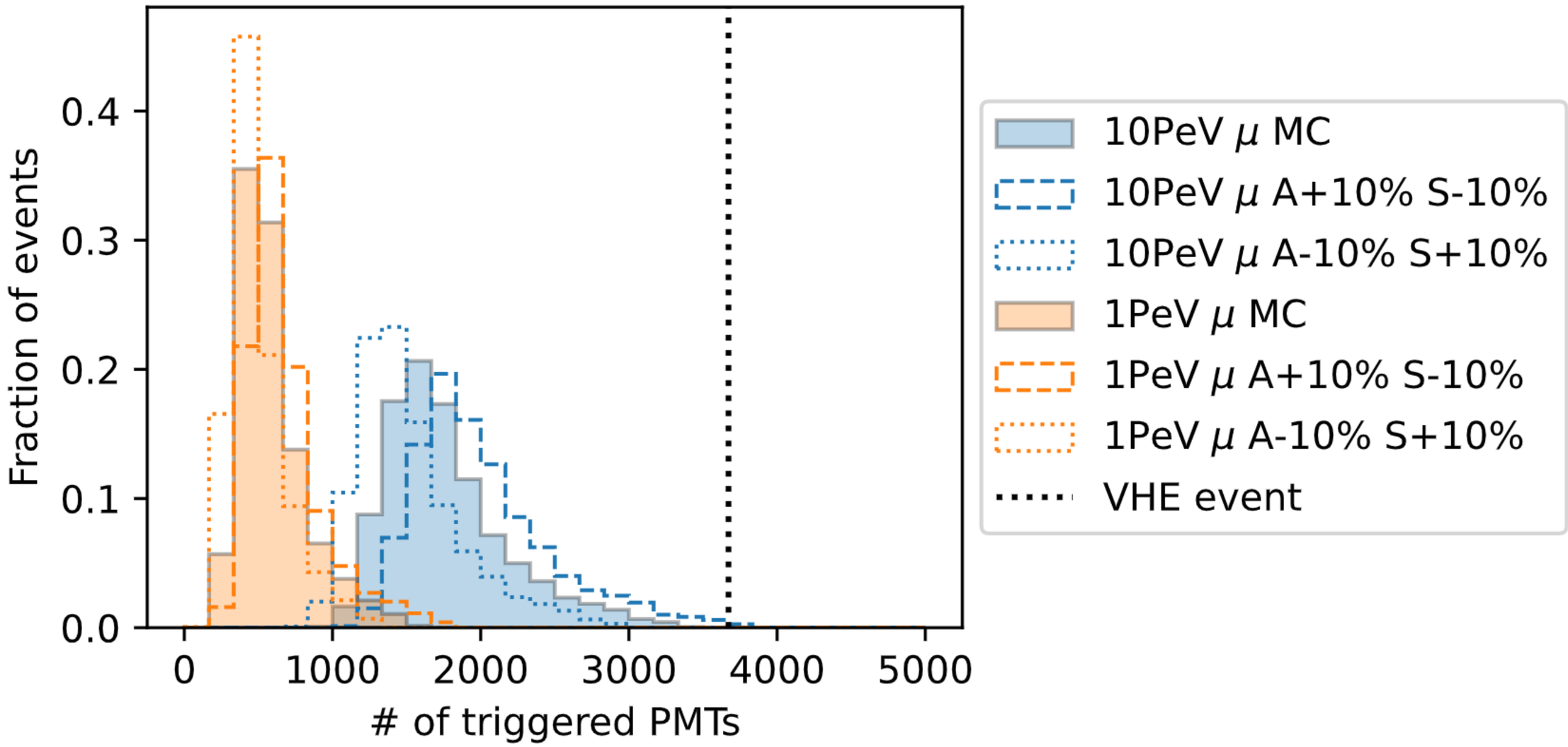


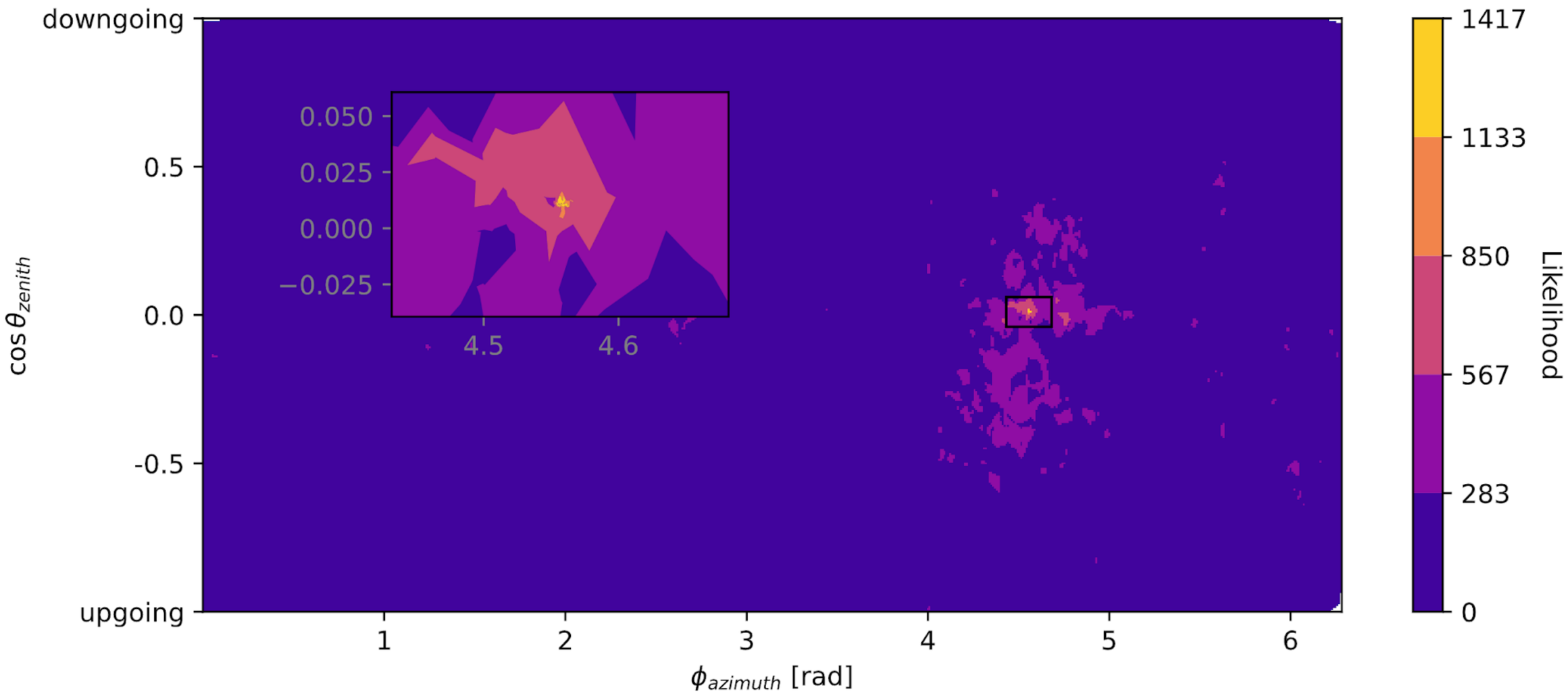
Thanks for your attention!

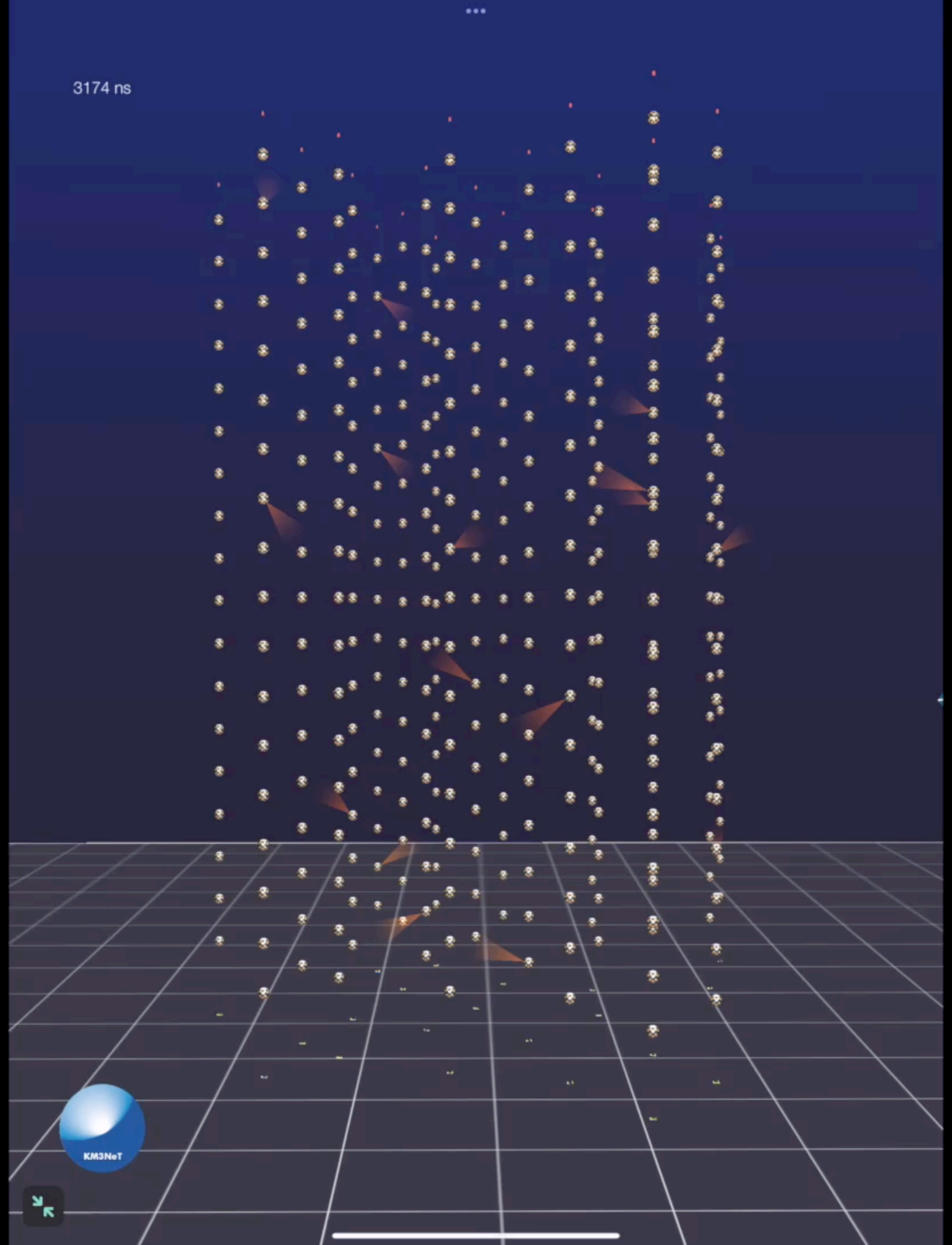


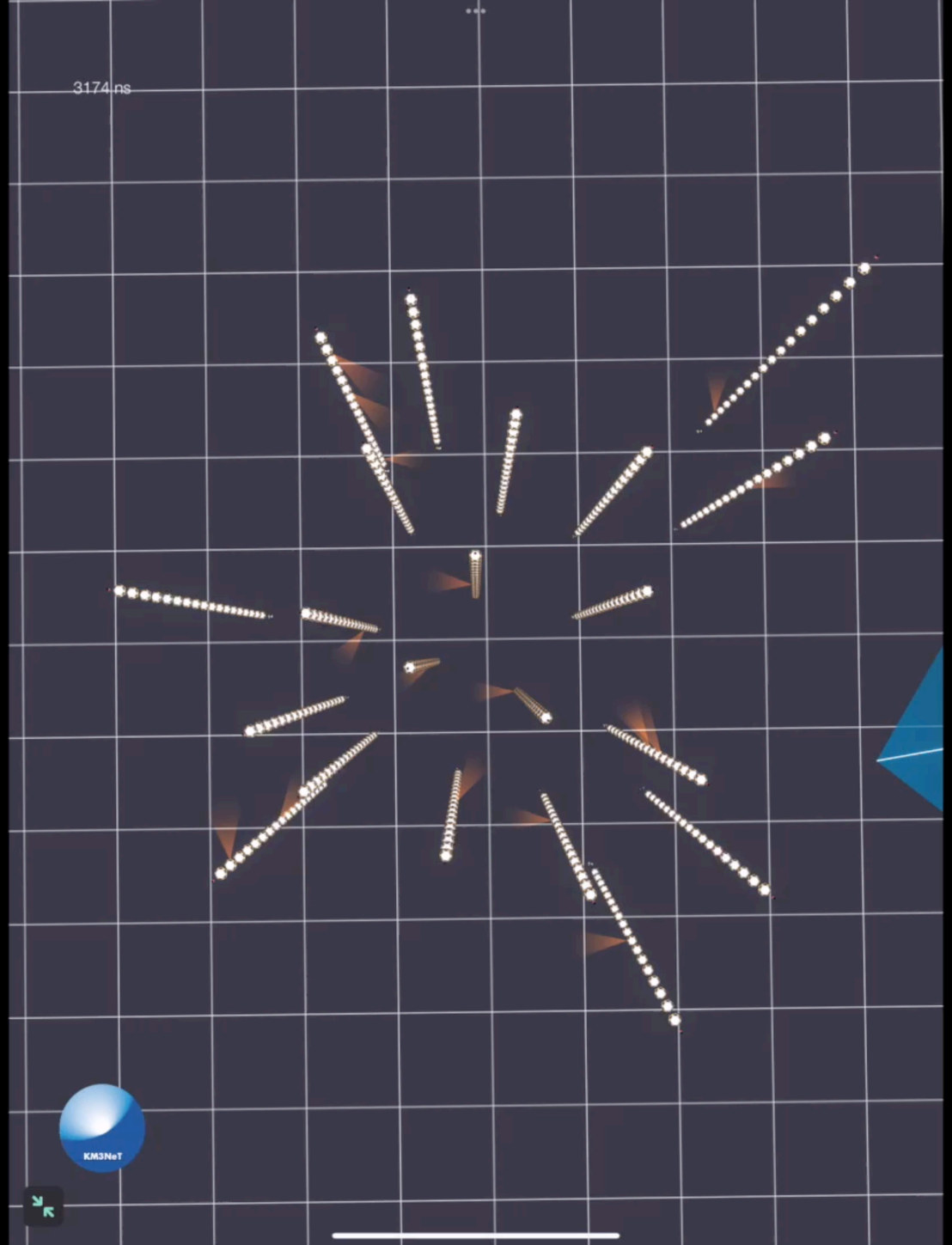
Thanks

Backup slides

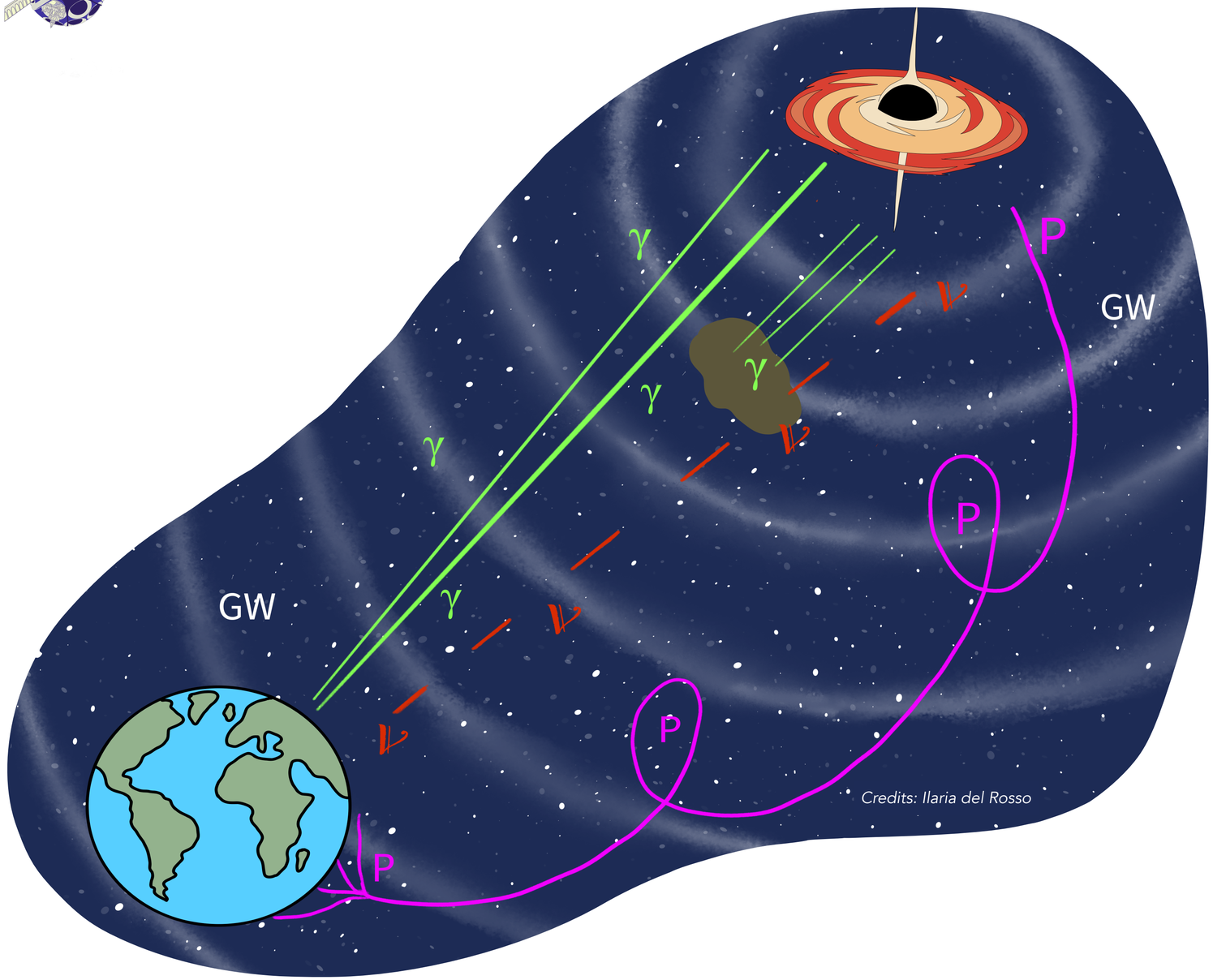

Fraction of events
0.0
0.1
0.2
0.3
0.4
0
1000
2000
3000
4000
5000
# of triggered PMTs
10PeV μ MC
10PeV μ A+10% S-10%
10PeV μ A-10% S+10%
1PeV μ MC
1PeV μ A+10% S-10%
1PeV μ A-10% S+10%
VHE event

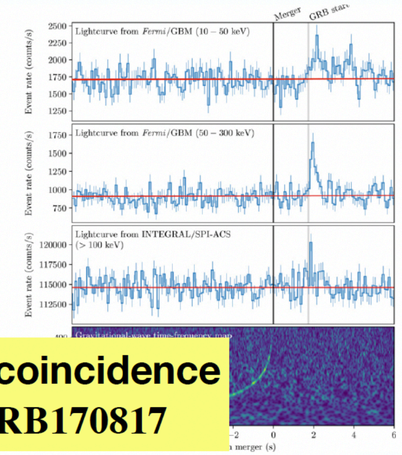

downgoing
0.5
0.0
-0.5
upgoing
$\cos\theta_{zenith}$
0.050
0.025
0.000
−0.025
4.5
4.6
1
2
3
4
5
6
$\phi_{azimuth}$ [rad]
1417
1133
850
567
283
0
Likelihood


3174 ns
KM3NeT

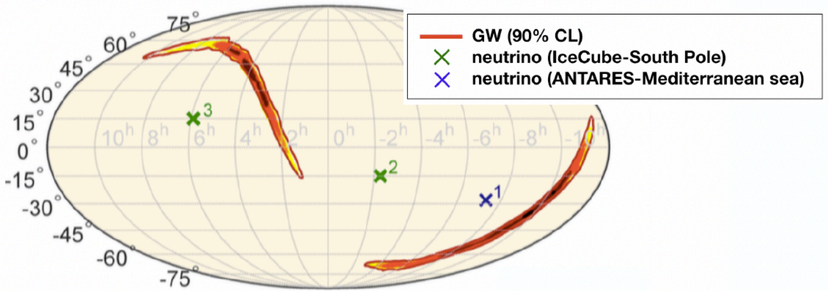

3174 ns
KM3NeT

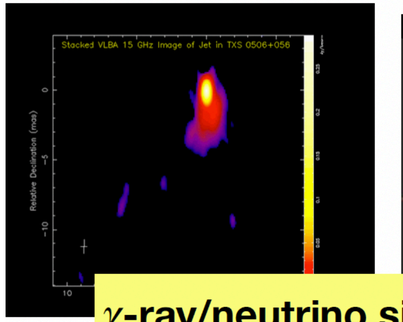
Multi-messenger astronomy: the beginning of an era

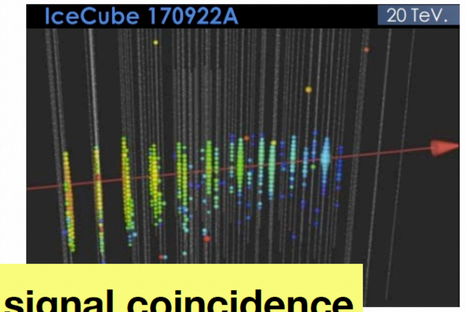




GW/GRB signal coincidence
GW170817 / GRB170817

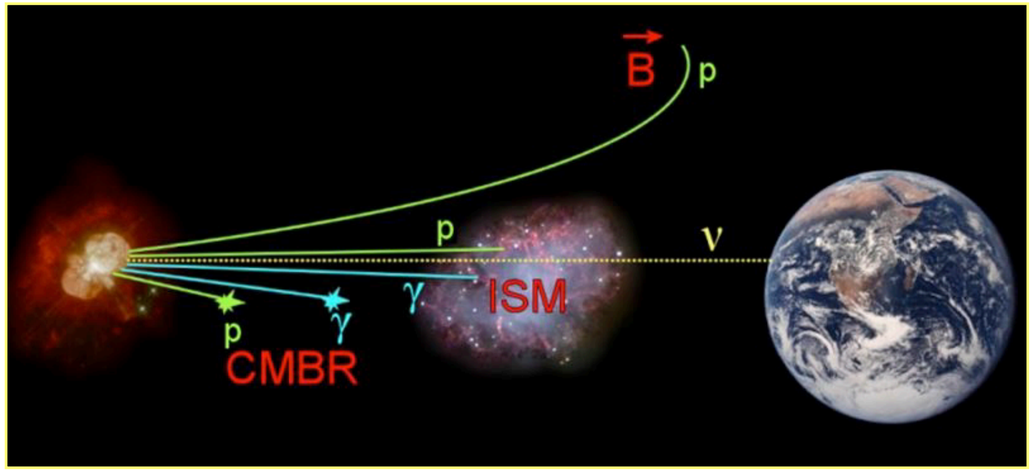




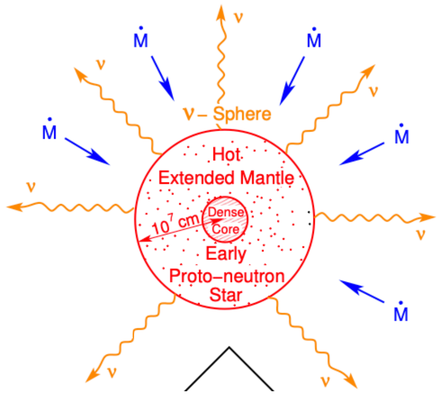


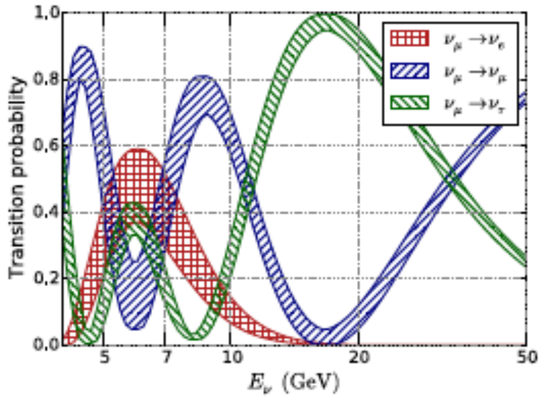
γ-ray/neutrino signal coincidence
IC170922 / TXS 0506+056

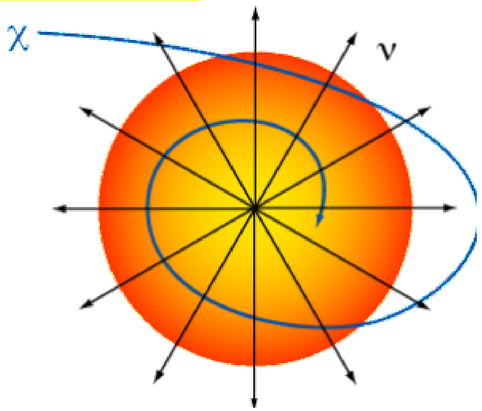
Neutrino astronomy: astrophysics cases

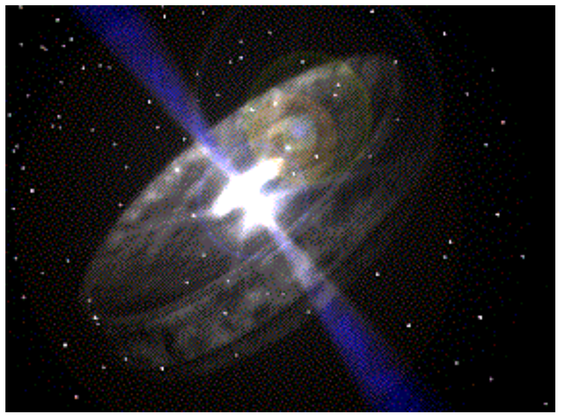


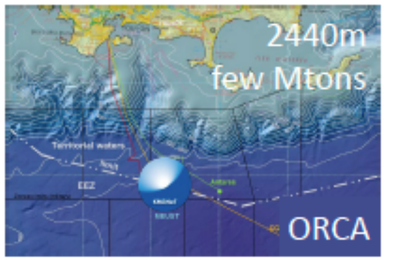
- Origin of Cosmic Rays
- Neutral messengers point back to their sources
  - Neutrons are short-lived, photons are likely to interact
    ⇒ **Neutrinos as cosmic probe**
- Neutrinos are produced at sources via hadronic interactions
  - Cosmic diffuse flux
  - Point-like sources
  - Multi-messenger approach









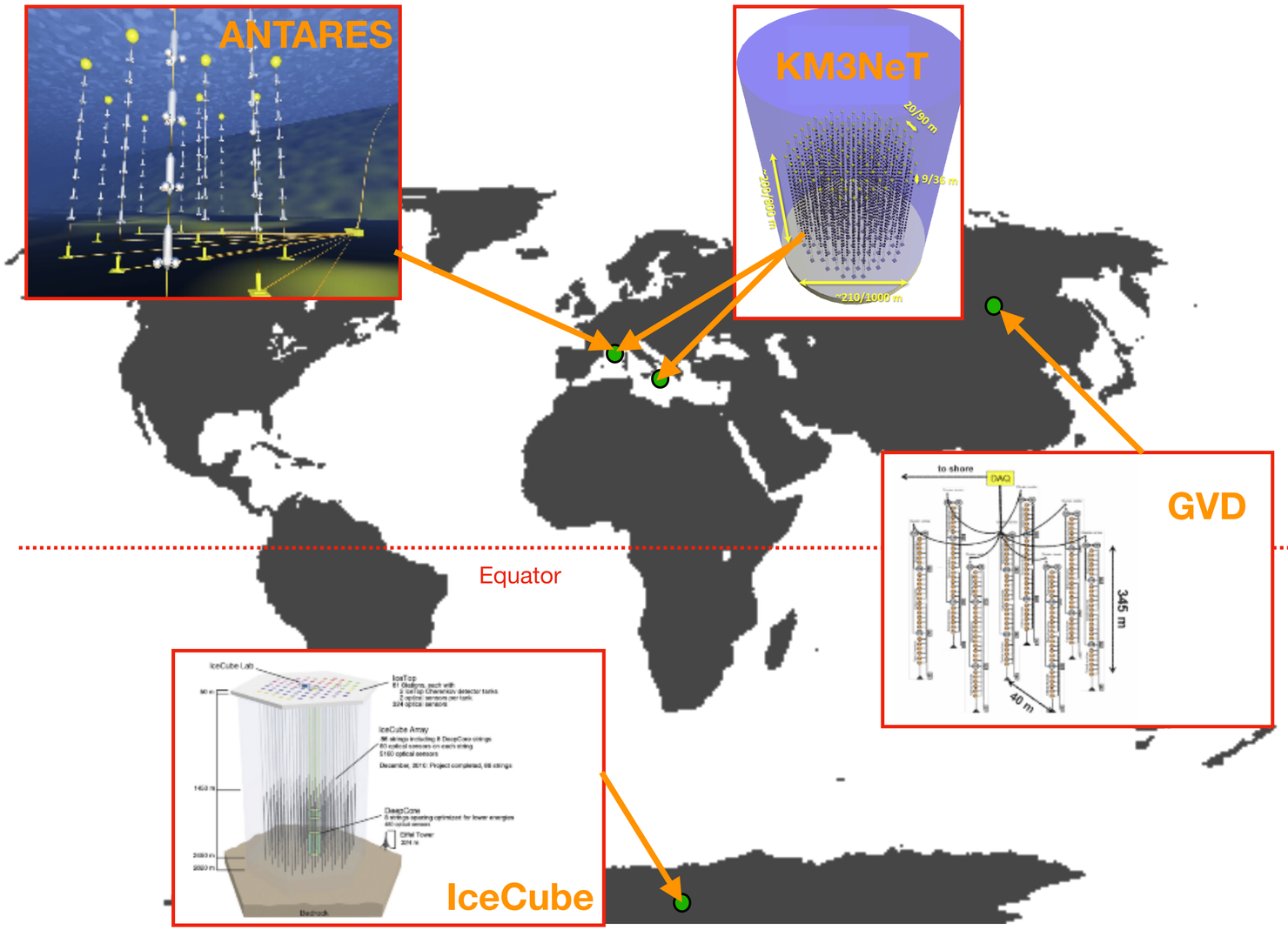


KM3NeT/ORCA
***O**scillation **R**esearch*
*with **C**osmics in the **A**byss*

KM3NeT/ARCA
***A**stroparticle **R**esearch*
*with **C**osmics in the **A**byss*

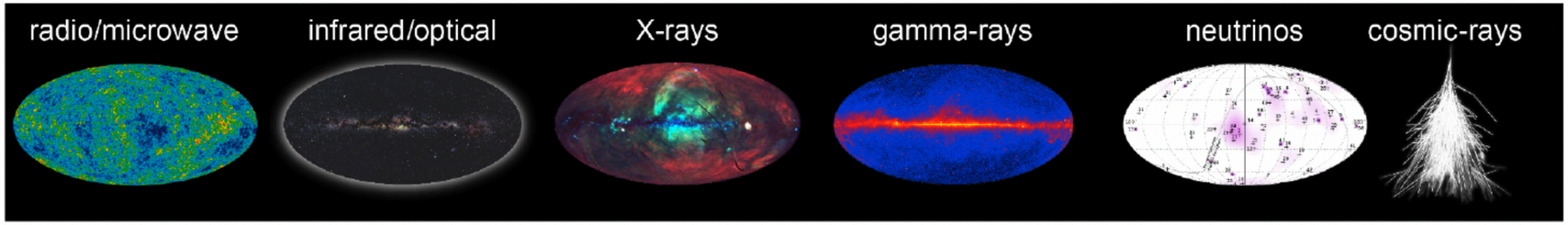
Super Novae explosion MeV	Neutrino oscillation GeV	Dark Matter GeV-TeV	HE neutrinos, CRs Multi-messenger program TeV-PeV
	ORCA		
ARCA		ARCA	

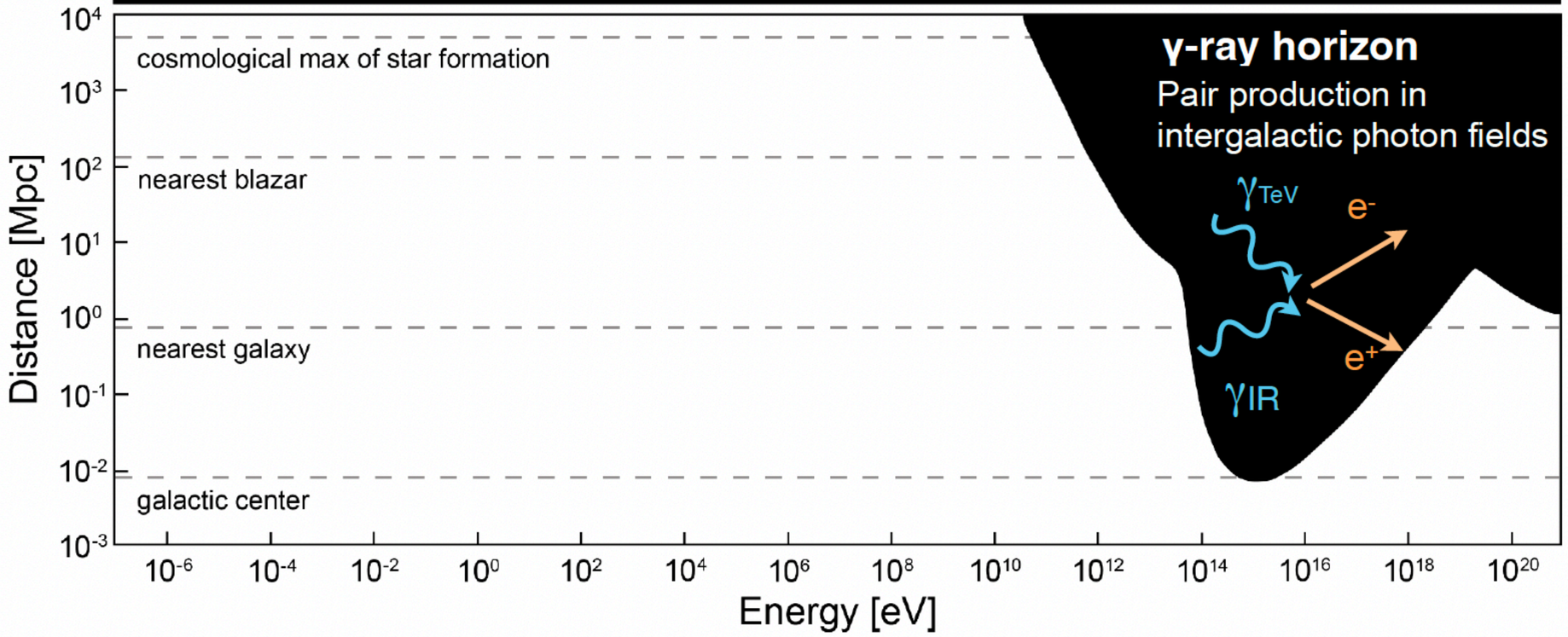
Data from neutrino telescopes

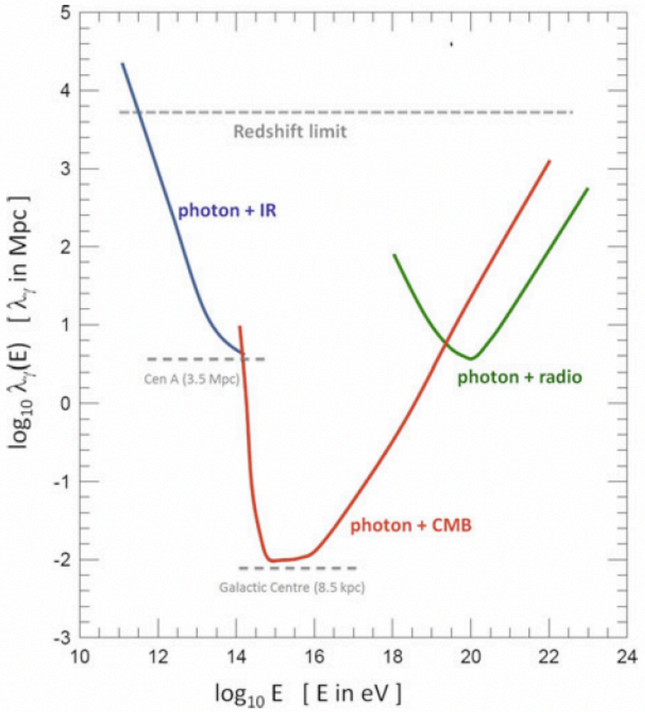


GNN
The Global Neutrino Network

Gamma ray absorption





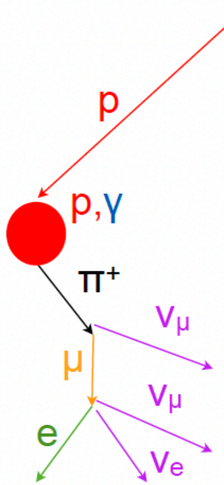


Oscillation astronomical distances - flavor ratio

- Neutrinos are produced when high-energy hadrons interact with gas or photons in astrophysical sources

- Study of flavor ratios can help to distinguish production processes and environments

free decay of secondaries

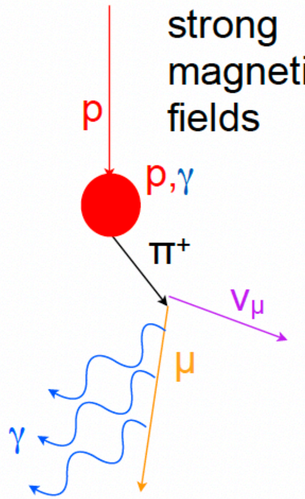


Flavor ratio

$\nu_e : \nu_\mu : \nu_\tau$

1 : 2 : 0

strong magnetic fields

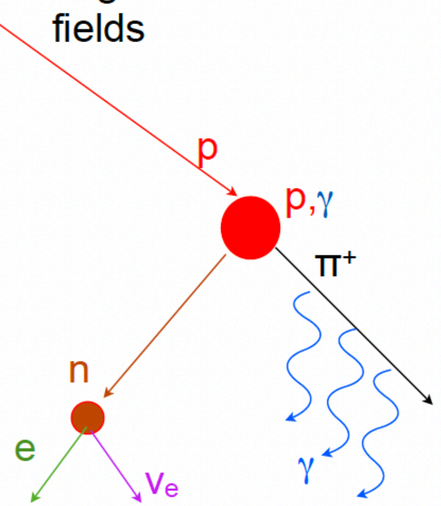


Flavor ratio

$\nu_e : \nu_\mu : \nu_\tau$

0 : 1 : 0

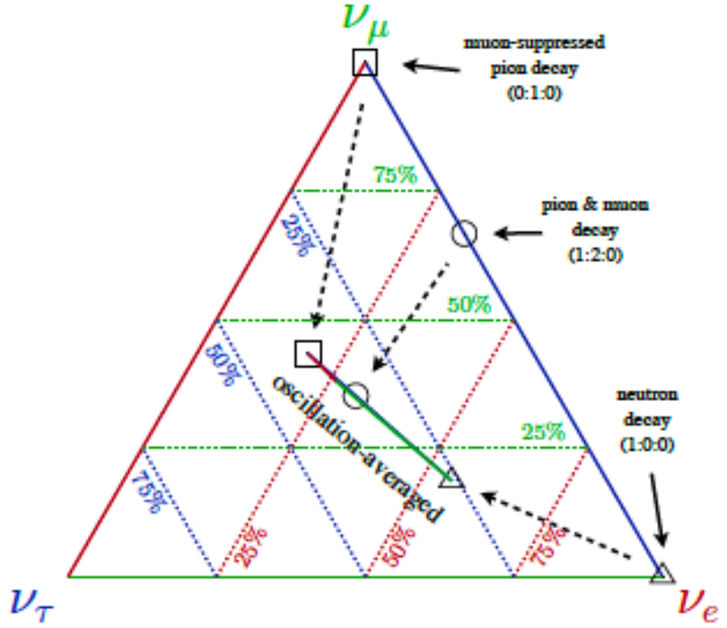
very strong magnetic fields



Flavor ratio

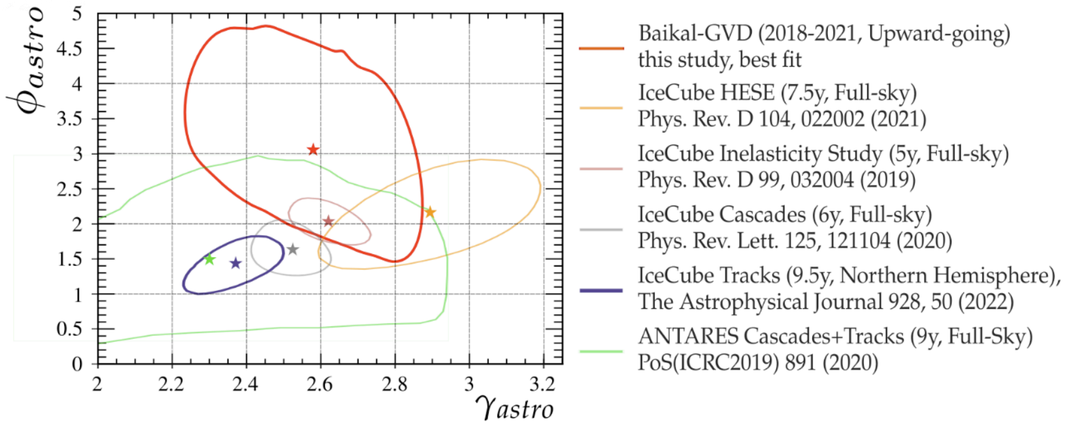
$\nu_e : \nu_\mu : \nu_\tau$

1 : 0 : 0



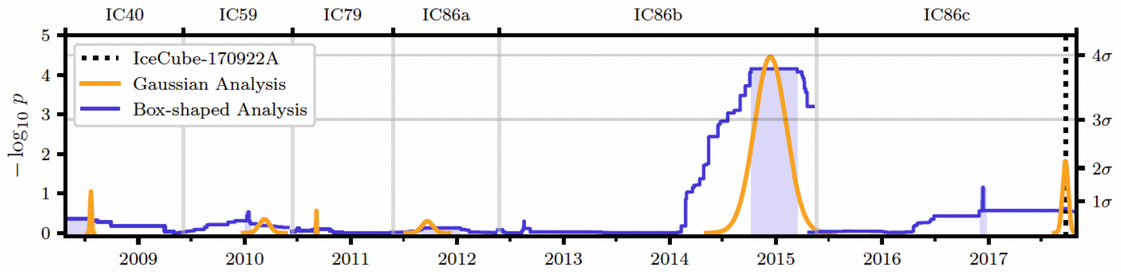
Status and prospects for neutrino astronomy

All-sky neutrino emission



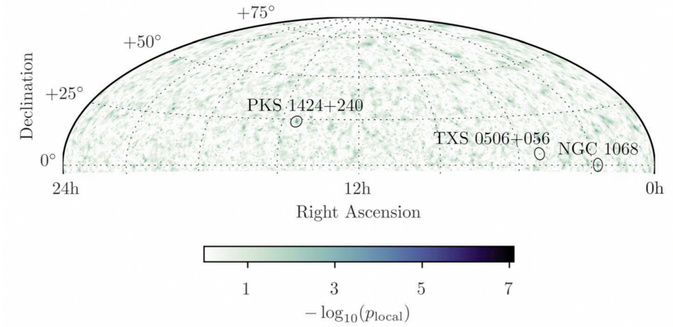
Different detectors with different data sets observed it;
Tension over 3σ concerning single power-law fitted parameters.

Untriggered flaring searches: TXS0506+056



Searches for clusters of events in time in coincidence of well-known sources.
Search performed for the source TXS0506+056. Observed cluster back in time, December 13th 2014 with 3.5 σ significance.

Point-source searches and catalogue correlation

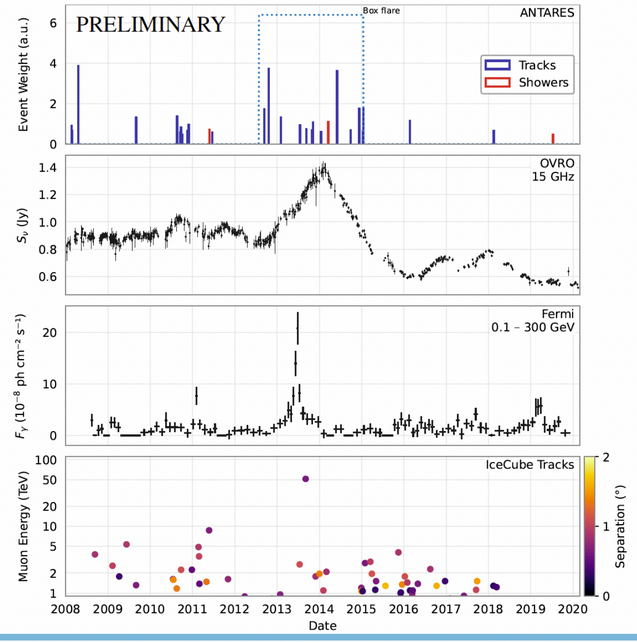


Time integrated observation with IceCube data set, at the level of 4.2 σ, of a possible neutrino emission from the source **NGC1068**.

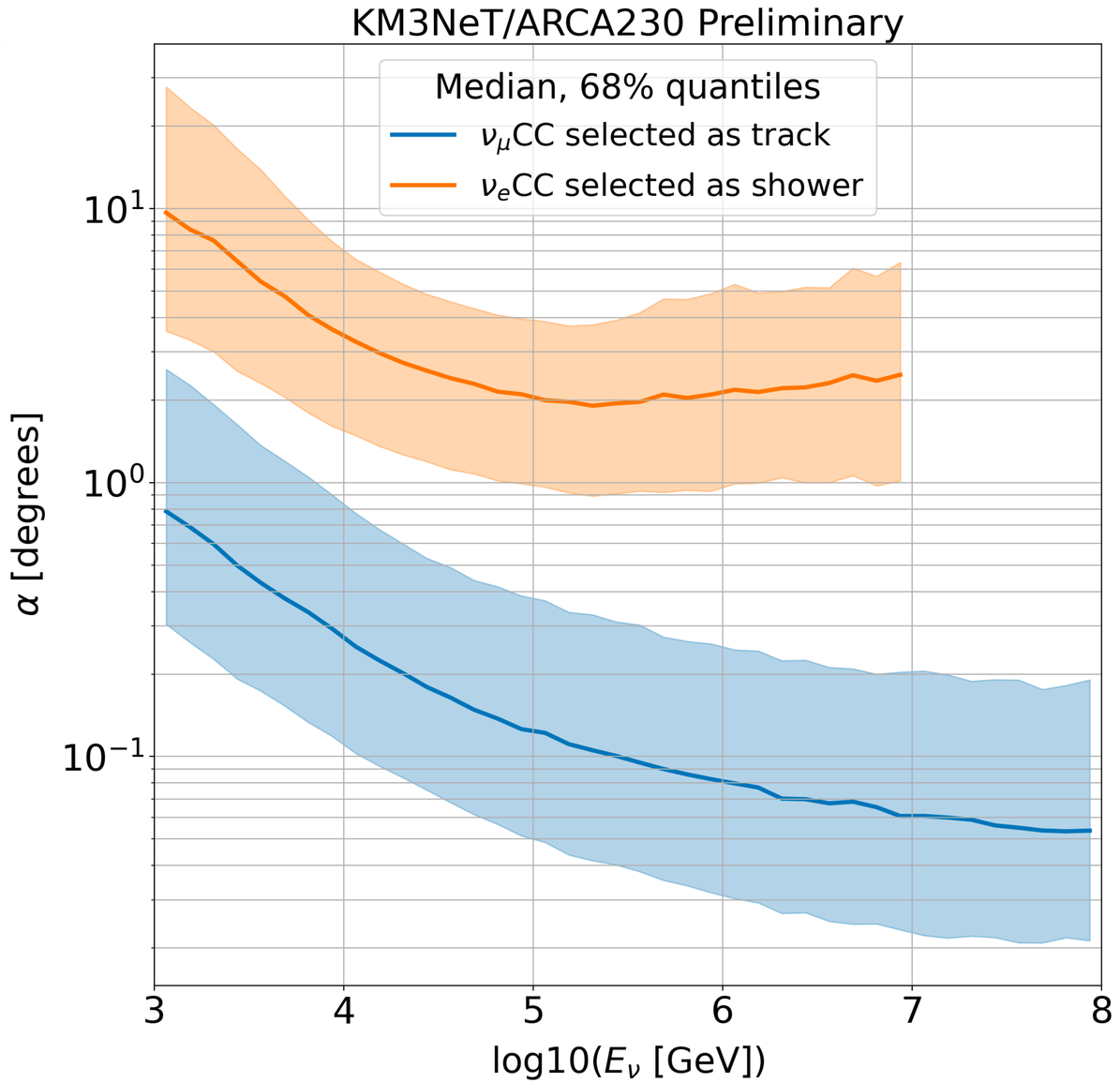
Searches of neutrino directional association with catalogues of known sources.
Two main categories found in the recent years showing striking evidence:

- **Tidal Disruptive Events**: association at the level of 3.7 σ;
- **Blazars**: association at the level of 4.1 σ;

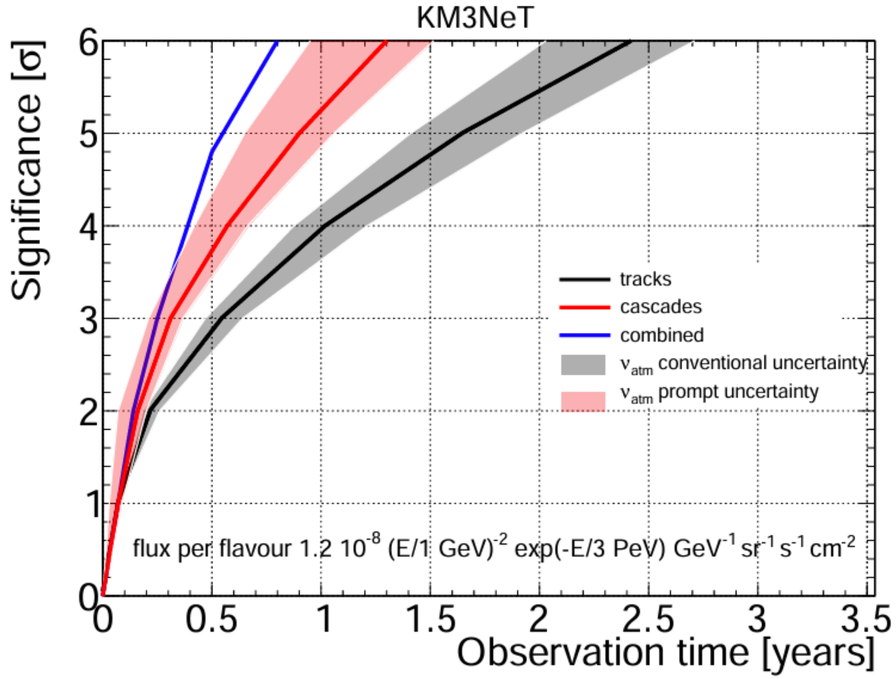
Association performed also with ANTARES data. Intriguing coincidence of the triggered signal by ANTARES with the most significant flaring status of the source **J0242+1101** in radio, gamma ray and neutrino emission.

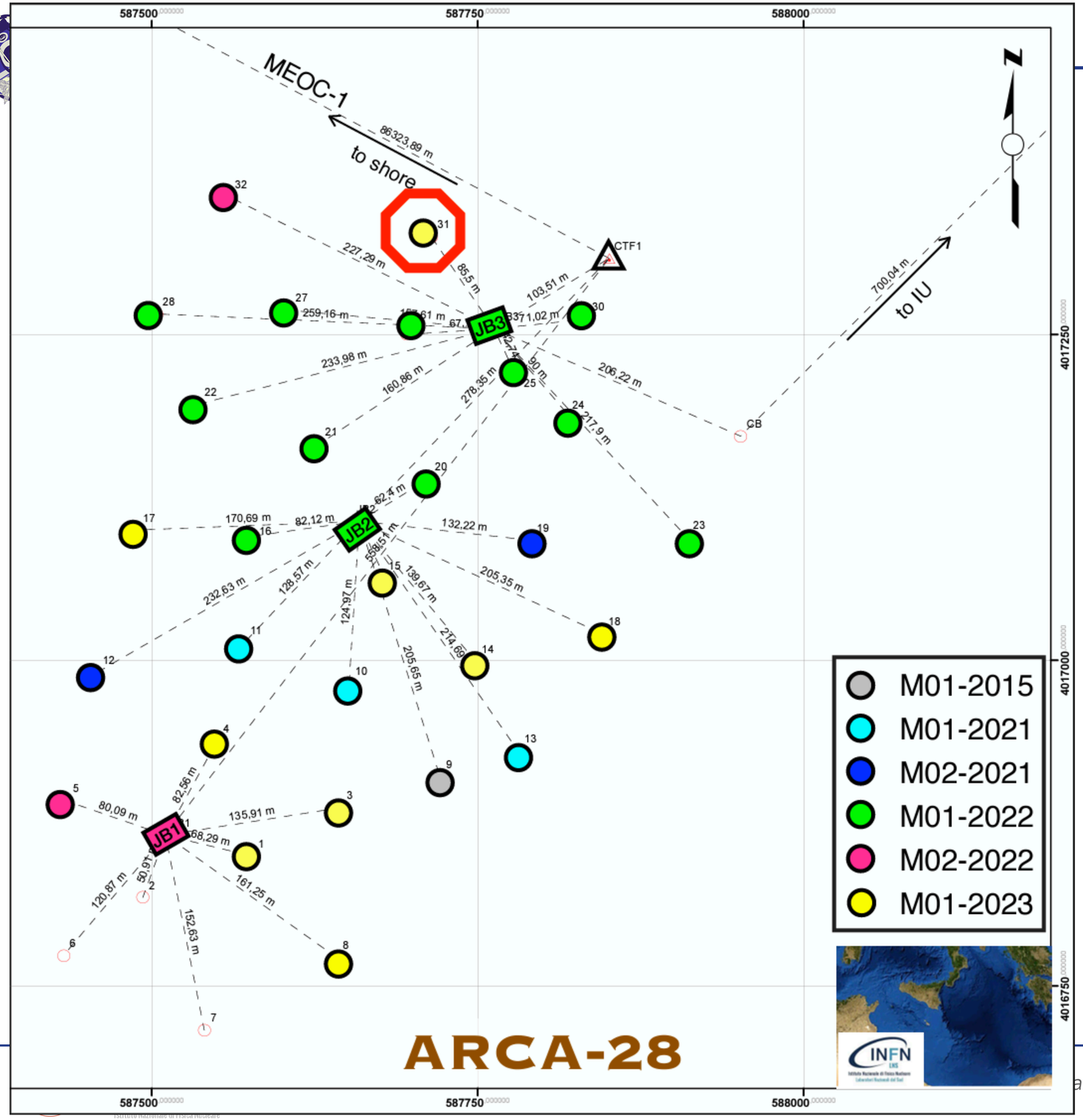


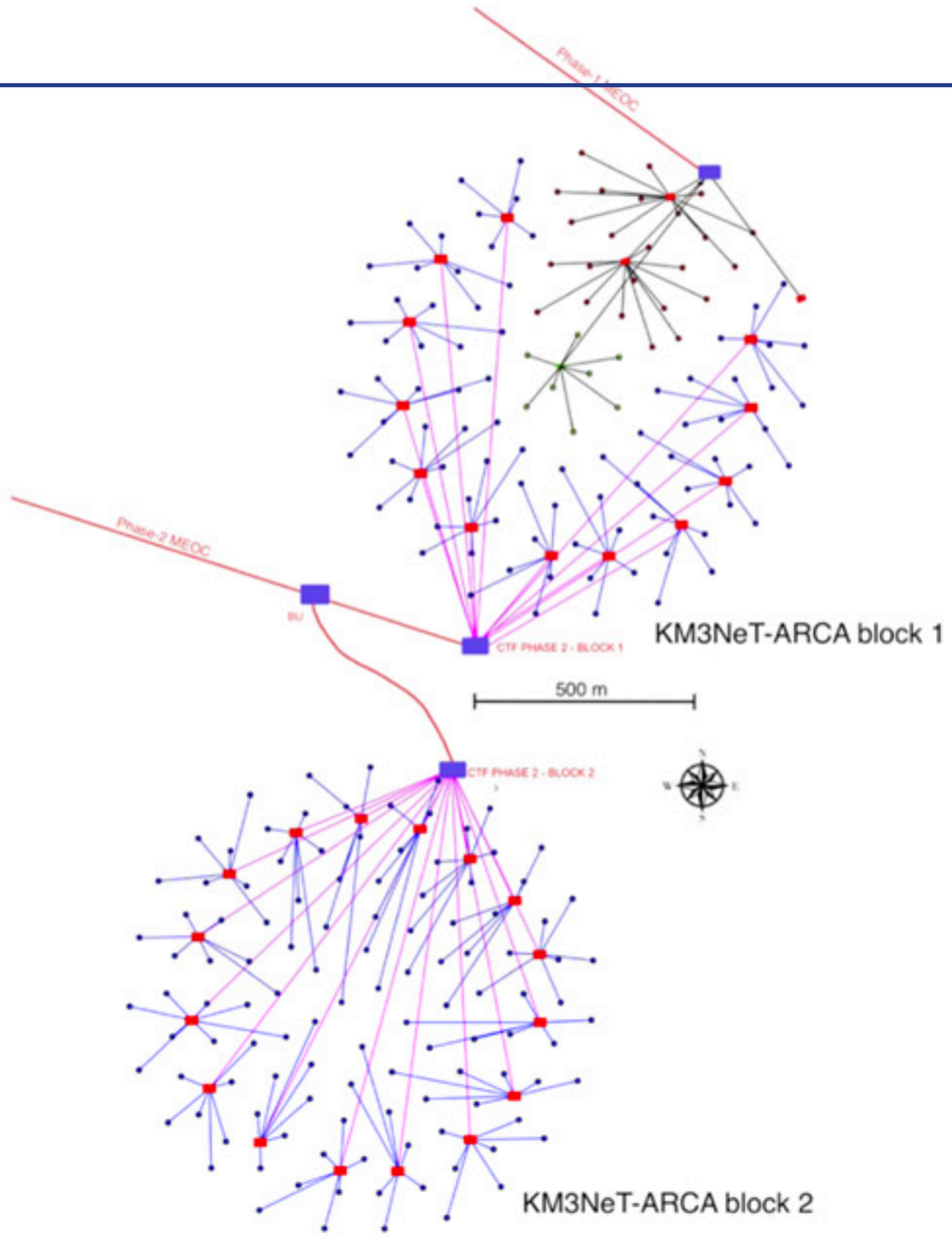
FULL ARCA Resolution



Shower expected energy resolution 5%
Angular resolution at 1.5 deg

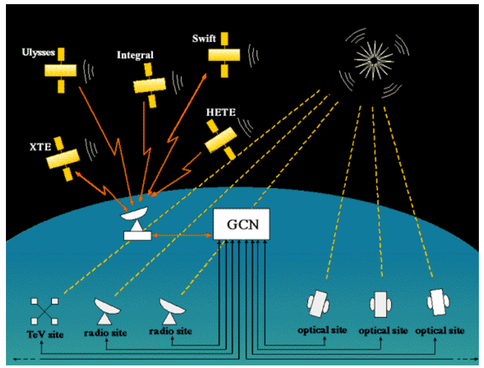


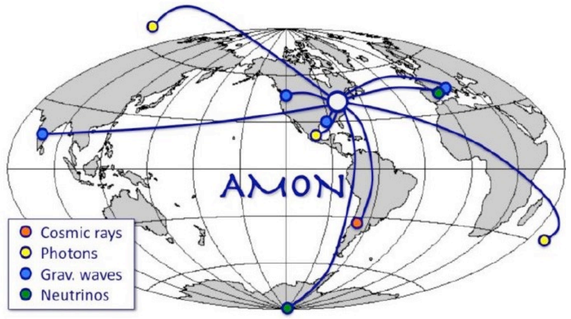

587500
587750
588000
MEOC-1
86323.89 m
to shore
CTF1
700.04 m
to IU
JB1
JB2
JB3
CB
M01-2015
M01-2021
M02-2021
M01-2022
M02-2022
M01-2023
ARCA-28


Phase-1 MEOC
Phase-2 MEOC
BU
CTF PHASE 2 - BLOCK 1
CTF PHASE 2 - BLOCK 2
500 m
KM3NeT-ARCA block 1
KM3NeT-ARCA block 2

Online follow-up strategies for KM3NeT

- IC170922A event and subsequent follow-up (see first slide) showed the potentiality of combined rapid observations;
- Detector constantly exchanging informations through circulars on interesting events;
- Specific "brokers" can be subscribed to receive alert stream (GCN, AMON, SNEWS and many others);





SNEWS

Worldwide effort of the astroparticle community. Many detectors involved in different areas:

LSC LIGO Scientific Collaboration
VIRGO
KAGRA

GW interferometers

IceCube
KM3NeT
SUPER-K
ANTARES

Neutrino telescopes

Fermi Gamma-ray Space Telescope
Swift
HAWC High Altitude Water Cherenkov Gamma-Ray Observatory
CALET
integral
H.E.S.S.
VERITAS
MAXI

γ-ray telescopes and ground based detectors

PIERRE AUGER OBSERVATORY

…and many others.