KM3NeT

Astroparticle Research with Cosmics in the Abyss

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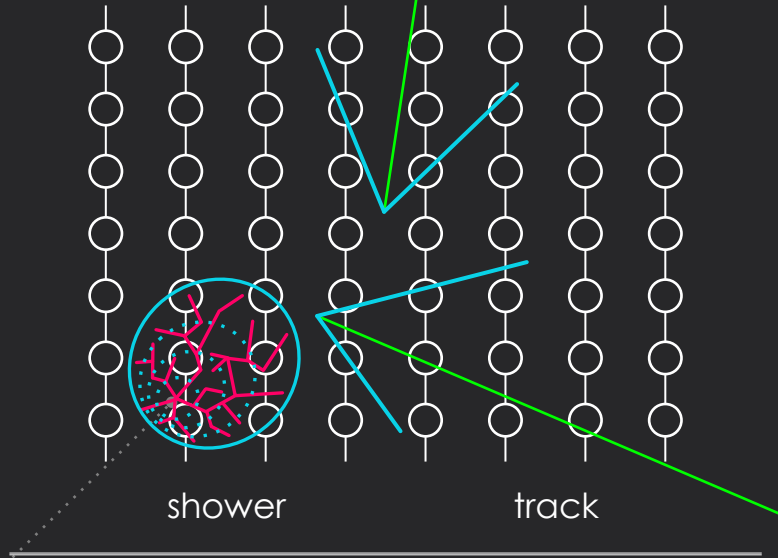
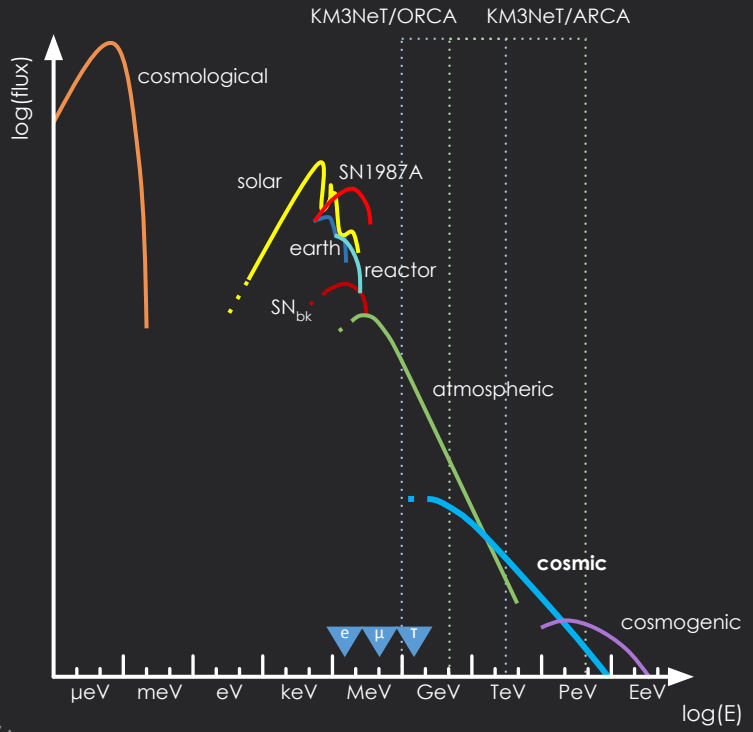
on behalf of the KM3NeT Collaboration
IFIC (CSIC-UV) | VEGA
Lake Louise Winter Institute 2025

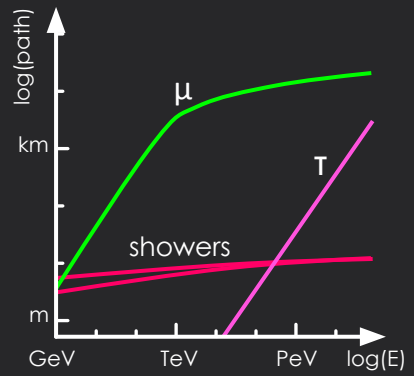
A Neutrino Telescope

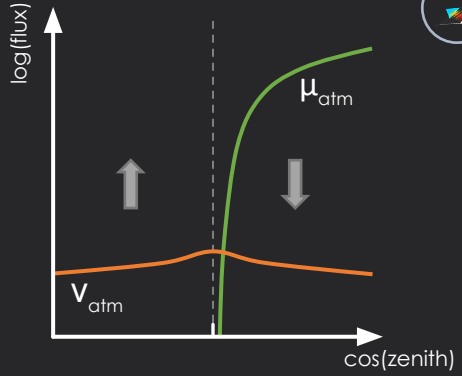
"We propose setting up apparatus in an underground lake or deep in the ocean in order to separate charged particle directions by Čerenkov radiation", **Markov 1960**

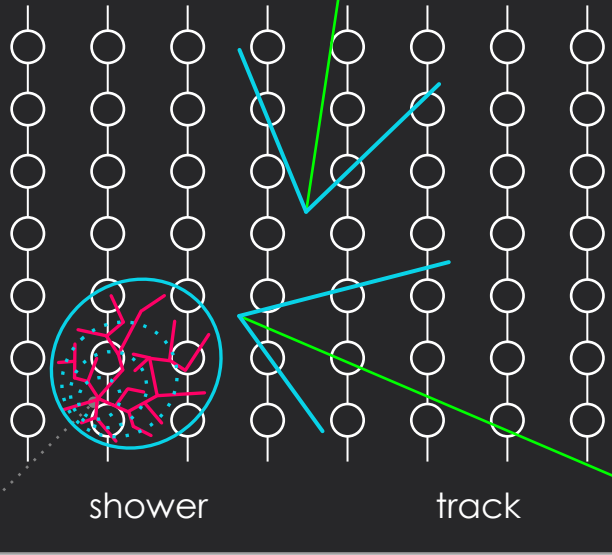




A Neutrino Telescope

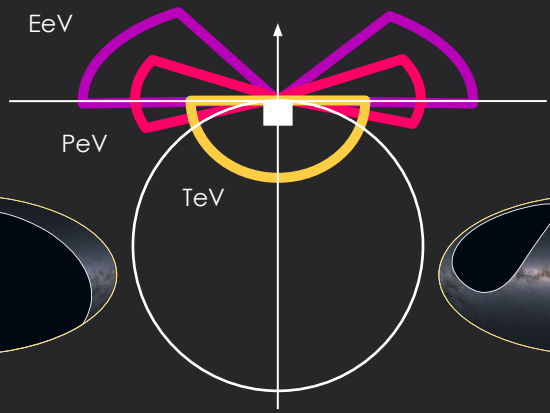


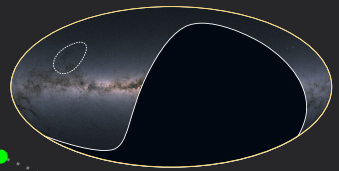


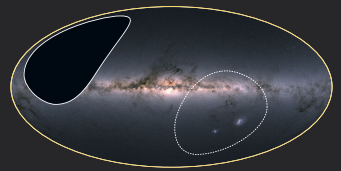


	1 km^3
μ_{atm}	~ 2000 / s (1)
ν_{atm}	~ 400 / day (2)
ν_{cos}	~ 200 / year (2)

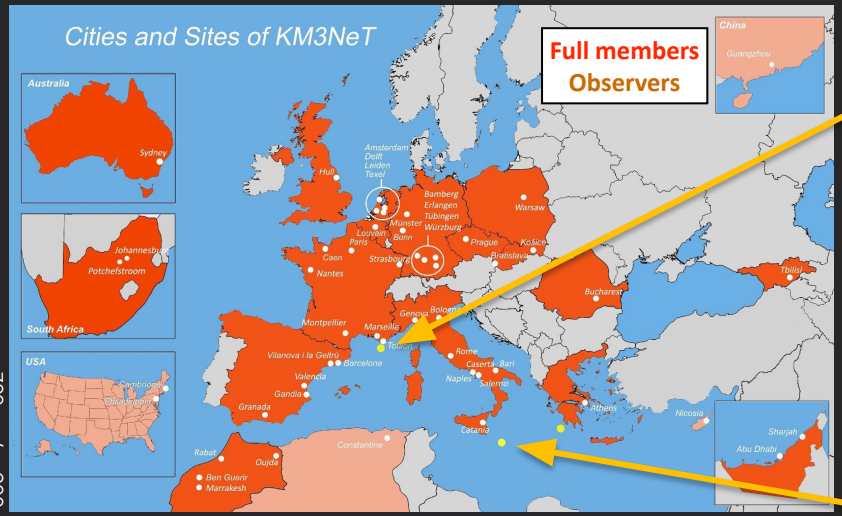
(1): depth dependent
(2): analysis dependent

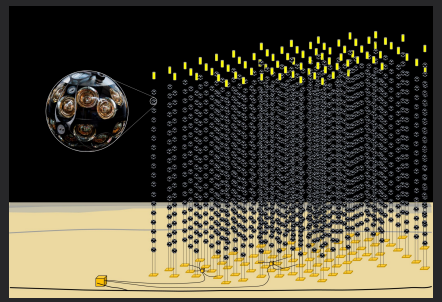


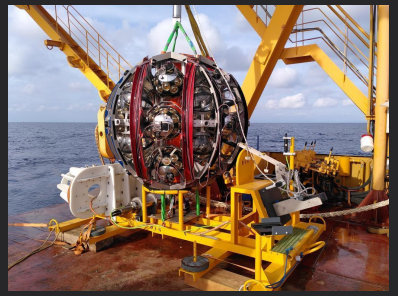


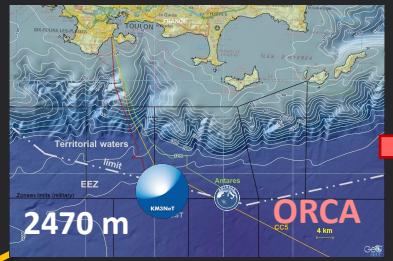


The KM3NeT Detector





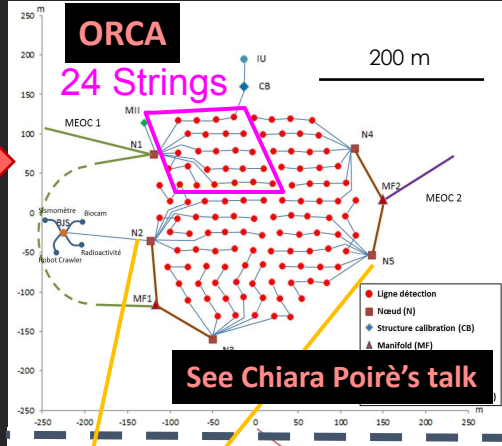




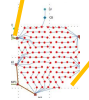
Oscillation Research with Cosmics in the Abyss

	ORCA	ARCA
Strings	115	115 × 2
String spacing	20 m	90 m
DOM spacing	9 m	36 m
Instrumented mass	7 Mton	500 × 2 Mton
Energy range	GeV	TeV – PeV

Astroparticle Research with Cosmics in the Abyss

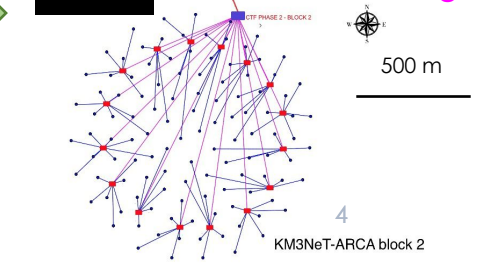


See Chiara Poirè's talk


for scale

ARCA

33 Strings



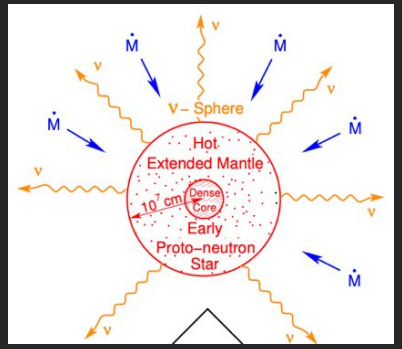
Broad Physics Scope

KM3NeT - ARCA

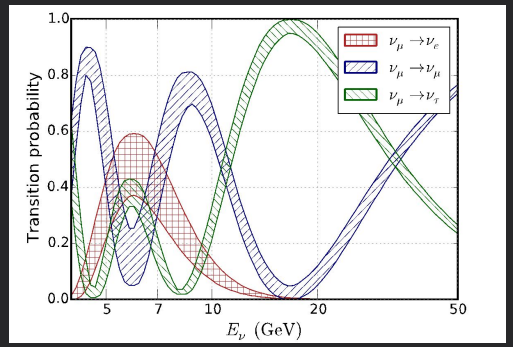
KM3NeT - ORCA

KM3NeT - ARCA

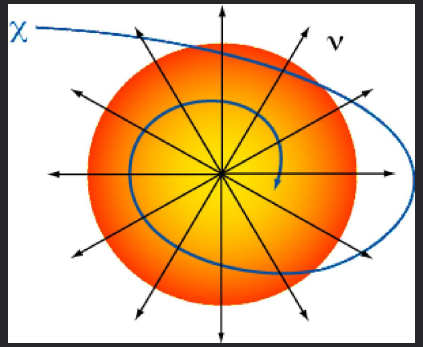
Low Energy
~ MeV



Low Energy
> 10 GeV



Medium Energy
10 GeV < E_ν < 10 TeV



High Energy
E_ν > 1 TeV

E

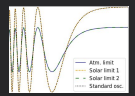
CCSN detection

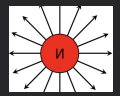
ν oscillations

dark matter search

ν from extra-terrestrial sources, origin and production mechanism of HE CR

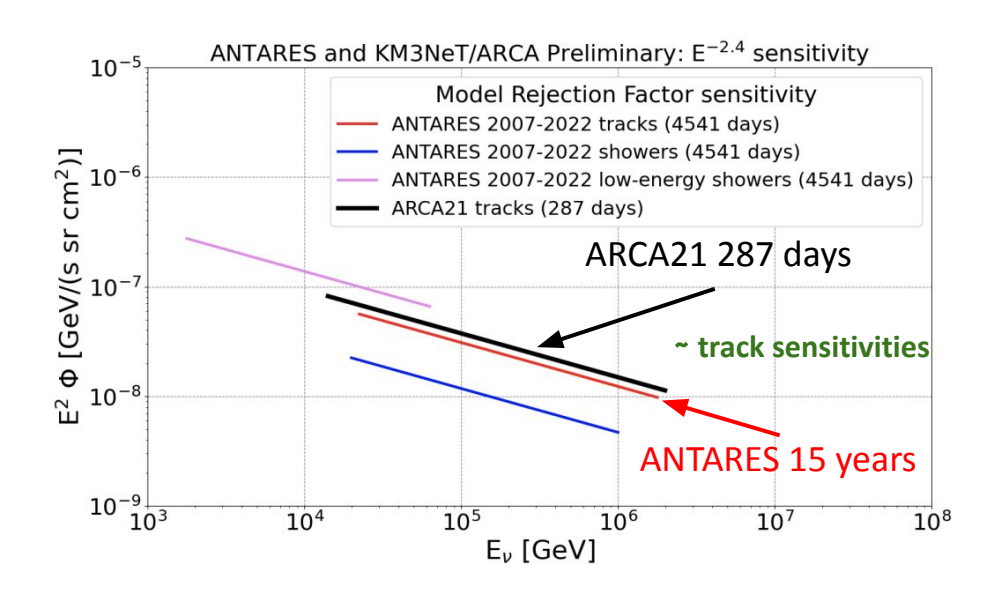
…and exotic searches

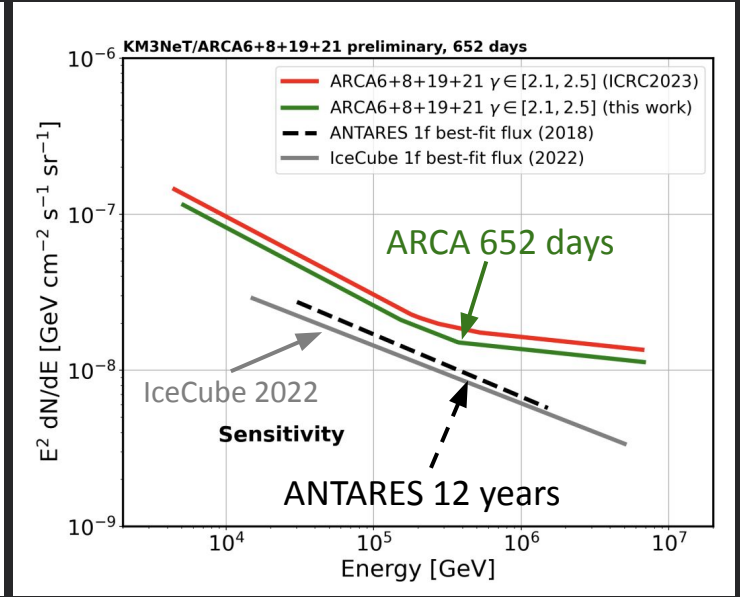




NEUTRINO ASTRONOMY

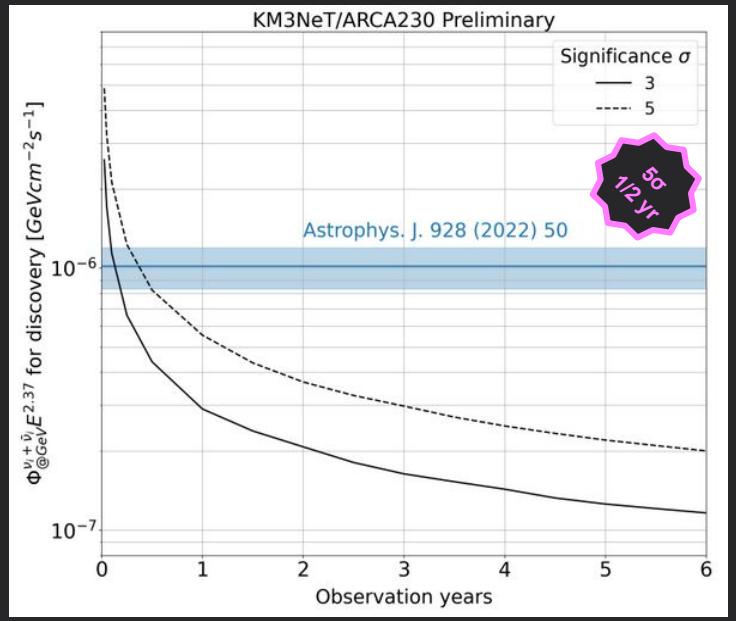
Diffuse searches



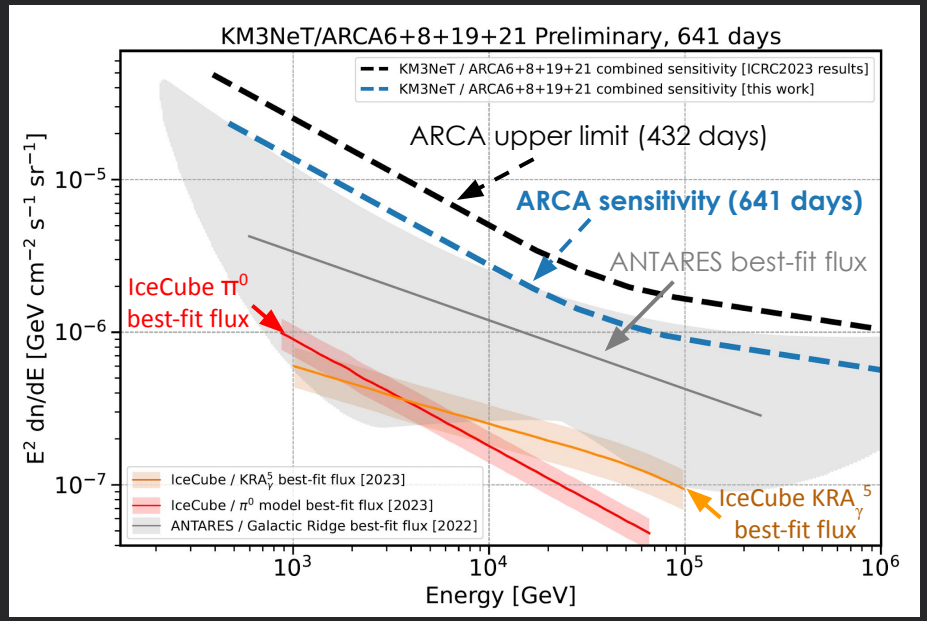


KM3NeT/ARCA rapidly approaching ANTARES/IceCube sensitivities

Diffuse searches

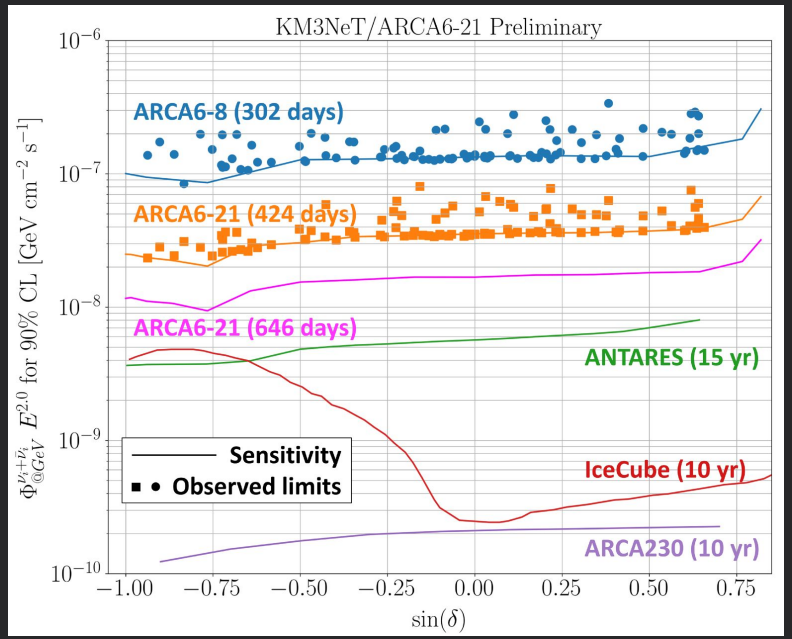


Full KM3NeT/ARCA
diffuse flux discovery

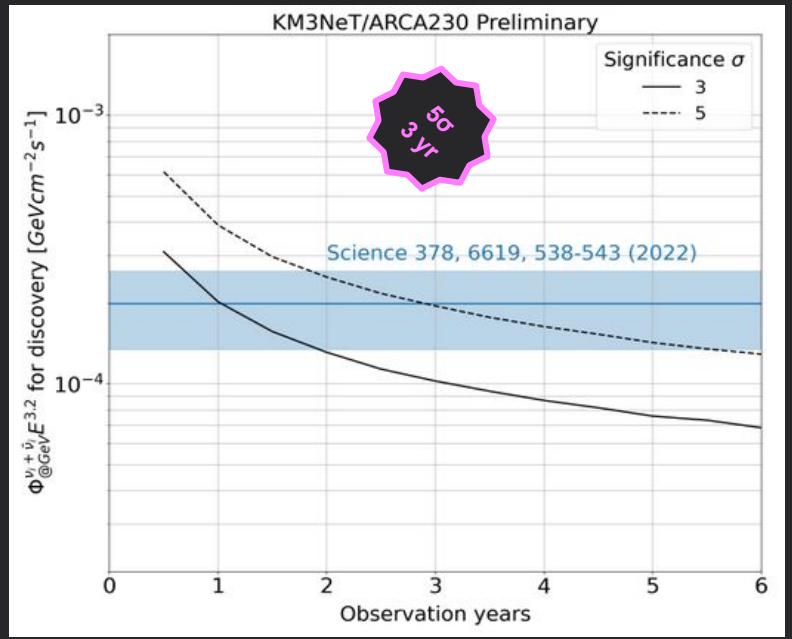


KM3NeT/ARCA Galactic Plane
$|l| < 31^o$ $|b| < 4^o$-5^o

Point source searches



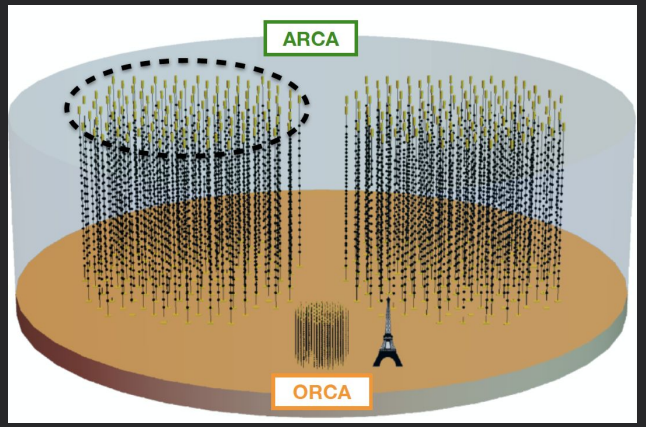
KM3NeT/ARCA partial configurations
PS sensitivities & upper limits



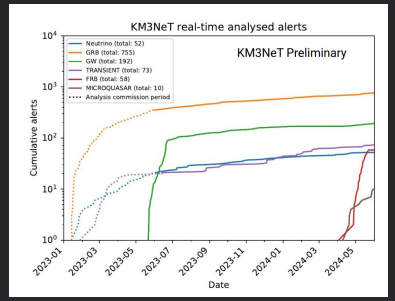
Full KM3NeT/ARCA
discovery for NGC 1068

Real Time Multi-Messenger Program

Dedicated software+hardware at shore stations for Real-Time Analysis (RTA)

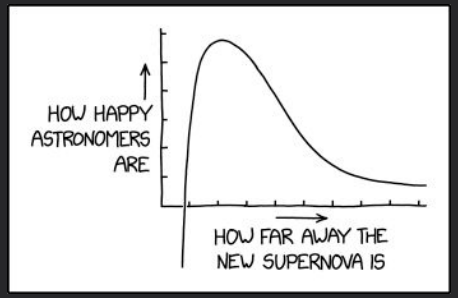


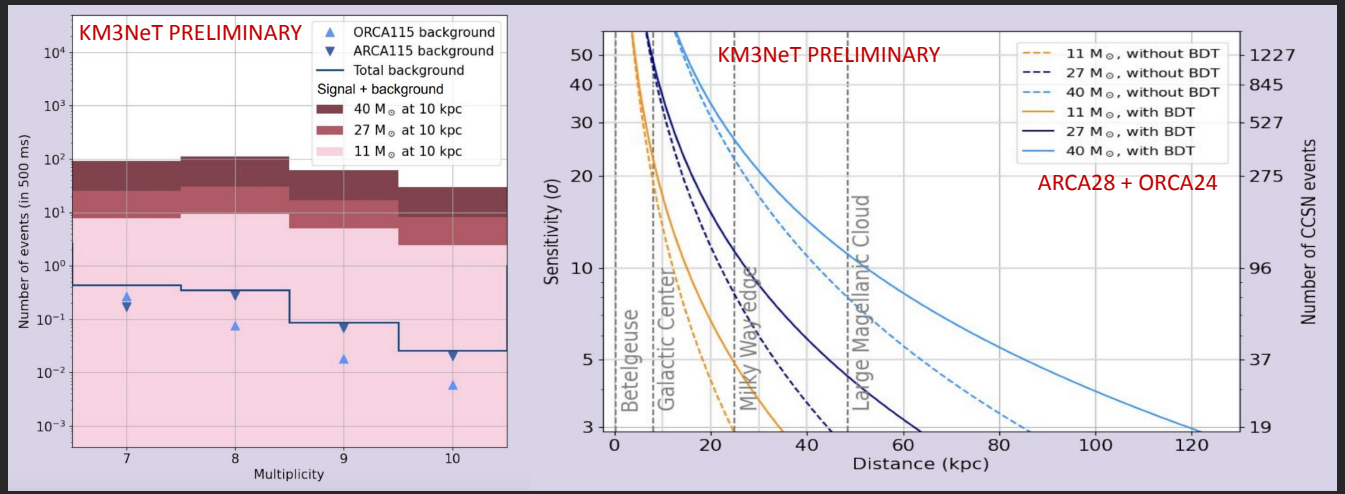
coming soon…



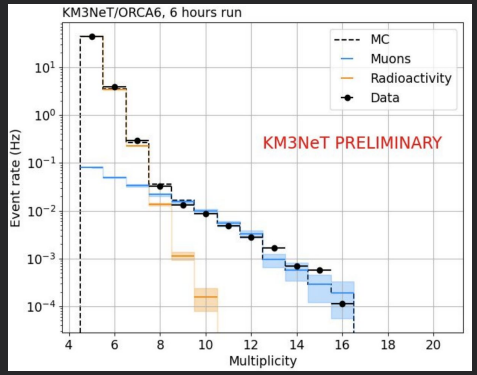
Receiving alert system: **OPERATIVE**, since November 2022, on-line analysis and follow-up
Sending alert system: **INCOMING**, HE neutrino alerts will be sent in real-time (commissioning in private with some partners starting this year)

CCSN searches





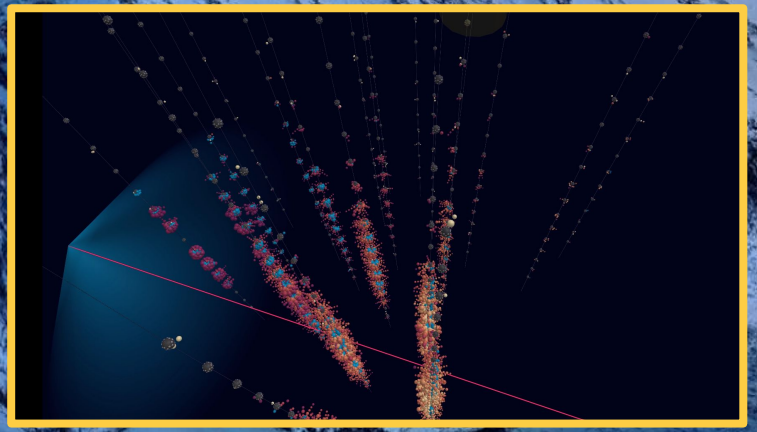
Each single DOM can act as a detector

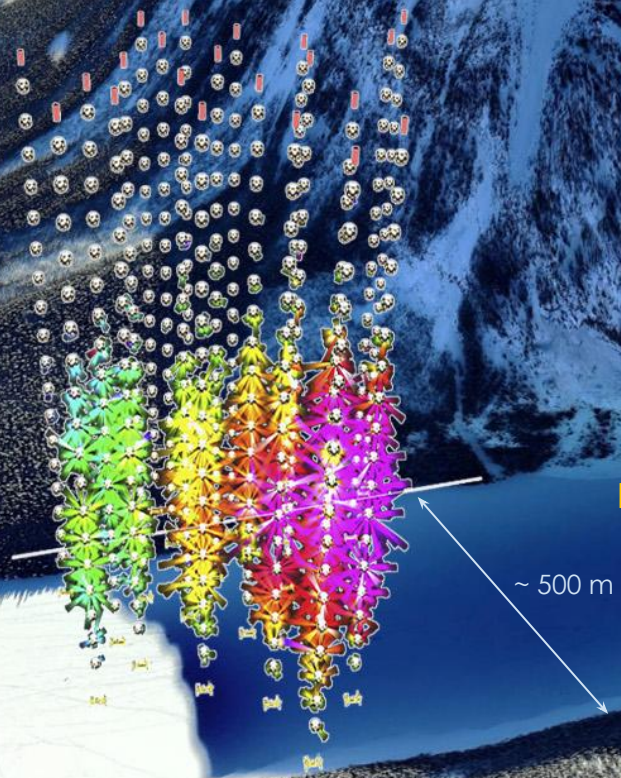


- Increase of DOM rates due to many MeV neutrinos from the collapse
- Alert system already operational and integrated in SNEWS network
- 5σ detection by ARCA+ORCA for 27 $M_\odot$ CCSN at <50 kpc distance

…and the unexpected

~ 700 m above lake level

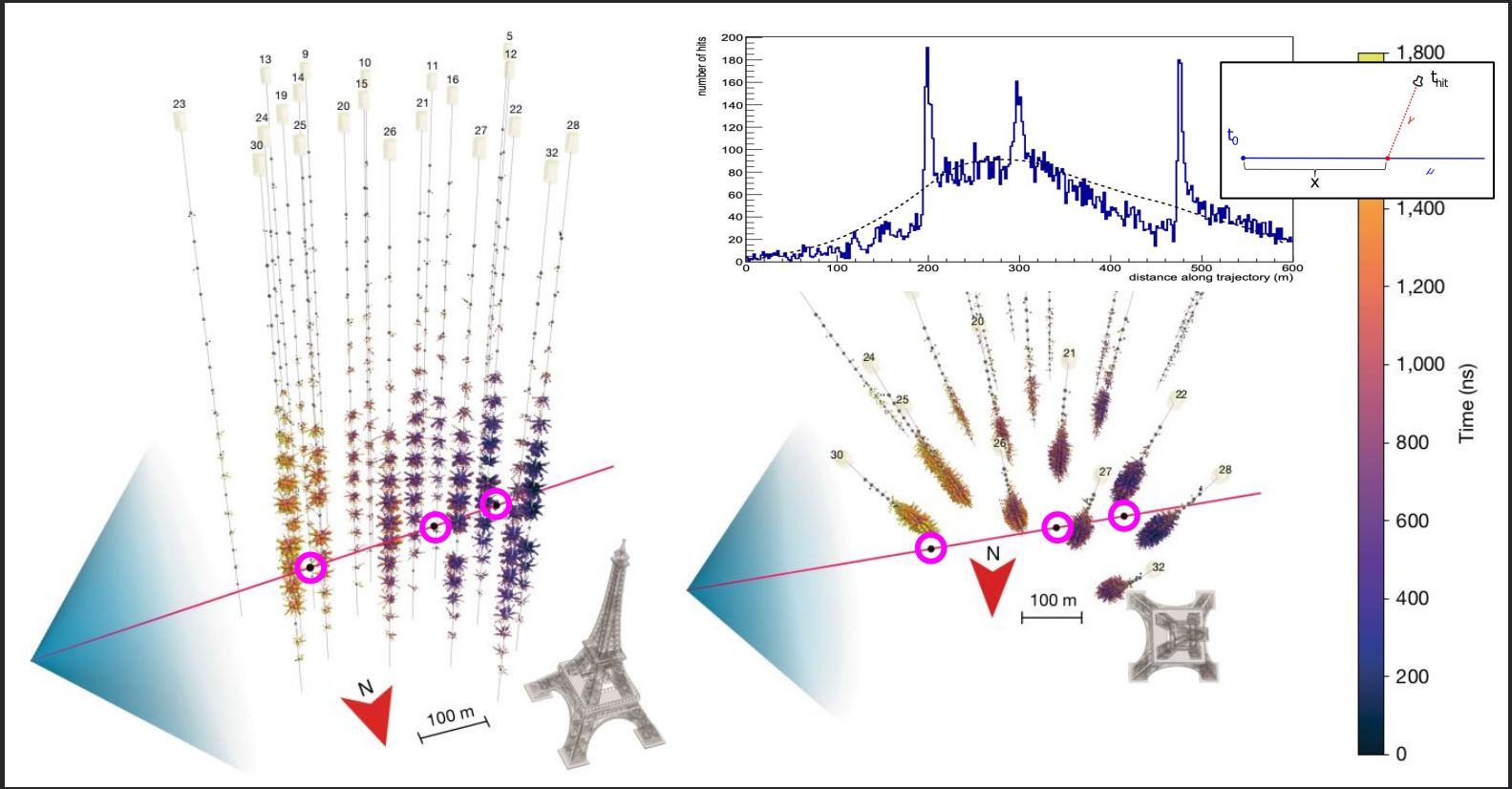




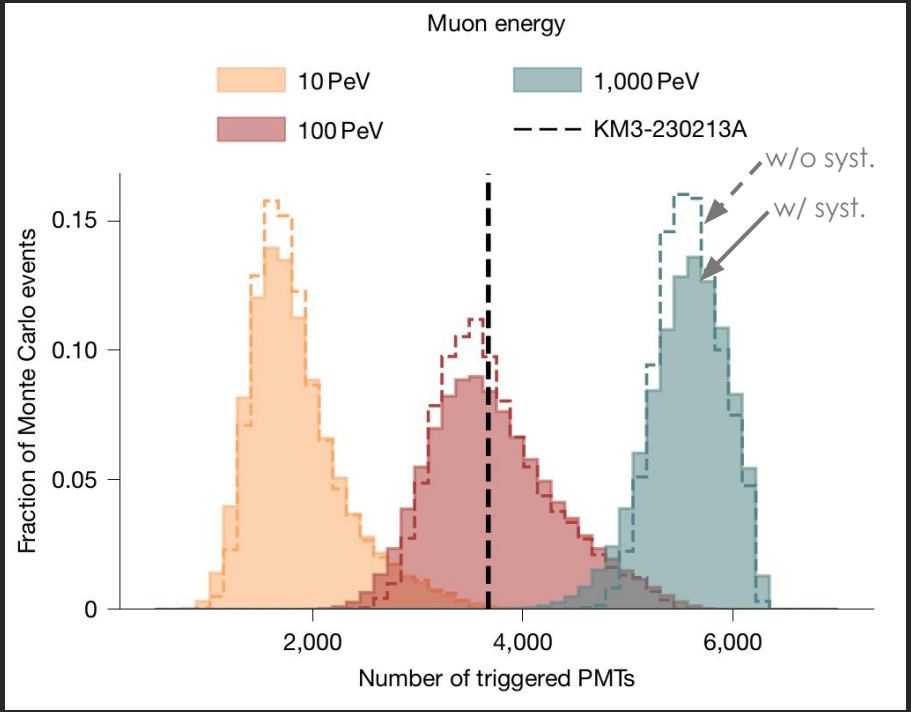
KM3-230213A: muon track compatible with a 220 PeV neutrino rendered in Lake Louise

KM3-230213A event

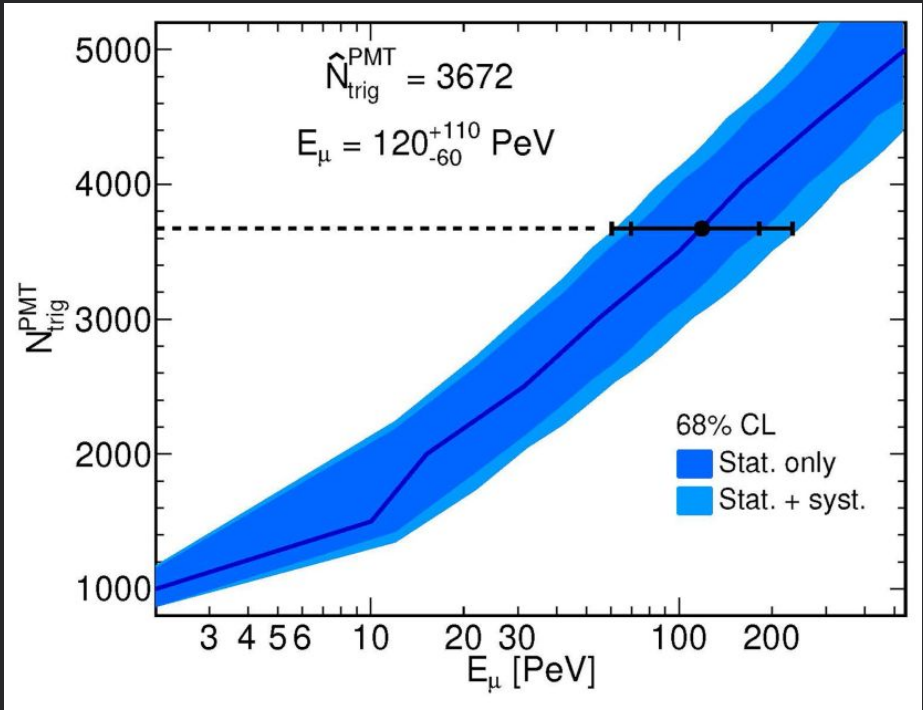
Event well reconstructed as a track, showing 3 large energy depositions through the detector



KM3-230213A energy



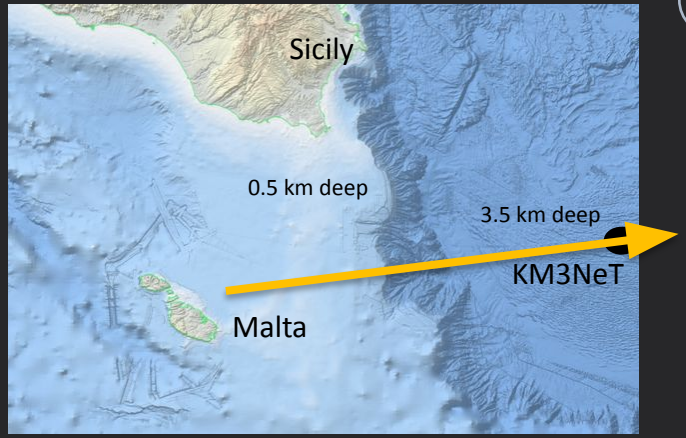
Number of triggered PMTs as a proxy of the energy
KM3-230213A triggered 3,672 PMTs (35%)

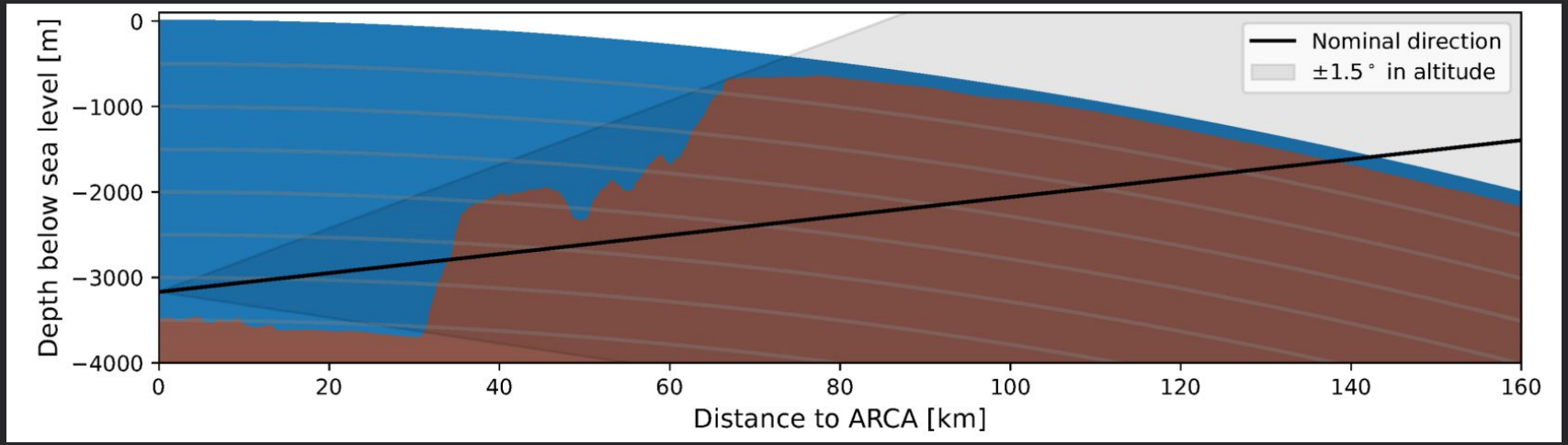


Muon energy estimation results in 120^{+110}_{-60} PeV (1σ)

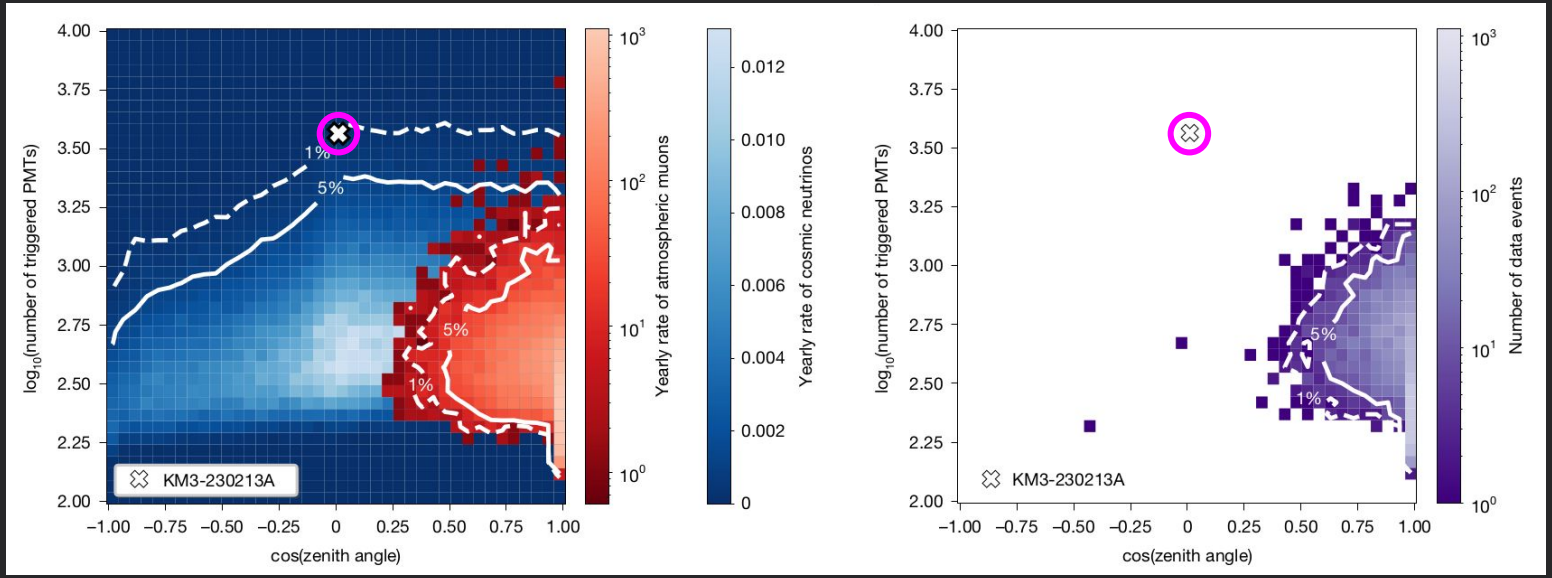
KM3-230213A direction

- (az. , el.) = (259.8^{o} , 0.6^{o})
- Event coming from west, slightly downgoing
- Angular uncertainty ~1.5^{o}, dominated by absolute pointing
- EeV muons range <60 km (<30 km for a 10 PeV detection)
- Track 140 km from the surface (300 km w.e.)
- Even with zenith +2^{o} (~90% containment) are ~60 km w.e.





KM3-230213A Earth origin

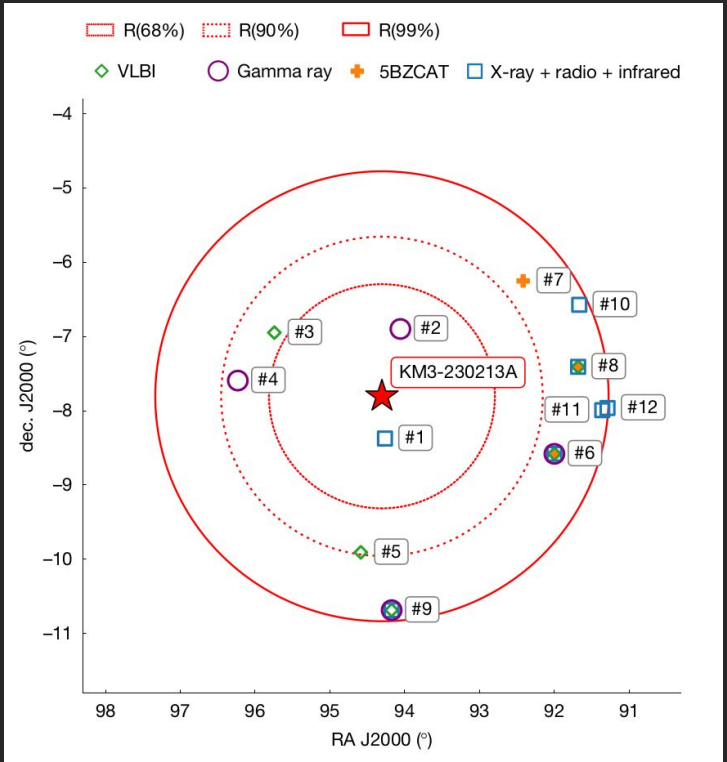


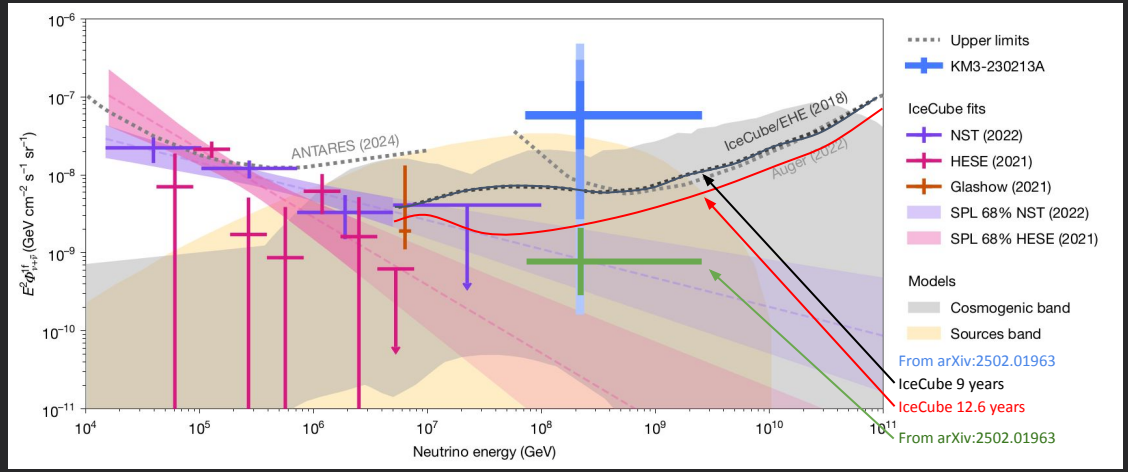
Unlikely atmospheric origin:

$P(\nu_{atm})$ beyond 4σ (less than 10^{-5} ev/year for >100 PeV)

$P(\mu_{atm})$ beyond 6σ (less than 10^{-9} ev/year for 10 PeV)

KM3-230213A celestial origin





- (R.A. , dec.) = (94.3° , -7.8°)
- Neutrino energy estimation: 220^{+570}_{-110} PeV (1σ)
- No clear counterpart identified
- Corresponding E^{-2} flux: $5.8^{+10.1}_{-3.7} \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} (90%)
- Tension of 2.2σ, around once in 70 years in ARCA21

KM3-230213A numbers summary

Energy estimation summary

	|←90%	|←1σ	**E (PeV)**	1σ→|	90%→|
E_μ	35	60	**120**	230	380
E_ν	72	110	**220**	790	2600

Background probability summary

$P(\mu_{atm})$	**>6σ**	10^{-10} ev/year for 100 PeV
		10^{-9} ev/year for 10 PeV
$P(\nu_{atm})$	**>4σ**	1–5 x 10^{-5} ev/year for >100 PeV

Angular estimation summary

(RA , dec)		(94.3º , -7.8º)		
(az , el)		(259.8º , 0.6º)		
ang. error	50%	**1σ**	90%	99%
	1.2º	**1.5º**	2.2º	3º
From absolute pointing:				
Moon shadow		0.24º		
Absolute orientation		**1º**		
From track reconstruction:		50%	90%	
100 PeV		0.12°	0.28°	
500 PeV		0.17°	0.38°	

Conclusions

- Over 15% of the KM3NeT detector already operational.
- Completion expected within the decade.
- Performances are fastly catching up the state of the art.
- Excellent angular resolution and an unprecedented survey of the Southern sky.
- Exceptional event detected with unknown origin.
- **…exciting times ahead for neutrino astronomy!**

"ARCA WWRS DU splash in the Mediterranean sea at the sunrise"
winner of the KM2NeT 2024 picture contest
Andrea Simonelli

Thanks for your attention

KM3NeT

VEGA Valencia Experimental Group of Astroparticles