Neutrino astronomy with KM3NeT/ARCA

First results and perspectives

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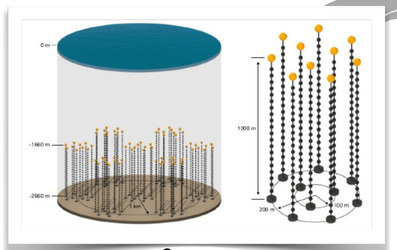
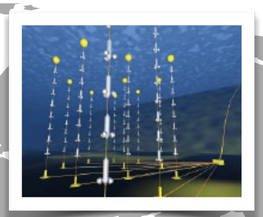
On behalf of the KM3NeT Collaboration

High-energy neutrino telescopes: World map



1 km^3, R&D

P-ONE (Canada)

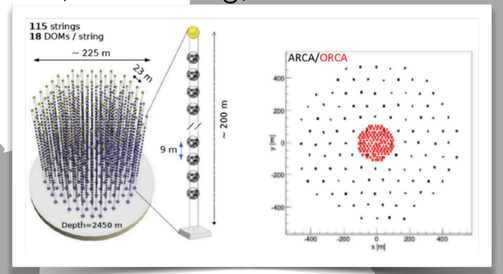


ANTARES, dismantled
>0.01 km^3, 2008-2022

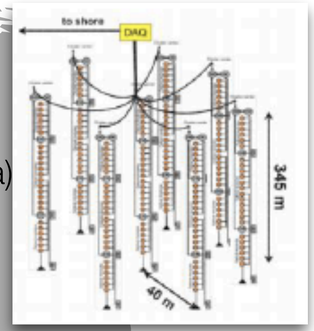
KM3NeT-ORCA (France)

KM3NeT-ARCA (Sicily, Italy)

>1 km^3, data taking, **in construction**

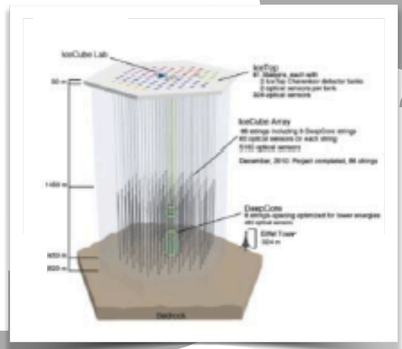


Baikal/GVD (Russia)
1 km^3, in construction



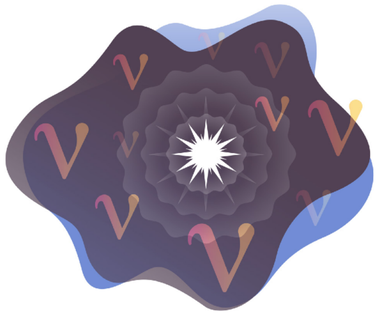
IceCube
(South Pole)
1 km^3, 2011-data taking

IceCube-Gen2
(South Pole)
10 km^3, R&D

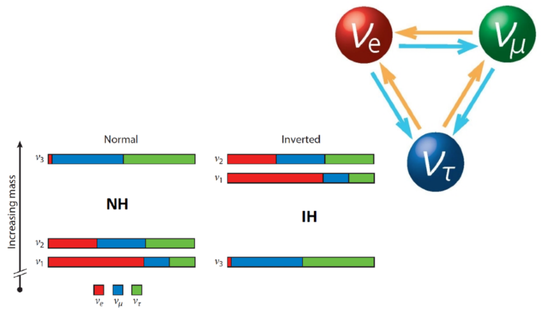


High-energy neutrino telescopes: science

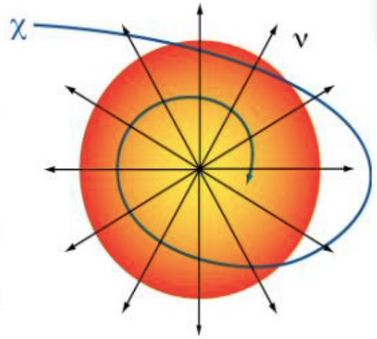
Supernova neutrinos



Neutrino mass hierarchy
Neutrino oscillations



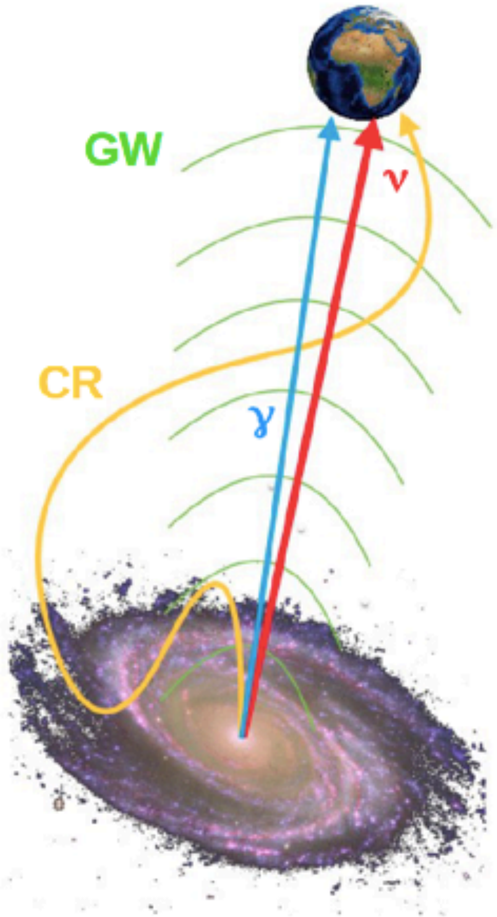
Dark matter



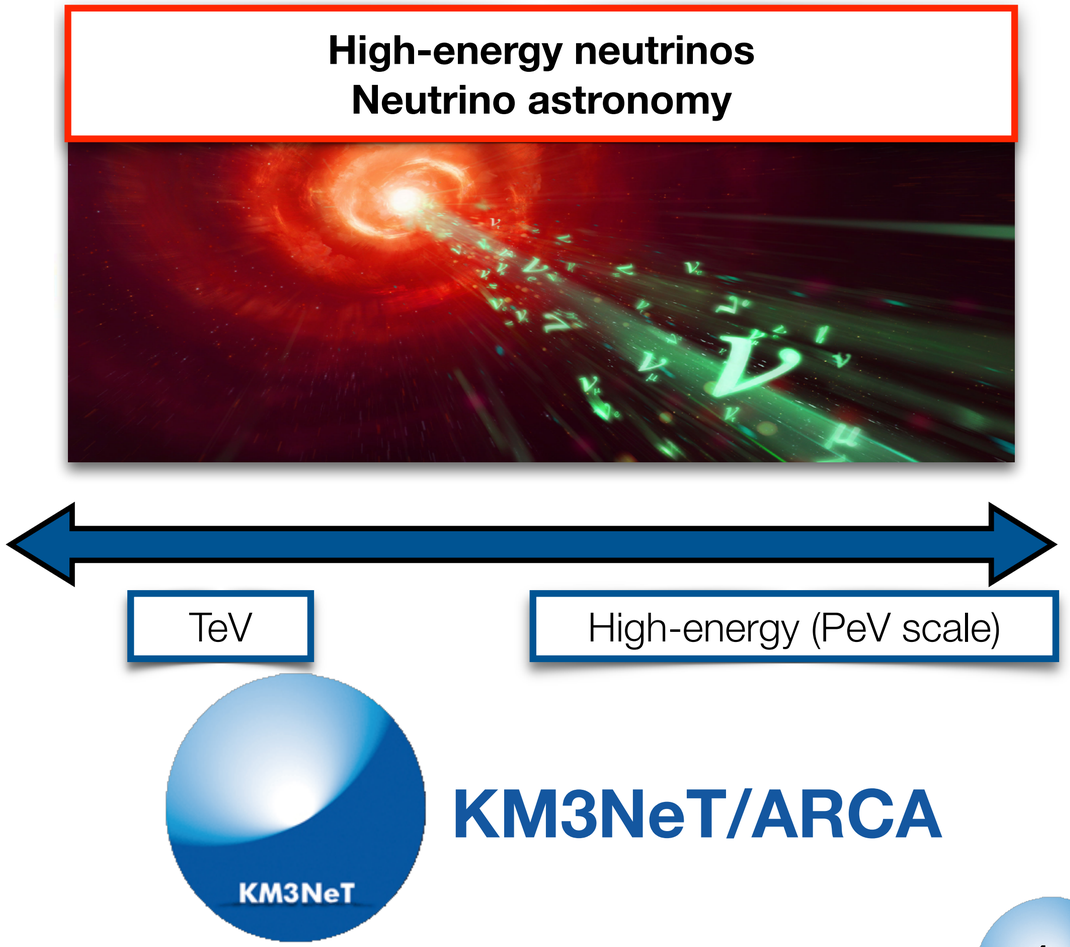
High-energy neutrinos
Neutrino astronomy

Low-energy (MeV scale) — GeV — TeV — High-energy (PeV scale)

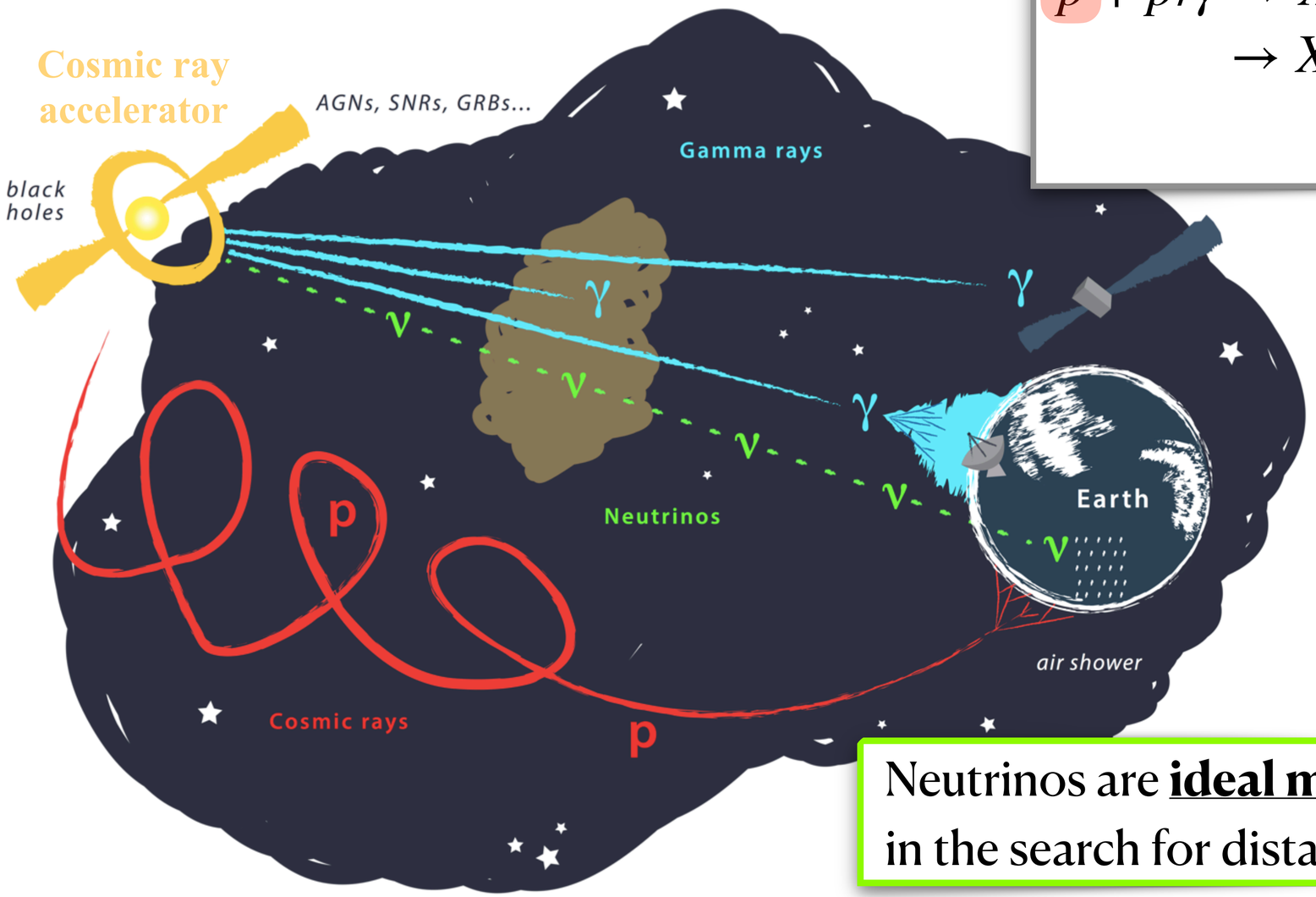
This talk…



- Why neutrinos to do astronomy
- What is KM3NeT
- Focus on KM3NeT/ARCA
- Detection principle
- Performances for the full detector
- Some results obtained with first KM3NeT/ARCA data
- Multi-messenger framework of KM3NeT



Multi-messenger astronomy and role of neutrinos



HADRONIC scenario

$$p + p/\gamma \rightarrow X + \pi^0 \rightarrow \gamma\gamma$$
$$\rightarrow X + \pi^{\pm} \rightarrow \mu^{\pm} + \overset{(-)}{\nu}_{\mu}$$
$$\mu^{\pm} \rightarrow e^{\pm} + \overset{(-)}{\nu}_{e} + \overset{(-)}{\nu}_{\mu}$$

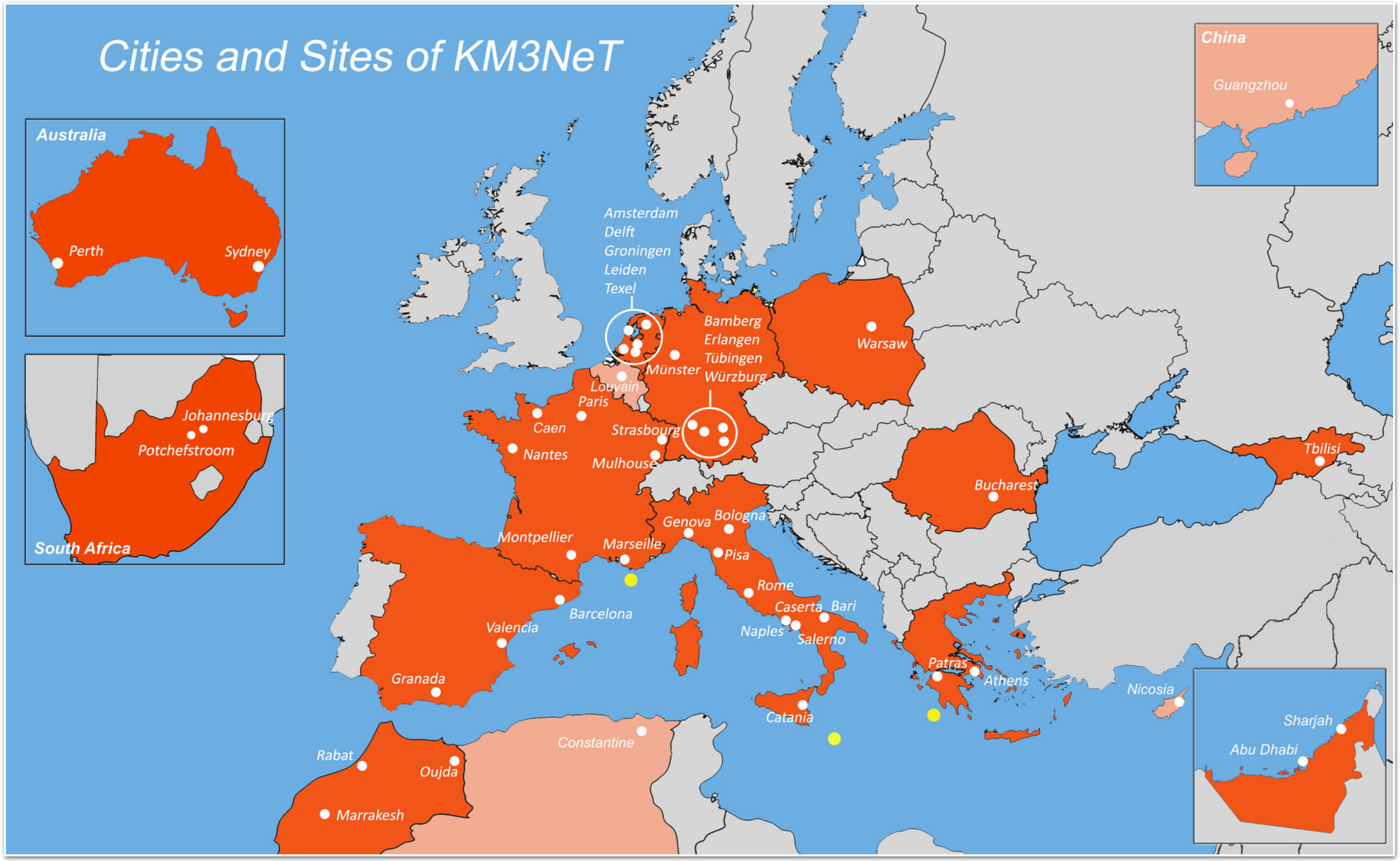
Unique properties of **neutrinos**: electrically neutral, stable, and weakly interacting particles

- ★ **No deflection** in magnetic field (unlike cosmic rays)
- ★ **No absorption** in cosmic backgrounds, as Extragalactic Background Light (unlike gamma-rays)

Neutrinos are **ideal messengers** in the search for distant astrophysical objects

The KM3NeT Collaboration

KM3NeT
www.km3net.org



KM3NeT in numbers

- 4 continents
- 16 countries
- 55 groups

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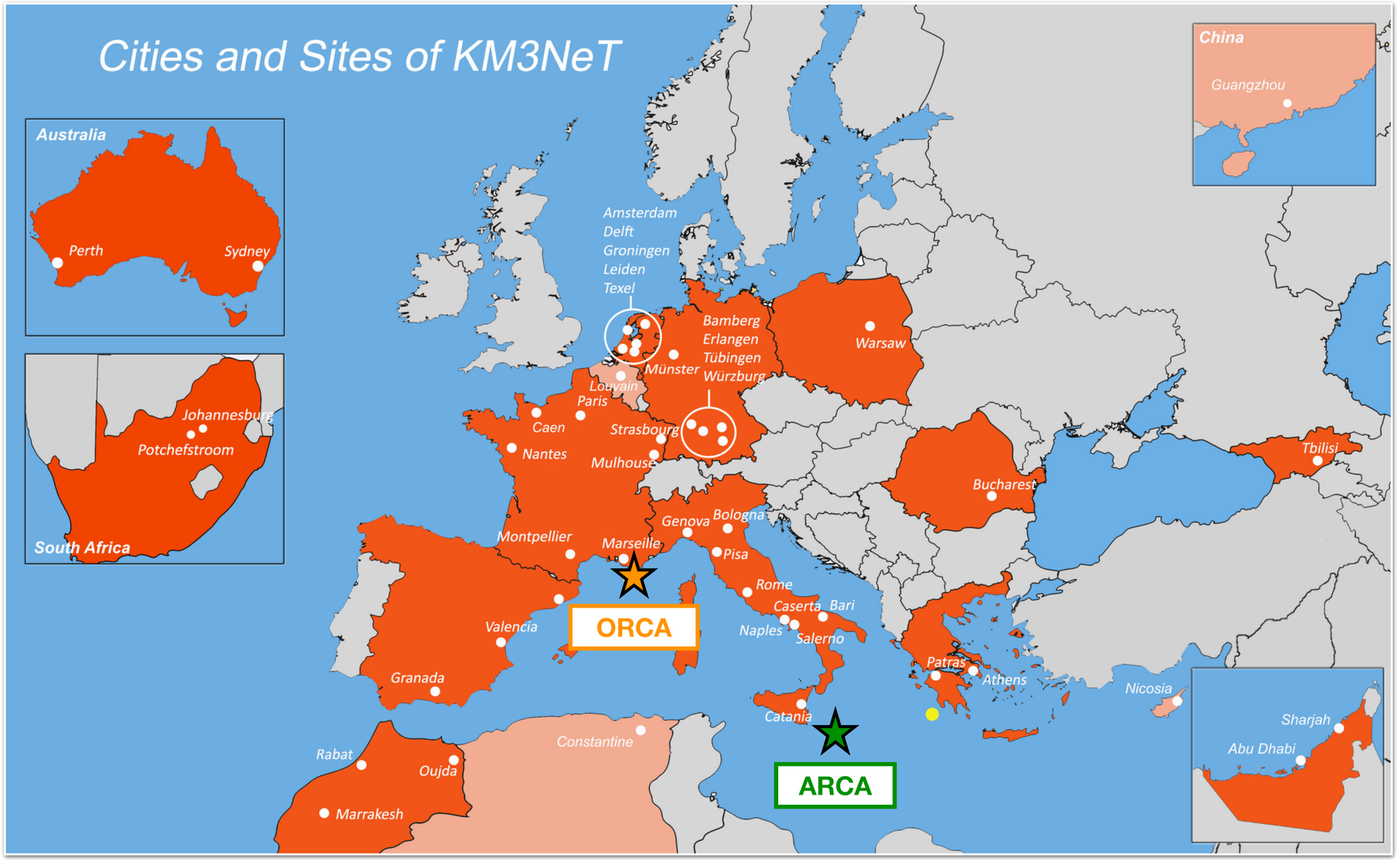


KM3NeT in numbers

- 4 continents
- 16 countries
- 55 groups
- **2 detectors**

~ GeV ⟷ ~10 PeV

Oscillation **R**esearch with **C**osmics in the **A**byss

Designed for **low-E** studies

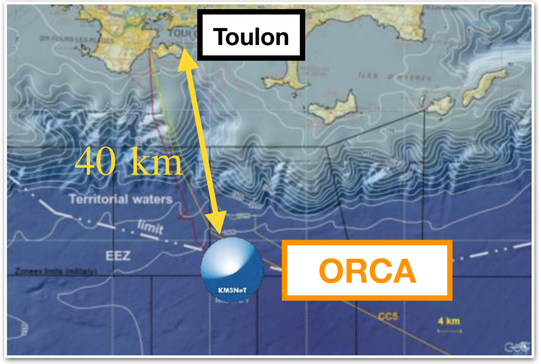
Astroparticle **R**esearch with **C**osmics in the **A**byss

Designed for **high-E** studies

The KM3NeT neutrino telescope

KM3NeT
www.km3net.org

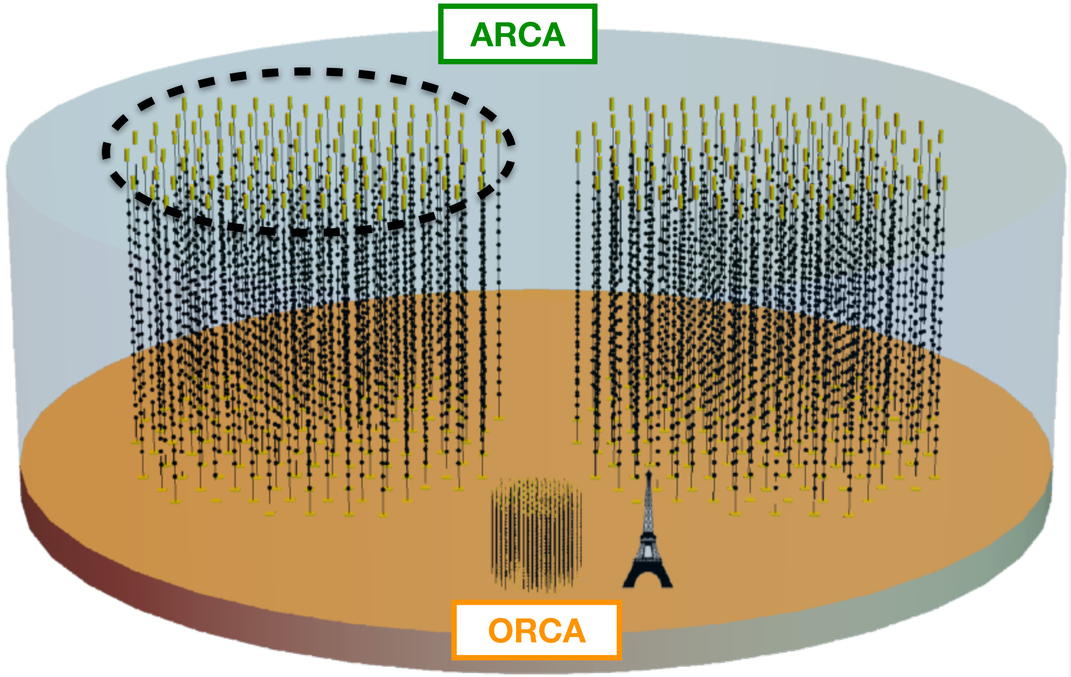
- Deep infrastructure under construction in the Mediterranean Sea
- Two instrument sites: ORCA (France) and ARCA (Italy) ⟶ **Same technology** used for both detectors but **different physics**



	ARCA	ORCA
Location	Italy (Sicilian coast)	France (coast of Toulon)
Depth	3450 m	2450 m
Distance from shore	100 km	40 km
Number of DUs	**115 x 2 (2 BB)**	**115 (1 BB)**
Instrumented volume	~ 1 Gton	~ 7 Mton

> 1 km^3 neutrino telescope

3D array of optical sensors



1 Building Block = 115 Detection Units
(1 BB = 115 DUs)

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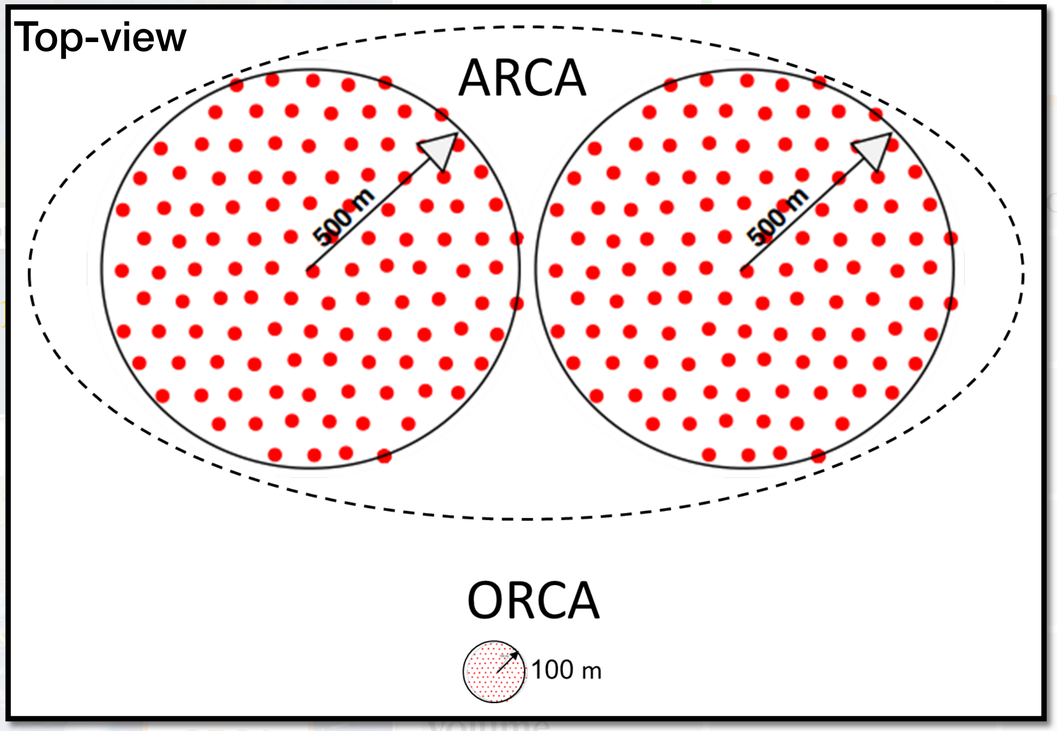
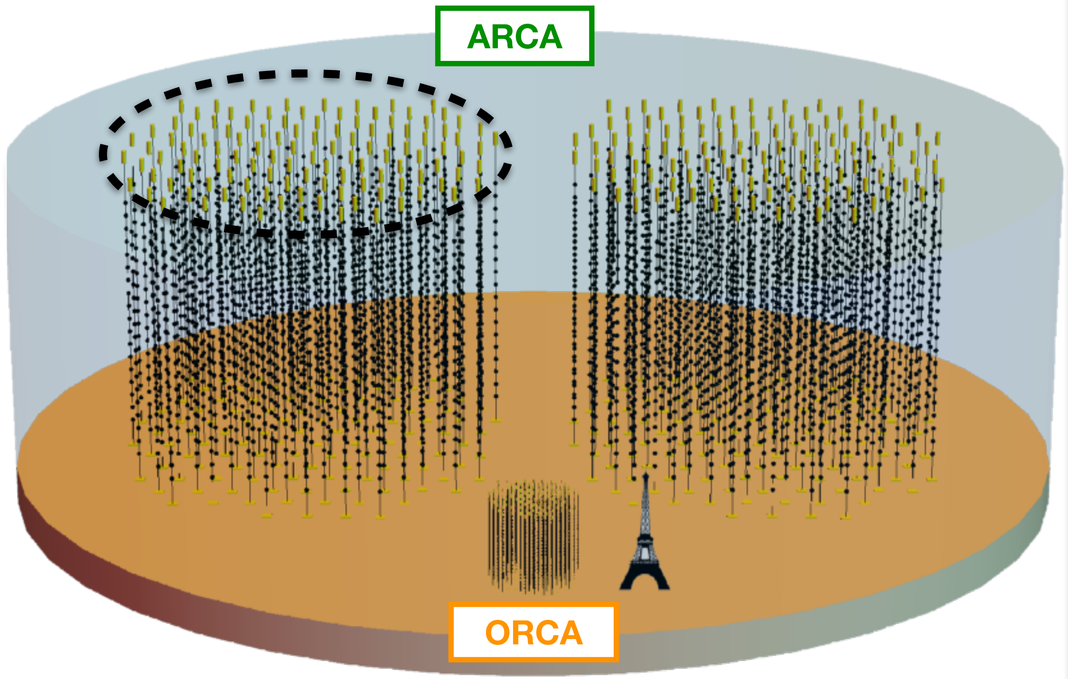


3D array of optical sensors



1 Building Block = 115 Detection Units

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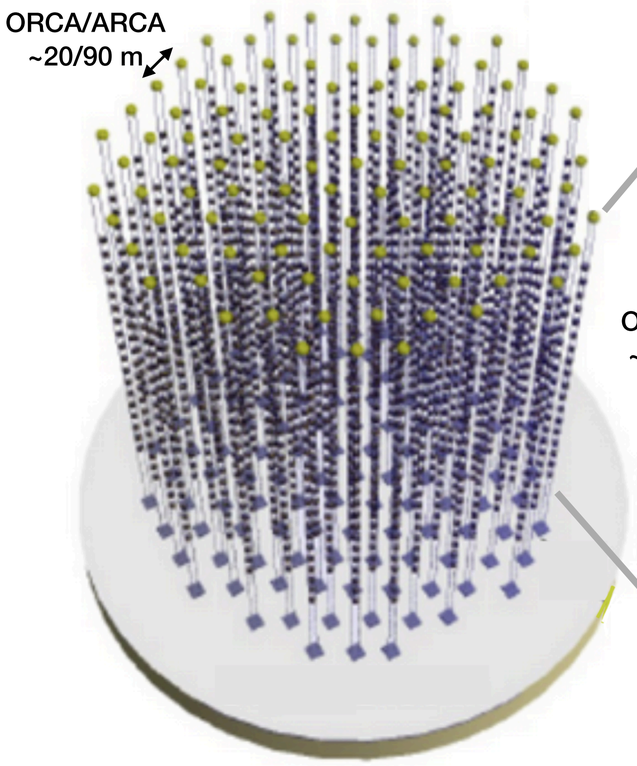
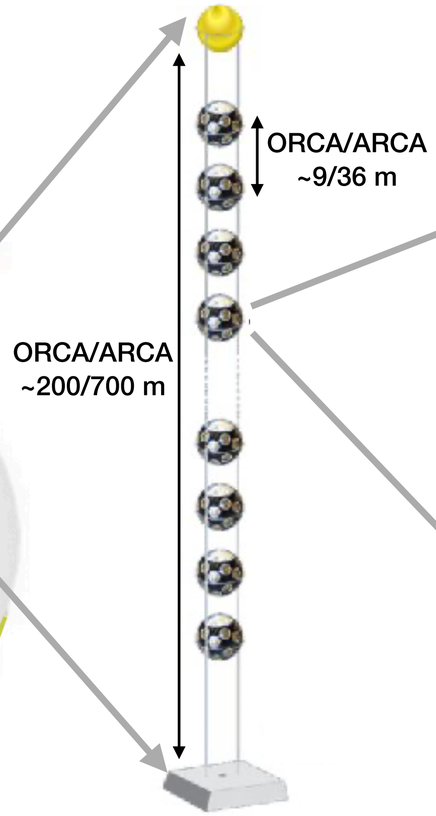
KM3NeT: detector design

KM3NeT
www.km3net.org

Building Block



Detection Unit



Digital Optical Module

17" glass sphere containing:

- 31x3" PMTs
- LED and Piezo
- Front and electronics

1 BB = 115 DUs

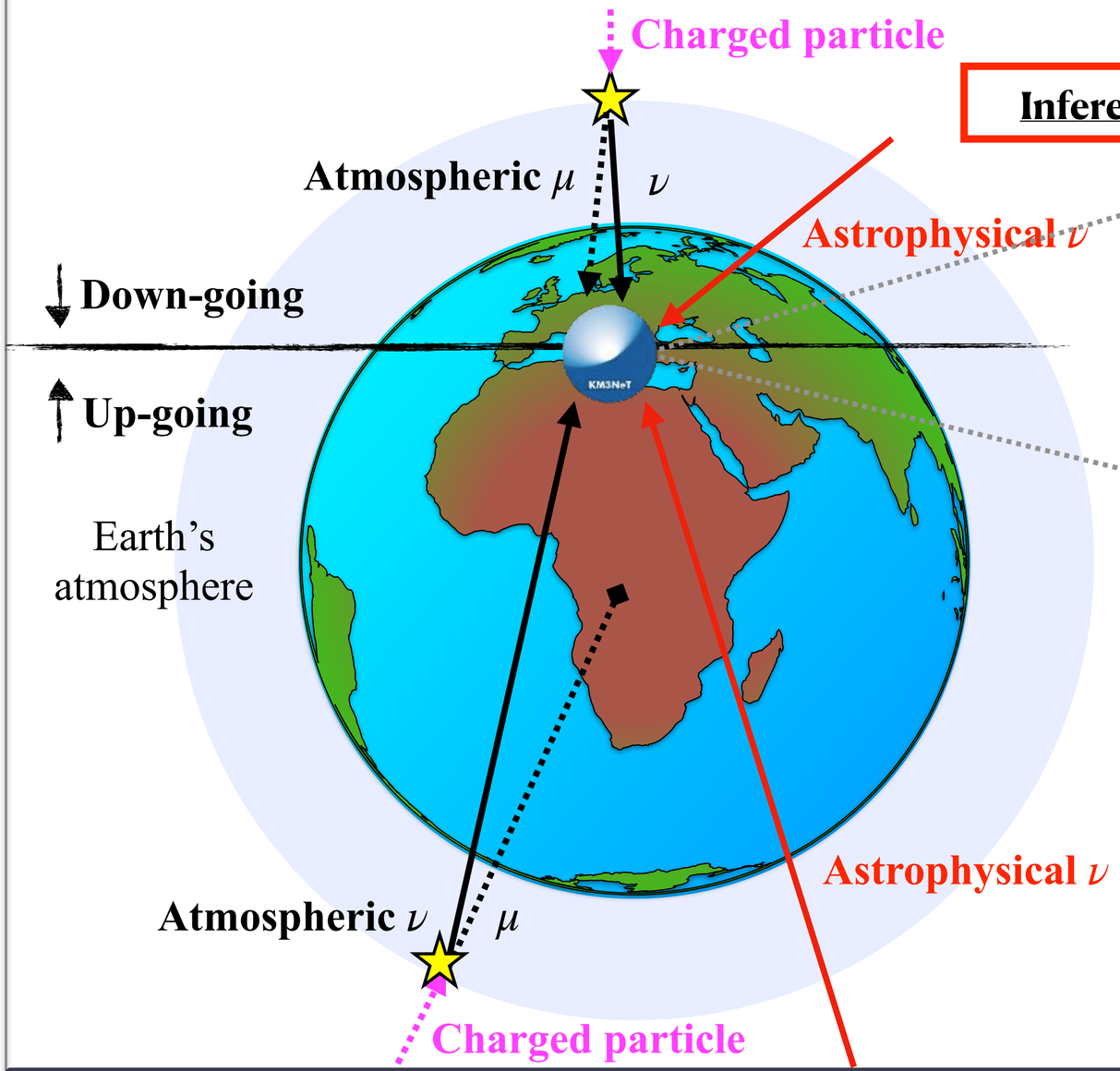
1 DU = 18 DOMs

1 DOM = 31 PMTs

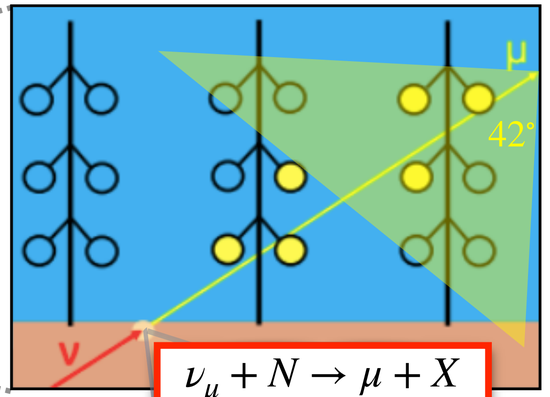
71 unique components
(in solid or liquid phase)

Technical publications

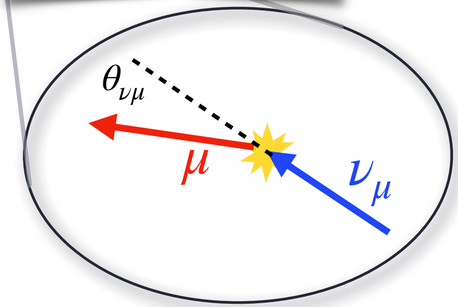
Neutrino telescopes: detection principle



Inference of energy and direction of incoming neutrinos from hits on PMTs



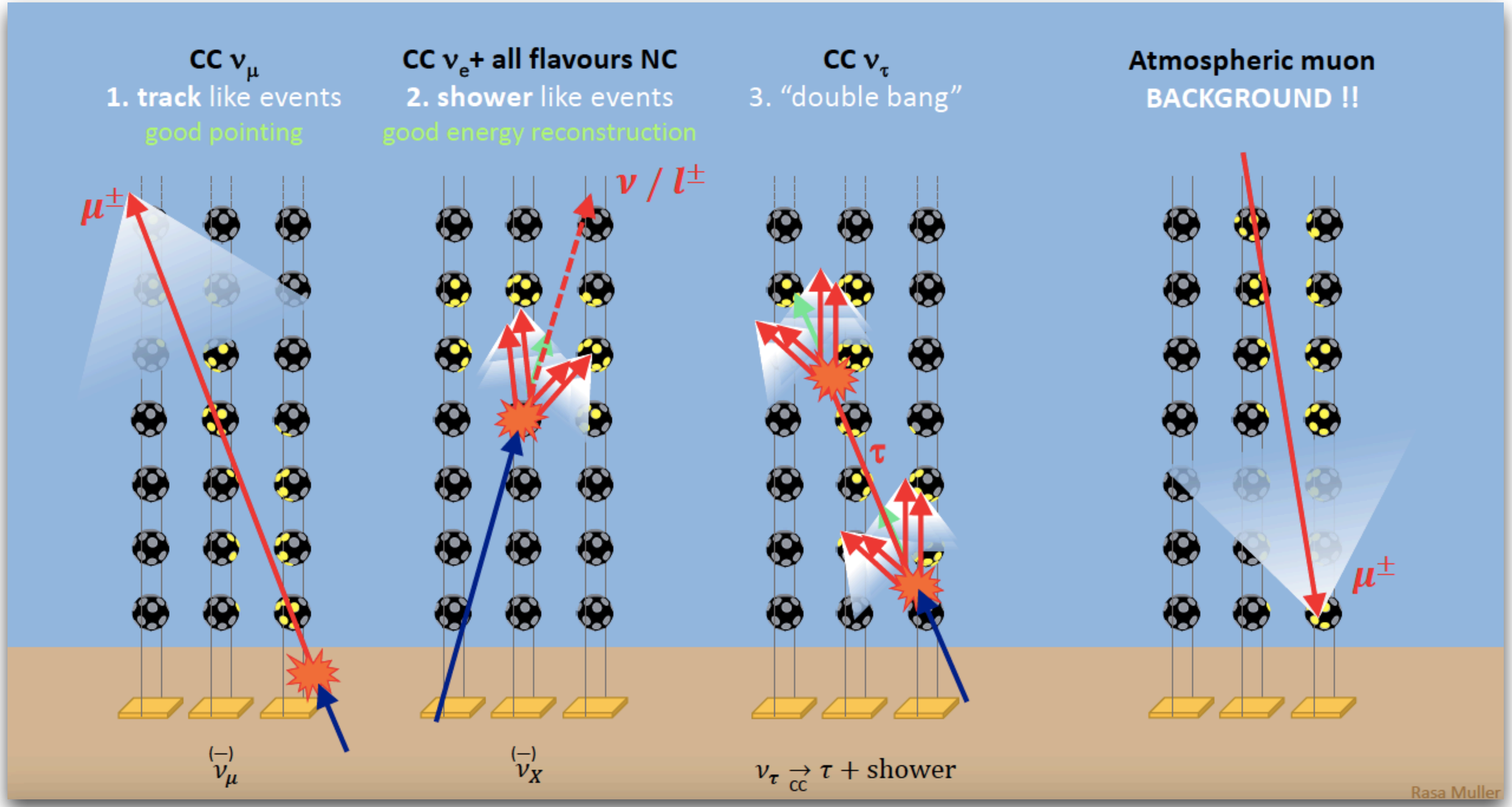
Cone of **Cherenkov light** originated **by secondary particles** produced in the medium as result of neutrino interactions with quarks inside or nearby the detector volume



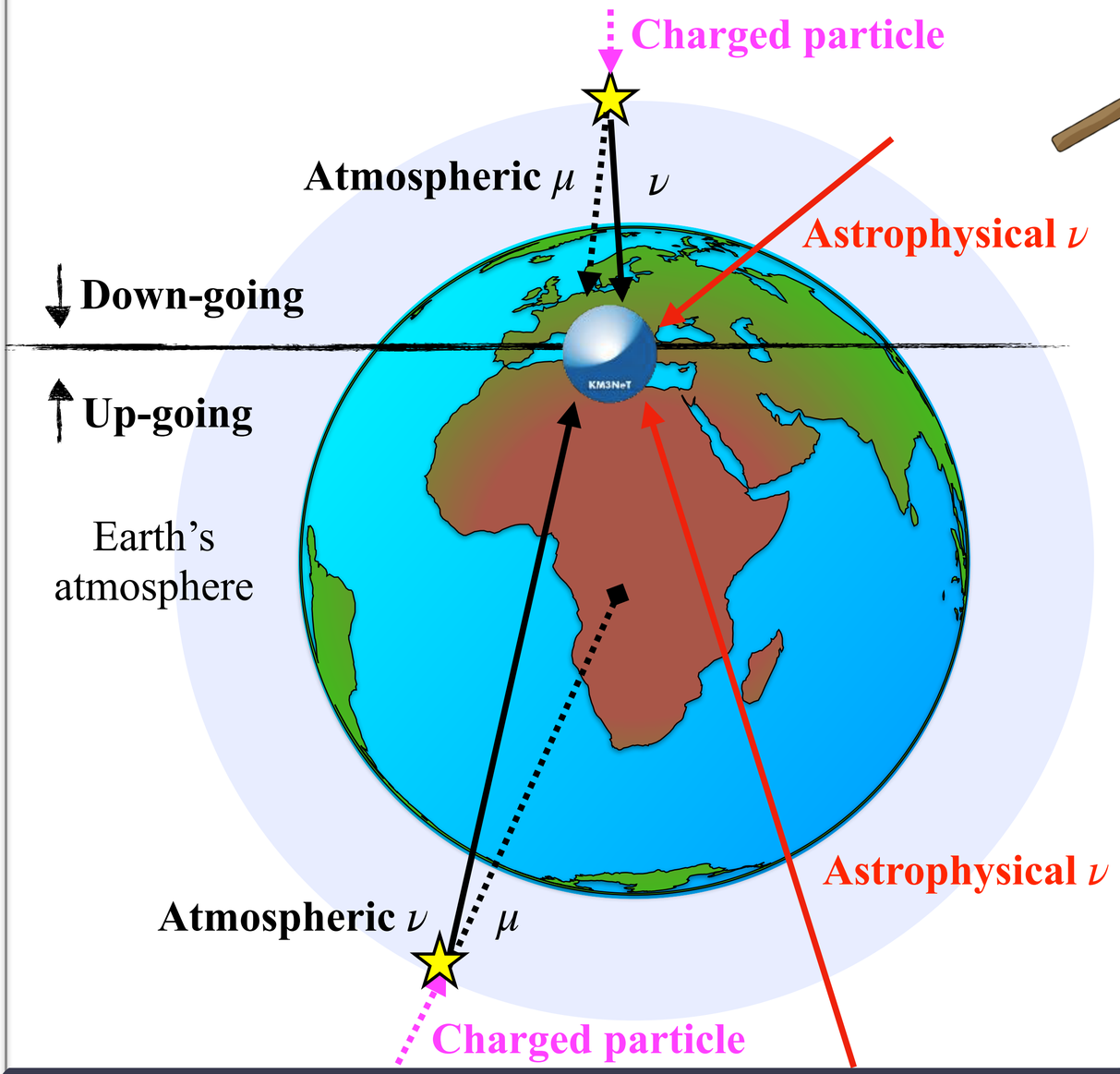
$$\theta_{\nu\mu} \simeq \frac{0.7^\circ}{[E_\nu(\mathrm{TeV})]^{0.7}}$$

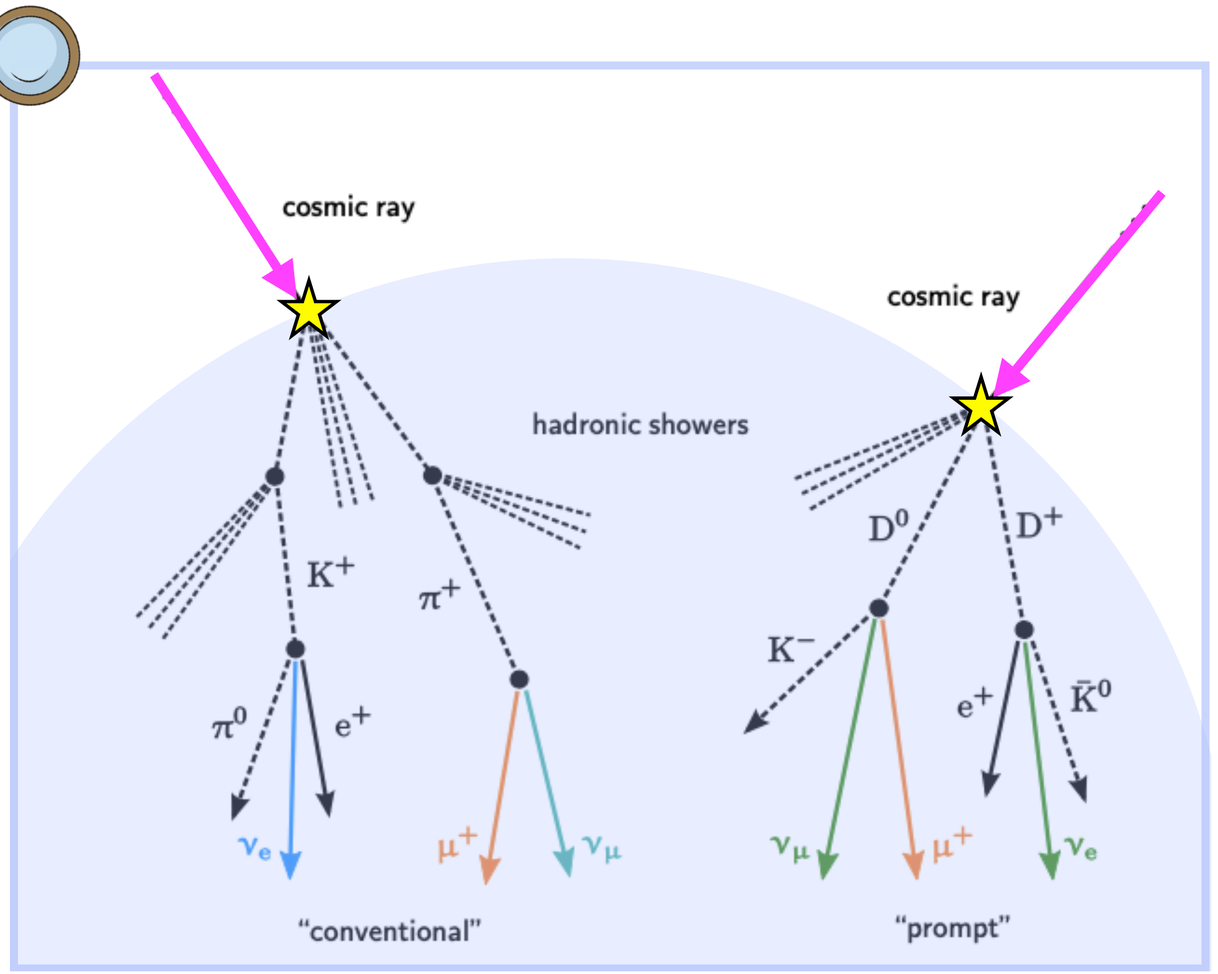
★ Main channel ⟶ charged current ν_μ interactions (**long muon path** inside the detector)

Neutrino telescopes: event topologies



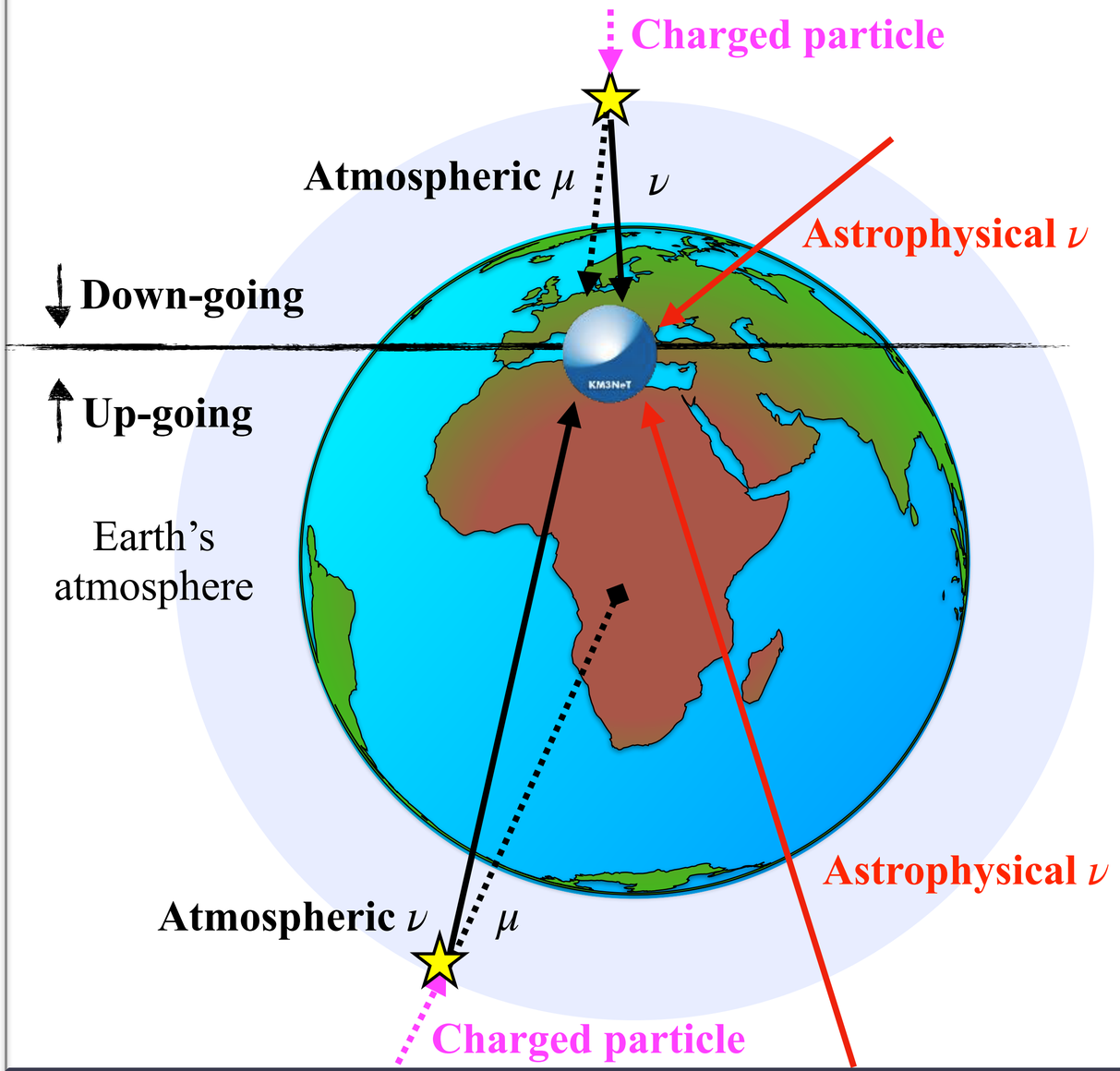
Neutrino telescopes: atmospheric background



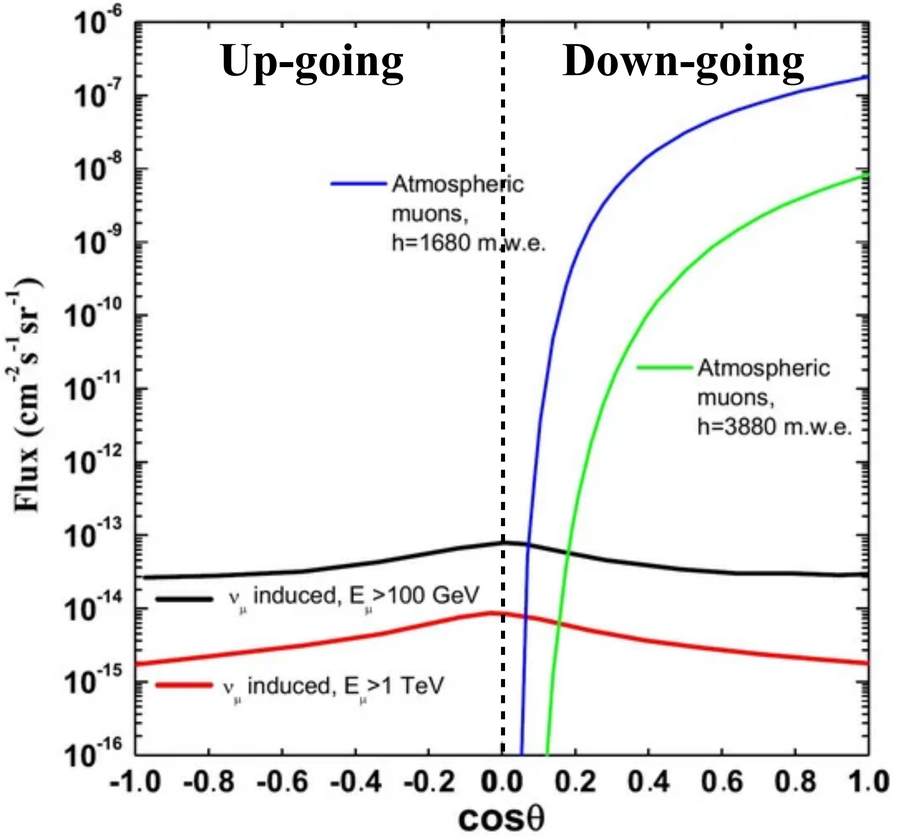


Atmospheric muons and neutrinos can reach neutrino telescopes

Neutrino telescopes: atmospheric background

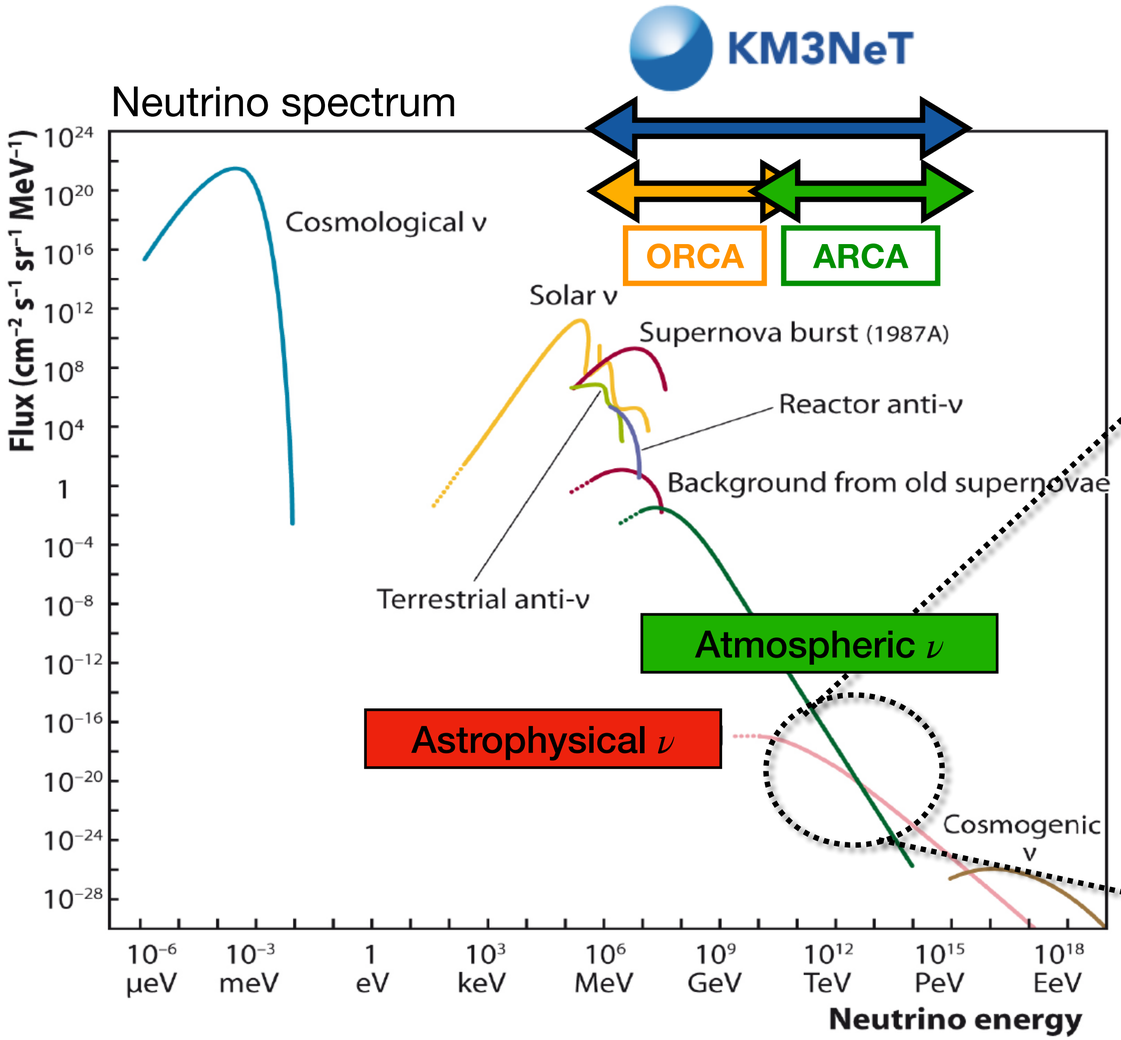


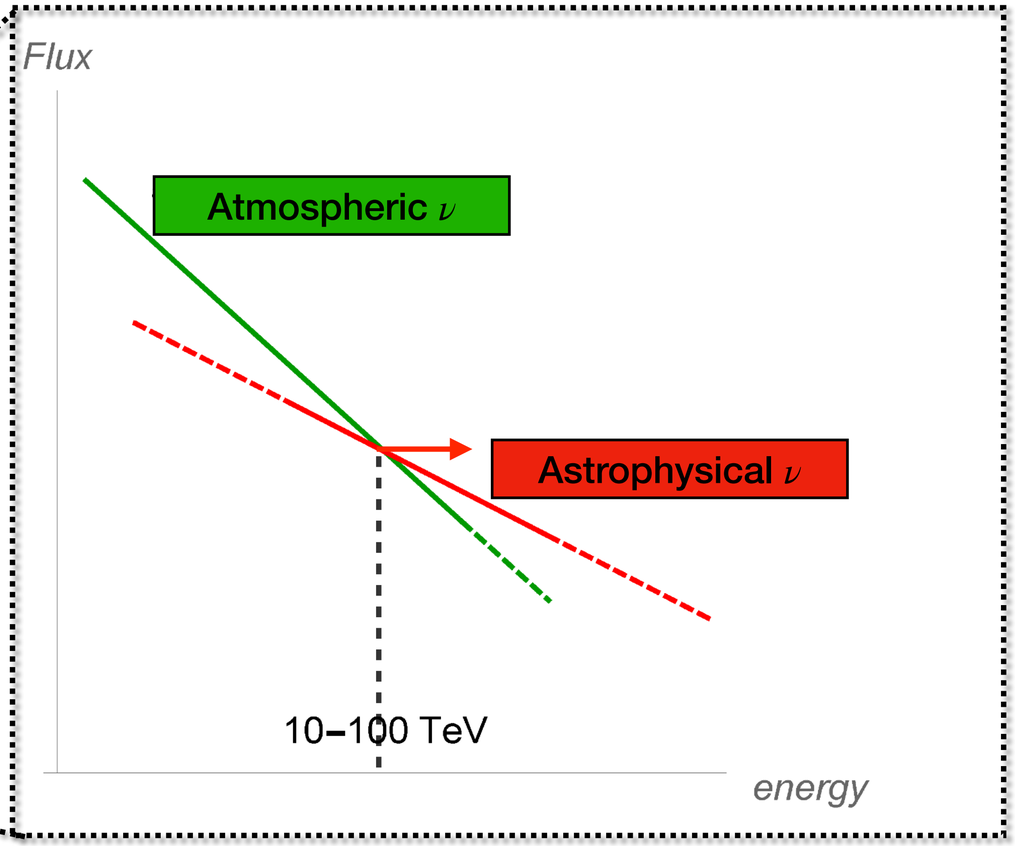
The **Earth** is used as **screening against all particles, except neutrinos** that can traverse the Earth



Neutrino telescopes: ν_{astro} vs ν_{atm}

Cosmic neutrinos can stand out over the atmospheric neutrinos at high energies (>10-100 TeV), becoming observable.



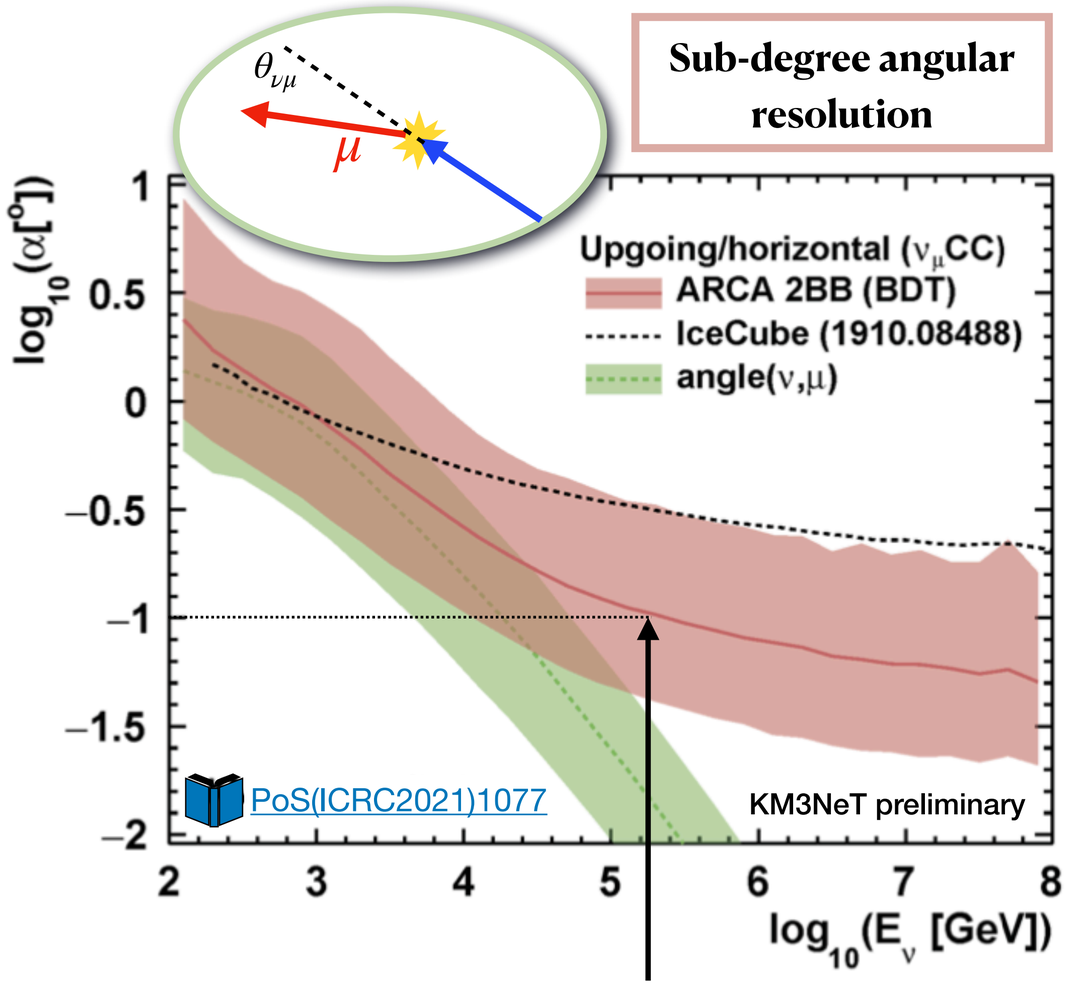


KM3NeT/ARCA performances: angular resolution

Full detector

Tracks

Sub-degree angular resolution

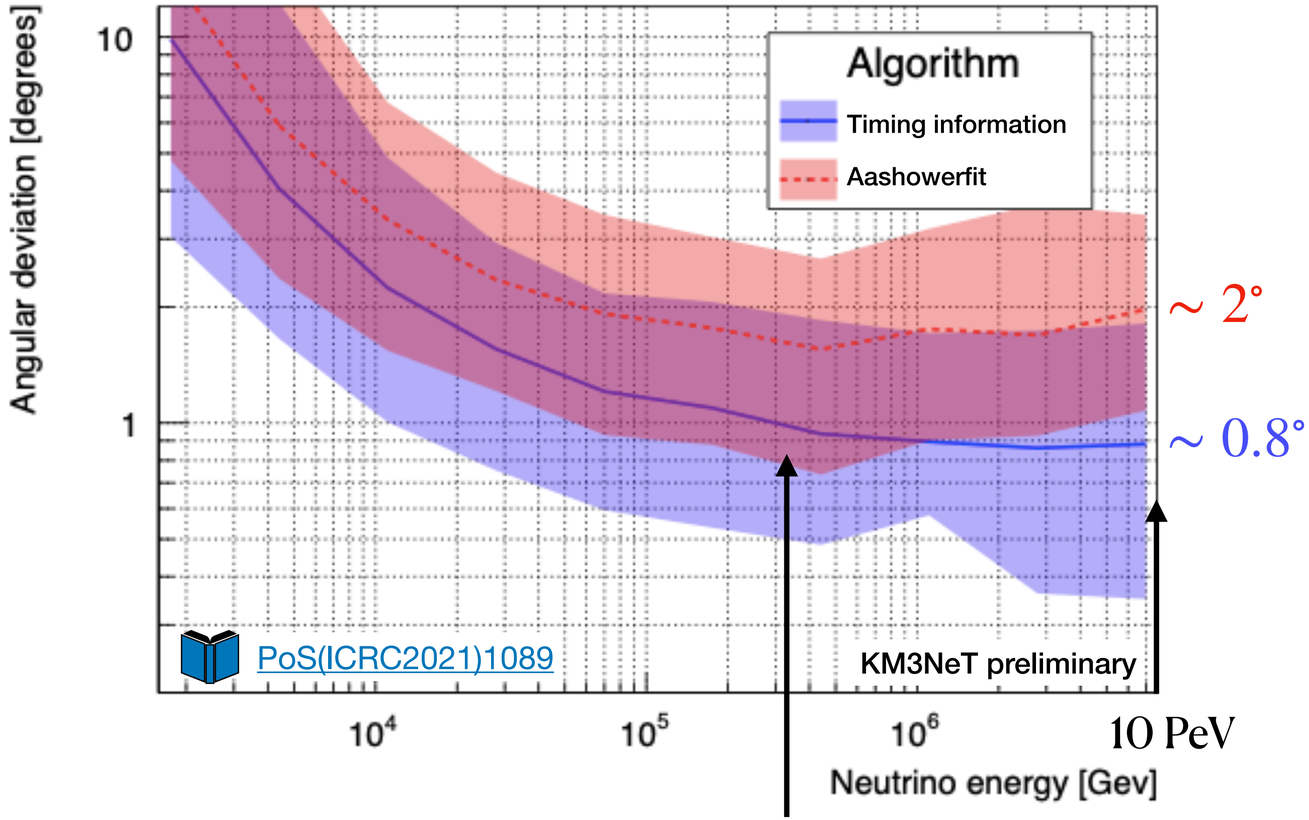


Better than 0.1° at 100 TeV

Showers

New algorithm that includes additional info on hit times

Standard shower reconstruction in use for KM3NeT/ARCA



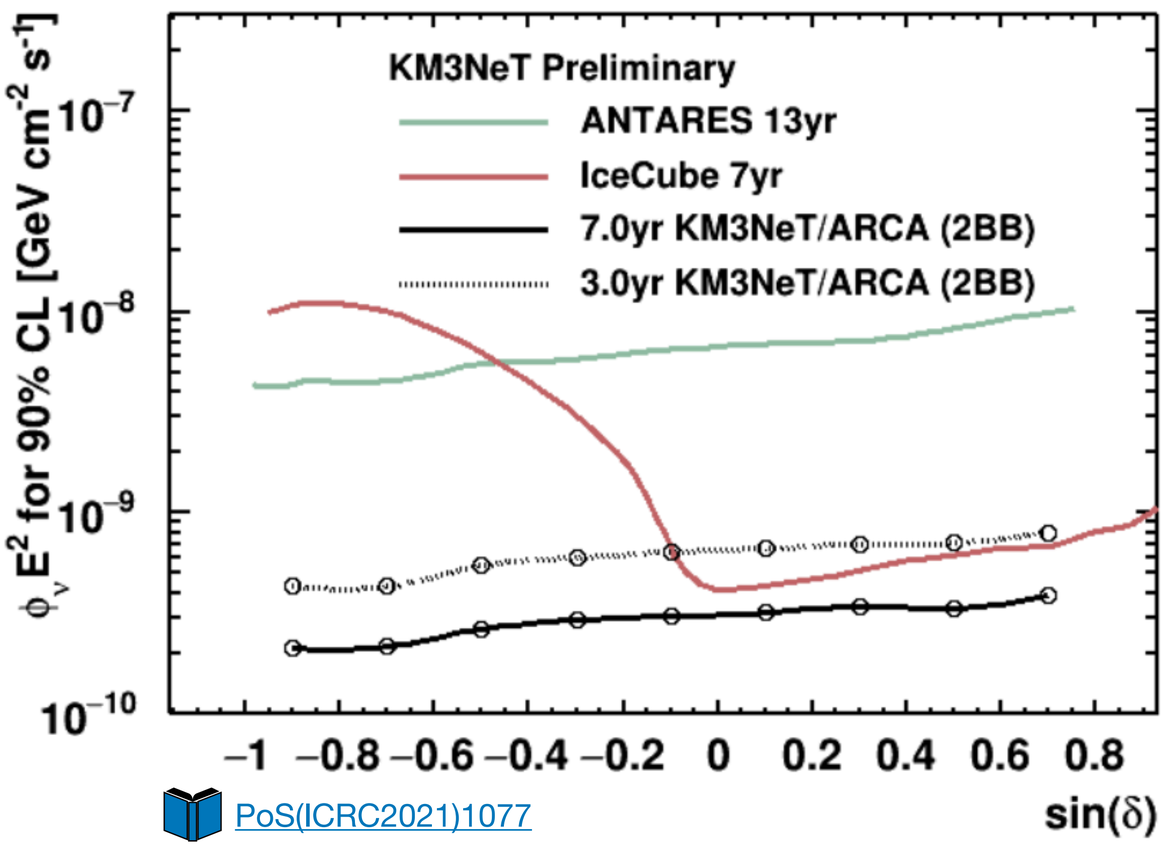
Better than 1° at 30 TeV

KM3NeT/ARCA sensitivity to cosmic sources

Full detector

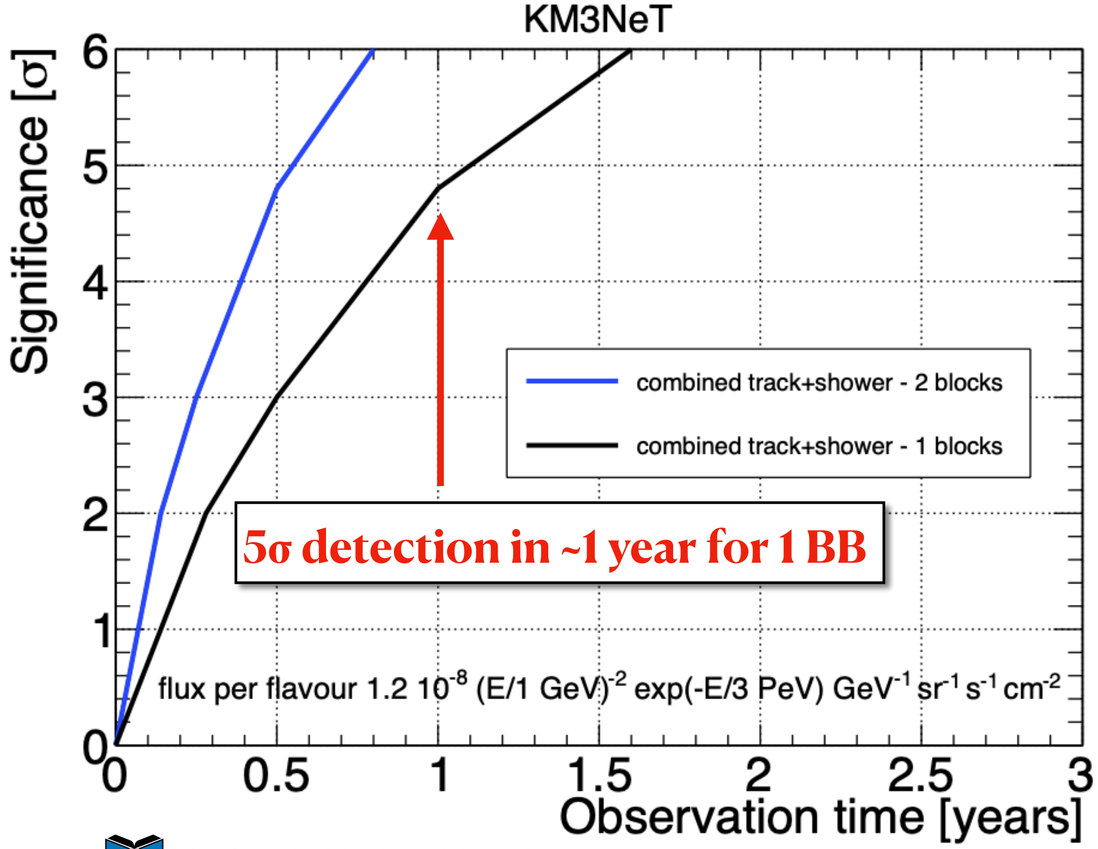
Point-like source with spectrum $\propto E^{-2}$

Upgoing/horizontal $\nu_\mu + \bar{\nu}_\mu$ tracks



PoS(ICRC2021)1077

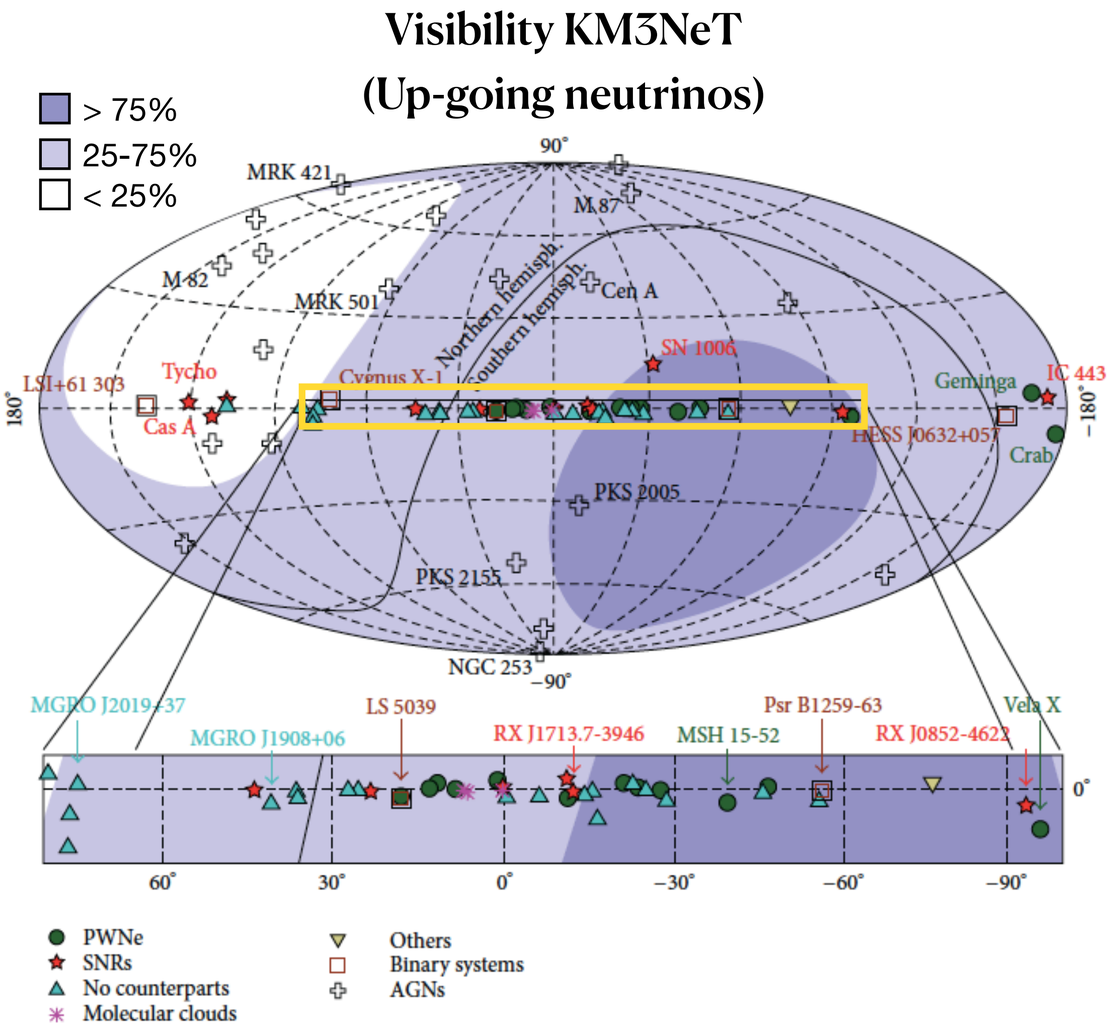
Diffuse astrophysical flux



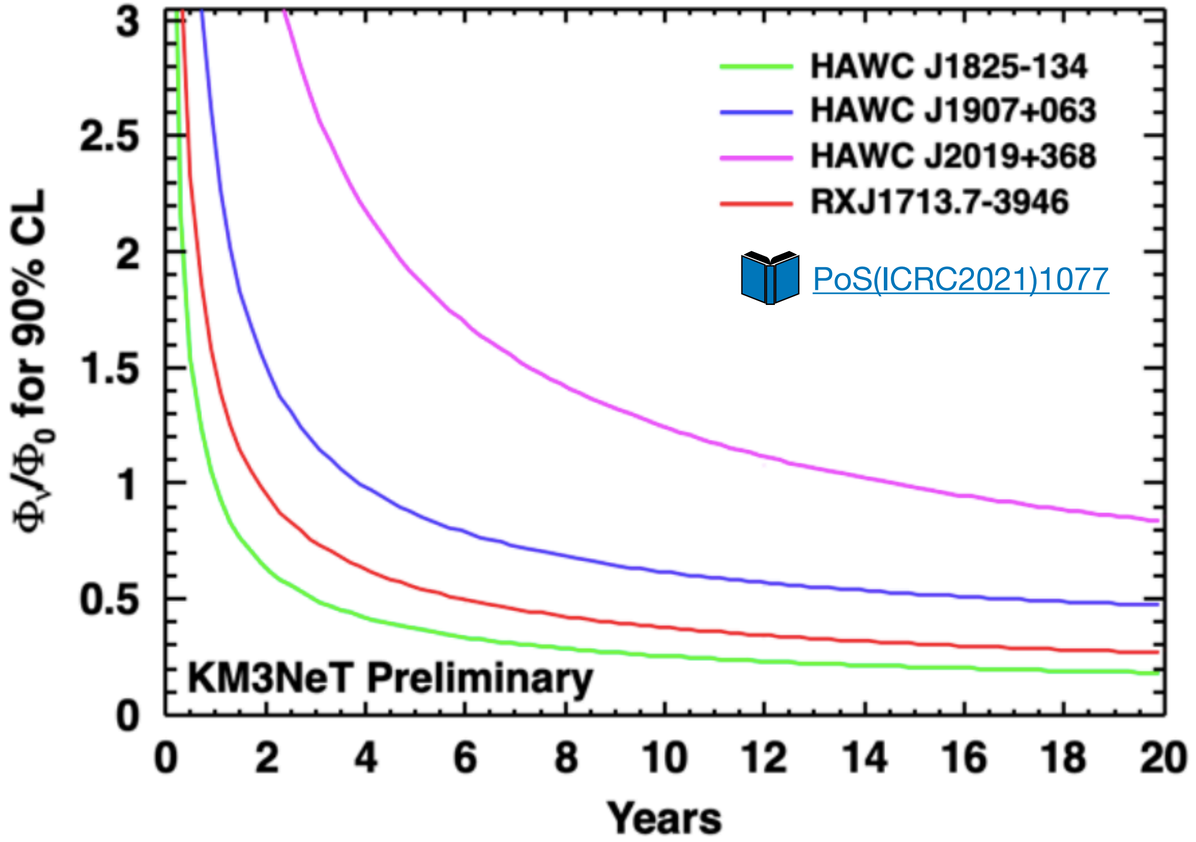
ApJ 111 (2019), 100-110

KM3NeT/ARCA sensitivity to galactic sources

Full detector



Visibility of most of the Galactic Center

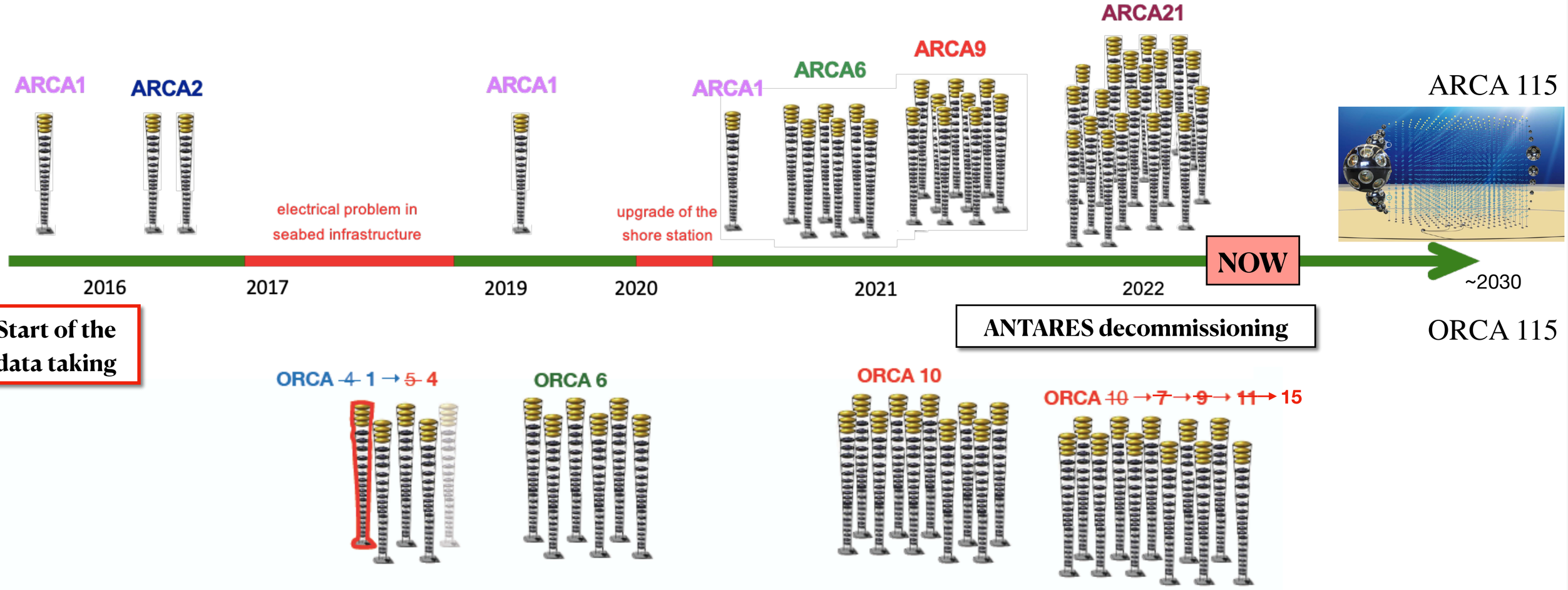


Investigation of neutrino emissions from Galactic sources in few years

KM3NeT: current status

KM3NeT
www.km3net.org

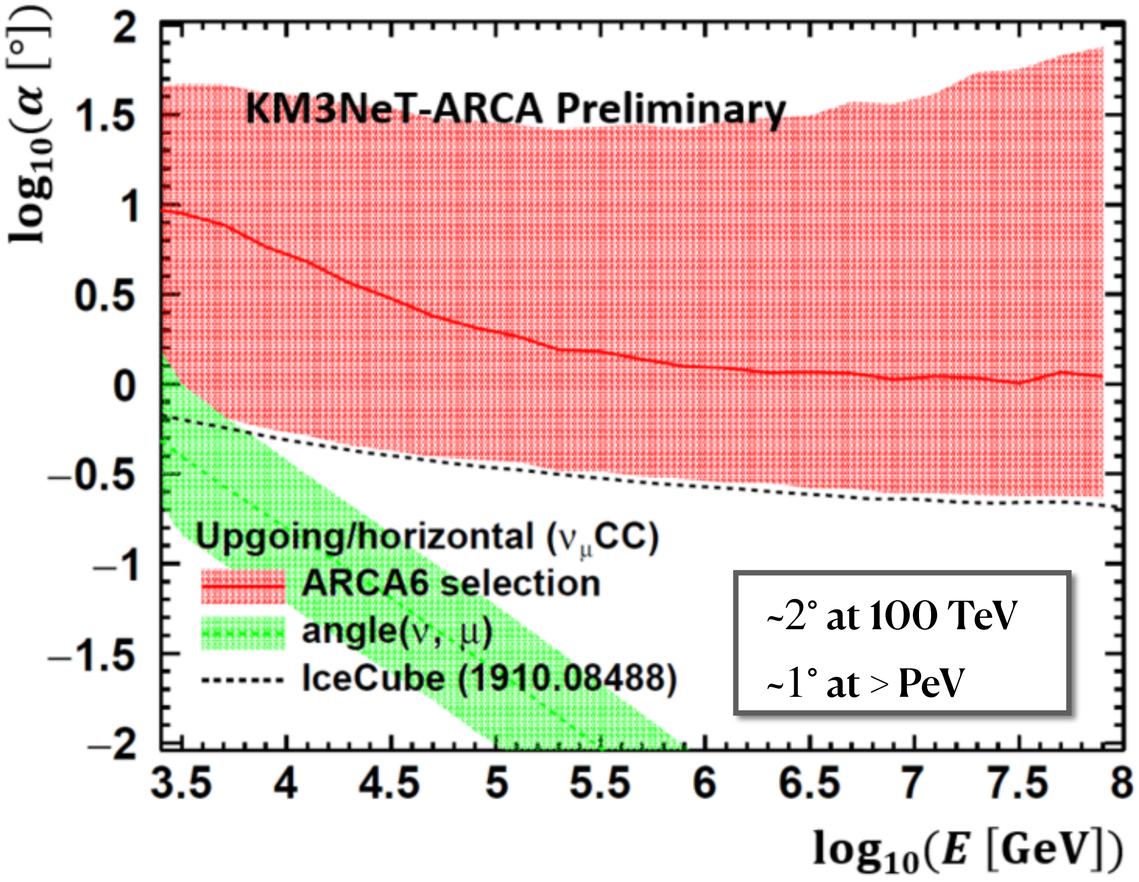
We are now in the construction phase



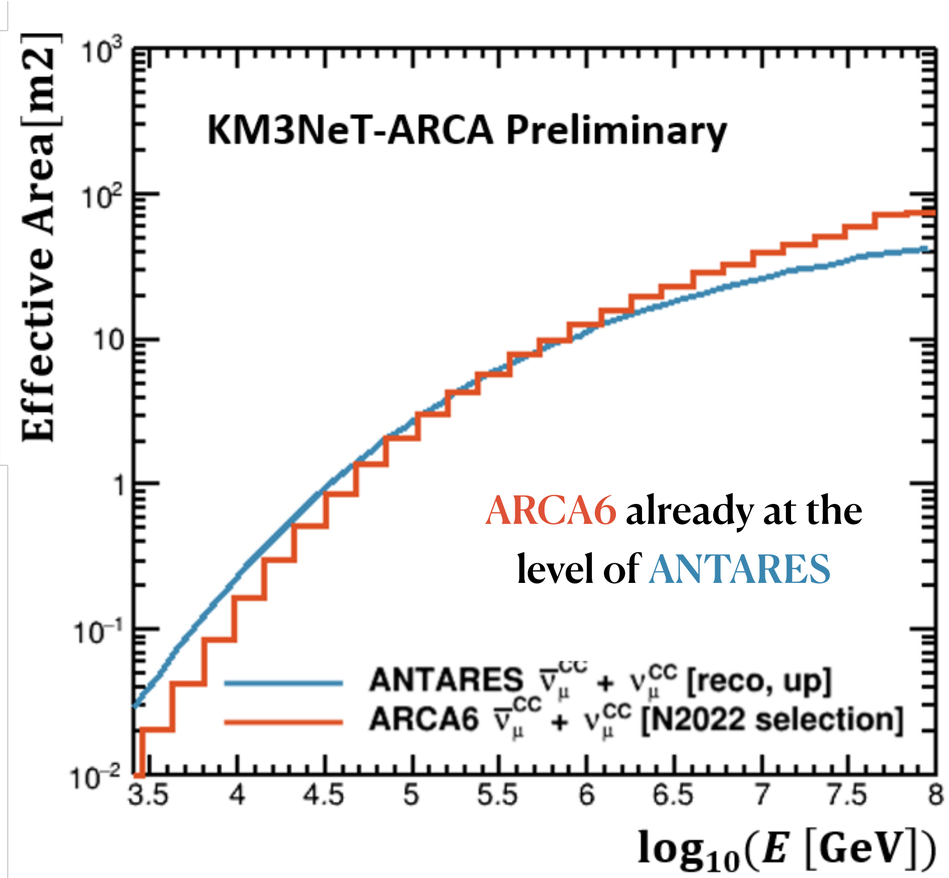
Let’s look at data...

ARCA6: Search for cosmic point sources and extended sources

Angular resolution



Effective area



$$A_{\mathrm{eff}}(E_\nu) = V_{\mathrm{eff}}(E_\nu)\sigma_{\nu N}(E_\nu)\rho N_A = \frac{N_{\mathrm{detected}}}{\int \phi \mathrm{d}E \mathrm{d}\Omega \mathrm{d}t}$$

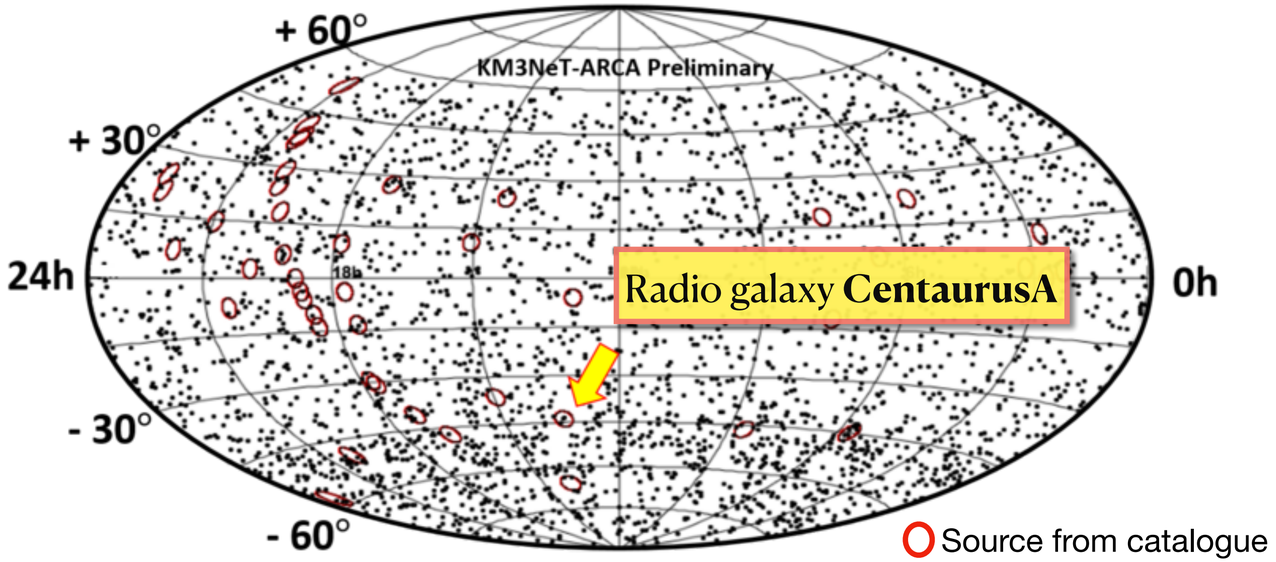
Poster 0745, Neutrino2022

ARCA6: Search for cosmic point sources and extended sources

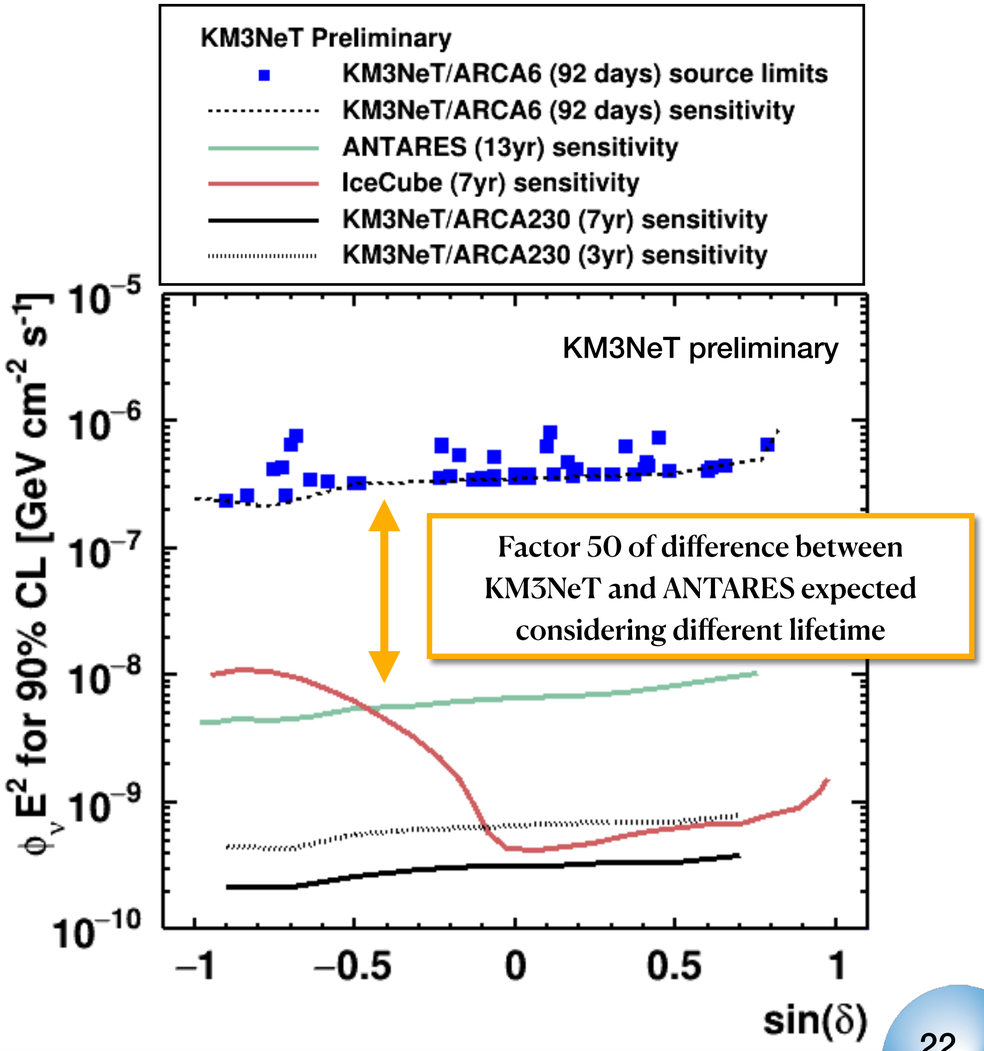
- **92 days of data** (May 2021-September 2021) with KM3NeT/ARCA 6 lines
- Time integrate point-like search for neutrino excess (spectrum $\propto E^{-2}$):
  - **40 known point sources**
  - **6 extended sources**

CentaurusA with smallest p-value (~0.02) but still compatible with background

Skymap with unblinded data



No strong neutrino emission observed



Poster 0745, Neutrino2022

ARCA6: diffuse all-sky emission

- **101 days of data** with KM3NeT/ARCA 6 lines
- **Background:**
  atmospheric muons + atmospheric neutrinos
- **Simulated flux for cosmic neutrinos** corresponding to the **diffuse astrophysical ν_μ spectrum with 10 years of IceCube data** (PoS(ICRC2019) 1017)

$$1.44 \times 10^{-18} \left(\frac{E_{\nu_\mu}}{100\ \text{TeV}} \right)^{-2.28} \quad [\text{GeV}^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}]$$

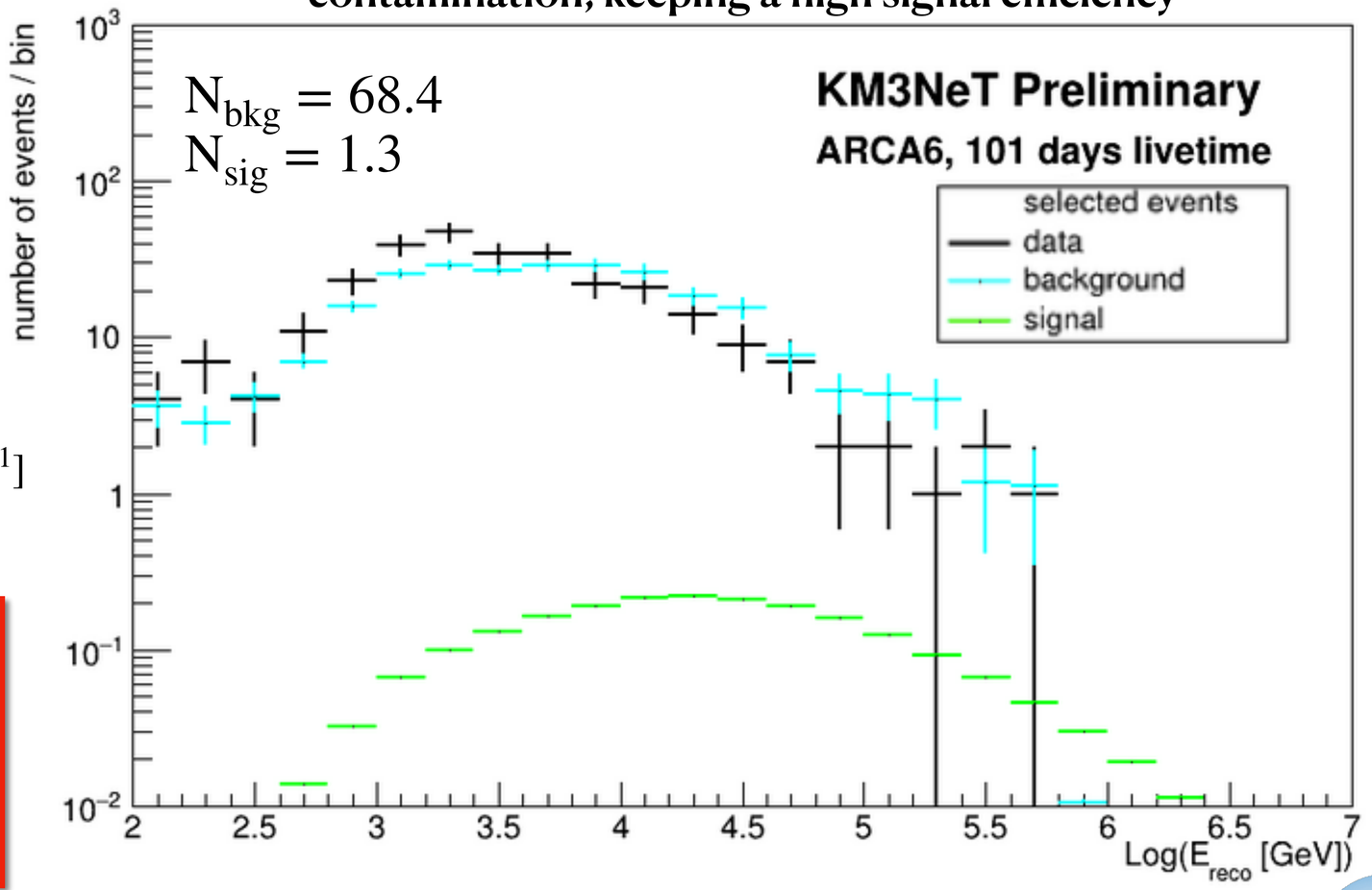
Obtained sensitivity for the corresponding flux

$$\phi_{90\%,\text{CL}} = 17.3 \times 10^{-18}\ [\text{GeV}^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}]$$

Factor 12 more than the simulated signal flux

Poster 0173, Neutrino2022

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



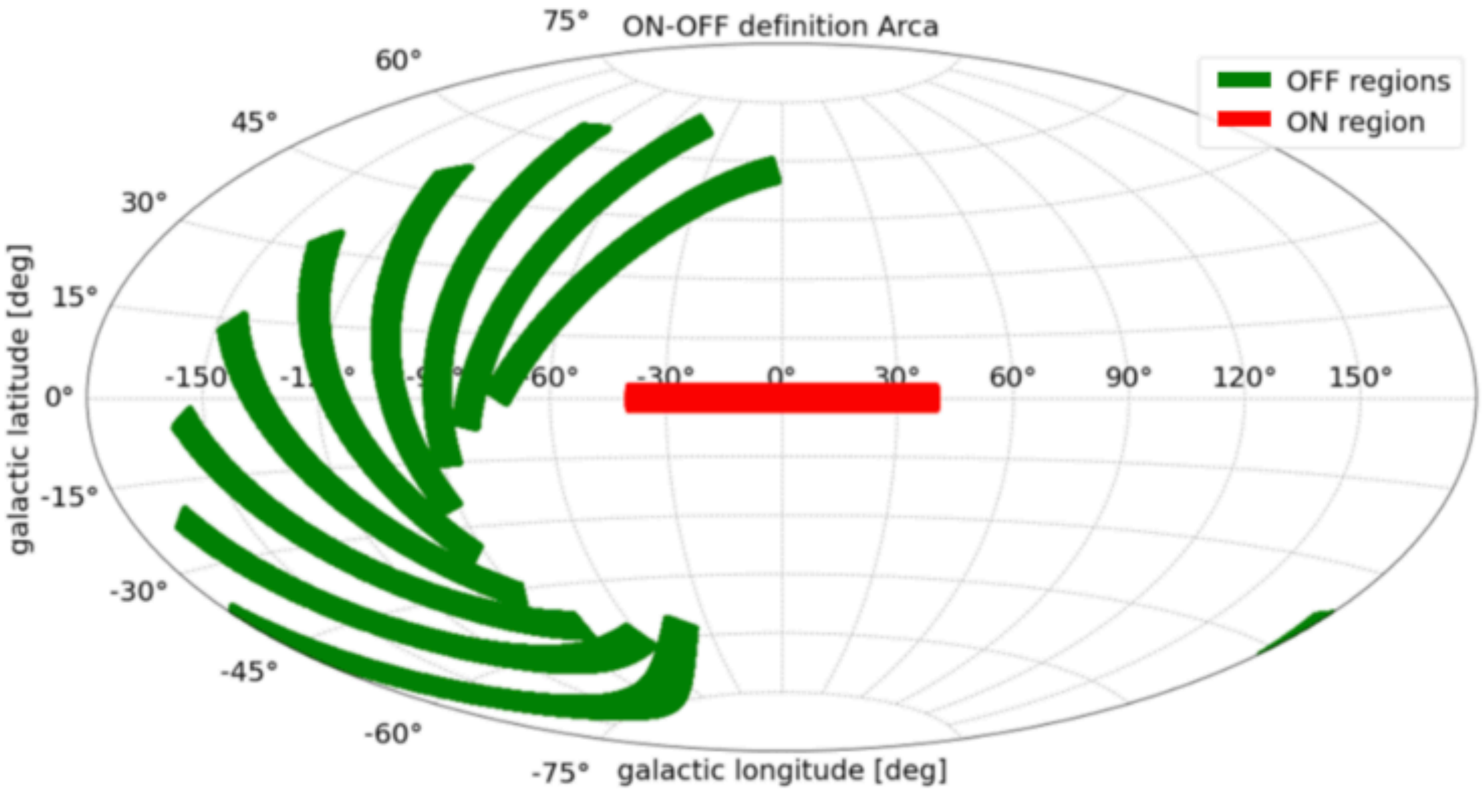
ARCA6: Galactic ridge diffuse emission

- **101 days of data** with KM3NeT/ARCA 6 lines
- Spectrum $\propto E^{-2.4}$

Poster 0173, Neutrino2022

Galactic ridge $|L_{gal}| < 40°$, $|B_{gal}| < 3°$

Shift in time of the ON region, avoiding the Fermi bubbles



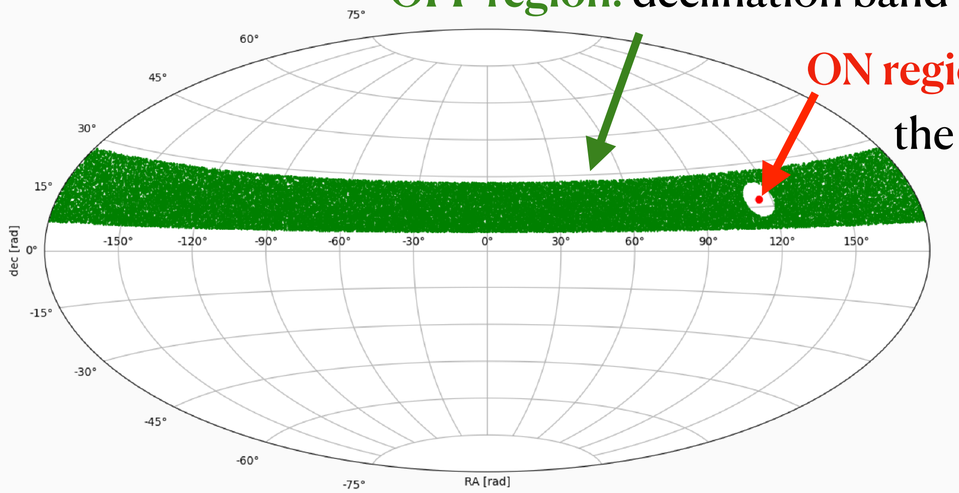
No statistically significant excess found → **Upper limit:** 6.2×10^{-4} [GeV^{-1} cm^{-2} s^{-1} sr^{-1}]

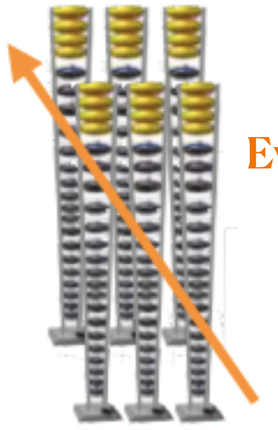
IceCube alert follow-ups (ARCA8+ORCA10)

- Follow-ups in ± 1 **day** around the IC alert
- Spectrum assumed $\propto E^{-2}$

OFF region: declination band for background

ON region: cone centered at the source position





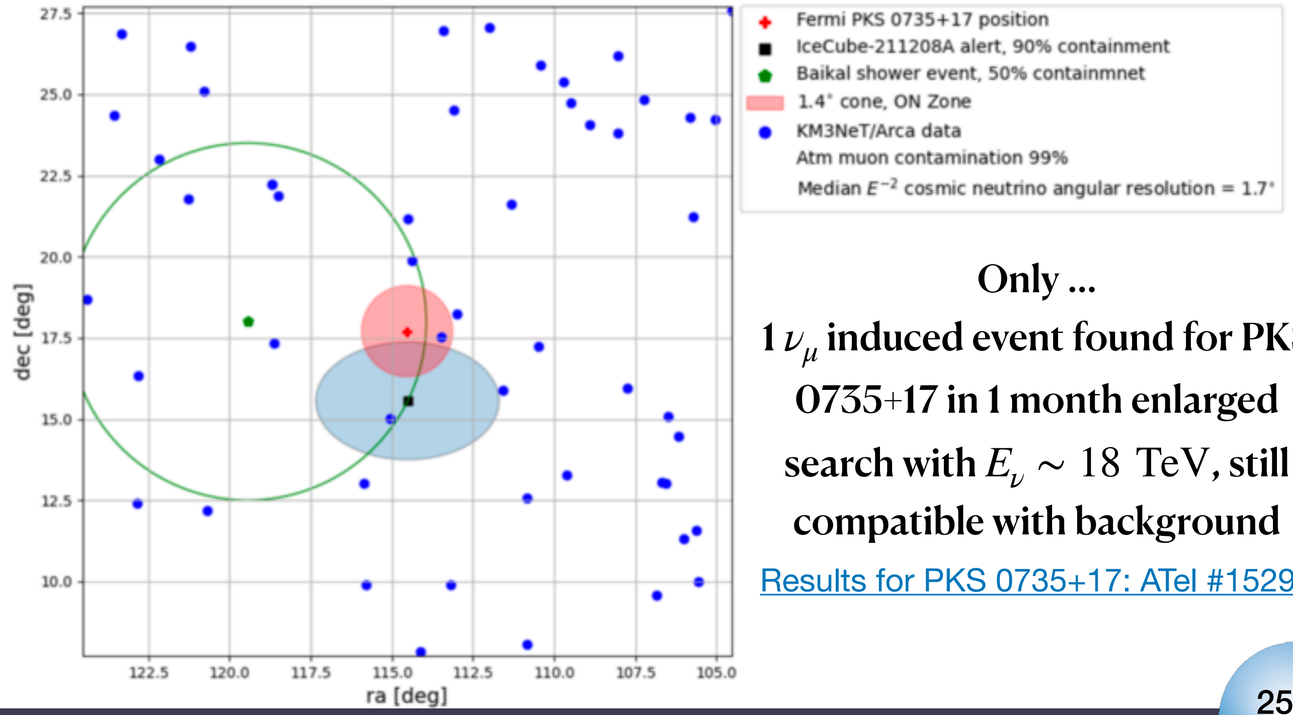
Event selection: upgoing track-like events

No significant discovery

Poster 0739, Neutrino2022

- IC 211208A (bronze alert): blazar PKS 0735+17
- IC 220205B (gold alert): radio blazar PKS 1741-03
- IC 220225A (bronze alert): quasar PKS 0215+015
- IC 220304A (gold alert): TXS 0310+022

PKS 0735+17: also enlarged search in 1 month around the alert



Only ...

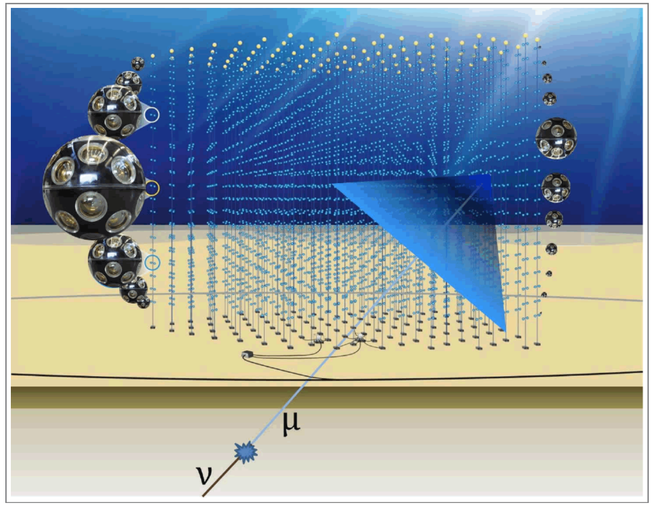
1 ν_μ induced event found for PKS 0735+17 in 1 month enlarged search with $E_\nu \sim 18$ TeV, still compatible with background

Results for PKS 0735+17: ATel #15290

KM3NeT: the multimessenger program

Poster 0751, Neutrino2022

Data AcQuisition (DAQ) level



KM3NeT ORCA and ARCA

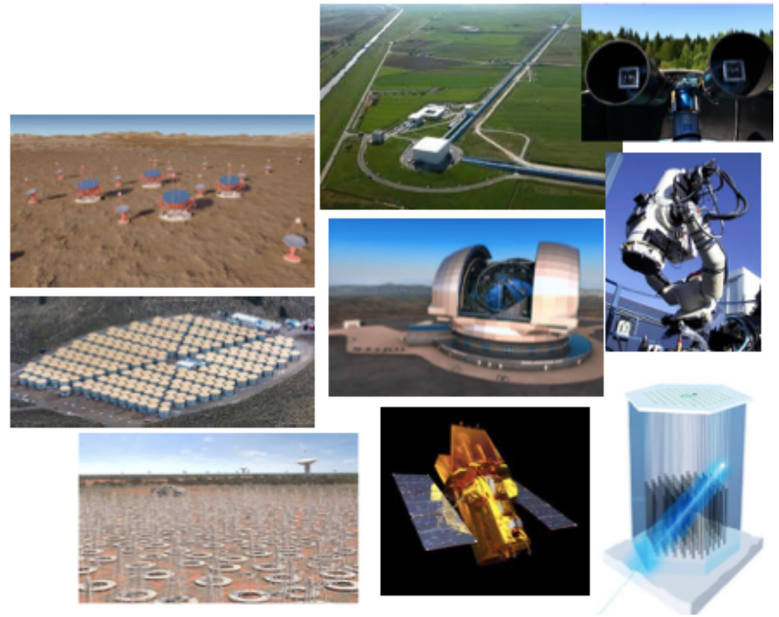
SENDING ALERTS

Send neutrino alerts to external communities for subsequent follow-ups

- Follow-up of EM/GW alerts
- Offline time/space correlation search with catalogues (GRB, AGN, SN, etc.)

RECEIVING ALERTS

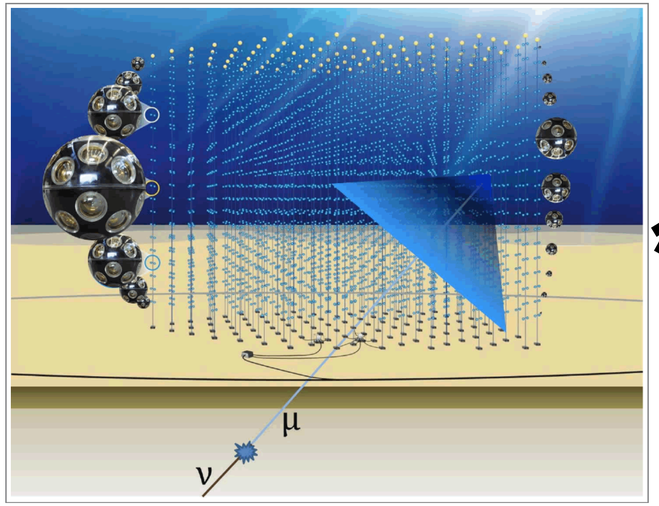
EM/MM external communities



KM3NeT: the multimessenger program

Poster 0751, Neutrino2022

Data AcQuisition (DAQ) level

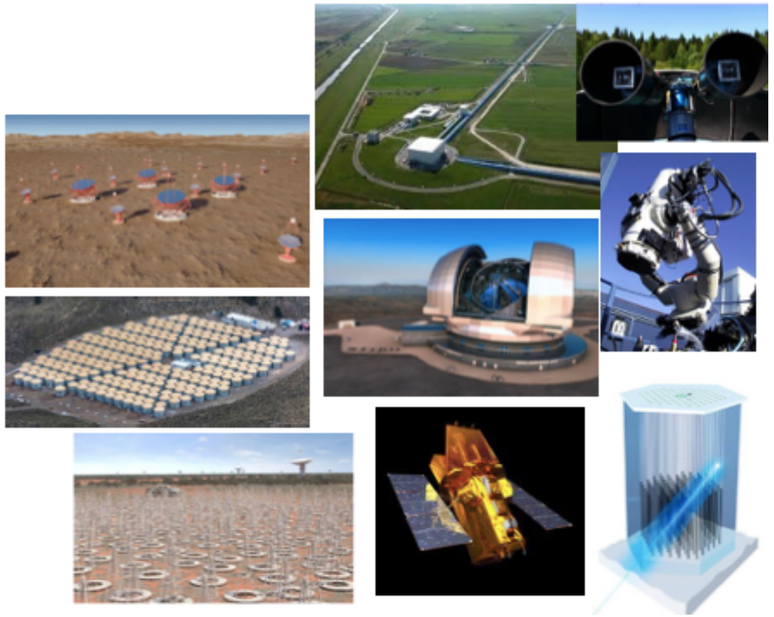


KM3NeT ORCA and ARCA

ARCA:
Portopalo di Capo Passero (Sicily)

ORCA:
Toulon (France)

EM/MM external communities



1) Neutrino induced events inside the detectors

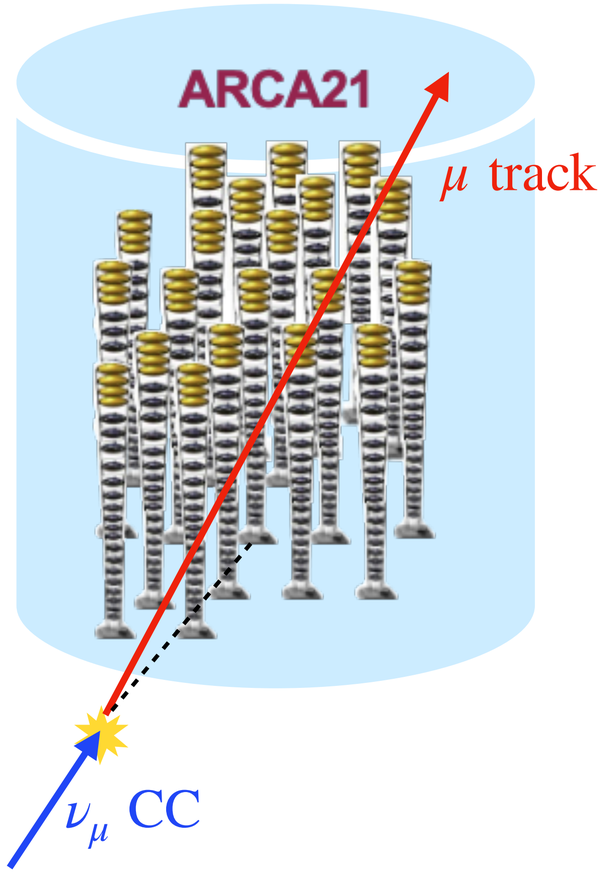
2) All data are immediately sent to the shore stations

3) All the events are reconstructed, selected and classified

4) Interesting events are sent to other multi-messenger instrumentations

KM3NeT/ARCA: real-time multimessenger analysis framework

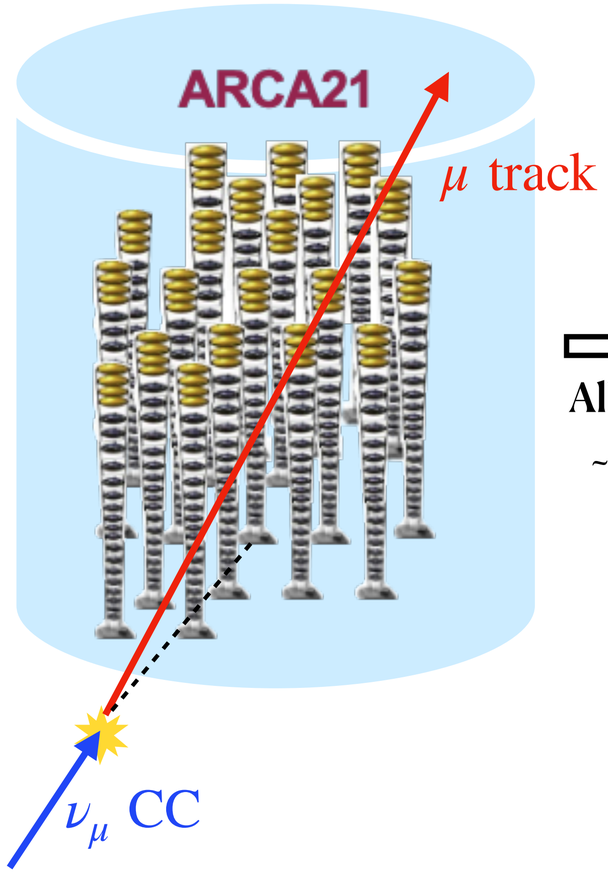
OFF-SHORE



Event rate ~8 Hz

KM3NeT/ARCA: real-time multimessenger analysis framework

OFF-SHORE



Event rate ~8 Hz

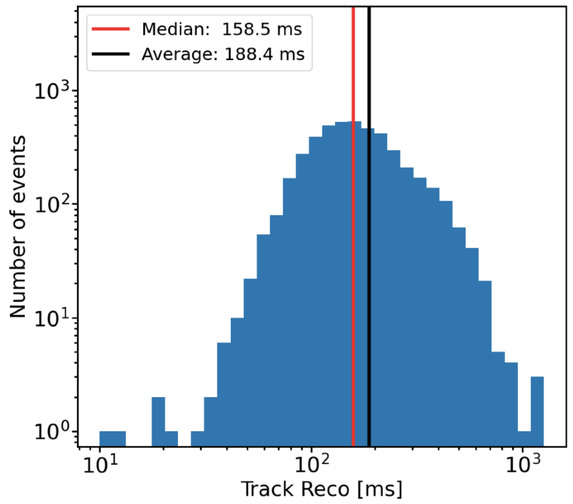
All data to shore

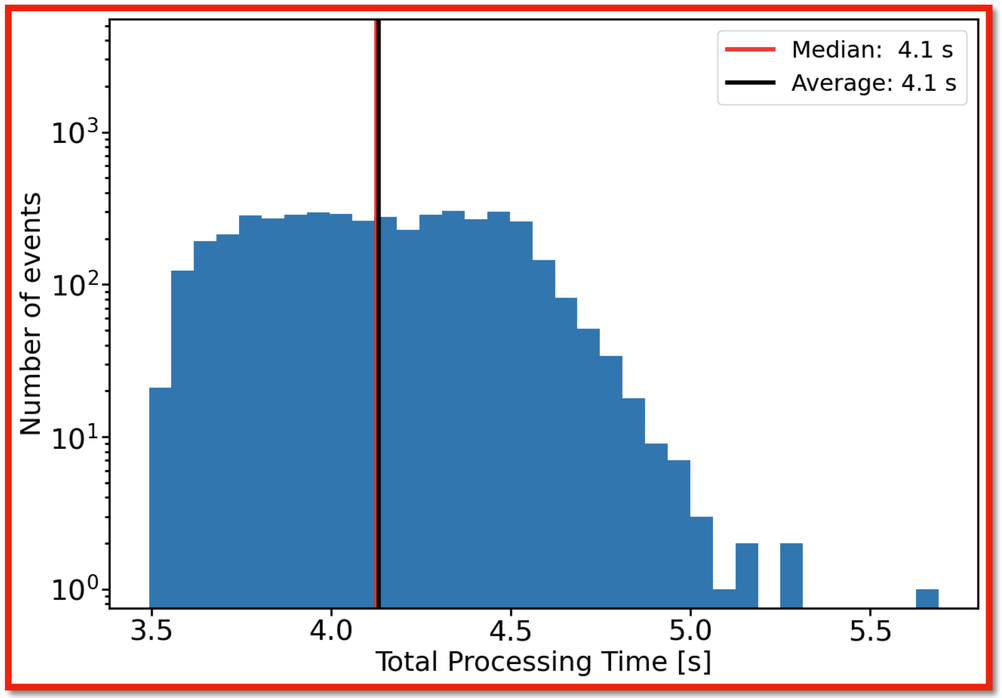
~ 4 seconds

SHORE STATION

Event reconstruction

Portopalo di Capo Passero (Sicily)





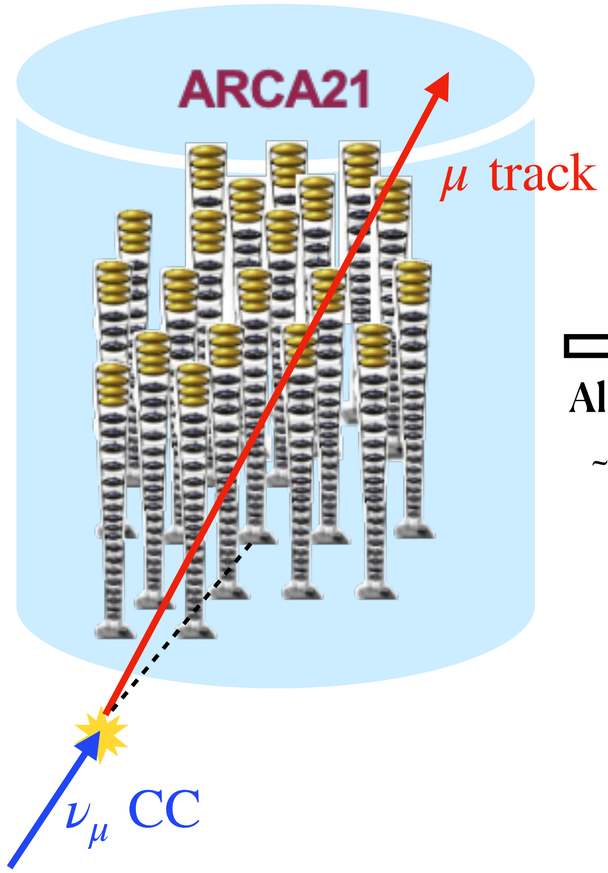
Track reco

Rate ~5 Hz

Time ~160 ms

KM3NeT/ARCA: real-time multimessenger analysis framework

OFF-SHORE



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SHORE STATION

Event reconstruction

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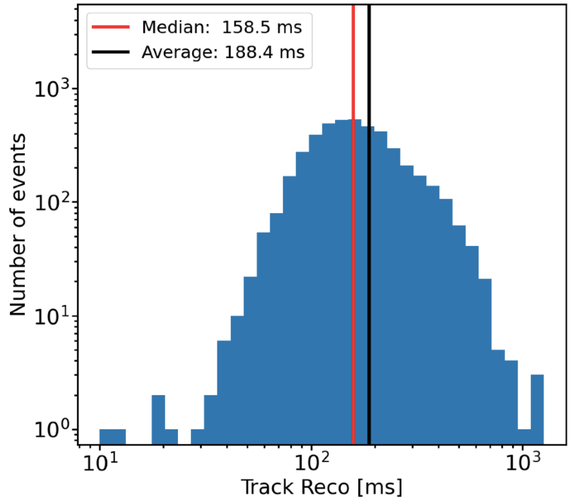


Reconstructed data transfer

Common dispatcher with ORCA and other remote repositories

Automatic analysis pipeline

<u>Track reco</u>

Rate ~5 Hz

Time ~160 ms

KM3NeT real-time analyses: the recent case of GRB 221009A

- ~ 3 months ago the **brightest long GRB** ever detected was observed, relatively close to us ($z \sim 0.15$, corresponding to 2.4 billion light-years away), at 13:16.59 UT
- This event produced the **most energetic GRB photon ever seen by Fermi LAT** (ATel #15656), that of **99 GeV**
- LHAASO during 2000 sec after the GRB trigger detected **photons up to 18 TeV, highest energies ever detected from a GRB** (GCN #32677)

KM3NeT GCN Circular 32741

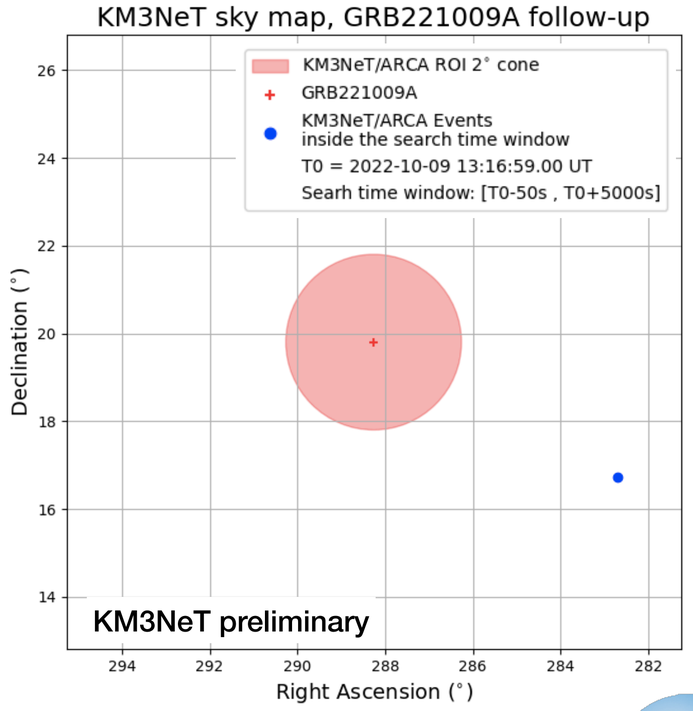
TITLE: GCN CIRCULAR
NUMBER: 32741
SUBJECT: GRB 221009A: search for neutrinos with KM3NeT
DATE: 22/10/13 18:57:37 GMT
FROM: Damien Dornic at CPPM,France <dornic@cppm.in2p3.fr>

The KM3NeT Collaboration (https://www.km3net.org/) reports:

Using the data from the online fast processing chain, the KM3NeT Collaboration has performed a dedicated search for track-like muon neutrino events arriving from the direction of GRB 221009A (Dichiara et al. GCN 32632 (Swift); Veres et al. GCN 32636 (Fermi-GBM)). The search covers the time range of [T0-50s, T0+5000s], with T0 being the trigger time reported by Fermi-GBM (T0=2022-10-09 13:16:59.00 UTC), during which both KM3NeT detectors were collecting good quality data. However, the GRB location was above the KM3NeT horizon (mean elevation of about ~40deg) during the search time window, significantly reducing the point-like source sensitivity. In both detectors, zero events were observed in the search window, while o(0.1) were expected from the background. The online fast processing uses preliminary calibrations and detector alignment, which will be superseded in a future elaborated analysis.

A parallel search has been performed in the MeV range (Eur.Phys.J.C 82 (2022) 4, 317) without any significant neutrino coincidence.

KM3NeT is a large undersea (Mediterranean Sea) infrastructure hosting two neutrino detectors, sensitive to burst of supernova neutrinos in the MeV range and to astrophysical neutrinos in the GeV-PeV energy range: ARCA at high energy and ORCA at low energy. A total of 21 and 11 detection lines are currently in operation in ARCA and ORCA, respectively.



No events found in the signal region. More elaborated analysis ongoing!

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- LHAASO during 2000 sec after the GRB trigger detected **photons up to 18 TeV, highest energies ever detected from a GRB** (GCN #32677)

KM3NeT has started to play his role in the field of the real-time multimessenger astronomy!

TITLE: GCN CIRCULAR
NUMBER: 32741
SUBJECT: GRB 221009A: search i
DATE: 22/10/13 18:57:37 GM
FROM: Damien Dornic at CPPM

The KM3NeT Collaboration (http

Using the data from the online
events arriving from the direct
the time range of [T0-50s, T0+5
KM3NeT detectors were collecting good quality data. However, the GRB location was above the KM3NeT horizon (mean elevation of about -40deg)
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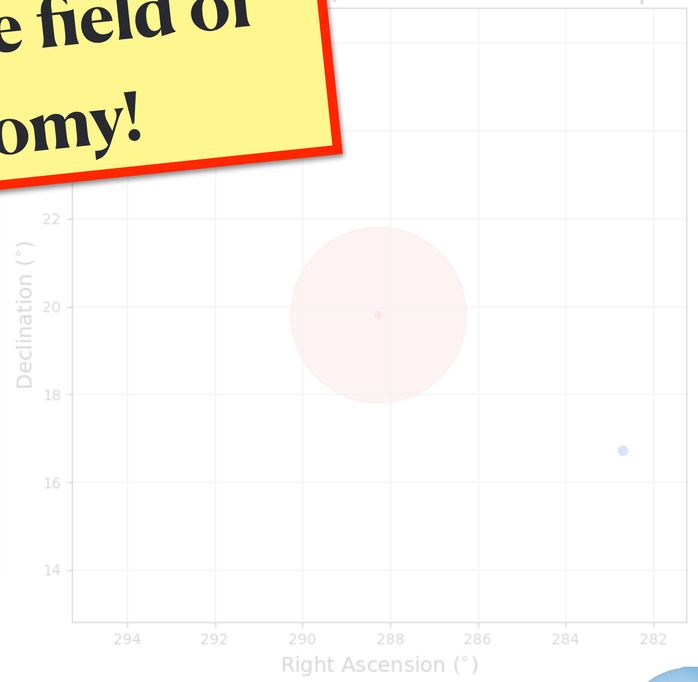
, GRB221009A follow-up



No events found in the signal region. More elaborated analysis ongoing!

Summary

- The next generation neutrino telescope **KM3NeT** (ORCA + ARCA) is **under construction in the Mediterranean Sea**
- **KM3NeT/ARCA** (in Sicily, Italy) is designed for the detection of **high-energy neutrinos (from ~100 GeV to PeV)** , thus is optimized for **neutrino astronomy & multimessenger studies**
- **First string** is operating since **more than 6 years**
- **First results** in the field of **neutrino astronomy** published by using data taken with **KM3NeT/ARCA 6 lines configuration (May-September 2021)**
- **KM3NeT/ARCA is taking data with 21 strings since September 2022**
- KM3NeT/ARCA is already **better than ANTARES**
- **Real-time multimessenger analysis framework** for KM3NeT **in progress and already operative**
- KM3NeT/ARCA will be able to provide information about the origin and acceleration mechanisms of extragalactic and Galactic cosmic rays (**optimal visibility of the Galactic center being located in the Northern hemisphere**)

More works in place …

KM3NeT
www.km3net.org

Gamma-Ray Bursts

Starburst diffuse analysis

Core Collapse Supernovae

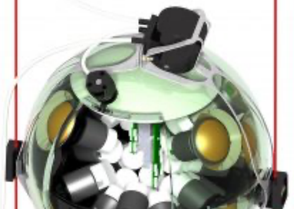
Periodic sources (pulsars)

Double bang ν_τ reconstruction

Combined $\gamma - \nu$ analysis

Analysis updates with new data on-going …
STAY TUNED!



Thank you for the attention!