Point source analysis with ARCA21

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IRN meeting (Lyon)

June 2025

Point source analysis with ARCA21

topics:

- Neutrino Astronomy:

  Why study high energy neutrinos from astrophysical sources?

- Neutrino Telescopes (KM3NeT/ARCA):

  How to detect such astrophysical neutrinos?

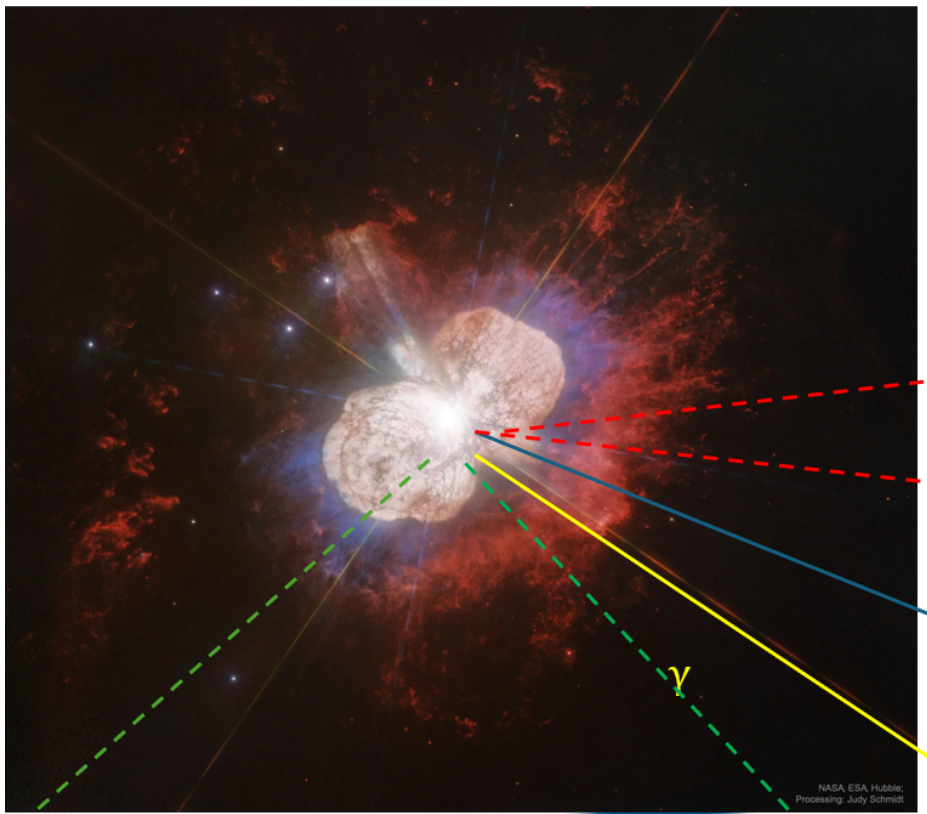
- Point Source Search (Binned Likelihood Method):

  How can data be analysed to search for a neutrino signal from astrophysical sources?

Section 1

Neutrino Astronomy

Neutrino Sources: CR accelerators



Leptonic: Synchrotron Radiation and Inverse Compton Scattering.

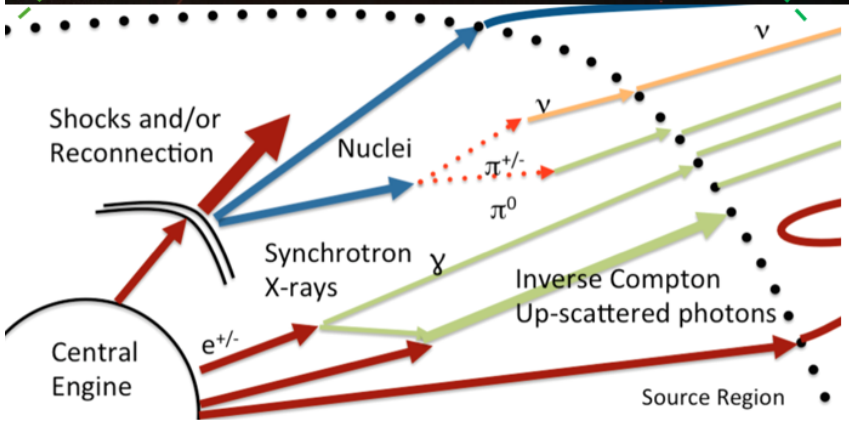
→ No neutrino production expected

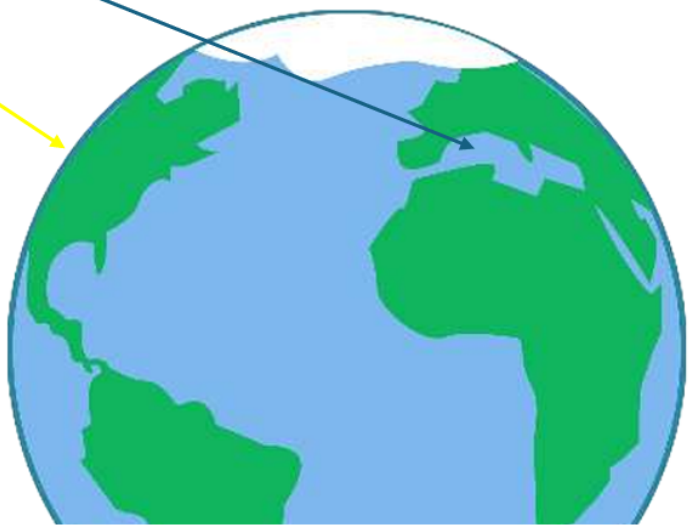
Hadronic Process:

$$pp(pn) \rightarrow pp\,\pi^0(pn\,\pi^0)$$
$$\pi^0 \rightarrow \gamma + \gamma$$
$$pp(pn) \rightarrow pn\,\pi^+(pp\,\pi^-)$$
$$\pi^{\pm} \rightarrow \mu^{\pm}\overset{(-)}{\nu_\mu} \quad \begin{cases} \mu^+ \rightarrow & e^+\nu_e\overline{\nu}_\mu \\ \mu^- \rightarrow & e^-\overline{\nu}_e\nu_\mu \end{cases}$$

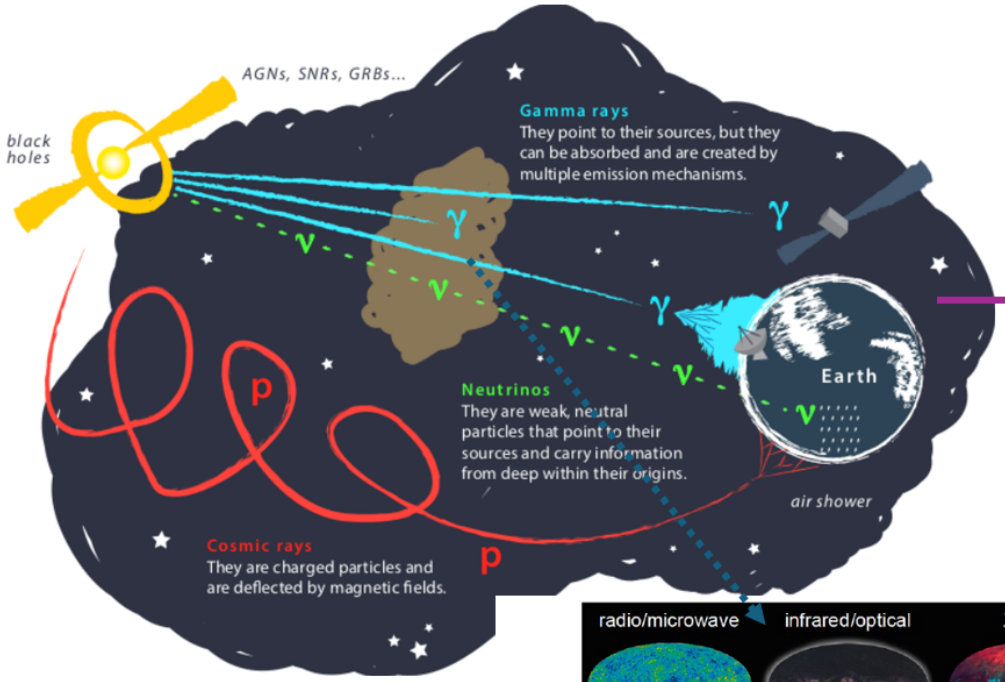
ν

γ

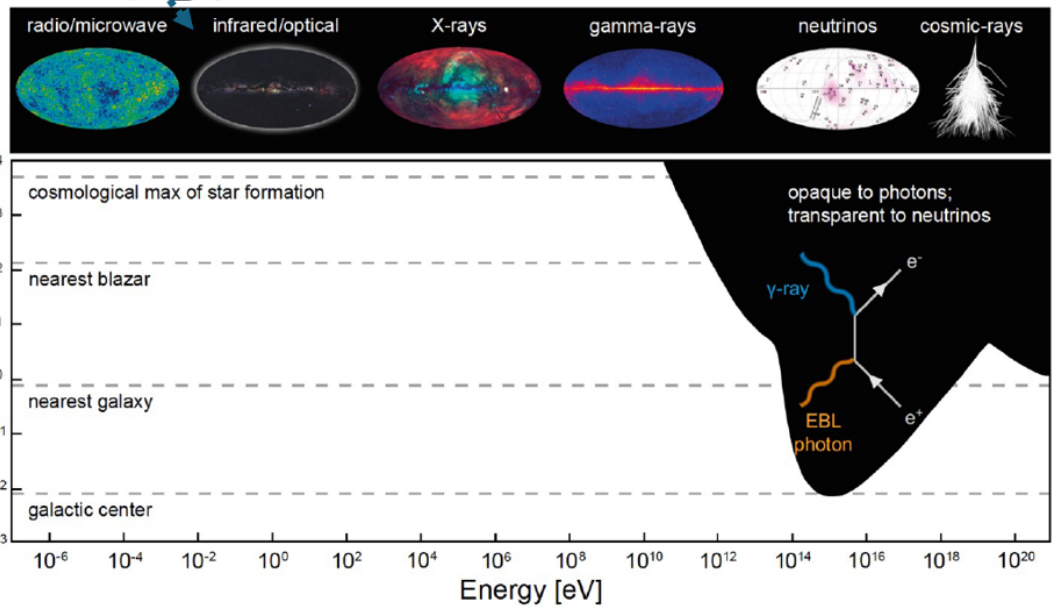




Neutrino Astronomy

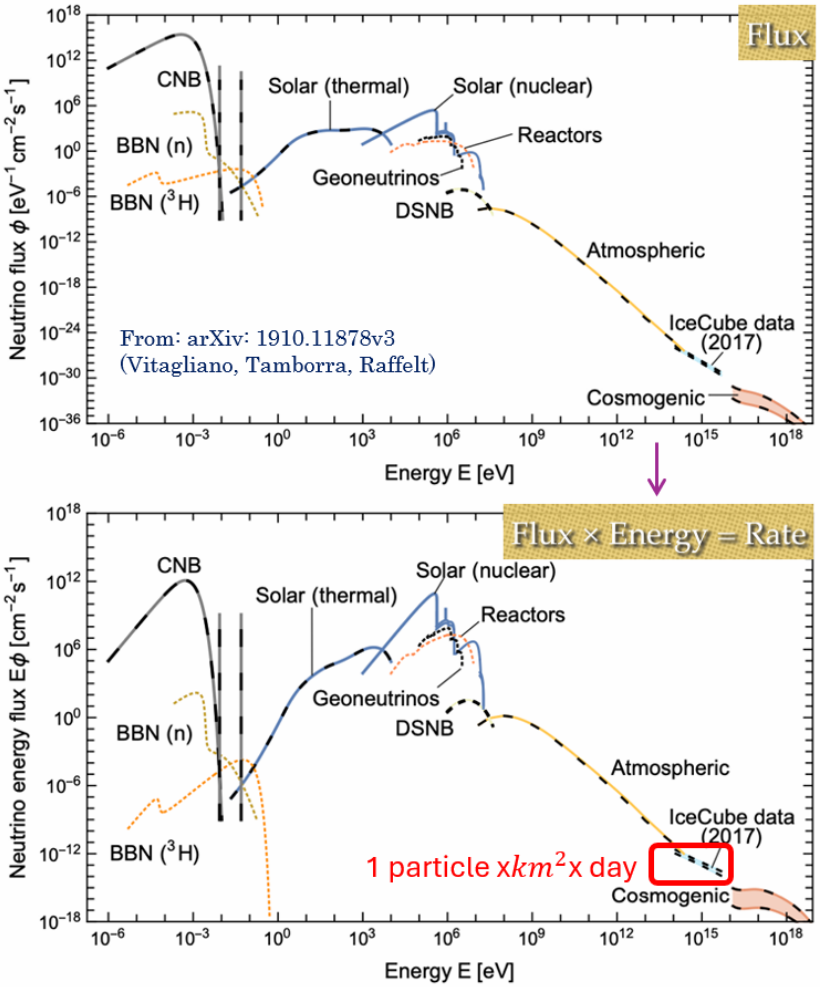


- CRs → deflected by magnetic field.
- Gamma-rays → could be absorbed.
- Neutrinos → weakly interact, hard to detect



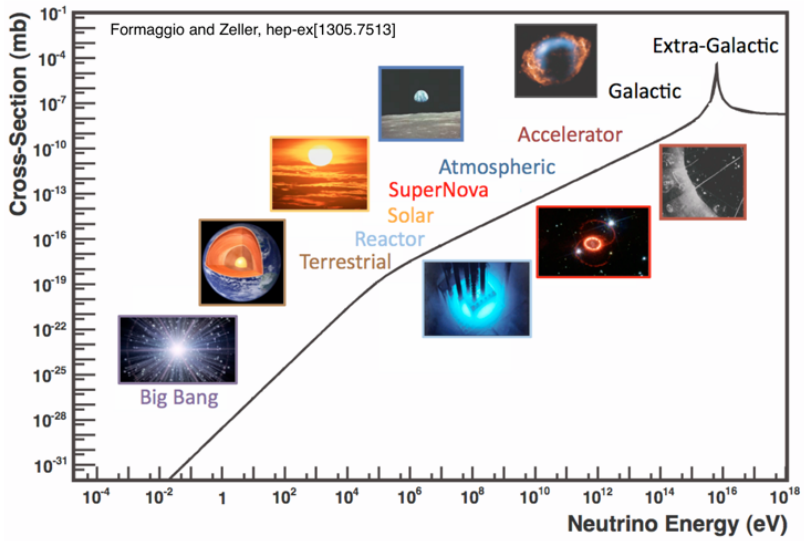
Above 10 GeV gamma-ray absorption starts to impact on the distance that we can study using them

Neutrino Astronomy



How many events are expected ?

Low rate of event is expected
(1 particle x km^2x day)
⇒ Large size detector are needed to collect enough statistics of events



Section 2

Neutrino Telescopes

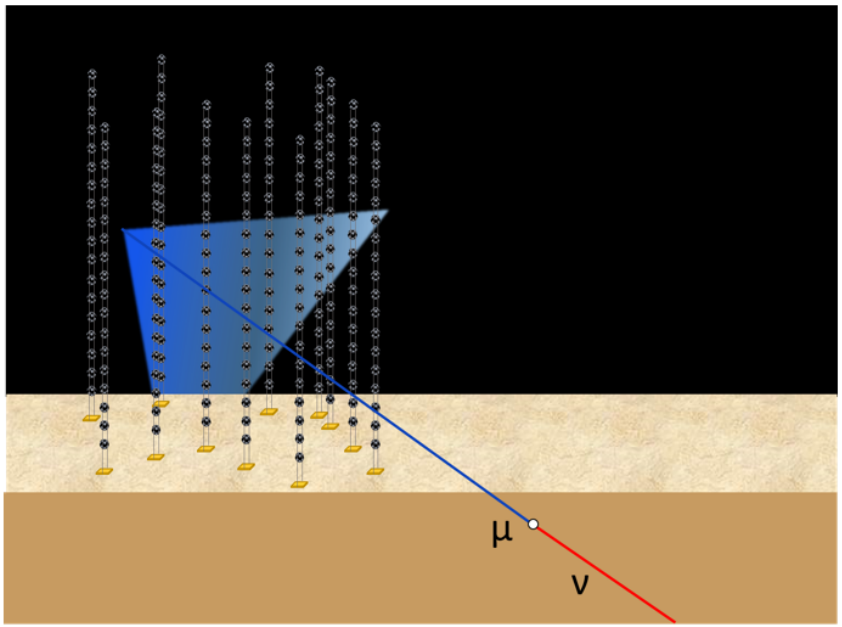
Neutrino Telescope

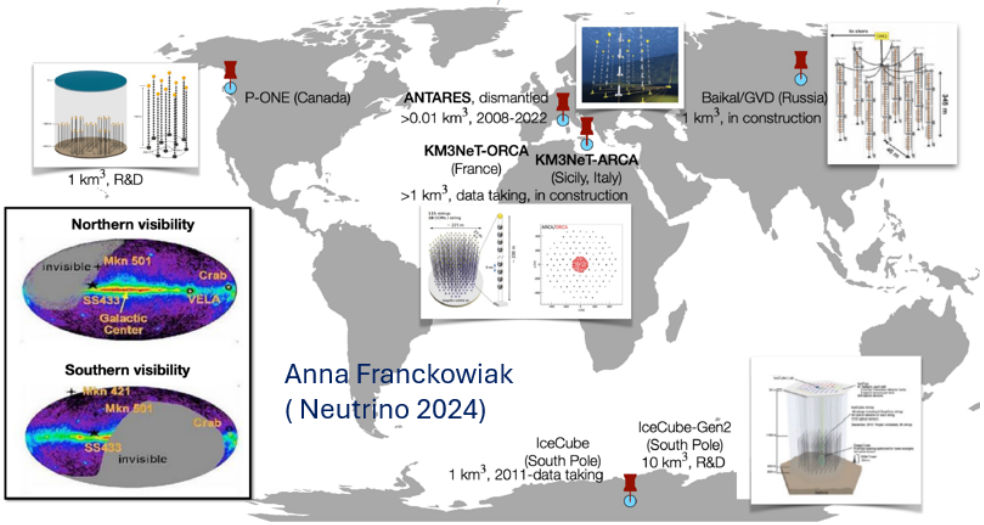
Large volume arrays of "optical modules" installed in a transparent media like water or ice, at depths that completely block the daylight.

Optical modules OM

A pressure tight glass sphere housing one or several PMTs and electronics for control and calibration.

⇒ OMs record Cherenkov light induced by charged secondary particles produced in reaction of neutrino in/around instrumented





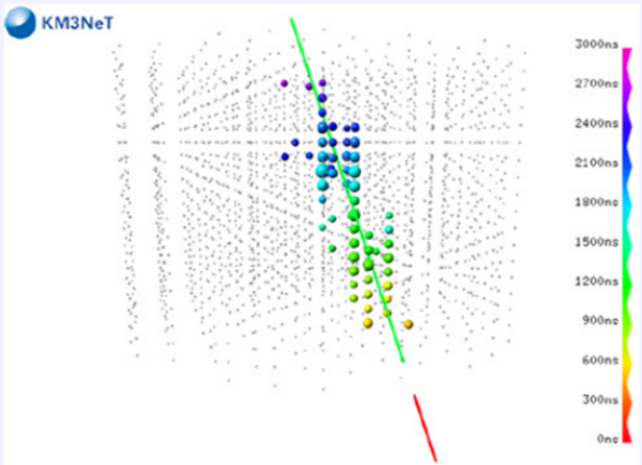
Neutrino event topology:

Track (μ signature)

ν_μ CC

ν_τ CC ($\tau \to \mu + \bar{\nu}_\mu + \nu_\tau$ $BR \sim 17.39\%$)

$\Rightarrow$ μ final state



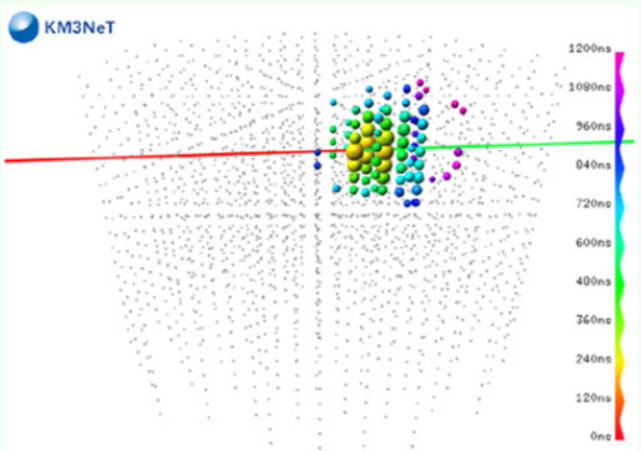
- Good angular resolution
  (Needed feature for ps studies)
- Bad energy resolution

Shower (e signature)

all flavours NC, ν_e CC

ν_τ CC ($\tau \to e + \bar{\nu}_e + \nu_\tau$ $BR \sim 17.82\%$)

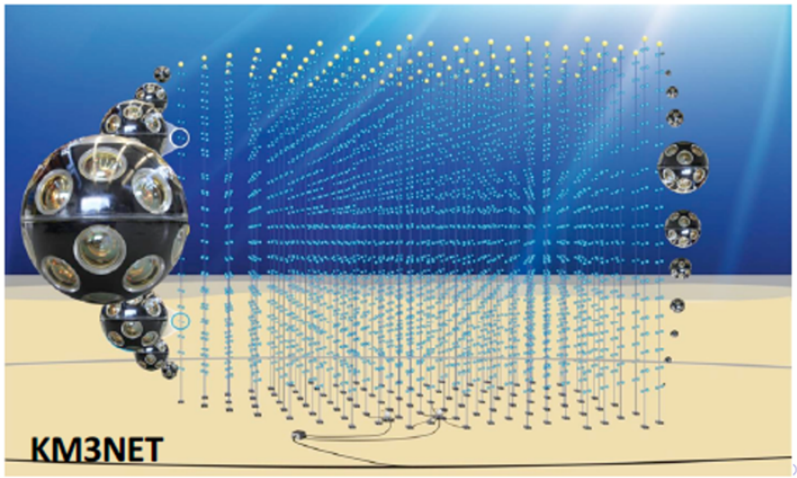
$\Rightarrow$ e final state



- Bad angular reusolution
- Good energy resolution

KM3NeT

Location=Mediterranean sea
It will consists of building blocks BBs of 115 strings each, with 18 OMs per string. In every OMs are located 31 PMTs.



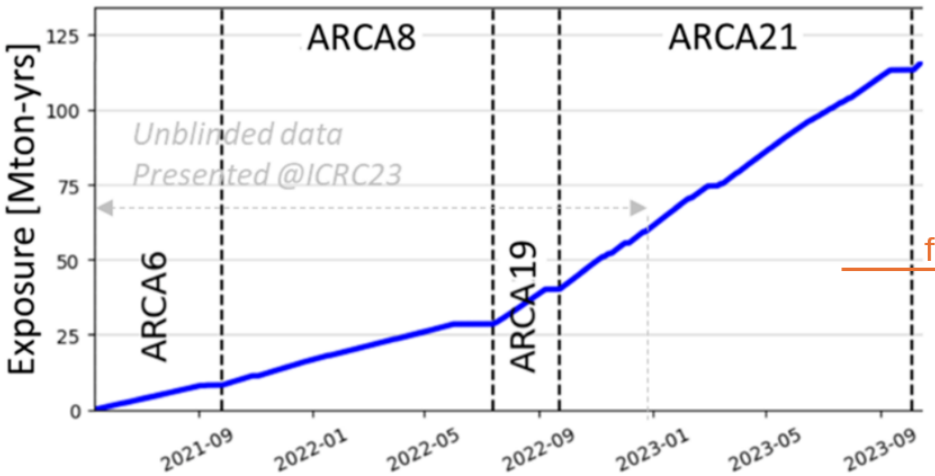
ARCA

- 2 BBs for neutrino astronomy (located near Capo Passero, Italy).
- Vertical distance between OMs of 36 m, lateral distance between adjacent strings of 90 m.
- $E_\nu \sim$ TeV-PeV

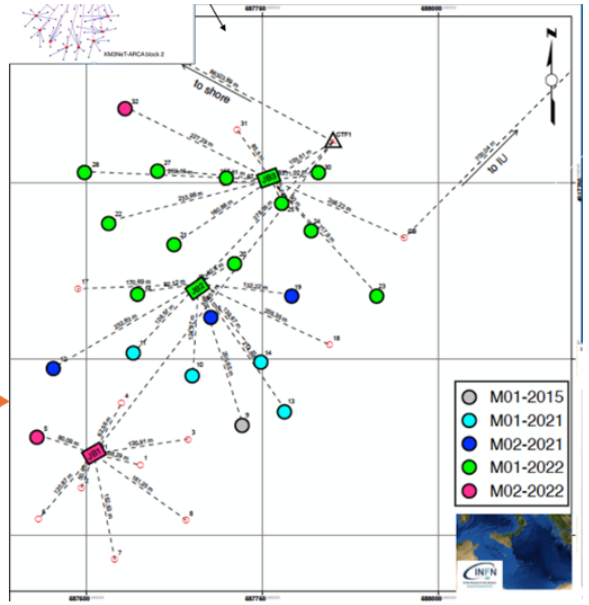
ORCA

- 1 BB for measurements of neutrino mass hierarchy (located near Tolone, France).
- Vertical distance between OMs of 9 m, lateral distance between adjacent strings of 20 m.
- $E_\nu \sim$ GeV

Once a D.U. is installed, it starts to collect data.

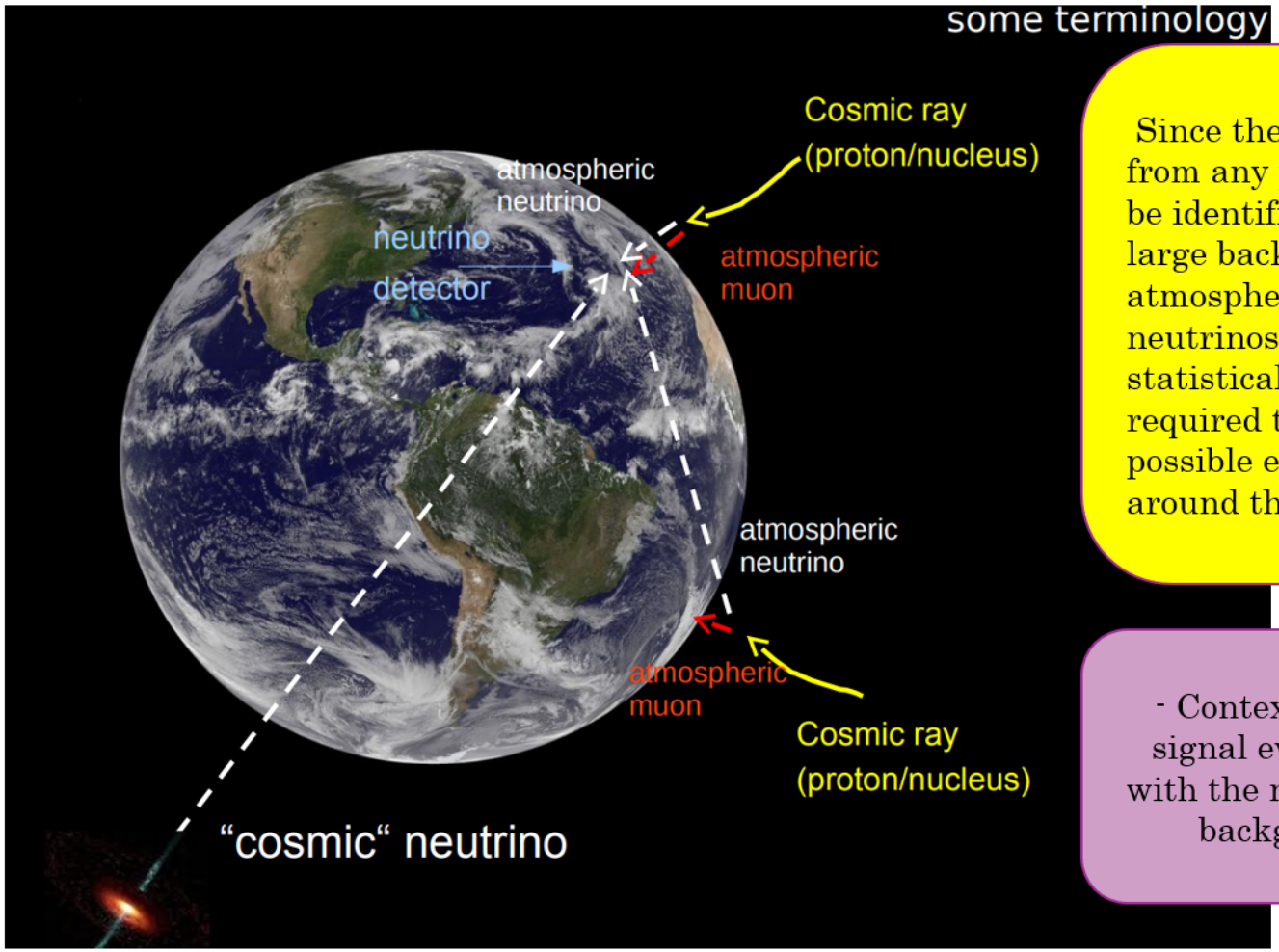


footprint



Neutrino telescope events:

Signal/Background expectation



Since the neutrino signal from any point source must be identified ontop of a large background of atmospheric muons and neutrinos, statisticaltechniques are required to quantify a possible excess of events around thesource position.

- Context:Low number of signal events comparable with the number of expected background events.

Section 3

Likelihood PS analyses

Basic Idea:

Binned Likelihood (Standard): It is checked in a 5 degree cone around each source weather the position, and energy distributions are in line with a cosmic neutrino excess. The log-likelihood is the Poisson probability of the bin-contents

$$\log L \approx \sum_{\text{bins}} N_i \log\left(B_i + \mu S_i\right) - \left(B_i + \mu S_i\right)$$

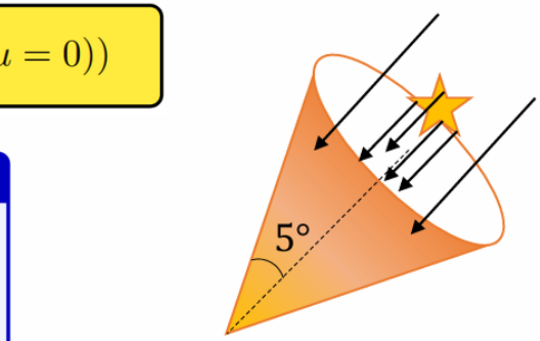
$$\lambda = \log(L(\mu = \widehat{\mu})) - \log(L(\mu = 0))$$

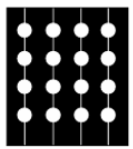
Discovery potential:

flux that could produce a significant (e.g. 3σ or 5σ) observation with probability 50%.

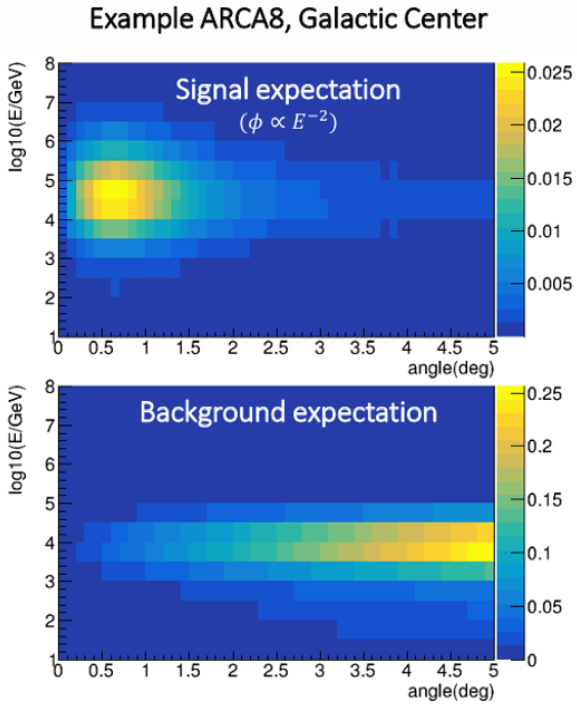
Sensitivity:

flux that can be excluded at a given confidence level (for example 90%), if no significant signal is observed





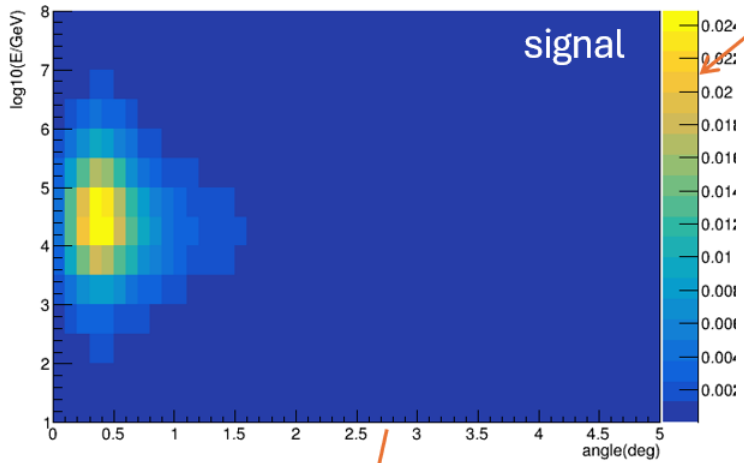
KM3NeT/ARCA6-8-19-21

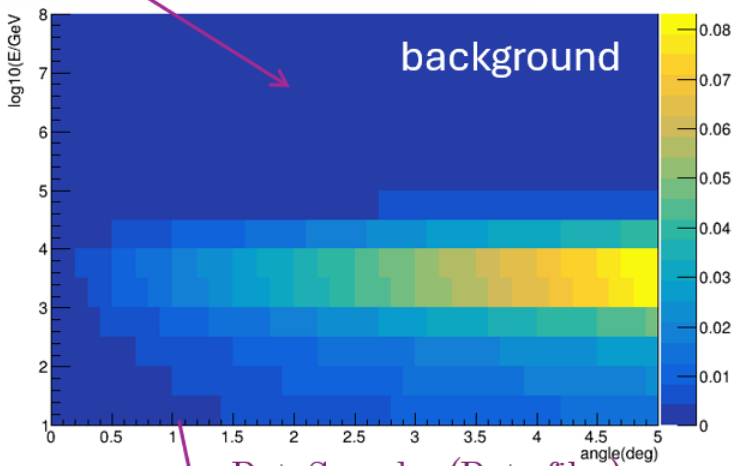


Likelihood Ingredients

(a simple scheme)

$$\log L \approx \sum_{\text{bins}} N_i \log\left(B_i + \mu S_i\right) - \left(B_i + \mu S_i\right)$$



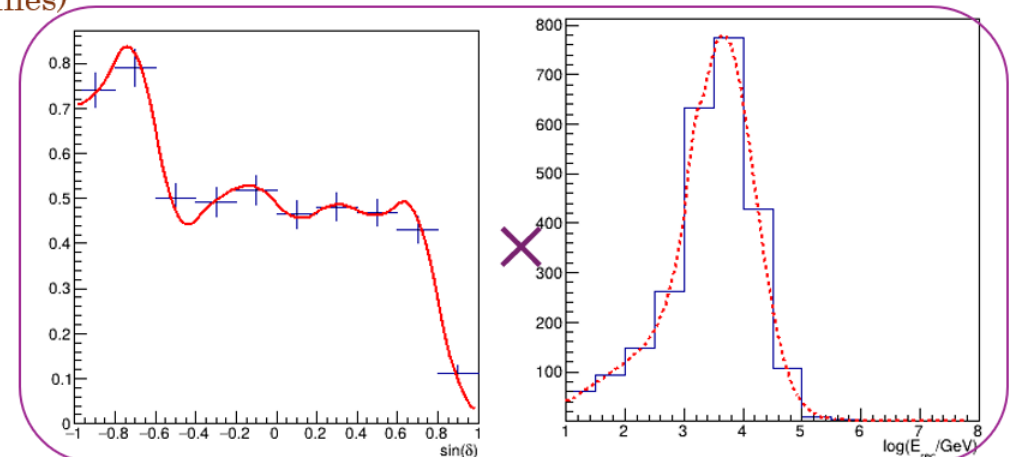


Instrument Response functions(MC files)

$$\Phi_\nu = \Phi_0 \left(\frac{E}{1GeV}\right)^{-2}$$

$$\Phi_0 = \frac{1}{10^4}\frac{1}{GeV\ m^2 s}$$

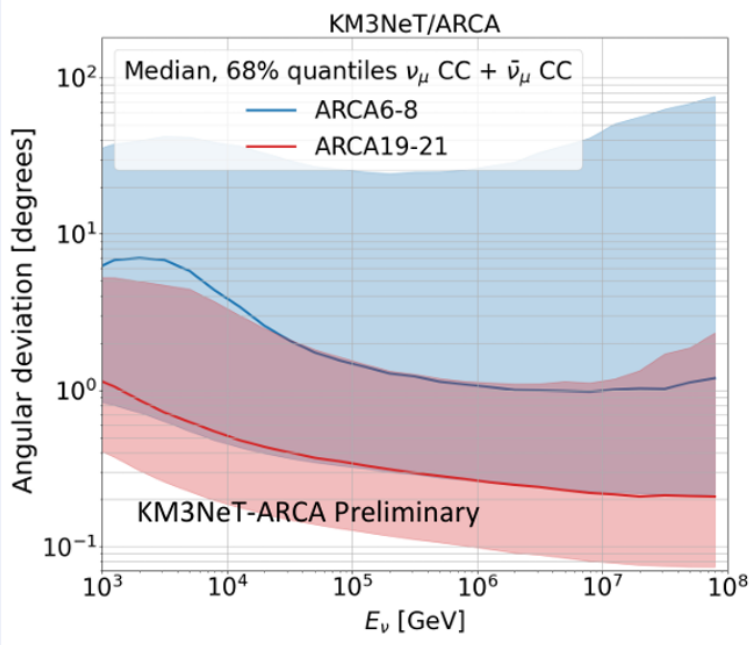
DataSamples (Data files)



Data-Samples and Event Selections:

In total, 640 days of data

Detector lifetimes:
- ARCA6 → 7949520.0 sec → 92 days
- ARCA8 → 18346400.0 sec → 212 days
- ARCA19 → 4181527.4 sec → 48.397 days
- ARCA21 → 24830910.5 sec → 287.394 days



Signal definition
- A cosmic neutrino with an outgoing muon

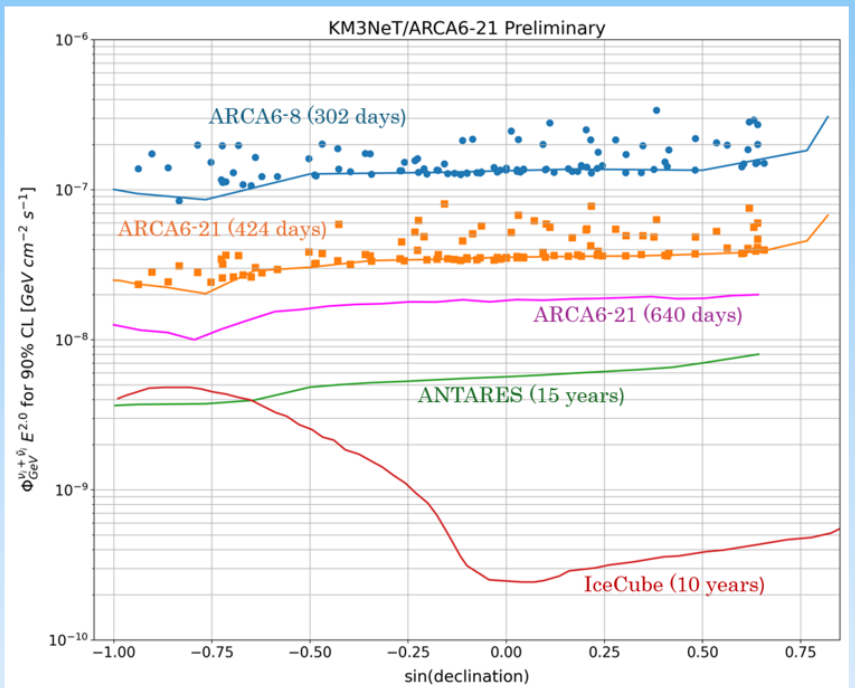
Selection criteria
- Select horizontal / upgoing tracks ($\cos(\theta) > -0.1$)
- Select events with high number of hits used in the reconstruction
- Select events with good fit quality (based on the likelihood of the reconstruction)
- Boosted decision tree

Aim
- Provide a sample of well reconstructed tracks coming from up-going or horizontal ν's interacting inside or in the vicinity of KM3NeT/ARCA
- Since the analysis method does not require a-priori optimisation of the signal to background ratio, but will perform best with as much signal as possible, the event-selection criteria are quite loose keeping the signal efficiency high

Energy integrated median angular resolute]s are:
ARCA6 2.11° ARCA8 1.56°
ARCA19 0.37° ARCA21 0.38°

The full KM3NeT/ARCA230 detector will achieve<0.1° for E<300TeV

Preliminary Sensitivity



- Sensitivity = flux that can be excluded at 90% confidence level if no significant signal is observed.

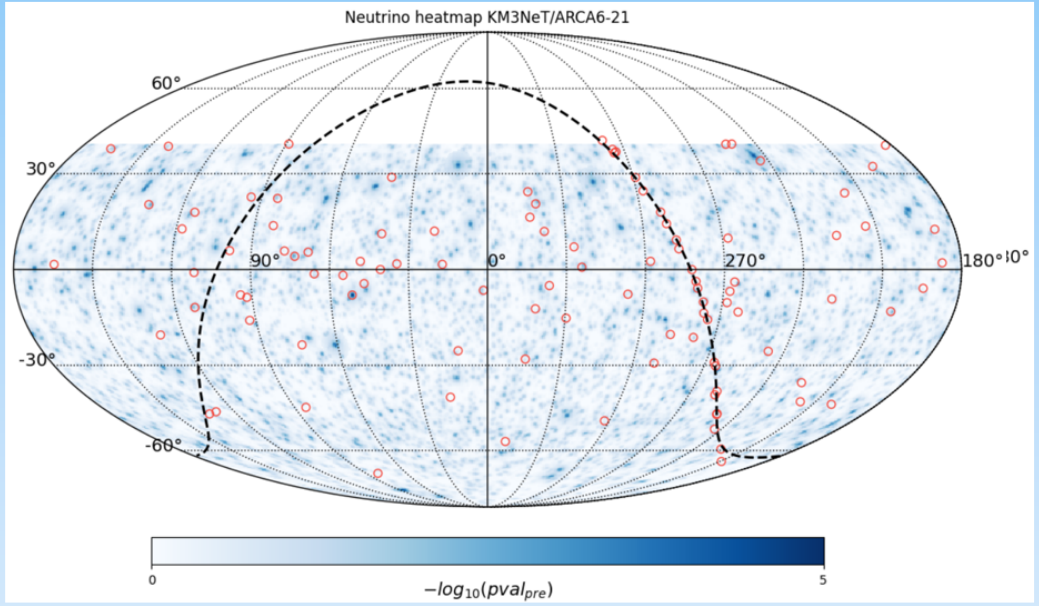
- Sensitivity as a function of $sin(\delta)$ for $-90° < \delta < 40°$, $E^{-\gamma}$ spectrum is assumed for each source, with γ=2.0

- For previous ARCA PS analysis, 107 candidate sources* were considered.

- No strong neutrino emitters are found among the preselected candidate sources. Since no significant detection is made, upper limits are set on the flux for each source.

*References for selected candidate sources: https://arxiv.org/pdf/1910.08488.pdf | https://pos.sissa.it/395/1161/pdf | [7] https://arxiv.org/pdf/2012.15082.pdf | [https://iopscience.iop.org/article/10.1088/1748-0221/16/10/C10005/meta | https://arxiv.org/abs/2103.15526 | Alexander Plavin| https://www.nature.com/articles/s41586-021-03498-z & https://pos.sissa.it/395/1161/pdf | IC211208A, GVD211208A, Baksan| IC220205B | IC220225A | IC220304A

Preliminary All-Sky scan



- Sky map in equatorial coordinates of the local p-values from the sky scan for $-90° < \delta < 40°$ (where KM3NeT has >35% visibility for the selected upgoing and horizontal events $\cos\theta > -0.1$)
- p-value distribution obtained scanning the full sky divided in $2.6 \cdot 10^6$ bins,
- Candidate sources are visualized in the sky map by red circles.

Conclusions:

Summary:

- At present, we are working on an alternative event selection in order to reduce the atm. muons background.
- Neutrino emission will be searched among 107 known candidate neutrino point sources, as well as in $2 \cdot 10^6$ bins dividing the whole sky.
- A binned likelihood method is involved for this search (analysis framework is in place and working).
- KM3NeT experiment is going to take more data and new deployments are foreseen, work is ongoing to expand the framework in order to improve our performance and do more extended studies.

Thanks
for the attention.