Search for neutrinos from the Galactic Plane with ANTARES

Journée des doctorants
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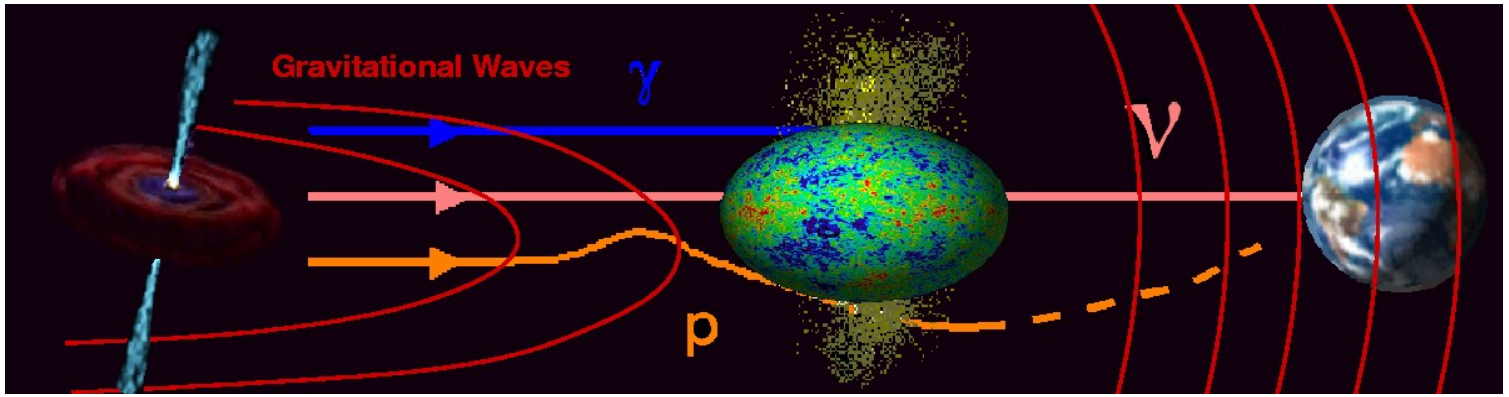
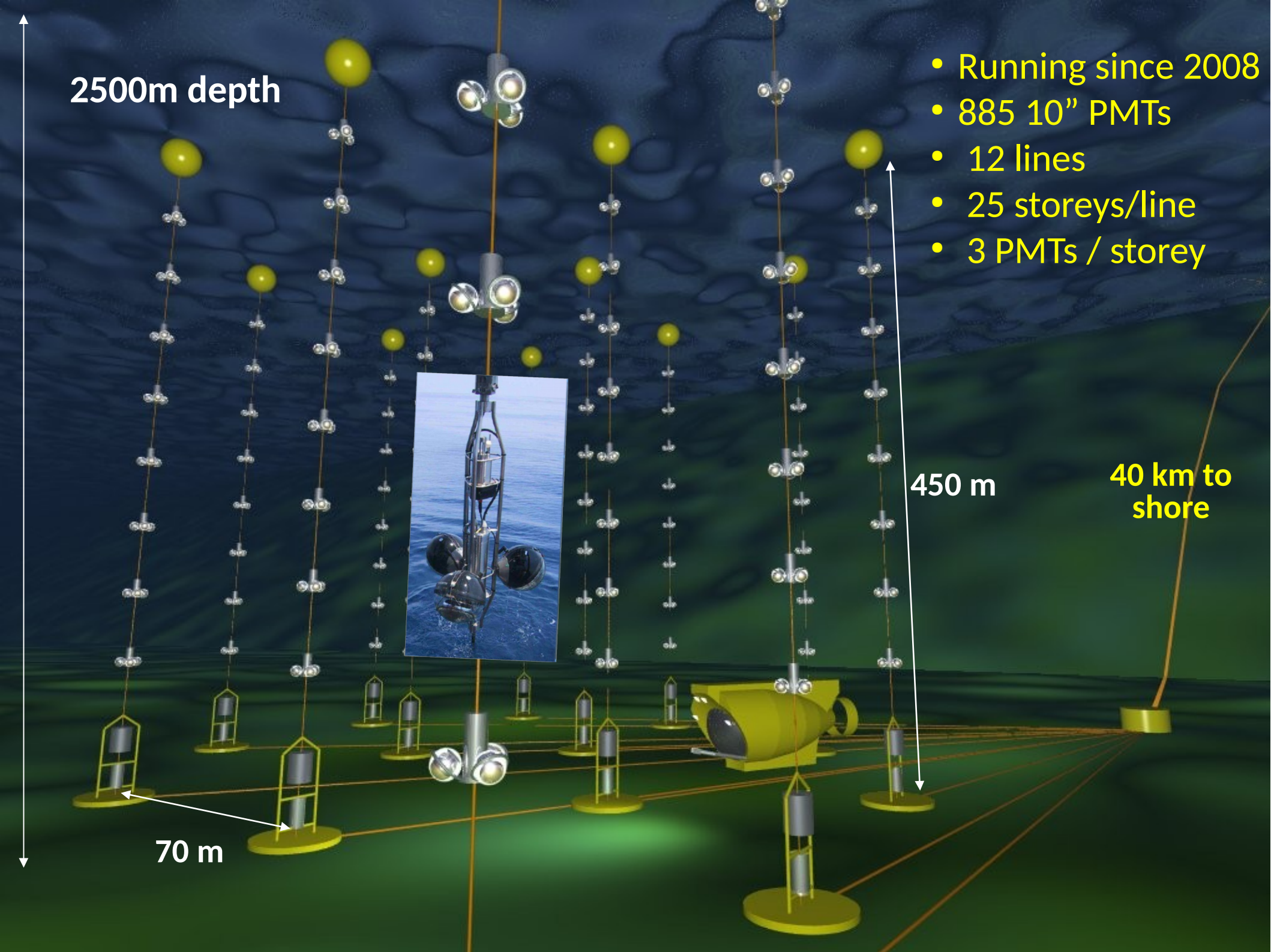
Multimessenger astronomy

- Cosmic Rays (CR) deflected by the magnetic fields ⟶ sources hard to determine

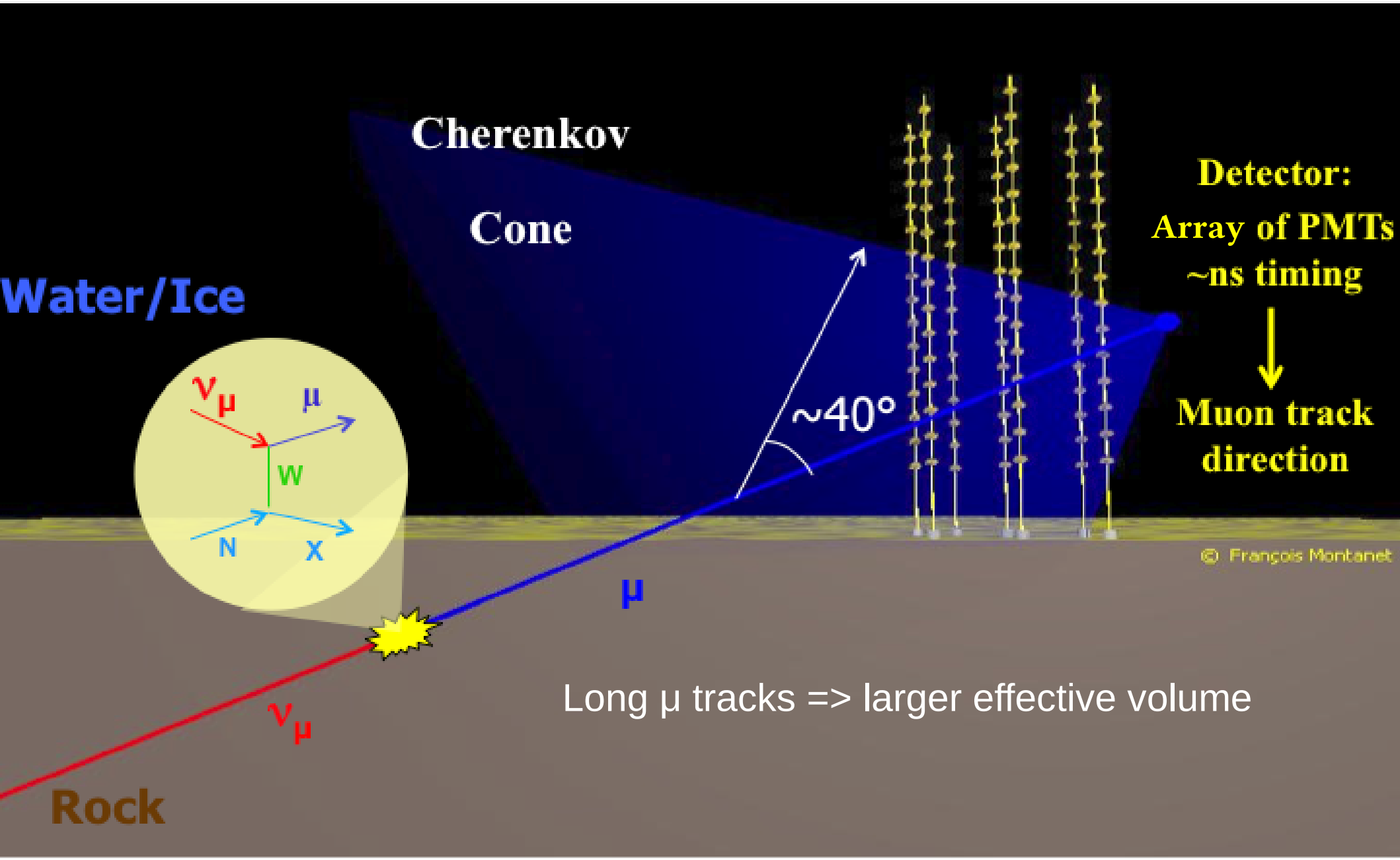


- Observation depth limited:
  - ➔ Interaction of γ and high energy CR with the CMB or IRB
  - ➔ Absorption of γ by the dense media

- Neutrinos don't suffer from those effects

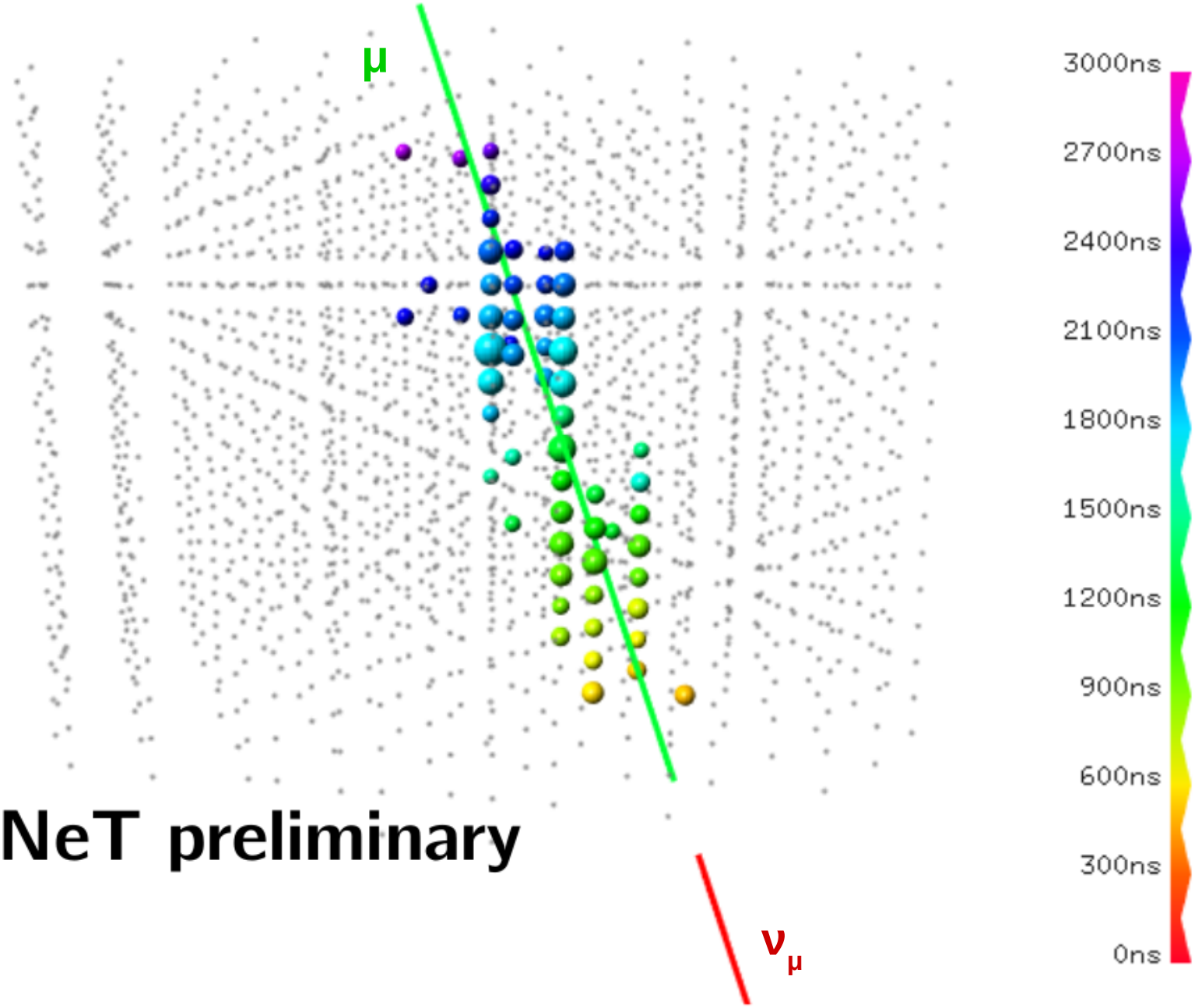

2500m depth
• Running since 2008
• 885 10” PMTs
• 12 lines
• 25 storeys/line
• 3 PMTs / storey
450 m
40 km to shore
70 m

Detection principle

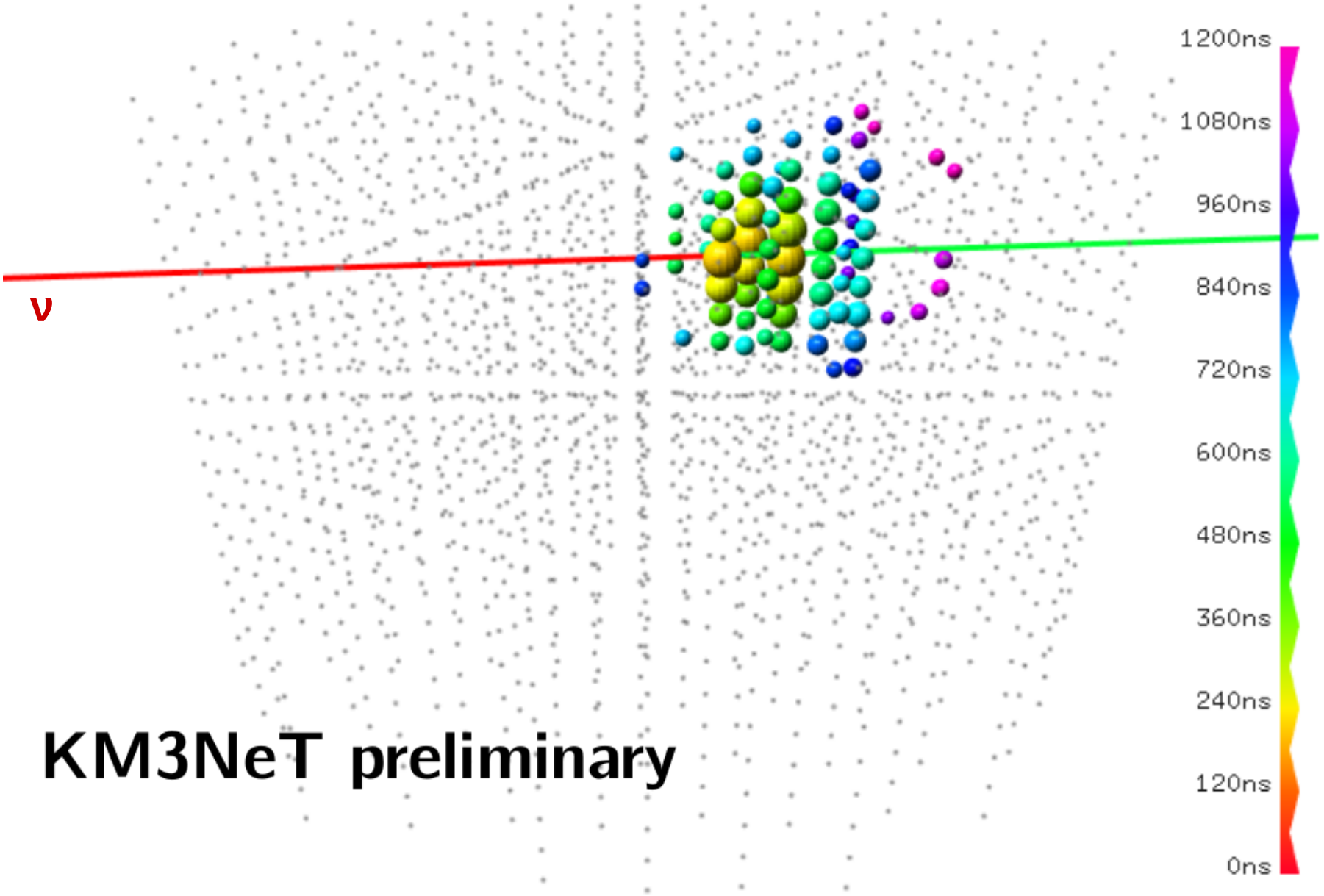


Long μ tracks => larger effective volume

Track


μ
3000ns
2700ns
2400ns
2100ns
1800ns
1500ns
1200ns
900ns
600ns
300ns
0ns
KM3NeT preliminary
ν μ

Shower


ν
1200ns
1080ns
960ns
840ns
720ns
600ns
480ns
360ns
240ns
120ns
0ns
KM3NeT preliminary

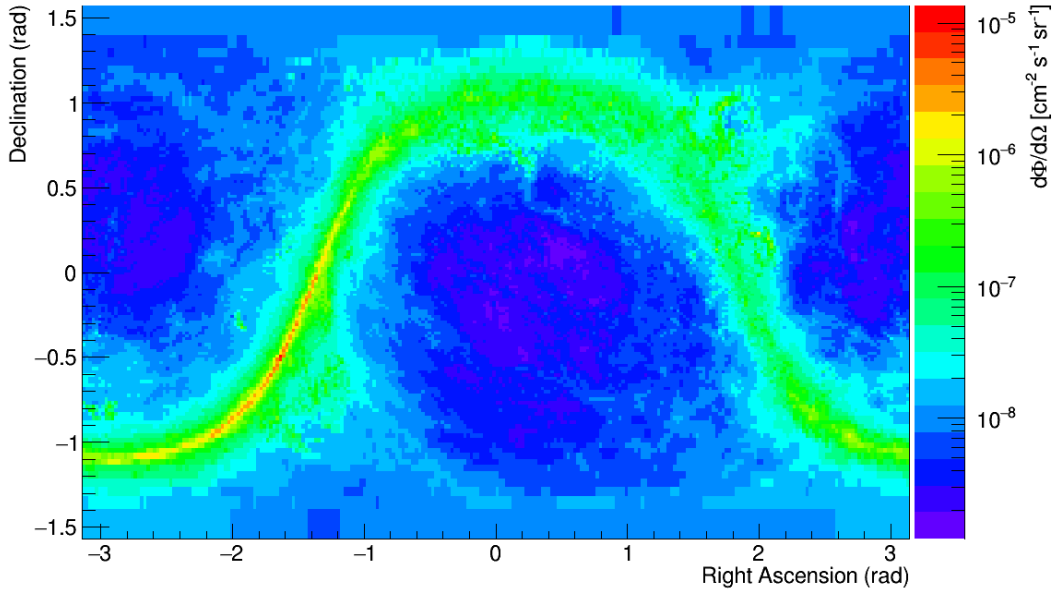
KRAγ model

Test the KRAγ model (Gaggero et al. 2015)

- Phenomenological model
- CR diffusion in the Galaxy
  → interaction with the medium
  → ν production
- Designed to reproduce Fermi-LAT γ-ray data and local cosmic ray observables

KRAγ model

- Naturally reproduces the Milagro anomaly from the inner GP region at 15 TeV median energy
- Gives a possible interpretation of the hints of an excess of IceCube events along the Galactic plane
- KRAγ model ⟶ ν flux 2 (5) times larger in full-sky (Galactic Center region)



Galactic Plane analysis

Data from 2007 to 2015: 9600 tracks + 175 showers

- How likely data contains some signal with KRAγ characteristics?
  - ➔ Build a likelihood function:

$$L_{sig+bg} = \prod_{evts} \left[n_{sig} \cdot pdf_{sig}(\alpha, \delta, E) + n_{bg} \cdot pdf_{bg}(z, \delta, E) \right]$$

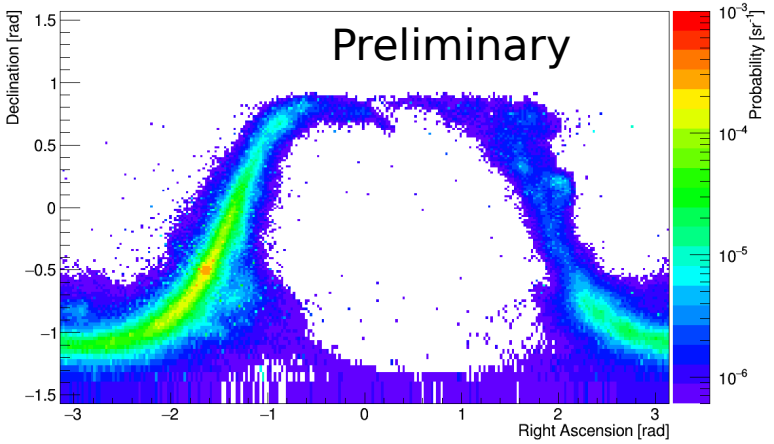
  - ➔ Get the probability density function (pdf) to be a **signal** or **background** event

Signal

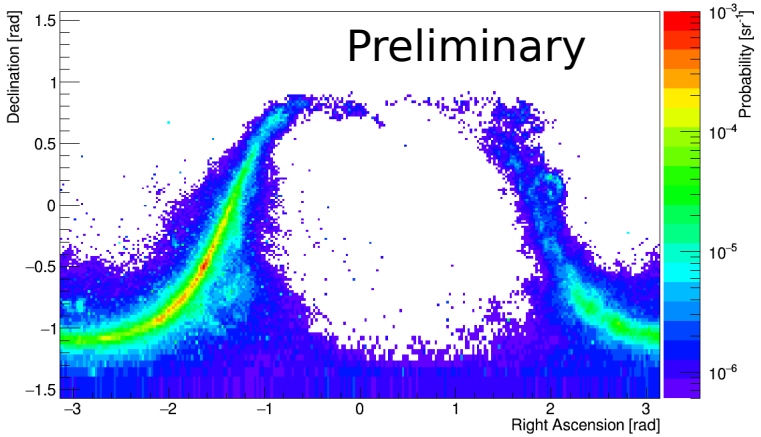
- Pdf to be a **signal** event:

$$pdf_{sig}^{tr/sh}(\alpha,\delta,E) = M_{sig}^{tr/sh}(\alpha,\delta)\cdot\varepsilon_{sig}^{tr/sh}(E,\alpha,\delta)$$

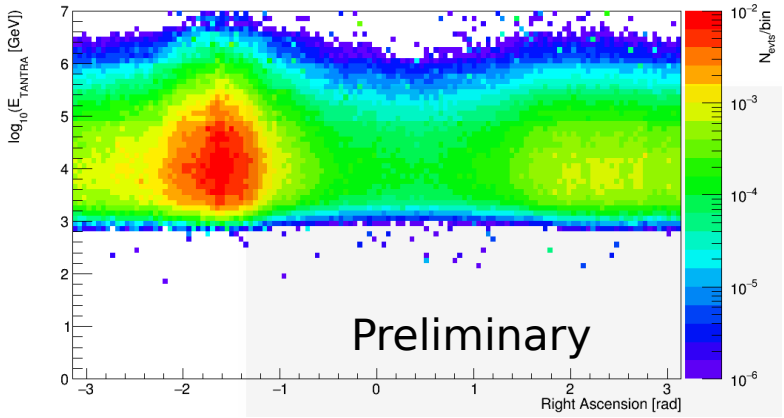
M_{sig}^{sh}

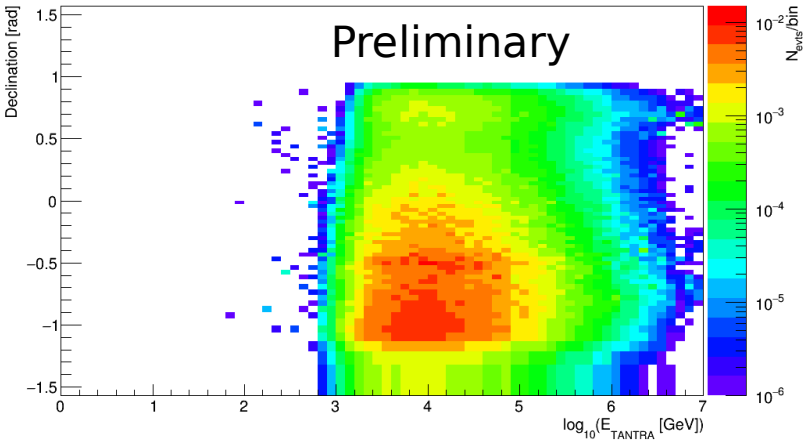


M_{sig}^{tr}



ε_{sig}^{sh}



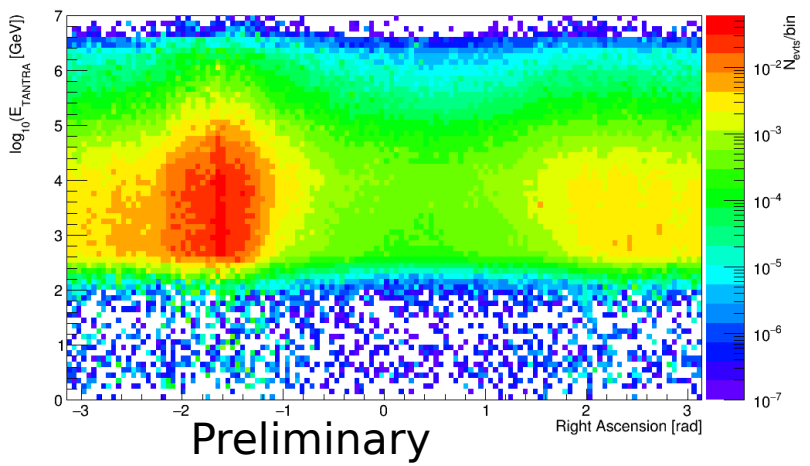


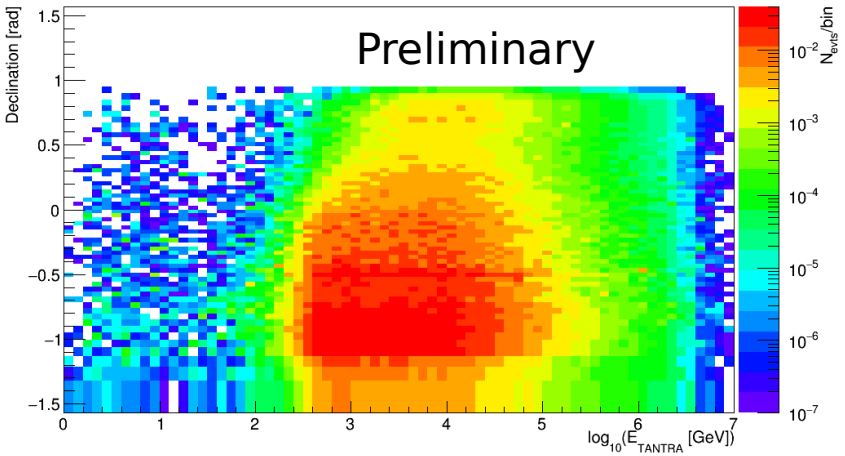
Signal

- Pdf to be a **signal** event:

$$pdf_{sig}^{tr/sh}(\alpha,\delta,E) = M_{sig}^{tr/sh}(\alpha,\delta)\cdot\varepsilon_{sig}^{tr/sh}(E,\delta,\alpha)$$

ε_{sig}^{tr}



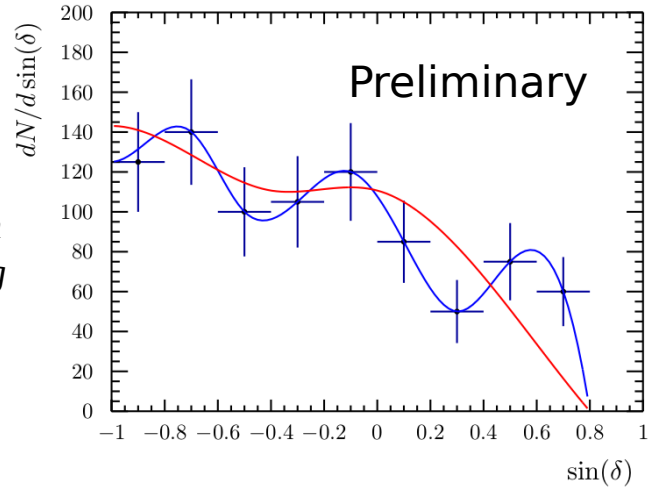


Background

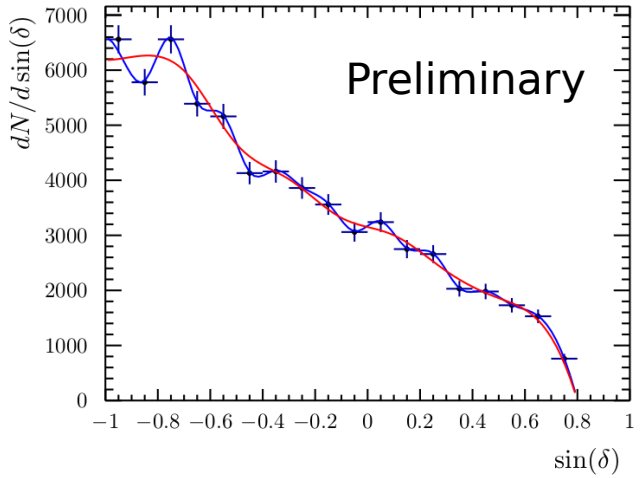
- Pdf to be **background** event:

$$pdf_{bg}^{tr/sh}(z,\delta,E) = M_{bg}^{tr/sh}(\delta)\cdot\varepsilon_{bg}^{tr/sh}(E,z)$$

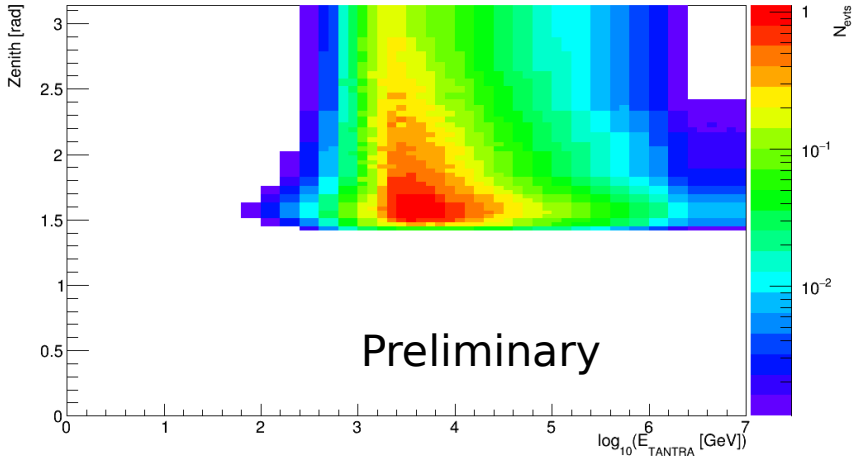
M_{bg}^{sh}



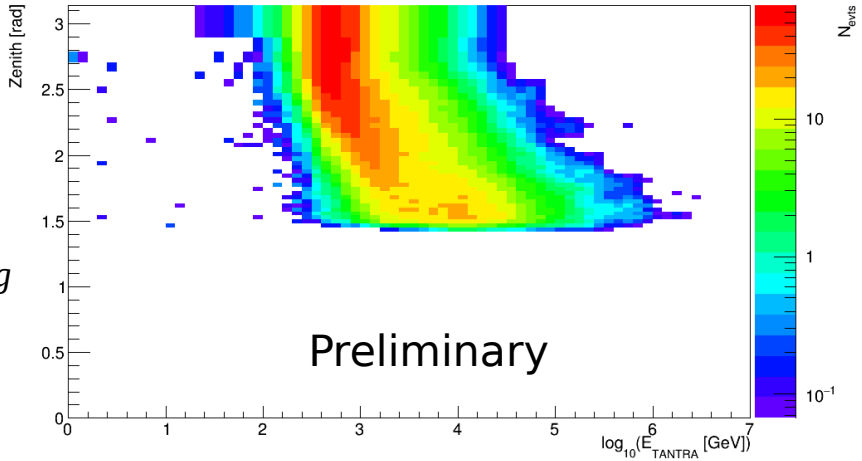
M_{bg}^{tr}



ε_{bg}^{sh}



ε_{bg}^{tr}



Likelihood function

- **Likelihood** function:

$$L_{sig+bg} = \prod_{evts} [\, n_{sig} \cdot pdf_{sig}(\alpha, \delta, E) + n_{bg} \cdot pdf_{bg}(z, \delta, E)\,]$$

- Which number of signal events is the most likely?
  - ➔ Fit n_{sig} by maximizing the likelihood

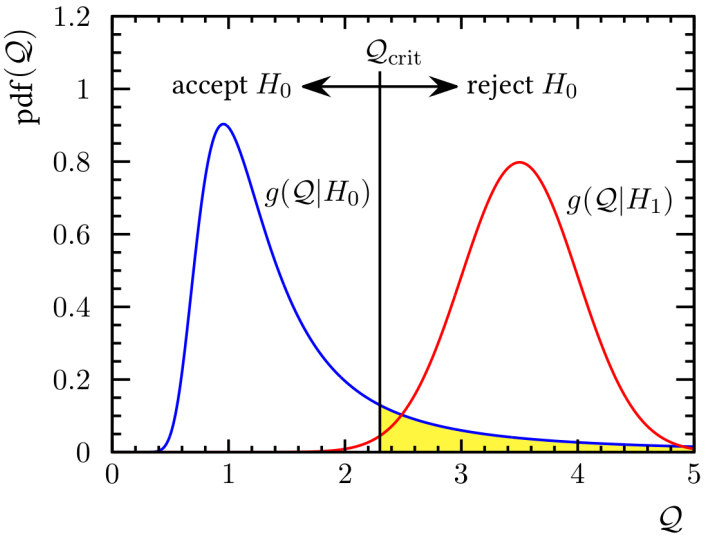
- Weight L_{sig+bg} against L_{bg}
  - ➔ Build a **test statistic** (TS):

$$TS = logL_{sig+bg} - logL_{bg}$$

$$L_{bg} = L_{sig+bg}(n_{sig} = 0)$$

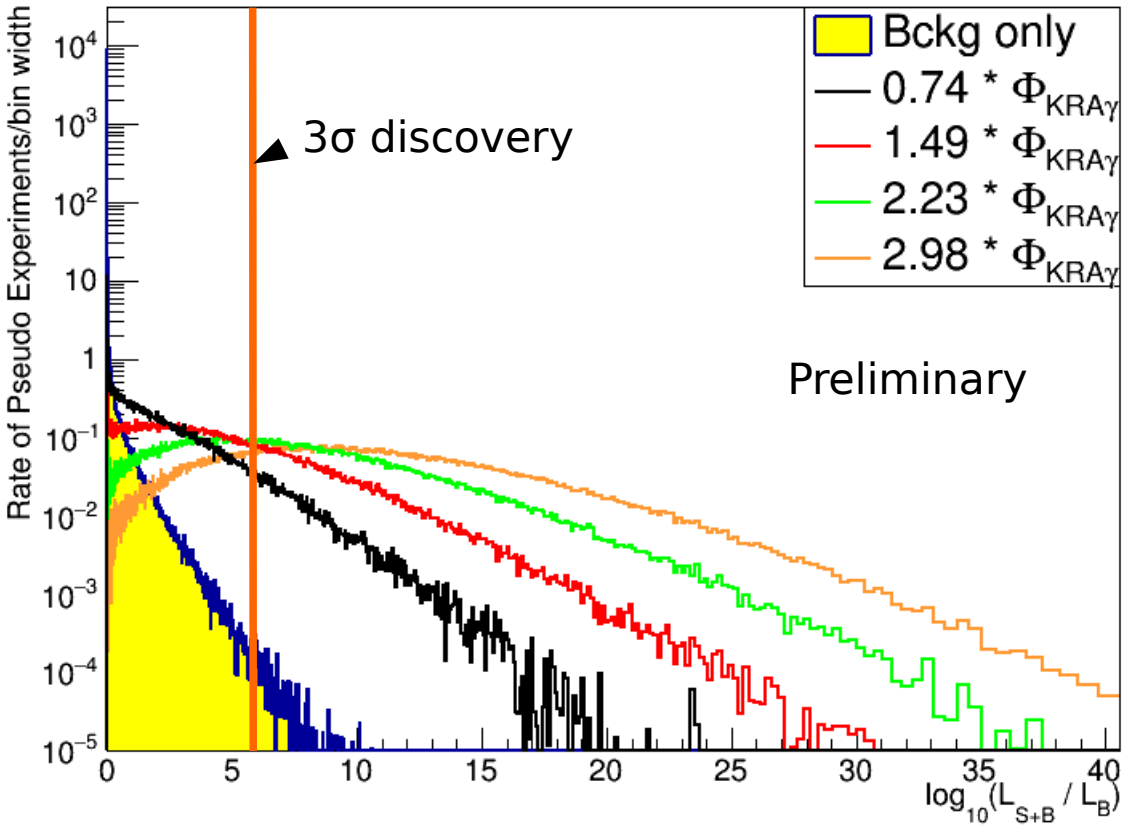
  - with $\Longrightarrow$ $logL_{bg} = \sum_{S} \sum_{i \in S} \log[\, n_{tot}^{S} \cdot M_{bg}^{S}(\delta_i) \cdot N_{bg}^{S}(N_i)\,]$

Test Statistic



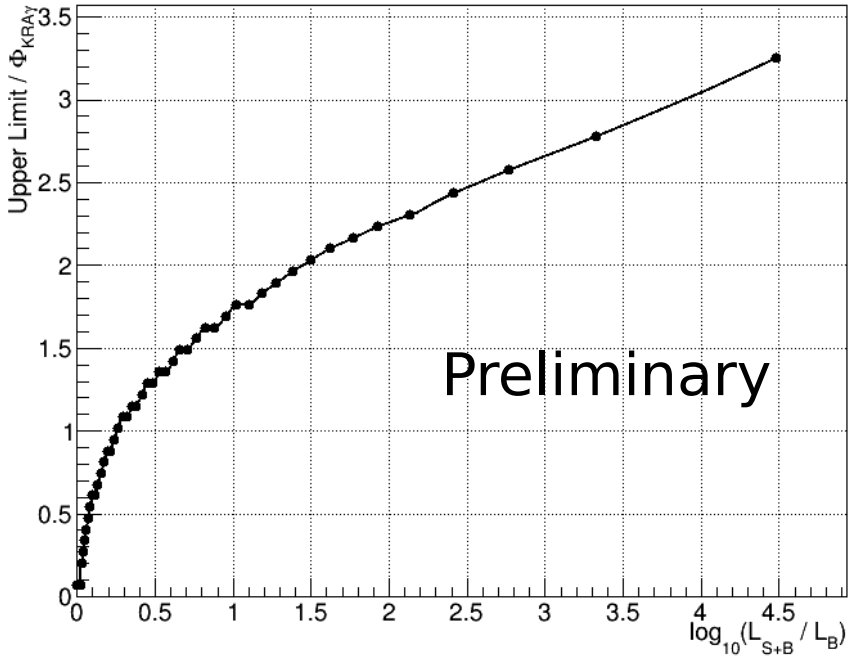
- For each possible values of nsig, we generate 10,000 pseudo-experiments
  - ➔ Pdf of TS

- Hypothesis rejection



First estimation and Outlook

- We should have a mean of 15 events coming from the KRAγ model
- First estimation of the median upper limit at 90% confidence level is roughly 1.2 times the flux predicted by the KRAγ model
- Probability to have a 3σ discovery is ~12%
- Further improvements of the analysis:
  - ➔ Optimise the quality cuts
  - ➔ Plans for a combined analysis with IceCube



Backup slides

High energy neutrino production

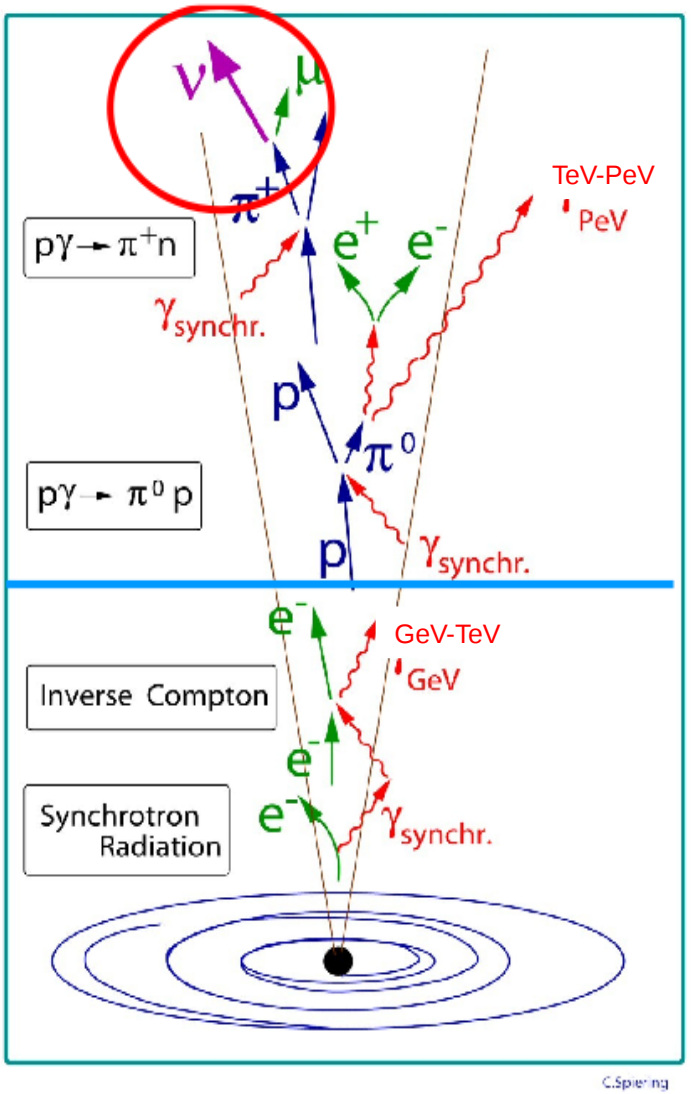
- Hadronic interaction, e.g.: relativistic jets:
- Production during acceleration or propagation

$$P+(A/\gamma) \rightarrow \pi^0 + \pi^+ + \pi^- + N + \ldots$$

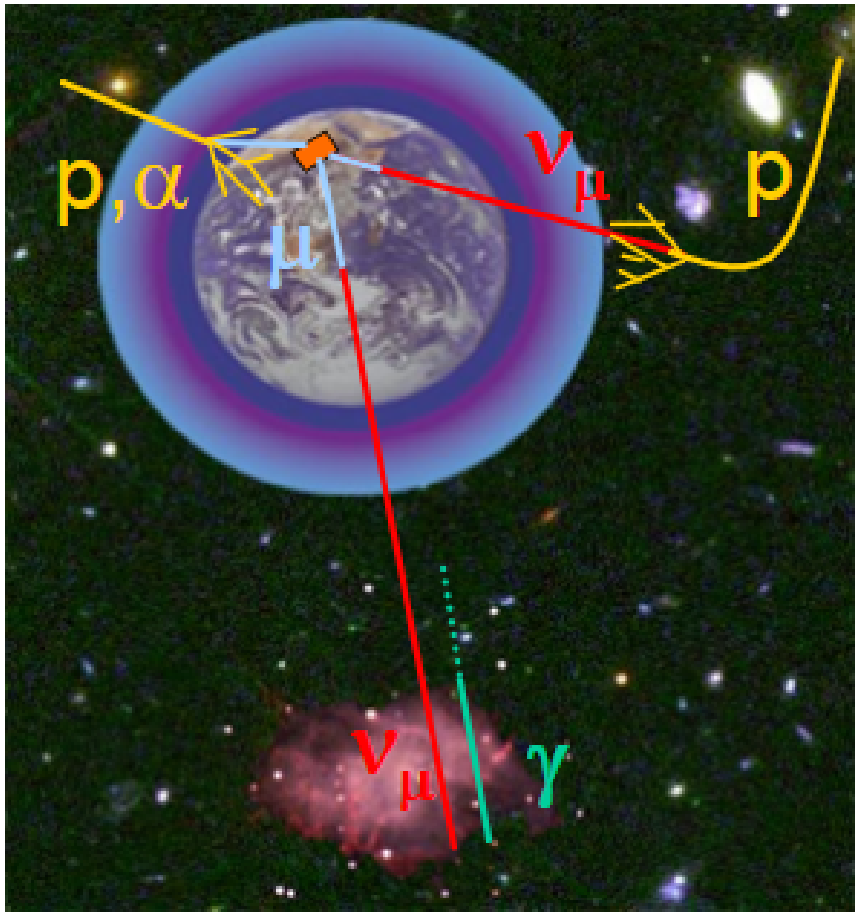
$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$



Background



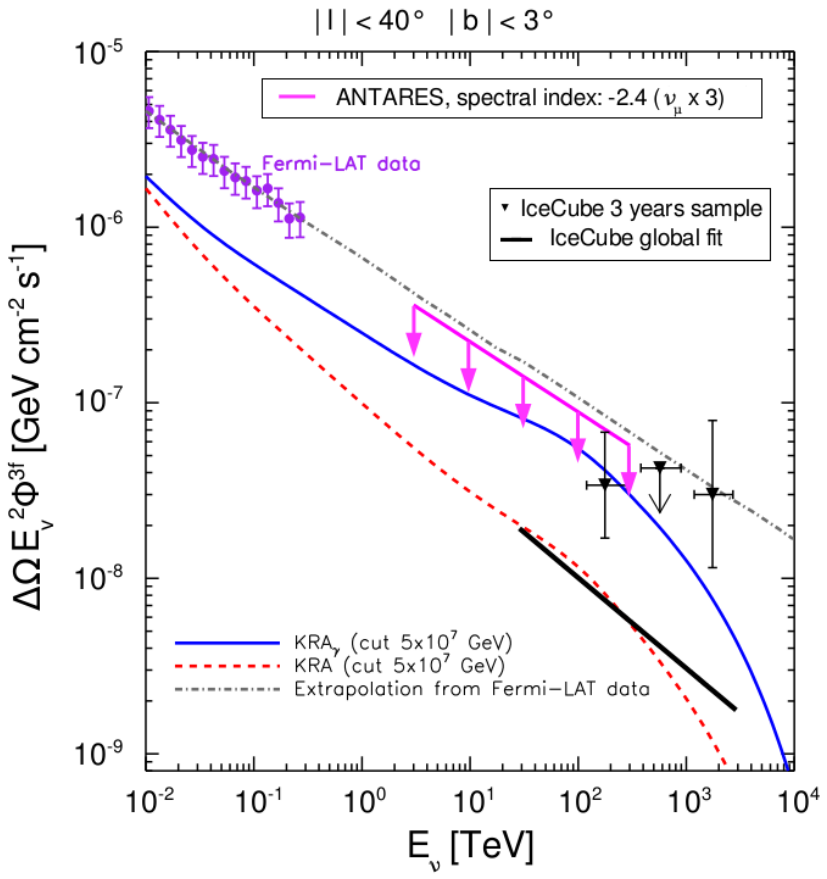
Two types of physical background

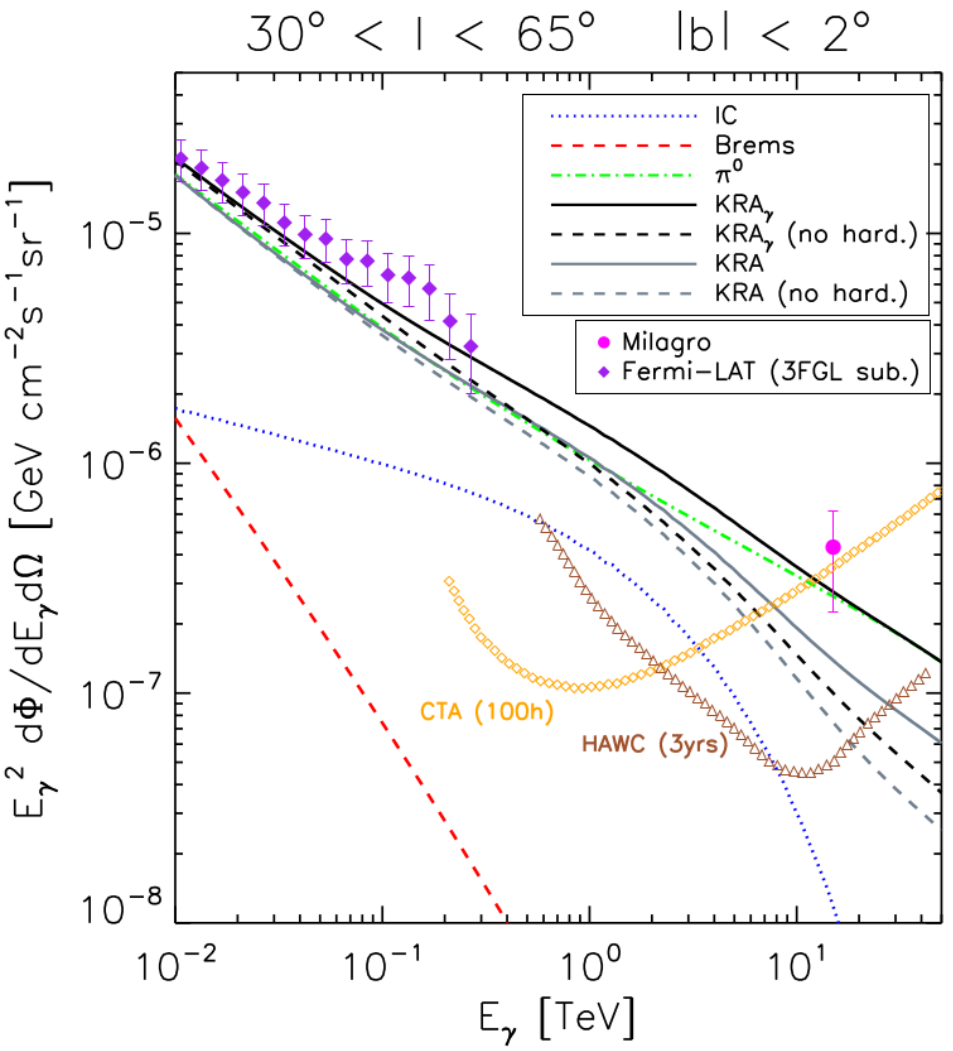
- Atmospheric muons
  - ➔ Selection of up-going events
- Atmospheric neutrinos
  - ➔ Unavoidable background

Other background

- β decay of ^{40}K
- Bioluminescence

KRAy model


|l| < 40° |b| < 3°
ANTARES, spectral index: -2.4 (ν_μ x 3)
Fermi−LAT data
IceCube 3 years sample
IceCube global fit
KRA$_\gamma$ (cut 5x10^7 GeV)
KRA (cut 5x10^7 GeV)
Extrapolation from Fermi−LAT data
$\Delta\Omega\, E_\nu^2 \Phi^{3f}$ [GeV cm^{-2} s^{-1}]
E_ν [TeV]


30° < l < 65° |b| < 2°
IC
Brems
π^0
KRA$_\gamma$
KRA$_\gamma$ (no hard.)
KRA
KRA (no hard.)
Milagro
Fermi−LAT (3FGL sub.)
CTA (100h)
HAWC (3yrs)
$E_\gamma^2\, d\Phi/dE_\gamma d\Omega$ [GeV cm^{-2}s^{-1}sr^{-1}]
E_γ [TeV]