The ANTARES Detector and I

A story about food, the weather and a PhD thesis

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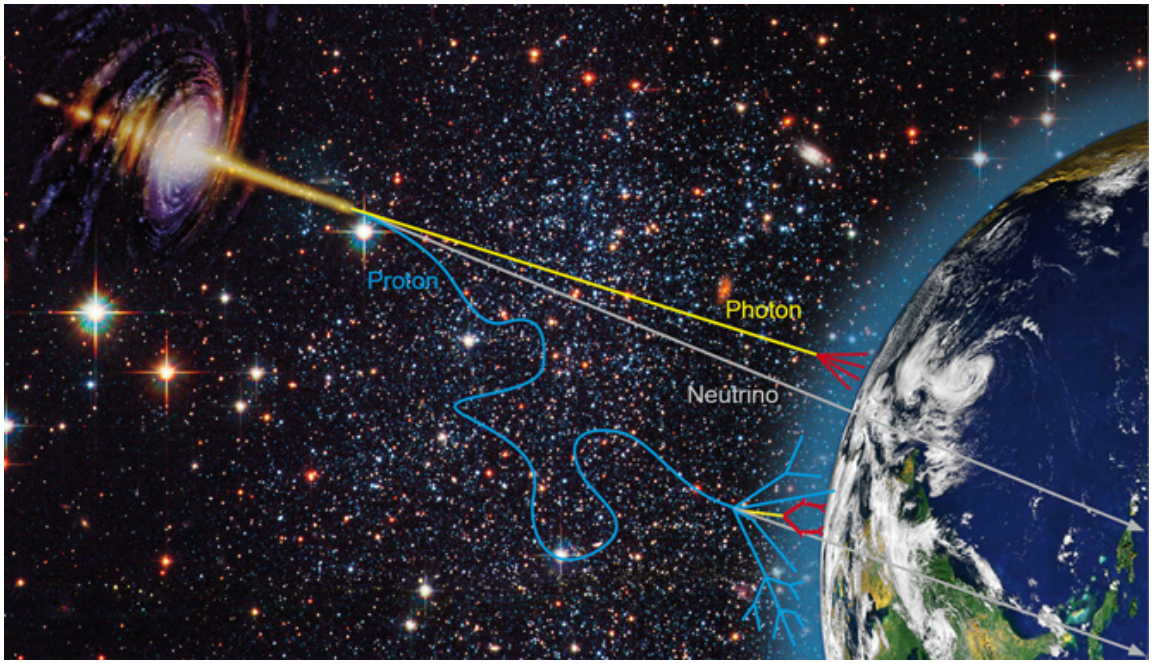
National Institute for Subatomic Physics, Amsterdam

Nikhef annual Meeting

2015-12-15

Why Neutrinos?



- photons absorbed by interstellar medium and scatter at CMB
  $\rightarrow$ highest energies not accessible
- cosmic rays deflected by galactic magnetic fields
  $\rightarrow$ hardly point back to their origin

Solution: Neutrinos

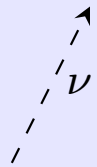
- pass unhindered through interstellar medium
- electrically neutral $\rightarrow$ no deflection
- point back right to their source
- open access to highest energies

Detection Principle

- neutrino interacts with ambient water nuclei
- creating charged particles in the process
- enough energy to induce Cherenkov radiation
- light gets picked up by 3D array of optical modules with photo multiplier tubes (PMTs)

- small interaction cross section

→ need a huge, transparent volume at a dark place



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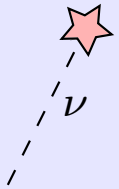

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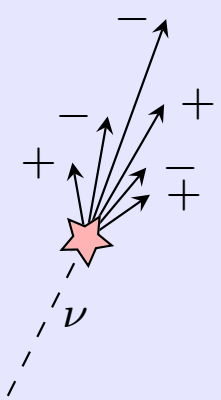

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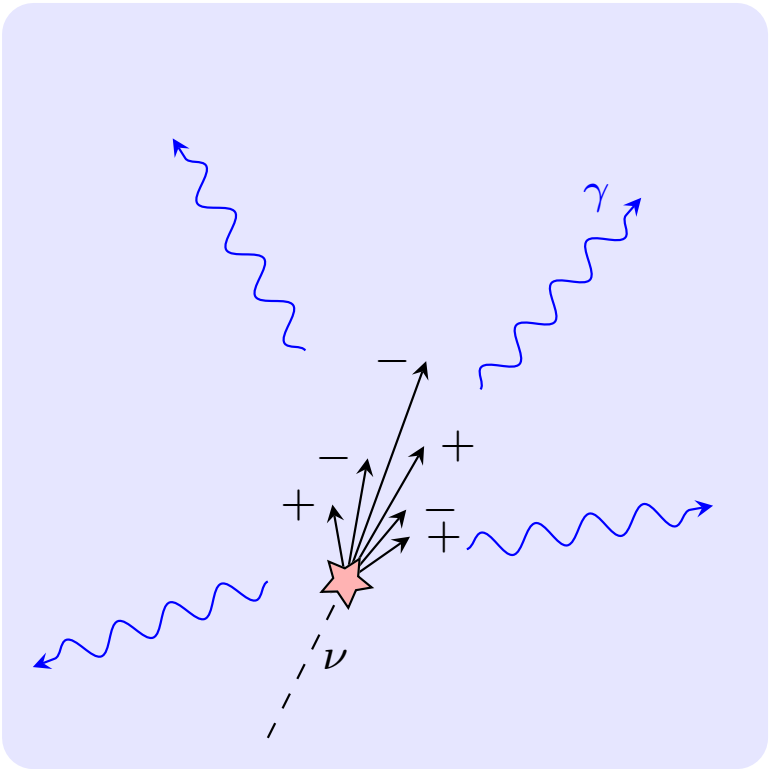

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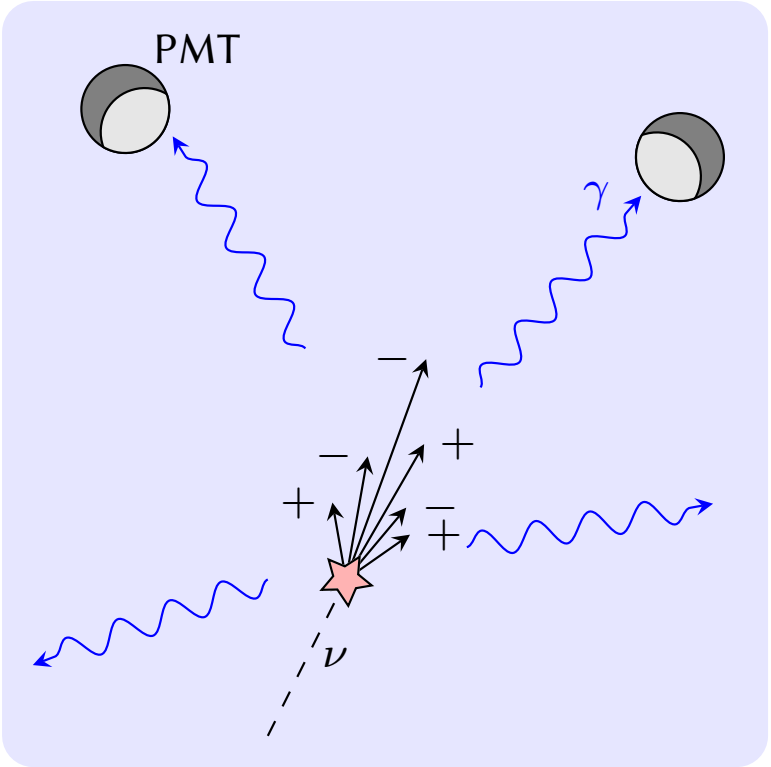


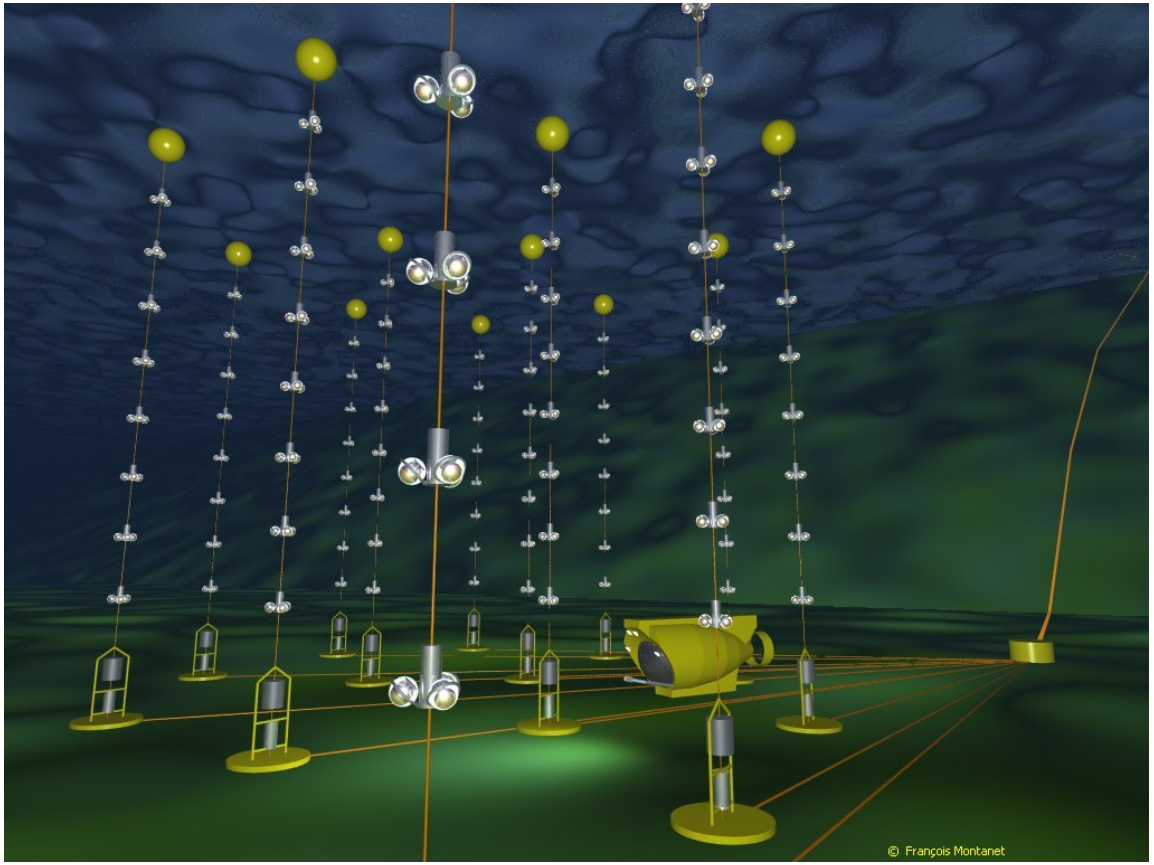
ANTARES – Location

ANTARES:

- 2500 m below sea surface
- 40 km off the coast of Toulon, France
- connected via electro-optical cable
- shore station right at waterfront

- bottom of the sea ideal location
- depth shields off daylight (and atmospheric background)
- long scattering length in water

ANTARES – The Detector



- complete since 2008-05
- 12 Lines, 885 PMTs
- 75 PMTs per line, grouped in triplets
- radius: 90 m
  height: 400 m

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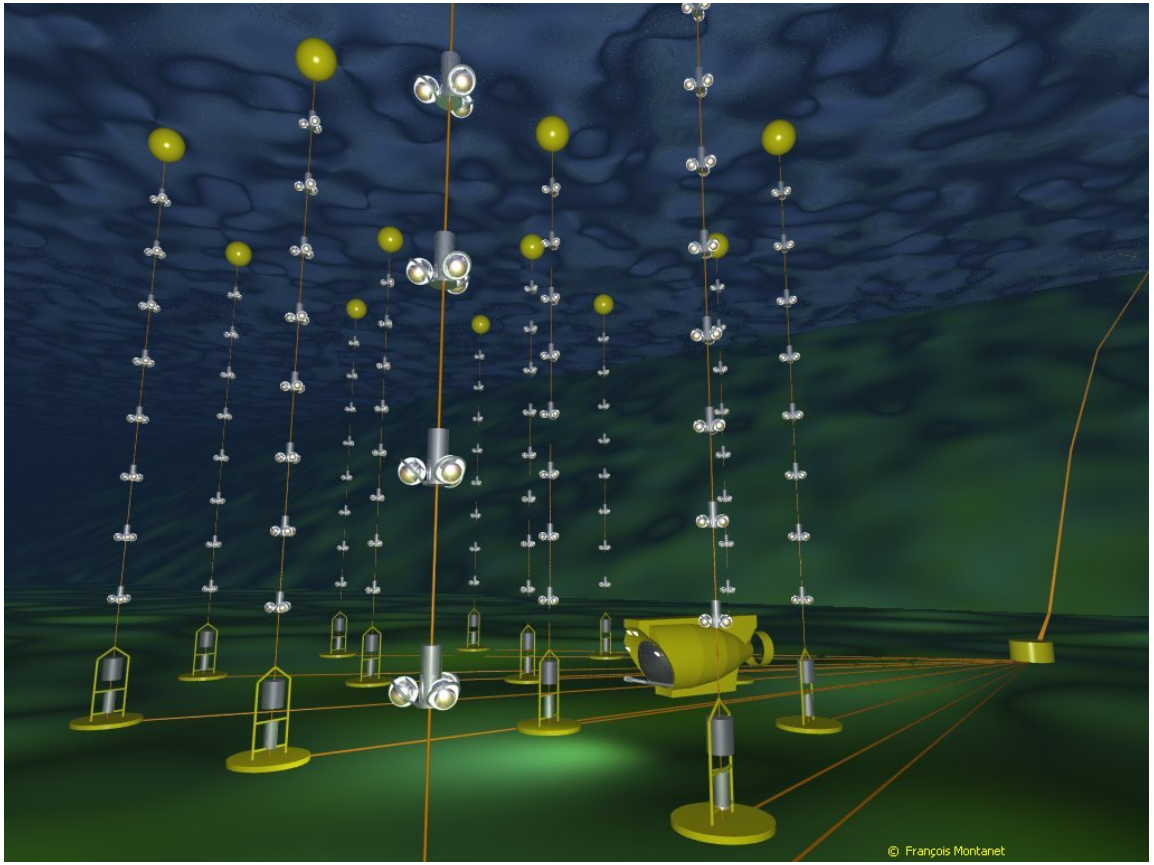
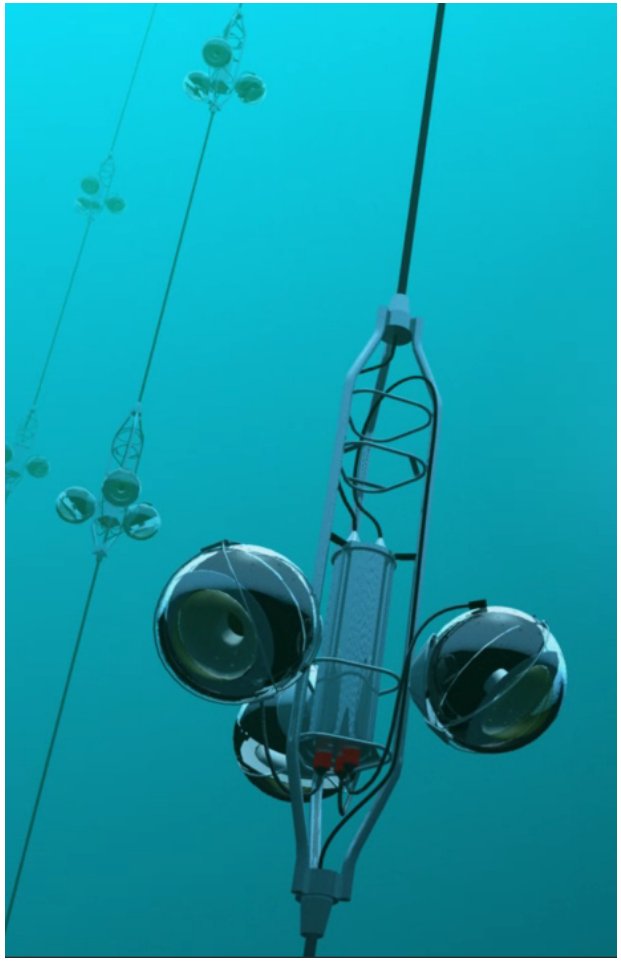
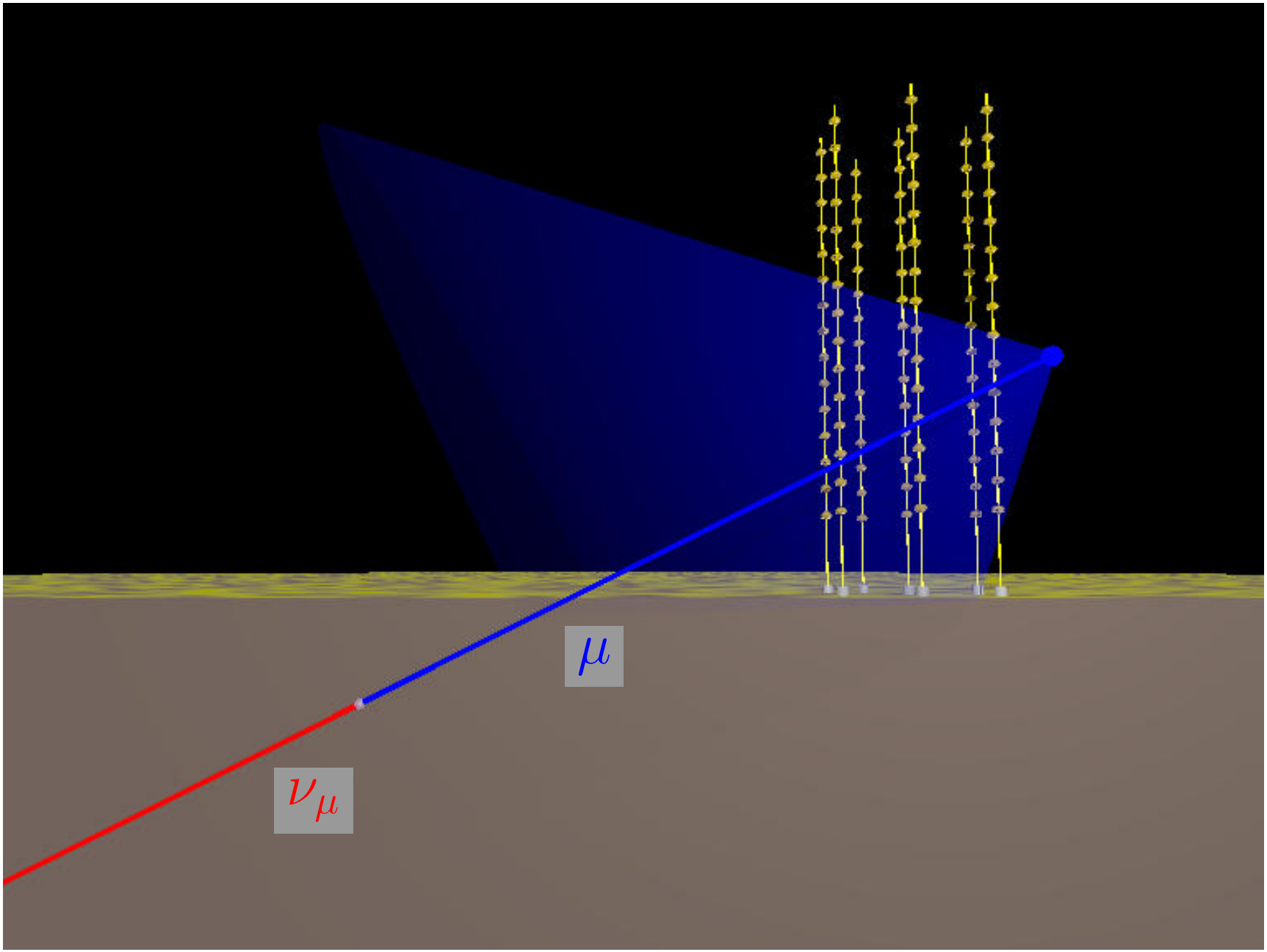




Muon Track Reconstruction

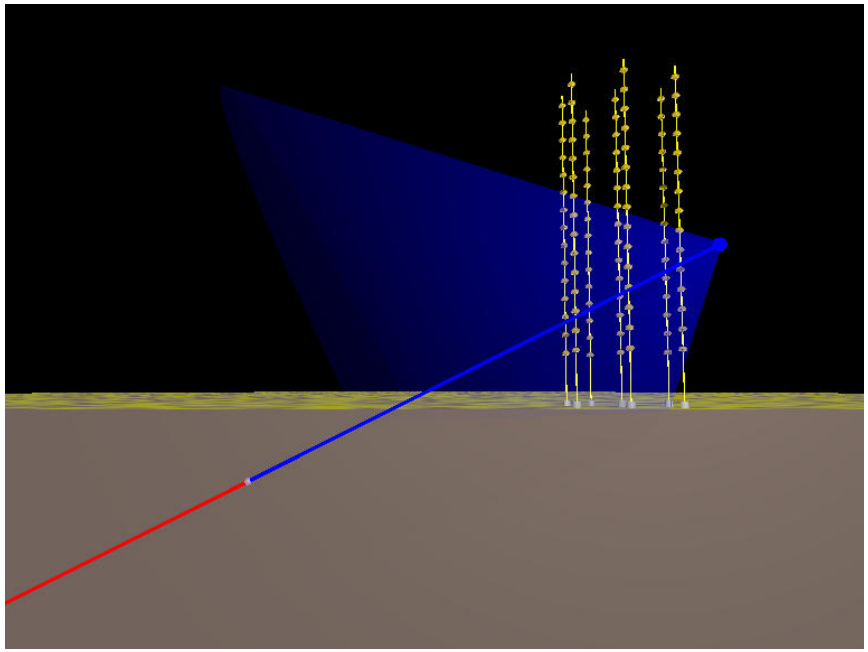


Muon Track Reconstruction

- can pass through detector
- Cherenkov radiation along track
- photons emitted at $\varphi_{\mathrm{Ch}} \approx 42^{\circ}$
- clean signature

- maximum likelihood fit based on hit time residuals
- $\approx 0.4^{\circ}$ median angular resolution

- limit us to $\nu_\mu \to \mu$ (and $\nu_\tau \to \tau \to \mu$) interactions



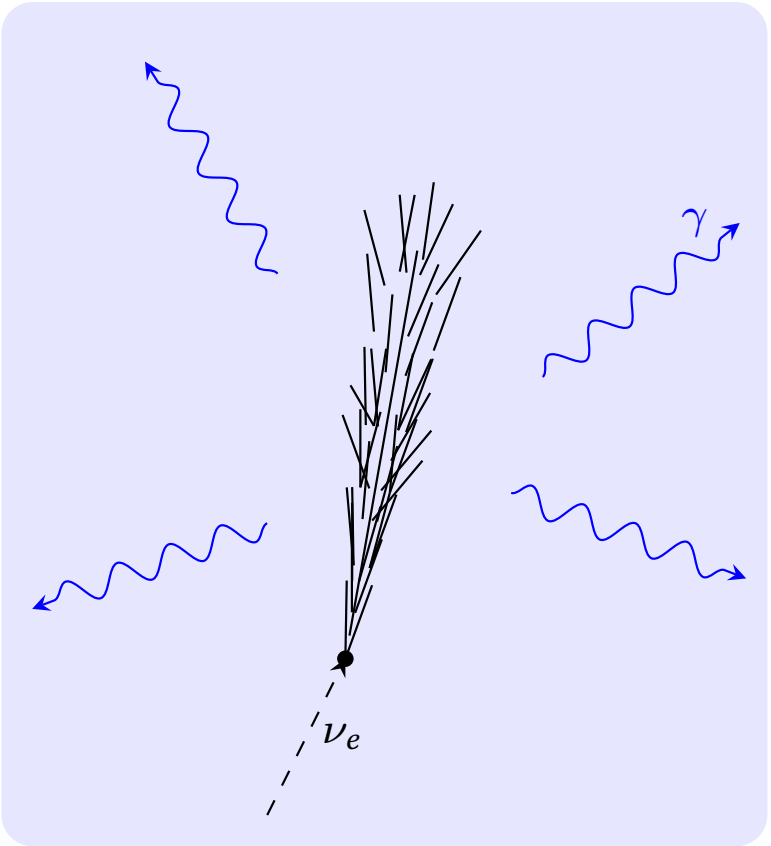
Shower Reconstruction

- shower events open window to
  $\nu_e \rightarrow e$
  $\nu_x \rightarrow \nu_x + hadr.$
  $\nu_\tau \rightarrow \tau \rightarrow e/hadr.$

- cascade of particles within few metres
- can be approximated as point source
- emits shell of light in all directions
- still, more light emitted under “Cherenkov angle”

in ice:

- effect almost completely gone due to scattering



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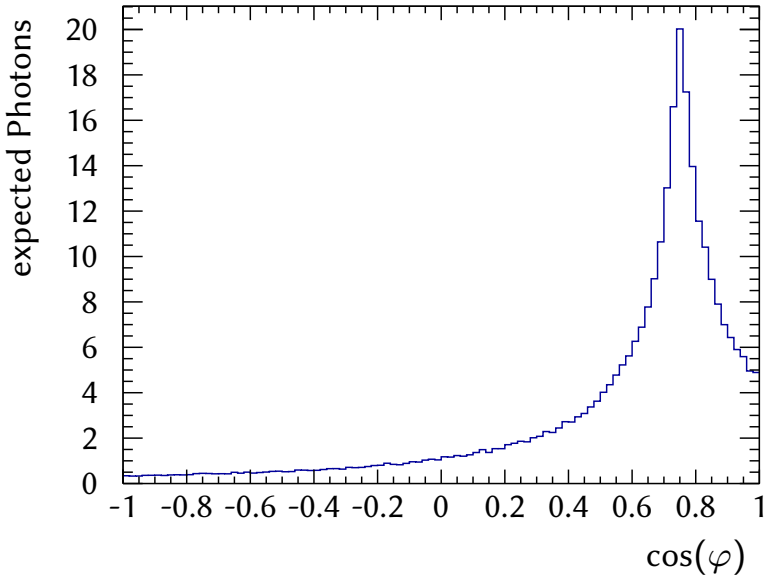


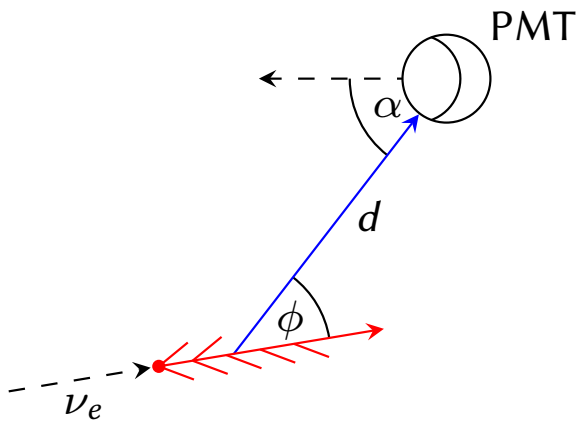
expected number of Photons from a 1 TeV shower on a PMT in 100 m distance

Shower Reconstruction – Likelihood Function

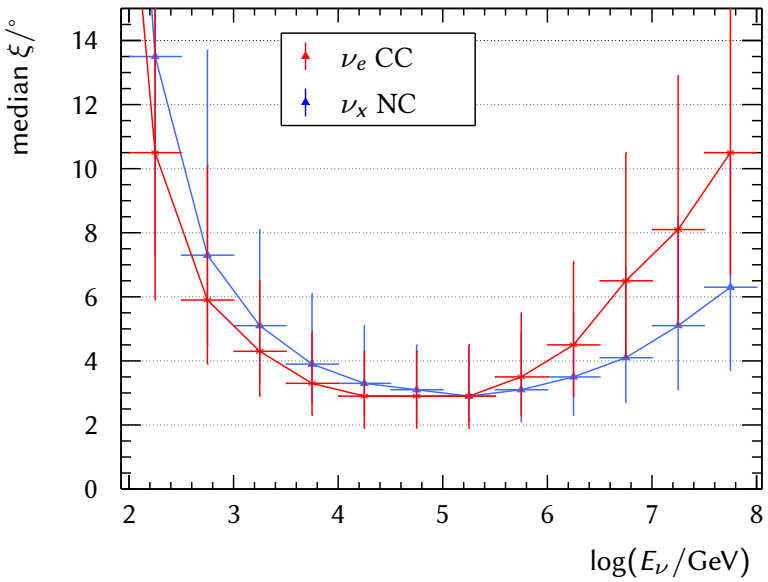
I developed an algorithm to reconstruct those shower events:

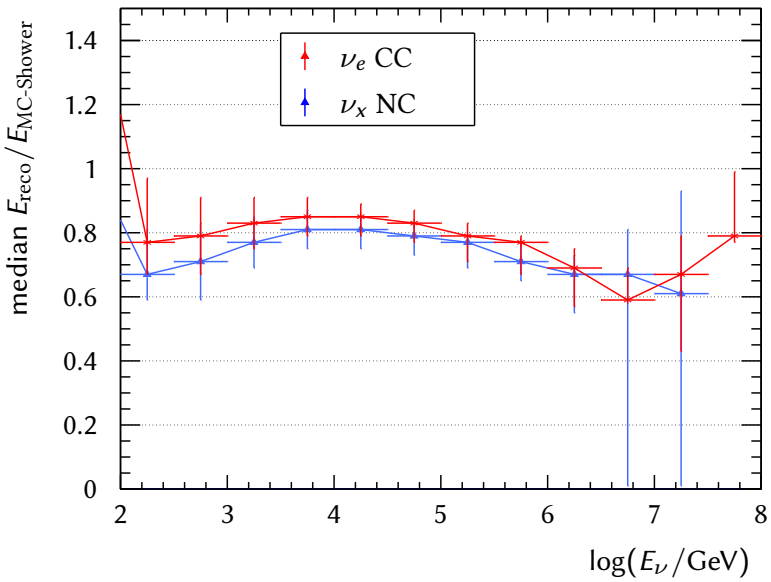
- expected charge q on a PMT described by tabulated PDF
- likelihood depends on neutrino energy, direction, distance to PMT, incident angle
- unhit PMTs and Background rate taken into account

$$\mathscr{L} = \sum_{i=1}^{N_{\text{selected Hits}}} \log\left\{P_{q>0}(q_i|E_\nu, d_i, \phi_i, \alpha_i) + P_{\text{bg}}(q_i)\right\}$$
$$+ \sum_{i=1}^{N_{\text{unhit PMTs}}} \log\left\{P_{q=0}(E_\nu, d_i, \phi_i)\right\}$$



Shower Reconstruction – Performance: Direction & Energy





- position of shower mean reconstructed with accuracy of about 1 m
- median angular error $\xi \approx 3^\circ$ in relevant energy range
- systematic offset in energy of 20 % easily corrected
- energy resolution of 5 % – 10 %

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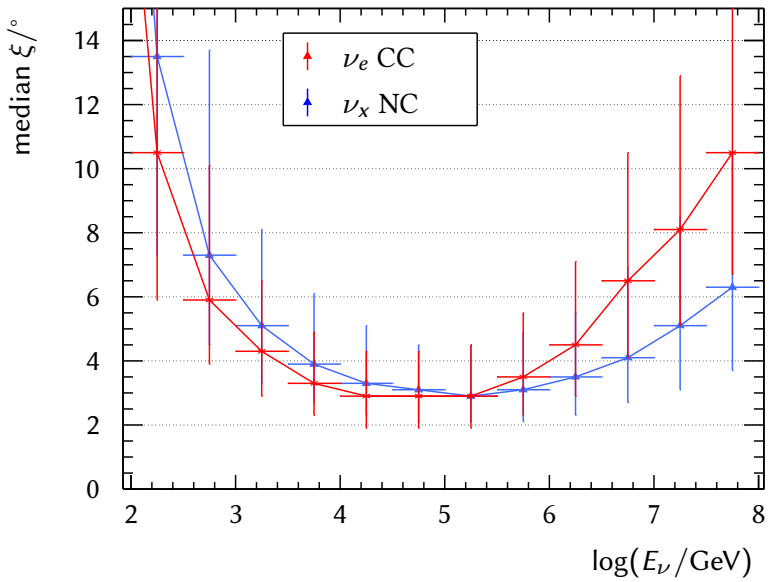

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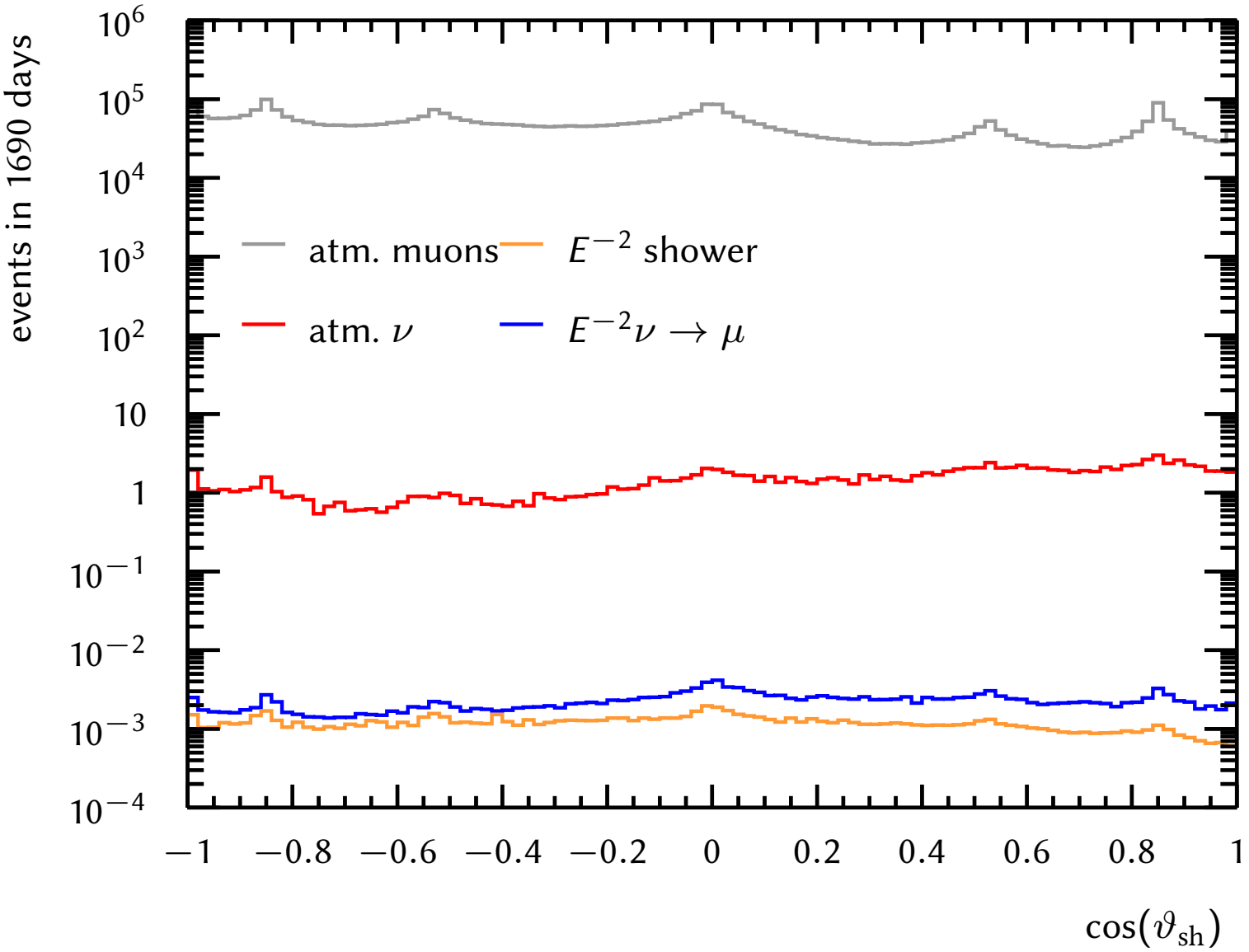
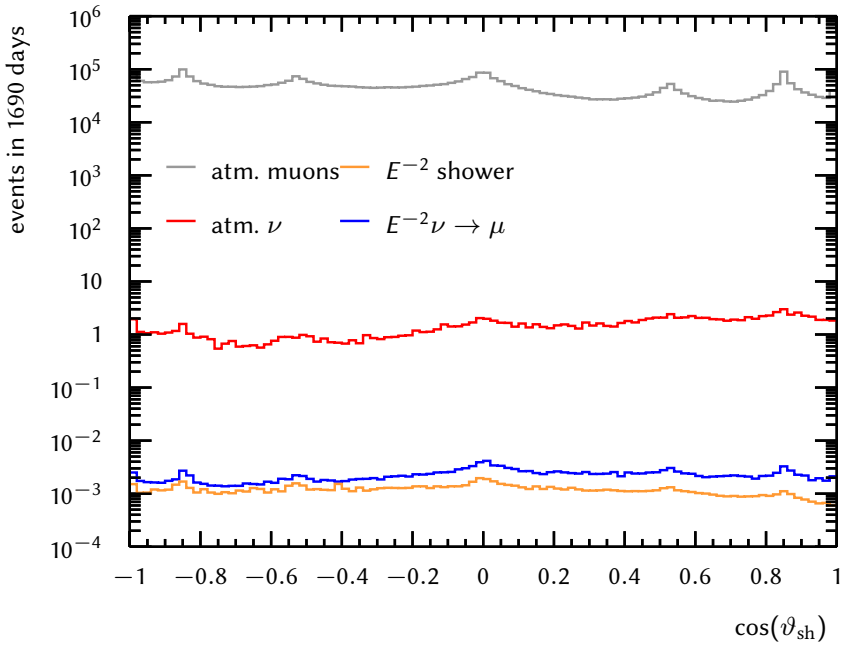


Event Selection

many events from atmospheric background
need selection criteria to get rid of them
being deep under water helps



Muons:

as in last, muon-only analysis

- quality parameter $\Lambda > -5.2$
- angular error estimate $< 1^\circ$
- up-going: $\cos(\vartheta) > -0.1$

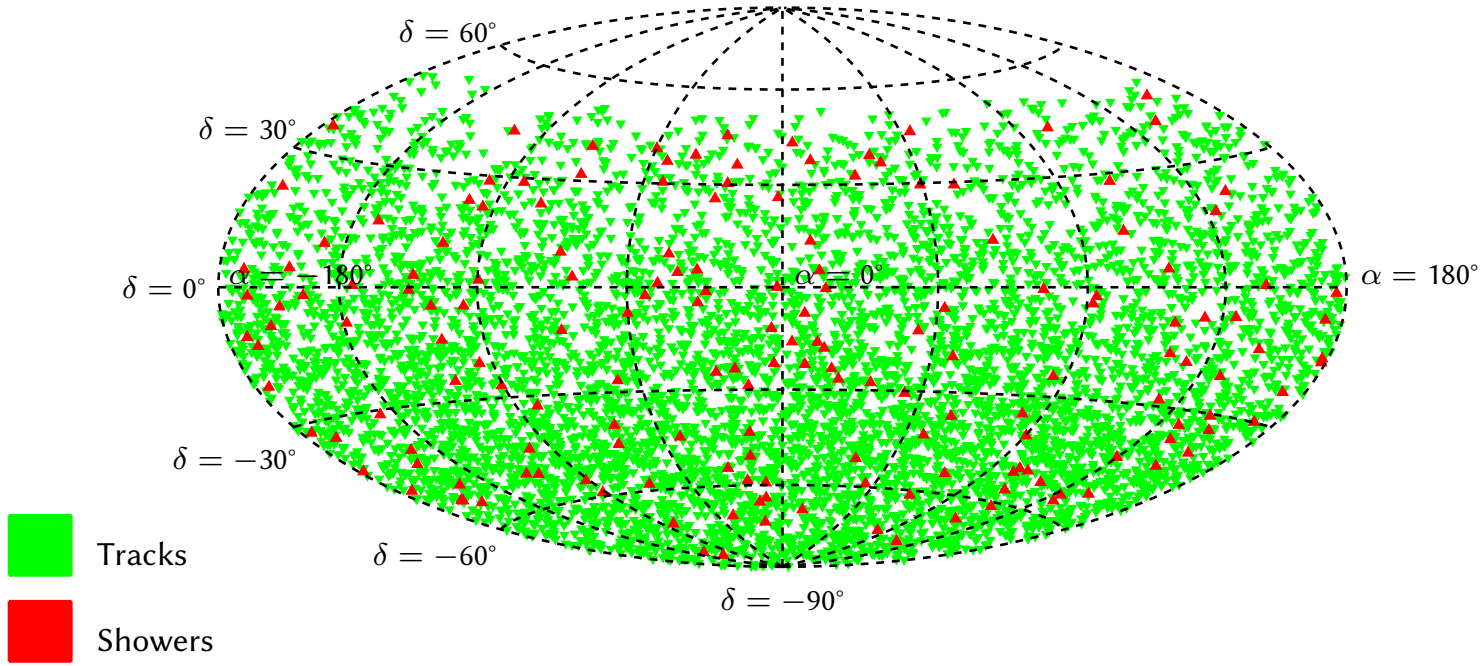
Showers:

lots of cuts, i.a.

- containment $\rho < 300\,\mathrm{m}$, $|z| < 250\,\mathrm{m}$
- angular error estimate $< 10^\circ$
- up-going: $\cos(\vartheta) > -0.1$
- ratio between charge of early and on-time hits

Data Set

- 1690 days of life time from 2007 to the end of 2013
- contains 6490 muon candidates and 172 cascade events
- for E^{-2} flux with 1:1:1 flavour composition, shower channel increases signal event rate by 30 %



Search Methods

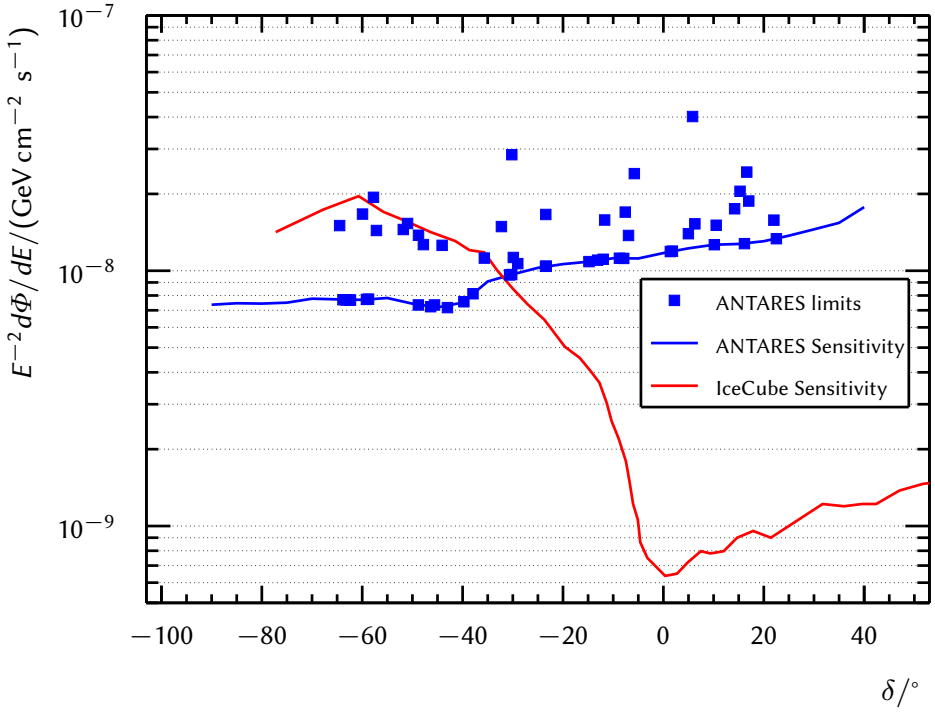
- signature of a point source is cluster of events
- sensitivities determined with Pseudo Experiments:
- background distribution as seen in data
- injecting artificial signal at various points in the sky
- trying to find back the signal

Various approaches used:

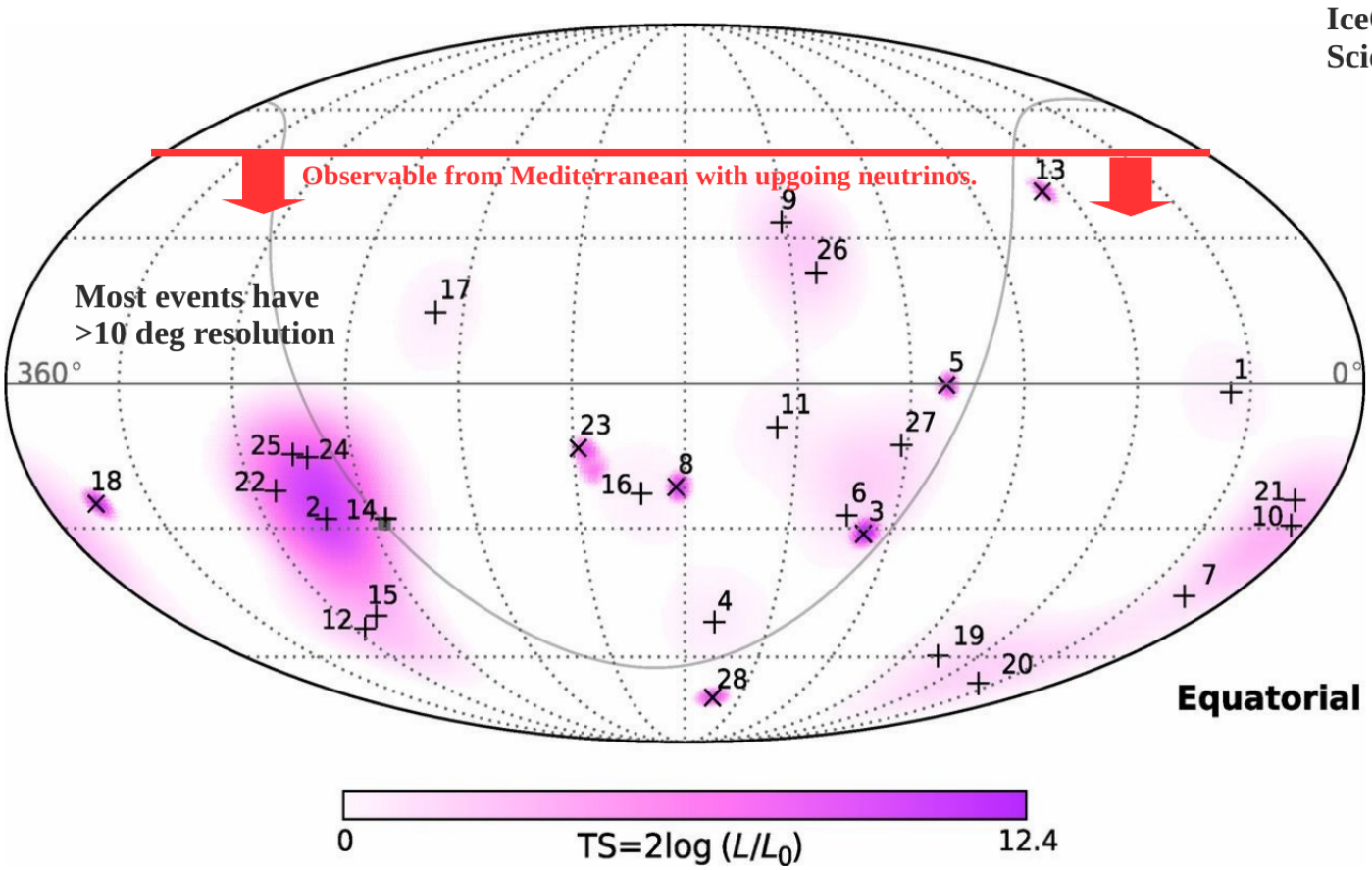
- Full Sky search
- Fixed Point search
- IceCube HESE candidates
- Galactic Centre Region
- Extended Source at Galactic Centre

Sensitivity and Limits

- no significant cluster in Full Sky Search
- Sensitivity for source in lower hemisphere: $E^{-2} d\Phi/dE \approx 7.2 \times 10^{-9}\,\mathrm{GeV\,cm^{-2}\,s^{-1}}$
- best limits for many candidates in galactic region from single experiment



Cosmic Neutrinos discovered by IceCube



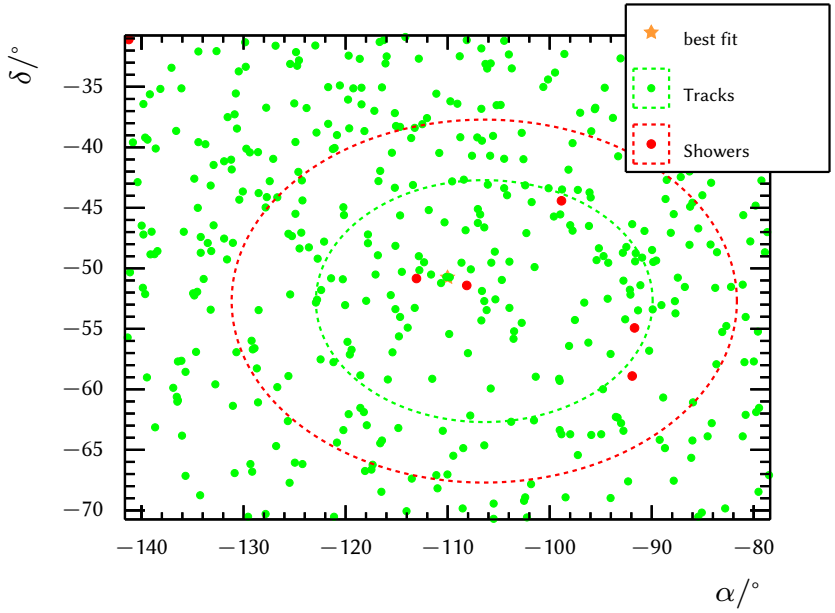
- IceCube detected cosmogenic neutrino flux
- extends to PeV energies
- most events are showers with resolution $> 10^\circ$ $\rightarrow$ sources unknown!
- possible point-like or extended source around Galactic Centre?

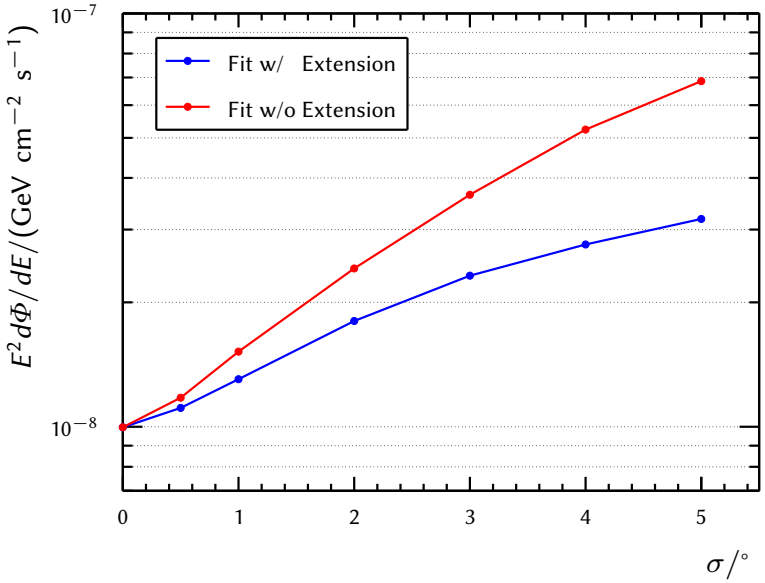
Search around Galactic Centre

- no significant point-source cluster near Galactic Centre

  extended Galactic Centre

- simulated extended source at the GC ($\alpha = -93.58°, \delta = -29.01°$)
- only fit number of signal events (coordinates are known)
- fit with (correct) extension or assuming point source
- also no discovery here





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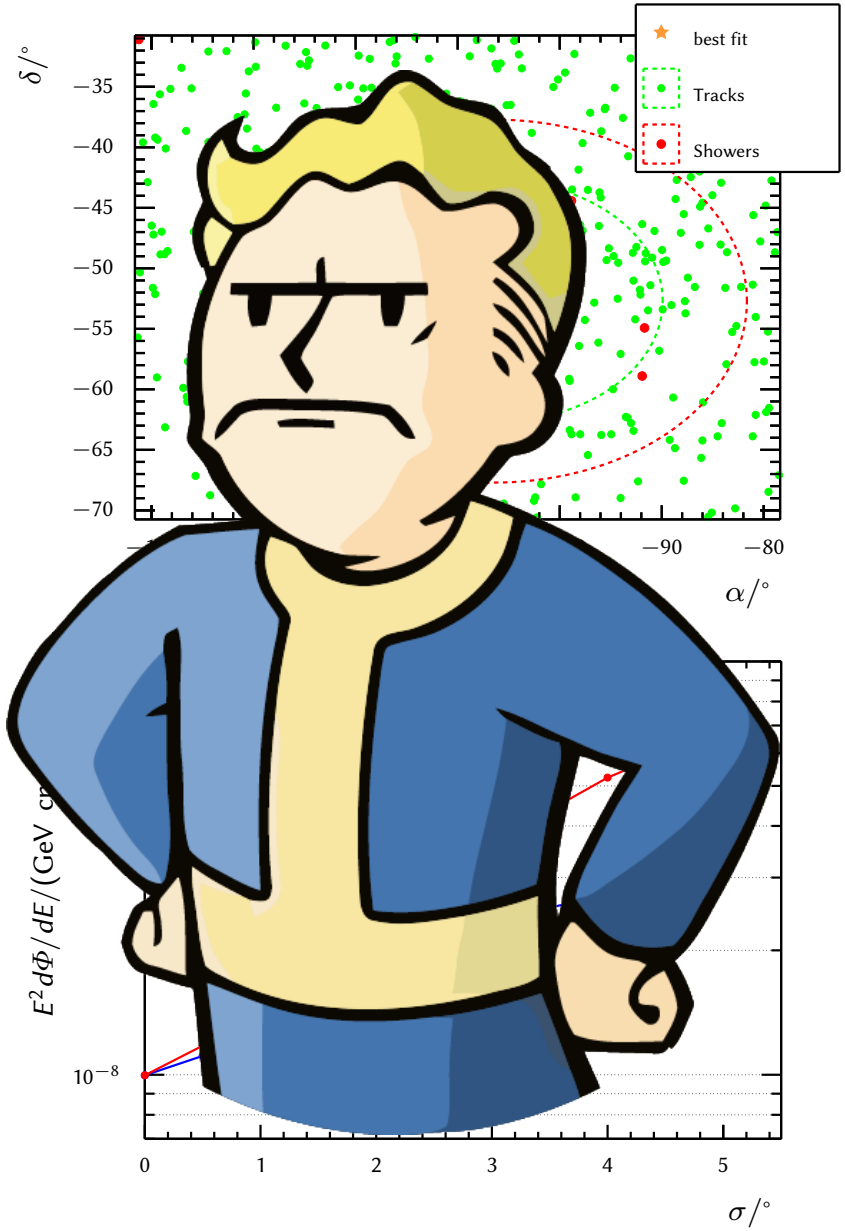
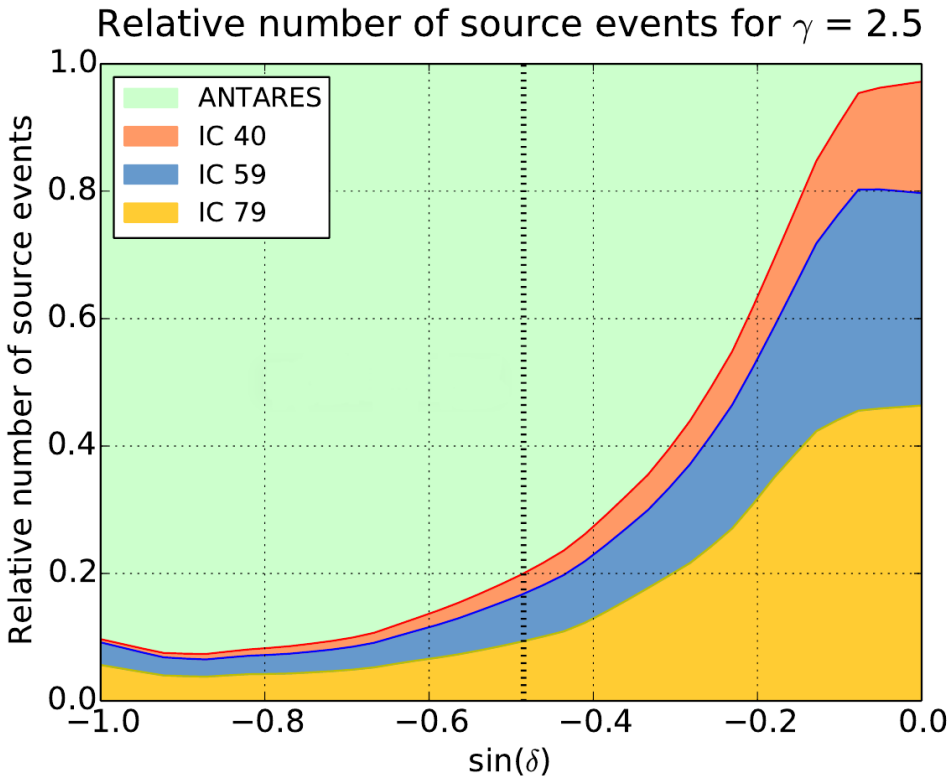
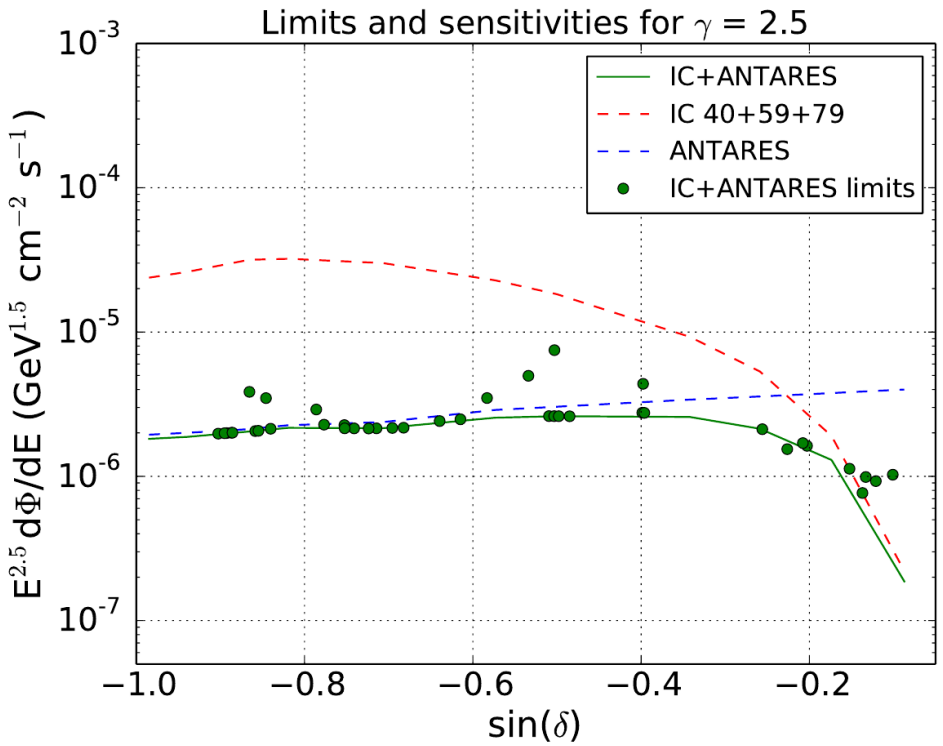


ANTARES IceCube joint search

- combining events from ANTARES and IceCube (muons only)
- ANTARES has better angular resolution (less scattering in seawater)
- IceCube has more events with better energy resolution (it's bigger!)
- Different declination dependencies – complementary regions

(J. B.-Martí, IFIC)



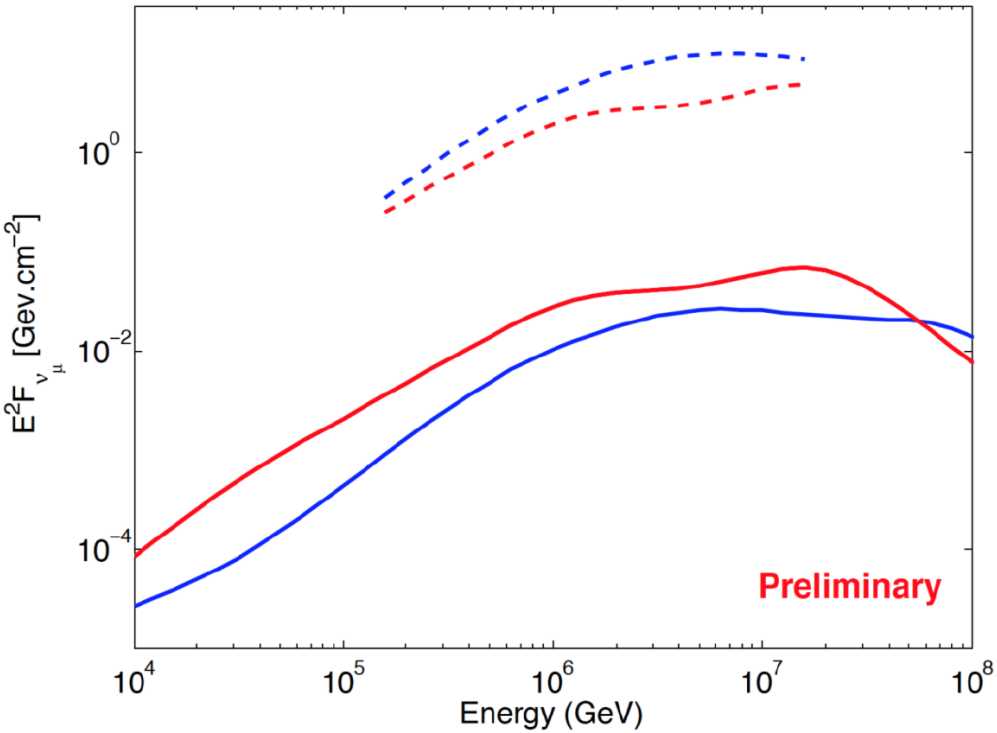


GRB searches

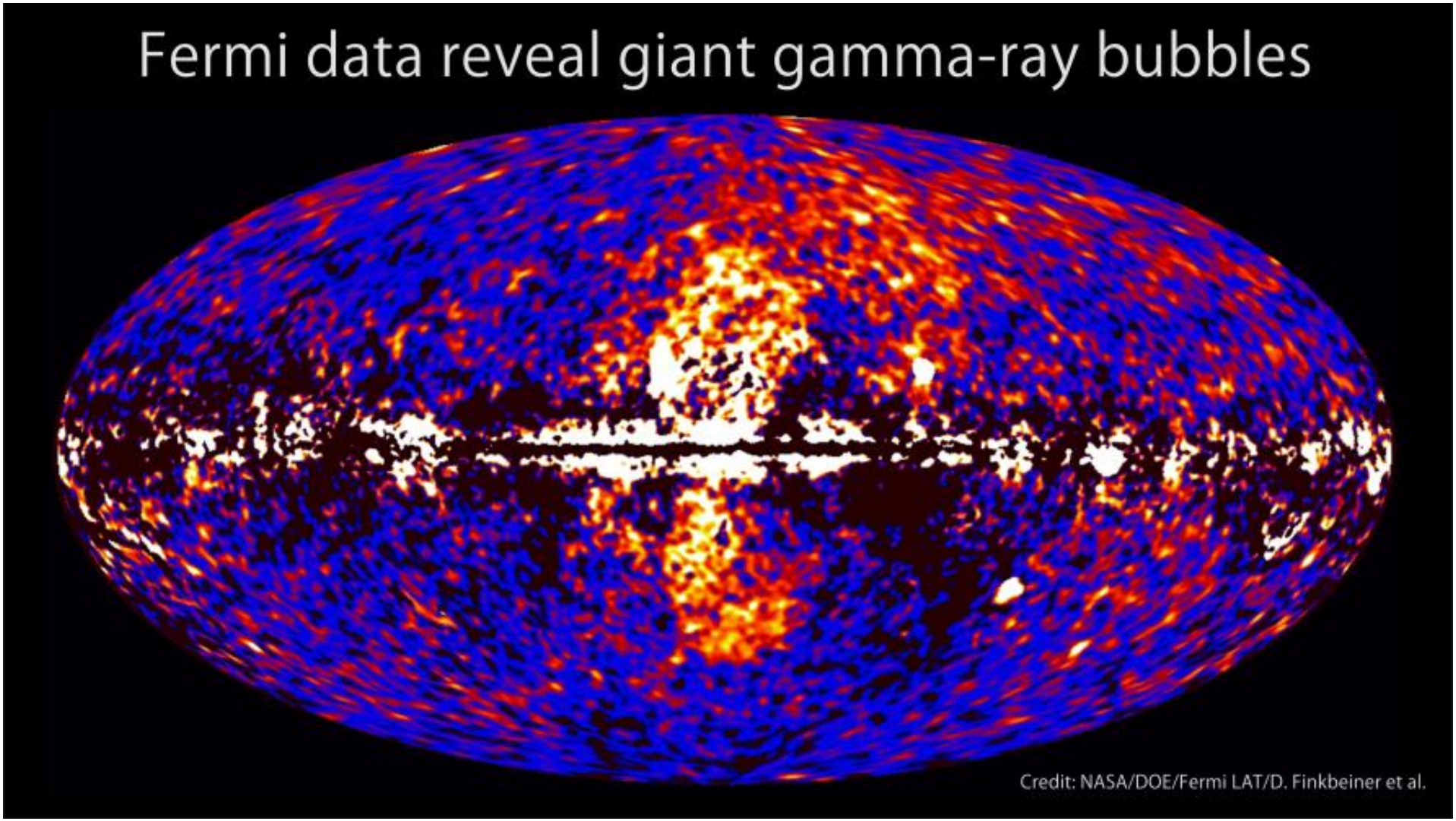
Search for neutrino events in coincidence with observed GRBs
$\rightarrow$ time window reduces background
(J. Schmidt, ECAP – D. Turpin, CPPM)

- analysis of 296 long GRBs from 2007–2011
- information from FERMI/SWIFT/GCN
- two most prominent GRBs:
  GRB110918A and GRB130427A
- dashed lines: sensitivities
- full lines: expected ν-flux from individual GRBs

- no event coincident with a GRB found



Fermi Bubbles



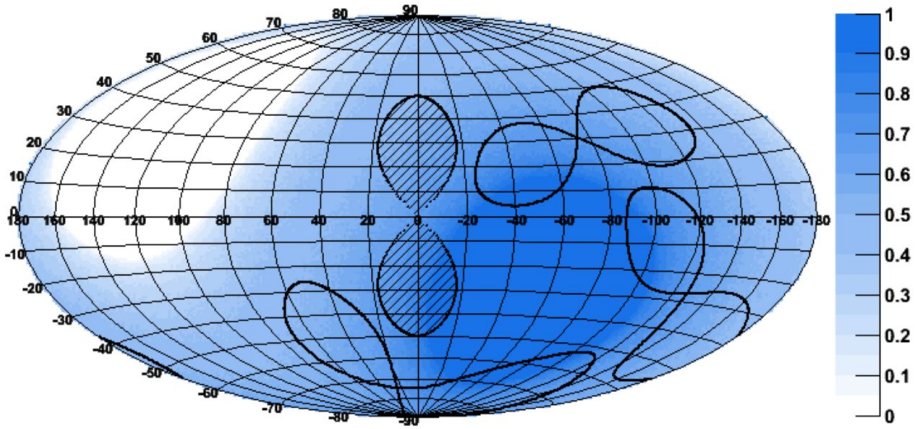
Fermi Bubbles

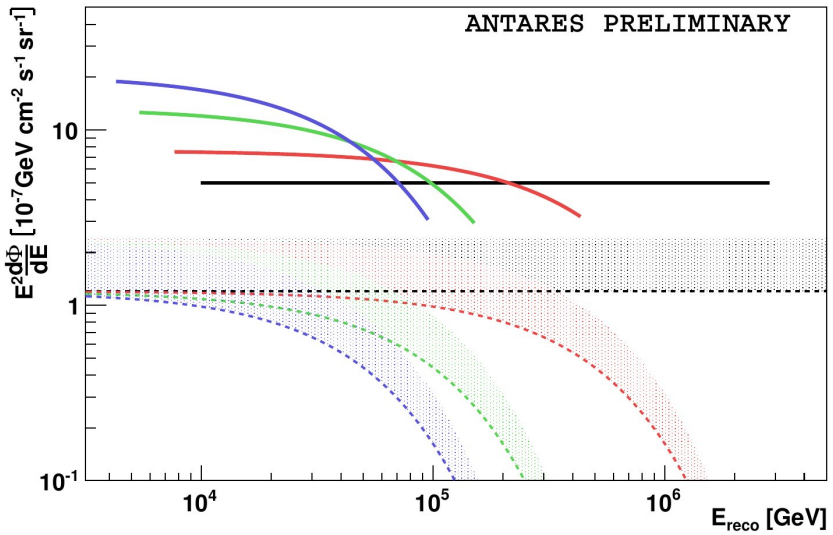
- cut-and-count method
- define on- and 3 off-zones
- 22 on-zone events
  39 events in 3 off-zones

$\rightarrow$ 1.92σ excess

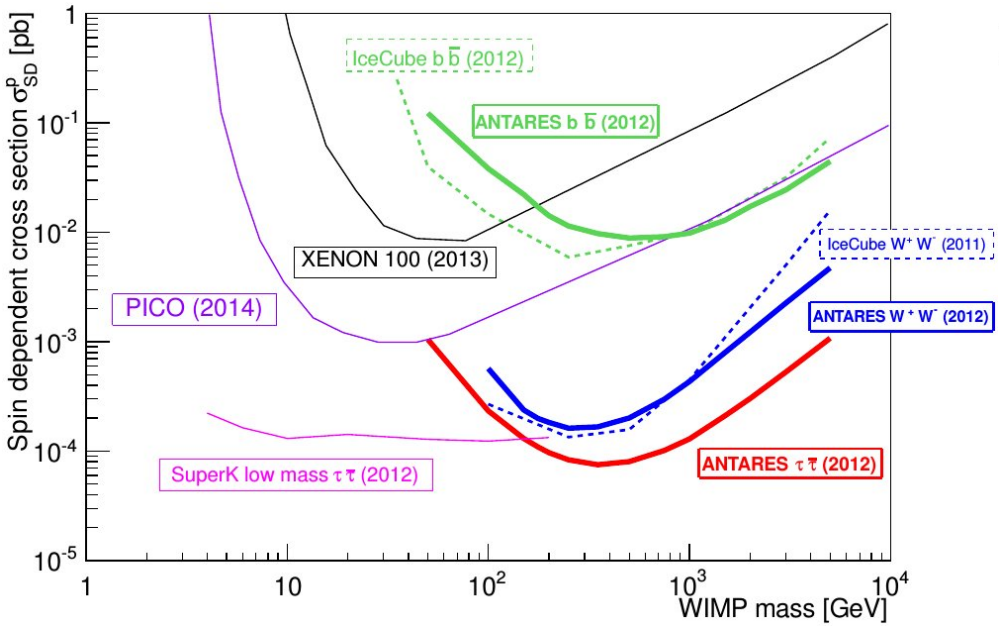
- solid lines: upper limits for different energy cut-off
- dashed lines: expected ν-flux from γ-flux

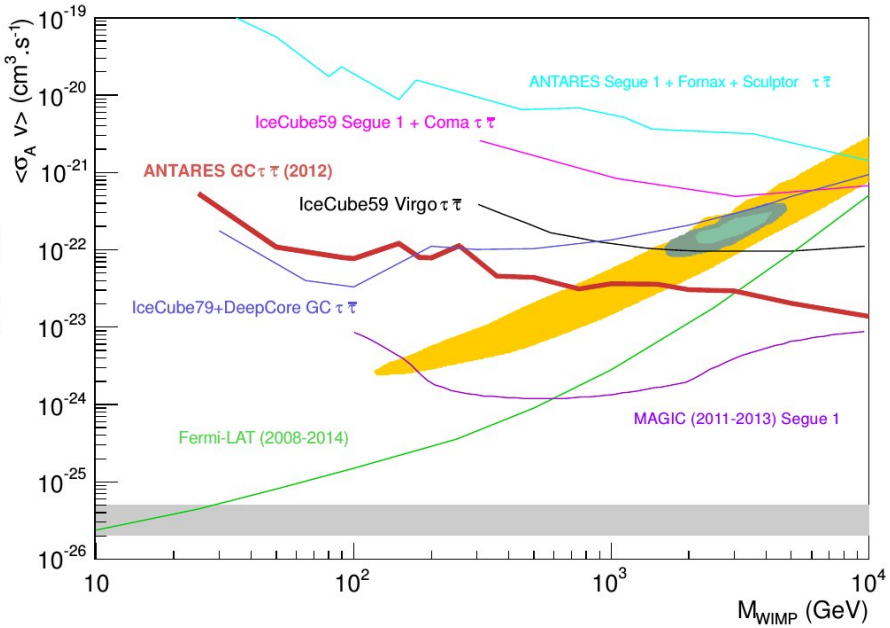
  (S. Hallmann, ECAP)





Dark Matter Searches





left: Dark Matter from the Sun
right: Dark Matter from the Galactic Centre
(M. Ardid, IGIC – C. Tönnis, IFIC)

Summary I

- developed shower reconstruction algorithm for ANTARES
- unprecedented direction resolution of 3° and energy resolution of $5\,\% - 10\,\%$
- $\rightarrow$ water allows pointing with showers
- implementation into other analyses are ongoing
- will play even bigger role for KM3NeT

- combined point source search performed on data from 2007 to 2013
- various approaches investigated
- no significant clusters have been found
- most stringent limits set for many galactic candidates

Summary II

- ANTARES produces competitive results on many topics
  - point-like sources anywhere in the sky
  - diffuse flux from Fermi Bubbles and Galactic Plane
  - extensive multi-messenger program
  - Dark Matter
  - magnetic monopoles
  - nuclearites
- so far, no discoveries; but there is still more data coming in
- detector operation secured until end of 2016

- proves the feasibility of large-scale, deep-sea Cherenkov detectors
- paves the way for KM3NeT