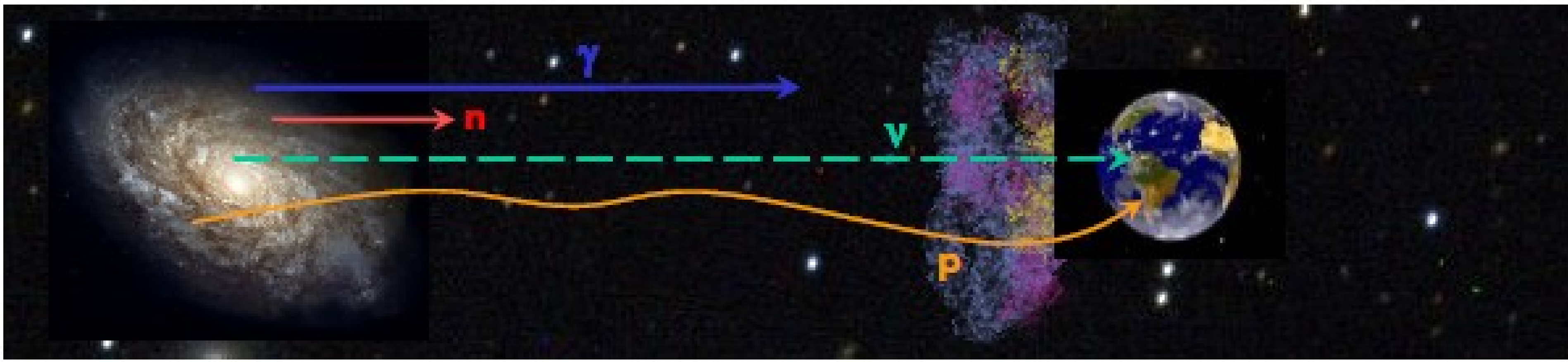
Source stacking analysis of blazar neutrino sources with the ANTARES neutrino telescope

Francesco Borracci

Neutrino Astronomy



Photons: interact with matter and radiation

Protons: deflected by magnetic fields and (at high energy) interact with CMBR

Neutrons: unstable particles

Neutrino problem: necessity of huge detectors

Neutrino production channels

Proton-photon Interaction

$$p\gamma \longrightarrow \Delta^{+} \longrightarrow p\pi^{0}$$

$$p\gamma \longrightarrow \Delta^{+} \longrightarrow n\pi^{+}$$

Proton-proton Interaction

$$pp \longrightarrow pp\pi^{0}$$

$$pp \longrightarrow pn\pi^{+}$$

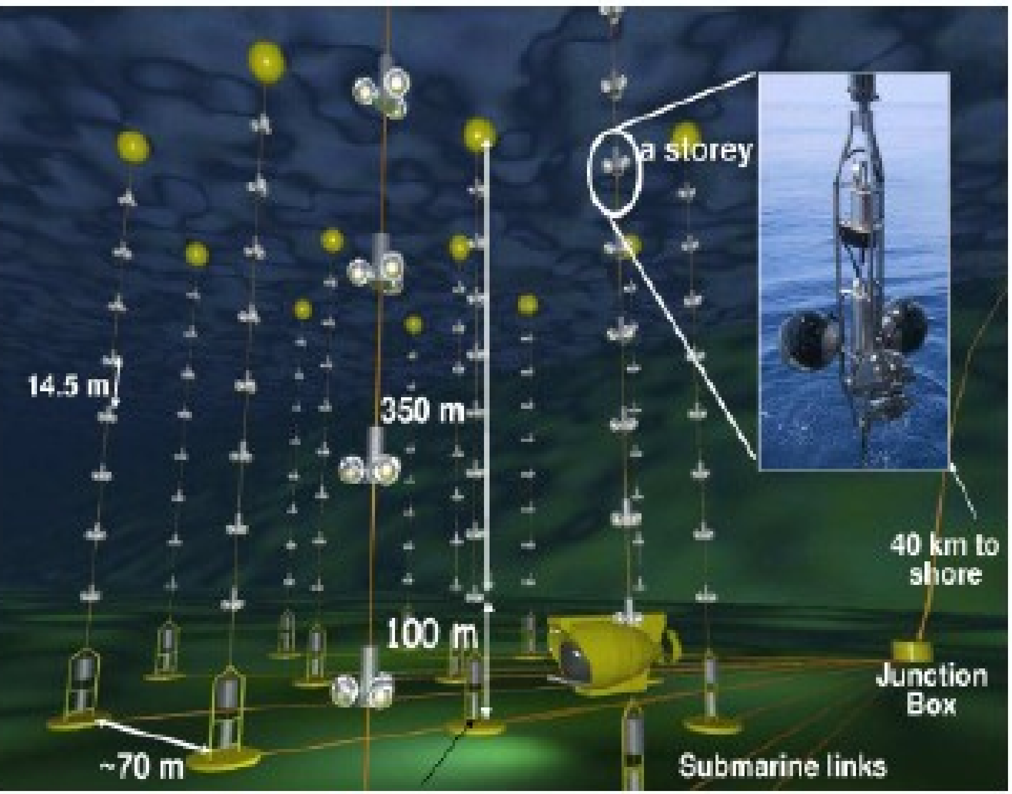
With subsequent production of neutrinos and photons:

$$\pi^{+} \longrightarrow \mu^{+}\nu_{\mu} \longrightarrow e^{+}\nu_{e}\overline{\nu}_{\mu}\nu_{\mu}$$

$$\pi^{-} \longrightarrow \mu^{-}\overline{\nu}_{\mu} \longrightarrow e^{-}\overline{\nu}_{e}\nu_{\mu}\overline{\nu}_{\mu}$$

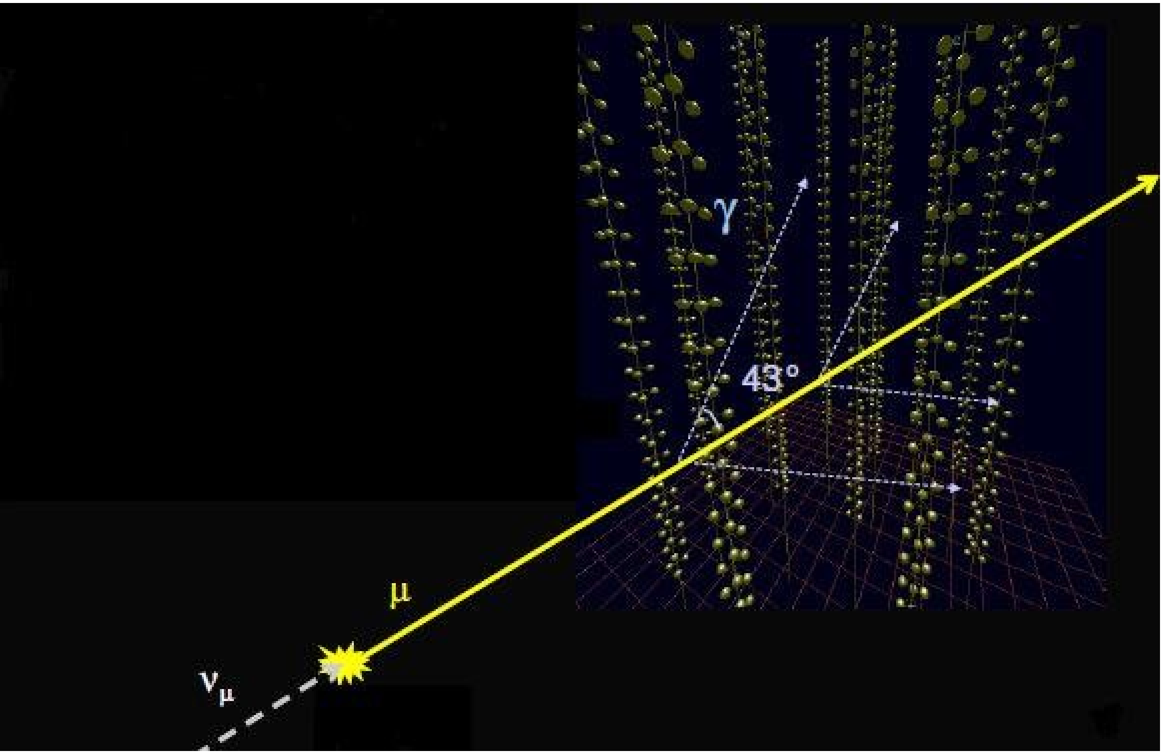
$$\pi^{0} \longrightarrow \gamma\gamma$$

ANTARES neutrino telescope



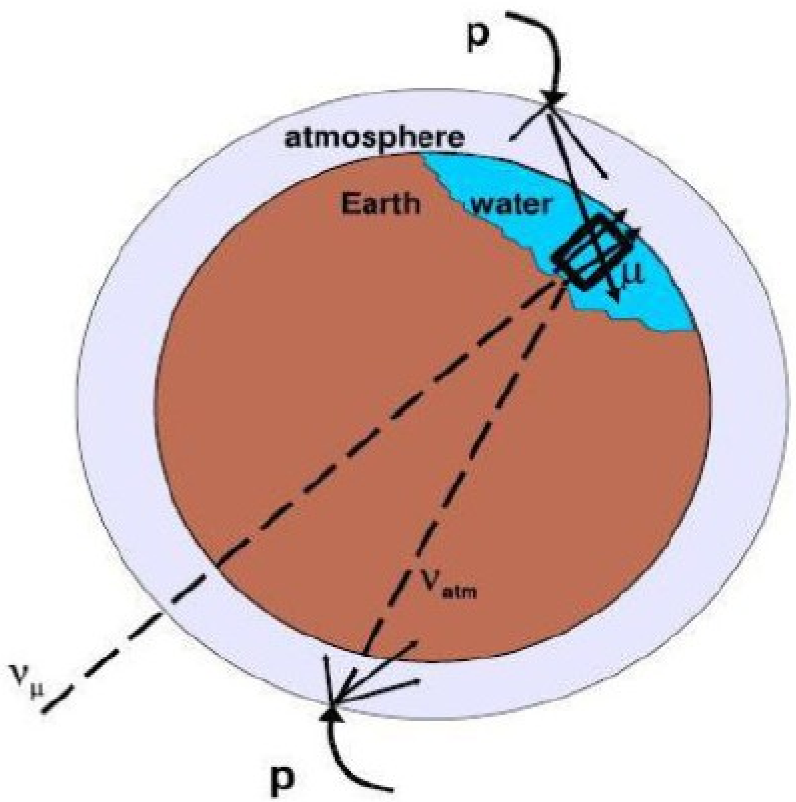
- It's an underwater telescope used for studying high energy neutrinos of cosmic origin
- It is situated in the Mediterranean Sea off the coast of Toulon, France, at 2500 metres depth

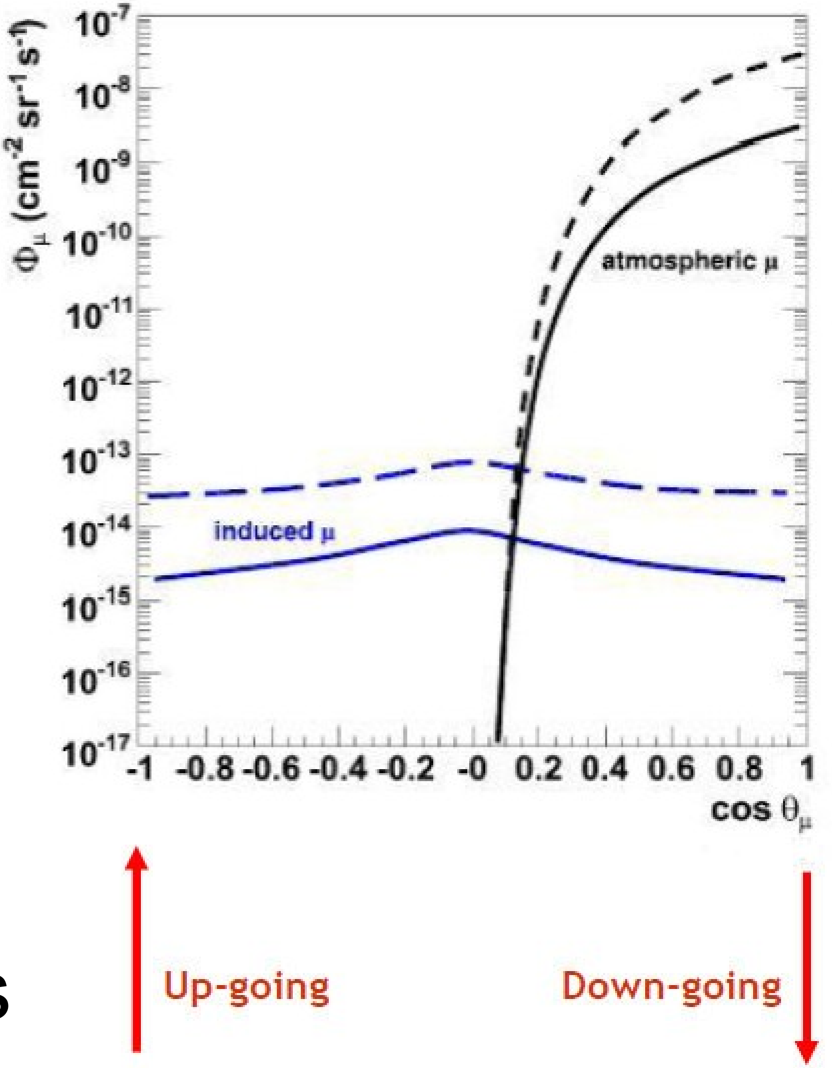
How ANTARES works?



- "Electronic eyes" (PMTs) detect photons emitted by muons through Cerenkov radiation
- For muons above TeV muon-neutrino and muon tracks are almost collinear

Neutrino detection





A neutrino telescope looks at up-going events

Extragalactic neutrino source candidates : Blazars

- Neutrino production is directly linked with high energy photons (>TeV)

- Photons can interact: TeV signal avalanches to lower energies (GeV)

- Blazars represent the most important population of extragalactic objects in the GeV sky

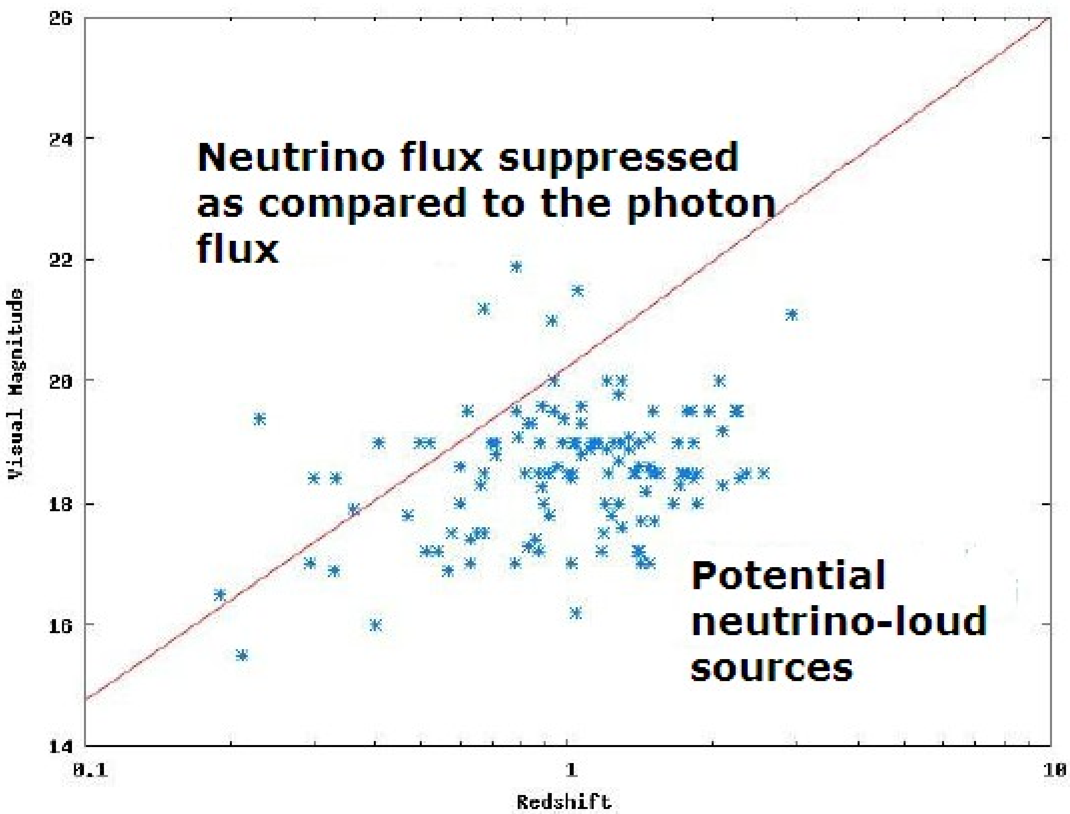
Blazars from Fermi Catalogue

- Fermi-LAT detects high energy photons (100 MeV – 300 GeV)
- The first catalogue of AGN detected by Fermi (1LAC) has 599 sources (clean sample)
- About the 90% of 1LAC sources is classified as Blazar
- Huge sample for a better classification of BL Lac and FSRQ properties

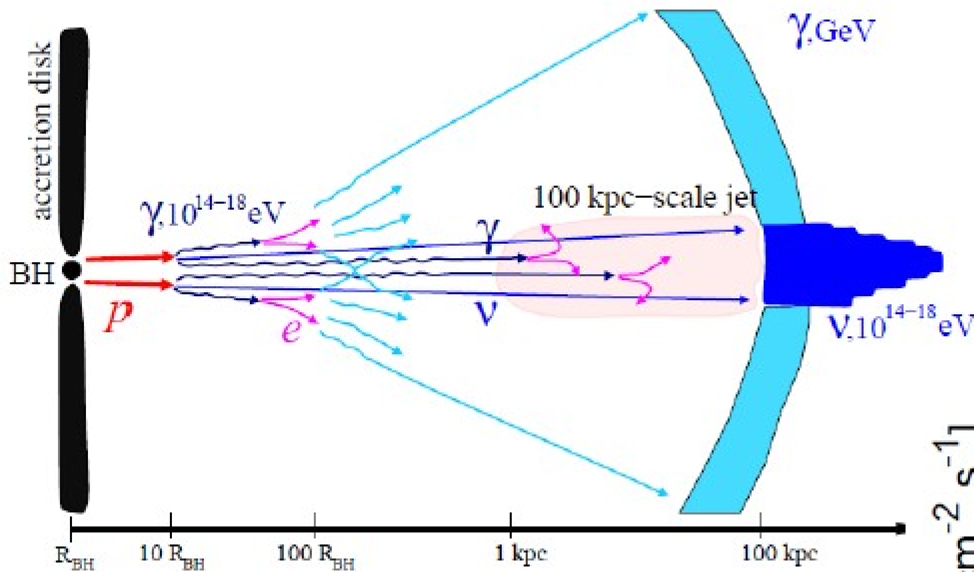
Cuts applied on the sample

Excluded from the analysis:

- Blazars detected also at TeV or at hard-X energies
- BL Lac
- FSRQ not viewable from ANTARES
- Blazars which do not satisfy the redshift - visual magnitude relation

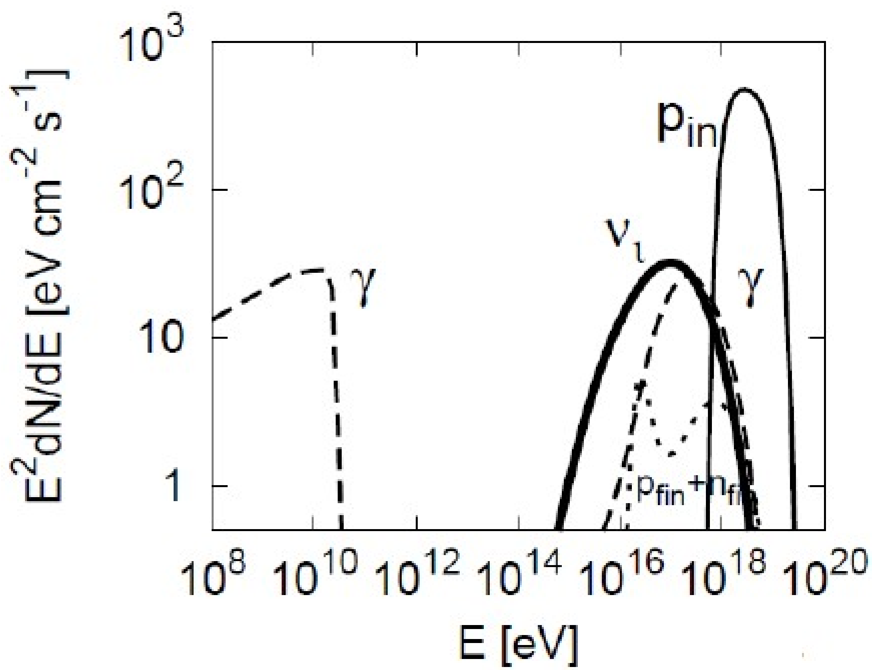


Neronov-Semikoz model for the neutrino production



A.Neronov and D.Semikoz,
Phys. Rev. D66 (2002) 123003

Proton-photon interaction in the core



Why a *stacking analysis* ?

•The aim of the stacking is to maximize the significance S_k of the signal:

$$S_k = \frac{\sum_{i=1}^{k\leq N} N_\mu(\gamma_i, \delta_i, \theta)}{\sqrt{\sum_{i=1}^{k\leq N} N_\mu(\gamma_i, \delta_i, \theta) + \sum_{i=1}^{k\leq N} N_{bg}(\delta_i, \theta)}}$$

•$N_\mu(\gamma_i, \delta_i, \theta)$: is the number of expected neutrinos from a single source
•$N_{bg}(\delta_i, \theta)$: is the number of background neutrinos

• Virtual superposition of a sample of sources

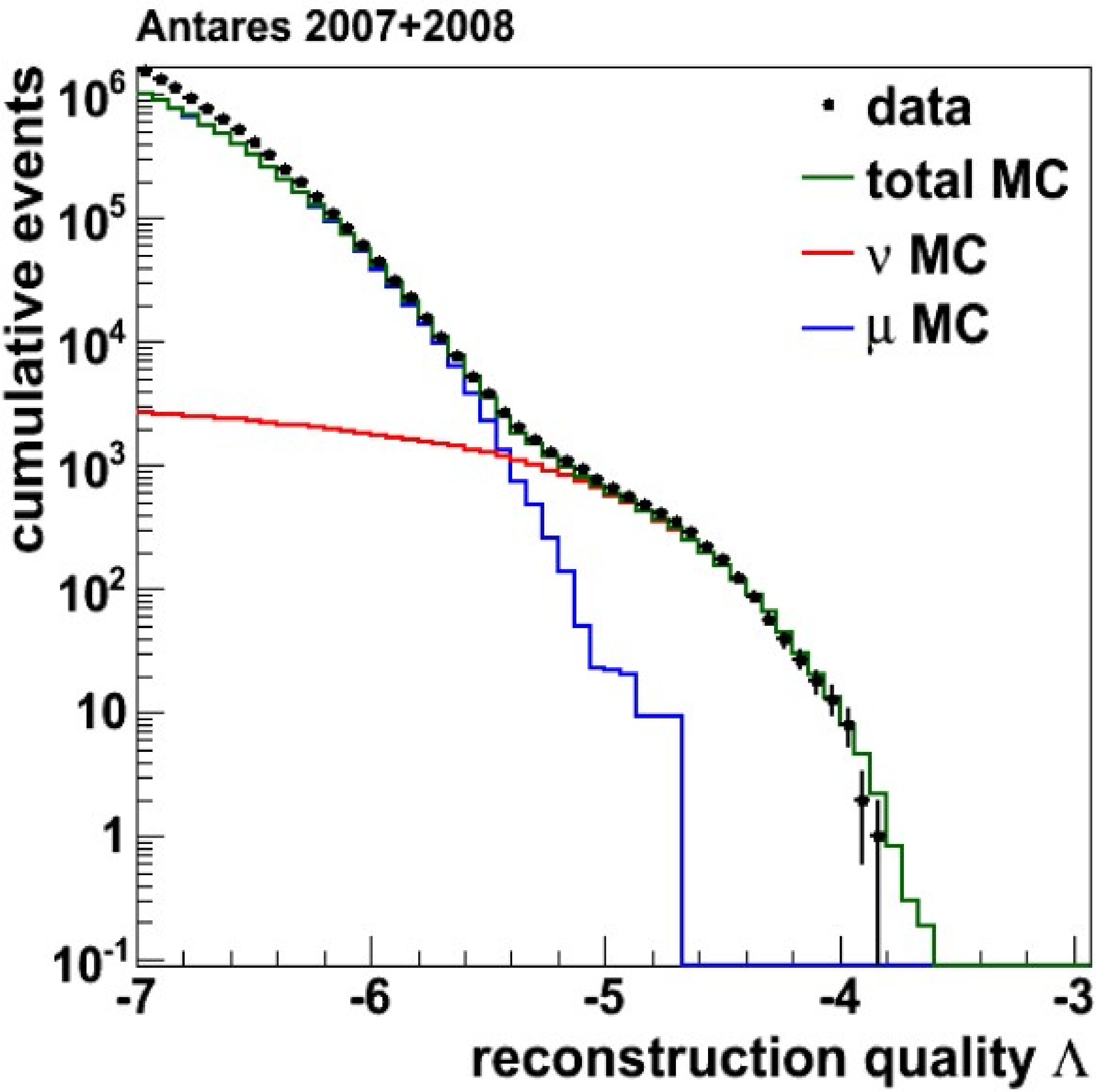
Number of expected neutrinos

$$\int \frac{dN_\gamma}{dE_\gamma} E_\gamma dE_\gamma = x_{\nu/\gamma} \cdot \int \frac{dN_\nu}{dE_\nu} E_\nu dE_\nu$$

$$N_\mu = T \cdot f(\delta) \cdot P(\theta) \cdot \int_{4.8\cdot 10^{13} eV}^{10^{16} eV} \frac{dN_\nu}{dE} \cdot A_\nu^{eff}(\mathrm{E}) \cdot \mathrm{dE}$$

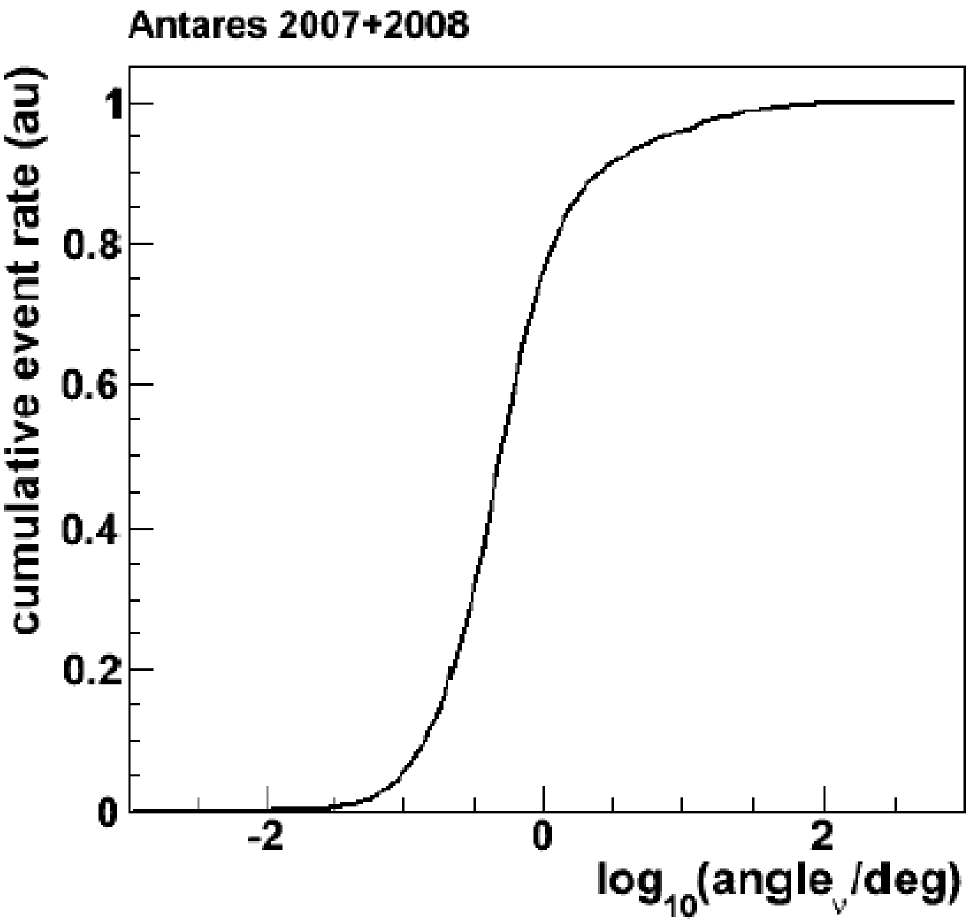
- T : is the period of time of ANTARES taken data
- $f(\delta)$: is the visibility factor
- $A_\nu^{eff}(\mathrm{E})$: is the effective area
- $P(\theta)$: is the probabilty that a muon induced by a neutrino is viewable within the chosen bin

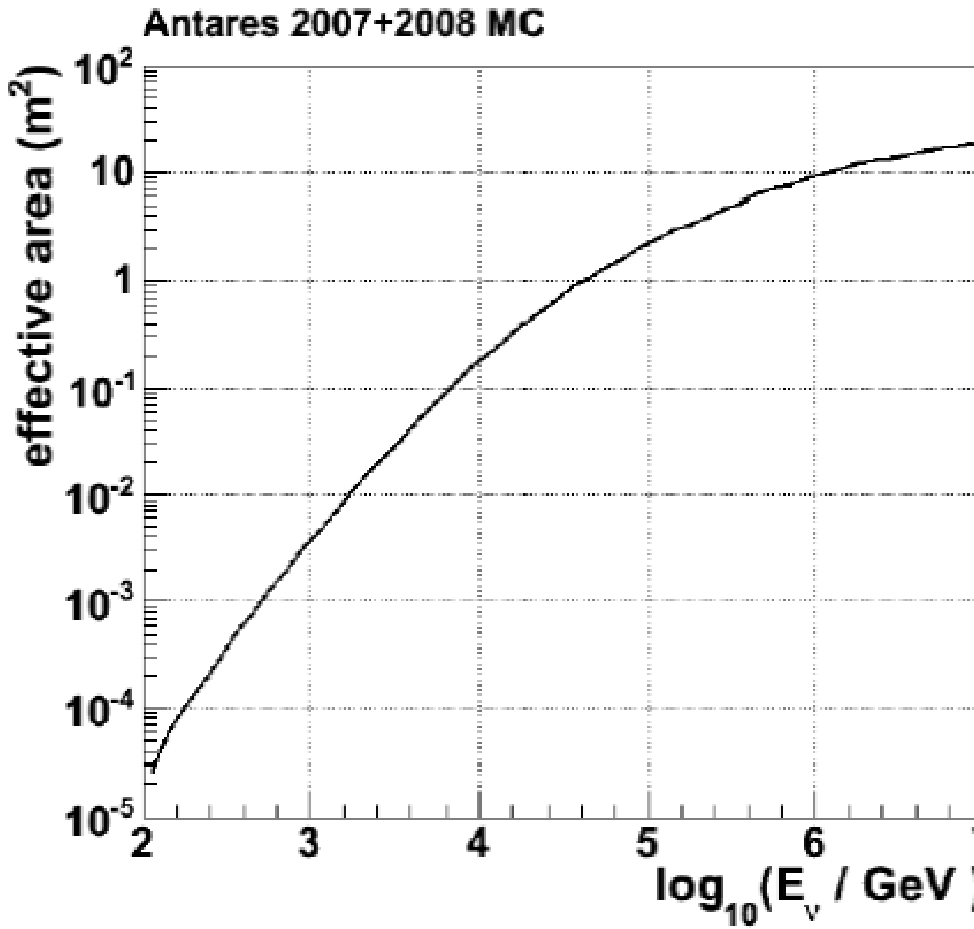
ANTARES data 2007-2008



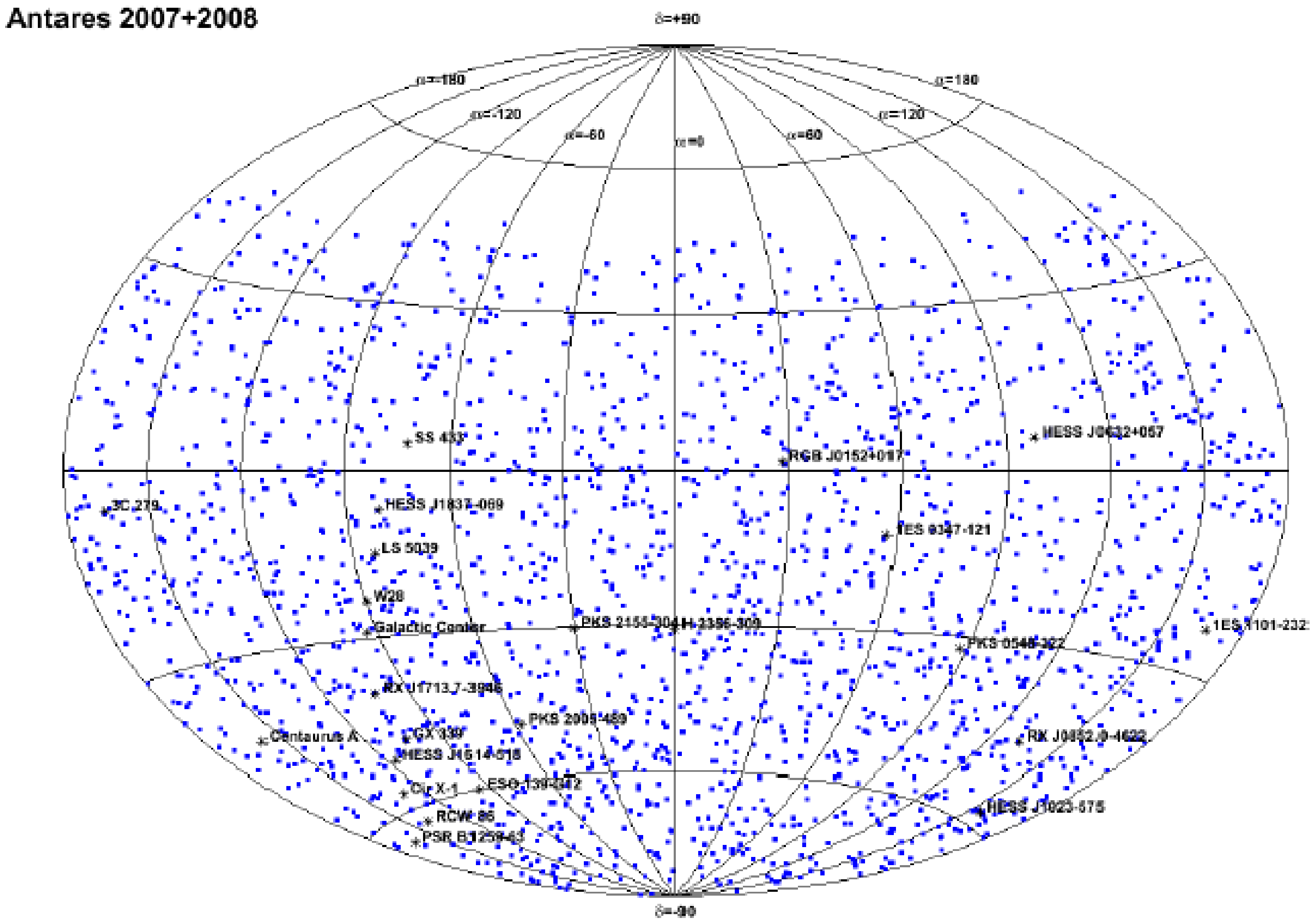
- About 300 days of taken data
- A dedicated program for the event reconstruction assigns a quality parameter to each track.
- Data fufil the Monte-Carlo simulations

ANTARES parametrizations 07-08



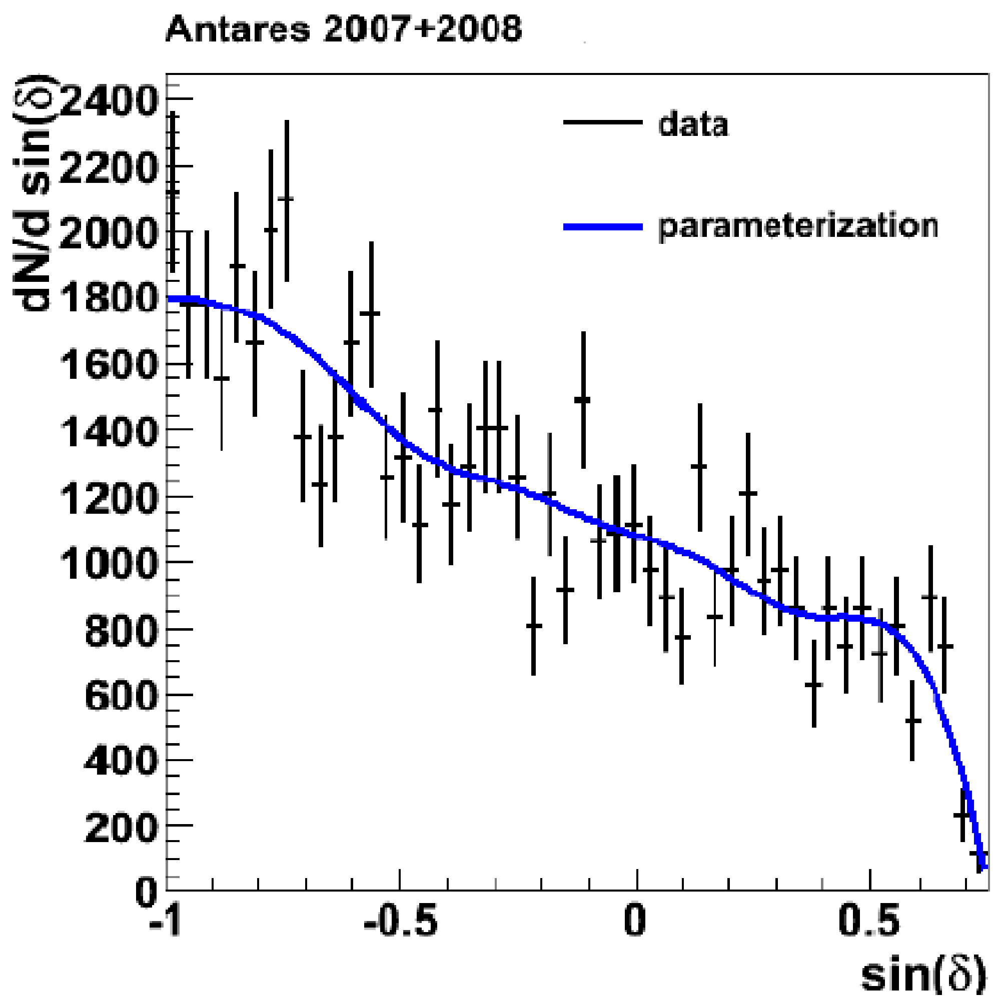


ANTARES background 07-08 (1)



- 2040 well reconstructed events

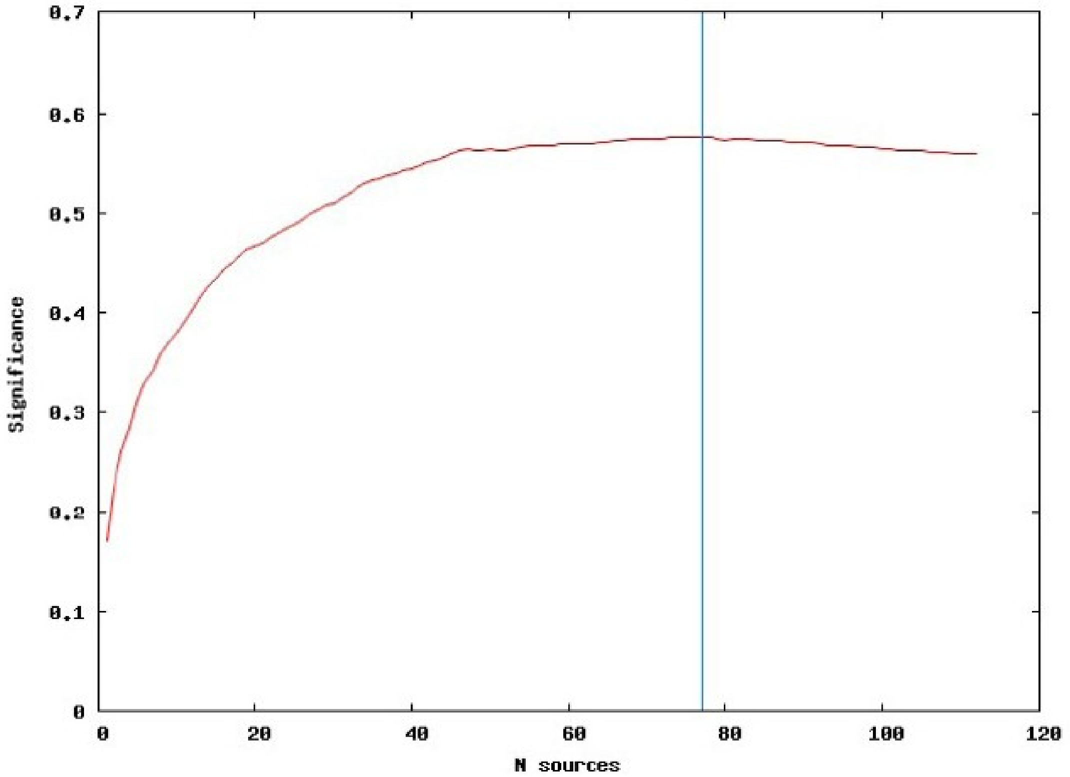
ANTARES background 07-08 (2)



$$N_{bg}(\delta, \theta) \approx \frac{dN(\delta)}{d\sin(\delta)} \cdot (1 - \cos(\theta))$$

Significance optimization

- Significance depends from the number of superposed sources and from the bin



Stacked Sources 77	Total sources 112	Bin(arcmin) 31
Total expected events 1.3	Total background 3.9	Significance 0.57σ

ANTARES sensitivity with respect to the FSRQ sample (1)

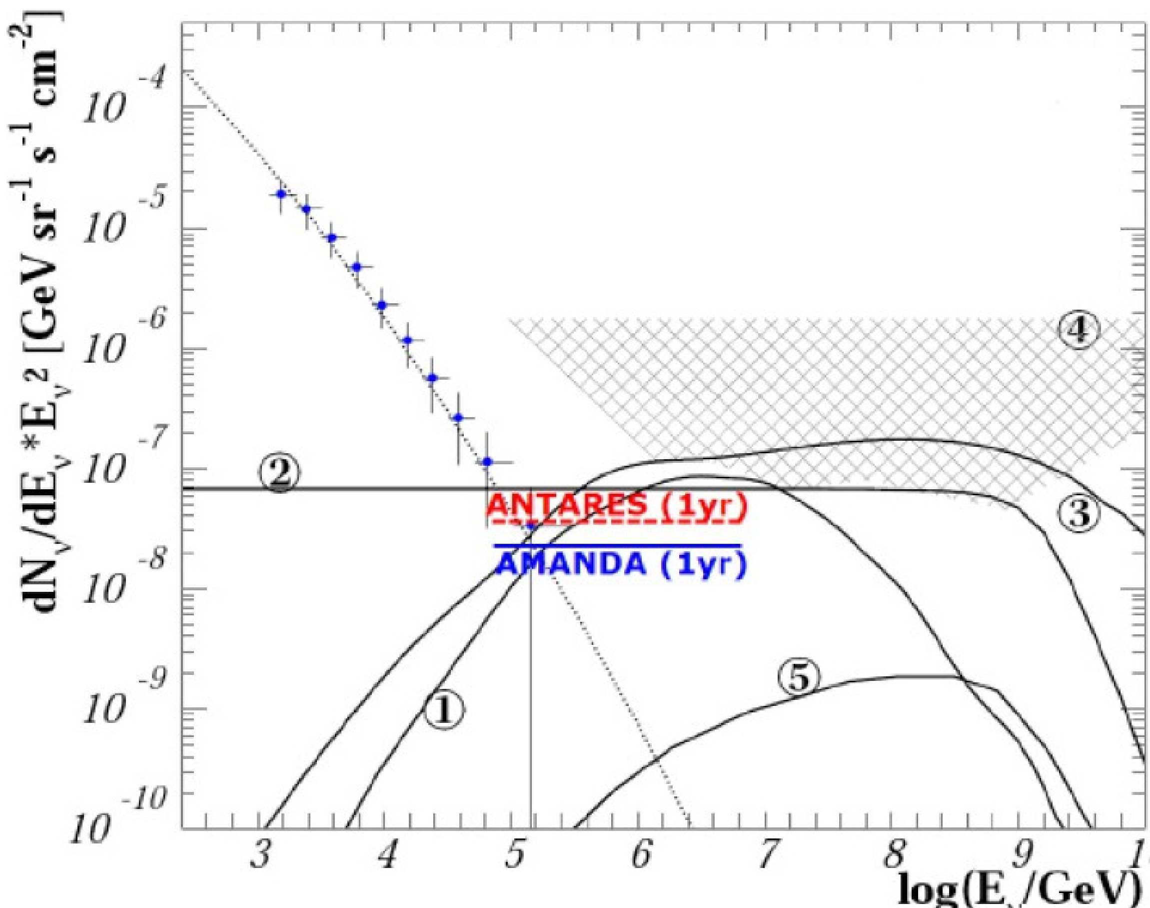
- Sensitivity is derived from the Feldman-Cousins statistic

$$N_\mu^S = T \cdot \overline{f}(\delta) \cdot P(\theta) \cdot \int_{4.8\cdot 10^{13} eV}^{10^{16} eV} k_\nu^S \cdot \frac{A_\nu^{eff}(E)}{E^2} \cdot dE$$

$$k_\nu^{DS} = \epsilon \cdot \xi \cdot \frac{k_\nu^S}{1.6\pi} \, \mathrm{sr}^{-1}$$

- ϵ : is the stacking factor
- ξ : is the diffusive factor

ANTARES sensitivity with respect to the FSRQ sample (2)



$$k_\nu^{DS} = 3.3 \cdot 10^{-8} \quad \mathrm{GeV\,cm^{-2}\,s^{-1}\,sr^{-1}}$$

Conclusions

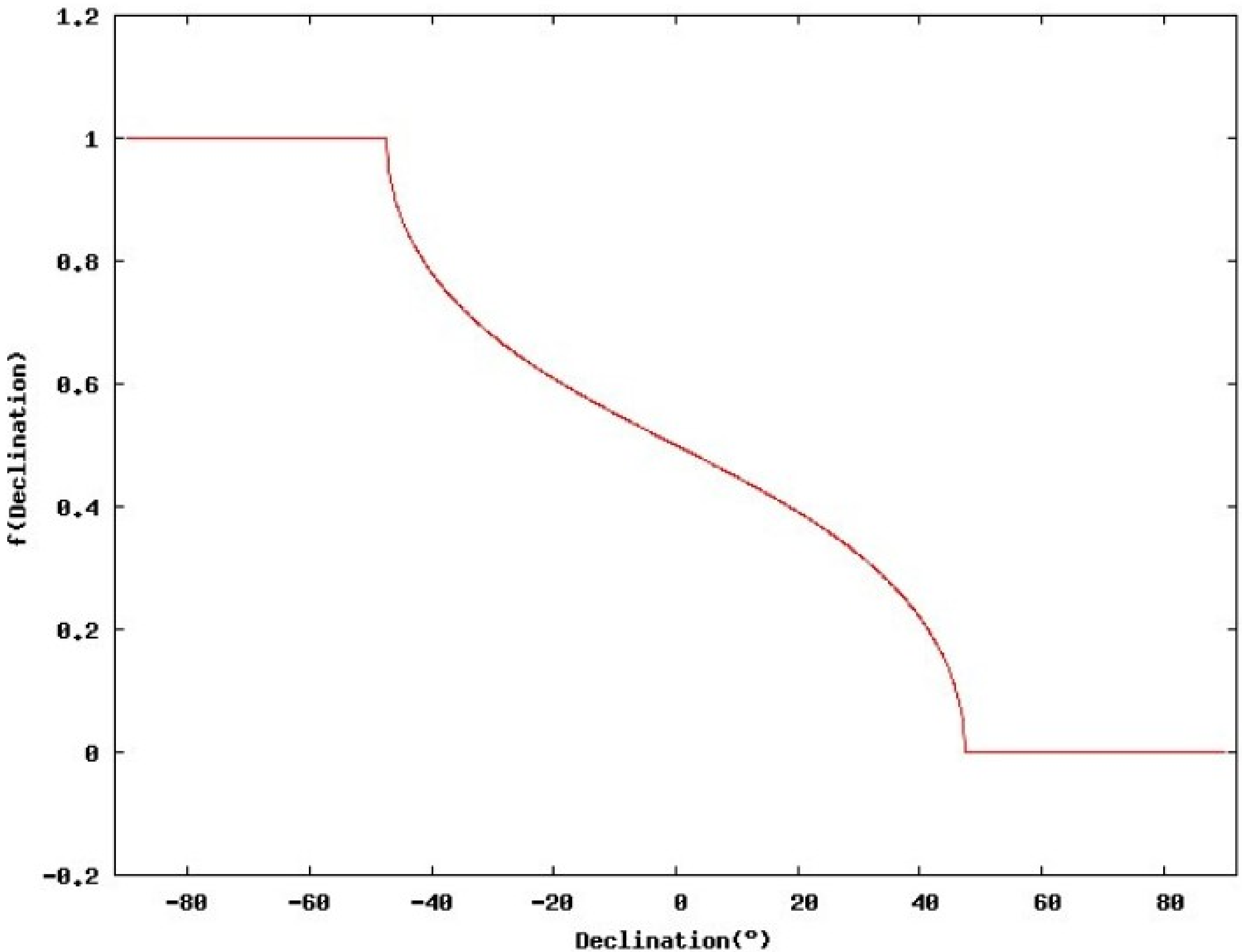
- The sample used for the stacking analysis is constitued by 112 FSRQ

- Assuming the Neronov-Semikoz model, the number of neutrino events has been evaluated

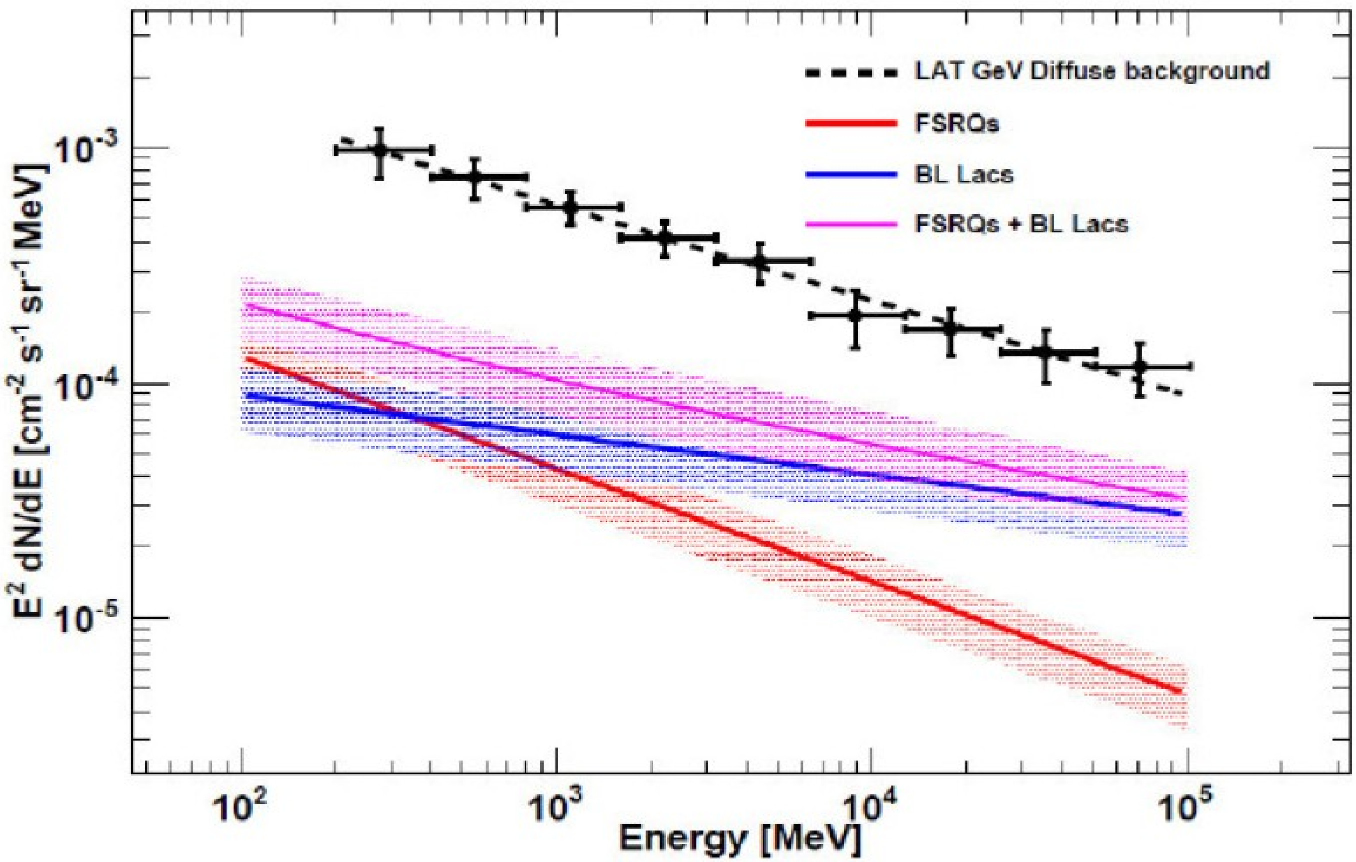
- Optimization has been done using ANTARES 2007-2008 data

- It has been derived ANTARES diffuse sensitivity with respect to the considered sample

Visibility factor



Diffuse gamma flux (FERMI-LAT)



- FSRQ contributes at 10% to the gamma diffuse flux