



# High energy cosmic neutrino search with ANTARES

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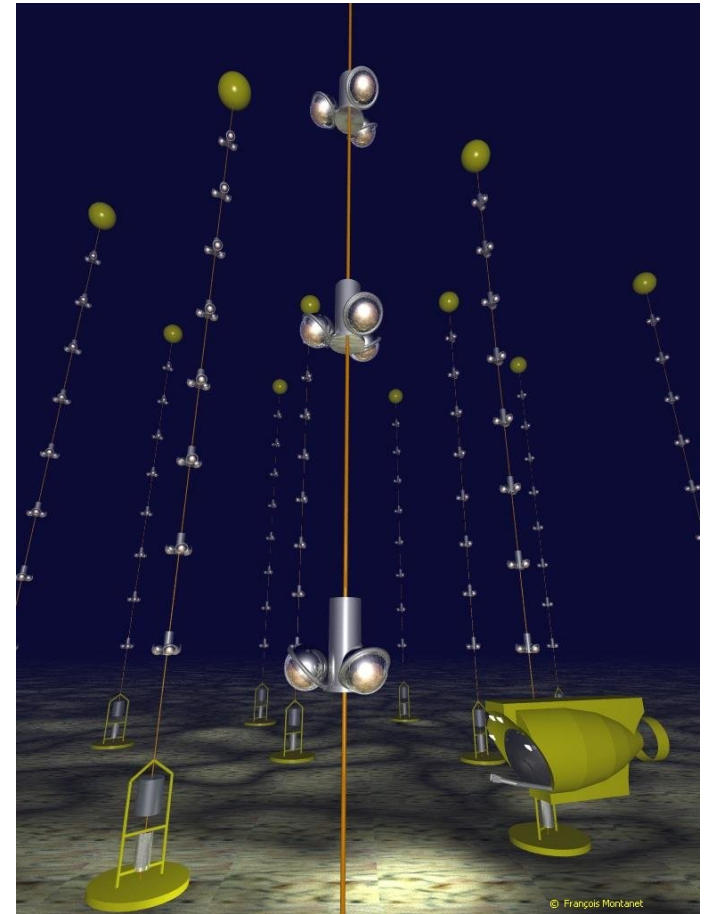
Working group  $\gamma$ -cr- $\nu$ , Observatoire de Paris-Meudon  
January 26<sup>th</sup>, 2010



# Outline



- Neutrino astronomy
- ANTARES telescope
- Point source searches
- Transients with ANTARES
- KM3NeT

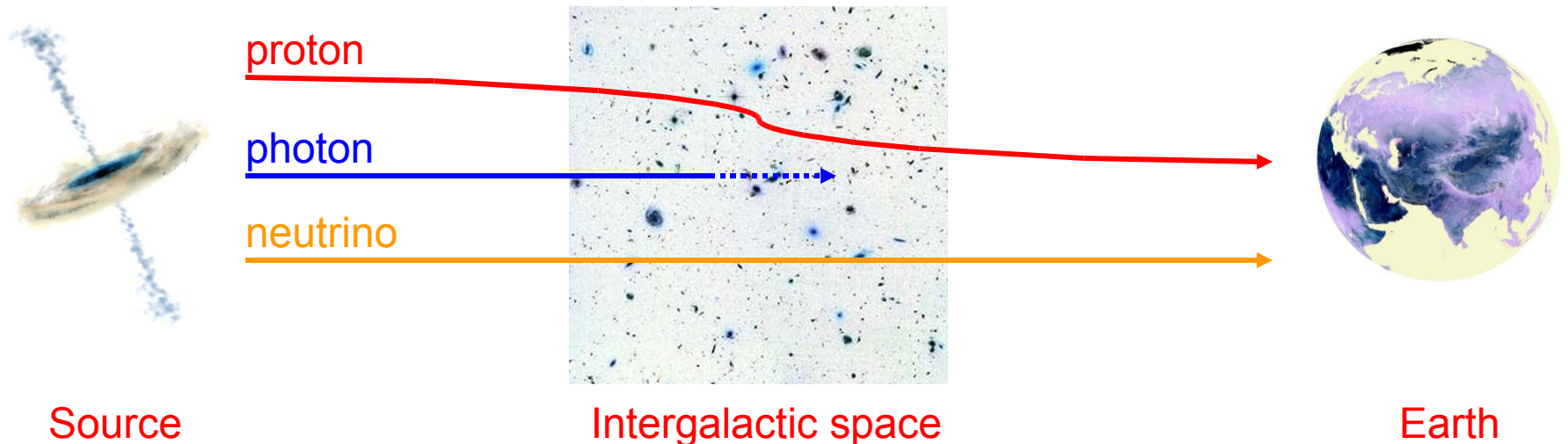




# Neutrino astronomy

## Neutrino advantages :

- Stability  $\Rightarrow$  No disintegration on its path
- Electrical neutrality  $\Rightarrow$  No deviation because of magnetic fields, localization of the source direction
- Low cross section of interaction with matter  $\Rightarrow$  Escape from the dense areas of the Universe

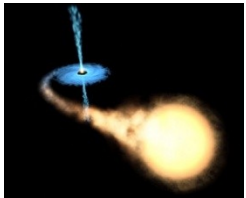




# High energy neutrino sources



## Galactic sources



Microquasar

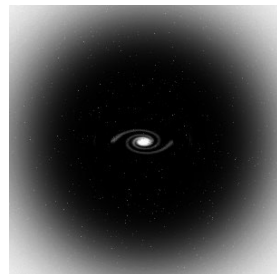


Supernovae



Pulsar

## Dark matter



## (Exotic physics)

- Magnetic monopole
- Nuclearite



## Extragalactic sources



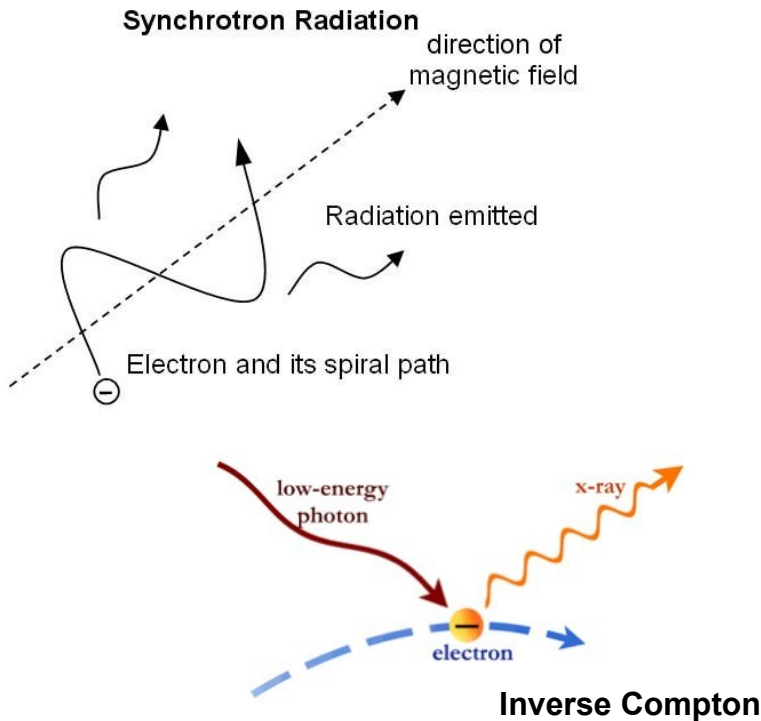
Active galactic nucleus



Gamma ray burst

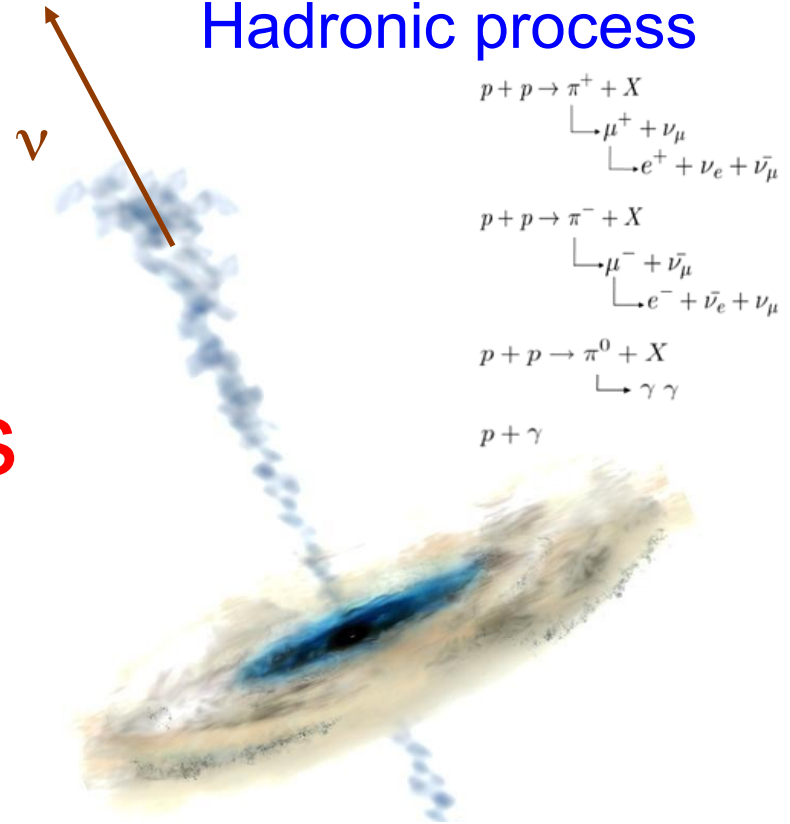
# Acceleration processes

## Leptonic process



## Hadronic process

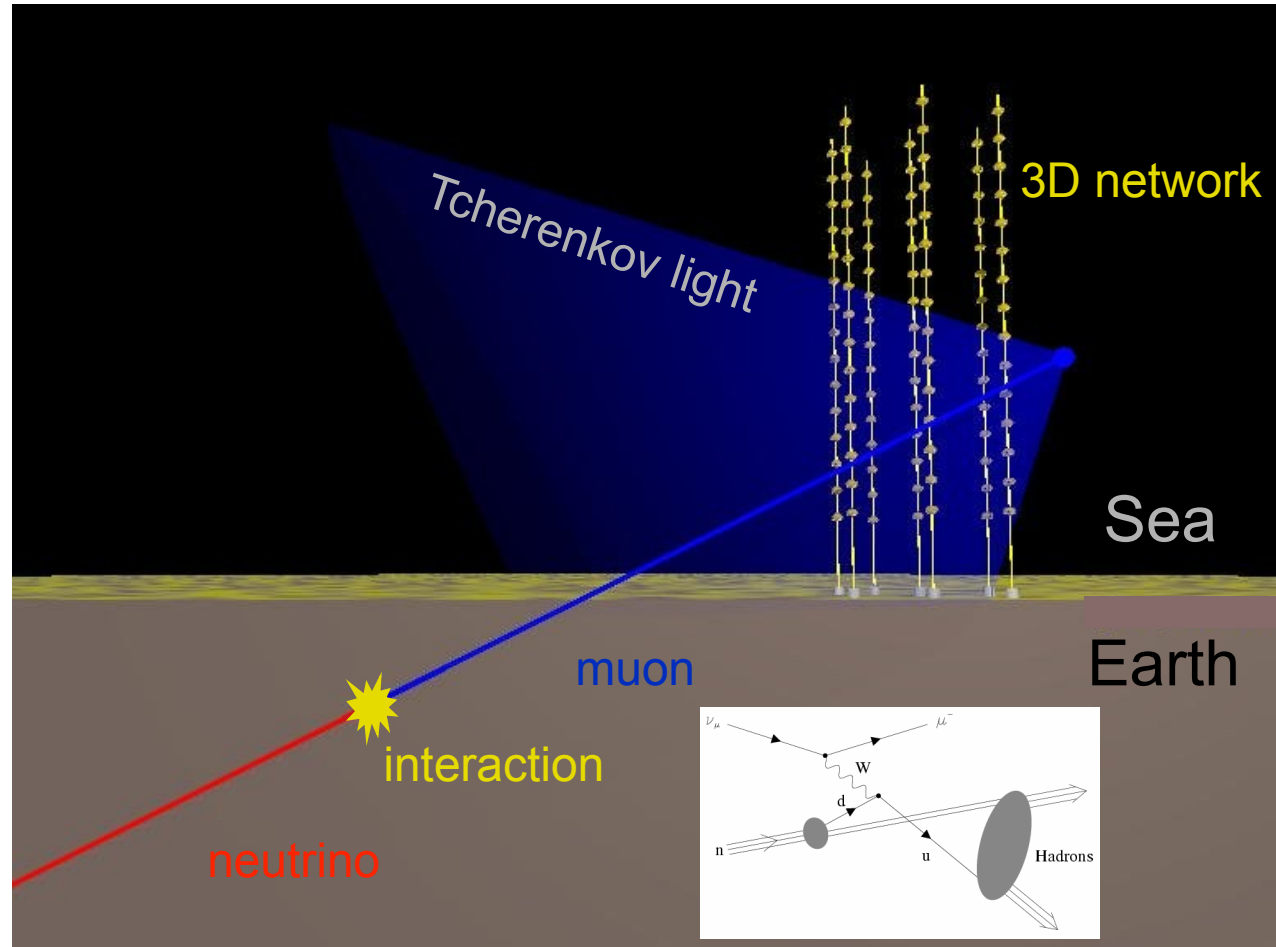
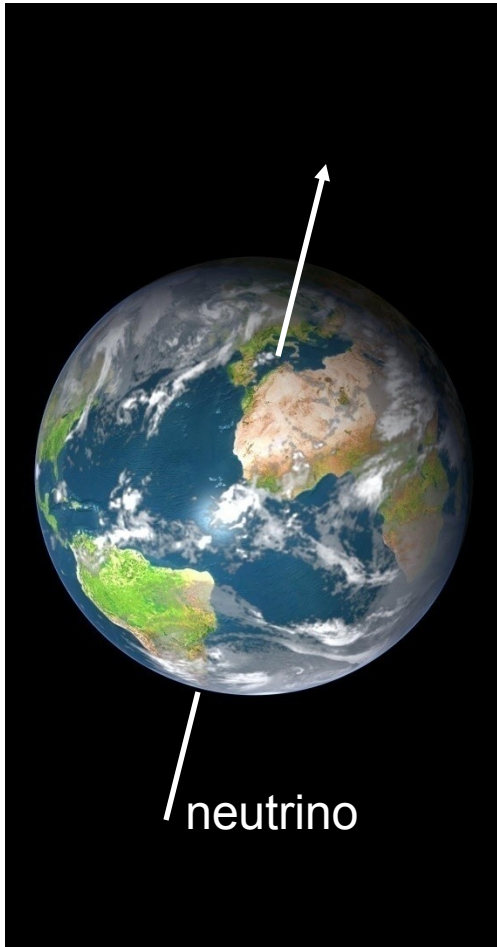
VS



The neutrino detection emitted by the extragalactic sources is an unambiguous prove for the existence of hadronic process in this sources



# Detection principle





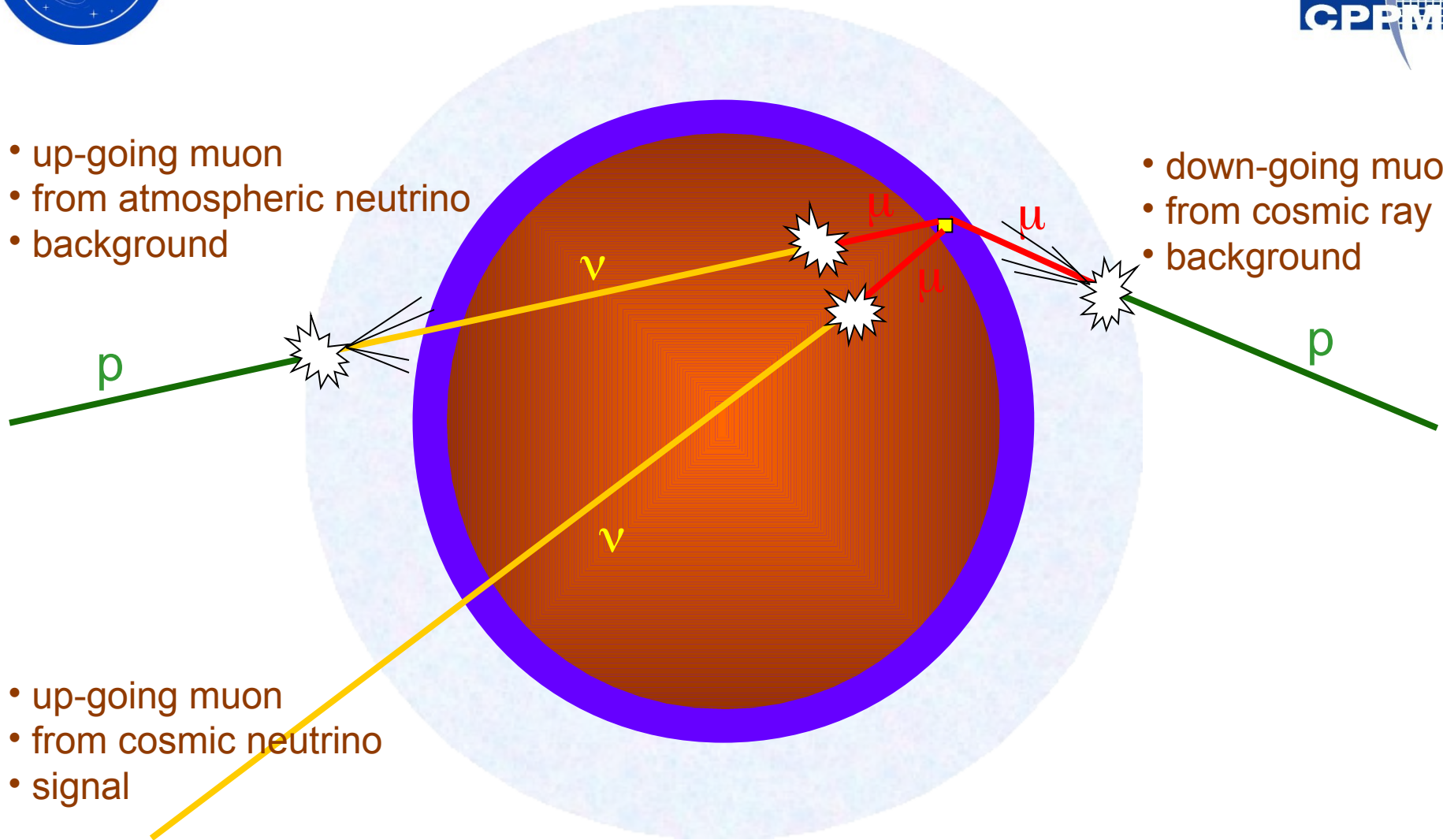


# Up-going & down-going muons



- up-going muon
- from atmospheric neutrino
- background

- down-going muon
- from cosmic ray
- background



- up-going muon
- from cosmic neutrino
- signal



# Neutrino Telescopes

Centre  
de Physique  
des Particules  
de Marseille

NORTHERN HEMISPHERE (TOULON)  
ANTARES



SOUTHERN HEMISPHERE (SOUTH POLE)  
AMANDA - ICECUBE



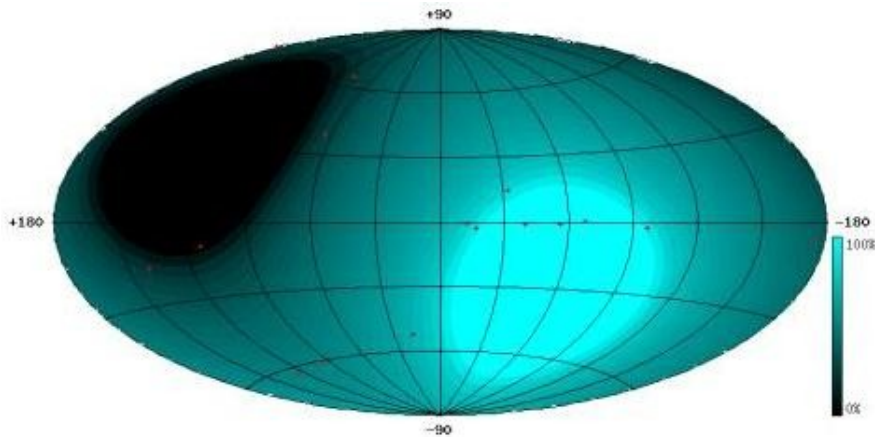




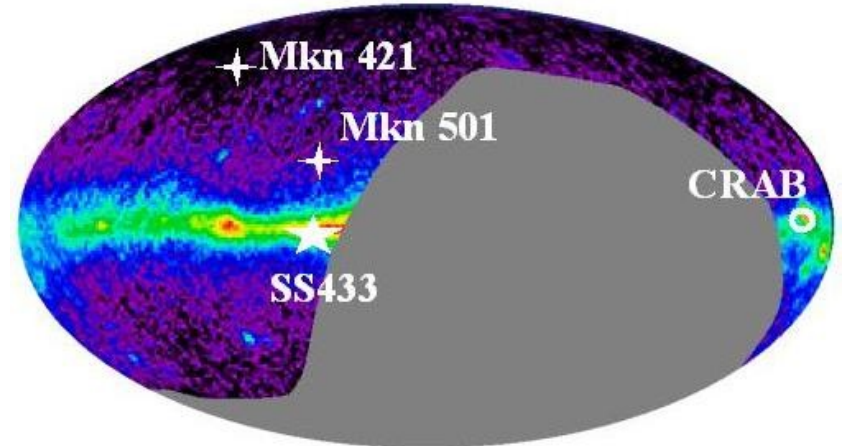
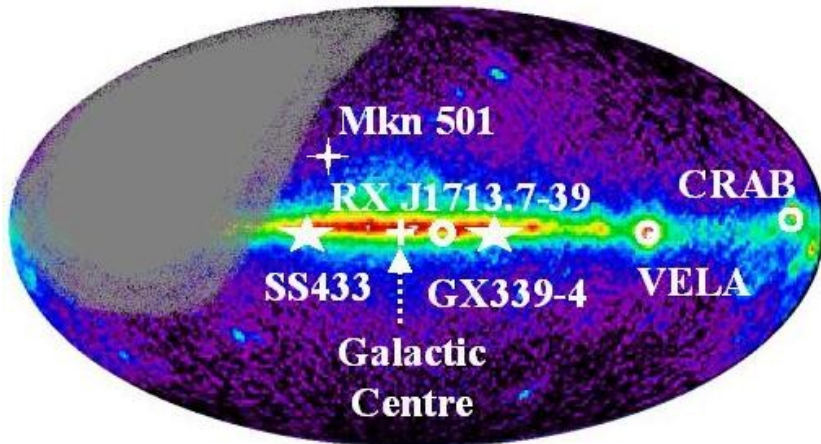
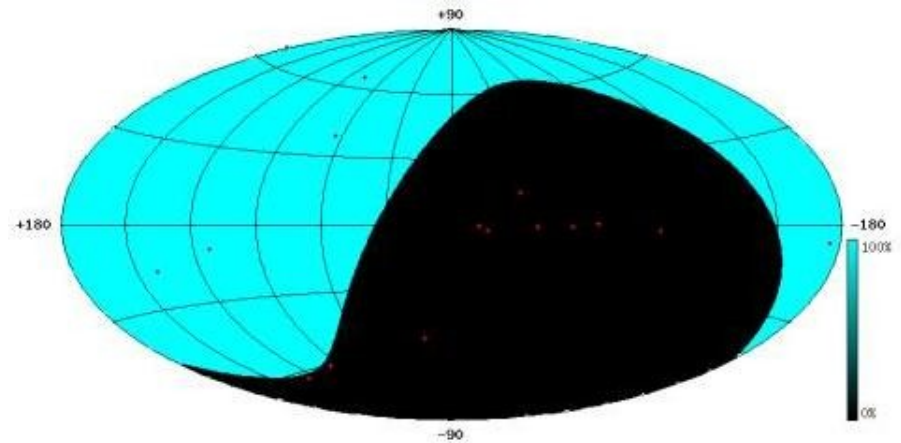
# Sky Map (observable regions)



## ANTARES

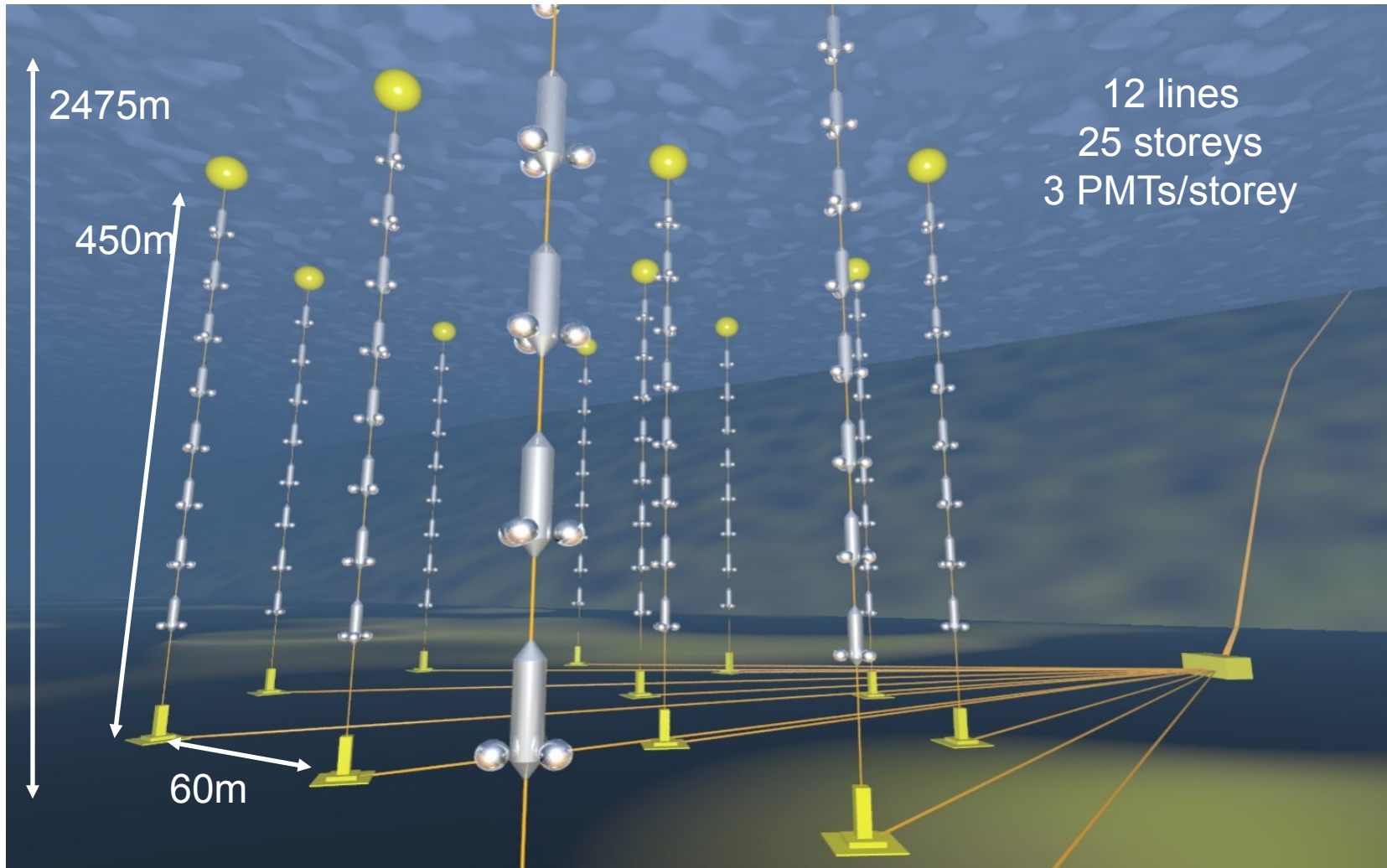


## Ice Cube





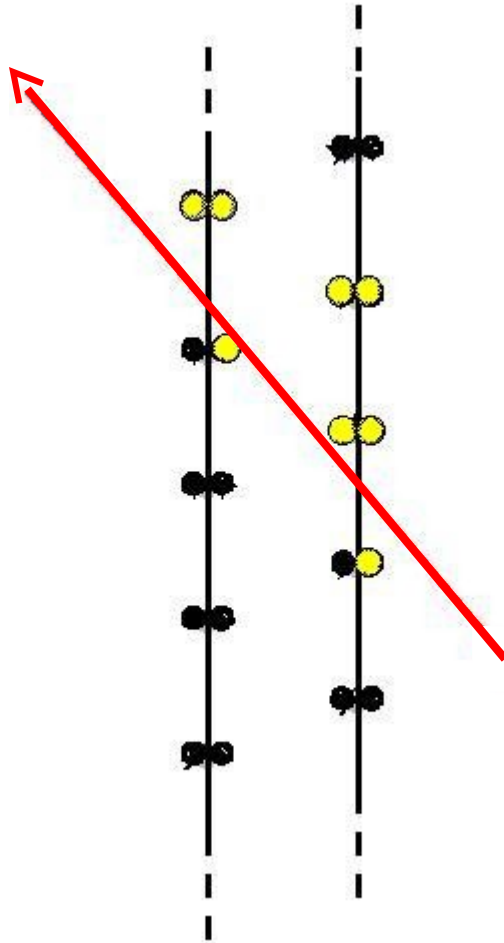
# ANTARES telescope



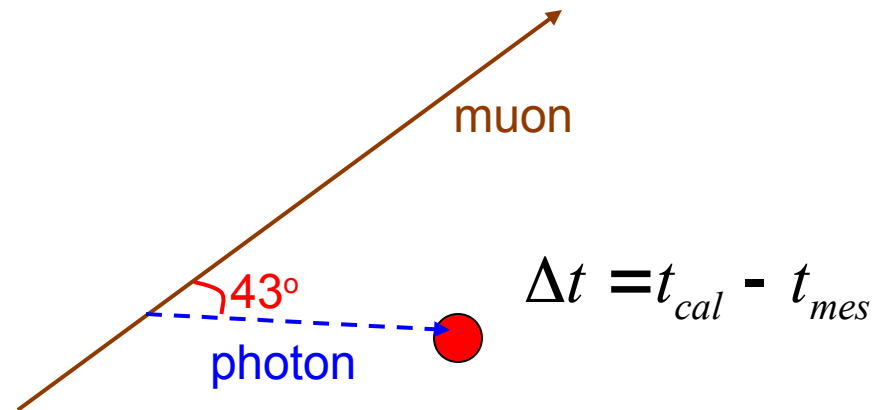


# Track reconstruction

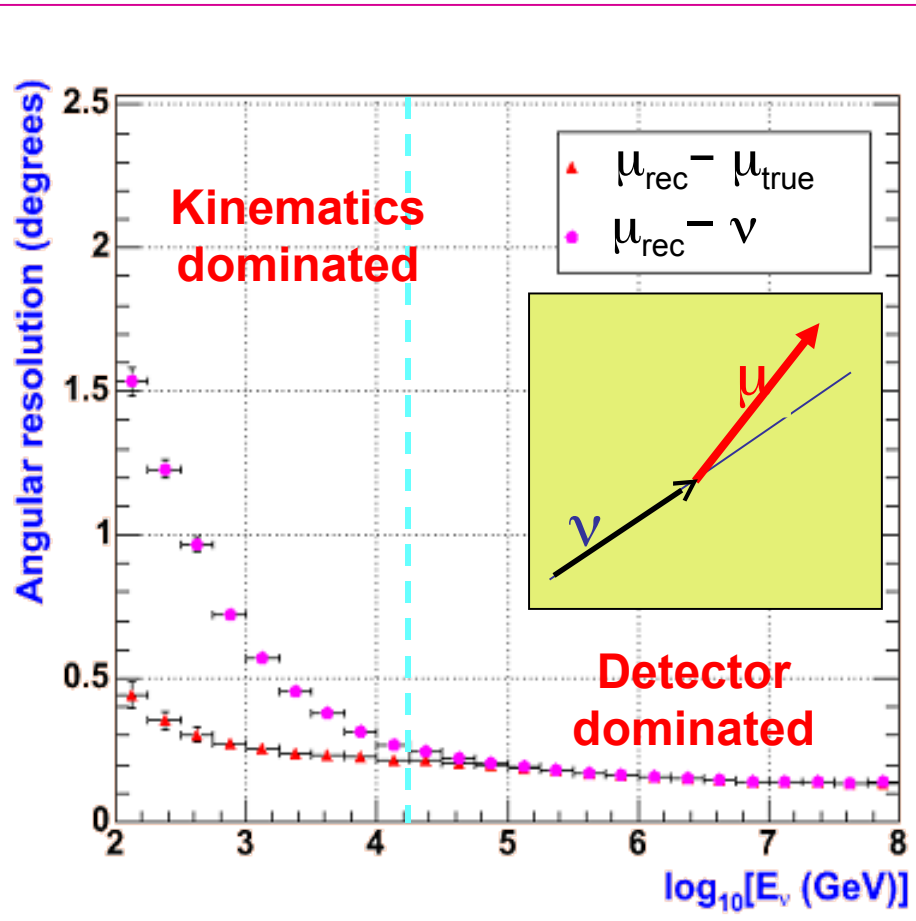
- Search local hit coincidences in 20 ns time window
- Need 5 local coincidences (minimum) on 2 lines (minimum)
- Reconstruction is based on 3 main steps:
  - Prefit : chi2 minimization
  - Mainfit : M-Estimator maximization
  - Postfit : Likelihood maximization



$$\Lambda = \frac{\log(L)}{N_{DOF}}$$



# Angular resolution



Angular resolution better than  $0.3^\circ$  above a few TeV, limited by:

- Light scattering + chromatic dispersion in sea water:  
 $\sigma \sim 1.0 \text{ ns}$
- TTS in photomultipliers:  
 $\sigma \sim 1.3 \text{ ns}$
- Electronics + time calibration:  
 $\sigma < 0.5 \text{ ns}$
- OM position reconstruction:  
 $\sigma < 10 \text{ cm} (\leftrightarrow \sigma < 0.5 \text{ ns})$



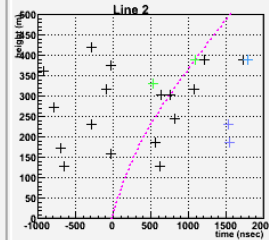
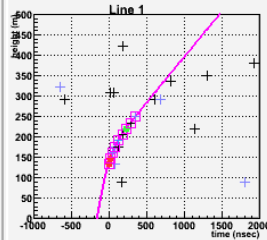




# Up-going muon

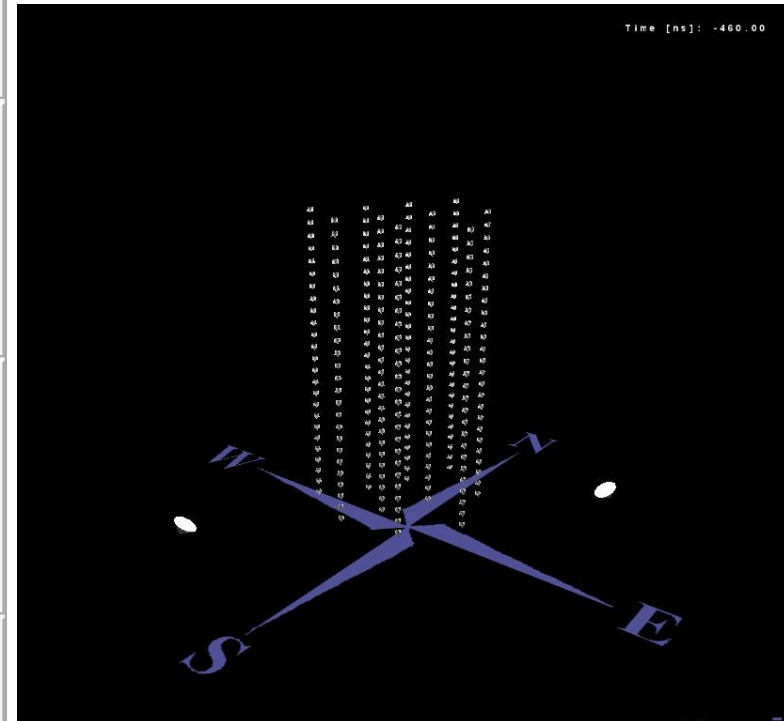
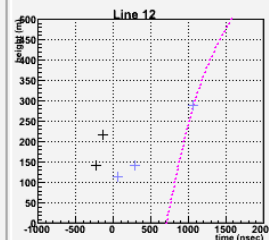
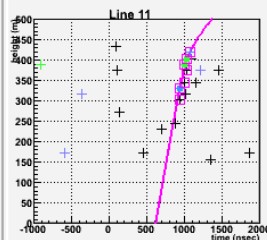
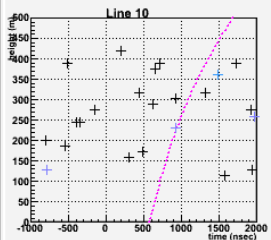
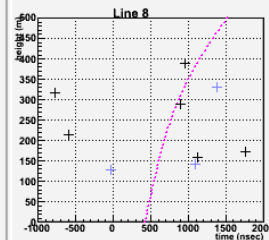
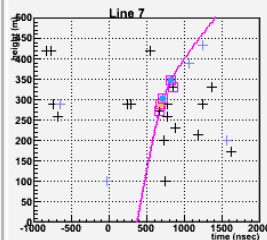
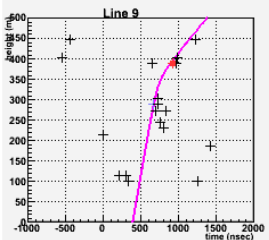
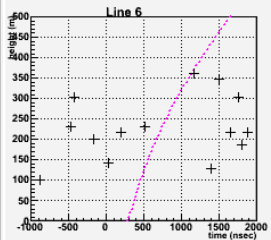
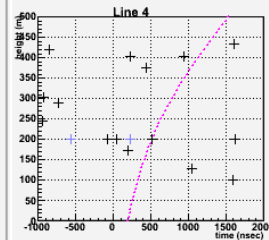
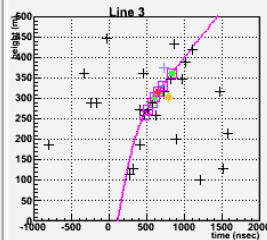
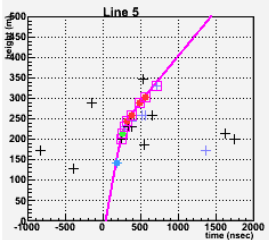


Zenith : 34.8  
Fit on 5 line(s)



Run 34927 Frame 7155  
Wed Jun 18 00:08:10 2008  
Trigger bits 80002020  
Line 1-12 Physics Trigger (th

1 2 3 4 5 6 photons  
● ● ● ● ● ●

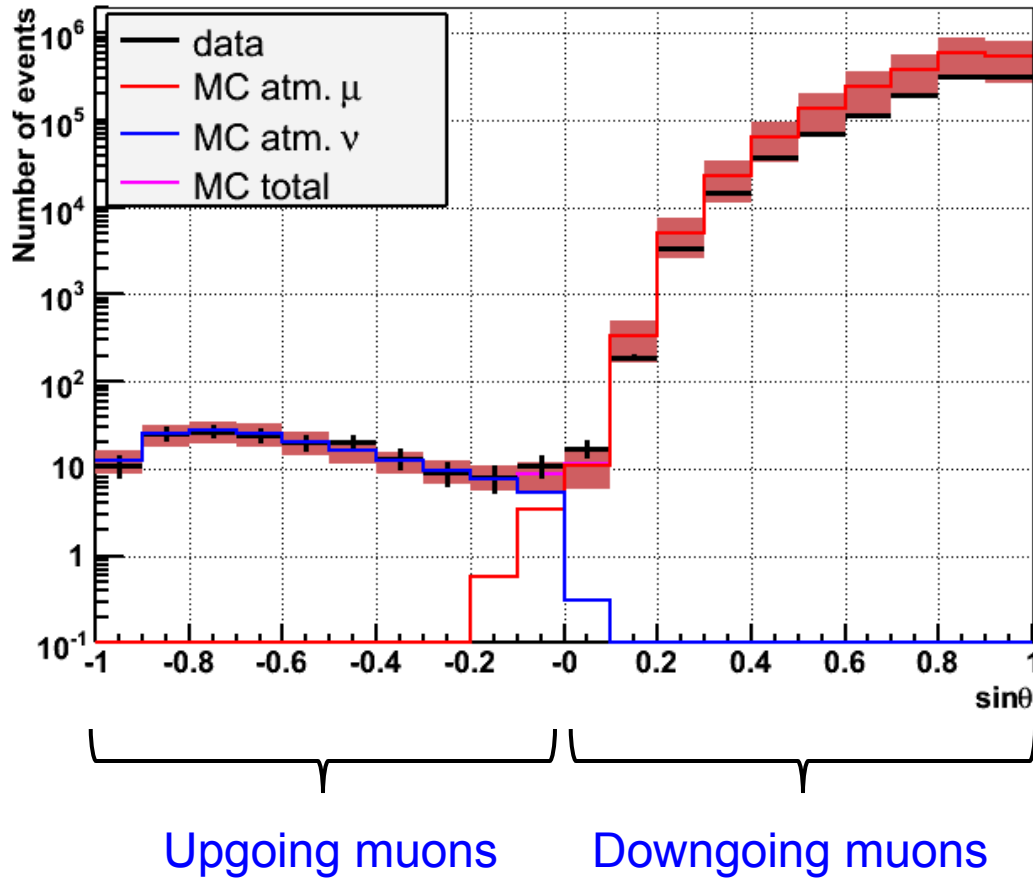




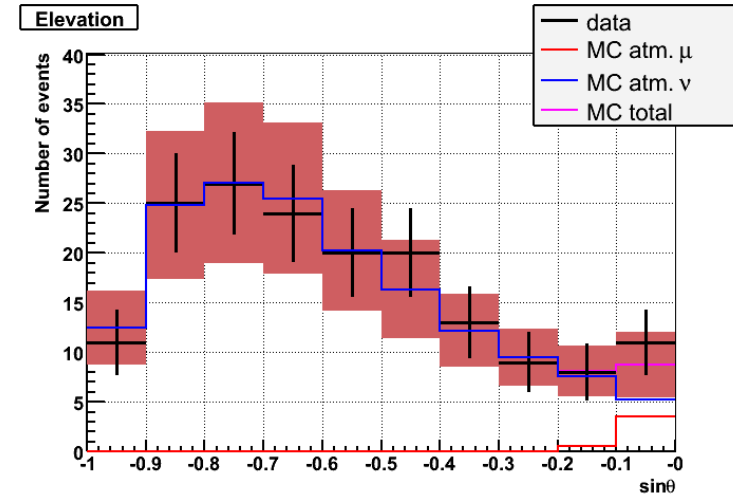
# 2007 data



Elevation



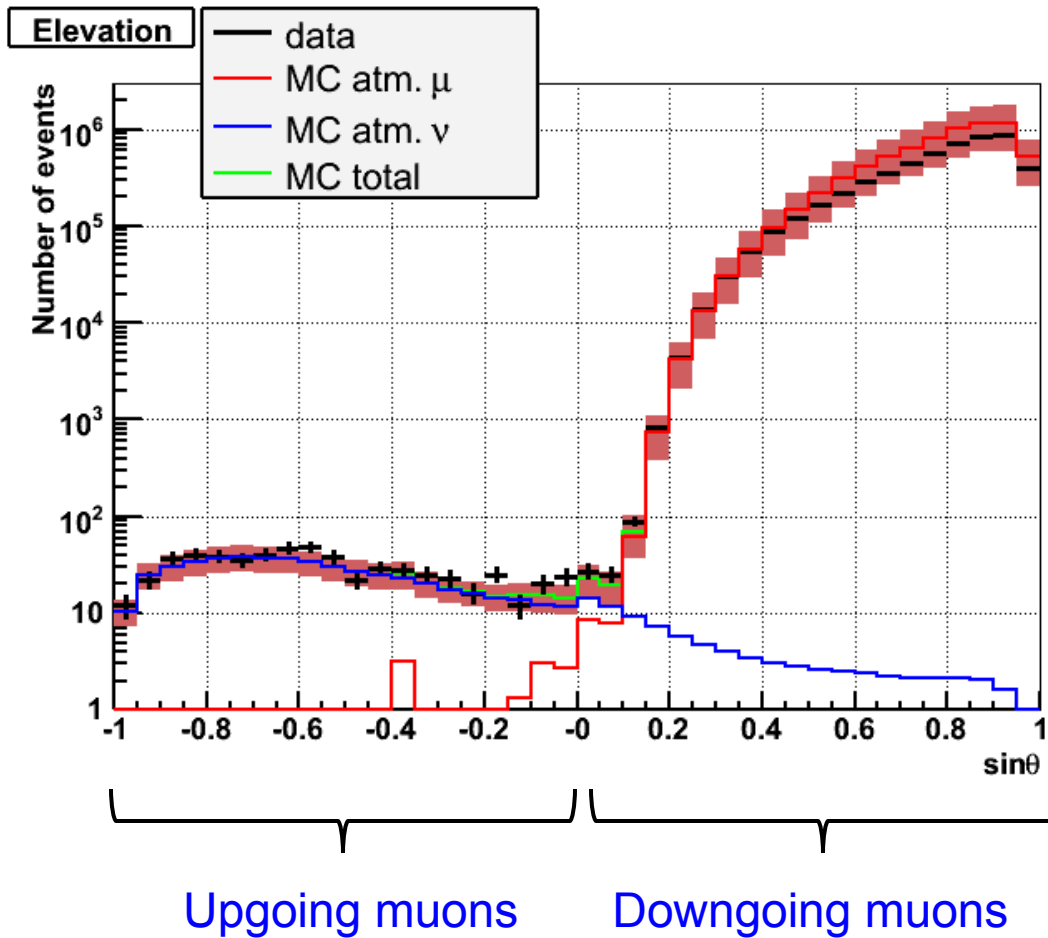
## Upgoing muons



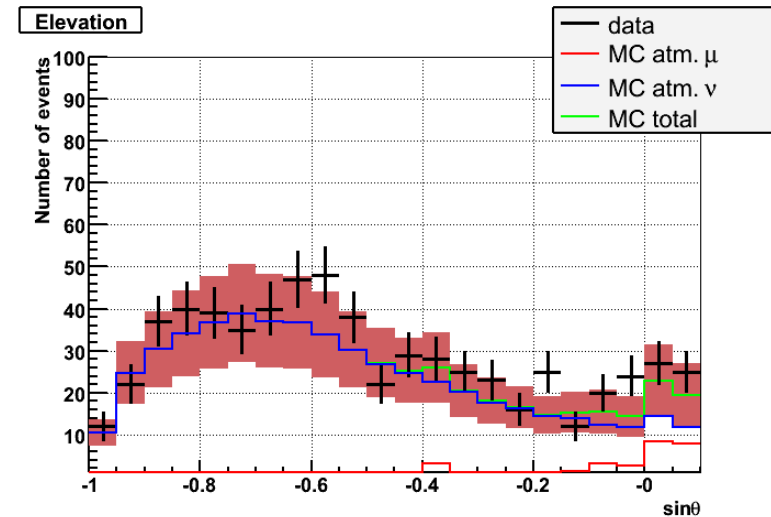
168 active days  
168 upward events  
(multi-line fit)



# 2008 data



## Upgoing muons



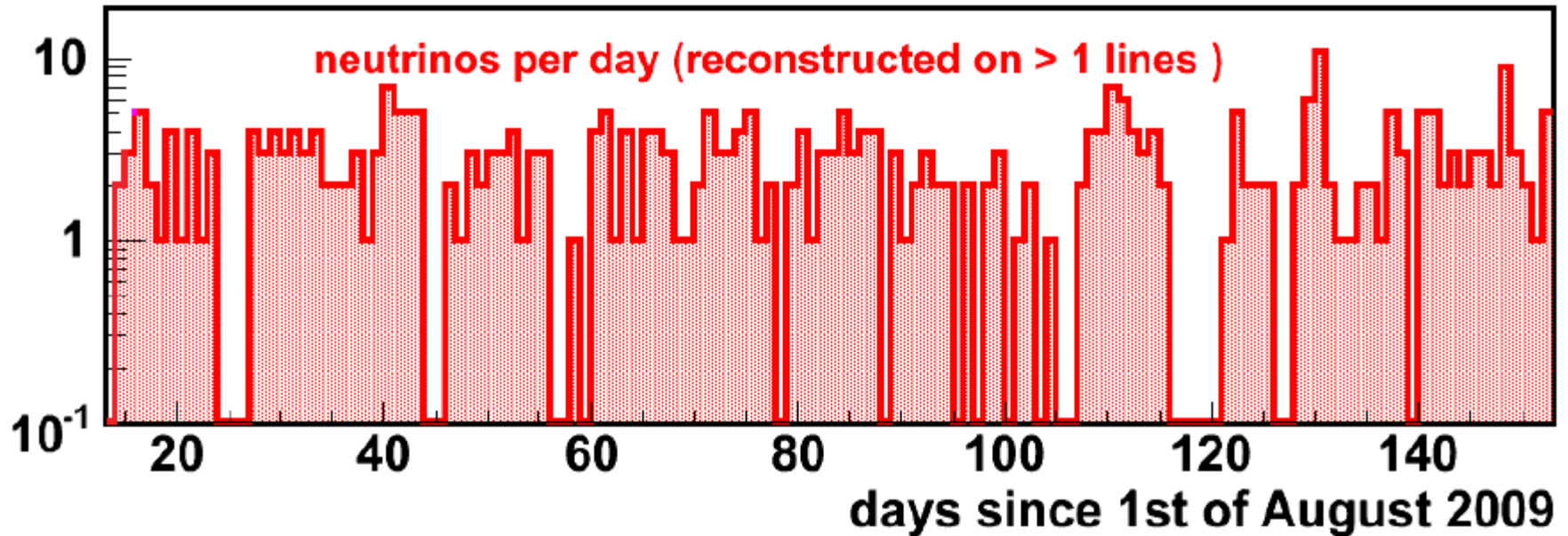
174 active days  
582 upgoing events  
(multi-line fit)





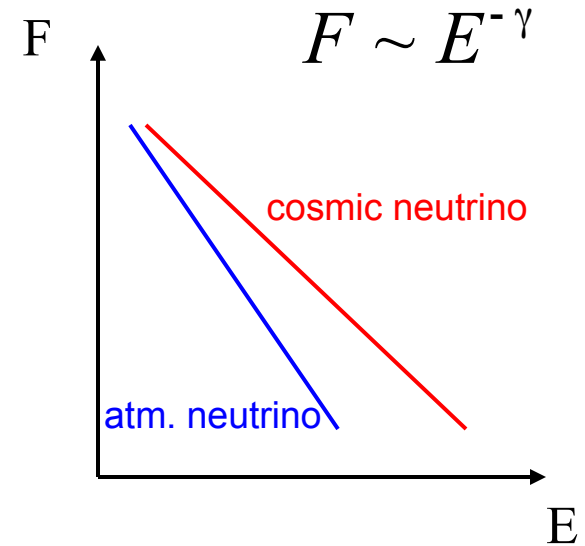
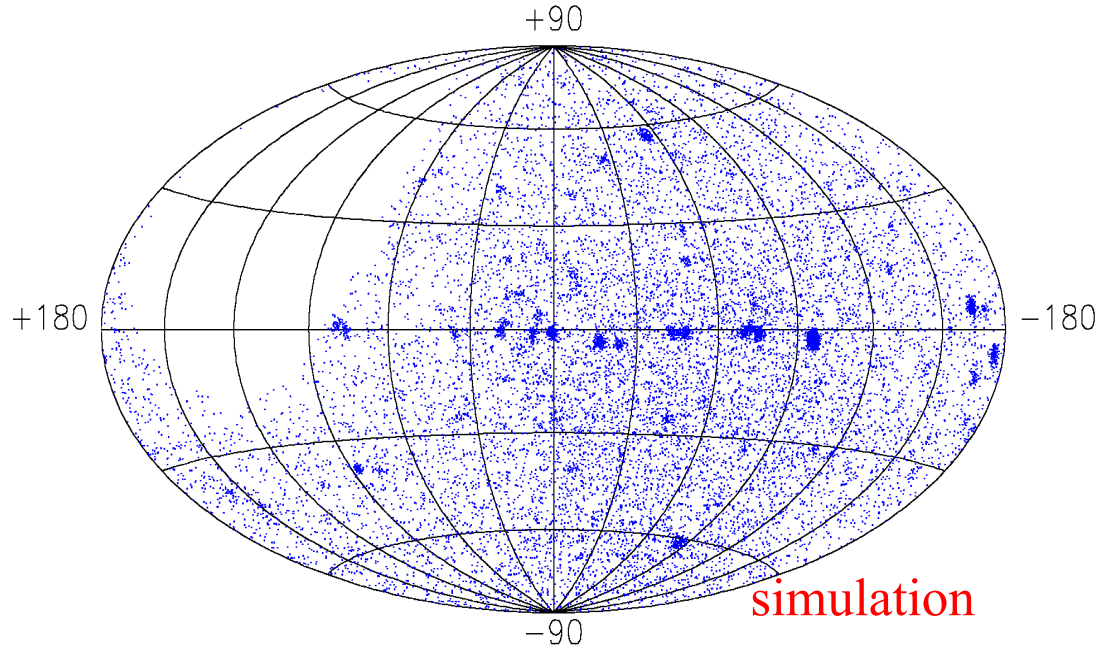
# Data acquisition

3 candidates cosmic neutrino / day





# Point source search



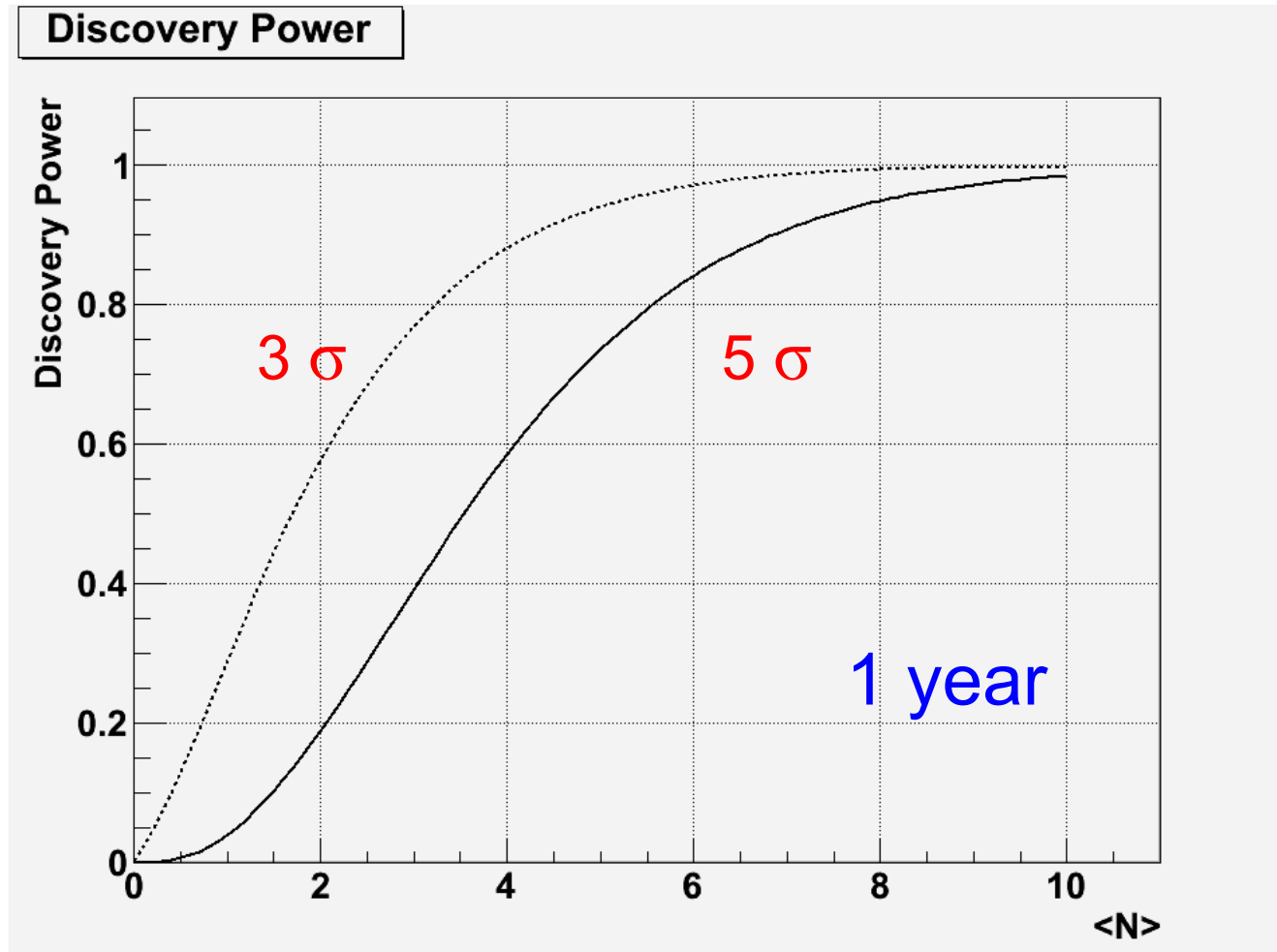
Evidence search for any statistically significant neutrino excess for a given algorithm

- Energy spectrum study:
- $\gamma = 2.0$  for cosmic neutrinos
  - $\gamma = 3.4$  for atm. neutrinos



# Discovery Power

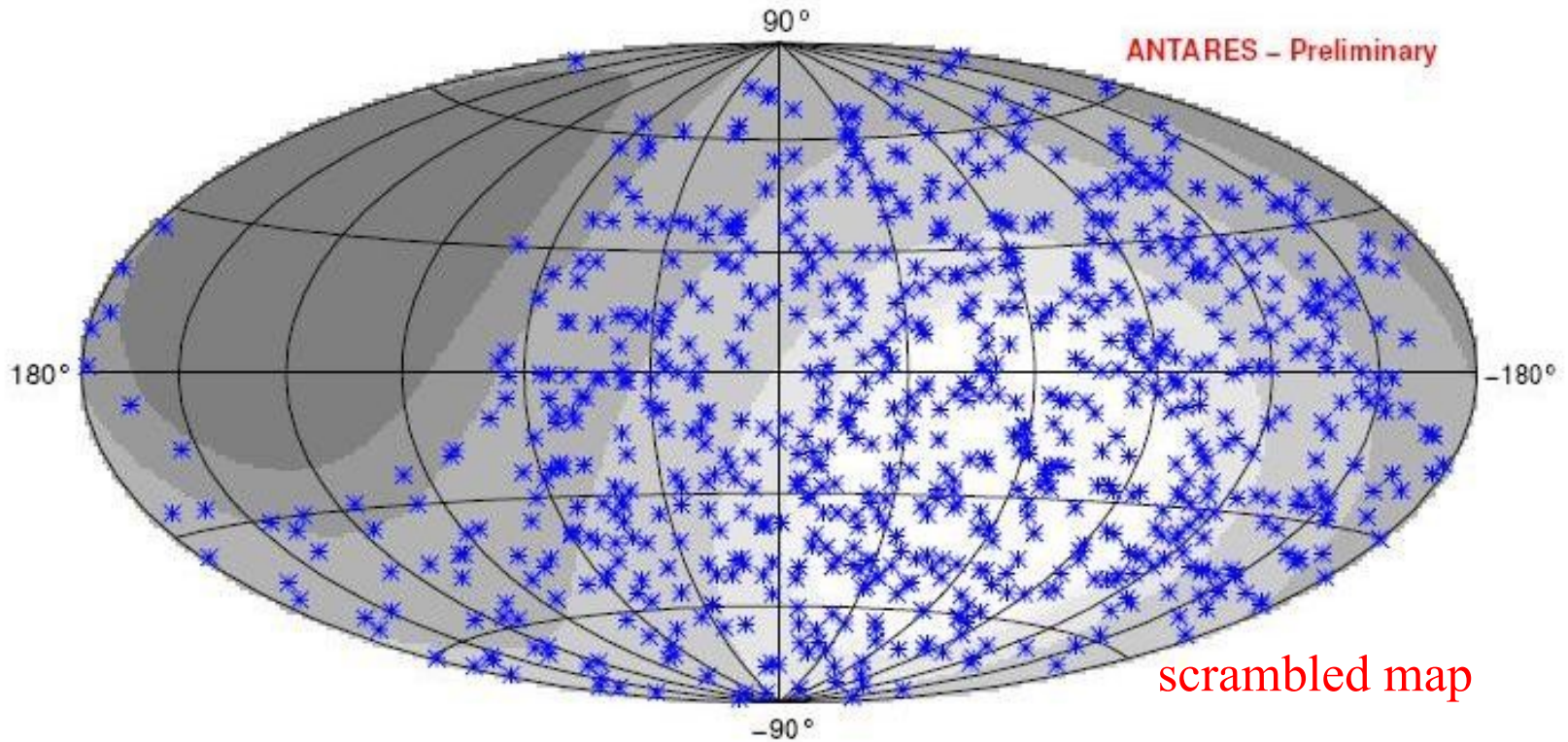
(for a given source)





# 2007+2008 Sky Map

750 up-going neutrinos

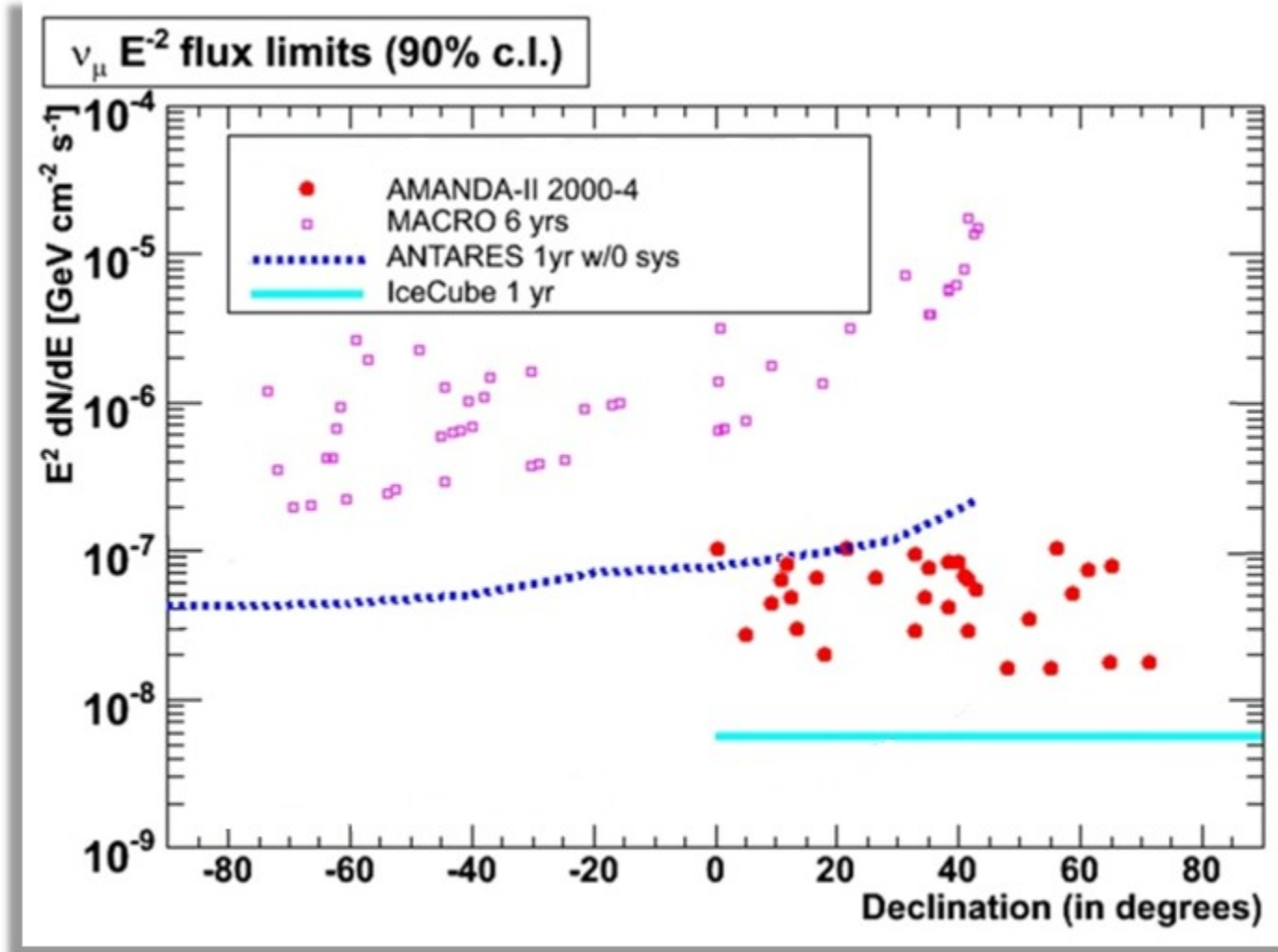


Galactic coordinates

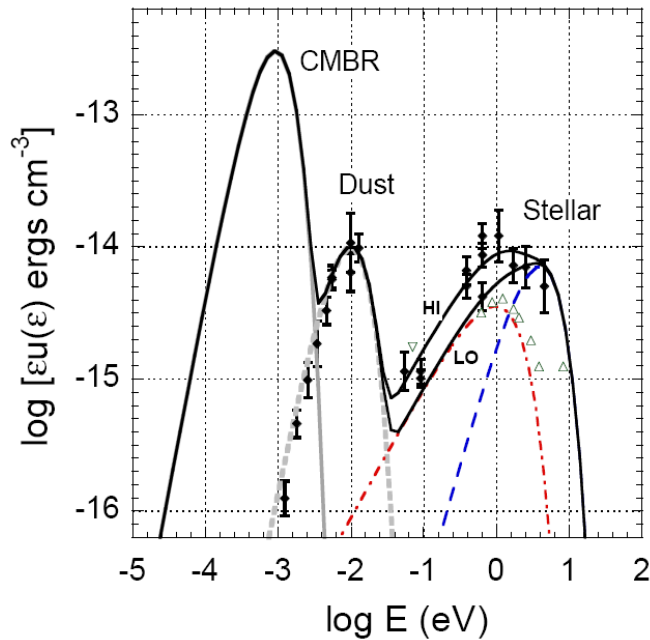
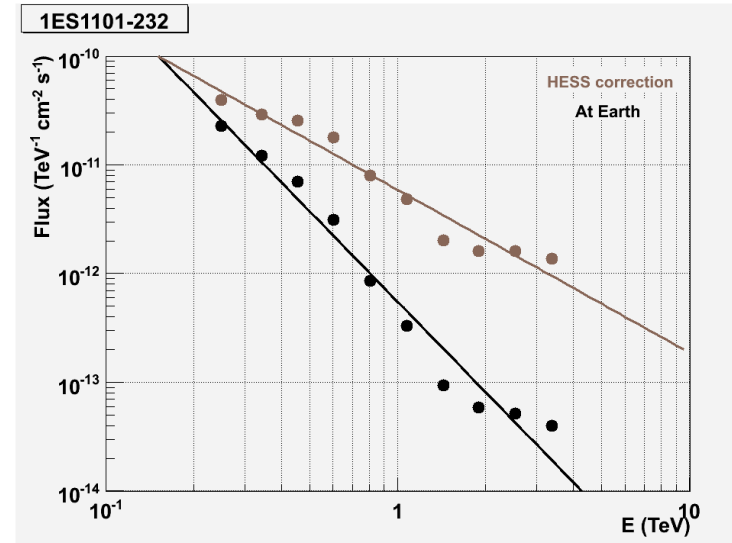




# Sensitivity to the point source



The gamma ray absorption will increase with energy increasing  
 ⇒ gamma GeV source will be add to the candidate TeV source list



$$\tau(E, z) = \int_{\tilde{z}} dz' \int_1^{\tilde{z}'} d\mu \int_{\epsilon_{th}}^{\infty} d\epsilon' \frac{dl}{dz'} \times \frac{1-\mu}{2} \times n_{\epsilon}(\epsilon', z') \times \sigma_{\gamma\gamma}(E', \epsilon', \mu)$$

$$\frac{dl}{dz} = \frac{R_H}{(1+z) \left[ (1+z)^2 (\Omega_m z + 1) + z(2+z) \left[ (1+z)^2 \Omega_r - \Omega_{\Lambda} \right] \right]^{1/2}}$$

$$\sigma(E, \epsilon, \mu) = \frac{3\sigma_T}{16} (1-\beta^2) \left[ 2\beta(\beta^2-2) + (3-\beta^4) \ln\left(\frac{1+\beta}{1-\beta}\right) \right]$$

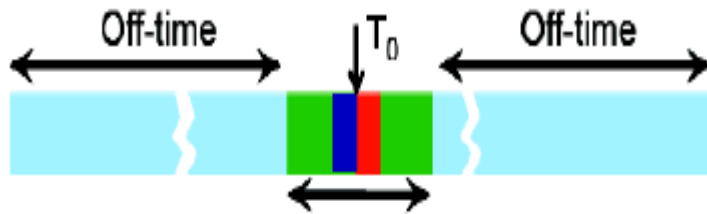
$$\beta = \sqrt{1 - \frac{\epsilon_{th}}{\epsilon}} \quad \epsilon_{th}(E, \mu) = \frac{2m_e^2}{E(1-\mu)} \quad \begin{matrix} \epsilon'_{th} = \epsilon_{th}(E', \mu) \\ E' = E(1+z') \end{matrix}$$



# Transients with ANTARES

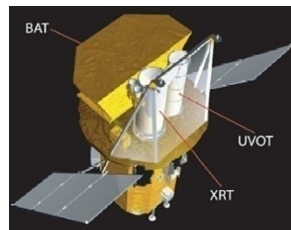


## Triggered search

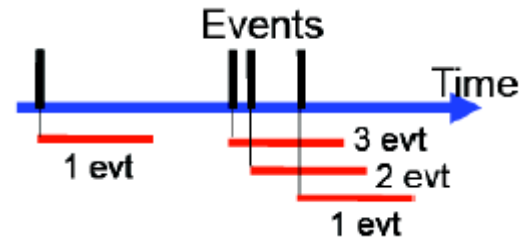


Requires Satellite trigger

Low backgrounds due to direction and time coincidences



## Rolling search



Full sky search (see all GRBs)

24hr/24hr

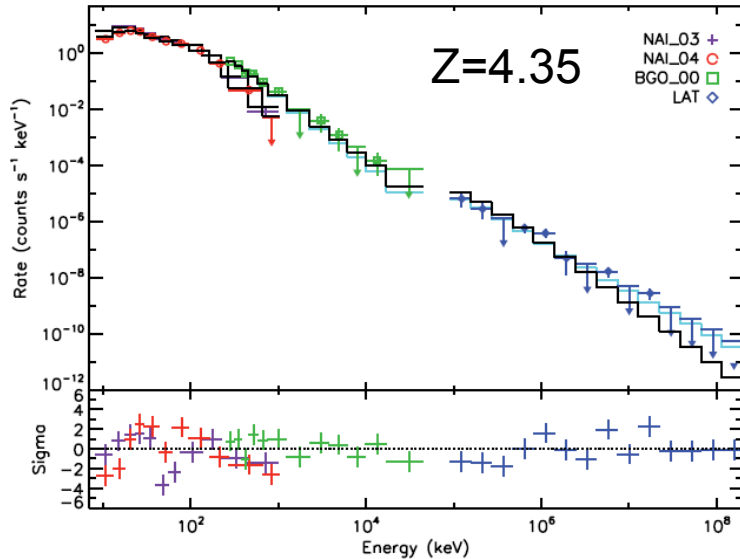
Sliding time window around events

Sensitive to dark bursts

Fast online reconstruction  $\Rightarrow$   
optical follow up to identify source



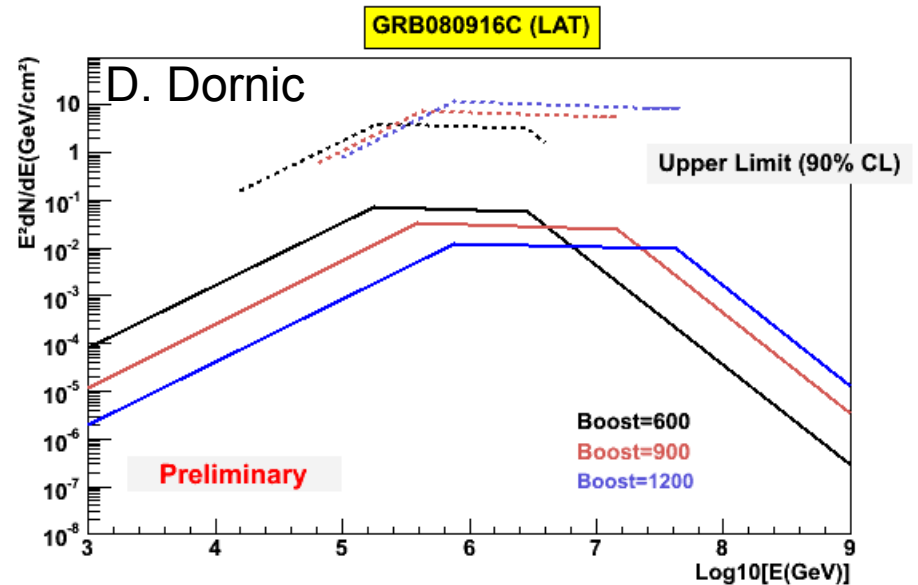
# Sensitivity of the ANTARES to GRB080916C (LAT)



Fermi: full gamma-ray spectrum up to GeV

Opacity constraints → lower limit on the boost Lorentz factor (600-900)

- sensitivity ~50 above the W&B fireball model ( $\Gamma=600$ )
- apply stacked analysis of all triggered alerts (~176 in 2007-2008)
- analysis of the ANTARES data on-going (unblinding requested)



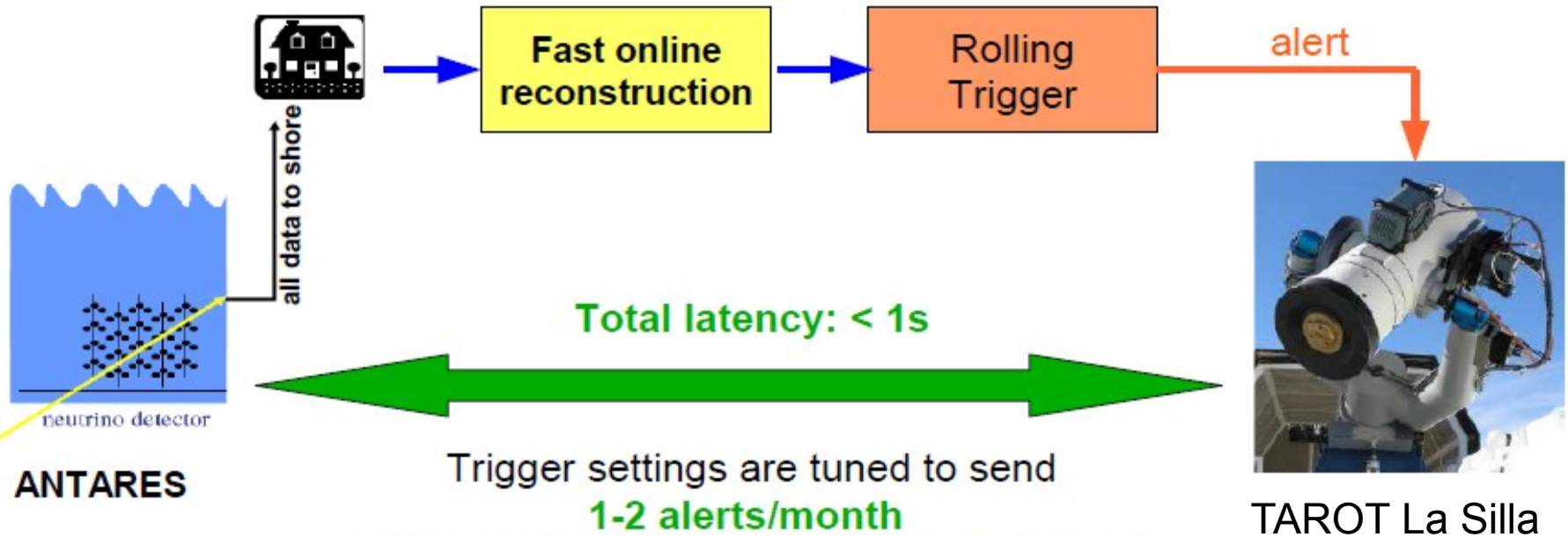




# Optical Follow-Up with TAROT



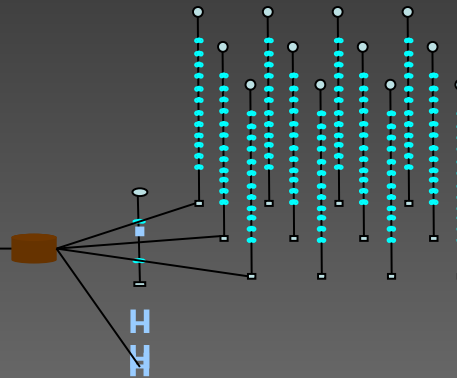
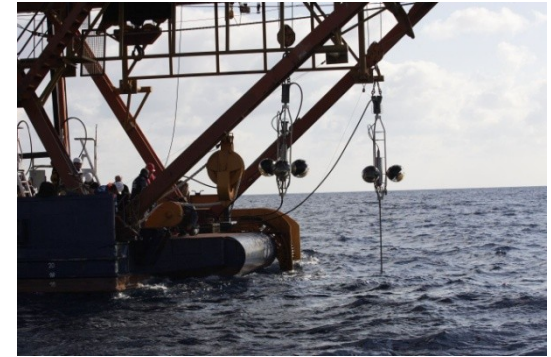
Operational since Feb 2009, supported by PCHE



Doublets (15min,  $3^\circ \times 3^\circ$ ) or  
Singlet (high-energy) triggers



# ANTARES, today



12 lines  
900 photo-detectors  
Construction & deployment :  
2 years

~ 200 m

Instrumented line  
Environment science



# KM3NeT, the future

Instrumentation  
volume  
 $\sim 1 \text{ km}^3$

- $\sim 100\text{-}200$  lines
- $\sim 20$  storeys with photo-detectors  
spacing  $\sim 40 \text{ m}$
- $\sim 5000\text{-}10000$  photo-detectors

$\sim 800 \text{ m}$

A schematic diagram of the KM3NeT detector structure. It shows a series of vertical lines representing detector strings, each composed of multiple photo-detectors. The strings are connected to a central hub on the left. A vertical double-headed arrow indicates a height of approximately 800 meters. A horizontal double-headed arrow at the bottom right indicates a spacing of approximately 150 meters between strings. A horizontal scale bar at the bottom left indicates a length of approximately 200 meters. The background is a dark blue sky with stars and a nebula.

$\sim 200 \text{ m}$

$\sim 150 \text{ m}$





# Sensitivity to the point source

