The *Antares* Neutrino Telescope and MultiMessenger Astronomy

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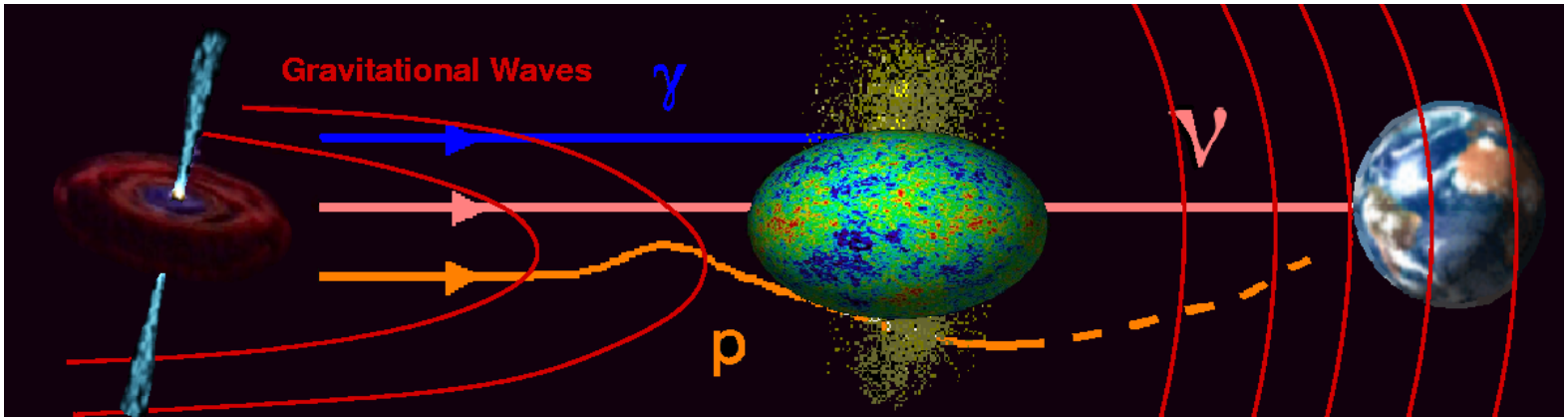
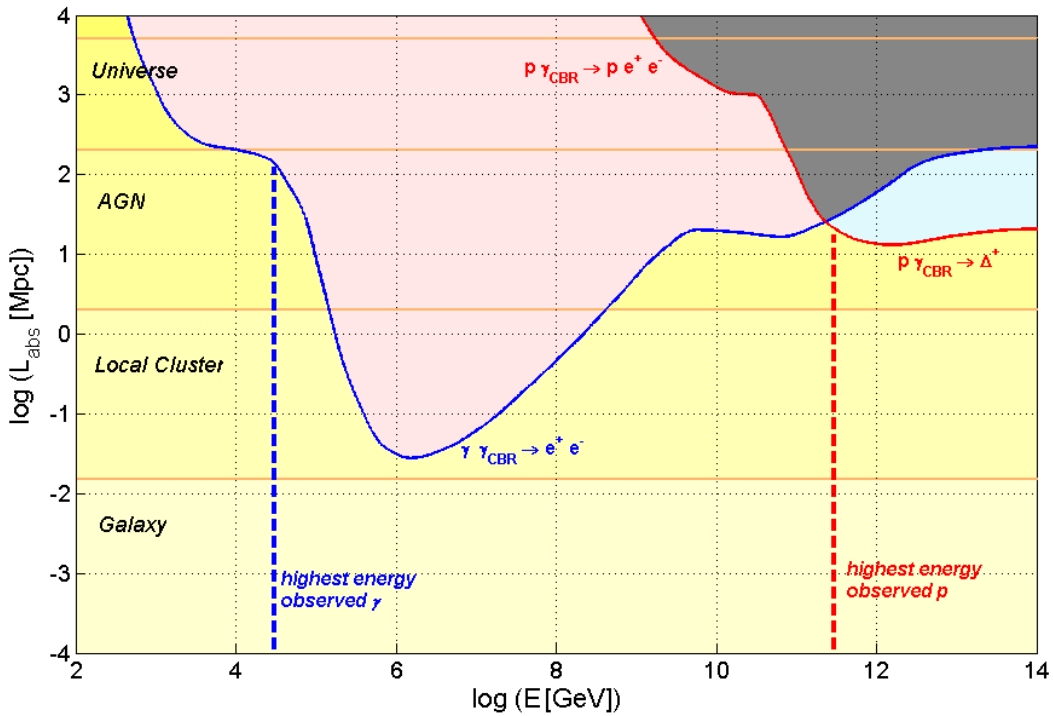
for the *Antares* Collaboration

IPHC (IN2P3) & University of Strasbourg

http ://antares.in2p3.fr

The neutrino as a new messenger





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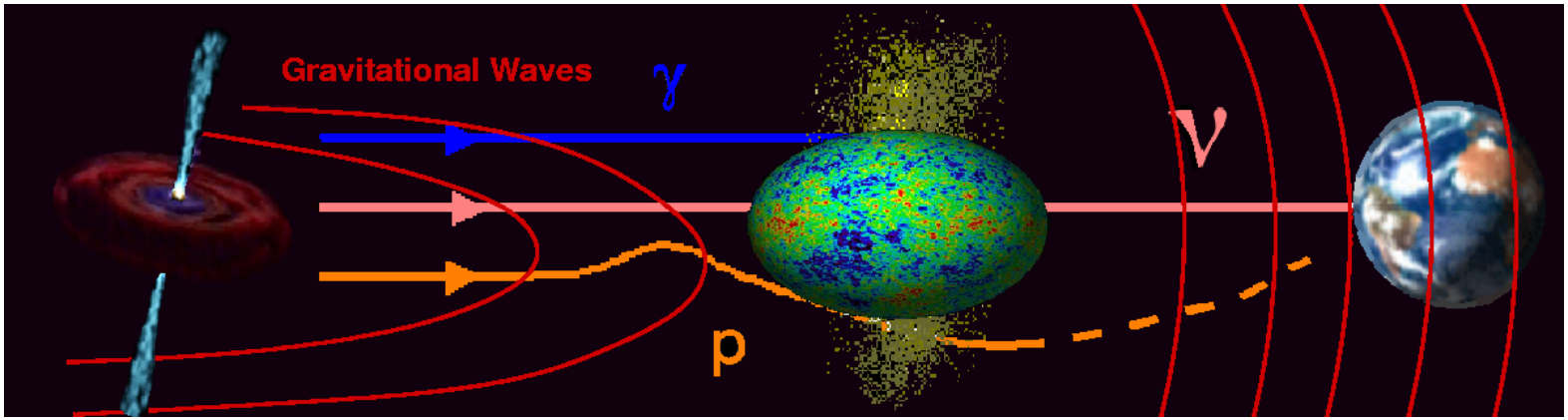
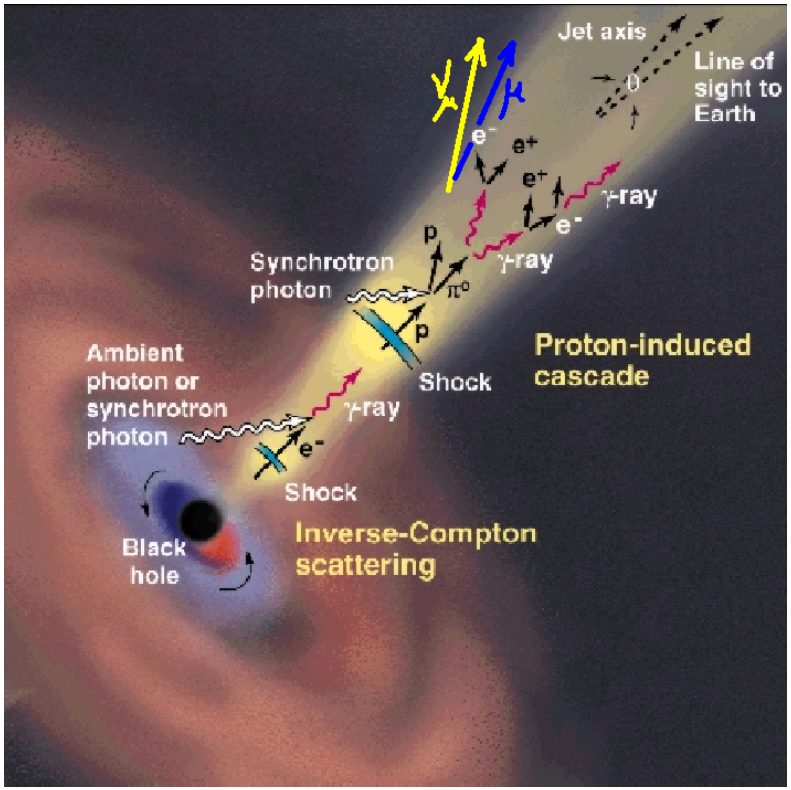


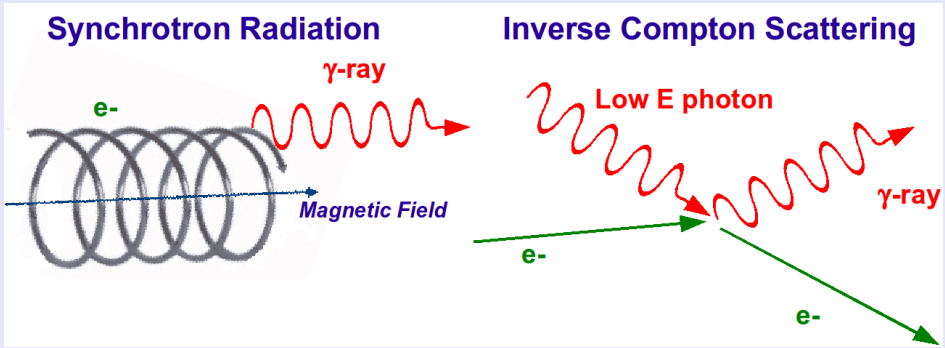
MicroQuasars SGRs — **Galactic**

AGNs GRBs — **ExtraGalactic**

The Cosmic-Ray Connection



Leptonic Production of HE γ :

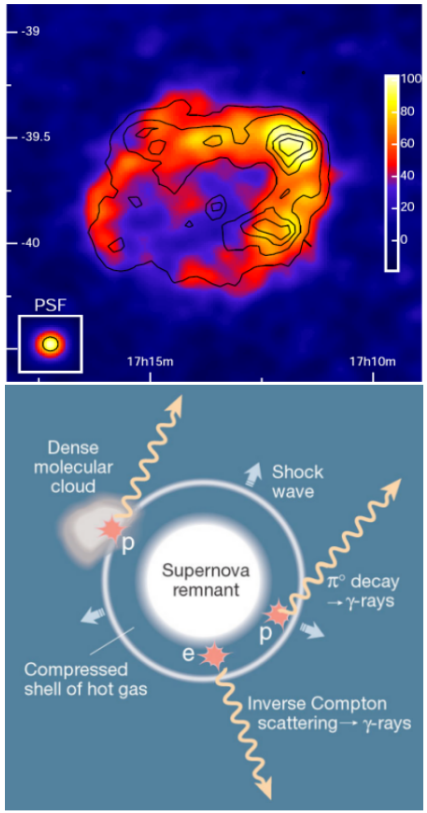


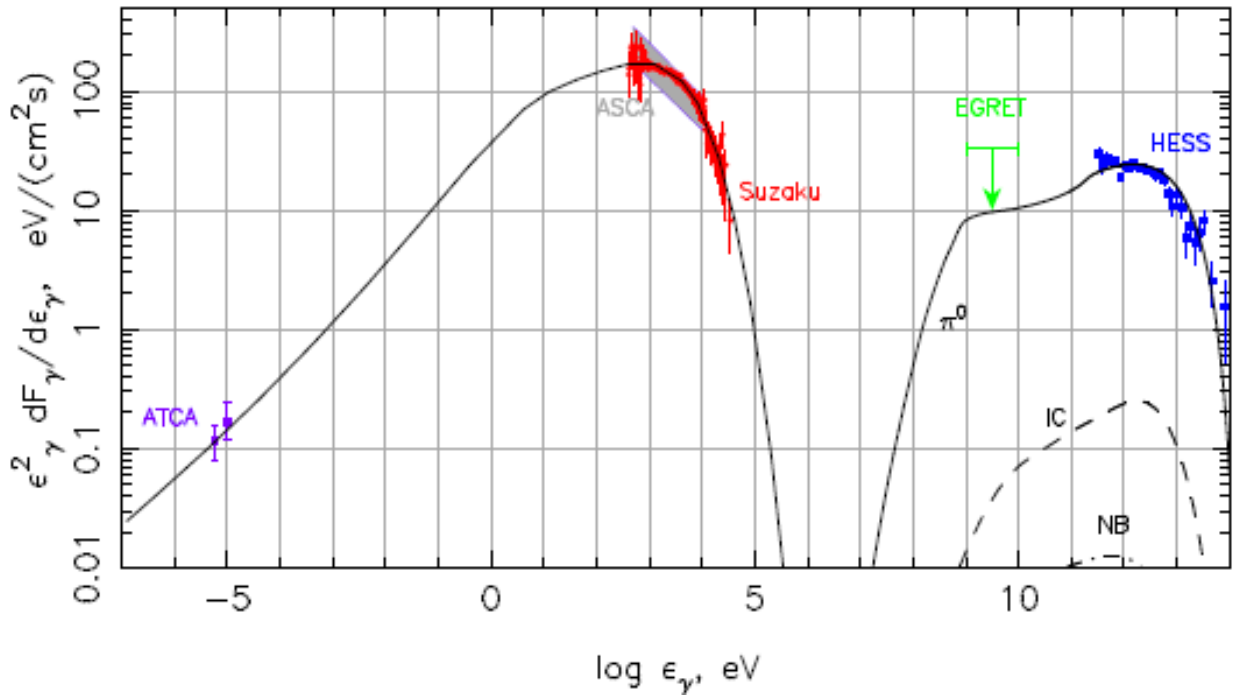
Hadronic Production of HE γ/CRs :

$$p/A + p/\gamma \longrightarrow \begin{array}{cc} \pi^0 & \pi^{\pm} \\ \downarrow & \downarrow \\ \gamma\gamma & \mu\ \nu_\mu \\ & \downarrow \\ & \nu_\mu \nu_e e \end{array}$$

Neutrinos are the **smoking gun** of hadronic processes

A Hadronic origin for γ emission ?



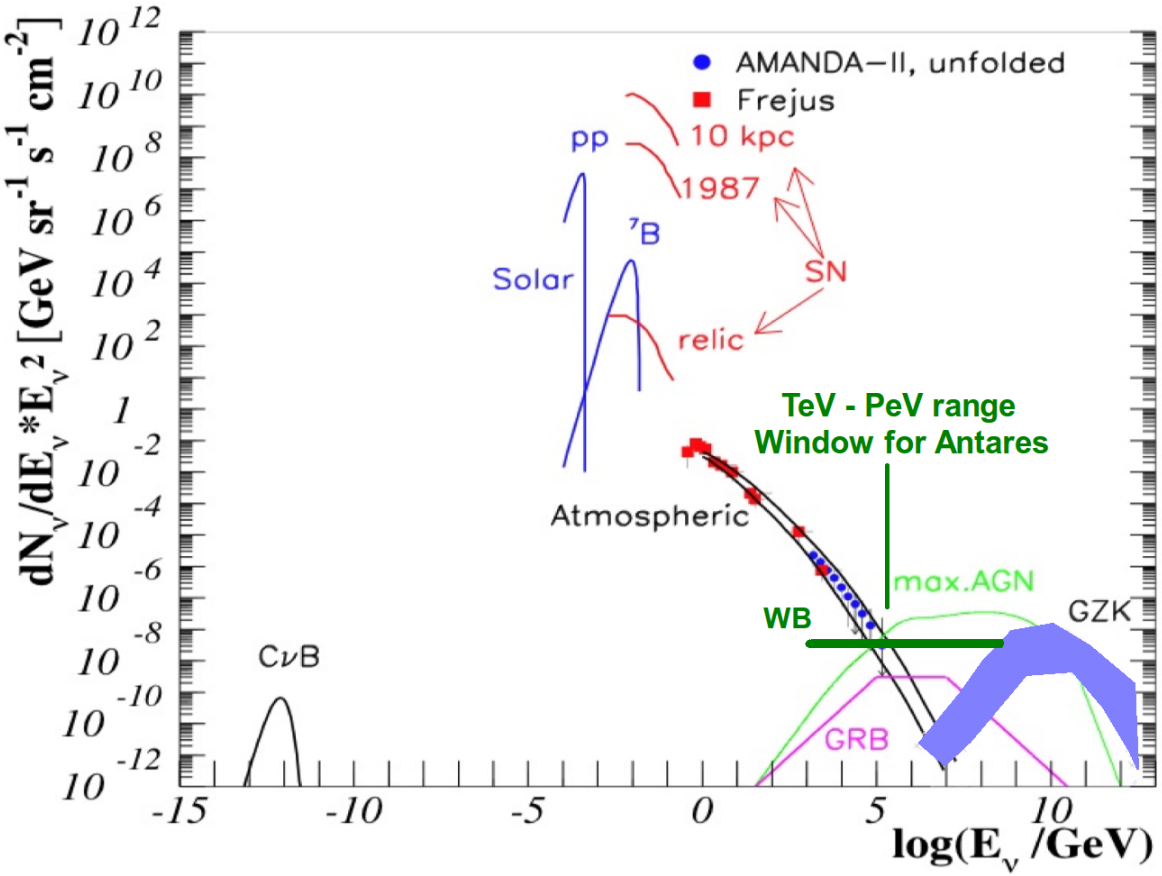


The case of RXJ 1713-3946

- Purely leptonic models not satisfactory
- Proton acceleration + beam dump on nearby molecular clouds ?

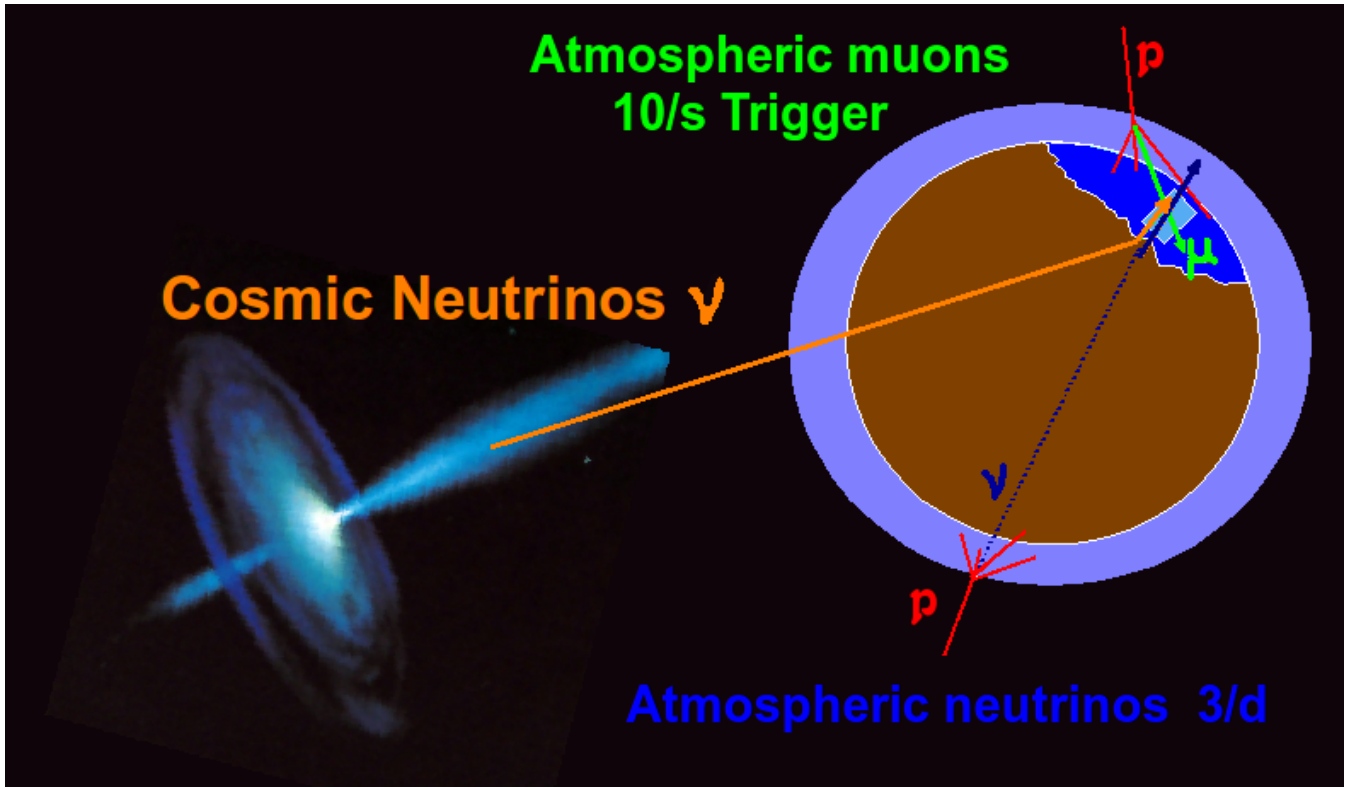
Berezhko & Völk, `arXiv-08100988v2`

Neutrino Fluxes - Detection Rates



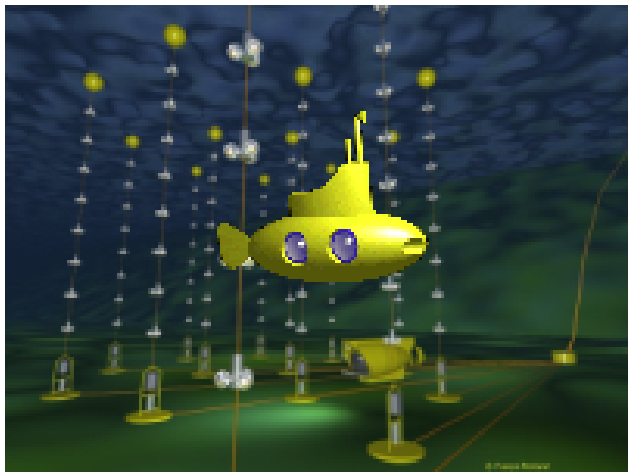
- Waxman-Bahcall Reference Flux $\Rightarrow \epsilon_\nu^2 \Phi_\nu \lesssim 4.5 \times 10^{-8}$ GeV/cm^2/s/sr
  Waxman & Bahcall, Phys. Rev. D 59 (1998) 023002
- $N_\mu(\epsilon_\nu = 100\,TeV) \approx 70\ A_{\rm eff} \times T_{\rm obs}[km^2 yr] \Rightarrow A_{\rm eff} \sim$ km^2 for detection

Detection of Cosmic TeV Neutrinos

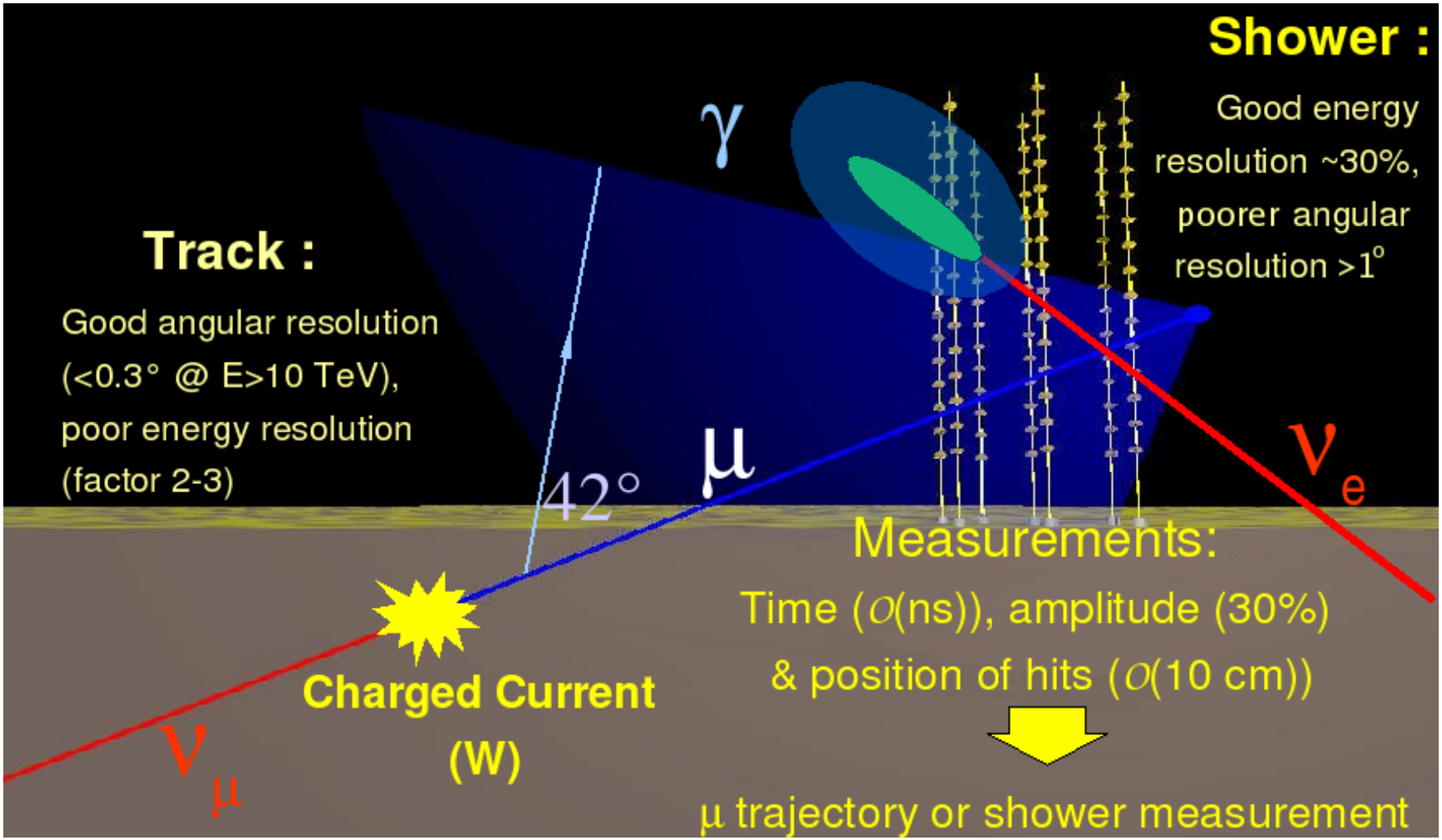


Antares :

A Quick Presentation

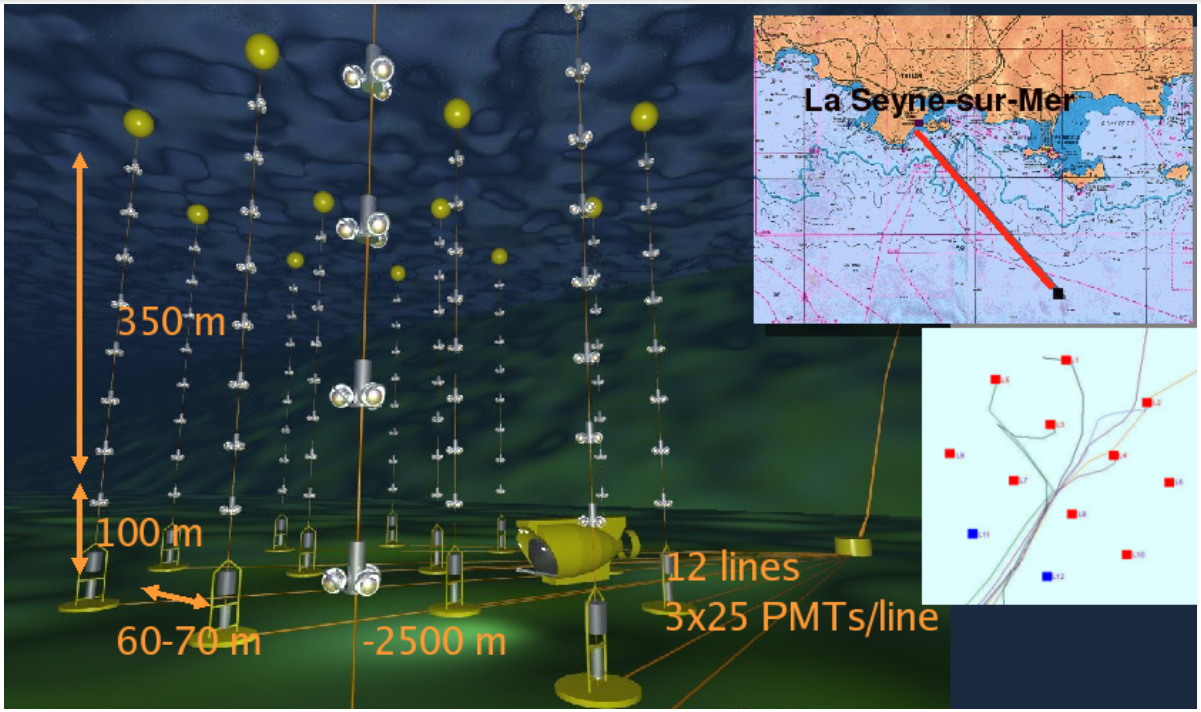


Detection Principles



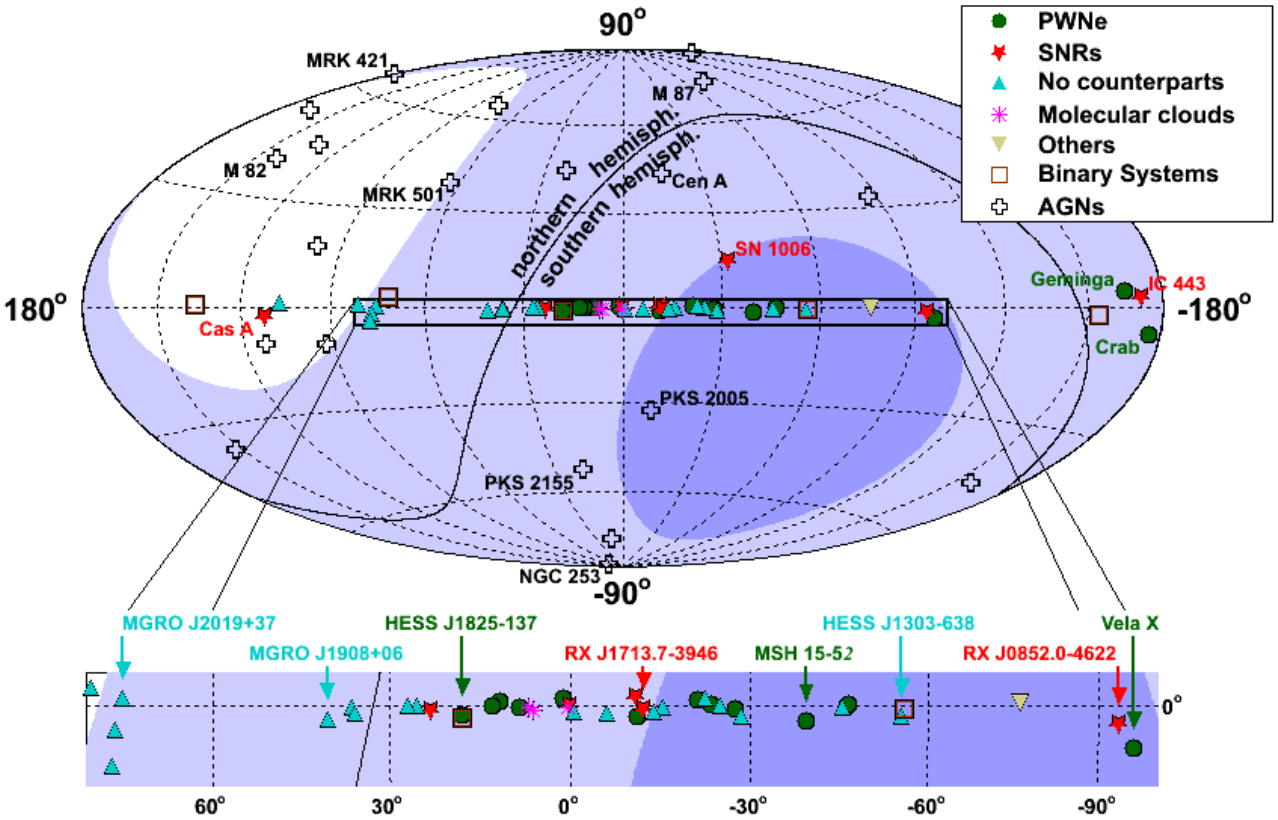
Antares Layout

Astronomy with a **N**eutrino **T**elescope
and **A**byss environmental **RES**earch



- March 2006 : Line 1 $\longrightarrow$ September 2006 : Line 2
- January 2007 : Lines 3-5 $\longrightarrow$ 10 Lines in December 2007
- Detector completed end of May 2008 (12 Lines)

HESS Sources and *Antares*



Kappes et al. Astrophys. J. 656 (2007) 870-896

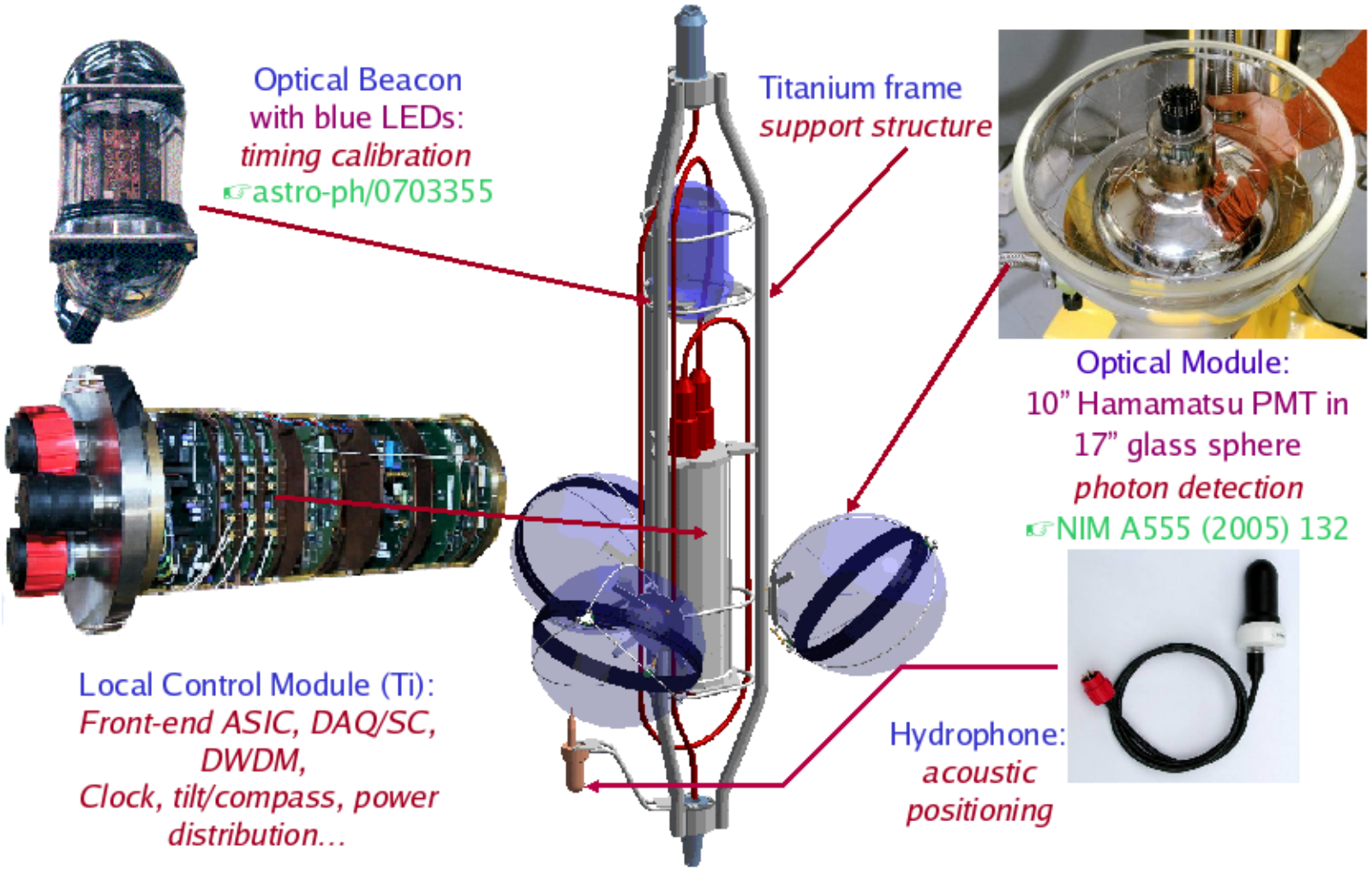
- Complementarity with IceCube
- Visibility of HESS Sources
- Water as detection medium :

⇒ Long scattering length

- Logistics :

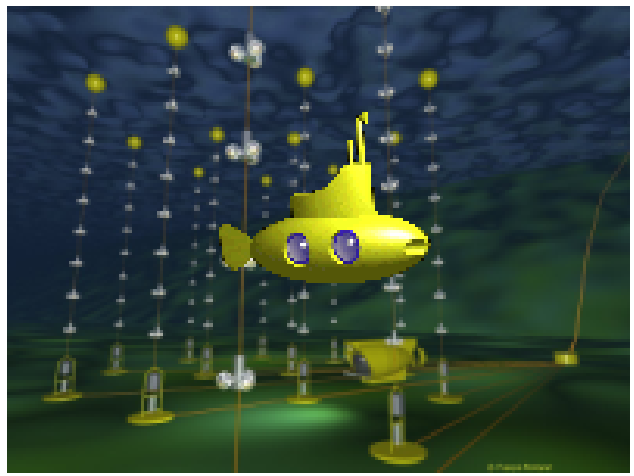
⇒ Recovery/Repair

Antares basic element : a storey

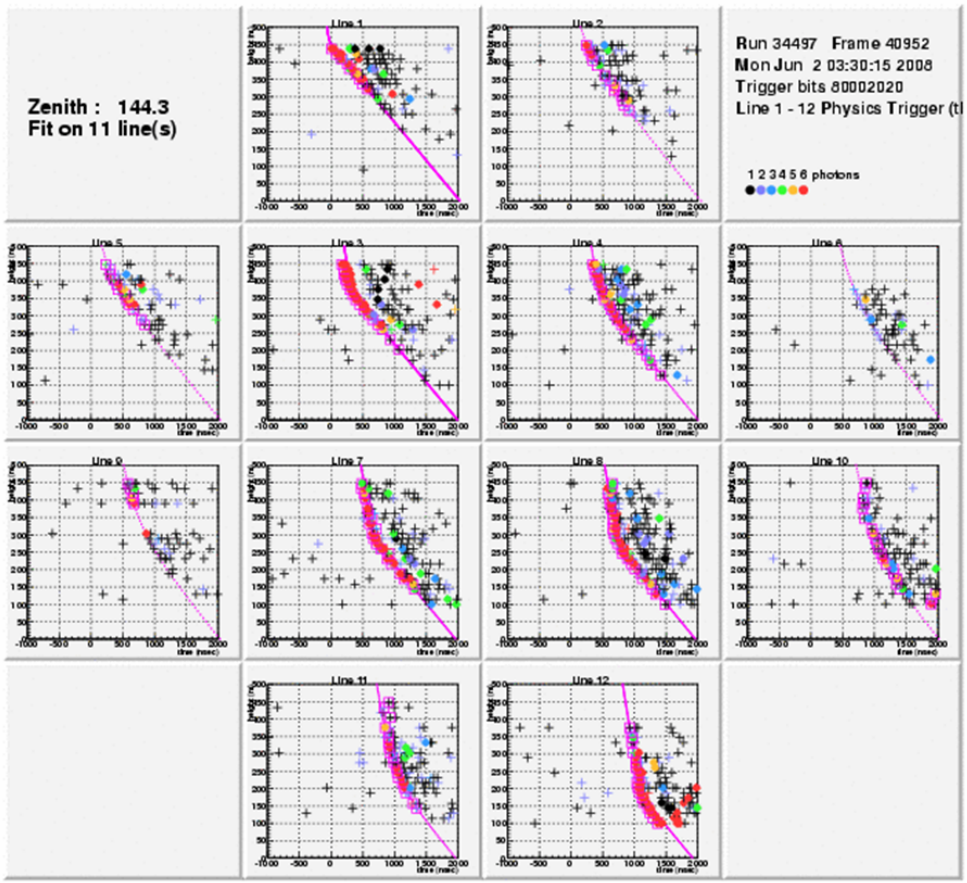


Antares :

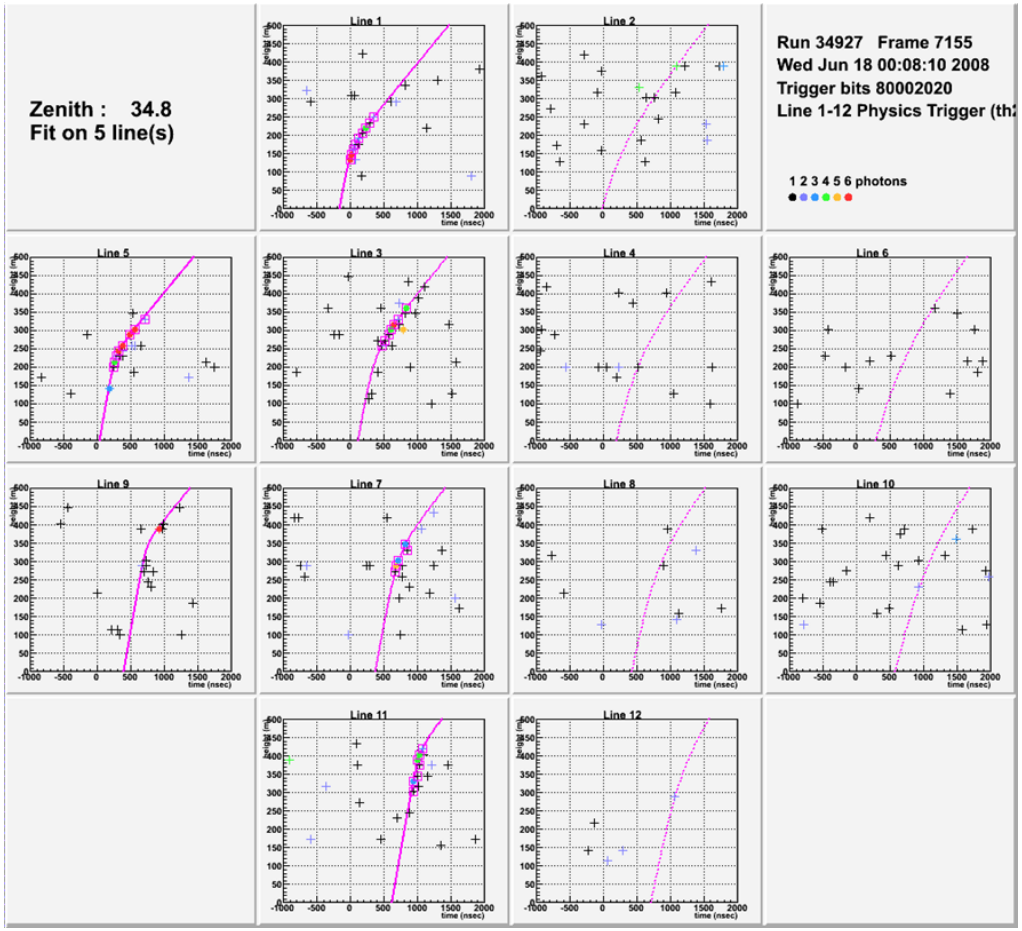
Selected Results

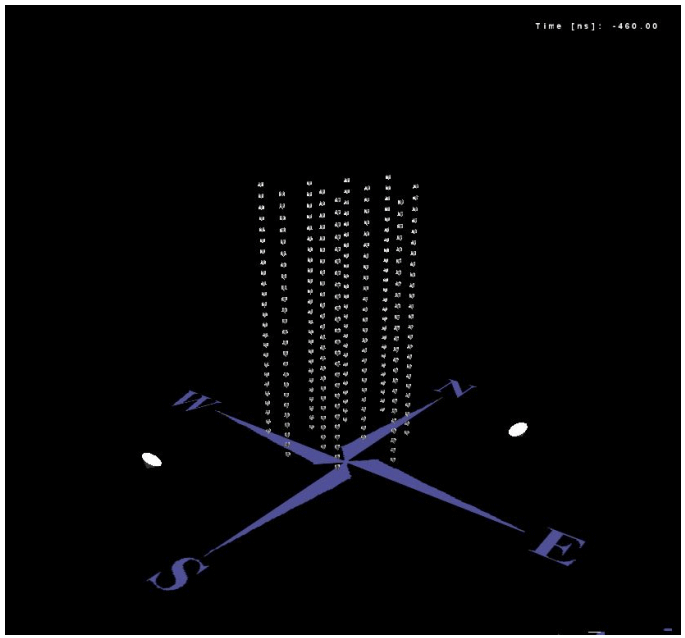


Atmospheric μ (downward) event

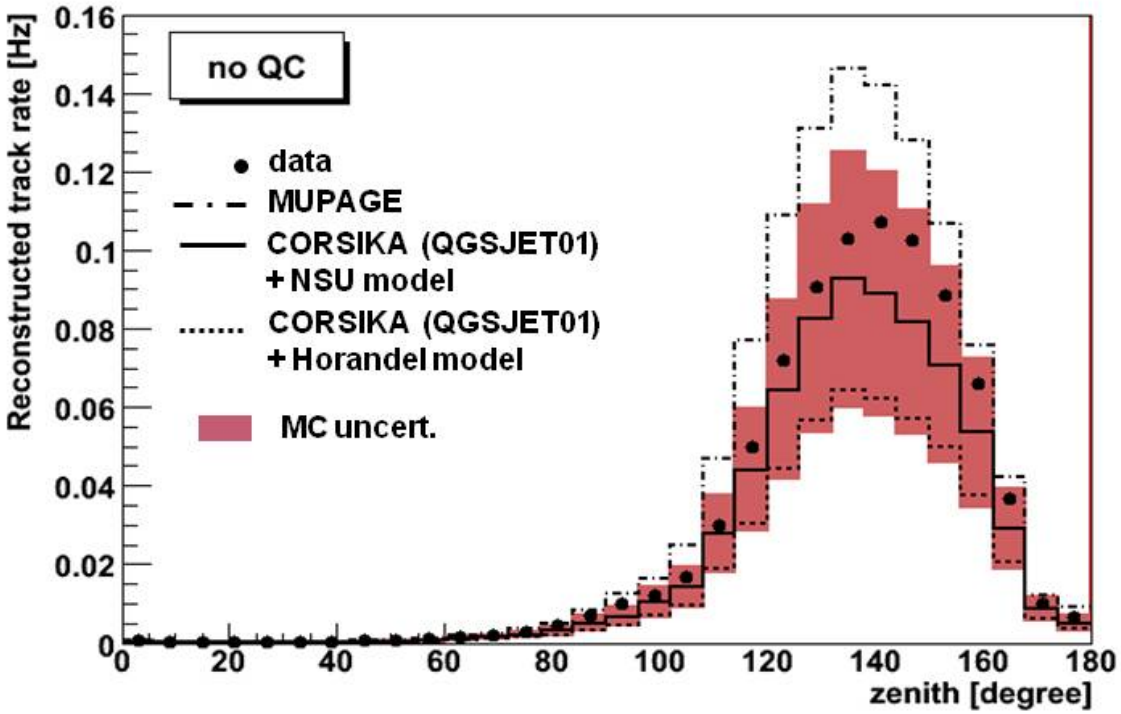


Atmospheric ν (upward) event





Atmospheric muons flux



2007/2008 data :

- Trigger Rate $\sim$ 10 Hz
- Good Agreement Data/MC
- MC Uncertainties

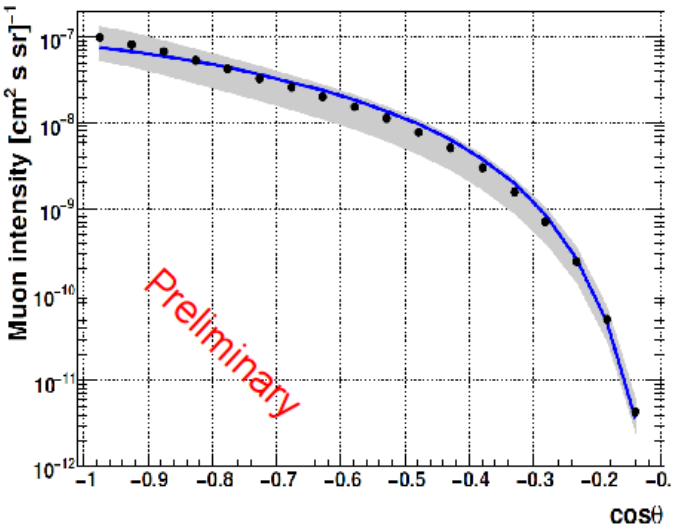
$\Rightarrow$ OM response

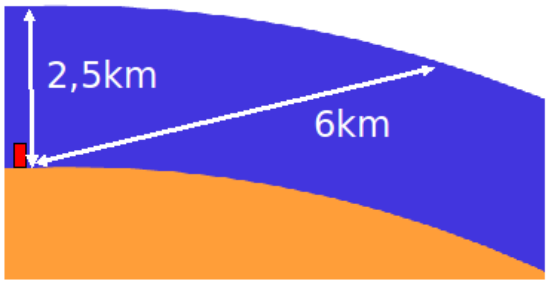
$\Rightarrow$ Absorption in water

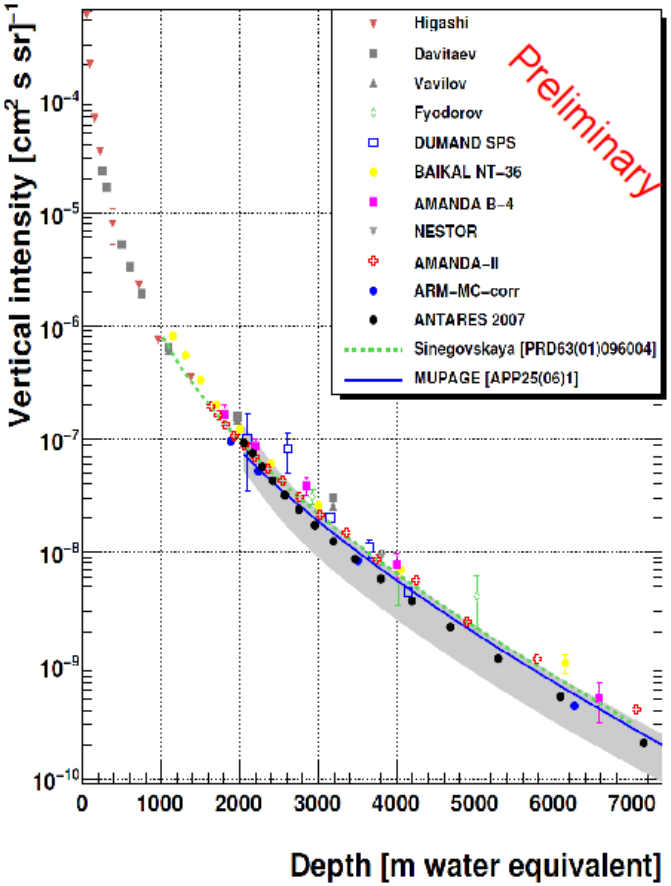
Antares, **to be published in AstroPart. Phys.**

Atmospheric muons flux

- Dependence in θ translated in Depth-Intensity







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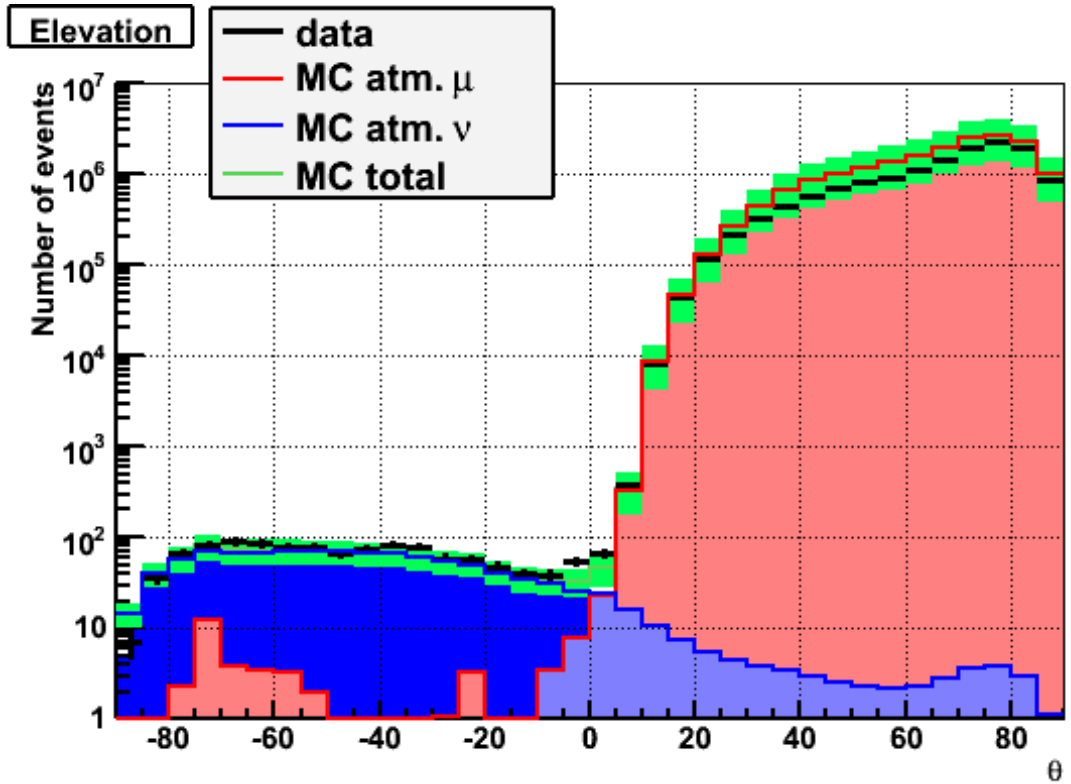
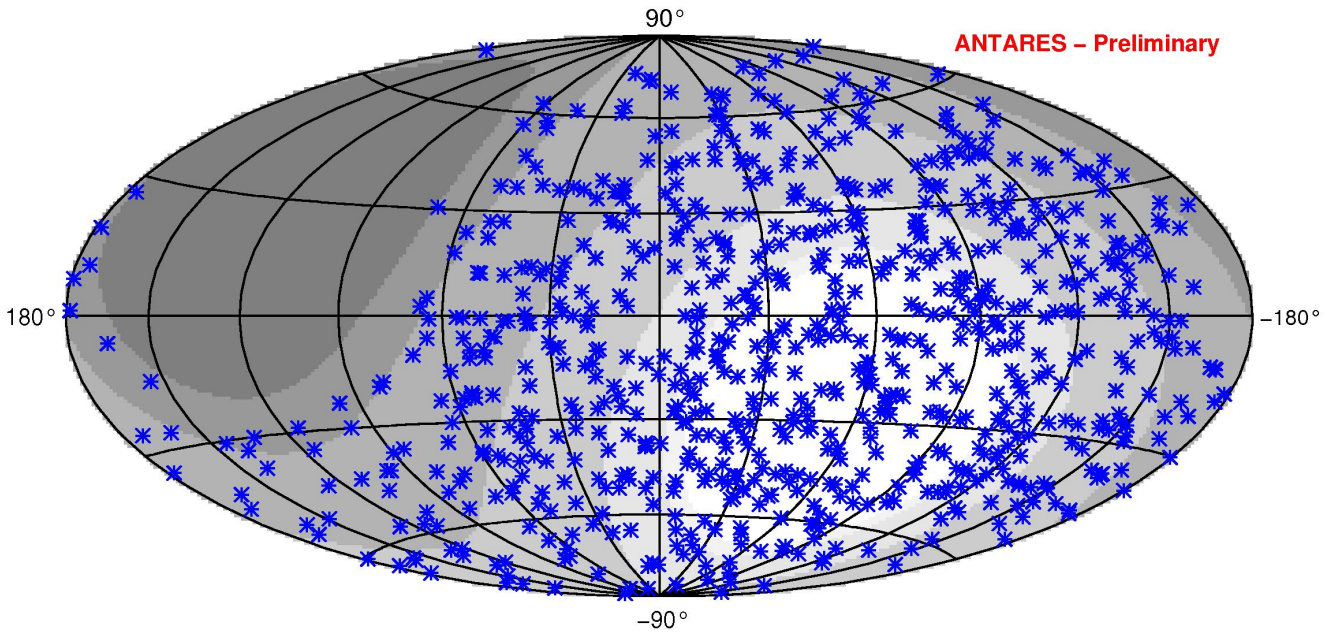
Cosmic Neutrinos ?



2007/2008 data :

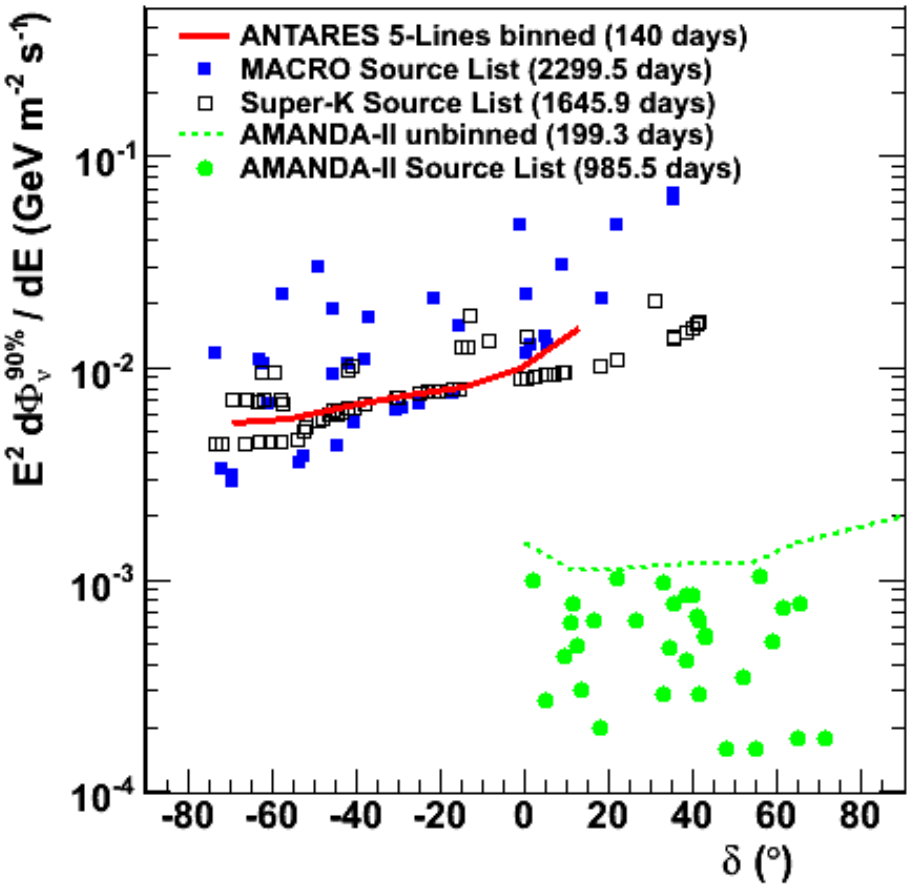
- 5 Lines in 2007, 9-12 Lines in 2008
- 341 days of detector lifetime
- 1062 upward going events in Data
  - $\Rightarrow$ MC : 916 Atm. ν
  - $\Rightarrow$ MC : 40 misreconstructed Atm. μ

Cosmic Neutrinos ?



- 2007/2008 data : **Ongoing Analysis**

Cosmic Neutrinos ?



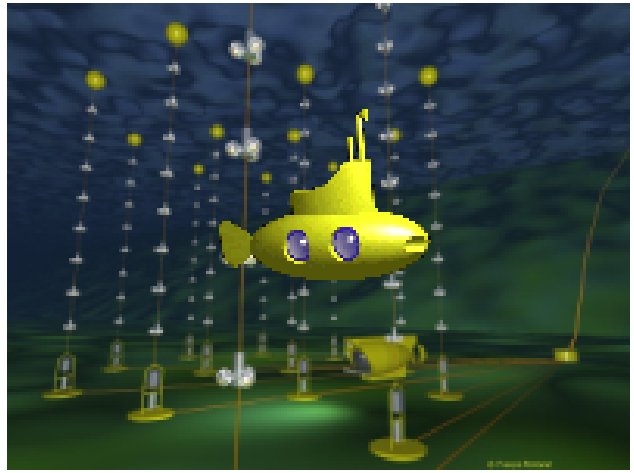
Search for Point-Like Sources with 5 Lines

- Expected Sensitivity for 5 Lines, competitive with existing limits
- Effective livetime of only 140 days !

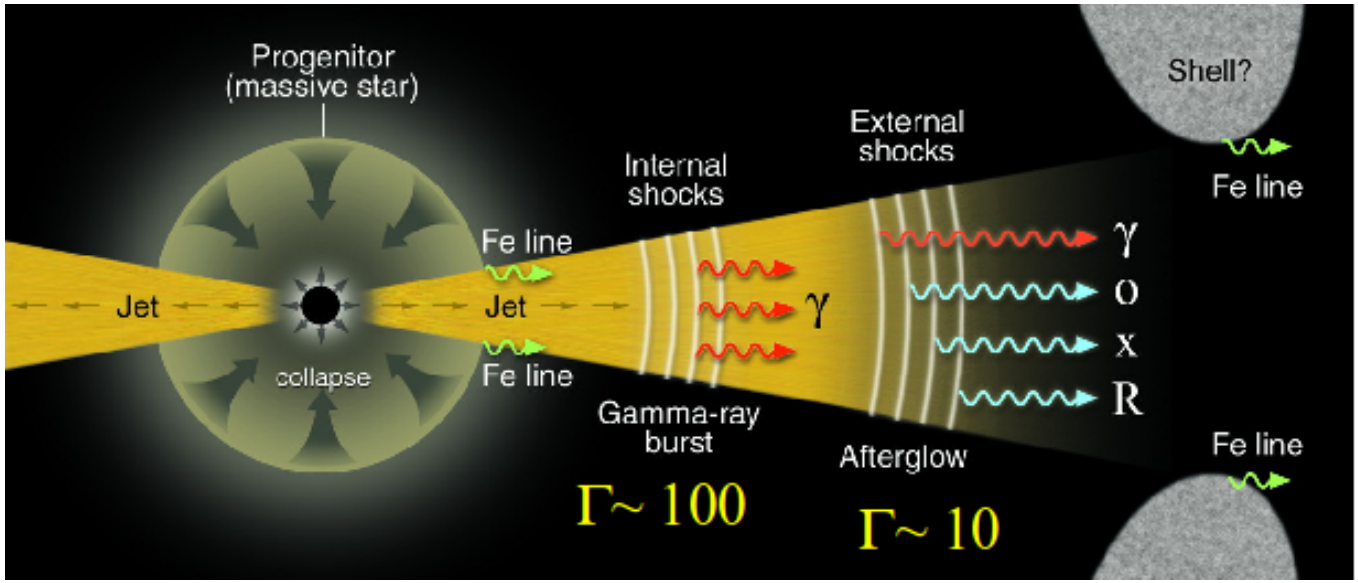
Sensitivies for 5 Lines to be published soon

Antares :

MultiMessenger Studies



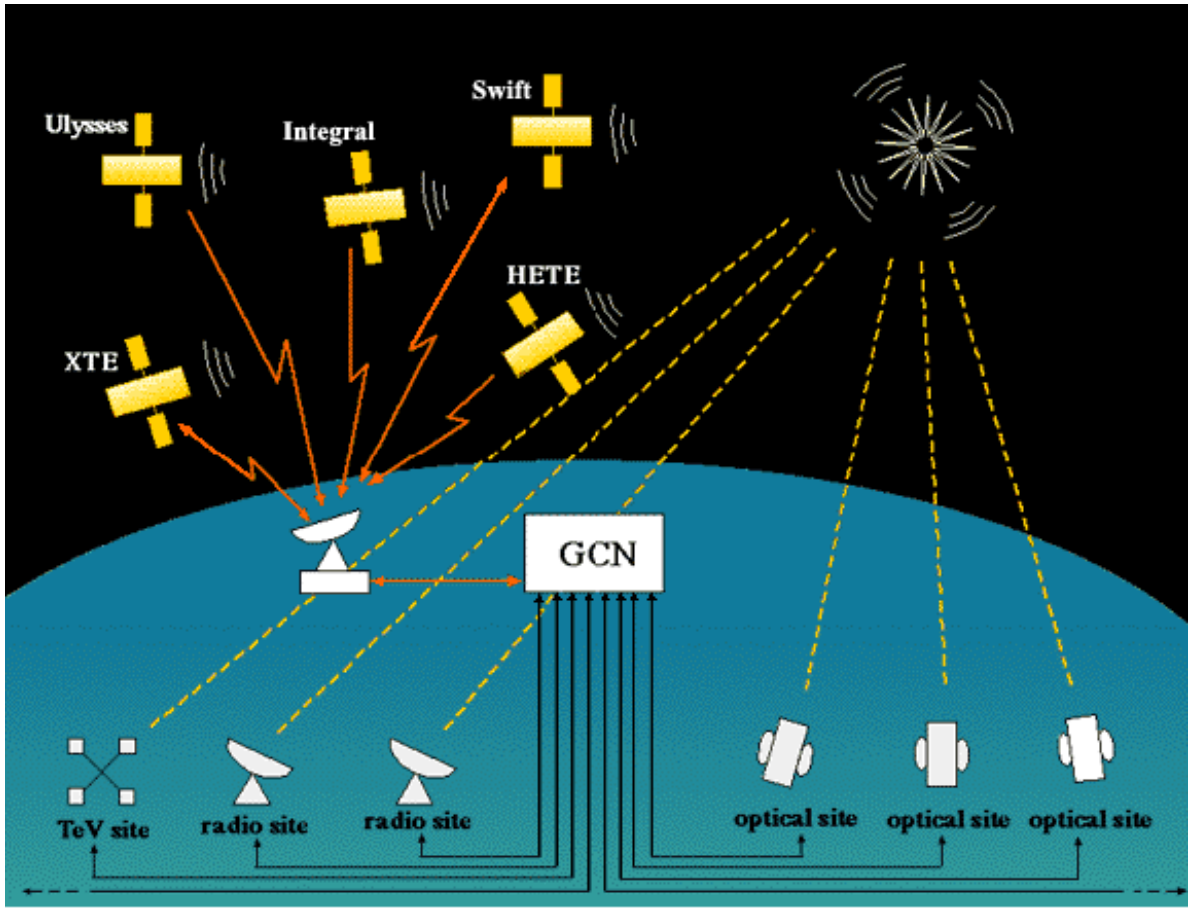
Gamma-Ray Bursts



Search Techniques

- *Triggered* : accurate timing and positional information provided by an external source
- *Rolling* : multiplet of ν events from the same direction and within a short time window/unique HE event

1 - Triggered Search



Antares client of GCN

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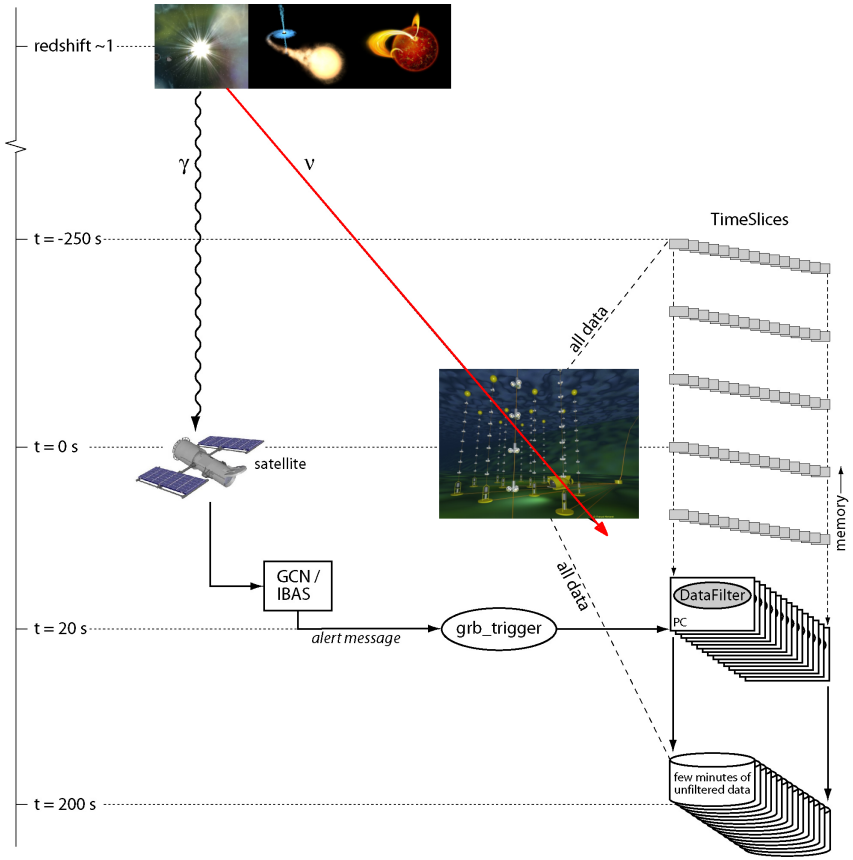

Antares client of GCN

- All data recorded without filtering within ∼1 min of Alert (60 Gb)

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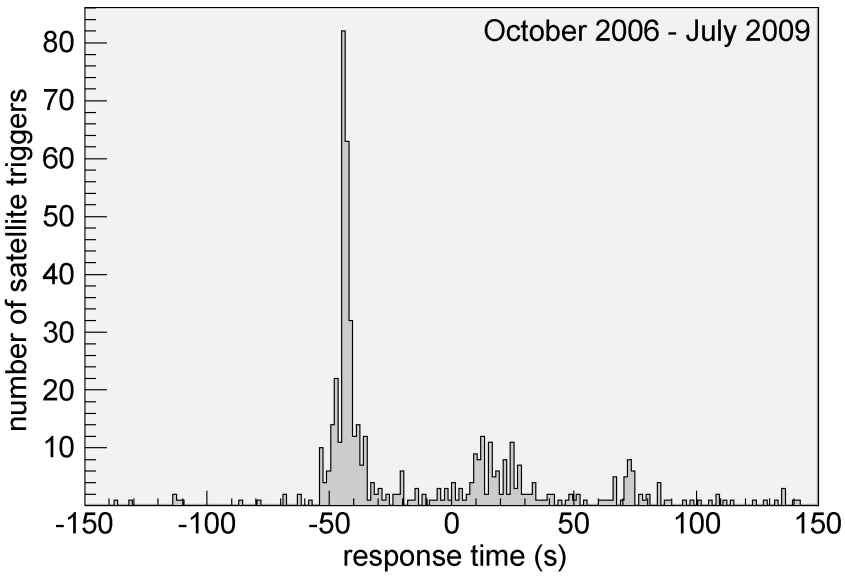

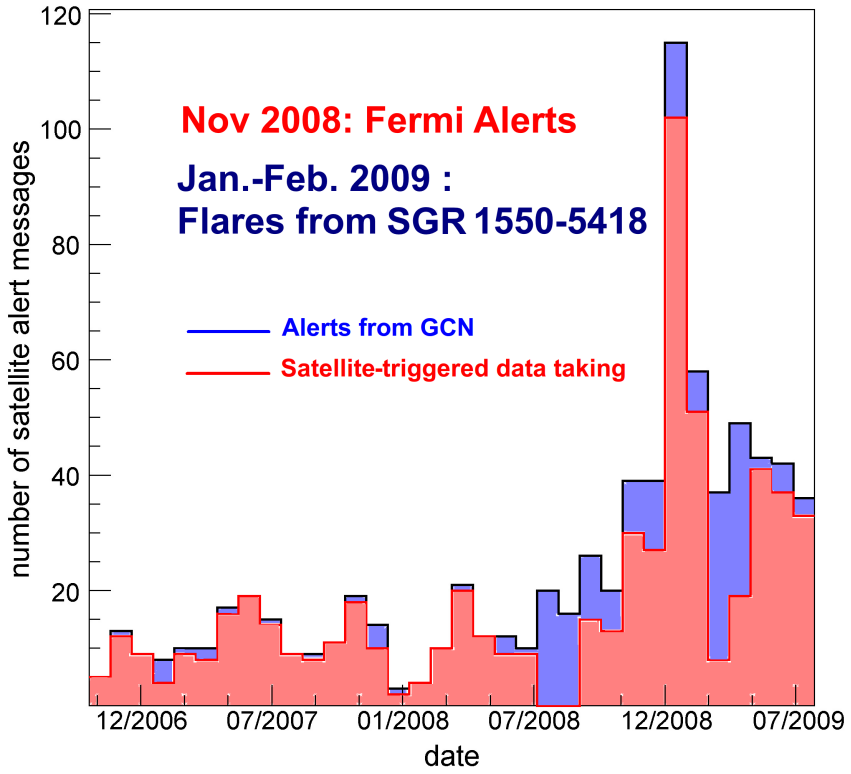

Response time

- $\Delta t_{\mathrm{Response}} = t_{\mathrm{GRB}}^{\mathrm{Satellite}} - t_{\mathrm{earliest\ hit}}^{\mathrm{Antares}}$ can be < 0

  $\Rightarrow$ **allow to recover data prior to the Alert (precursor signal)**

M. Bouwhuis for *Antares*, ICRC09 `arXiv-0908.0818`

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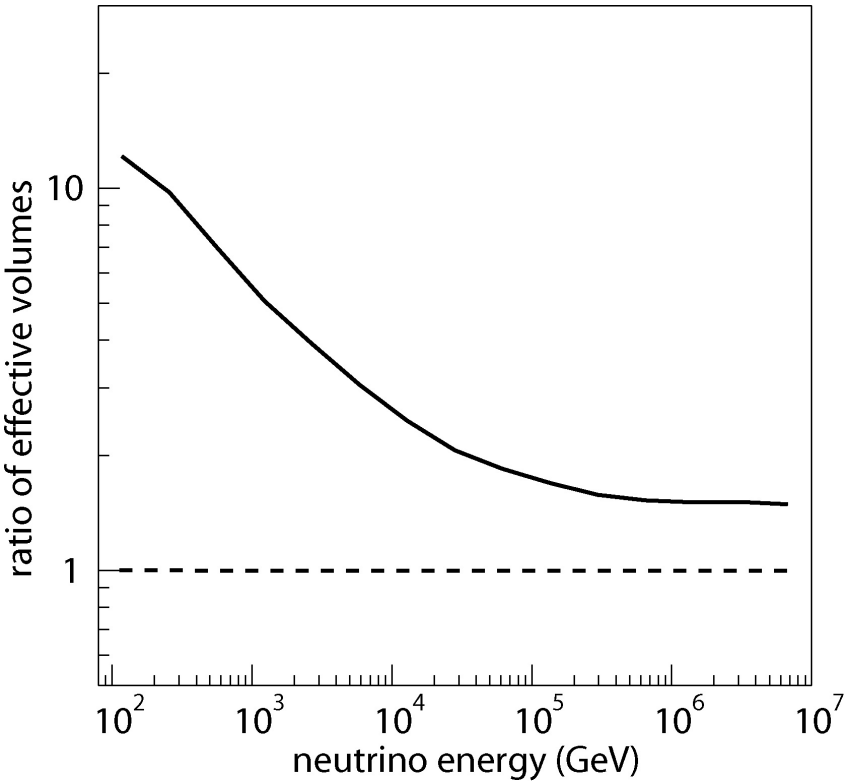


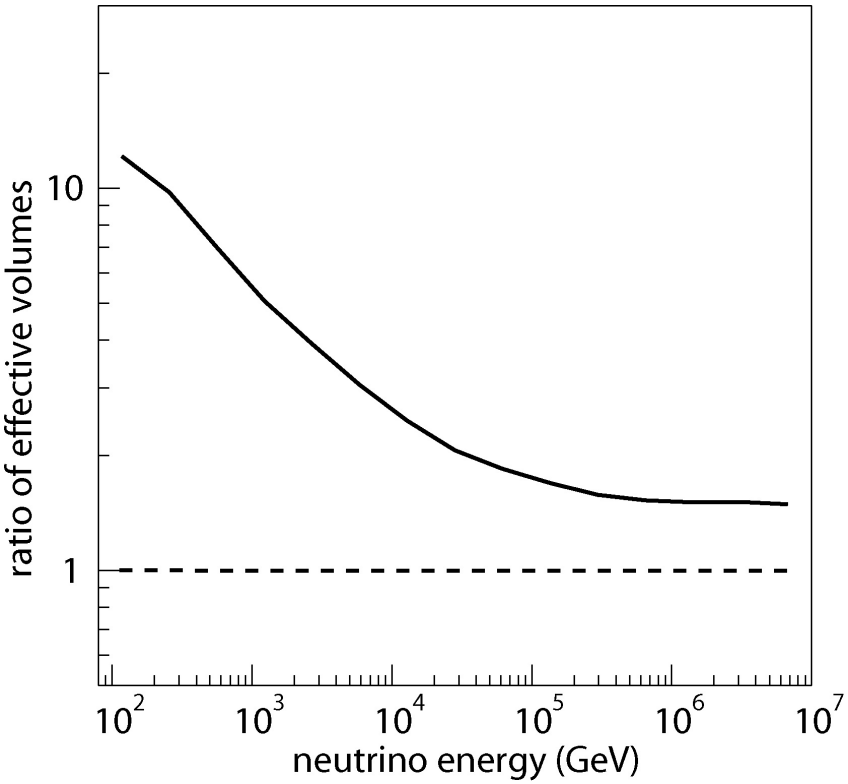
Reconstruction :

- 6 time-position correlated photons required
- Position to constrain track fit

Advantages :

- Nature and the location of the source is known
- Very low background rate
- Low energy threshold

1 - Triggered Search



Reconstruction :

- 6 time-position correlated photons required
- Position to constrain track fit

Disadvantages :

- Depends on external sources
- SWIFT (1.4 sr fov) : only $\sim$1/9 GRB is detected
- No external trigger for choked GRBs

2 - Rolling Search

Aim : Select Special ν Events Online

Advantages :

- Large sky coverage
- $\sim$100 % efficient
- No assumption on the nature of the source

Disadvantages :

- Nature of the source is unknown
  - $\Rightarrow$ Follow-up program to confirm detection
    - $\Rightarrow$ Very fast analysis with a good angular resolution

D. Dornic for *Antares*, ICRC09 arXiv-0908.0804

Appropriate to follow the time profile of different transient sources :

- GRB afterglows ($\sim$minutes)
- core-collapse SNe ($\sim$days)

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2 - Rolling Search : TAToO

1 - Multiplet of ν

$$R_2 \approx \left(\frac{\Delta\Omega}{2\pi}\Delta t\right) R_{\rm atm}^2$$

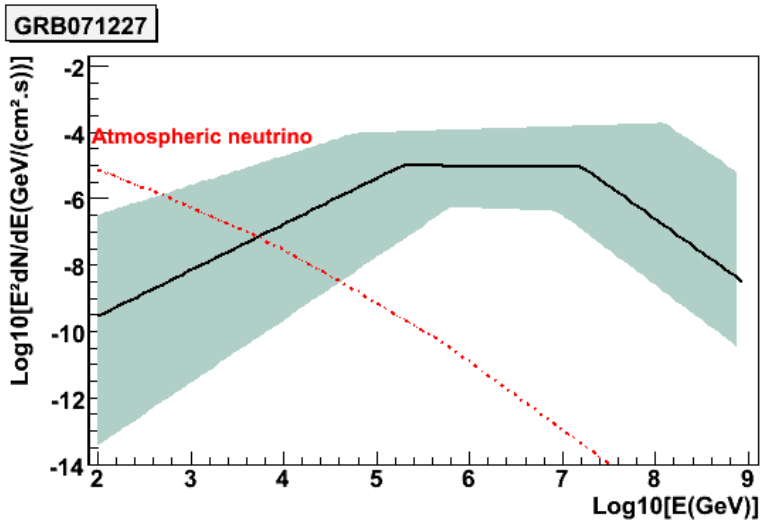
For *Antares*

- $R_{\rm atm} \sim 600\ {\rm yr}^{-1}$
- $\Delta\Omega \approx 2^\circ \times 2^\circ$
- $\Delta t \approx 15$ min

  $\Rightarrow$ $R_2 \approx 0.004/{\rm yr}$

2 - Single HE ν

- Above 50 TeV, bkg negligible



$\Rightarrow$ Cuts defined for $\sim$ 1-2 alerts/month

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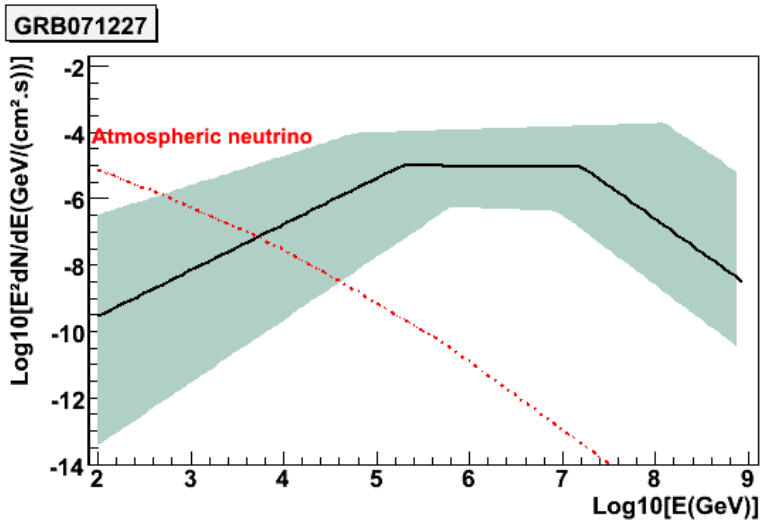

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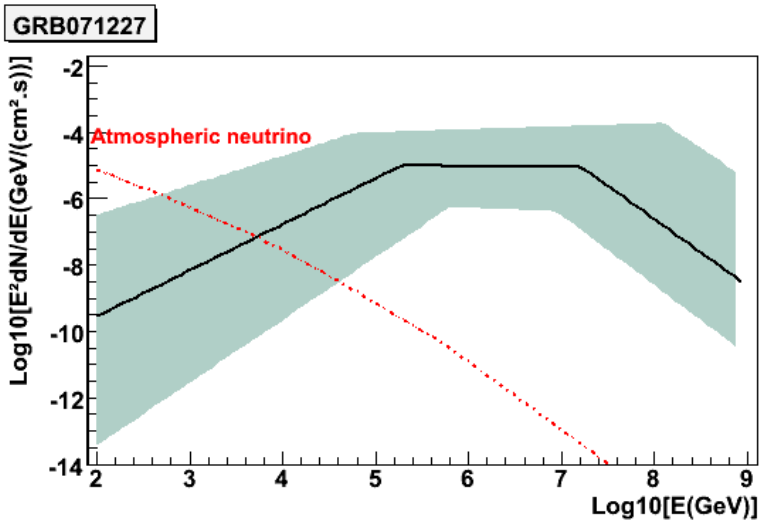

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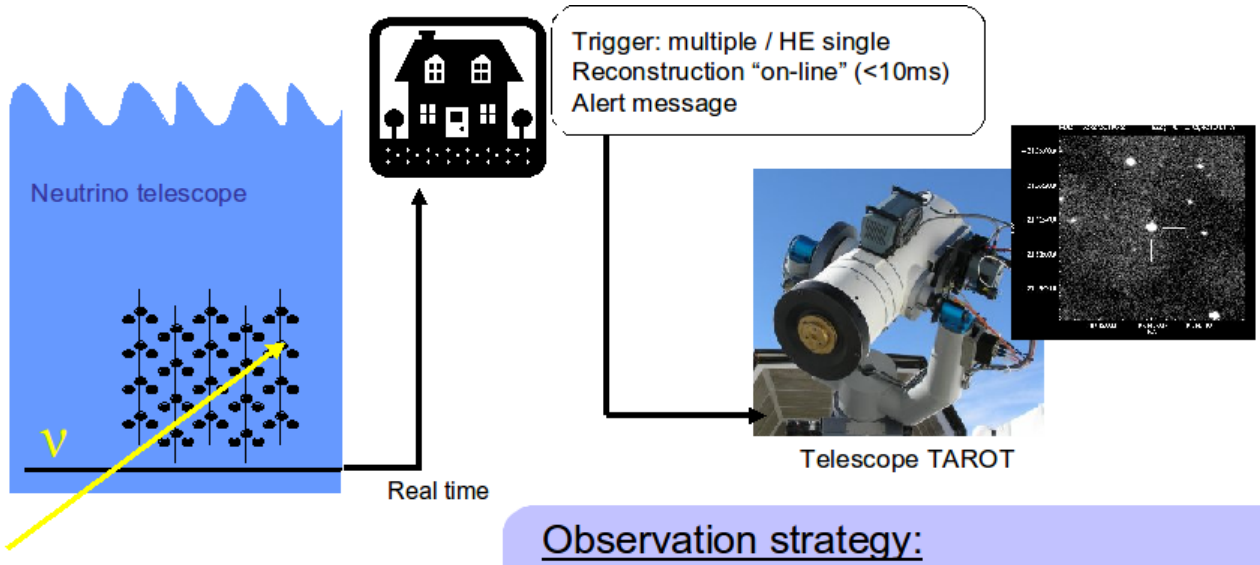
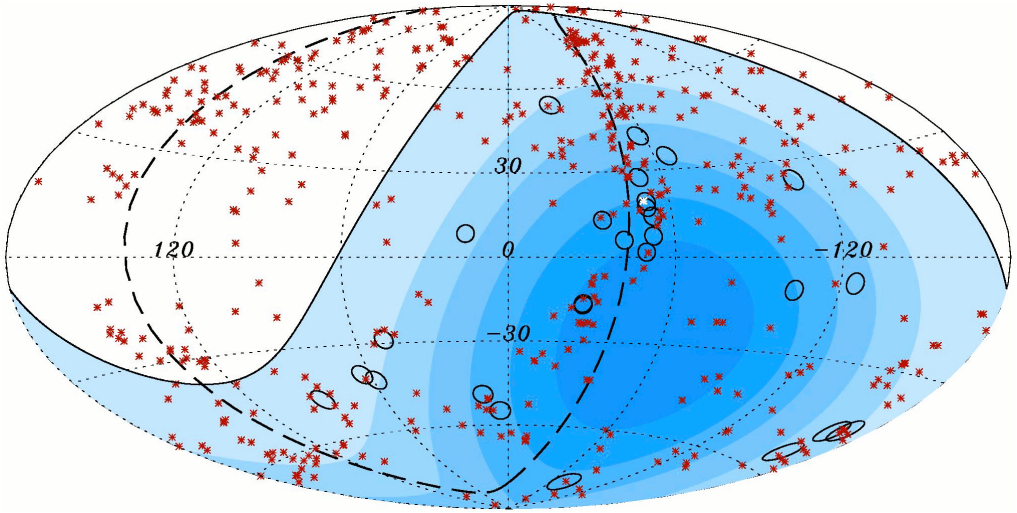


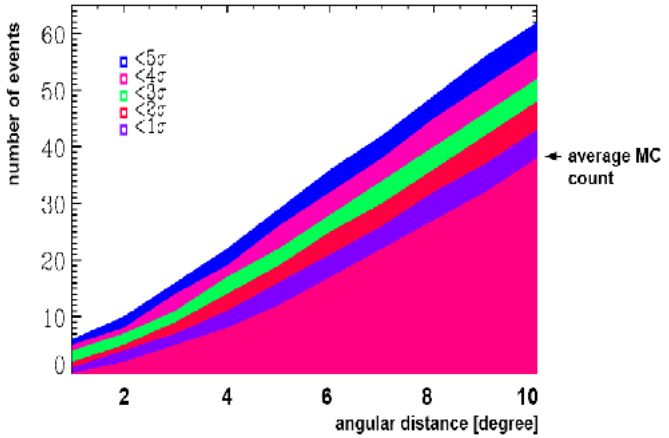
Observation strategy:
Real time (T_0) 6 images of 3 minutes
T0+1 day, +3 days, +9 days and +27 days

Tarot-Antares Target of Opportunity

- Fully operational since Feb. 2009, several alerts sent to TAROT
- Total Latency :
  - ⇒ Reconstruction : 5-10 ms/evt
  - ⇒ Alert Sending : < 1s
  - ⇒ Repositioning : < 10s

Correlations with AUGER UHE CRs





Auger Results

- Correlation of UHE CRs arrival directions with nearby AGNs

Auger Collaboration,

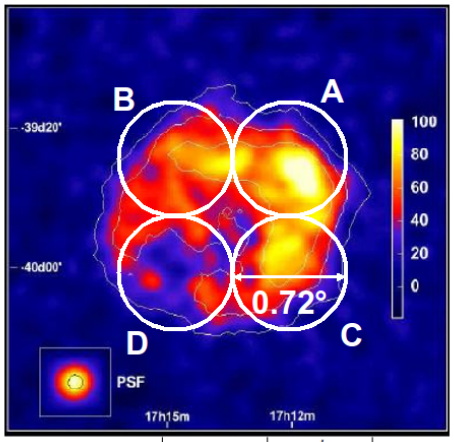
Science 318 (5852) 938 (2007)

Correlations AUGER-*Antares*

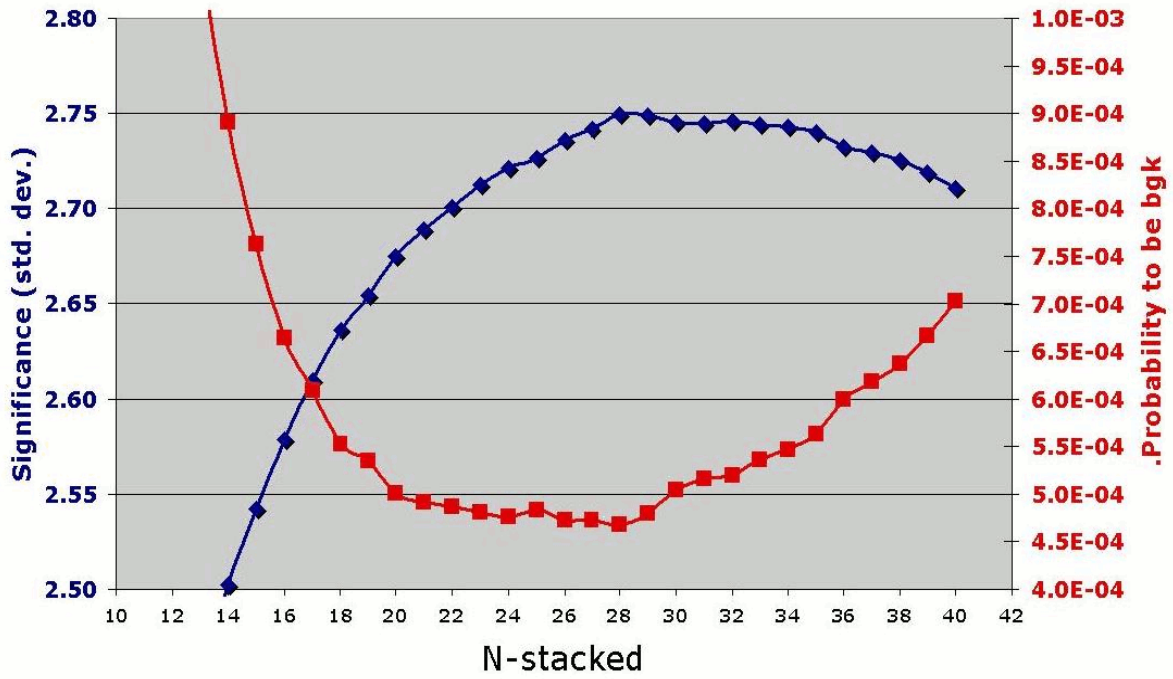
- Deviations from MC expectation (hypotheses on UHECRs composition & propagation)

J. Petrovic, `arXiv-0908.1235`

TeV γ/HESS Sources : Stacking



	n^{on}	n^{bg}	$(S/N)_i$
RX1713 (sub-reg. A)	0,79	0,21	0,79
RX1713 (sub-reg. B)	0,59	0,21	0,66
RX1713 (sub-reg. C)	0,61	0,21	0,67
RX1713 (sub-reg. D)	0,55	0,21	0,63



RXJ 1713.7-3946

- Hadrons ?

Stacking Analysis (Assumption : all Hadronic Sources)

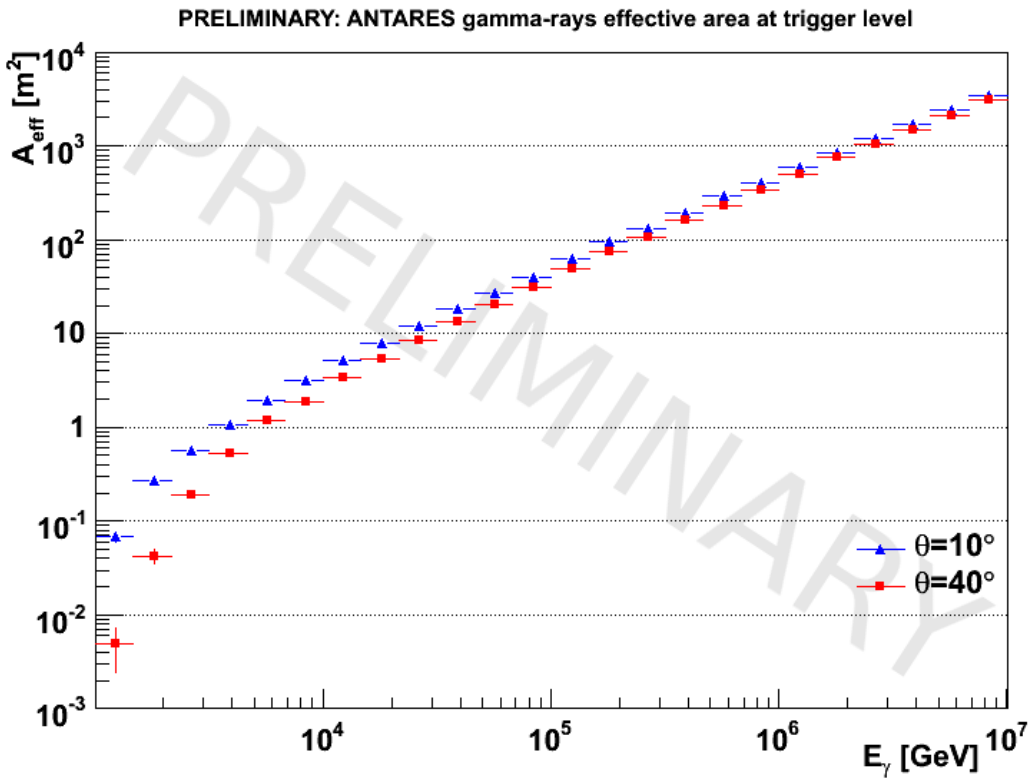
- Expected detectability is poor

TeV γ/HESS Sources : downgoing μ

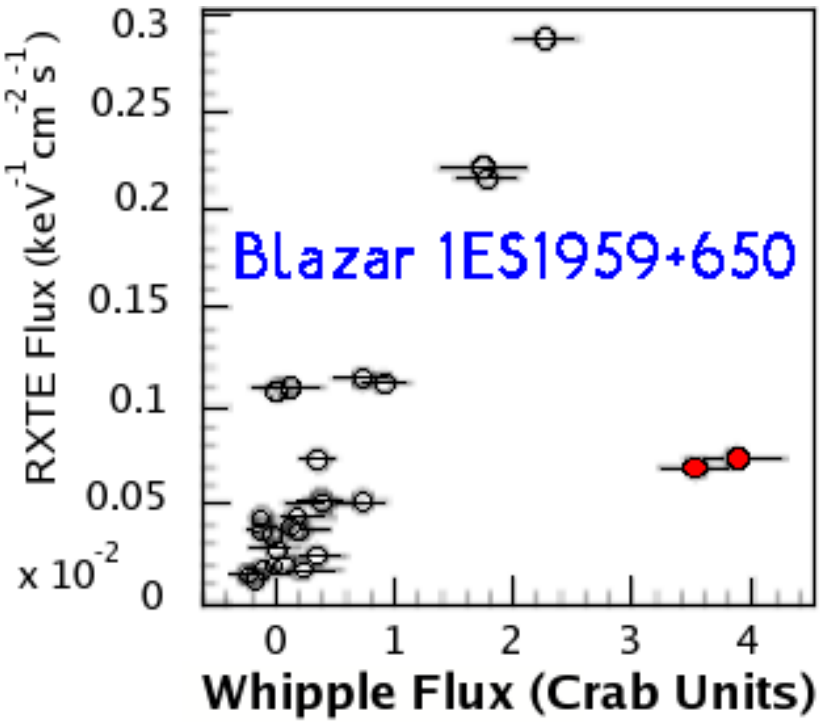
Detection of downgoing μ produced in γ-showers

- Photoproduction : $\pi \longrightarrow \mu\nu$
- Pair production : $\gamma \longrightarrow \mu^+\mu^-$
- Charm decay : $c \longrightarrow s\mu^+\nu_\mu$

G. Guillard for *Antares*, ICRC09 `arXiv-0908.0855`



TeV γ/HESS Sources : the unknown...

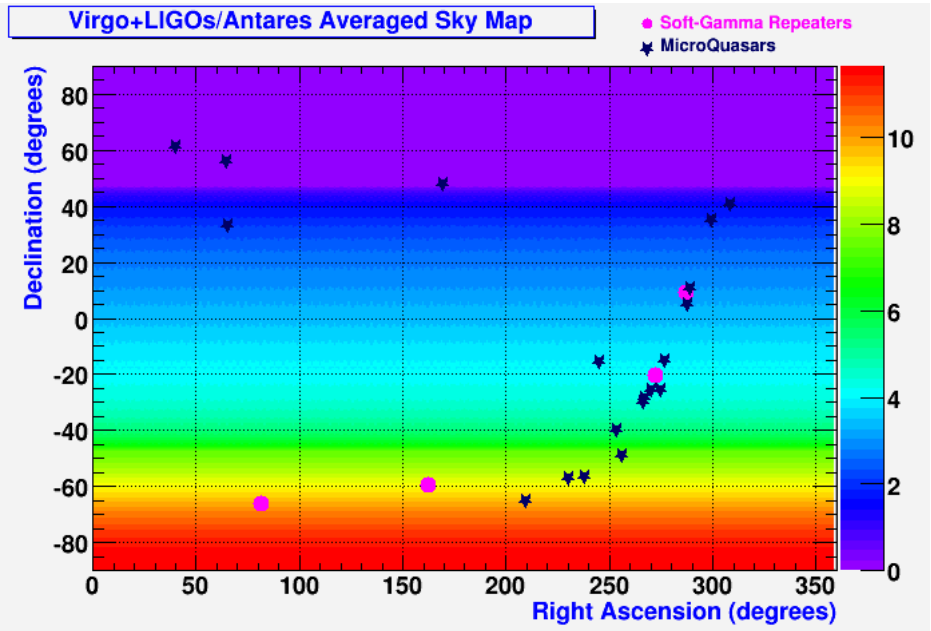


Orphan Flares in Neutrinos still possible !

Antares/Virgo-LIGO Coincidences : GW+HEN Project

- Confirm detection(s)
- Unique information on processes

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ANTARES KM3NeT	5L	10L	12L						KM3NeT	
VIRGO	VSR1		VIRGO+						Advanced VIRGO	
LIGO	LSR1		eLIGO						Advanced LIGO	



Th. P. NIM A 602 (2008) 268-274

Antares/Virgo-LIGO Coincidences : GW+HEN Project

- First proposed in 2008
- MoU *Antares/Virgo-LIGO* signed in 2009
- See **E. Chassande-Mottin**'s talk

Conclusions & Perspectives

Antares taking data since May 2008 with 12 Lines

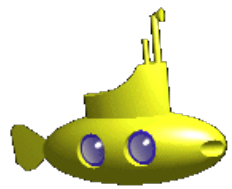
- Atmospheric muons results consistent with other experiments
- 5 Lines results (point-sources) competitive with Amanda-II
- **Potential detection of ν from GC and Galactic HESS Sources**

Antares handles alerts both ways with small latency

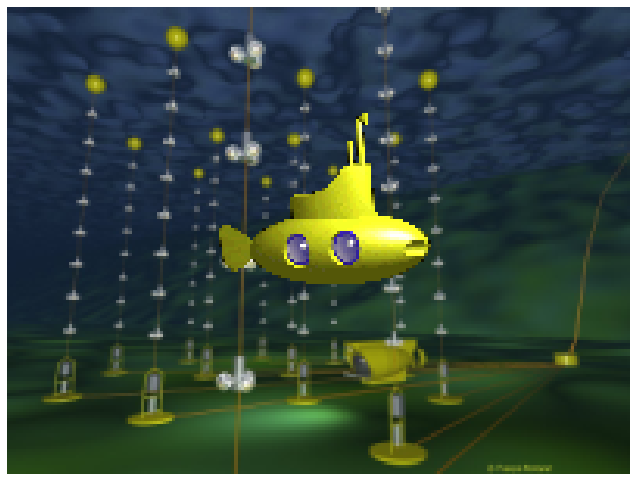
- **In :** External triggers (GCN)
- **Out :** Neutrino follow-up : TAToO (optical)
- Future extensions : X-Ray, γ ?

GWHEN pioneering work

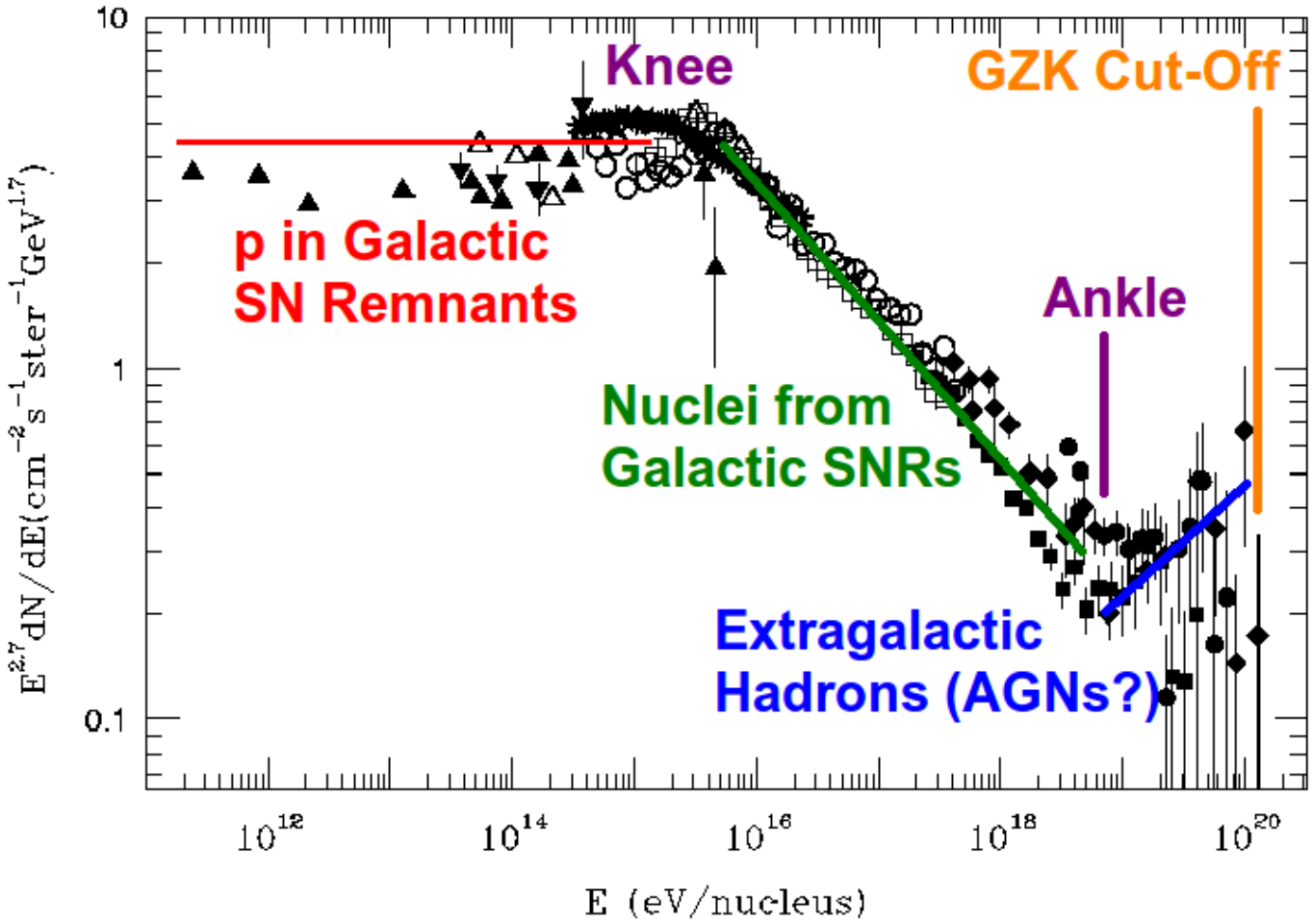
- Coincident detection enhances the significance of an observation
- Unique physical information from a GW+HEN event



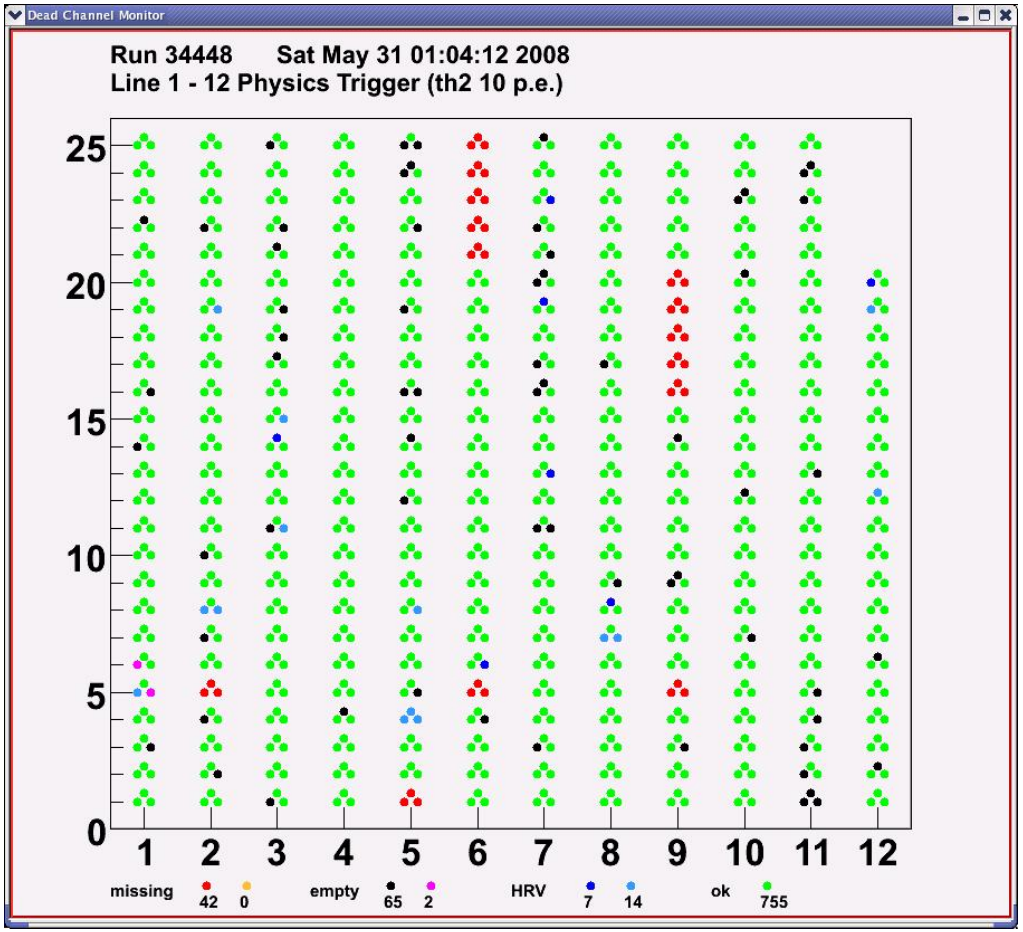
Back-up



The Cosmic-Ray Connection



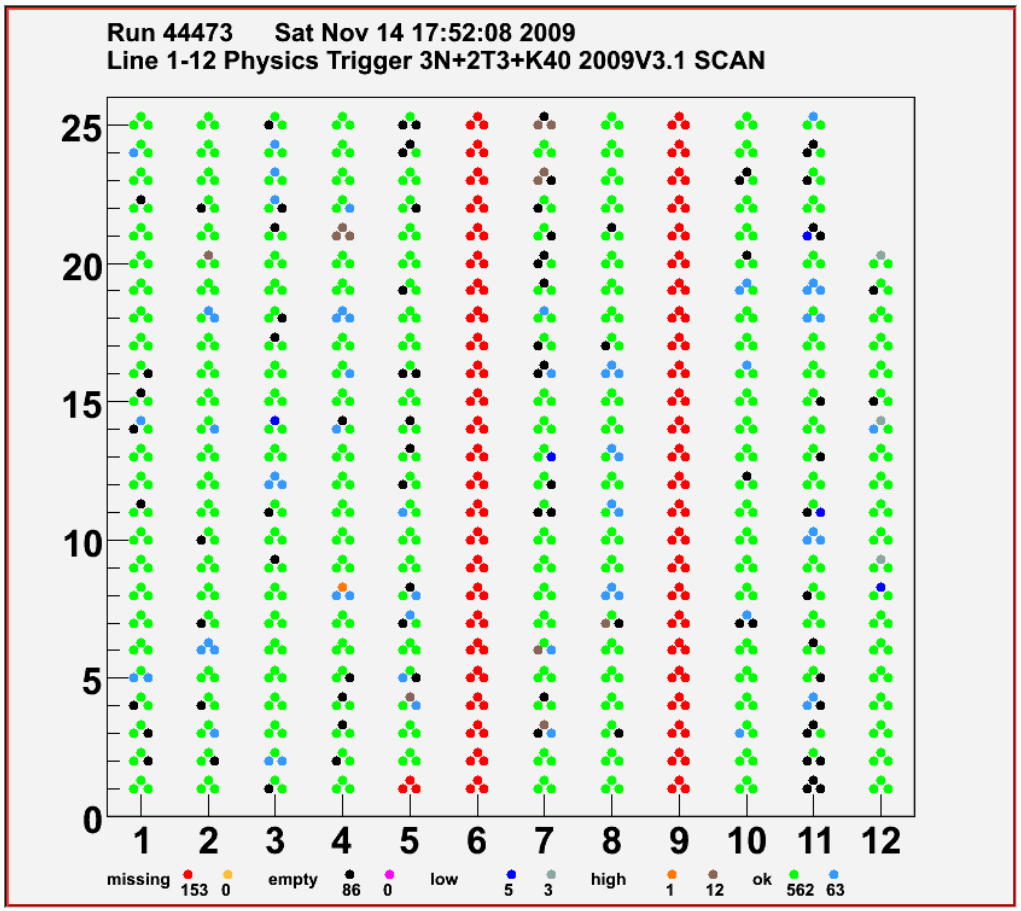
Maintenance of the Telescope



Status June 2008

- 90 % operational

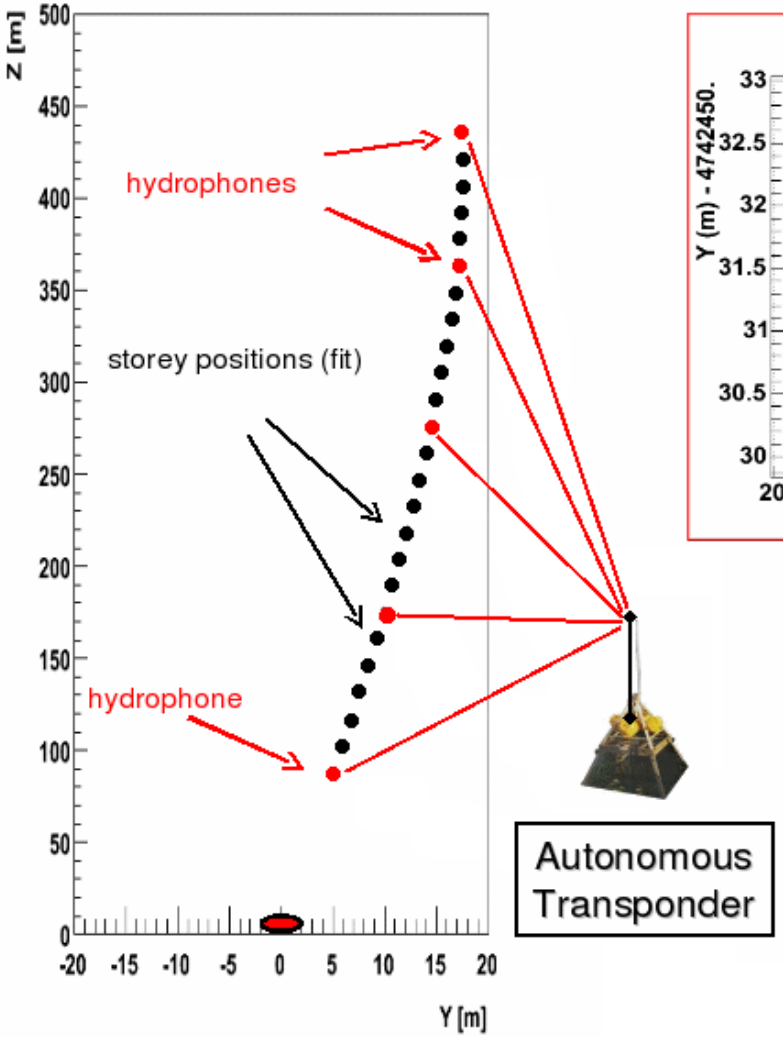
Maintenance of the Telescope

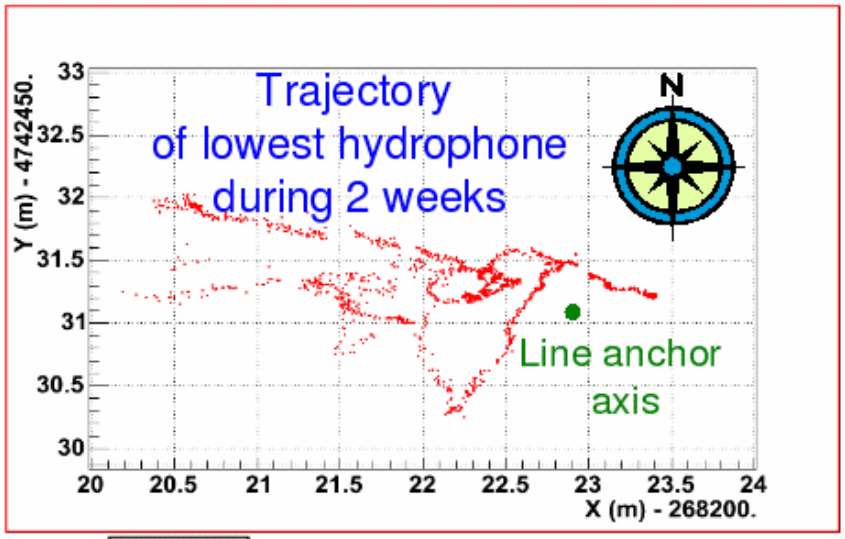


Status Early 2010

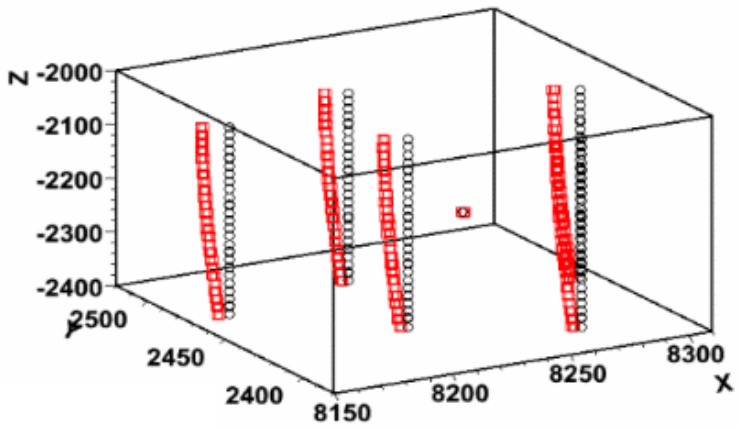
- Line 12
  - recovered
  - repaired
  - redeployed
  - reconnected
- Line 9 : planned
- Line 6 : recovered

Acoustic Triangulation



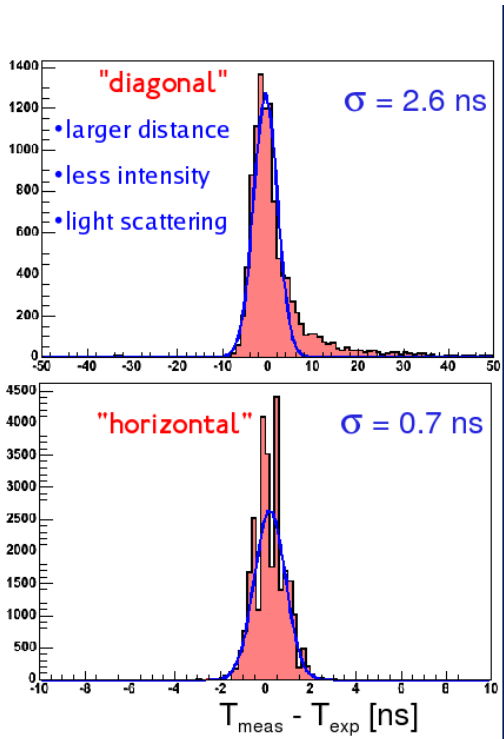


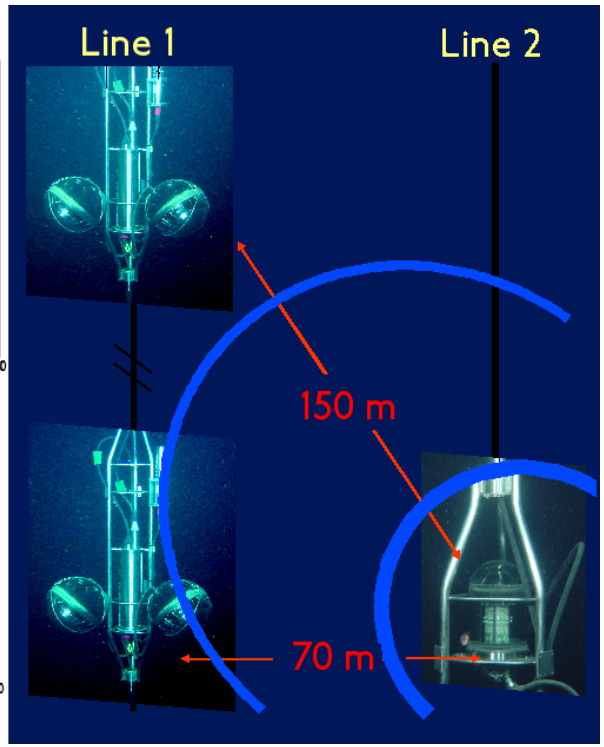
Geometry



Autonomous Transponder

Time Calibration with LED Beacons

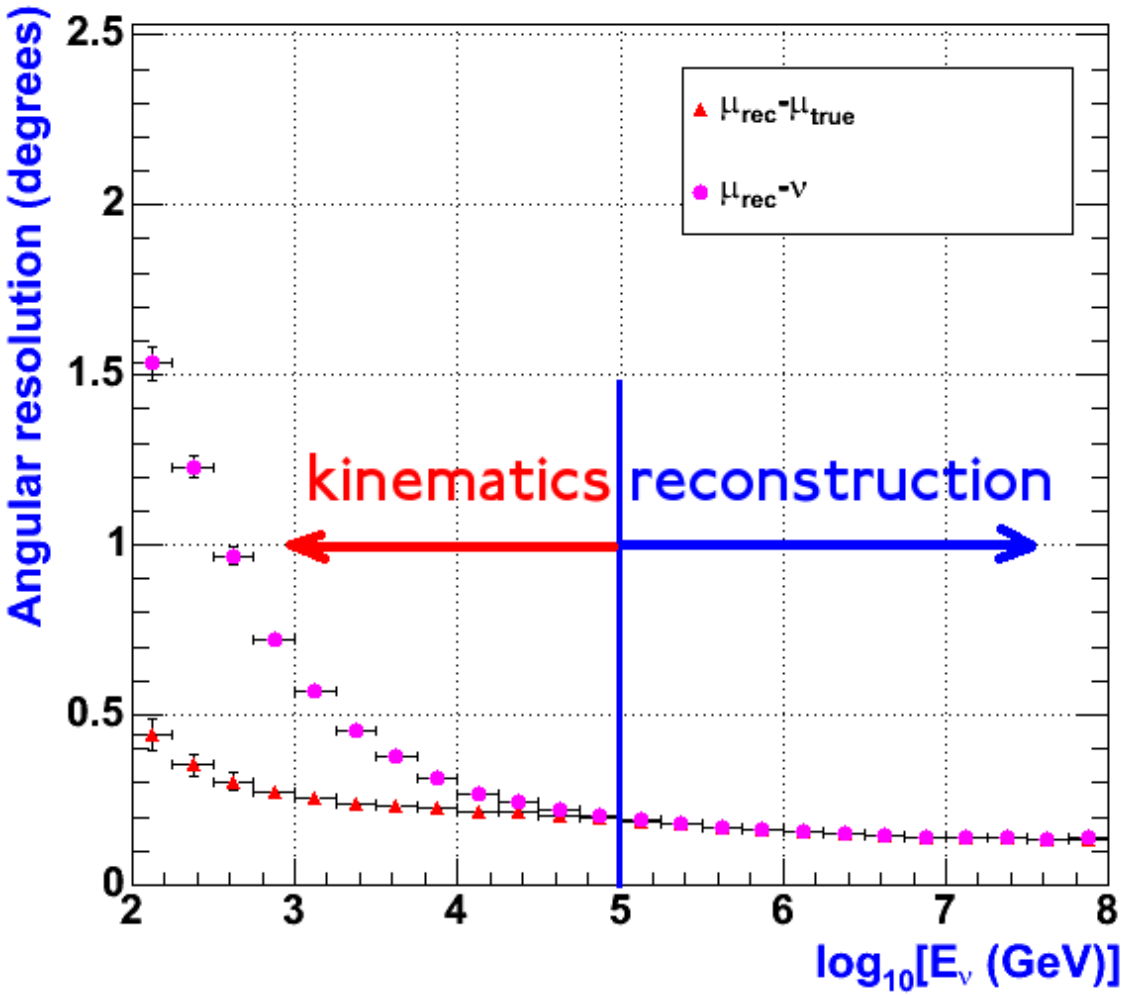




- Electronics and Calibration : $\sigma \sim 0.5$ ns
- TTS in PMs : $\sigma \sim 1.3$ ns
- Light scattering + dispersion in water : $\sigma \sim 1.5$ ns

$$\Rightarrow \Delta\theta \sim 0.2 - 0.3^\circ \text{ above few TeV}$$

Angular & Spectral Resolution

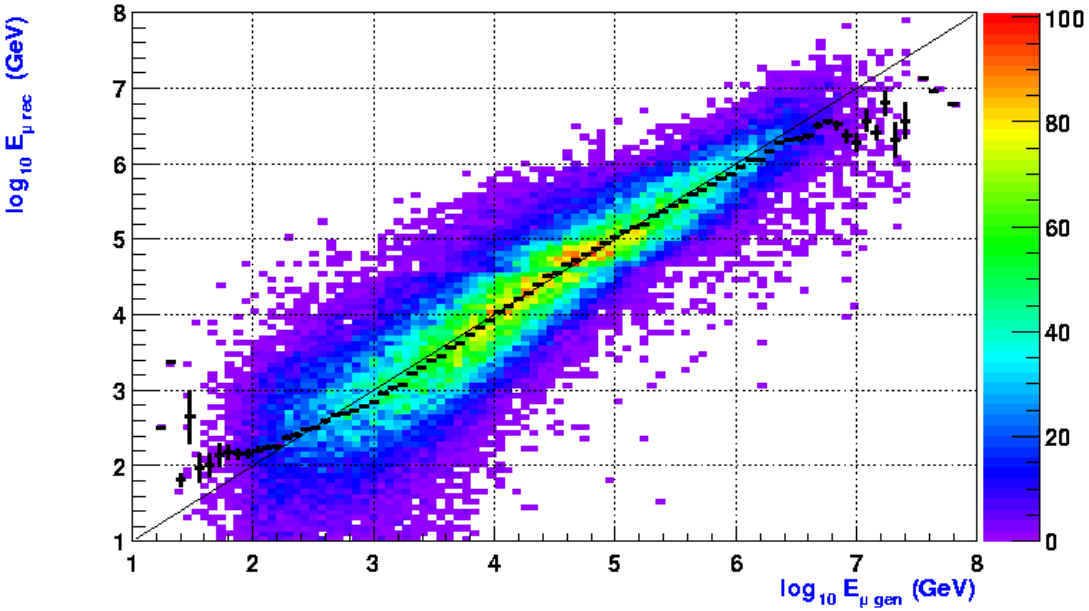


Angular Resolution

- $<$ 10-100 TeV : Kinematics
- $>$ 10 TeV : Reconstruction

  $\Rightarrow \Delta\theta \approx 0.2^\circ$

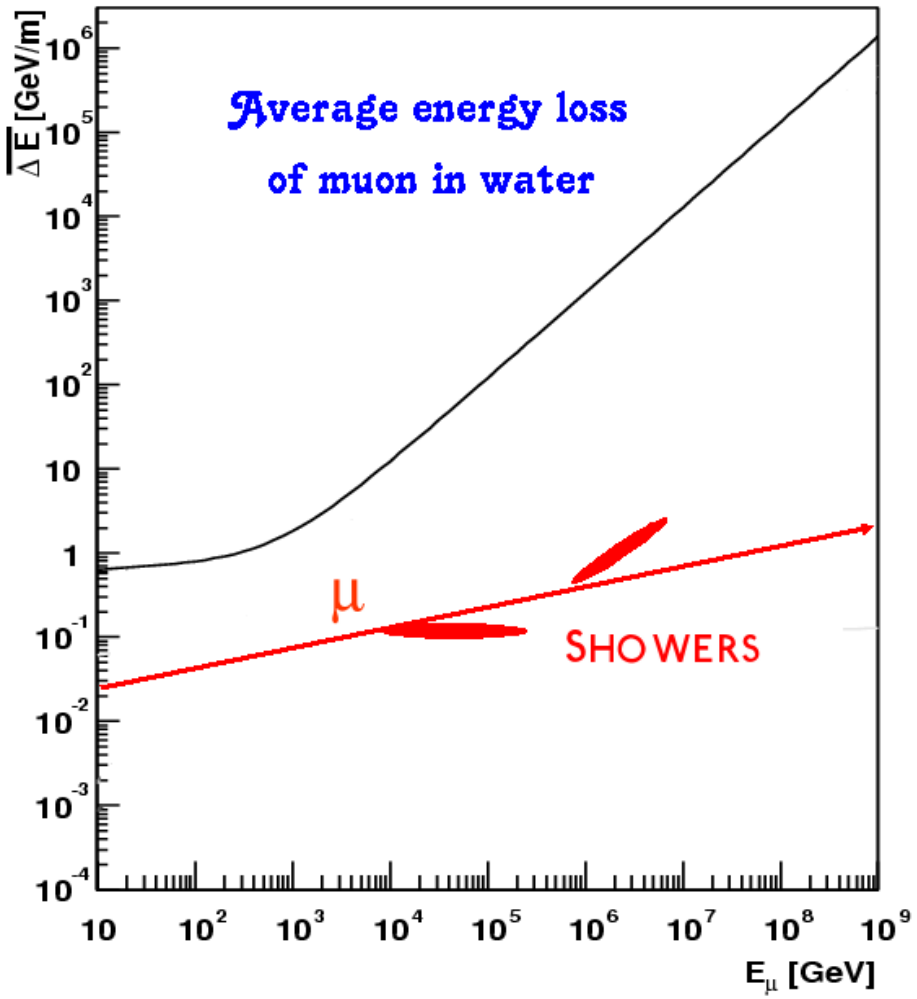
Angular & Spectral Resolution



Energy estimation

- < 100 GeV : μ path
- > 1 TeV : amount of light
  $\Rightarrow \frac{\Delta E_\nu}{E_\nu} \approx 2 - 3.$

Angular & Spectral Resolution



Energy estimation

- < 100 GeV : μ path
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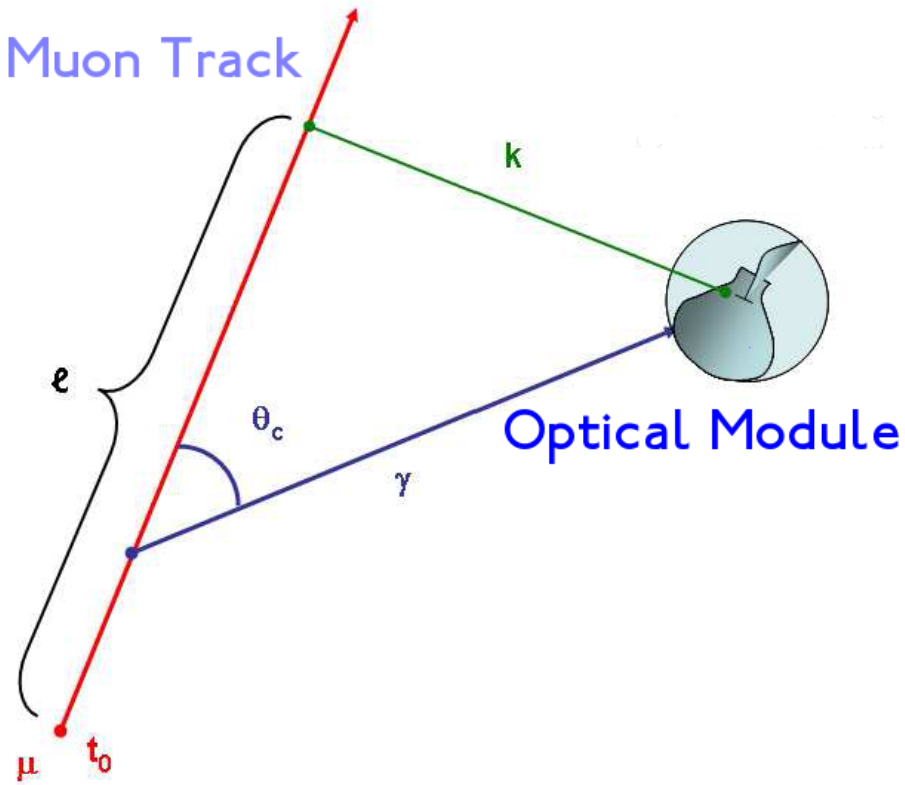
3D Reconstruction

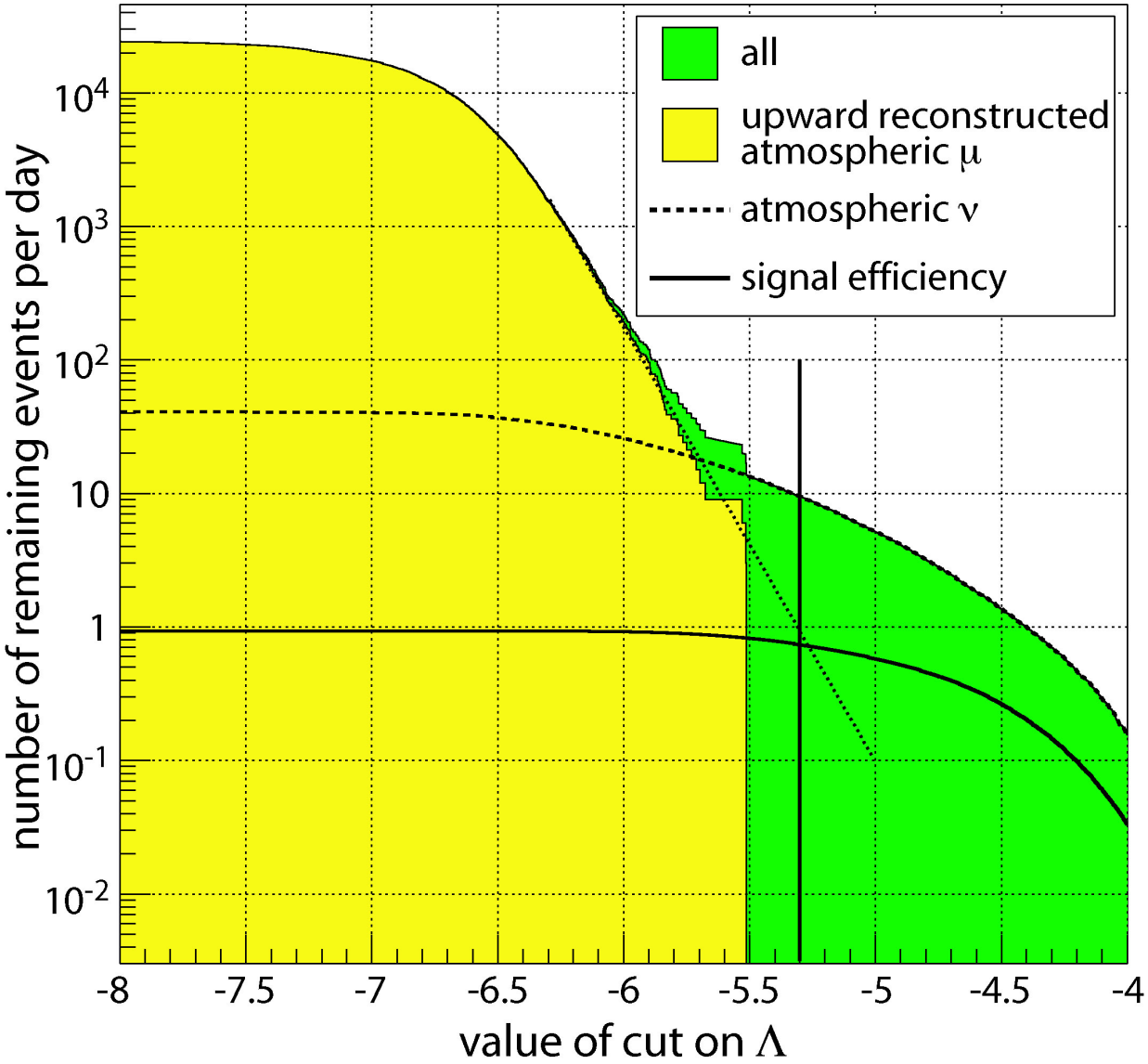


5 parameters fit : χ^2 minimisation

$$t_{\text{theory}} = t_0 + \frac{1}{c}\left(l - \frac{k}{\tan\theta_C}\right) + \frac{1}{v_g}\left(\frac{k}{\sin\theta_C}\right)$$

- $t_0, \theta, \phi, x_0, y_0$

Reconstruction Quality



- Reco. Quality Factor Λ :

$$\Lambda = \frac{\log(\mathcal{L})}{N_{DOF}} + 0.1\,(N_{\text{solutions}} - 1)$$

- $\mathcal{L}$ Maximum Likelihood