ANTARES

Status, first results and multimessenger astronomy

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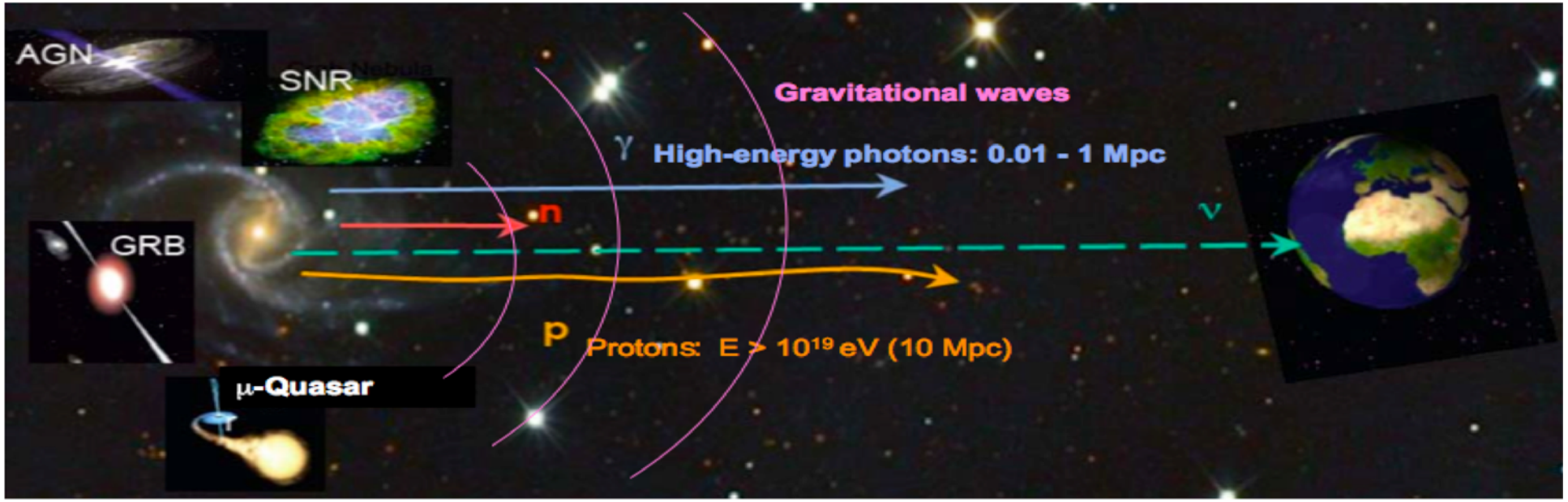
CPPM

Rencontres de Moriond EW 2011

Multimessenger Astronomy



- CRs astronomy feasible at energies higher than 10^{19} eV ➔extra-galactic origin
- UHECRs horizon limited to 10 -100 Mpc due to interaction with CMBR (GZK effect)

Multi-messenger astronomy is likely to open new insights into the physics of the most violent events, combining results from CRs, γ-rays and *traditional astronomy*, neutrinos and gravitational waves.

Neutrino Astronomy

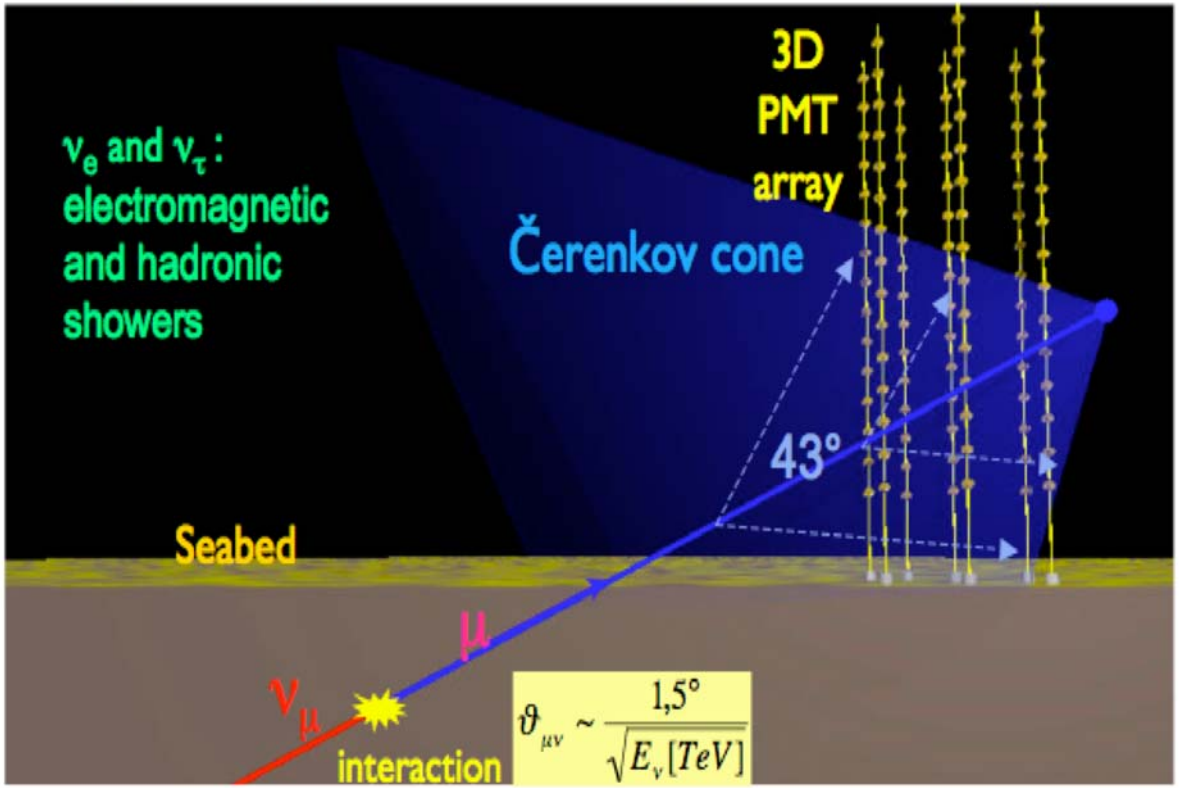
- HE νs are expected together with UHECRs, e.g.
$$p + \gamma \rightarrow \pi^{+} + n \rightarrow UHECRs + \nu' s$$
- Neutral particles ➔propagation not affected by B ➔point-back to the source
- Only weakly interacting particles:
  - observation over cosmological distances ➔identify production sites
  - inner layers of astrophysical objects ➔understand production mechanisms
- Always of hadronic origin
- Flavor mixing
  - even if at the source $(\nu_e : \nu_\mu : \nu_\tau) = (1:2:0)$ ➔at Earth $(\nu_e : \nu_\mu : \nu_\tau) = (1:1:1)$

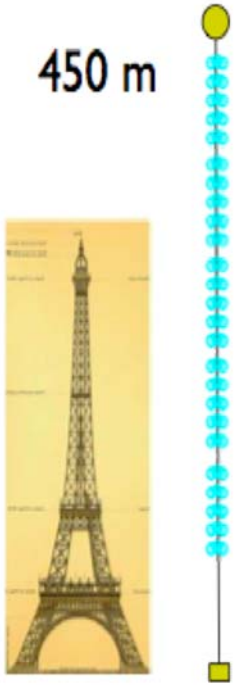
Only weakly interacting particles + Low fluxes expected from the sources

➔ Large detection volume (~km^3) is required

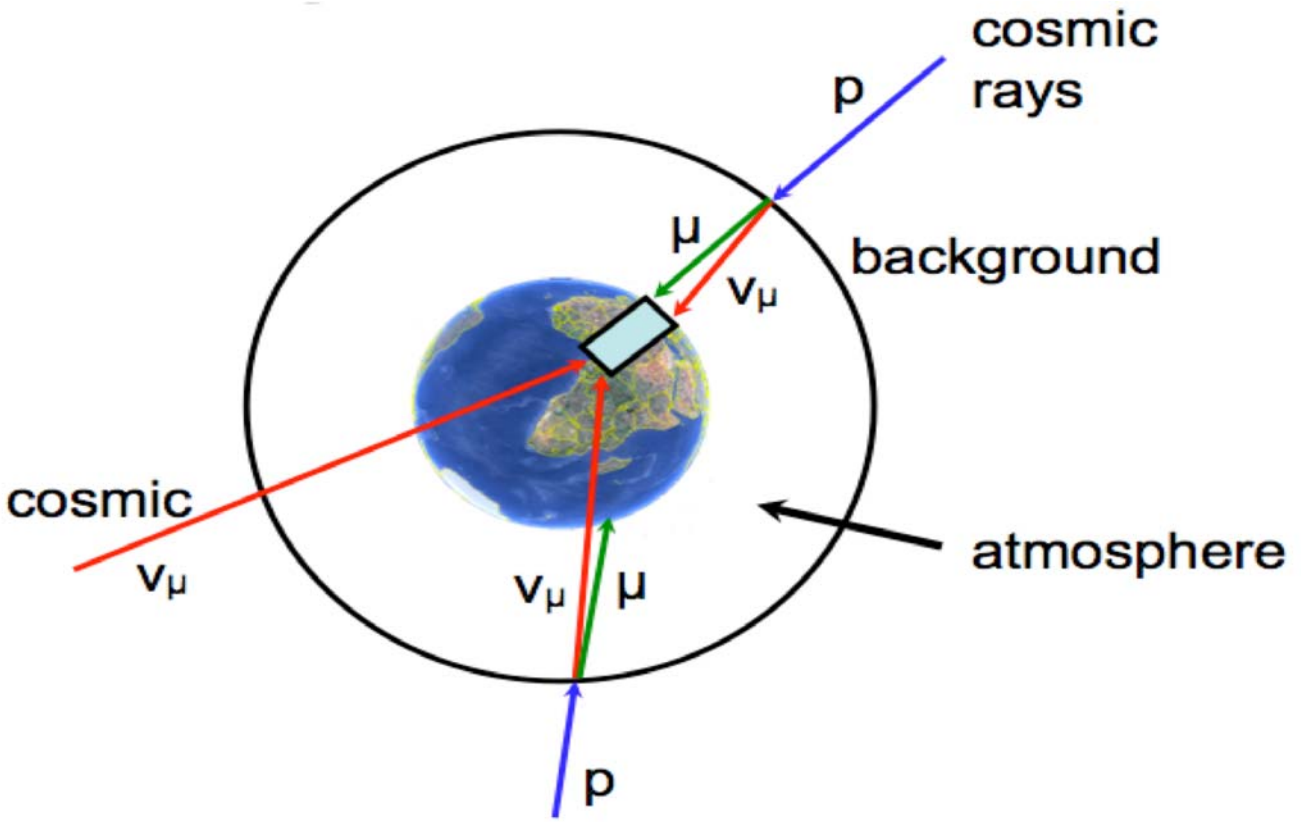
Detection Principle

Neutrinos (E > 100GeV) can be detected using the visible Cherenkov radiation produced as the high-energy charged leptons (final state of CC interactions) propagate through a transparent medium with superluminal velocity.





Particle Background

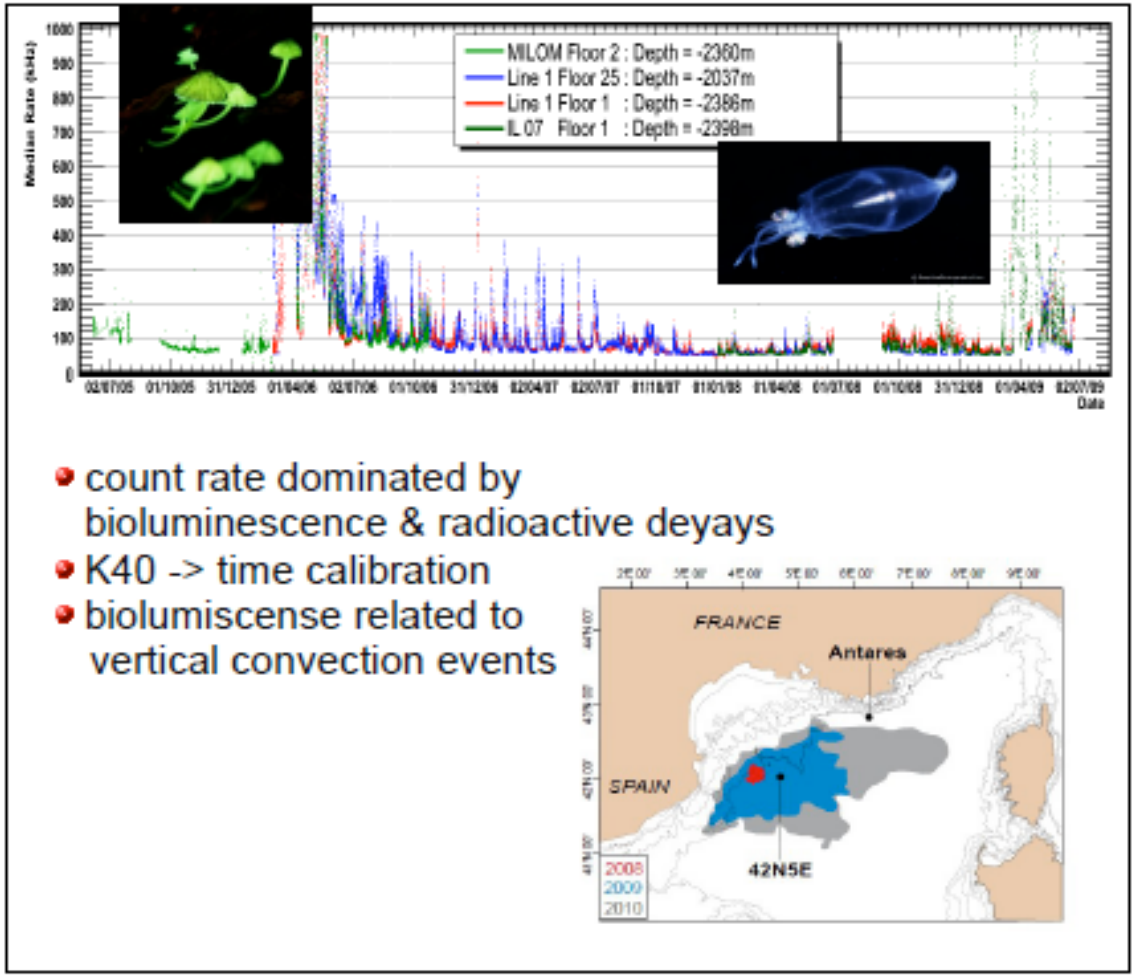


Atmospheric muons	~10 per second
Atmospheric neutrinos	few per day
Cosmic neutrinos	few per year (maybe)

Looking for up-going events

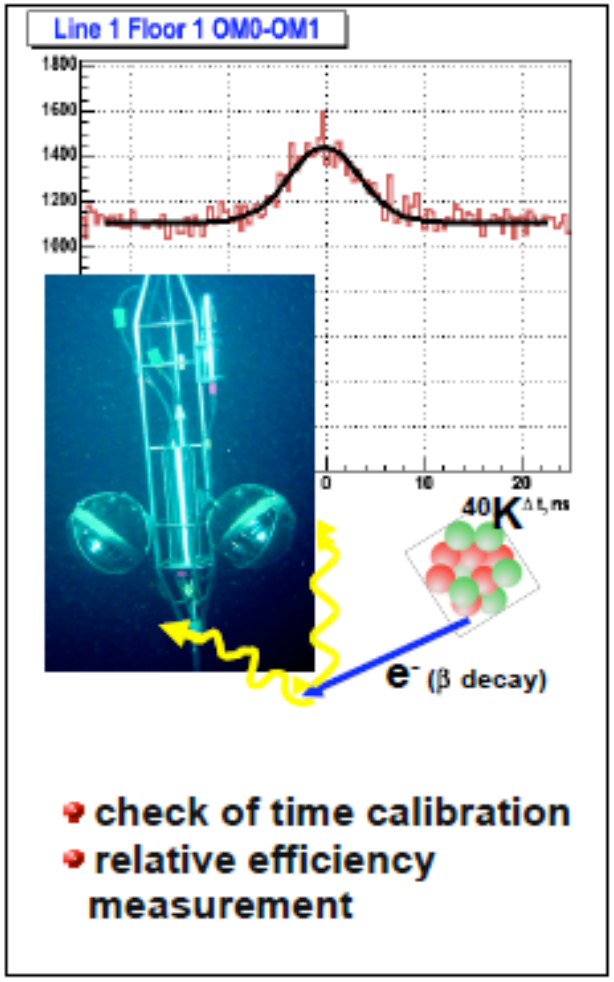
Environmental Background

bioluminescence



- count rate dominated by bioluminescence & radioactive deyays
- K40 -> time calibration
- biolumiscense related to vertical convection events

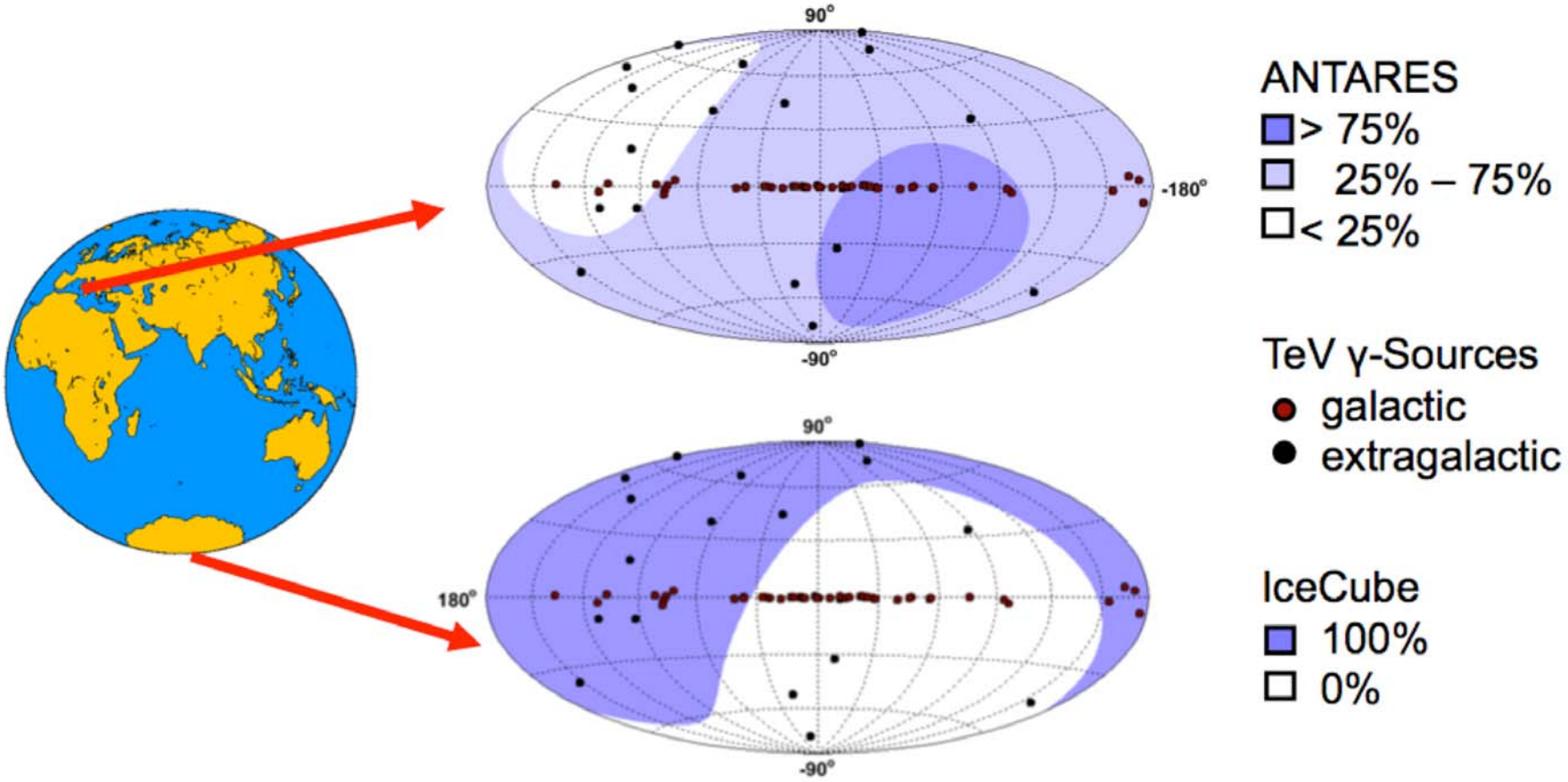
radio active decays



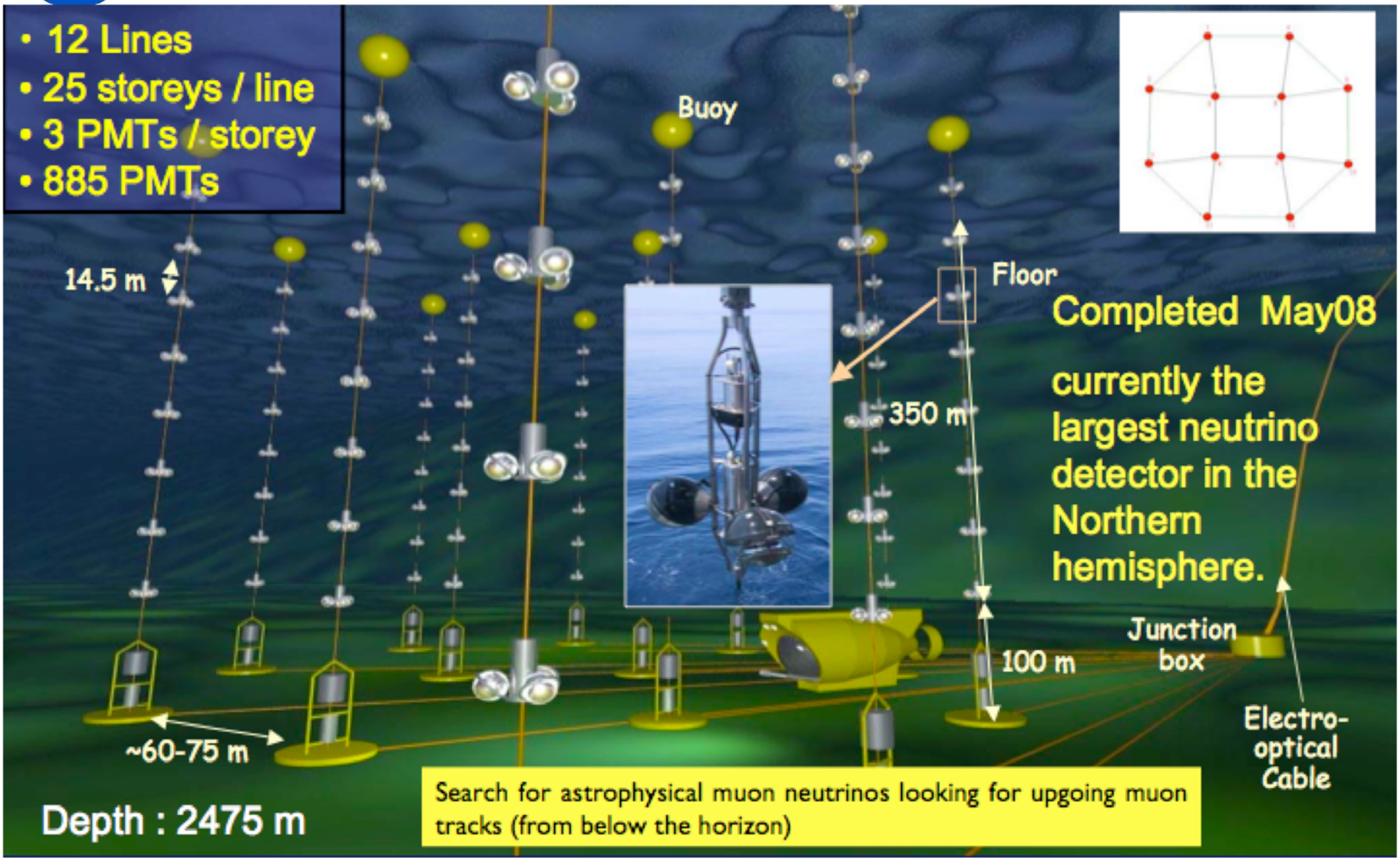
- check of time calibration
- relative efficiency measurement

J. Aguilar *et al.*, Astropart. Phys. 33, 86-90 (2010)

Sky Coverage

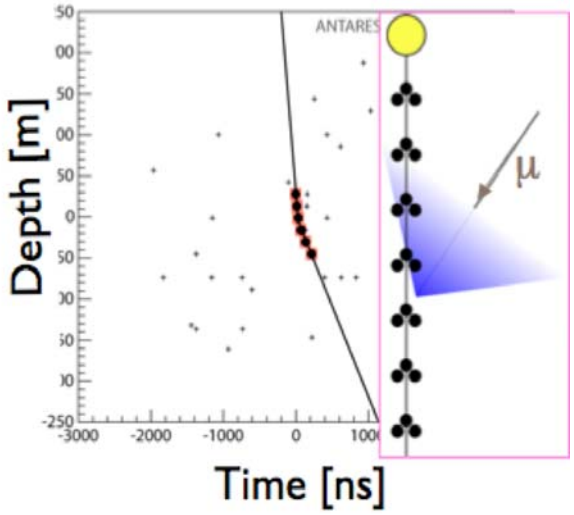


The ANTARES detector

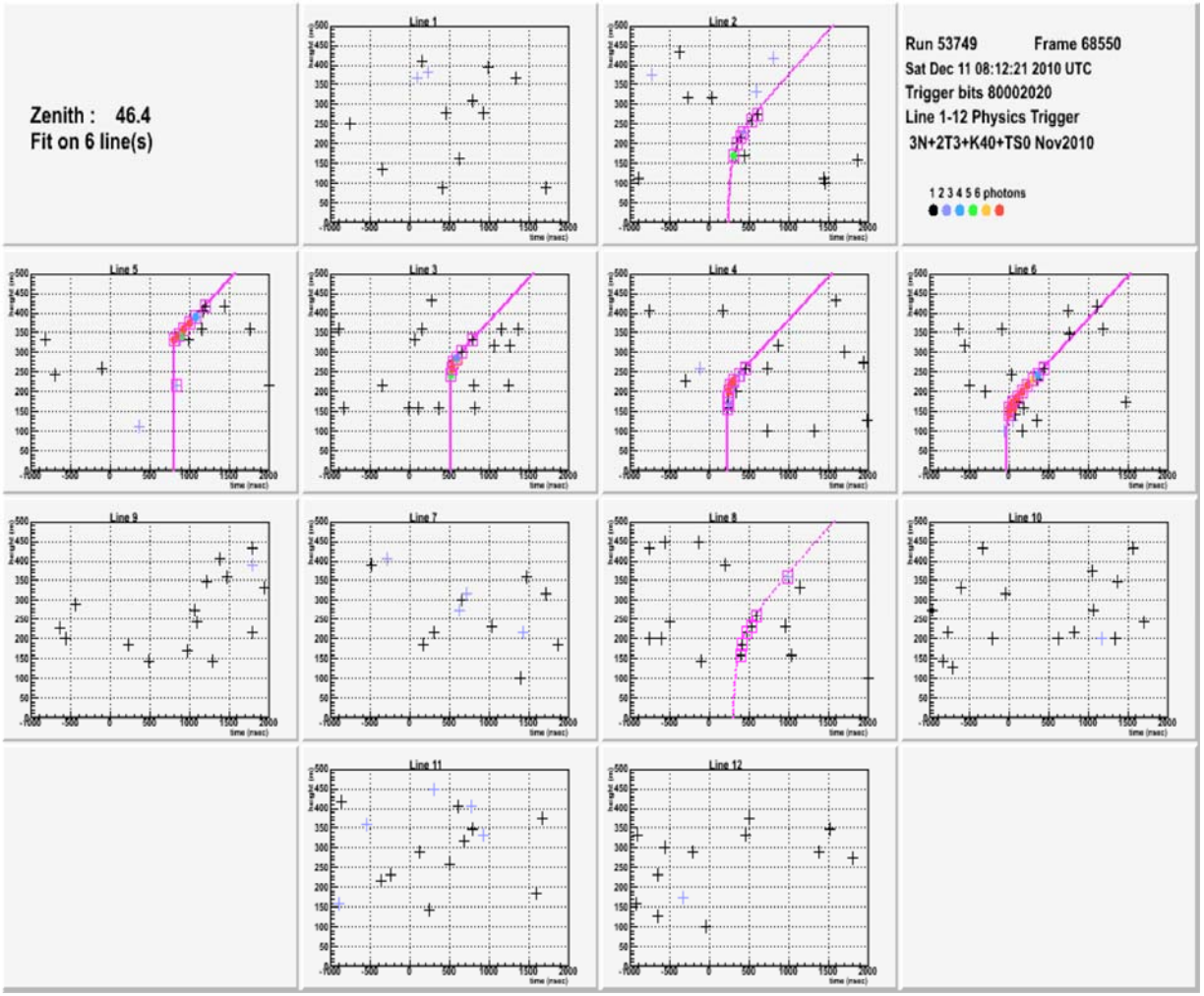


How does a muon look like?

A typical **down-going event** (atmospheric muon) and its Cherenkov cone, as seen in the detector

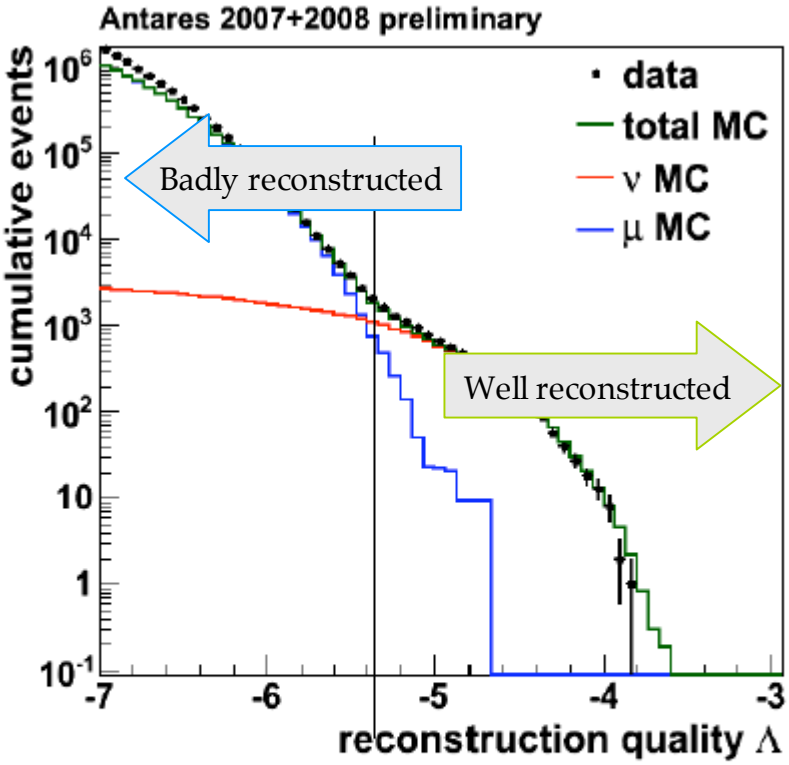


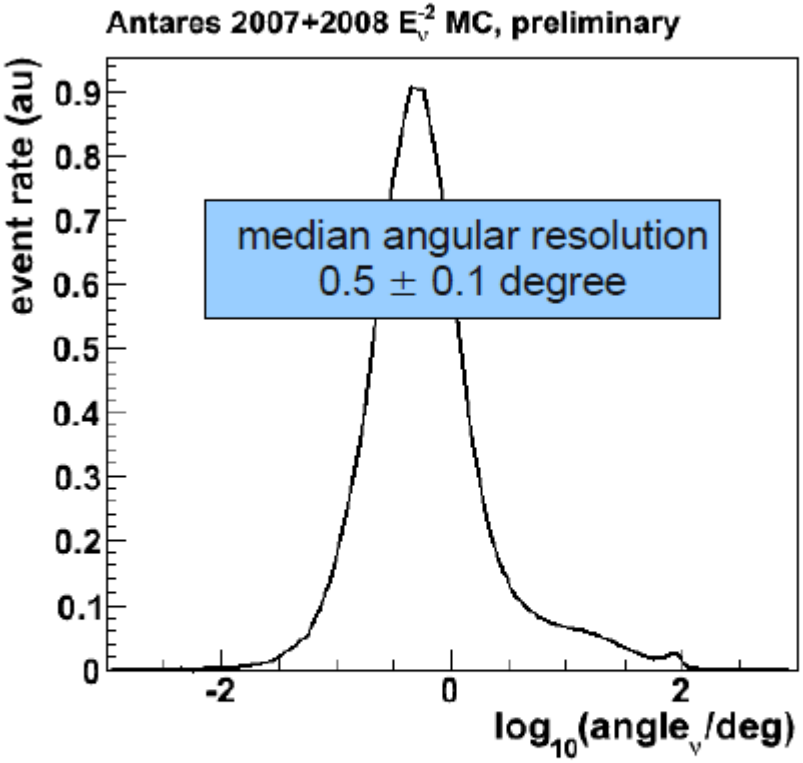
A typical **up-going event**



ANTARES: SELECTED RESULTS

Point-like source search





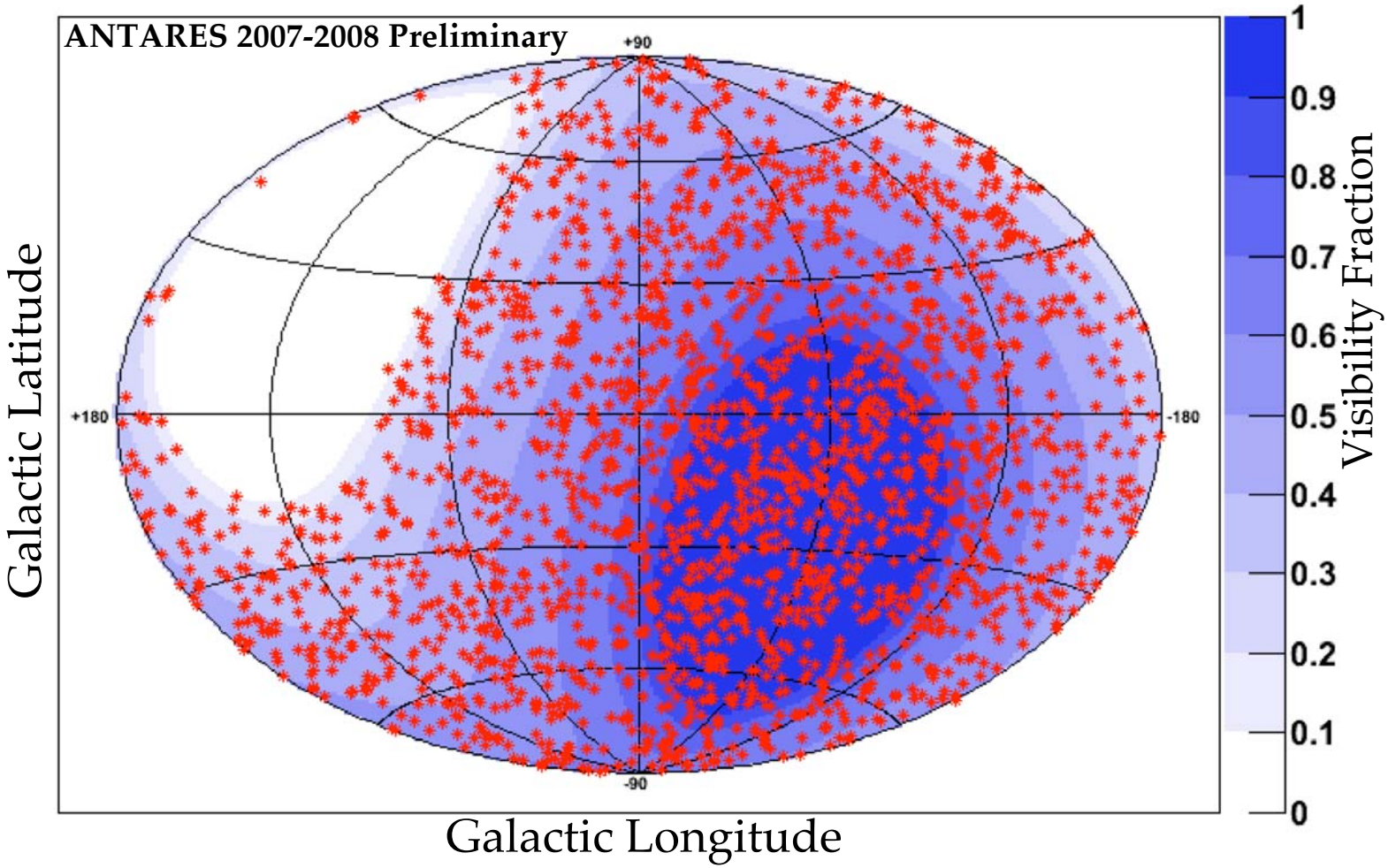
data from 5-line detector(2007) included.
loose selection for optimal sensitivity:

- error estimate < 1 degree
- reconstruction quality variable

- Angular resolution estimated from MC, but constrained using data.
- comparable to IceCube, despite much smaller detector → advantage of water over ice.

Point-like source search

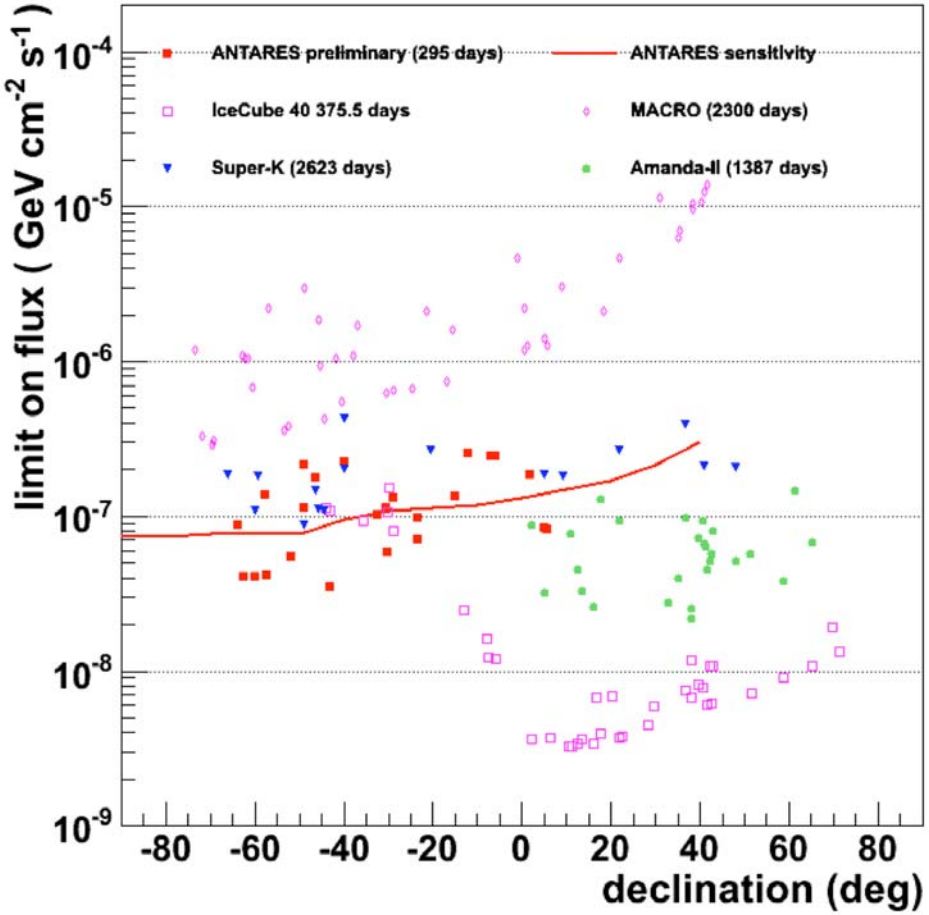
Optimization in order to have the best discovery power



all-sky (unbiased) + candidate lists search

Point-like source search

ANTARES: Best limits for the Southern sky !

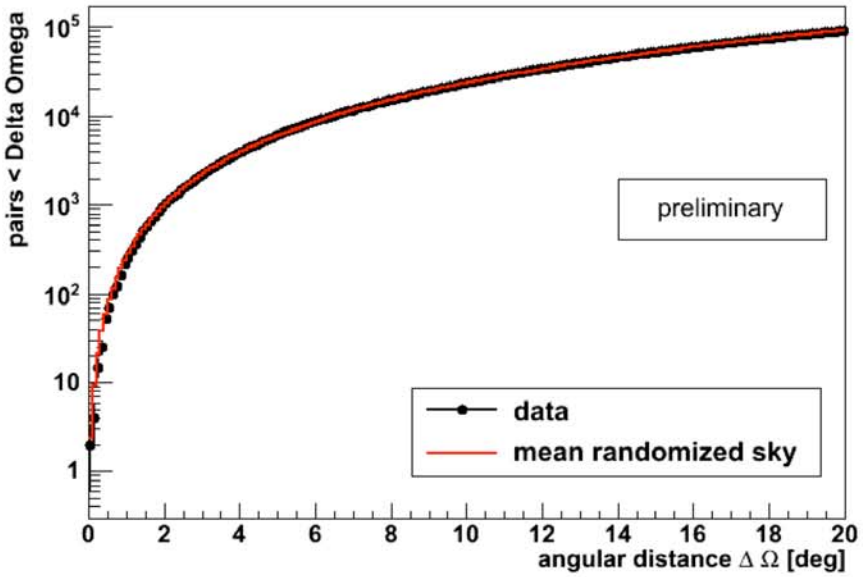


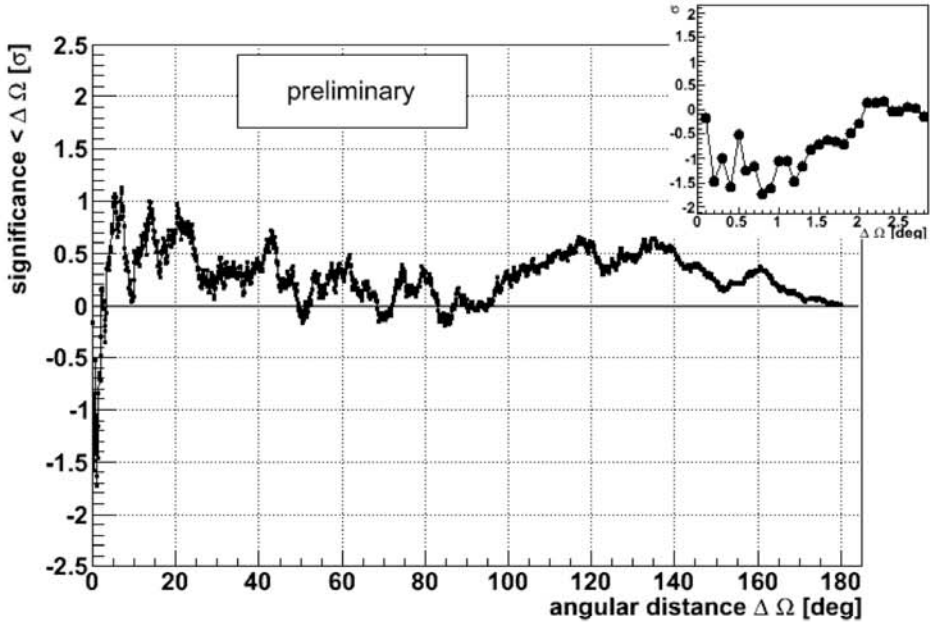
<u>preliminary result:</u>
no significant signal found

limits reported for few candidate neutrino sources
* interesting gamma/X-ray sources for which models predict neutrinos
* galactic center: no events within resolution

Autocorrelation studies

- Same data sample as point source search (2007-2008)
- Number of pairs at a given angular distance
- Sensitive to all kind of sources, also extended ones





No significant excess found

Search for a diffuse cosmic ν flux

idea:

- Background atmospheric neutrinos have steeply falling energy spectrum : $N \propto E^{-3.5}$
- Many cosmic neutrino models predict much harder spectra, typically $N \propto E^{-2}$

  => *Look for High-energy diffuse flux component*

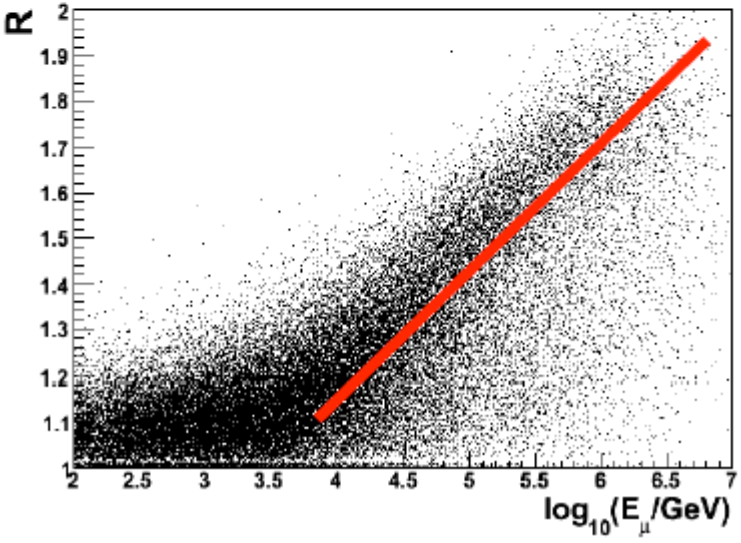
analysis:

- Live time: 334 days
- Stringent selection: 134 high energy ν candidates, ~ no atmospheric μ's
- Energy estimator R: a measure of number delayed photons

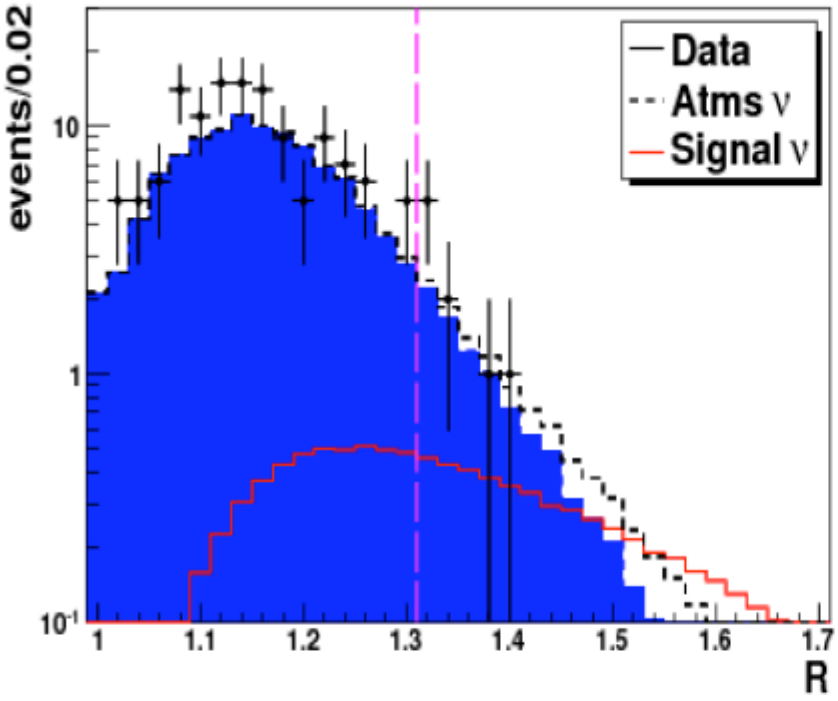
energy estimate:

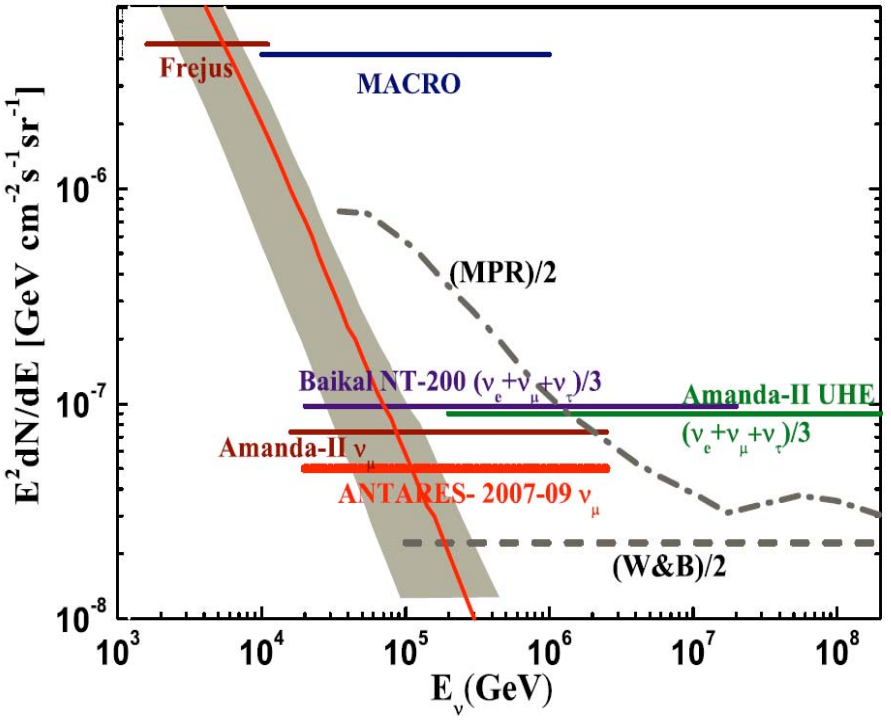
- can't see the neutrino, only the muon when it reaches the detector
- muons above 1 TeV produce additional Cherenkov light via secondaries ($\propto$ E)
- Energy estimate R based on number of repeating hits

$$R = \frac{\sum R_i}{N_{OM}}$$



Results on diffuse cosmic ν flux





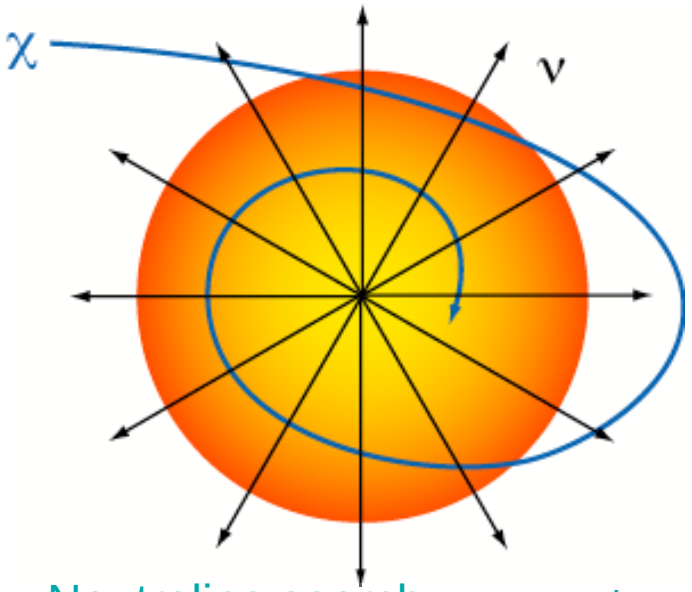
- No excess of high energy events found over expectation from atmospheric ν's
- set flux limit: $E^2 \Phi(E) < 5.3 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} for 20 TeV < E < 2.5 PeV

J. Aguilar *et al.*, Phys. Letter B 696, 16-22, 2011

… not only neutrino astrophysics…

… also open problems in particle physics …

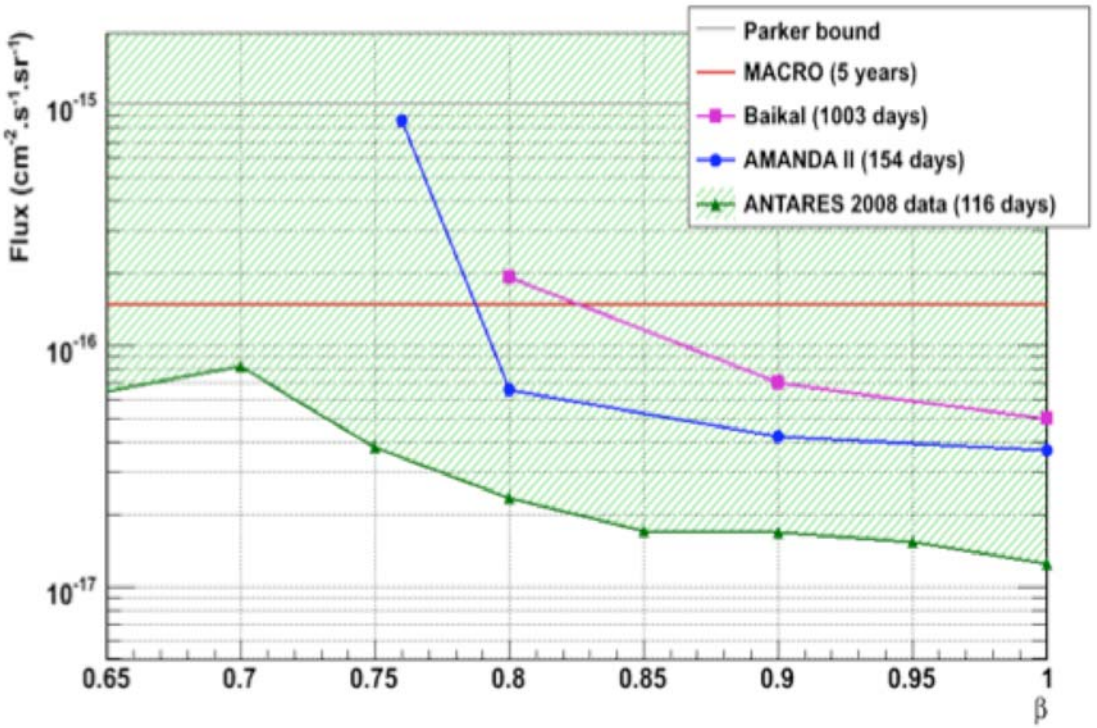
- Dark Matter searches:
  - Neutralino annihilation in Sun, Earth, Galactic Center
  - Dwarf galaxies
  - Galactic Halo
- **Magnetic Monopoles**
- Nuclearites
- …



Neutralino search: $\chi\chi \rightarrow \nu$+…

Magnetic Monopoles

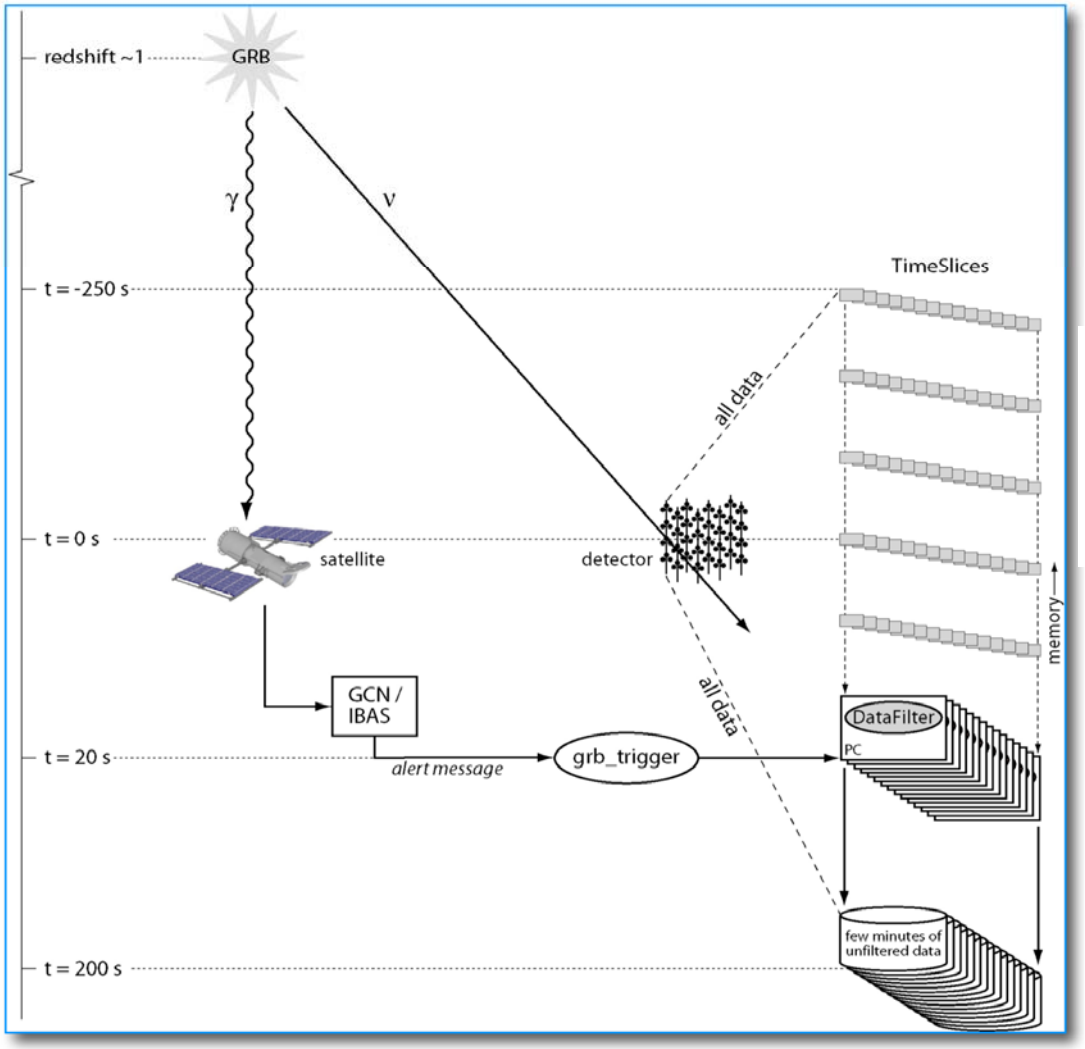
- High photon yield (>8x10^3 times a muon)
- monopole signature is muon-like
- selection optimized for the discovery potential



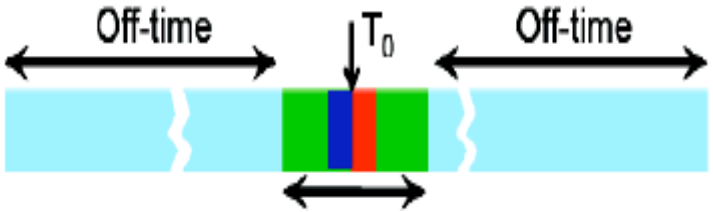
No signal found: competitive upper limit set.

ANTARES: MULTI-MESSENGER STUDIES

Triggered search method



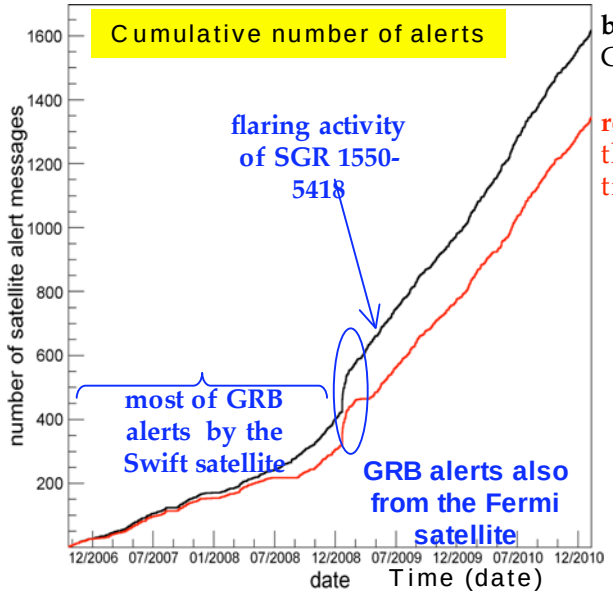
Triggered search method:
dedicated low level trigger after a gamma-ray satellite alert (GCN)



Requires Satellite trigger

Low backgrounds due to direction and time coincidences

2007 GRBs data analysis

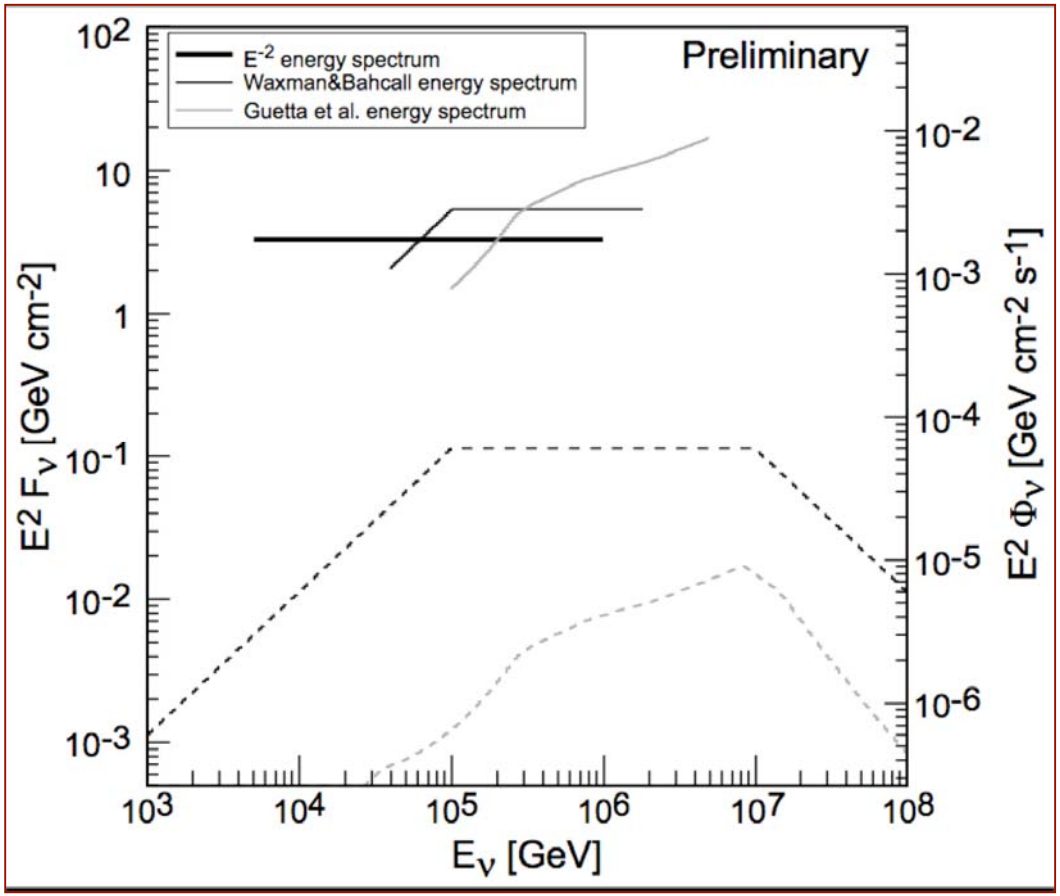


black:
GRB alerts received

red:
the ones Antares triggered on

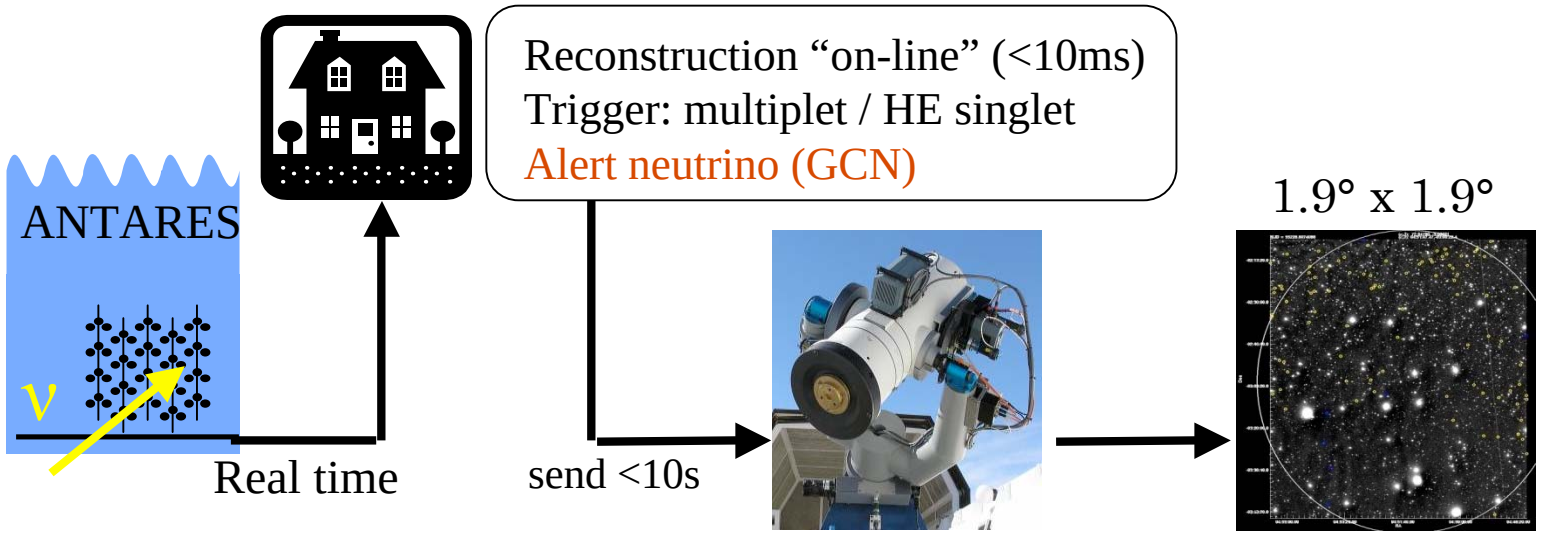
- More than 1300 alerts from GCN have been recorded (Jan 2011)
- Lines 1-5 data analysis is ongoing.
- 148 alerts received (exposure 1882 s):
  - 72 above the horizon
  - 23 rejected by run selection
  - 16 false trigger
  - **37 GRBs in the analysis**

90% CL Upper limits on nu fluxes from 37 GRBs



TAToO project

TAToO: optical follow-up of neutrino alerts in order to search for transient sources (GRB, chocked GRB, 'flare' d'AGN…)



Advantages:

- Large sky coverage (>2 π sr) + high duty cycle
- Sensitivity improved (1 neutrino may lead to a discovery !!!)
- No hypothesis on the nature of the source
- Non dependent on the availability of external triggers

Optical follow-up

The follow-up is performed by means of optical telescopes.

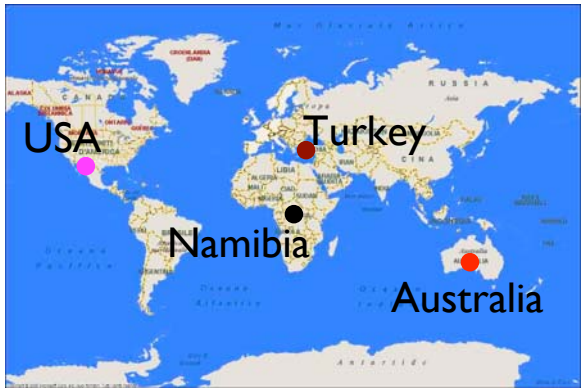
TAROT: two 25 cm telescopes

-fov 1.86° x 1.86°

- Magnitude V<17 (10s), V<19 (100s)
- sleewing time ~ 10s

ROTSE: four 45 cm telescopes

- fov 1.85° x 1.85°
- Magnitude V~19 (60s)
- sleewing time < 6-8 s



Optical image analysis

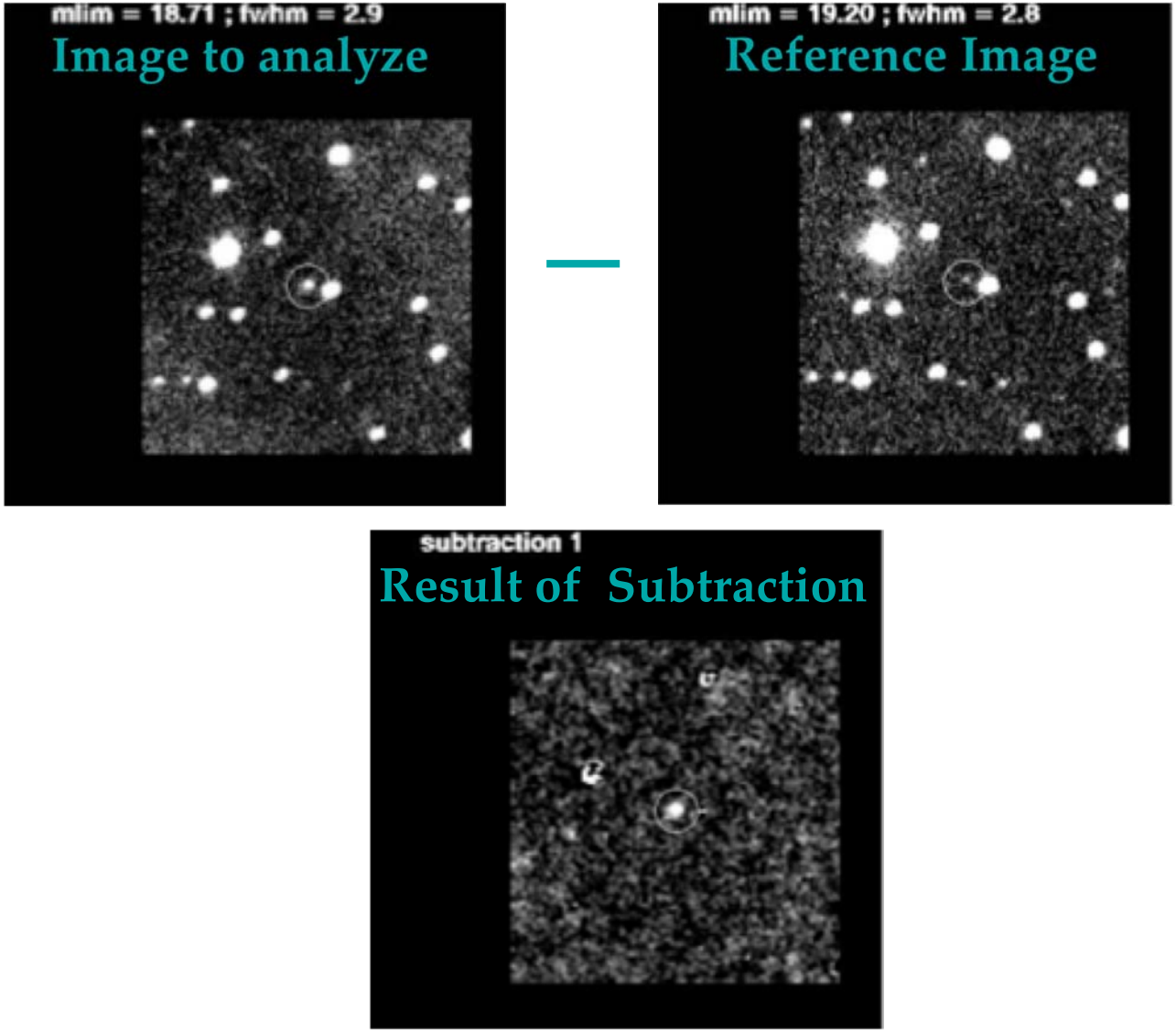
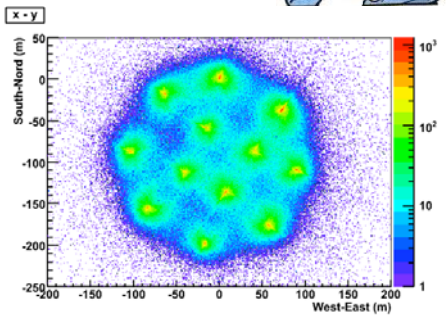
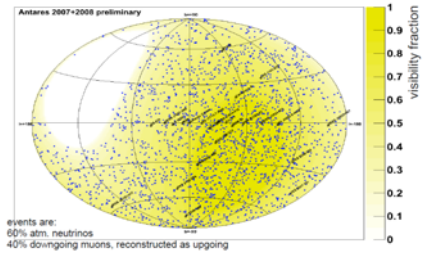


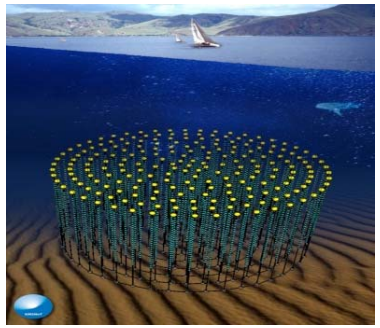
Image analysis ongoing using ROTSE pipeline

Summary

- **ANTARES is the largest neutrino telescope in the Northern hemisphere**
- **Detector is complete (12 lines) since 2008**
- **Detector is working within design specifications**
- **Best limits for point sources in the Southern sky**
- **Multi-messenger approach strongly pursued**
- **Multidisciplinary platform for associated sea sciences**
- **Ready for next step with KM3NeT**



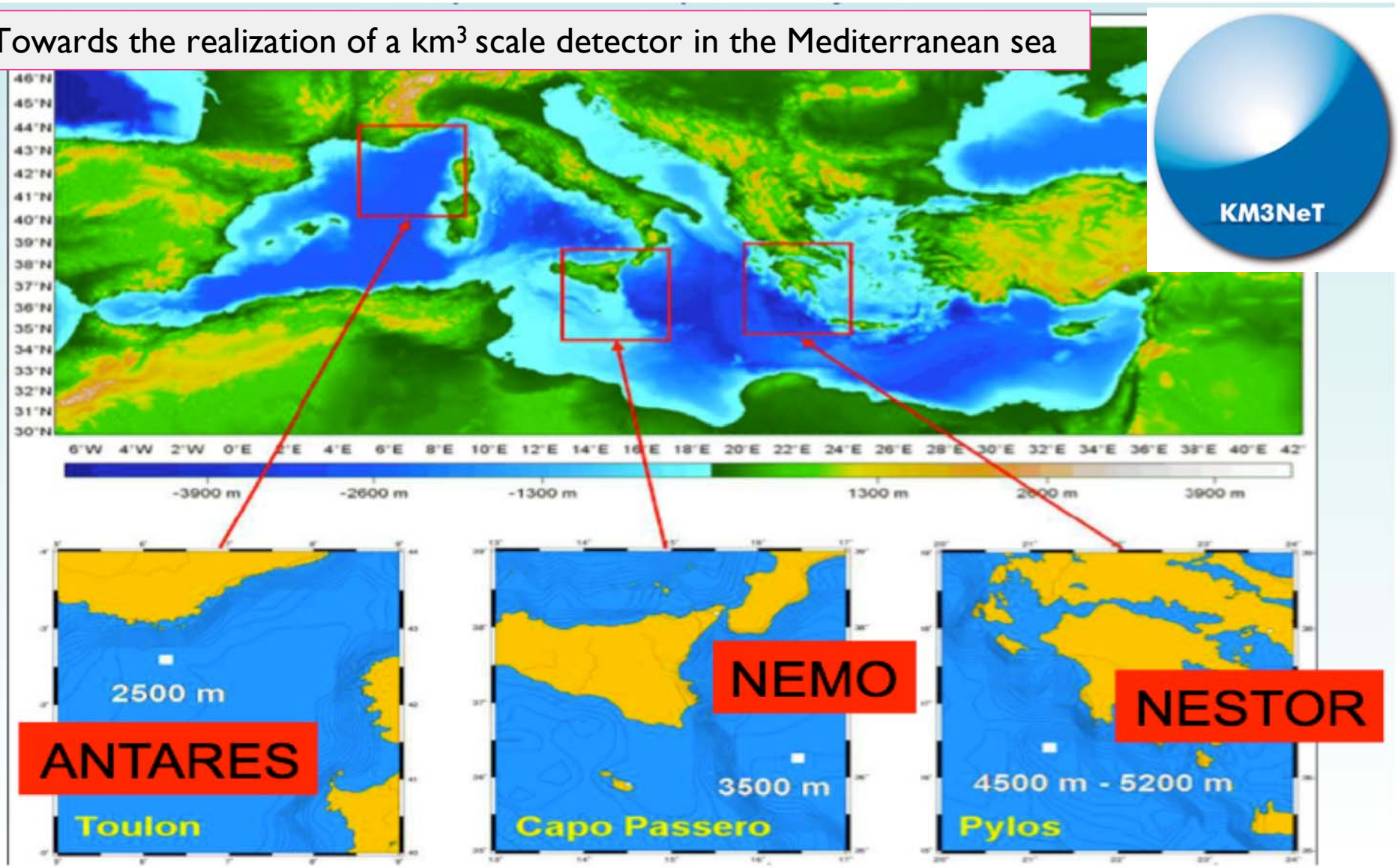




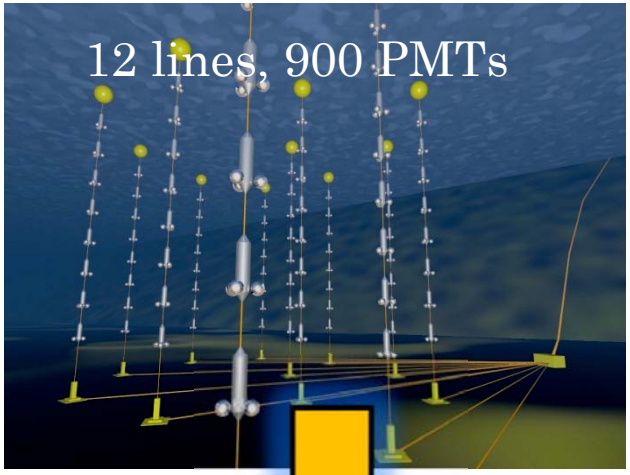
Backup slides

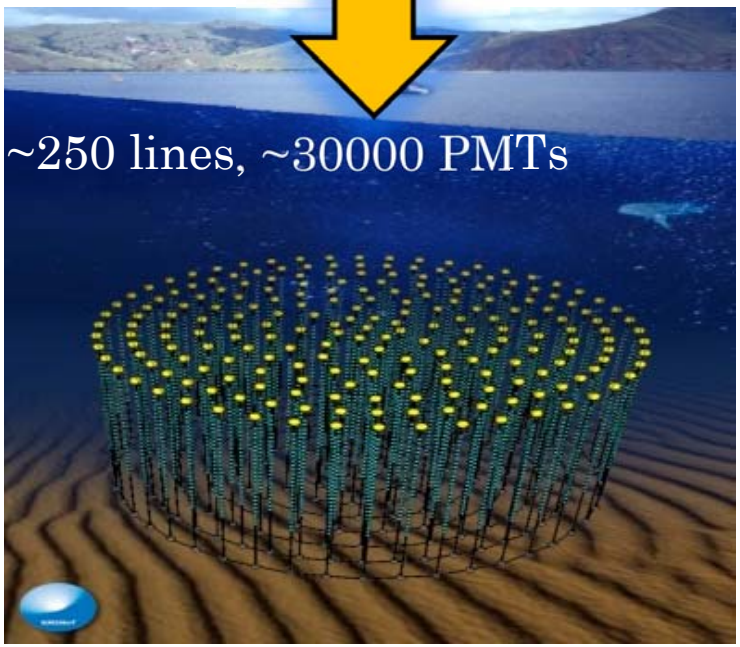
What's next ?

Towards the realization of a km^3 scale detector in the Mediterranean sea



The KM3NeT challenge





Maximize physics potential

- Substantial improvement over ICECUBE
- Instrumented volume ~5 km3
- Angular resolution ~0.1 degrees (E>10 TeV)

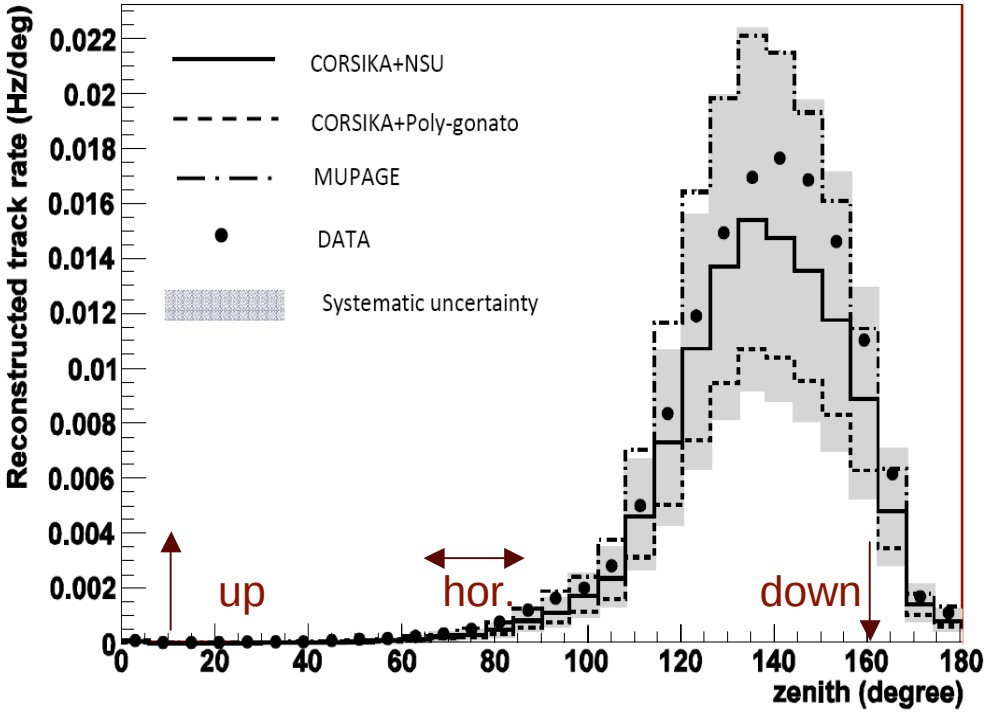
Deploy in a reasonable time ~ 4 years

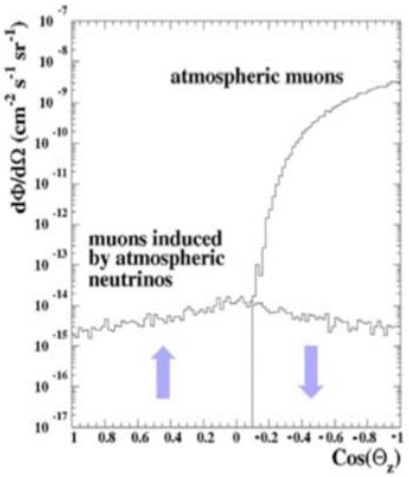
- New deployment techniques
- Speed-up integration time
- Sub contract part of the production
- …

At a reduced cost

- Factor 2 reduction cf ANTARES
- Simplified architecture
- Reduced maintenance
- Multi-line deployments
- …

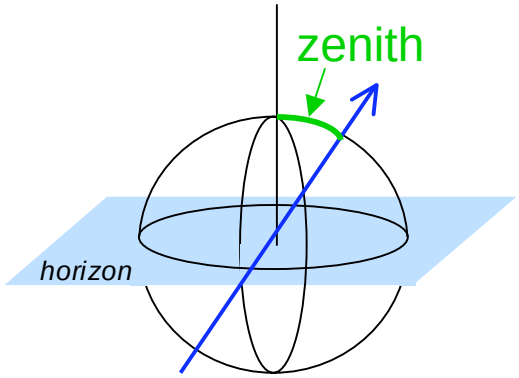
Downgoing muon analysis, 2007 data





- Track reconstruction based on χ^2 fit
- Main contributions to systematics:
  - $\Delta\lambda_{abs}/\lambda_{abs}$ ~ ±20%
  - OM acceptance ~ ±35%
  - PMT eff Area ~ ±20%

} Total ±45%



- Monte Carlo: two approaches

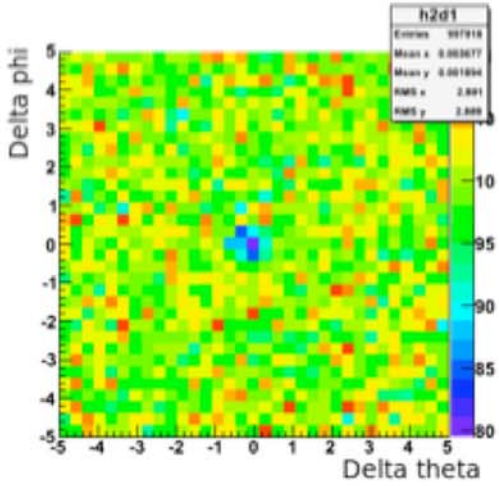
1st approach:
CORSIKA 6.2 +QGSJET 01
Primay CR models used:
– Polygonato (Hörandel)
- NSU (Bugaev)

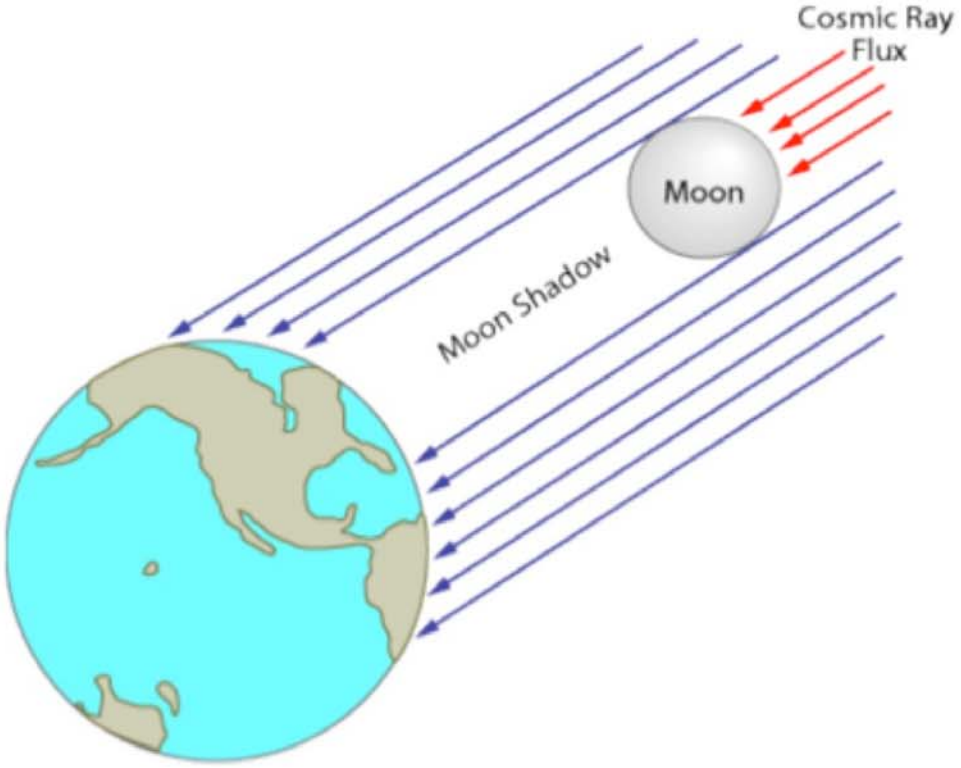
2nd approach:
- MUPAGE (parameterization)

Moon Shadow

Goal: Direct validation of absolute pointing of ANTARES

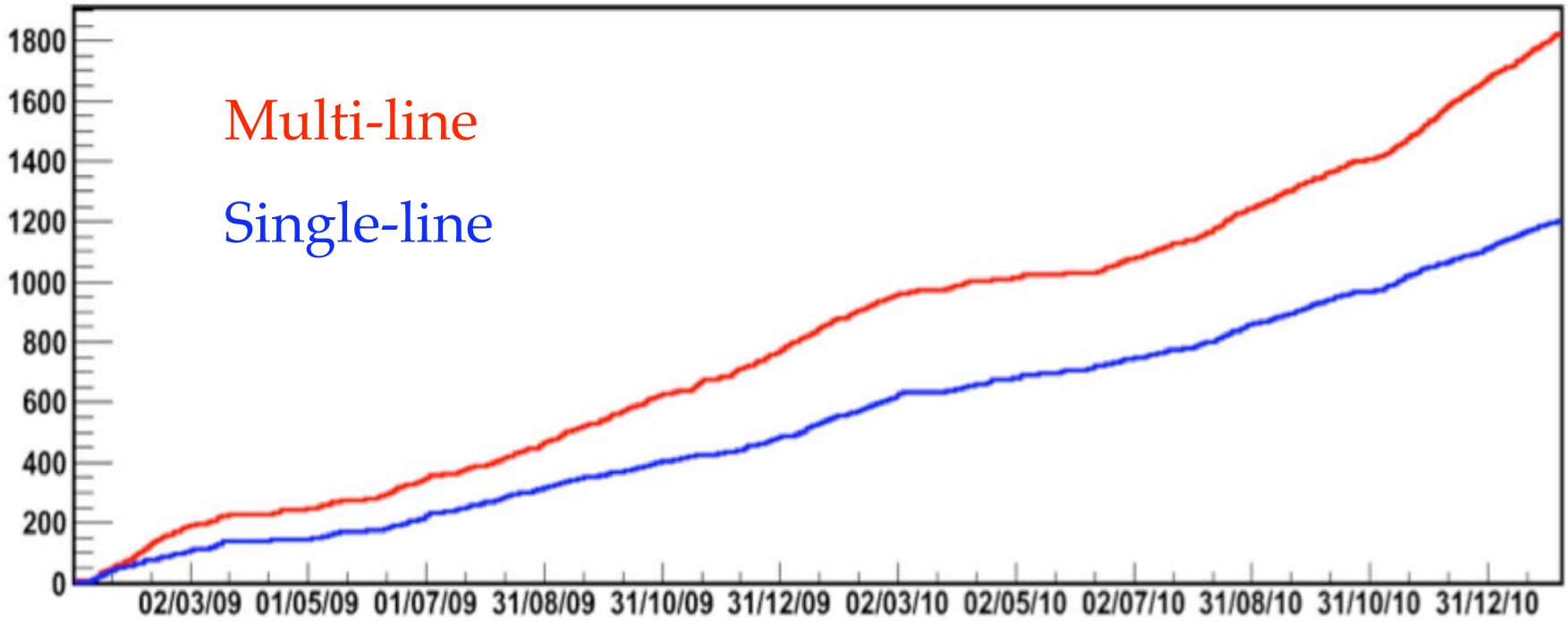
- Cosmic rays => Air showers => Muons => Reconstructed events
- Moon => Event deficit
- Key parameters:
  - CR deviation in Earth's geomagnetic field
  - Shower kinematics
  - Antares response





Data Taking

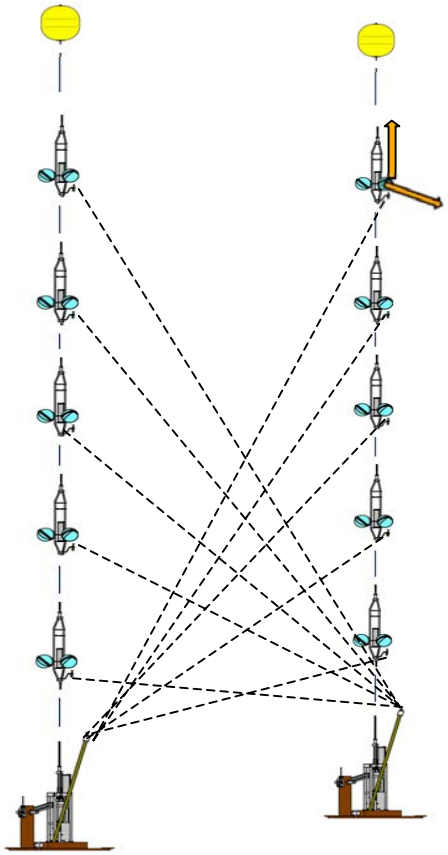
Online reconstructed neutrinos since 1/1/2009

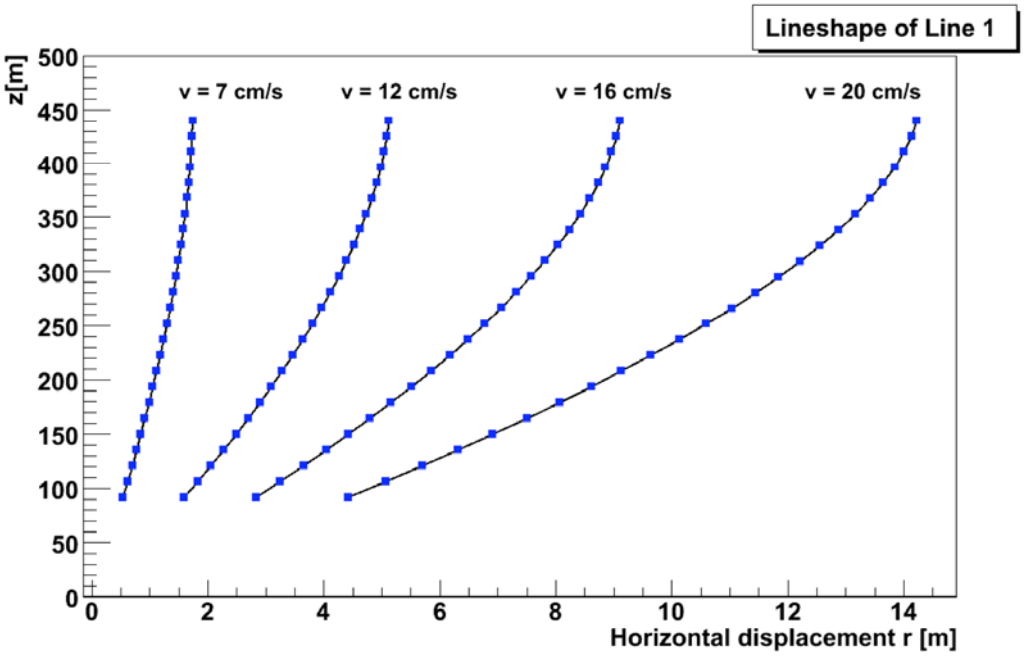


Positioning System

Shape of the line: acoustic device
Orientation of the storey: tiltmeter + compass

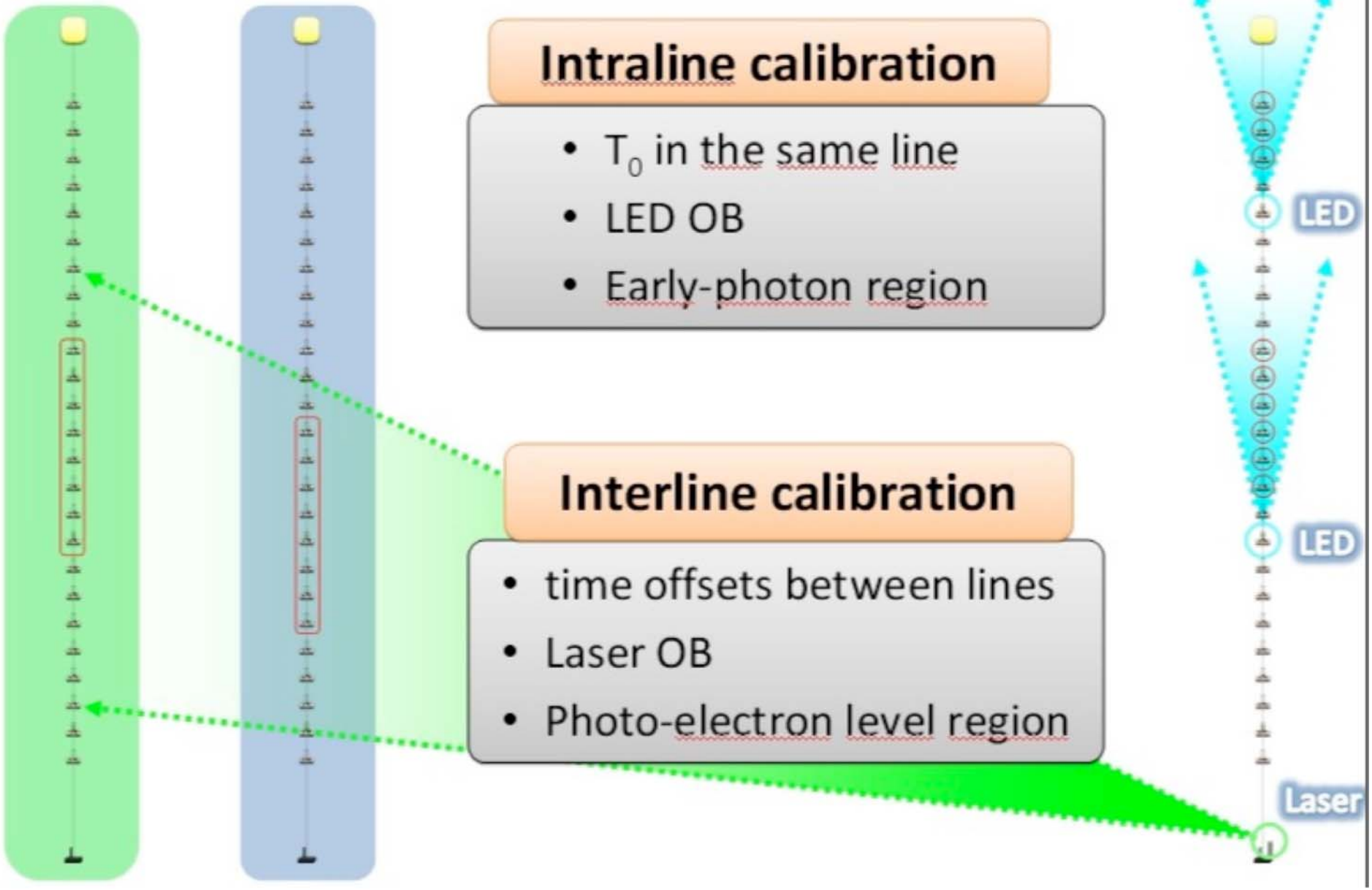
Precision ~10 cm





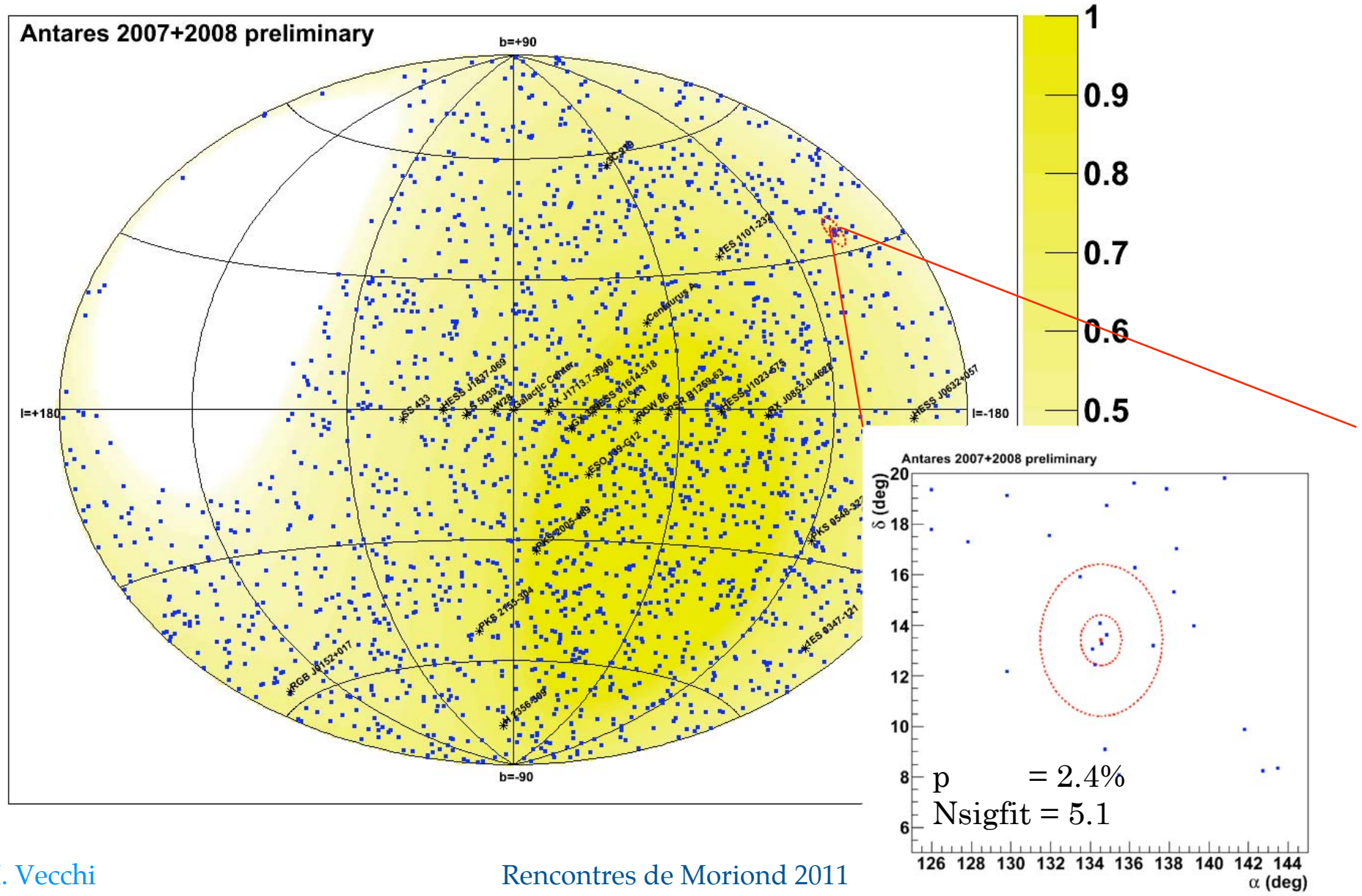
Measures every 2 minutes

Time calibration



POINT-SOURCE SEARCH

Preliminary



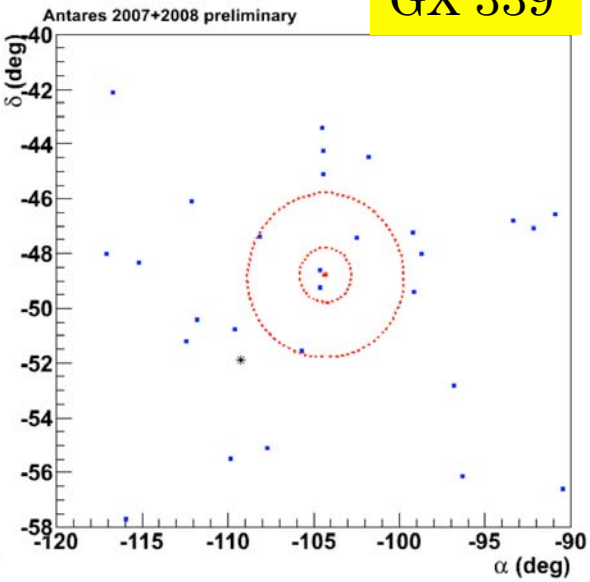
POINT-SOURCE SEARCH

Results for the search of 24 candidate neutrino sources:

Source	ra,decl	fit Nsig	Q	Limit Nsig	Limit ϕ	p-value
GX 339	-104.3, -48.79	2.24	3.41	6.590	2.13e-07	0.068
RX J0852.0-4622	133.0, -46.37	1.24	1.81	5.510	1.78e-07	0.397
RX J1713.7-3946	-101.75, -39.75	1.07	1.80	5.540	2.25e-07	0.399
1ES 0347-121	57.35, -11.99	1.49	1.43	4.840	2.57e-07	0.574
HESS J1837-069	-80.59, -6.95	1.04	1.11	4.620	2.45e-07	0.705
3C 279	-165.95, -5.79	1.01	1.00	4.600	2.44e-07	0.743
PSR B1259-63	-164.3, -63.83	1.03	0.56	4.520	1.45e-07	0.879
HESS J1023-575	155.83, -57.76	1.05	0.24	4.220	1.36e-07	0.952
PKS 2005-489	-57.63, -48.82	0.00	0.00	3.530	1.14e-07	~ 1
RGB J0152+017	28.17, 1.79	0.00	0.00	3.110	1.87e-07	~ 1
Galactic Center	-93.58, -29.01	0.00	0.00	2.790		
LS 5039	-83.44, -14.83	0.00	0.00	2.520		
H 2356-309	-0.22, -30.63	0.00	0.00	2.430		
PKS 0548-322	87.67, -32.27	0.00	0.00	2.160		
W28	-89.57, -23.34	0.00	0.00	1.940		
HESS J1614-518	-116.42, -51.82	0.00	0.00	1.690		
1ES 1101-232	165.91, -23.49	0.00	0.00	1.400		
Cir X-1	-129.83, -57.17	0.00	0.00	1.280		
RCW 86	-139.32, -62.48	0.00	0.00	1.270		
ESO 139-G12	-95.59, -59.94	0.00	0.00	1.270		
PKS 2155-304	-30.28, -30.22	0.00	0.00	1.240		
HESS J0632+057	98.24, 5.81	0.00	0.00	1.220		
Centaurus A	-158.64, -43.02	0.00	0.00	0.860		
SS 433	-72.04, 4.98	0.00	0.00	1.390		

Preliminary

GX 339



Signal of a magnetic monopole in ANTARES

- **Direct Cherenkov emission $\beta > 0.74$:**

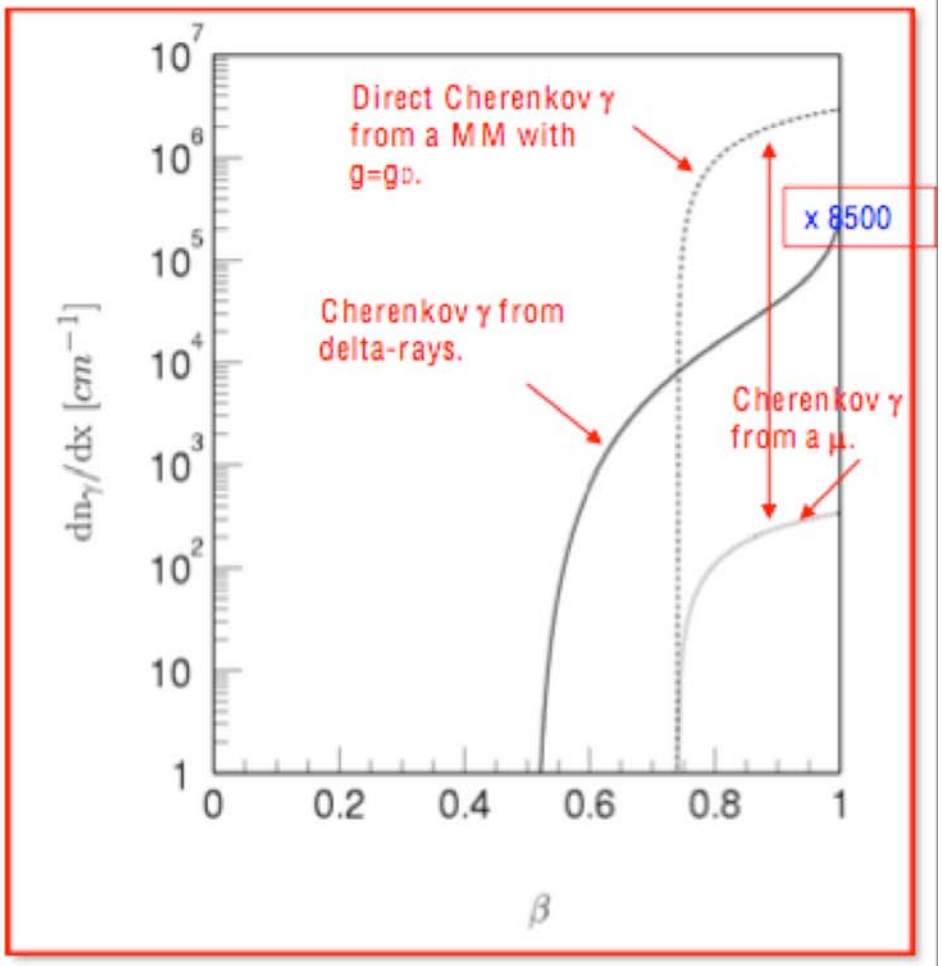
$n_{\text{sea water}} \sim 1.35$

$$\frac{d^2N_\gamma}{dxd\lambda} = \frac{2\pi\alpha}{\lambda^2}\left(\frac{gn}{e}\right)^2\left(1 - \frac{1}{\beta^2 n^2}\right)$$

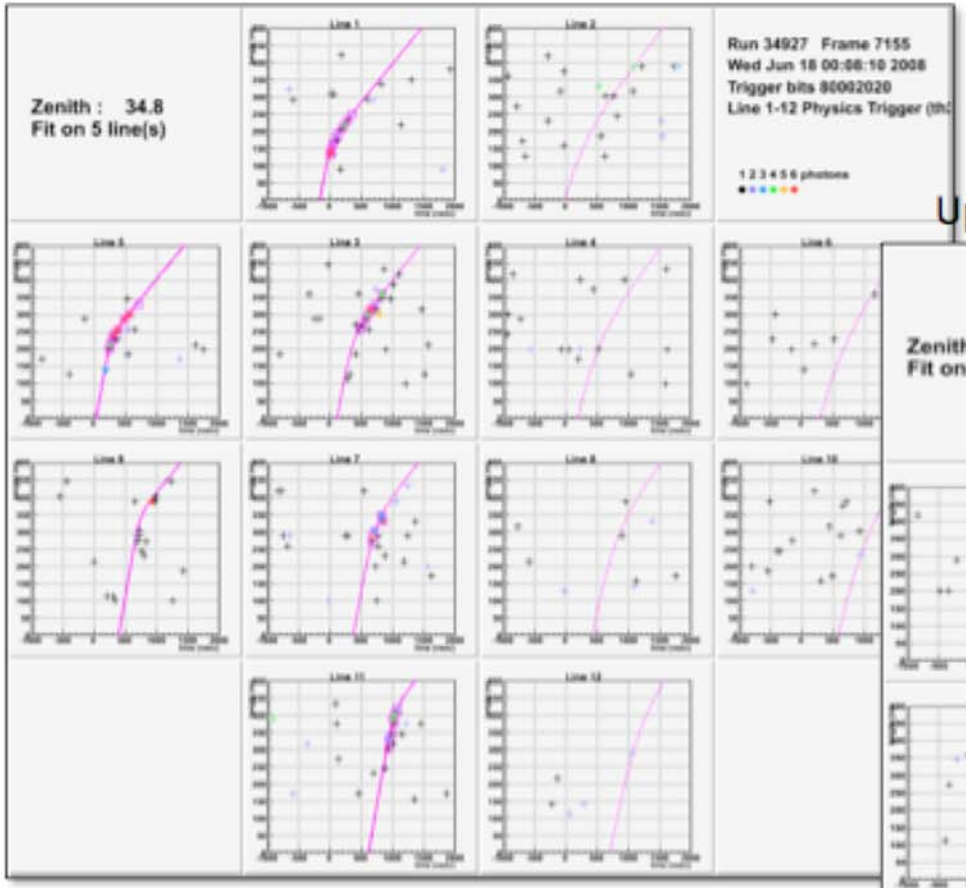
Number of photons emitted by a MM with the minimal charge $g_D \sim 68.5\ e$, compared to a muon of same velocity is about ~ 8500 more!

- **Indirect Cherenkov emission $\beta > 0.51$:**

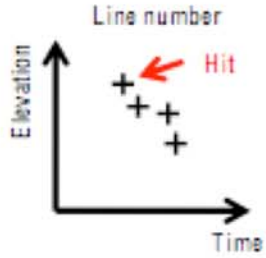
The energy transferred to electrons allows to pull out electrons (δ-rays), which can emit Cherenkov light.



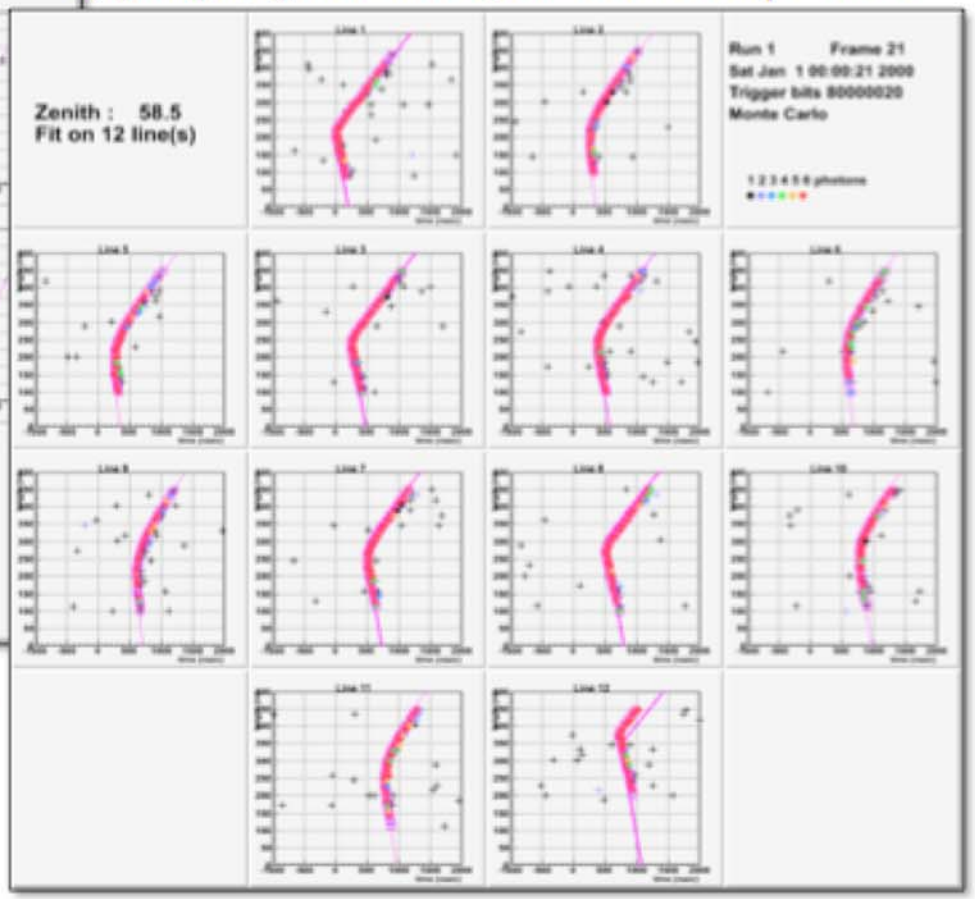
Signal examples of upgoing particles



Upgoing neutrino-induced muon candidate.

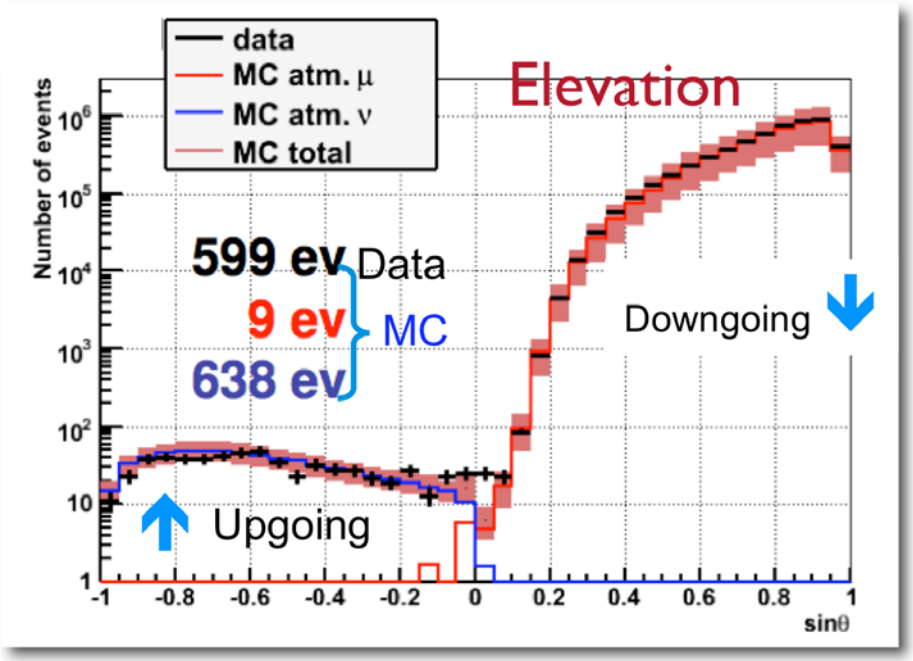


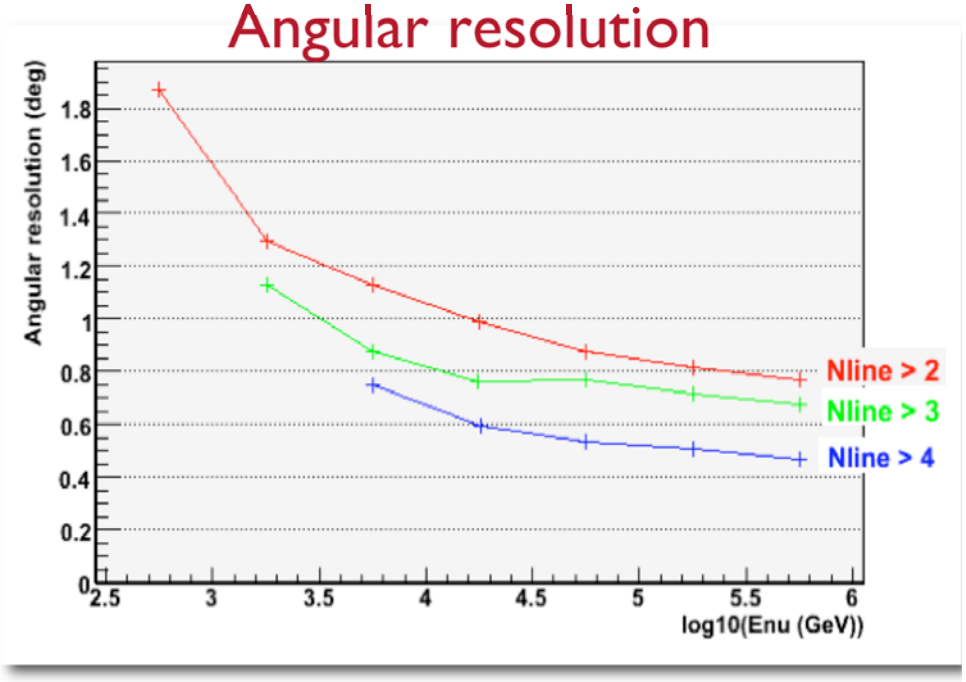
Upgoing magnetic monopole event with $\beta \sim 0.99$.



On-line reconstruction

Golden neutrino events are identified by means of a quasi-online reconstruction algorithm: it takes 5-10 ms to reconstruct each event.



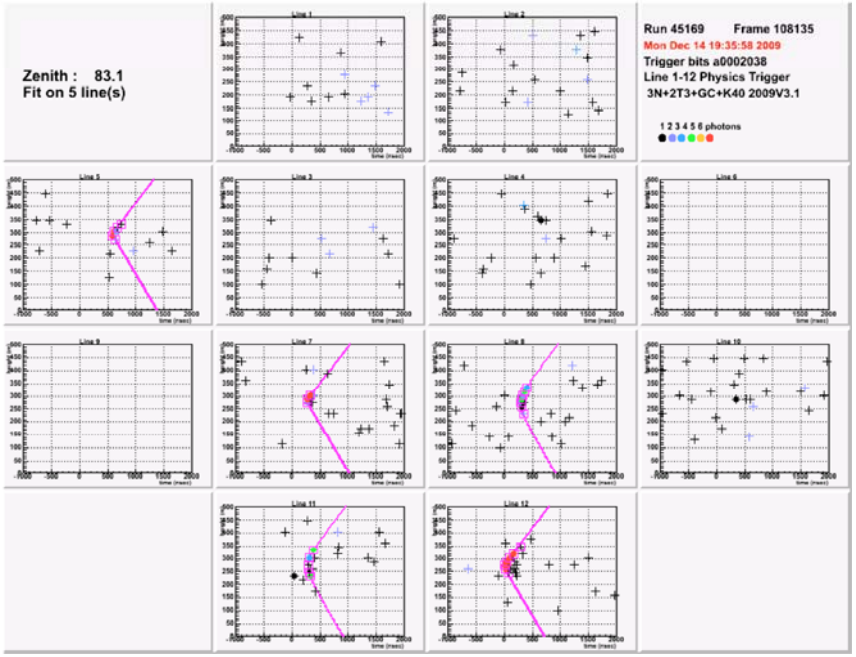


In order to achieve a better angular resolution a refined position can be obtained by means of an offline reconstruction algorithm.

J. Aguilar *et al.*, Astropart. Phys. 34, 652-662 (2011)

Observation Strategy: an example

Run_Number: 45169 Nframes: 108135
Amplitude: 296, nhit:28, nlines:5, tchi2: 2.3



ANTARES HE event

Optical Observation Strategy:

T_0

T_0+1

T_0+2

T_0+3

T_0+4

T_0+5

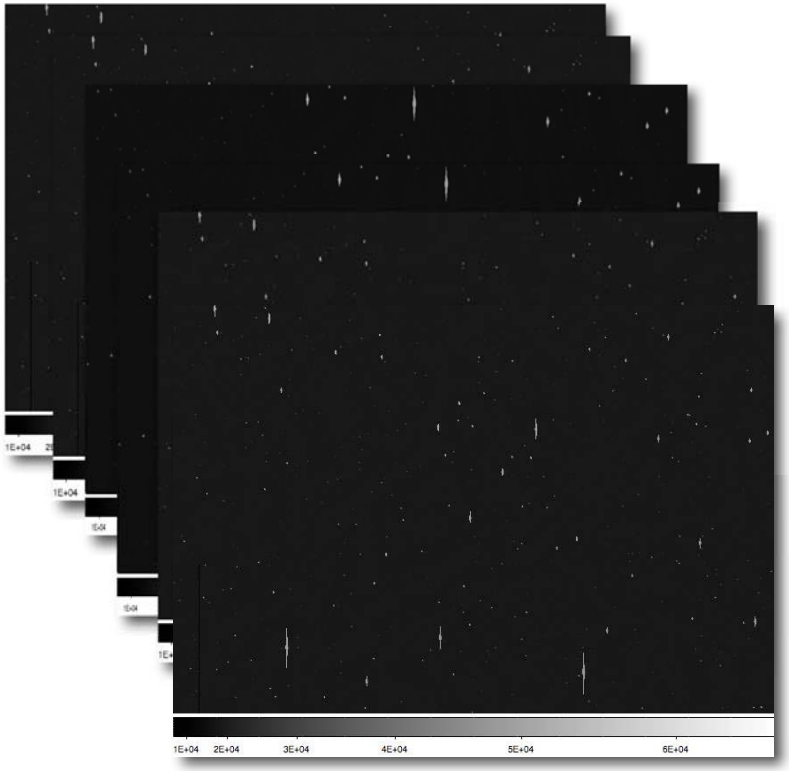
T_0+6

T_0+7

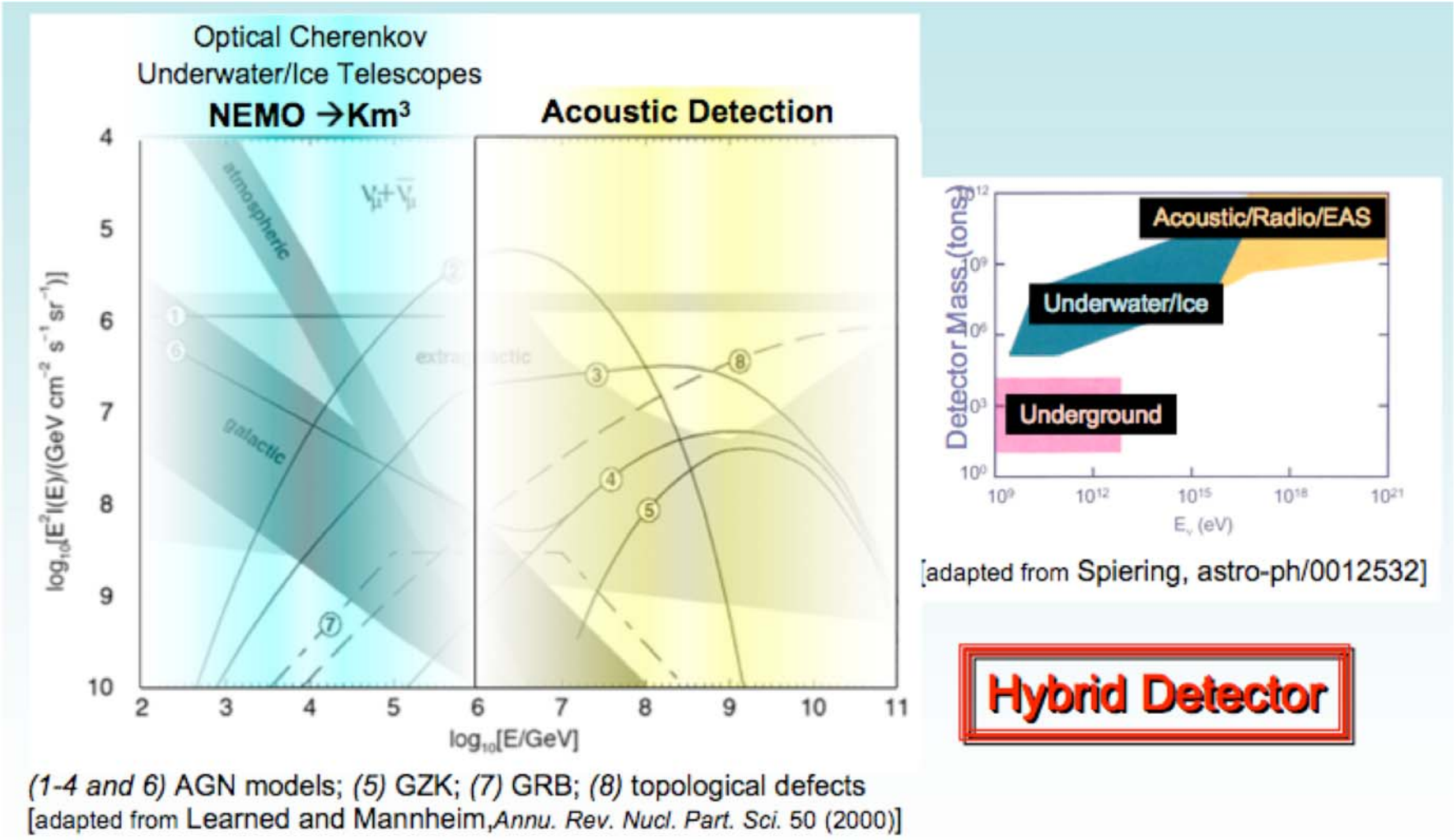
T_0+9

T_0+15

T_0+27

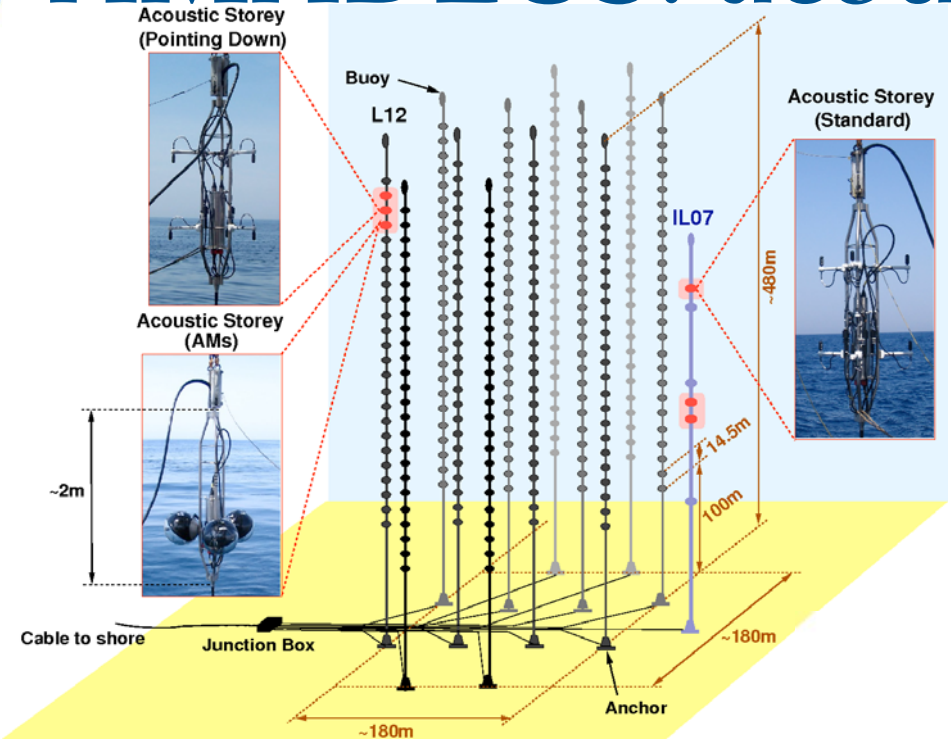


Acoustic detection of UHE νs

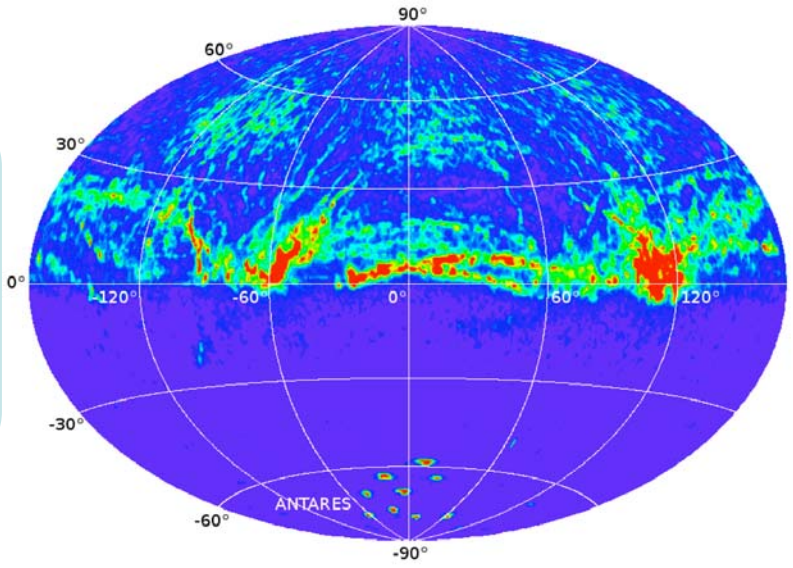


(1-4 and 6) AGN models; *(5)* GZK; *(7)* GRB; *(8)* topological defects
[adapted from Learned and Mannheim, *Annu. Rev. Nucl. Part. Sci.* 50 (2000)]

AMADEUS: acoustic detection



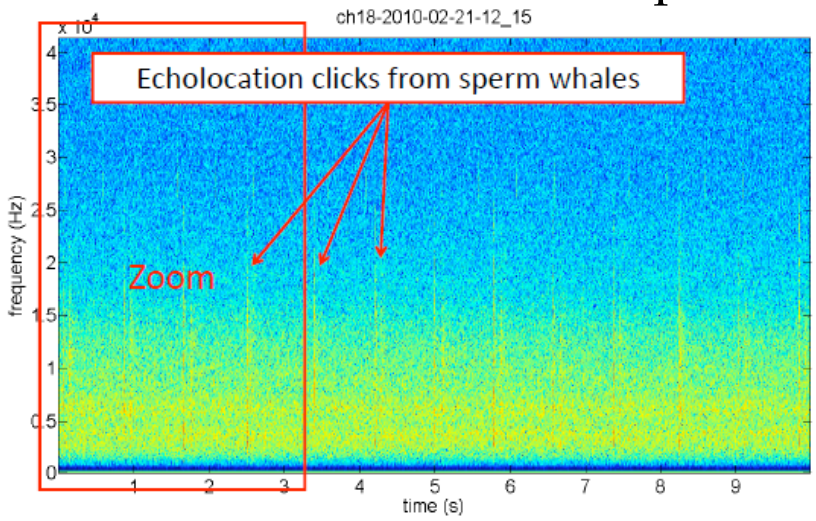
- Test bench to study the feasibility of a large acoustic UHE neutrino detector
- several hydrophones on 2 ANTARES lines
- study of acoustic environment and backgrounds
- particular effort for developing a reliable direction reconstruction

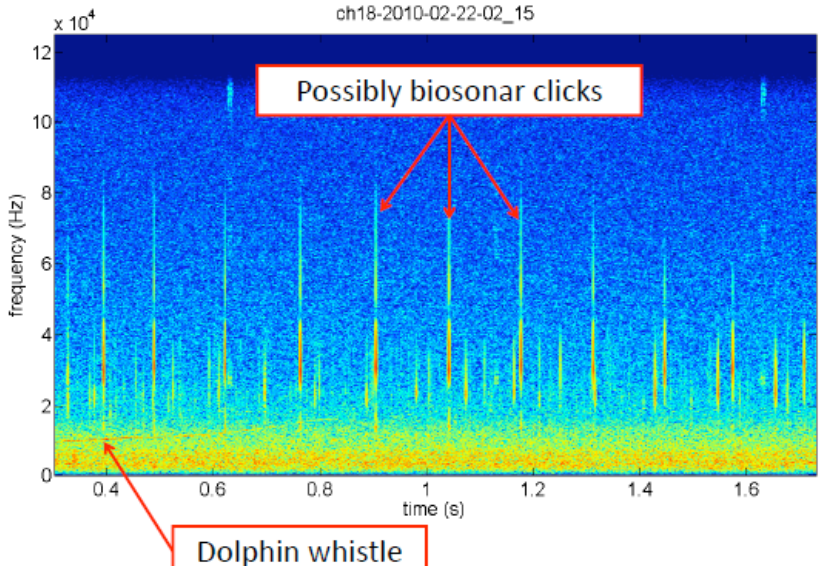


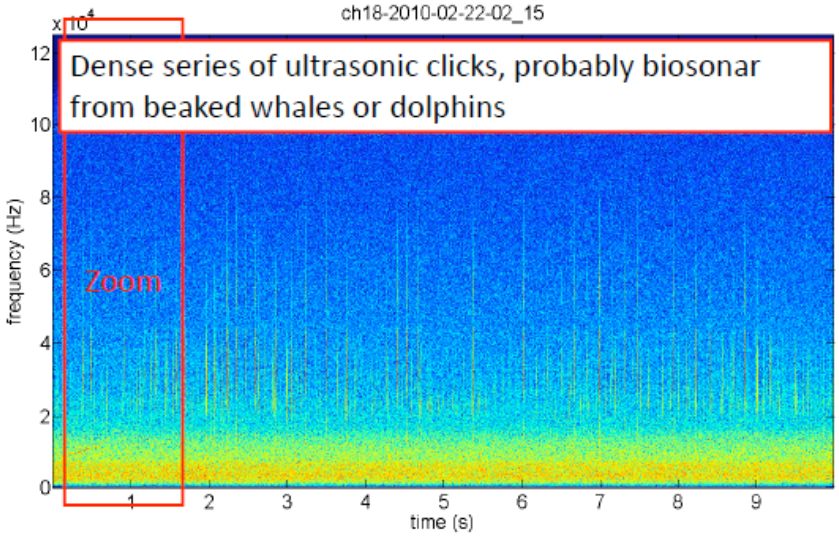
J. Aguilar *et al.*, NIM A 626-627, 128-143, 2011

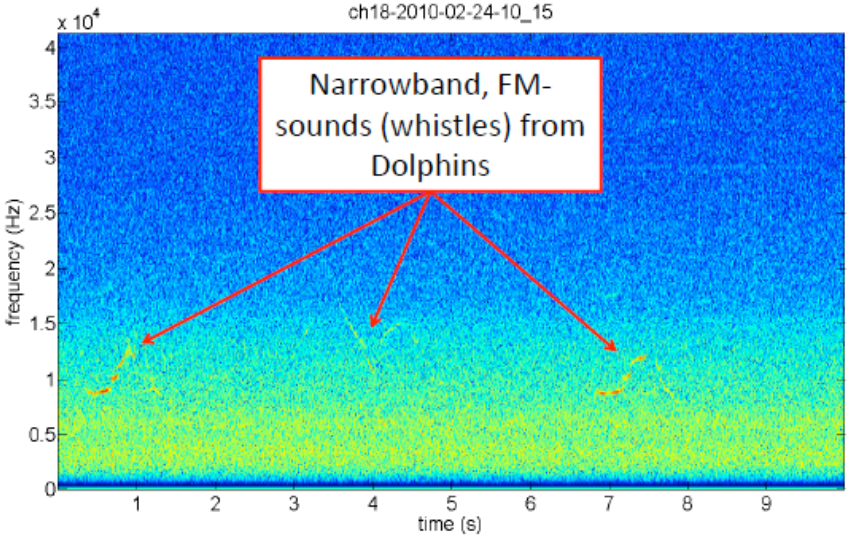
Deep sea acoustic background

The Mediterranean depths are much less silent than expected!









http://www.economist.com/blogs/babbage/2010/12/astroparticle_physics

The Economist

Science and technology

Babbage

Hang on, that's not a neutrino

Dec 1st 2010, 16:10 by J.P.

0 230 personn

PHYSICISTS are often accused by the public and other scientists of spending inordinate sums on fancy kit that does little apart from merely satisfying human curiosity. Besides stressing that there is nothing mere about knowledge, the boffins will typically respond by trotting out a long list of blue-sky projects that yielded serendipitous results, from microwave ovens to the internet. They can also offer plenty of examples of how their own research has aided colleagues in other fields, from climate science to, somewhat more improbably, marine biology.