Recent results of the ANTARES neutrino telescope

International Conference on High Energy Physics

Melbourne, July 2012

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on behalf of the ANTARES collaboration

CSIC

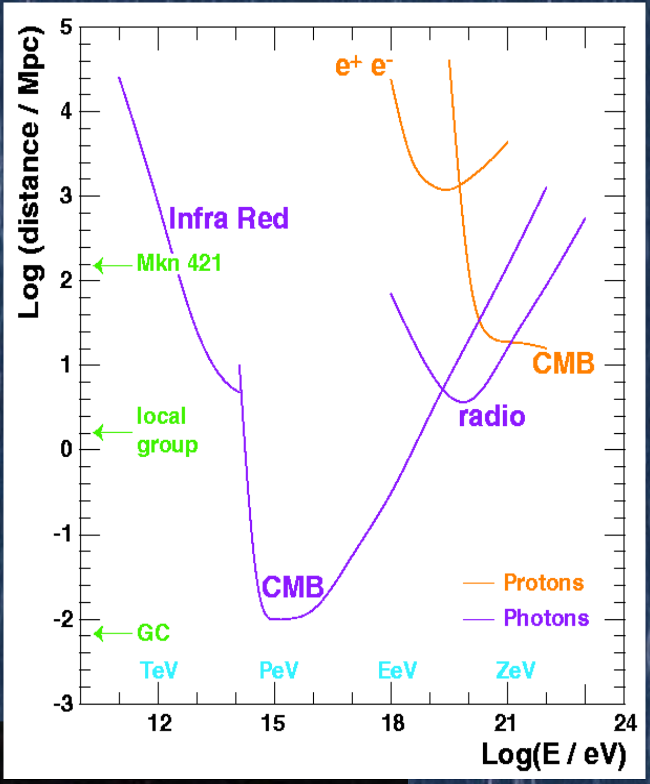
MultiDark
Multimessenger Approach
for Dark Matter Detection

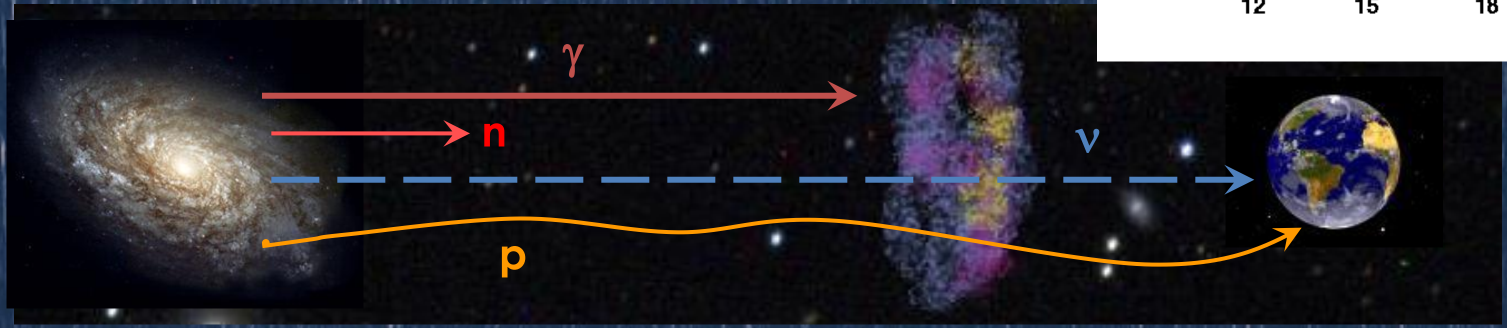
Neutrino Astronomy

- Advantages w.r.t. other messengers:
  - Photons: interact with CMB and matter
  - Protons: interact with CMB and are deflected by magnetic fields

- Drawback: large detectors (~GTon) are needed.

Photon and proton mean free range path





Production mechanism

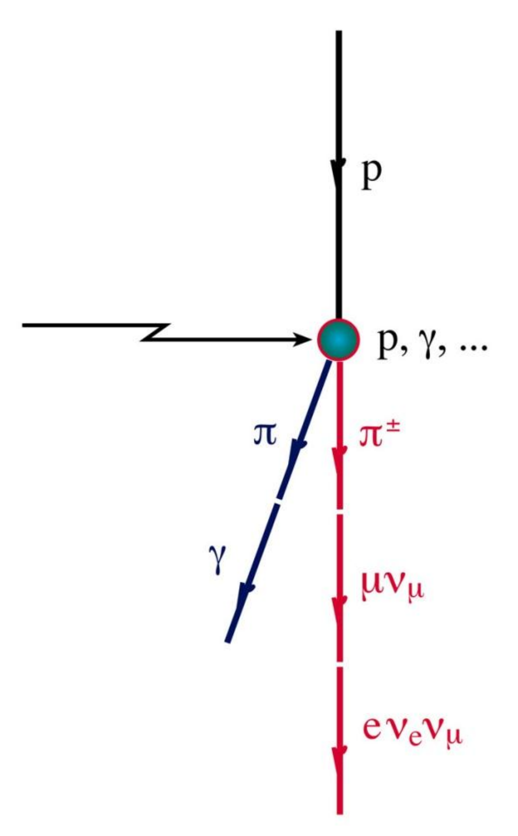
- Neutrinos are expected to be produced in the interaction of high energy nucleons with matter or radiation:

$$N + X \rightarrow p^{\pm}(K^{\pm}\ldots) + Y \rightarrow m^{\pm} + n_m(\bar{n}_m) + Y$$

$$\downarrow$$

$$e^{\pm} + \bar{\nu}_e(\nu_e) + \bar{\nu}_\mu(\nu_\mu)$$

Cosmic rays



- Moreover, gammas are also produced in this scenario:

$$N + X \rightarrow p^{0} + Y \rightarrow g\,g + Y$$

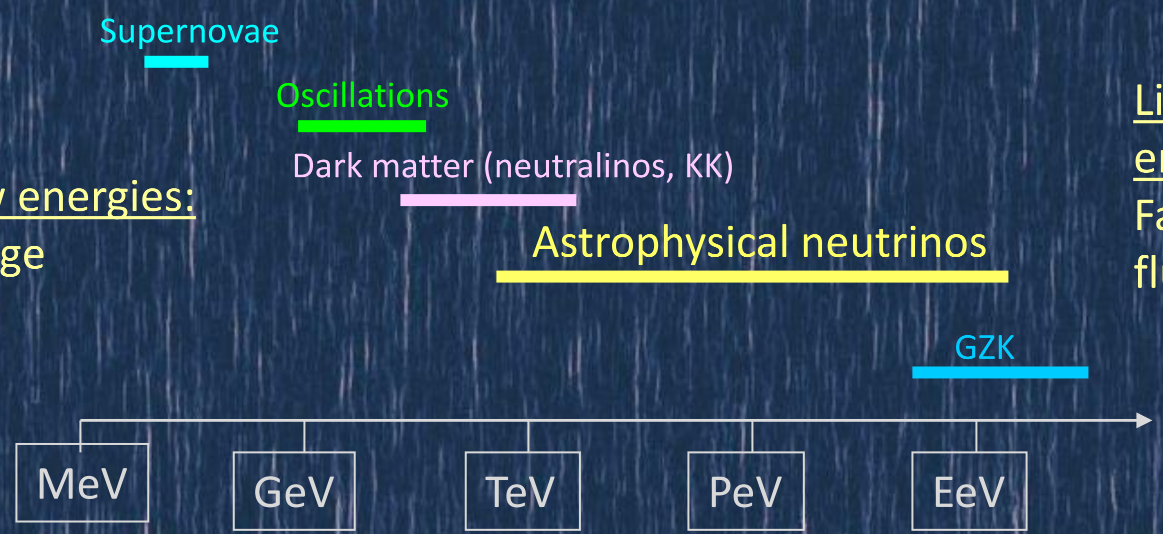
Gamma ray astronomy

Scientific scope

- Origin of cosmic rays
- Hadronic vs. leptonic signatures
- Dark matter

Detector size

Limitation at high energies:
Fast decreasing fluxes E^{-2}, E^{-3}

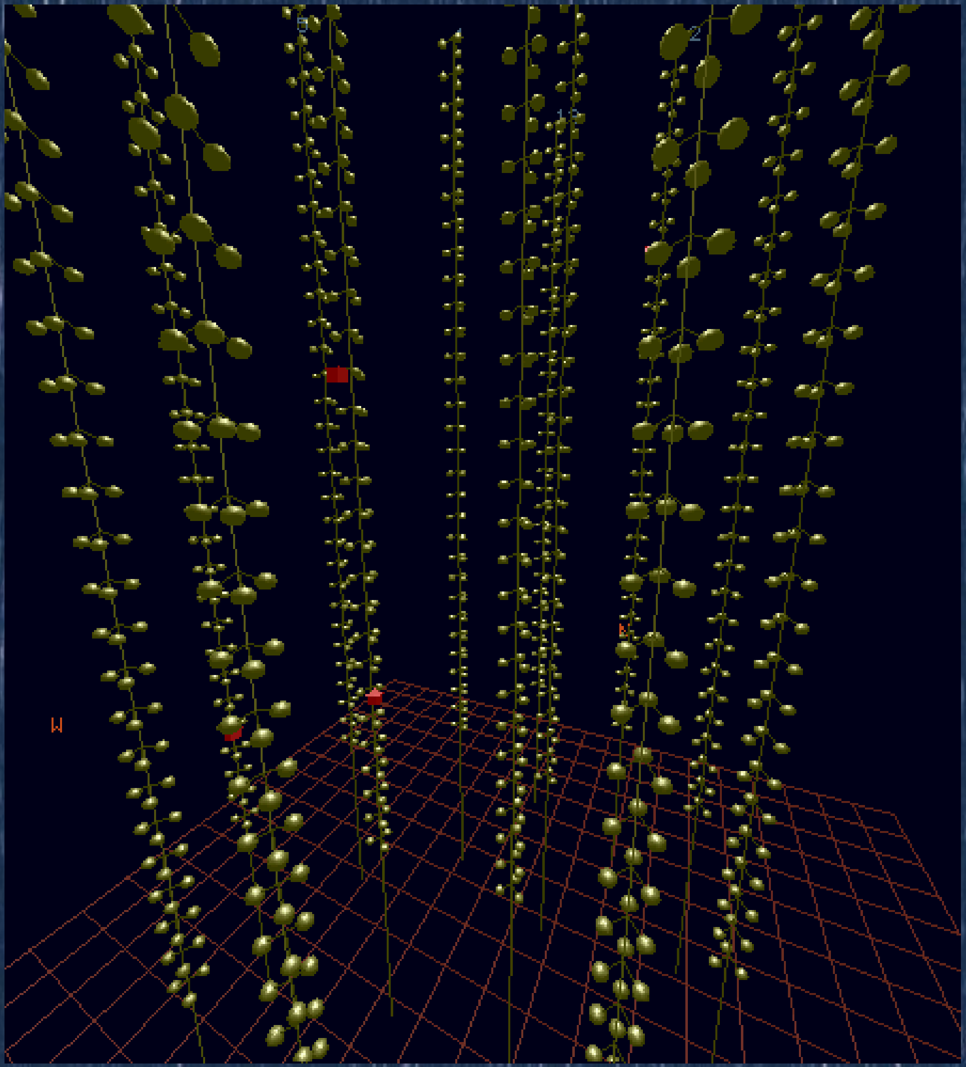


Limitation at low energies:
-Short muon range
-Low light yield
-^{40}K (in water)

Detector density

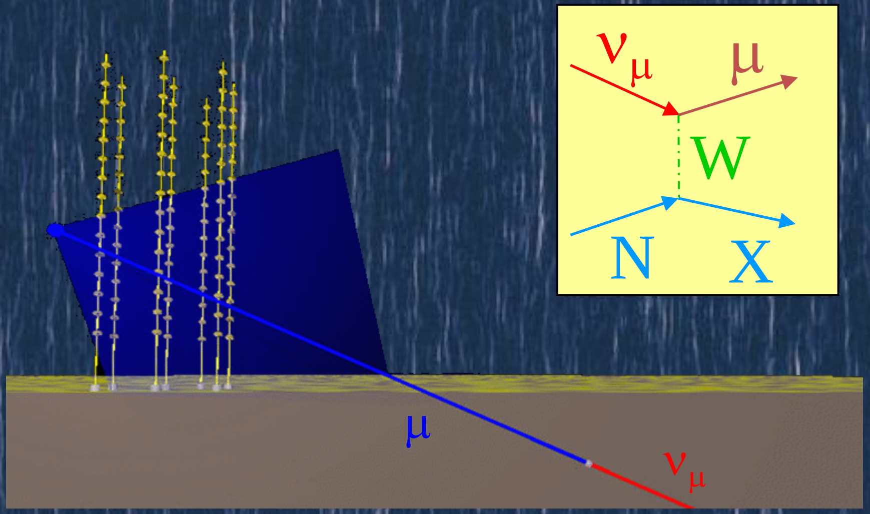
Other physics: monopoles, nuclearites, Lorentz invariance, etc...

Detection principle



1.2 TeV muon traversing ANTARES

- The neutrino is detected by the Cherenkov light emitted by the muon produced in the CC interaction.

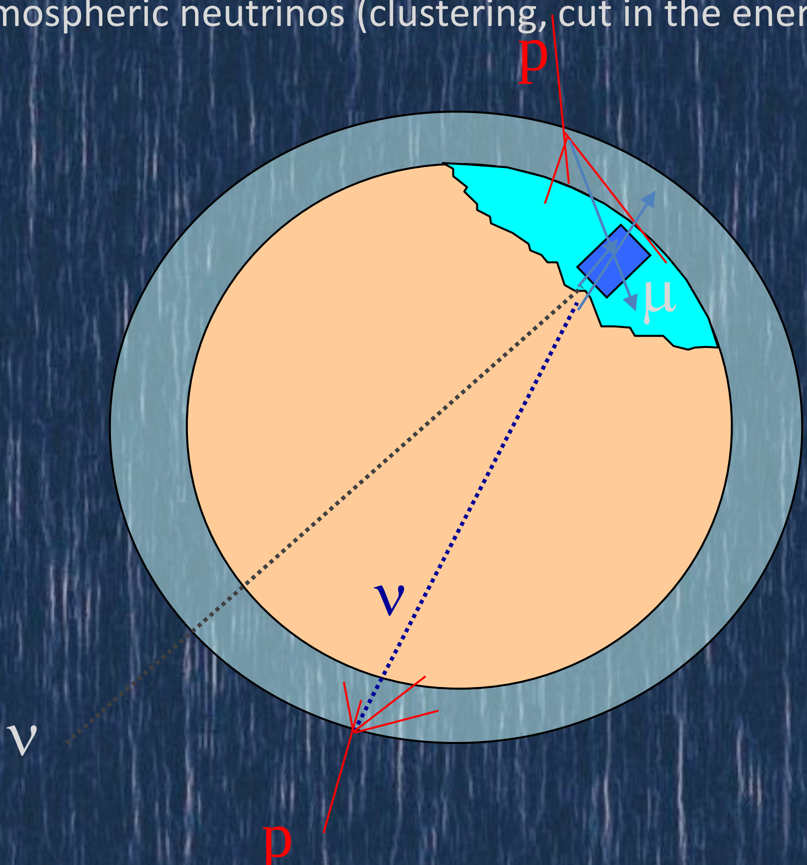


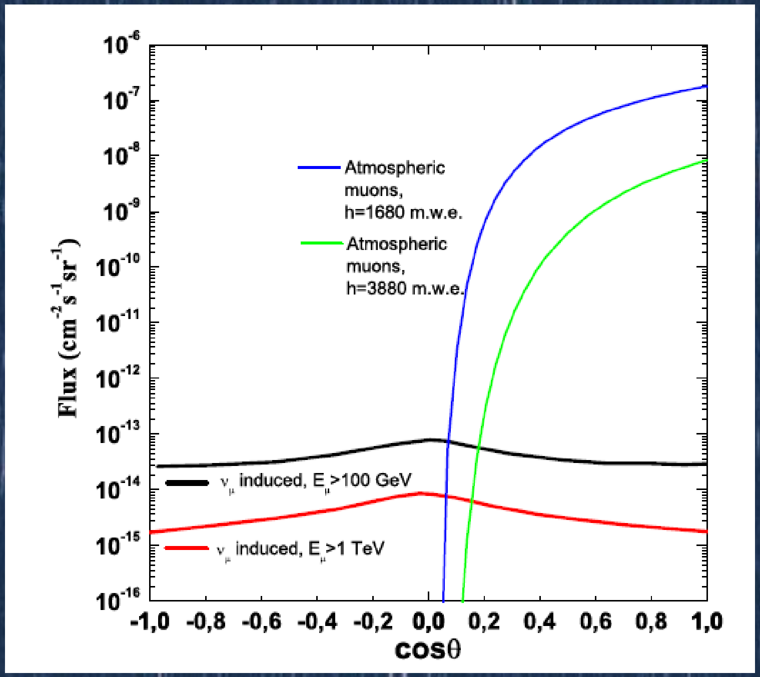
Background

- There are two kinds of background:
  - Muons produced by cosmic rays in the atmosphere (detector deep in the sea and selection of up-going events)
  - Atmospheric neutrinos (clustering, cut in the energy…)

$$p \to \pi^{+}(+K^{+}\ldots) \to \mu^{+} + \nu_{\mu}$$
$$\mapsto e^{+} + \overline{\nu}_{\mu} + \nu_{e}$$

$$n \to \pi^{-}(+K^{-}\ldots) \to \mu^{-} + \overline{\nu}_{\mu}$$
$$\mapsto e^{-} + \nu_{\mu} + \overline{\nu}_{e}$$





Eurocup 2008
Vienna

Many things have happened in the meantime…

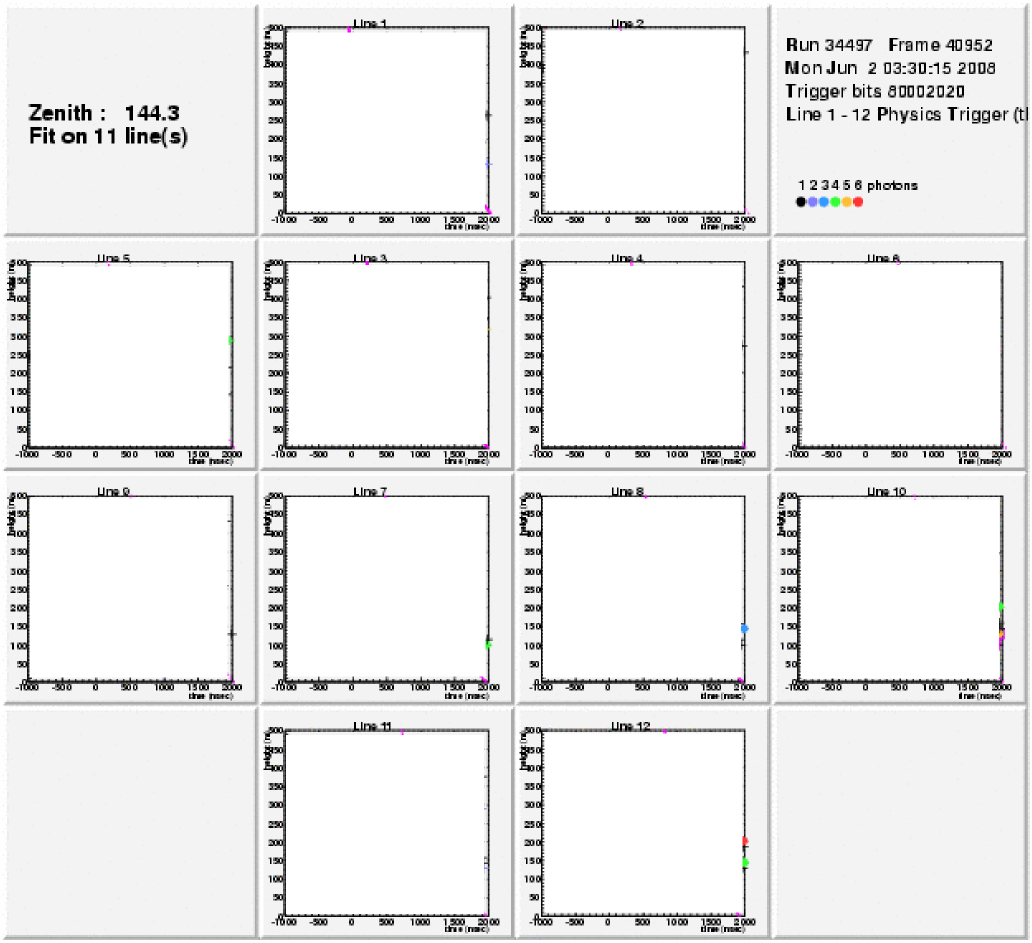
World Cup 2010
Johannesburg

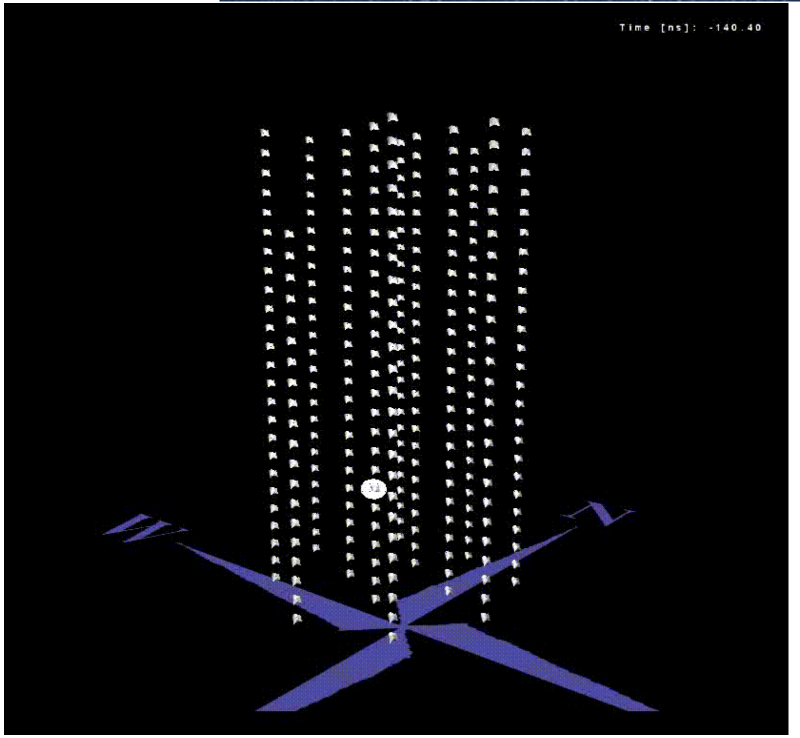
Eurocup 2012
Kiev

…but today we'll concentrate on neutrinos

Multi-muon event

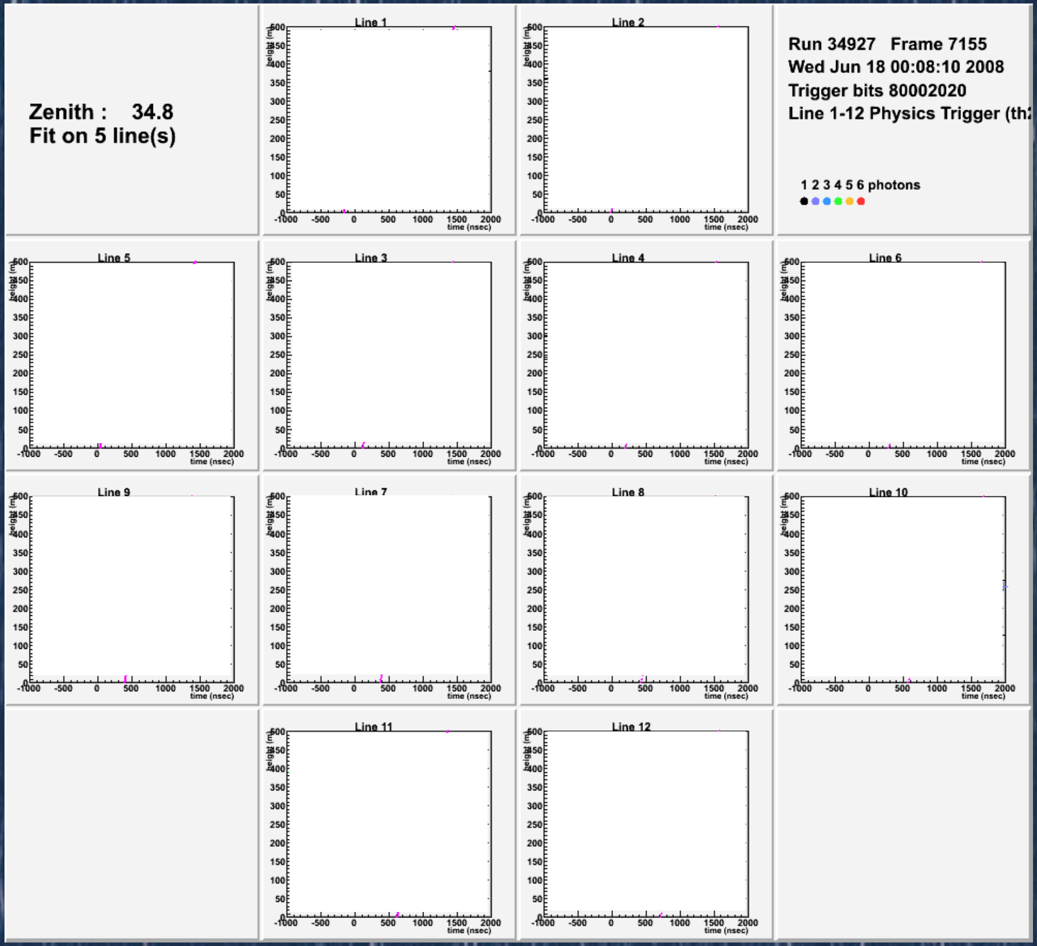
Example of a reconstructed down-going muon, detected in all 12 detector lines:

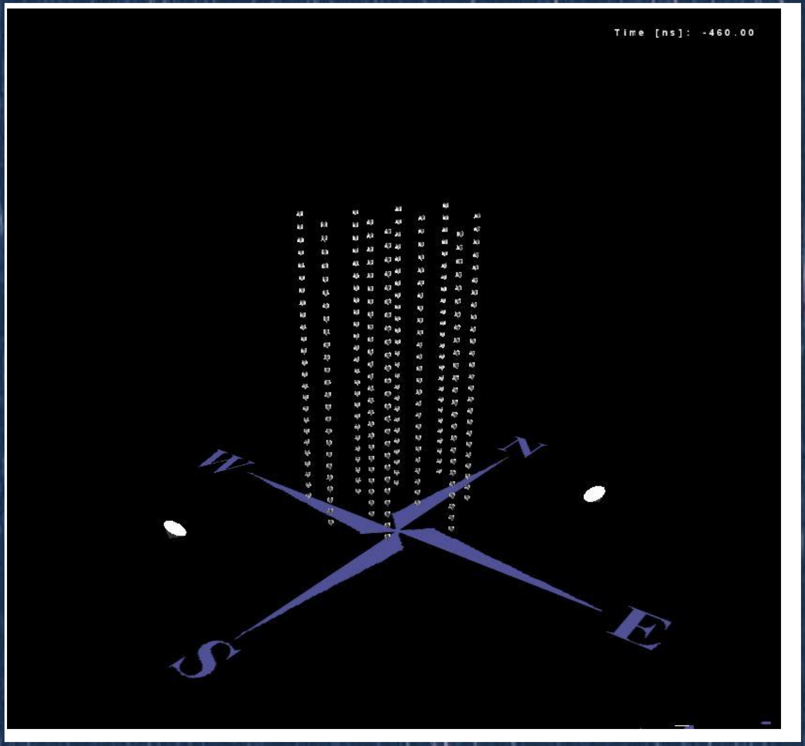




Neutrino candidate

Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:



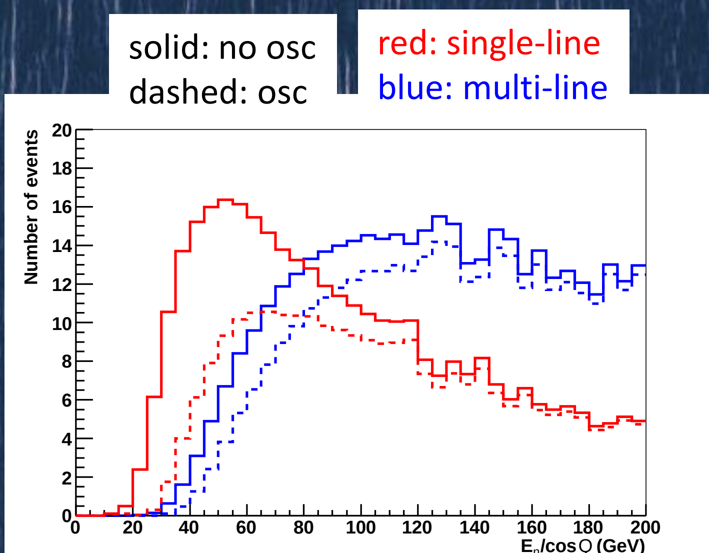


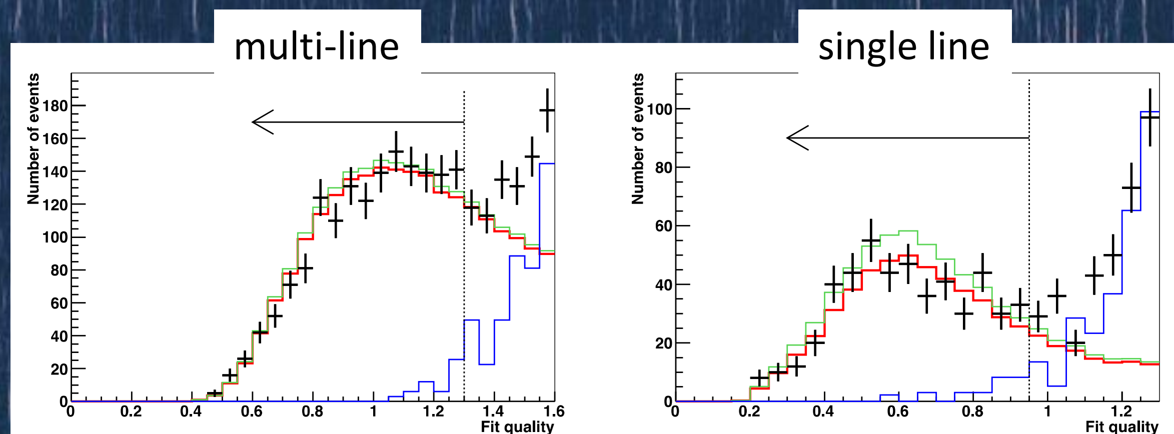
Oscillations: method

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{32} \sin^2\left(\frac{1.27\Delta m^2_{32} L}{E_\nu}\right) =$$

$$= 1 - \sin^2 2\theta_{32} \sin^2\left(\frac{16200\ \Delta m^2_{32} \cos\Theta}{E_\nu}\right).$$

No azimuth information is needed →
single-line reconstruction is enough →
lower energy threshold (20 GeV) →
oscillation effect observable!





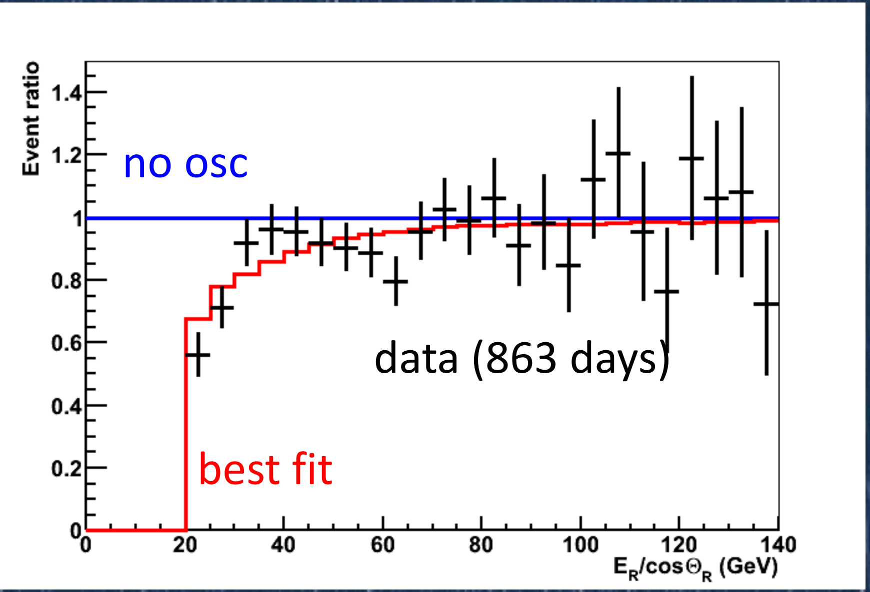
	Multi-line			Single-line		
	Data	ν MC	μ MC	Data	ν MC	μ MC
All	$1.42 \cdot 10^8$	8755	$1.23 \cdot 10^8$	$1.51 \cdot 10^8$	8242	$1.10 \cdot 10^8$
Nstorey > N_{cut}	$1.33 \cdot 10^8$	8248	$1.18 \cdot 10^8$	$4.44 \cdot 10^7$	1260	$3.03 \cdot 10^7$
Fit boundary	$1.32 \cdot 10^8$	8150	$1.17 \cdot 10^8$	$4.31 \cdot 10^7$	1242	$2.93 \cdot 10^7$
$\cos\Theta_R > 0.15$	$2.74 \cdot 10^6$	5512	$1.84 \cdot 10^6$	$7.97 \cdot 10^5$	1116	$6.96 \cdot 10^5$
Fit quality cut	1632 ± 40	1971 ± 6 1910 ± 6	52 ± 12	494 ± 22	651 ± 3 557 ± 3	28 ± 9

Oscillations: result

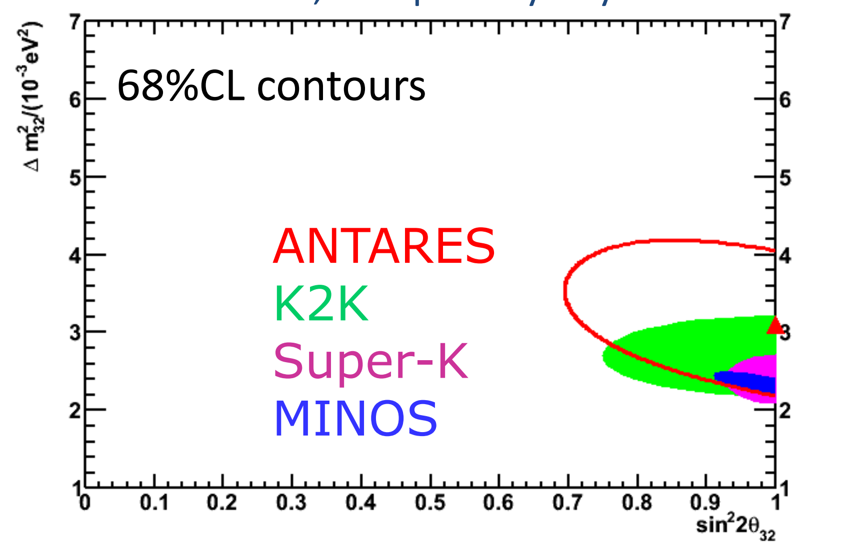
Systematic uncertainties:

- Absorption length: ±10%
- Detector efficiency: ±10%
- OM angular acceptance
- Spectral index of ν flux: ±0.03%

5% error on slope vs $E_R/\cos\Theta_R$



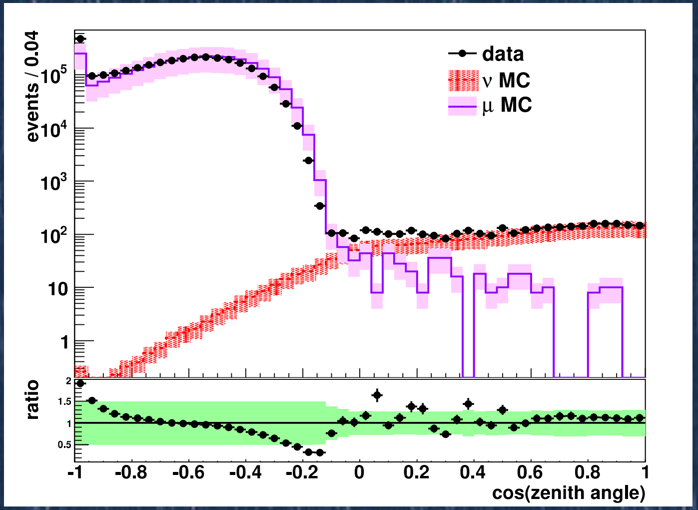
arXiv:1206.0645, accepted by Physics Letters B

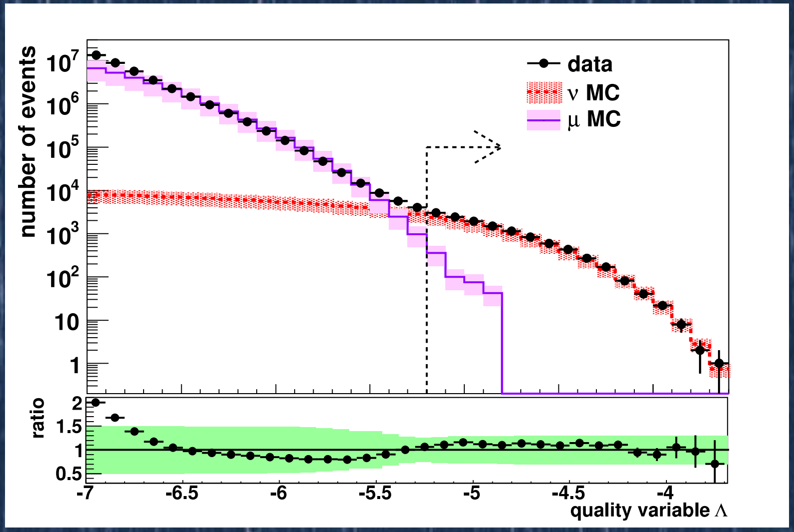


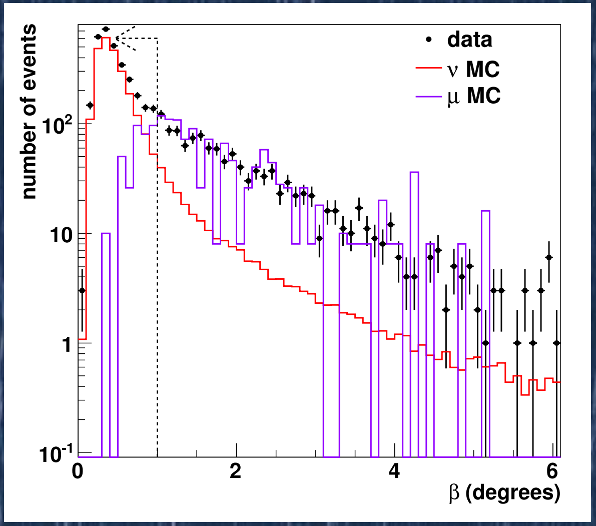
$\Delta m^2 = (3.1 \pm 0.9)\ 10^{-3}$ (assuming maximal mixing)

Point source search: selection cuts

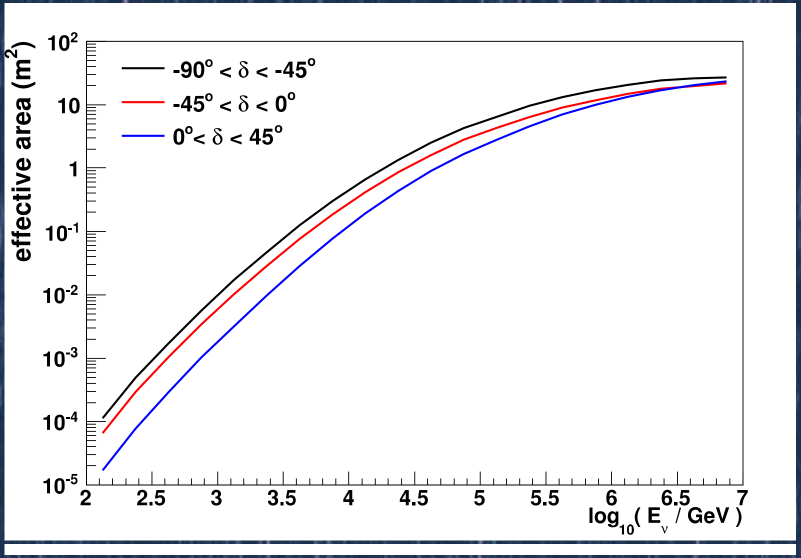
- Good agreement between data and Monte Carlo (detector understood!)
- For PS analysis, selection based on
  - Zenith angle (upgoing events)
  - Quality of reconstruction
  - Estimated angular error in reconstructed track
- Energy information (number of hits) used in the PDF





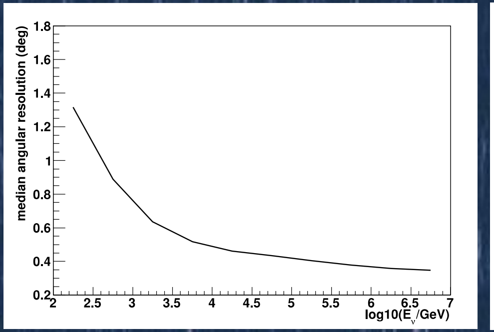


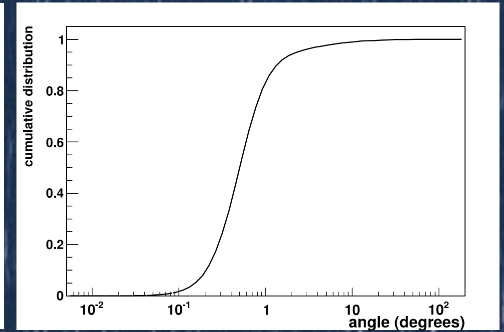
Point source search: detector performance



Effective area

- For E_ν<10 PeV, A_{eff} grows with energy due to the increase of the interaction cross section and the muon range.
- For E_ν>10 PeV the Earth becomes opaque to neutrinos.

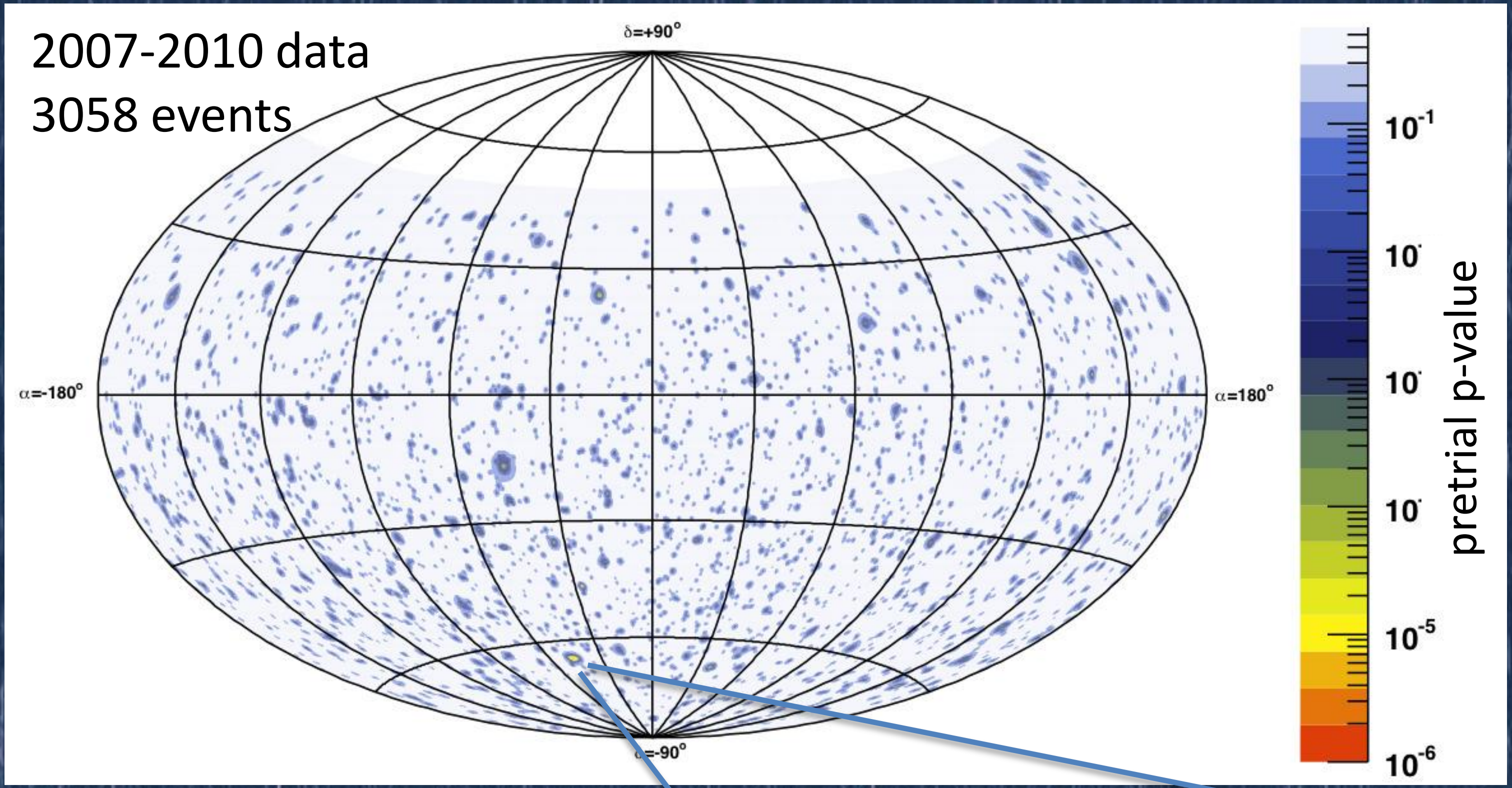


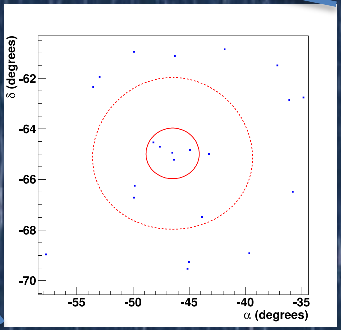


Angular resolution

- For E_ν < 10 TeV, the angular resolution is dominated by the ν-μ angle.
- For E_ν > 10 TeV, the resolution is limited by track reconstruction errors
- For E^{-2}: median=0.46 ± 0.10 deg

Point source search: skymap





Most significant cluster at:
RA = −46.5°
δ = −65.0°

N_{sig} = 5
Q = 13.02
p-value = 0.026
Significance = 2.2 σ

Point source search: list of candidates

- We look in the direction of a list of 51 candidate sources.
- Selection criteria: mostly based on γ-ray flux + visibility)
- Result compatible with only-background hypothesis

Flux upper limit on E^{-2} spectrum (in 10^{-8} GeV^{-1} cm^{-2} s^{-1} units)

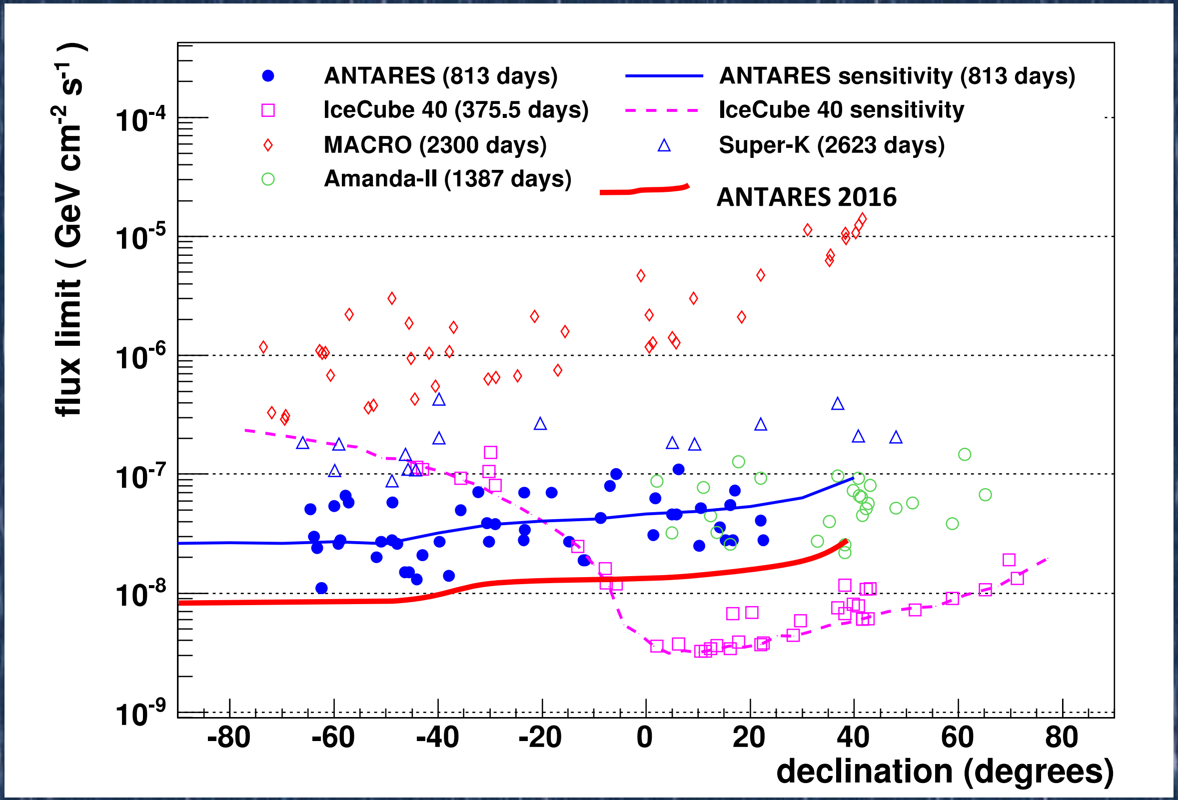
Sources with lhte owest p-values

Source name	$\alpha_s\,[^\circ]$	$\delta_s\,[^\circ]$	p	ϕ_ν^{90}
HESS J1023-575	155.83	-57.76	0.41	6.6
3C 279	-165.95	-5.79	0.48	10.1
GX 339-4	-104.30	-48.79	0.72	5.8
Cir X-1	-129.83	-57.17	0.79	5.8
MGRO J1908+06	-73.01	6.27	0.82	10.1
ESO 139-G12	-95.59	-59.94	0.94	5.4
HESS J1356-645	-151.00	-64.50	0.98	5.1
PKS 0548-322	87.67	-32.27	0.99	7.1
HESS J1837-069	-80.59	-6.95	0.99	8.0

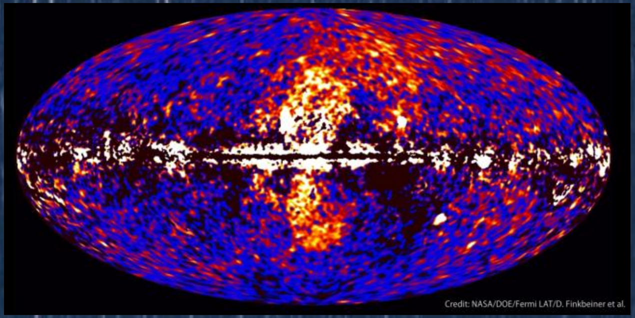
Most significant case: HESSJ1023-575 (p-value=41%)

Point source search: flux limits

- For most of the Southern-sky, ANTARES has the best limits
  (Moreover: IceCube threshold for SH ~1 PeV, while for Galactic sources, a cut-off in the energy spectrum is expected)
- By 2016, limits expected to improve by a factor 2.5



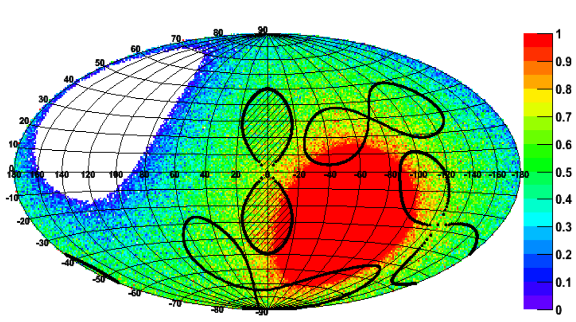
Fermi Bubbles



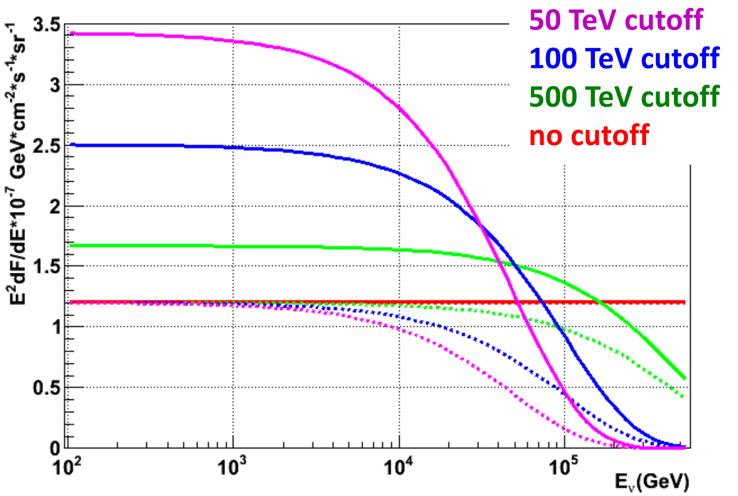
According to Villante & Vissani [Phys. Rev. D 78 (2008) 103007]

- $\Phi_{nu} \sim 1/2.5\Phi_{gamma} \sim E^{-2} 1.2 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}
- Neutrino cutoff may be obtained from the proton cut off $x_{nu} \sim x_p/20$ (50 TeV-500 TeV)

On/OFF source analysis: background estimated from average of three "bubbles" shifted in time



preliminary



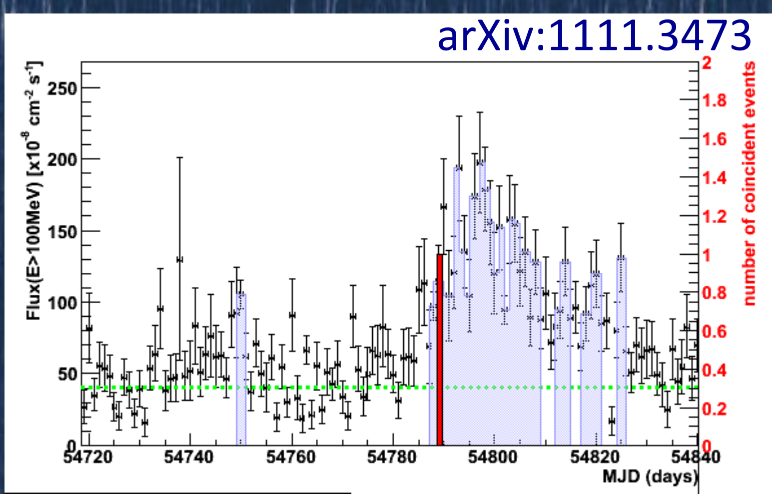
Nback (OFF) = 90±5(stat)±3(sys)
N_{ON} = 75 events → NO SIGNAL

Fully hadronic scenario with no cutoff excluded

Correlations with γ and X-ray flares

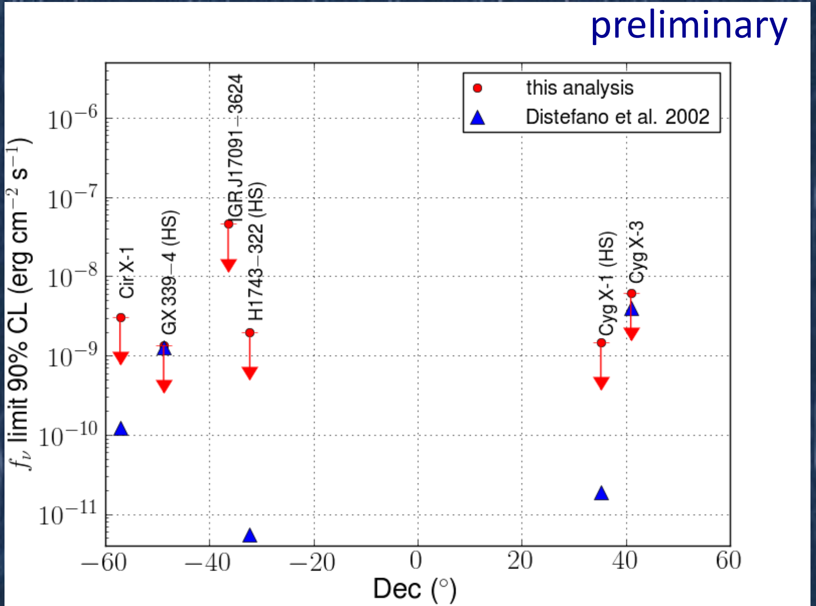
Blazars: AGNs with a jet pointing to us

- 10 flaring blazars in 2008: PKS0208-512, AO0235+164, PKS1510-089, 3C273, 3C279, 3C454.3, OJ287, PKS0454-234, Wcomae, PKS2155-304
- For 9 sources: 0 events
- 3C279: 1 event compatible with the source direction ($\Delta\alpha$=0.56º) and time distribution
- Post trial value 10%
- Upper-limit on the neutrino fluence



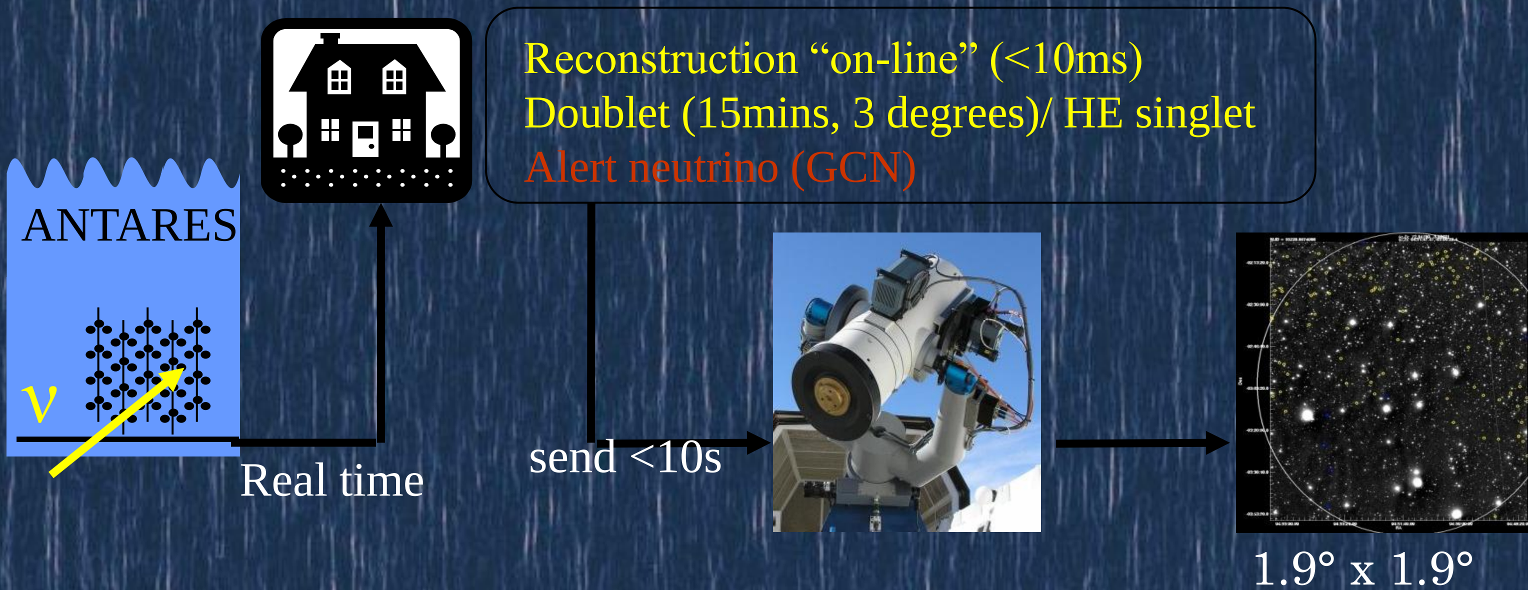
Microquasars: Binary system of compact star + normal star accreting to the former

- 6 flaring microquasars in 2007-2010: Circinus X-1, GX339-4, H 1743-322, IGRJ17091-3624, Cygnus X-1, Cygnus X-3
- No neutrinos found in coincidence with outbursts



TaToO: Telescopes and ANTARES Target of Opportunity

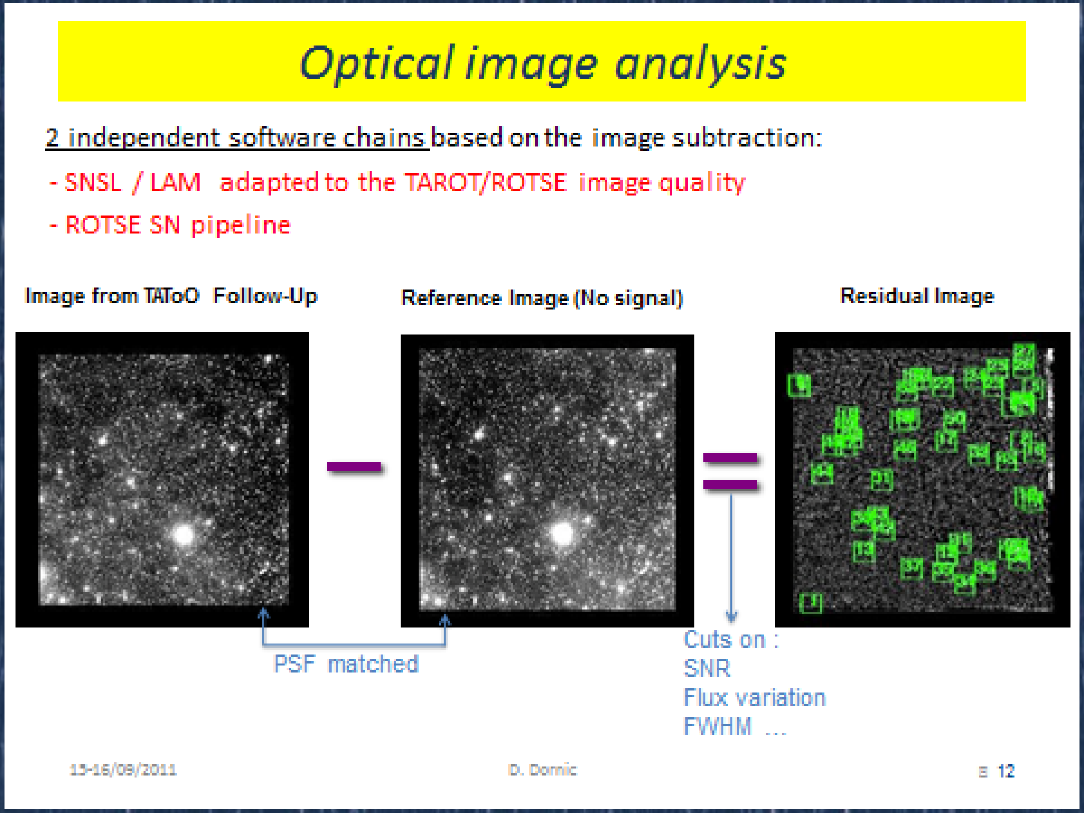
<u>TAToO</u>: optical follow-up of neutrino alerts in order to search for transient sources (GRBs, choked GRBs, AGN flares…)

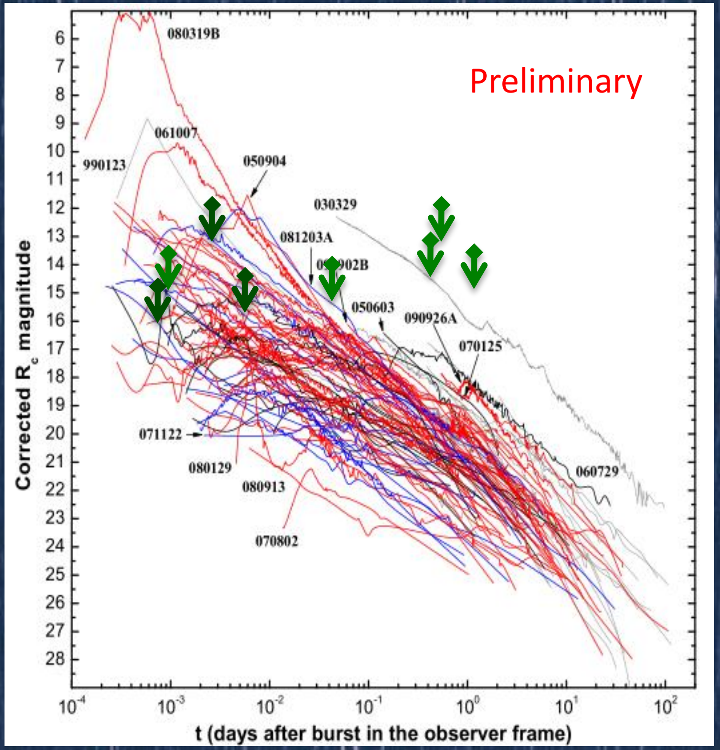


Large sky coverage (>2π sr) + high duty cycle
Improved sensitivity (1 neutrino⇒ 3 sigma discovery)
No hypothesis on the nature of the source
Independent of availability of external triggers

TAToO: GRB analysis

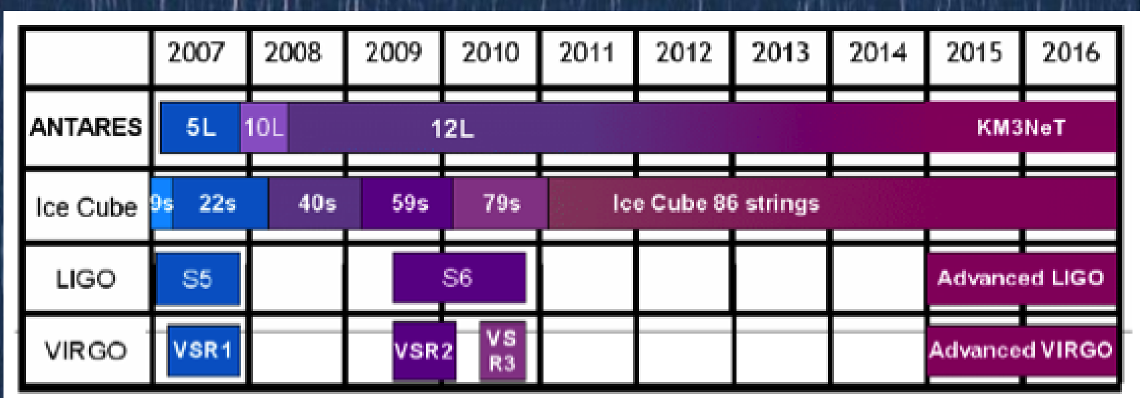
For each neutrino alert -> search for counterpart in optical originating from GRB (54 alerts sent since mid 2009)

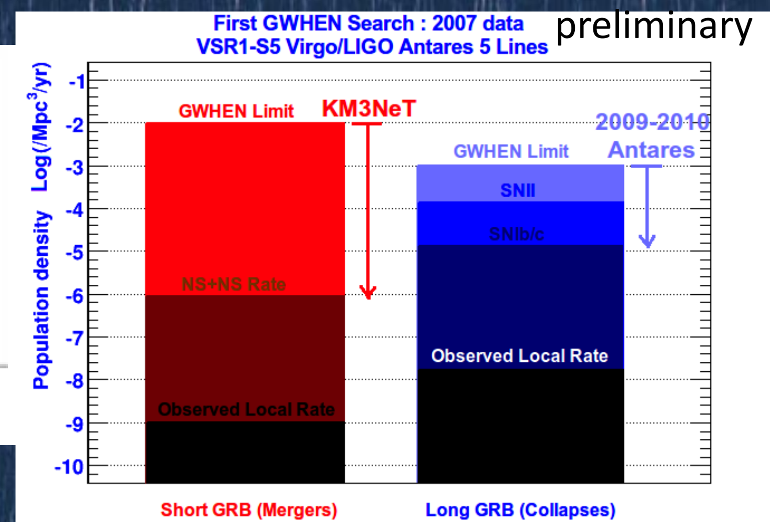




Correlation with gravitational waves

- Several sources can produce both GW and HE neutrinos: GRBs, micro-quasars, SGR…)
- Joint search → Improvement in sensitivity
- Hidden sources v.g (GRBs with choked jets…) are also interesting cases



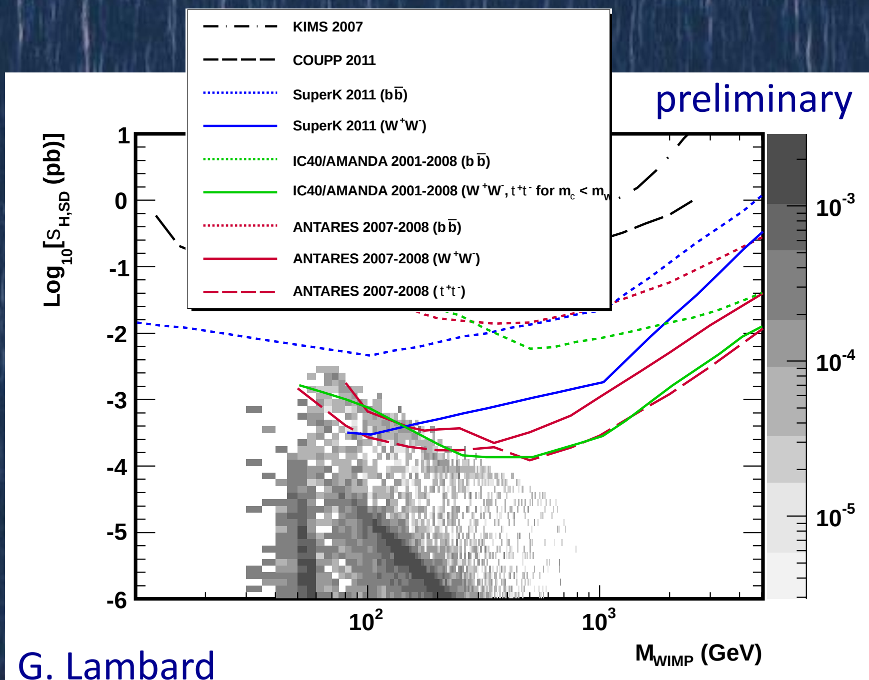


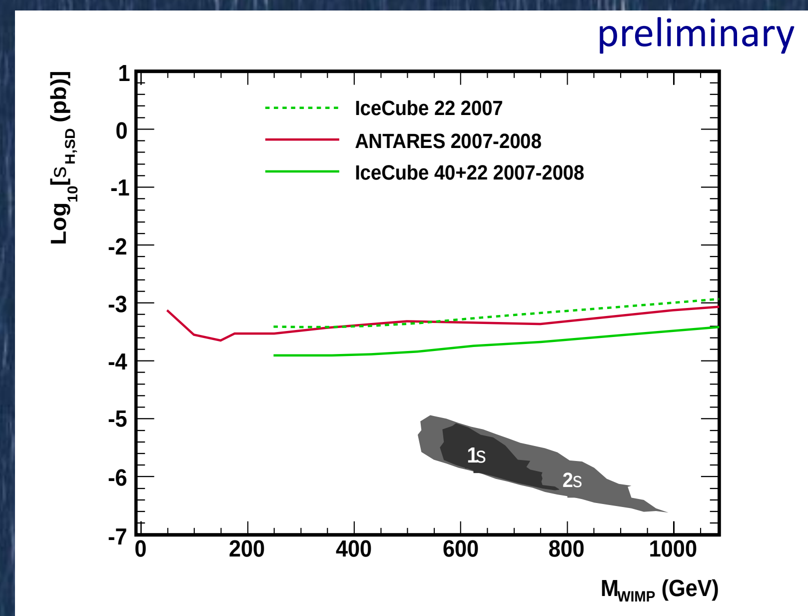
T_{obs}~ 100 days

Results: No significant correlation in 2007 data (ANTARES 5L + LIGO + VIRGO) arXiv:1205.3018v2
Limits on distance occurrence of NS-BH and NS-NS mergers

Dark matter

- WIMPs (neutralinos, KK particles) accumulate in massive objects like the Sun, the Galactic Center, dwarf galaxies…
- The products of such annihilations would yield "high energy" neutrinos, which can be detected by neutrino telescopes
- A signal would be a clean indication of DM (no plausible astrophysical explanation)

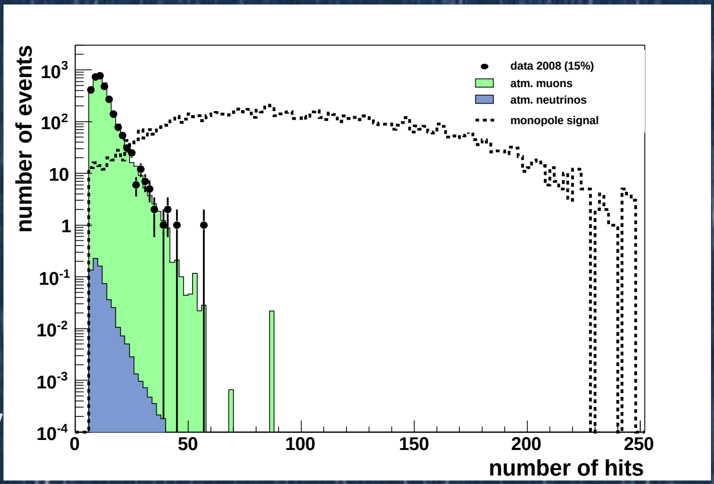




More details on specific talk in this afternoon…

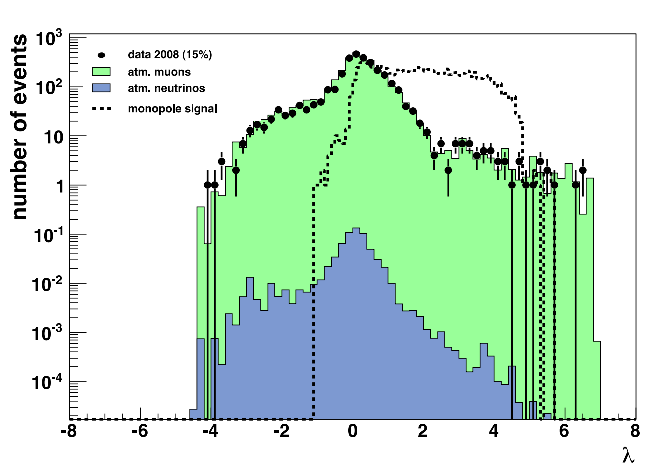
Magnetic monopoles

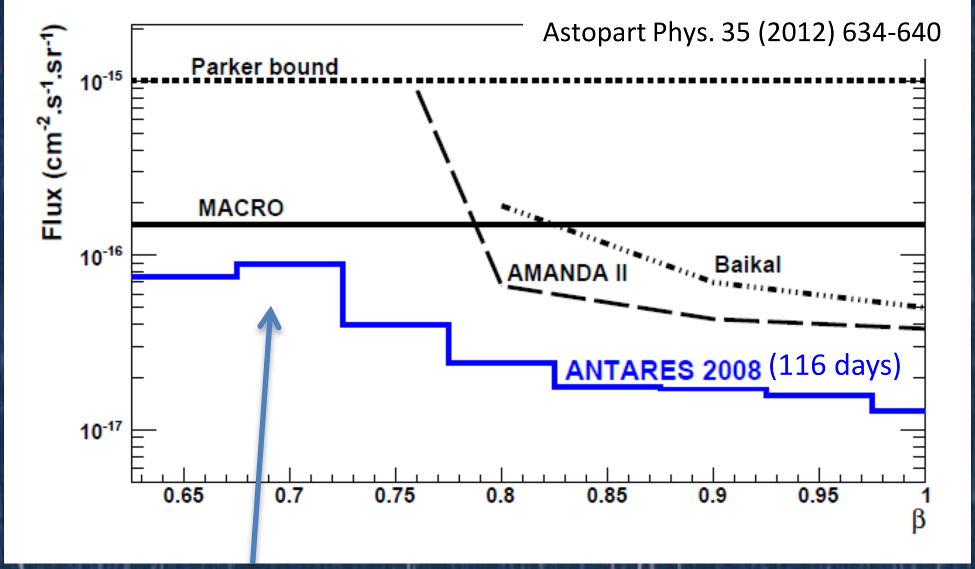
- Requirement in certain sponaneously broken gauge theories (‘Hooft and Poliakov, 1974)
- Two emission mechanisms:
  - -β>0.74 (Cherenkov threshold) direct emission (~8500 times photon yield wrt muons)
  - -β>0.51: ionization → Cherenkov from delta rays
- Selection based on number of hits and velocity (only upgoing events used)



$$\lambda = \log\left(\frac{Q_t(\beta_{rec} = 1)}{Q_t(\beta_{rec} = free)}\right)$$

Velocity used as a free parameter





One event found (compatible with background)

Summary

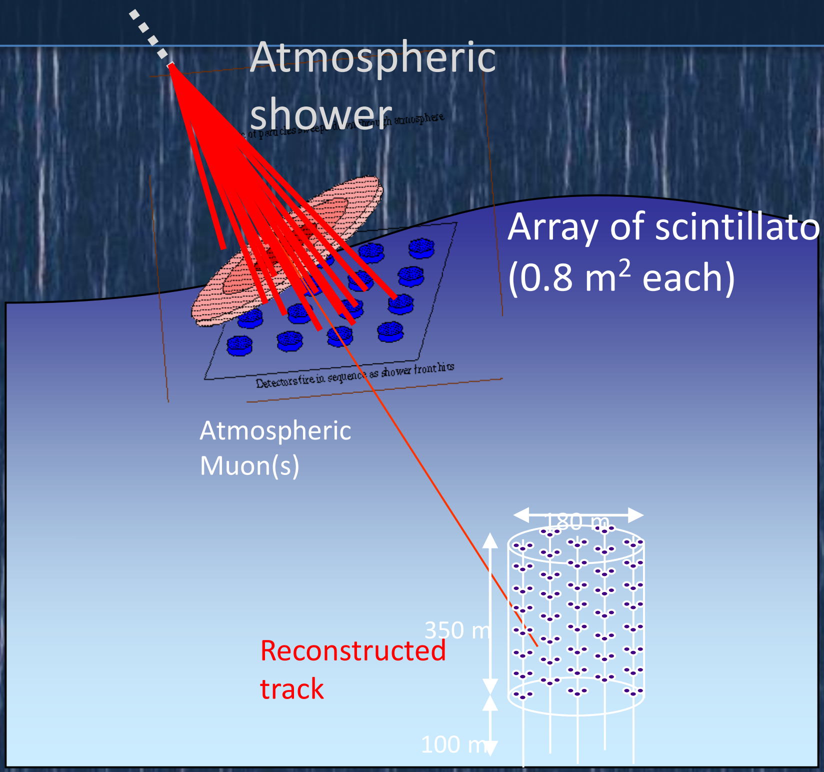
- Neutrino astronomy is becoming a powerful tool for Astrophysics and Particle Physics
- ANTARES has already been completed and is taking data for more than four years.
- Rich physics output already here: search for point-like sources, diffuse fluxes, dark matter, GRBs, flaring sources, monopoles, nuclearites, correlations with GWs, correlations with UHECRs…)

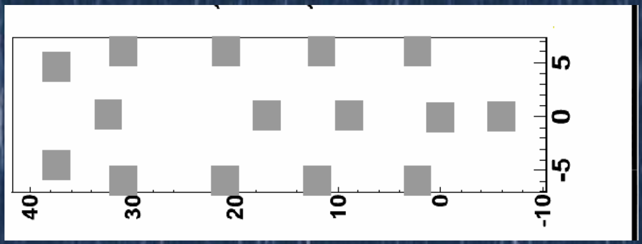
The technical success of ANTARES paves the way for the cubic kilometer detector in the Mediterranean Sea: KM3NeT

Still looking for Austral neutrinos!

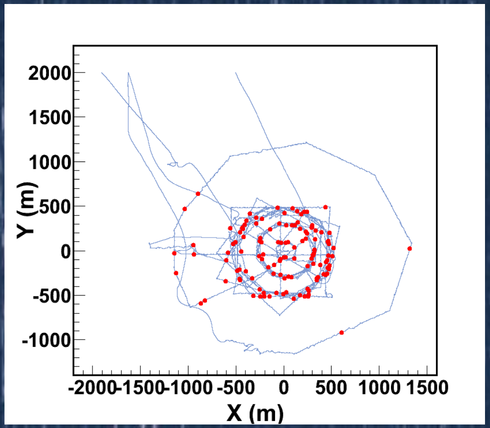
Backup

Surface array

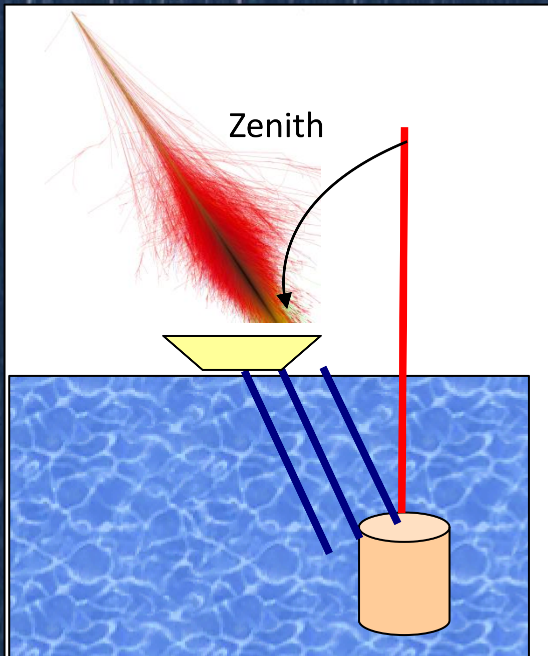


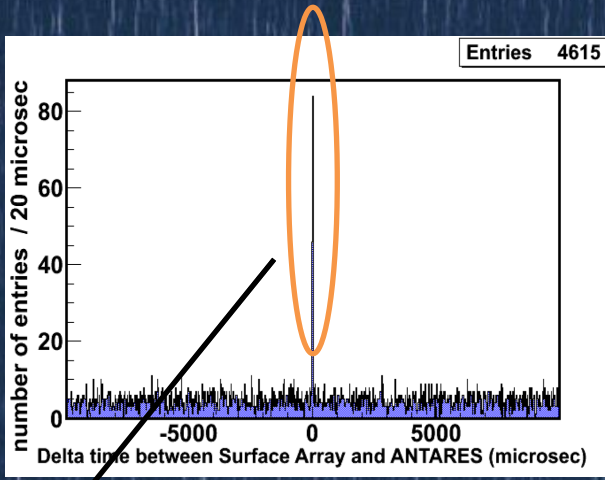


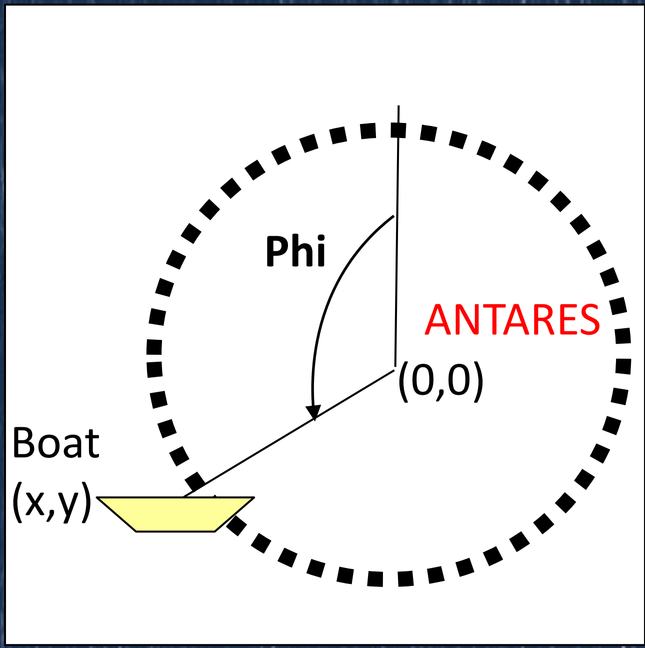
1st campaign 17-23 Oct
15 Detection units

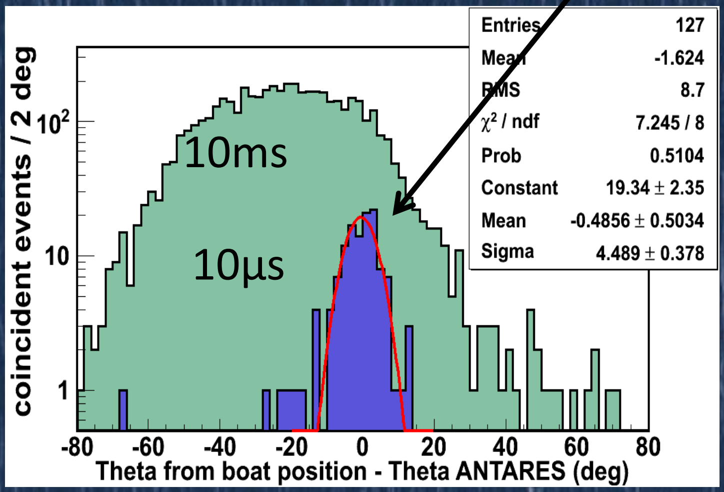


Surface array







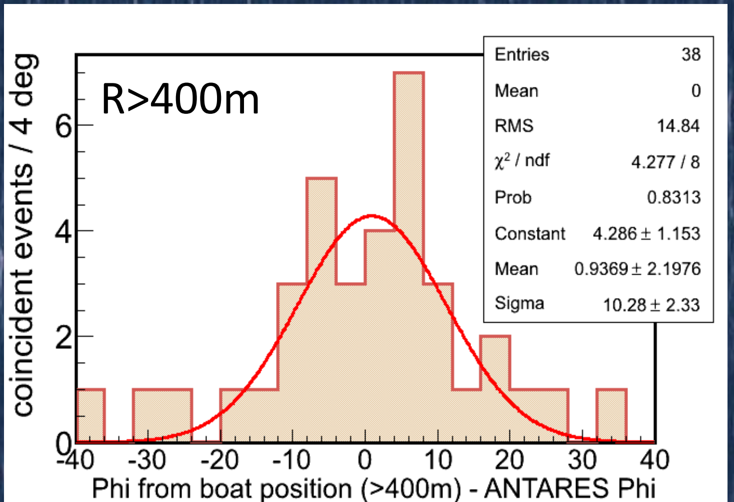


<u>Constraints</u>

Zenith: -0.5±0.5°

Azimuth: 0.9±2.2°

5 more days in the summer 2012



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