The Abdus Salam International Centre for Theoretical Physics

2246-9

Workshop on Cosmic Rays and Cosmic Neutrinos: Looking at the Neutrino Sky

20 - 24 June 2011

ANTARES and KM3NeT

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Neutrino Telescopes in the Mediterranean Sea

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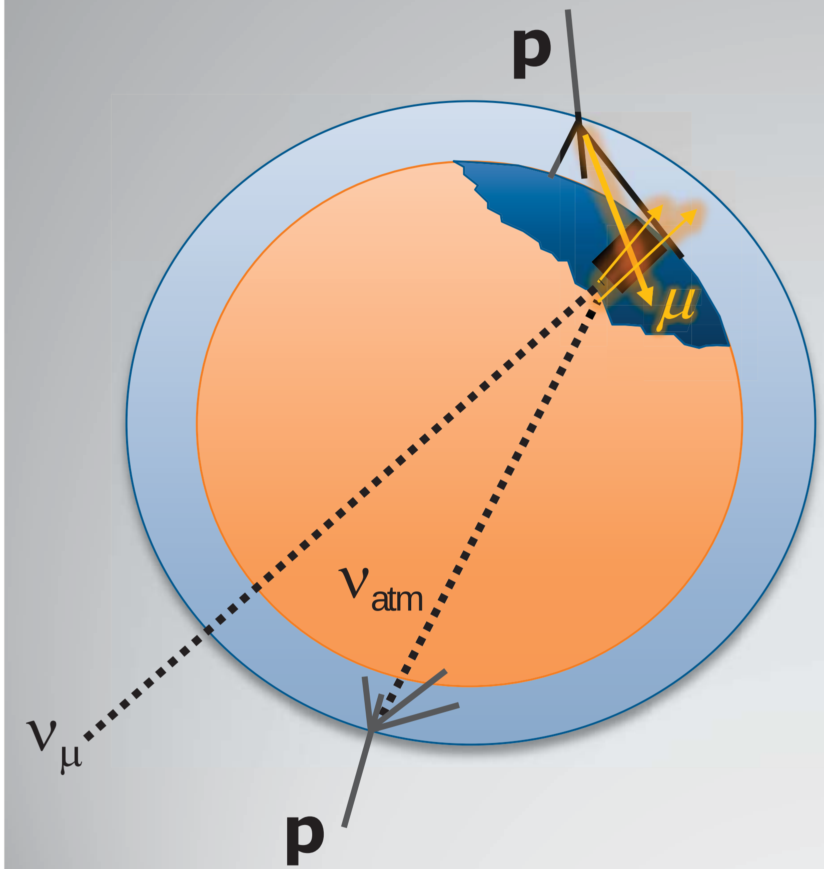
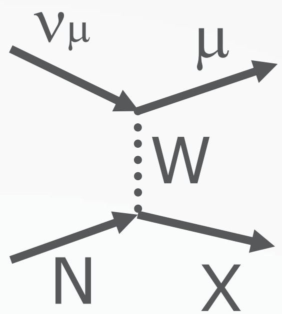
Instituto de Física Corpuscular

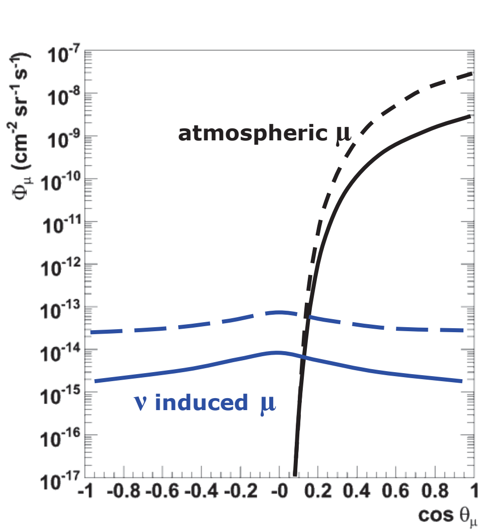
‘Looking at the Neutrino Sky’, NUSKY 2011, Trieste, June 20 - 24, 2011





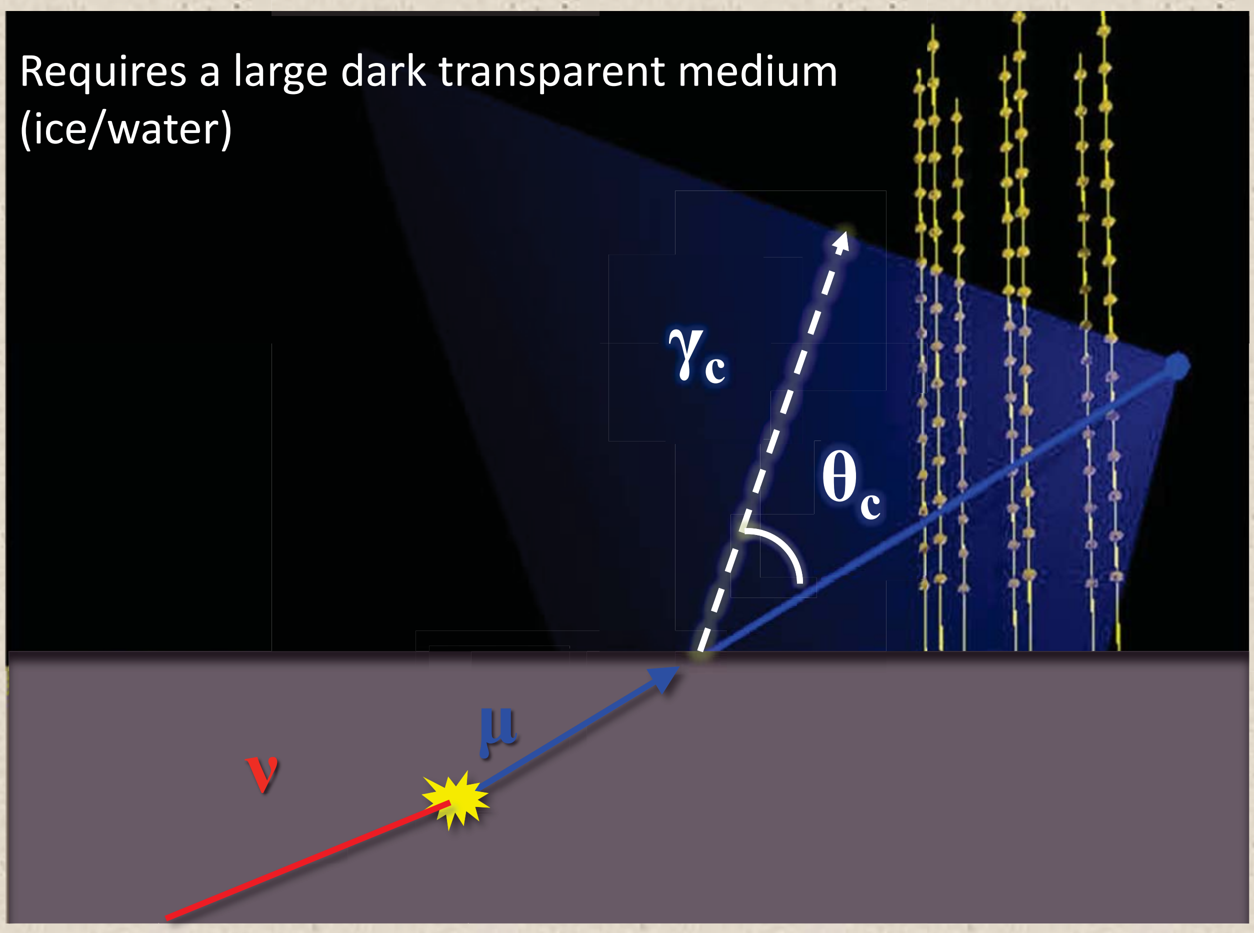
Cosmic neutrinos can interact in the Earth and release a muon

Atmospheric muons and neutrinos can also induce a signal at the detector



Detection principle

Cherenkov Neutrino detection



Muon neutrinos are well suited for HE detection (cross-section and muon range increase with energy)

Muons emit Cherenkov light collected by a lattice of PMTs.

Arrival time of photons enable track reconstruction.

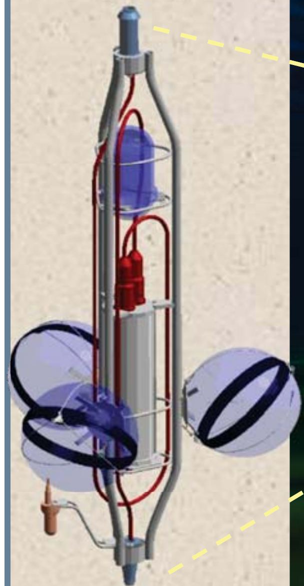
Other signatures can also be detected.

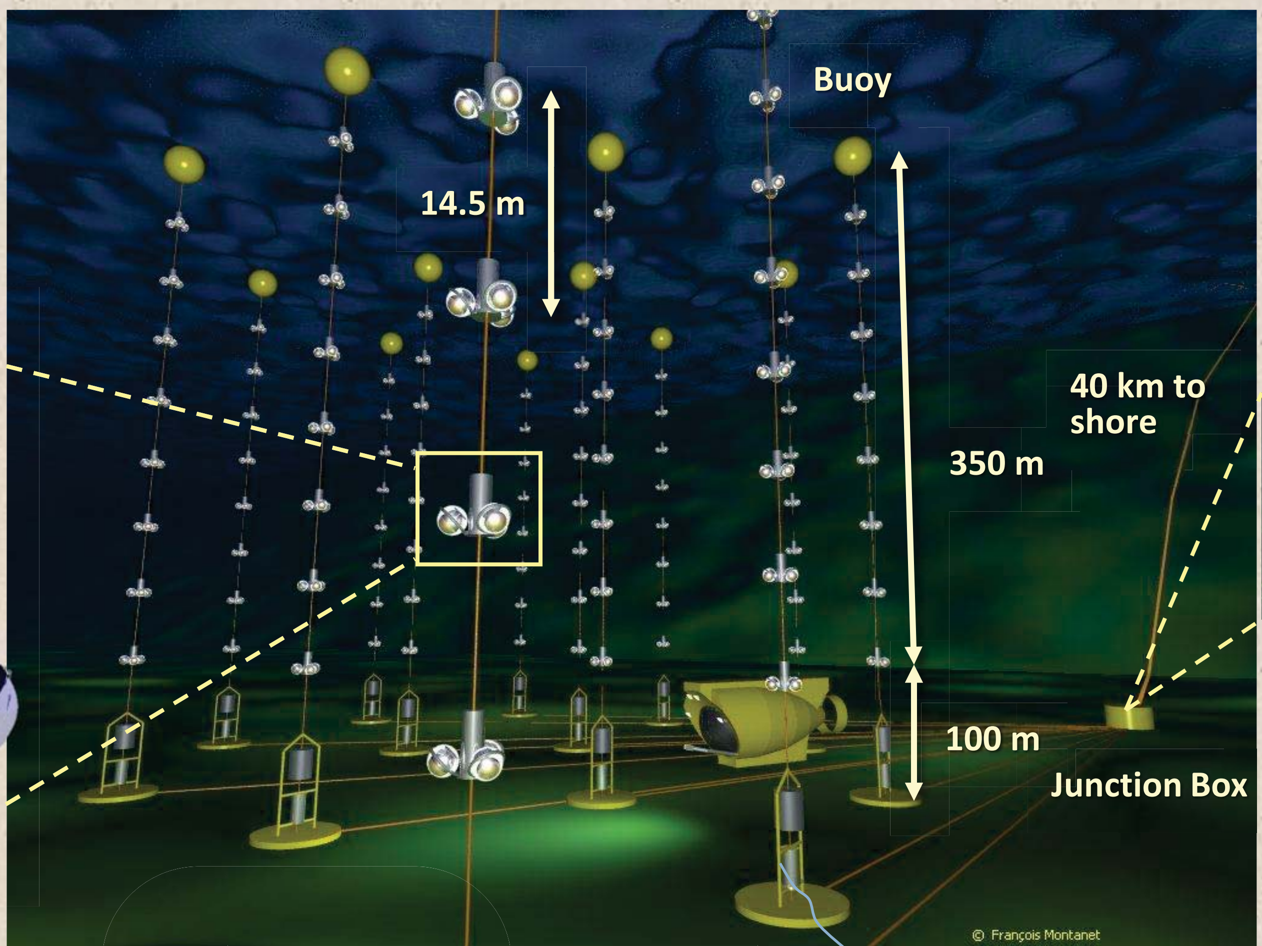
ANTARES

12 lines (885 PMTs)
25 storeys / line
3 PMTs / storey

5-line setup in 2007

Completed in 2008

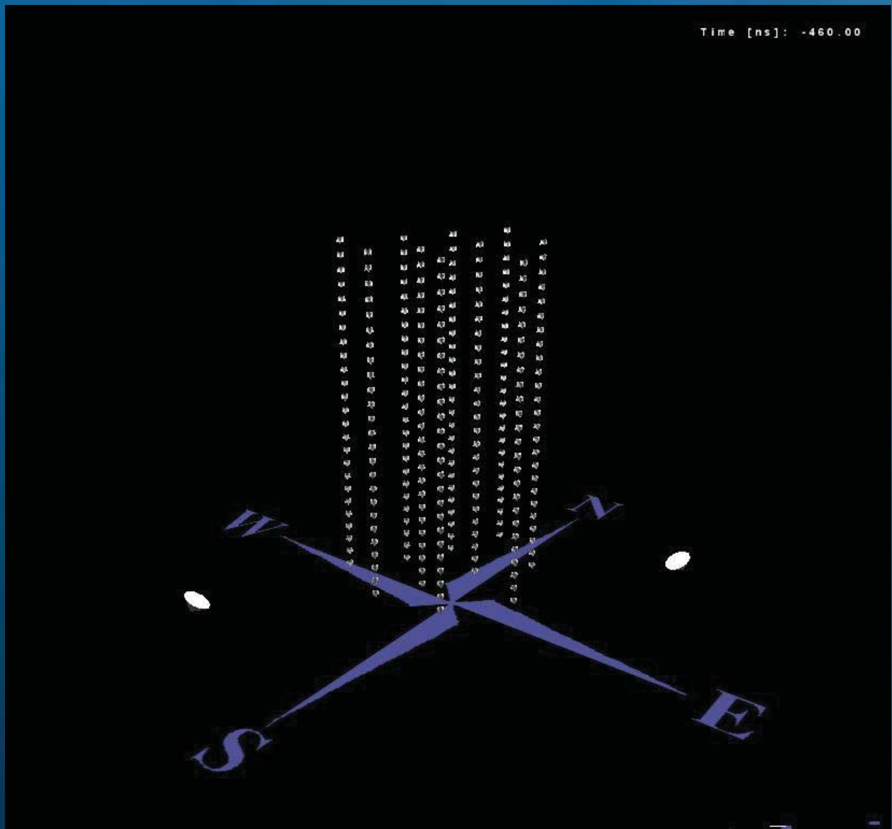




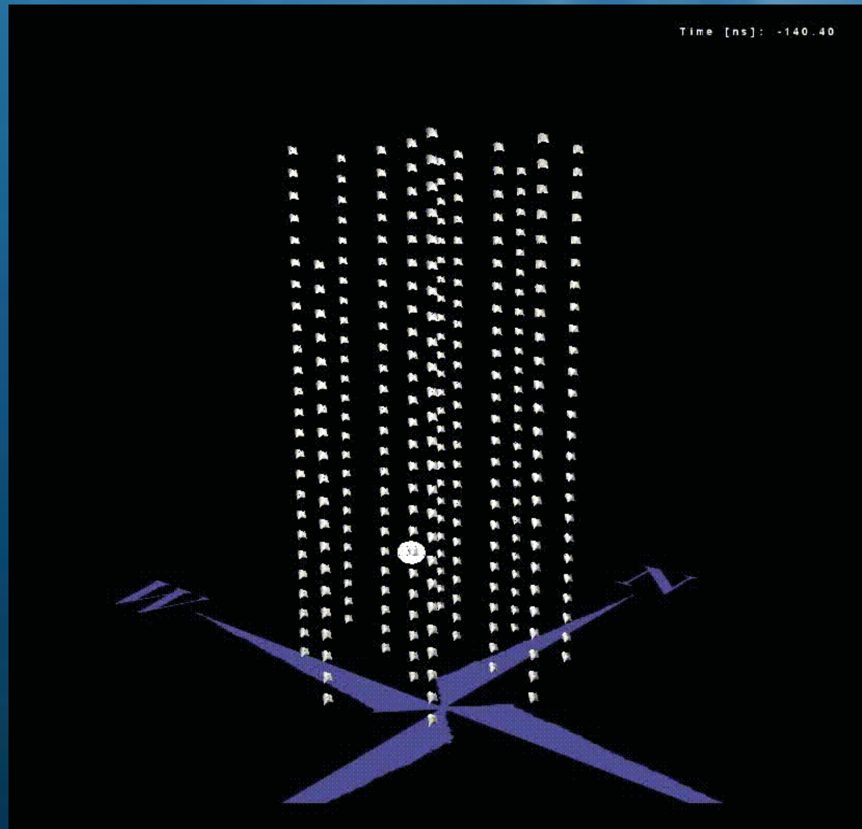
In the Mediterranean Sea
(near Toulon) at **2500 m** depth

Example Data Events

reconstructed up-going neutrino
detected in 6/12 detector lines:

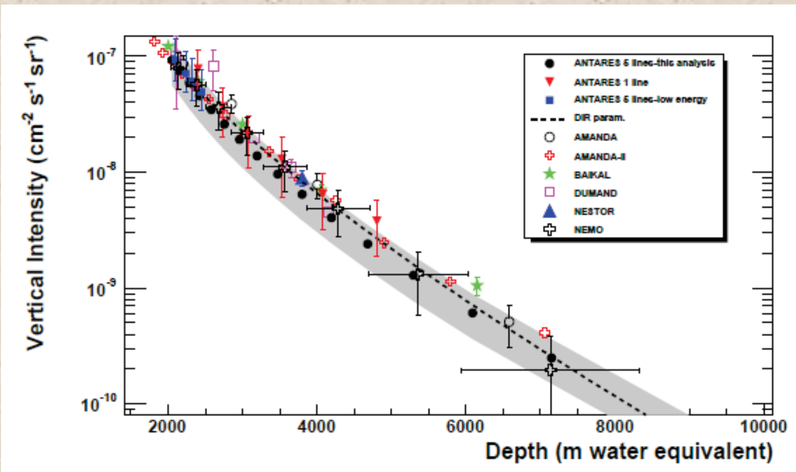


reconstructed down-going muon bundle
detected in all 12 detector lines:



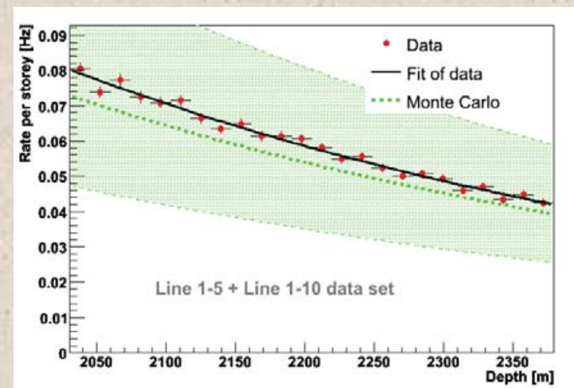
ANTARES – Atmospheric μ's

Depth intensity relation



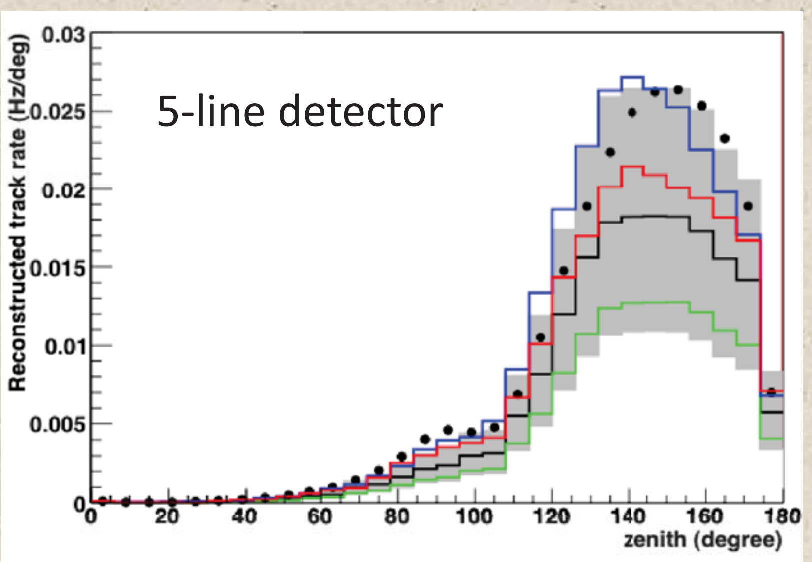
$$I(\theta = 0, h) = I(\theta, h_0) \cdot |\cos\theta| \cdot c_{corr}(\theta)$$

Downgoing reconstructed muons



coincidences between storeys
(low energy muons)

Zenith angle distribution



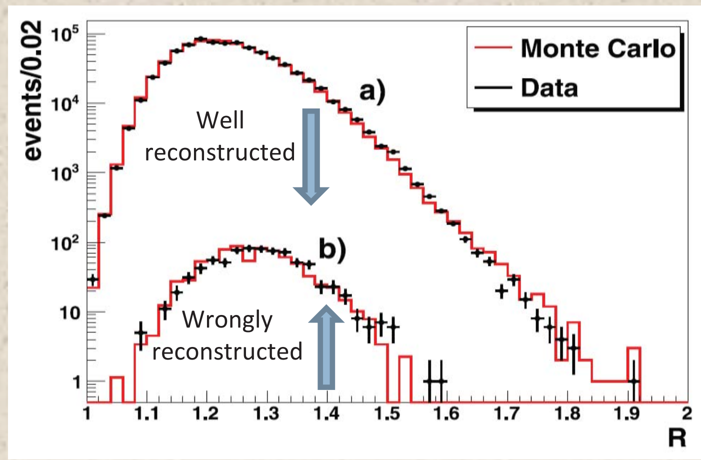
- **Data**
- MUPAGE Monte Carlo.
- CORSIKA + QGSJET + NSU
- CORSIKA + SIBYLL + NSU
- CORSIKA + QGSJET+ "poly-gonato" model
- Systematic uncertainty

Diffuse ν_μ flux

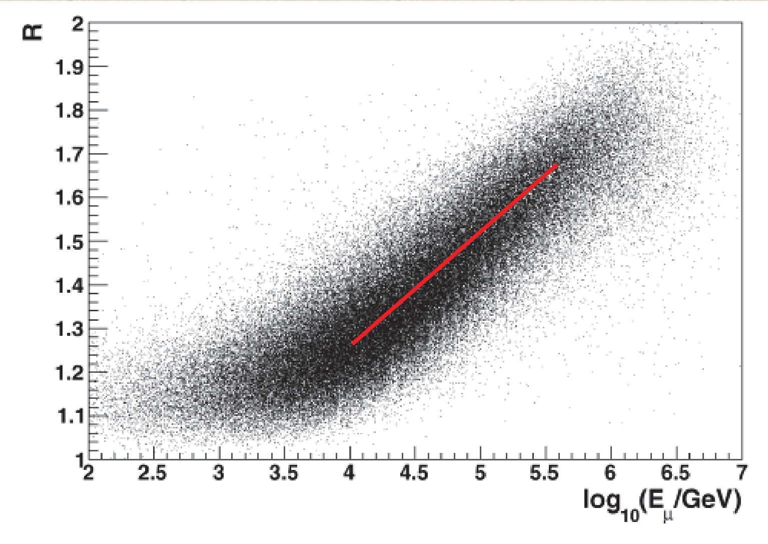
Analysis of 2007-2009 data

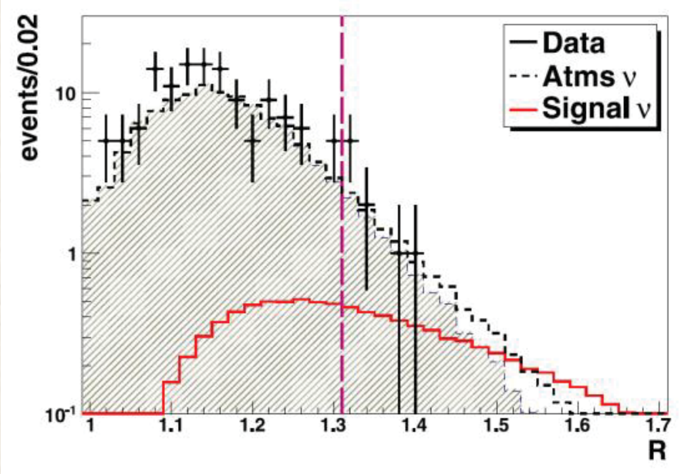
Good quality upgoing tracks:
Cuts on zenith angle, track quality, n_{lines} in prefit)

Background vs. signal discrimination by energy based on repetition *R* of hits in the same OM



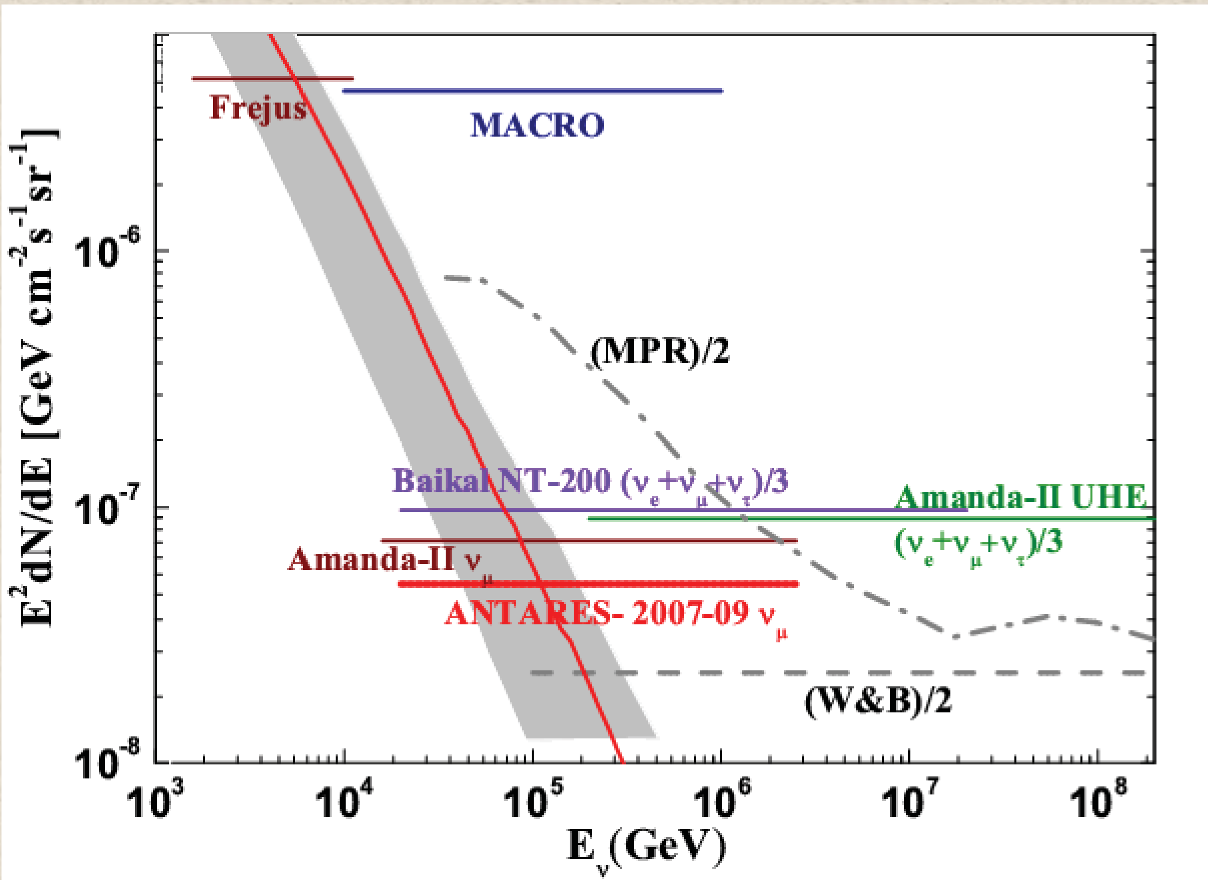
Blind analysis, MRF optimization of *R* cut on 10% of sample





Distribution of the *R* parameter for the neutrino candidates

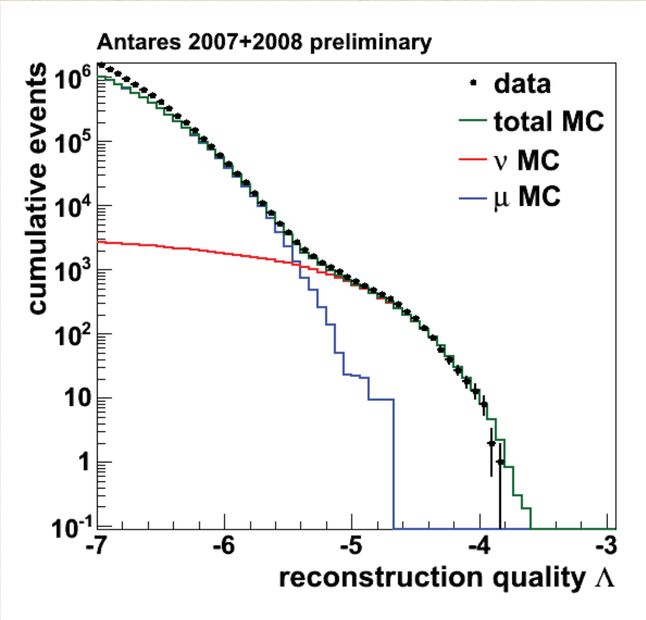
Diffuse ν_μ flux – Upper limits (E^{-2})

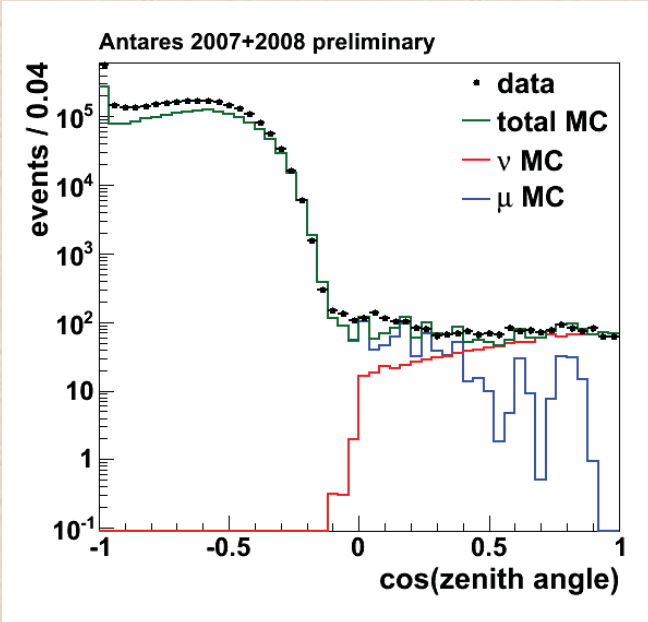


$E^2\Phi(E)_{90\%} = 4.7\times10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

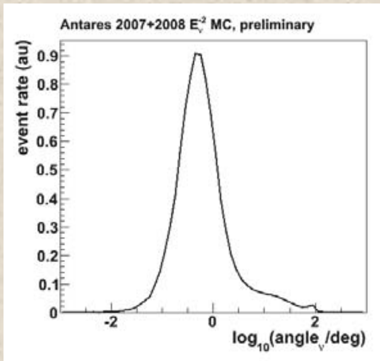
20 TeV < E < 2.5 PeV

Point sources - Track reconstruction





- Good quality runs are selected.
- A trigger based on number of causally related hits is applied.
- Events are accepted if the angular error estimate is < 1° (misreconstruted muons have a much larger error estimate).
- The cut on track quality is chosen to optimize the sensitivity to an E^{-2} flux.



MC estimated angular resolution: (0.5±0.1)°

Search for point sources

Look for cluster of events:

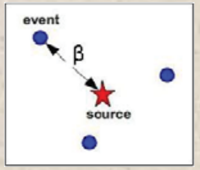
$$\log \mathcal{L}_{\mathrm{s+b}} = \sum_i \log[\mu_{\mathrm{sig}} \times \mathcal{F}(\beta_i(\delta_s, \alpha_s)) + \mathcal{B}_i] - \mu_{\mathrm{tot}}$$

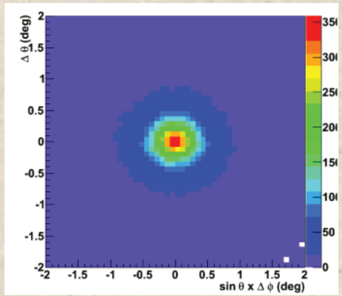
- All-sky search:

Fit μ_{sig}, δ_s and α_s

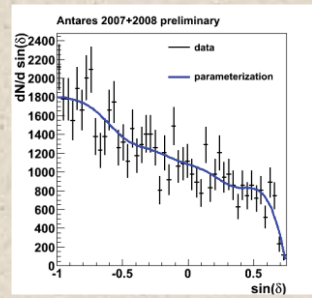
- List of candidates:

Fit μ_{sig} (δ_s and α_s fixed)





PSF from MC simulation



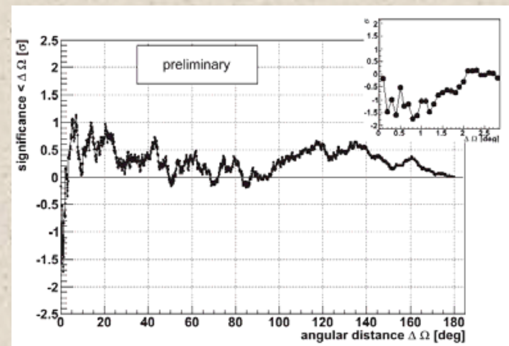
Background from real data (parametrization + scrambling)

Use likelihood ratio Q to discriminate if signal is present:

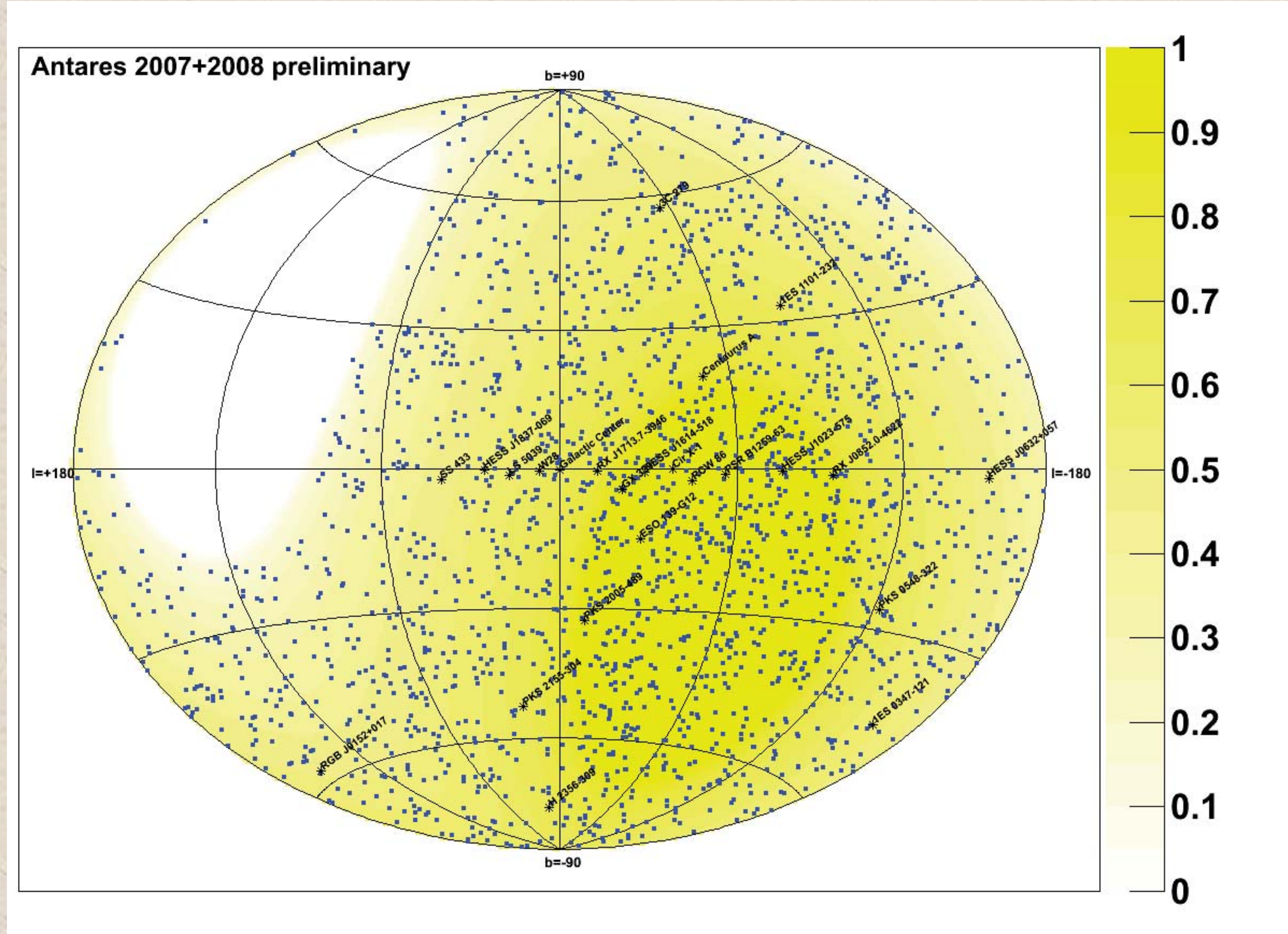
$$Q = \log \mathcal{L}_{s+b}^{max} - \log \mathcal{L}_b$$

Indepently: a search based on the autocorrelation function (number of pairs in a given angular distance)

- same dataset, but different systematics (not relying on MC simulations)
- sensitive to a large variety of source morphologies



All-sky search



Total live time 295 days (144 with 5-lines)

Optimized quality cut $\Lambda > -5.4$

2040 events selected (60% atmospheric neutrinos)

Sky map in Galactic coordinates

Hue of background colour indicates visibility

Most significant cluster at: RA=134.6°, δ=13.4°

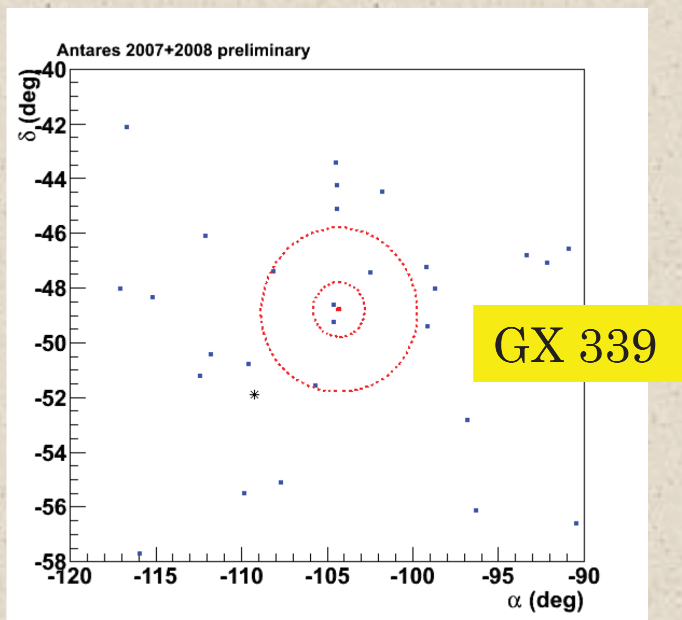
(post-trial probability to be background 2.4%)

Source candidate list

List of 24 candidate sources

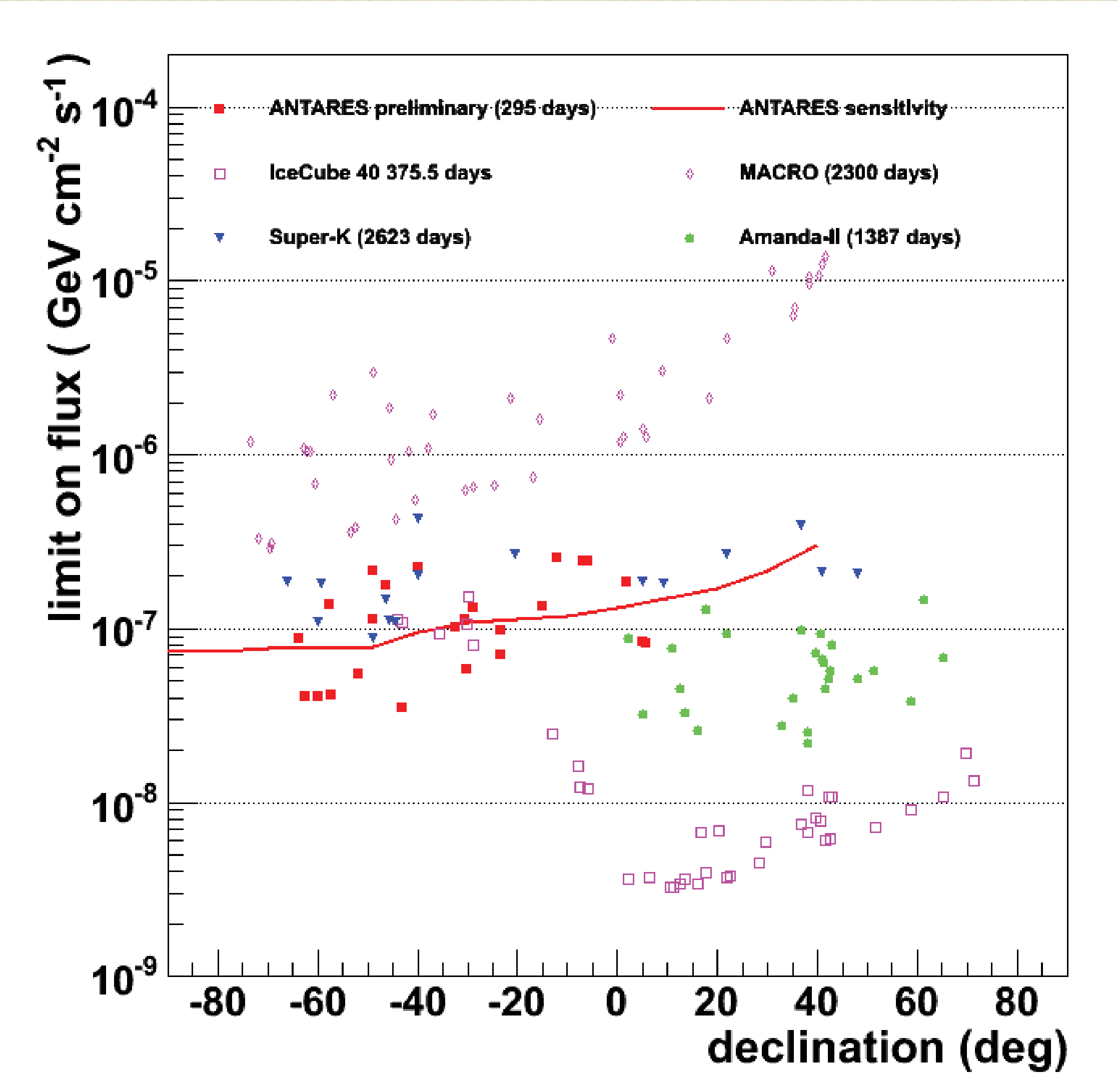
Source	ra,decl	fit Nsig	Q	Limit Nsig	Limit ϕ	p-value
GX 339	-104.3, -48.79	2.24	3.41	6.590	2.13e-07	0.068
RX J0852.0-4622	133.0, -46.37	1.24	1.81	5.510	1.78e-07	0.397
RX J1713.7-3946	-101.75, -39.75	1.07	1.80	5.540	2.25e-07	0.399
1ES 0347-121	57.35, -11.99	1.49	1.43	4.840	2.57e-07	0.574
HESS J1837-069	-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	1.3e-07	~ 1
LS 5039	-83.44, -14.83	0.00	0.00	2.520	1.34e-07	~ 1
H 2356-309	-0.22, -30.63	0.00	0.00	2.430	1.13e-07	~ 1
PKS 0548-322	87.67, -32.27	0.00	0.00	2.160	1.01e-07	~ 1
W28	-89.57, -23.34	0.00	0.00	1.940	9.71e-08	~ 1
HESS J1614-518	-116.42, -51.82	0.00	0.00	1.690	5.46e-08	~ 1
1ES 1101-232	165.91, -23.49	0.00	0.00	1.400	7e-08	~ 1
Cir X-1	-129.83, -57.17	0.00	0.00	1.280	4.12e-08	~ 1
RCW 86	-139.32, -62.48	0.00	0.00	1.270	4.09e-08	~ 1
ESO 139-G12	-95.59, -59.94	0.00	0.00	1.270	4.09e-08	~ 1
PKS 2155-304	-30.28, -30.22	0.00	0.00	1.240	5.78e-08	~ 1
HESS J0632+057	98.24, 5.81	0.00	0.00	1.220	8.2e-08	~ 1
Centaurus A	-158.64, -43.02	0.00	0.00	0.860	3.5e-08	~ 1
SS 433	-72.04, 4.98	0.00	0.00	1.390	8.34e-08	~ 1

Most significant candidate
GX 339-galactic micro-quasar



Post-trial probability to be background fluctuation= 6.8% $\Rightarrow$ not significant

Point source limits

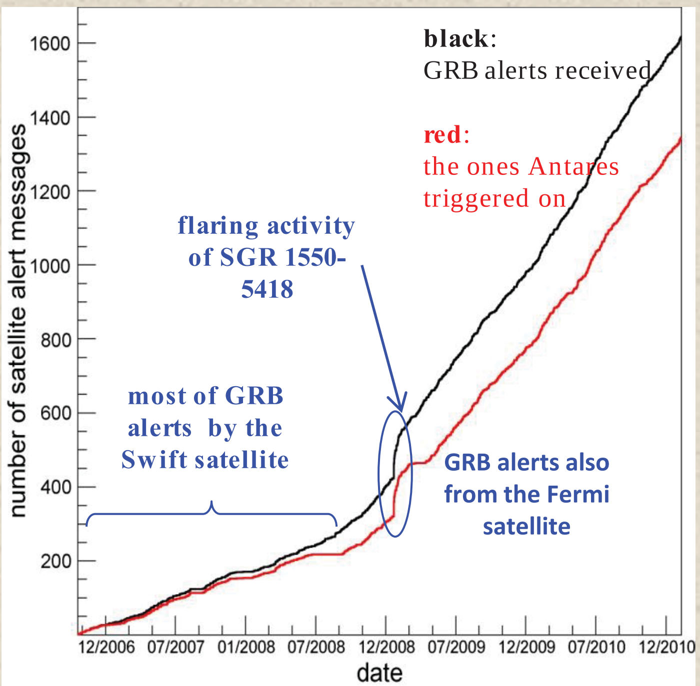


Assuming an E^{-2} flux for a possible signal

Much more data (2009-2011) being analysed plus further improvement once energy estimator is included

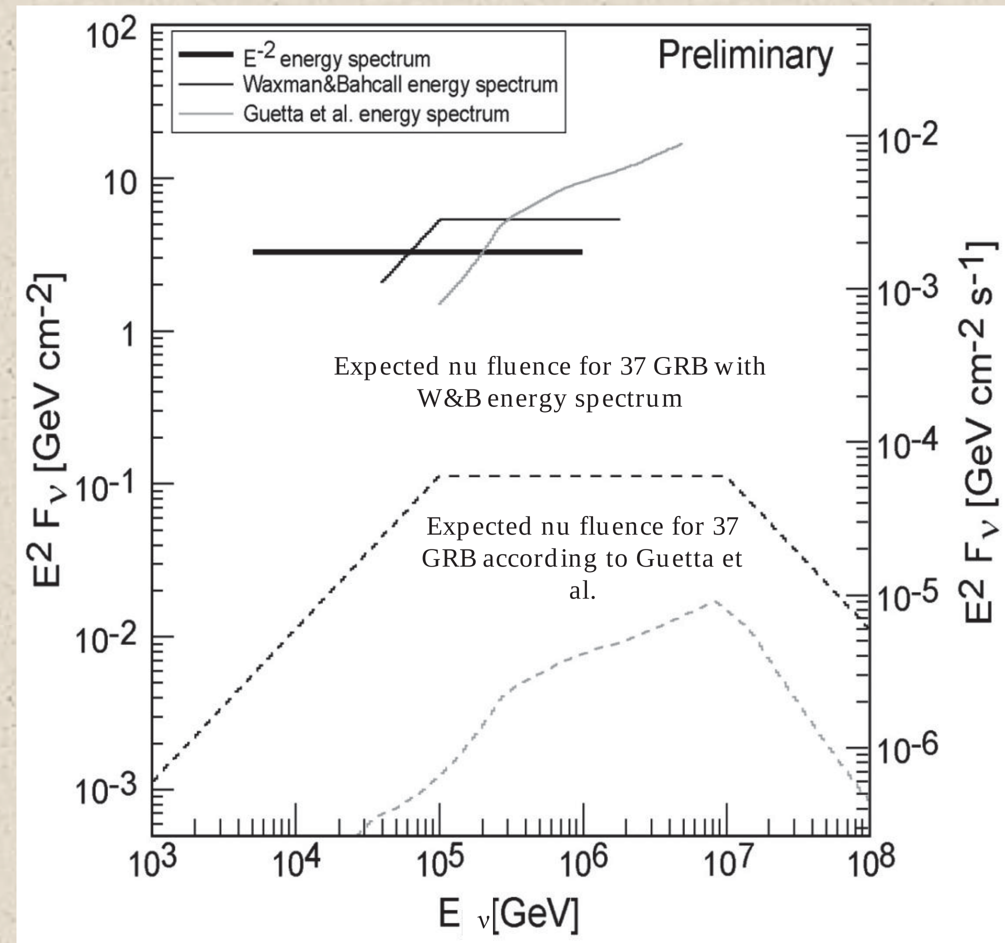
GRB Triggered Searches

Cumulative number of alerts

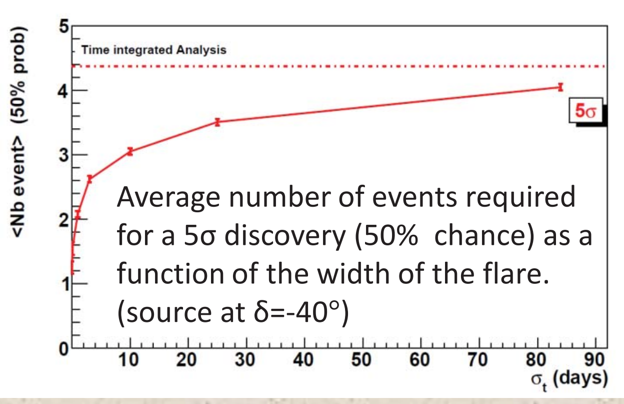


- > 1300 alerts from GCN have been recorded (Jan 2011)
- Lines 1-5 data unblinded: 37 GRB alerts
- The total prompt emission duration of the 37 GRBs is 1882 s

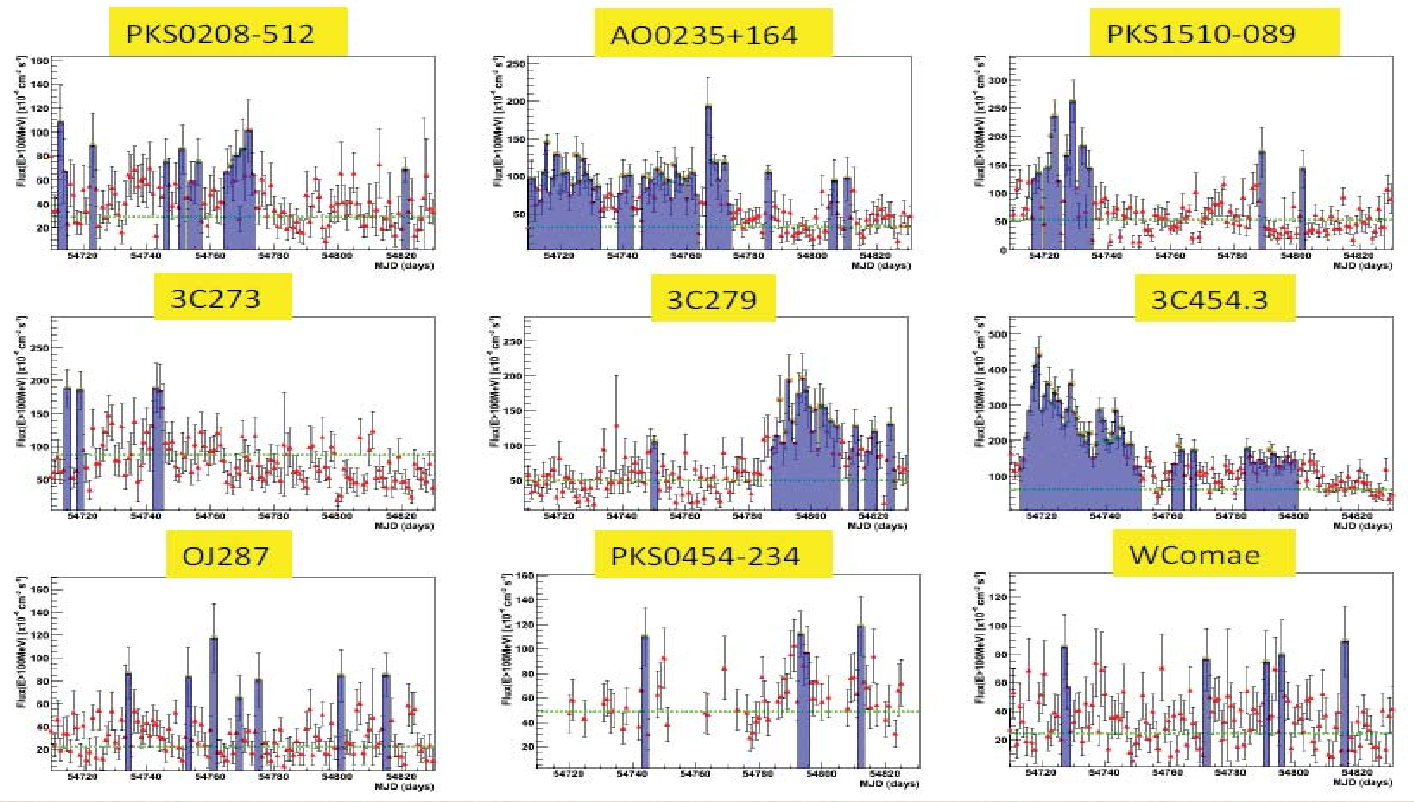
90% CL Upper limits on fluxes from 37 GRBs



Search for neutrino emission from γ-ray flaring blazars



1st year Fermi LBAS catalogue (LAT Bright AGN Sample):
10 sources with flares in 2008



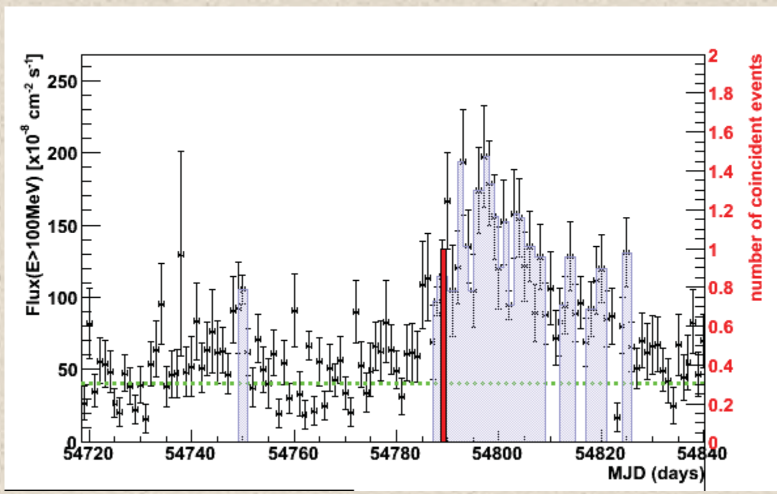
γ-ray flaring blazars

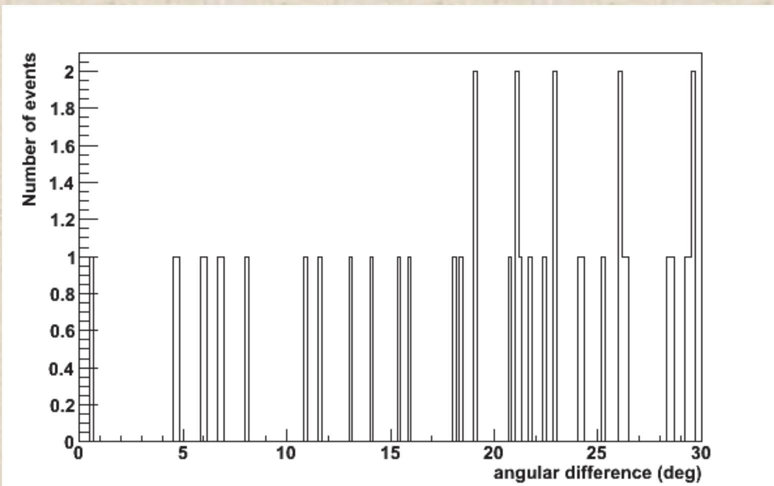
9 sources: 0 events ⇒ upper-limit on the neutrino fluence

3C279: 1 event compatible with the source direction (Δα=0.56º) and time distribution

⇒ pre trial p-value = 1.1%
post trial p-value ~10%

⇒ not significant





Magnetic Monopoles

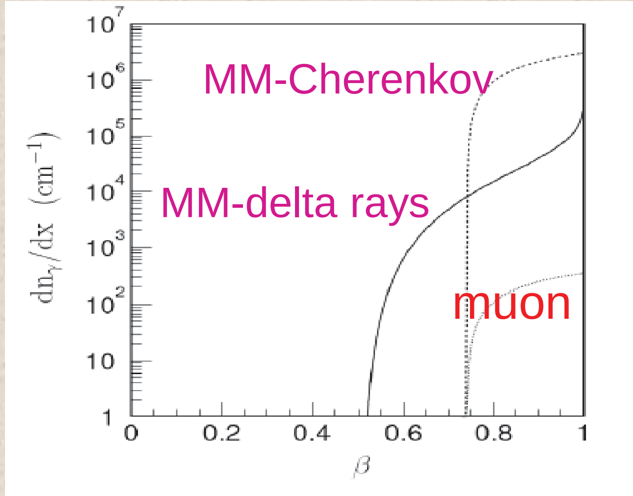
- Required in many models of spontaneous symmetry breaking ('t Hooft, Polyakov)

  upgoing ⇒ masses less than ~10^{14} GeV

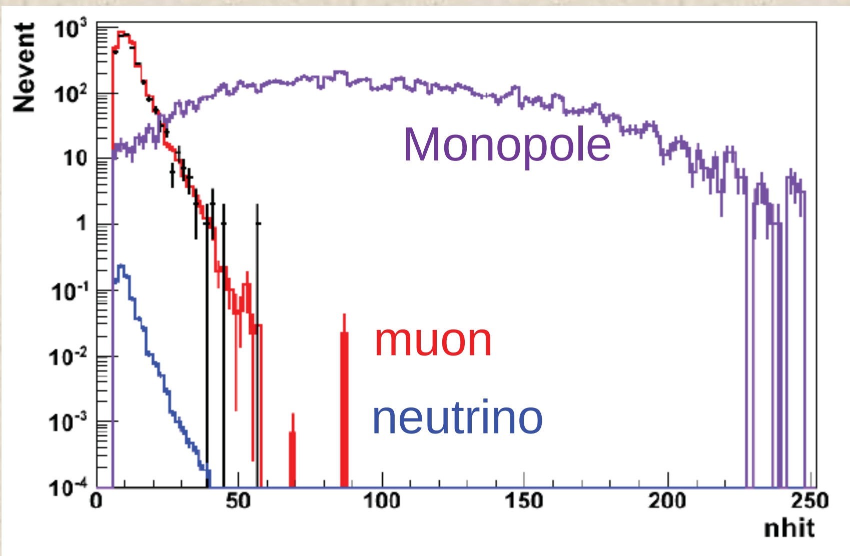
- High photon yield (8.5×10^3 times μ)

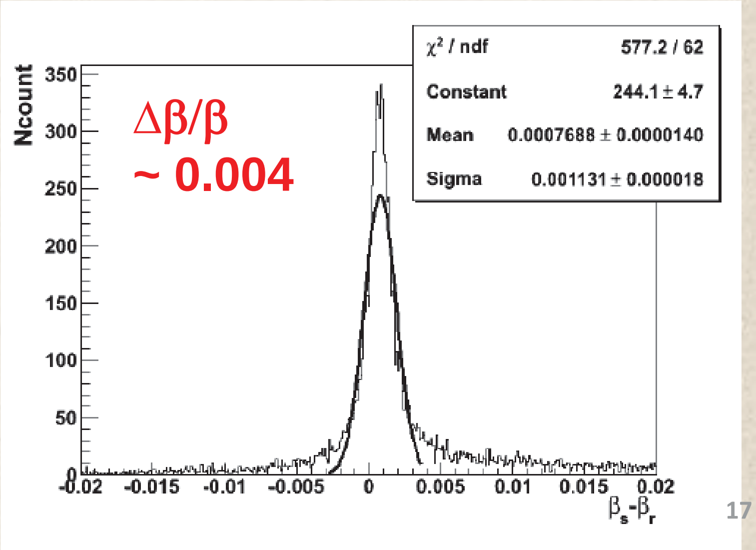
  Cherenkov threshold $\beta > 0.74$

  secondary δ-rays $\beta \geq 0.5$



- Modified track reconstruction with β free



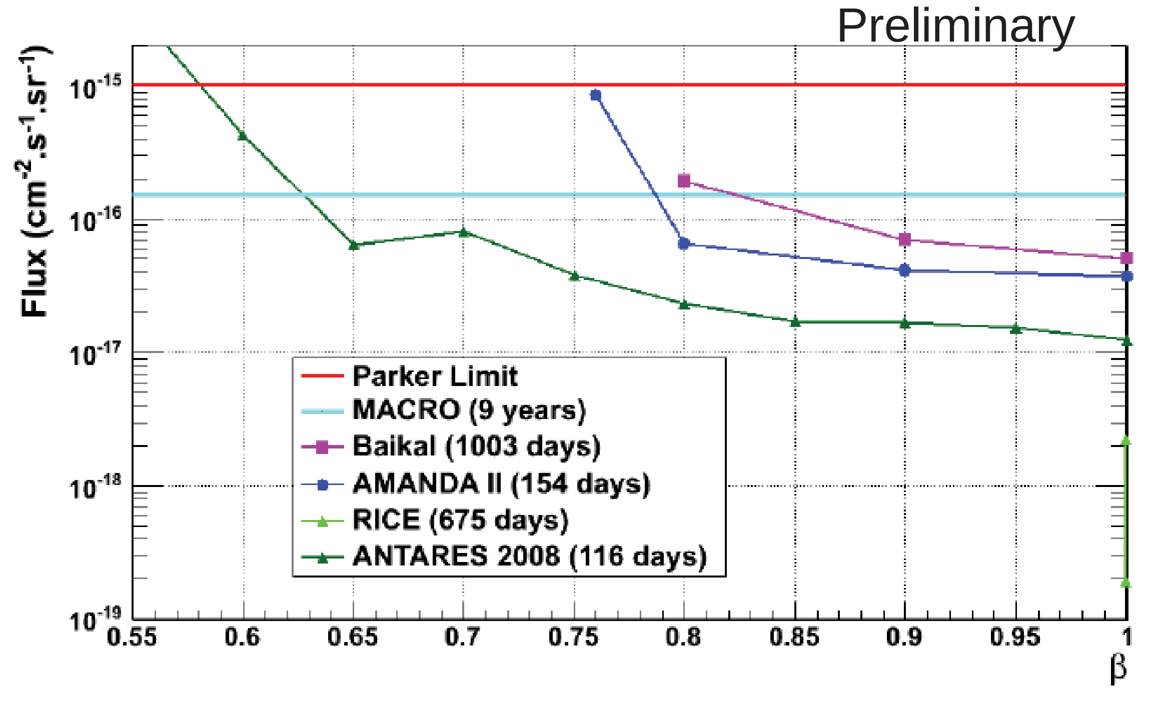


Magnetic Monopoles

Selection criteria based on:

- upward going direction
- reconstructed beta
  $\lambda = \log [\chi^2 (\beta=1)/\chi^2 (\beta=\text{free})]$
- number of hits

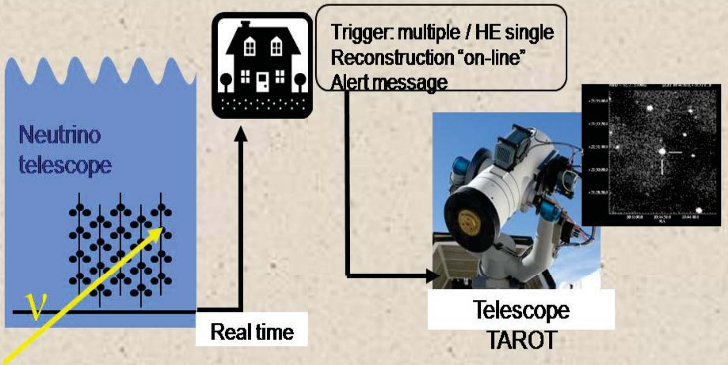
β	Number of observed events	90% C.L. upper flux limit ($cm^{-2}s^{-1}sr^{-1}$)
0.55	12	3.97×10^{-15}
0.60	3	4.29×10^{-16}
0.65	0	6.45×10^{-17}
0.70	1	8.20×10^{-17}
0.75	0	3.79×10^{-17}
0.80	0	2.33×10^{-17}
0.85	0	1.70×10^{-17}
0.90	0	1.68×10^{-17}
0.95	0	1.54×10^{-17}
0.99	0	1.24×10^{-17}



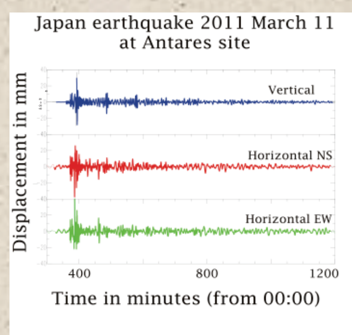
A variety of other analysis are ongoing…

Optical Follow-up

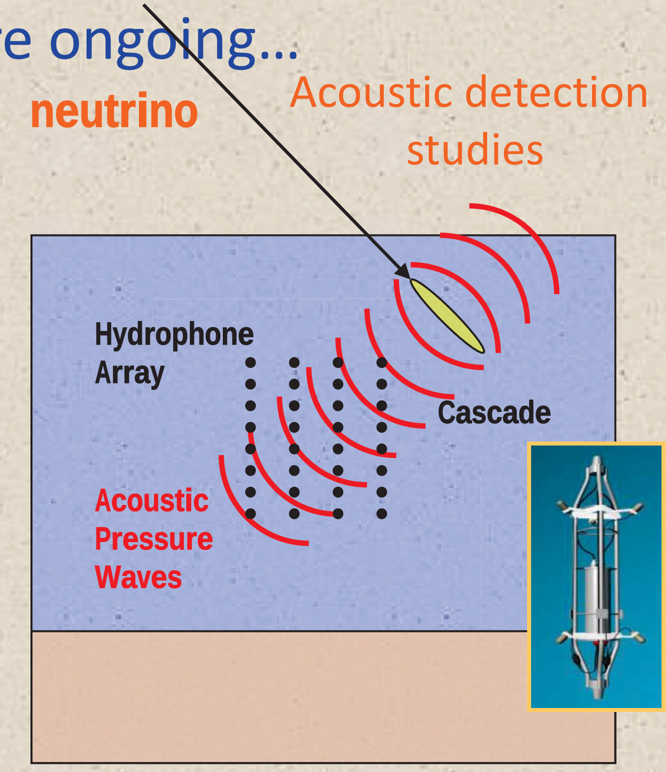
Alerts sent by ANTARES to robotic telescope systems such as TAROT and ROTSE.
(HE ν's or doublets in space-time window).
Image analysis quite advanced…



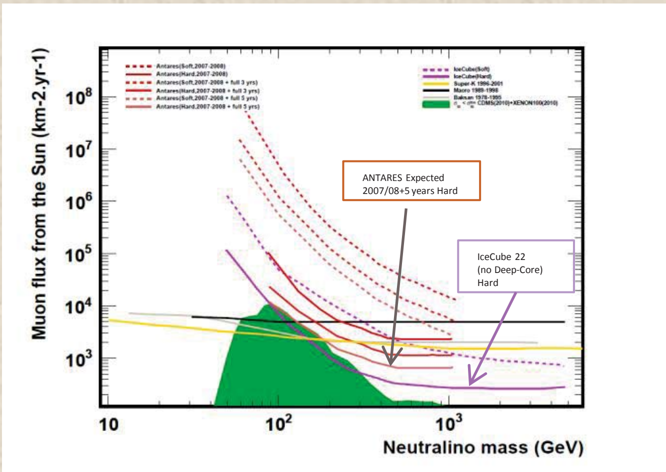
Geoscience



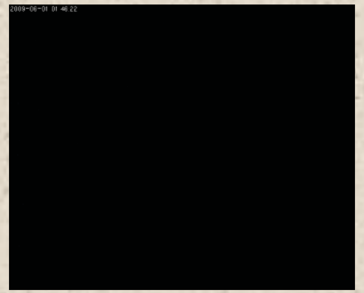
Acoustic detection studies



Indirect search for Dark matter



Marine Biology
Sea Sciences



The Economist

Hang on, that's not a neutrino

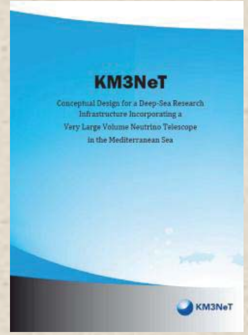
Dec 1st 2010, 16:10 by J.P.

Tweet 21 Like 230

SPL

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

KM3NeT

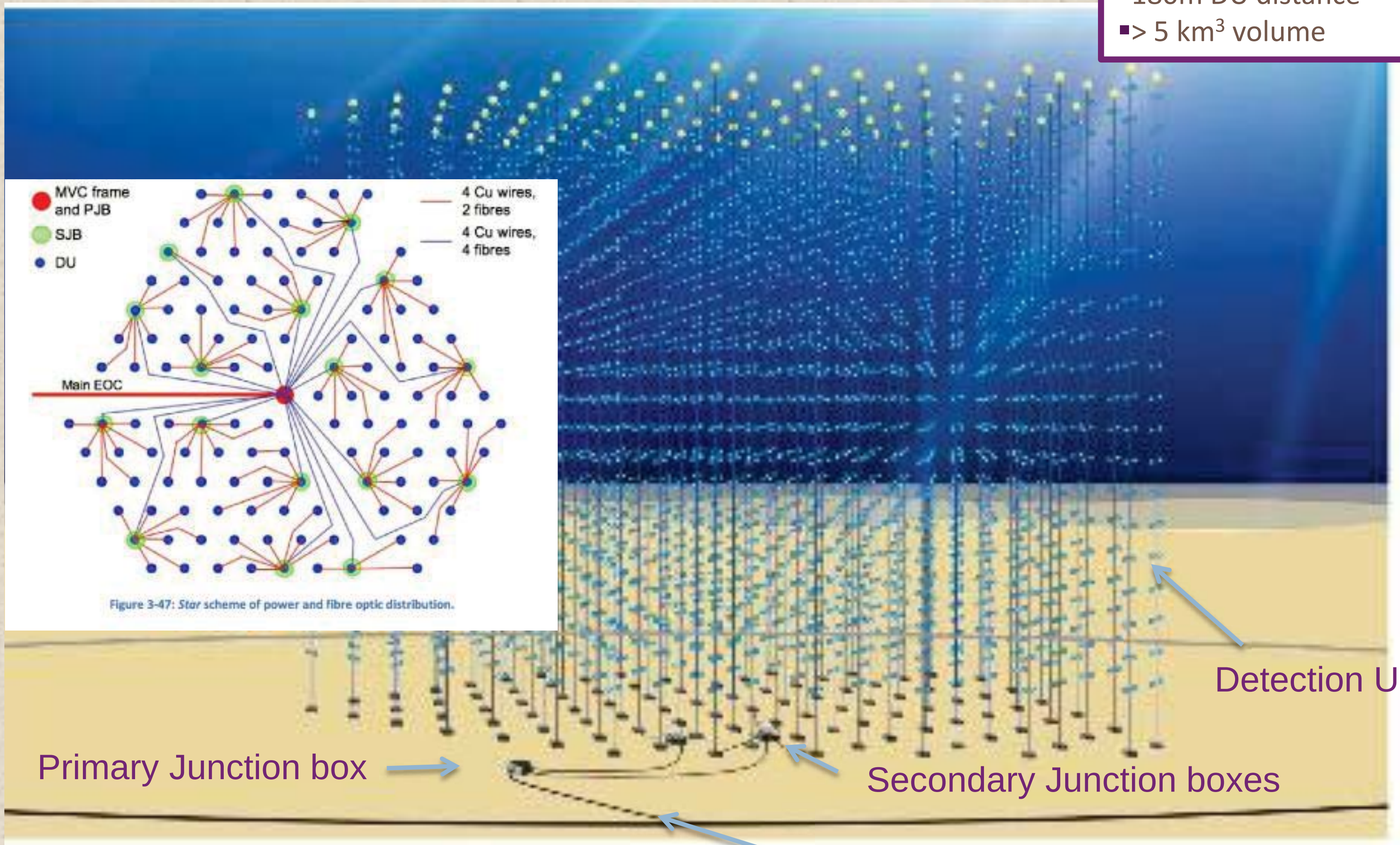


- Central physics goals:
  - Neutrino Astronomy under the Mediterranean Sea
  - Investigate neutrino “point sources” in the 100 GeV-1 PeV energy range
  - Complement IceCube field of view
  - Instrumented volume > 5 km^3
- Implementation requirements:
  - Construction time ≤ 5 years
  - Operation over at least 10 years without “major maintenance”

- KM3NeT consortium consists of 40 European institutes, including those in Antares, Nemo and Nestor, from 10 countries (Cyprus, France, Germany, Greece, Ireland, Italy, The Netherlands, Rumania, Spain, U.K)
- KM3NeT is included in the ESFRI and ASPERA roadmaps
- Design Study (2006-2009) funded by the EU VI^{th} Framework Program
- Conceptual Design Report (**ISBN** 978-90-6488-033-9) and Technical Design Report (**ISBN** 978-90-6488-031-5) available: www.km3net.org/public.php
- KM3NeT PreparatoryPhase (2008-2012) funded by the EU VII^{th} Framework Program
  Final design, production plans for the detector elements and infrastructure features. In-situ prototype validation is underway. Legal, governance and funding aspects are also under study.

KM3NeT

- 300 Detector Units
- 20 storeys per DU
- 40 m between storeys
- ~1 km DU height
- 180m DU distance
- > 5 km^3 volume



Detector Unit

Major technical decisions taken

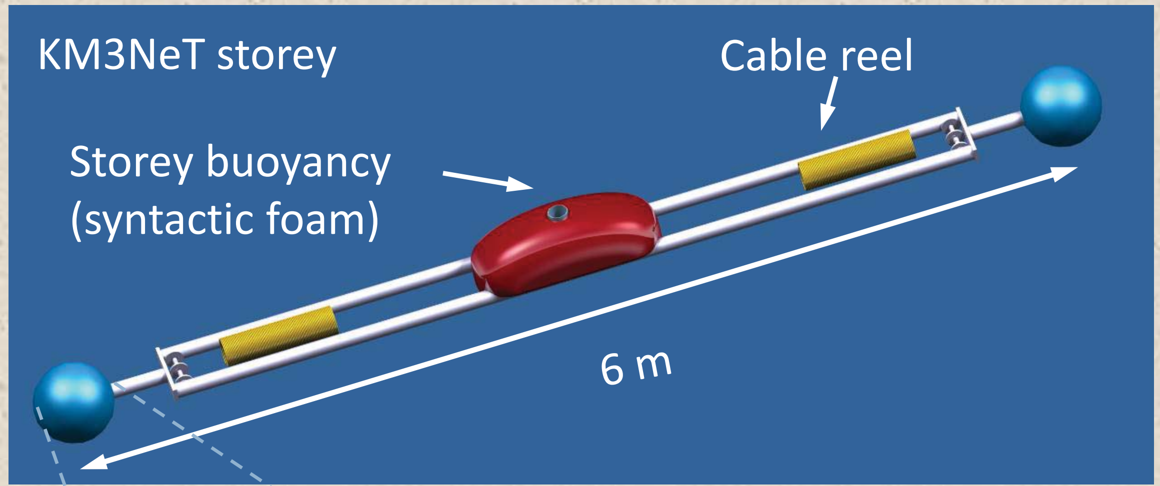
Flexible tower

Horizontal bars

40 m between storeys

1 km long

Self-unfolding



Multi-PMT Optical Module

Self-contained "plug-and-play" module (17" pressure-resistant sphere)

- Photo-sensors 31 (19+12) 3" PMTs
  - Equivalent of 4 x 8" PMTs
- Includes:
  - All read-out/control electronics
  - Calibration devices
- Single colour point to point connection via DWDM between each OM and the shore station.

Distinguish single from multiple photon hits:

- Photon counting = PMT counting
- Background rejection – ^{40}K

Looking upward:

- Background rejection – atmospheric muons
- More uniform angular acceptance

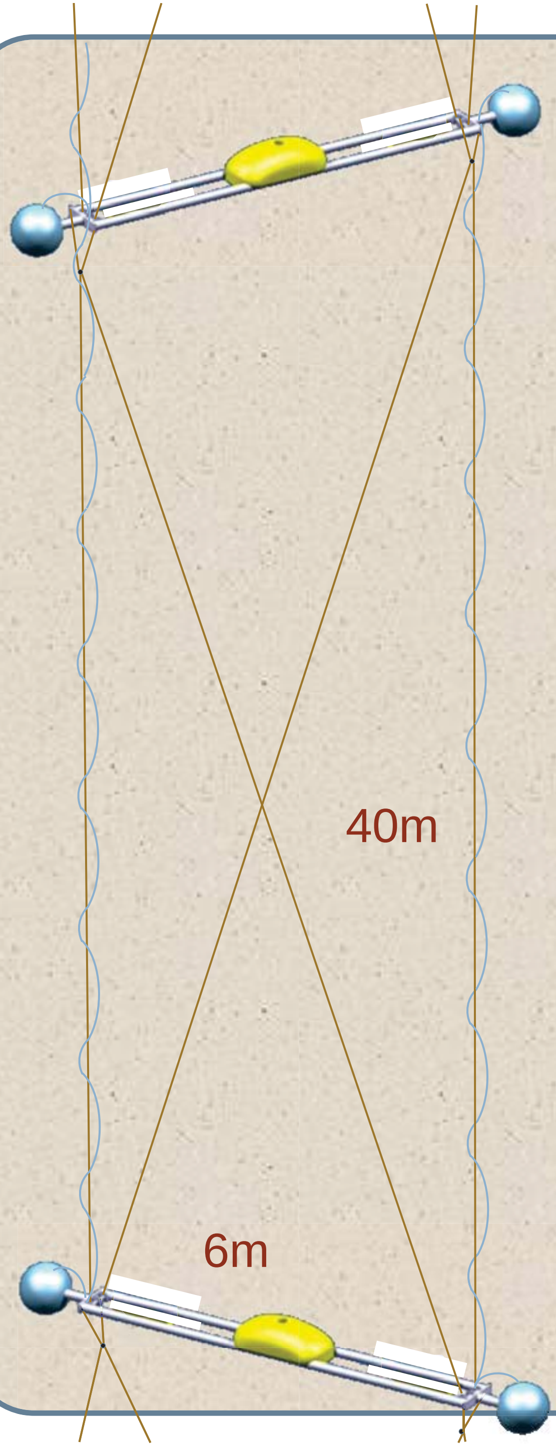
Directionality:

- Signal photons from one side

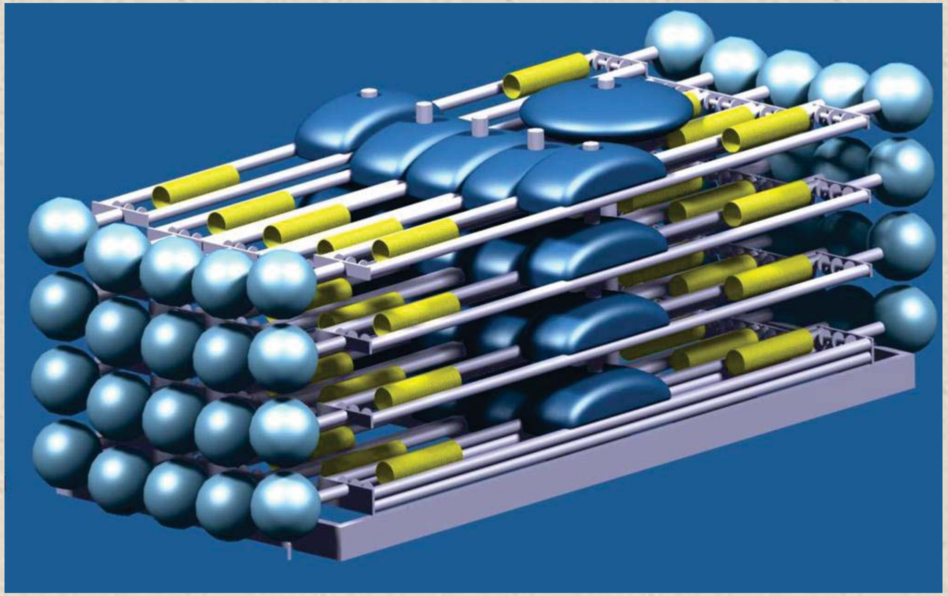
Ageing:

- lower gain ~10^6
- charge spread over multiple dynode chains

The packed flexible tower (20 storeys)



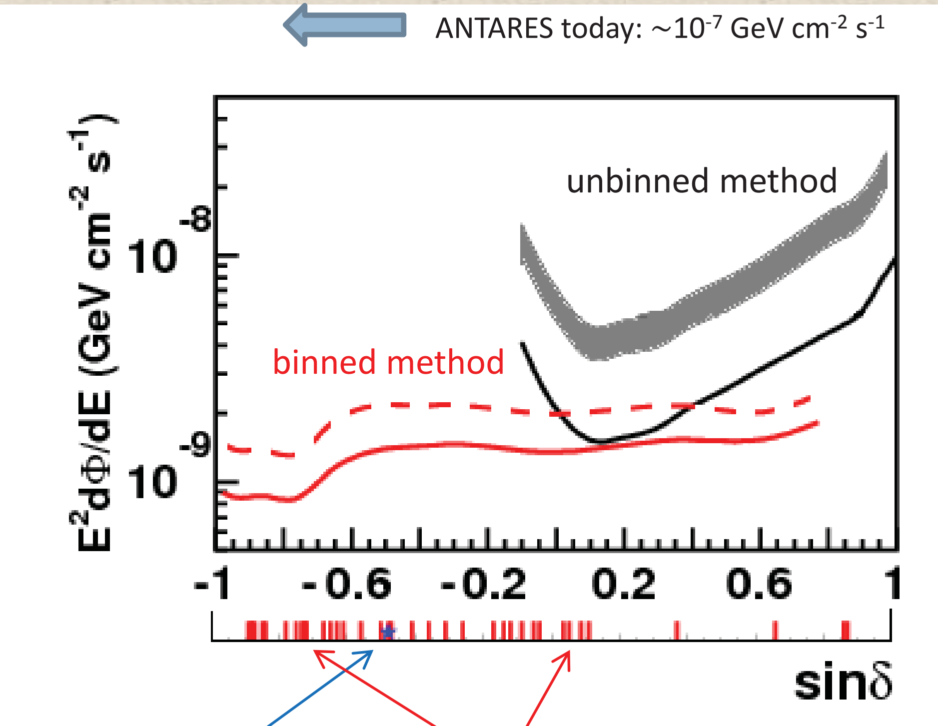
- Compact package
- Self unfurling
- Connection to seabed network by Remotely Operated Vehicle



Storeys	20
Height	900m
Compact Package	6 x 2.5 x 2.5m
Top drift @ 30 cm/s	~120 m
Total buoyancy	~10 kN
EO Cable	2 x 6.35 mm OD

KM3NeT Performances

Sensitivity and discovery fluxes for point like sources (E^{-2} spectrum) for 1 year of observation time



IceCube discovery 5σ 50% 2.5÷3.5 above sensitivity flux.

IceCube sensitivity 90%CL

KM3NeT discovery 5σ 50%

KM3NeT sensitivity 90%CL

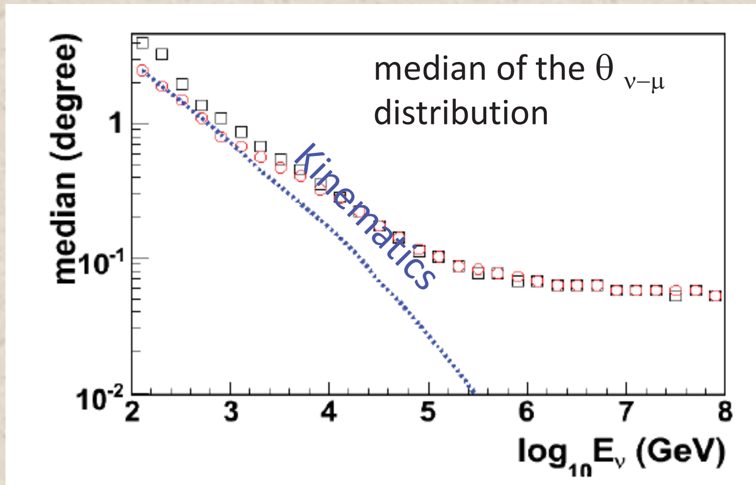
★ Galactic Centre

Observed Galactic TeV-γ sources (SNR, unidentified, microquasars)

F. Aharonian et al. Rep. Prog. Phys. (2008)

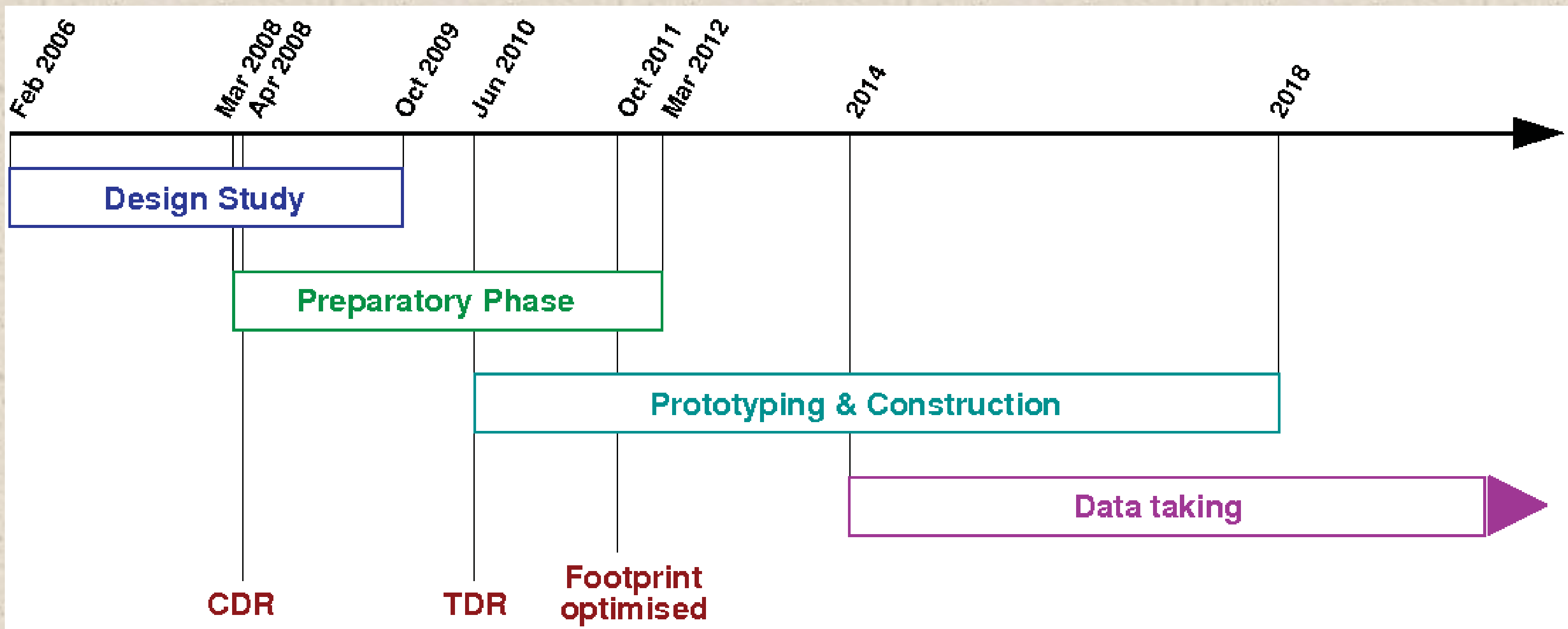
Abdo et al., MILAGRO, Astrophys. J. 658 L33-L36 (2007)

Detector resolution



Next Steps and Timeline

- Prototyping has started.
- Timeline:



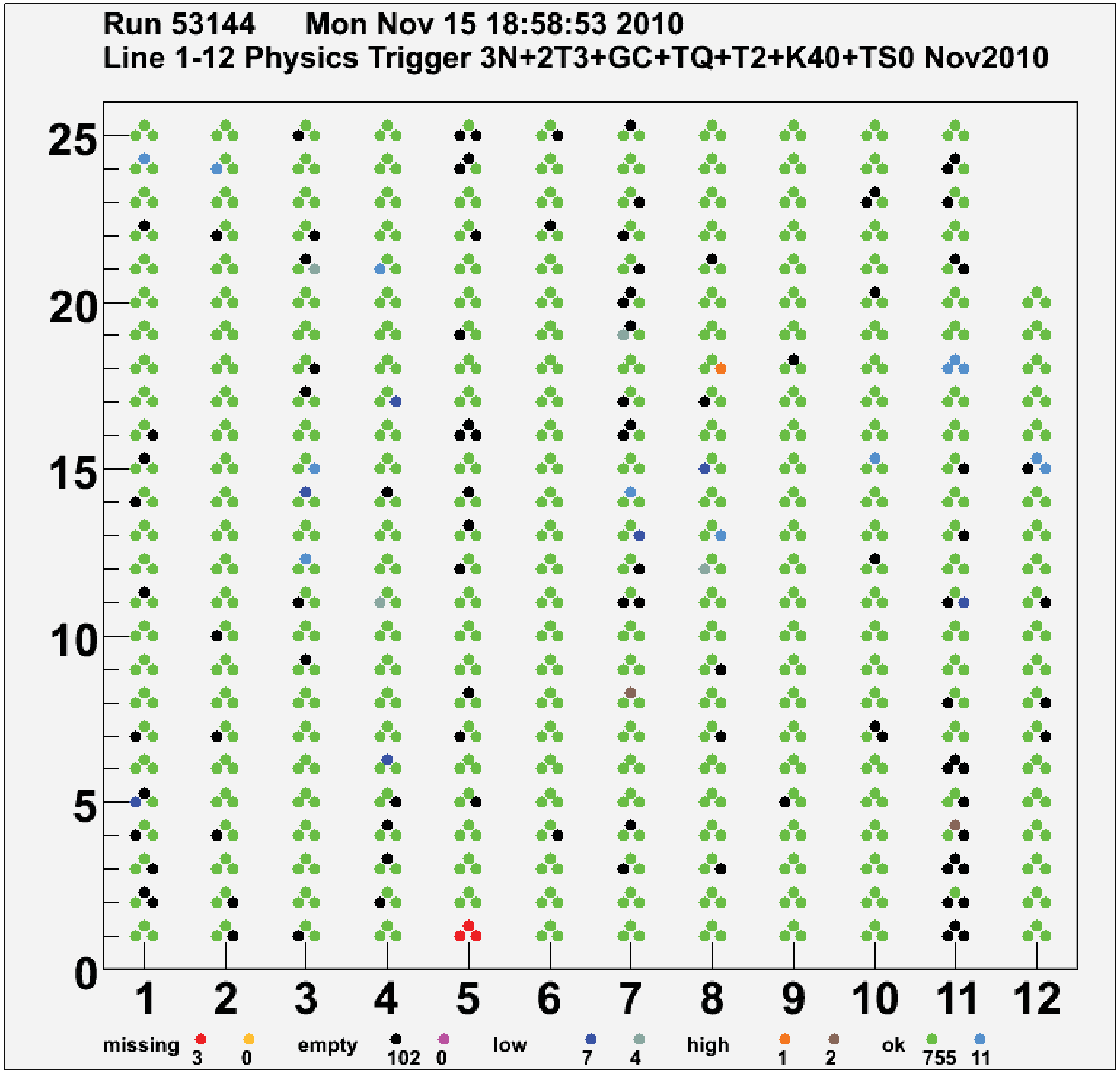
Conclusions

- The interest of neutrino telescopes and their technical feasibility are beyond doubt. The struggle is now to reach the required sensitivity.
- ANTARES is taking data in its final configuration since 2008. First results are being released and more will come soon.
- The initiatives for a Med-Sea neutrino telescope (Antares, NEMO and NESTOR) have joined forces in the KM3NeT consortium.
- Substantial progress towards a multi-km3 telescope in the Mediterranean Sea has been made. Major technical design decisions have been taken, minor points optimized for mass production. First pre-production models soon to be deployed.

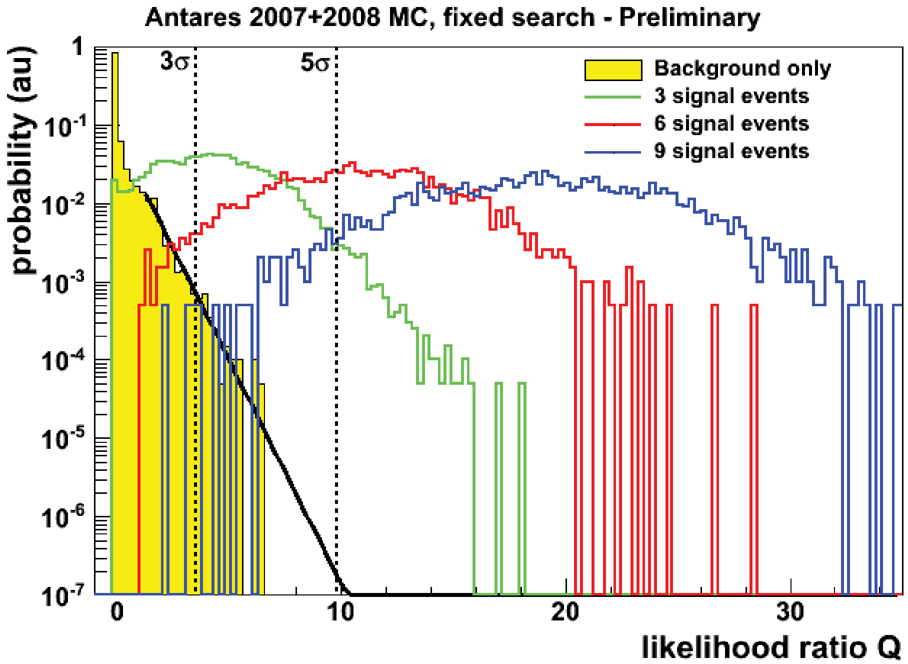
Backup slides

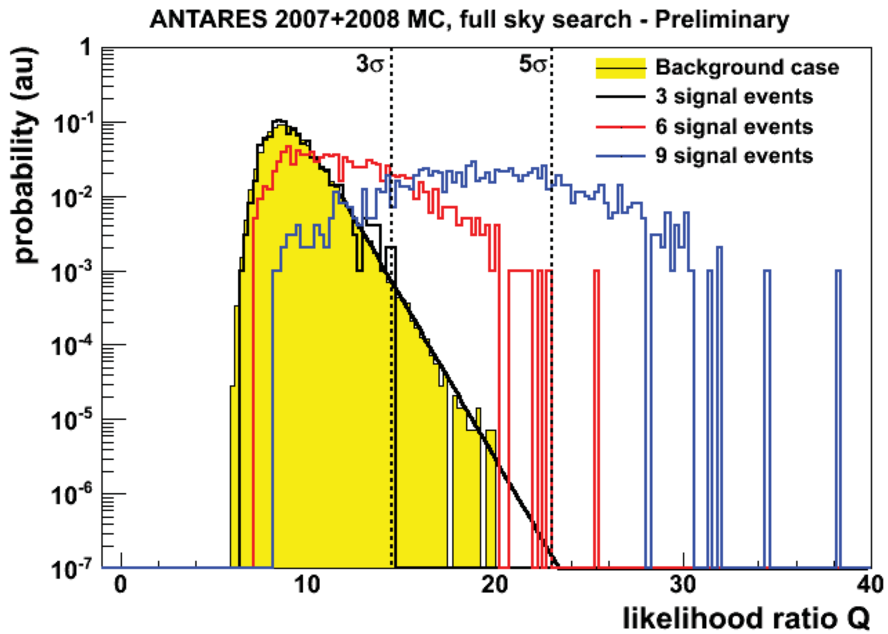
Detector Status

- Completion
  May 2008
- 885 PMTs
- 88% giving data
- Regular yearly maintenance



PS analysis. Discrimination





PS analysis. Effective area. Visibility