STATUS OF THE ANTARES NEUTRINO TELESCOPE

5th Iberian cosmology meeting

29-31 March 2010

Oporto

J. P. Gómez-González

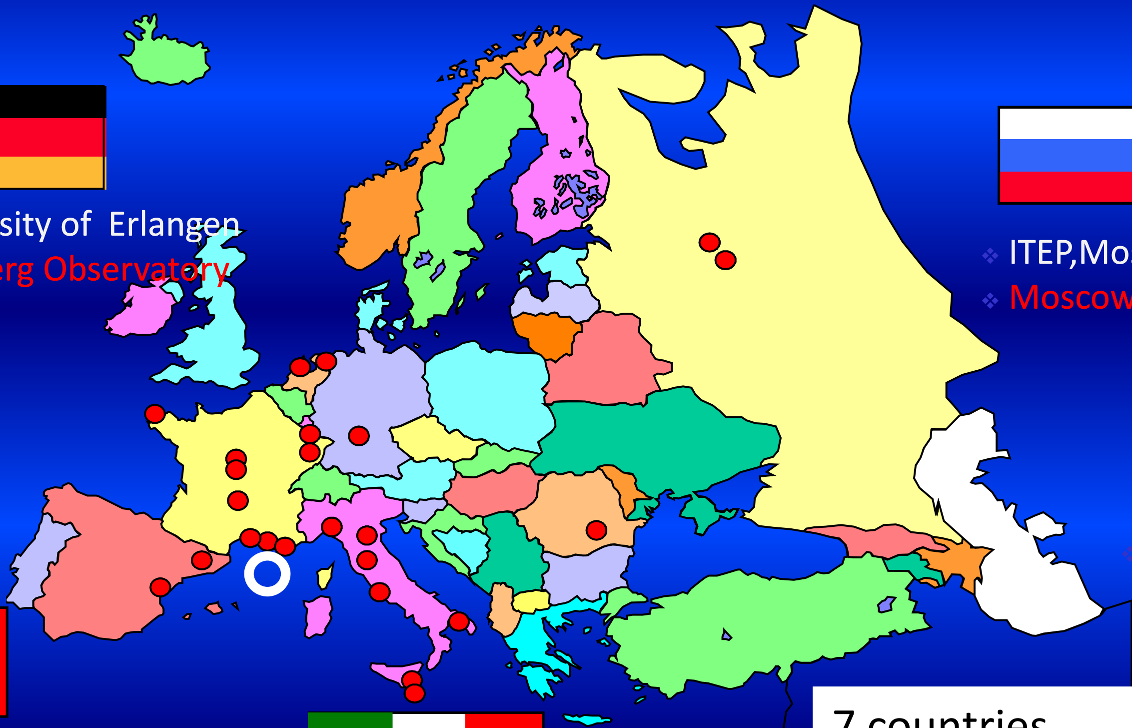
Outline

- **Physics with neutrino telescopes**
- **Detection principle and detector description**
- **Results from ANTARES**

The ANTARES collaboration

- NIKHEF,
- Amsterdam
- Utrecht
- KVI Groningen
- NIOZ Texel

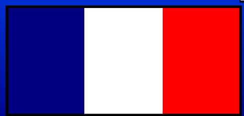
- University of Erlangen
- Bamberg Observatory



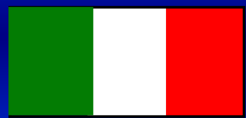
- ITEP,Moscow
- Moscow State Univ

- ISS, Bucarest

- IFIC, Valencia
- UPV, Valencia
- UPC, Barcelona



- CPPM, Marseille
- DSM/IRFU/CEA, Saclay
- APC, Paris
- LPC, Clermont-Ferrand
- IPHC (IReS), Strasbourg
- Univ. de H.-A., Mulhouse
- IFREMER, Toulon/Brest
- C.O.M. Marseille
- LAM, Marseille
- GeoAzur Villefranche

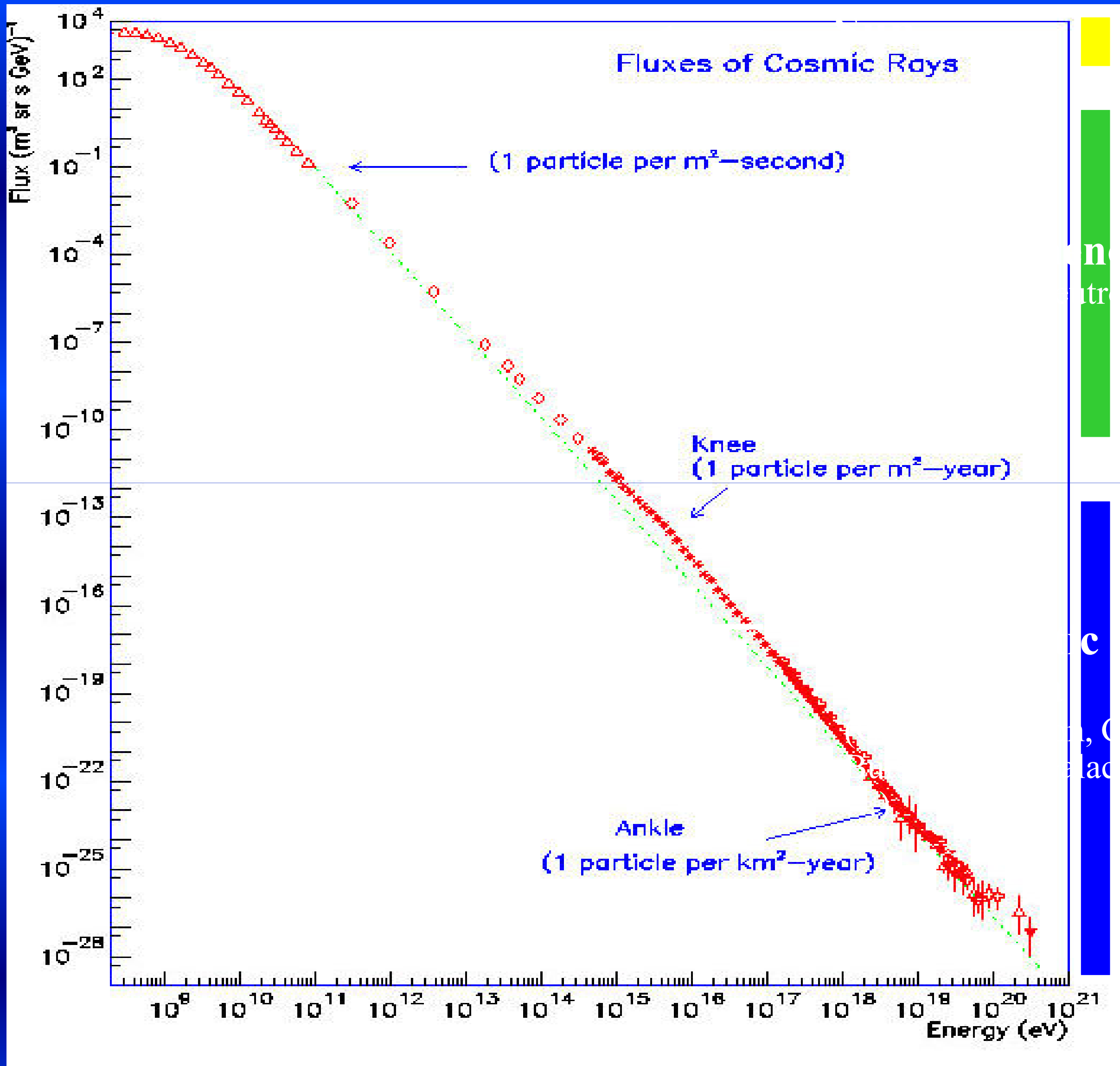


- University/INFN of Bari
- University/INFN of Bologna
- University/INFN of Catania
- LNS – Catania
- University/INFN of Pisa
- University/INFN of Rome
- University/INFN of Genova

7 countries
29 institutes
~150 scientists+engineers

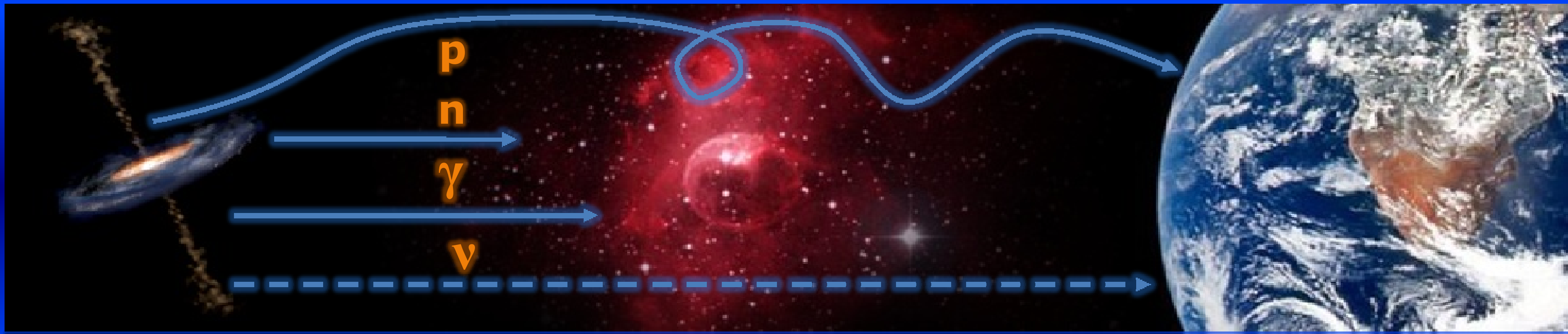
- **Physics with neutrino telescopes**
- Detection principle and detector description
- Results from ANTARES

Cosmic Ray Astronomy

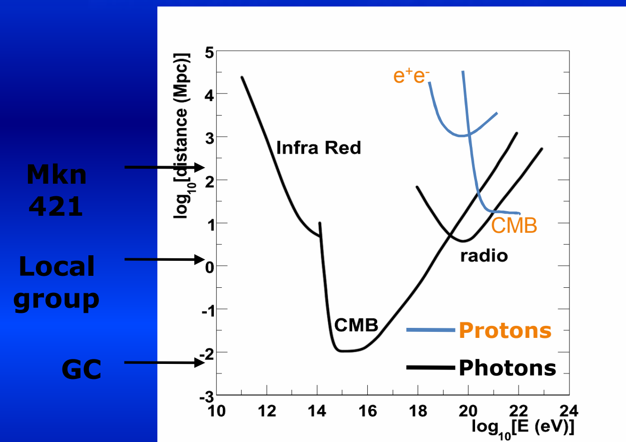


nomena
trons stars…)
c
, Gamma-Ray
lactic Nucleus

Neutrino as a messenger from the deepest universe



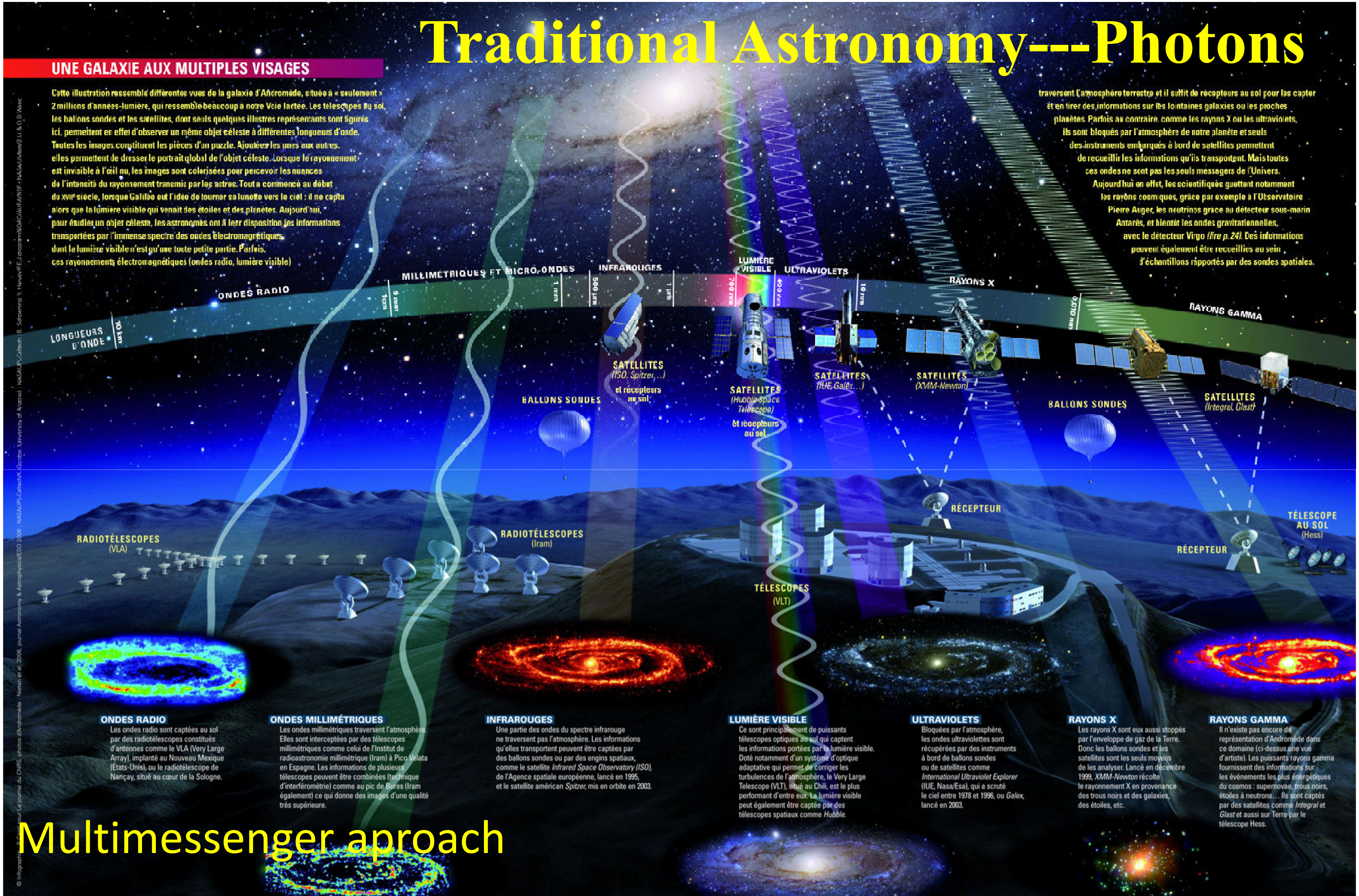
- Protons are deflected by magnetic fields ($E_p < 10^{19}$ eV) UHE protons interact with the CMB ($E_p > 10^{19}$ eV → 30 Mpc)
- Neutrons decay (~10 kpc at E ~ EeV)
- Photons interact with the EBL (~100 Mpc) and CMB (~10 kpc)
- Neutrinos are neutral weakly interactive particles.



Neutrinos point -back to the source of emission

Disadvantage → Over 10 billion neutrinos coming from the Sun and crossing the Earth, only 1 will interact

Traditional Astronomy---Photons

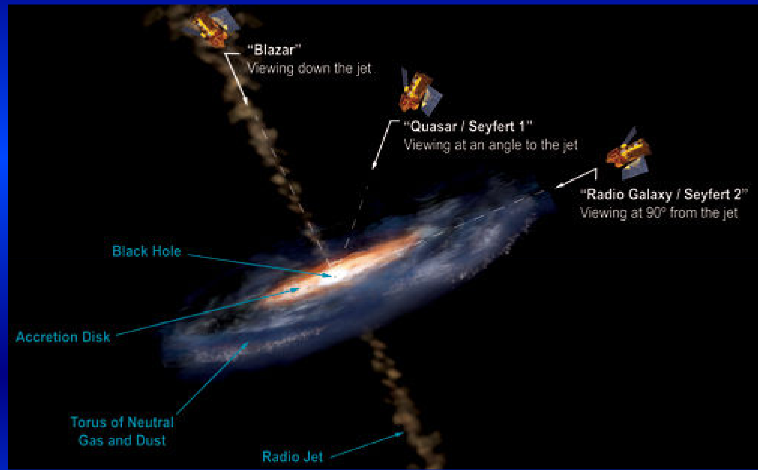


Multimessenger aproach

Astrophysical candidates

High energy neutrino sources

- Galactic: SNR, Microquasars, Galactic center, …
- Extragalactic: AGNs, GRBs, …

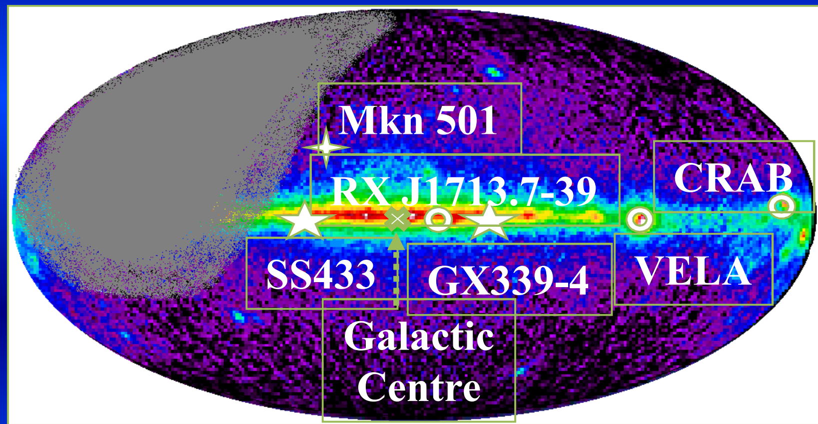


Hadronic models predict the production of high energy neutrinos in the vicinity of the acceleration scenarios

$$p + \gamma \rightarrow \Delta^{+} \rightarrow \pi^{0} + p$$
$$p + \gamma \rightarrow \Delta^{+} \rightarrow \pi^{+} + n$$

$$\pi^{+(-)} \rightarrow \nu_{\mu}(\bar{\nu}_{\mu}) + \mu^{+(-)}$$
$$\hookrightarrow \mu^{+(-)} \rightarrow \bar{\nu}_{\mu}(\nu_{\mu}) + \nu_{e}(\bar{\nu}_{e}) + e^{+(-)}$$

Field of view in galactic coordinates



The Galactic Center is visible during the 63 % of the time

Physics with neutrino telescopes

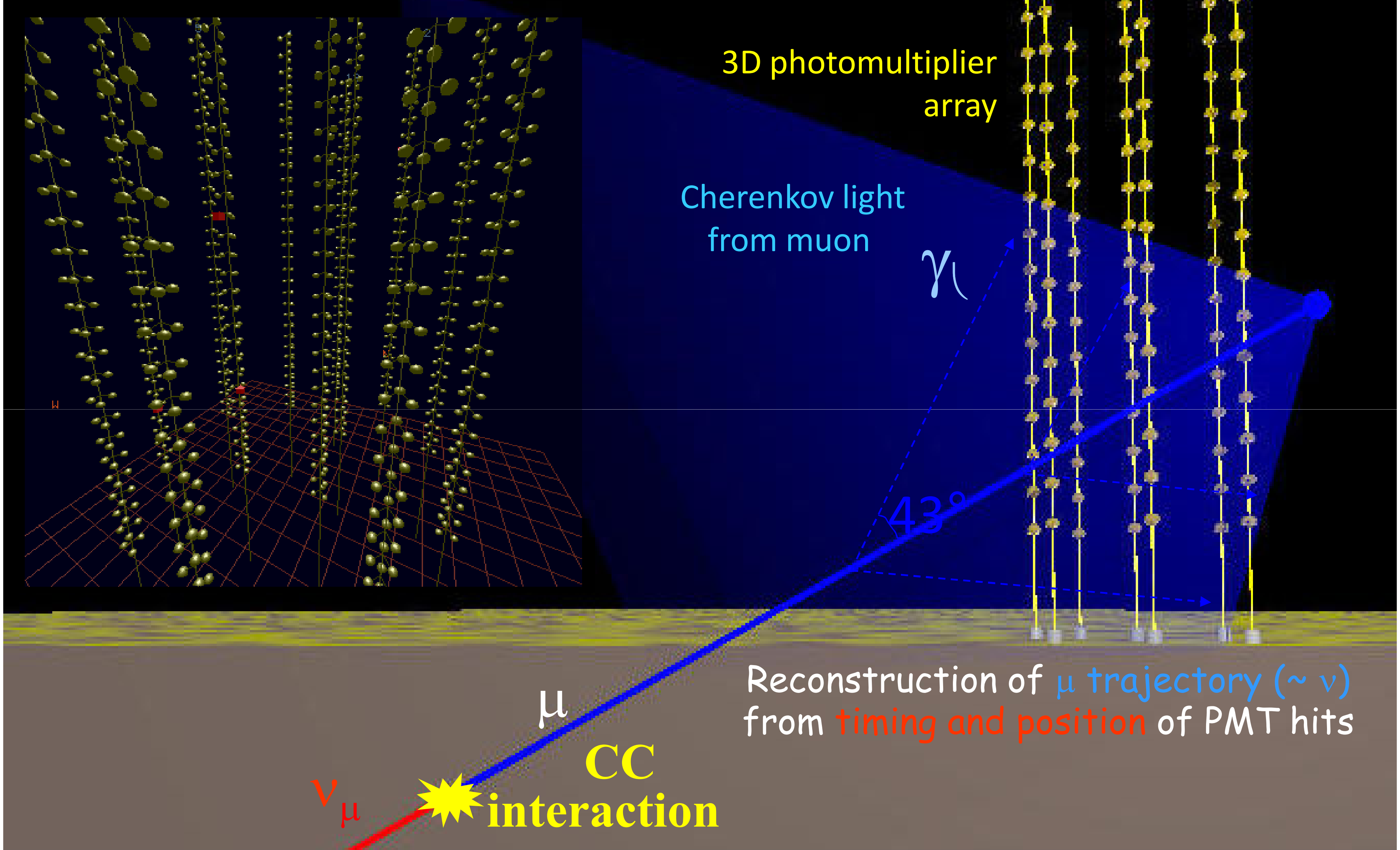
Neutrino telescopes are open to a large range high energy window

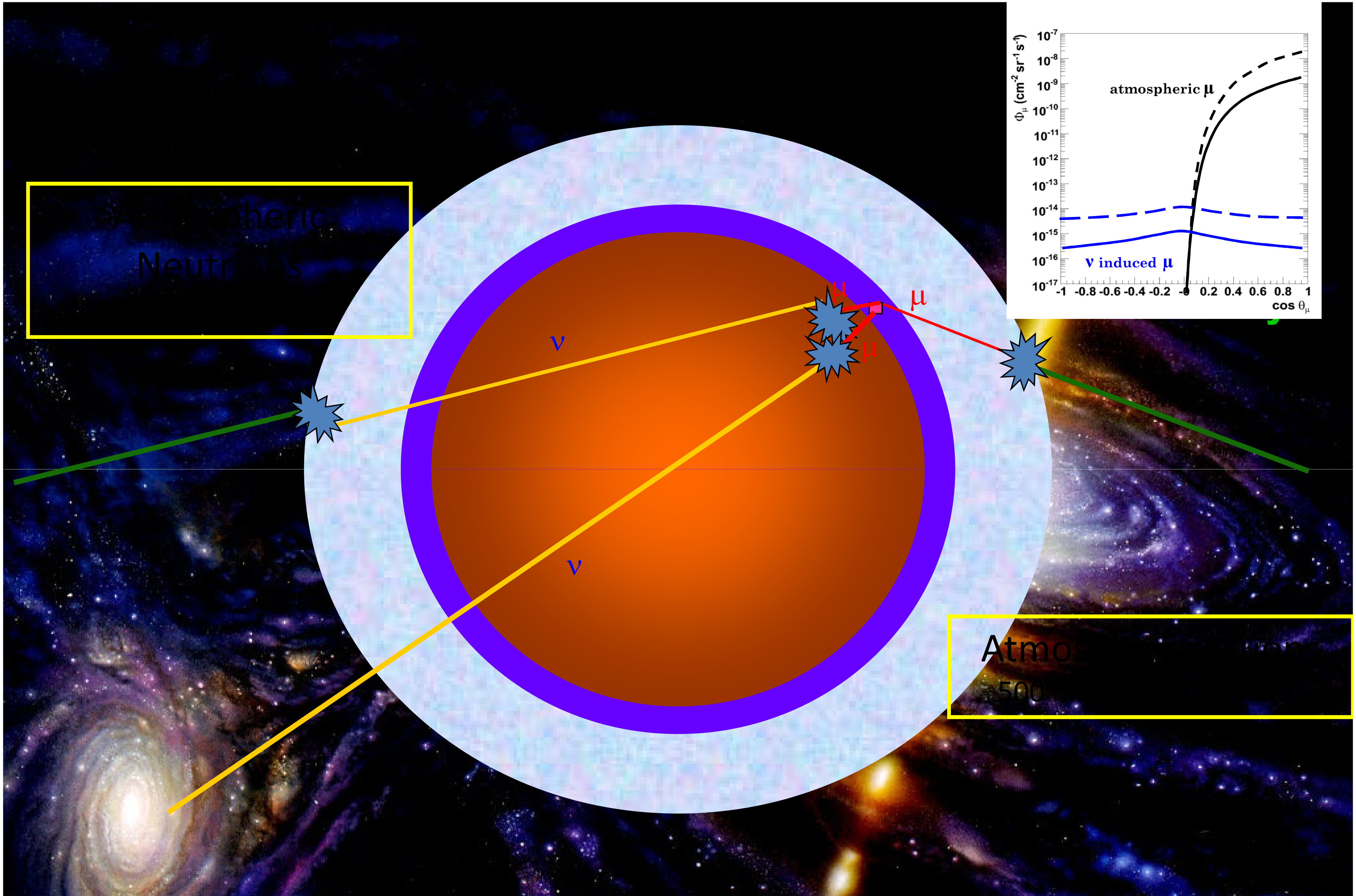
100 GeV – 1 PeV

- **Astroparticle physics**
  - Point sources of high-energy neutrinos
  - The diffuse neutrino flux
  - Neutrinos from Dark Matter annihilation
- **Particle Physics**
  - Cross sections at UHE
  - Neutrino oscillations
  - Tests of Lorentz invariance
- **Search for exotics**
  - Magnetic monopoles
  - Nuclearites, strangelets, …
- **Earth and marine sciences**
  - Measurements in the deep-sea
  - Marine biology, oceanography,
  - Neutrino tomography of Earth

- Physics with neutrino telescopes
- **Detection principle and detector description**
- Results from ANTARES

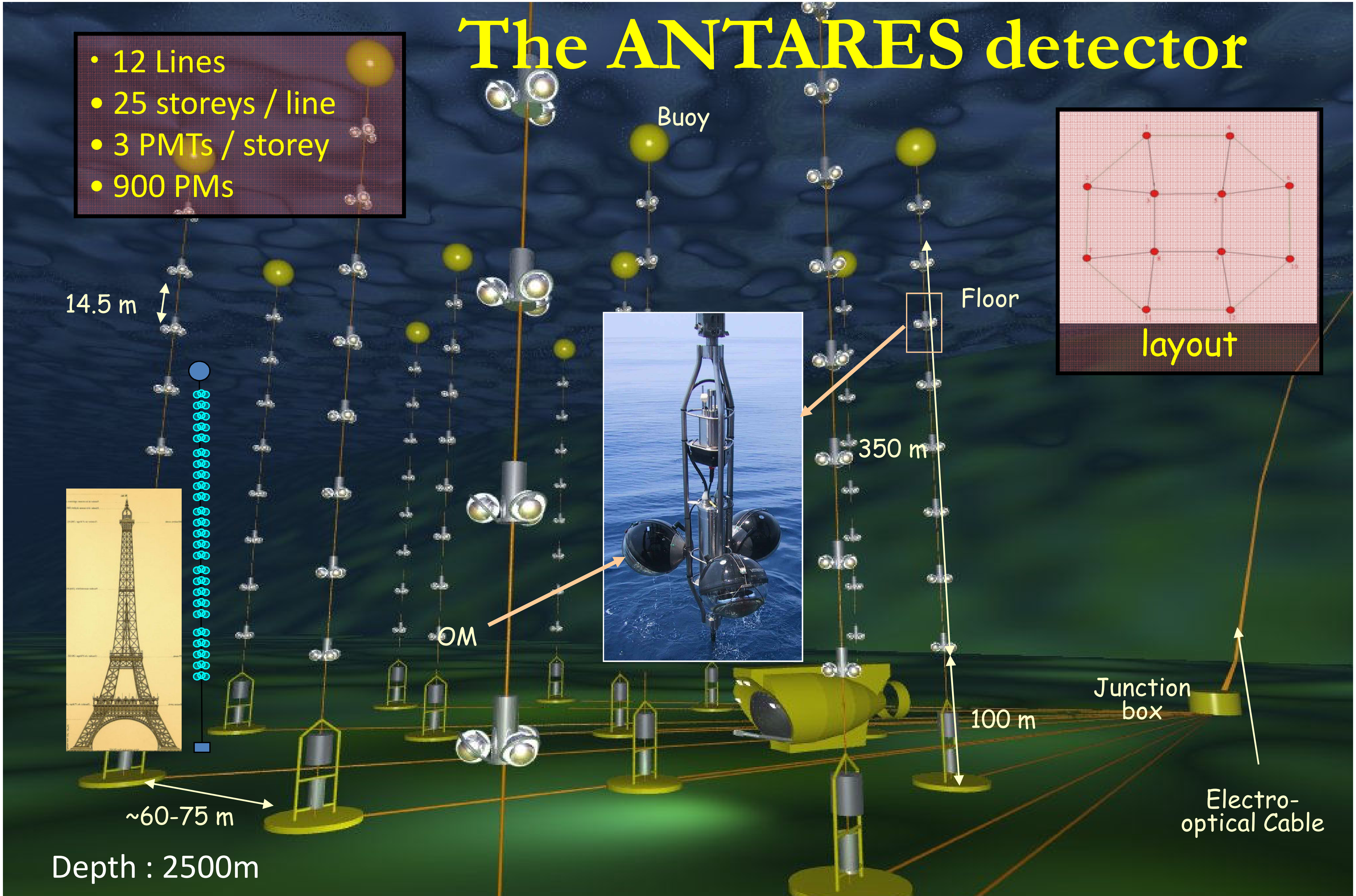
Neutrino telescope: Detection principle



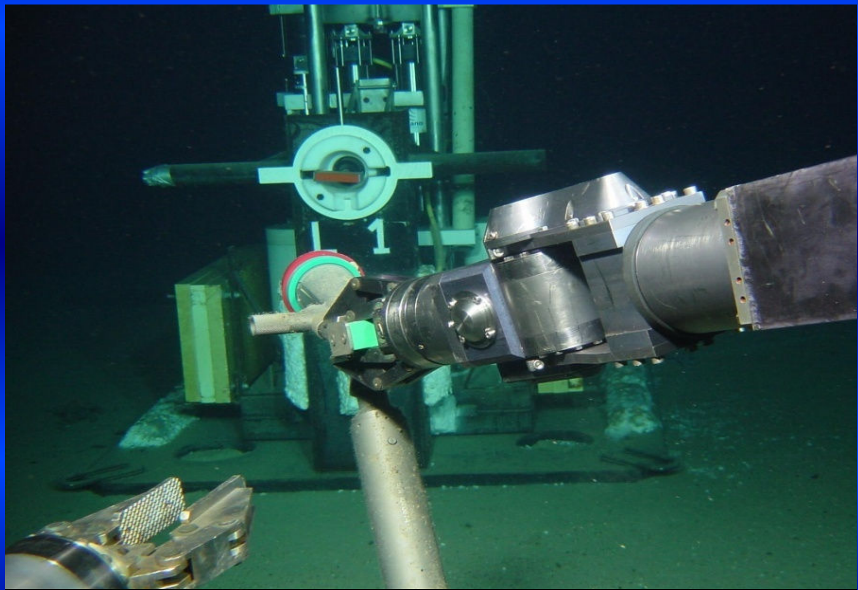


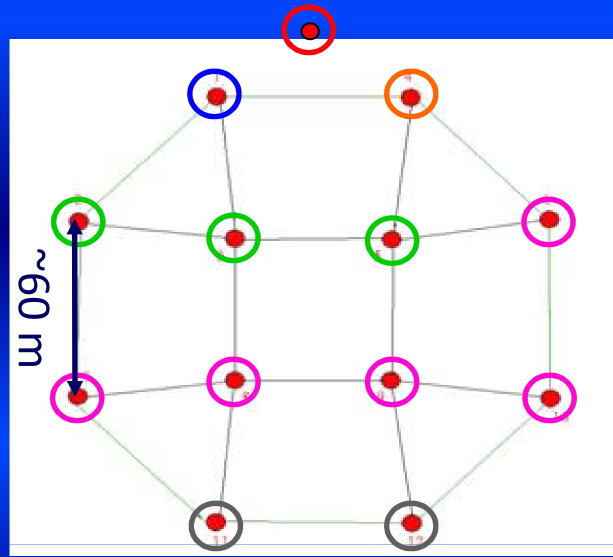
ν
ν
μ
μ
μ
atmospheric μ
ν induced μ
Φμ (cm-2 sr-1 s-1)
cos θμ

The ANTARES site


The ANTARES detector
• 12 Lines
• 25 storeys / line
• 3 PMTs / storey
• 900 PMs
Buoy
layout
14.5 m
Floor
350 m
OM
100 m
Junction box
~60-75 m
Electro-optical Cable
Depth : 2500m

Line Connection





MILOM: 17th Mar 2005

Line 1: 2nd Mar 2006

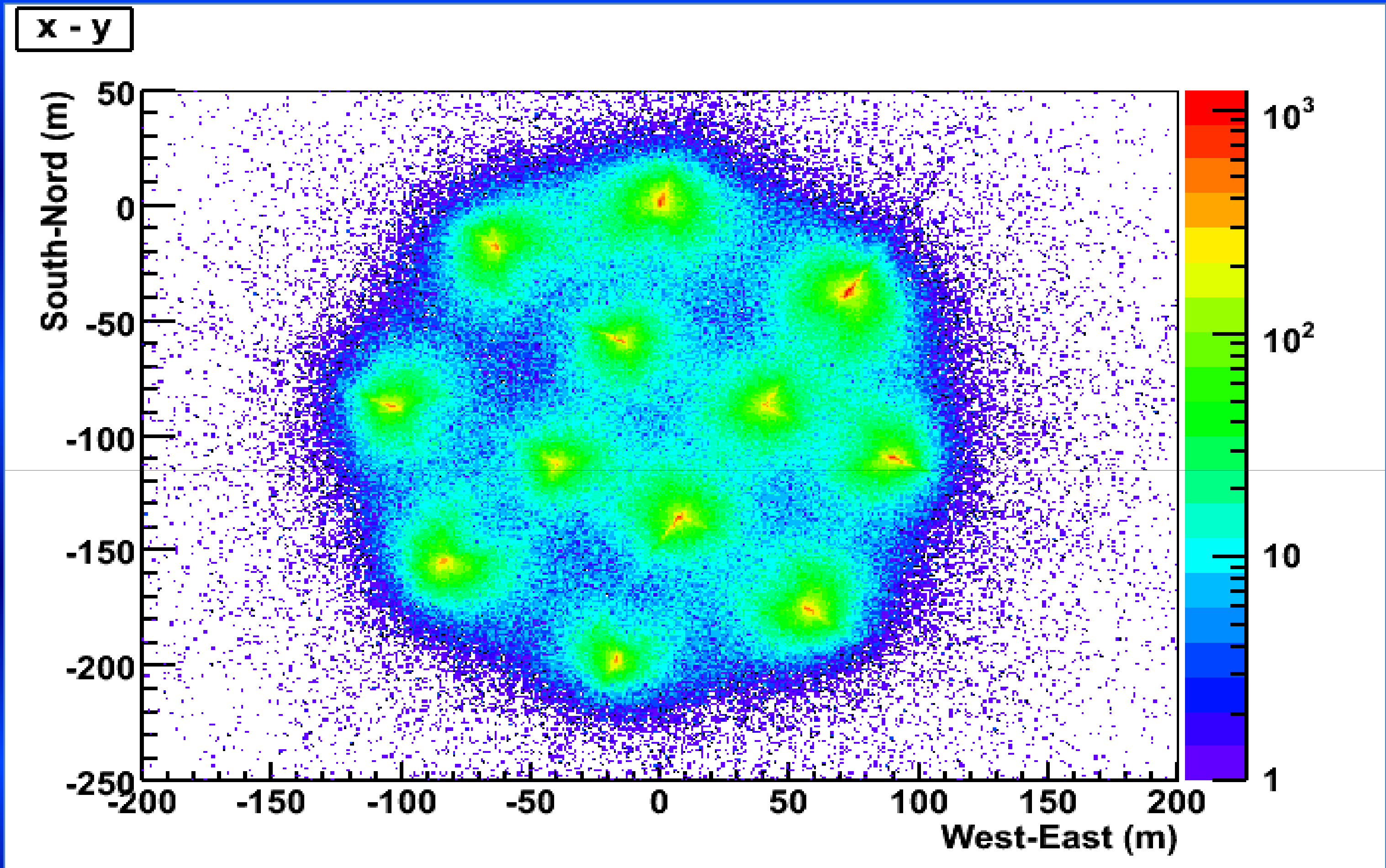
Line 2: 21st Sep 2006

Line 3, 4, 5: 29th Jan 2007

Line 6, 7, 8, 9, 10: 7th Dec 2007

Line 11, 12: 30th May 2008

ANTARES installation completed in May 2008



x, y coordinates of track fits at the time of the first triggered hit

~ 0.1 km^2 sensitive surface

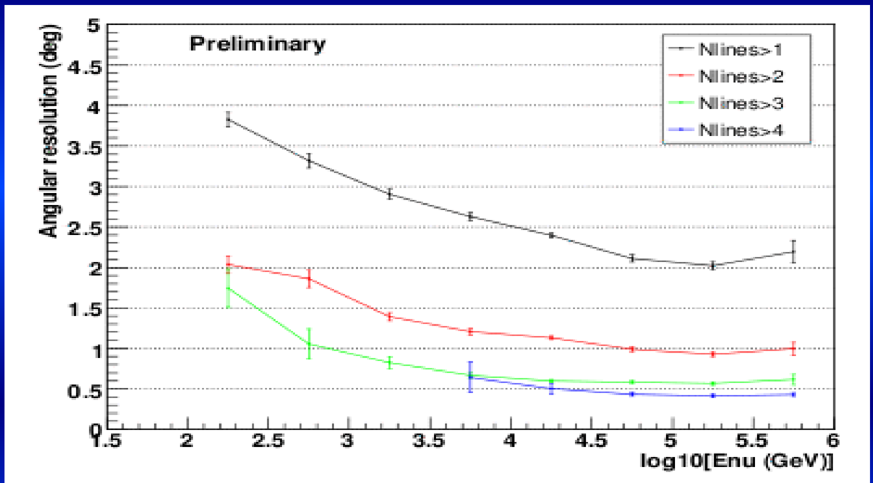
Footprint of the 12-line detector in atmospheric muons

Track reconstruction

Online Algorithm

- Triplets as single points
- Find clusters of floors allowing one skipped floor
- Only lines with at least one such cluster
- Add compatible single hits
- Chi square fit

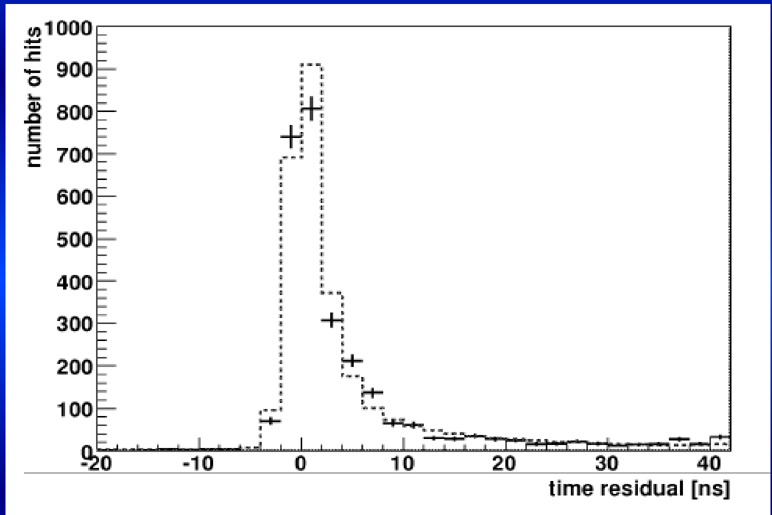
- **Immediately available**
- Non-optimal angular resolution



Offline Algorithm

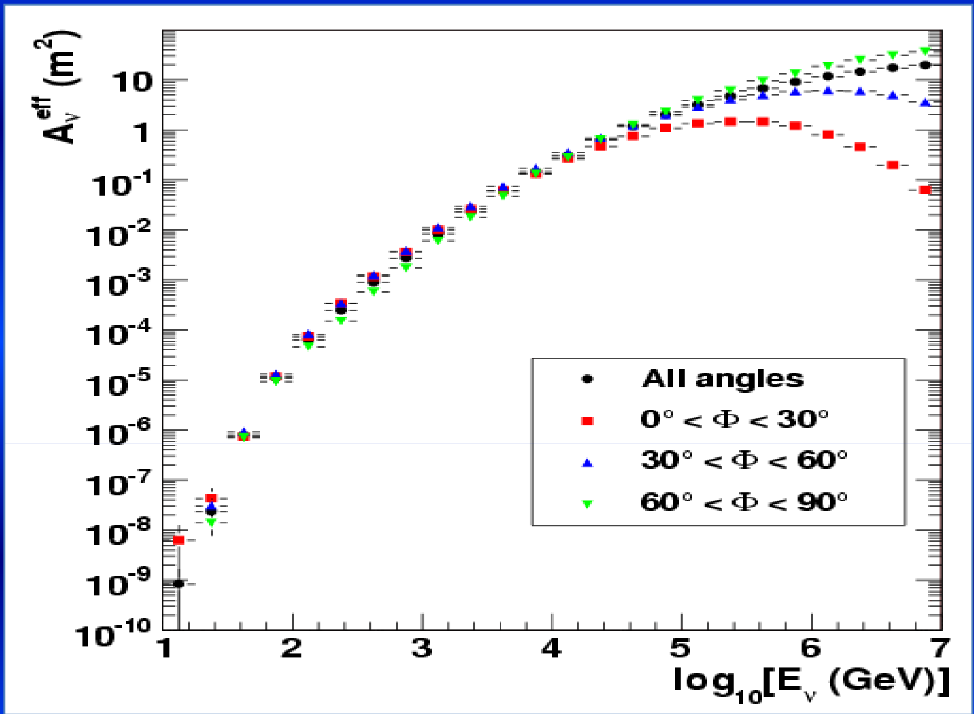
- Uses final alignment
- Loose selection
- Full likelihood fit
- Multiple starting points

- Not immediately available
- **Excellent angular resolution**

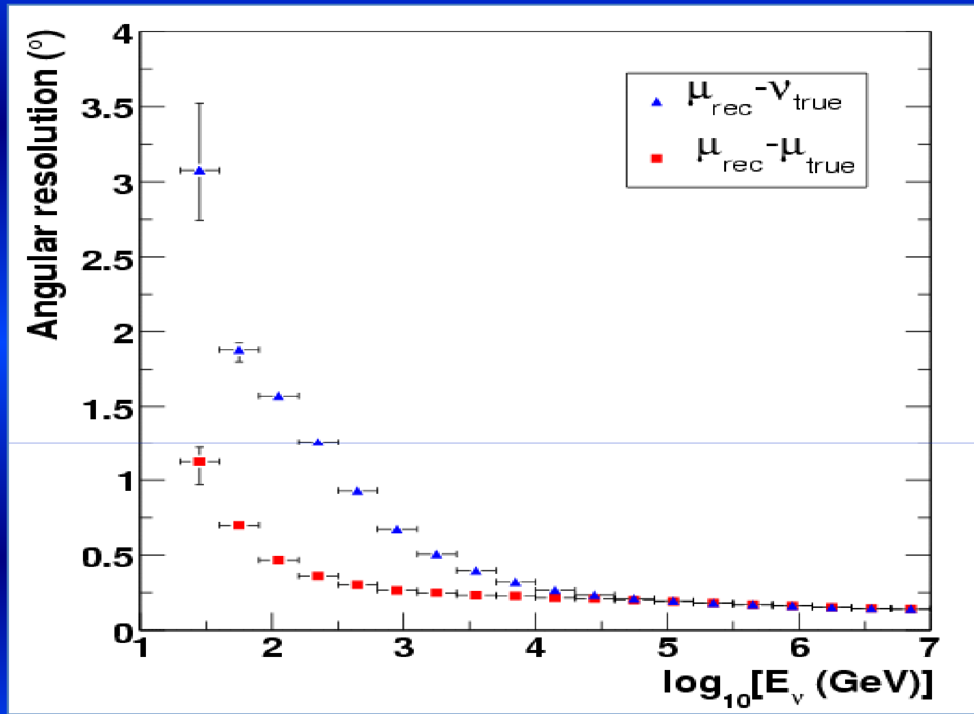


Expected performance

Neutrino Effective Area



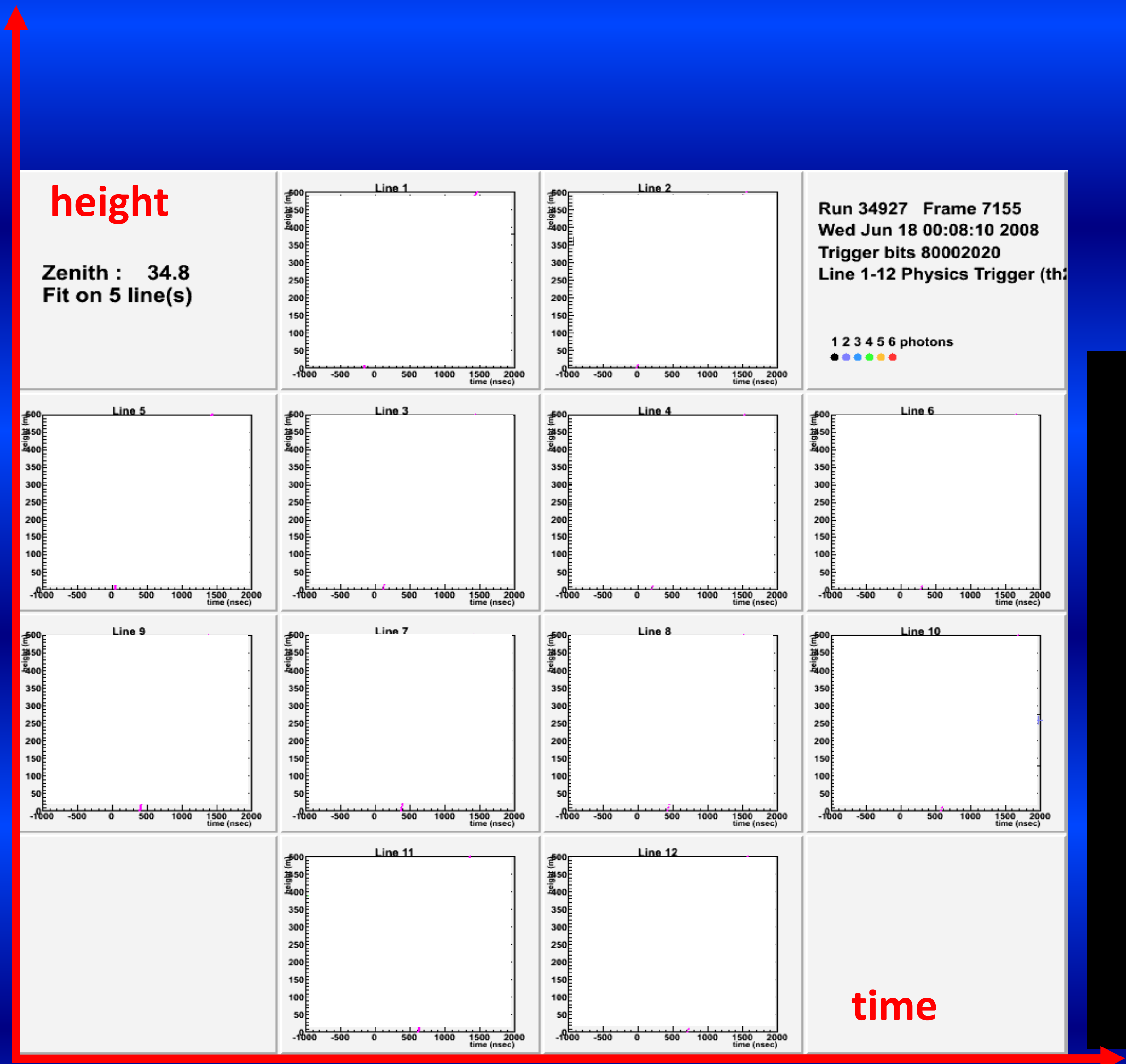
Angular resolution



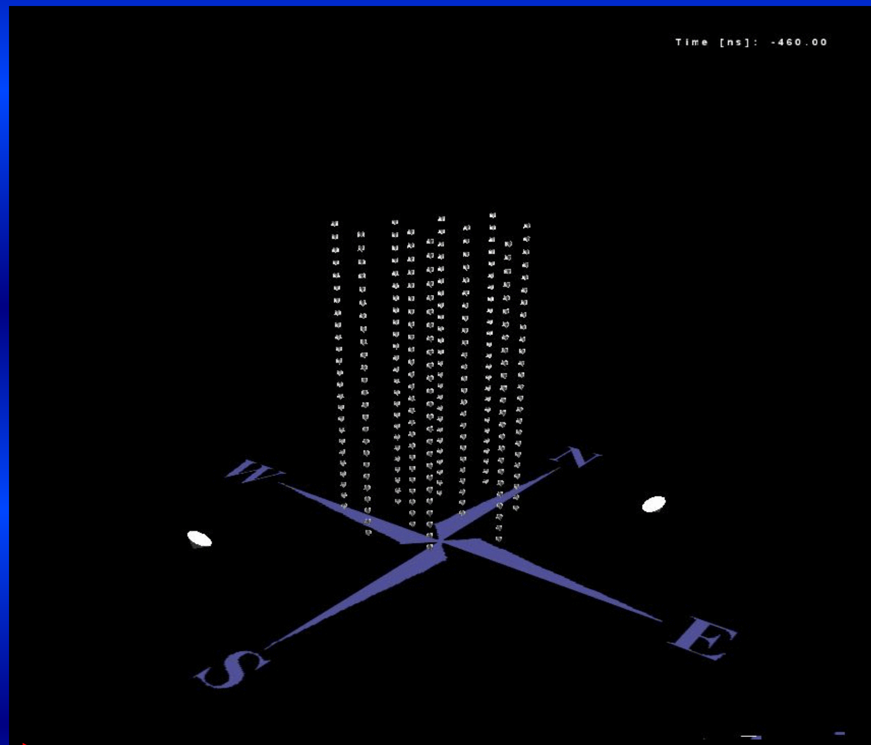
- ❑ For E_ν<10 PeV, A_{eff} grows with energy due to the increase of the interaction cross section and the muon range.
- ❑ For E_ν>10 PeV the Earth becomes opaque to neutrinos.

- ❑ 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 intrinsic detector capabilities (PMT transit time spread, dispersion and scattering of light).

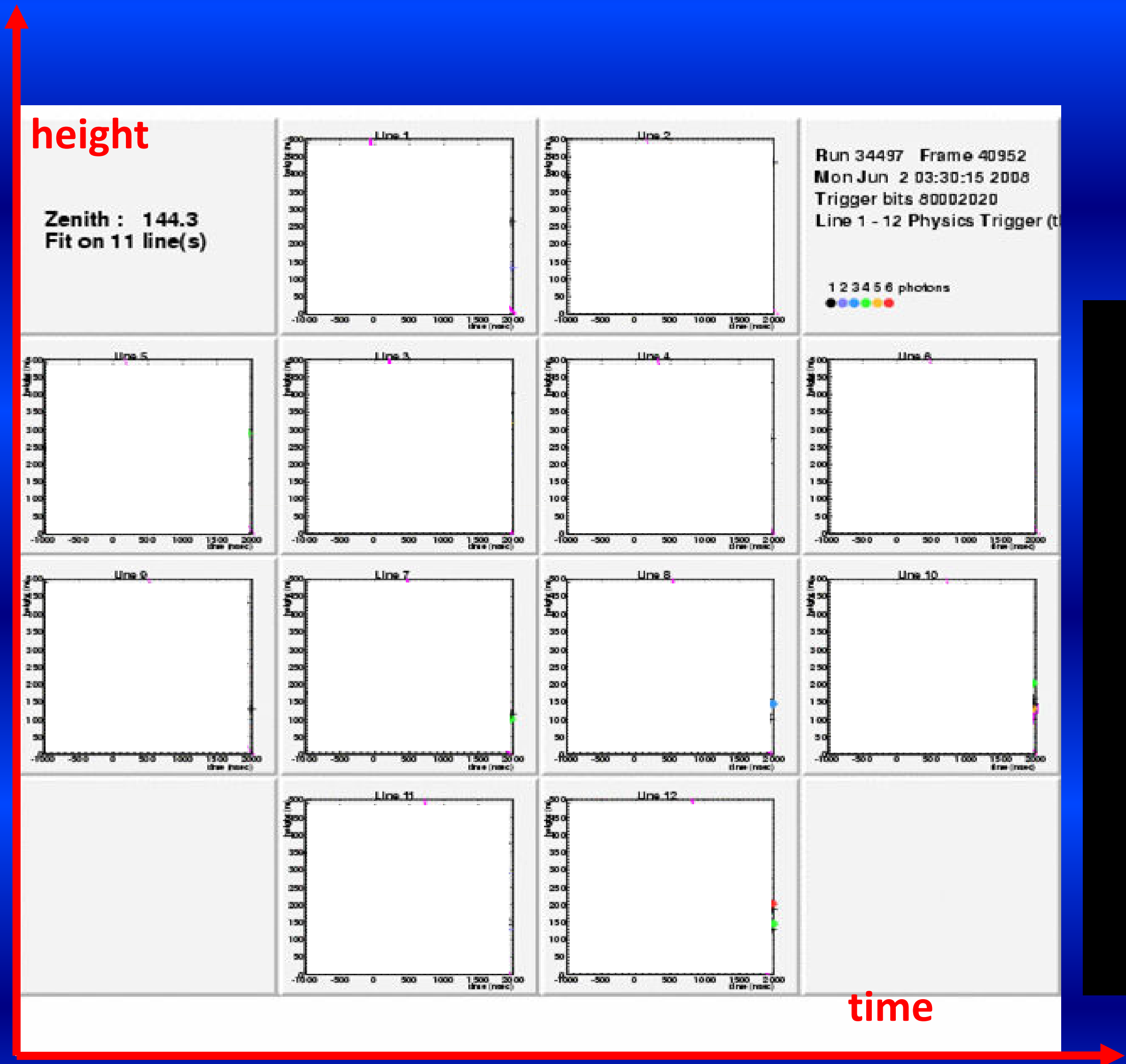
ANTARES event display: neutrino induced muon



Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 5/12 detector lines

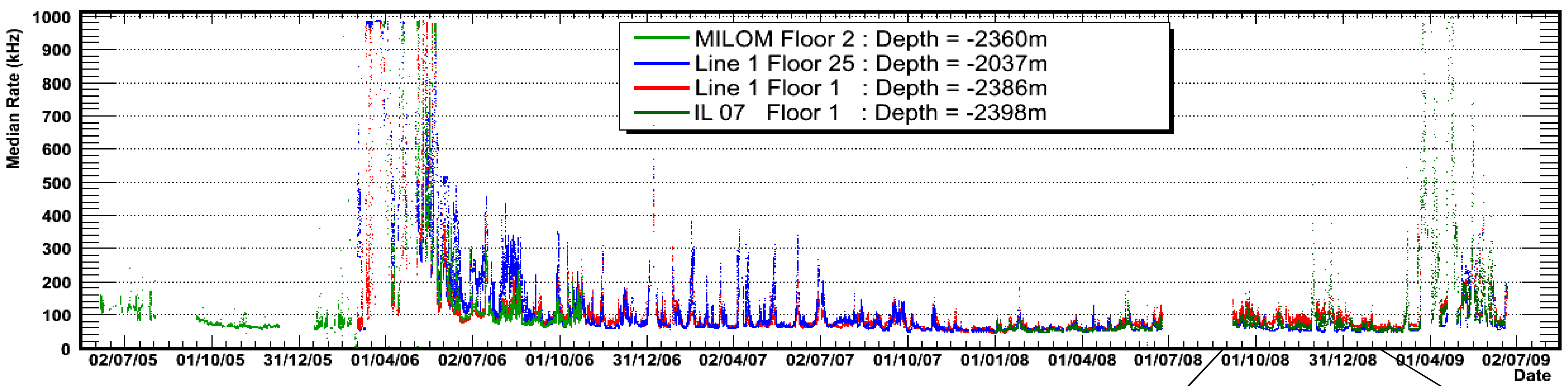


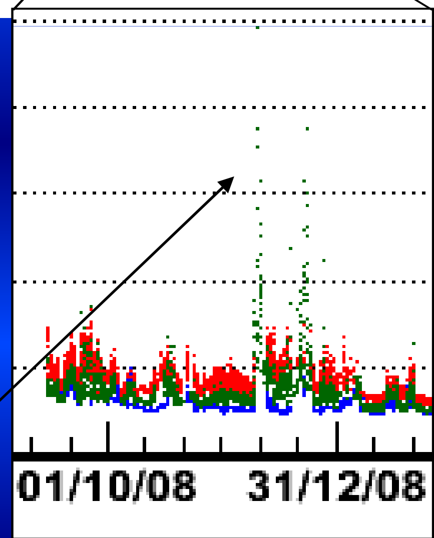
ANTARES event display: atmospheric muons



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

Detection rate





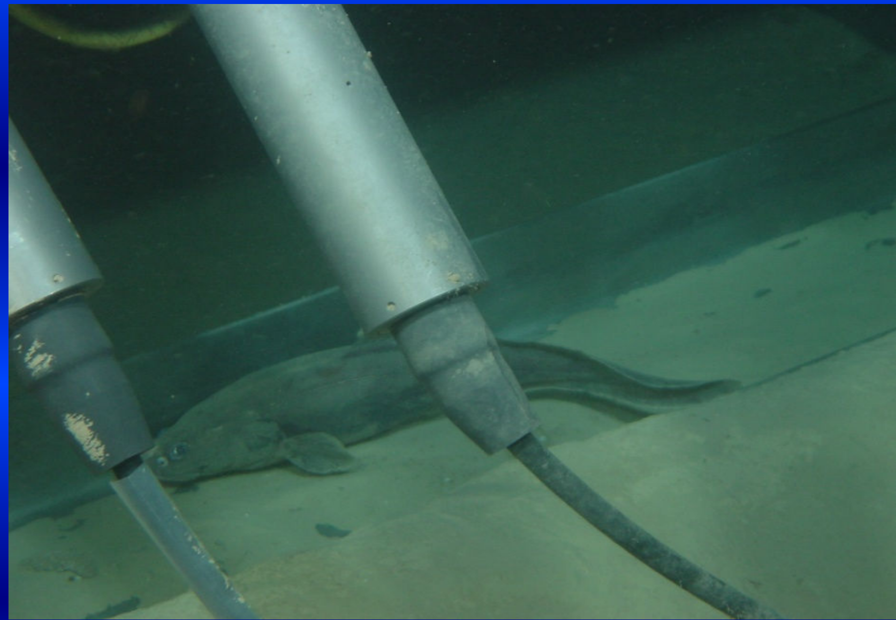
Median rate of measured single photon counts: typ. 60 – 80 kHz caused by **bioluminescence (~ 30 kHz) and ^{40}K decay (~ 40 kHz)**

Occasional bursts of extreme high rates (~ MHz) are caused by macro-organisms (depends on sea current):

Multidisiplinary research:
oceanographic studies



Multidisciplinarity



Deepest online cameras
in the world

Marine biologist collaboration
needed

Answer

ANTARES can find fish, but finds many more neutrinos

- Physics with neutrino telescopes

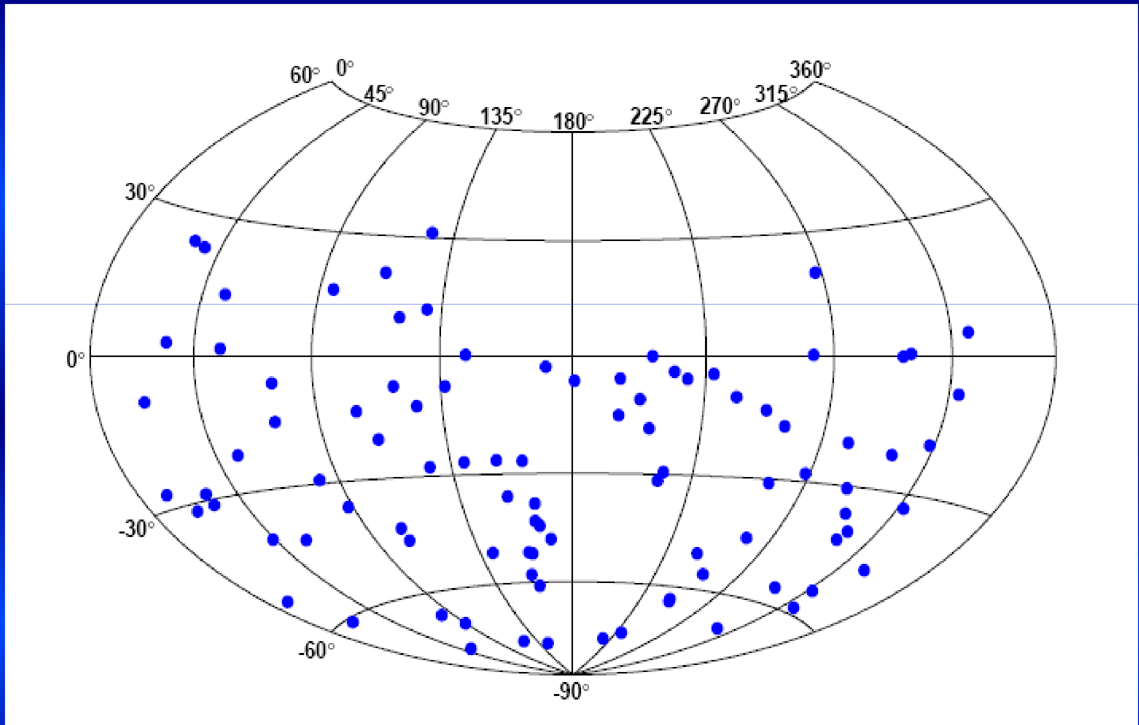
- Detection principle and detector description

- **Results from ANTARES**

Point-like source search

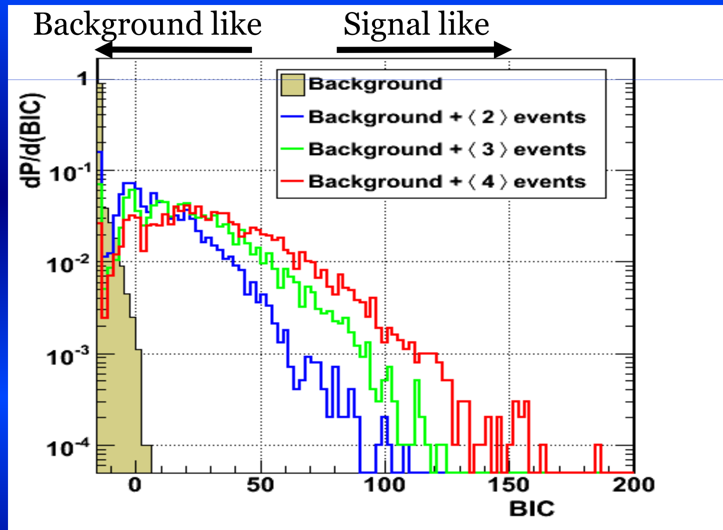
Several methods to look for neutrino sources have been developed:

- **Binned techniques** → cone search
- **Unbinned techniques** → EM algorithm and Likelihood ratio



Skymap in equatorial coordinates

A first 5Lines detector data analysis selected 94 events as cosmic neutrino candidates

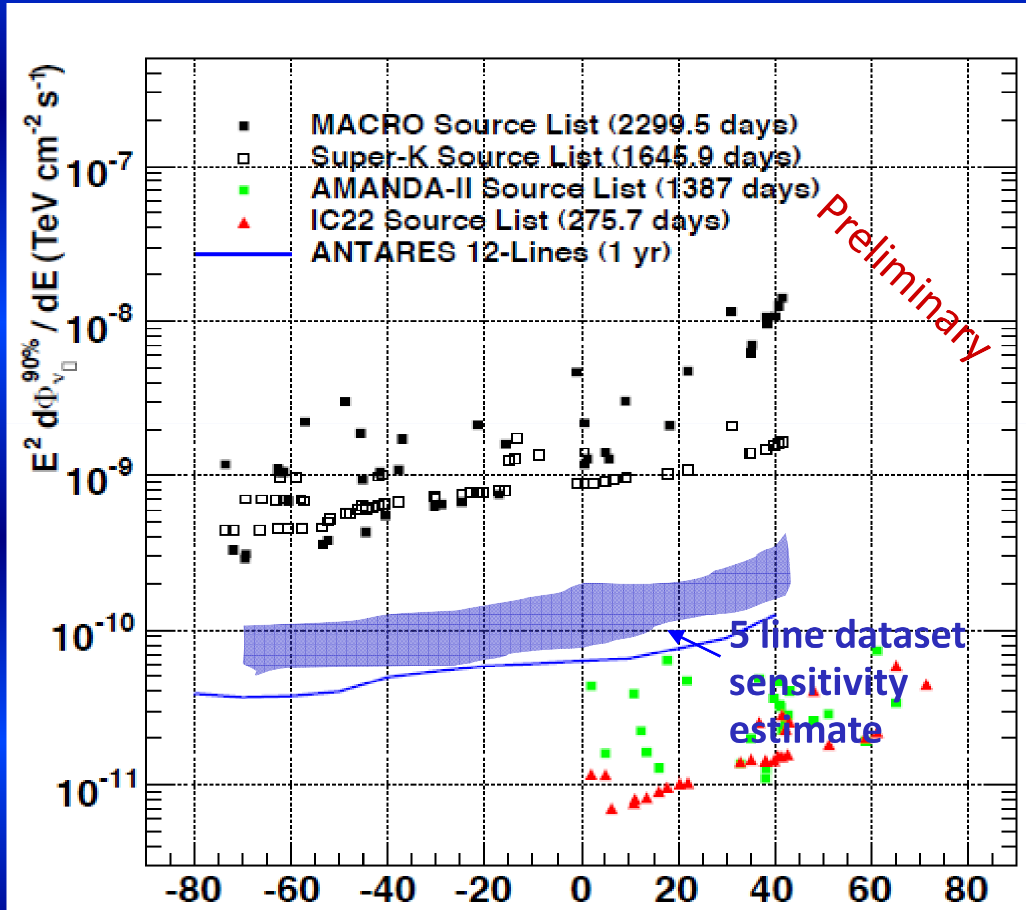


Distribution of the test statistic for the EM clustering algorithm

Point-like source search

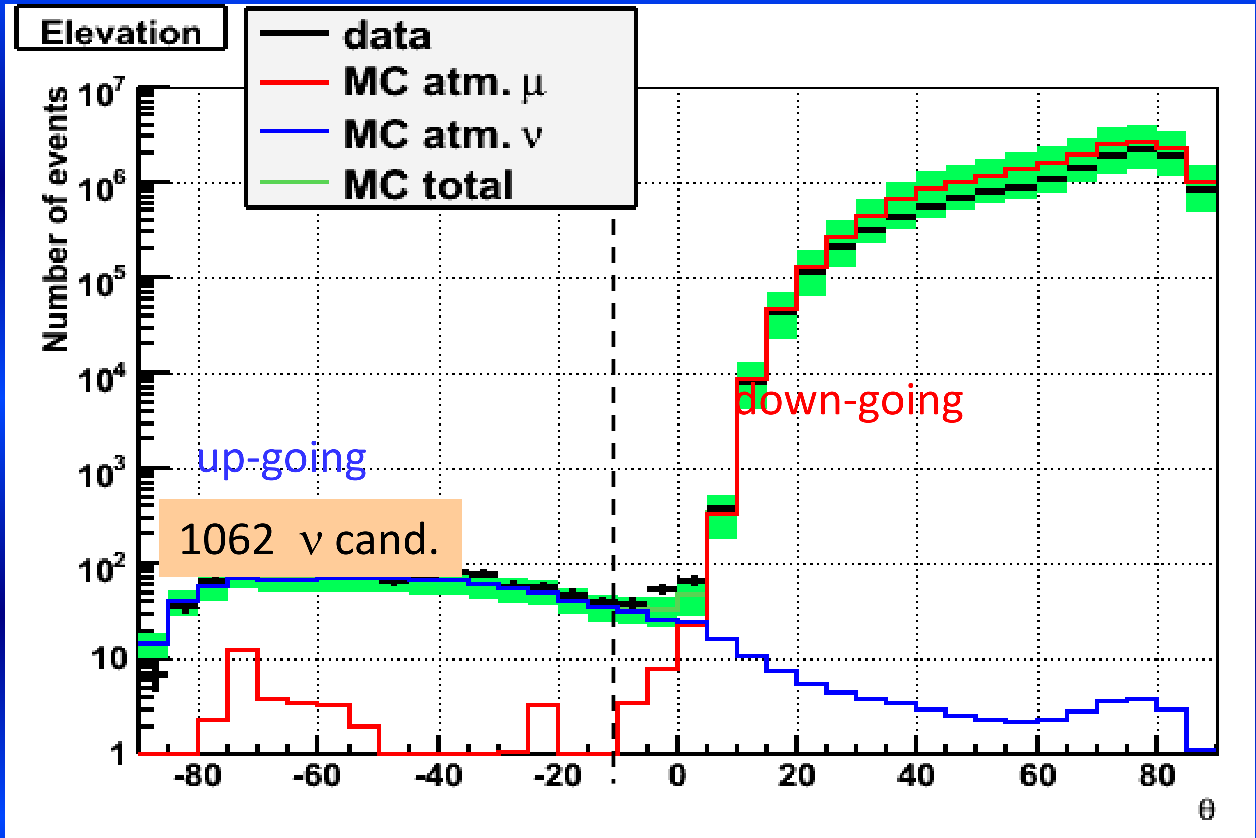
Source name	δ (°)	RA (°)	$n_{2.5°}$	P-value	ϕ_{90}
PSR B1259-63	-63.83	195.70	0	-	3.1
RCW 86	-62.48	220.68	0	-	3.3
HESS J1023-575	-57.76	155.83	1	0.004	7.6
CIR X-1	-57.17	230.17	0	-	3.3
HESS J1614-518	-51.82	243.58	1	0.088	5.6
GX 339	-48.79	255.70	0	-	3.8
RX J0852.0-4622	-46.37	133.00	0	-	4.0
RX J1713.7-3946	-39.75	258.25	0	-	4.3
Galactic Centre	-29.01	266.42	1	0.055	6.8
W28	-23.34	270.43	0	-	4.8
LS 5039	-14.83	276.56	0	-	5.0
HESS J1837-069	-6.95	279.41	0	-	5.9
SS 433	4.98	287.96	0	-	7.3
HESS J0632+057	5.81	98.24	0	-	7.4
ESO 139-G12	-59.94	264.41	0	-	3.4
PKS 2005-489	-48.82	302.37	0	-	3.7
Centaurus A	-43.02	201.36	0	-	3.9
PKS 0548-322	-32.27	87.67	0	-	4.3
H 2356-309	-30.63	359.78	0	-	4.2
PKS 2155-304	-30.22	329.72	0	-	4.2
1ES 1101-232	-23.49	165.91	0	-	4.6
1ES 0347-121	-11.99	57.35	0	-	5.0
3C 279	-5.79	194.05	1	0.030	9.2
RGB J0152+017	1.79	28.17	0	-	7.0
IC22 hotspot	11.00	153.00	0	-	9.1

Competitive limits in the southern sky



No correlation with 25 potential ν sources;
no excess (± 1σ) in all-sky search;
sensitivity competitive with multi-year
exposures of previous experiments

Getting more neutrinos



5-line data (May-Dec. 2007)+ 9-12 line data (2008)

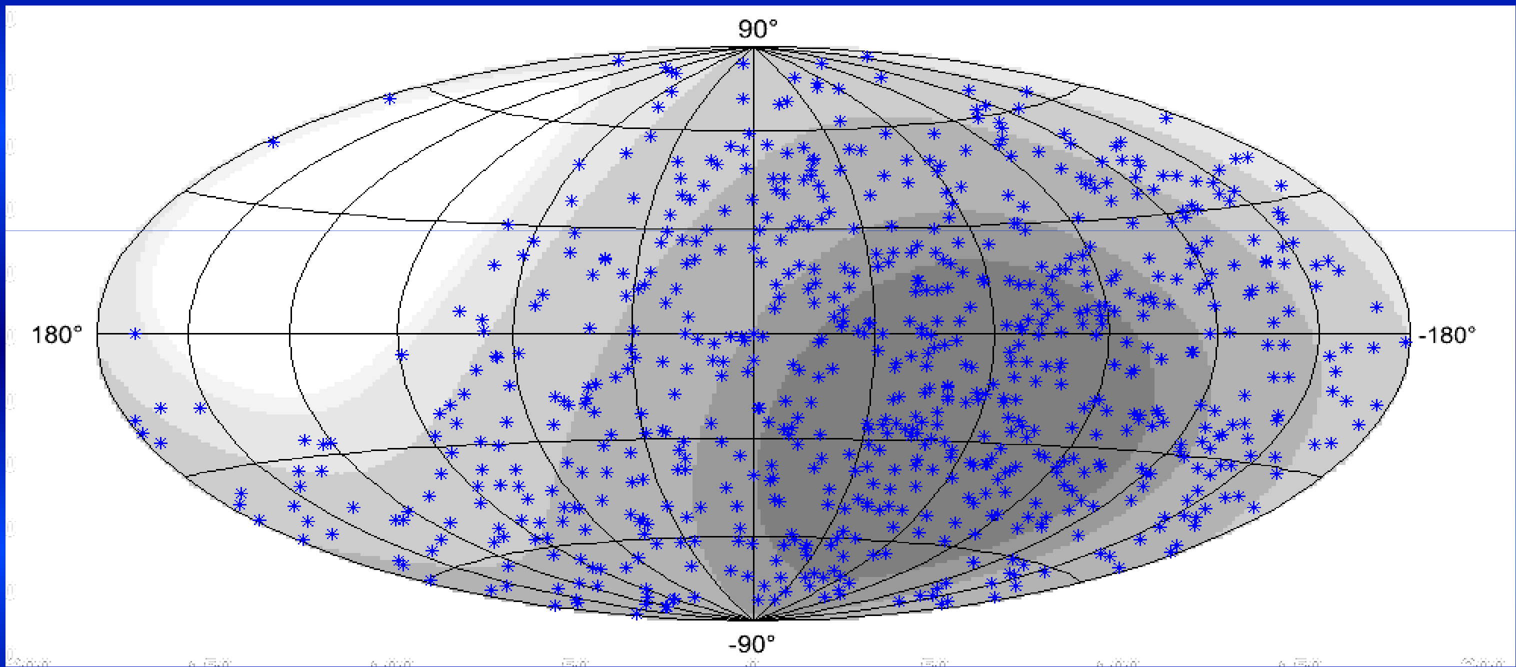
341 days detector live time, reconstruction BBfit v3r2, single- and multi-line fit:

1062 neutrino candidates:
3.1 ν candidates/day

good agreement with **Monte Carlo**: **atmospheric neutrinos → 916 (30% syst. error)**
atmospheric muons → 40 (50% syst. error)

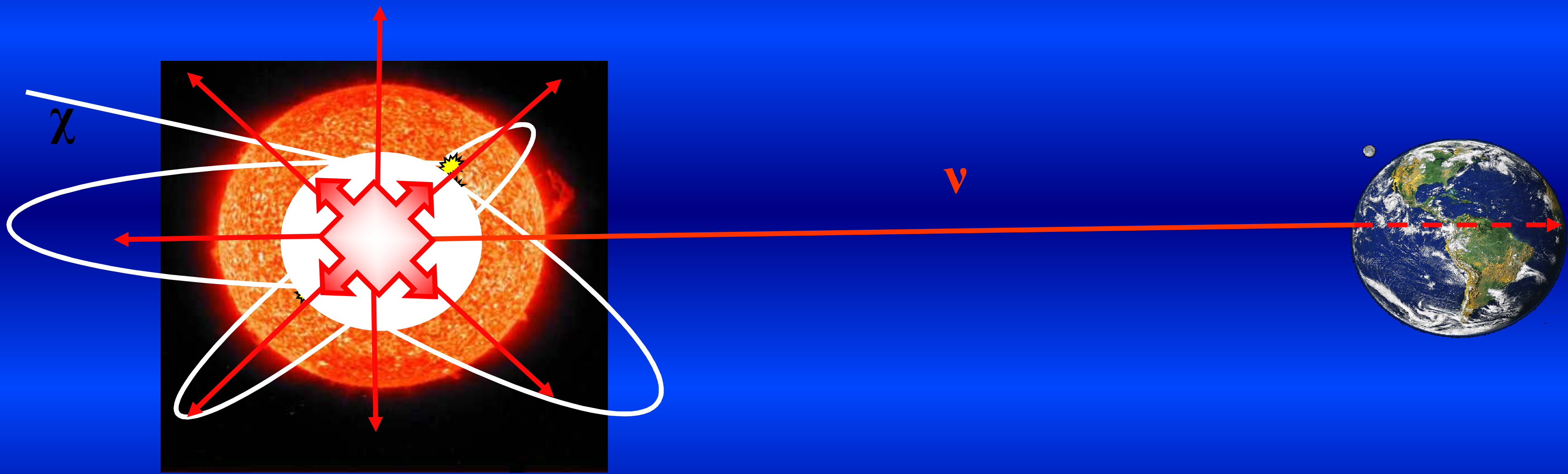
ANTARES neutrino sky map

From 2007 and 2008 data have been selected 750 “multi-line” neutrinos.
(data still blinded, positions are scrambled!)



(Galactic coordinates)

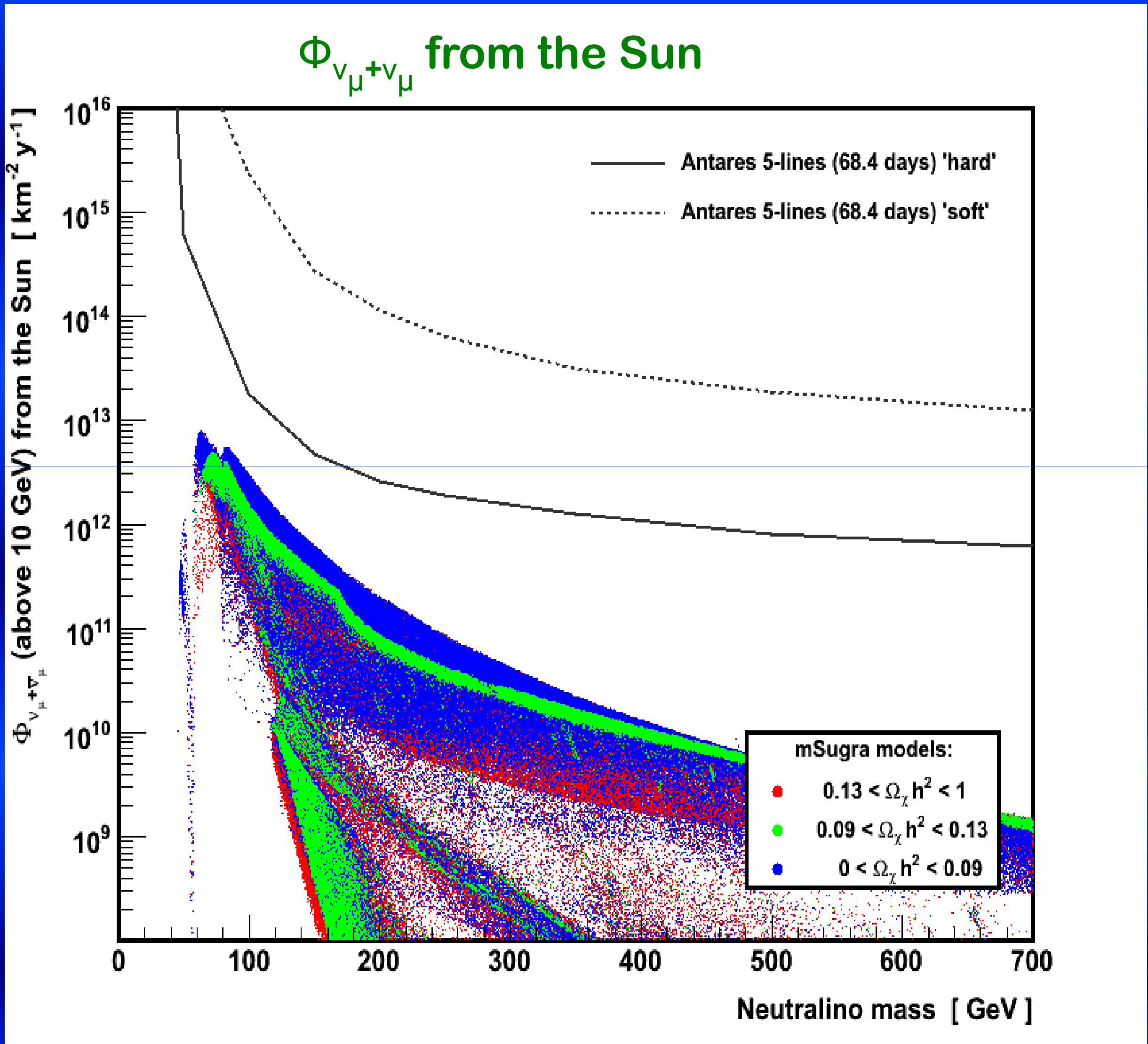
Dark matter model



- Relic WIMPs created in the early Universe can become gravitationally trapped in massive celestial objects like the Sun
- Over time, the WIMP density in the core of the object increases. This enhances the WIMP annihilation rate significantly, resulting in a high energy neutrino flux
- **The Sun is the most promising WIMPs source, but Earth, Galactic Center, Dwarf Galaxies are also investigated**

Dark matter results

Neutrino flux (SUN) vs Neutralino mass



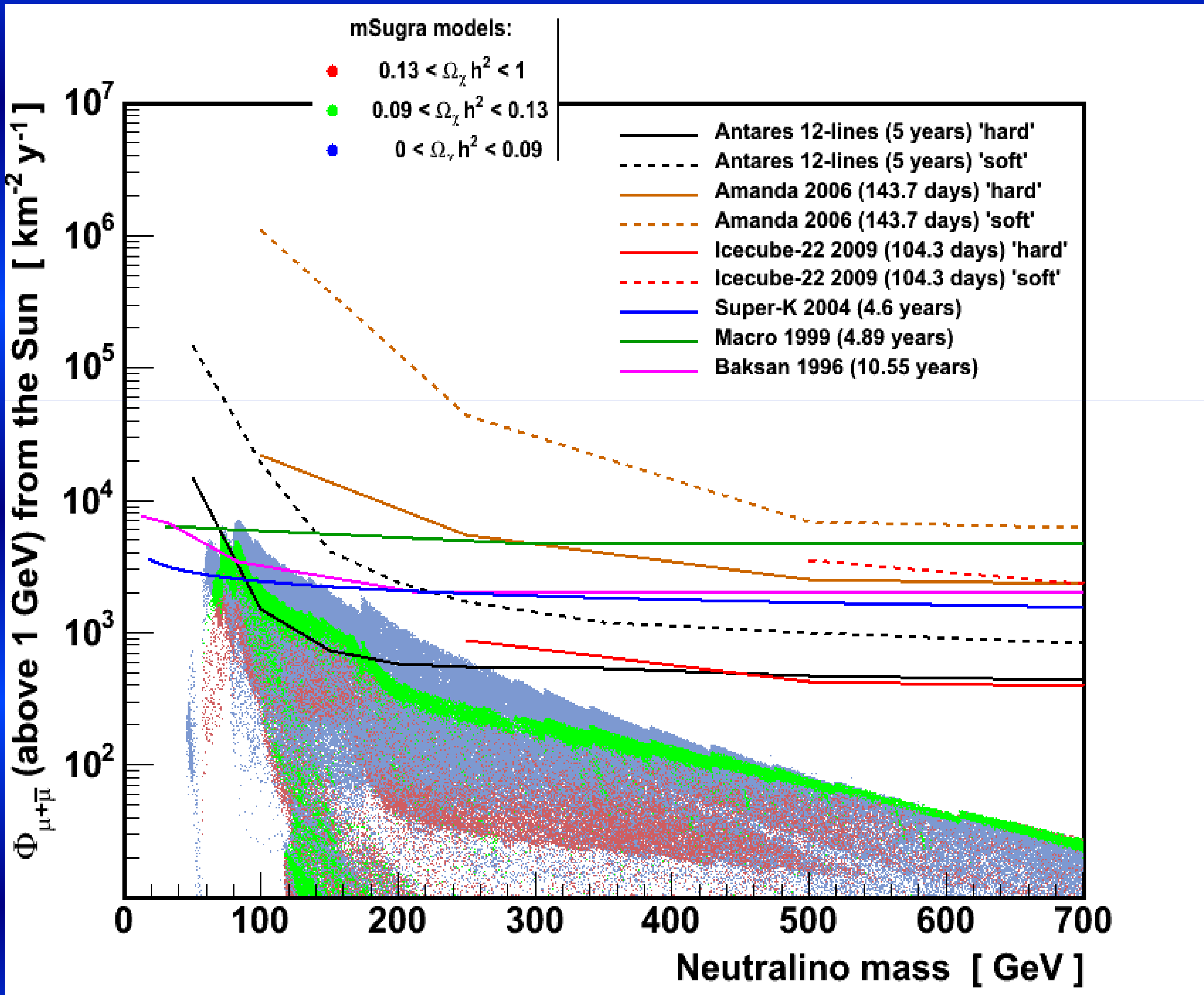
- 5-line data, 68.4 days
- **No excess observed**
  (90% C.L. limits) Feldman-Cousins
- mSugra model predictions

- **green** : WMAP favored relic density
- **red** : > WMAP favored relic density
- **blue** : < WMAP favored relic density

Promising Limits

Dark matter results

Expected sensitivity and comparison with other experiments



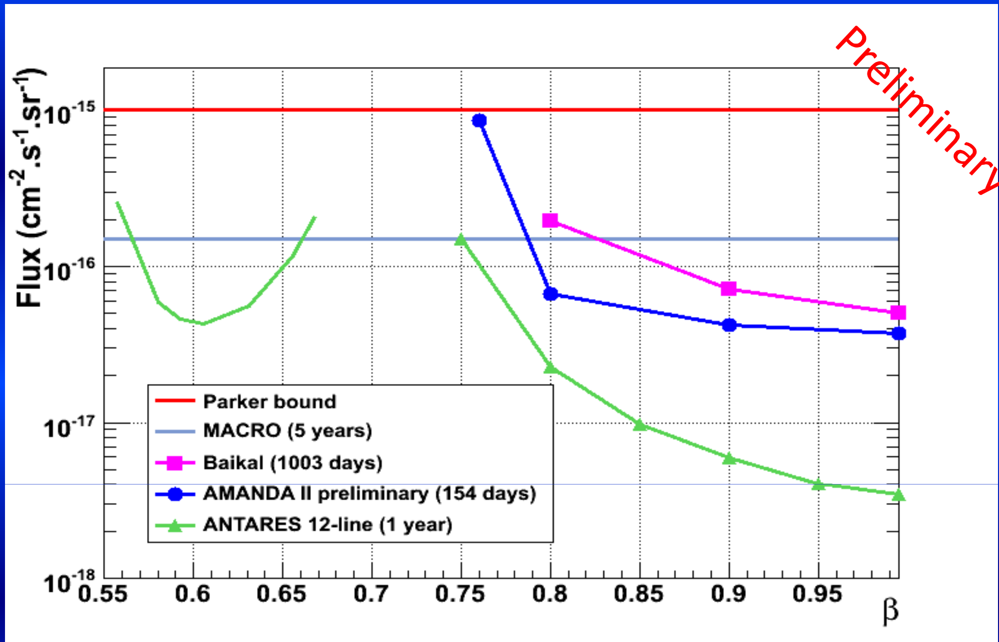
12 lines, 5 years, ν flux

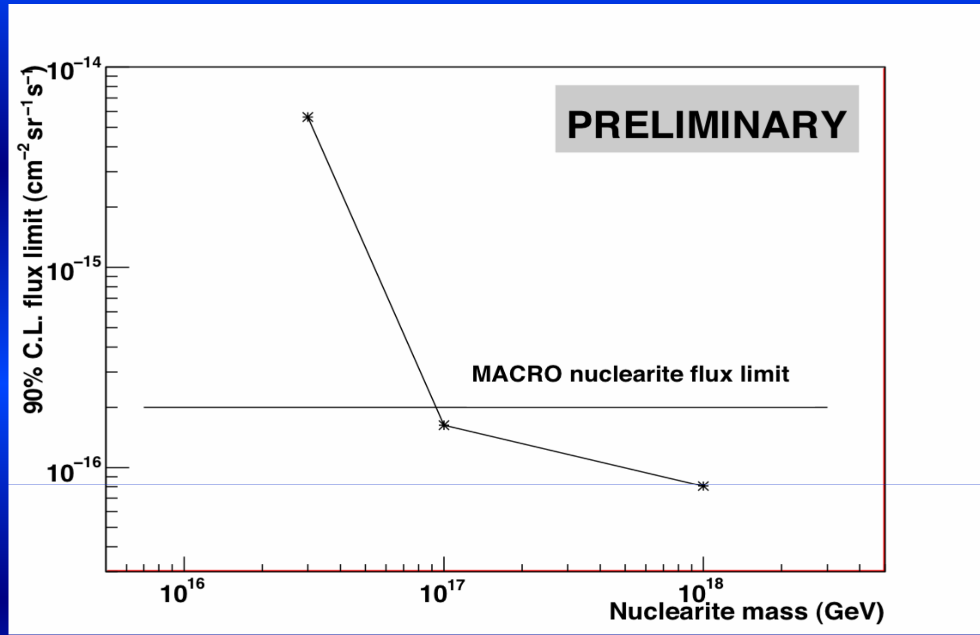
Most of focus point region excluded for m < 180 GeV

mSUGRA flux predictions:

- ● : > WMAP favoured relic density
- ● : within WMAP favoured relic density
- ● : < WMAP favoured relic density

Search for monopoles and nuclearities





Search for monopoles

- Extremely high energy deposition
- Direct Cherenkov light for $\beta > 0.74$
- δ-rays for $\beta > 0.51$

Search for nuclearites

(strangelets, quark nuggets, Q-balls).

- Very characteristic signature: extended source of photons "heated wire"
- 84 days of 5-line data

Multi-messenger astronomy

Strategy: higher **discovery potential** by observing different probes
higher **significance** by coincidence detection
higher **efficiency** by relaxed cuts

MoUs for joint research

Alerts

Ligo/Virgo

Gravitational waves: trigger + dedicated analysis chain

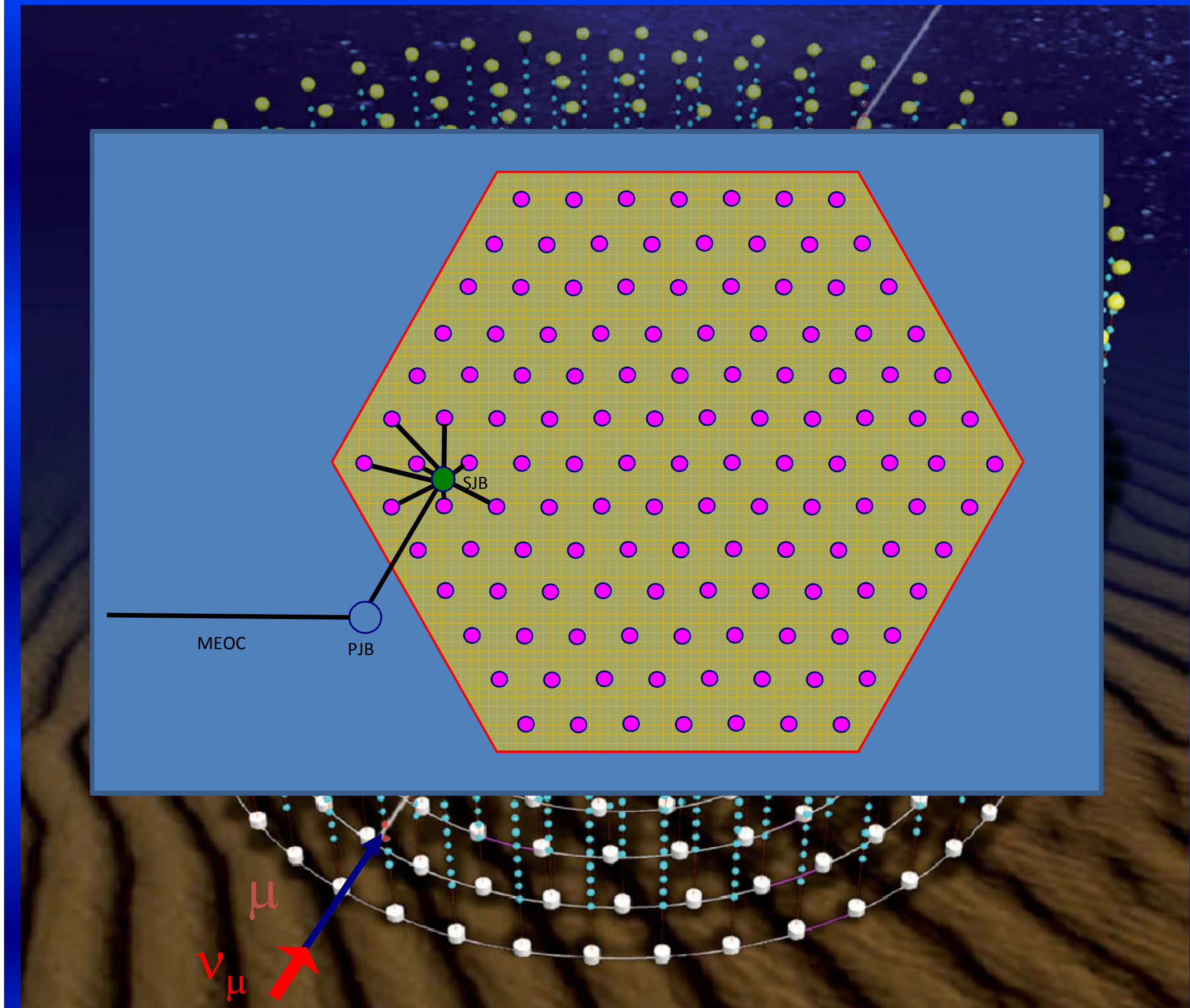
TAROT

optical follow up: 10 s repositioning

GCN

GRB Coord. Network: γ satellites

The future: KM3Net concept



- Array of optical modules (DU) sensing Cherenkov light
- Instrumented volume ~1 km^3
- Sensitive to all ν flavours
- E_ν > 0.1 GeV
- Angular resolution : min 0.1^o for E_ν > 10 TeV
- Acceptance: up-going tracks, up to 10^o above horizon

Summary

ANTARES is taking data since 2007 (infrastructure complete since May 29th 2008)

- Largest neutrino telescope in the northern hemisphere
- Observe galactic sources with unprecedented resolution
- Detector operation and its calibration understood

Exciting physics program ahead

- Over a thousand neutrinos already reconstructed
- Muons, neutrinos, dark matter, monopoles, ……
- Best limits for point sources in the southern sky
- Multi-messenger approach

Major step towards the KM3NeT multi-disciplinary deep-sea research infrastructure


THANKS FOR YOUR ATTENTION