First results of the ANTARES Neutrino Telescope

Thomas Eberl for the ANTARES collaboration

32nd International School of Nuclear Physics

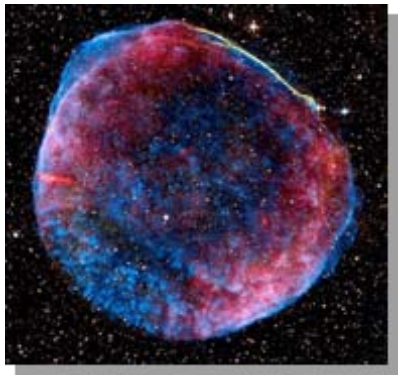
Erice Sept. 17th, 2010

Friedrich-Alexander-Universität Erlangen-Nürnberg

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

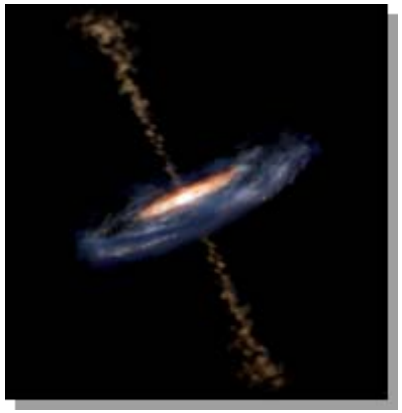
The High-Energy Universe

Supernova remnants
(SN1006, optical, radio, X-ray)



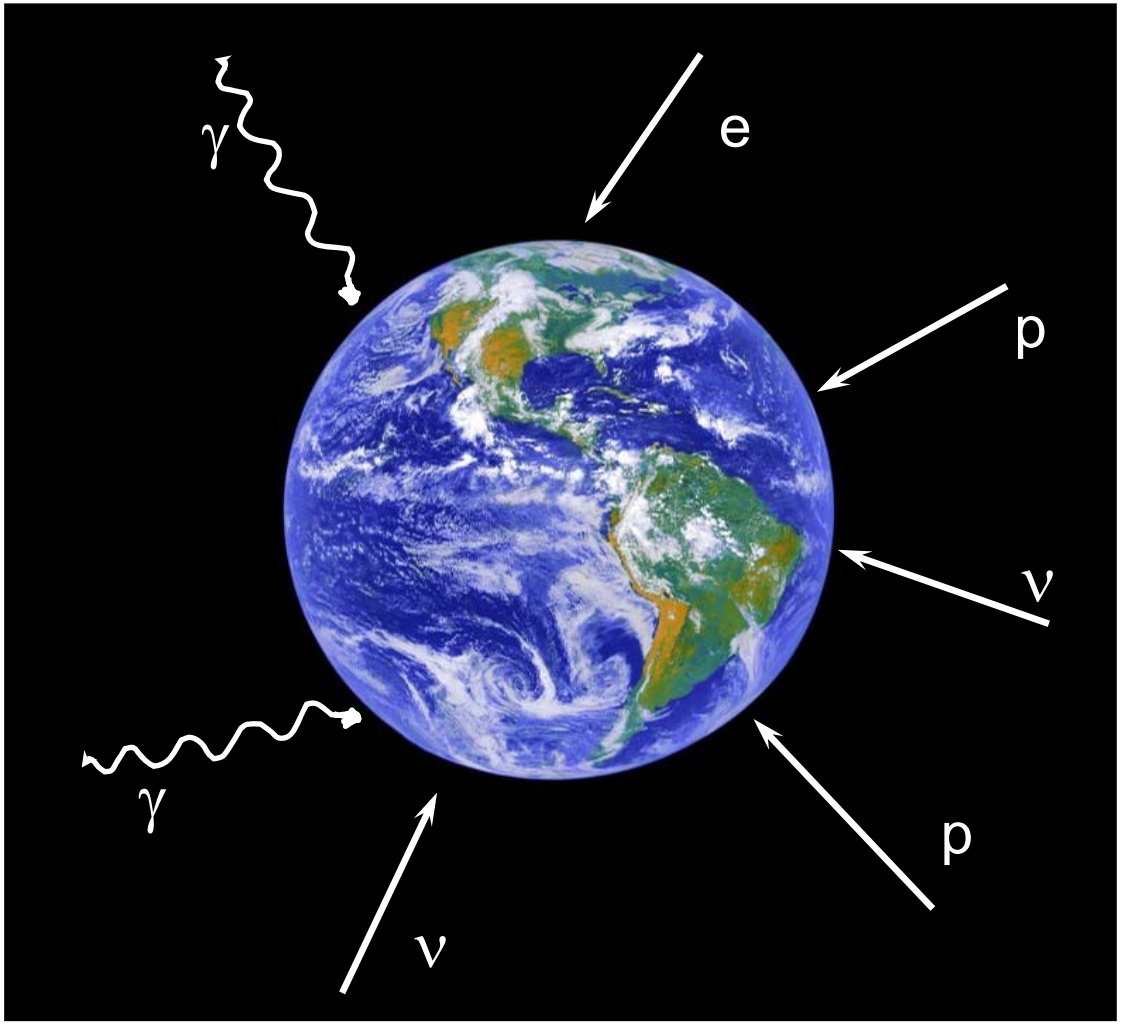
Microquasars
(artist's view)

Active Galactic Nuclei
(artist's view)

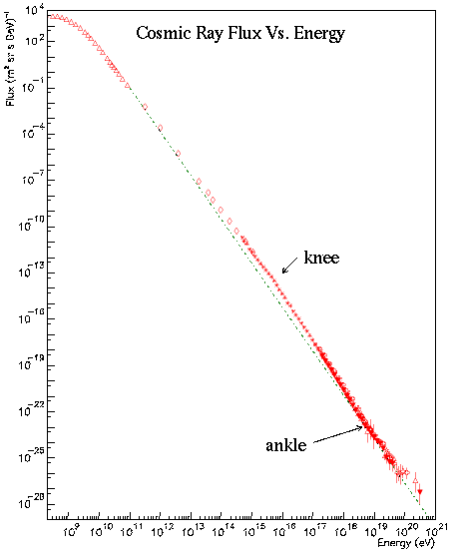


Gamma-ray Bursts
(GRB 080319B, X-ray, SWIFT)

Messengers of the High-Energy Universe



Cosmic ray spectrum



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High-energy particle production in the universe

- Accelerator (source)
- Shock fronts (Fermi acceleration)
- Strong magnetic fields up to 10^{15} Gauss (pulsars, magnetars)

- Beam dump (secondary particle production)
- Interaction with photon field, matter, interstellar medium
- Protons: pion decay

$$p + p(\gamma) \rightarrow \pi^{\pm} + X \quad \hookrightarrow \mu + \nu_\mu \quad \hookrightarrow e + \nu_\mu + \nu_e$$

$$p + p(\gamma) \rightarrow \pi^{0} + X \quad \hookrightarrow \gamma + \gamma \text{ (TeV)}$$

- Electrons: inverse Compton-scattering of photons
  $e + \gamma \rightarrow e + \gamma(\text{TeV})$

Why neutrino astronomy?

- Neutrinos point back to the source
- Neutrinos travel cosmological distances
- Neutrinos escape from optically thick sources
- Neutrinos are a clear sign for hadron acceleration
- Neutrinos provide complementary information to gamma-rays and protons

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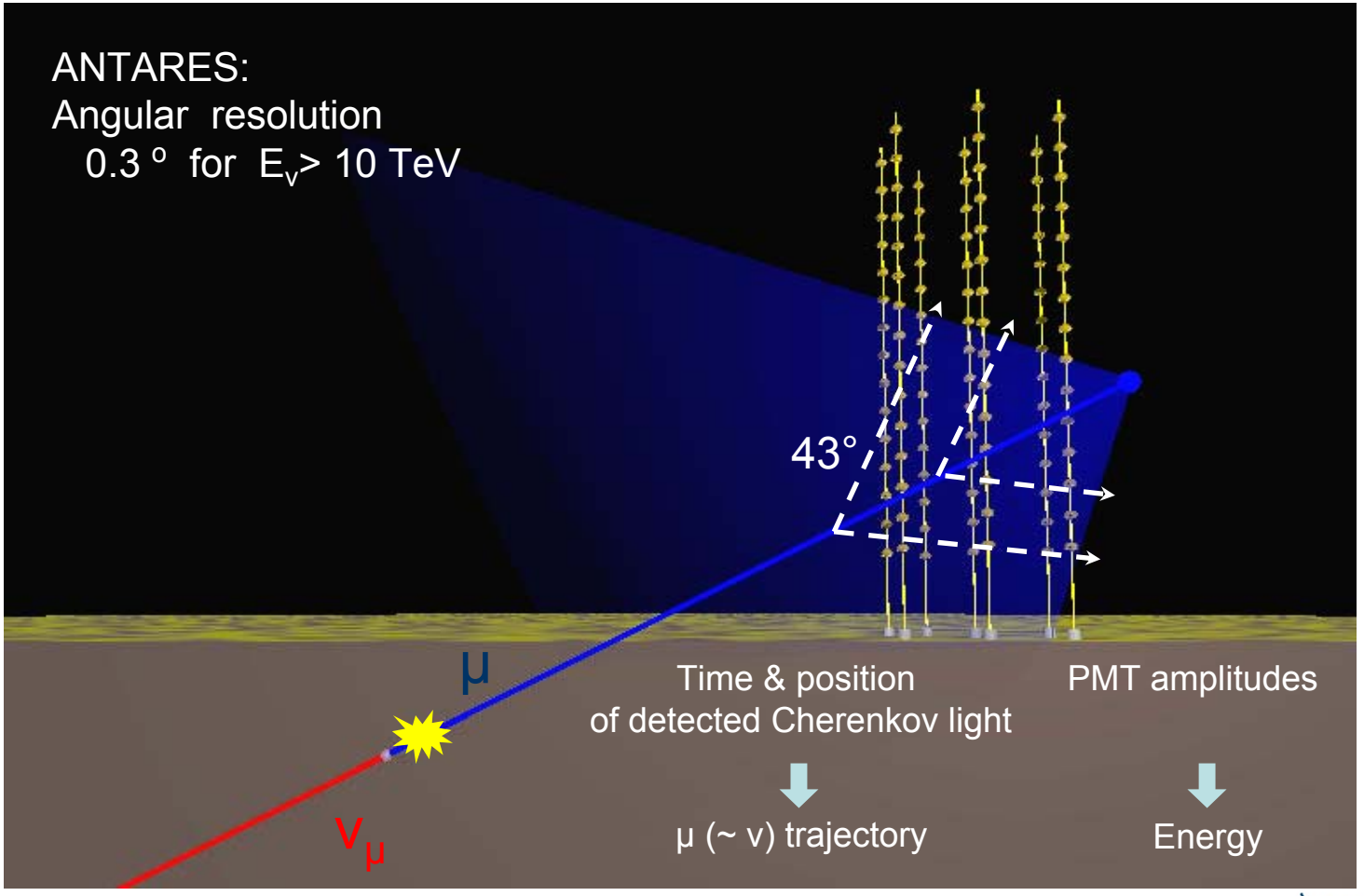
Physics with neutrino telescopes

- **Galactic sources**
  (Supernova remnants, Binary systems, Pulsar Wind Nebulae . . .)
- **Extra-Galactic sources**
  (Gamma-ray Bursts, Active Galactic Nuclei …)
- **Dark Matter**
  (WIMPs)
- **Cosmogenic neutrinos**
  (GZK, Top-down, . . .)
- Supernovae (MeV neutrinos)
- Neutrino oscillations (atmospheric neutrinos 10 - 100 GeV)
- Cosmic-ray anisotropy (atm. muons)
- Exotic physics
  (Lorentz violation, monopoles, . . .)

Principle of neutrino detection



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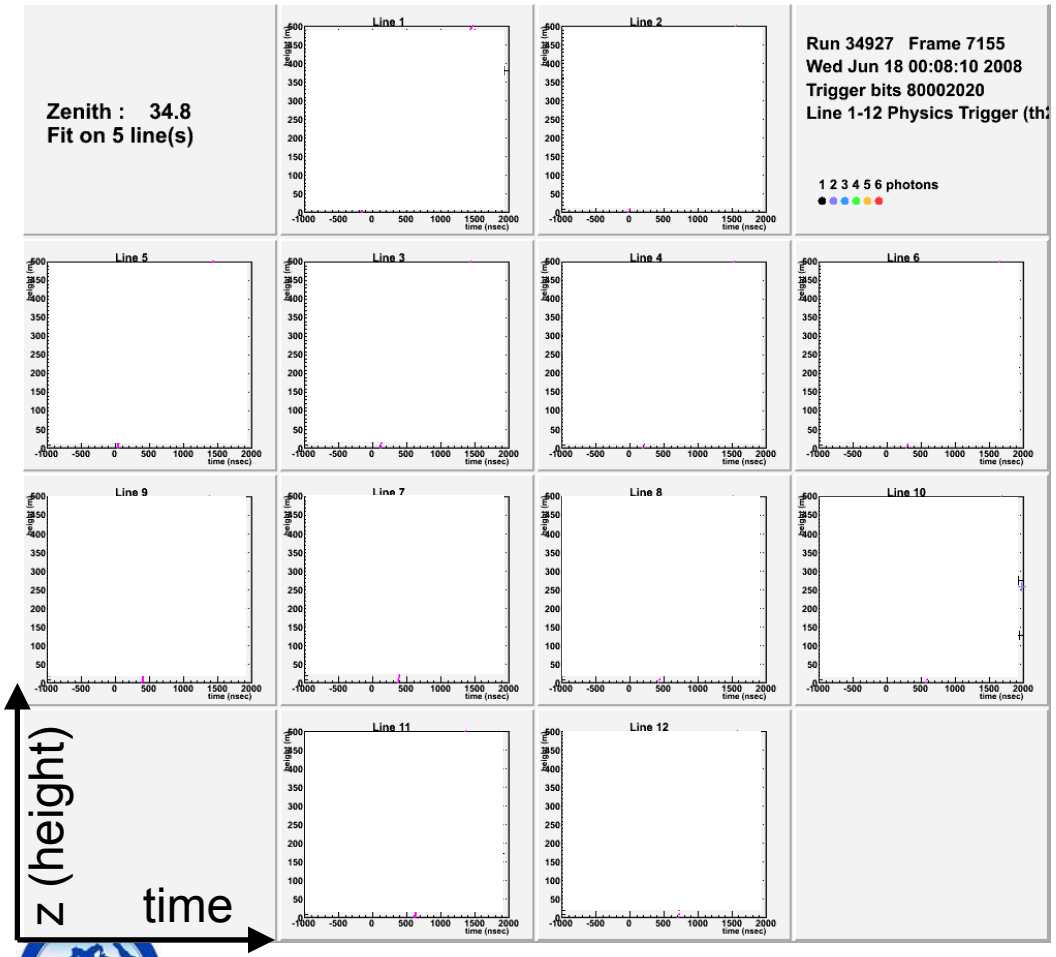
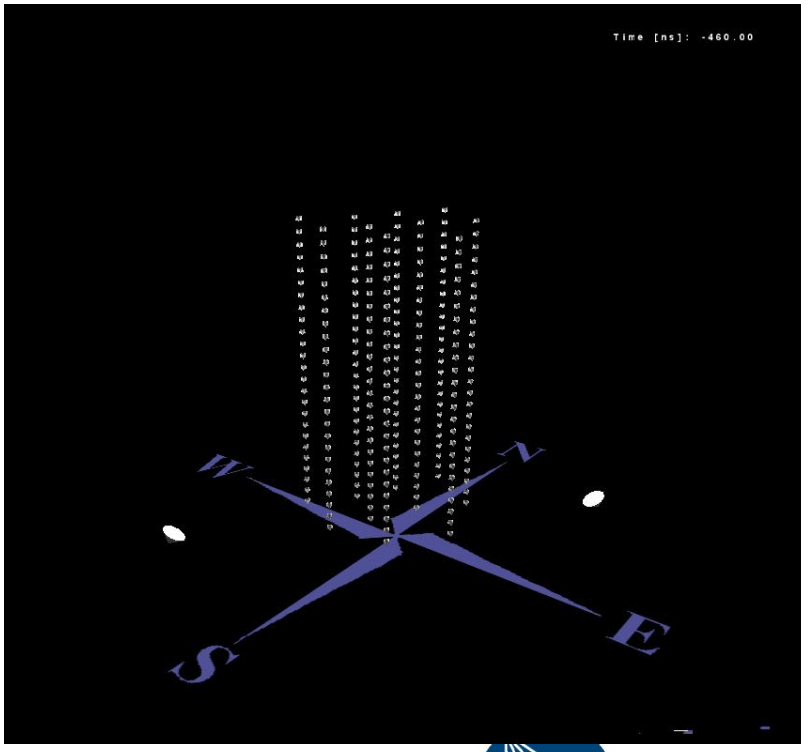
Neutrino Candidate



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



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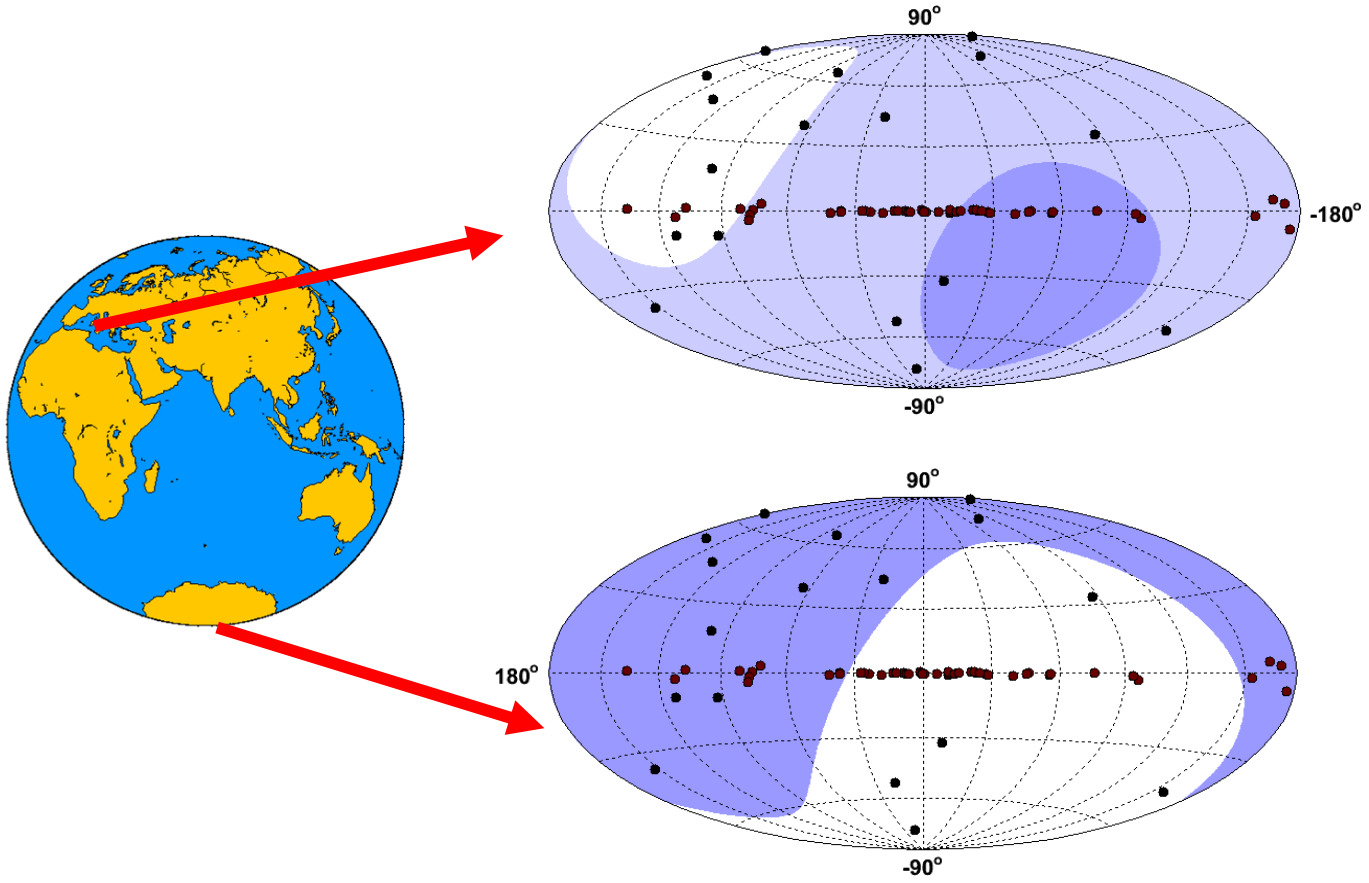
Sky coverage



ANTARES
- > 75%
- 25% – 75%
- < 25%

TeV γ-Sources
- galactic
- extragalactic

IceCube
- 100%
- 0%

0.5 π sr instantaneous common view
1.5 π sr common view per day

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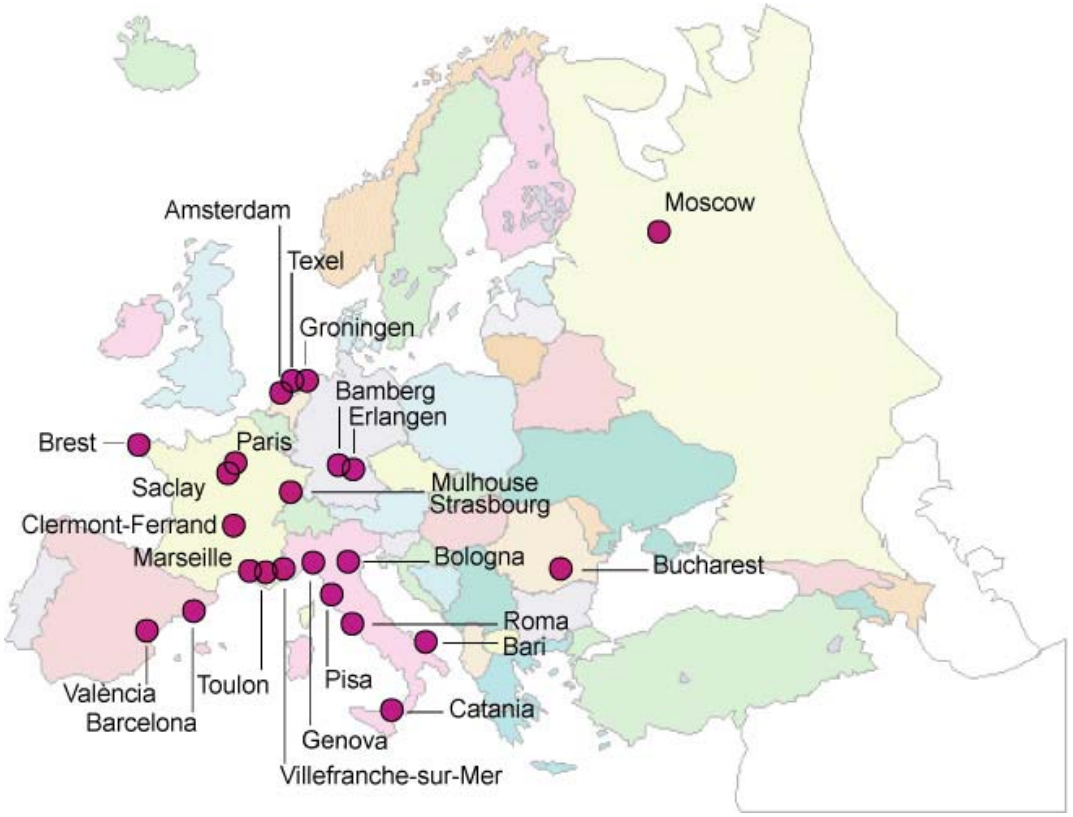
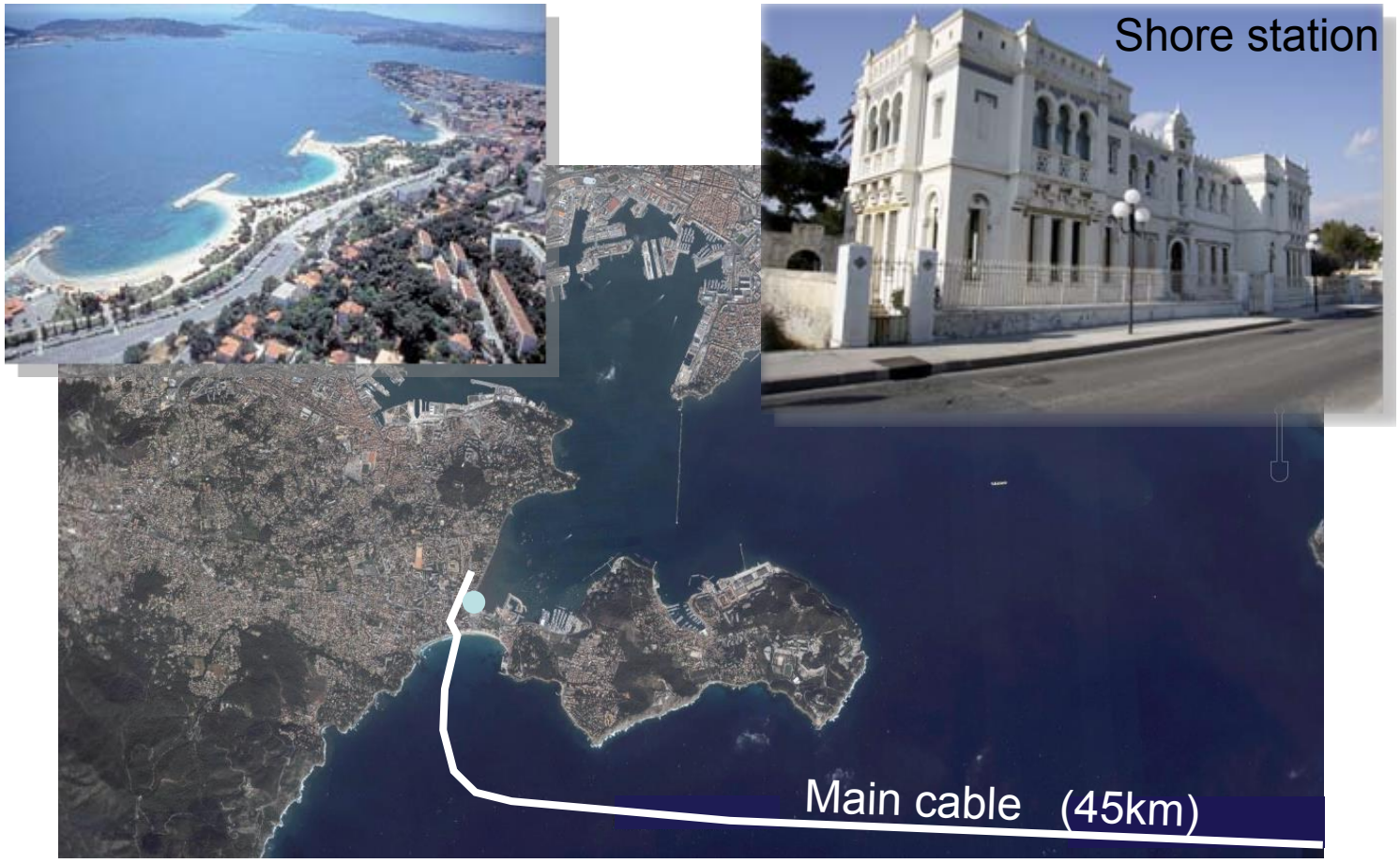
The ANTARES Collaboration



27 institutes in 7 European countries

ANTARES in the Mediterranean



La Seyne-sur-Mer, near Toulon, France

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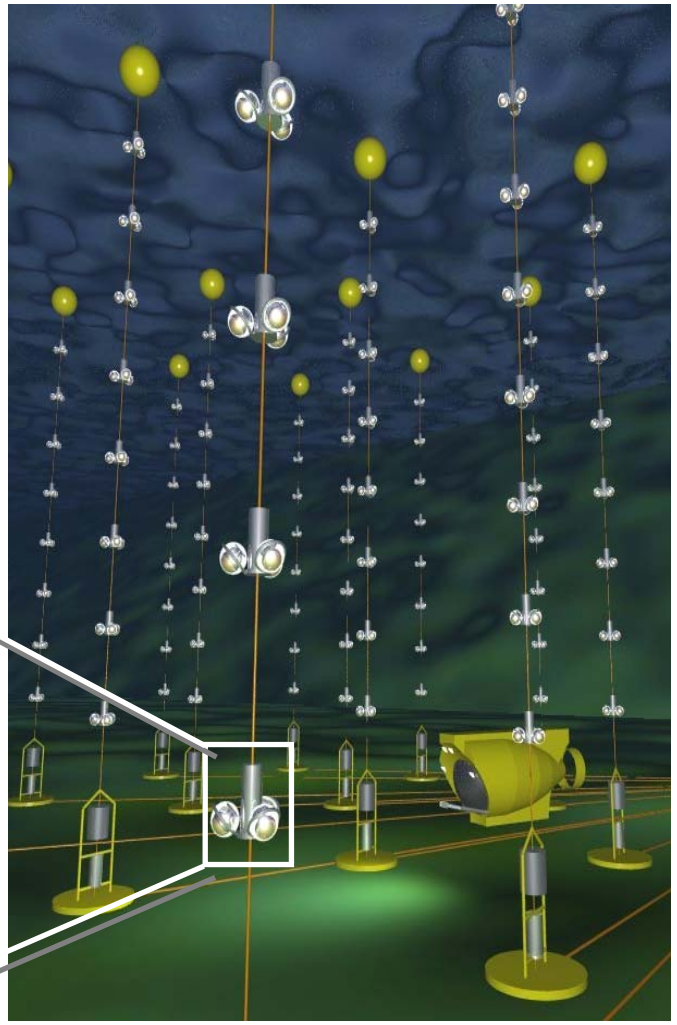
ANTARES

- 12 Lines (885 PMTs)
- Completion May 2008
- Instrumented volume: ~0.01 km^3



2100 m

2475 m

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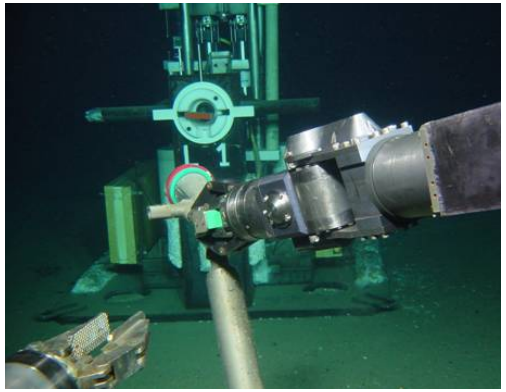
ANTARES deployment



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Calibration

(selection)

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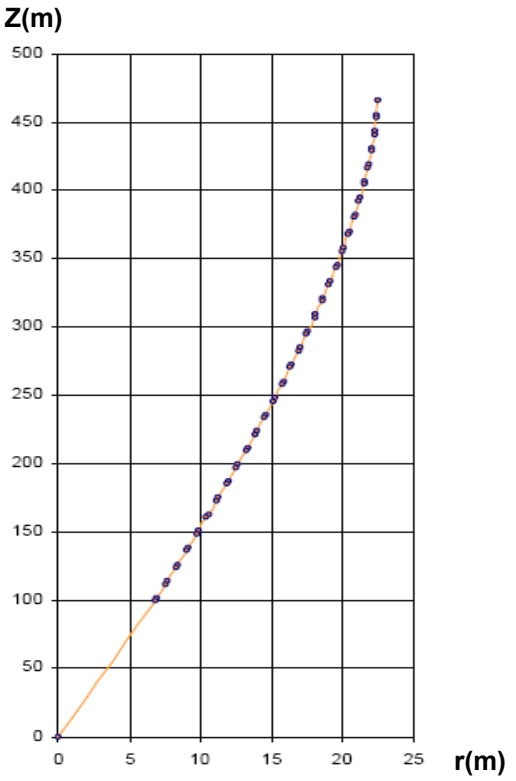
Detector positioning

- Acoustic system
  - 1 emitter(+ receiver)
    at each line socket
  - 5 receivers along each line
- Compass and Accelerometer
  - 1 Compass at each storey
  - 1 Acc. at each storey



- Measure every 2 min
  - Acoustics: **distance** sockets - receivers
  - Compass: **heading**
  - Accelerometer: **tilt**

} Line shape

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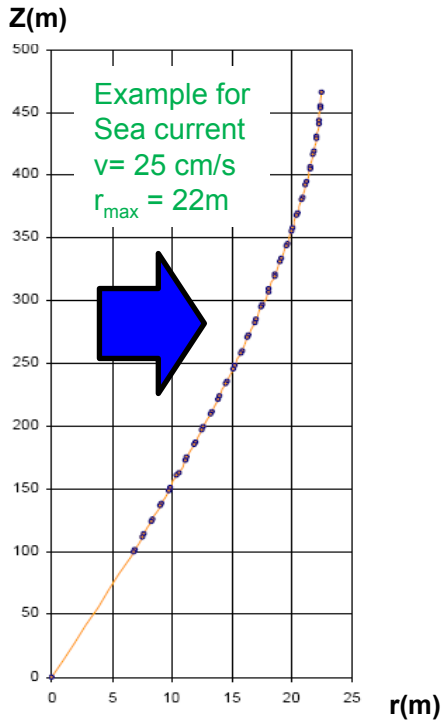
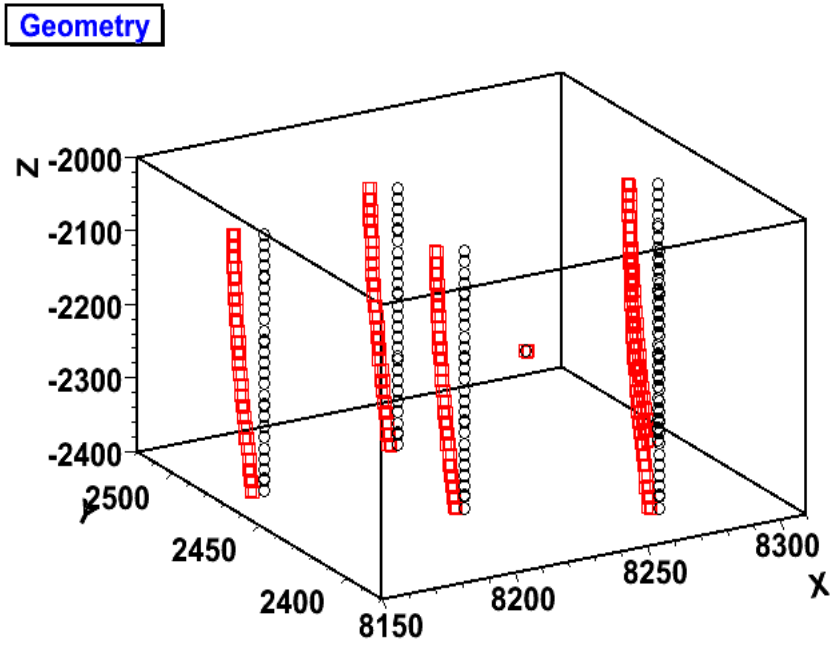
Detector positioning

typical line shape



$$r = (a\,z - b\,\ln[1-cz])\,v^2$$

mostly coherent movement of lines



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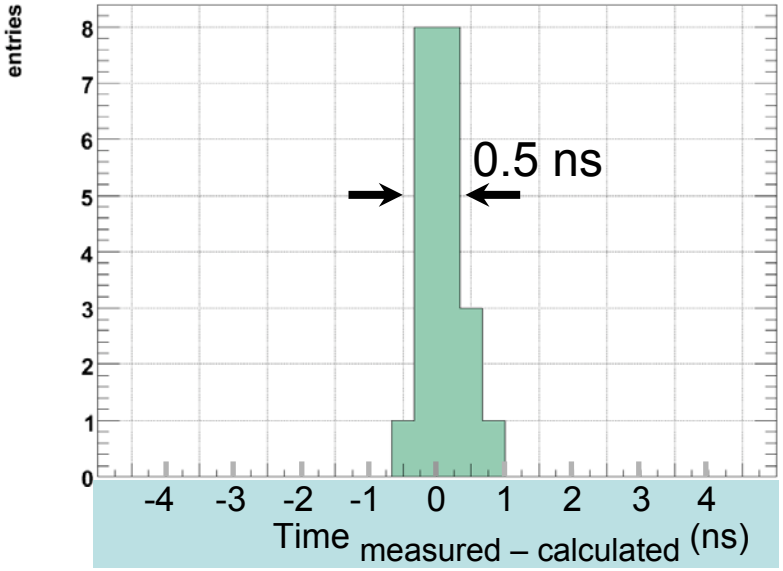
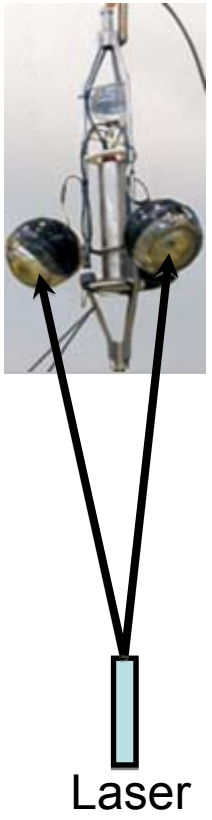
Position monitoring for PMTs

- Precision of positioning: $\Delta x < 10$ cm
- Monitoring of the positioning with laser pulses





→ Precision ~0.5 ns = 10 cm

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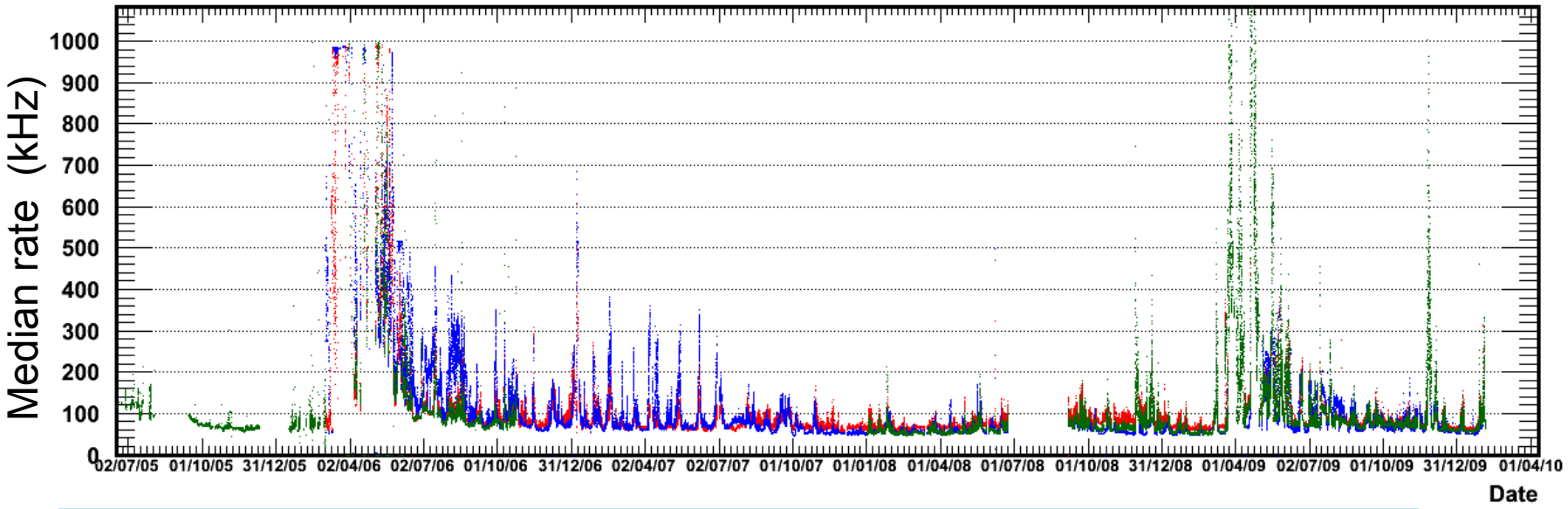
Background

Optical Background



Optical background due to ^{40}K-decay and bioluminescense

- Typical rate per PMT 60-120 kHz
- Additional short bursts and periods with higher rates

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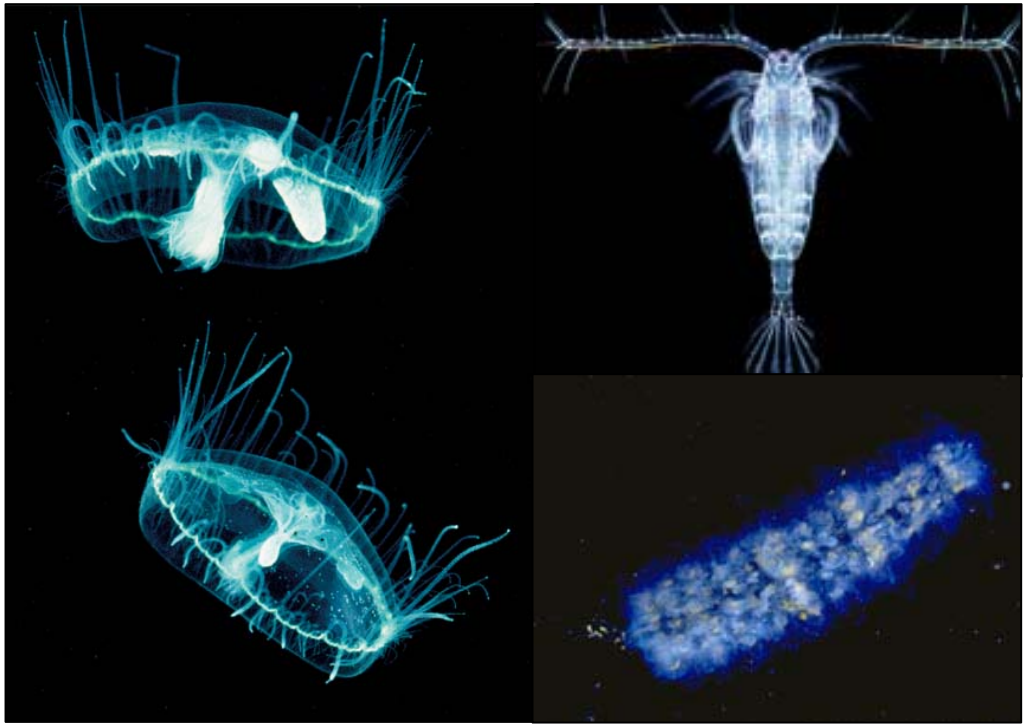
Bioluminescent Sources

- Bacteria: steady baseline source of light (30kHz in 10'' PMT)
- Macro-organisms: short flashes (up to MHz)

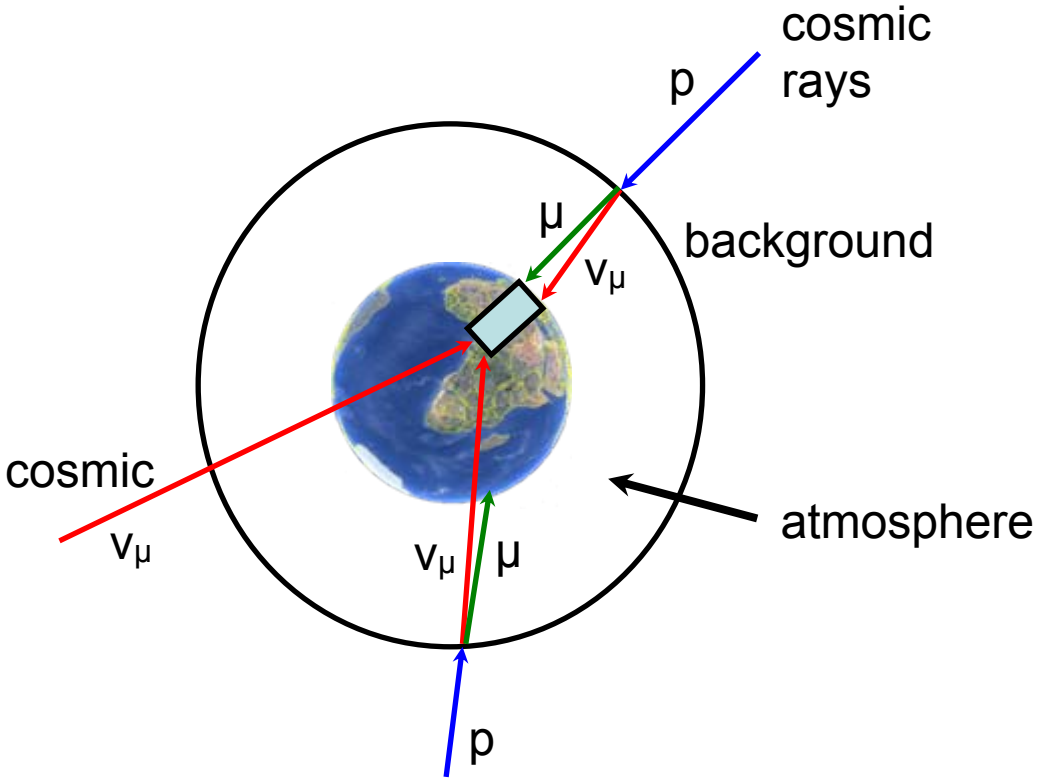


(J. Craig, Univ. Aberdeen, VLVNT 08)

e.g.
large colonial organisms such as pyrosomes (megaplankton)

size range:
0.2 - 2000 mm

Particle background: atm. muons and neutrinos



- Flux from above dominated by atmospheric muons
- Neutrino telescopes optimised to be sensitive to neutrinos from below

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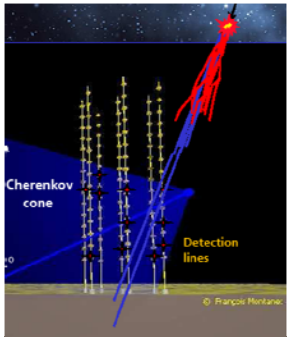
Selected Results

Reconstructed muon tracks: angular distribution



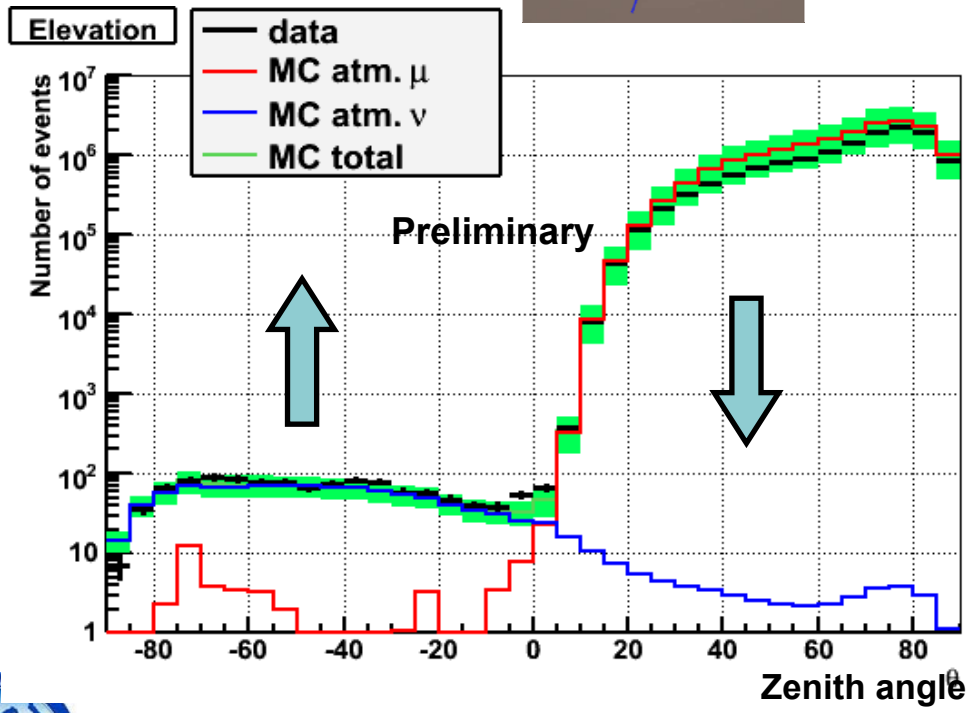
5-line data (May-Dec 2007)

+

9-12-line data (2008)

341 days detector live time

1062 neutrino candidates



good agreement with Monte-Carlo expectation:

upward-going: atmospheric neutrinos: 916
(30% syst. error)
atmospheric muons: 40
(50% syst. error)

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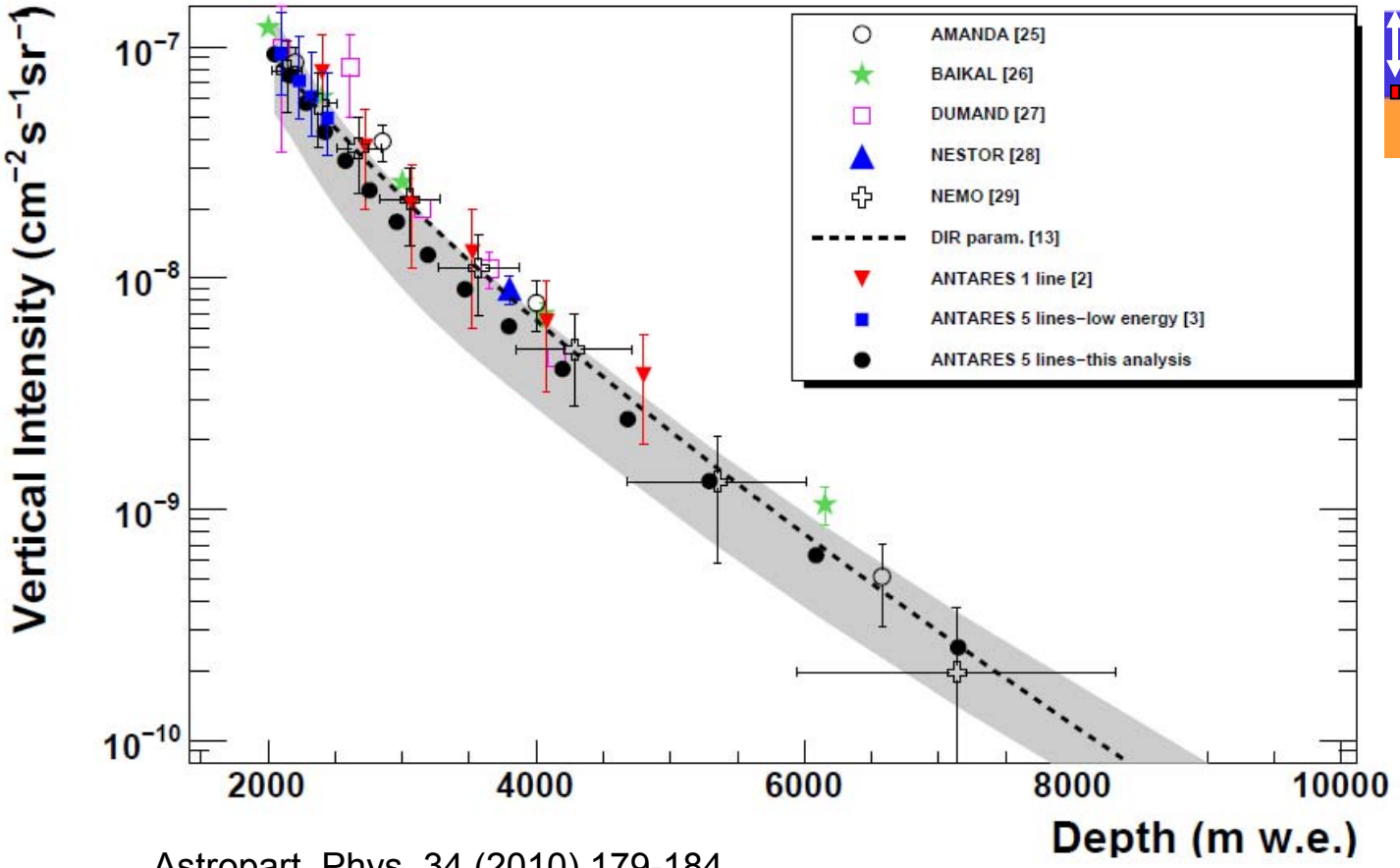
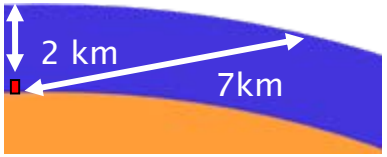
Muon flux:depth-intensity relation with 5 Lines





Astropart. Phys. 34 (2010) 179-184

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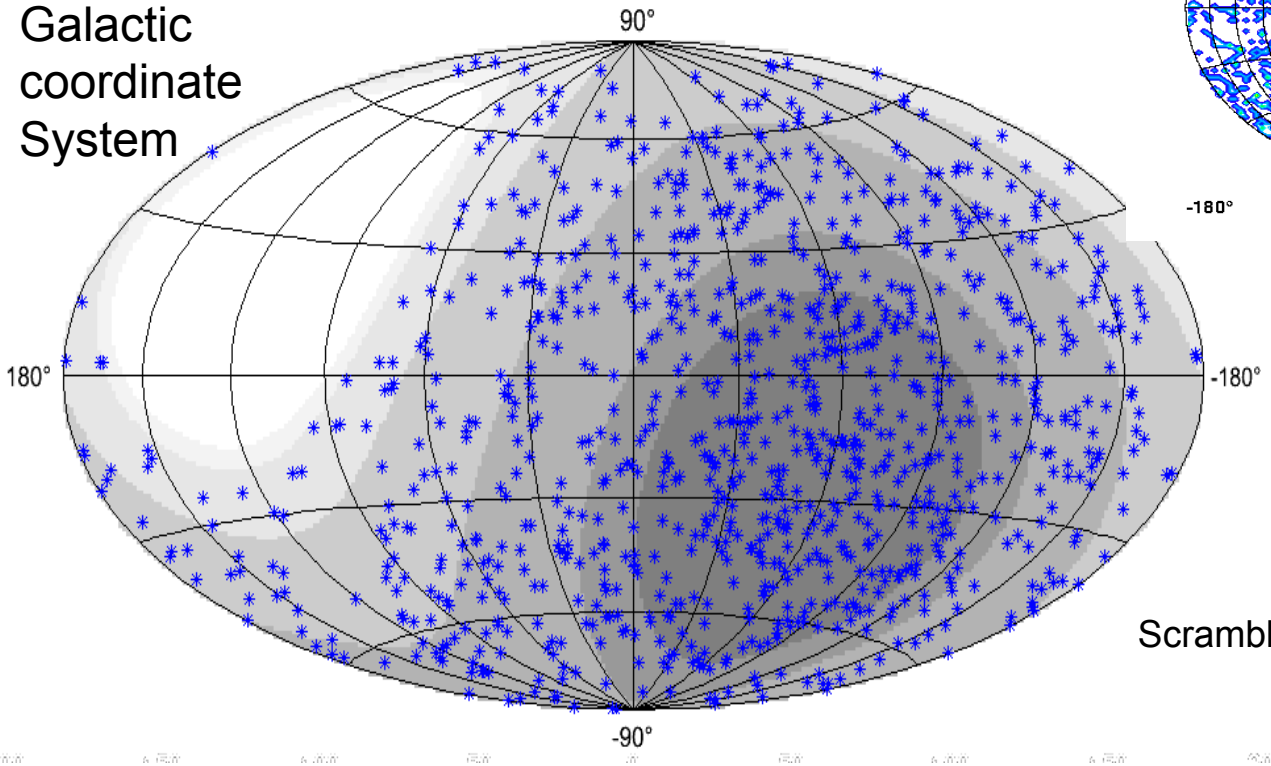
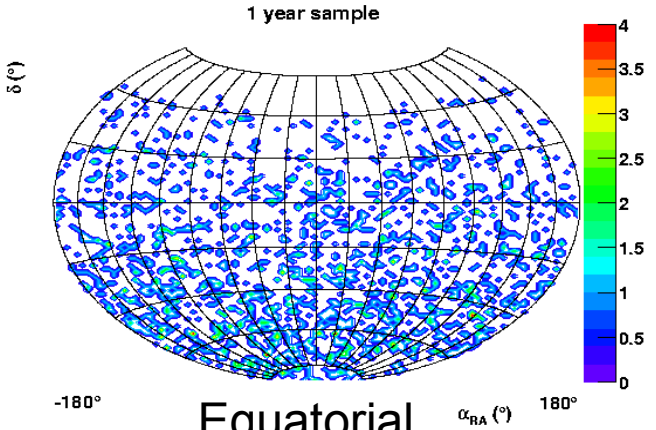
Scrambled sky map of 1000 neutrinos

Galactic coordinate System





Equatorial coordinate System

Scrambled in azimuth

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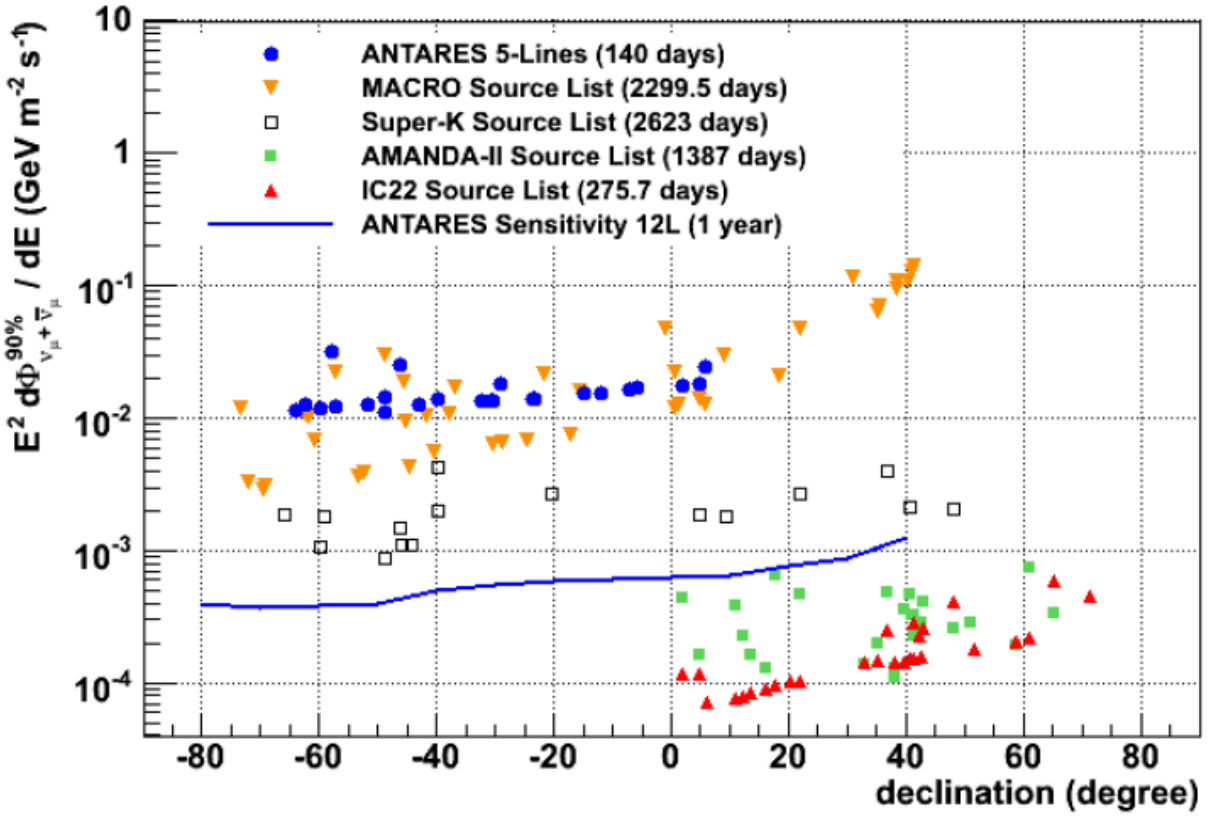
Point source sensitivity



5-line data 2007, **preliminary**

Increased sensitivity for full detector

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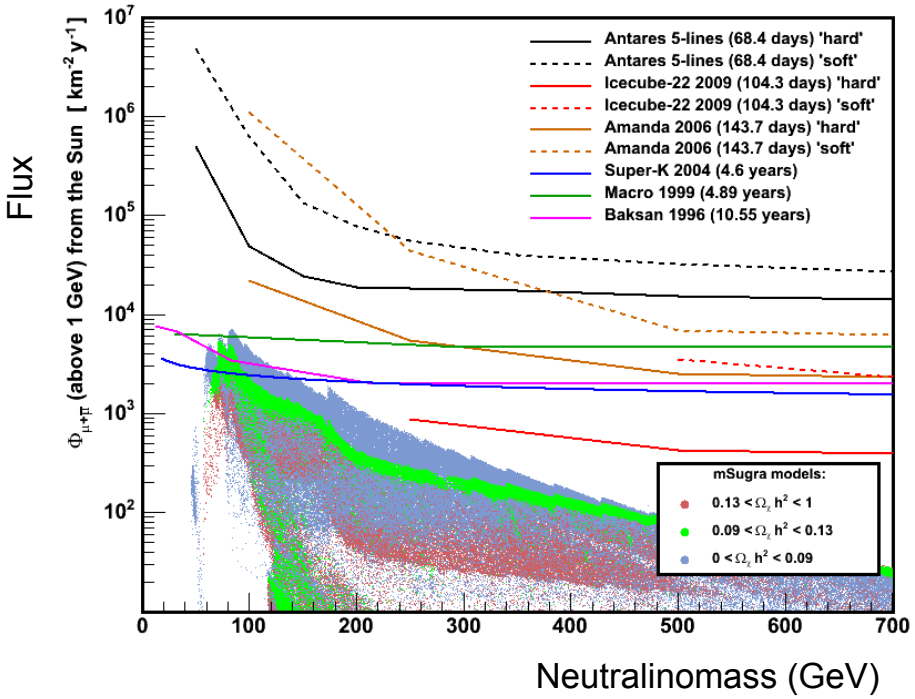
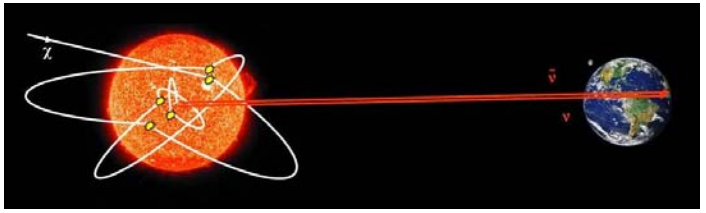
Dark matter search

upper limits from experiments





5-line data 2007

68 days detector live time

Competitive with direct detection for SD cross section

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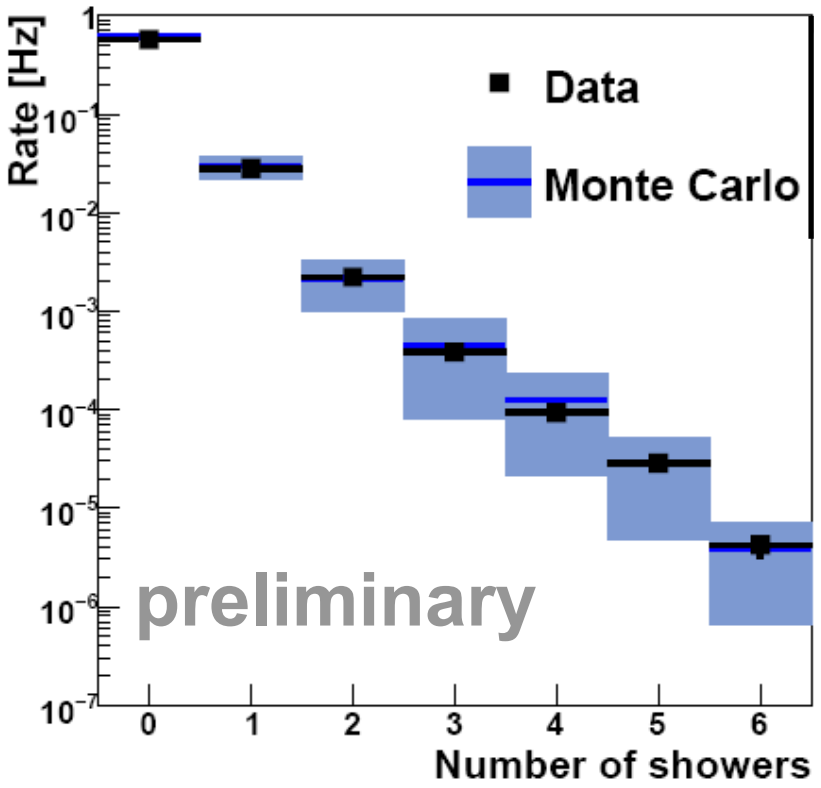
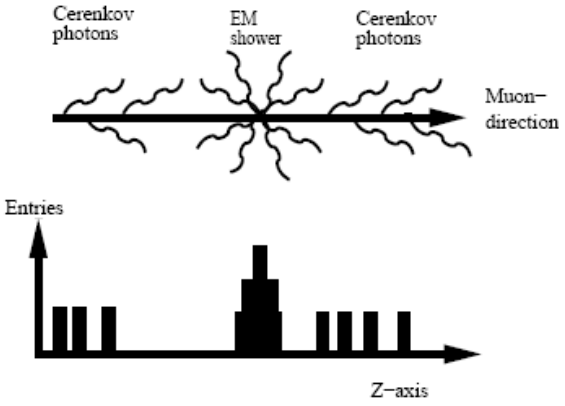
Observation of induced electromagnetic showers from muon tracks



Analysis Technique:

Projection of “late” photons onto reconstructed muon track



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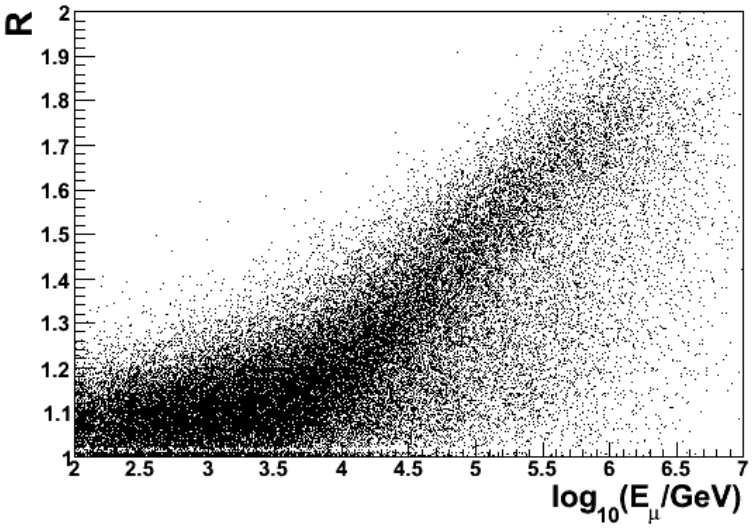
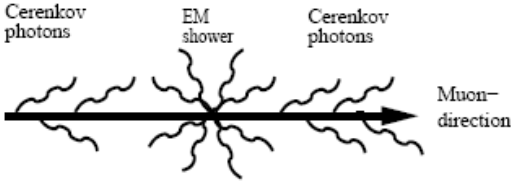
Energy estimator

$$R = \frac{\text{Number of prompt and late PMT signals}}{\text{Number of all PMTs contributing to the event}}$$





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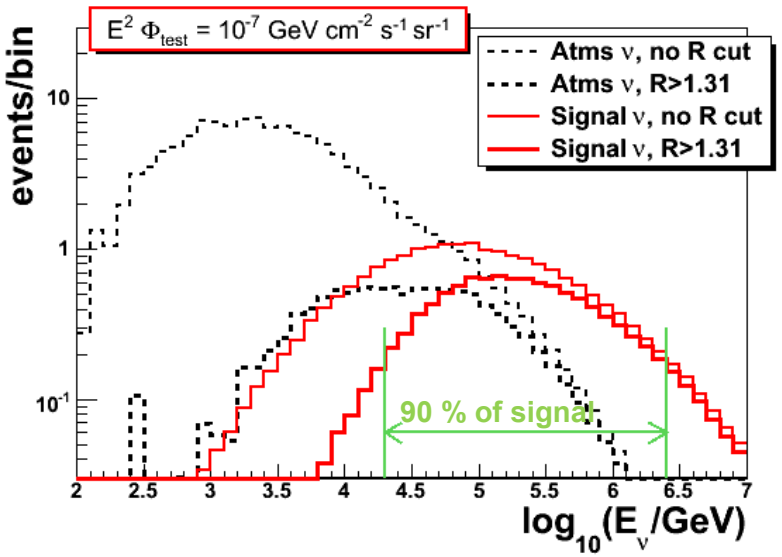
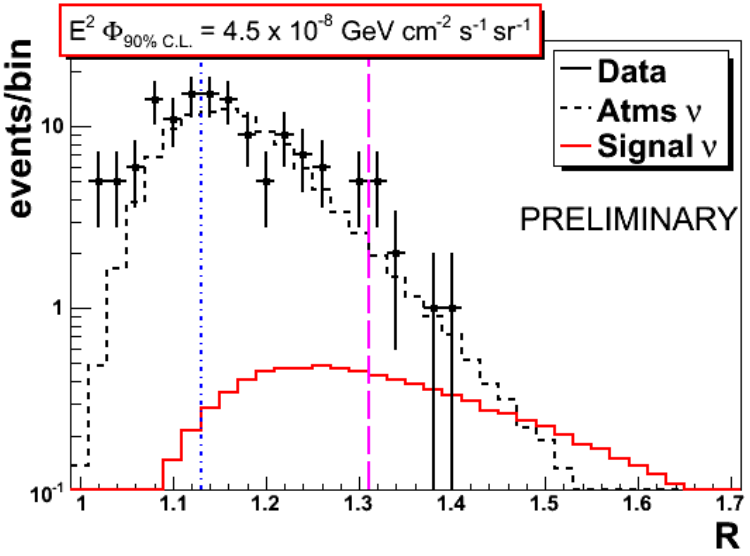
Energy estimator





$$R = \frac{\text{Number of prompt and late PMT signals}}{\text{Number of all PMTs contributing to the event}}$$

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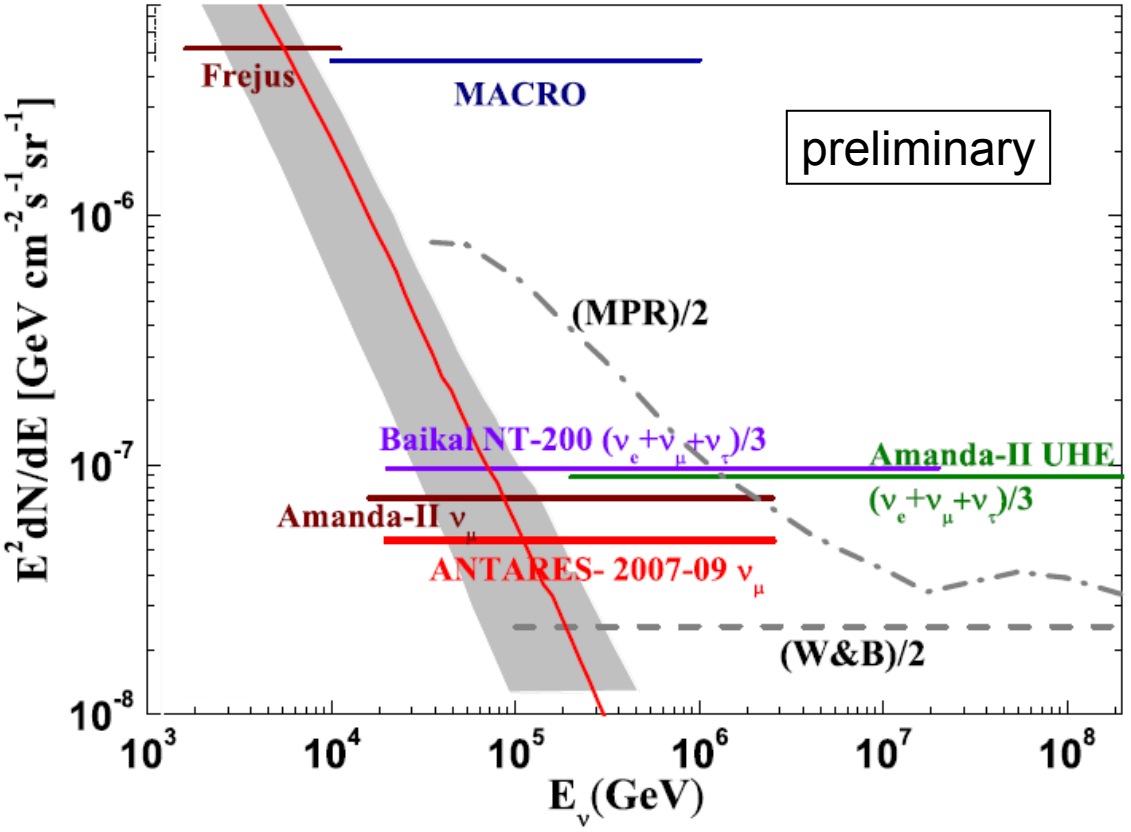
Upper limit on diffuse flux of HE ν



0.83 * 2π sr

monitored for

334 days

with
reduced detector setup
during
construction phase

$$E^2\ \Phi(E)_{90\%CL} = 4.5^{+2}_{-1} \times 10^{-8}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$$

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Summary and Outlook

- ANTARES is continuously taking data
- ANTARES complements the sky coverage of IceCube
- ANTARES has a broad physics program
- ANTARES determined sensitive upper limit on HE diffuse ν flux
- ANTARES paves the way for KM3NeT

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

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