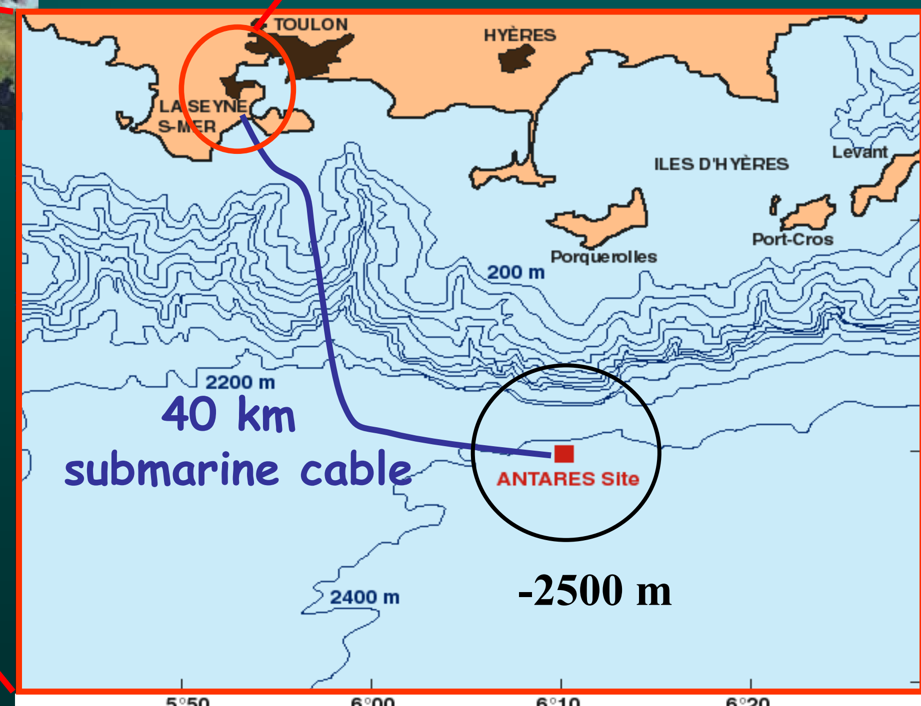
D. Zaborov (ITEP-Moscow)
on behalf of the ANTARES collaboration

The ANTARES experiment in the Mediterranean sea: overview and first results

14th Lomonosov conference on Elementary Particle physics
19-25 Aug 2009
Moscow

* ANTARES = Astronomy with a Neutrino Telescope and Abyss environmental RESearch

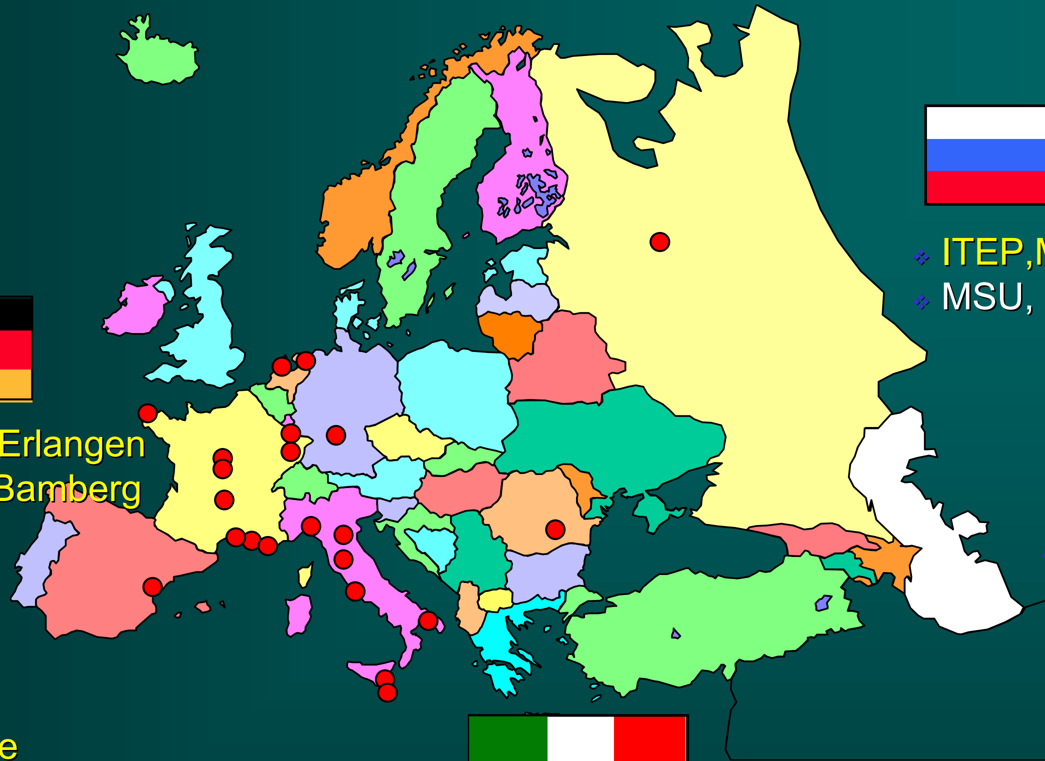
ANTARES site



42° 48’ N, 6° 10’ E

Deep site near Toulon (France)
Light absorption length 55 m (at λ=460 nm)
Effective diffusion length > 300 m

The ANTARES collaboration



- NIKHEF, Amsterdam
- KVI Groningen
- NIOZ Texel

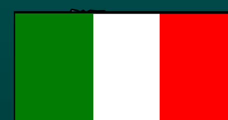
- University of Erlangen
- Rem. Stern., Bamberg

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

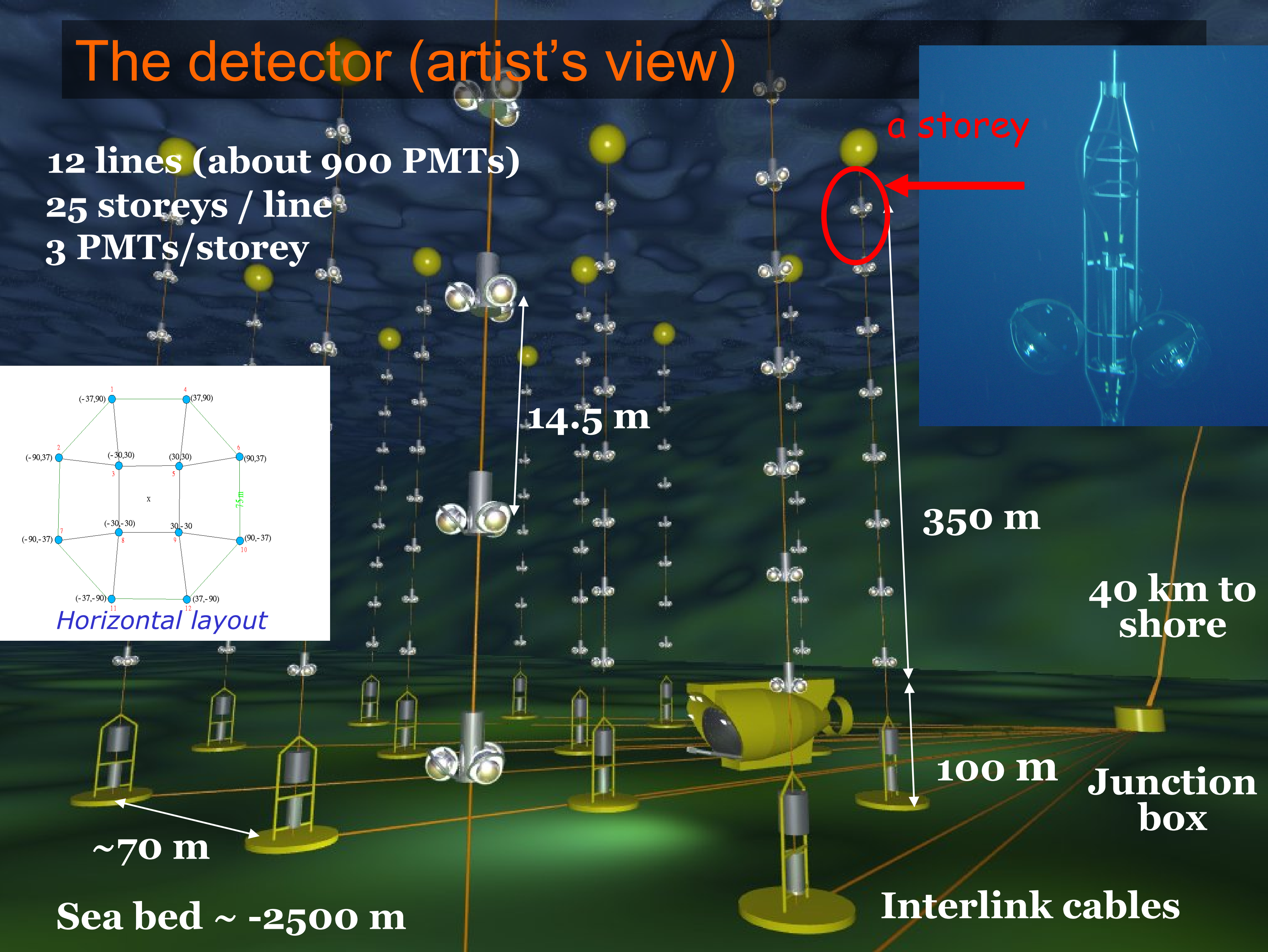
- CPPM, Marseille
- DSM/IRFU/CEA, Saclay
- APC, Paris
- LPC, Clermont-Ferrand
- IPHC (IReS), Strasbourg
- Univ. de H.-A., Mulhouse
- IFREMER, Toulon/Brest
- C.O.M. Marseille
- LAM, Marseille
- GeoAzur Villefranche

- ITEP,Moscow
- MSU, Moscow

- ISS, Bucarest



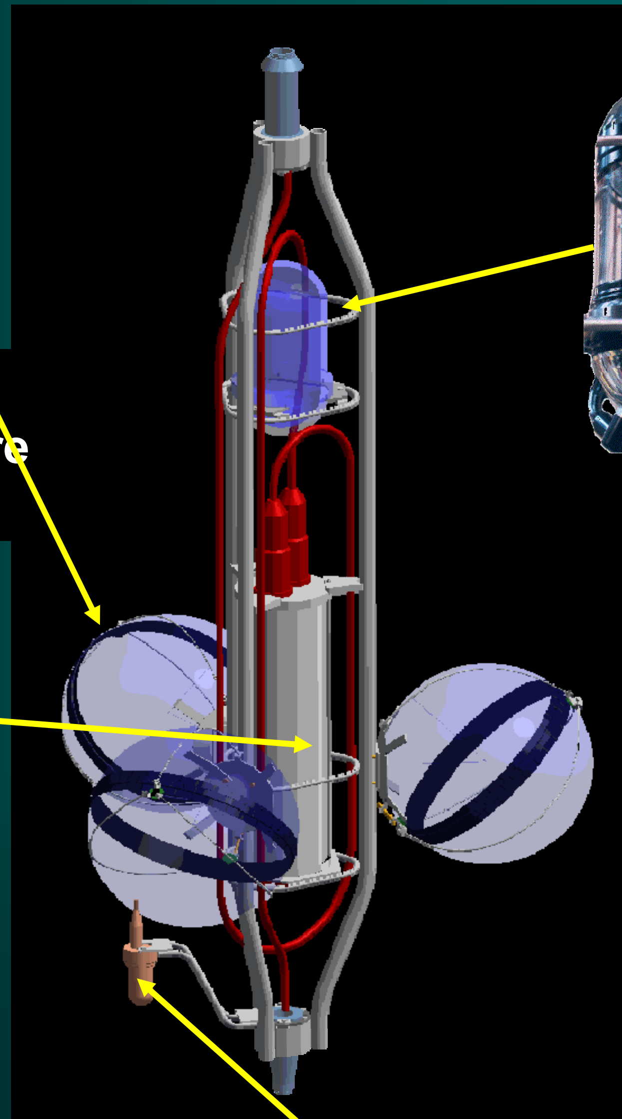
- University/INFN of Bari
- University/INFN of Bologna
- University/INFN of Catania
- LNS – Catania
- University/INFN of Pisa
- University/INFN of Rome
- University/INFN of Genova

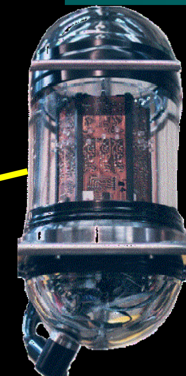


The detector (artist's view)
12 lines (about 900 PMTs)
25 storeys / line
3 PMTs/storey
a storey
14.5 m
350 m
40 km to shore
100 m
Junction box
Interlink cables
~70 m
Sea bed ~ -2500 m
(-37,90)
(37,90)
(-90,37)
(-30,30)
(30,30)
(90,37)
75 m
(-30,-30)
30,-30
(-90,-37)
(90,-37)
(-37,-90)
(37,-90)
Horizontal layout

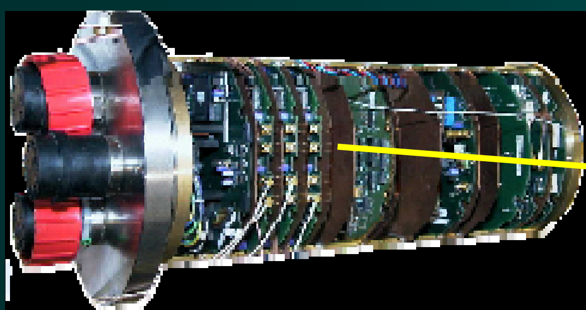
The storey

Optical Module:
10” PMT in 17” glass sphere
photon detection





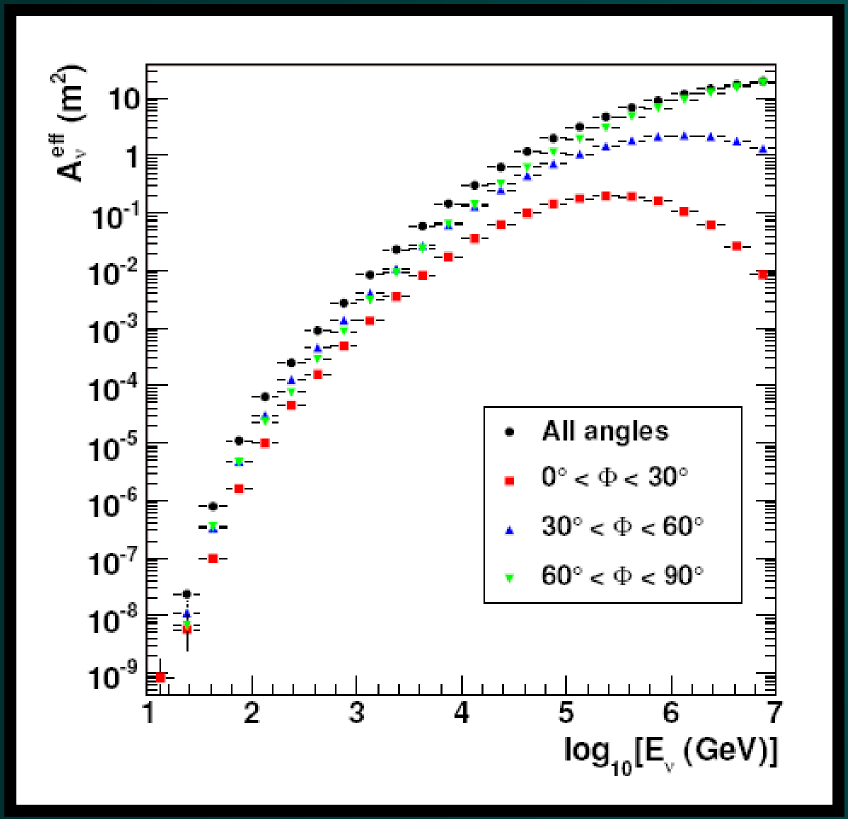
Optical Beacon with blue LEDs:
timing calibration

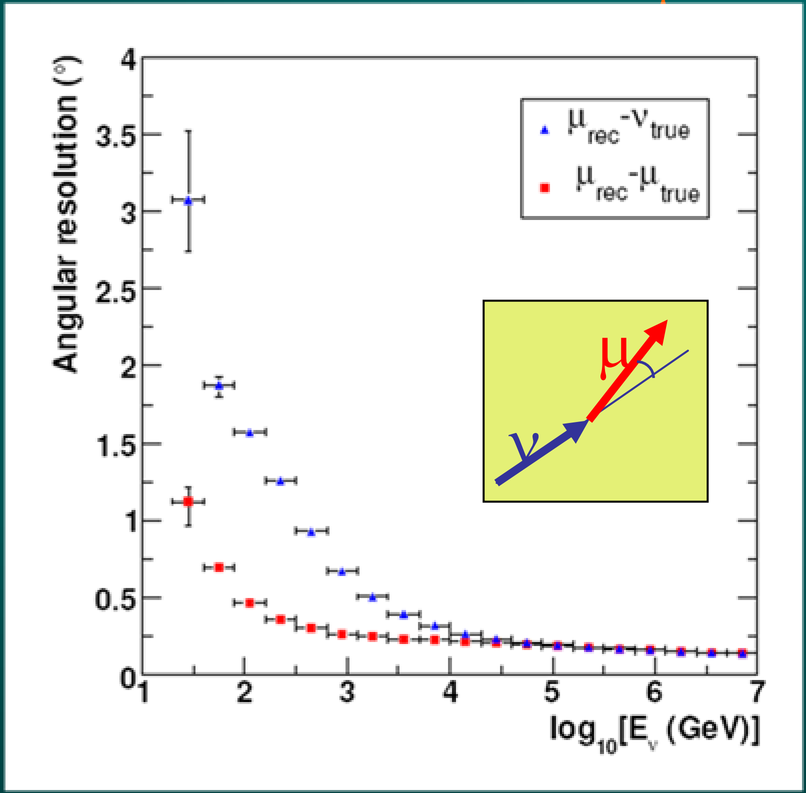


Local Control Module (in Ti container):
Front-end ASIC, Clock, DAQ/SC, compass/roll/pitch

Hydrophone:
acoustic positioning

Effective area and angular resolution for ν_μ





For E<10 PeV: Increase in interaction cross-section & muon energy & range

For E>10 PeV: Earth becomes opaque to neutrinos

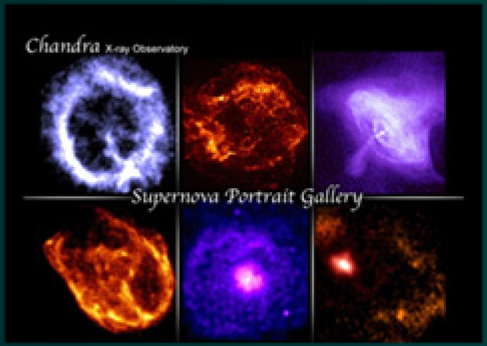
$N_{det} = A_{eff} \times$ Time $\times$ Flux

WB diffuse -> 3 events (7.5 atm) / yr

For E<10 TeV, the angular resolution is dominated by the ν-μ angle

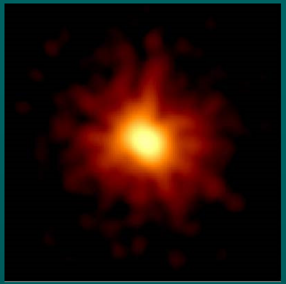
For E>10 TeV, the resolution is limited by track reconstruction errors

Possible neutrino sources

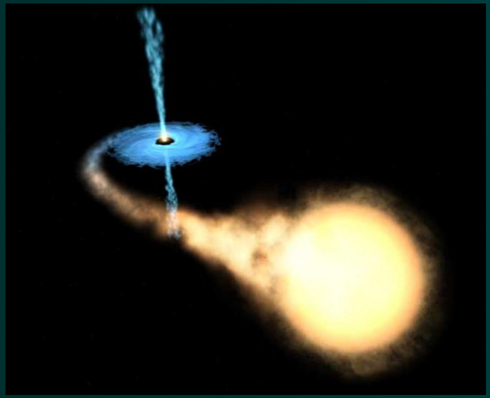


Supernova remnants

Gamma Ray Bursts

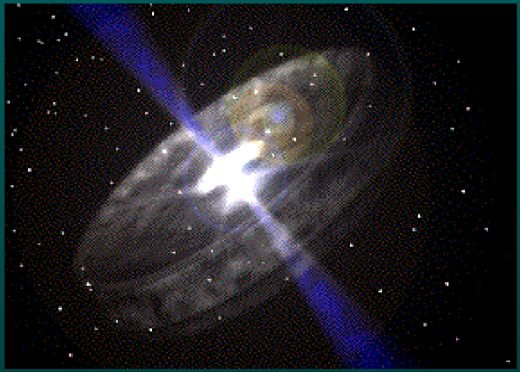


$p + A / \gamma \rightarrow \text{mesons} \rightarrow \nu, \gamma$



Microquasars
Binary systems

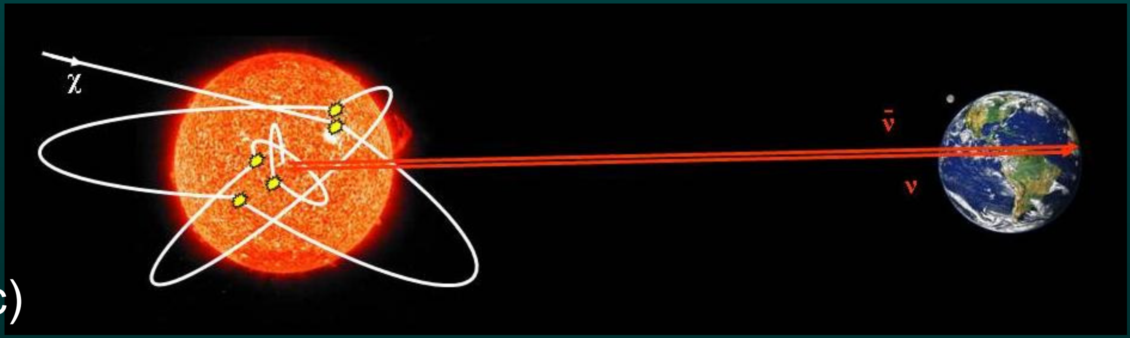
Active Galactic Nuclei



…

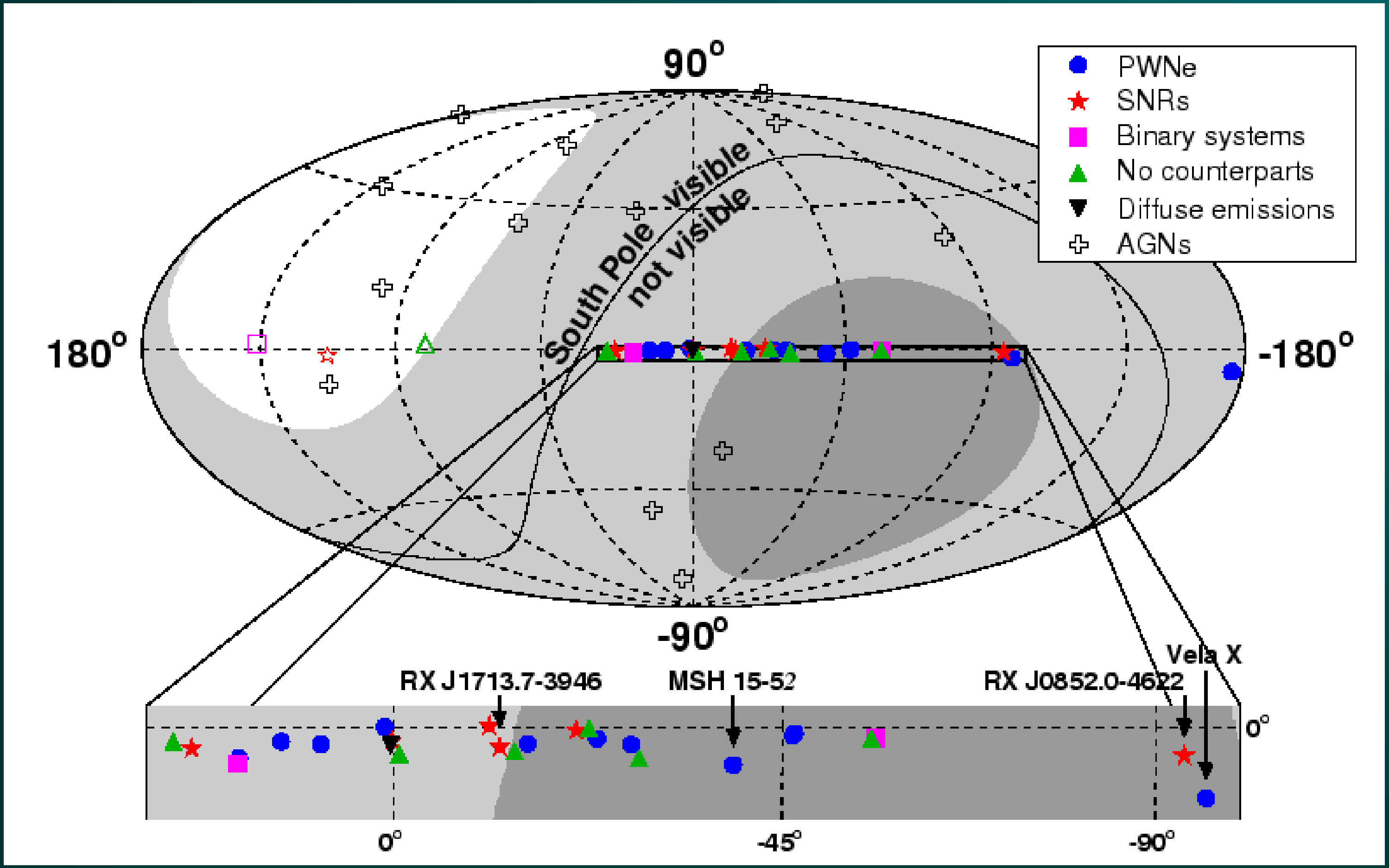
Dark Matter (Neutralino)

?



Exotics (Magnetic Monopoles, etc)

Sky coverage

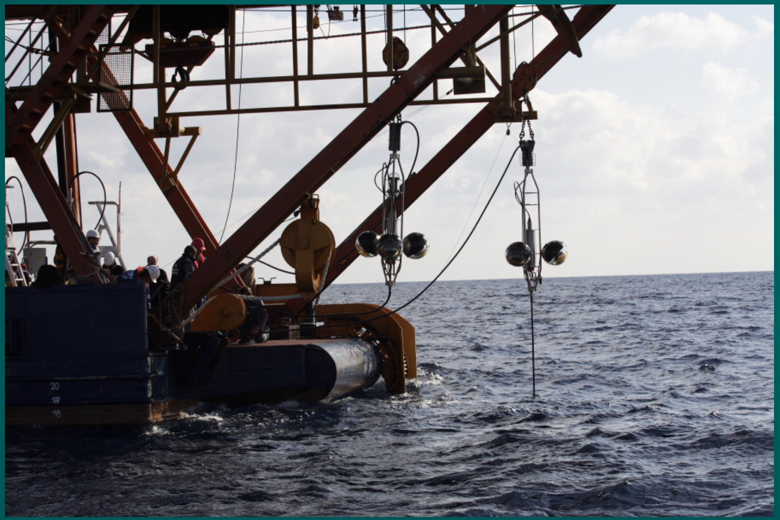


* Dark grey = visible 100% of the time
Light grey = visible part of the time

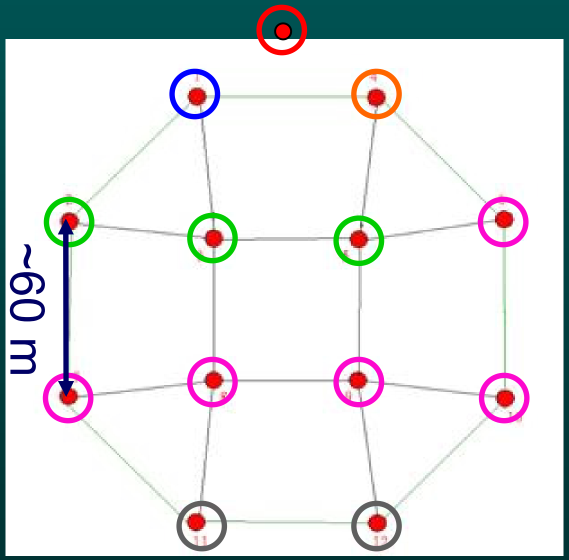
Most gamma TeV and UHECR sources in the field of view of ANTARES !

Detector construction

- 1996-2000: detector R&D, site exploration
- 2001: Deployment of 40 km main electro-optical cable (Alcatel)
- 2002: Deployment and connection of Junction Box
- 2003-2005: Various prototype lines
- 2006-2008: deployment and connection of 12 detector lines

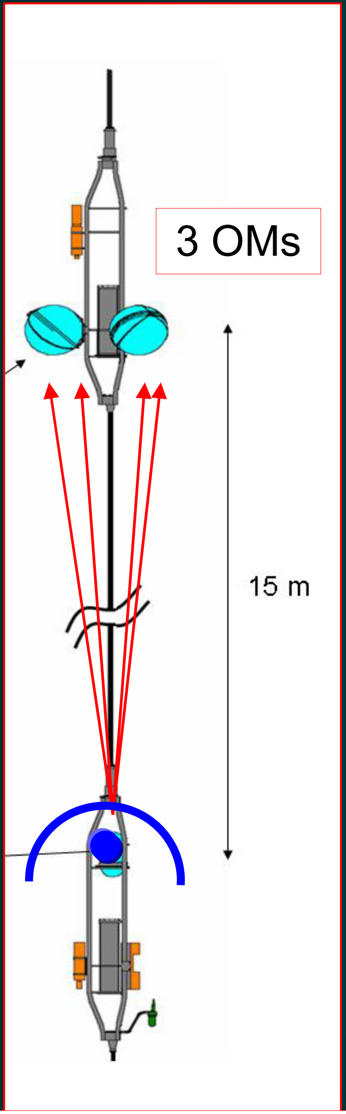


- **MILOM**: 17th Mar 2005
- **Line 1**: 2nd Mar 2006
- **Line 2**: 21st Sep 2006
- **Line 3, 4, 5**: 29th Jan 2007
- **Line 6, 7, 8, 9, 10 + IL07**: 7th Dec 2007
- **Line 11, 12**: 30th May 2008



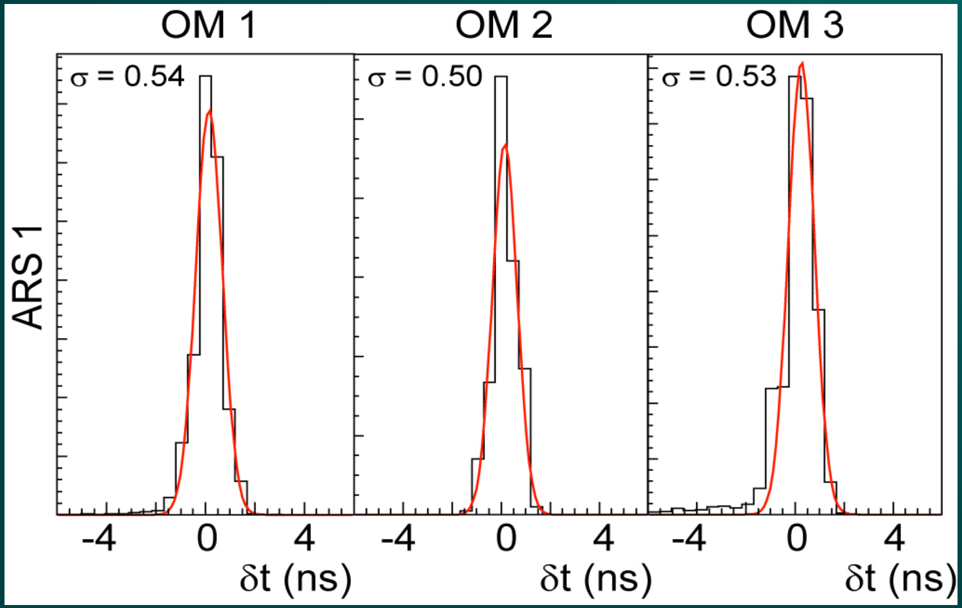
Apparatus completed!

In situ calibration with LED Beacons



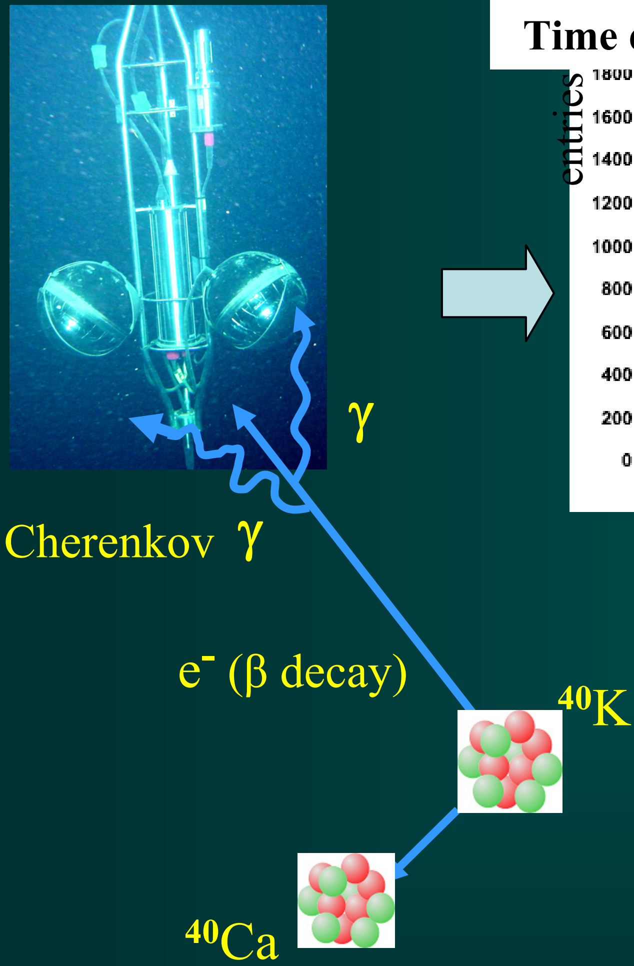
36 LEDs +
reference PMT

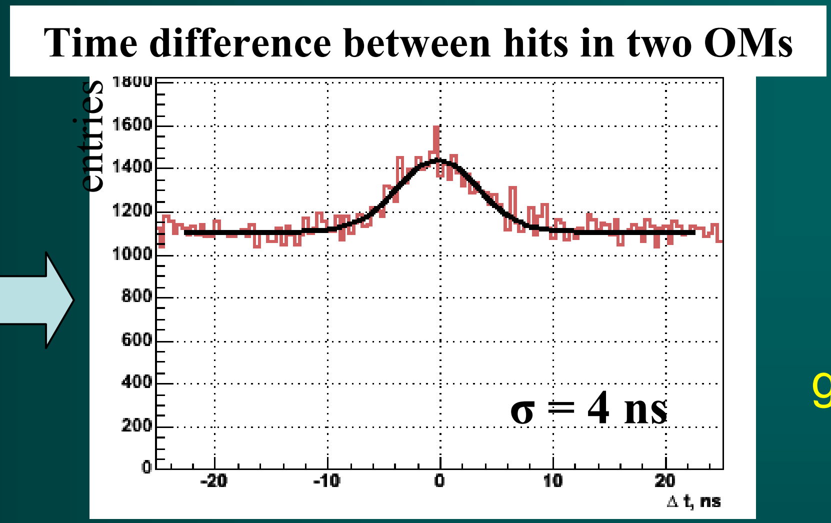
Time of signal in OMs relative to reference PMT for LED beacon flashes (example)



LED Optical Beacon (LOB) is a powerful source of light flashes, used to control PMT timing in situ
Precision ~ 0.5 ns

In situ calibration using sea water



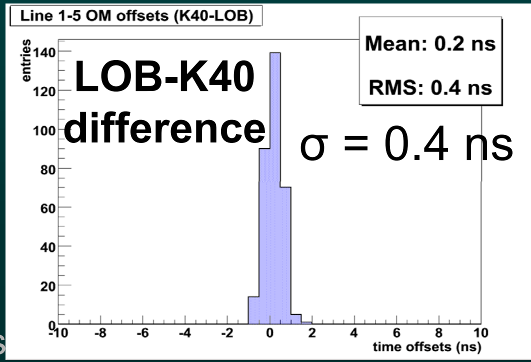


Pedestal = random coincidences (from ^{40}K and bioluminescence)

Gaussian peak = genuine coincidences from ^{40}K

Peak offset

Cross-check of time calibration



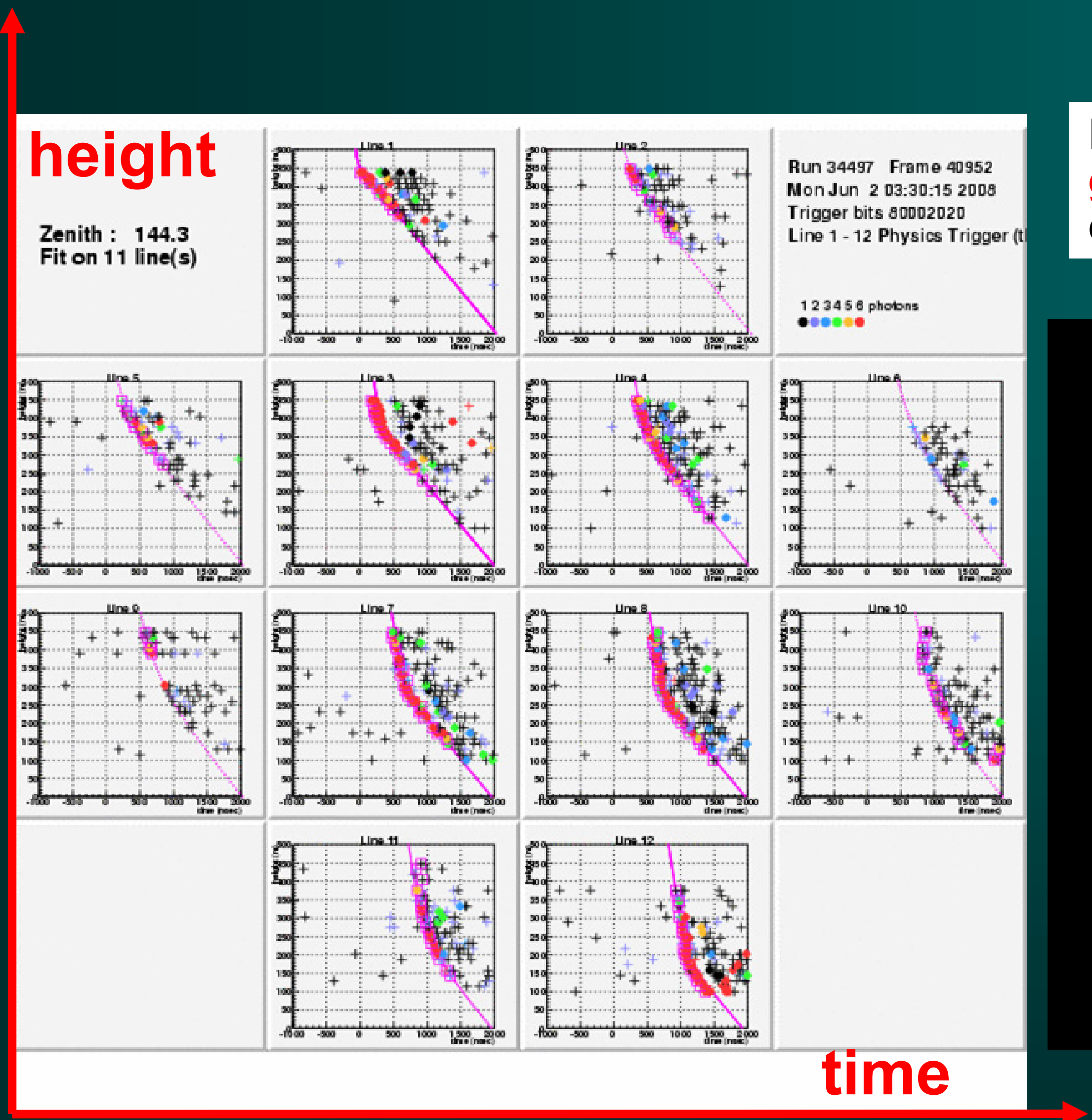
Integral under Gaussian fit curve = rate of genuine coincidences

High precision (~5%) monitoring of OM efficiencies

Concentration of ^{40}K is very stable

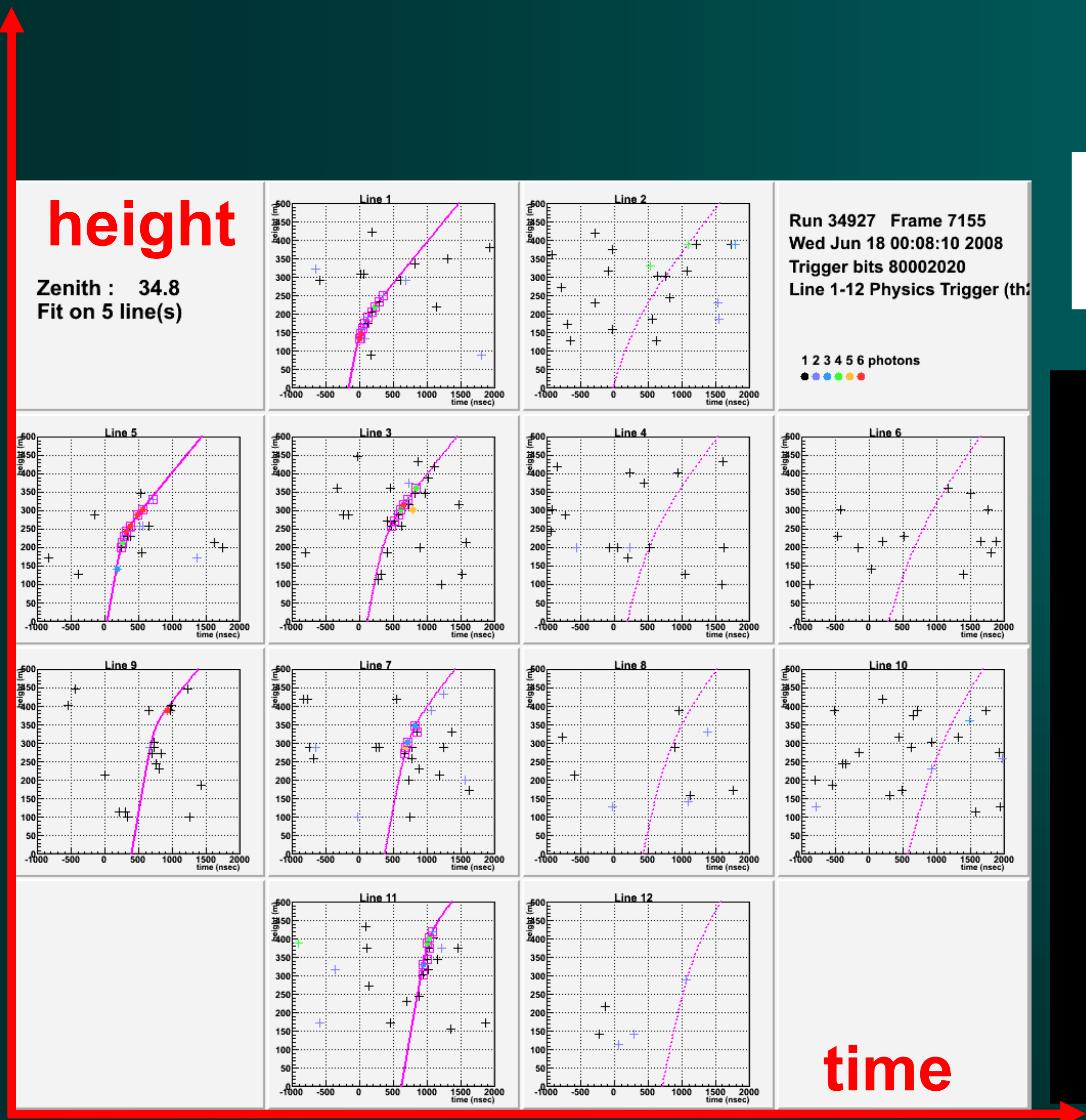
Rate of genuine coincidences: 16+/-3 Hz (independent of bioluminescent activity)

A high-energy muon bundle (event display)

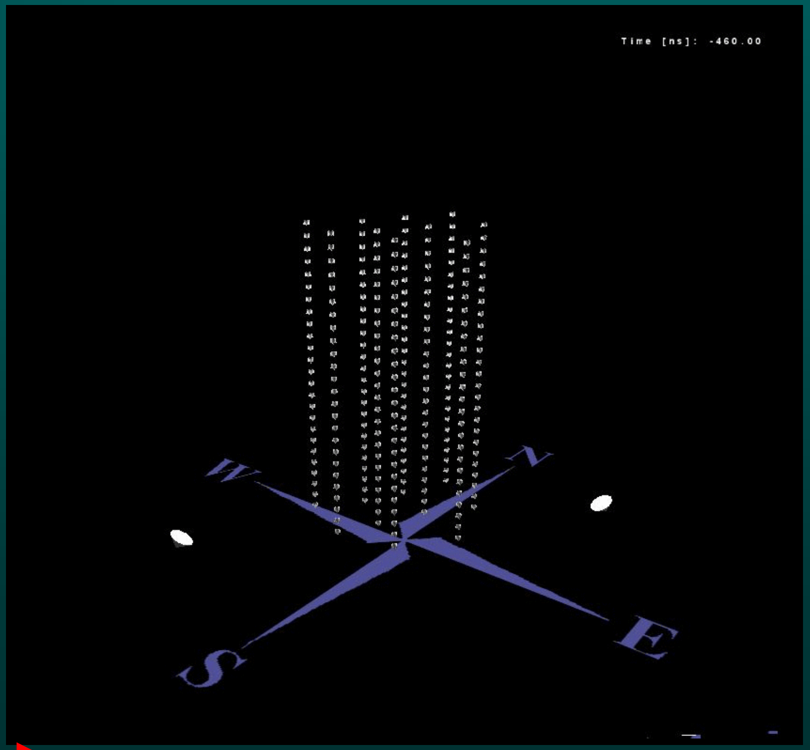


Example of a reconstructed down-going muon, detected in all 12 detector lines:

A neutrino-induced muon

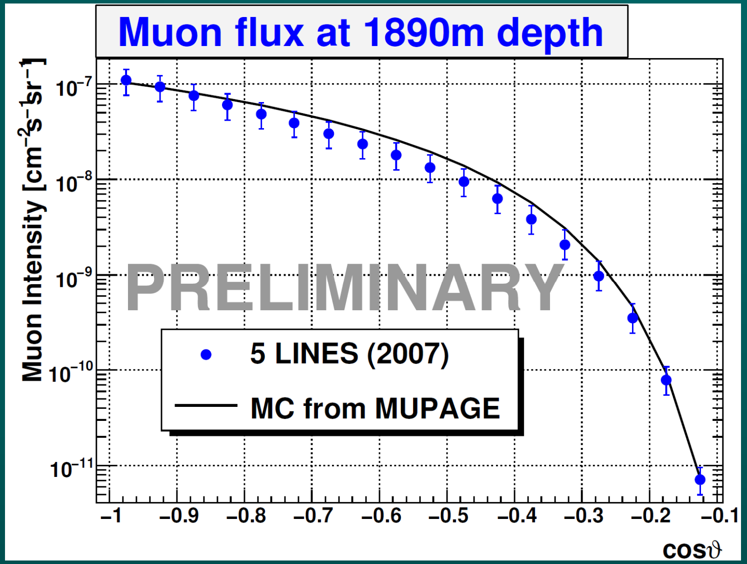


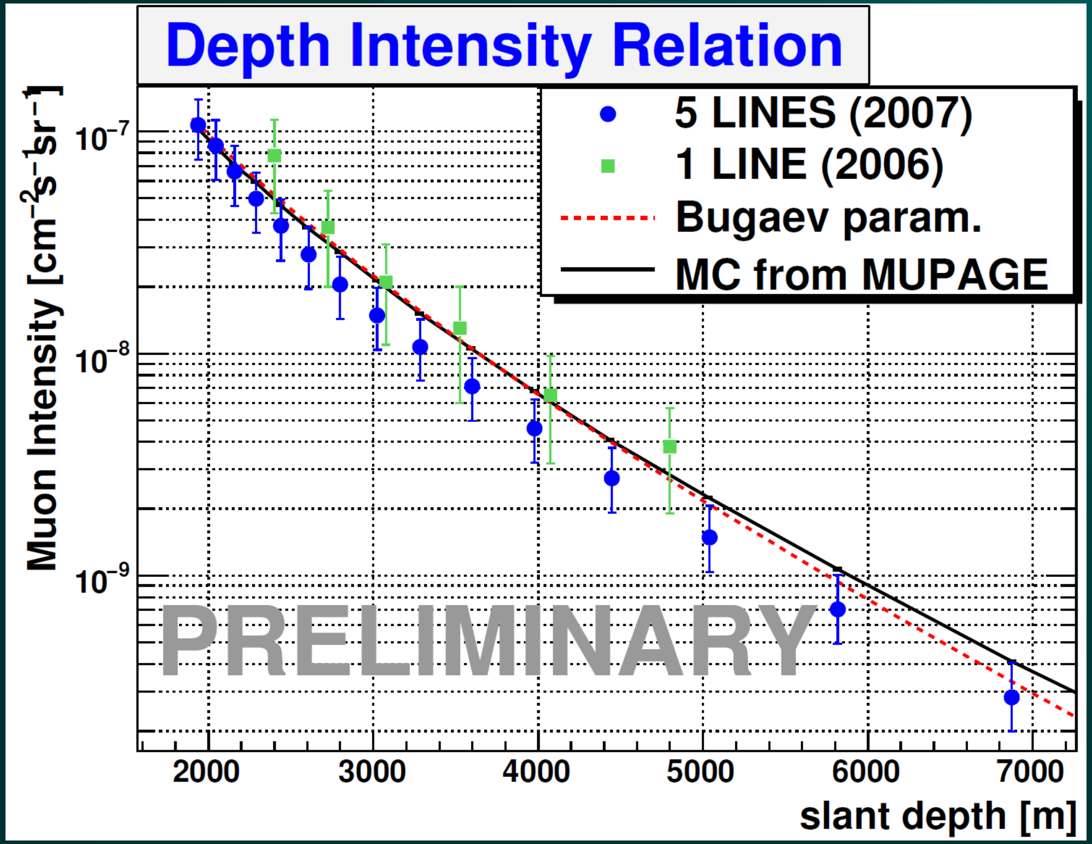
Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:



Depth Intensity Relation for the muon flux

1. Track reconstruction (zenith angle)
2. Convertion to “slant depth”

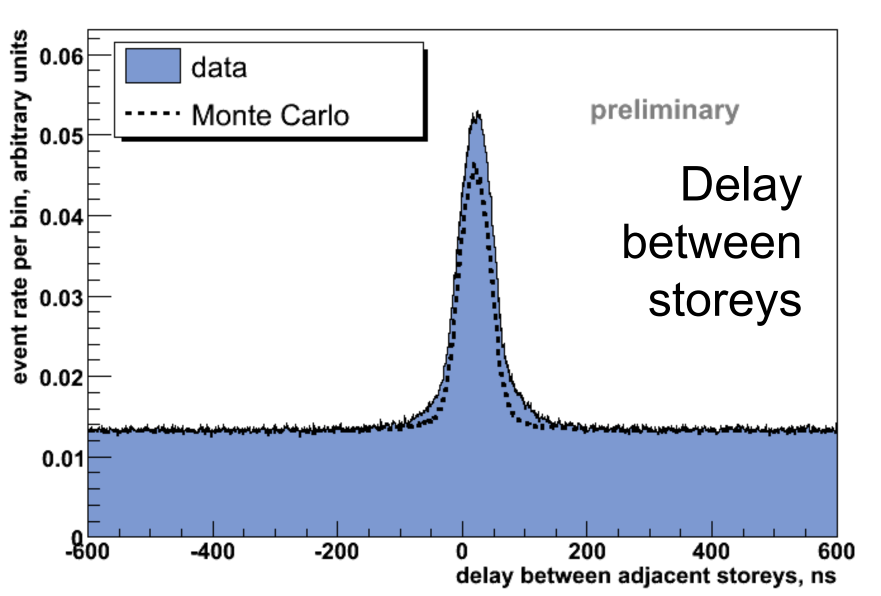




1-line data:
The ANTARES collaboration, *Performance of the First ANTARES Detector Line*, arXiv:0812.2095 [astro-ph]

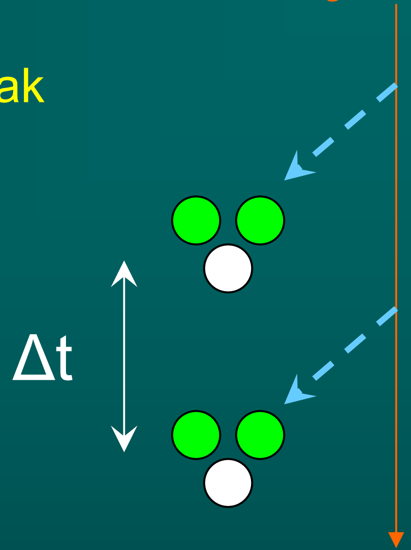
5-line data:
Paper in preparation

New method: coincidences in adjacent storeys



Integral under the peak ~ muon flux

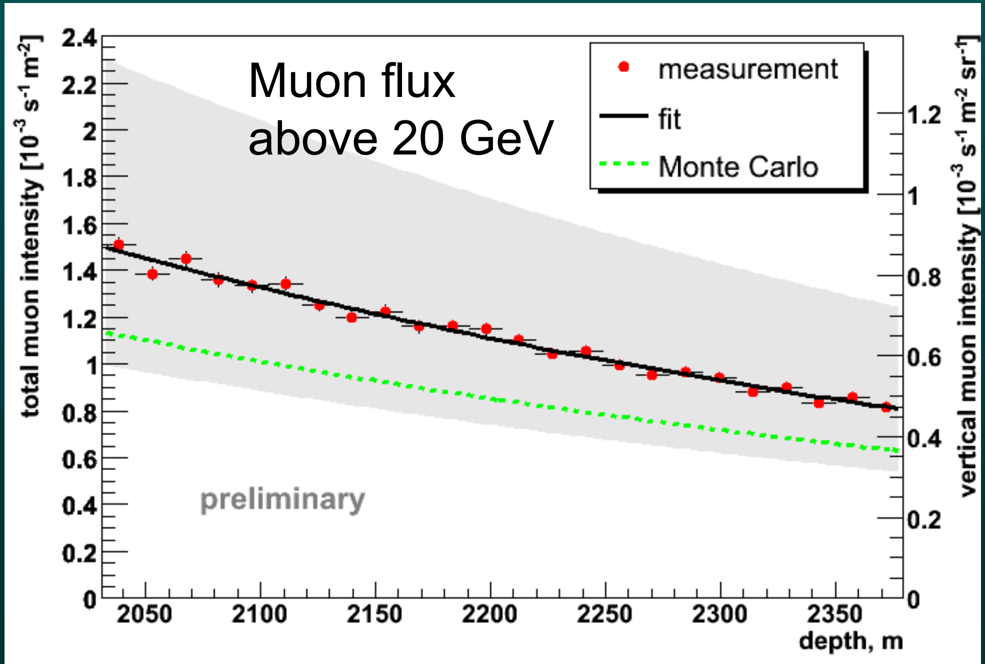
Energy threshold ~ 4 GeV (track length)



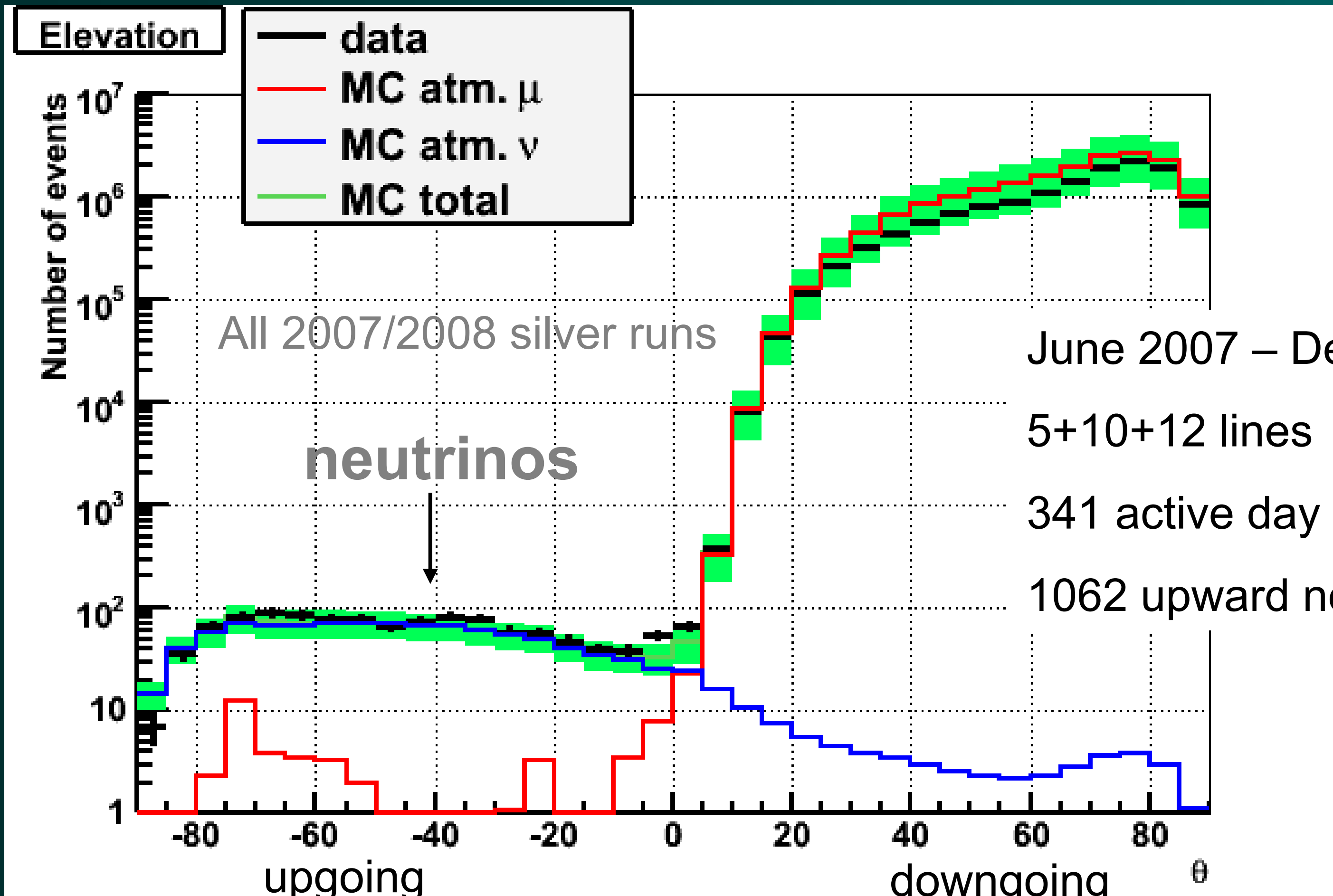
The analysis is repeated for every detector storey

The effect of muon flux reduction with depth is directly (!) measured

Systematic errors mainly in normalization (otherwise ~3%)



Zenith angle distribution



June 2007 – Dec 2008

5+10+12 lines

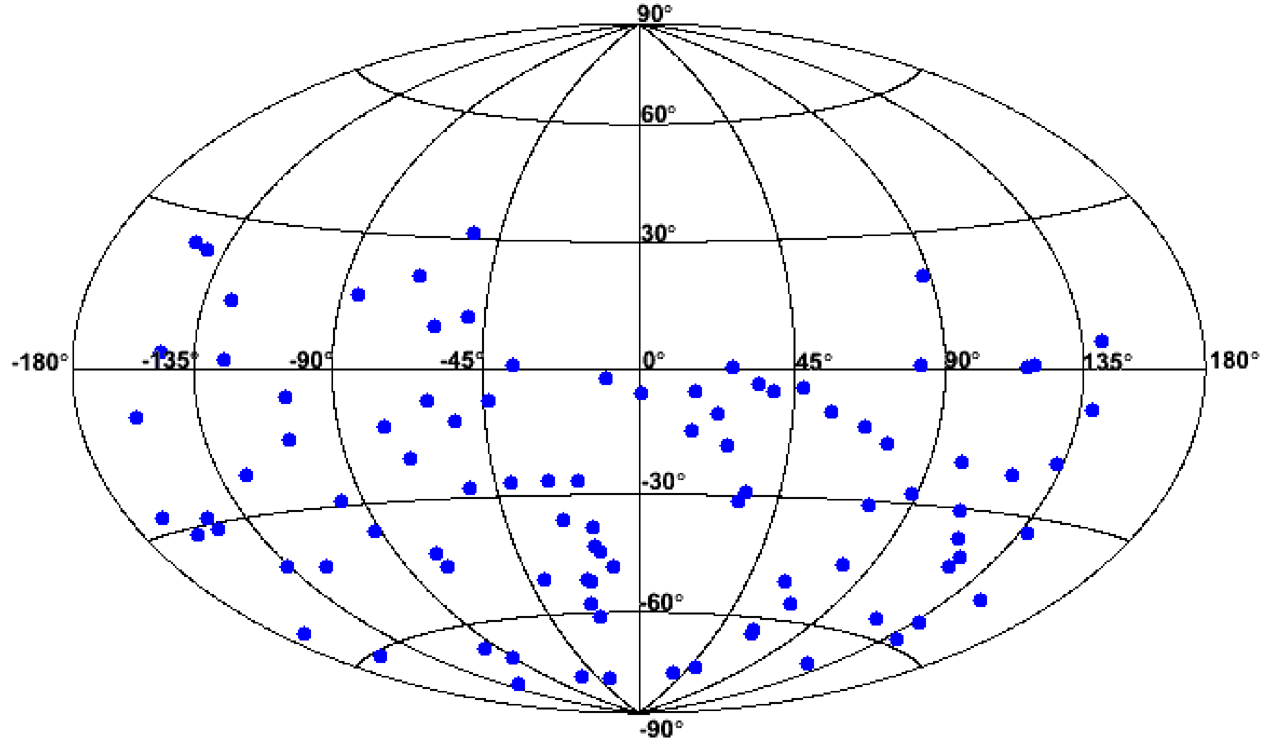
341 active day

1062 upward neutrino candidates

Good agreement with “standard” neutrino oscillations: $\sin^2 2\theta = 1$; $\Delta m^2 = 2.4 \cdot 10^{-3}$ eV^2

Neutrino sky map (all sky search)

2007 neutrino sky map



Equatorial coordinates

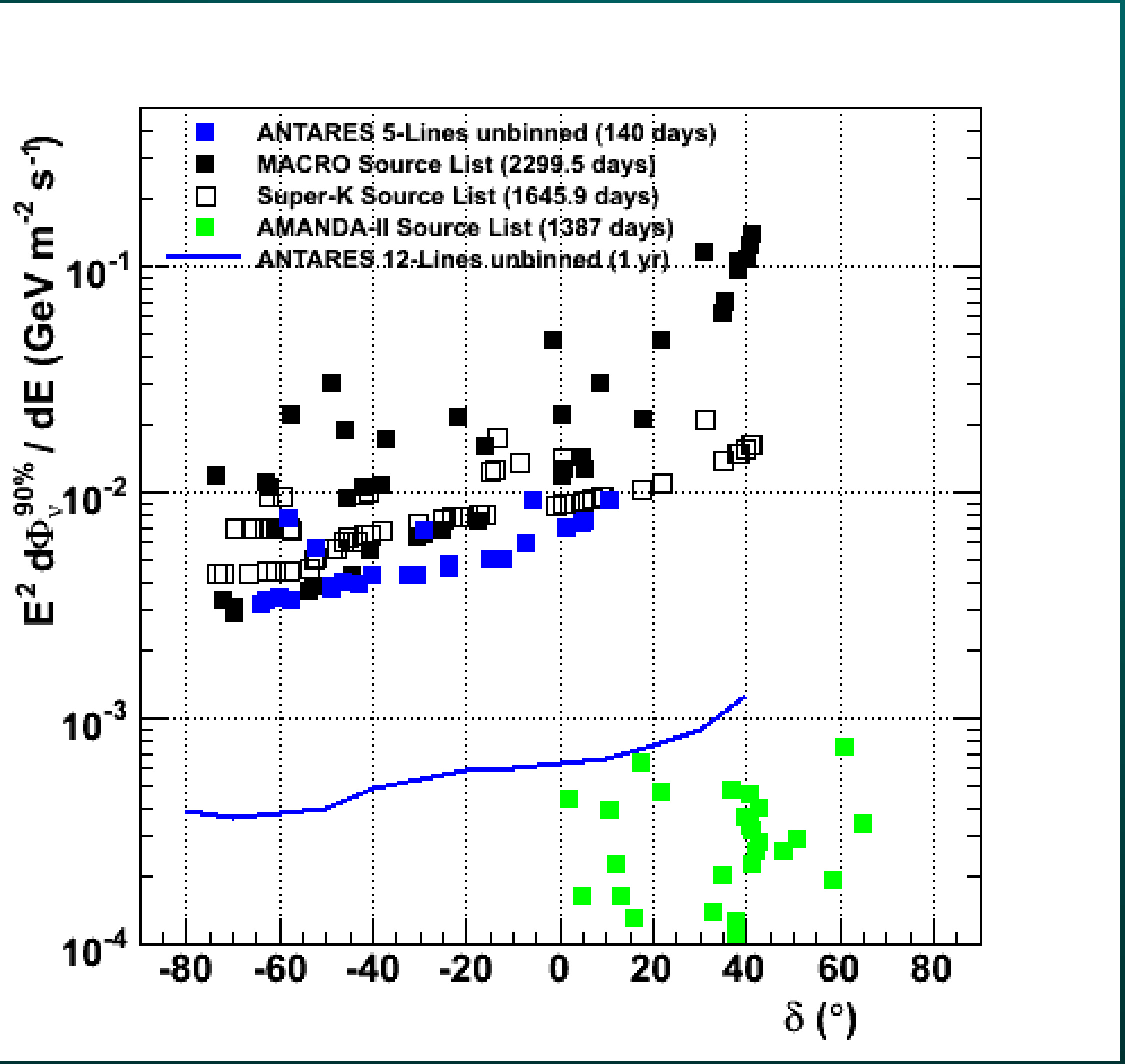
Data: silver runs 2007 (5 line)
Effective live time: 140 days
94 upgoing multi-line events (neutrino candidates)

No significant excess found

Search for point-like sources (candidate list)

Upper limits obtained with 2007 data (5 lines, 140 livetime days), compared with 1 year of complete detector (12 lines) and other experiments

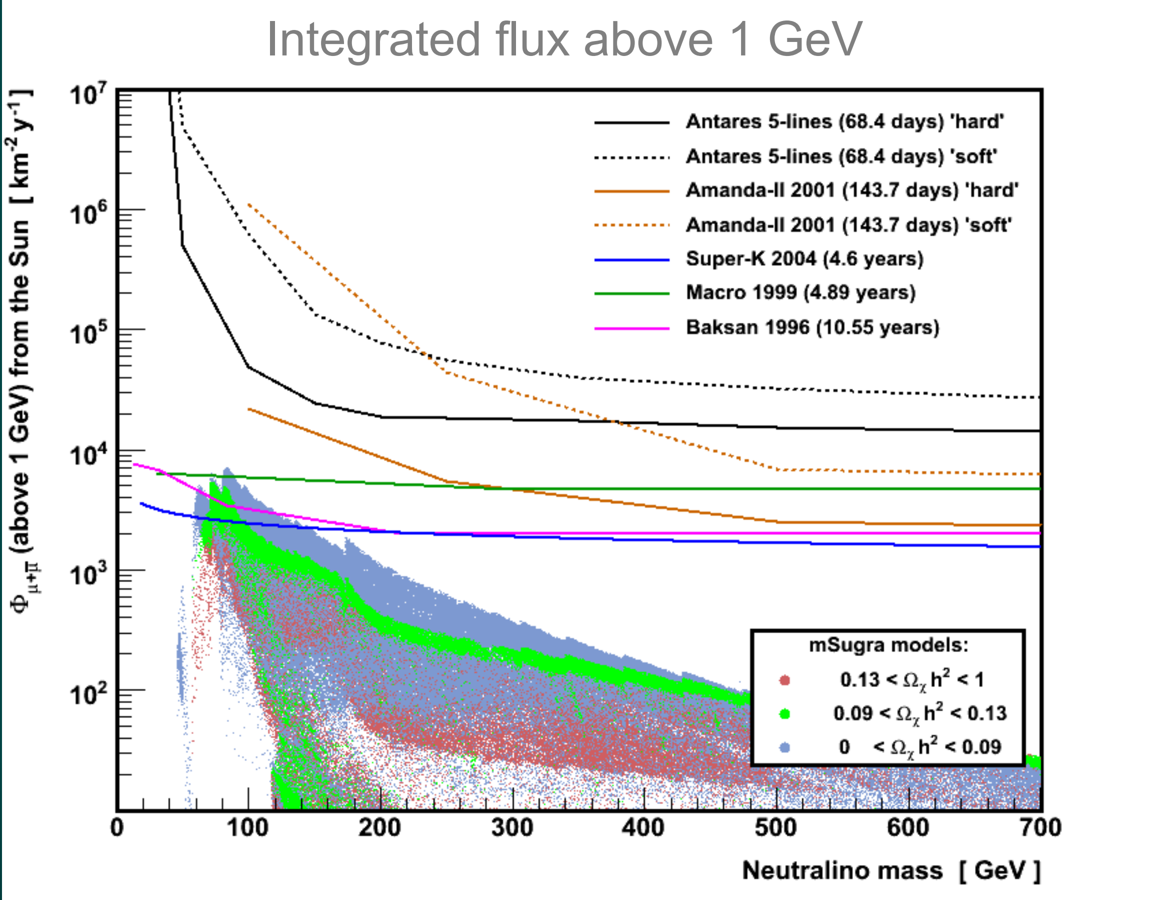
Analysis of 12-line data is ongoing



Search for Dark Matter (neutralino annihilation in the Sun)

- Random walk in mSUGRA parameter space:
  $0 < m_{1/2} < 2000$ GeV
  $0 < m_0 < 8000$ GeV
  $0 < \tan\beta < 60$
  $-3\,m_0 < A_0 < 3\,m_0$
- Calculated with DarkSUSY and ISASUGRA (RGEcode) with $m_{top} = 172.5$ GeV
- Including oscillations

Using all 5 Line data, and only considering time when sun was below the horizon, including quality cuts, effective lifetime of 68.4 days



Flux limit as a function of neutralino mass for two extreme annihilation cases:

- W-bosons ‘hard’
- b-quarks ‘soft’

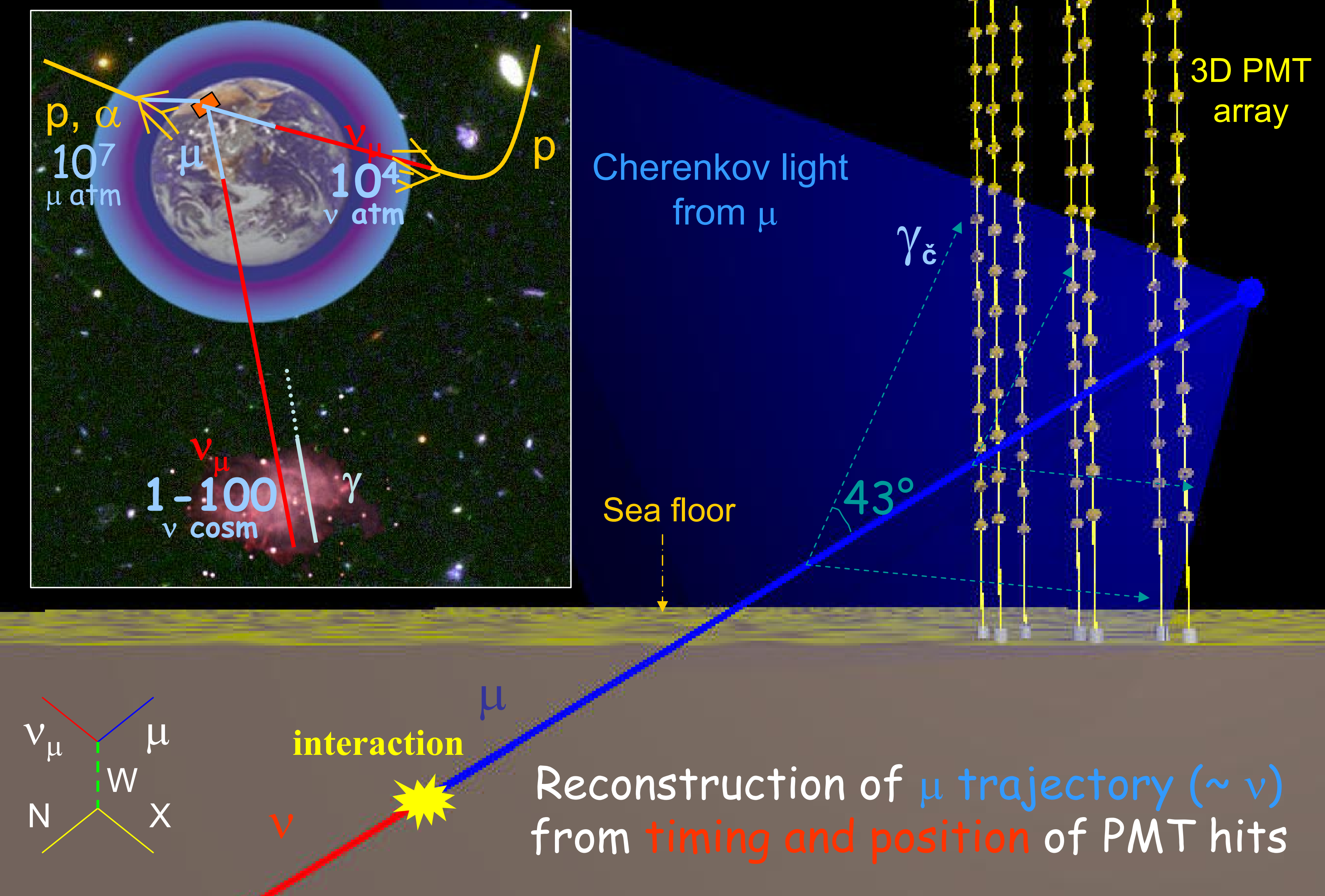
Outlook

- The construction of ANTARES has been completed in May 2008, regular maintenance foreseen for at least 5 years
- The setup is operating well, calibration is good
- The background of atmospheric muons is well under control
- Over 1000 neutrinos have been recorded, zenith angle distribution agrees with MC prediction assuming "standard" neutrino oscillations ($\sin^2 2\theta = 1$; $\Delta m^2 = 2.4\ 10^{-3}\ eV^2$)
- The search for astrophysical neutrino sources is ongoing, as well as Dark Matter searches, and other exciting studies
- ANTARES is presently the largest neutrino detector operated in the Northern hemisphere, and it is taking data


Thank you for your attention!

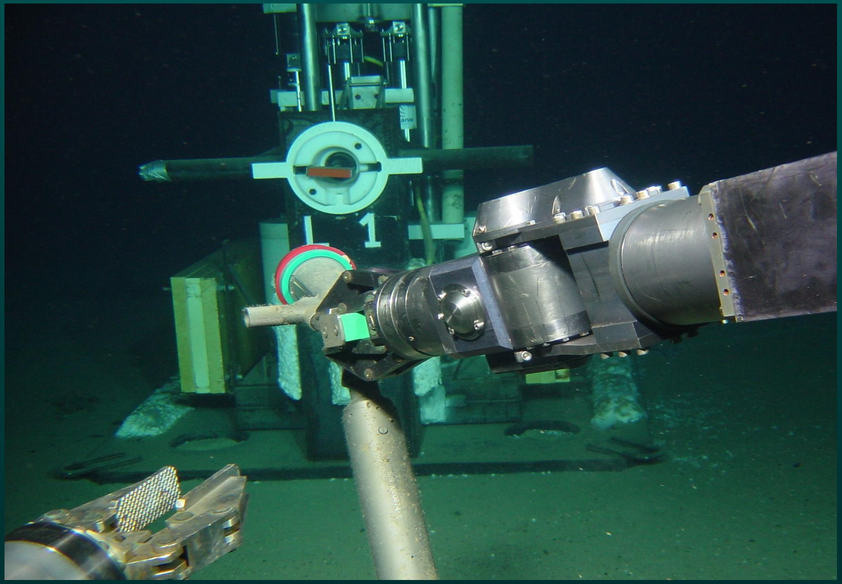
Backup slides

Detection principle



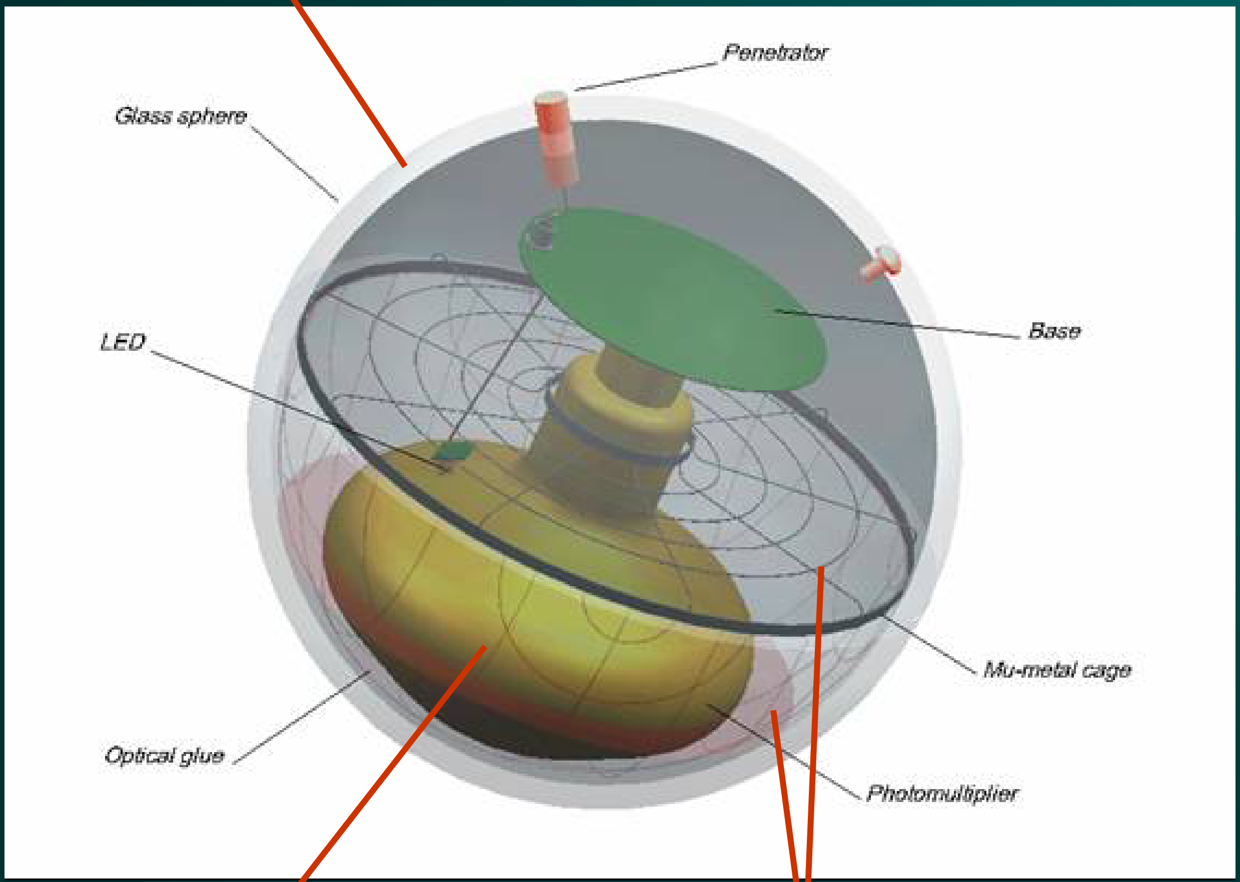
Reconstruction of μ trajectory (~ ν)
from timing and position of PMT hits

Deployment & connection



Optical Module (OM)

Glass sphere



PMT

Magnetic screen

The OM

Hamamatsu R7081-20
(440 cm^2 photocathode)

TTS 1.3 ns

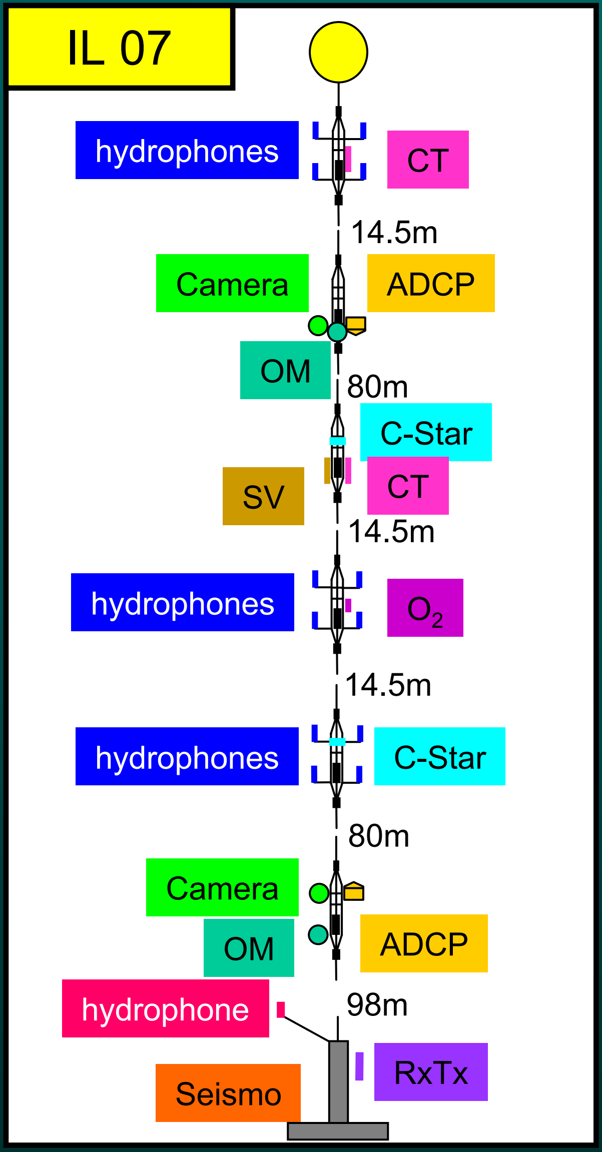
Instrumentation Line IL07

Goals:

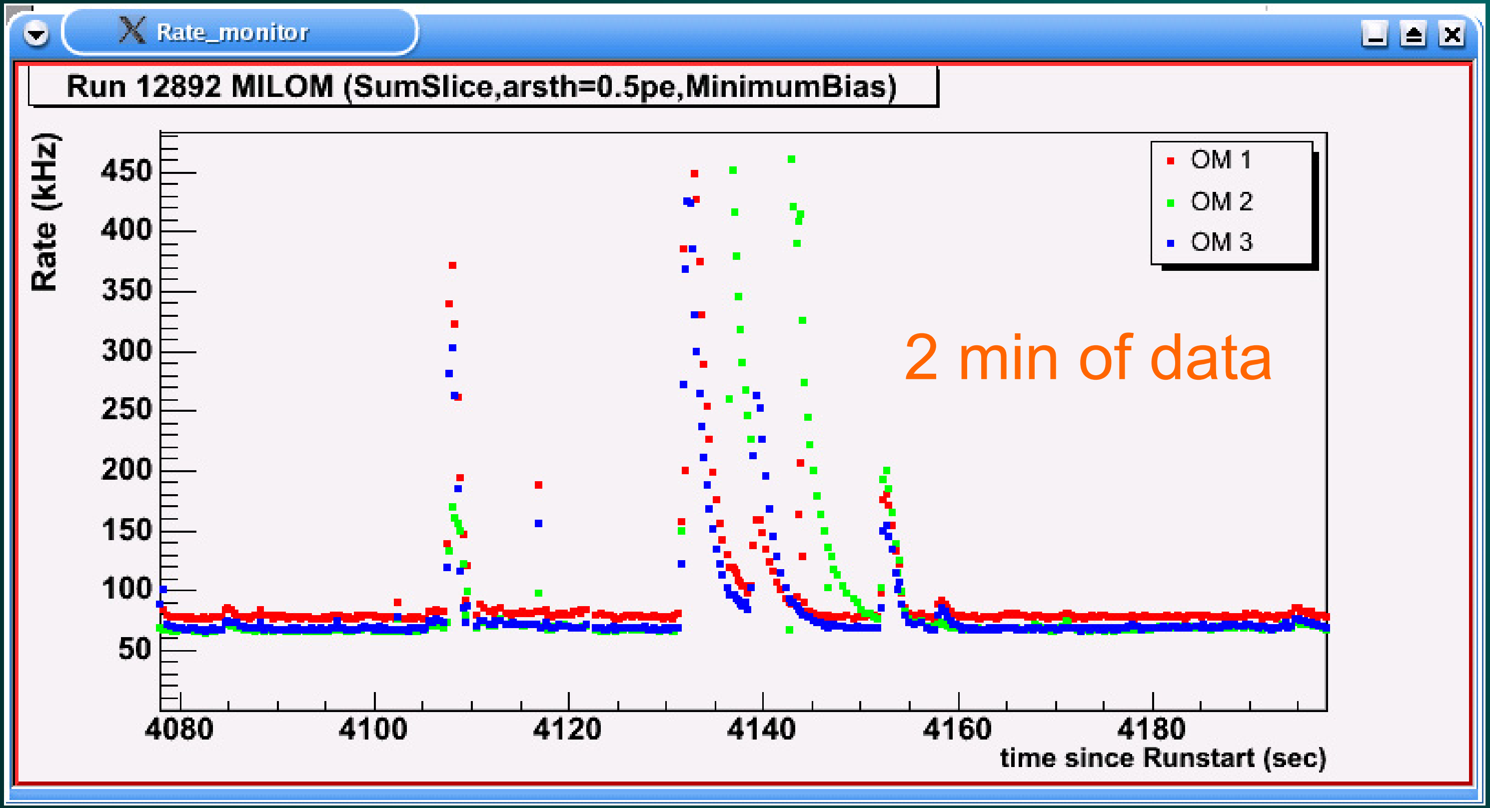
- monitor of environmental sea parameters
- apparatus calibration

+ <u>acoustic detection prototyping</u>

- Components:
- WetLabs CSTAR light transmissometer (2)
- CT = Seabird Conductivity-Temperature probe with water pump (2)
- SV = Sound Velocimeter
- ADCP = Acoustic Doppler Current Profiler (1 up, 1 down)
- GURALP seismometer with direct Ethernet link
- 2 OMs
- 1 Laser + 2 Led Beacon
- Acoustic Positioning RxTx & Rx
- 0_2-probe
- 2 sensitive cameras + IR flash light
- Three floors equipped for acoustic detection R&D (6 hydrophones/storey, part of the AMADEUS system)



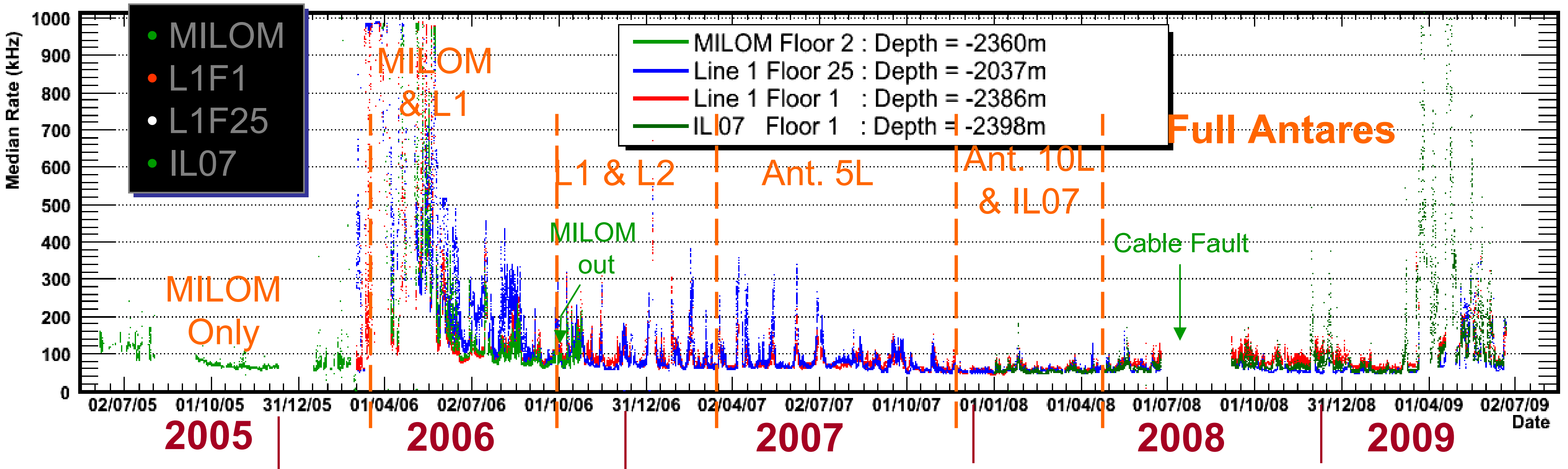
Counting rates (short timescale)



Continuous baseline:
Radioactivity of sea water (^{40}K)
+ bioluminescent bacteria

Bursts:
bioluminescence from
Macroscopic organisms

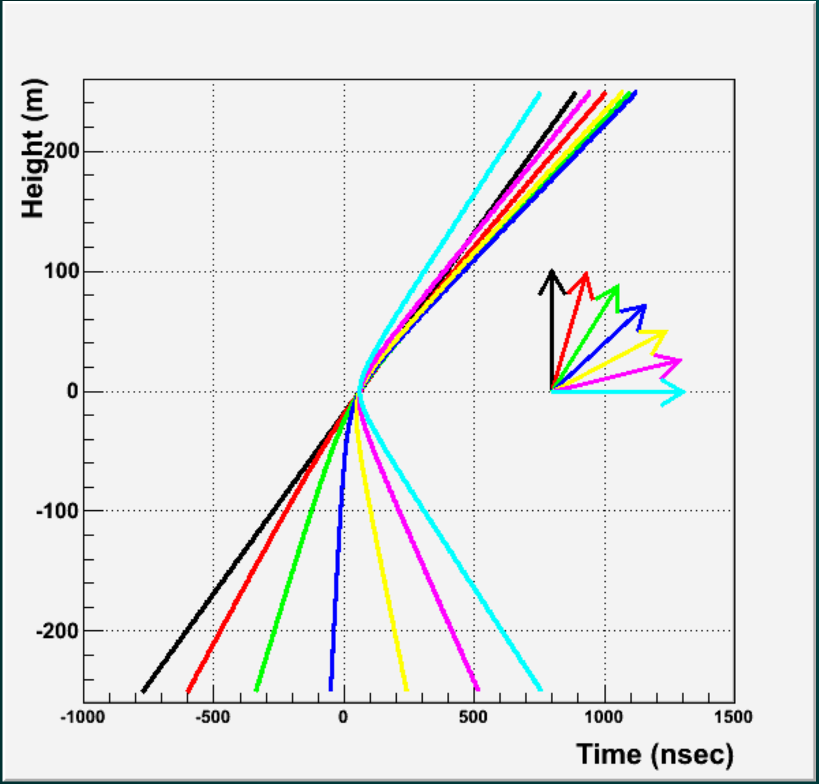
Counting rates (long timescale)

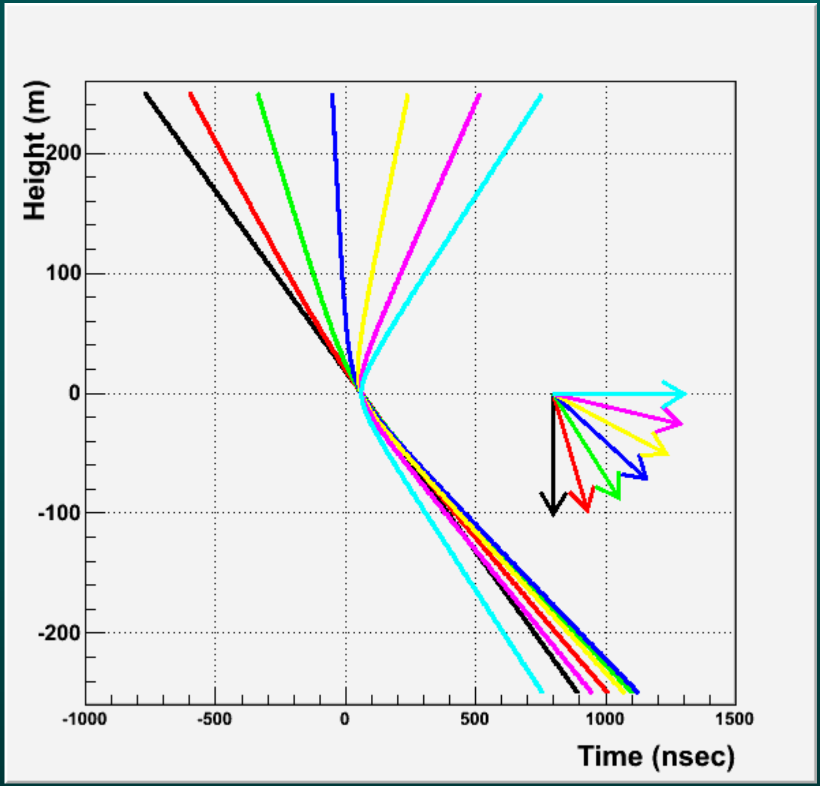


Long term variations due to seasonal and sea current variability

Event display basics

upgoing **downgoing**



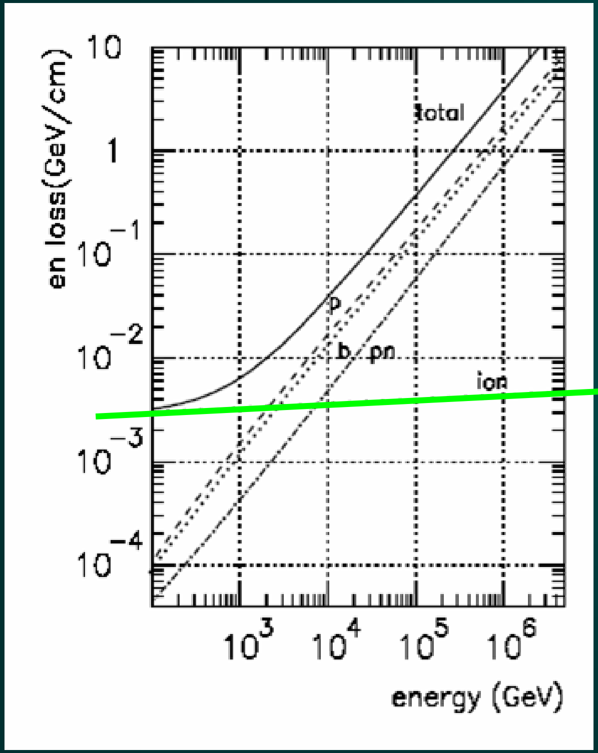


h = 0 – point of closest approach

Energy reconstruction (muons)

Two different methods:

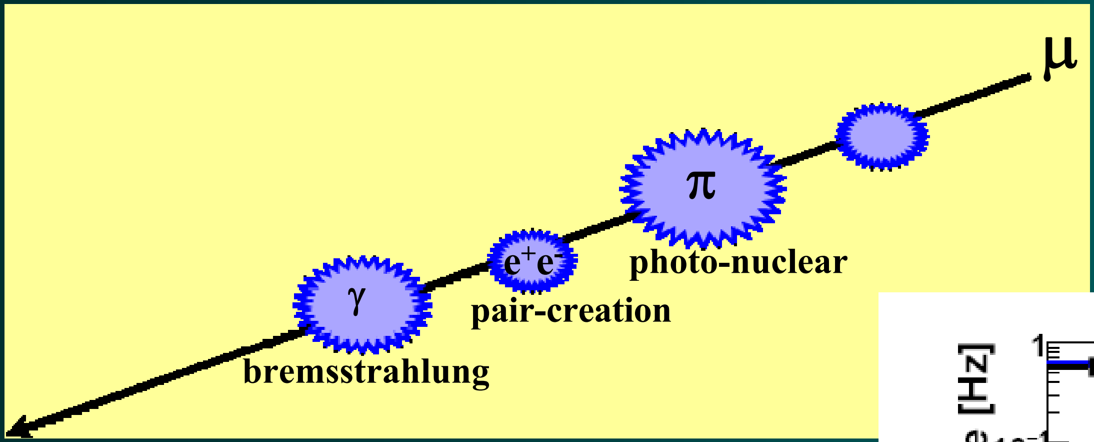
- **10 GeV < E_m < 100 GeV ⇒ muon range (hit positions)**
- **E_μ > 1 TeV ⇒ muon energy loss (hit multiplicity/charge)**



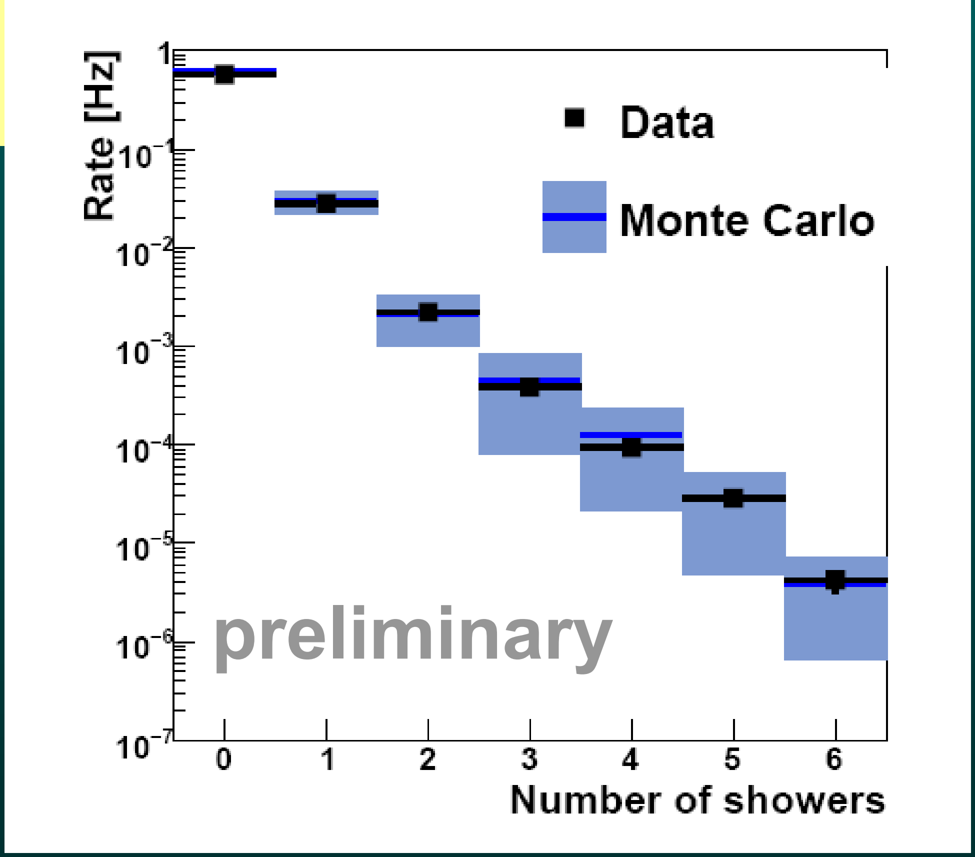
Average energy loss of muon in water:
High energies dominated by pair production, bremsstrahlung

Energy resolution ~ factor 2-3

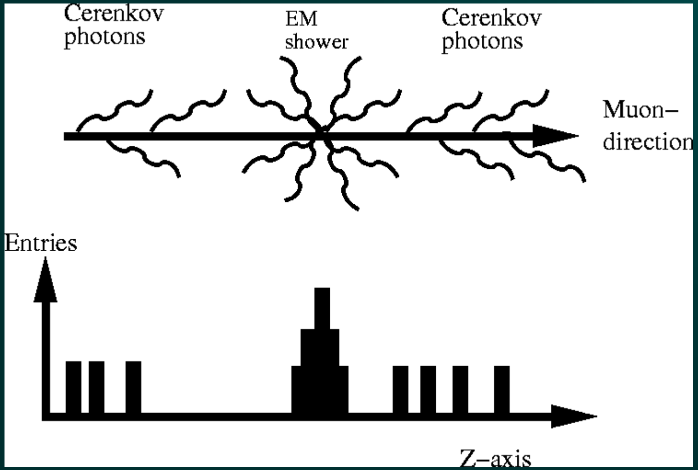
Observation of induced electromagnetic showers from atmospheric muons



Light from EM shower is produced in “one point” on the muon path and arrives delayed



Use of dense clusters of hits to estimate shower multiplicity



Other analyses

- Search for anisotropies
  - downgoing and upgoing muon flux
- Multi-messenger approach
  - Neutrino from GRB
    - Dump raw data when receiving a GRB alert from GCN
    - >300 alerts acuumulated, data analysis in progress
  - Optical follow-up program
    - collaboration with TAROT
  - Coincidences with gravitational wave detectors
    - Collaboration with VIRGO and LIGO being discussed
- Galactic center trigger
  - First directional trigger in ANTARES
- Diffuse flux limits
  - Using muons or hadronic showers (all-flavor neutrino)
- Exotics
  - Magnetic Monopole, nuclearites, etc