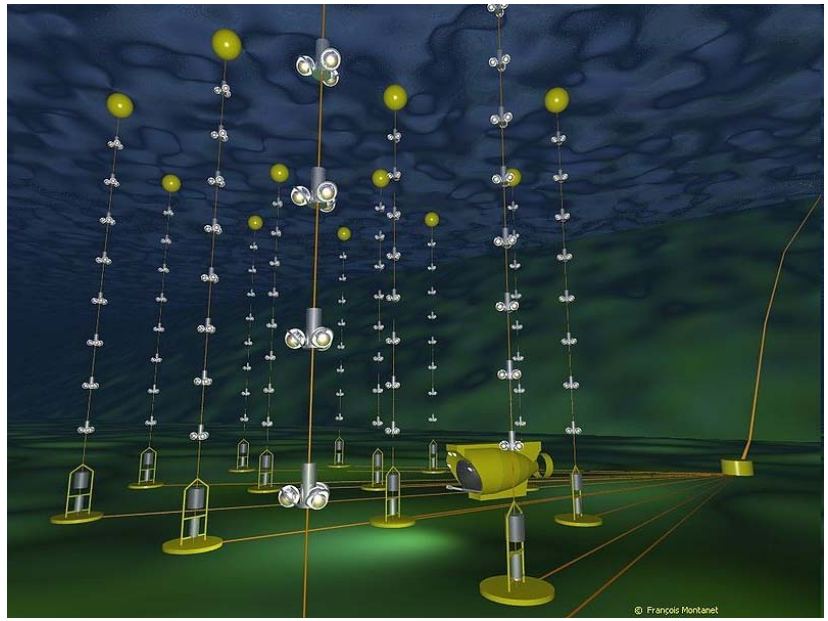
Status and first results of the ANTARES neutrino telescope

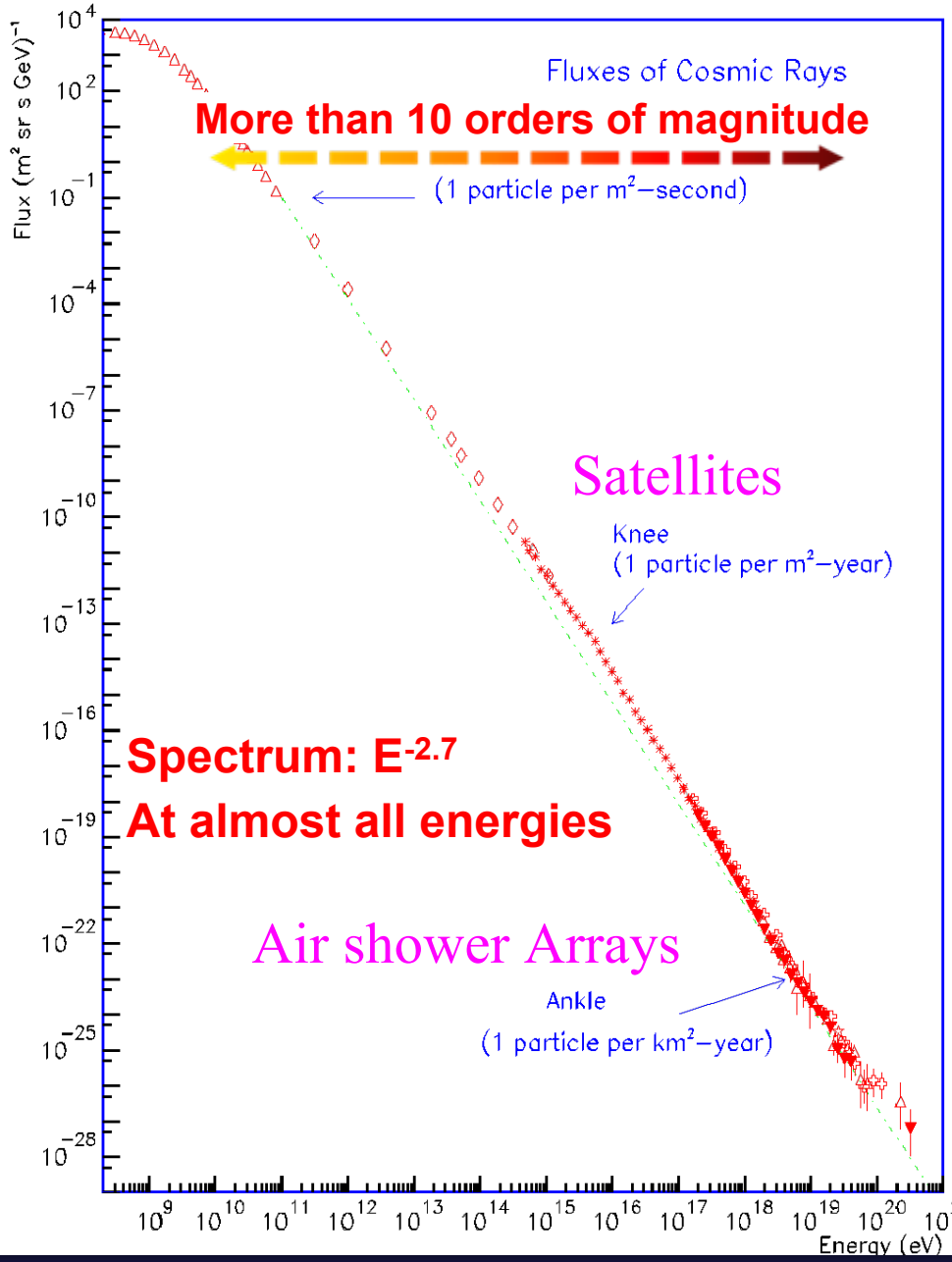
- research goals
- the detector setup
- status and performance
- first results

summary

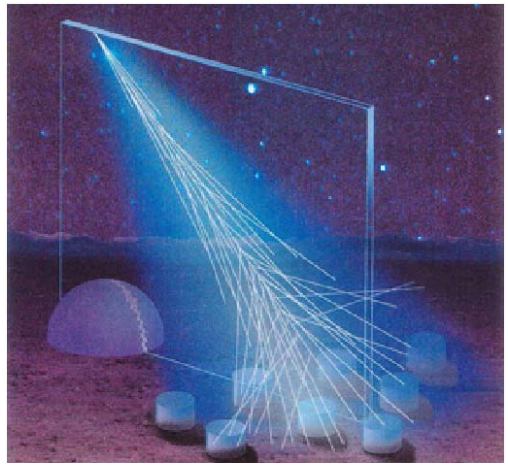


Heide Costantini
INFN, Genova, Italy

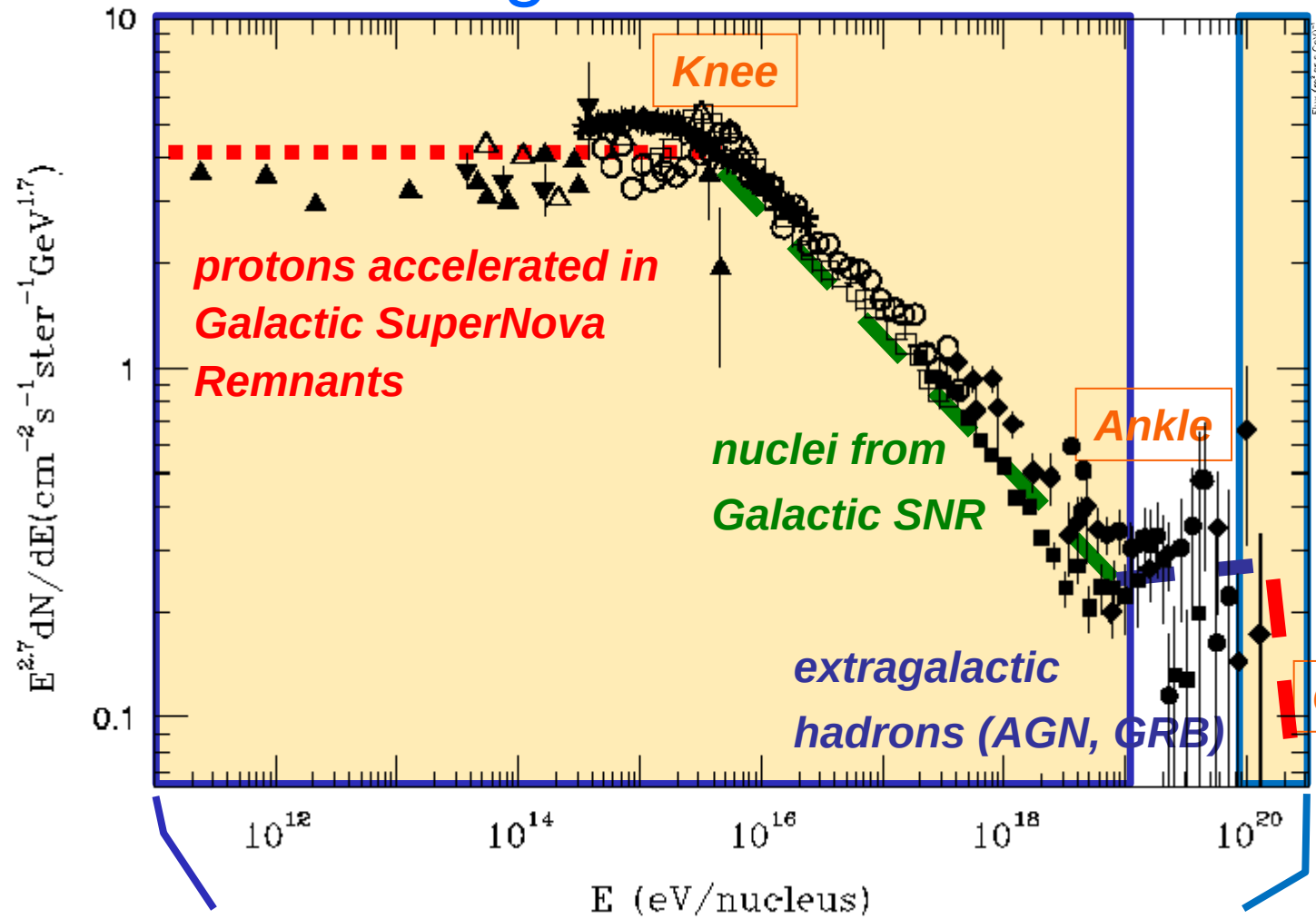
The Cosmic Ray (CR) Spectrum

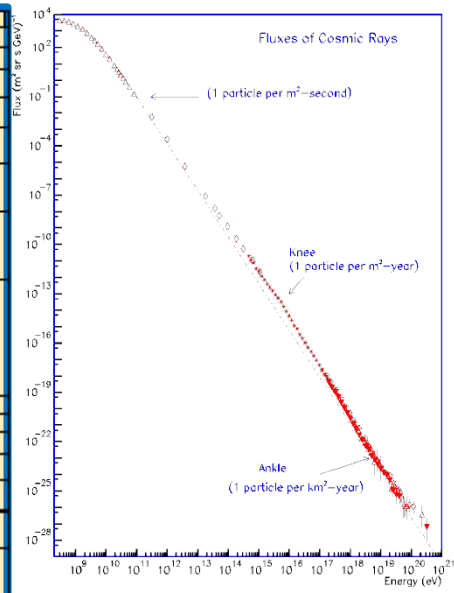


The CR sources are still unkown



CR Origin: the Standard Scenario





Greisen-Zatsepsin-Kuz'mi

Hadrons deflected by the Galactic magnetic fields

Hadrons absorbed by the interaction with CMBR: $p + CMBR \rightarrow \Delta^+$

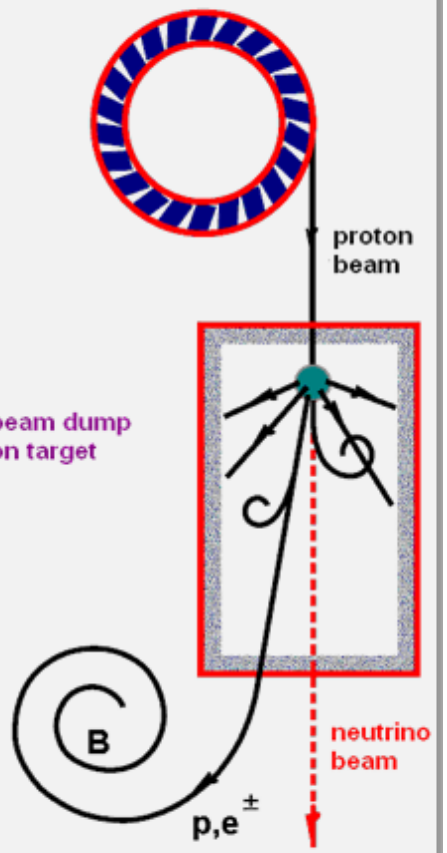
Sources of high energy hadrons exist

but just a little energy window for proton astronomy

The Astrophysical Beam Dump

Fermi acceleration of protons and electrons in astrophysical sources

Particle accelerator



Hadronic HE ν and γ production

$p/A + p/\gamma \rightarrow \pi^0 + \pi^{\pm} + \ldots$

$\pi^0 \rightarrow \gamma\ \gamma$

$\pi^{\pm} \rightarrow \nu_\mu\ \mu$

$\mu \rightarrow \nu_\mu\ \nu_e$

Decay of pions

neutral pions → HE gammas

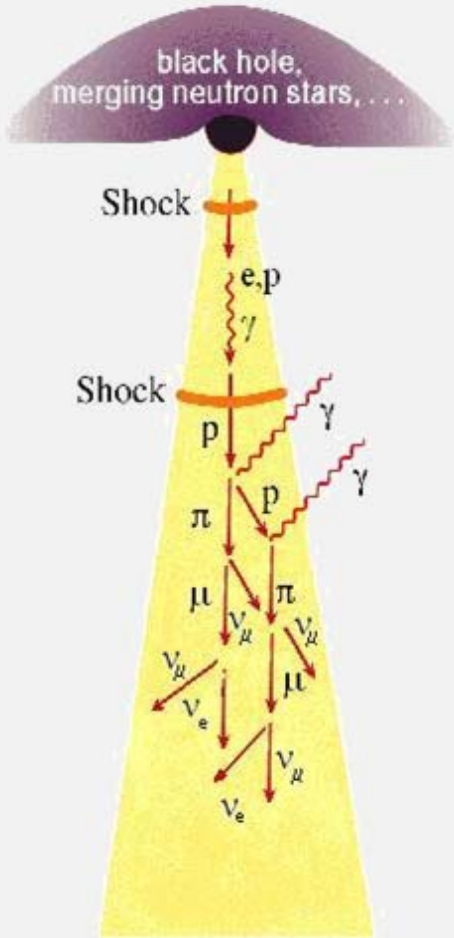
charged pions → HE neutrinos

Leptonic HE γ production

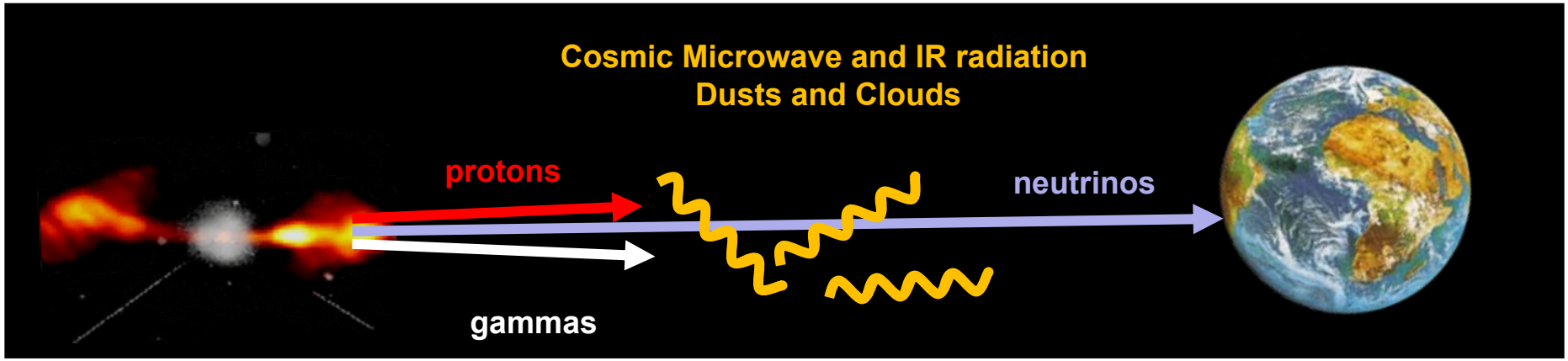
synchrotron radiation followed by IC

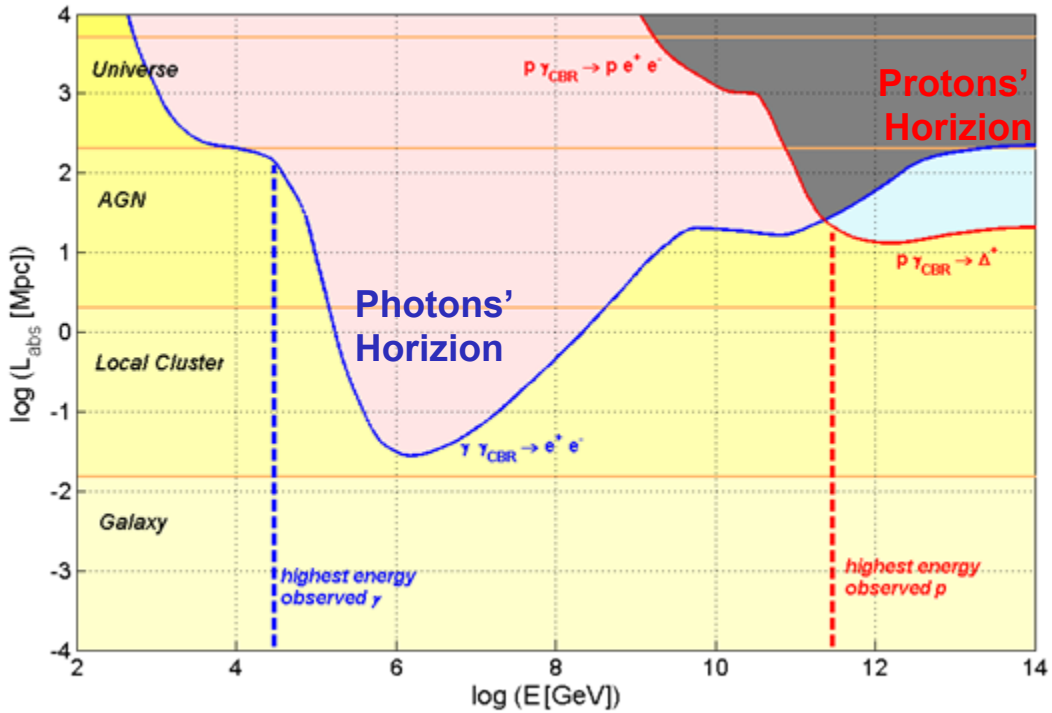
$e + \gamma_{synchrotron} \rightarrow e' + \gamma'_{HE}$

Astrophysical accelerator



Absorption length of protons and gammas in the Universe



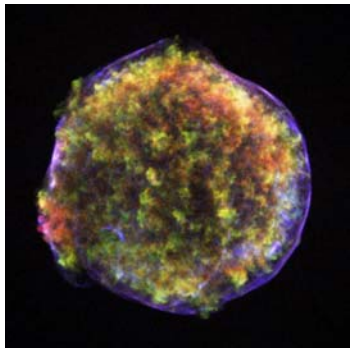


Neutrinos can probe the far and violent Universe

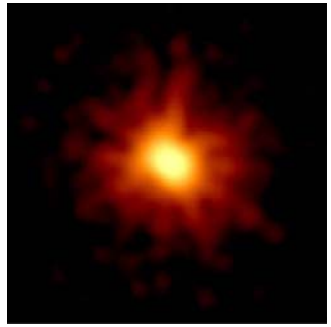
Potential neutrino sources

GALACTIC

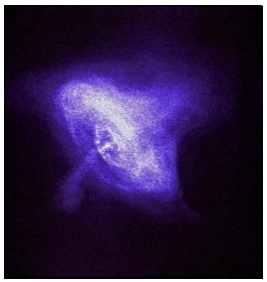
EXTRAGALACTIC



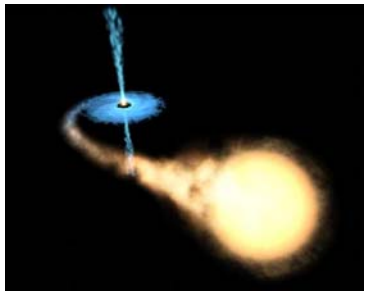
Supernova remnants



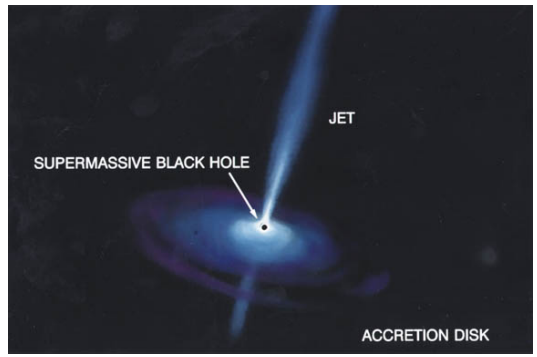
GRBs



Pulsars

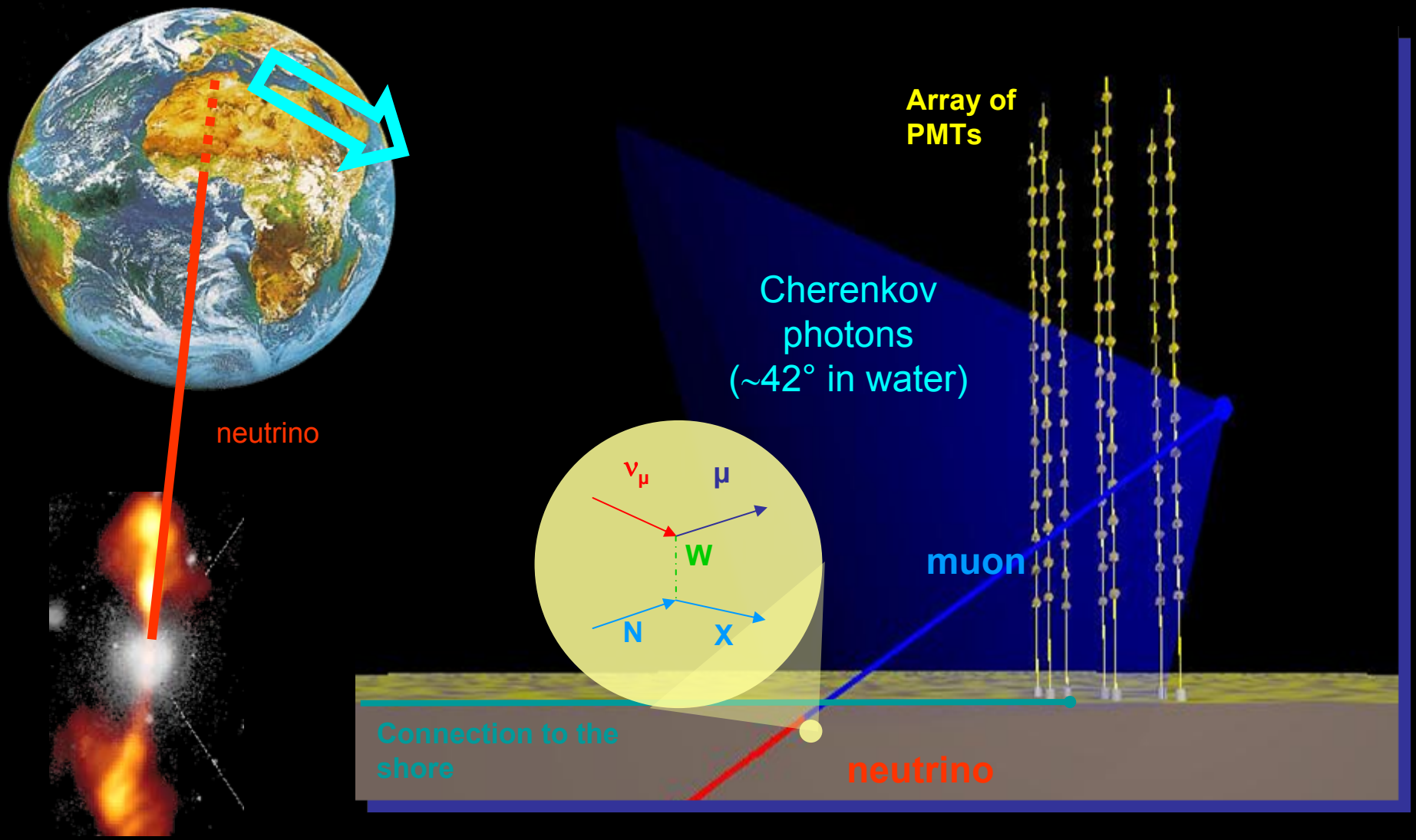


Microquasars



AGNs

Principle of neutrino astronomy



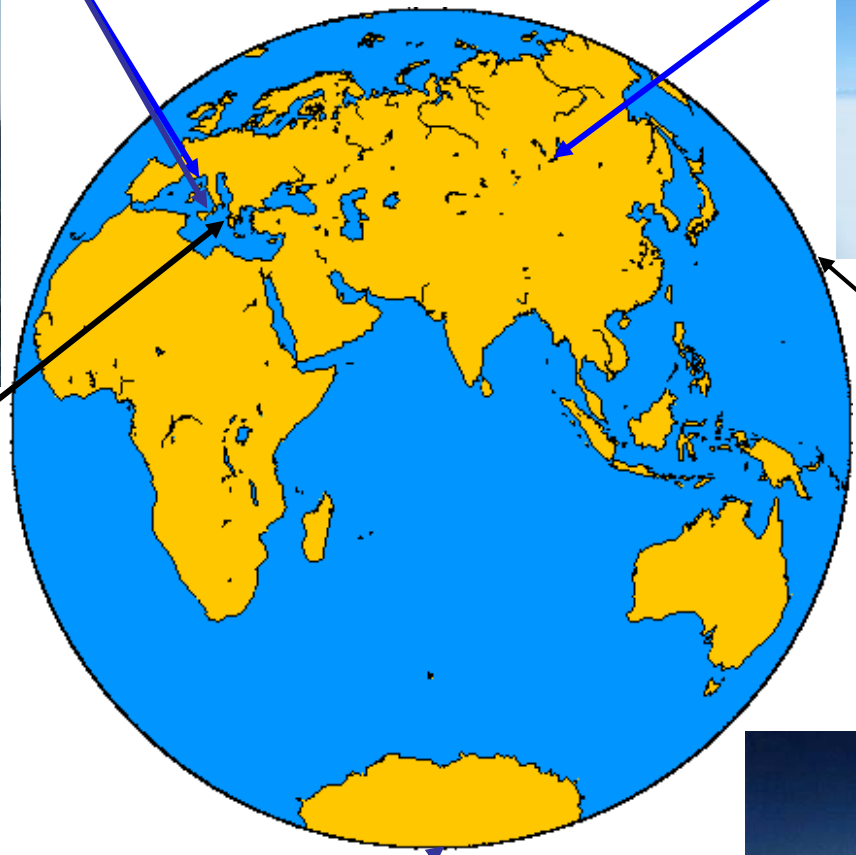
Main detection channel: ν_μ interaction giving an ultrarelativistic μ

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

H_2O Neutrino Telescope Projects

ANTARES La-Seyne-sur-Mer, France
(NEMO Catania, Italy)

BAIKAL: Lake Baikal, Siberia



NESTOR : Pylos, Greece

DUMAND, Hawaii
(cancelled 1995)

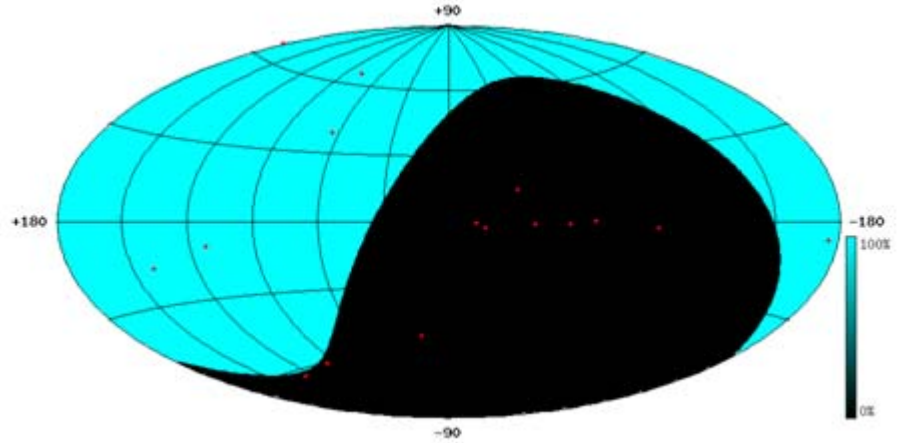
IceCube, South Pole, Antarctica

The ANTARES site

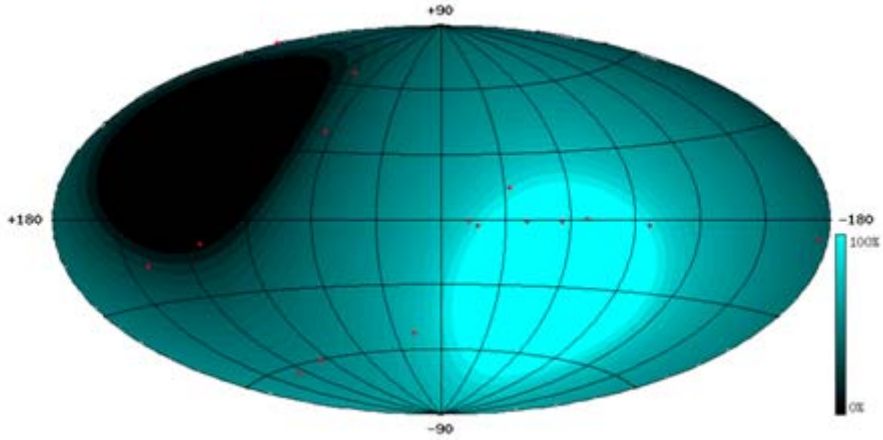
- 42°50’ latitude Nord
- 6°10’ longitude Est

The Galactic center is visible
75% of the day

AMANDA/IceCube (South Pole)

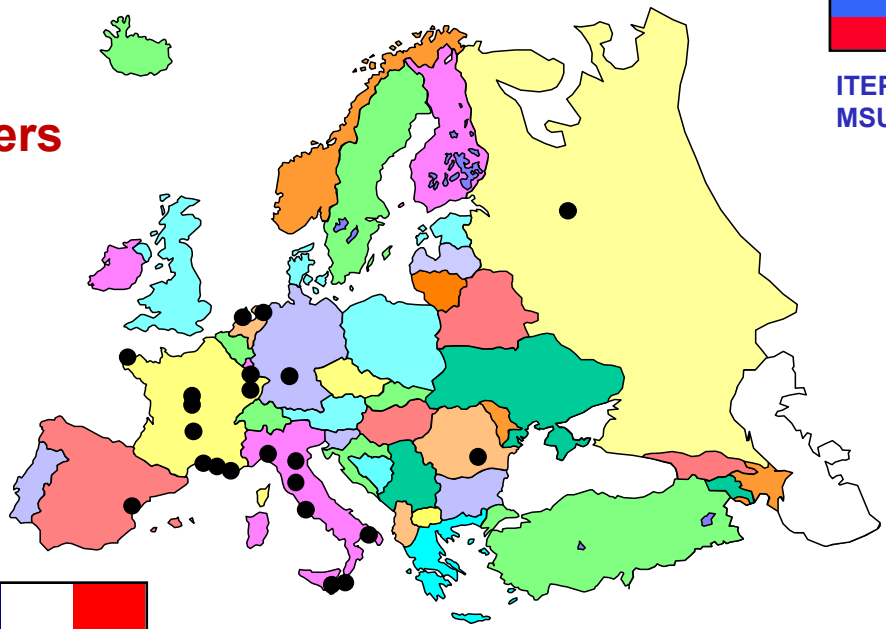


ANTARES



Who is in ANTARES

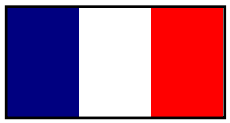
7 countries
27 institutes
150 scientists+engineers



NIKHEF, Amsterdam
KVI Groningen
NIOZ Texel

IFIC, Valencia
UPV, Valencia

University/INFN of Bari
University/INFN of Bologna
University/INFN of Catania
LNS – Catania
University/INFN of Pisa
University/INFN of Roma
University/INFN of Genova



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

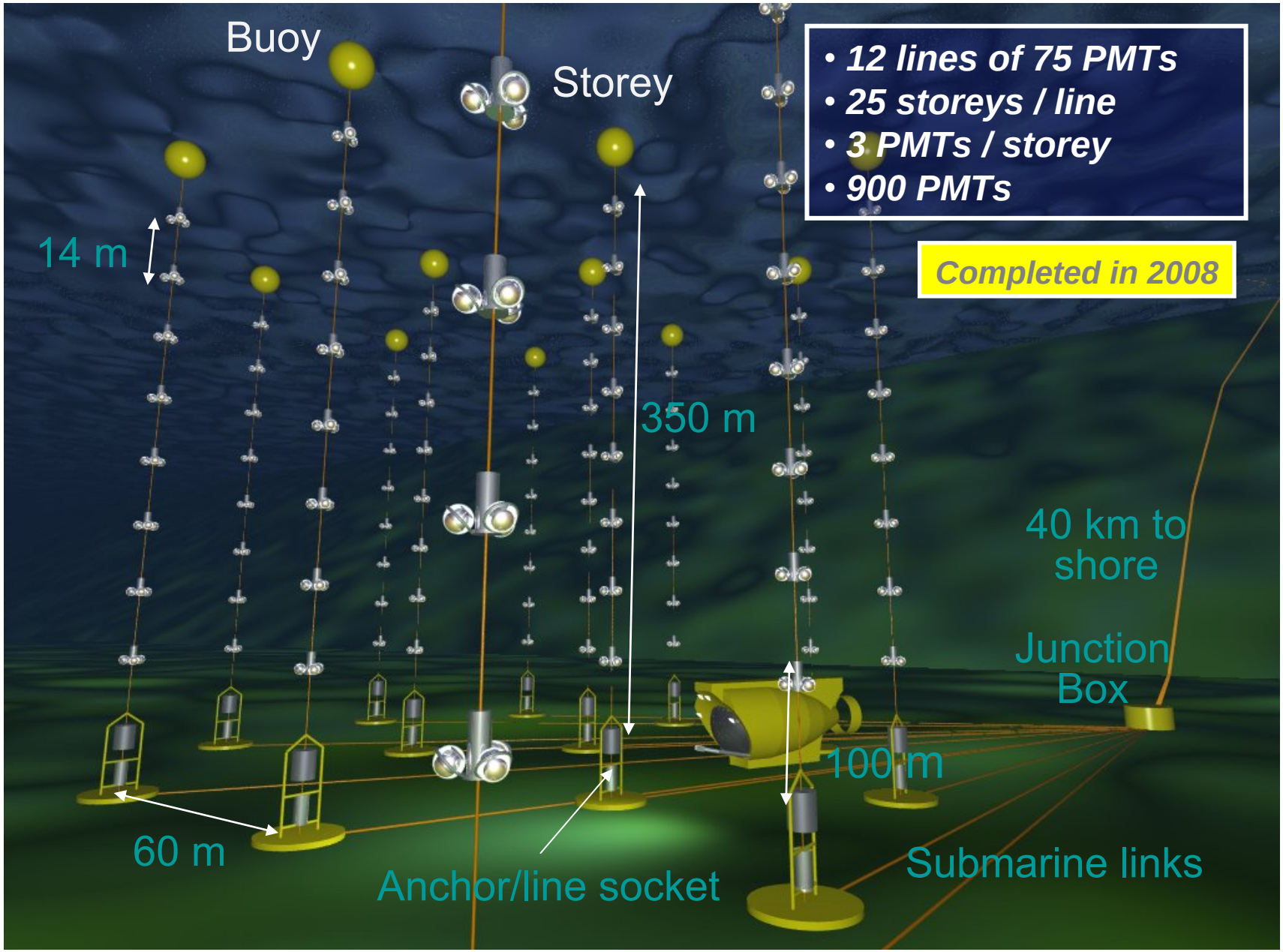
University of
Erlangen

The ANTARES Site infrastructures

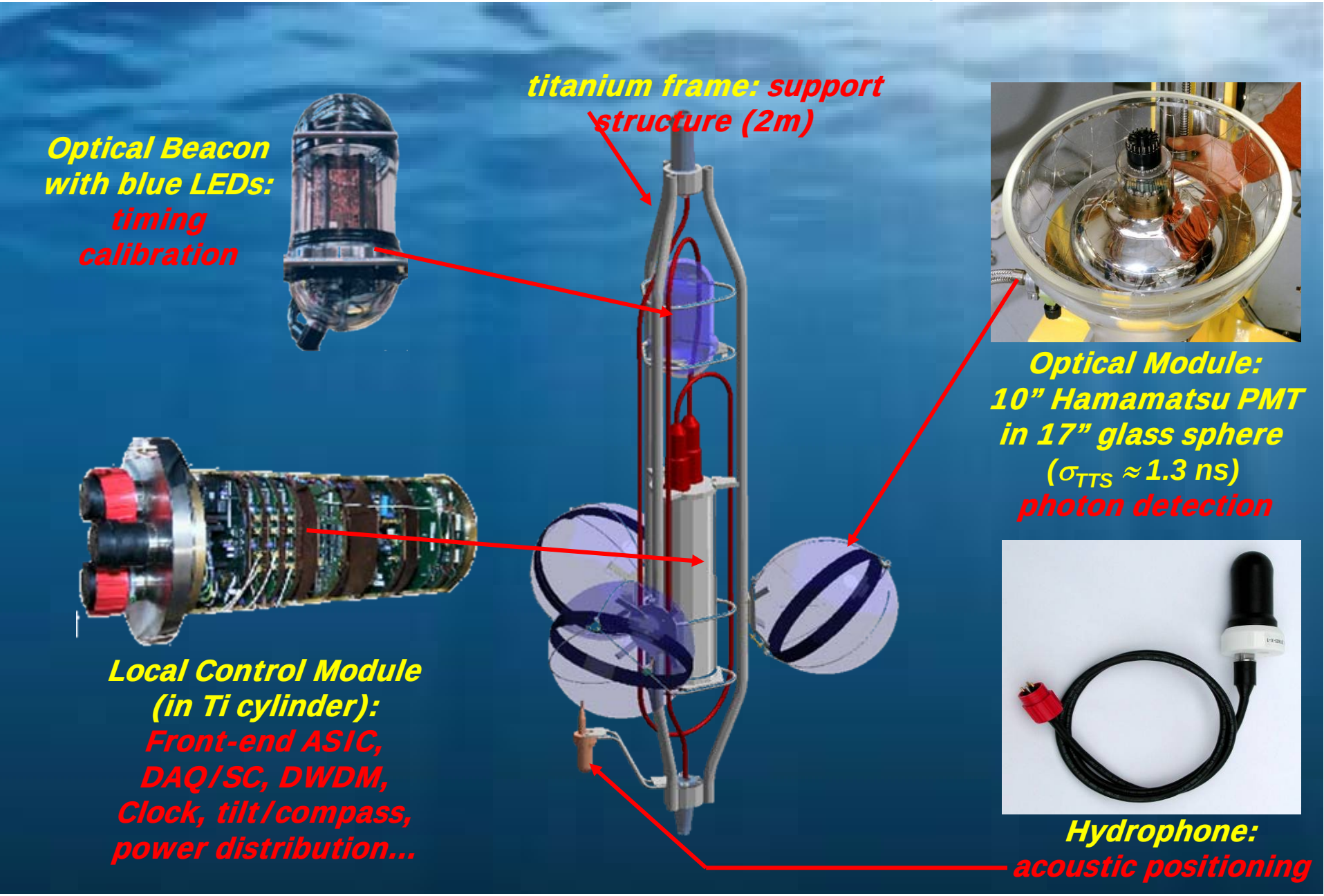
IFREMER Toulon Centre

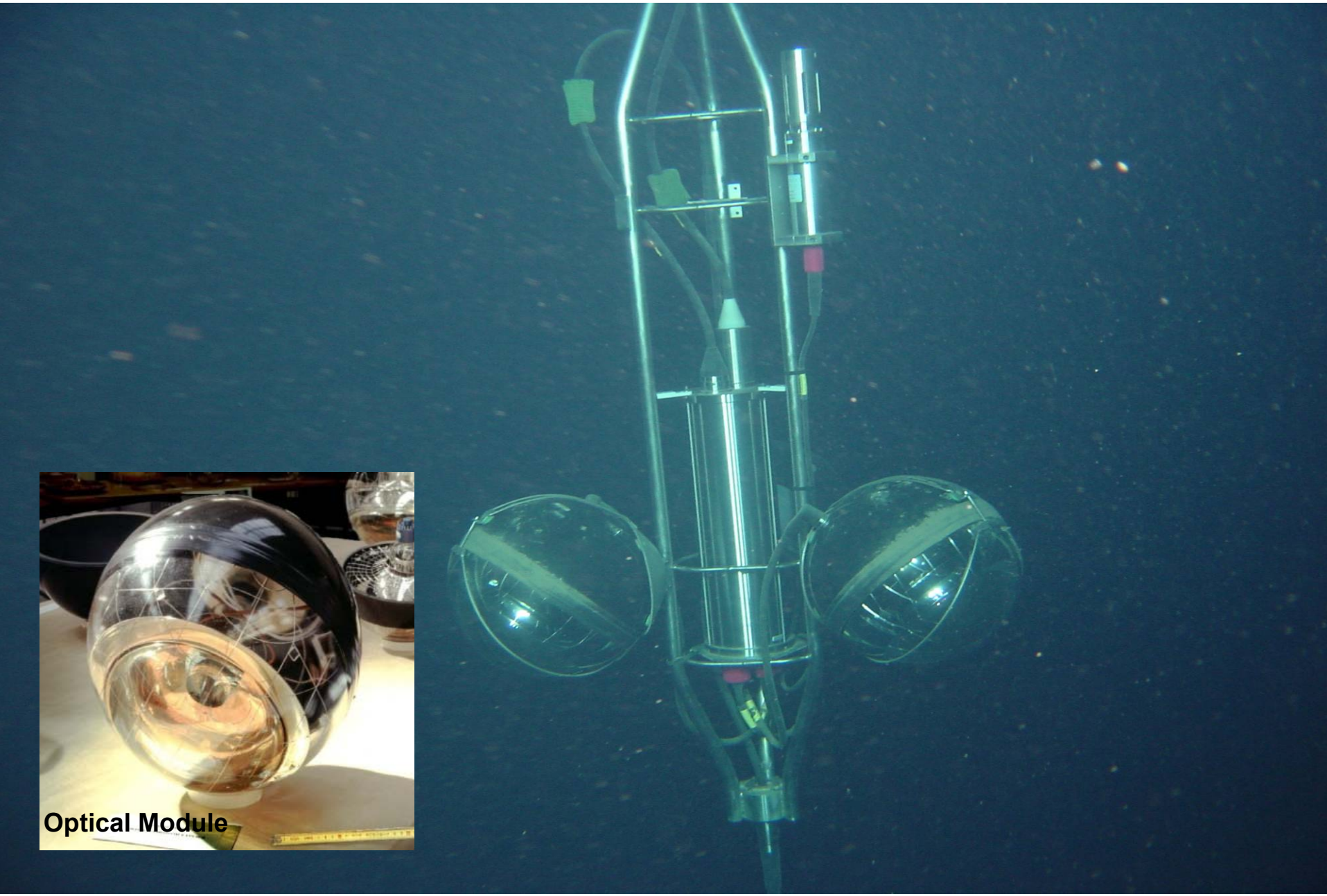
Onshore station,
Institut Michel Pacha, La Seyne s/M

FOSELEV Marine Shipyard, La Seyne s/M

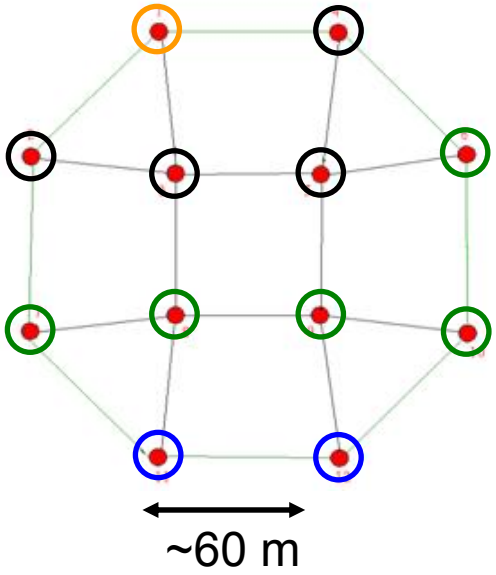

Buoy
Storey
• 12 lines of 75 PMTs
• 25 storeys / line
• 3 PMTs / storey
• 900 PMTs
Completed in 2008
14 m
350 m
40 km to shore
Junction Box
100 m
60 m
Anchor/line socket
Submarine links

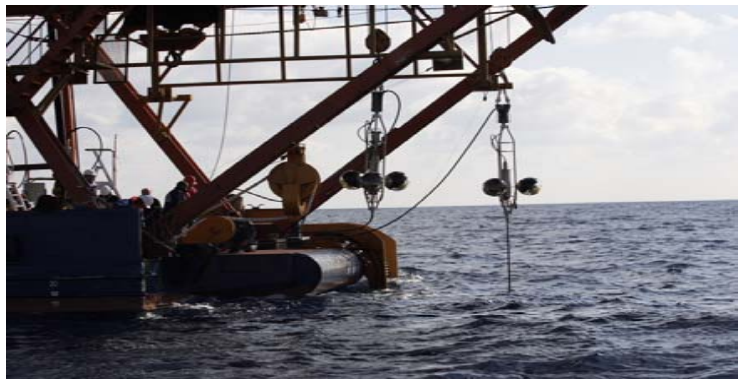
The ANTARES Storey




Optical Module

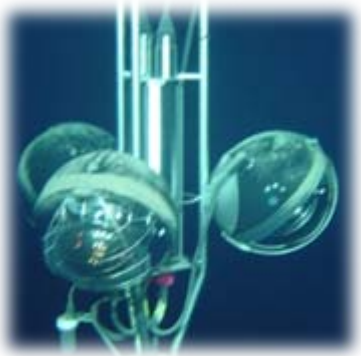
2006 – 2008: deployments of the detector lines

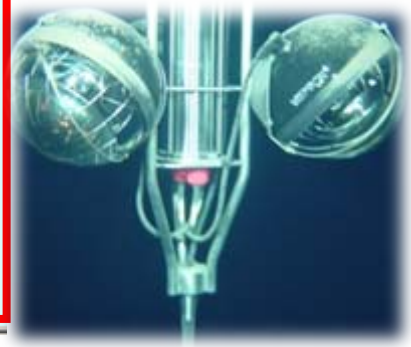


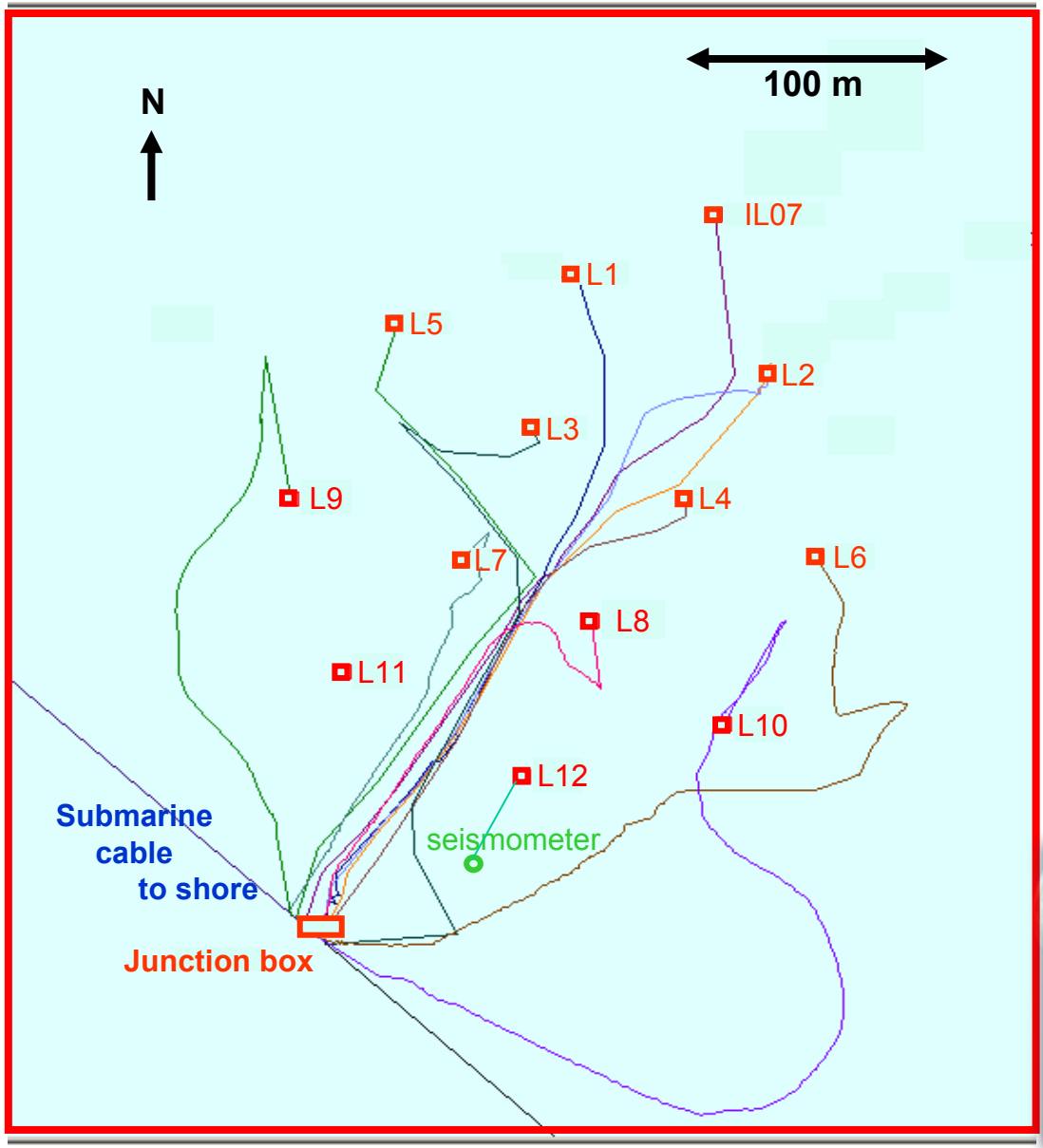


- **Line 1**: 03 / 2006
- **Line 2, 3, 4, 5**: 01 / 2007
- **Line 6, 7, 8, 9, 10**: 12 / 2007
- **Line 11, 12**: 05 / 2008

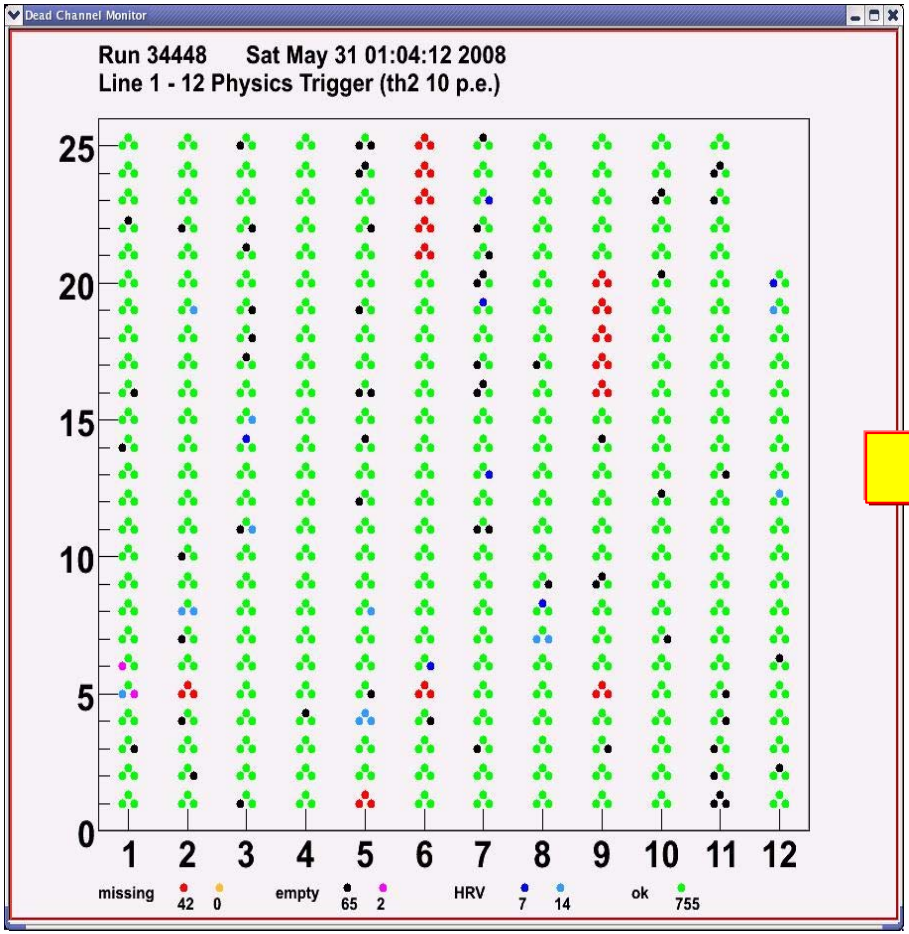
The full detector on Seabed

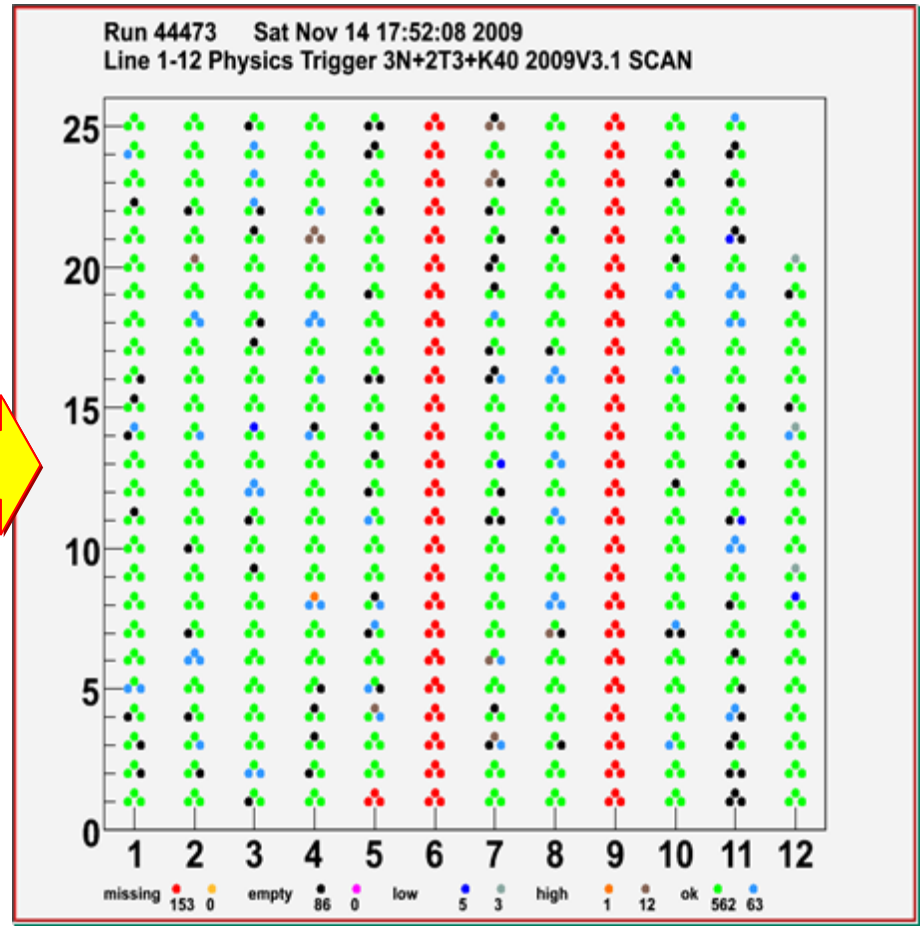






Status of the apparatus





At end of construction

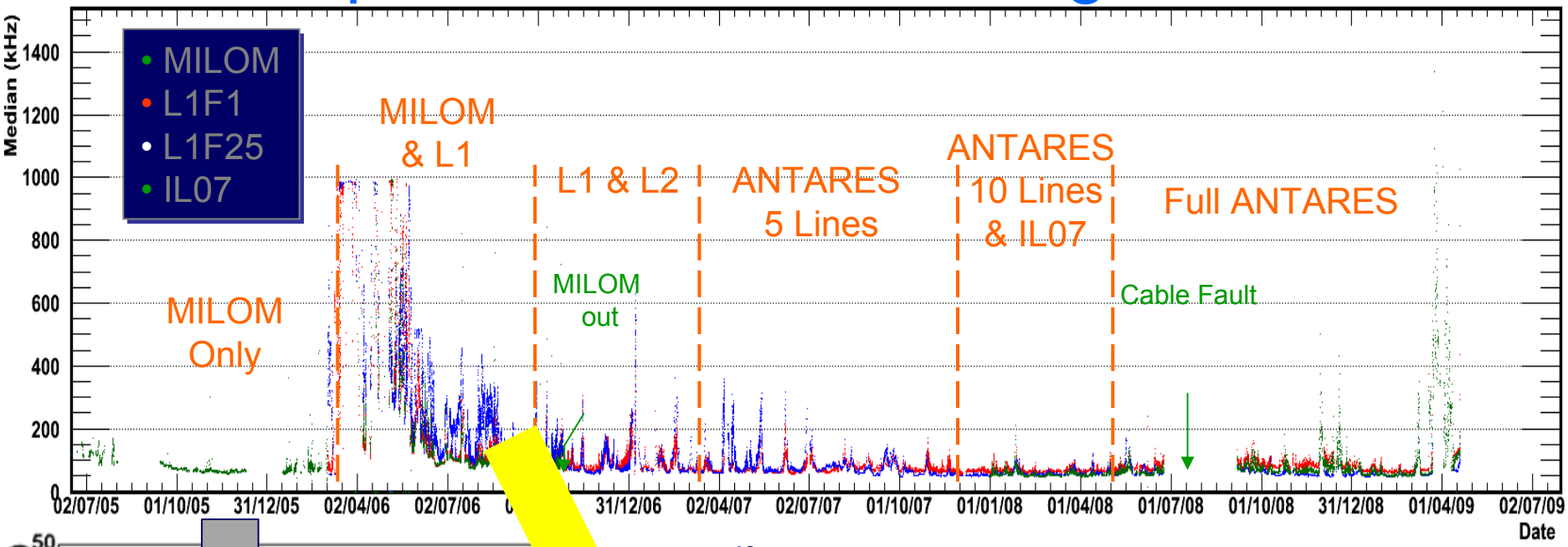
- **~90% of optical modules operational**

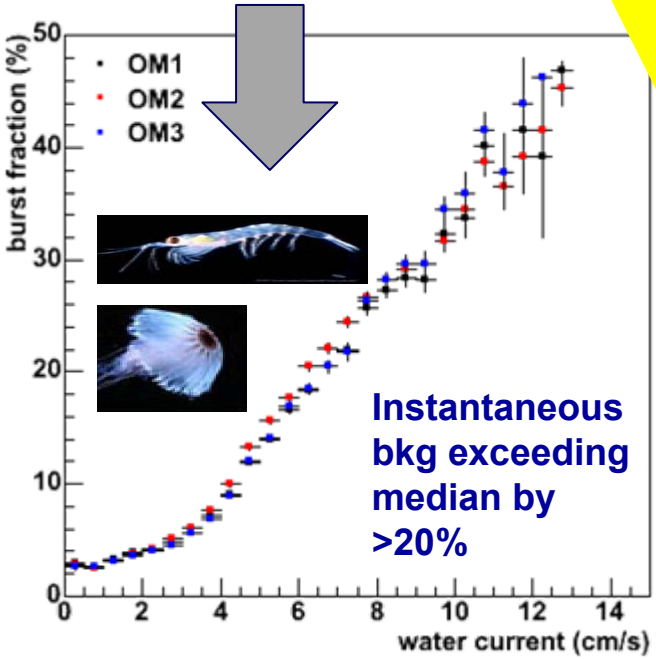
Regular maintenance of in-situ infrastructure

Today

- **Line 6 recovered, Line 9 planned to be recovered**
- **Line 12 repaired and reconnected**

Optical Modules Counting Rates





^{40}K decays and bioluminescence of micro-organisms (rate ~70 kHz)

Plus bursts from macro-organisms (strongly affected by sea currents)

Theory: cold winter caused descent of nutrient-bearing colder water (correlated change in salt content)

The Trigger

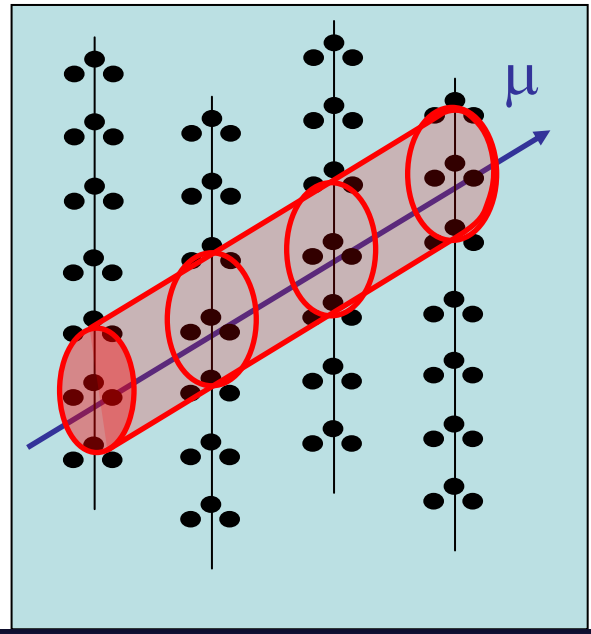
- Front end chip digitizes charge and time of a light signal

  "ALL DATA TO SHORE" SCHEME:

- All data transmitted through multiplexed Gigabit links
  - the whole data flow can not be written to disk

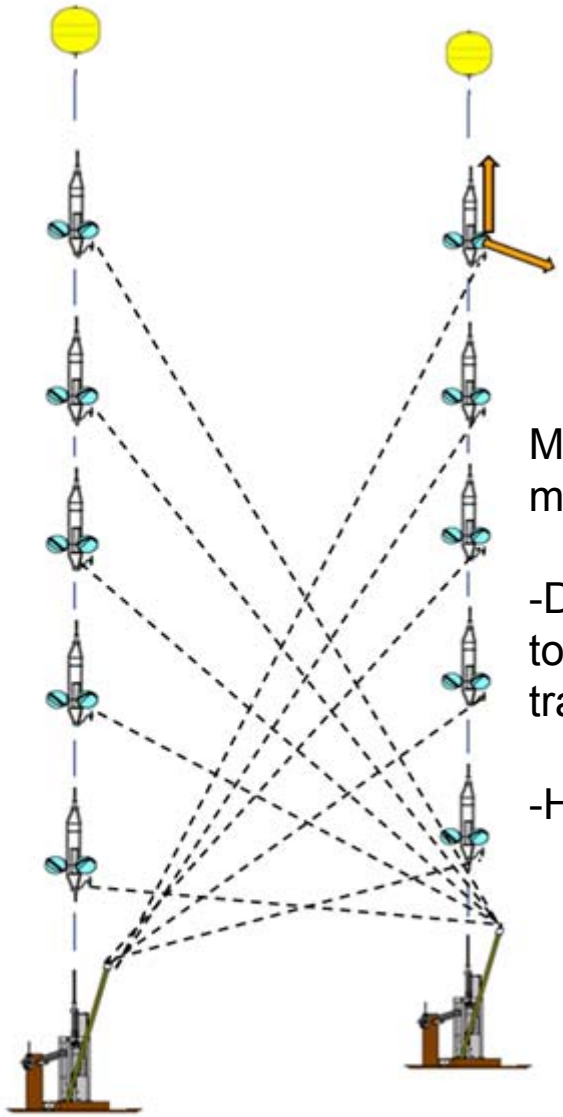
- Computer farm running a software trigger:
  - look in all directions for light signals compatible with a muon track
  - when found, write a Physics Event

- Other triggers exist: cluster of storeys, Galactic Center, …



Calibration: positioning

- Acoustic system:
  - One emitter-receiver at the bottom of each line
  - Five receivers along each line
  - Four autonomous transponders on pyramidal basis
- Additional devices provide independent sound velocity measurements

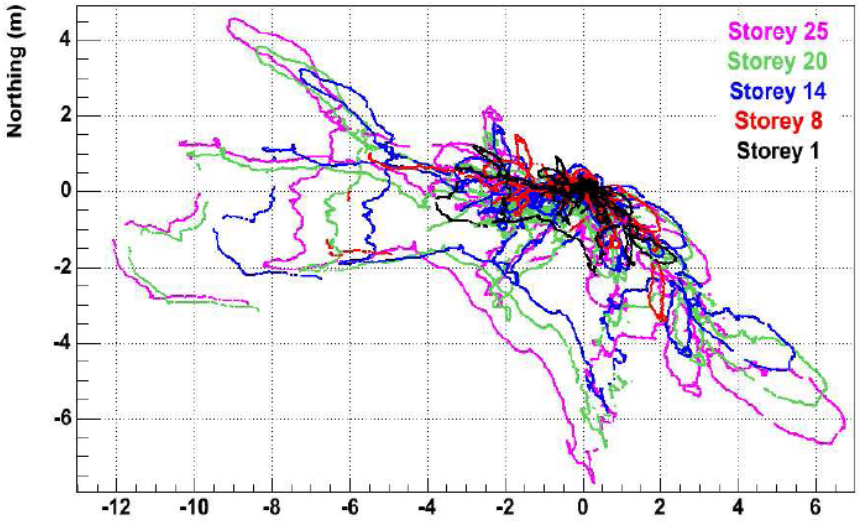


Measure every 2 min

-Distance line bases to 5 storeys/line and transpoders

-Headings and tilts

Positioning results

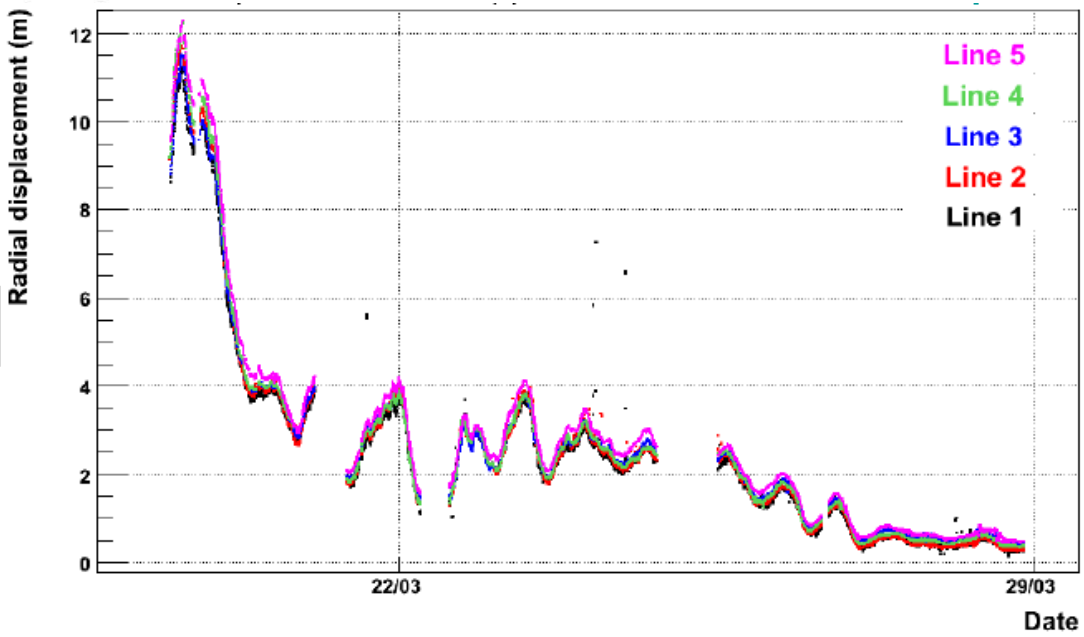


Comparison among storeys

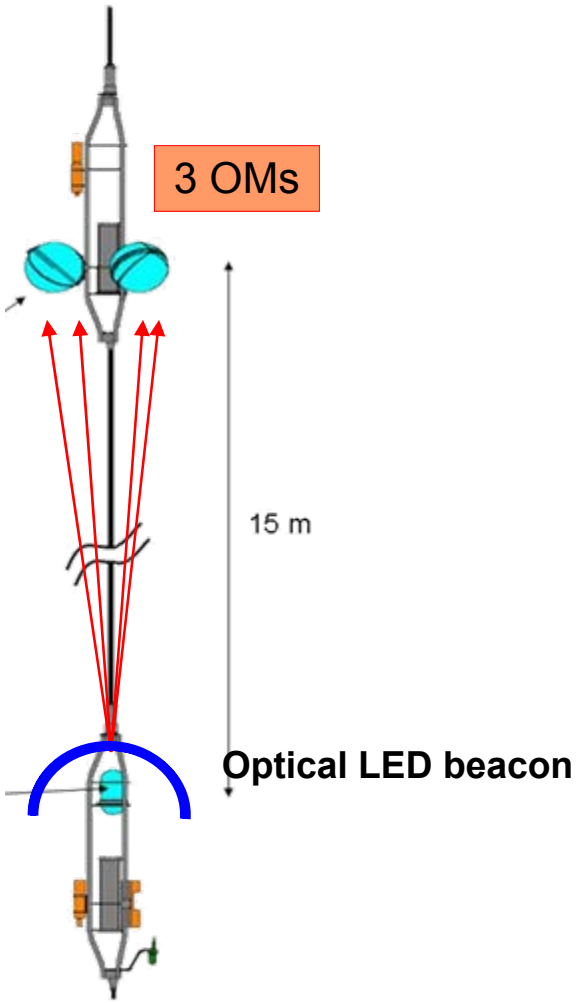
Larger displacements for upper top floor

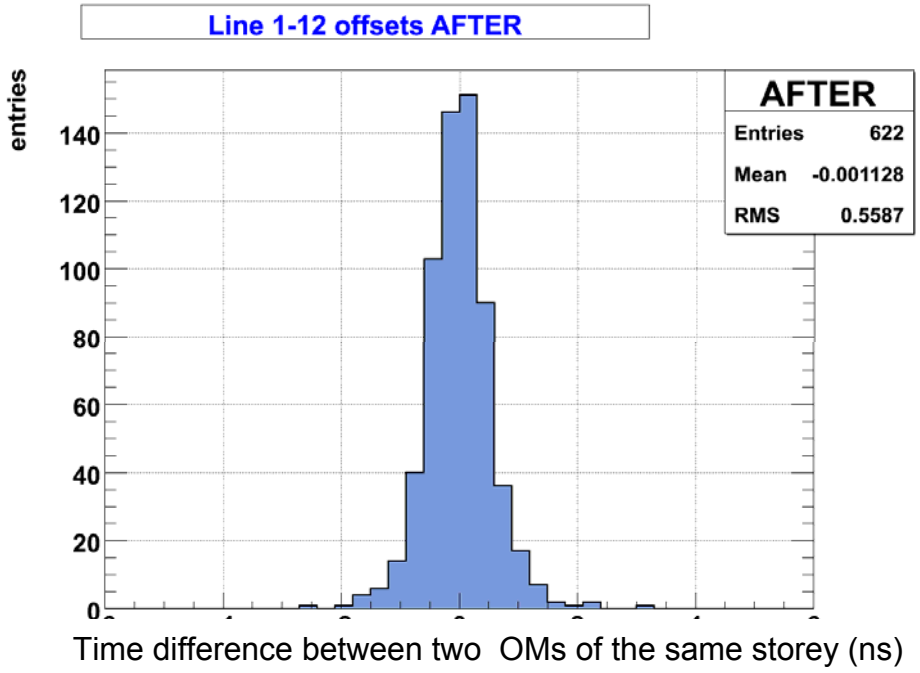
Comparison among lines

Coherent movement for all the lines of the detector



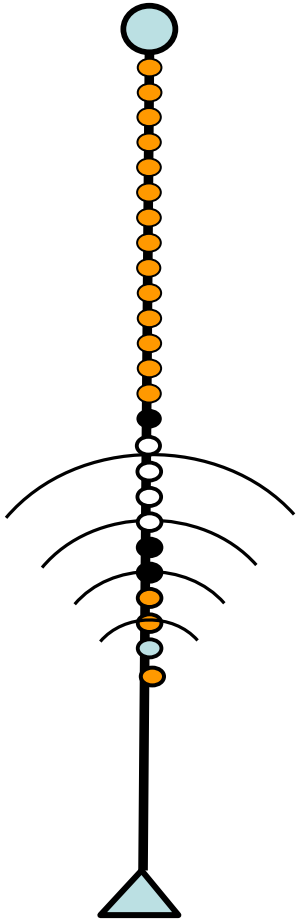
Time calibration with led-beacon

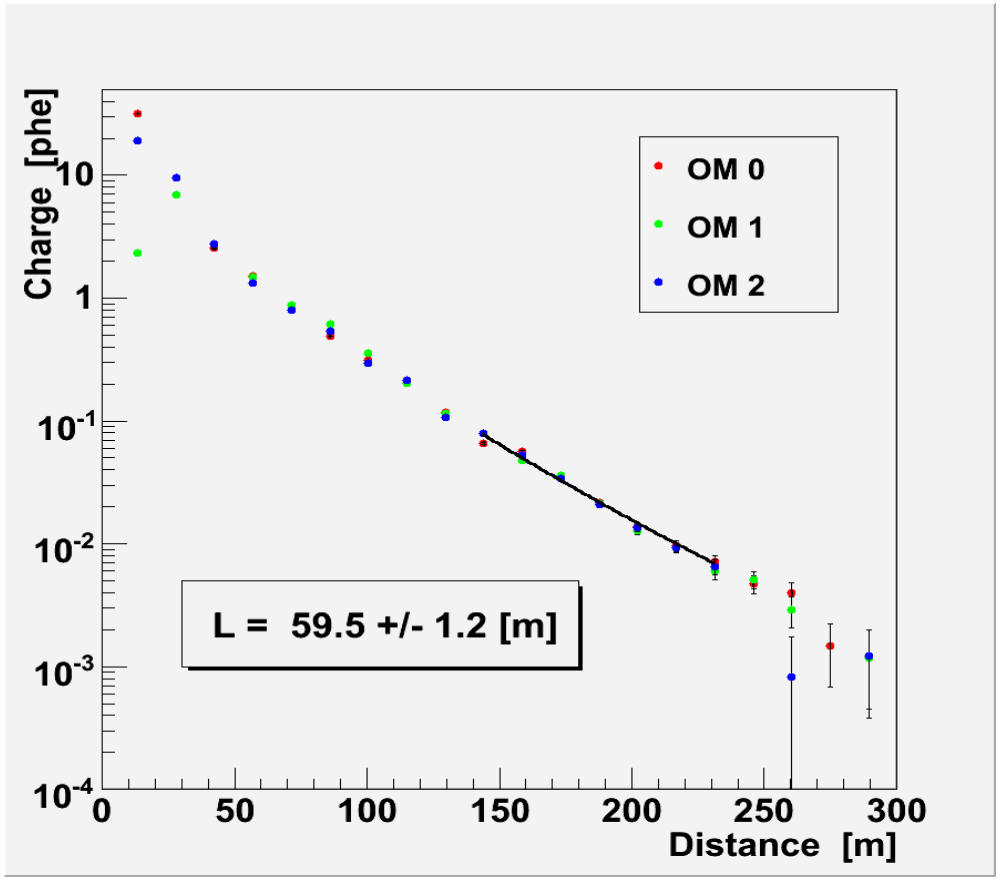




- **Electronics + calibration → σ ~ 0.5 ns**
- **TTS in photomultipliers → σ ~ 1.3 ns**
- **Light scattering + dispersion in sea water → σ ~ 2 ns**

Attenuation length measurements

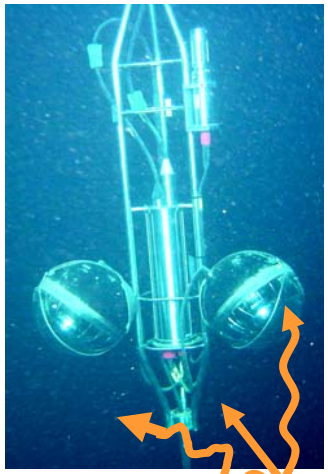




$$Q(R) = \frac{Q_0 \exp(-R/L)}{R^2}$$

- The biggest challenge is to determine the separate contribution of absorption and scattering contribution

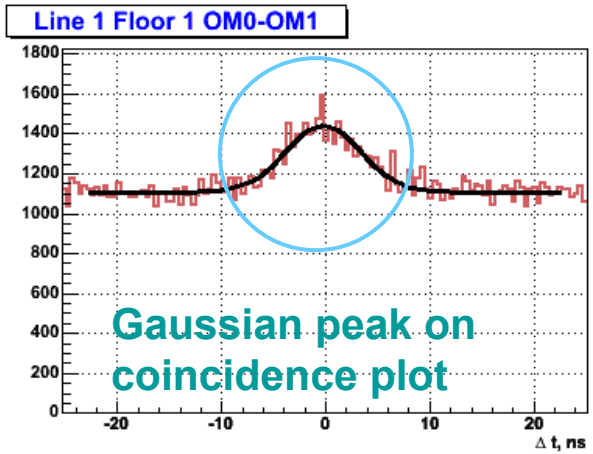
In situ calibration with Potassium-40



γ

γ

Cherenkov



Gaussian peak on coincidence plot

Integral under peak = rate of correlated coincidences

^{40}K

^{40}Ca

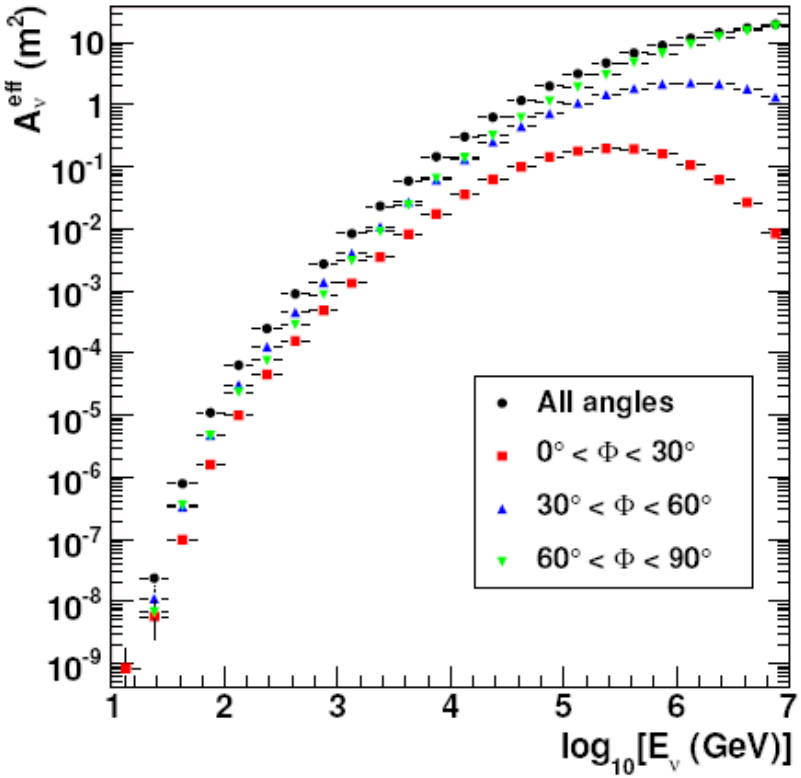
Peak offset

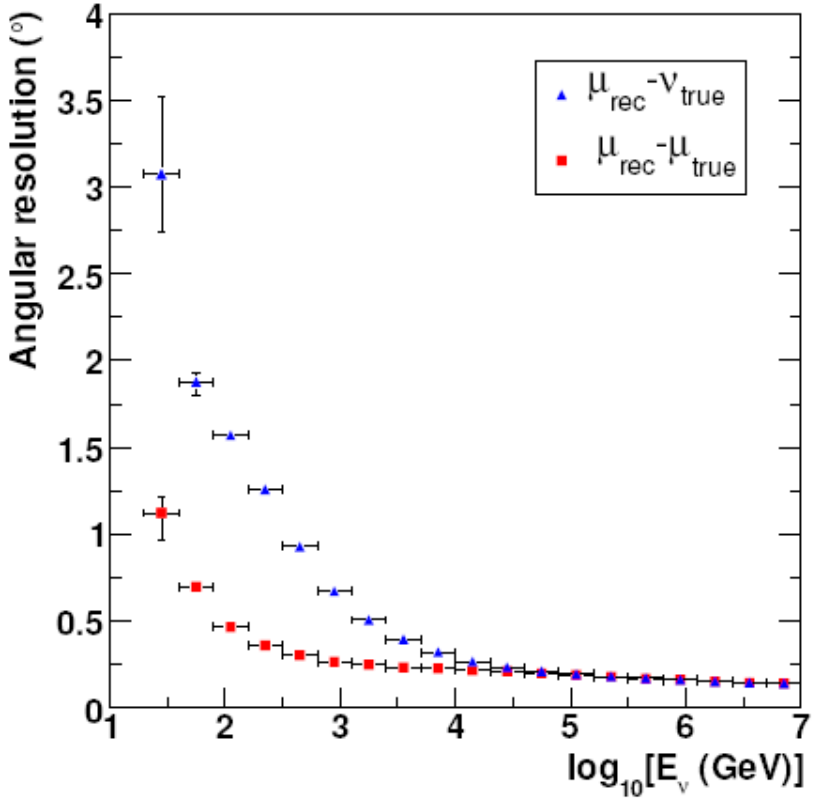
Cross check of time calibration

High precision (~5%) monitoring of OM efficiencies

No dependence on bioluminescent activity has been observed

Expected Performance (full detector)



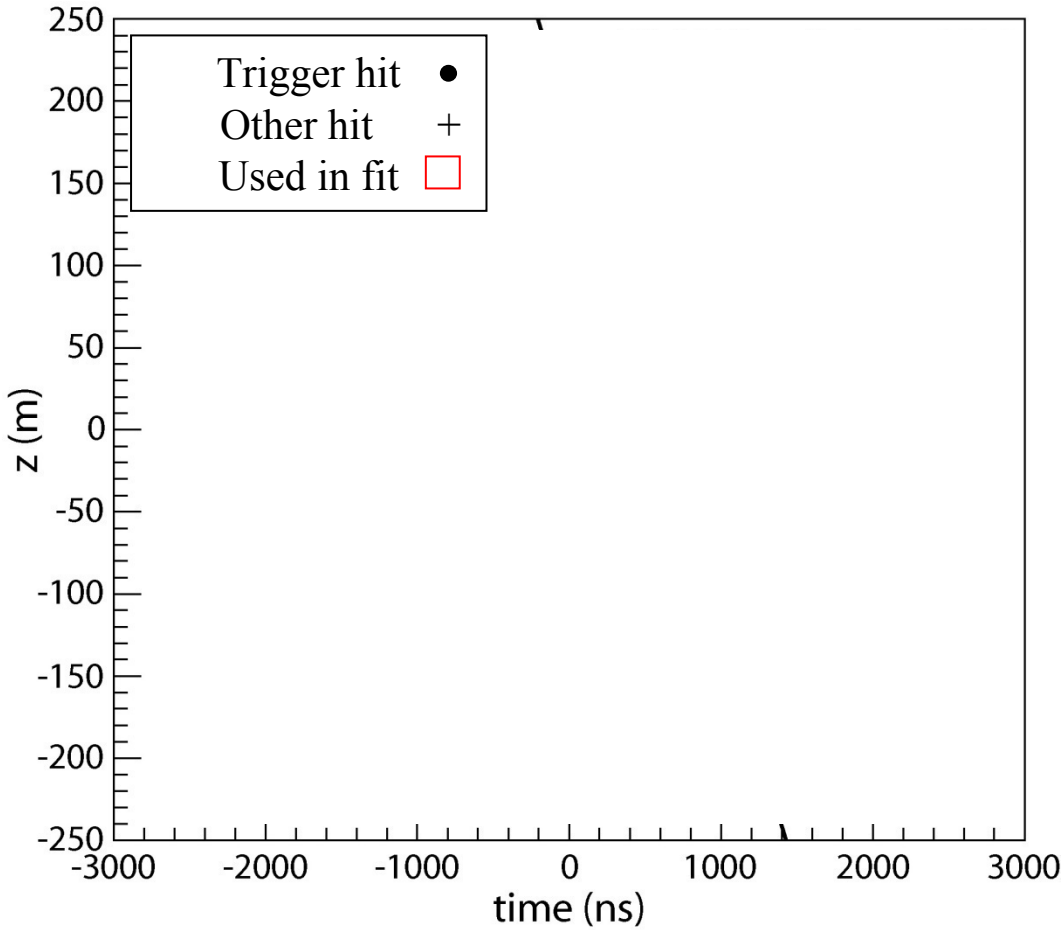


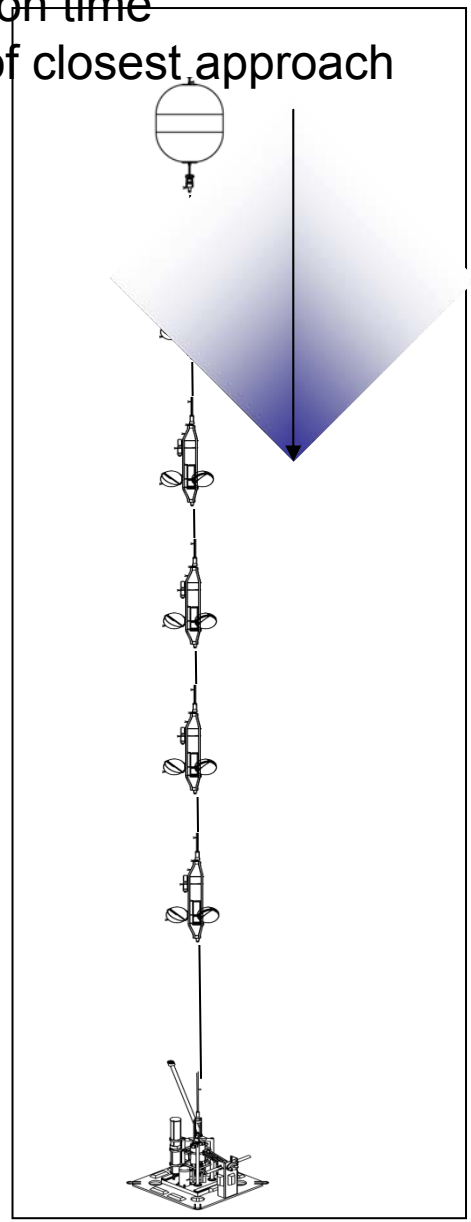
•For E_ν<10 PeV, A_{eff} grows with energy due to the increase of the interaction cross section and the muon range.
•For E_ν>10 PeV the Earth becomes opaque to neutrinos.

•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 track reconstruction errors.

Muons tracks: event display principle

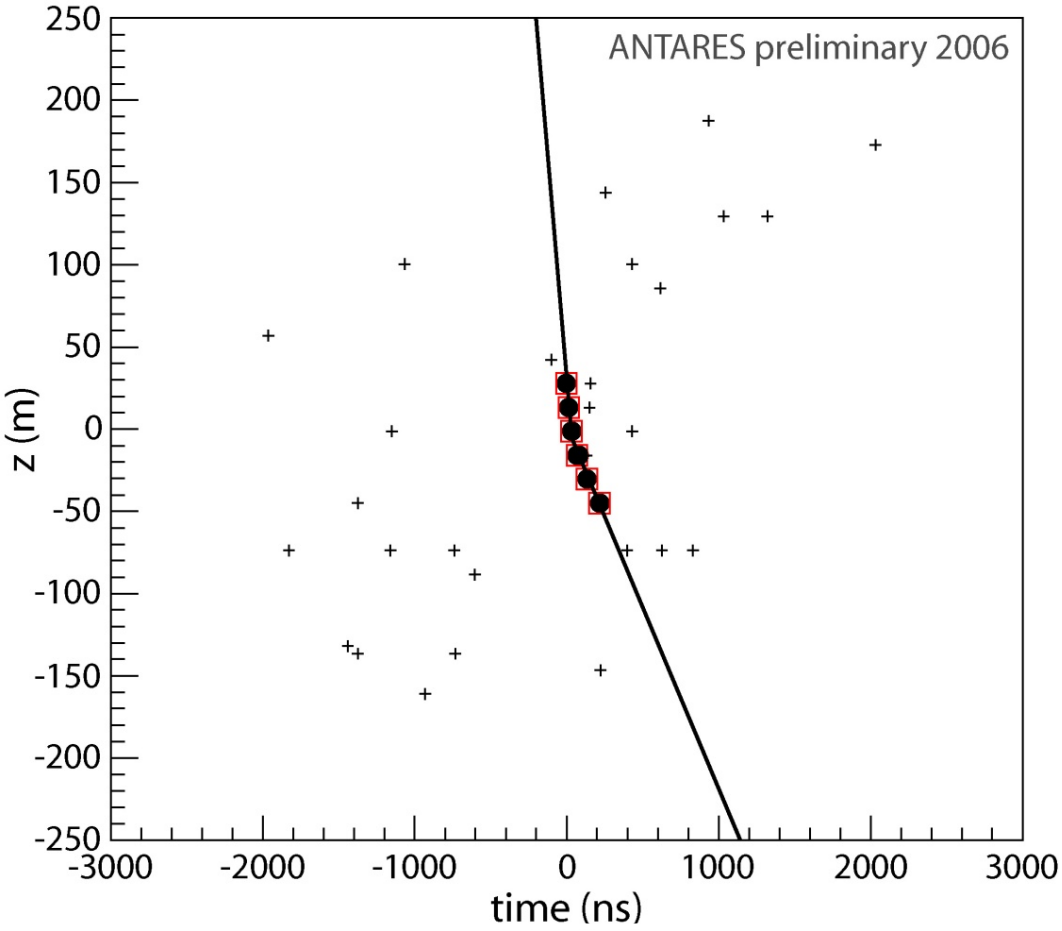
Hits are plotted for each line: z coordinate (height) as function time
Characteristic pattern in function of zenith angle and point of closest approach between line and track

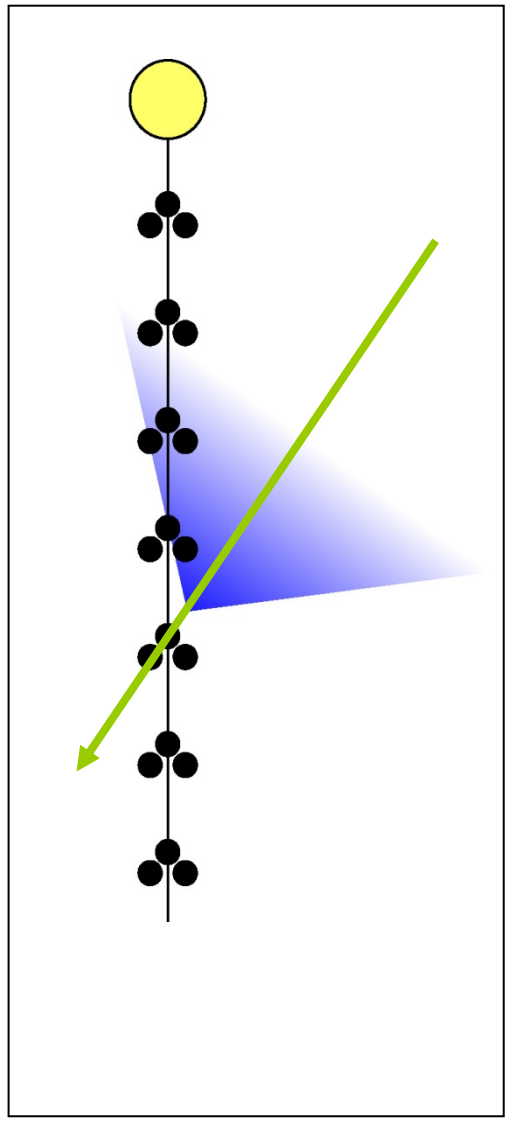




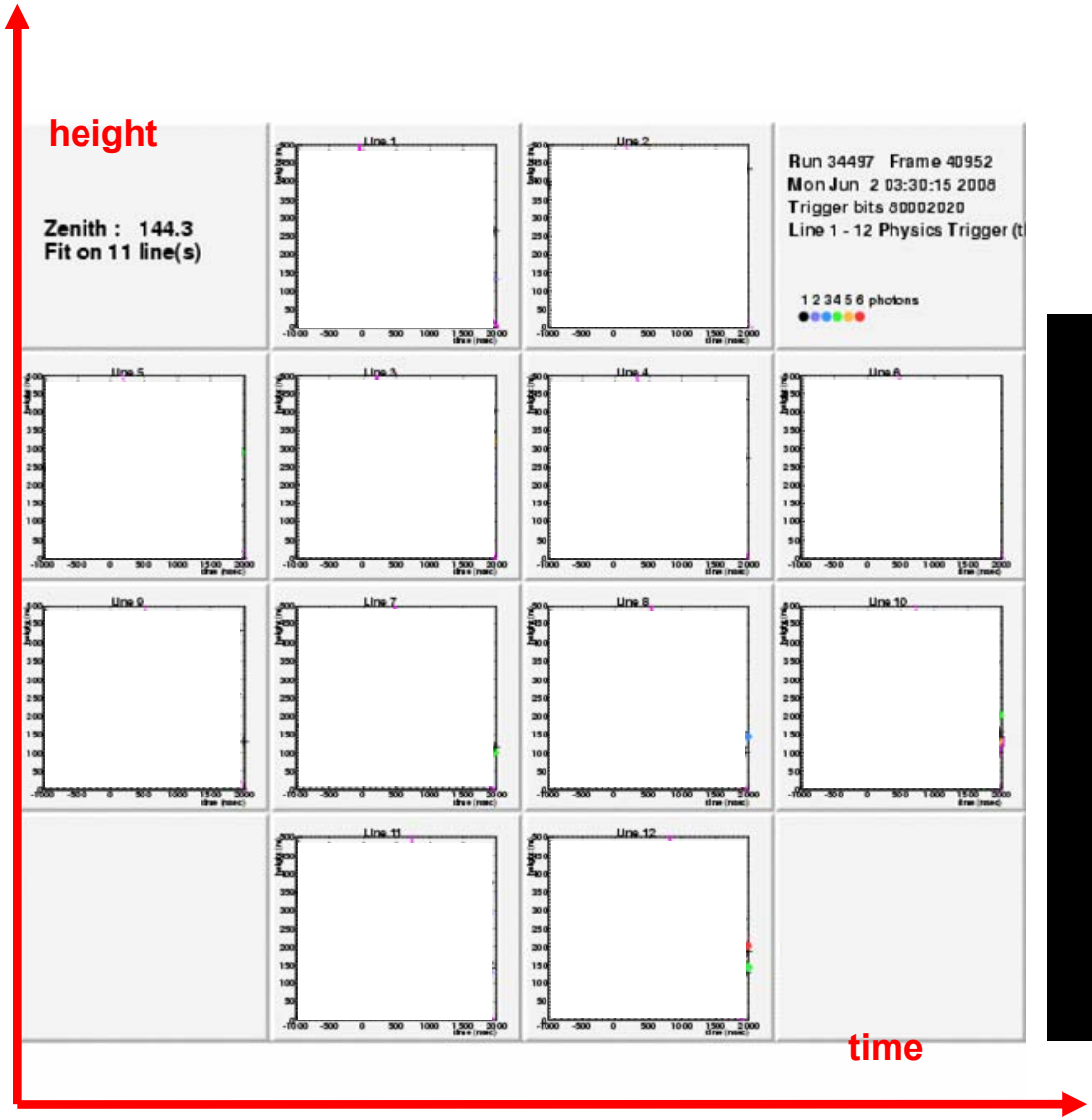
Muons tracks: event display principle

Characteristic pattern depending on zenith angle and distance of closest approach



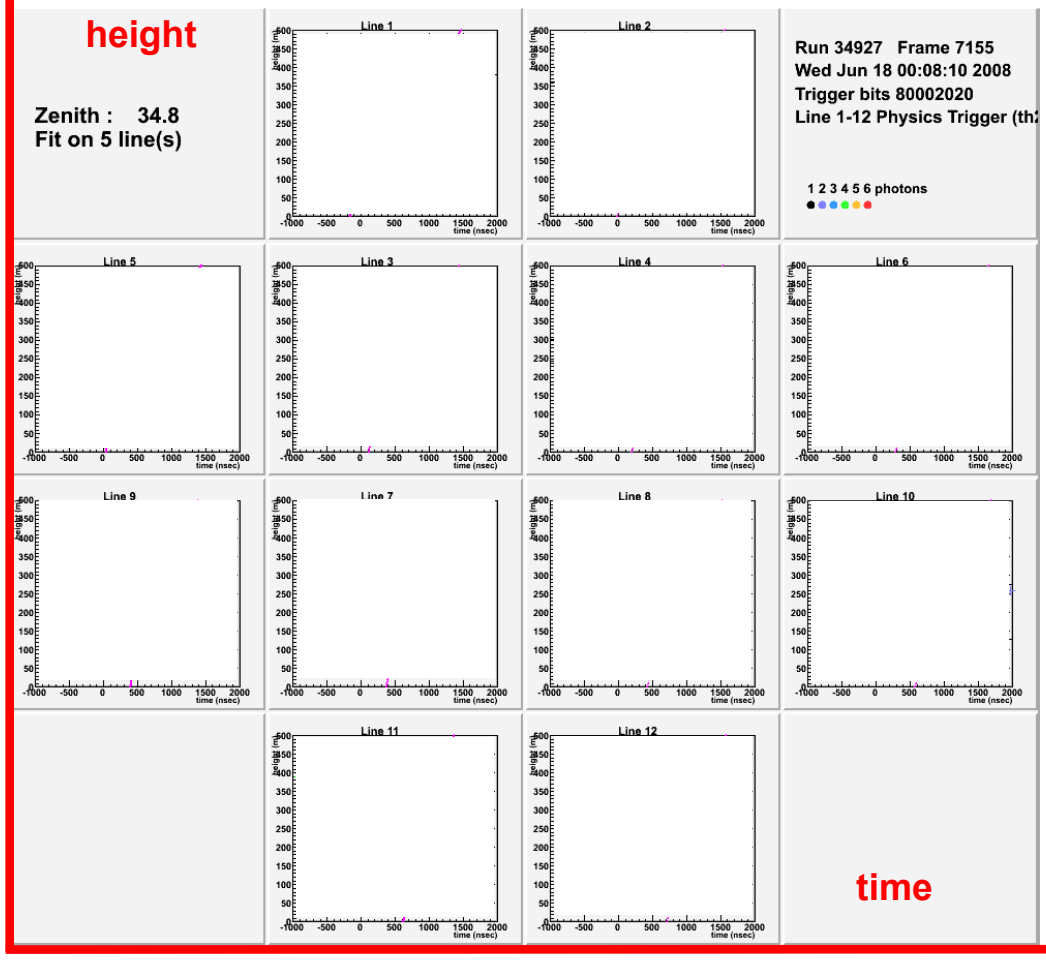


Reconstruction: a downgoing muon (atmospheric)

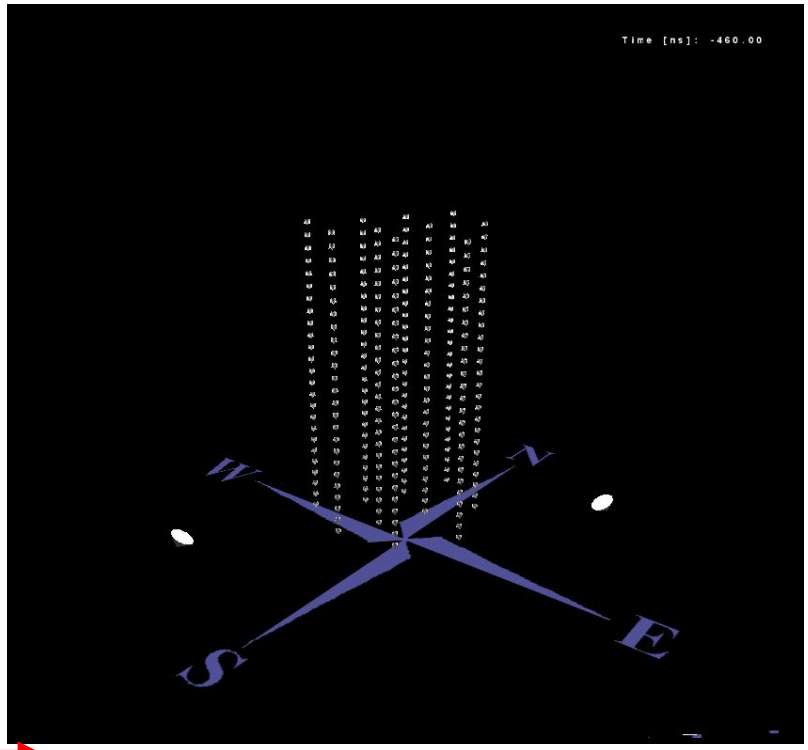


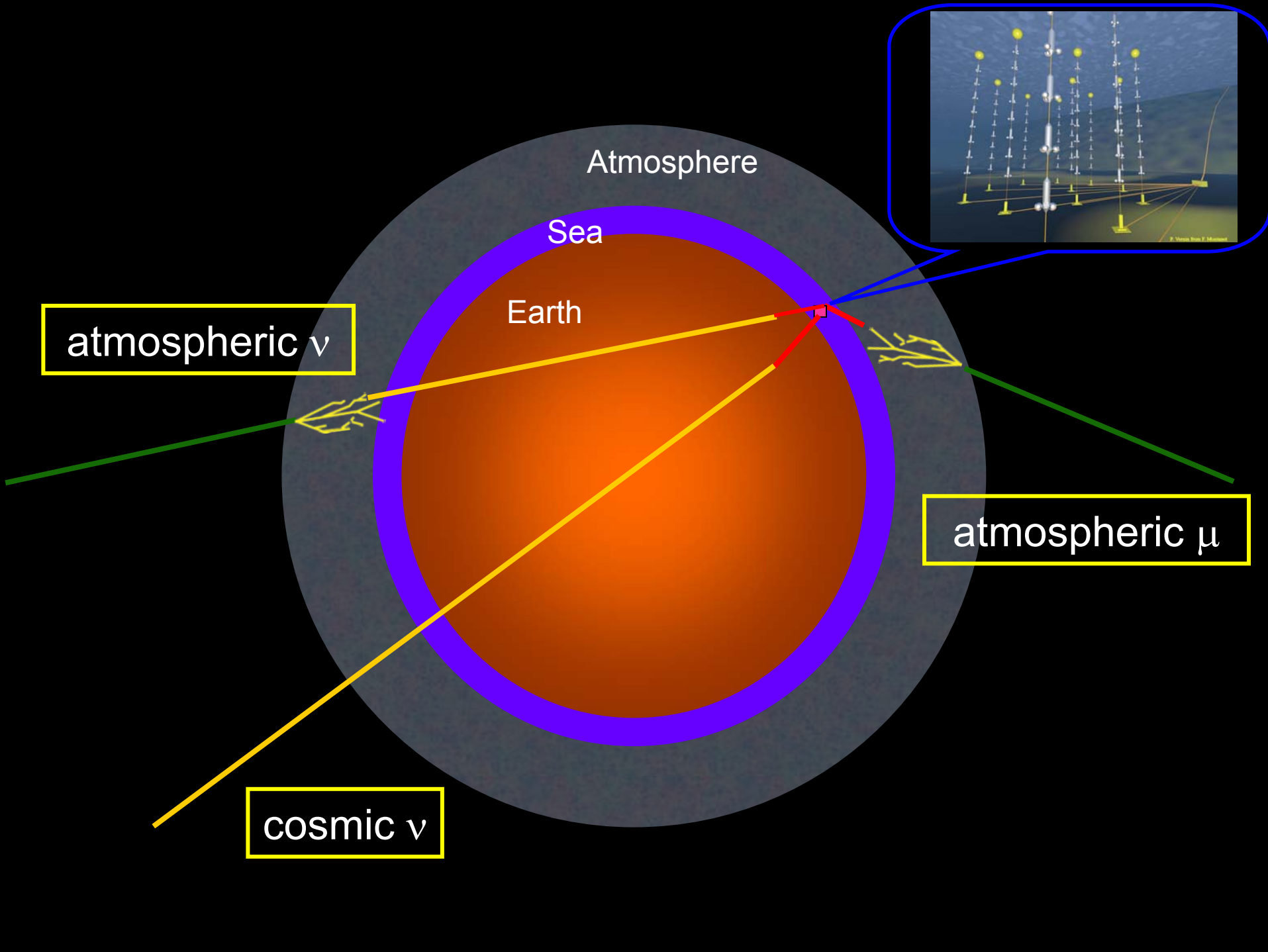
Example of a reconstructed down-going muon, detected in all 12 detector lines:

Reconstruction: an upgoing muon (neutrino induced)

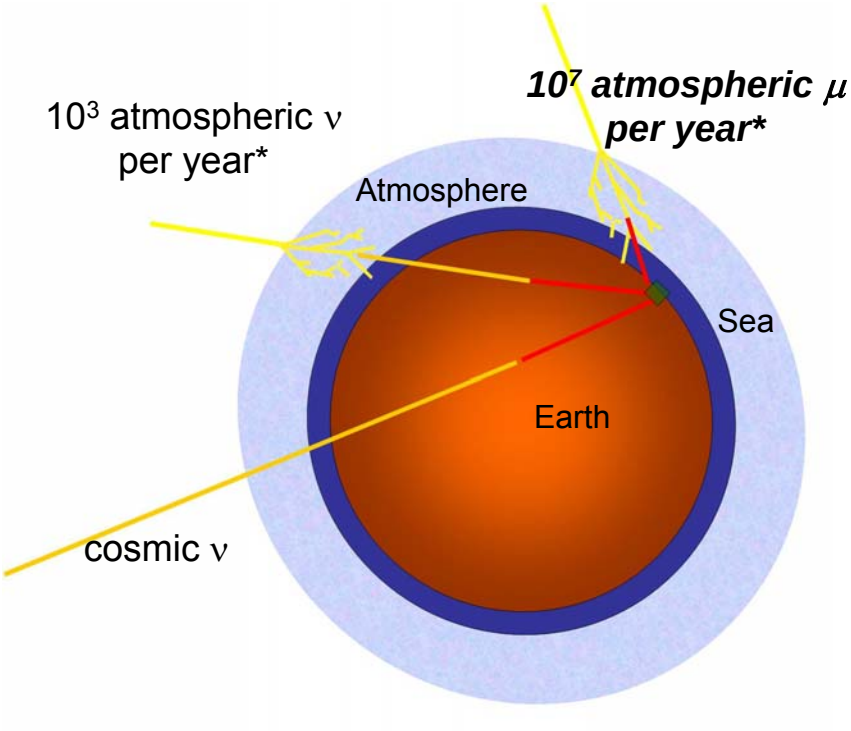


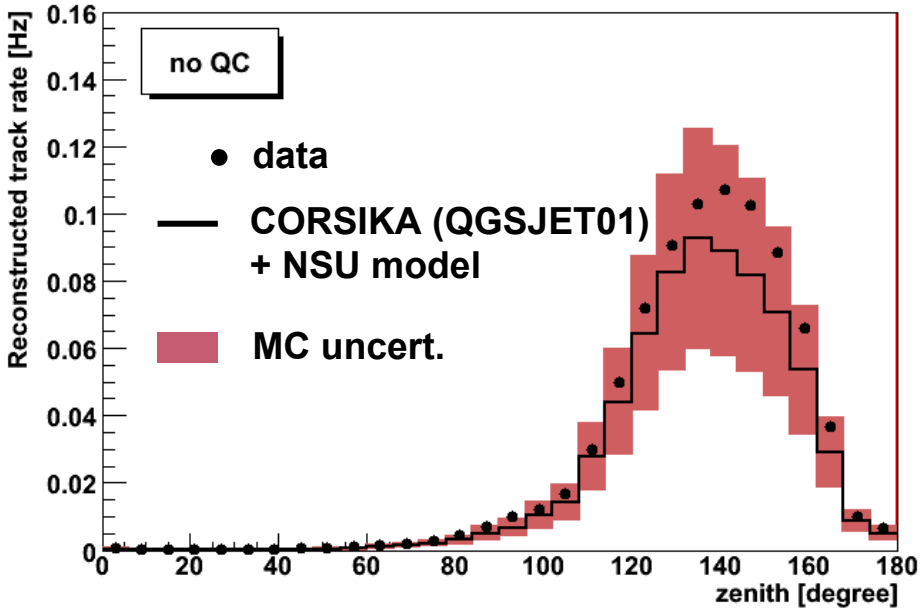
Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:



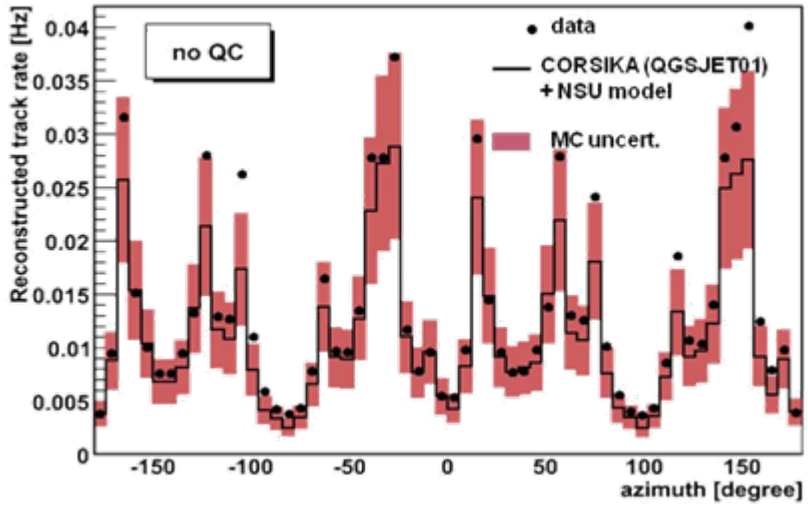

Atmosphere
Sea
Earth
atmospheric ν
atmospheric μ
cosmic ν

Analysis: Atmospheric muons

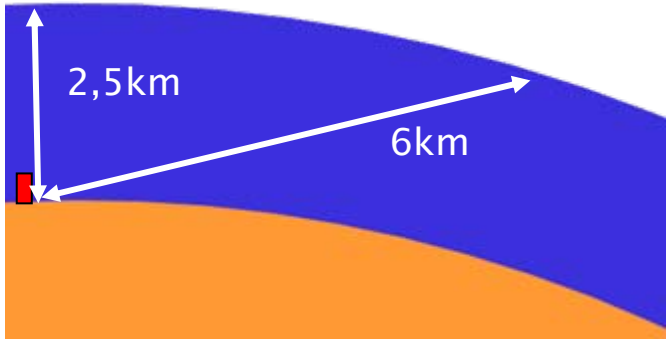


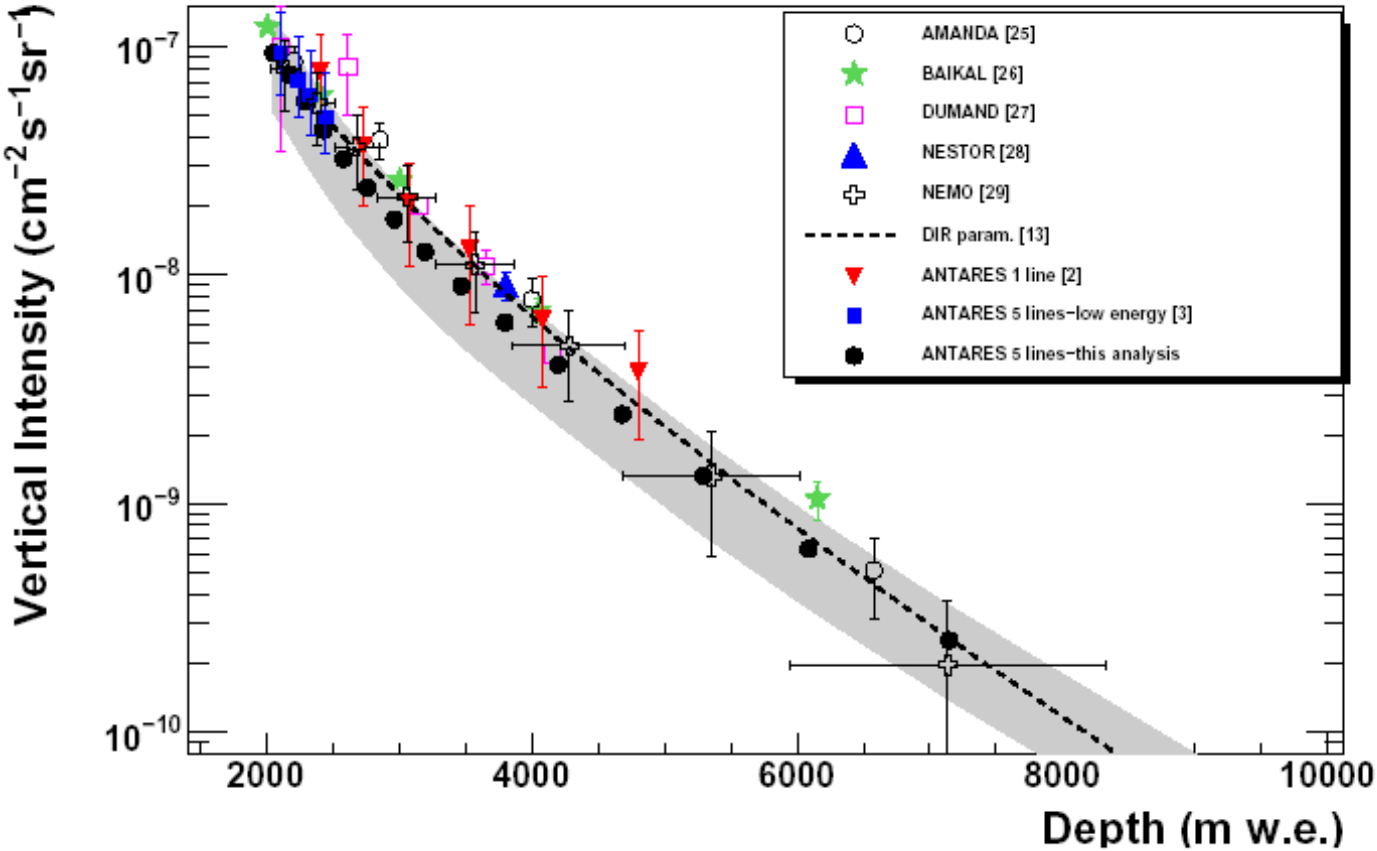


- Agreement between simulations and data is satisfactory
- Details of apparatus geometry and performance well understood
- Main sources of simulation uncertainty are:
  - optical module response
  - absorption length of light in water



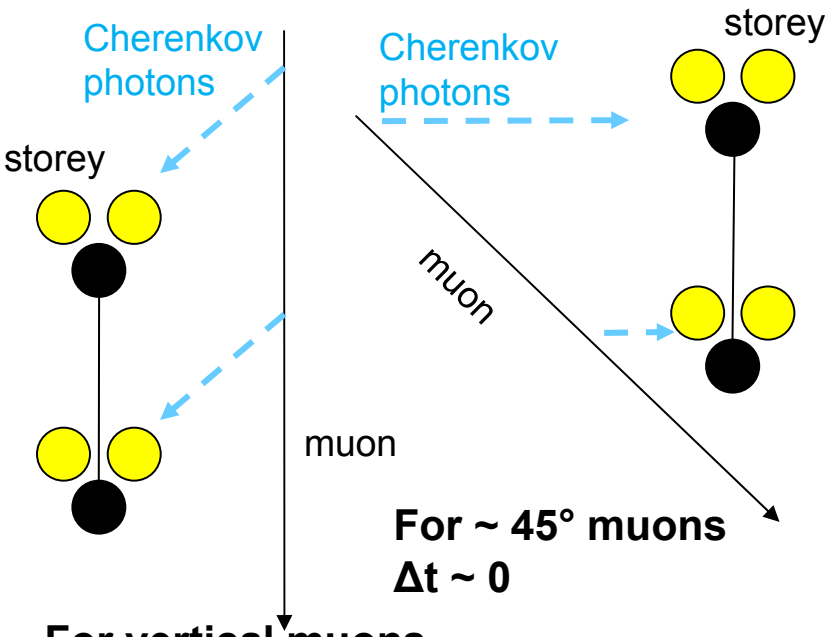
Depth intensity Relation





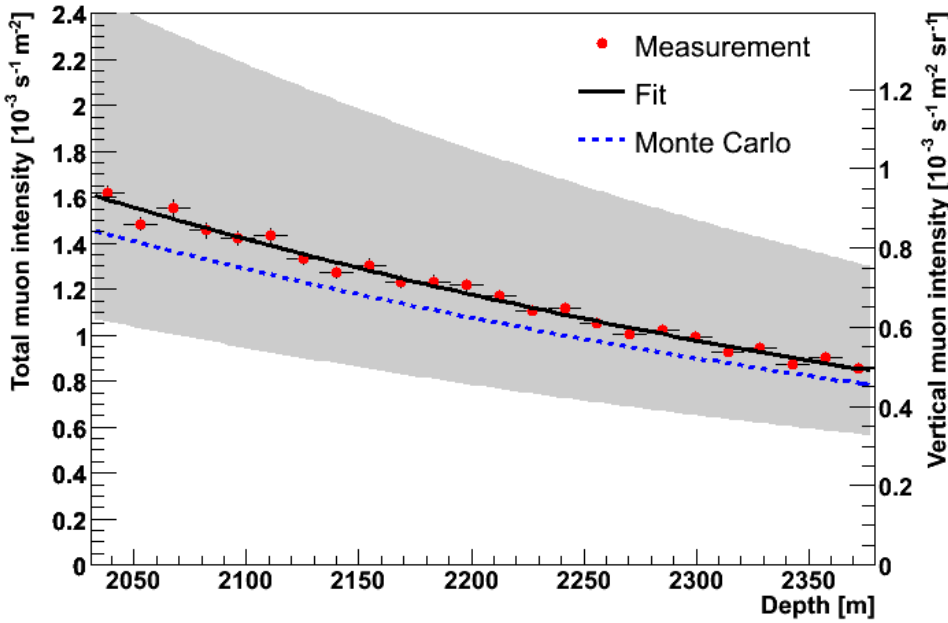
Depth intensity Relation without muon reconstruction

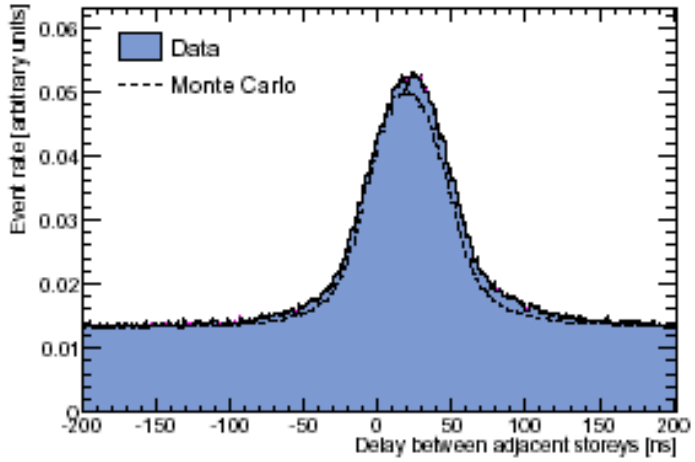
Simple method based on coincidences on adjacent storeys. No reconstruction needed.



For ~ 45° muons
Δt ~ 0

For vertical muons
Δt = L / c ≈ 50 ns



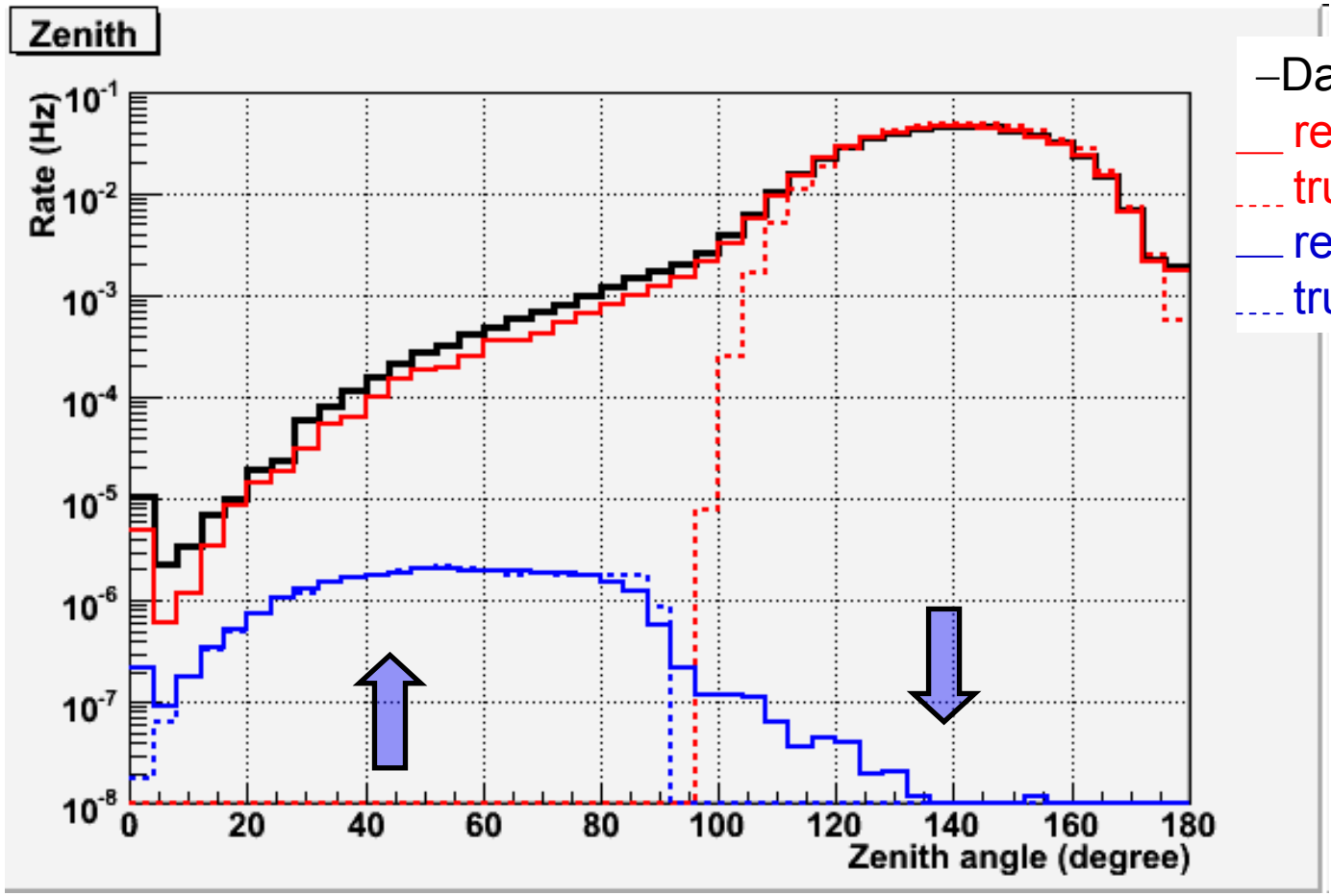


Rate vs. depth distribution can test optical module efficiency and acceptance

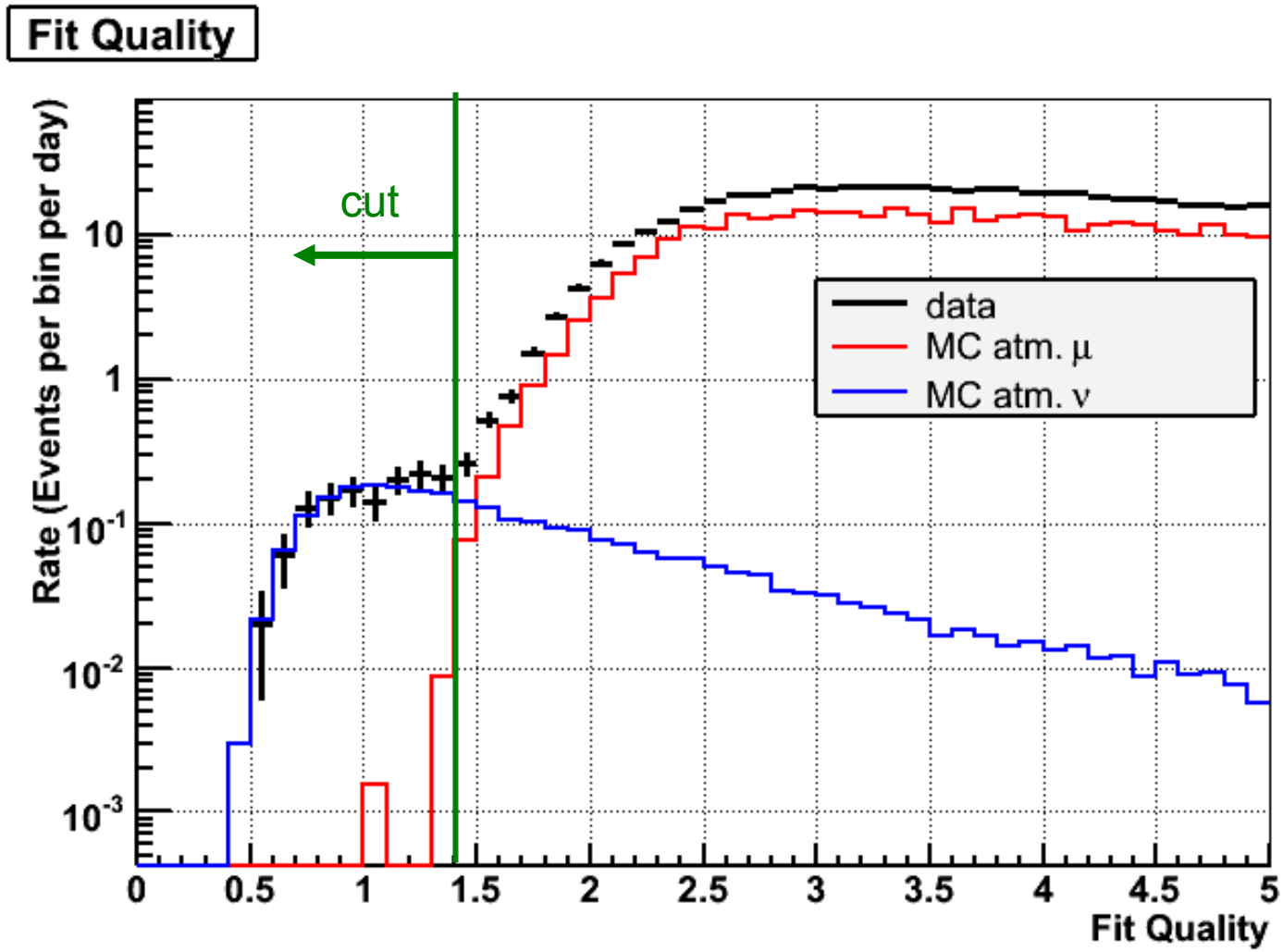
Method allows to measure the depth-intensity relation of muons with no systematic errors from trigger or reconstruction algorithms (main uncertainty: optical module acceptance)

Neutrinos :comparison MC-data

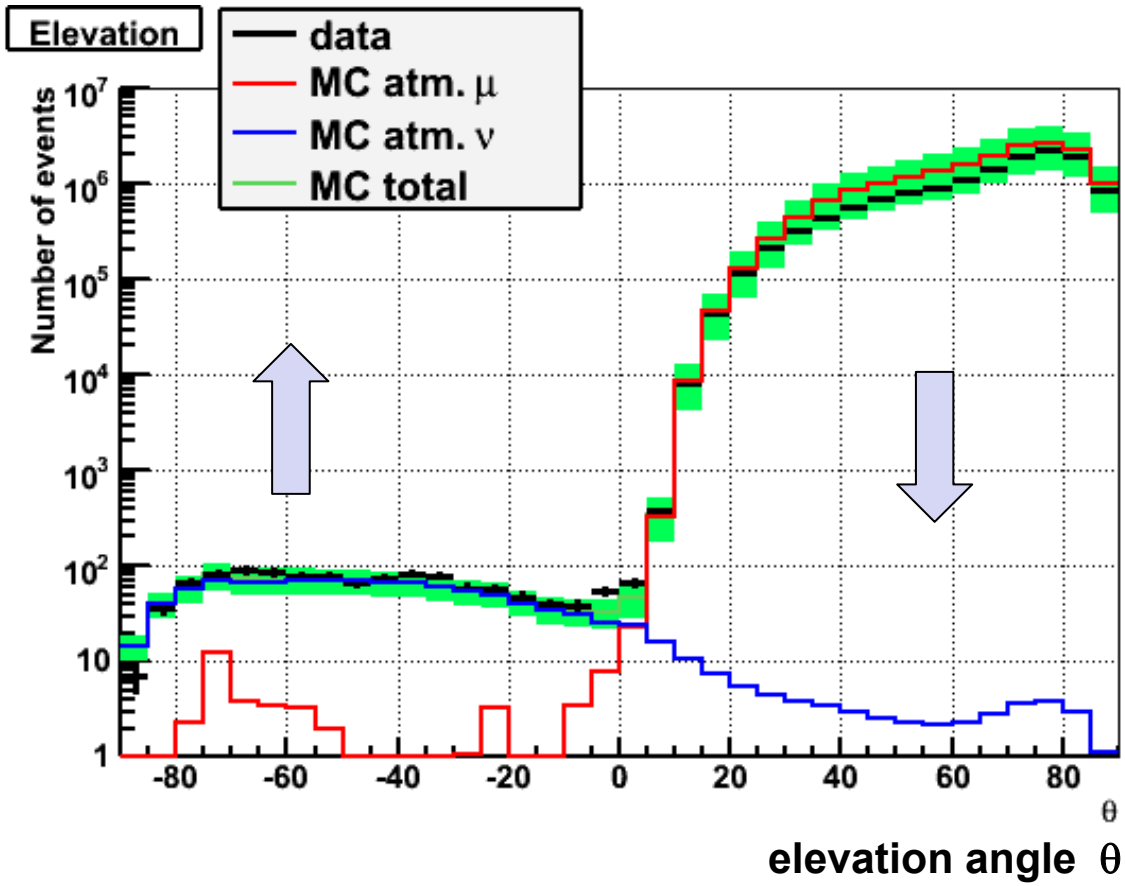
-5 lines data: 37 active days
- quasi-online reconstruction
-No quality cuts applied

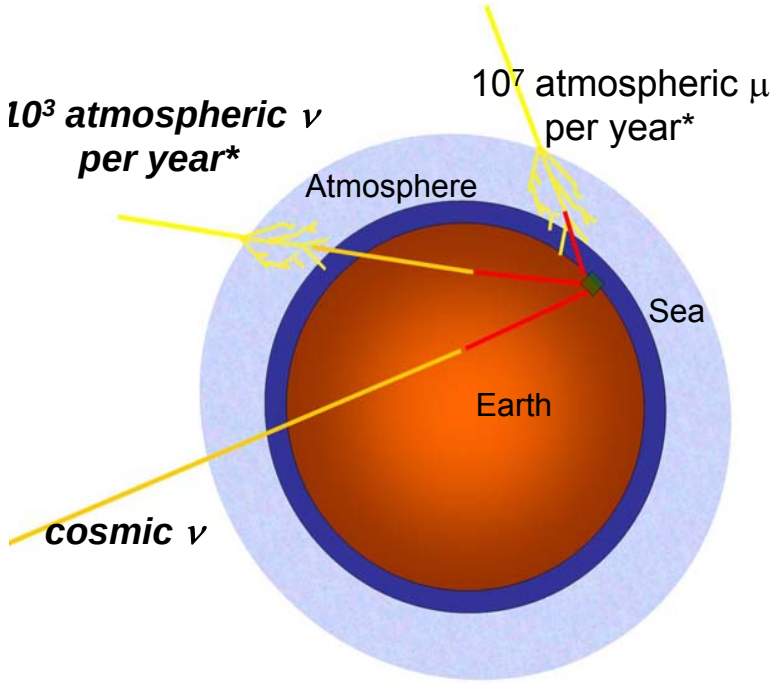


Quality cut


Fit Quality
cut
data
MC atm. μ
MC atm. ν
Rate (Events per bin per day)
10
1
10^-1
10^-2
10^-3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Fit Quality

Analysis: Atmospheric neutrinos





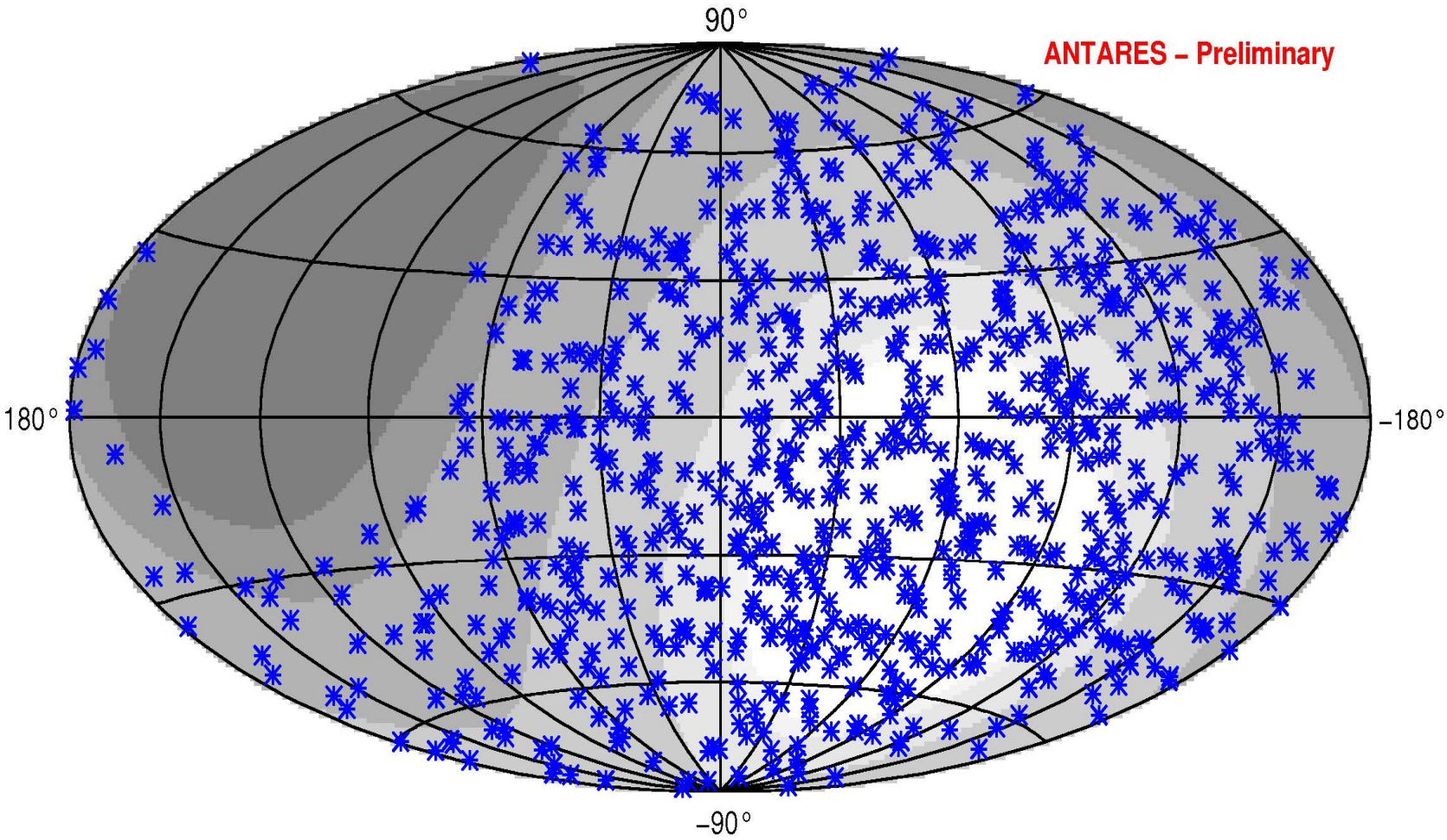
5-line data (May-Dec. 2007)+
9-12 line data (2008)

341 days detector live time,
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)

Neutrino Events: sky map

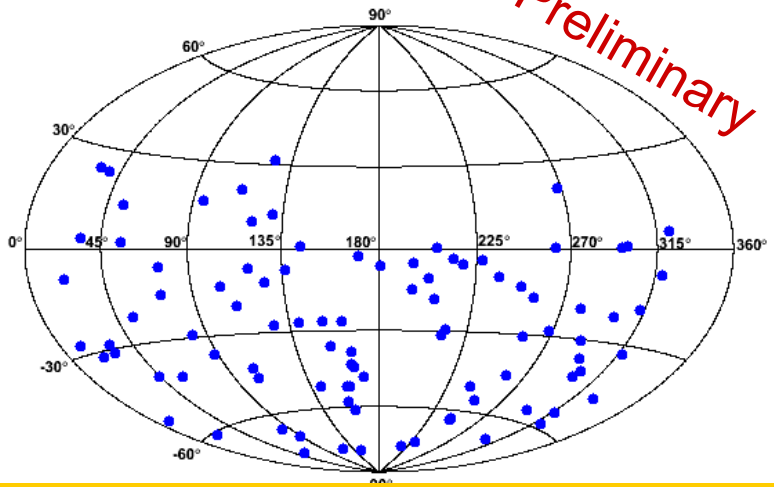


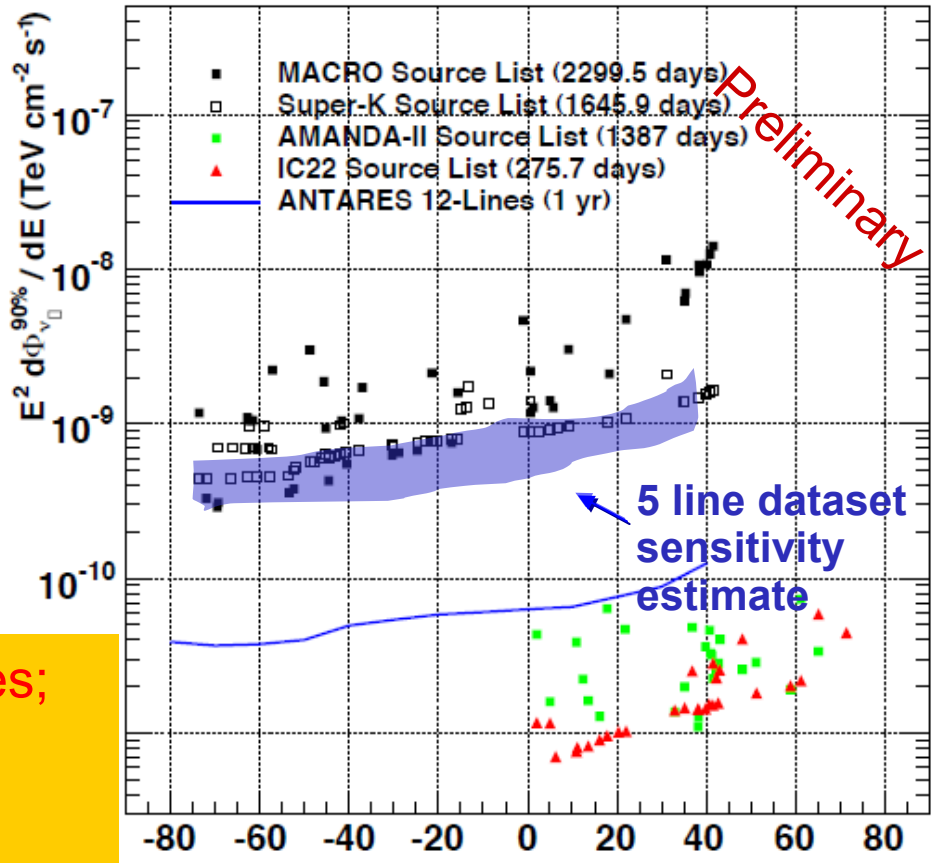
750 upgoing neutrinos: 2007+2008 data

Search for point-like neutrino sources

with the 2007 (5-line) data: effective live time 140 days
stringent selections: low background
high reconstruction quality (ang. resolution < 0.5°)

binned, unbinned searches
on data with scrambled coordinates
of 94 events (equatorial coordinates):





no correlation with 25 potential ν sources;
no excess ($\pm 1\sigma$) in all-sky search;
sensitivity competitive with multi-year exposures of previous experiments

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

?

SNEWS
SuperNova Early Warning Syster

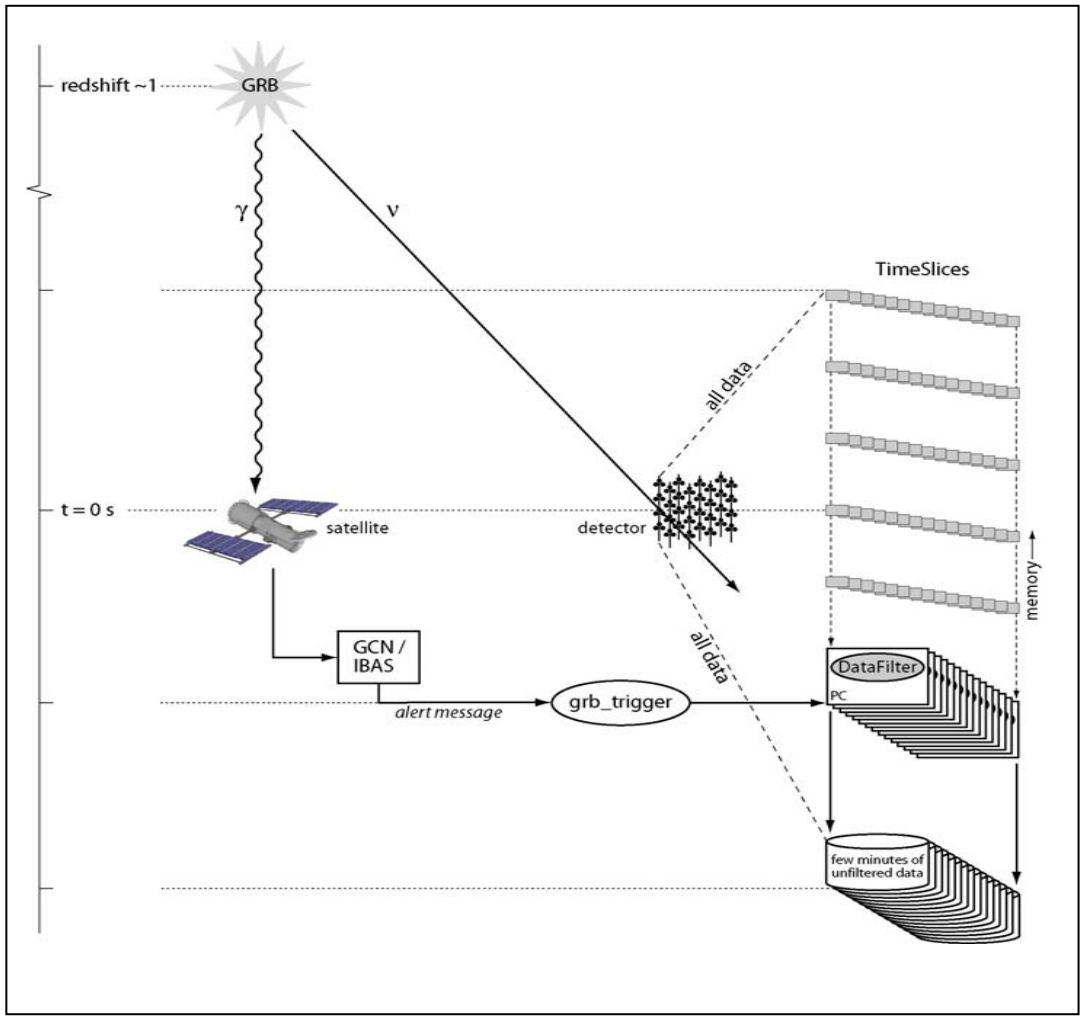
Ligo/Virgo
Gravitational waves: trigger + dedicated analysis chain

TAROT
optical follow up: 10 s repositioning

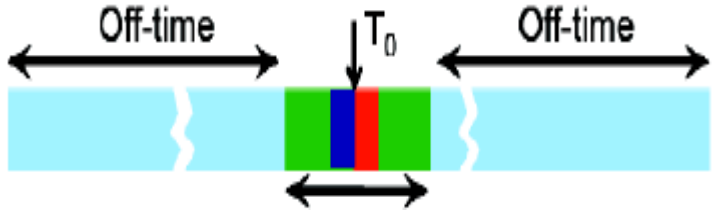
GCN
GRB Coord. Network: γ satellites

Triggered search method

SWIFT, INTEGRAL, Fermi alerts reception

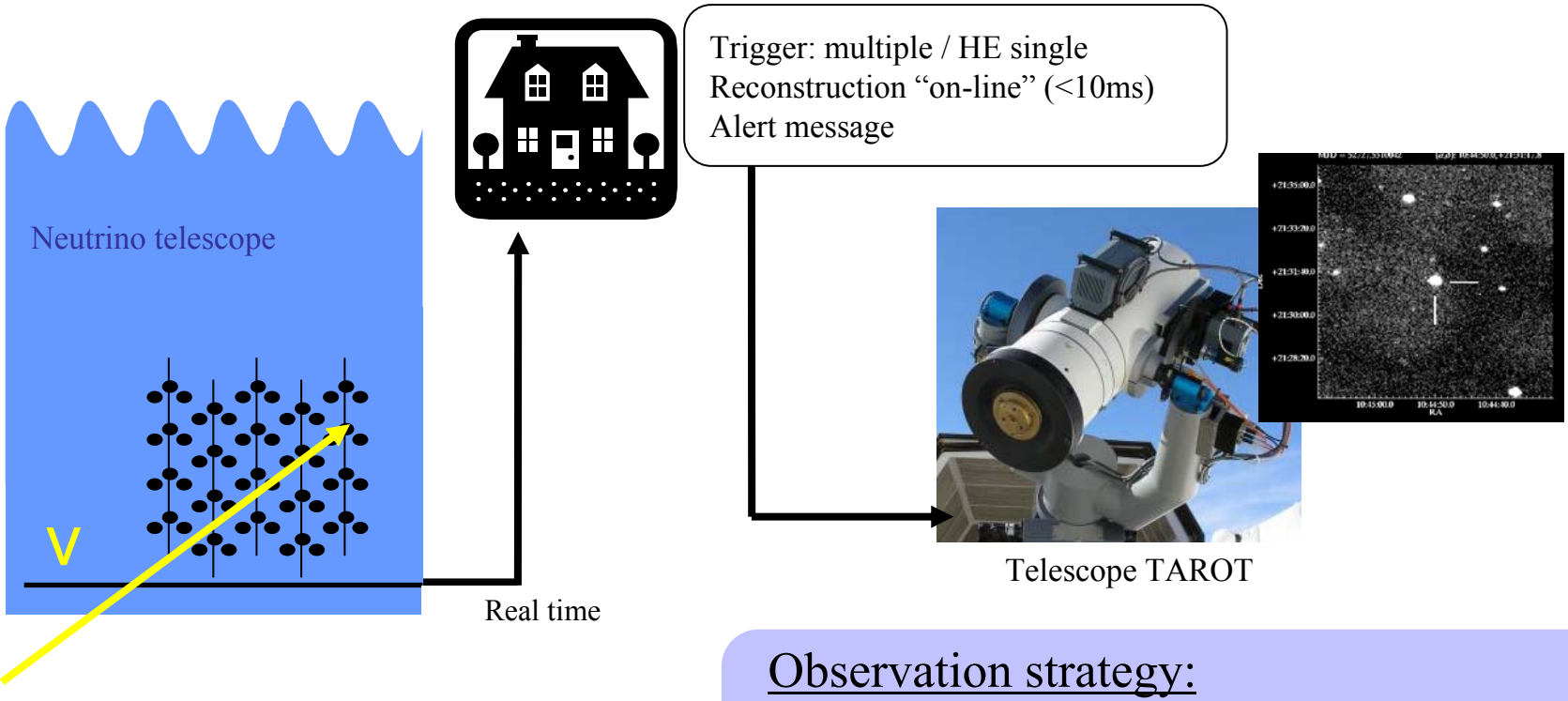


GRB data storage during 2 minutes without filtering



Rolling search method

Principle



Observation strategy:

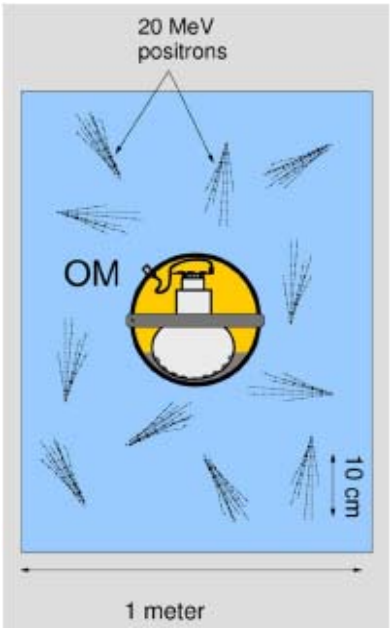
Real time (T_0) 6 images of 3 minutes

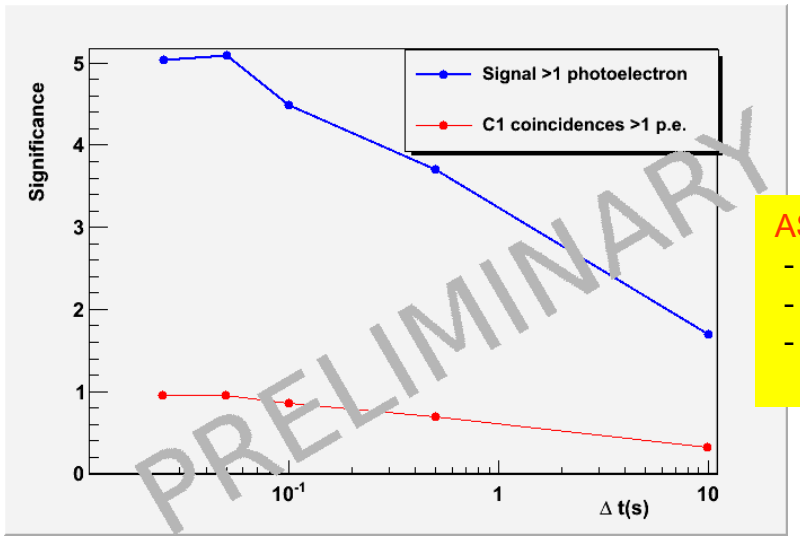
T0+1 day, +3 days, +9 days and +27 days

Supernova neutrinos in ANTARES?

- MeV neutrinos are produced in first seconds of a SN explosion
- Detect the global rate increase in the whole detector

First suggested for AMANDA: F. Halzen, et al Phys. Rev. D49(1994), 1758



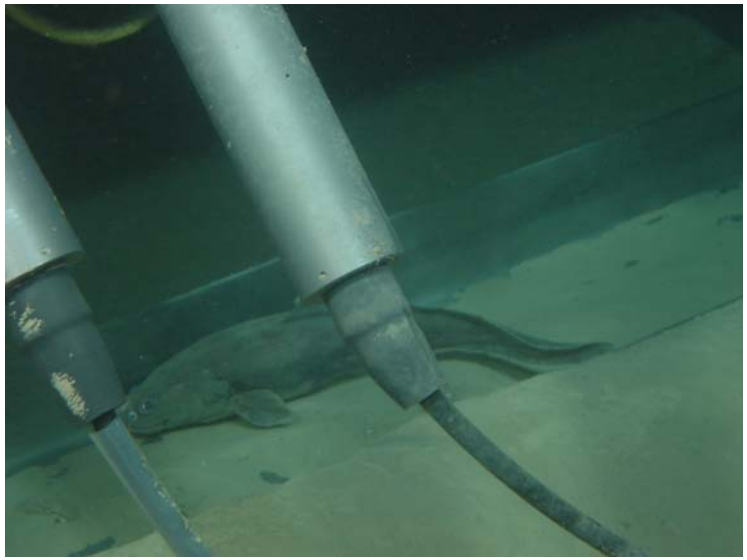


$$S = \frac{\Delta R}{\sigma}$$

ASSUMPTIONS:
- NO bioluminesce bursts
- 900 OMs
- Bck has Poissonian fluctuations

- Amanda-Ice Cube is participating to SNEWS network
- ANTARES could detect global rate increase above background fluctuations due to galactic SN if bioluminescence bursts are cut efficiently

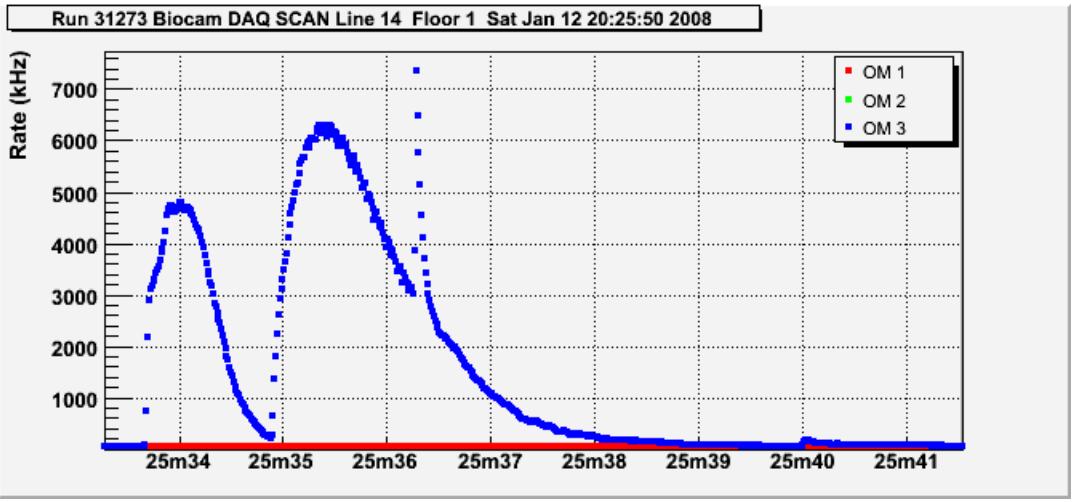
Associated Science
bioluminescent marine life



Installation of Camera + IR source

Self triggering on bioluminescence event
IR switch ON after trigger, photomultiplier read out as well

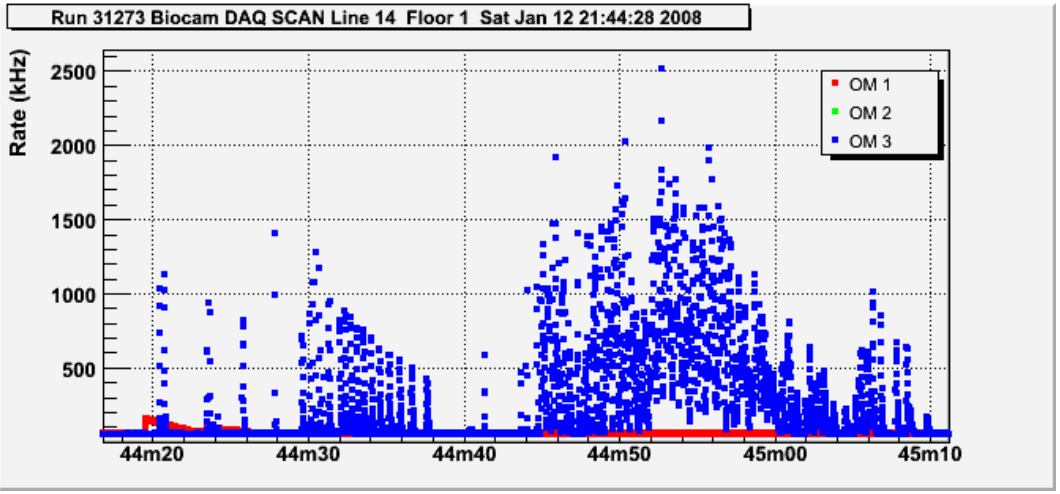
Examples of bioluminescence events



-150 bioluminescent triggers registered

- 4 different types of signals

DEEPEST ONLINE CAMERA IN THE WORLD!



Conclusions

- ANTARES today
  - Successful end of construction phase
    - Technology proven
    - Data taking ongoing
  - First physics outputs
    - Atmospheric μ and ν, cosmic neutrino sources
    - Dark matter, neutrino oscillations, magnetic monopoles, GRB
- On the road for the next step
  - KM3Net…