High Energy Astrophysics with underwater neutrino detectors

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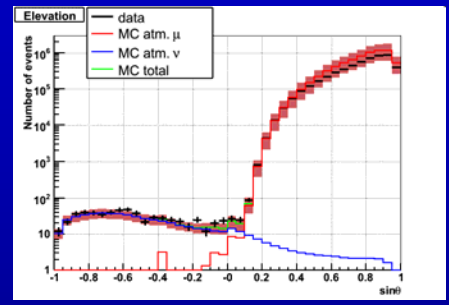
Outline of the talk

- Neutrino astronomy
  - The potential sources
- The ANTARES detector and the first physics analyses:
  - Construction milestones
  - Atmospheric muons
  - Atmospheric neutrinos
  - Search for cosmic neutrino sources



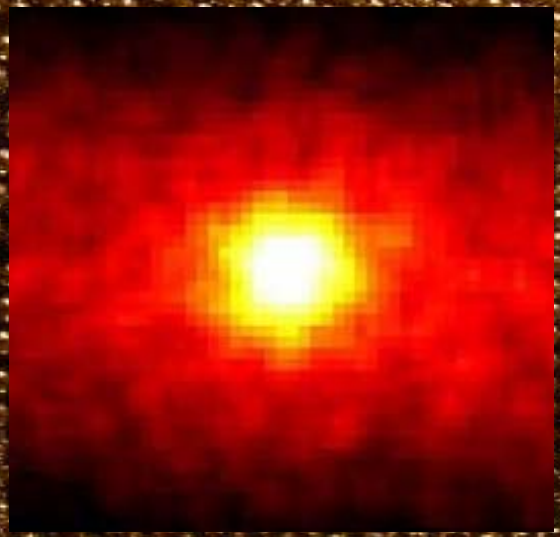
- The NEMO project
- The KM3NET network
- The MSU-Genova collaboration

First Extraterrestrial neutrinos

Are there neutrinos with E>GeV ??

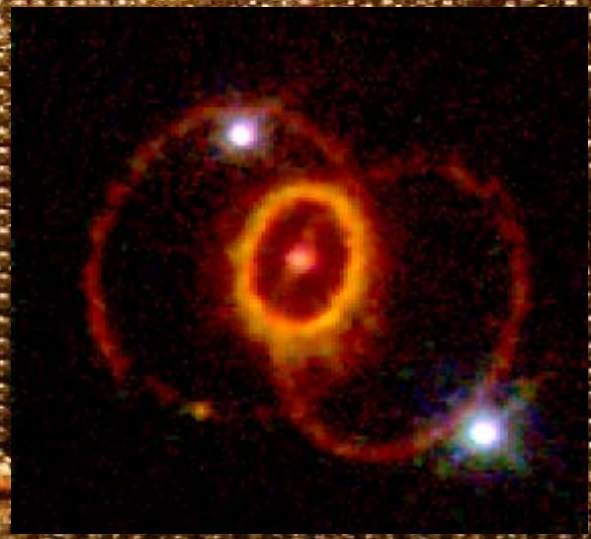
Galactic

Extragalactic



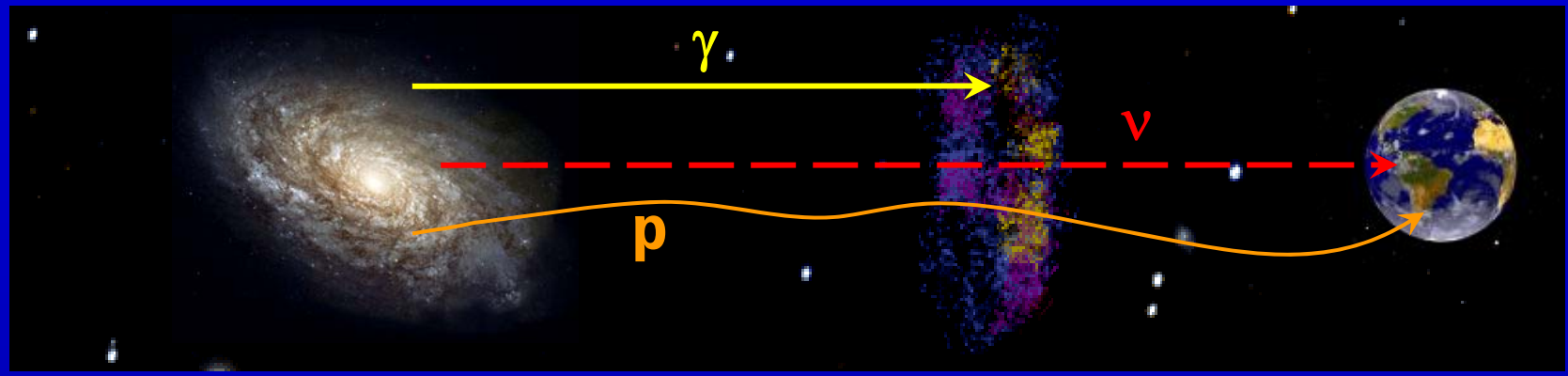
The sun seen by the SuperKamiokande experiment

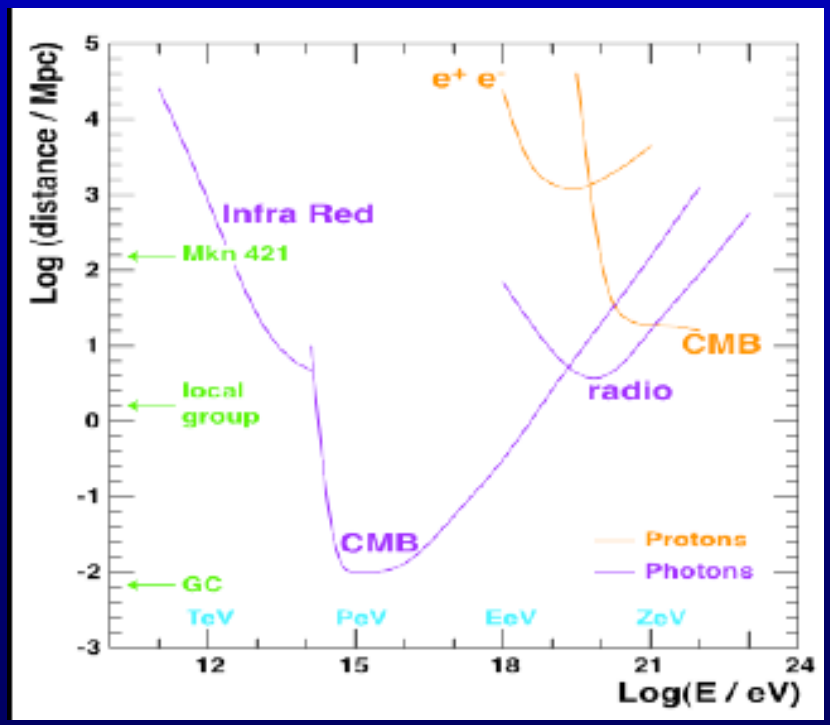
E_ν ~ MeV



Neutrinos from SN1987A

Neutrino astronomy





- γ: interact with CMB and matter
- Protons: deflection by magnetic fields
- ν: weakly interacting→huge target needed

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

$$\downarrow \qquad \downarrow$$

$$\nu_\mu\ \mu \qquad \gamma\ \gamma$$

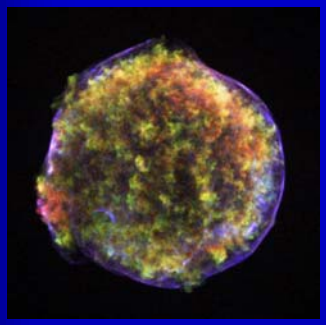
$$\downarrow$$

$$\nu_\mu\ \nu_e\ e$$

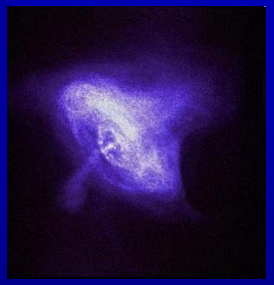
Potential sources

GALACTIC

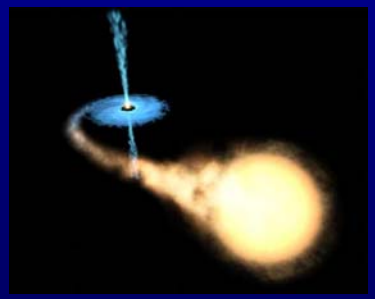
EXTRAGALACTIC



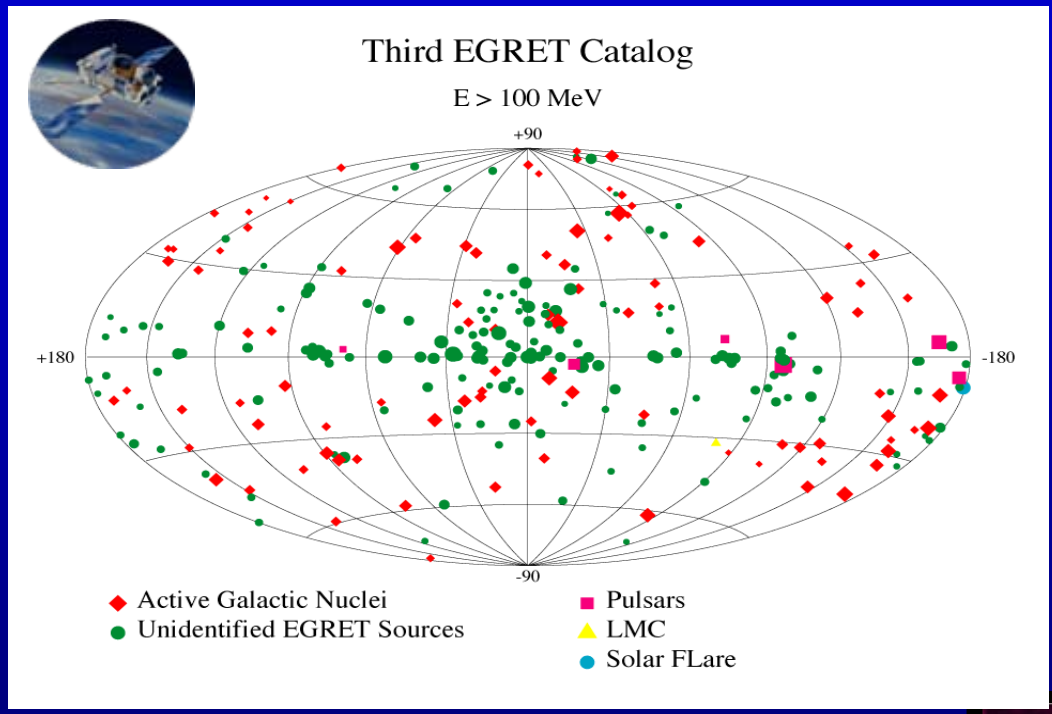
Supernova remnants

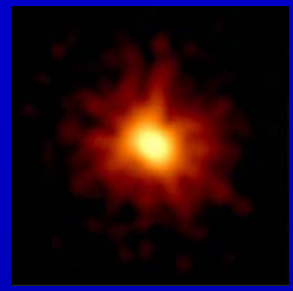


Pulsars

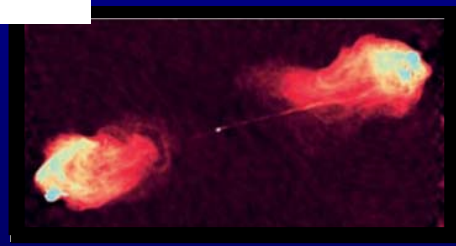


Microquasars



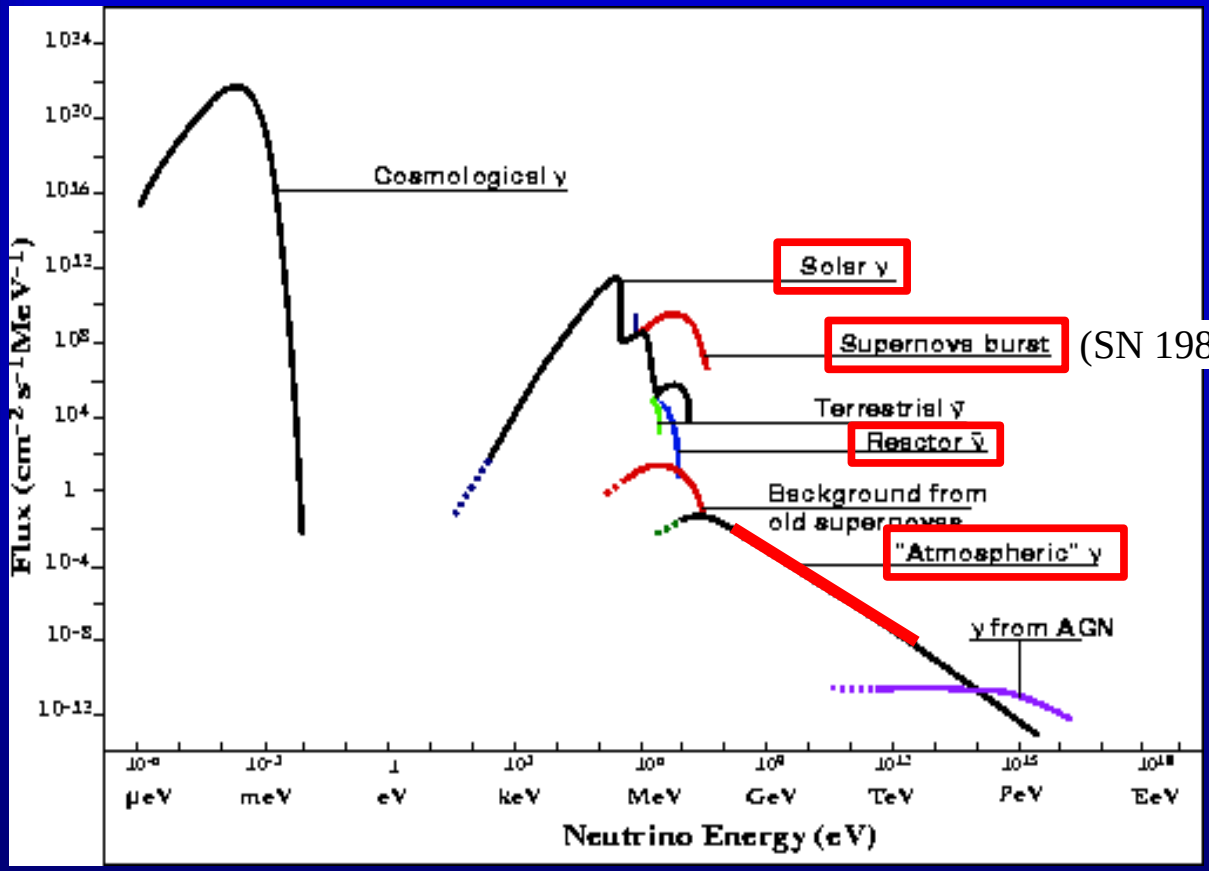


GRBs



AGNs

Neutrino flux on Earth



= measured

(SN 1987A)

(other components are hypothetical)

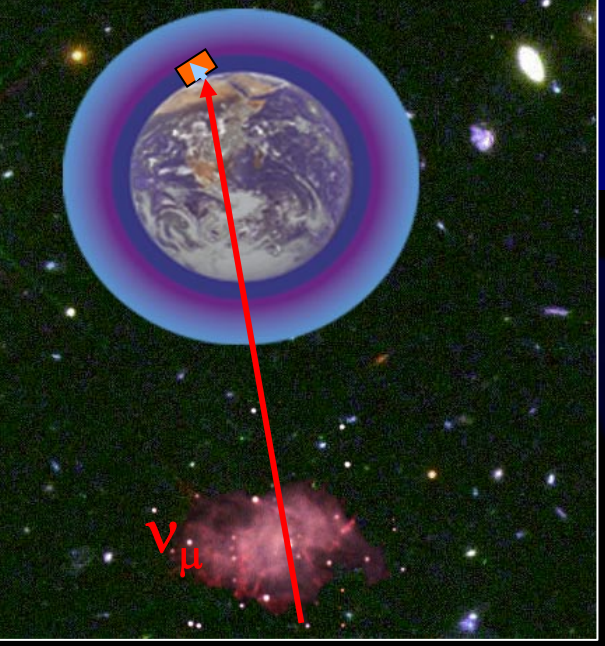
Energy range of Neutrino telescopes

{

Solar neutrino experiments

Water-Cherenkov Detectors in natural environments

Detection principle



3D PMT array

Cherenkov light from μ

42°

Sea floor

μ

ν_μ

interaction

The reconstruction is based on local coincidences compatible with the Cherenkov light front

- Main detection channel: ν_μ interaction giving an ultrarelativistic μ
- Energy threshold ~ 10 GeV

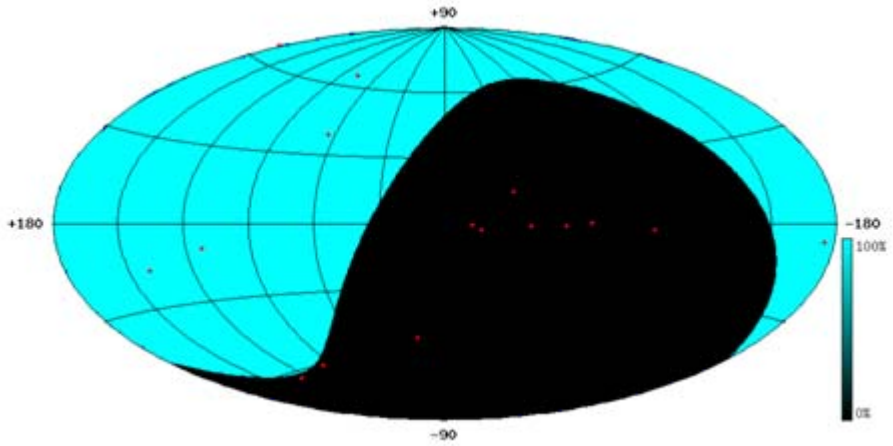
The ANTARES detector

The ANTARES site

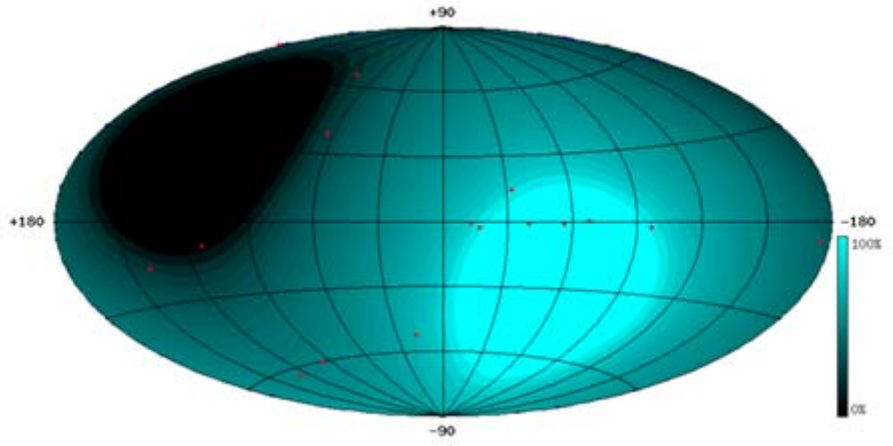
- 42°50’ latitude Nord
- 6°10’ longitude Est

The Galactic center is visible
75% of the day

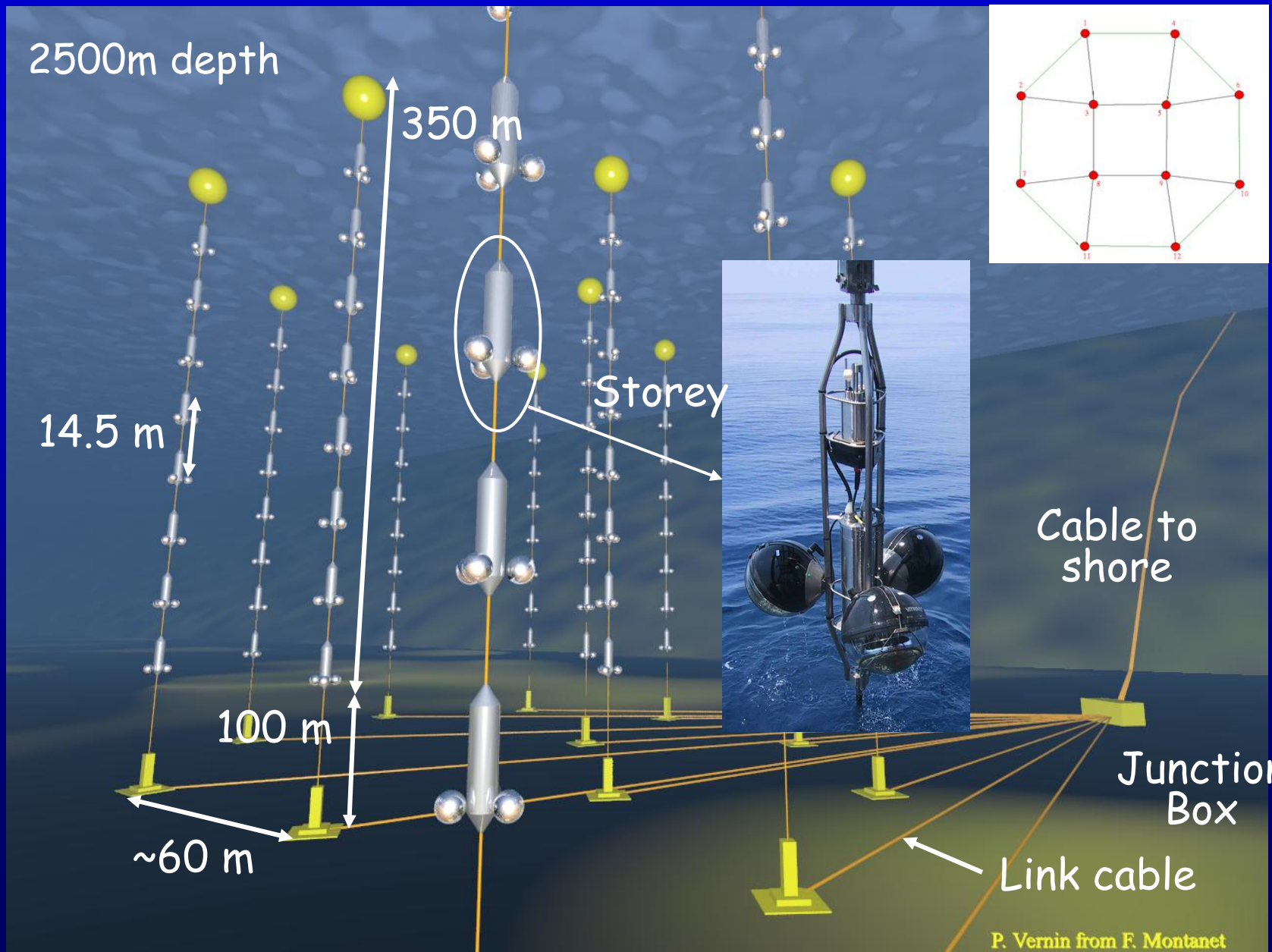
AMANDA/IceCube (South Pole)



ANTARES

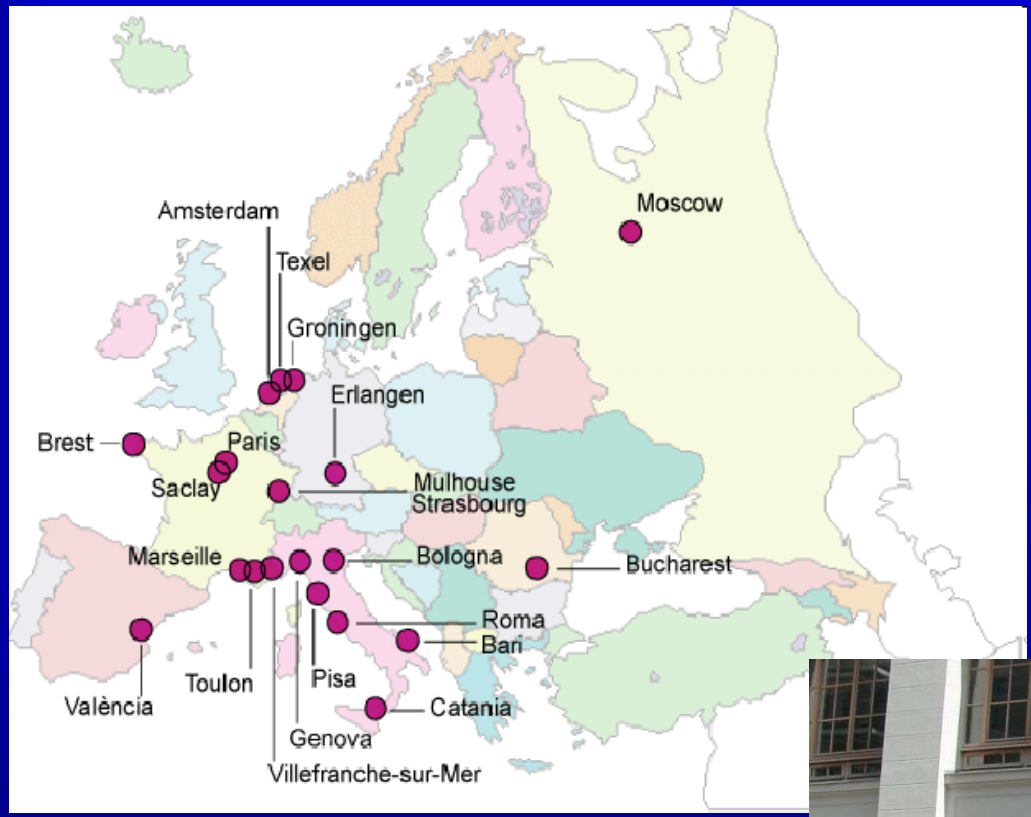


The ANTARES detector



The ANTARES site

The ANTARES Collaboration

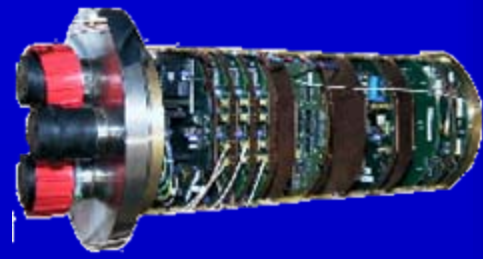


- Since 1996
- 7 countries
- 22 laboratories
- 200 physicists, engineers, sea scientists

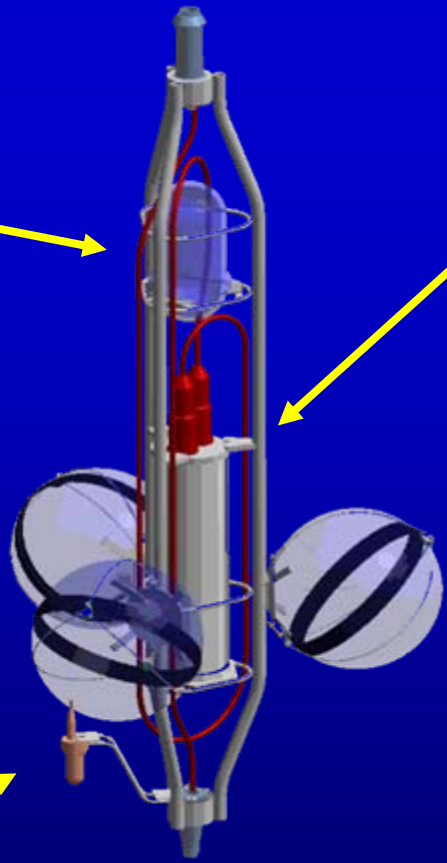
A detector storey

LED
Beacon

~0.6 ns resolution



DAQ
Slow Control



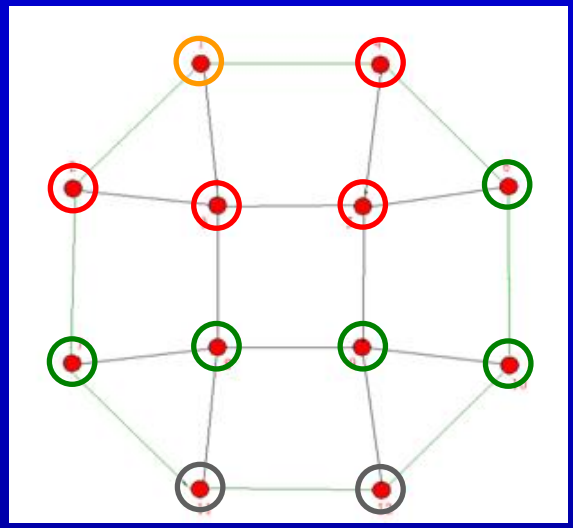
Titanium
frame

17″ glass sphere
10″ PMT

Hydrophone

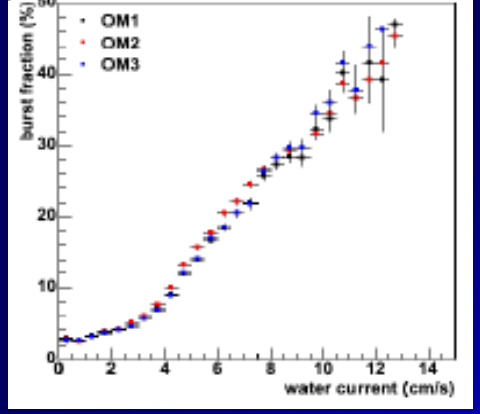
~10 cm resolution

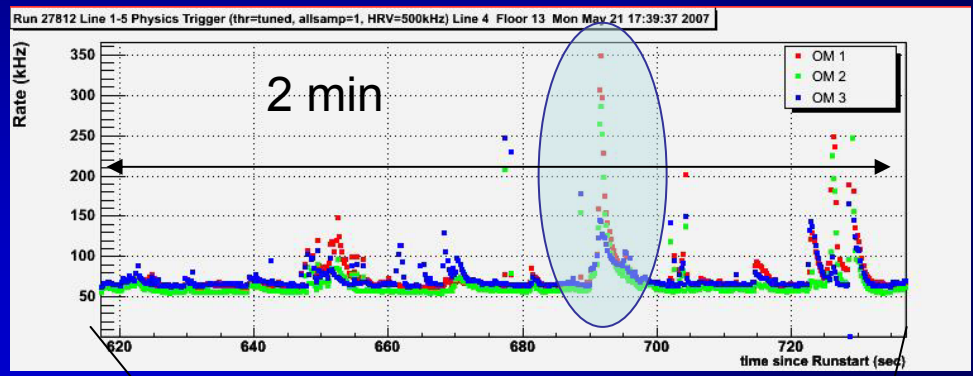
2006 - 2008: deployments of the detector lines



- **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 sea: optical background

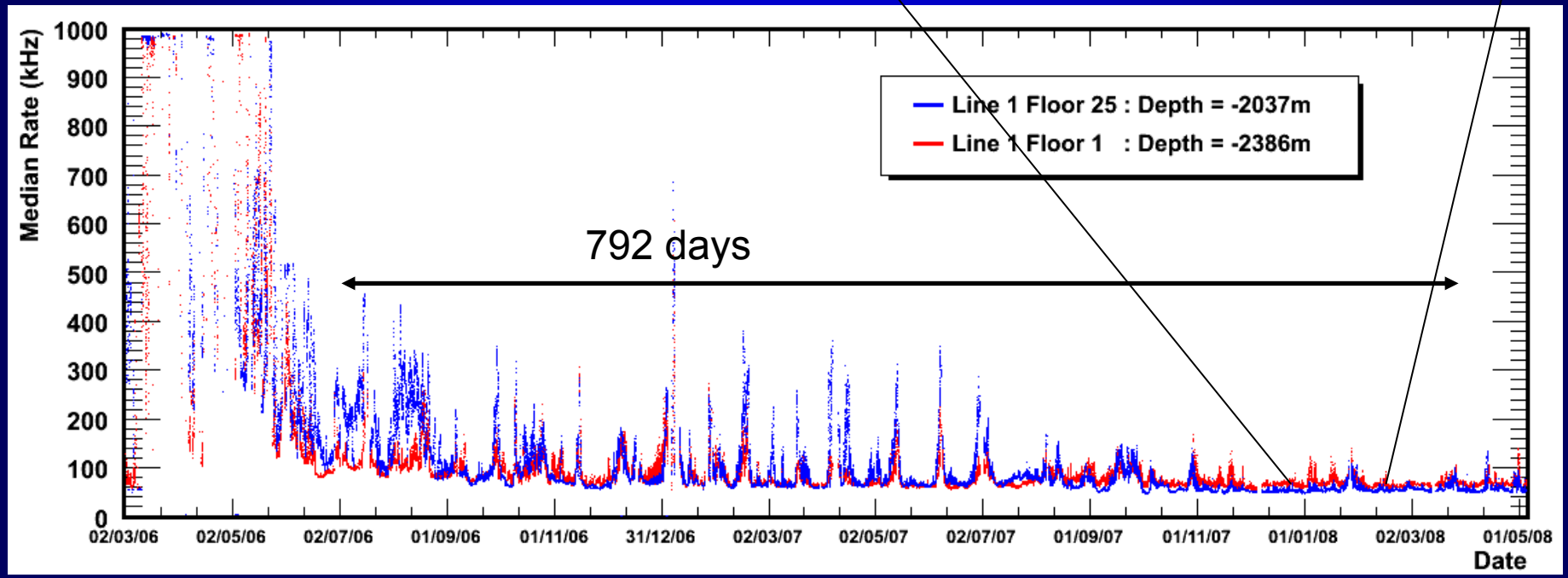




Mean rate~ 70 kHz

↓

40 kHz (^{40}K)+30 KHz (bioluminescence)

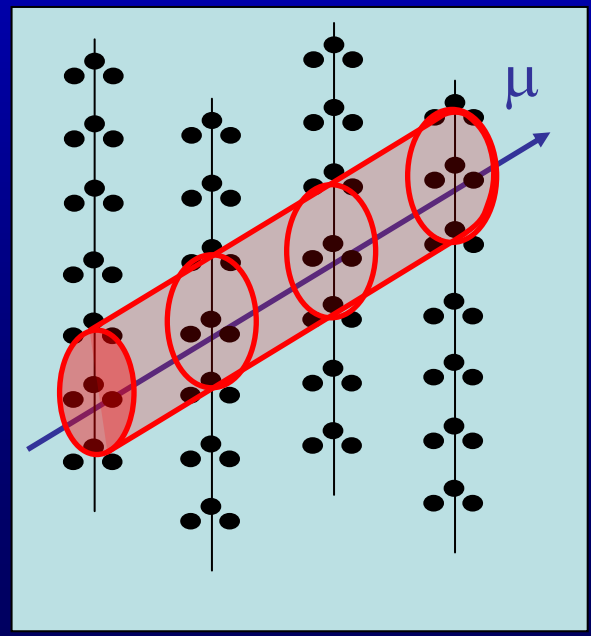


The Trigger

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

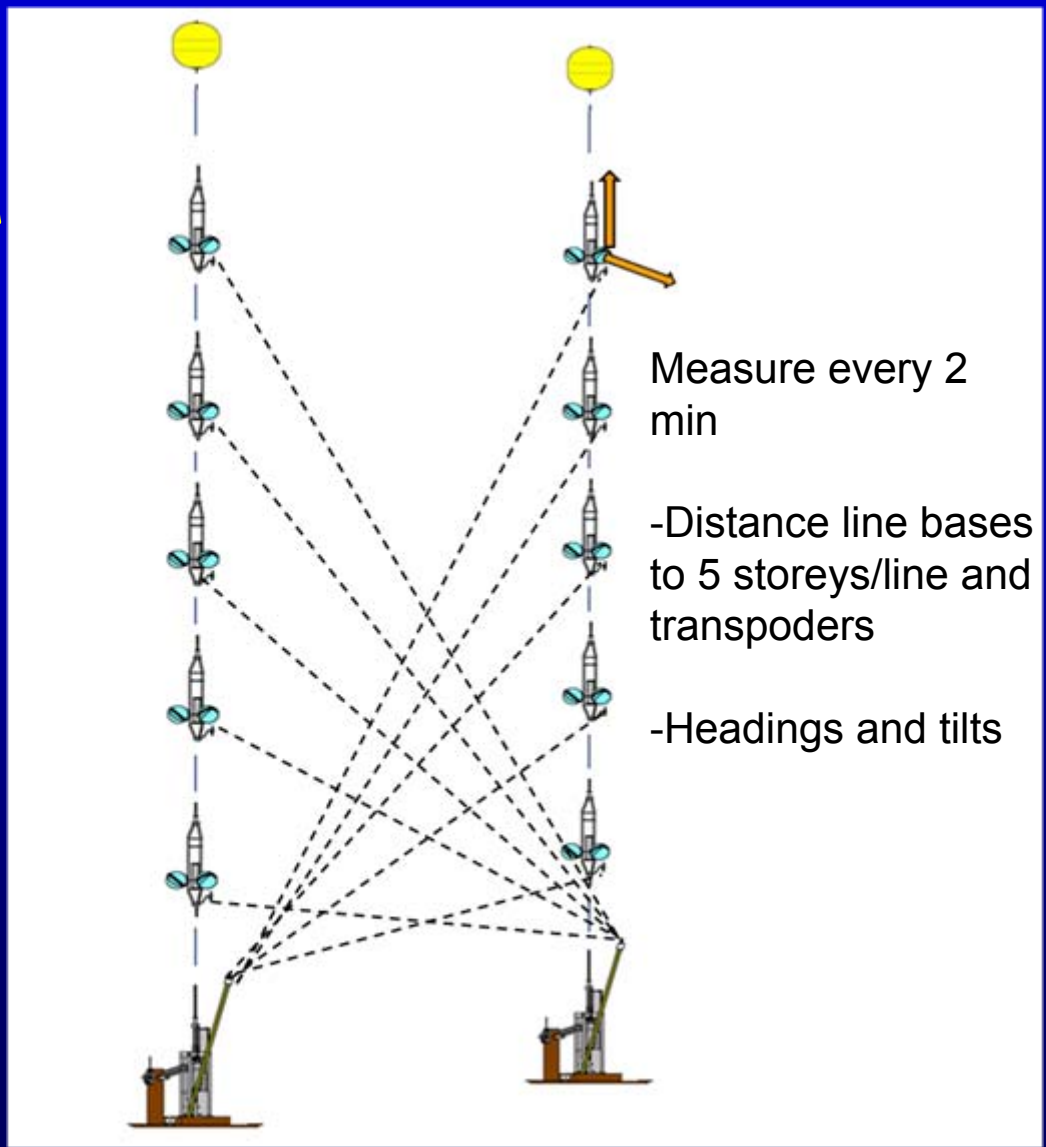
"ALL DATA TO SHORE" SCHEME:

- 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, …

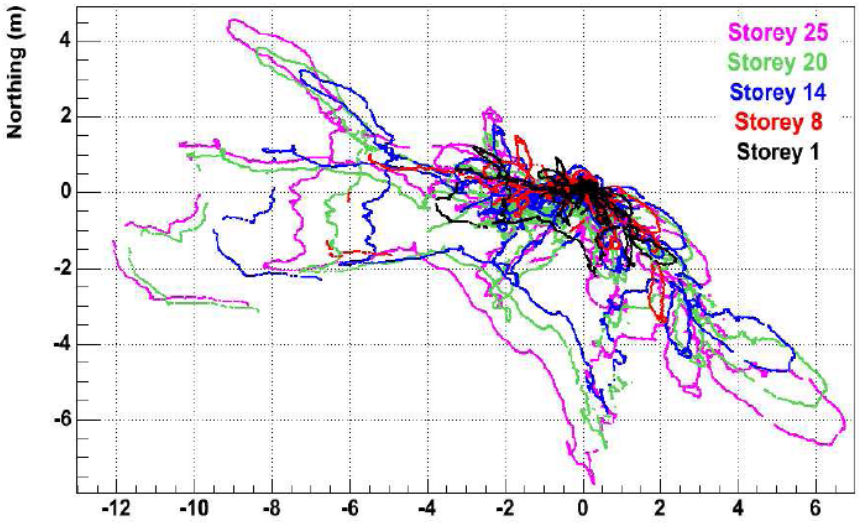


Calibration: positioning

- 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

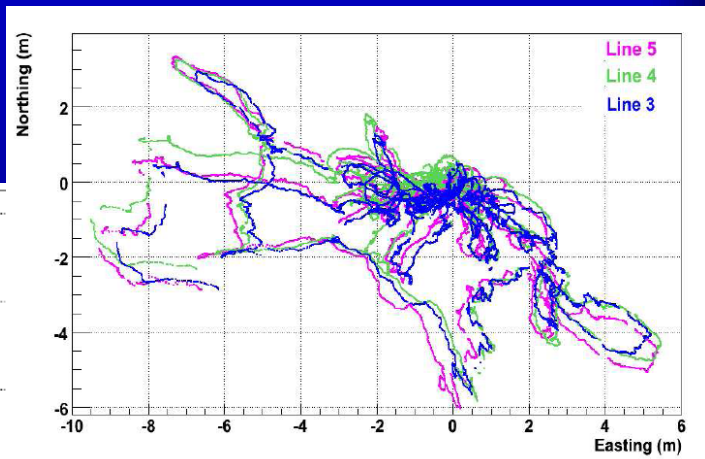


Positioning results



Comparison among storeys

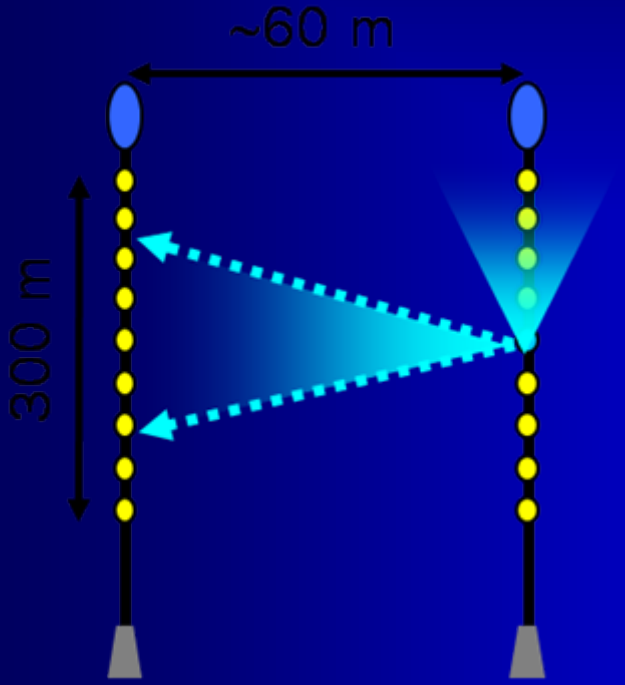
Larger displacements for upper top floor

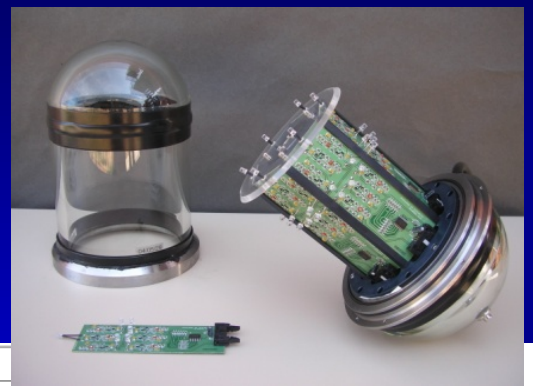


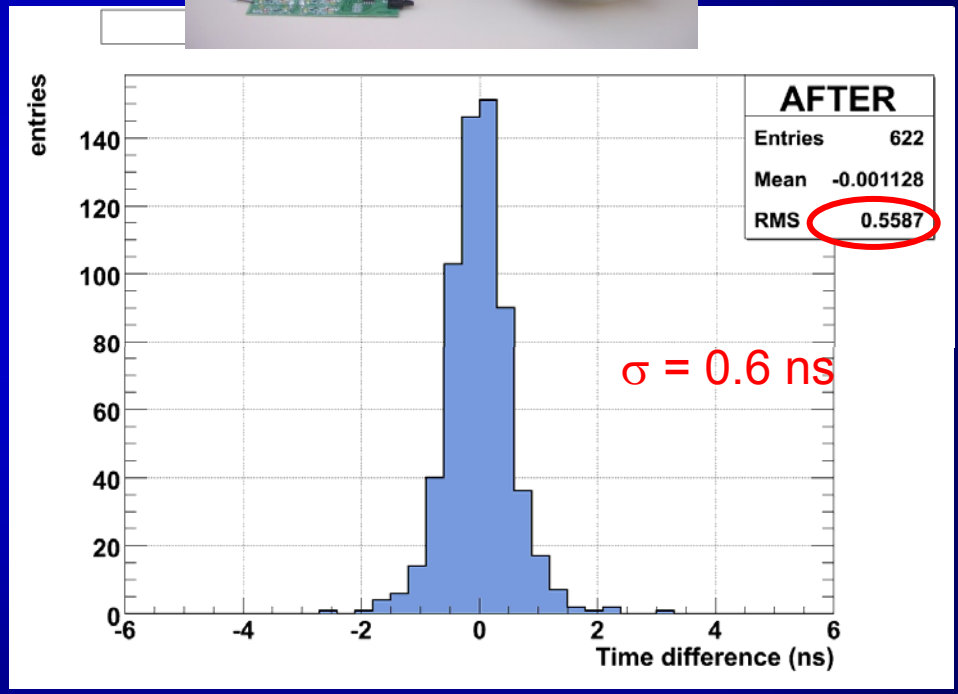
Comparison among lines

Coherent movement for all the lines of the detector

Time calibration with led-beacon



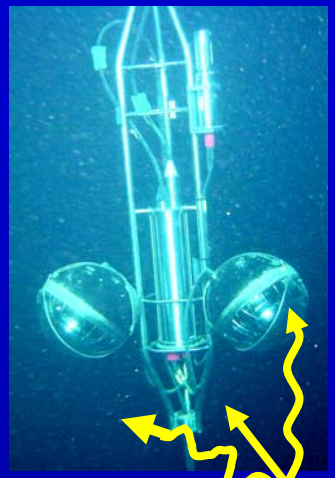




Time difference between two OMs of the same storey

- Additional output: water optical parameter measurement

In situ calibration with Potassium-40 (overview)



γ

γ

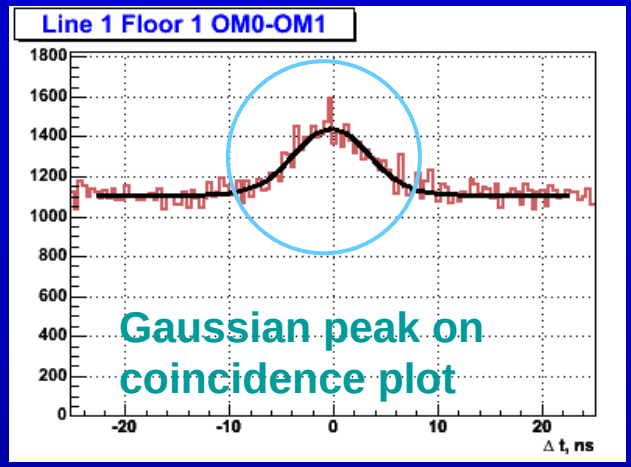
Cherenkov

e^- (β decay)

^{40}K

^{40}Ca

No dependence on bioluminescent activity has been observed



Integral under peak = rate of correlated coincidences

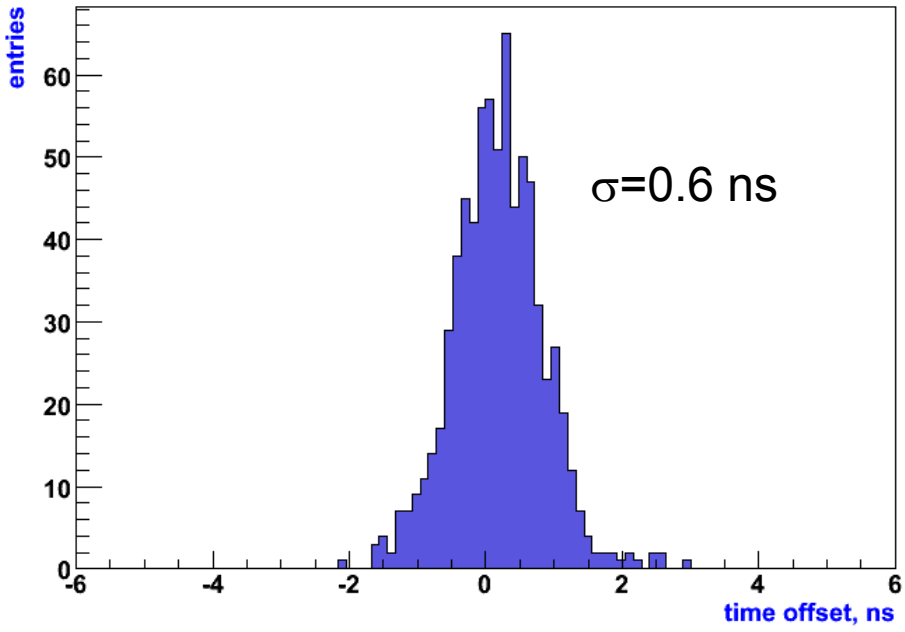
Peak offset

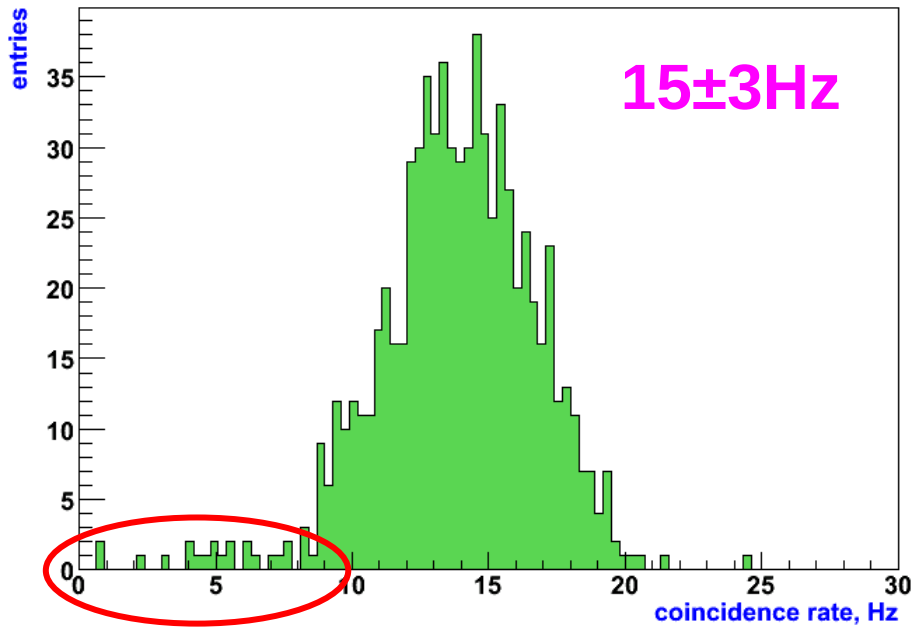
Cross check of time calibration

High precision (~5%) monitoring of OM efficiencies

K40 calibration results

- Monitoring of tme offsets of photomultipliers of the same floor → ok
- Monitoring of relative efficiency between photomultipliers

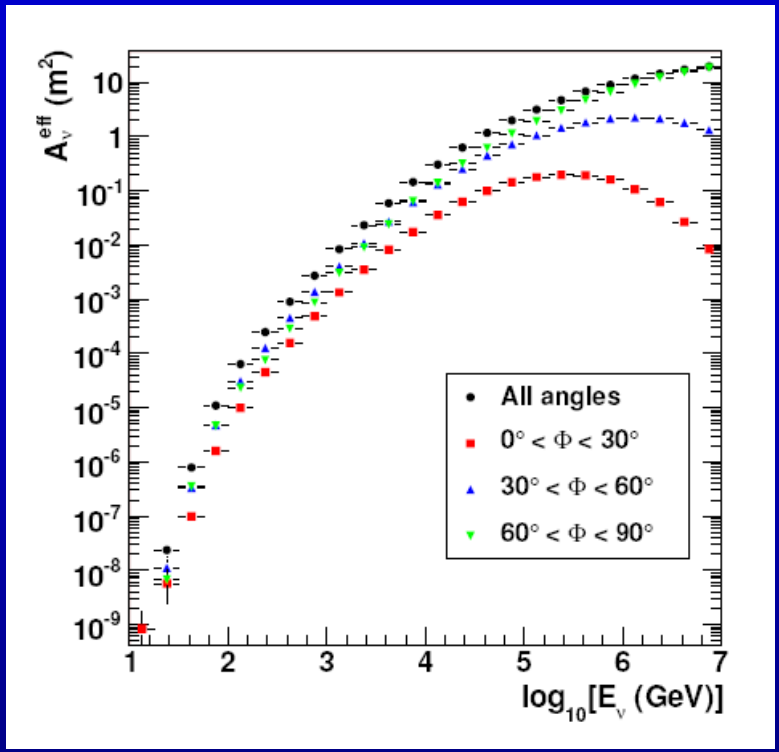




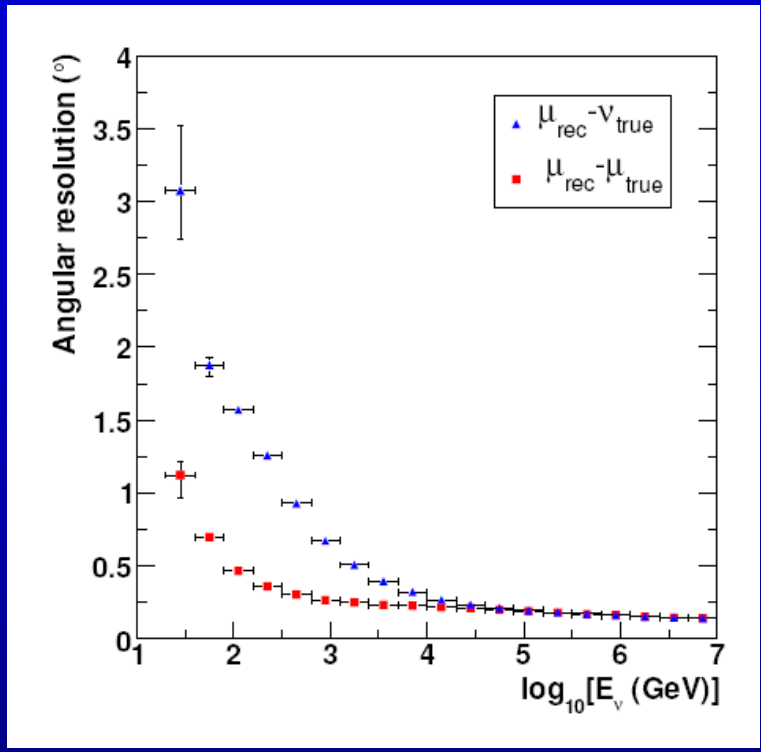
Channels which need retuning

Expected Performance (full detector)

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 track reconstruction errors.

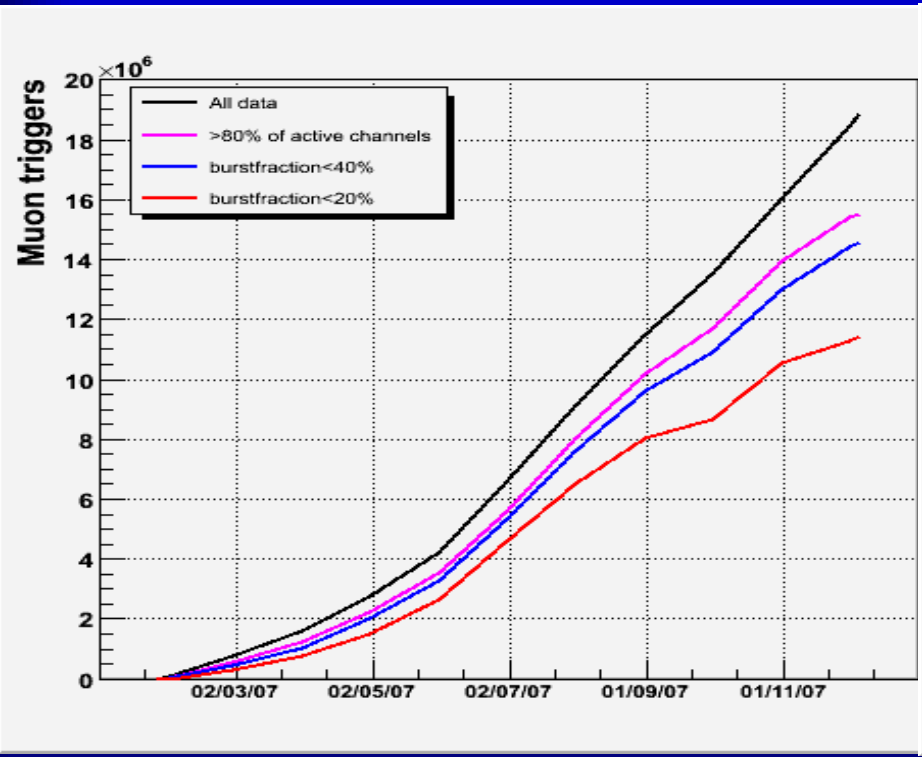
Number of triggers

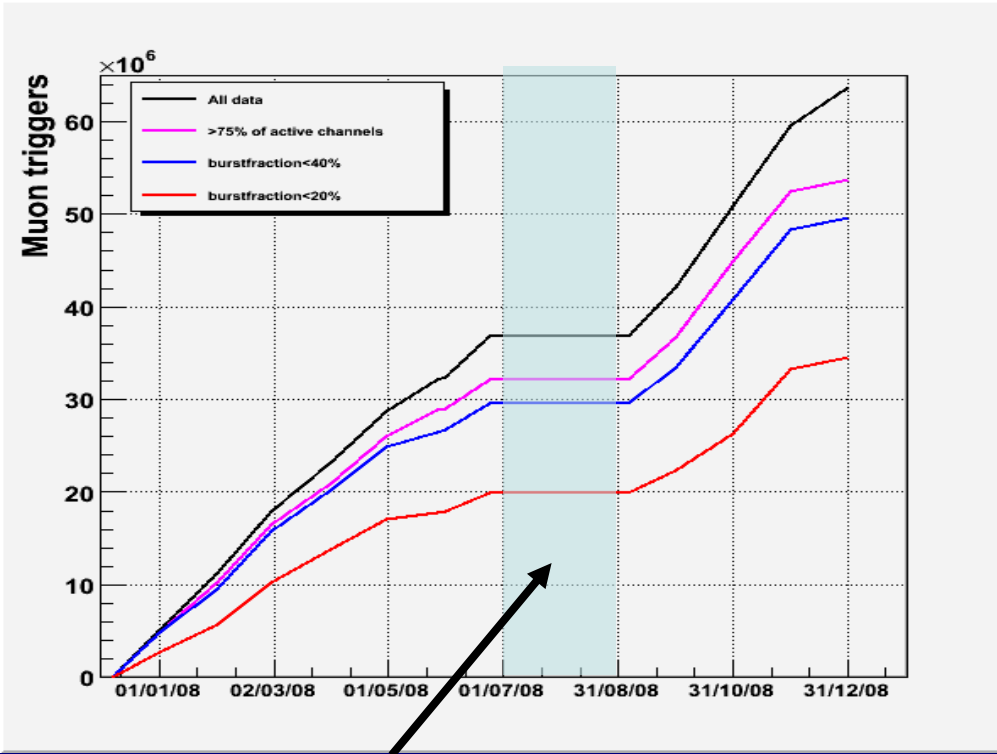
5 lines (2007)

19.10^6 μ

10 or more lines (2008)

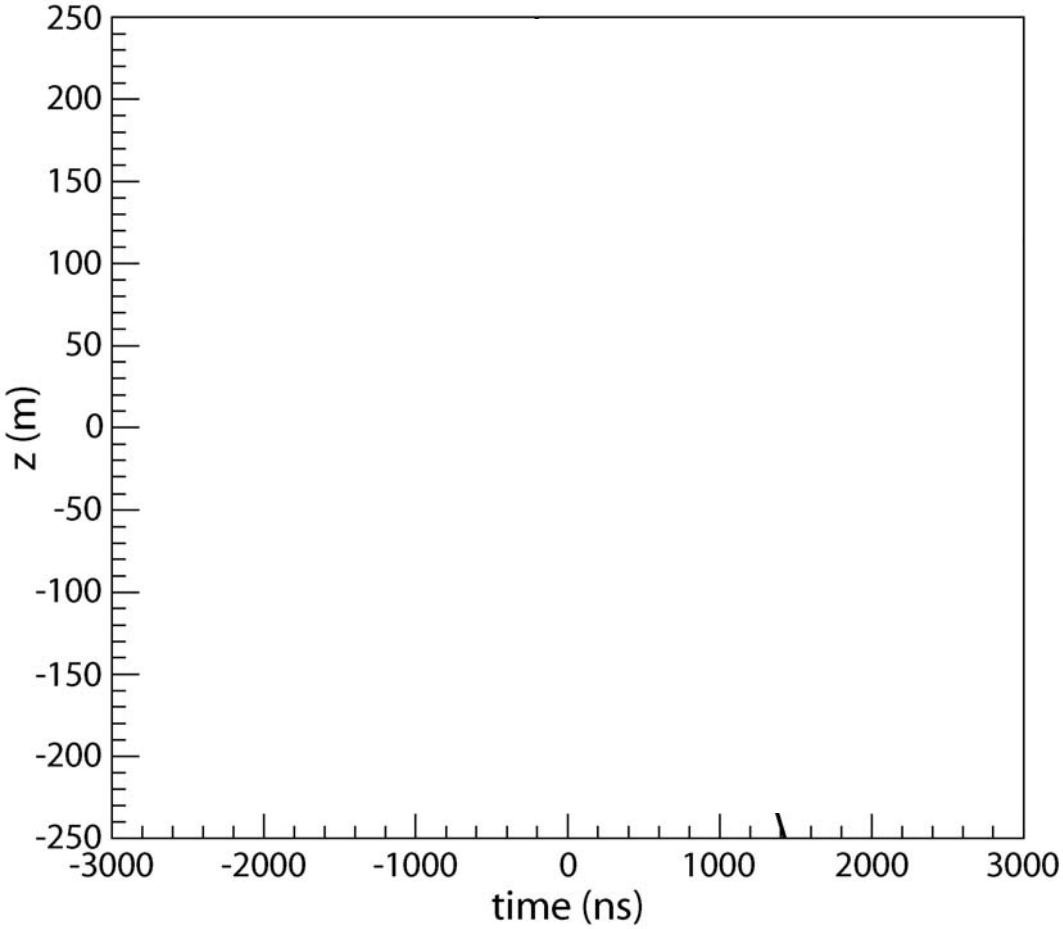
60.10^6 μ

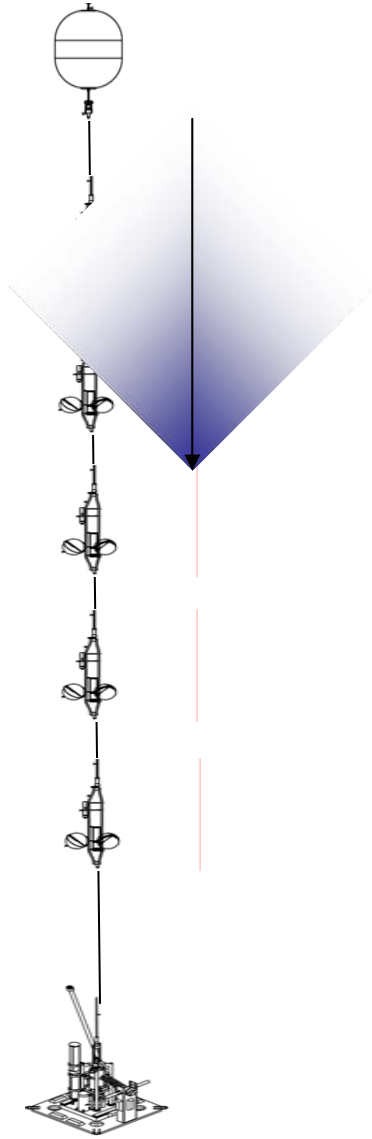




CABLE FAULT !

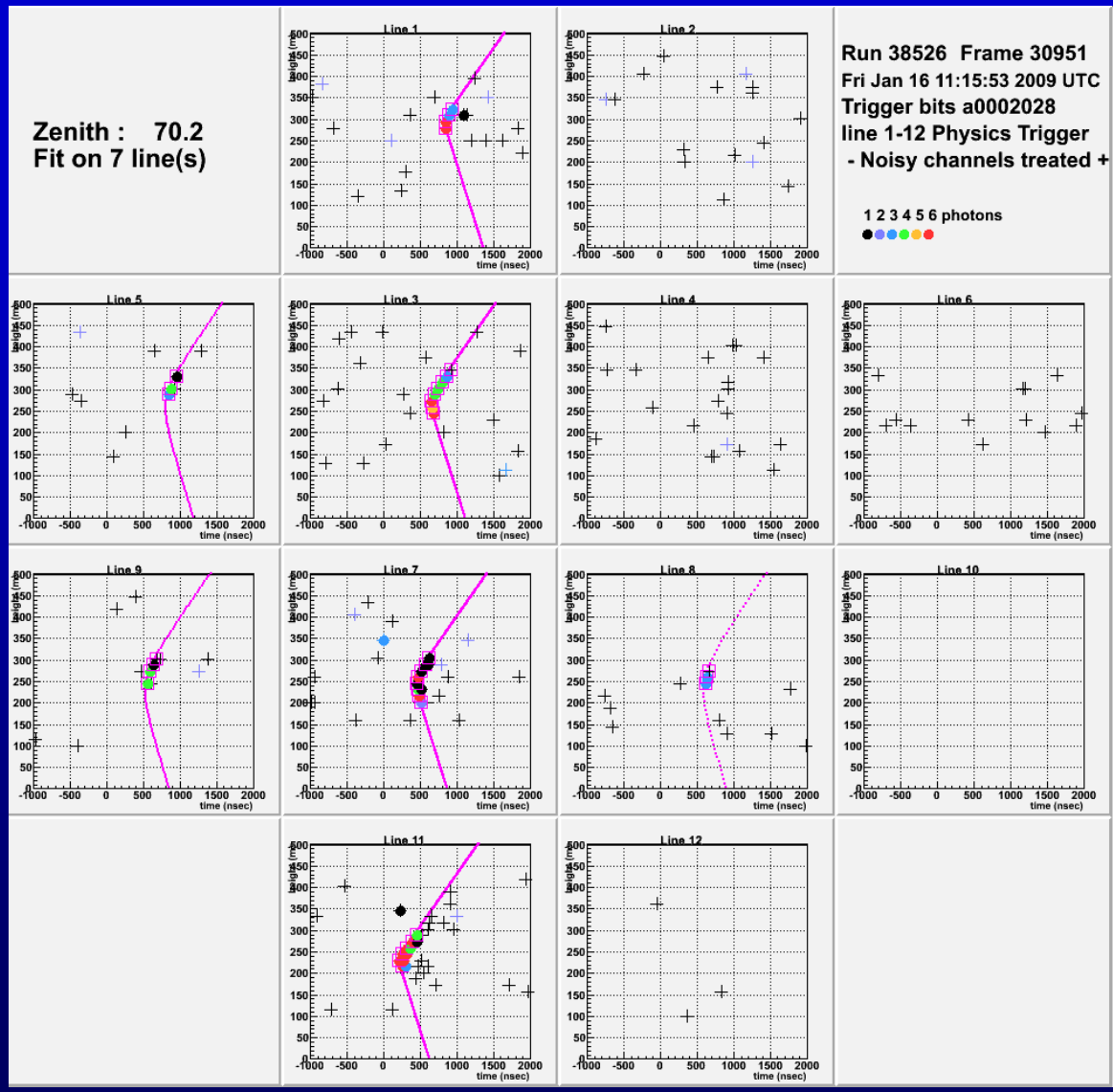
Vertical muon

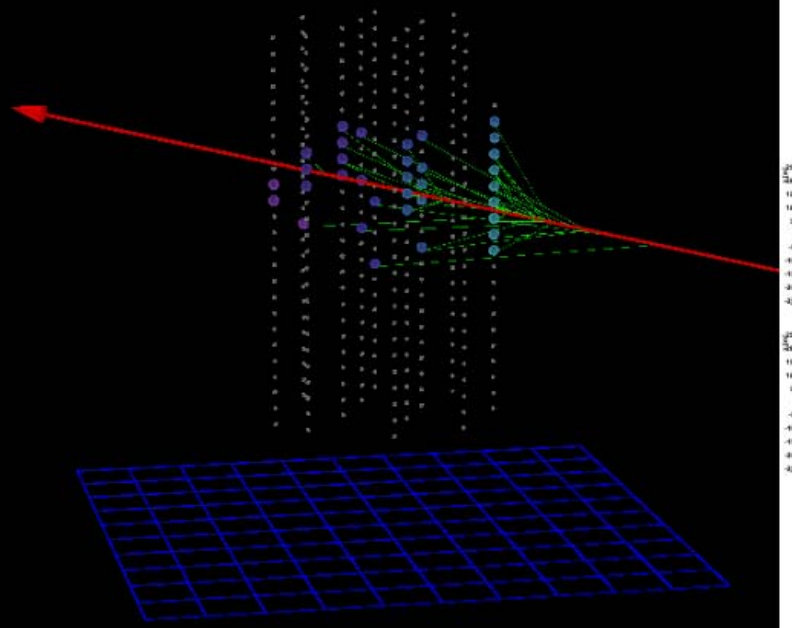


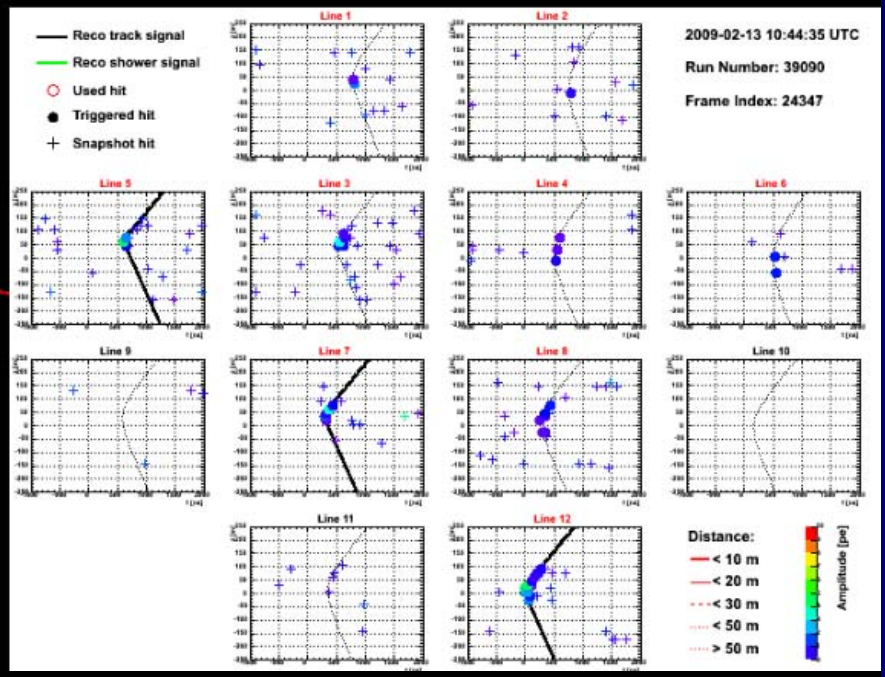


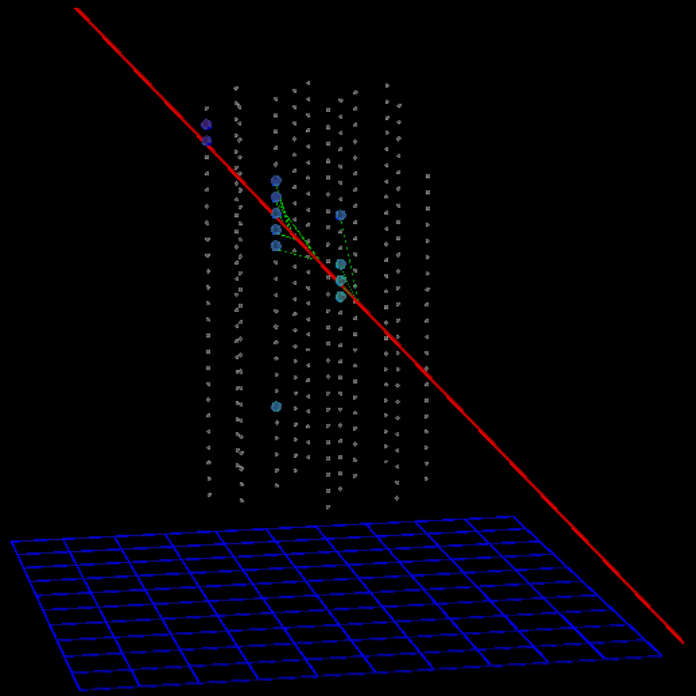
Neutrino seen recently

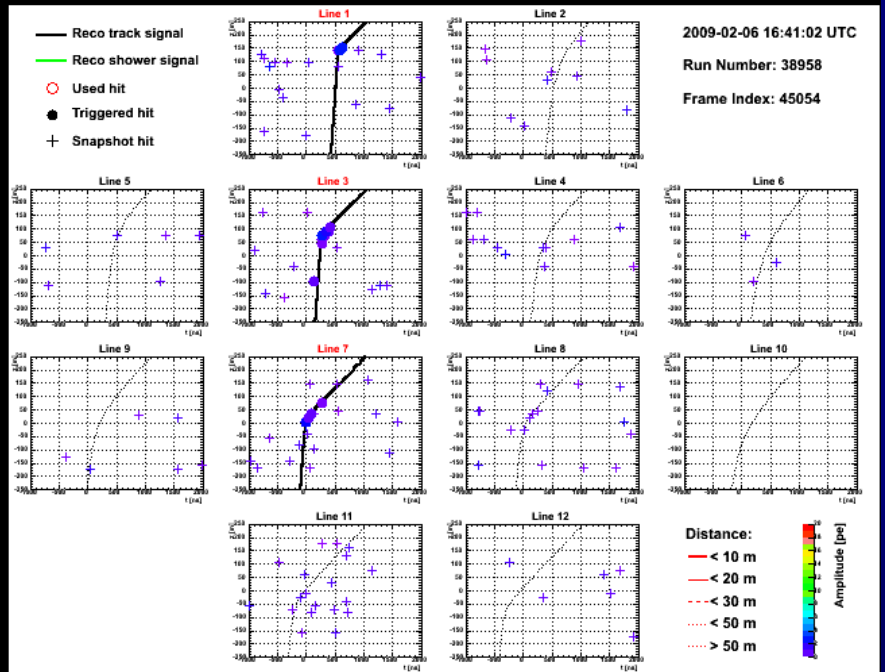
- No precise energy estimate yet
- Seen on 7 lines ("Normal" neutrinos are seen 2,3 rarely 4 lines)

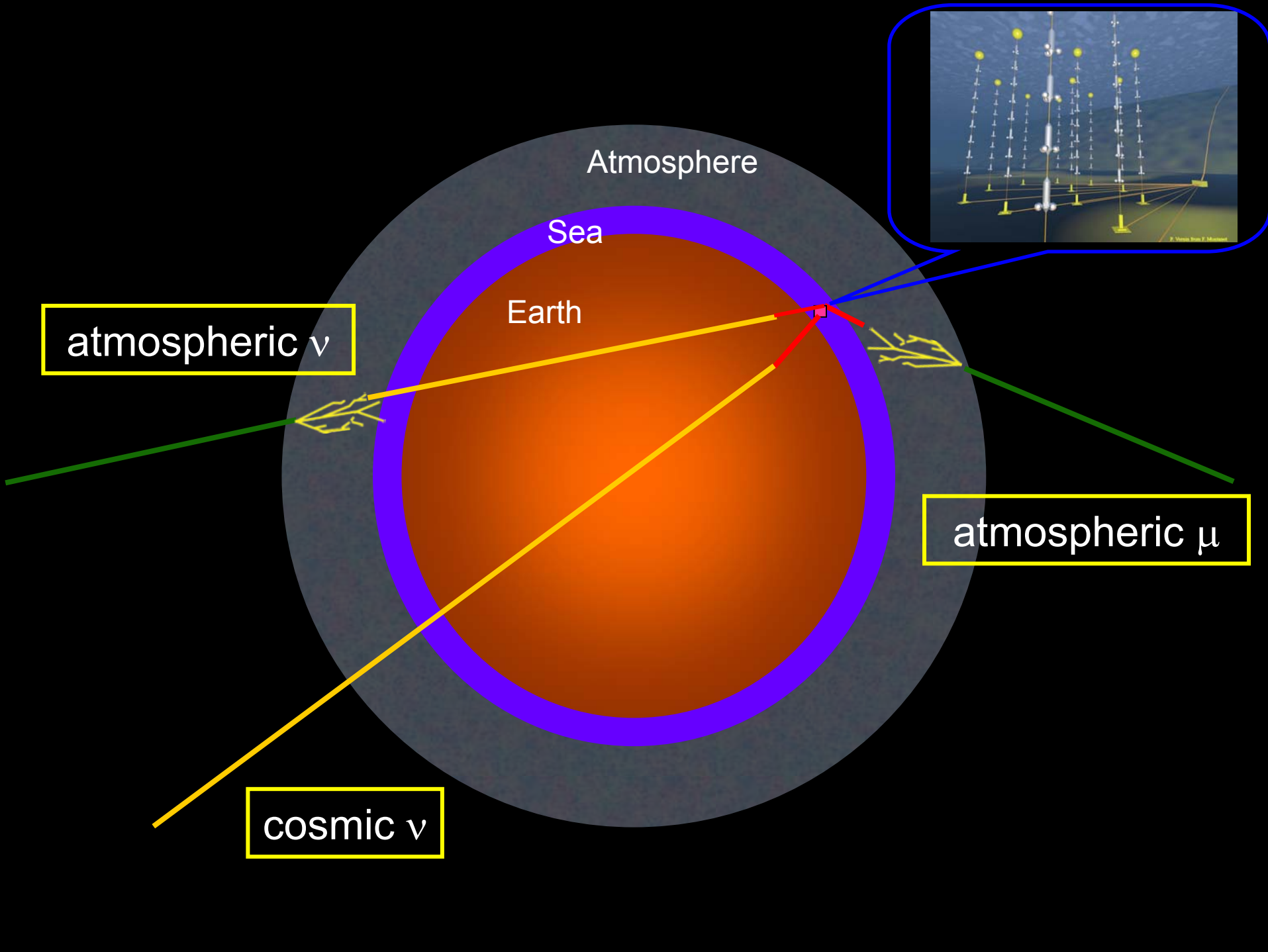




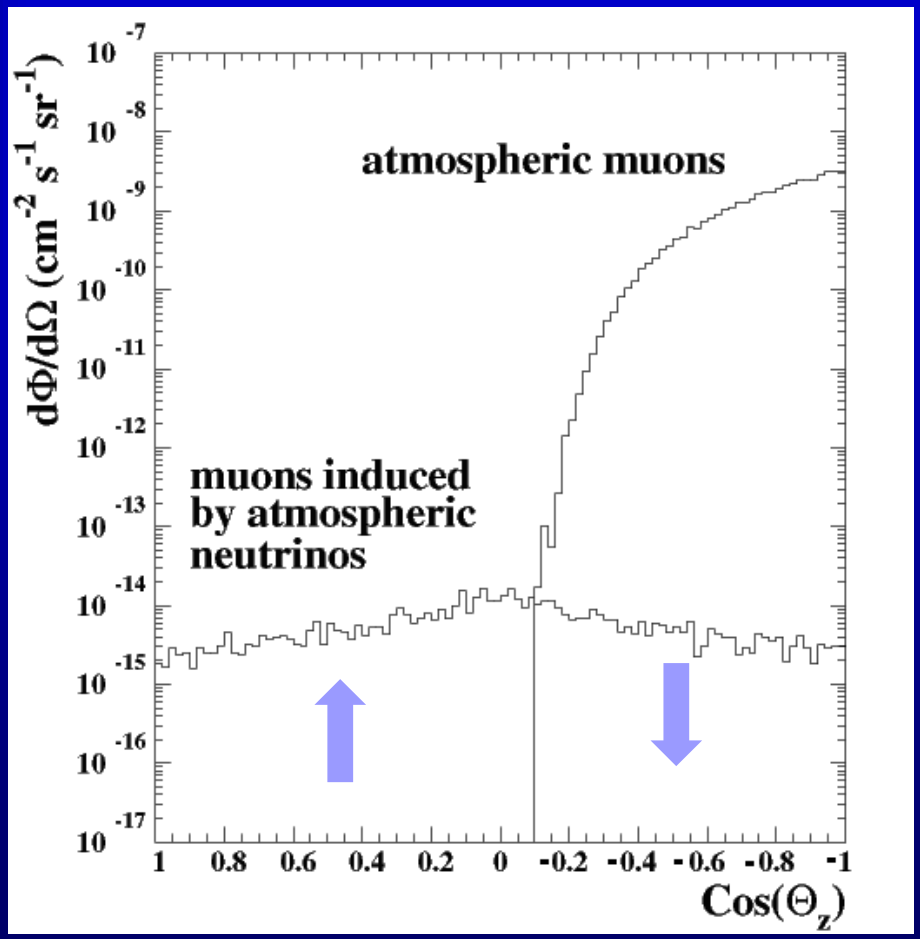

Reco track signal
Reco shower signal
Used hit
Triggered hit
Snapshot hit
2009-02-13 10:44:35 UTC
Run Number: 39090
Frame Index: 24347
Line 1
Line 2
Line 3
Line 4
Line 5
Line 6
Line 7
Line 8
Line 9
Line 10
Line 11
Line 12
Distance:
< 10 m
< 20 m
< 30 m
< 50 m
> 50 m
Amplitude [pe]

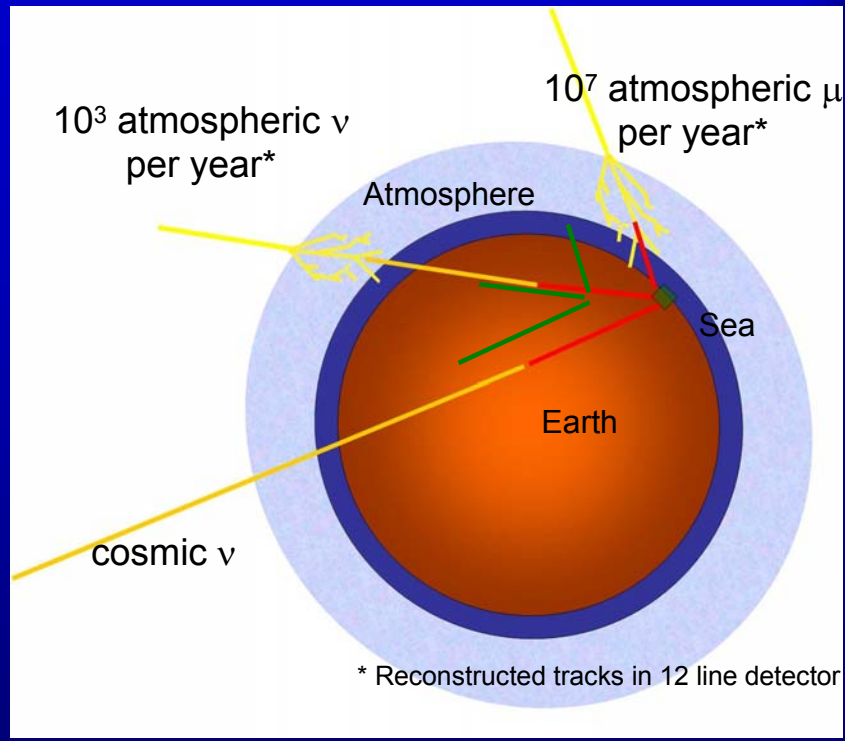



Reco track signal
Reco shower signal
Used hit
Triggered hit
Snapshot hit
2009-02-06 16:41:02 UTC
Run Number: 38958
Frame Index: 45054
Line 1
Line 2
Line 3
Line 4
Line 5
Line 6
Line 7
Line 8
Line 9
Line 10
Line 11
Line 12
Distance:
< 10 m
< 20 m
< 30 m
< 50 m
> 50 m
Amplitude [pe]


Atmosphere
Sea
Earth
atmospheric ν
atmospheric μ
cosmic ν

Muon flux at the detector



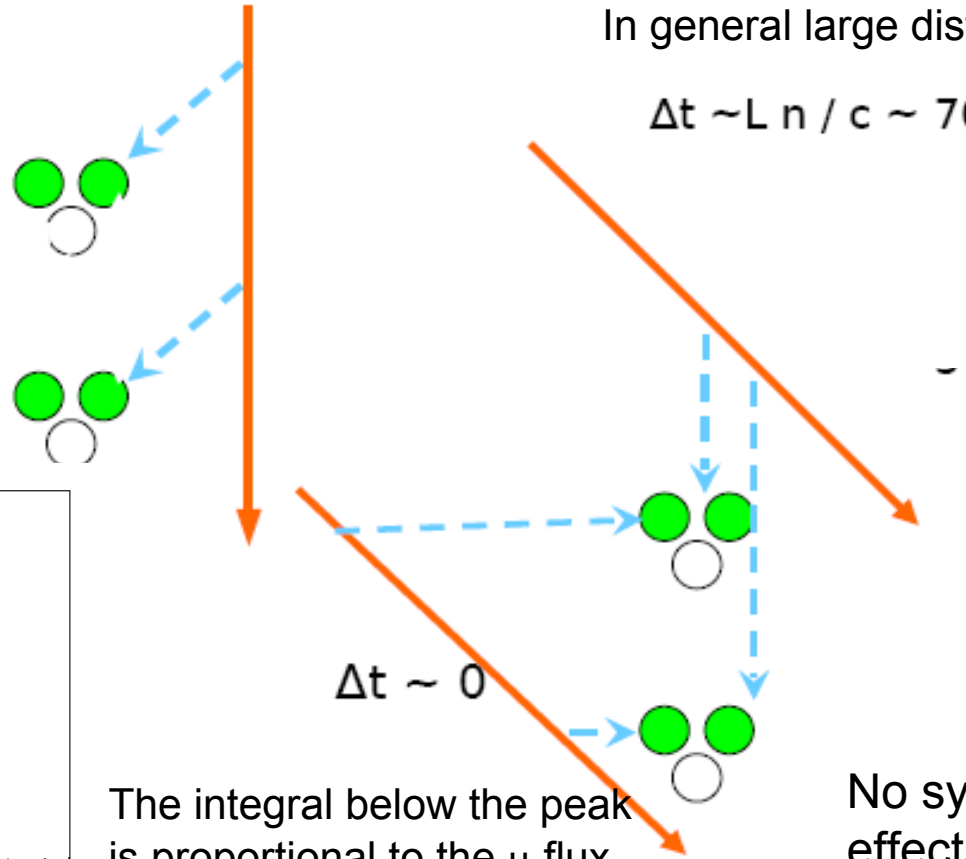


Muon flux:delay between adjacent storeys

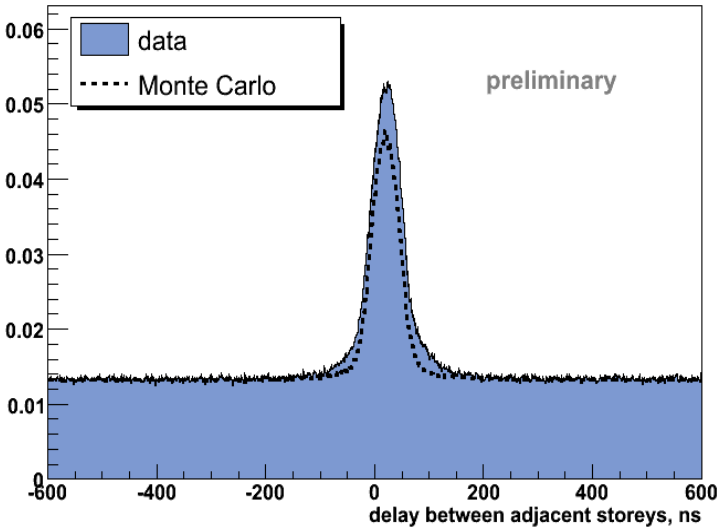
Basic correlation signature of muon: adjacent floor coincidences

Fixed for vertical muons

$\Delta t = L / c \approx 50$ ns



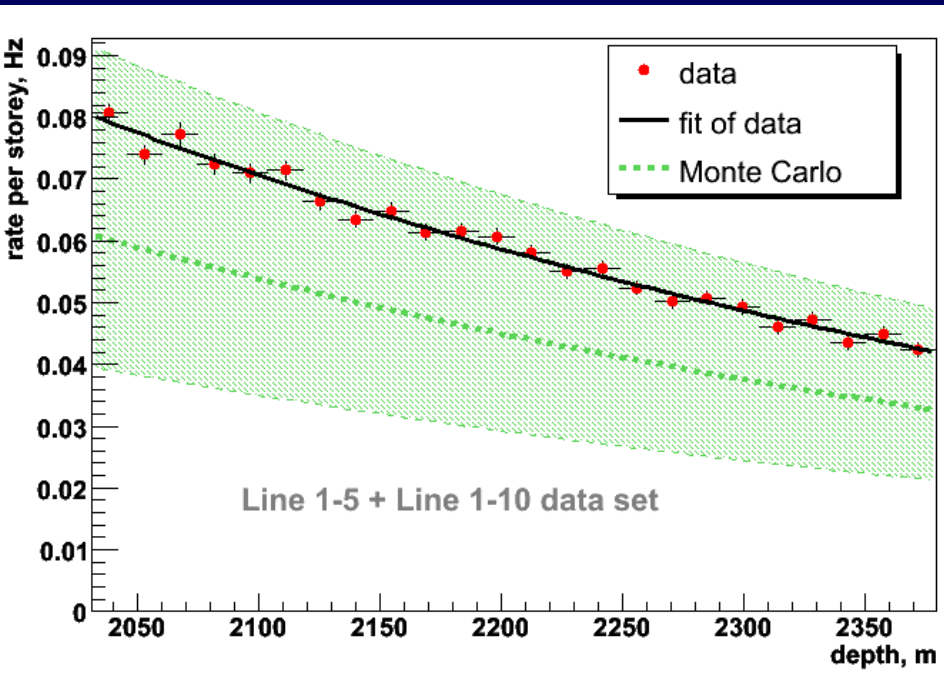
Coincidences in adjacent floors



The integral below the peak is proportional to the μ flux

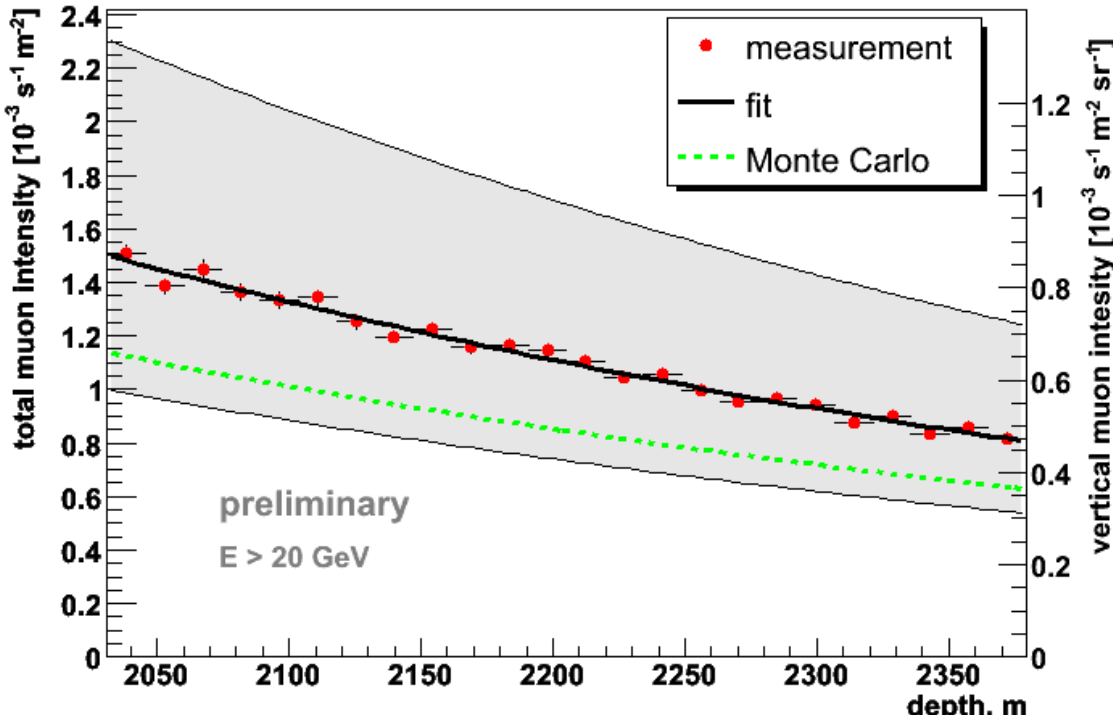
Shape is sensitive to angular acceptance of optical modules and angular distribution of muon flux

No systematic effects of trigger or reconstruction

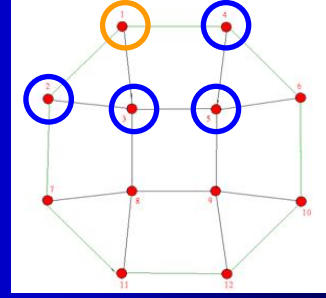


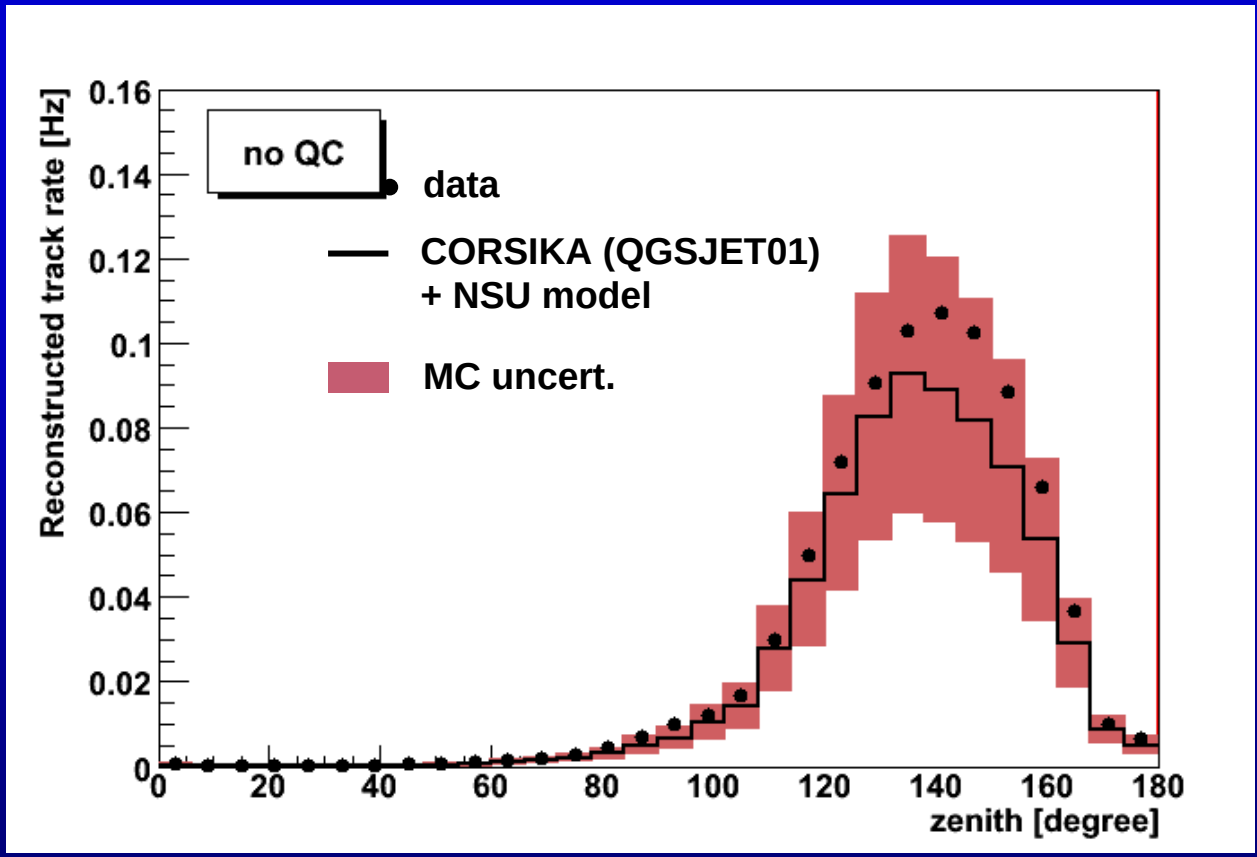
Rate per storey

Vertical muon intensity



Atmospheric muon studies with 5 lines

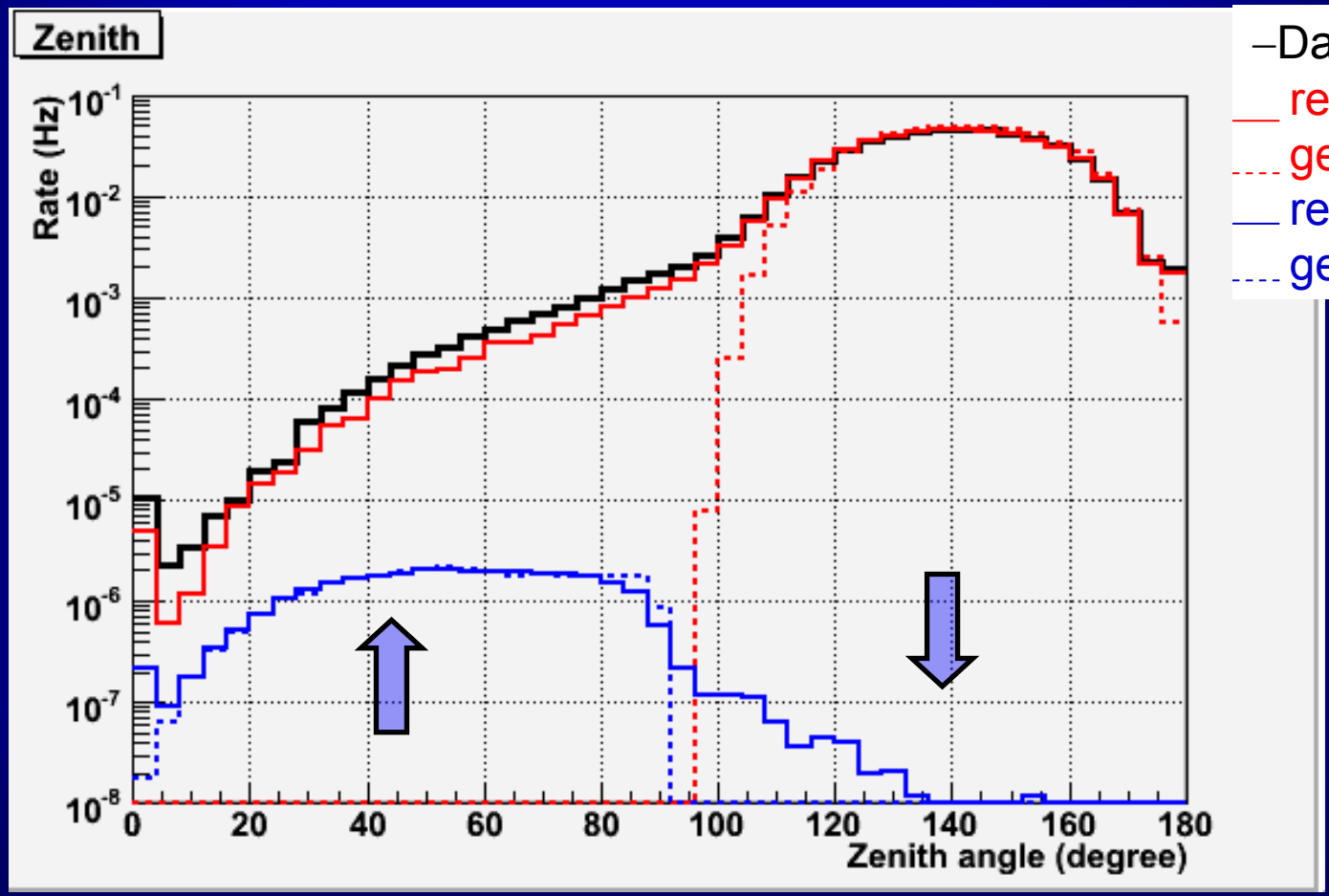




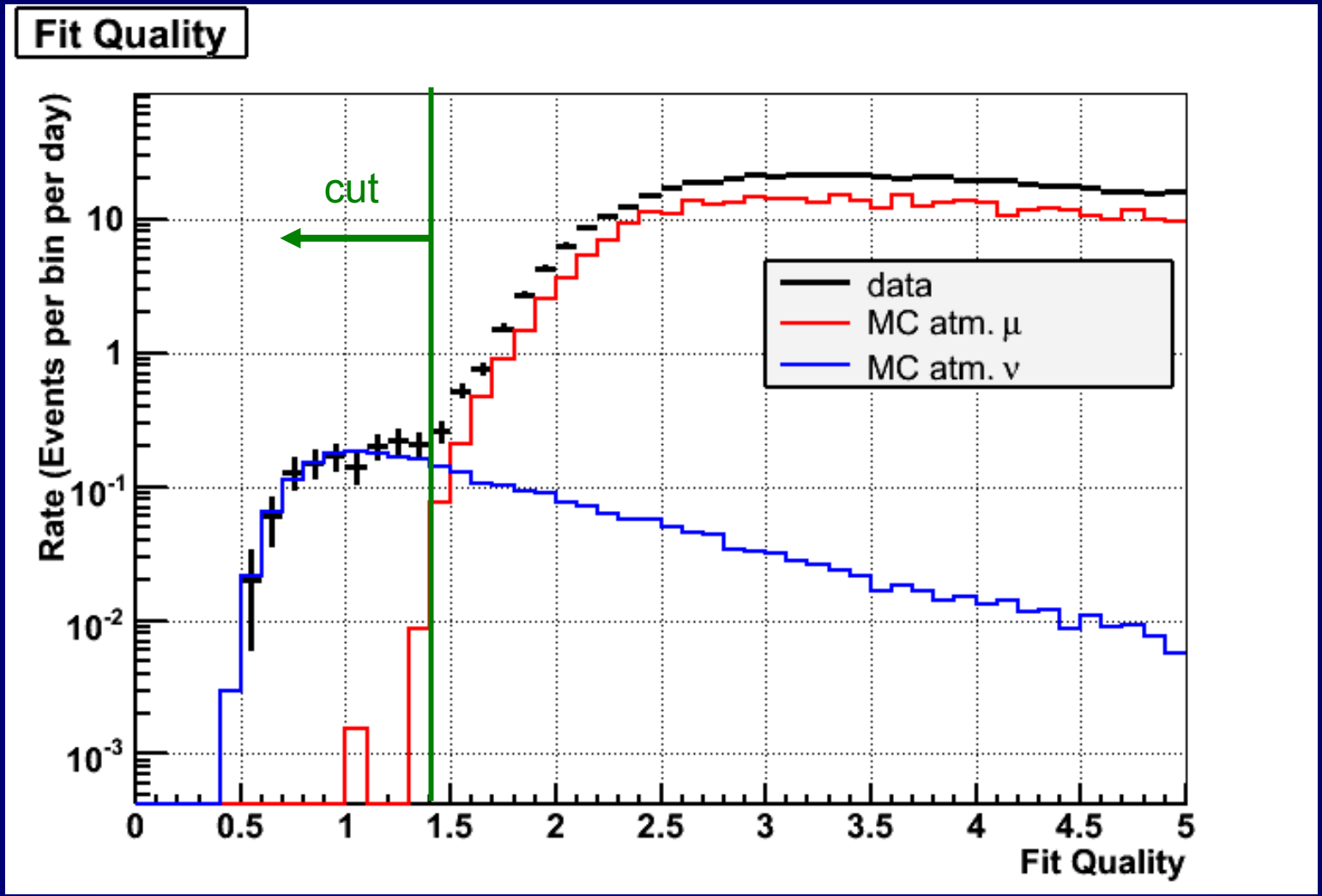
- Systematic uncertainty ± 30%
- Main contributions
  - optical module response
  - absorption length of the light in water

Neutrinos :comparison MC-data

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



upgoing μ with quality cuts



data	For Q<1.4 muons	neutrinos
1.29/day	0.01/day	1.22/day

Total neutrinos (multiline+1 line rec.):

2007: 243 ν (5 lines)

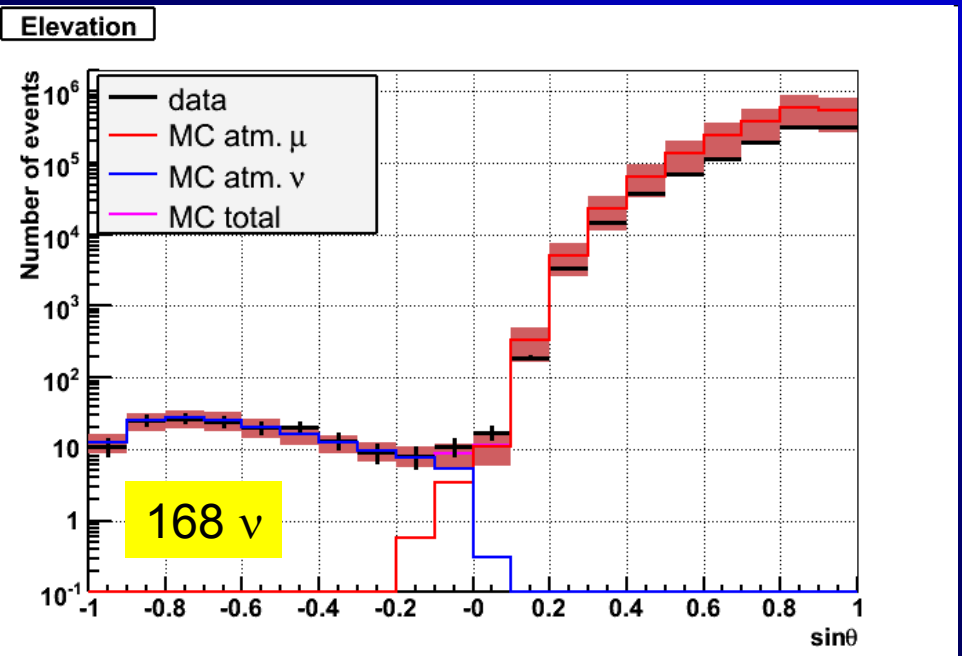
2008: 749 ν (9-10-12 lines)

~10^3 reconstructed neutrinos

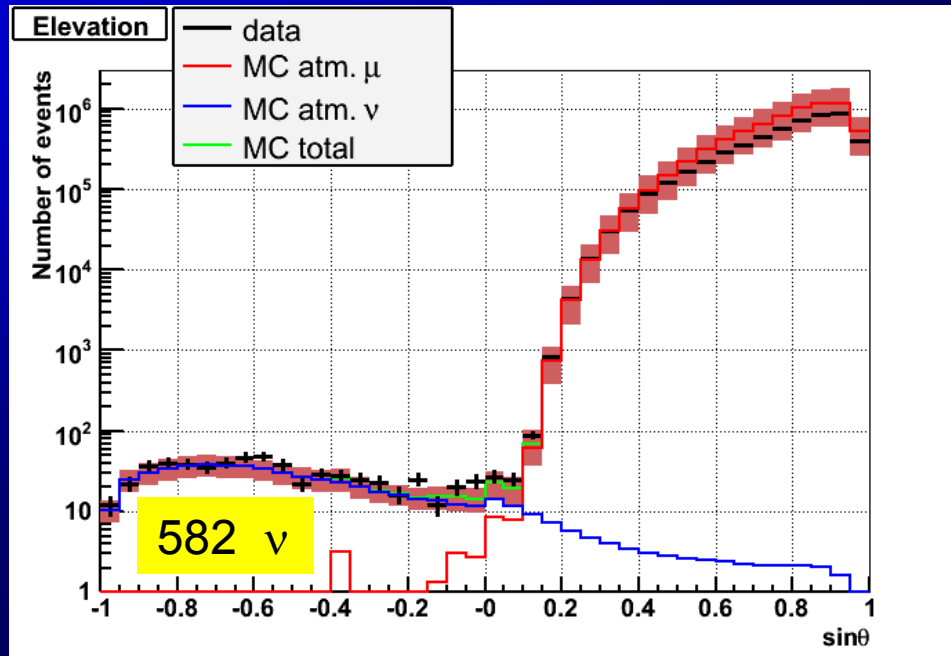
2007: 5 lines

Dec 2007 -Feb 2008 : 10 lines
March - May 2008 : 9 lines
June - Dec 2008: 12 lines

Multiline reconstruction



Multiline reconstruction



Point-like source search

-Analysis of 5 line data
-140 active days
- analysis optimized on background obtained by scrambling real data

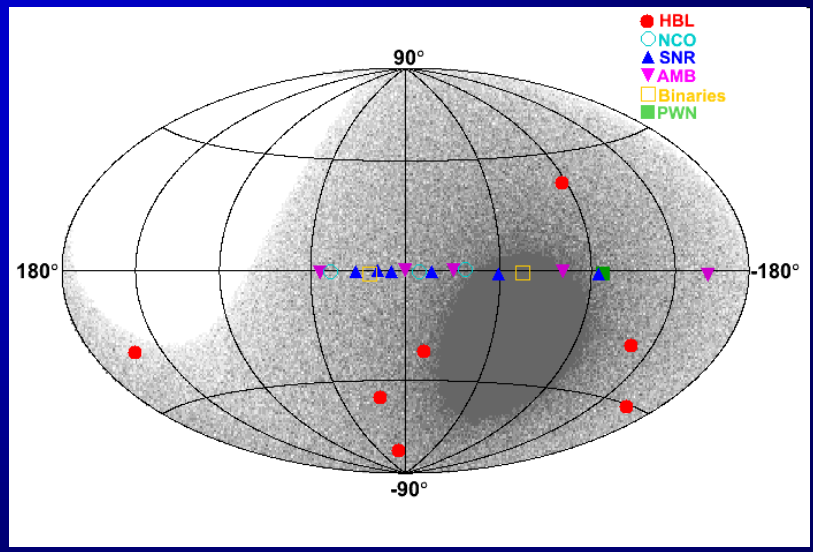
Binned method:

-optimization of the size of the search cone in order to maximize the probability of finding a cluster of events incompatible with background
-minimization of the Model Rejection Factor (MRF): the ratio between the average upper limit, which depends on the expected background inside the search cone, and the signal in this cone.

Unbinned method:

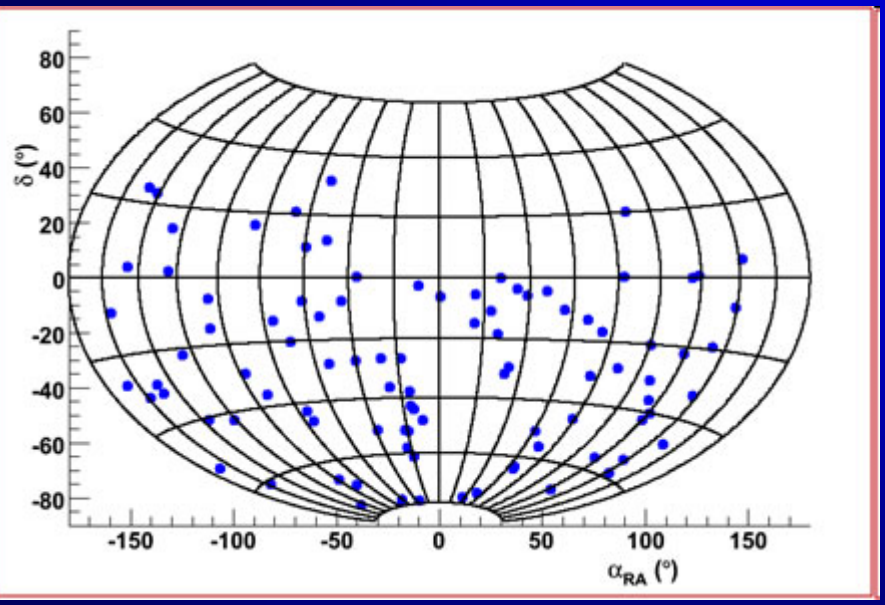
-Uses a clustering analysis that searches for structure in the data
- maximization of the Likelihoods ratio of Signal/Noise

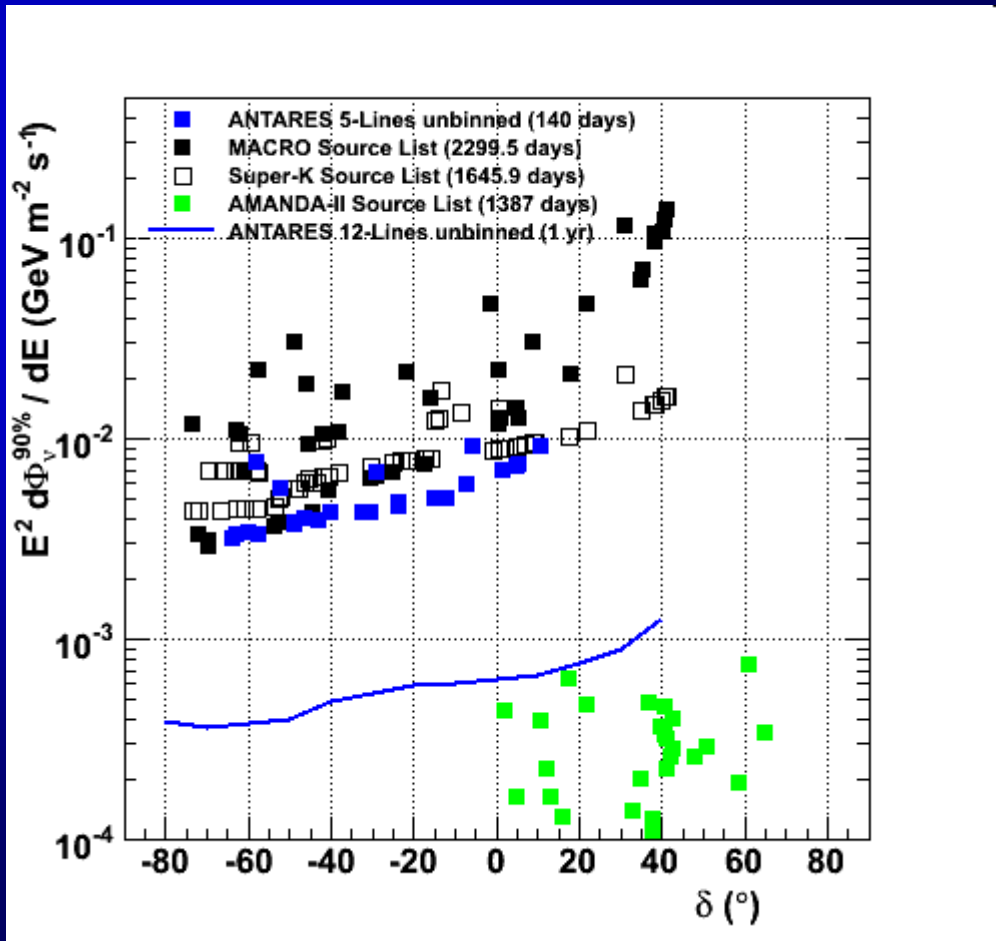
25 preselected sources



Point-like source search: limits

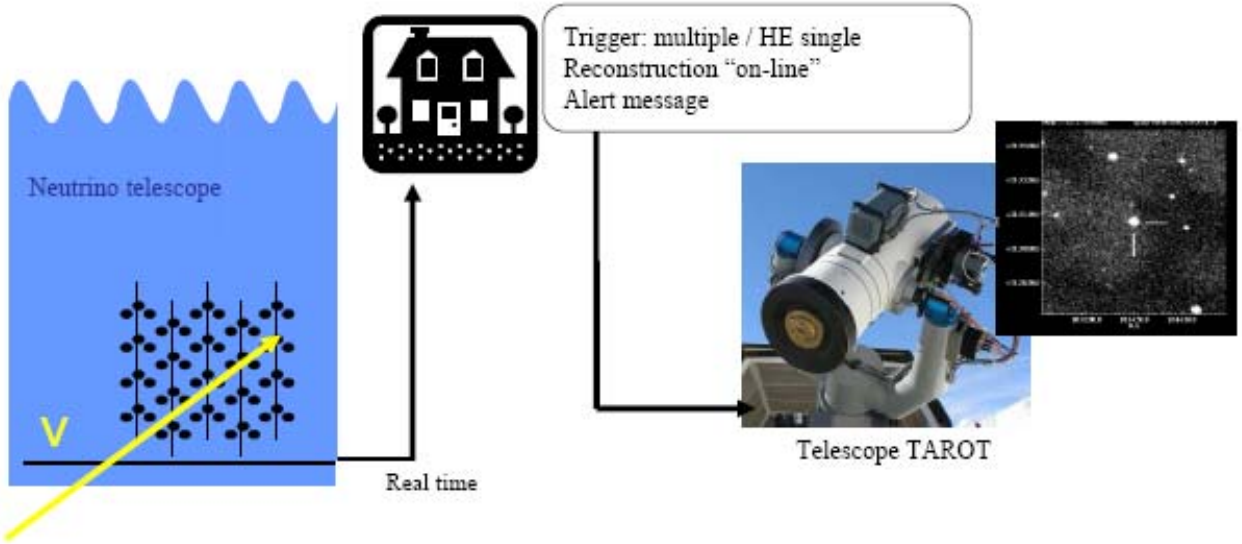
- 94 events obtained
- no excess statistically significant has been found
- competitive limits have been set





ANTARES & other detectors
•the TAToO project

Principle



2 programs: Create the neutrino alert (BBalert)

Send it to the TAROT telescopes (TAToO run control)

2 trigger logics

Doublet of neutrino events (burst):

2 events coincidence rate:

$$R_2^{atm} \approx 2\left(\frac{\Delta\Omega}{2\pi}\Delta t\right)\left(R_1^{atm}\right)^2$$

Application to ANTARES:

$R_1^{atm} \approx 1500\,yr^{-1}$

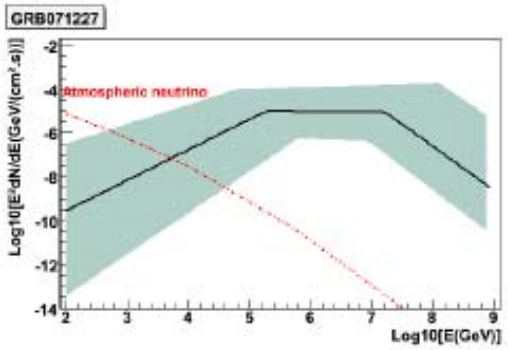
$\Delta\Omega = 3° \times 3°$

$\Delta t = 15$ min

$$R_2^{atm} \approx 0.05\,yr^{-1}$$

Single neutrino event with HE:

Above ~20 à 50 TeV, the background rate begins to be negligible



We want to send 1 or 2 alerts per month

TAROT

TAROT: two 25 cm telescopes located at Calern (South France) and La Silla (Chile)

- fov 1.86° x 1.86°
- Magnitude V<17 (10s)
  V<19 (100s)
- ~ 10s repositioning after the alert reception

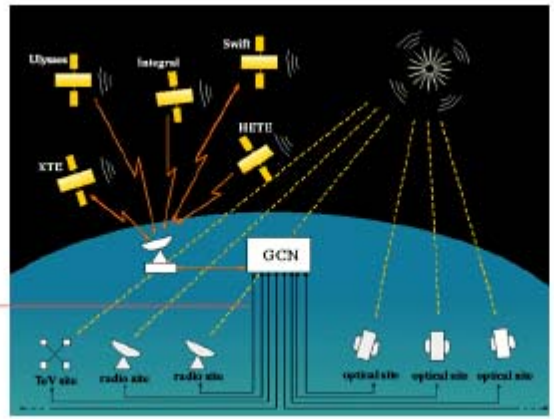
Limit: no observation in the galactic plane

GCN

Gamma-ray burst Coordinates Network

http://gcn.gsfc.nasa.gov/

ANTARES is a client for the GRB alerts

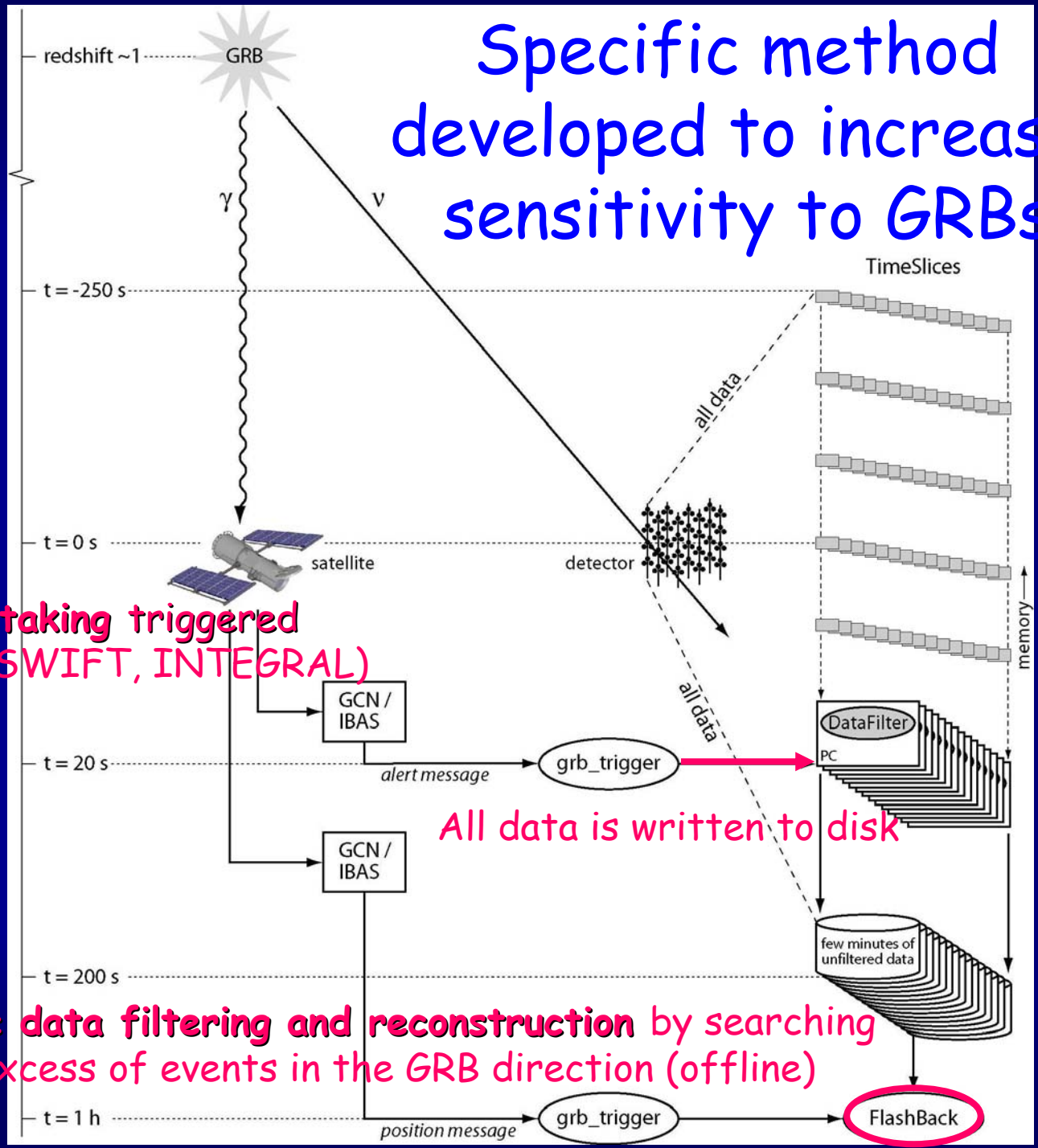


Two parts to the GRB Coordinates Network :

(1) Real-time (& near real-time) distribution of GRB locations detected by various spacecrafts (Swift, HETE, INTEGRAL, Fermi…)

(2) Distribution of follow-up observation reports submitted by the GRB community.

Specific method developed to increase sensitivity to GRBs



Specific data taking triggered by a satellite (SWIFT, INTEGRAL)

All data is written to disk

Specific data filtering and reconstruction by searching for an excess of events in the GRB direction (offline)

M. Bouwhuis, ANTARES PhD Thesis

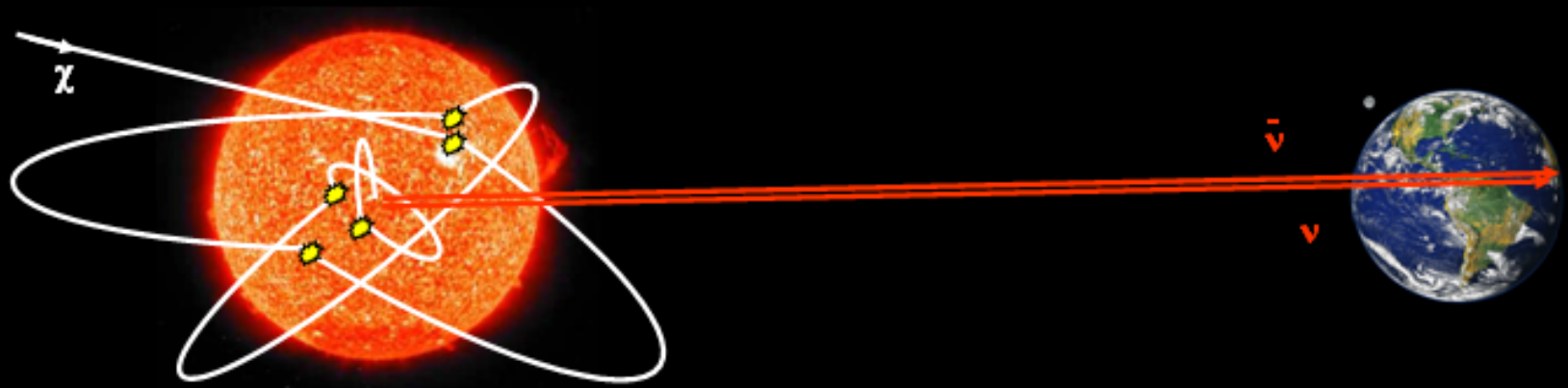
On going studies in Dark Matter group

- Determination of ν/μ flux from SUSY Dark Matter annihilations in the Sun :

  →extensive scan of mSUGRA parameter space, determination of ANTARES and KM3NeT sensitivities
  →on going studies of other SUSY models
- Search for neutrino signal from the Sun :

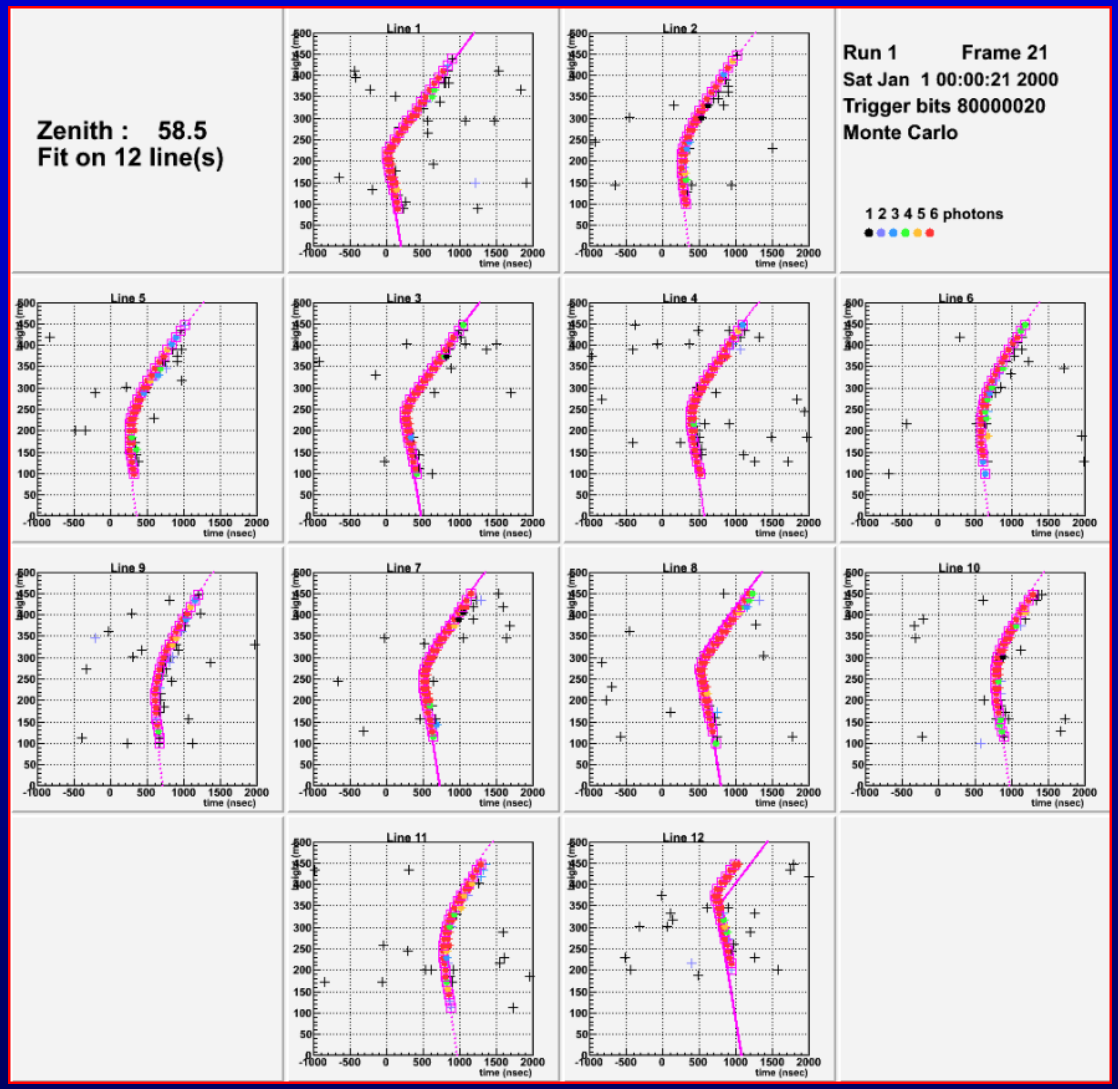
  →First limit with 5-line data using Aart strategy selection
  →Sensitivity for full ANTARES detector
- Search for neutrino signal from KK Dark Matter annihilation in the Sun :
  →Analysis of 5-line data using Aart strategy selection
  →Sensitivity for full ANTARES detector
- Search for Dark Matter annihilation in the Earth :
  →Analysis of 5-line data using Aart strategy selection (not yet presented in ANTARES meeting…)
- Improvement of reconstruction for low energy muons :
  →new hits selection, prefit/fit strategies under development…

Upper limits on Φ_{ν} and Φ_{μ} from neutralino annihilation in the Sun using Line 1-5 data

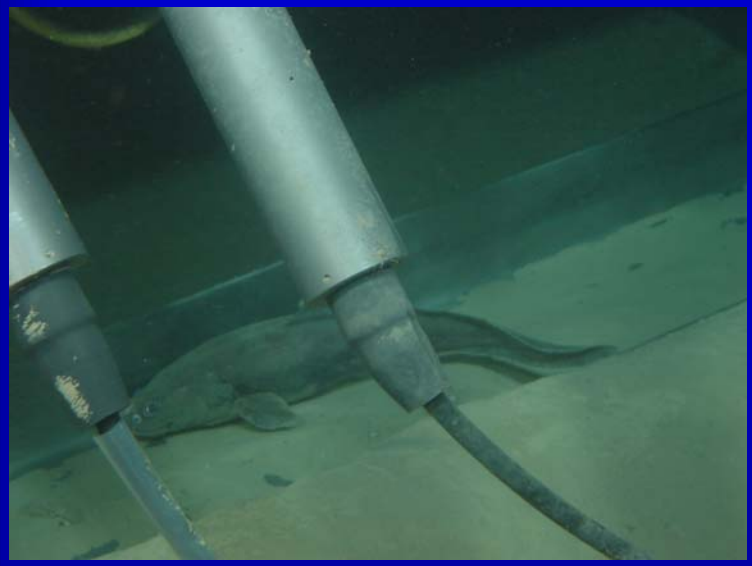


Gordon Lim – University of Amsterdam / Nikhef

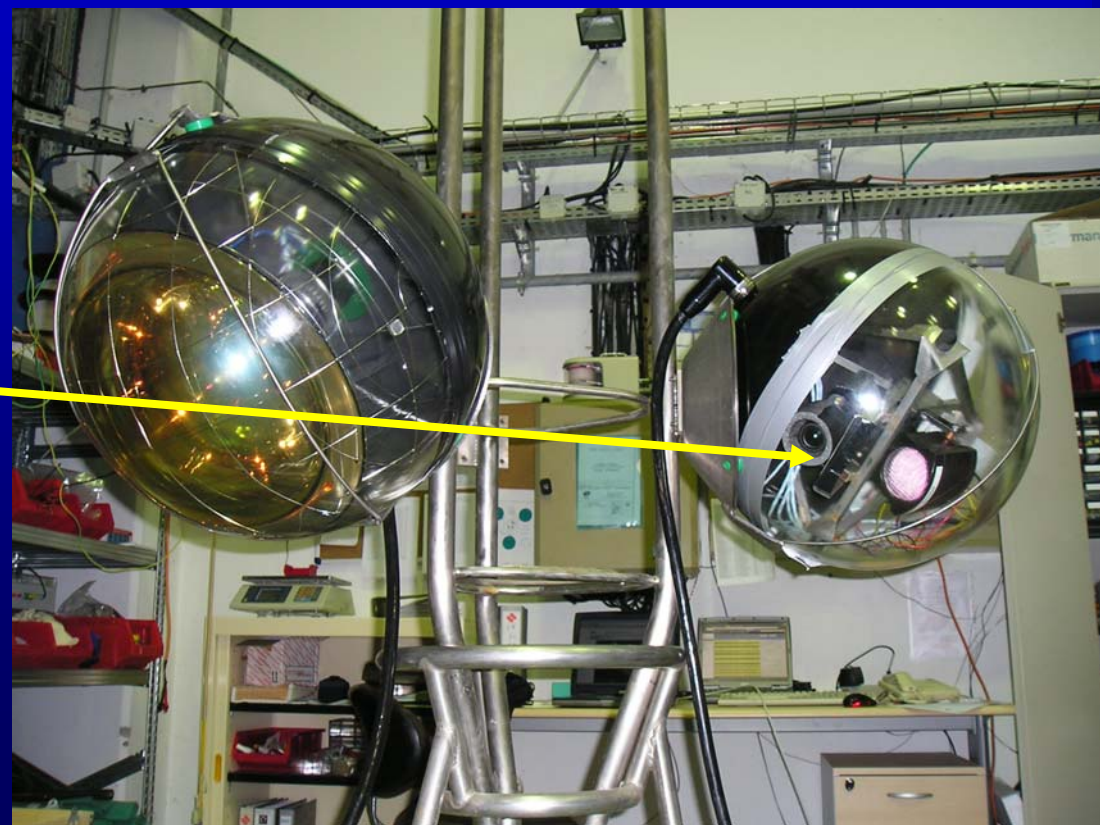
Upgoing Magnetic Monopoles with a 12-Line Detector



Associated Science
bioluminescent marine life

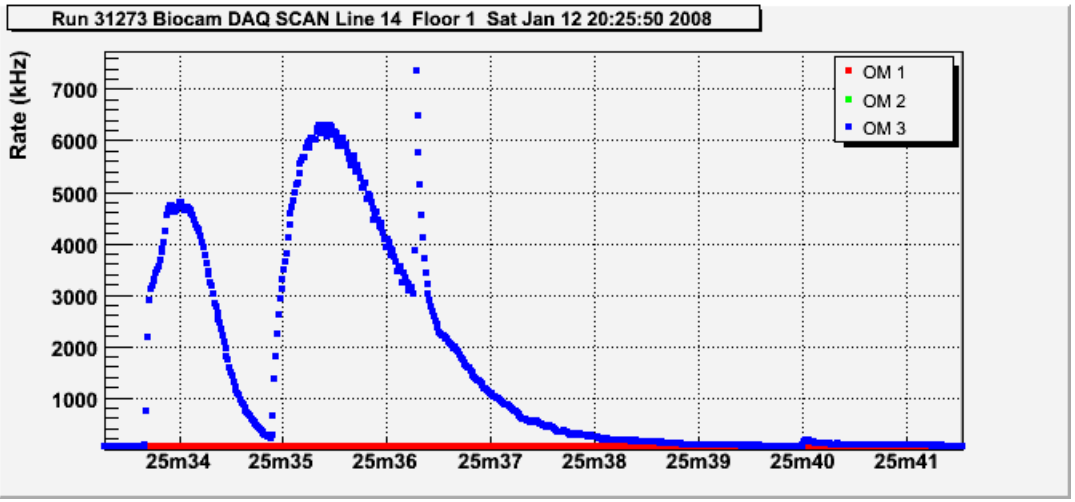


Installation of Camera + IR source



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

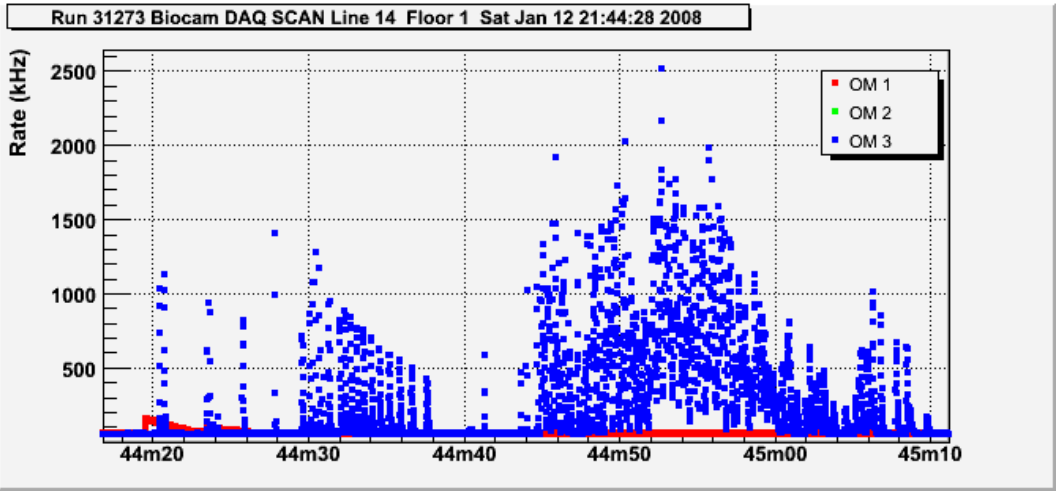
Examples of bioluminescence events



-150 bioluminescent triggers registered

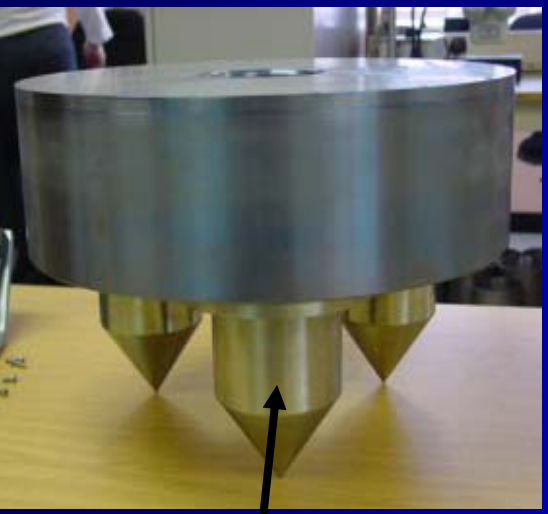
- 4 different types of signals

DEEPEST ONLINE CAMERA IN THE WORLD!



Multidisciplinary research activities:

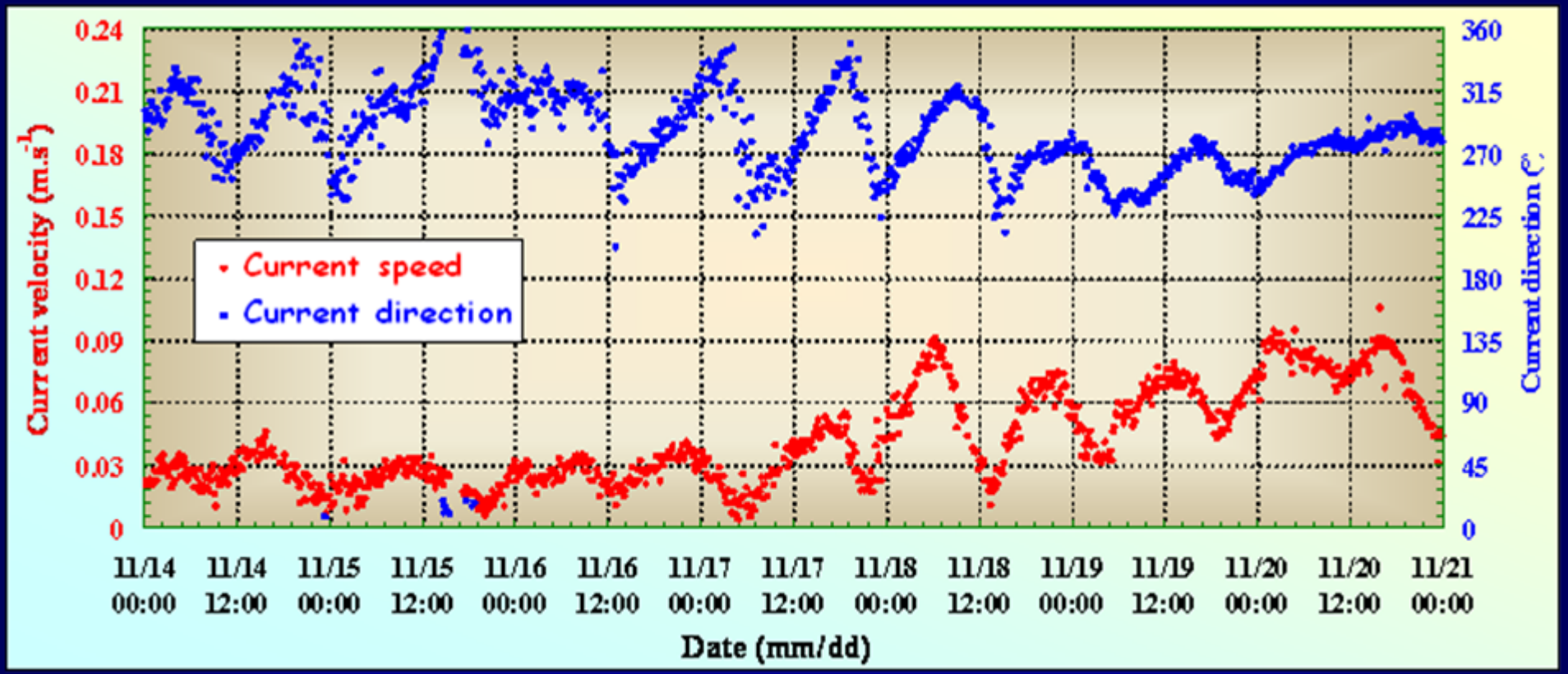
seismometer



Already used on the MILOM line (2005-2006) and now installed on line 12

Multidisciplinary research activities:

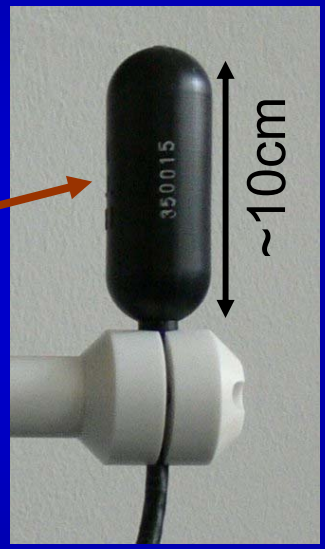
sea current



Data from the ADCP are currently being analyzed by NIOZ

Setup of Acoustic Storeys with Hydrophones

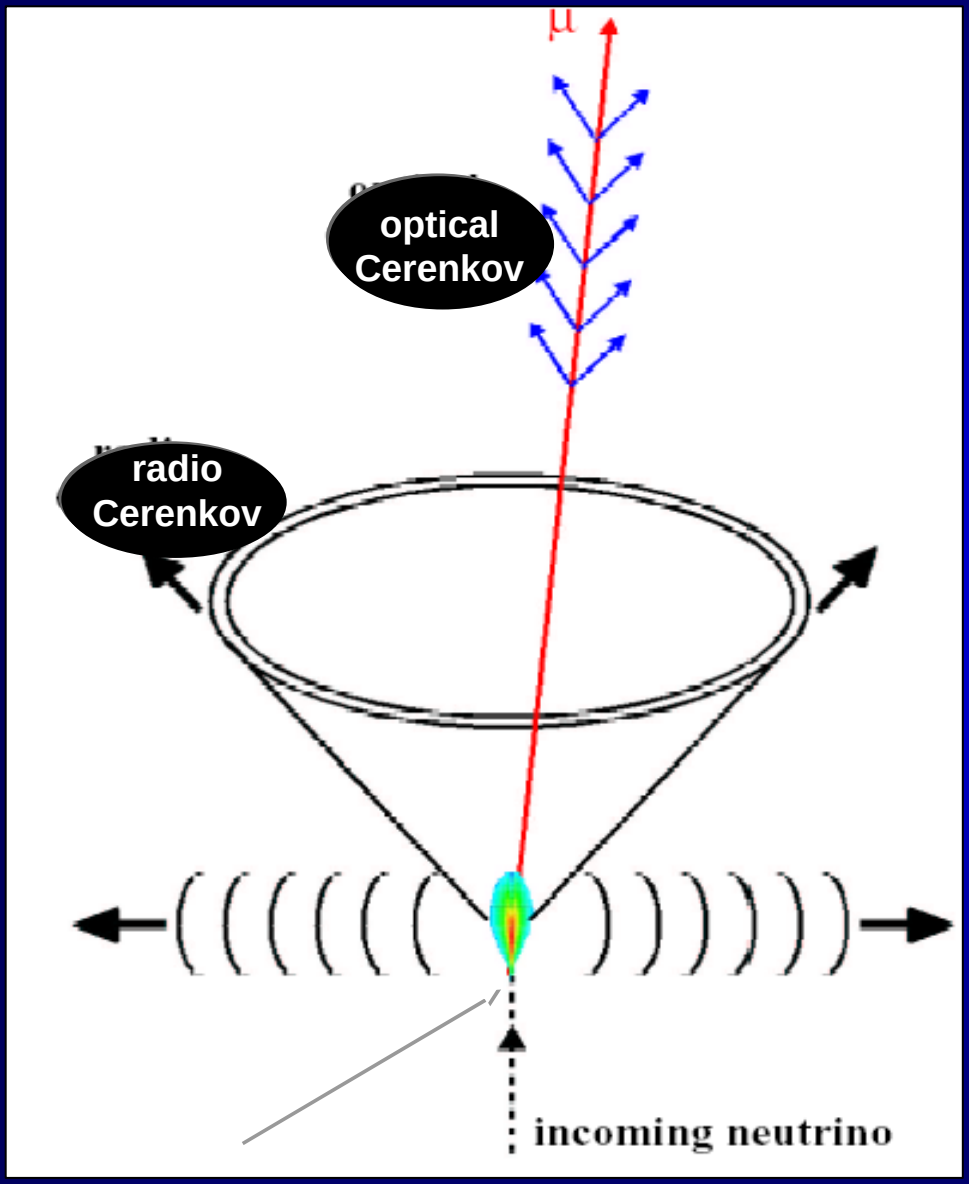
Hydrophone:
Piezo element with pre-amplifier and filter in PU (Polyurethane) coating



Titanium cylinder with electronics

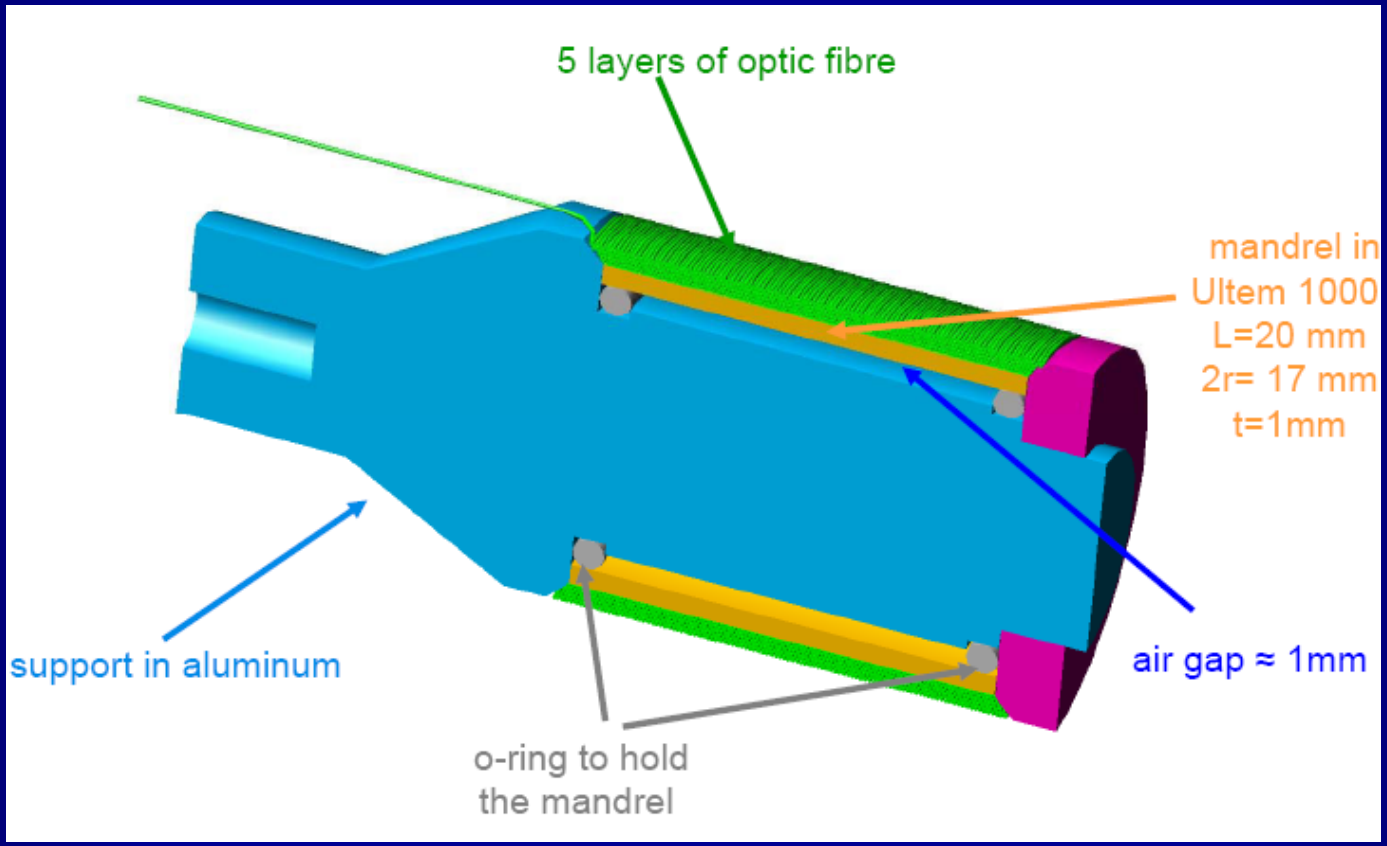
3 Acoustic ADC boards

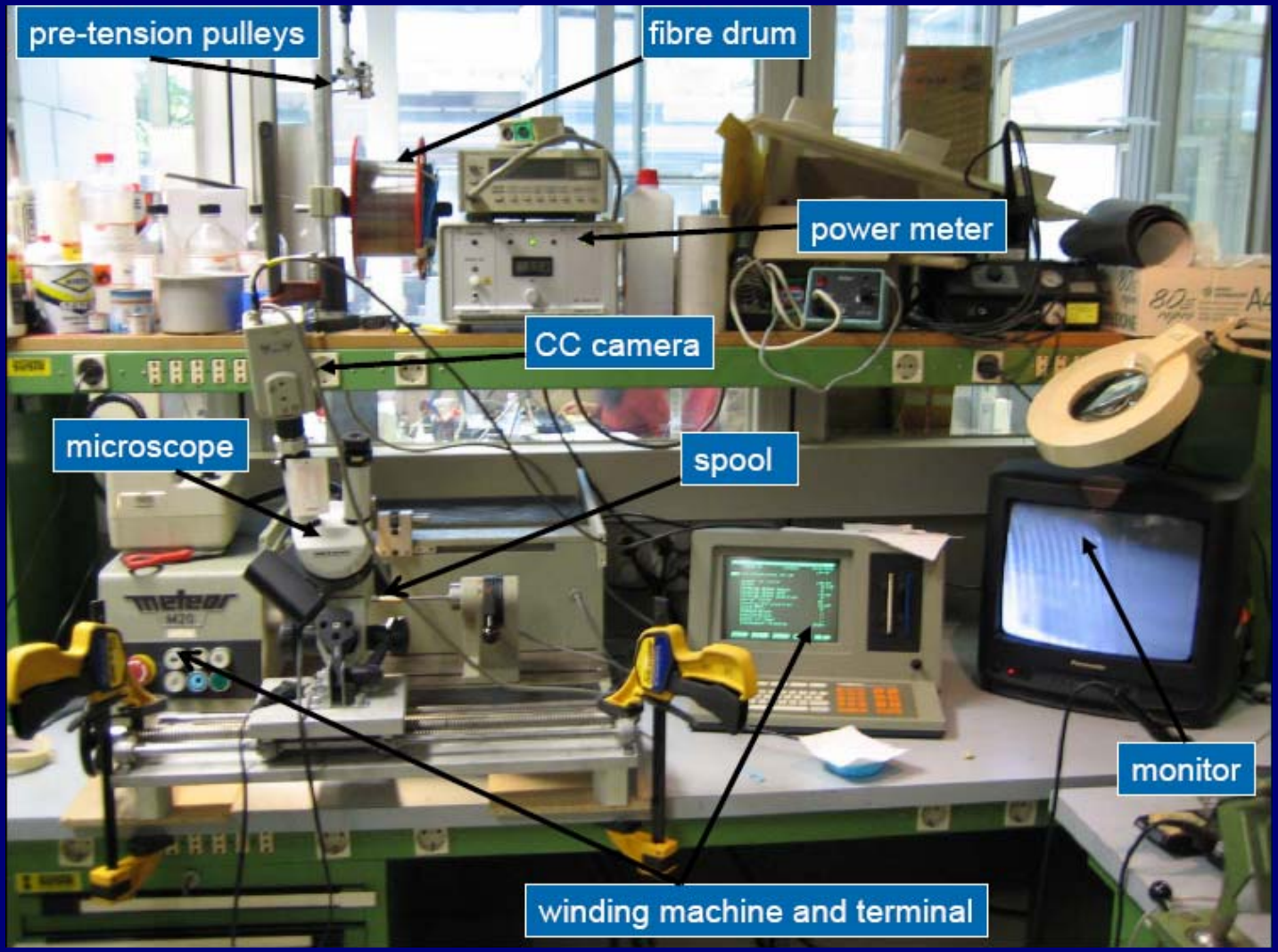
Detection principle

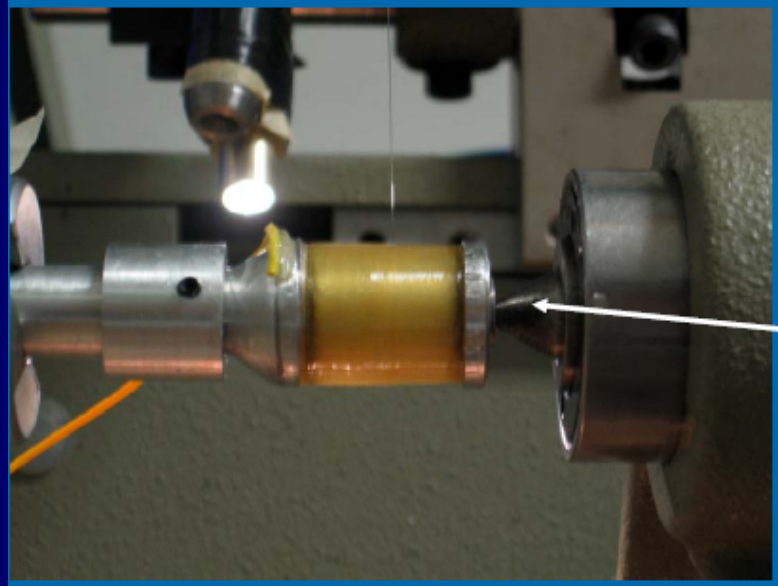


acoustic waves produced by the hadronic shower
neutrino must have 10^{17}-10^{18} eV

G.A.Askarian, B.A.Dolgoshein, A.N.Kalinovsky, N.A.Mokhov: Acoustic detction of high energy particle showers in water. Nucl. Inst. and Meth., 164 (1979), 267.


5 layers of optic fibre
mandrel in
Ultem 1000
L=20 mm
2r= 17 mm
t=1mm
support in aluminum
air gap ≈ 1mm
o-ring to hold
the mandrel


pre-tension pulleys
fibre drum
power meter
CC camera
microscope
spool
monitor
winding machine and terminal



One prototype already realized

The hydrophone without the polyurathane coating in the winding pahse

INFN ISTITUTO NAZIONALE DI FISICA NU

Sezione di Genova

INF
Oct

A FIBER OPTIC AIR BACKED MANDREL HYDROPHONE TO D
ENERGY HADRONIC SHOWERS IN THE WATER

M.Anghinolfi[1], A.Calvi[3], A.Cotrufo[3], M.Ivaldi1, O.Yershova[2], F.Parodi
A.Plotnikov[2] and L.Repetto[3]

[1] INFN-Sezione di Genova, Via Dodecaneso 33, I-16146 Genov
[2] Moscow State University, 119992 Moscow, Russia
[3] Università degli Studi di Genova, Dipartimento di Fisic
Via Dodecaneso 33, I-16146 Genova, Italy

INFN ISTITUTO NAZI

Sezi

THE REALIZATION OF AN C
HYDROPHONE FOR

M.Anghinolfi[1], A.Calvi[3], A.Cotrufo[3],
A.Plotnil

[1] INFN-Sezione di Genova, V
[2] Moscow State Univ
[3] Università degli Studi di Genova, Di
G

INFN ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Genova

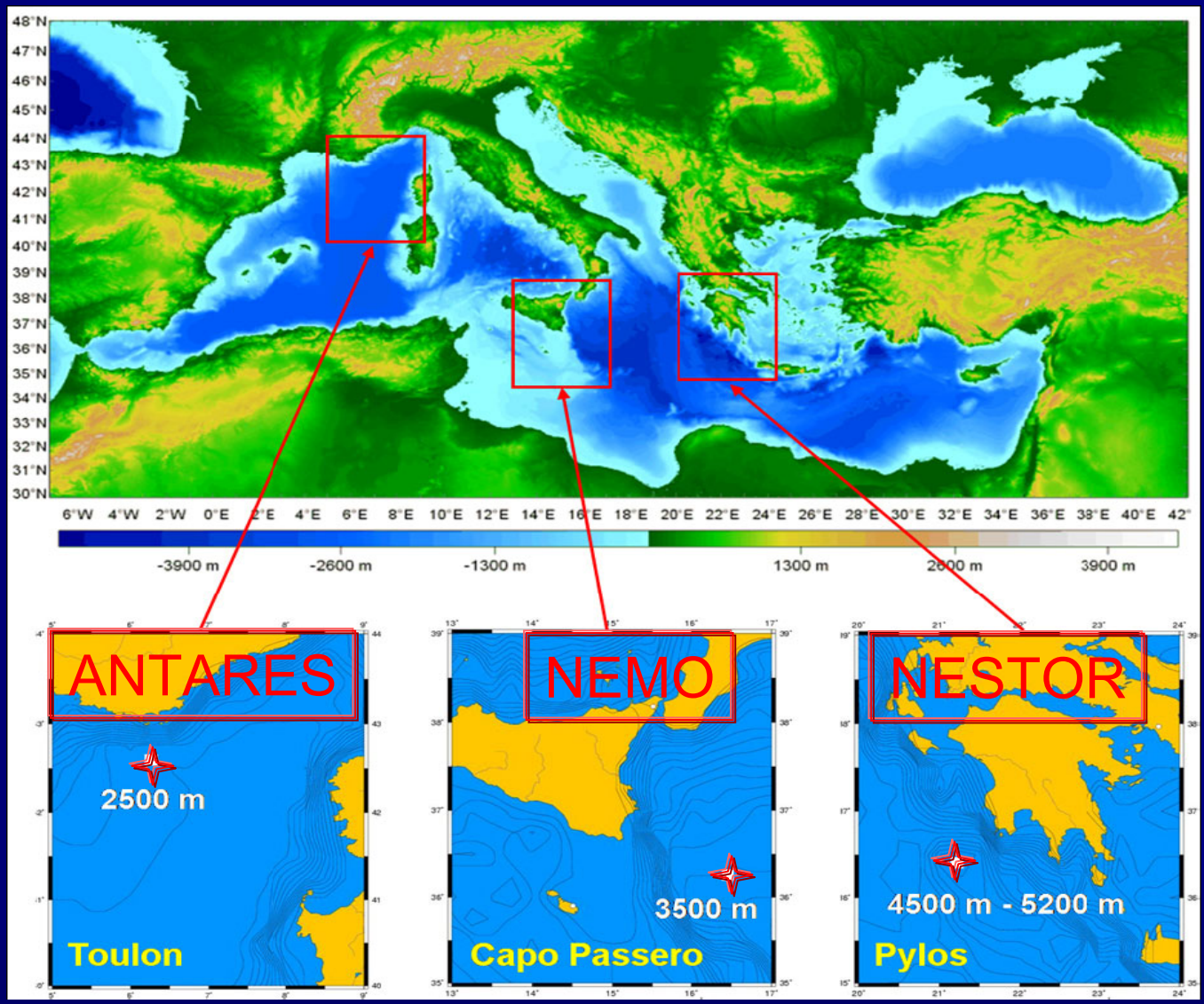
INFN/code-98/001
October 4, 2007

MEASUREMENT OF THE FREQUENCY RESPONSIVITY OF A FIBER OPTIC AIR BACKED MANDREL HYDROPHONE UP TO 10 KHZ IN AIR

M.Anghinolfi[1], A.Bersani[1], A.Calvi[3], A.Cotrufo[3], M.Ivaldi[1], O.Ershova[2], F.Parodi[1], D.Piombo[1], A.Plotnikov[2] and L.Repetto[3]

[1] INFN-Sezione di Genova, Via Dodecaneso 33, I-16146 Genova, Italy
[2] Moscow State University, 119992 Moscow, Russia
[3] Università degli Studi di Genova, Dipartimento di Fisica,
Via Dodecaneso 33, I-16146 Genova, Italy

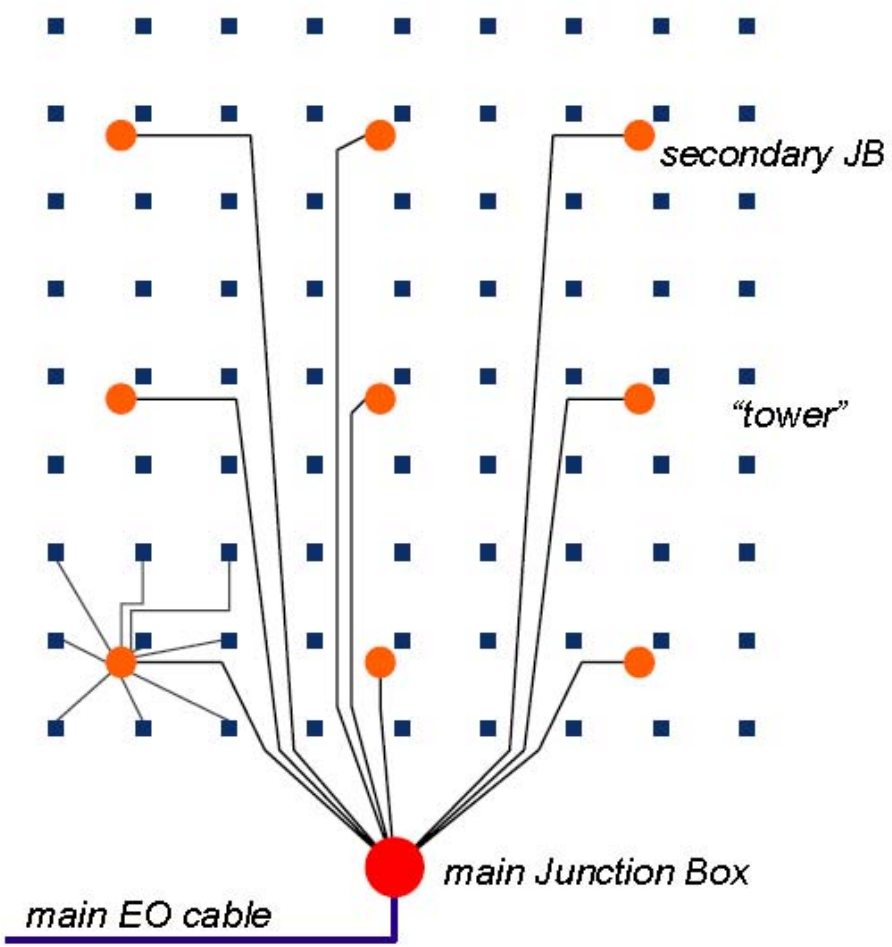
...other projects in the Mediterranean sea

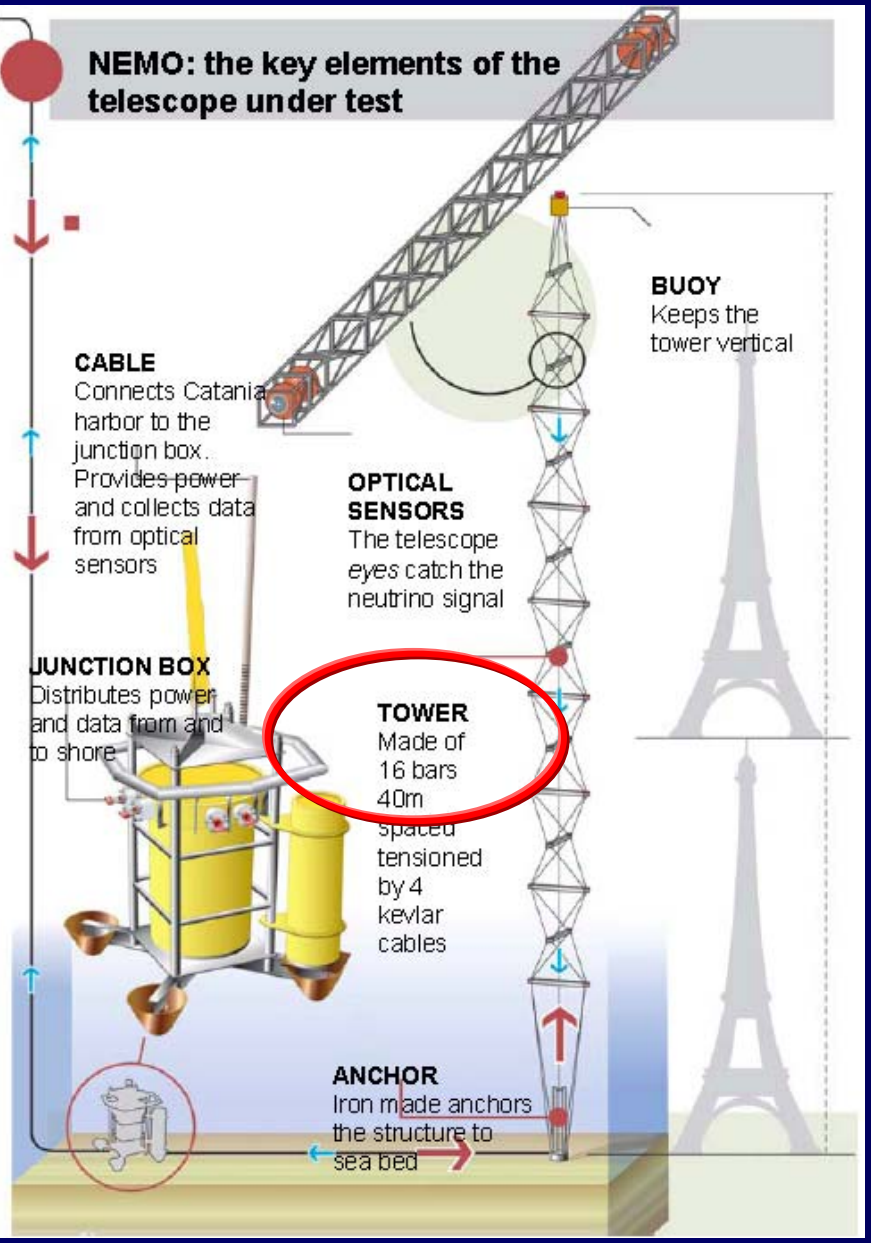


NEMO-the design

Reduce the number of structures to reduce the number of underwater connections and allow operation with a ROV

Detector modularity





the future: a bigger detector at a km^3 scale

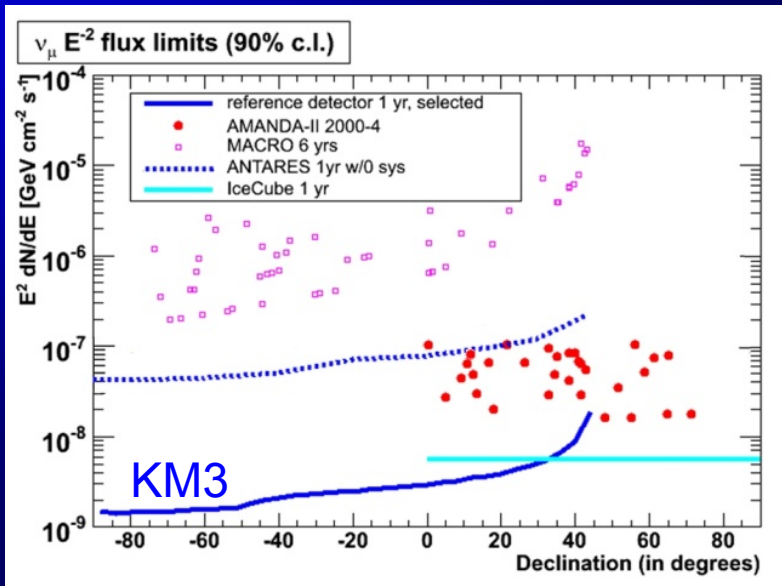
- Science & technology
  - Successful prototype deployments by NEMO and NESTOR
  - Installation and operation of ANTARES

    → A large deep-sea neutrino telescope is feasible!
- Politics & funding
  - Endorsement by ESFRI and ApPEC
  - Funding through EU: Design Study, Preparatory Phase

- Towards construction
  - Strong collaboration
  - Design concepts in CDR

Conclusion

- 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…



MSU –Genova collaboration

-started many years ago… wish to continue
-two main lines:

- Nuclear Physics @ CEBAF
- High Energy Astrophysics with under water telescopes

ANTARES: detector completed, data analysis is underway
possible argumets of research

- atmospheric muon flux
- energy recontruction
- neutrino from supernova explosion
- dark matter search
- …

NEMO& KM3NET

- may have a boost if funds will be agreed
- engineering aspects will dominate

The ANTARES telescope has the opportunity to detect transient neutrino sources, such as gamma-ray bursts, core-collapse supernovae, flares of active galactic nuclei... To enhance the sensitivity to these sources, we have developed a new detection method based on the optical follow-up of “golden” neutrino events such as neutrino doublets coincident in time and space or single neutrinos of very high energy.

The ANTARES Collaboration has therefore developed a very fast on-line reconstruction with a good angular resolution. These characteristics allow to trigger an optical telescope network; since February 2008, ANTARES is sending alert trigger one or two times per month to the two 25 cm robotic telescope of TAROT. This optical follow-up of such special events would not only give access to the nature of the sources but also improves the sensitivity for transient neutrino sources.