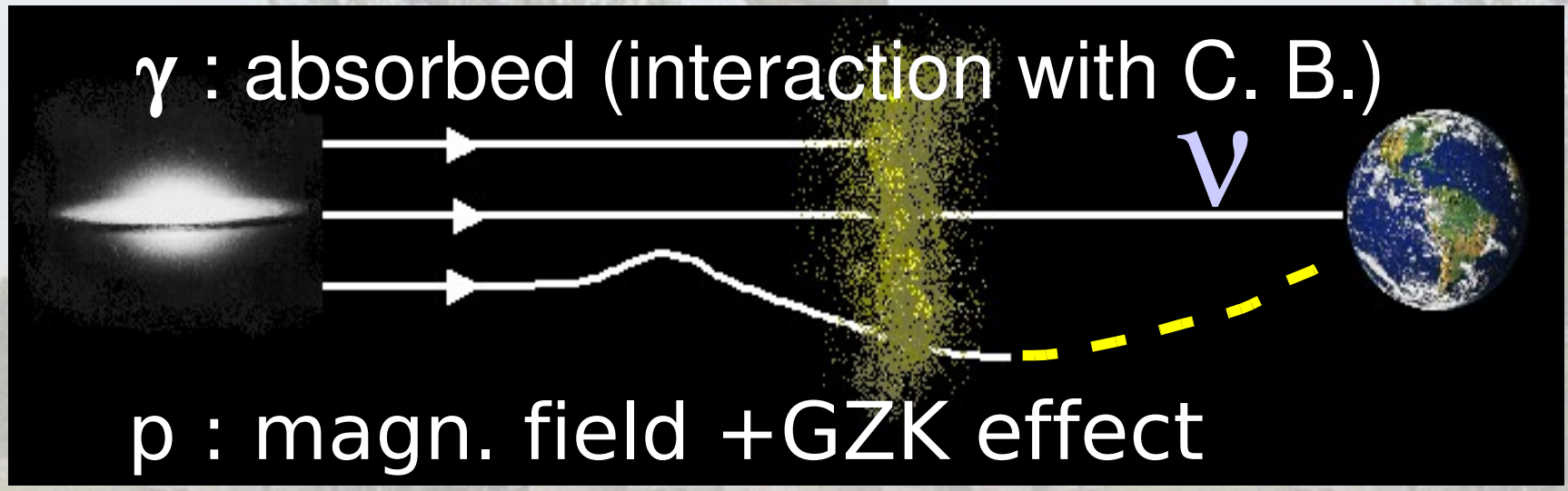
XXVI Workshop on Recent Developments in High Energy Physics and Cosmology

Ancient Olympia, April 2008

HIGH ENERGY NEUTRINO TELESCOPES

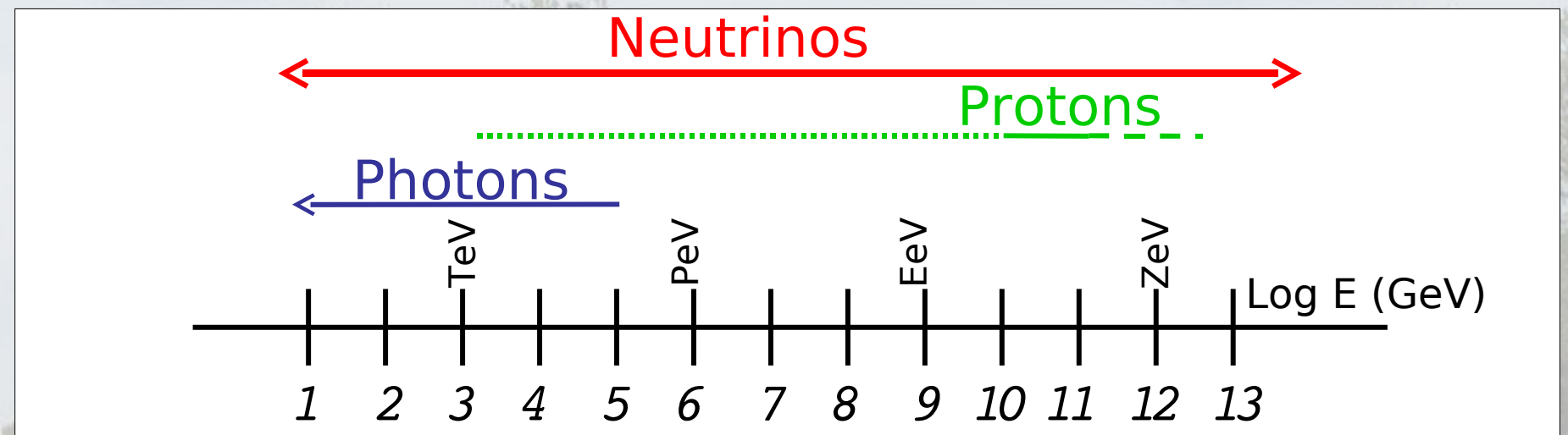
J.P. ERNENWEIN, Université de Haute Alsace, Mulhouse, FRANCE.

Why the neutrino ?



Neutrino ν :

- Weakly interacting → Source exploration on cosmological distances
- Access to the heart of sources
- Weakly interacting → large detection volume required

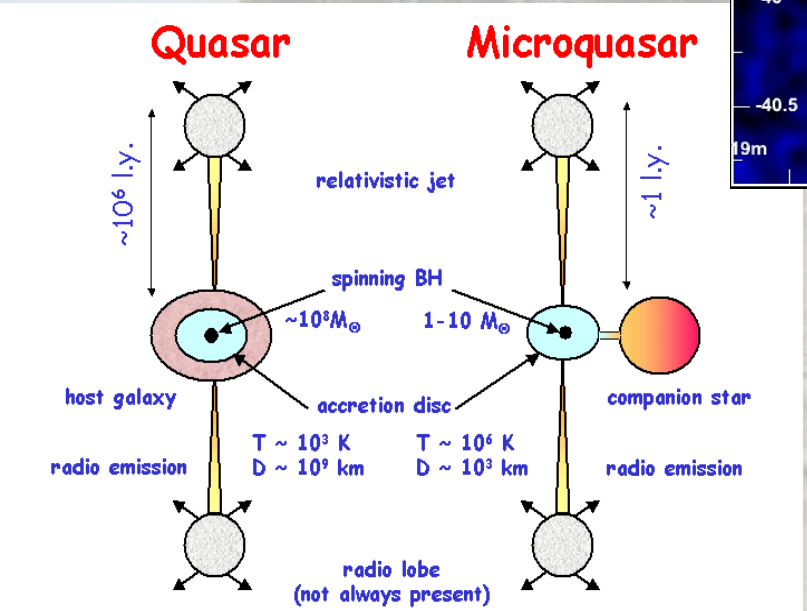


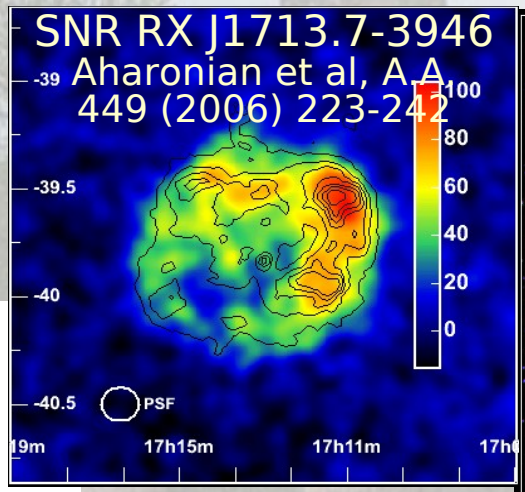
Potential sources of neutrinos

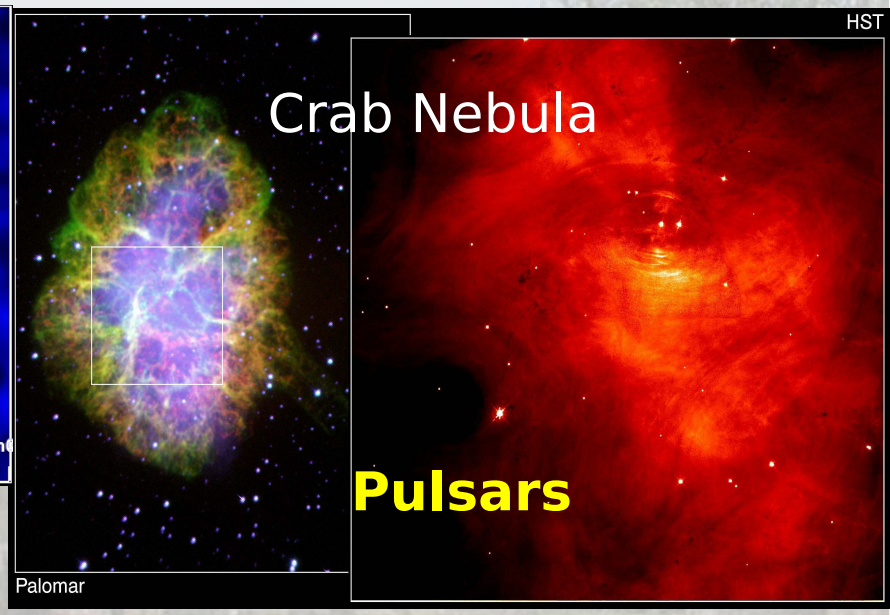
GALACTIC SOURCES:

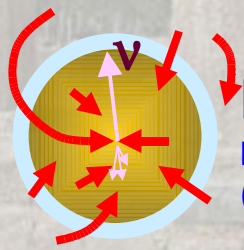
Supernovae,
Supernova remnants,

Micro Quasars:

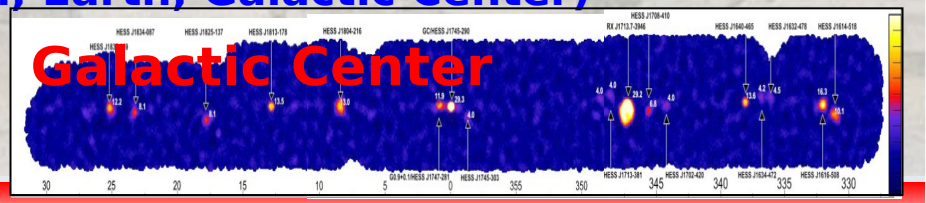






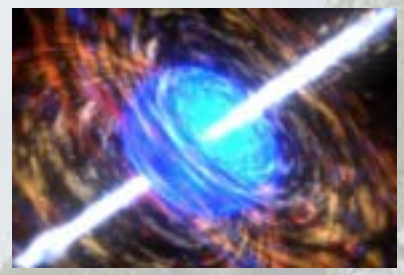


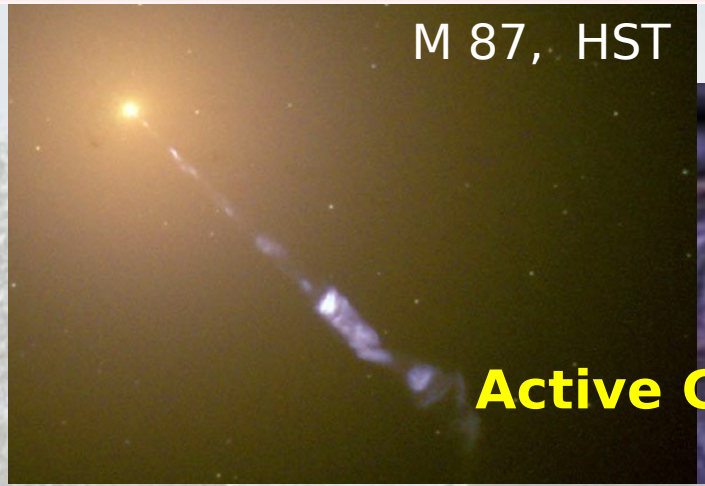
Dark Matter : annihilation of neutralinos inside massive objects (Sun, Earth, Galactic Center)



EXTRA GALACTIC SOURCES:

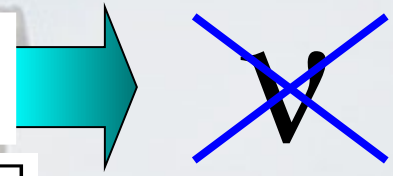
Gamma Ray Bursts

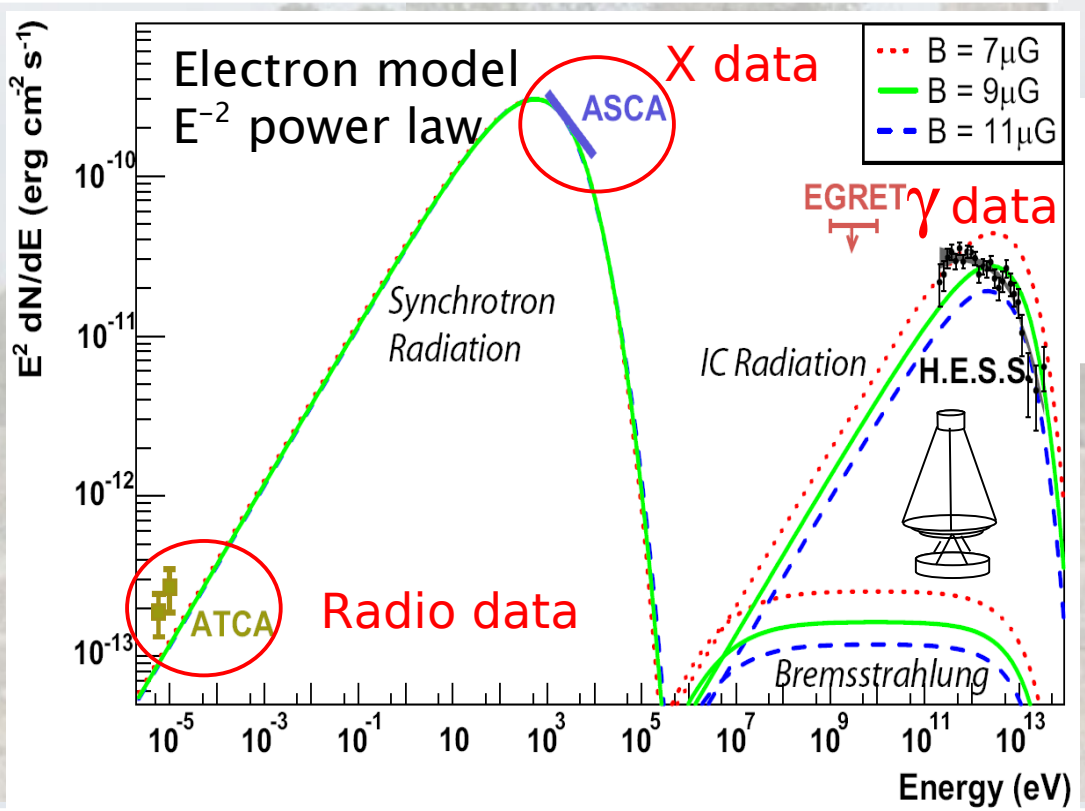




Electromagnetic or hadronic ?

e → γ (Inverse Compton, Synchrotron)

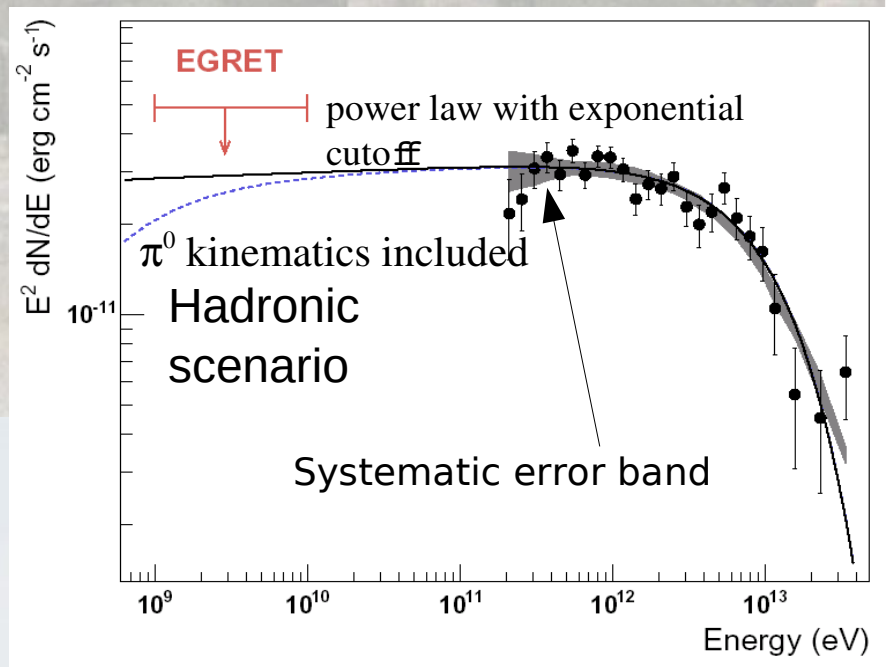




supernova remnant RX J1713.7-3946

Simplest electronic models do not work well
(very low magnetic field)

HESS, Astron. Astrophys. 449:223-242, 2006



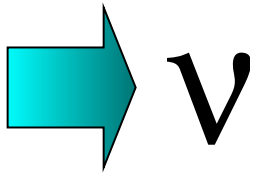
p/A + p/γ → π⁰ + π± + …

↓ ↓

γ γ **ν_μ μ**

↓

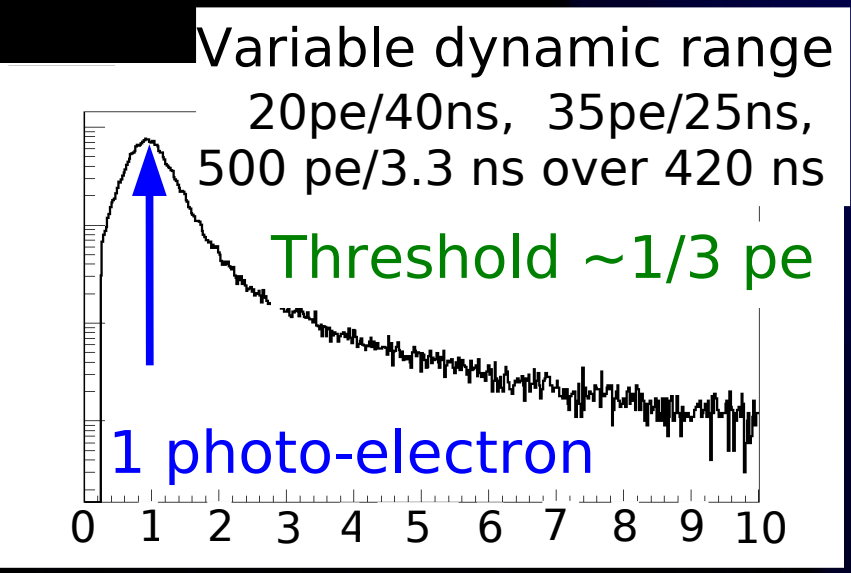
ν_μ ν_e e



Hadronic interactions

Neutrino detection principle

3D PMT array



Cherenkov light from μ

Needs to be sensitive to the single photo-electron

$\gamma_{č}$

42°

shower

Good energy resolution ($\mathcal{O}$(30%)), poor angular resolution ($\mathcal{O}$(10°))

ν_e

2500-5000 m depth

© François Montanet

Charged current interaction (W)

ν_μ

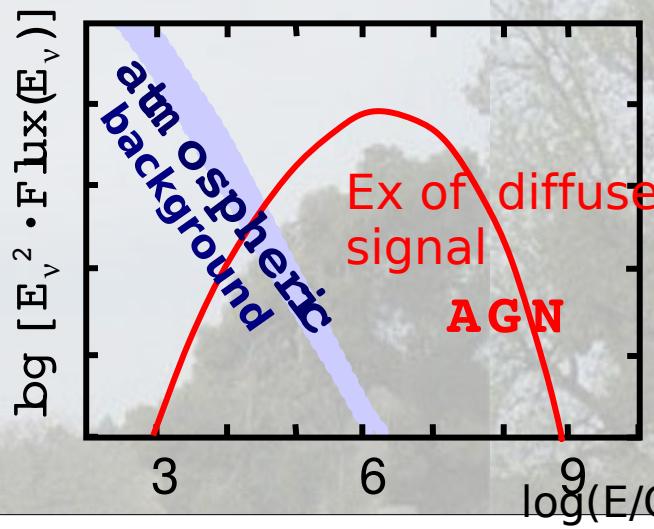
μ **track:**

Good angular resolution ($\mathcal{O}$(degree) @ E>10 TeV), poor energy resolution (factor 2-3)

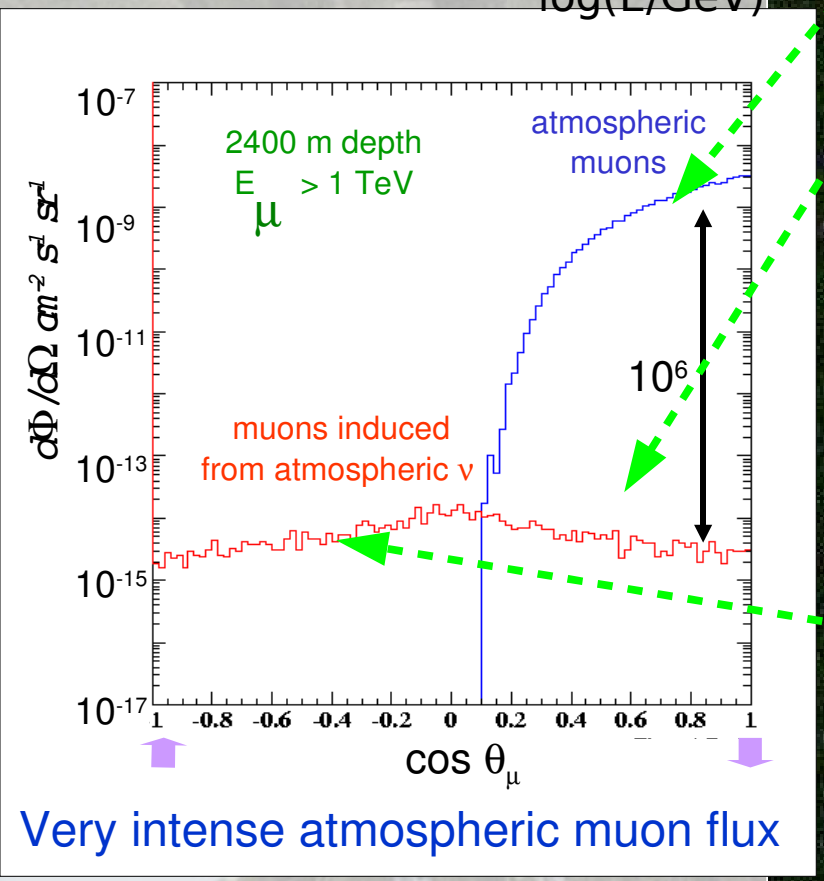
Measurements:
Time ($\mathcal{O}$(ns)), amplitude (30%) & position of hits ($\mathcal{O}$(10 cm))

μ trajectory or shower measurement

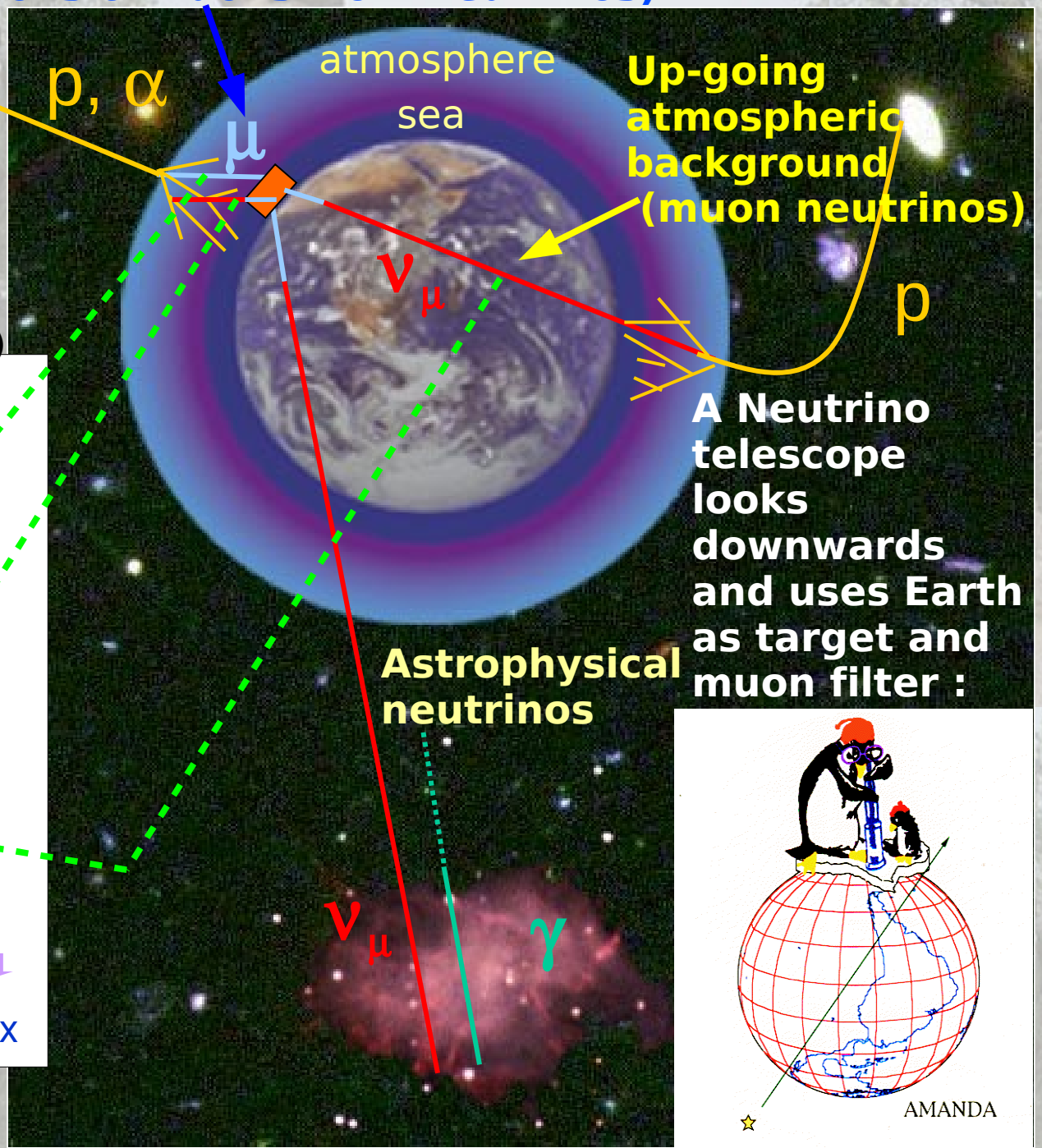
Signal & Backgrounds



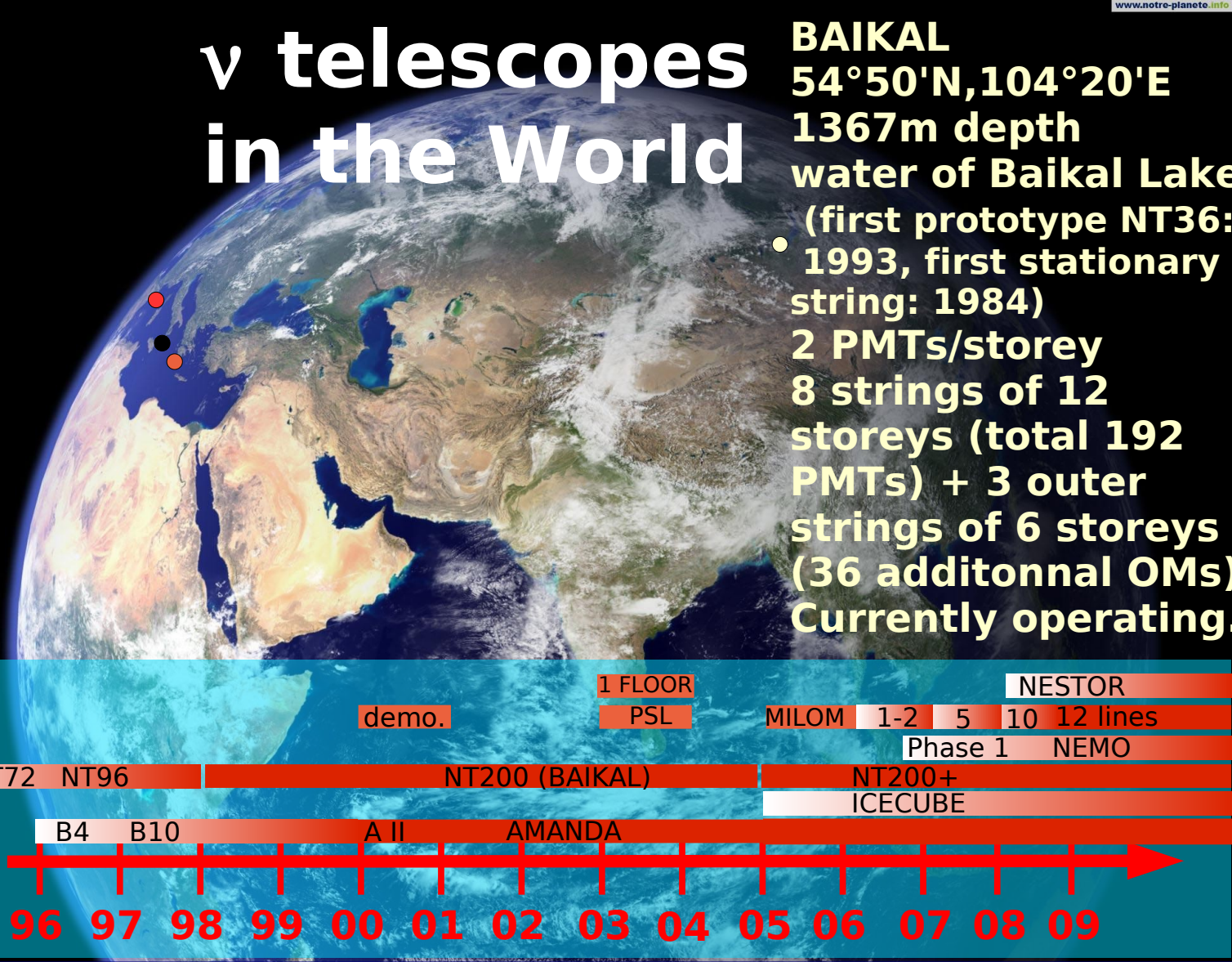
Down-going atmospheric background (direct muons & muons from neutrinos)



Very intense atmospheric muon flux



ν telescopes in the World



ANTARES
42°50'N, 6°10'E
2475m depth,
sea water
3 PMTS/floor
12 lines of 25 floors
(total 900 PMTs)
this Summer.

NEMO
36°20'N,16°E
3500m depth
sea water
4 PMTs/floor.
Currently run of a mini tower of 4 floors.
Final design: Towers of 16 floors (64 PMTs)

NESTOR
36°36'N,21°30'E
3800m depth
sea water
12 PMTs/floor
One floor immersed in 2003.
Final design : towers of 12 floors (144 PMTs)

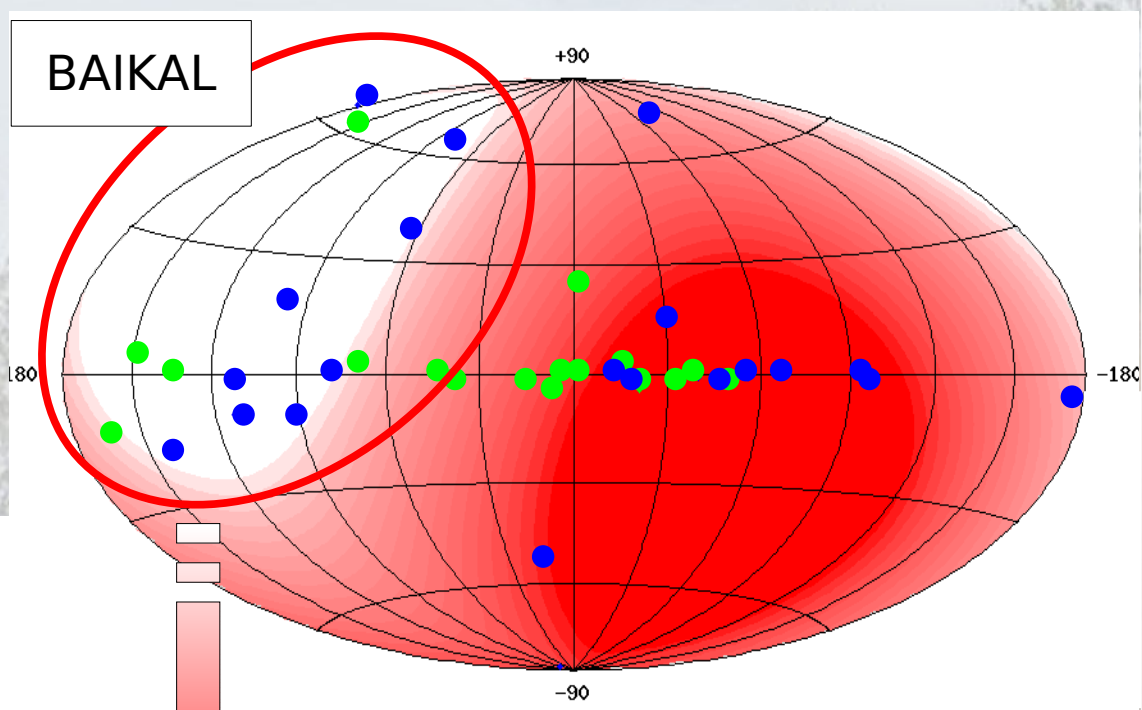
BAIKAL
54°50'N,104°20'E
1367m depth
water of Baikal Lake
(first prototype NT36: 1993, first stationary string: 1984)
2 PMTs/storey
8 strings of 12 storeys (total 192 PMTs) + 3 outer strings of 6 storeys (36 additonnal OMs)
Currently operating.

AMANDA: South Pole, ICE, 900-2350m depth, 1 PMT/floor:
AMANDA-B4 (1996): 4 strings, 80 PMTs
AMANDA-B10(1997): 10 strings, 302 PMTs
AMANDA-II(2000->now): 19 strings, 677 PMTs

ICECUBE (2450m depth):
80 strings of 60 storeys (4800PMTs). 40 strings deployed

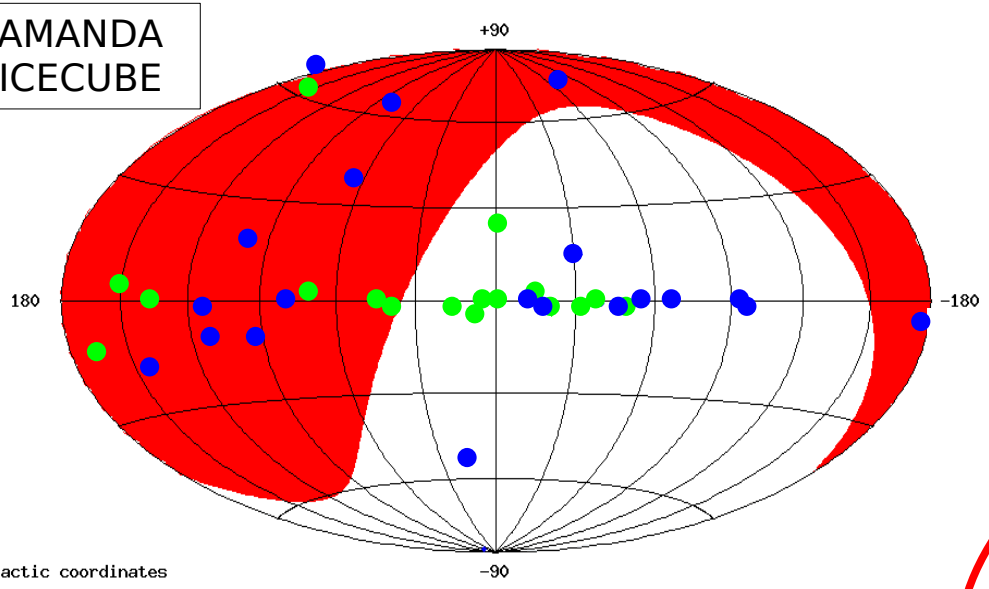
VISIBLE SKY

BAIKAL

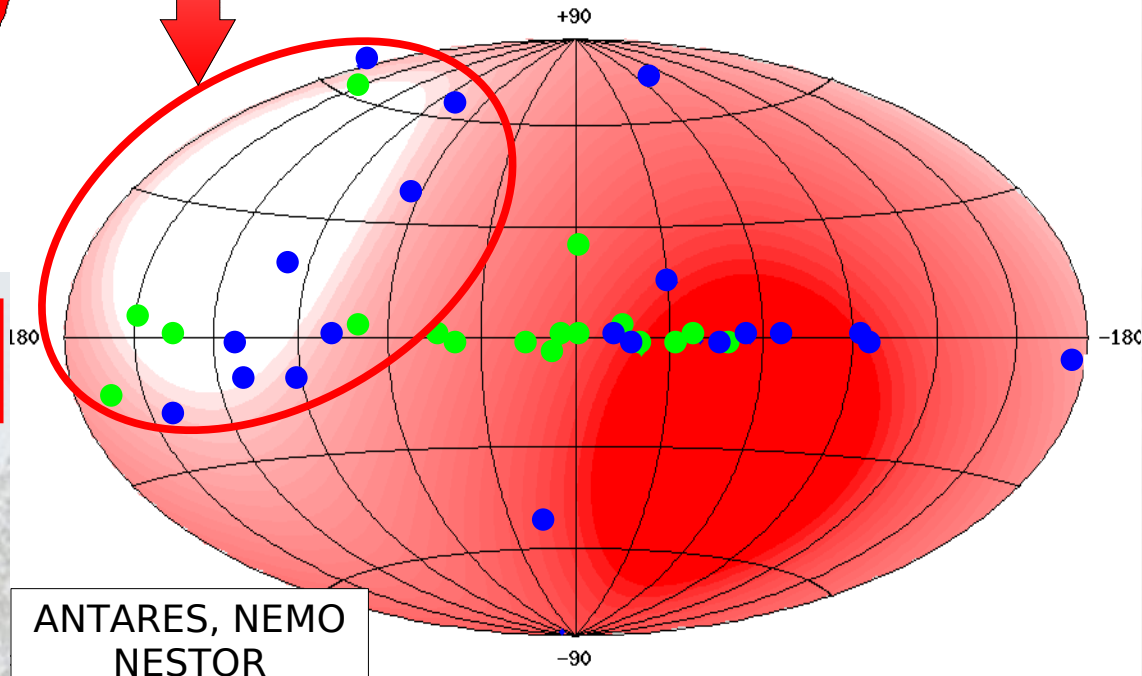


Galactic coordinates

AMANDA
ICECUBE



Effect of latitude (rotation of Earth)



ANTARES, NEMO
NESTOR

Never visible — **Always visible**

On maps :
microquasars (green)
TeV sources (blue)

The sites ...

France

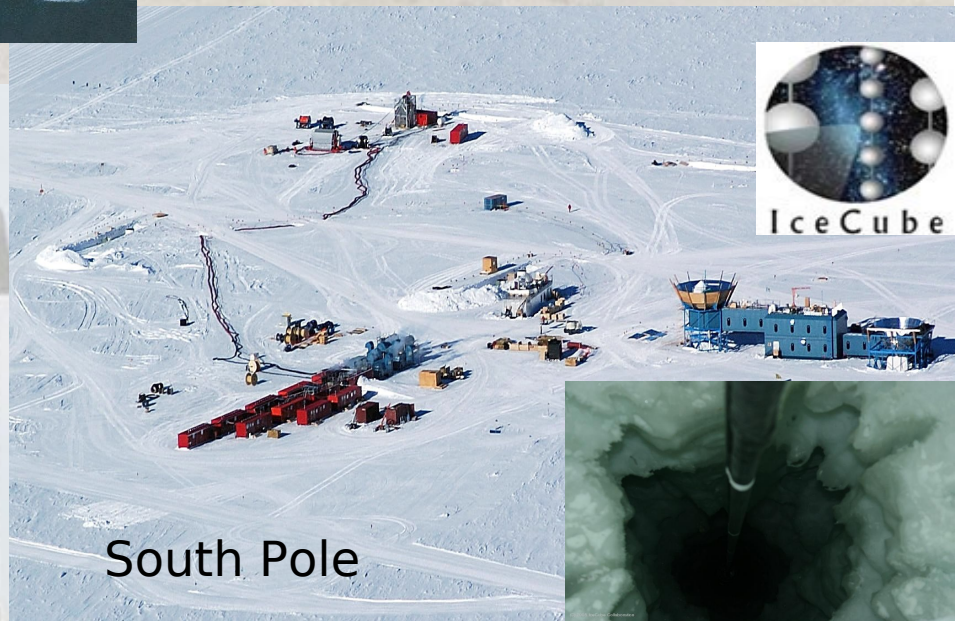
Greece

NEMO

ΝΕΣΤΩΡ

Italy

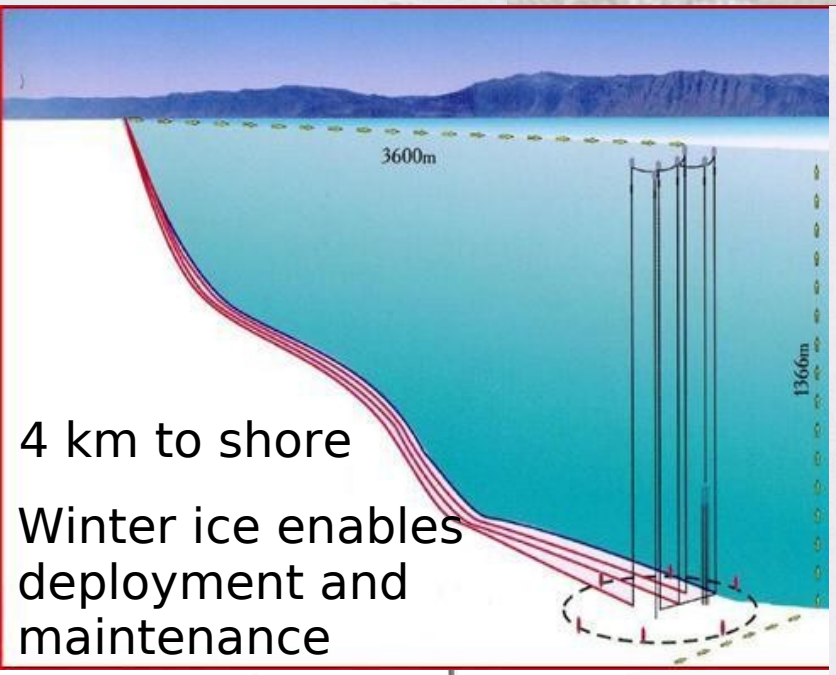
Russia (Siberia)



IceCube

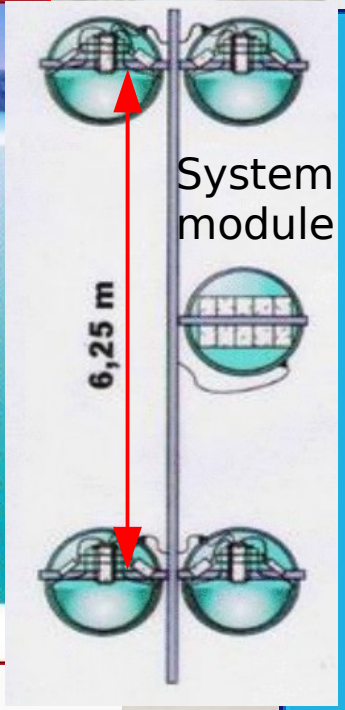
South Pole

BAIKAL, 1367m depth
2 PMTs/floor
8 strings of 12 floors (total 192 PMTs: NT200, since 1998)
+ 3 outer strings of 6 floors (total 36 additonnal PMTs: NT200+, since 2005)

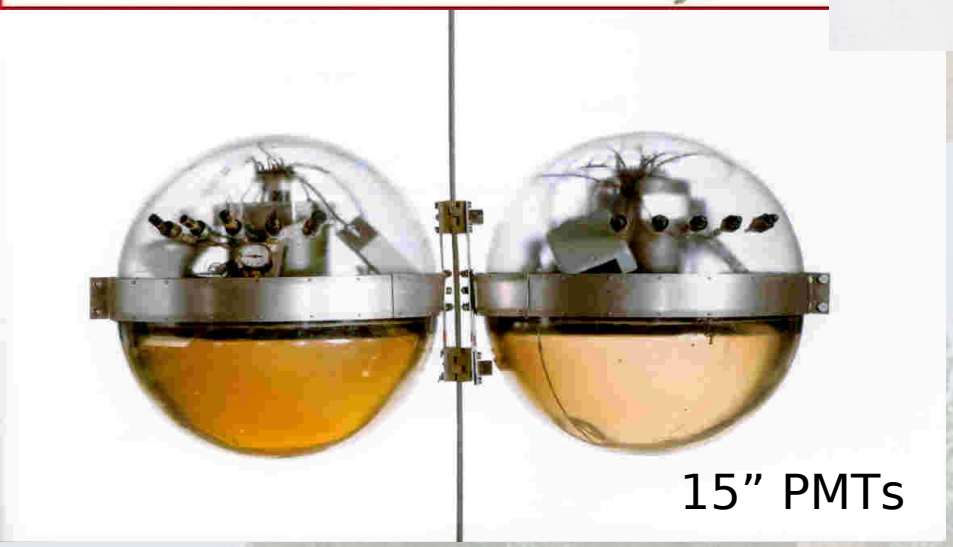


4 km to shore

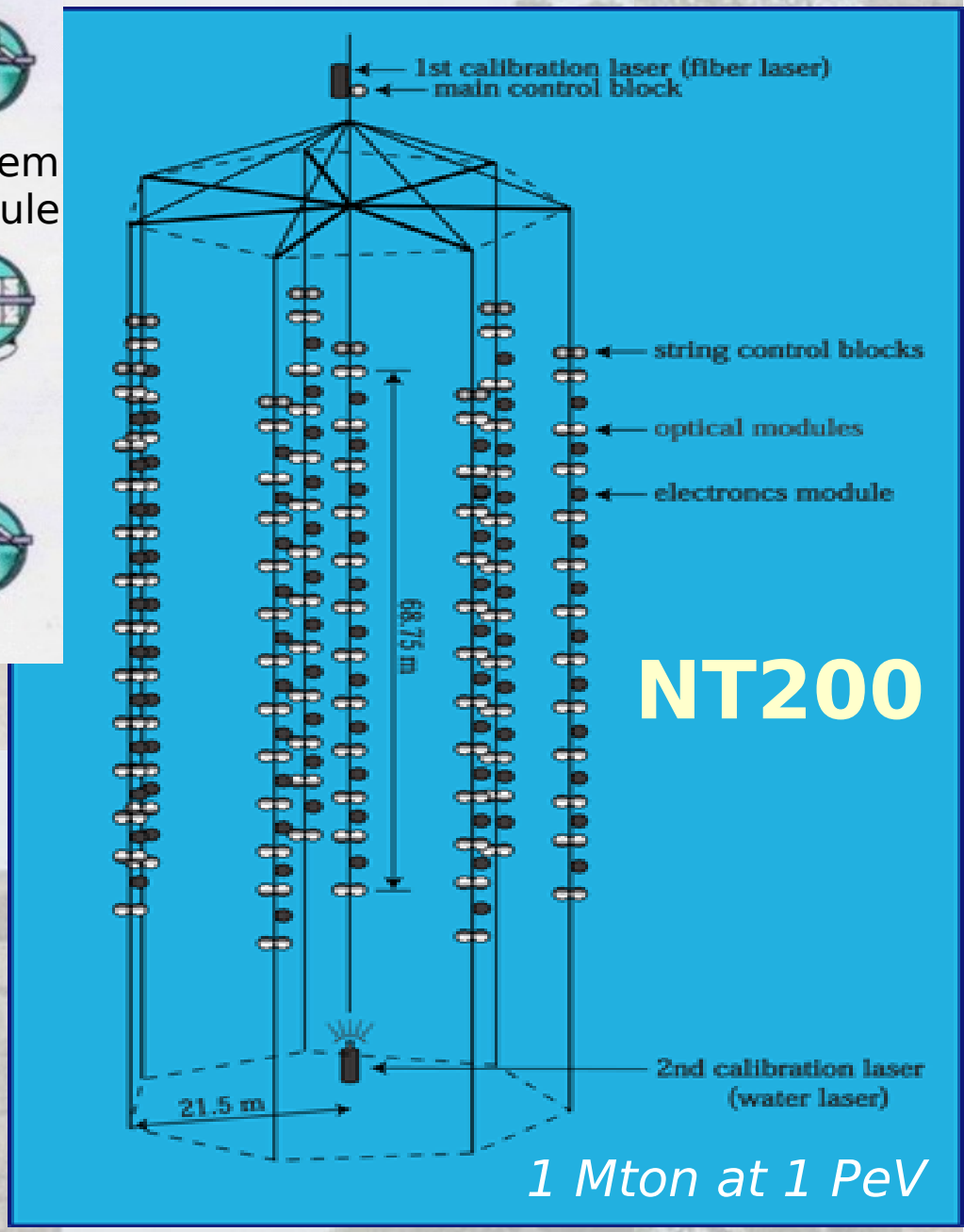
Winter ice enables deployment and maintenance



System module



15” PMTs



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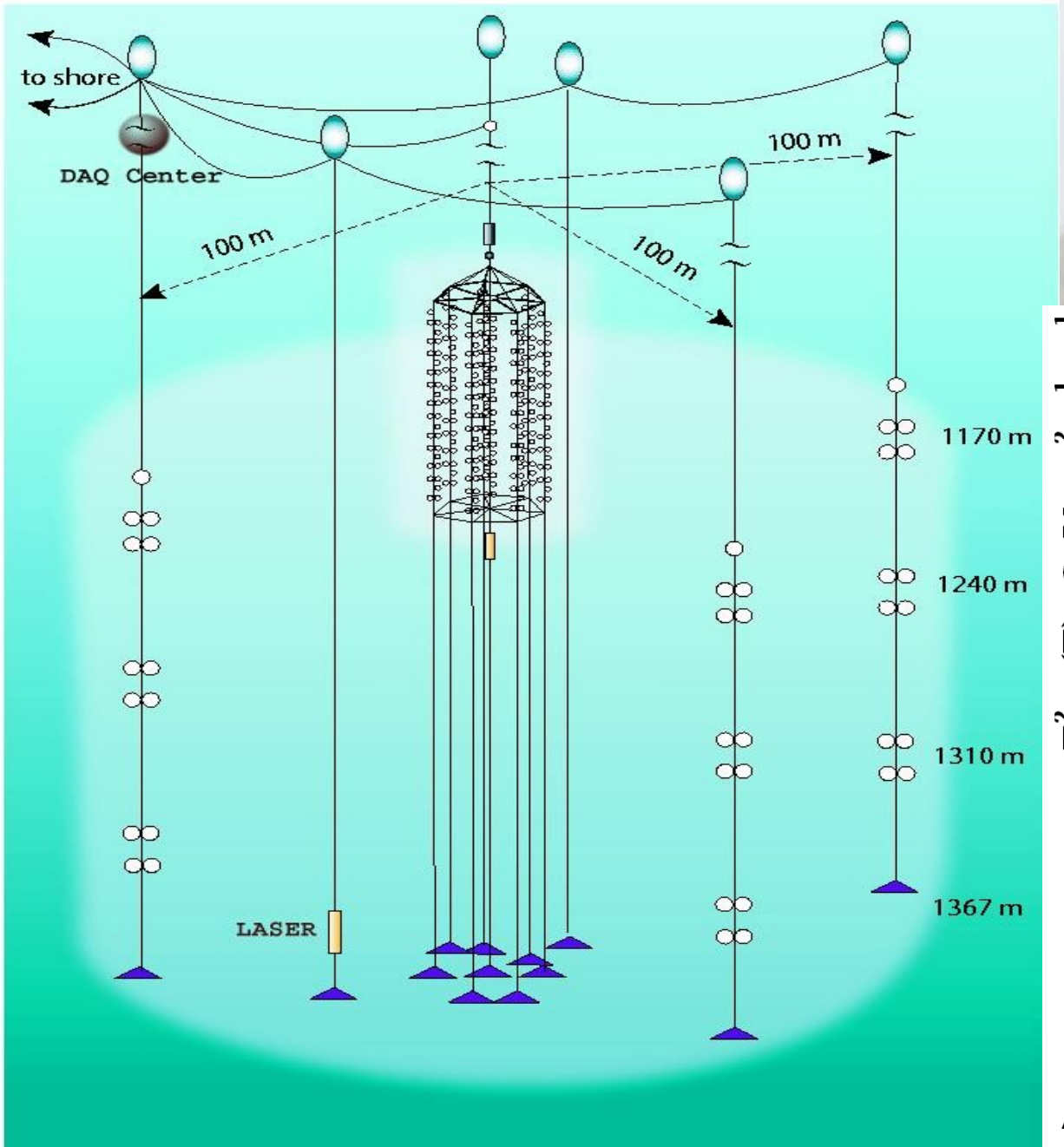
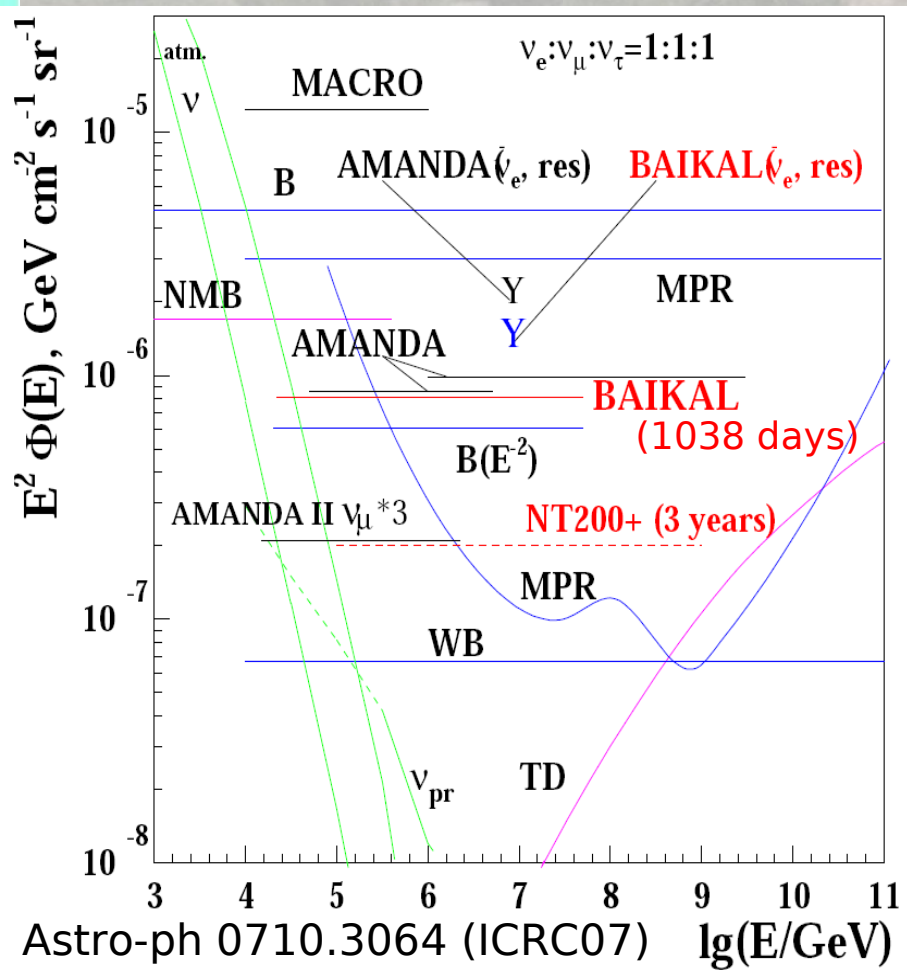


NT200+

+20% PMTs ➡
sensitivity improved by a factor 4.
Tailored for UHE cascades:

V_{eff} ~ 10 Mton at 10 PeV



Astro-ph 0710.3064 (ICRC07)

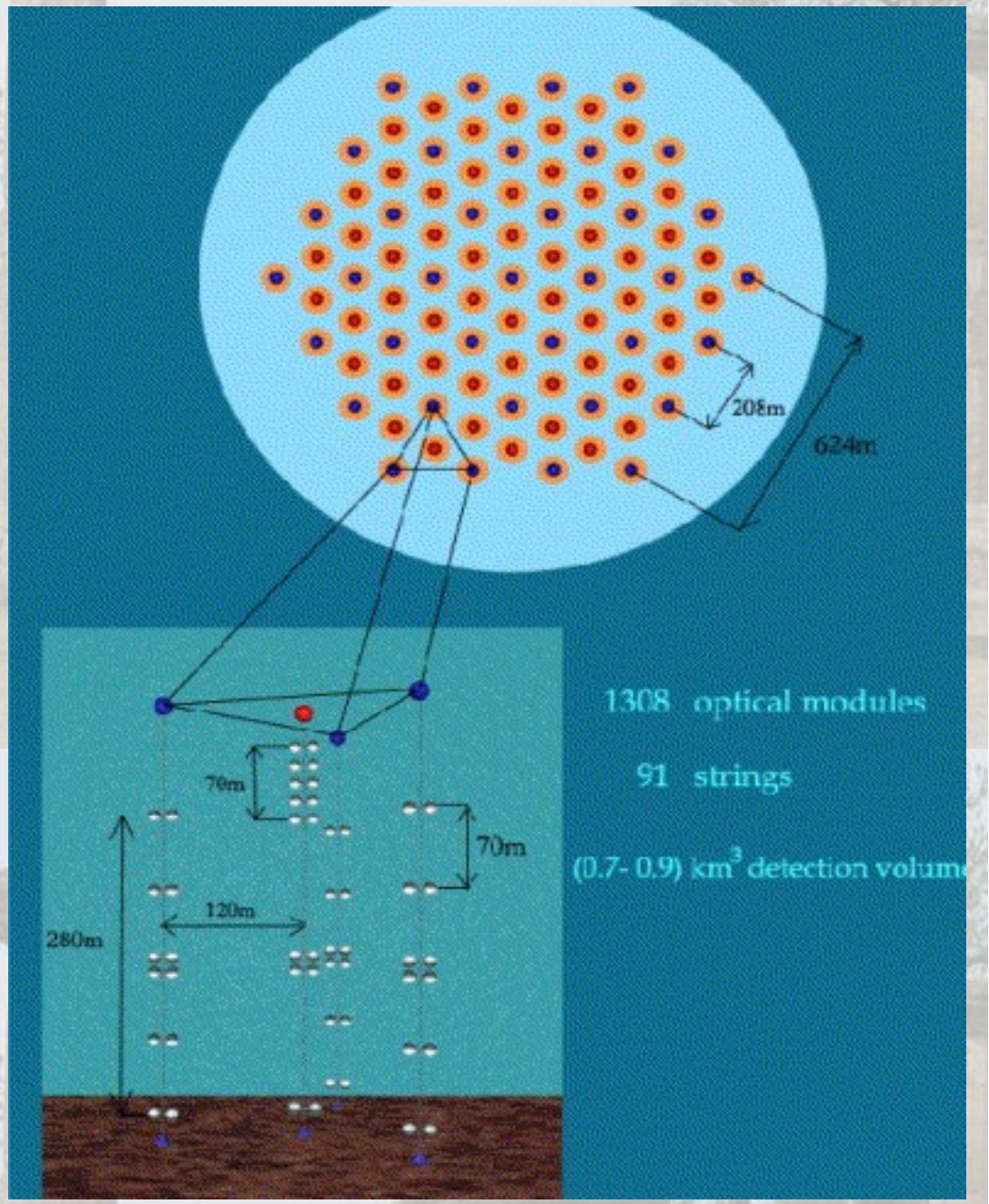
BAIKAL, towards a km³ project :

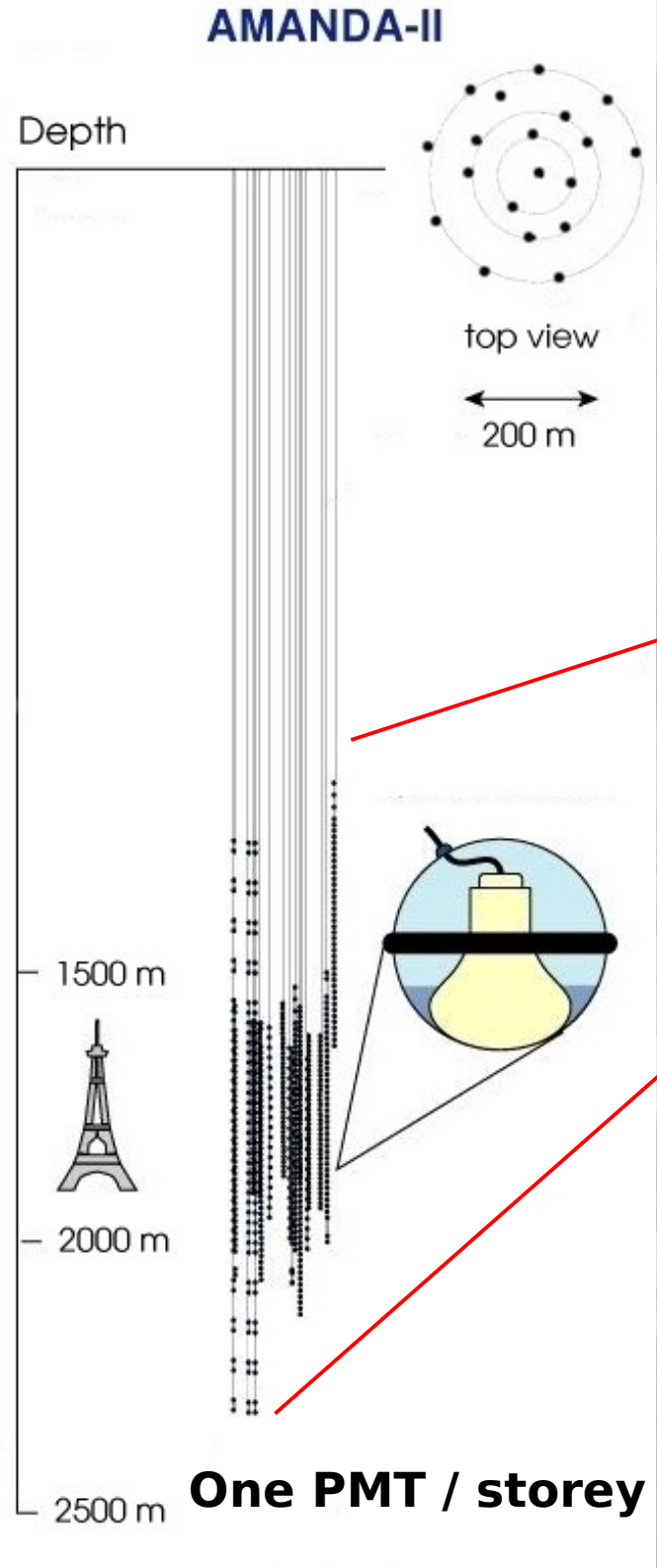
Sparse instrumentation:

91 strings with 12/16 OM= 1308 OMs

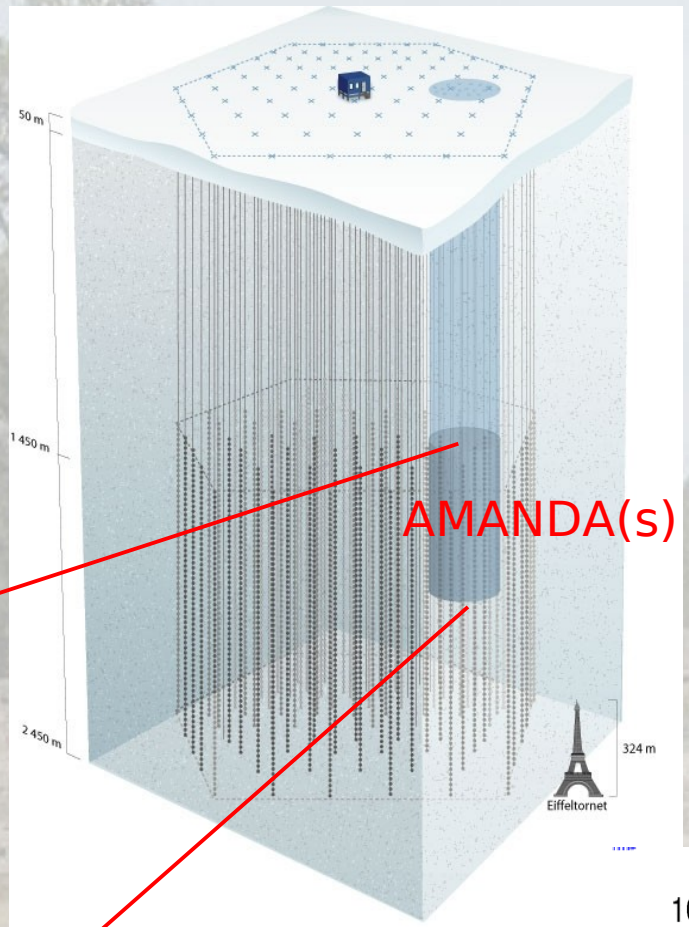
Effective volume for 100 TeV cascades
~ 0.5 –1.0 km³

μ threshold between 10 and 100 TeV





One PMT / storey

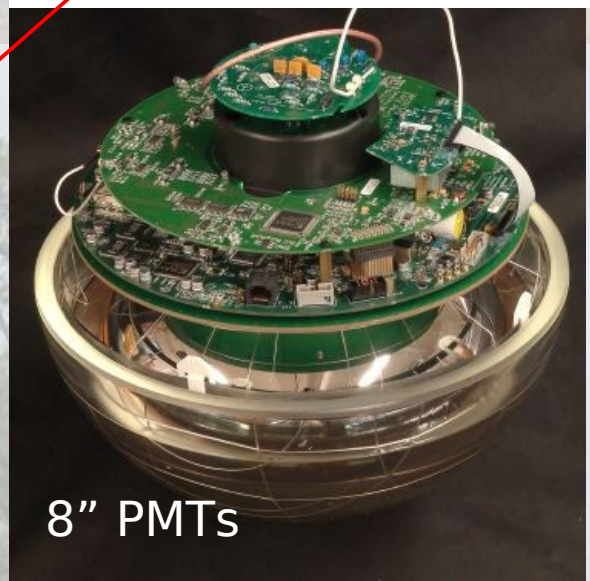


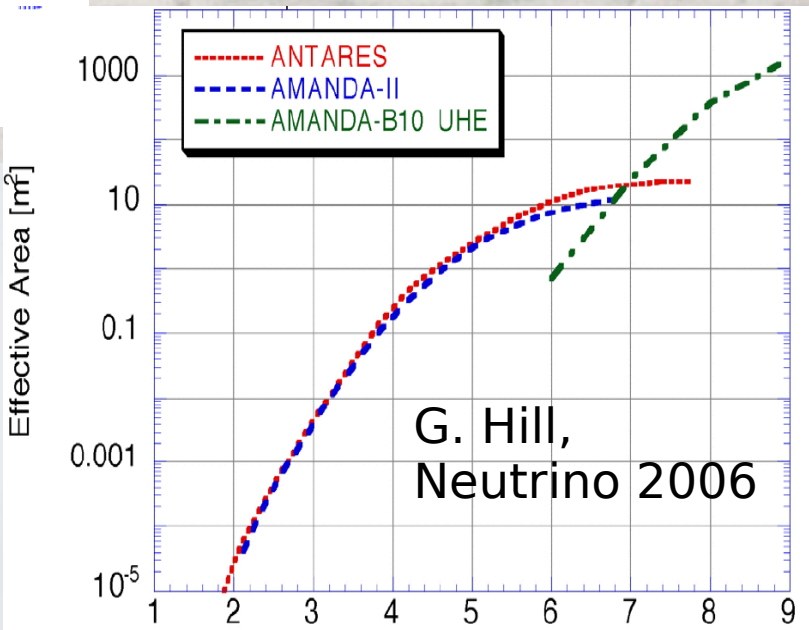
AMANDA(s)

AMANDA-II: 19 strings, 677 PMTs

15m between OMs of a string

AMANDA is operating its 19 strings since 2000

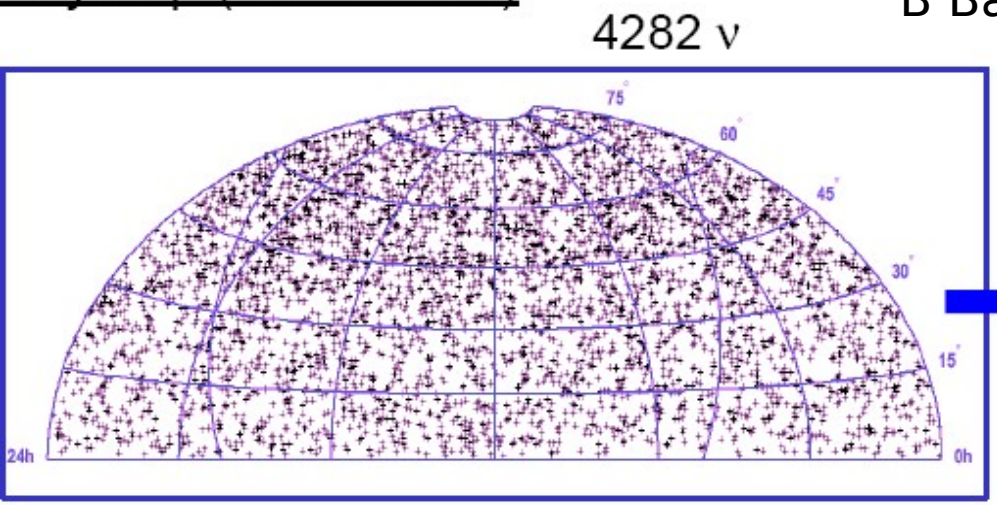


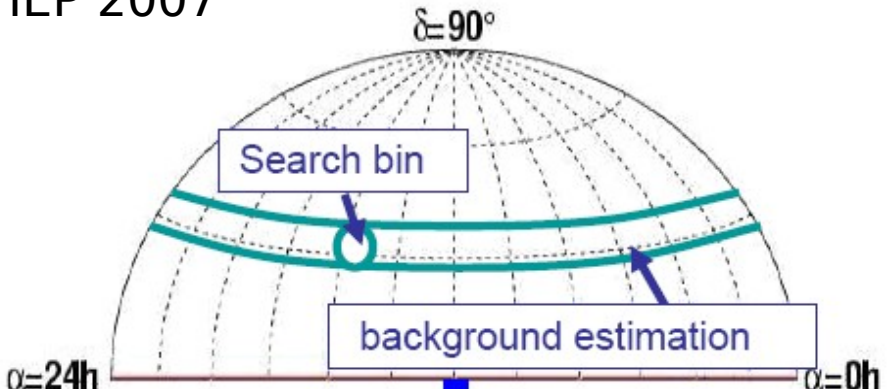


Point source search : AMANDA sky maps : no significant excess

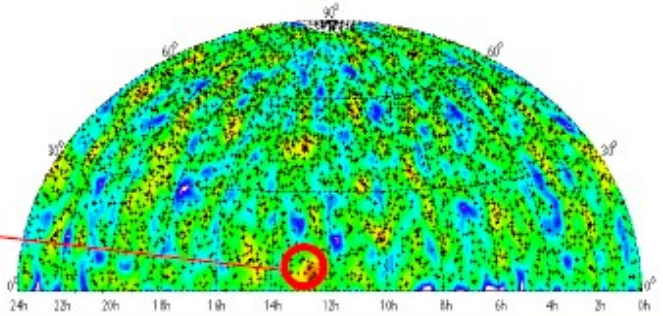
Skymap (2000-2004)

B Baret, EPS-HEP 2007





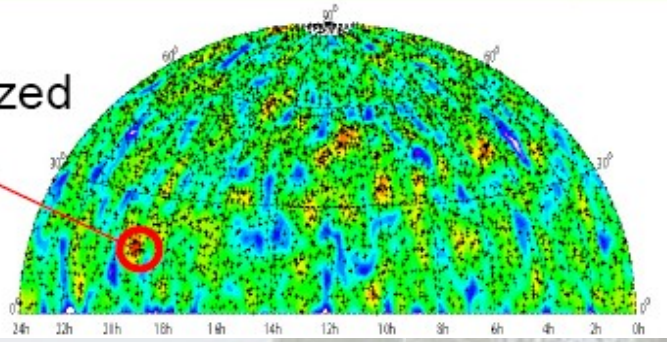
Real sky



Highest excess=3.7σ
Statistical probability=69%

Significance maps

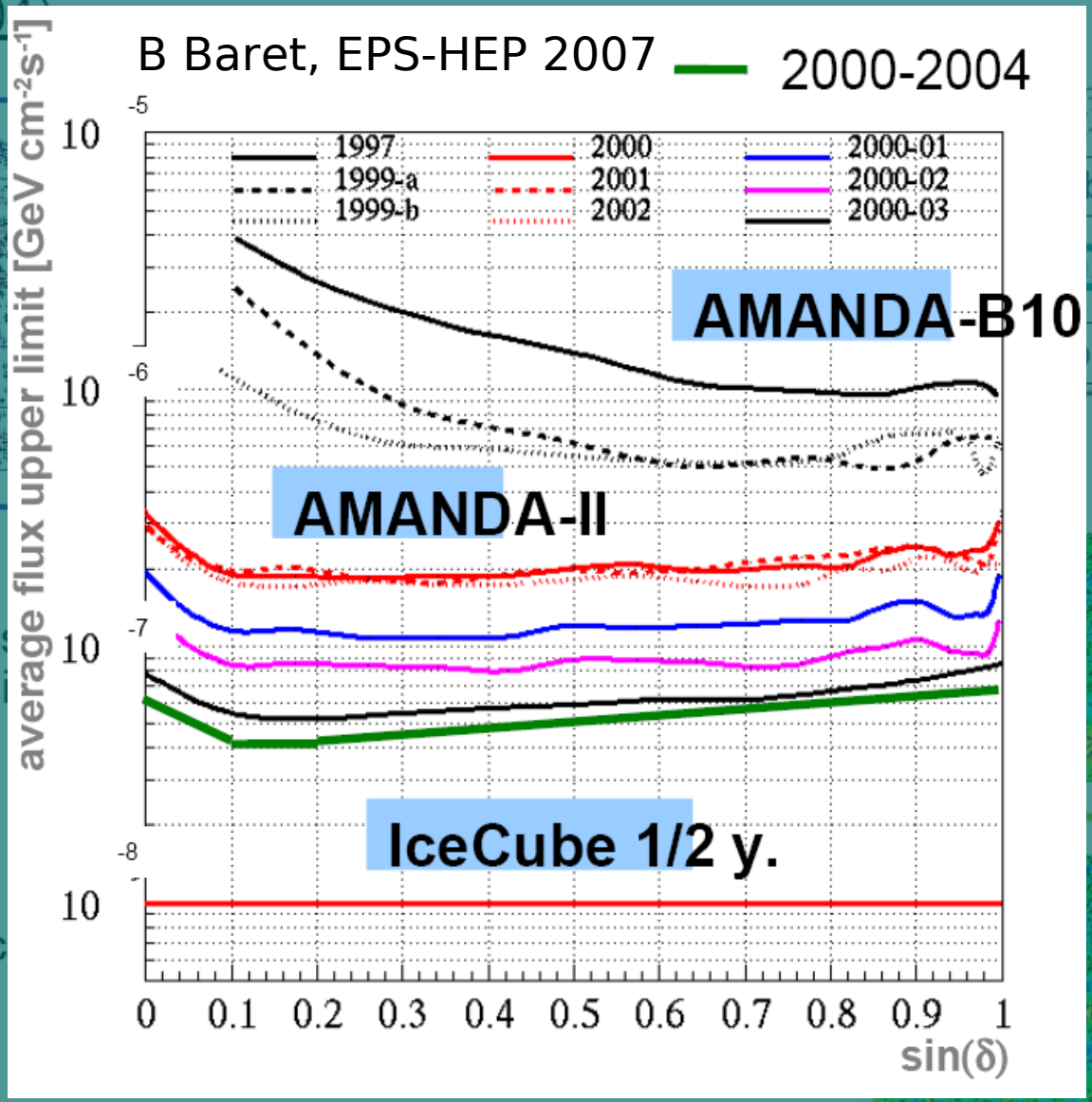
Randomized
MC sky



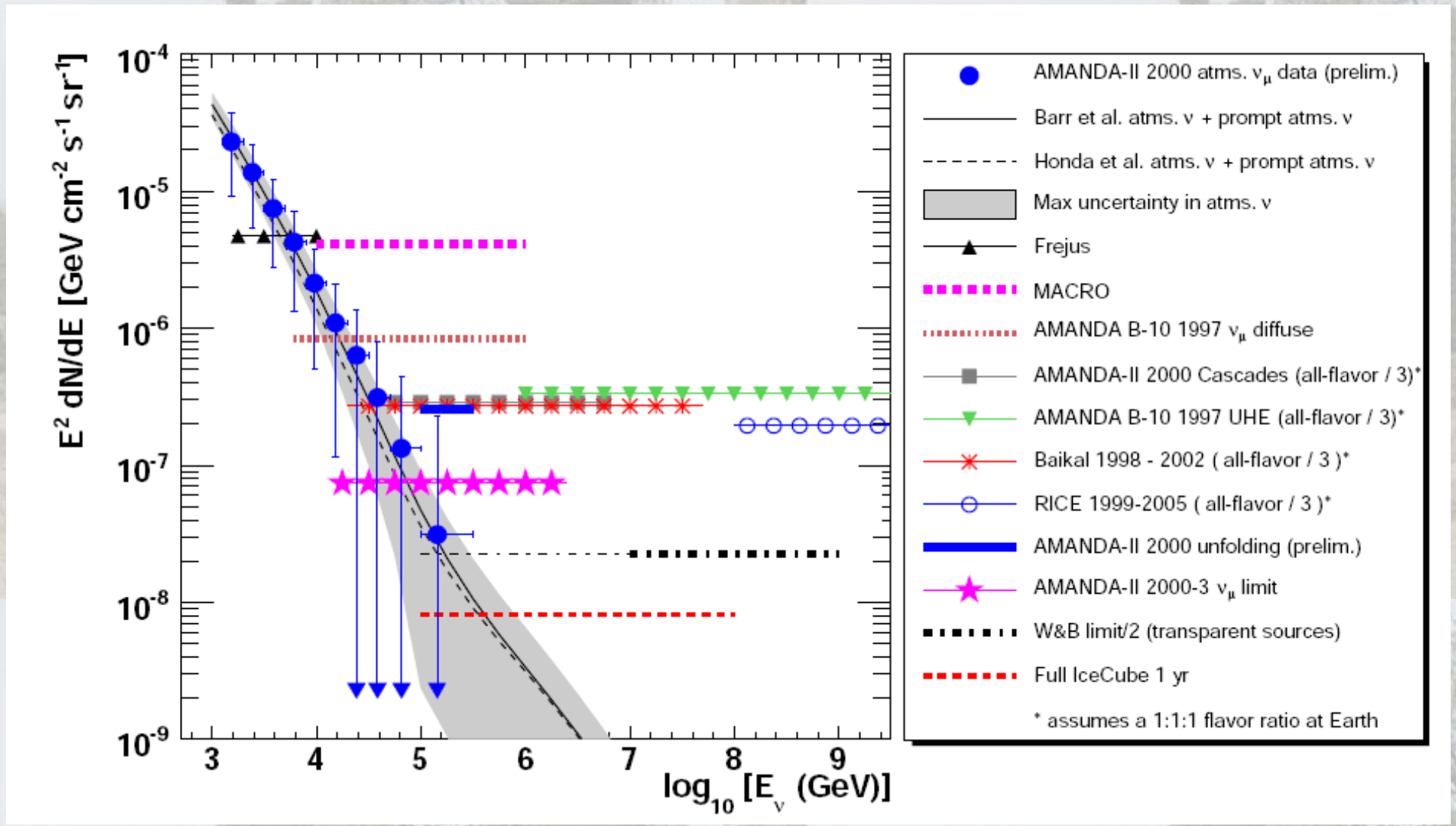
No source

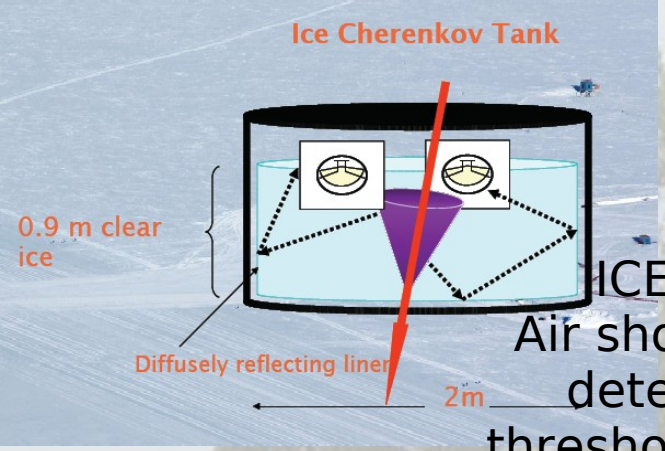
Limits

Point source search : AMANDA sky maps : no significant excess



AMANDA diffuse flux search (astro-ph 0705.1315)





ICETOP
Air shower detector threshold ~ 300 TeV

ICECUBE (-2450m): 80 strings of 60 storeys = 4800 PMTs. 17m between OMs, 125 m between strings

2007-2008:
18 strings

2006-2007:
13 Strings

2005-2006:
8 Strings

2004-2005:
1 String

AMANDA

50 m

2 450 m

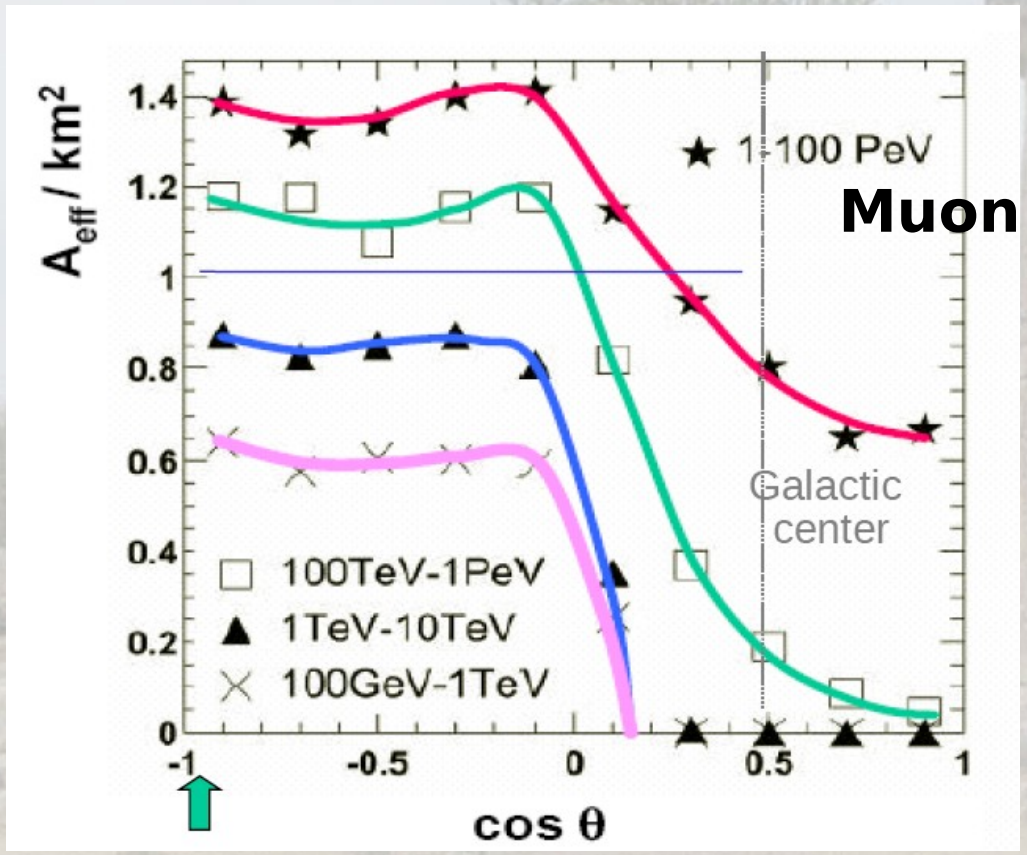
324 m

Eiffeltornet

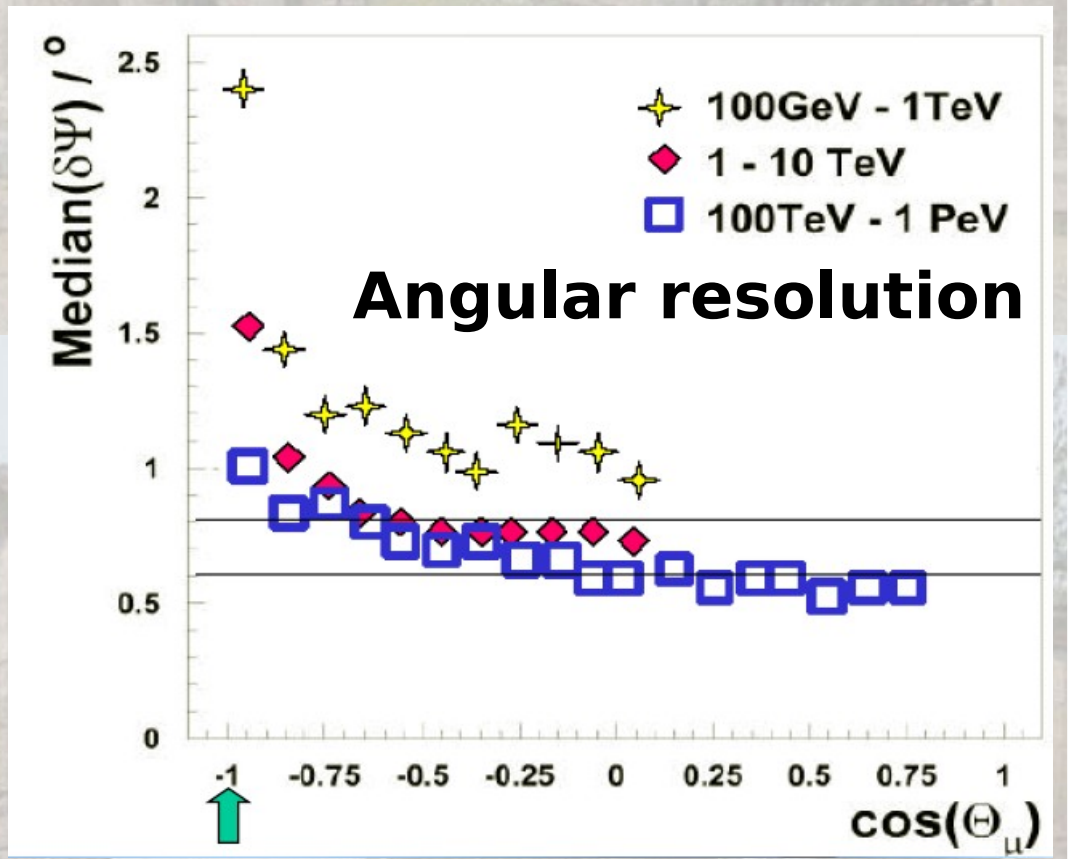
2008 :
40 strings connected

M. Ribordy
Moriond 2008

ICECUBE expected performances (M Ribordy, Moriond 2008)

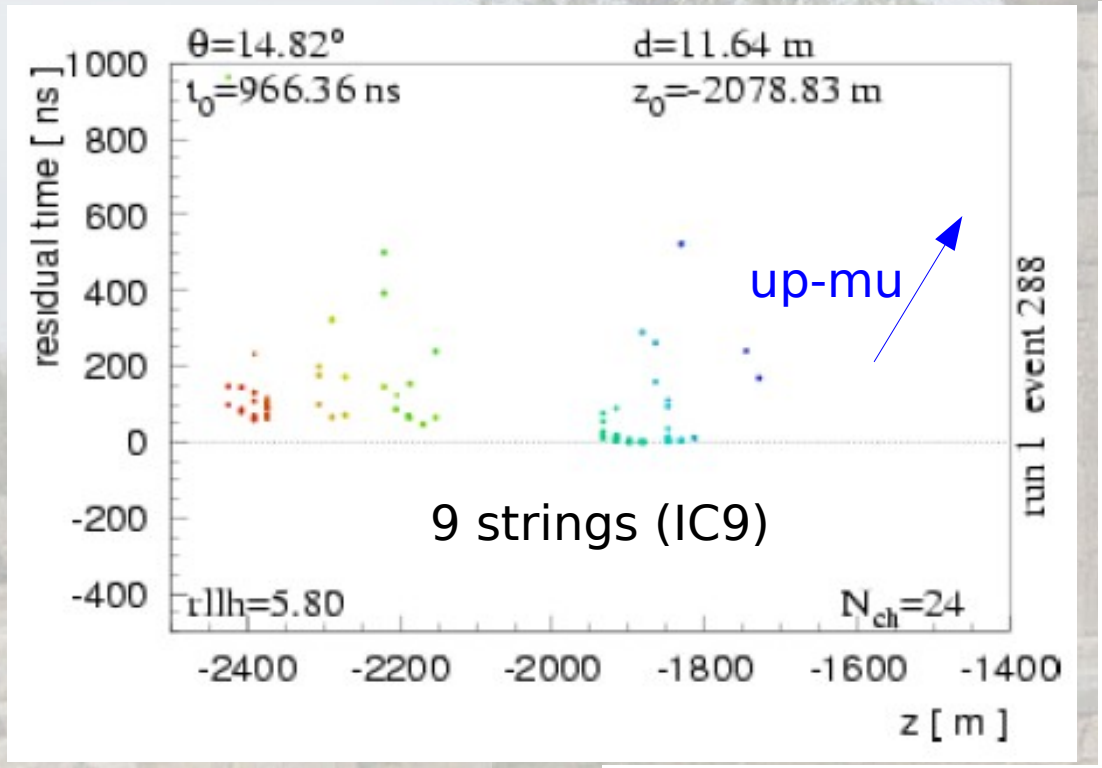


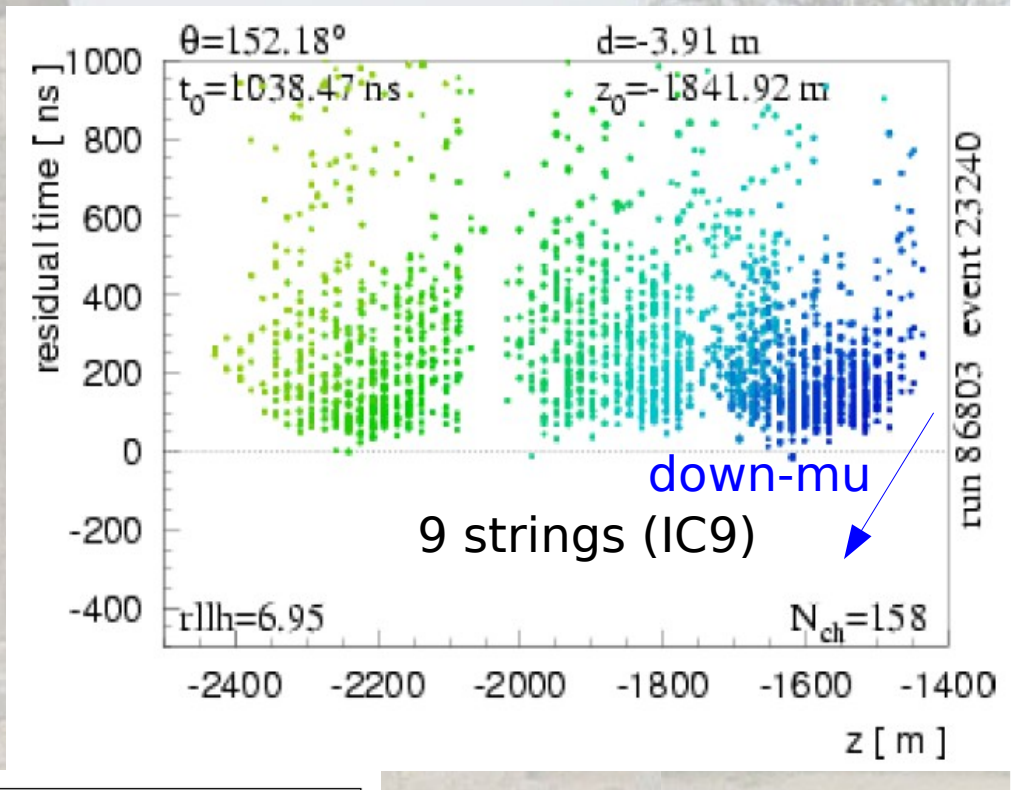
Muon effective area

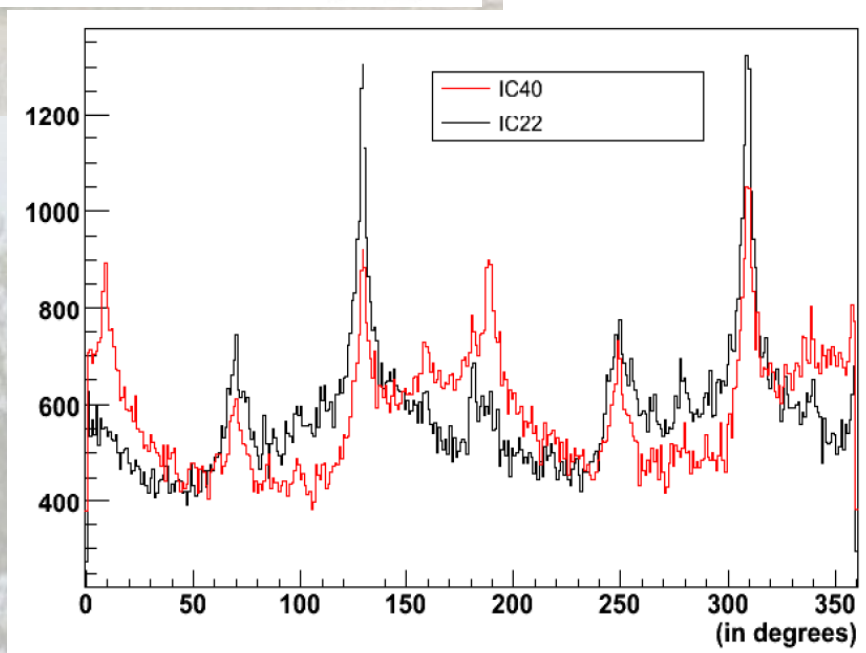


Angular resolution

ICECUBE commissioning (M Ribordy, Moriond 2008, G Hill, ν2006)



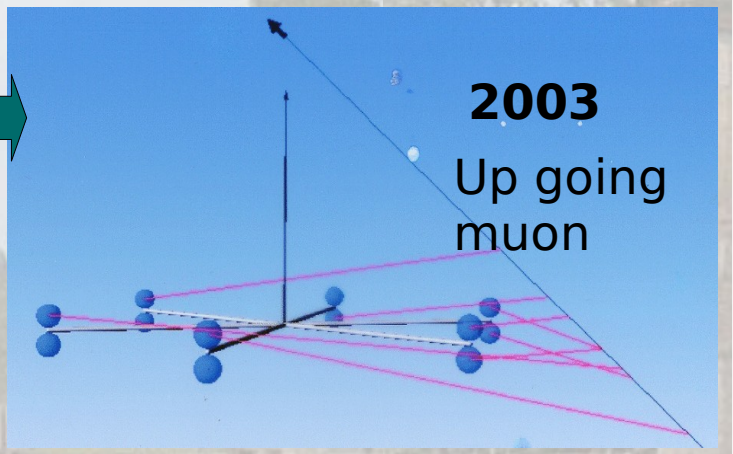


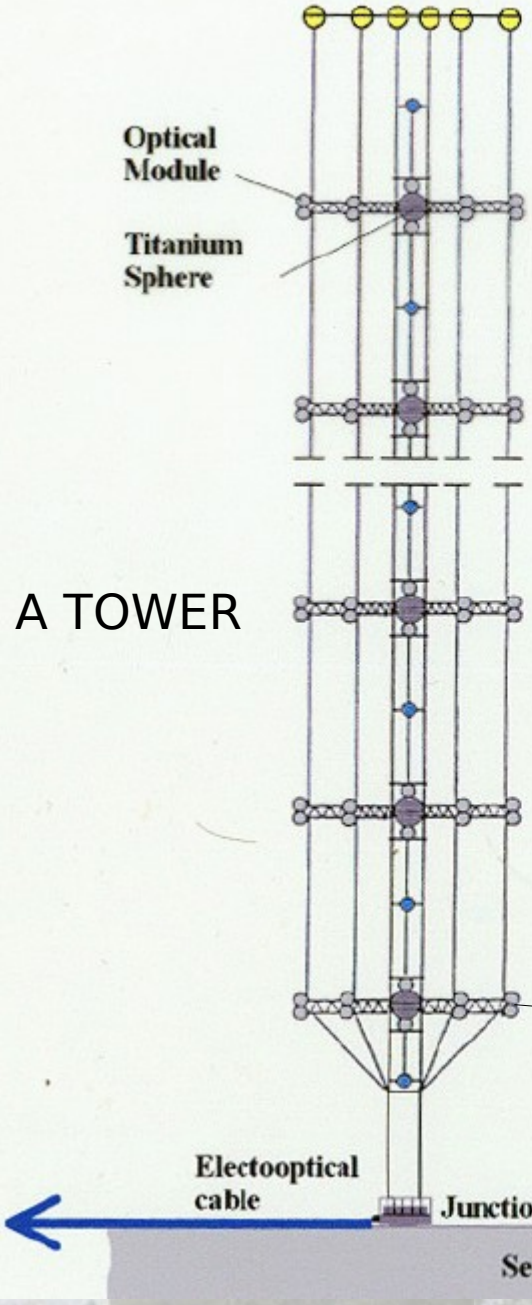


22 strings
vs
40 strings :
reconstructed azimuth
of tracks.

NESTOR
3800m depth
12 PMTs/storey
12 storeys/tower

One storey immersed





A TOWER

32 m diameter floor
30 m between floors

144 PMTs
(facing up & down)

15” PMTs

G. Aggouras et al. / Nuclear Instruments and Methods in Physics Research A 552 (2005) 420–439

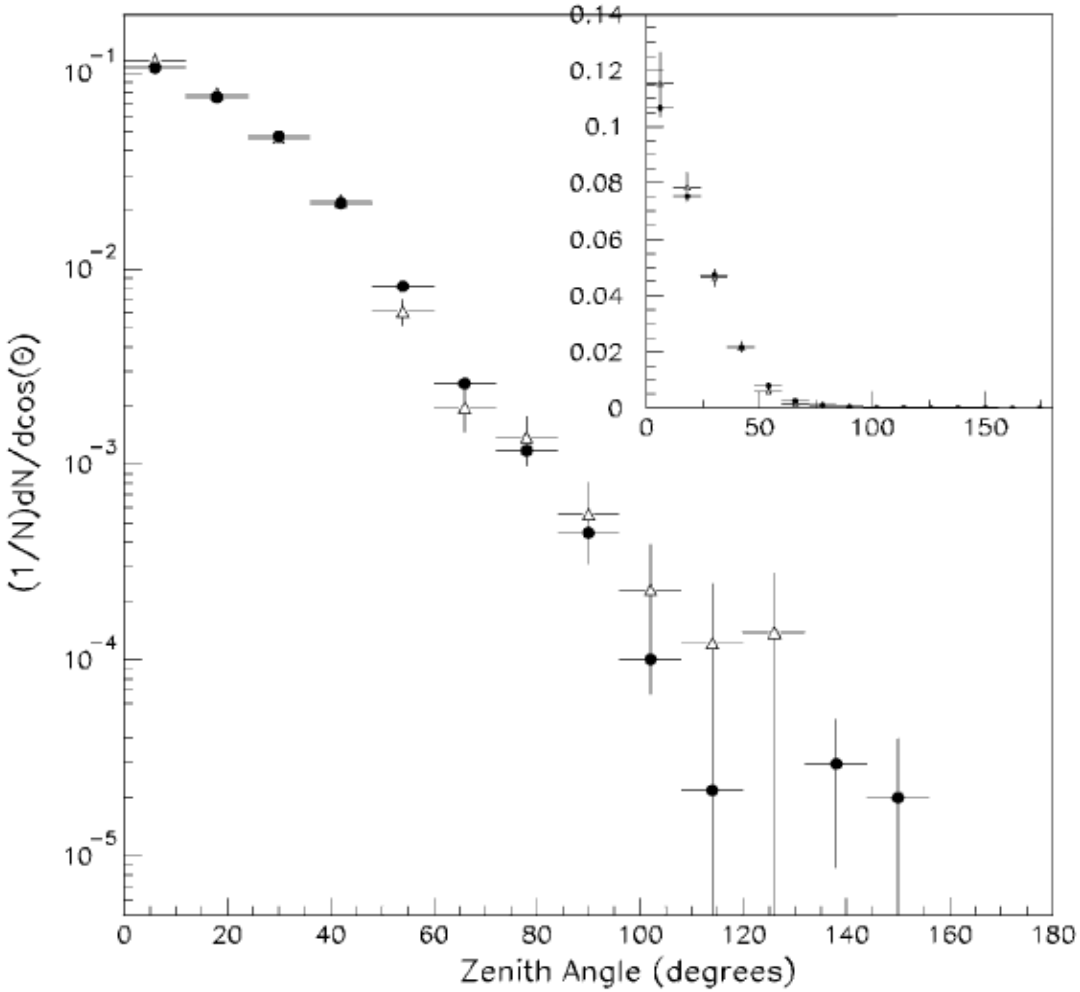


Fig. 18. Distribution of the Zenith angle (θ) of reconstructed tracks for the data (triangles) and Monte Carlo (solid points) event samples. The insert plot shows the same distributions on a linear scale.

A result from
2003 operation:
Atmospheric muon flux.

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega\,\mathrm{d}t\,\mathrm{d}S} = I_0 \cos^{\alpha}(\theta)$$

$$I_0 = 9.0 \times 10^{-9} \pm 0.7 \times 10^{-9}(stat) \pm 0.4 \times 10^{-9}(syst) cm^{-2} s^{-1} sr^{-1}$$

$$\alpha = 4.7 \pm 0.5(stat) \pm 0.2(syst)$$

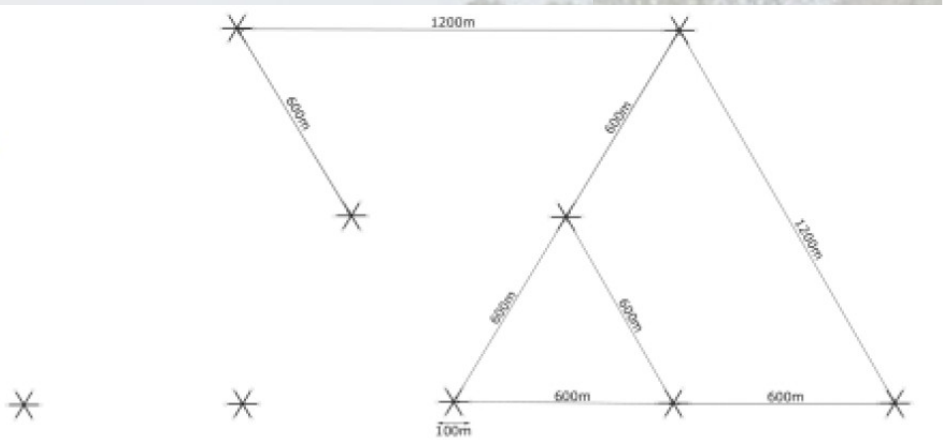
Plans :

KM3NeT participation:

An example from: *Recent Results from Nestor,LK Resvanis, Neutrino Oscillations in Venice, 2006, (p.461-474)*

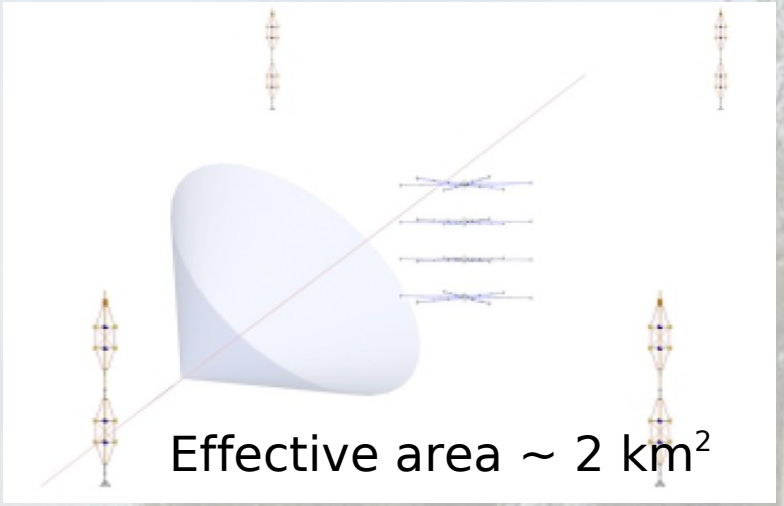
100m diameter , Optical Modules every 18.5 m

1 floor



Deployment of these structures:
specialized surface vessel (Delta-Berenike platform) developped by the NESTOR collaboration

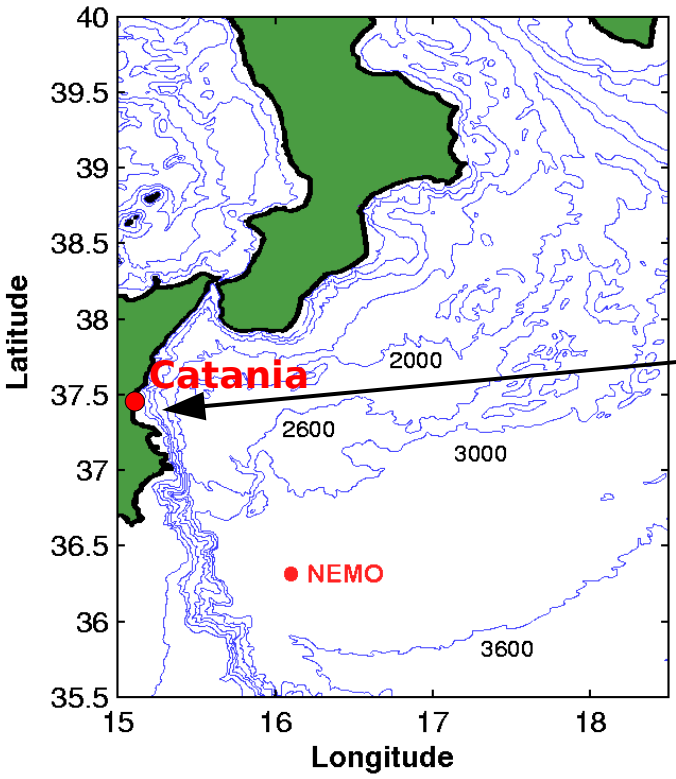
13 towers
of 12 floors
(5928 PMTs):
~ 1 km^3



Effective area ~ 2 km^2

NuBe-NESTOR (collaboration with US physicists):
(Neutrino Burst Experiment-NESTOR) :
search for 100 TeV neutrinos
in coincidence with GRB emission.

NEMO, 3500m depth,
4 PMTs/storey
16 storeys/tower (64 PMTs)

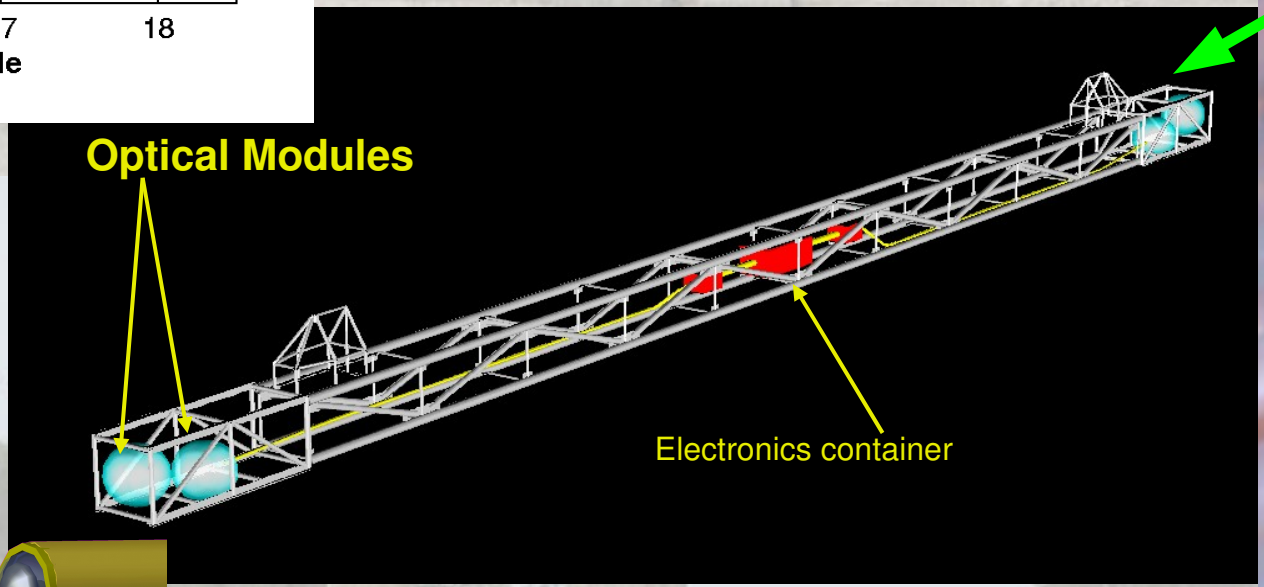


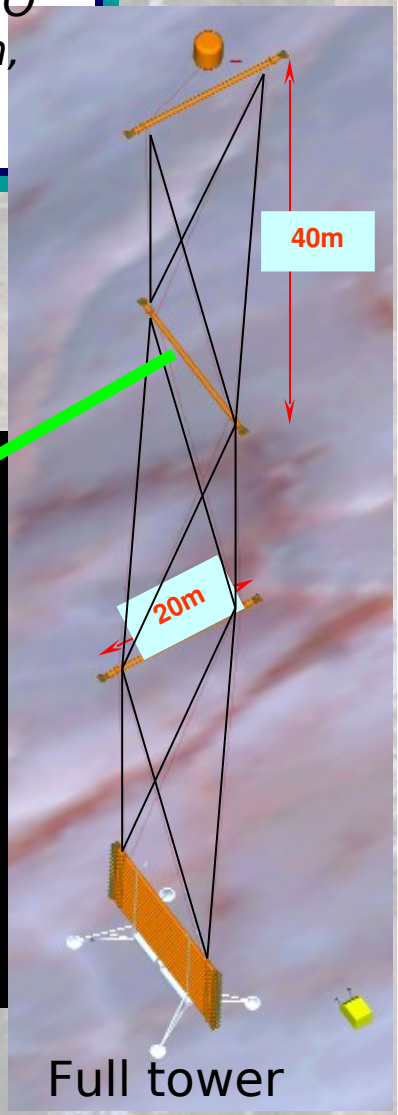
Phase 1 (Dec. 2006) : 1 mini-tower installed at a depth of 2000 m, 30 km offshore Catania (still in operation)

NEMO mini-tower (4 floors, 16 OM)

Isabella Amore : NEMO Phase 1: construction, operation and first results, ISAPP 2007

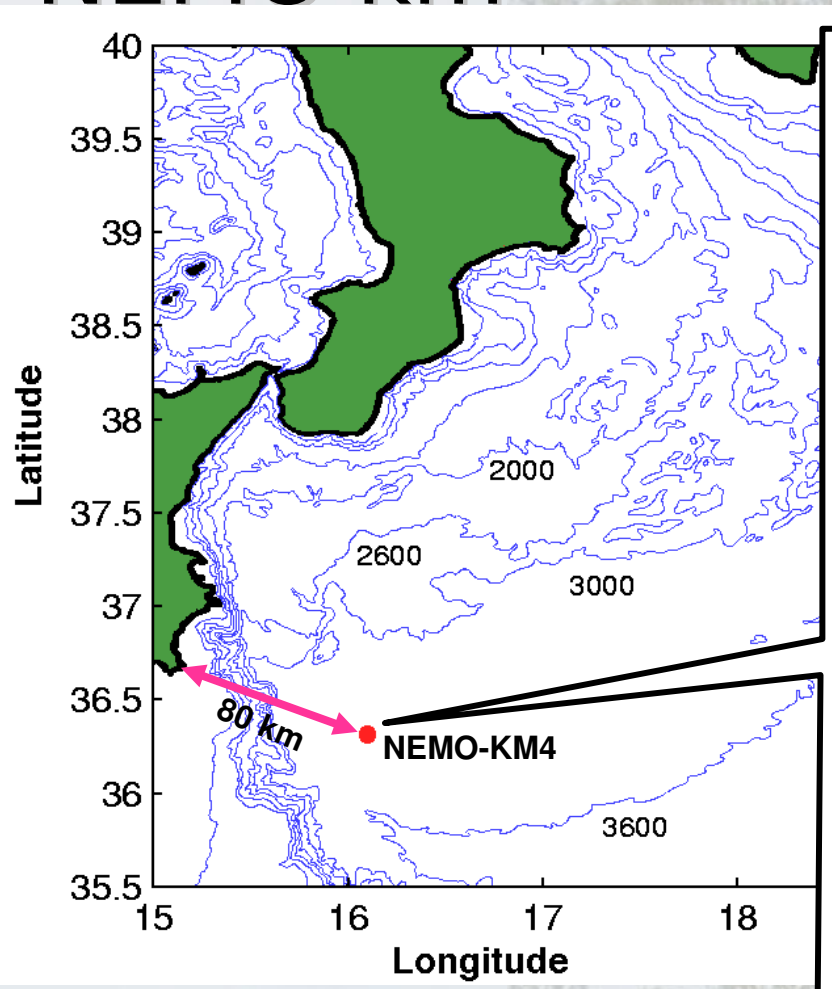
Full project :

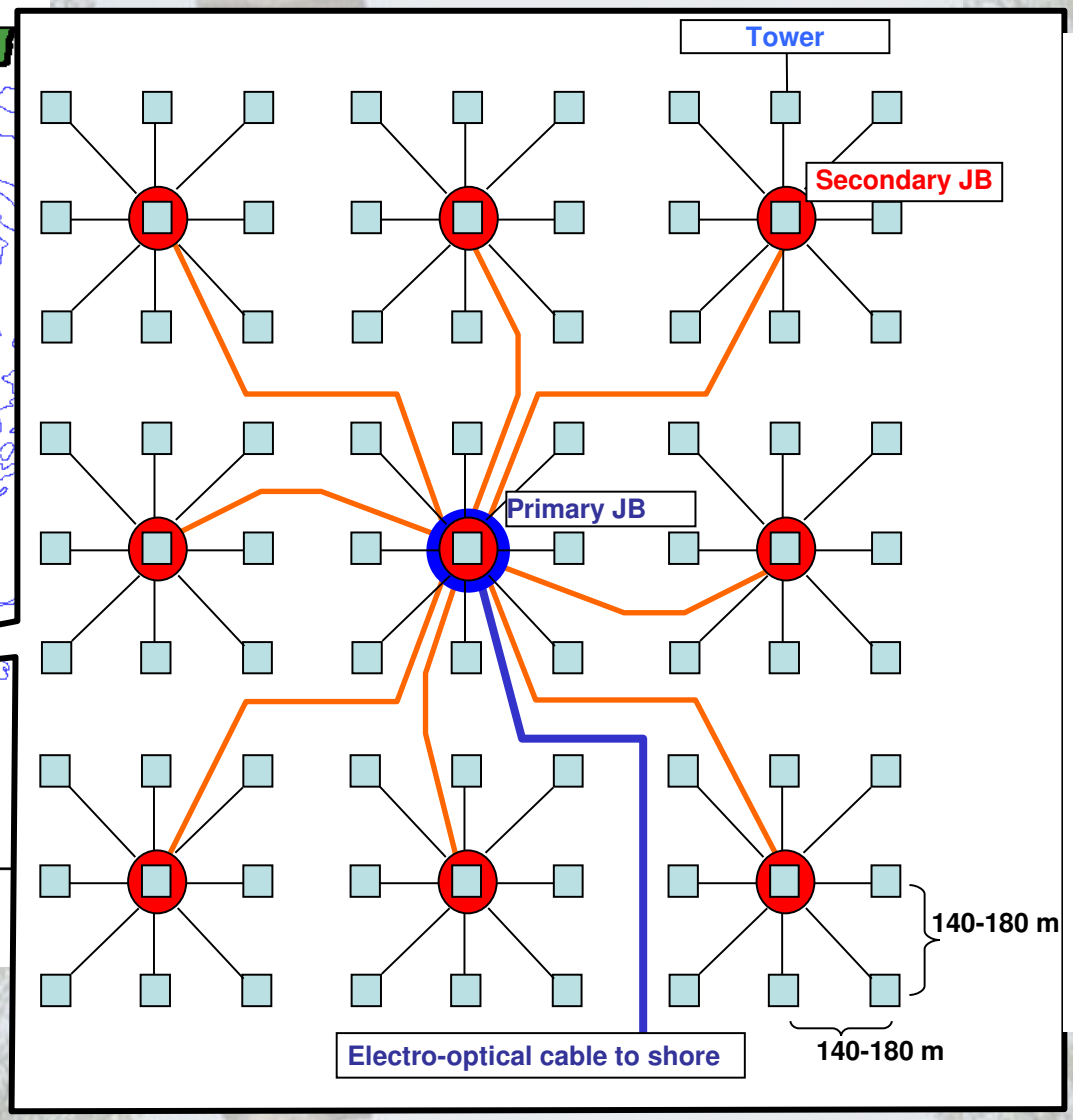


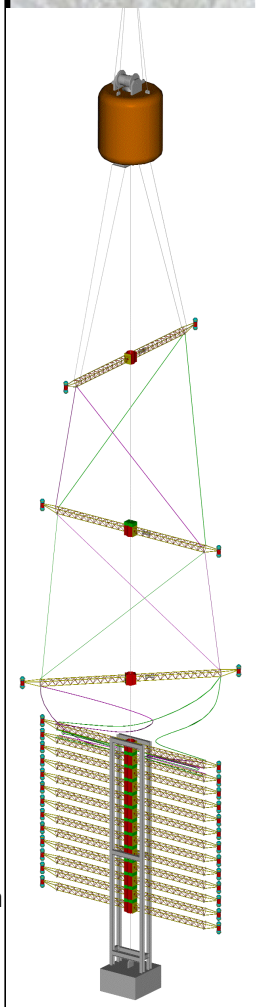


NEMO km³

M Circella, NUPPAC-05





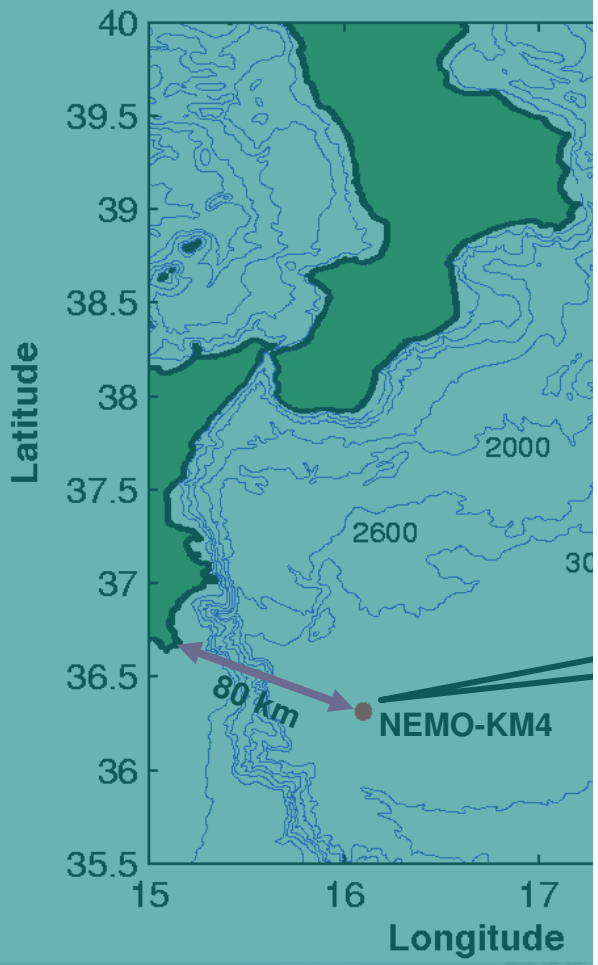


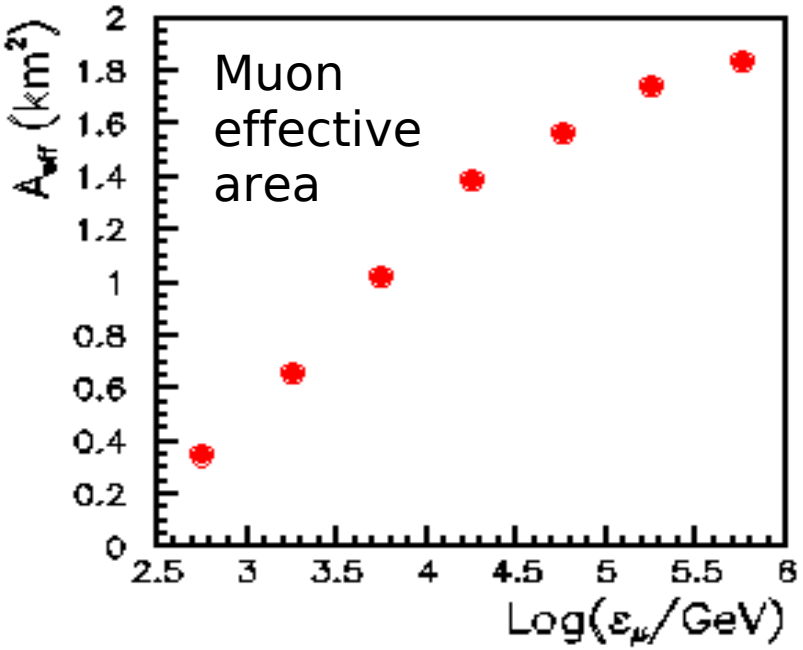
NEMO km³ proposal: 10 junction boxes, 81 towers, 5832 PMTs

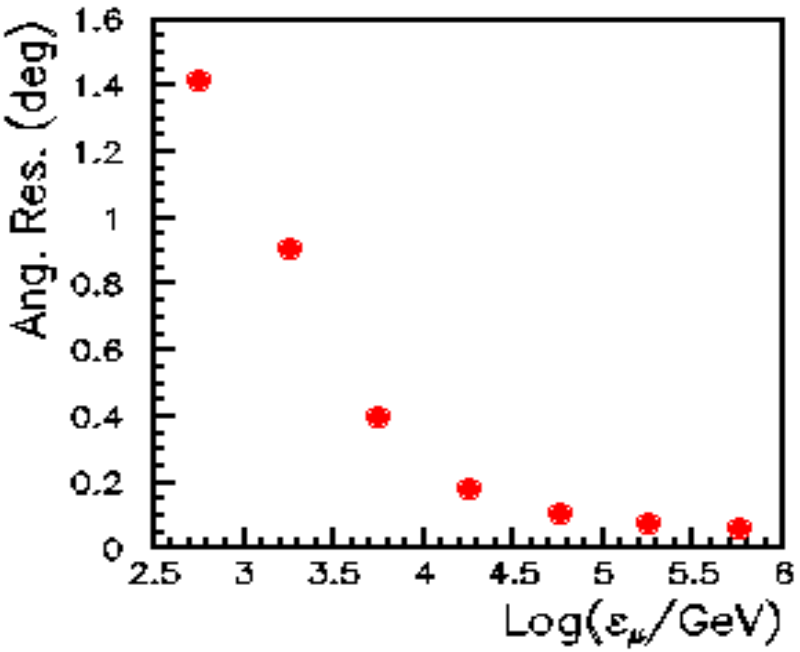
C Distefano,
THE MULTI-MESSENGER APPROACH TO UNIDENTIFIED GAMMA-RAY SOURCES
Barcelona July 4 – 7, 2006

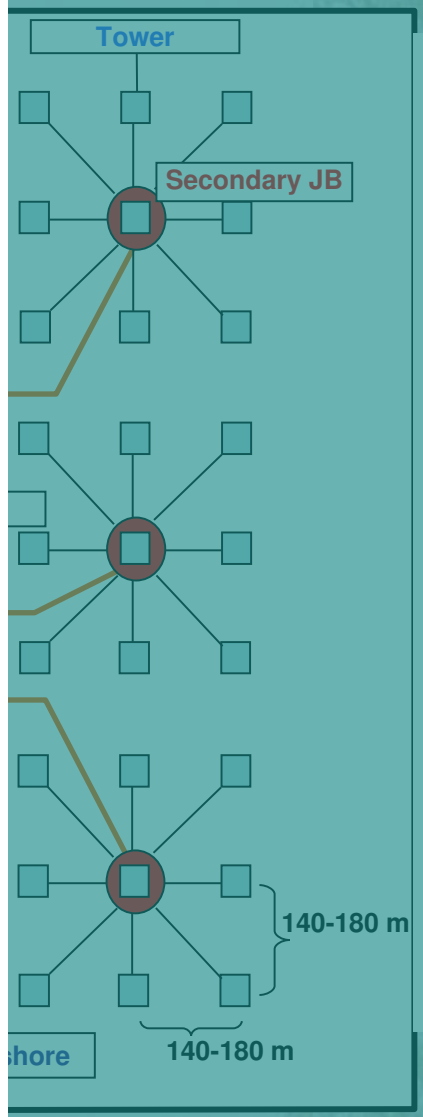
NEMO km^3

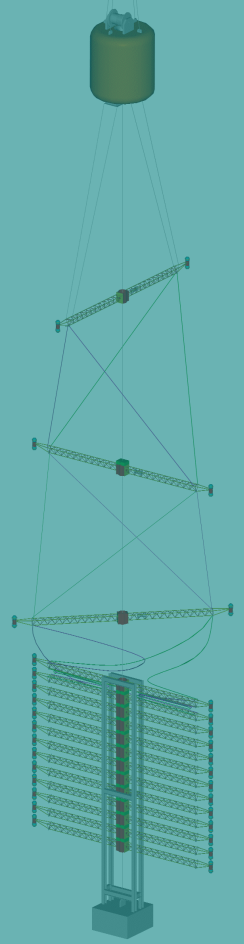
M Circella, NUPPAC-05





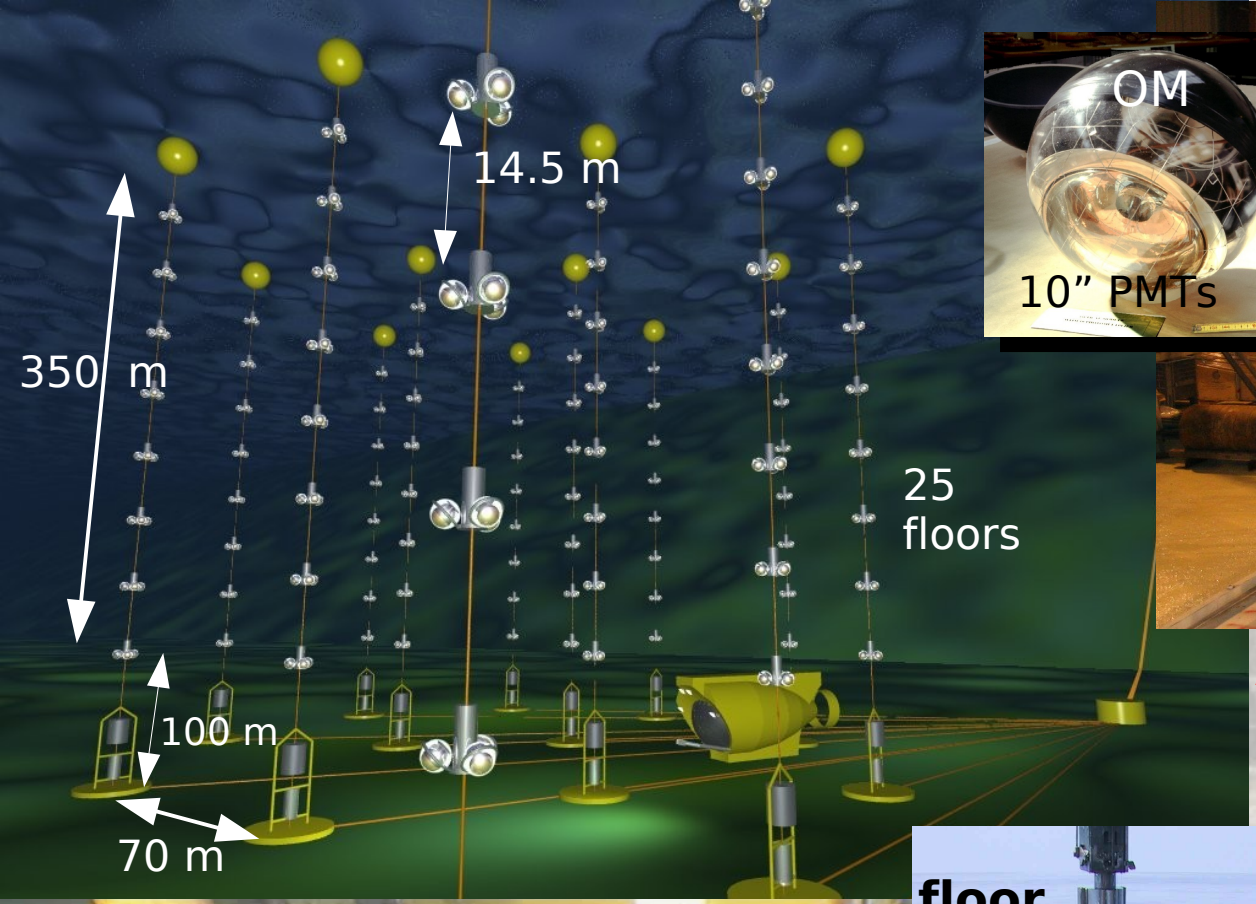




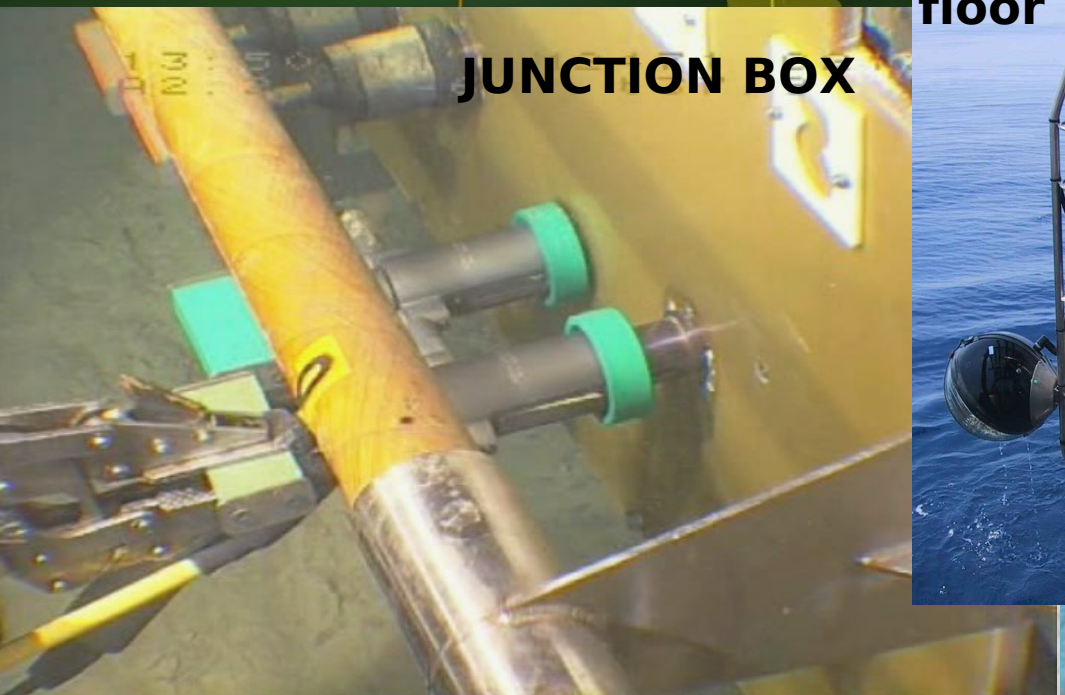


NEMO km^3 proposal: 10 ju
boxes, 81 towers, 5832 PM

C Distefano,
THE MULTI-MESSENGER APPROACH TO UNIDENTIFIED GAMMA-RAY SOURCES
Barcelona July 4 – 7, 2006



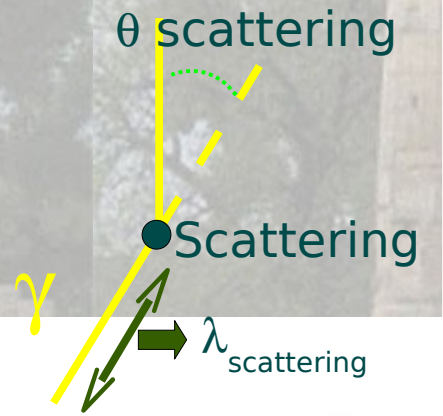
ANTARES, 2475m, 3 PMTS/floor
12 lines of 25 floors
900 PMTs this Summer

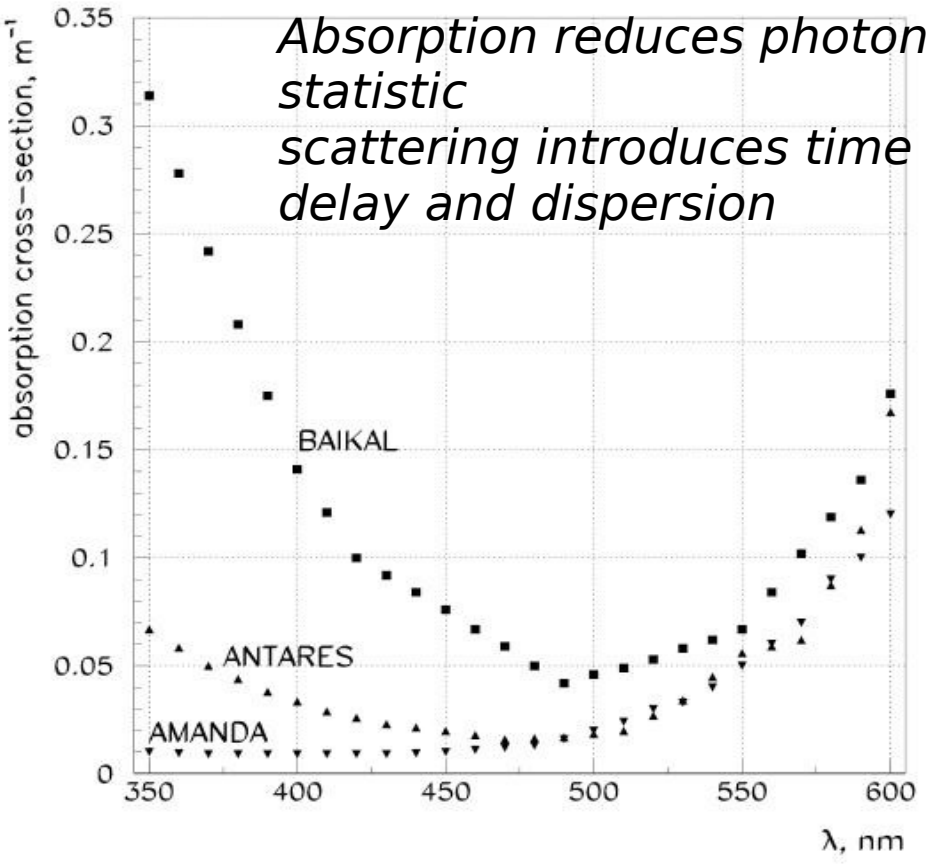


MEDIUM PROPERTIES for Cherenkov light propagation

BAIKAL	λ abs ~ 20 m & λ eff sca ~ 300 m @ 470 nm
AMANDA	λ abs ~ 70 m & λ eff sca ~ 25 m @ 470 nm
NESTOR	λ att ~ 55 m @ 460 nm: λ att includes abs & scat
NEMO	λ abs ~ 70 m @ 440 nm
ANTARES	λ abs ~ 60 m & λ eff sca ~ 300 m @ 470 nm

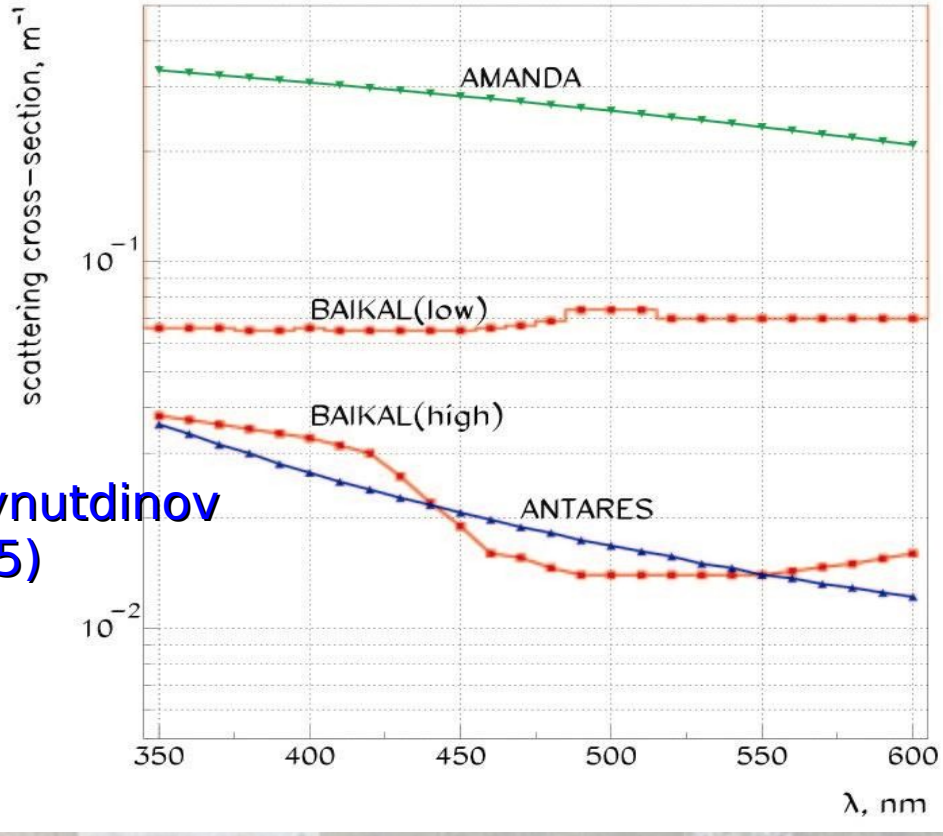
$\lambda_{effective\ scattering} = \lambda_{scat}/(1-\langle\cos\theta_{scat}\rangle)$





Absorption reduces photon statistic
scattering introduces time delay and dispersion

V. Aynutdinov (2005)

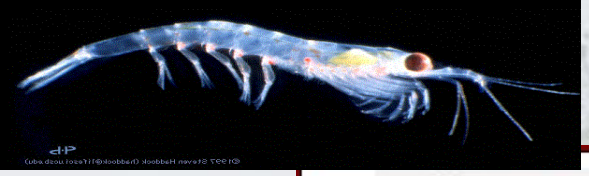


OPTICAL BACKGROUND : additional light coming from medium

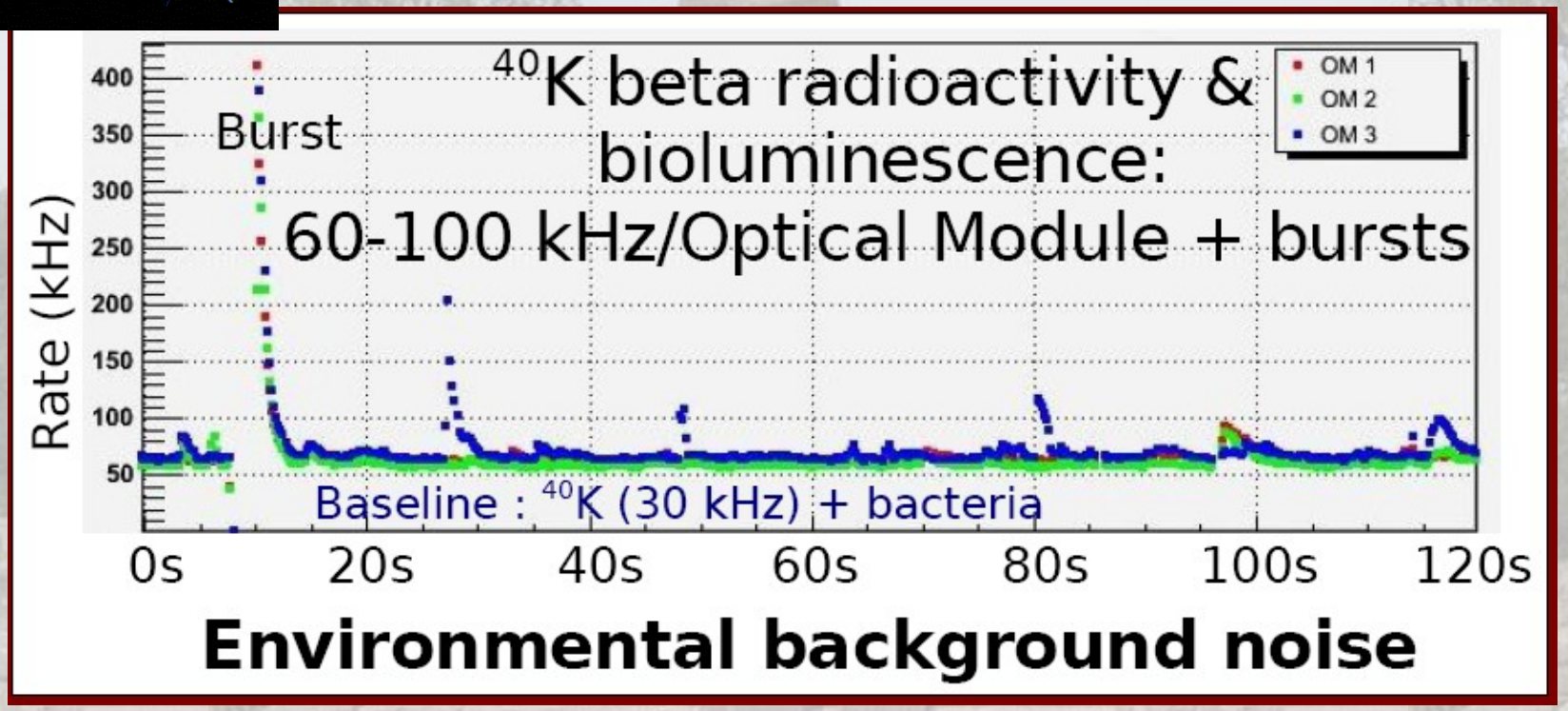
Depends on OM configuration (photocathode size) and on trigger threshold : ~ 1/3 photoelectron

BAIKAL (15" PMT)	0.1-0.3 kHz/**2** OMs : coincidence within 15ns, no ^{40}K
AMANDA (8")	1 kHz/OM : no radioactivity, no bioluminescence : only photocatode noise
NESTOR (15")	50 kHz/OM : ^{40}K + few bioluminescence (-3800 m)
NEMO (10")	30 kHz/OM : ^{40}K + few bioluminescence (-3500 m)
ANTARES (10")	60-100 kHz/OM : ^{40}K + bioluminescence (-2500 m)

^{40}K : beta emitter
e^- 1.12 MeV~40 γ

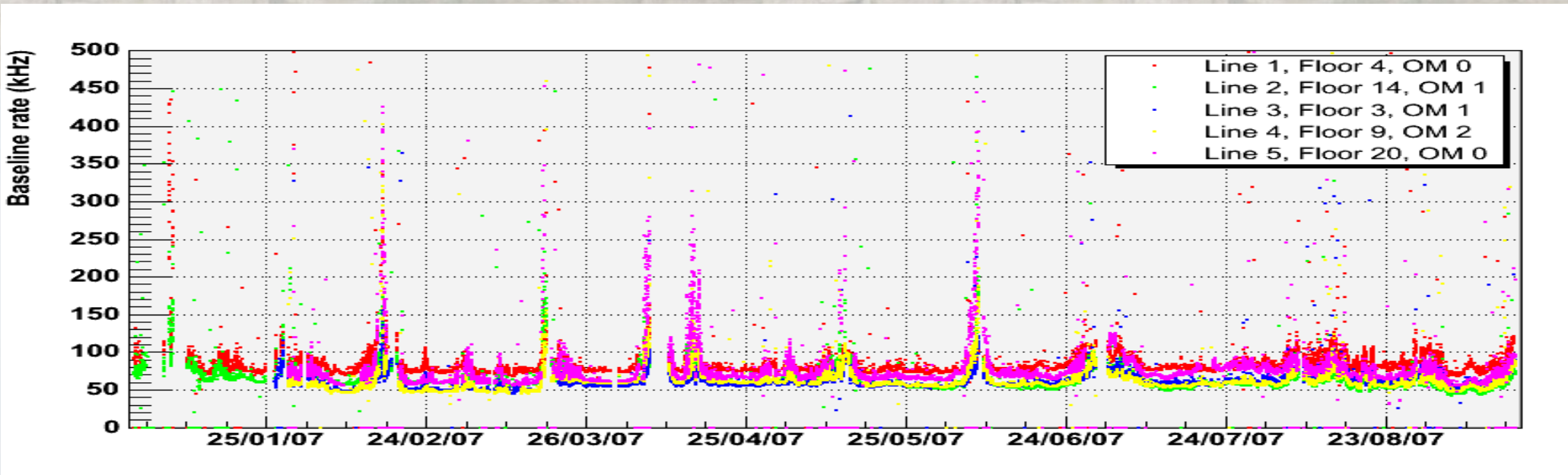


ANTARES



Environmental background noise

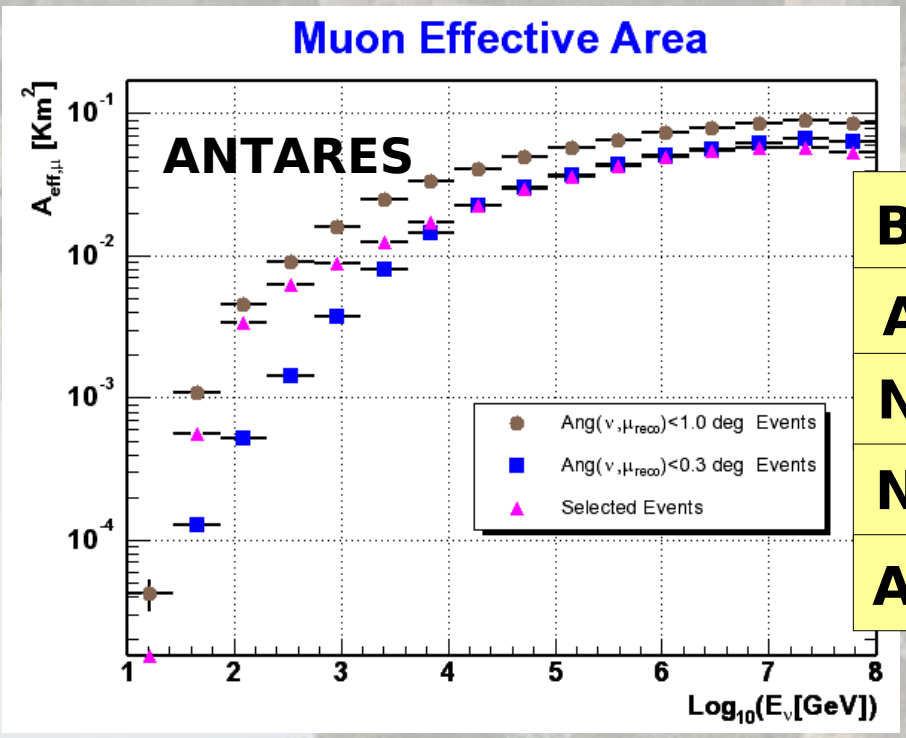
2007



Muon EFFECTIVE AREAS

BAIKAL NT200	2000 m^2	@ 1 TeV
AMANDA 19 strings	30 000 m^2	(ICECUBE: 1 km^2)
NESTOR 1 tower	20 000 m^2	
NEMO 9x9 towers, 140m spaced	1 km^2	
ANTARES 12 lines	20 000 m^2	

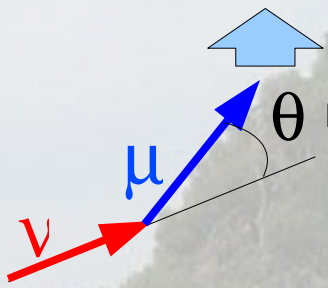
@ 10 TeV



ANGULAR RESOLUTION

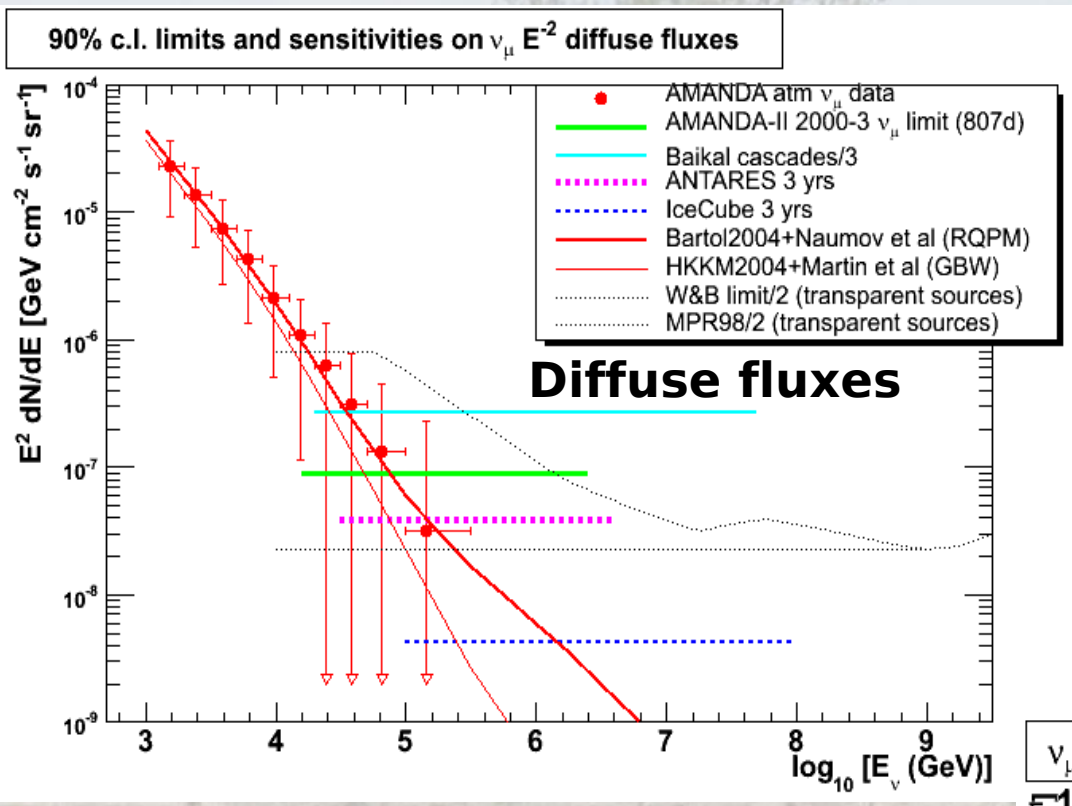
BAIKAL NT200	4°
AMANDA 19 strings	2° (ICECUBE : 0.7°)
NESTOR 6 towers	better than 1°
NEMO 9x9 towers	0.1°
ANTARES 12 lines	0.3°

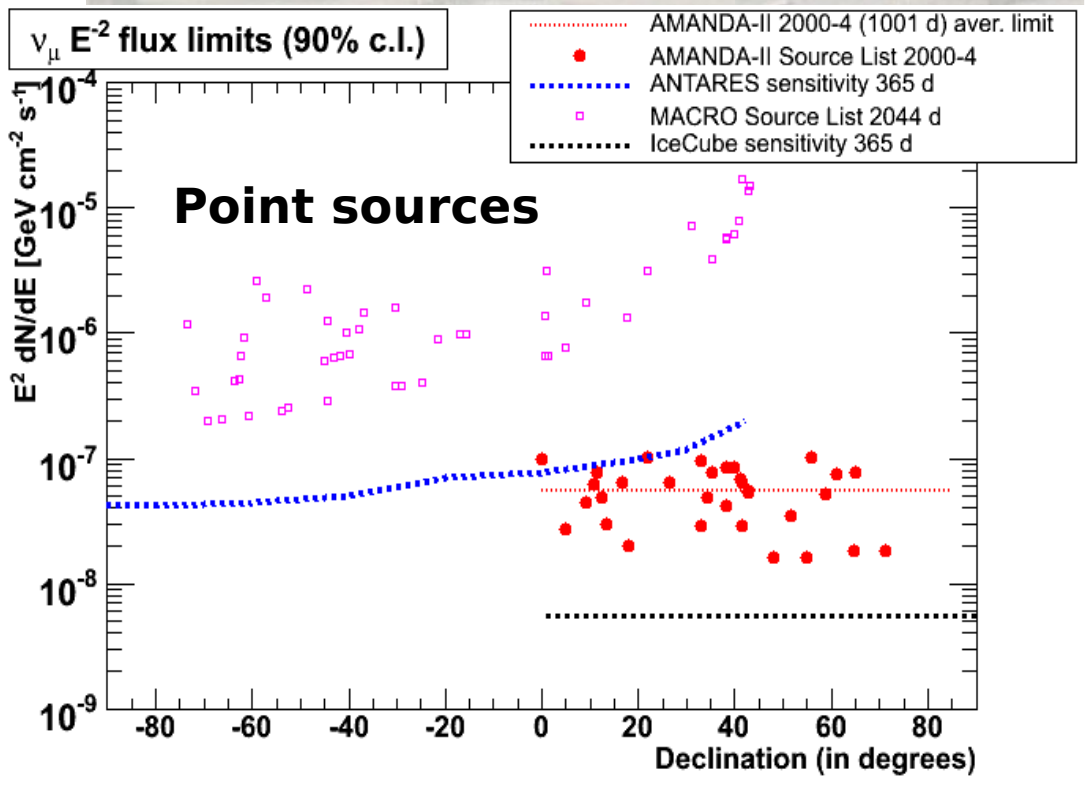
@ 10 TeV



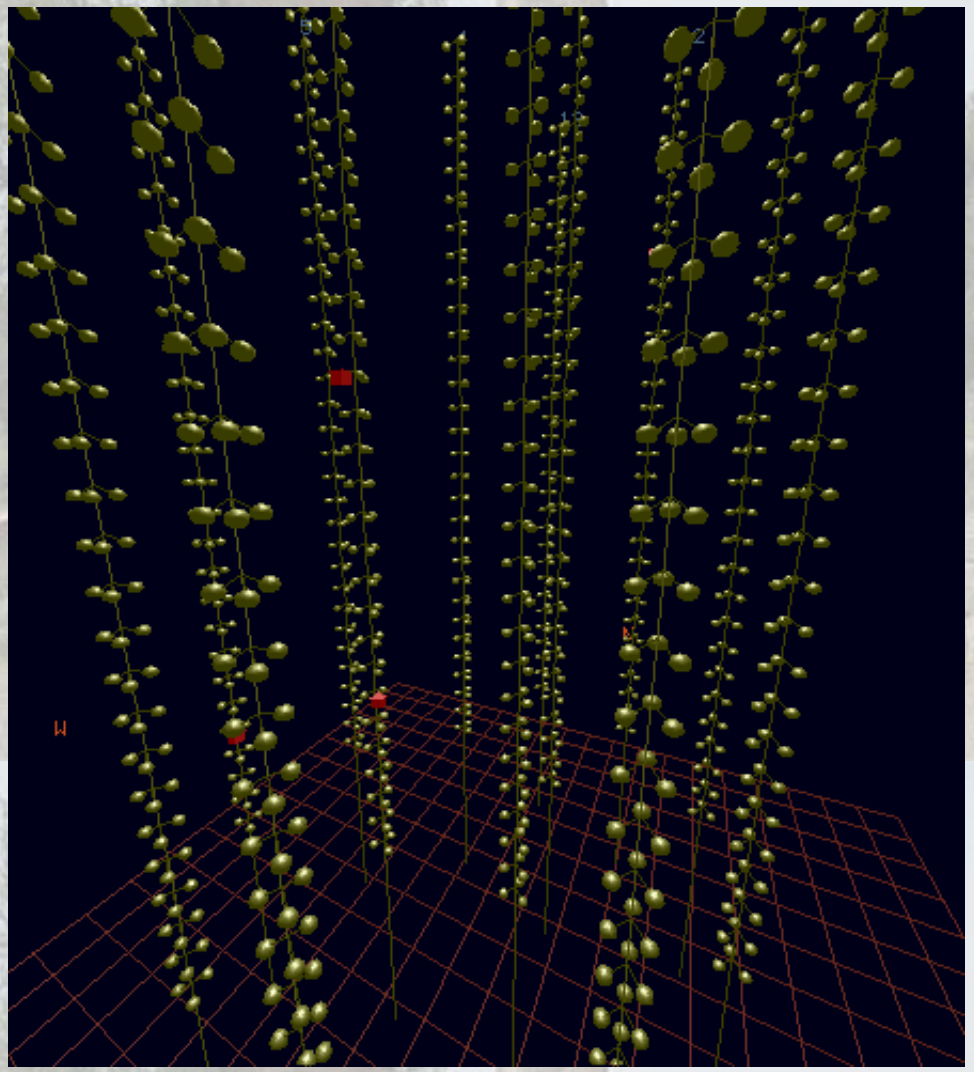
Dominated by reconstruction

ANTARES expected sensitivities





From the simulation ...

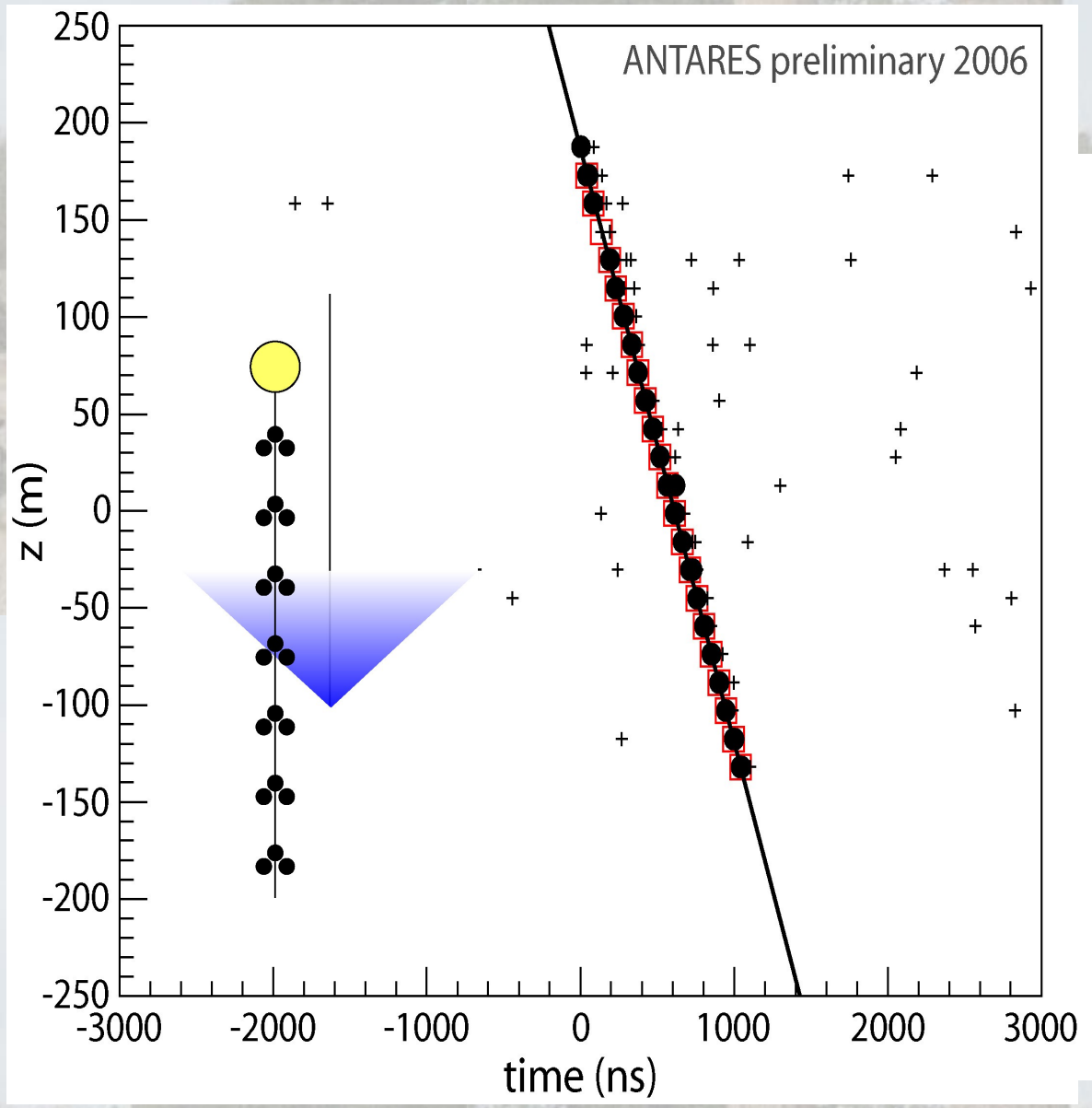


MC TeV muon traversing the detector.

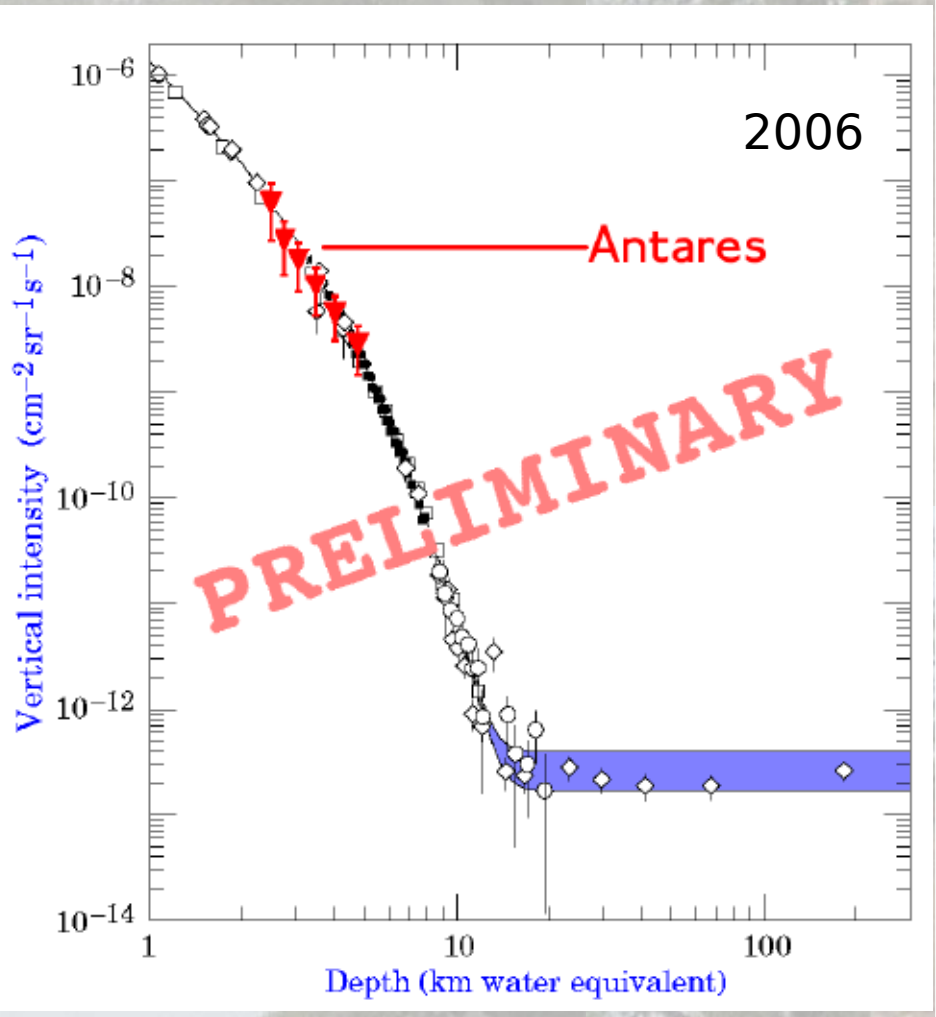
12 lines

... to the data : 2006, the first line:

Line 1 analysis, May-September 2006,
low sea current : 10 days equivalent

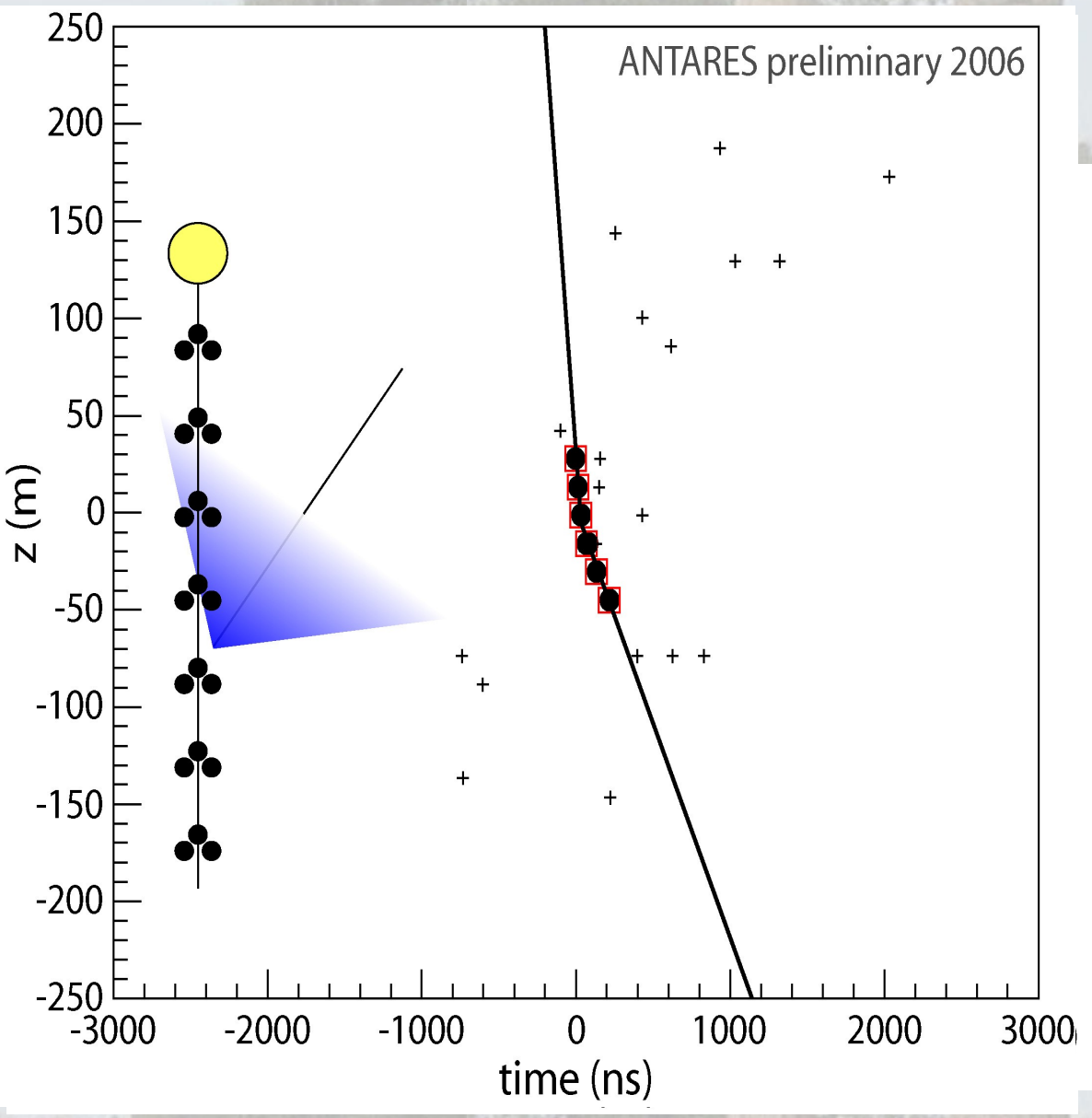


Atmospheric muon flux estimate (Zenith angle <-> depth)

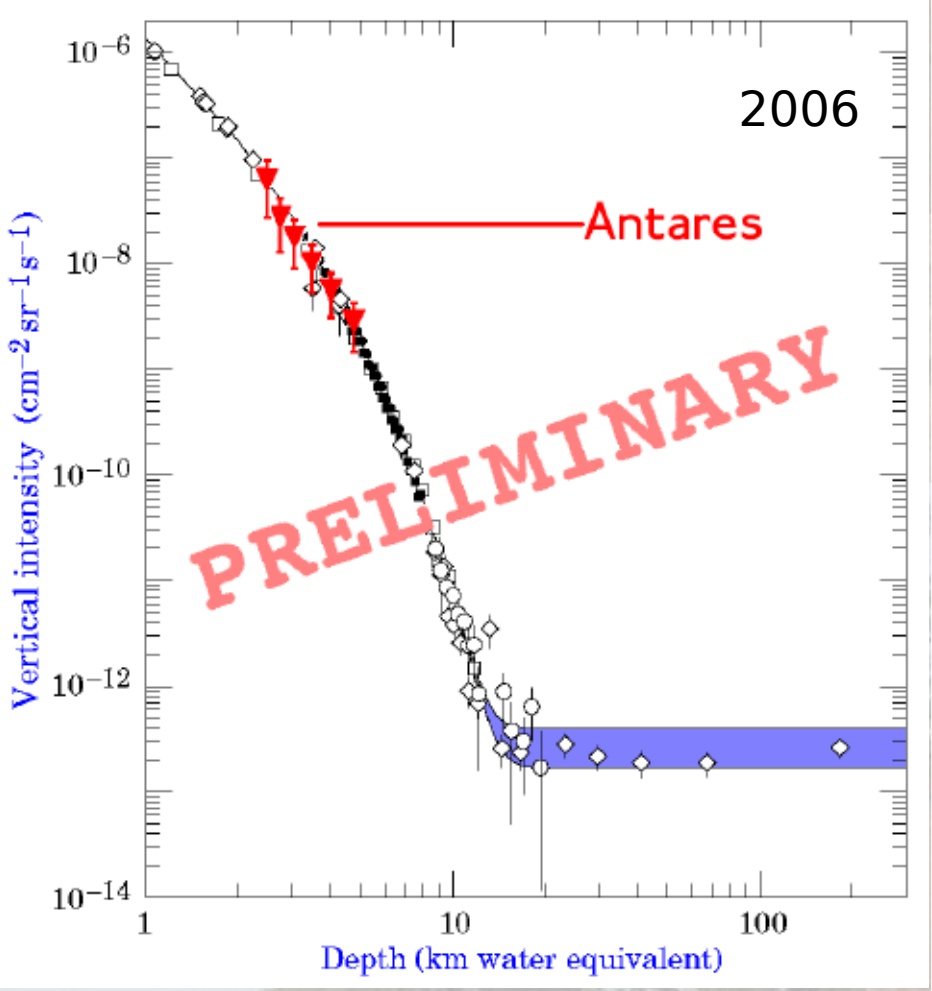


... to the data : 2006, the first line:

Line 1 analysis, May-September 2006,
low sea current : 10 days equivalent



Atmospheric muon flux estimate (Zenith angle <-> depth)

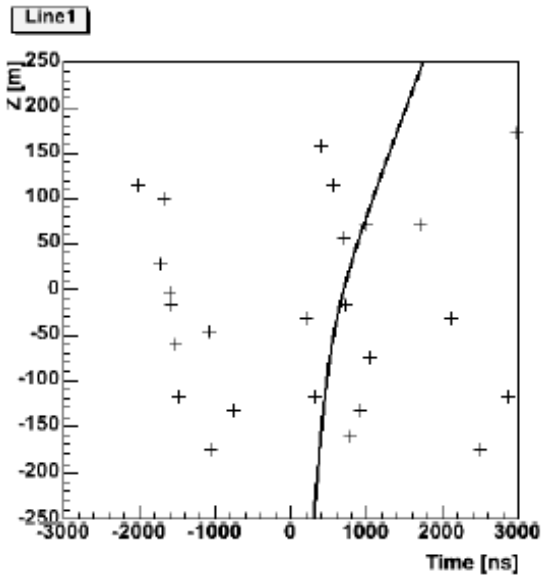


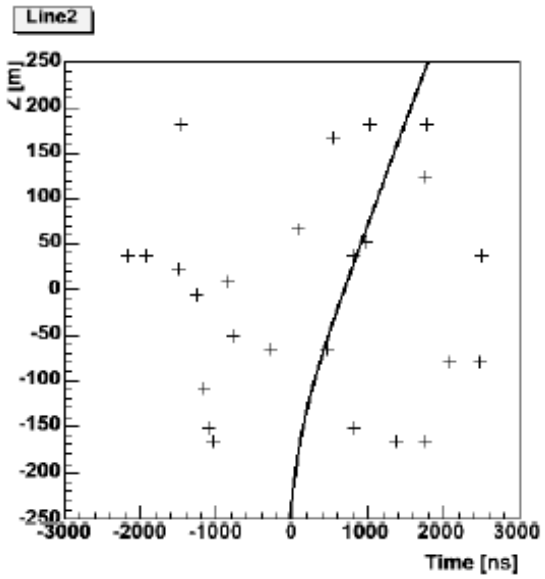
2007: 5 lines: Up going neutrino candidate

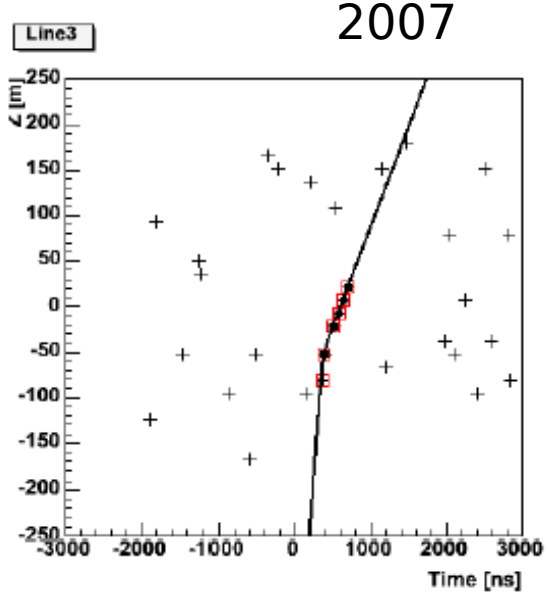
Θ=35°

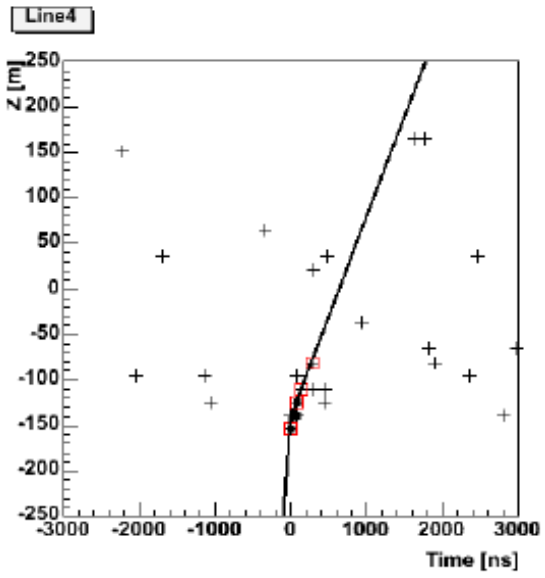
Run : 25929 Event : 6742 FrameTarget : 18 FrameIndex : 61770
a: 37.1598 b: 22.0721 t0: 164892932.2 θ: 0.61779 ϕ: -3.7146 fit : 1/4

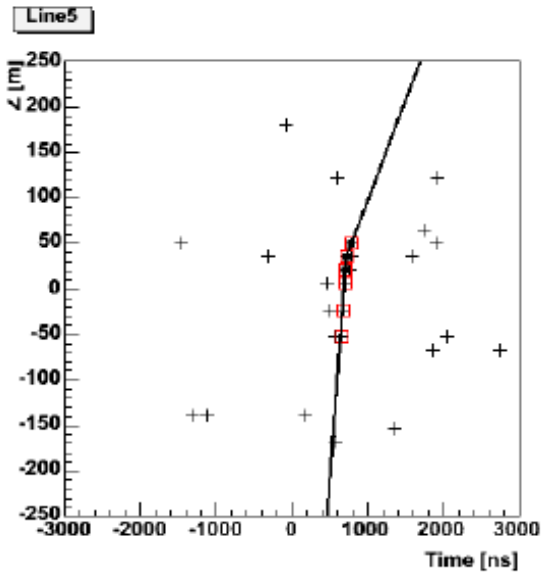
5 lines
2007

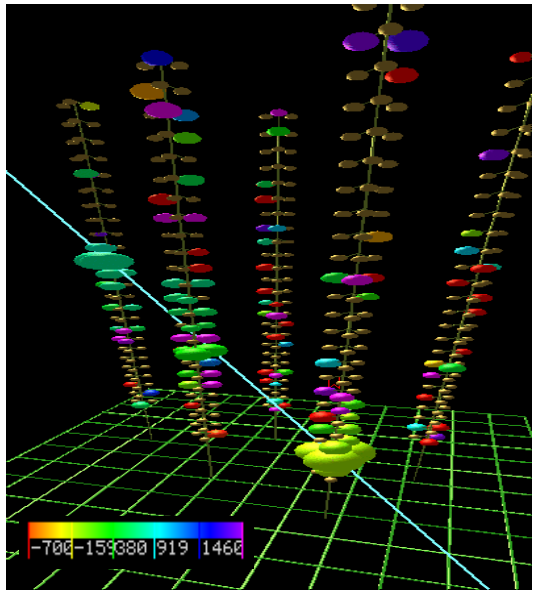




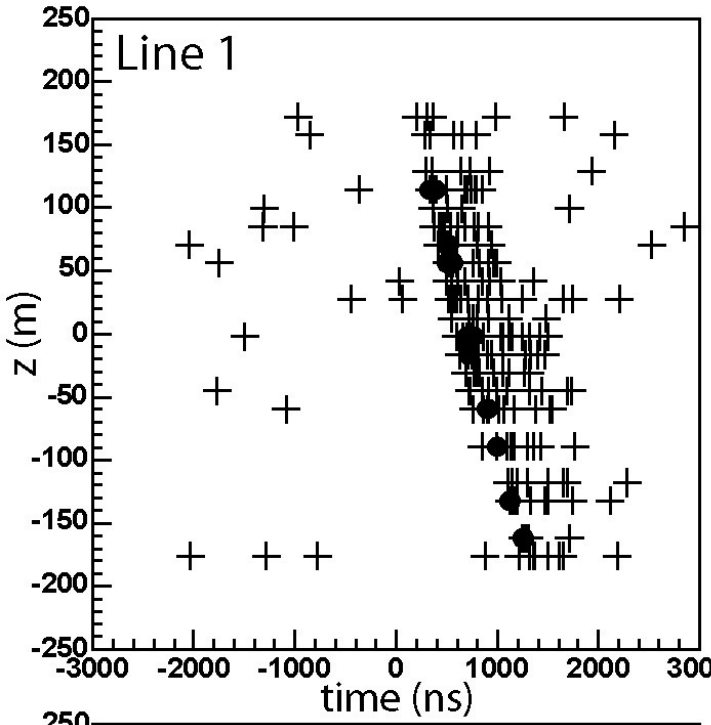


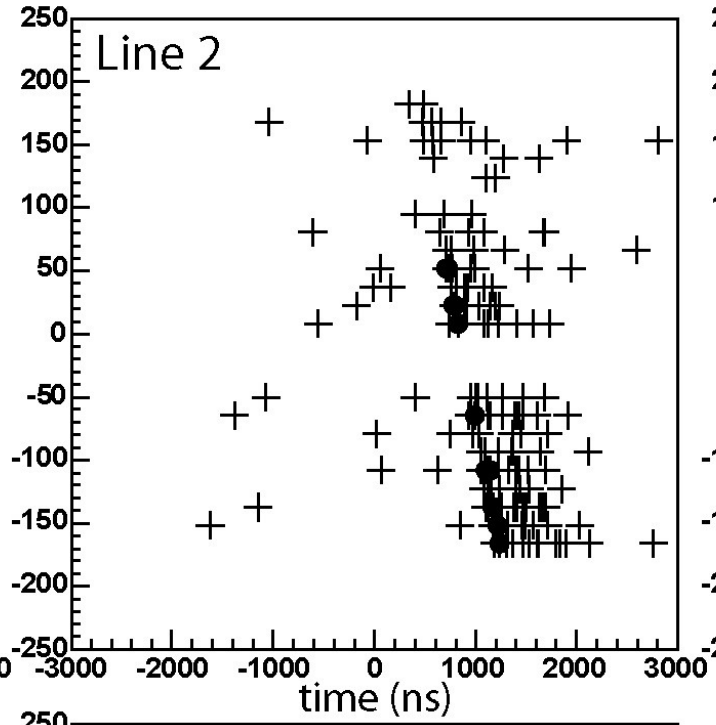


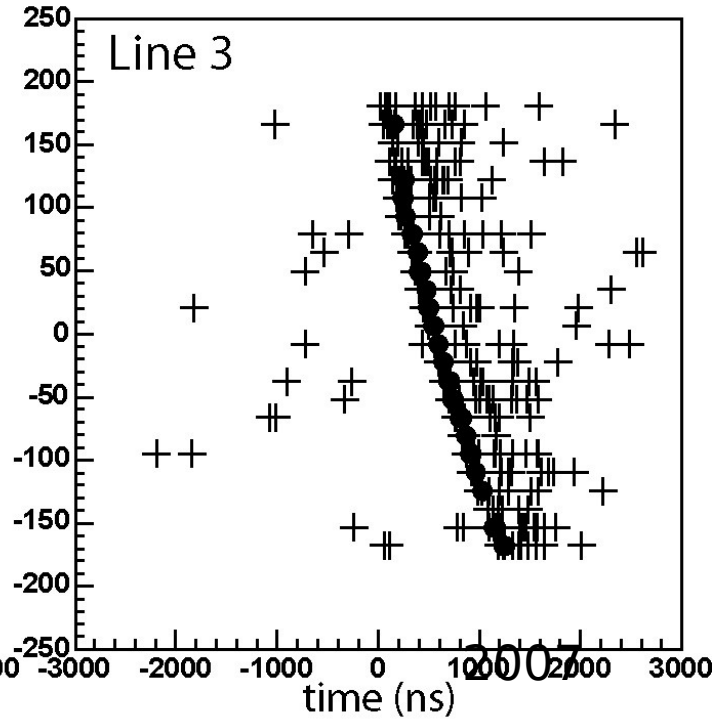




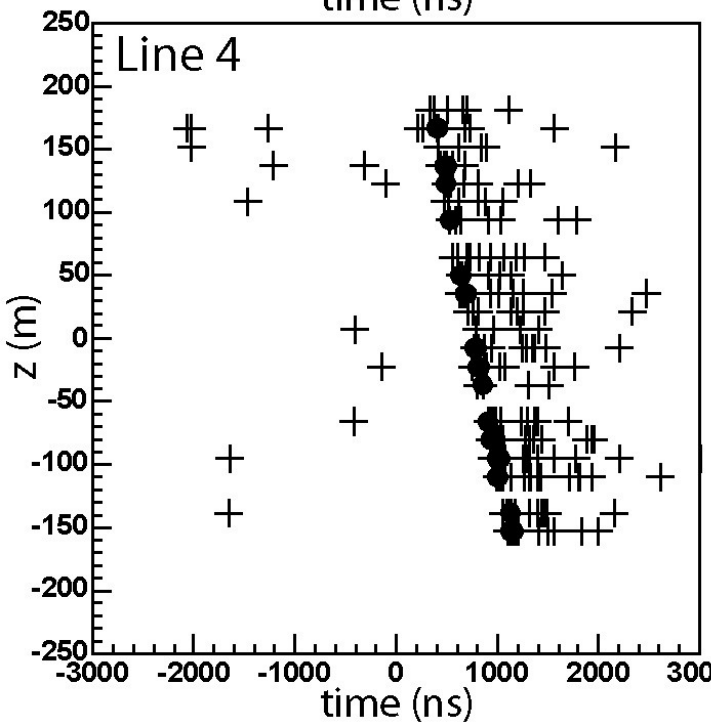
Atmospheric muon bundles

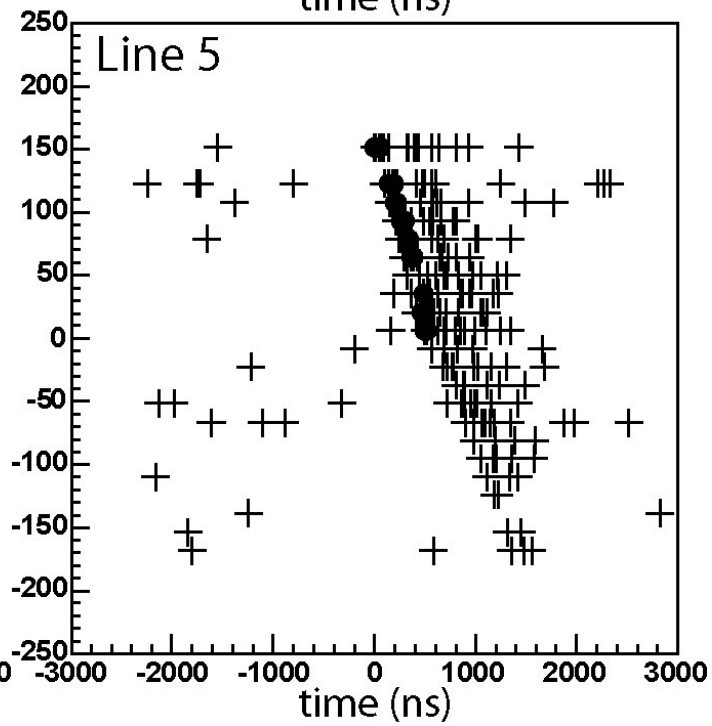


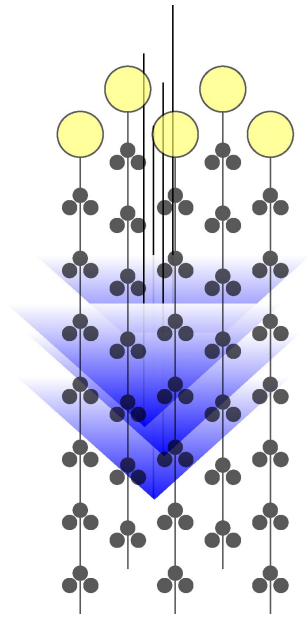




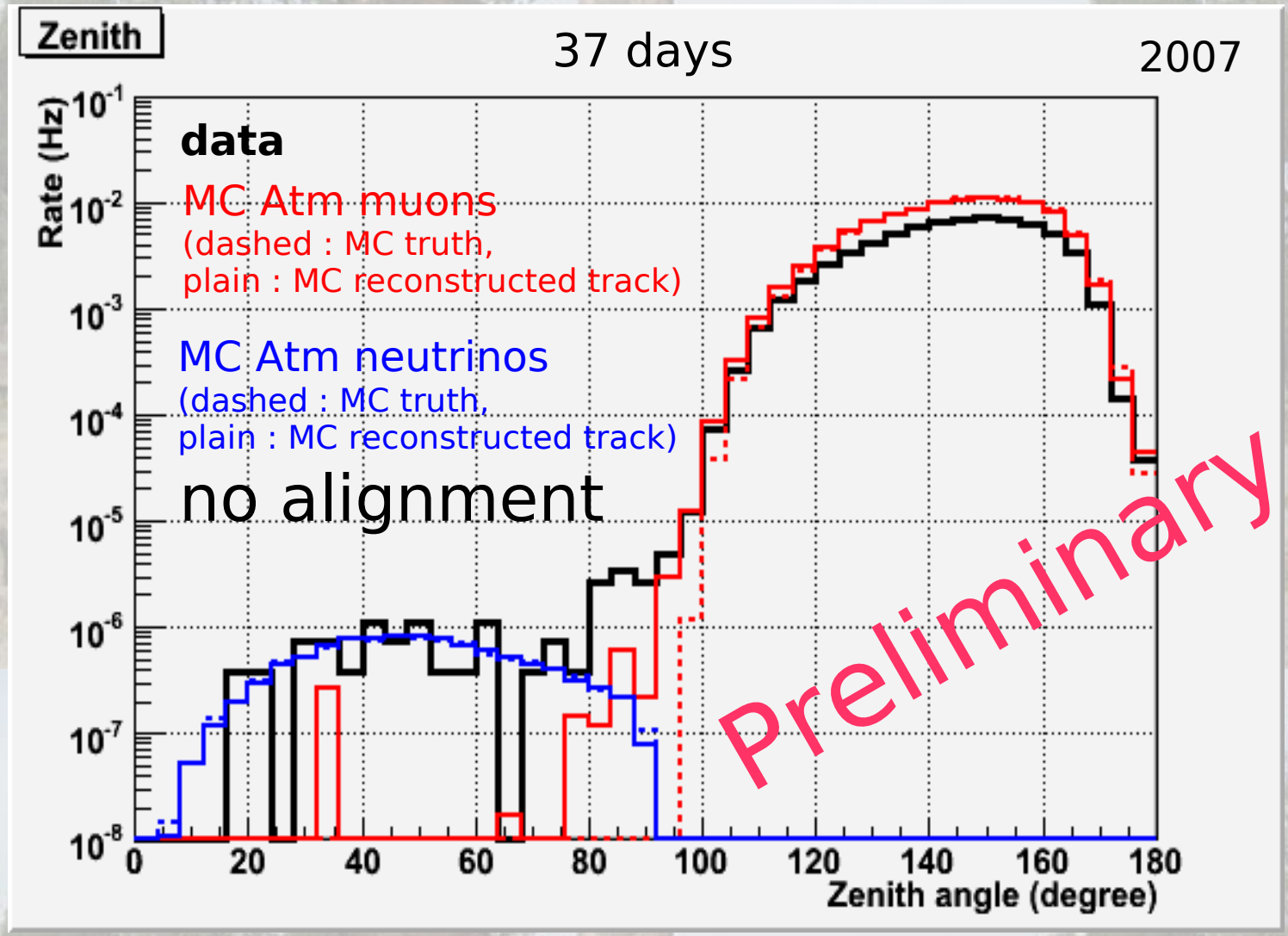
2007



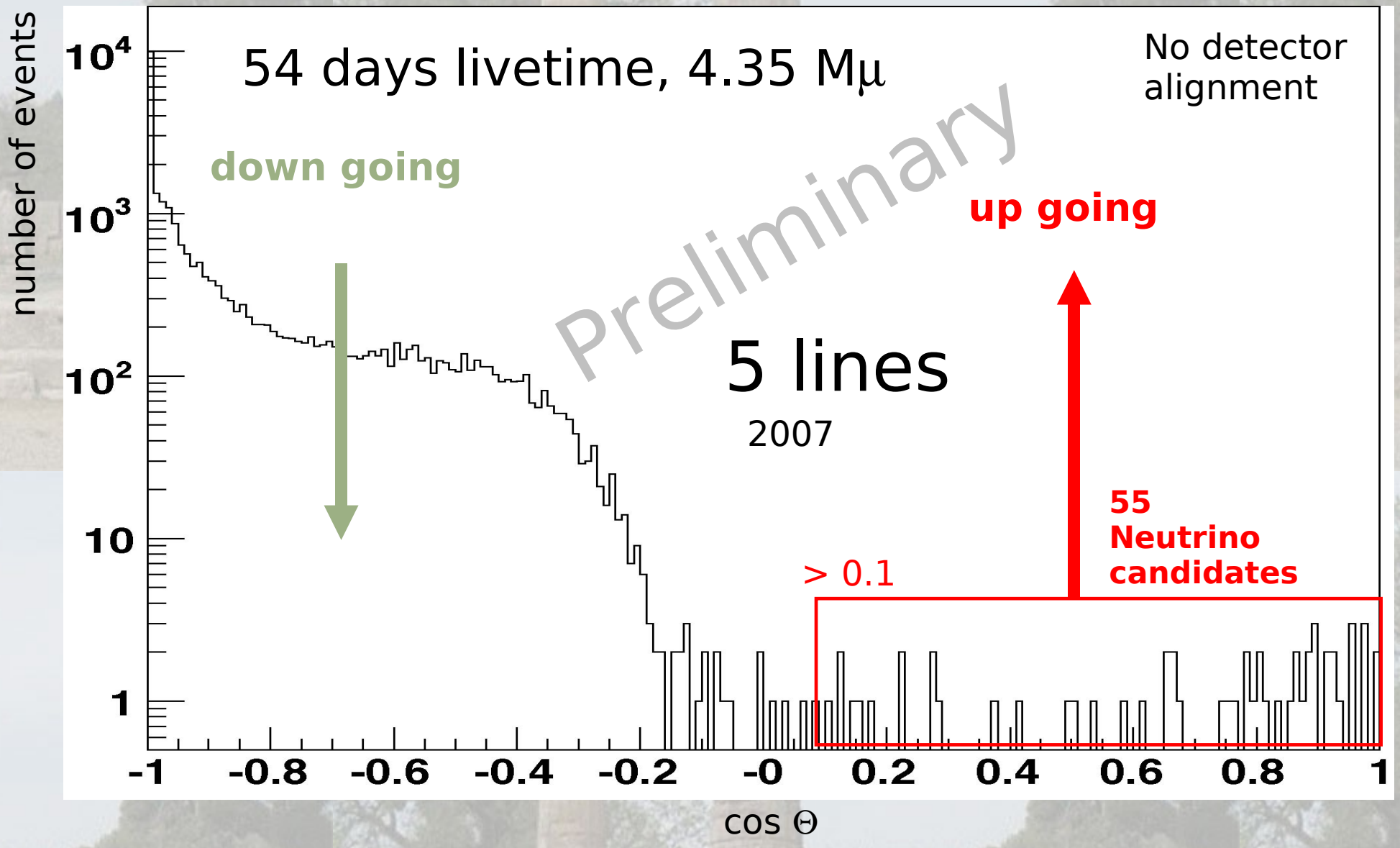




“Online” reconstruction with 5 lines

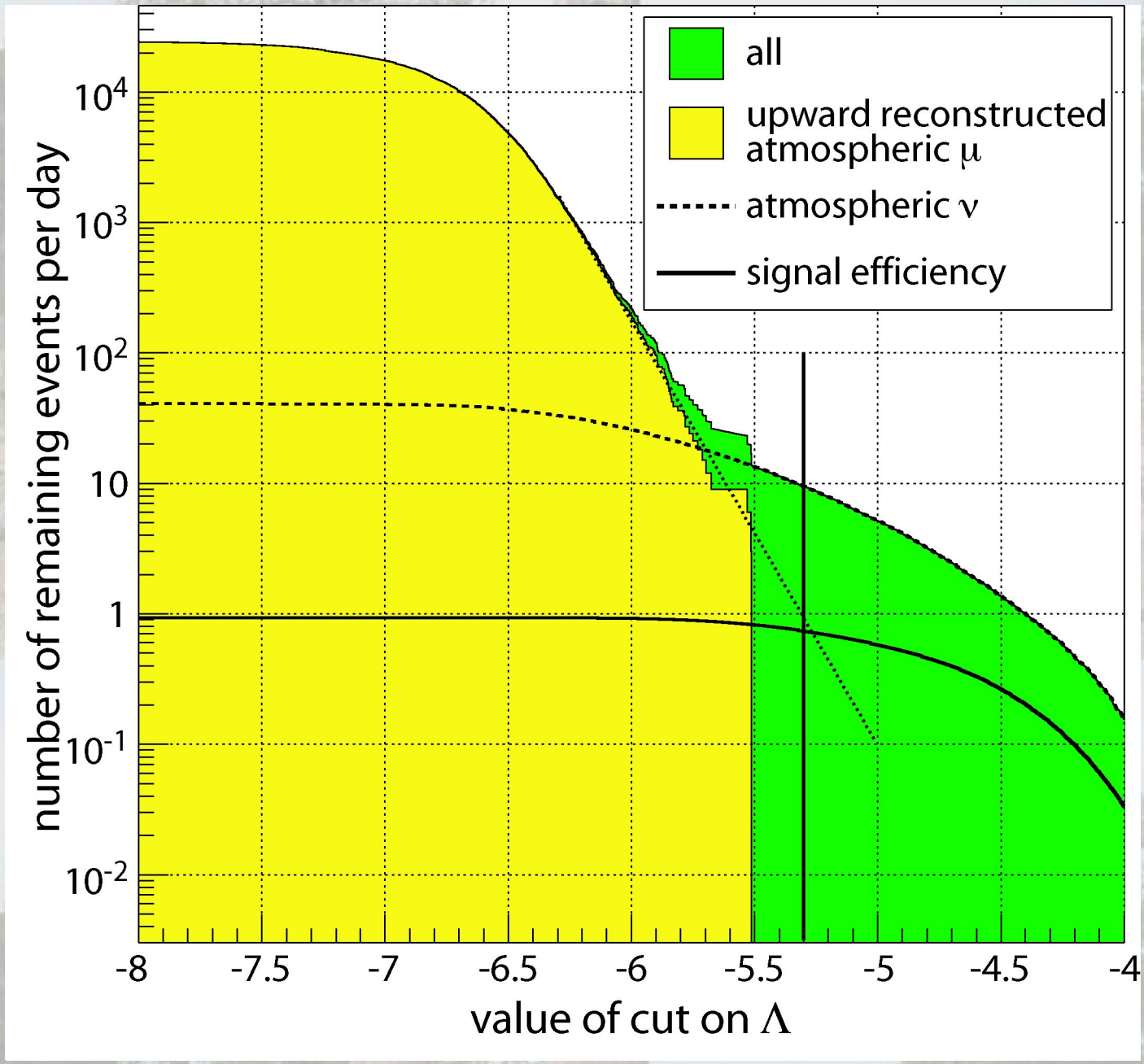


Atmospheric neutrinos

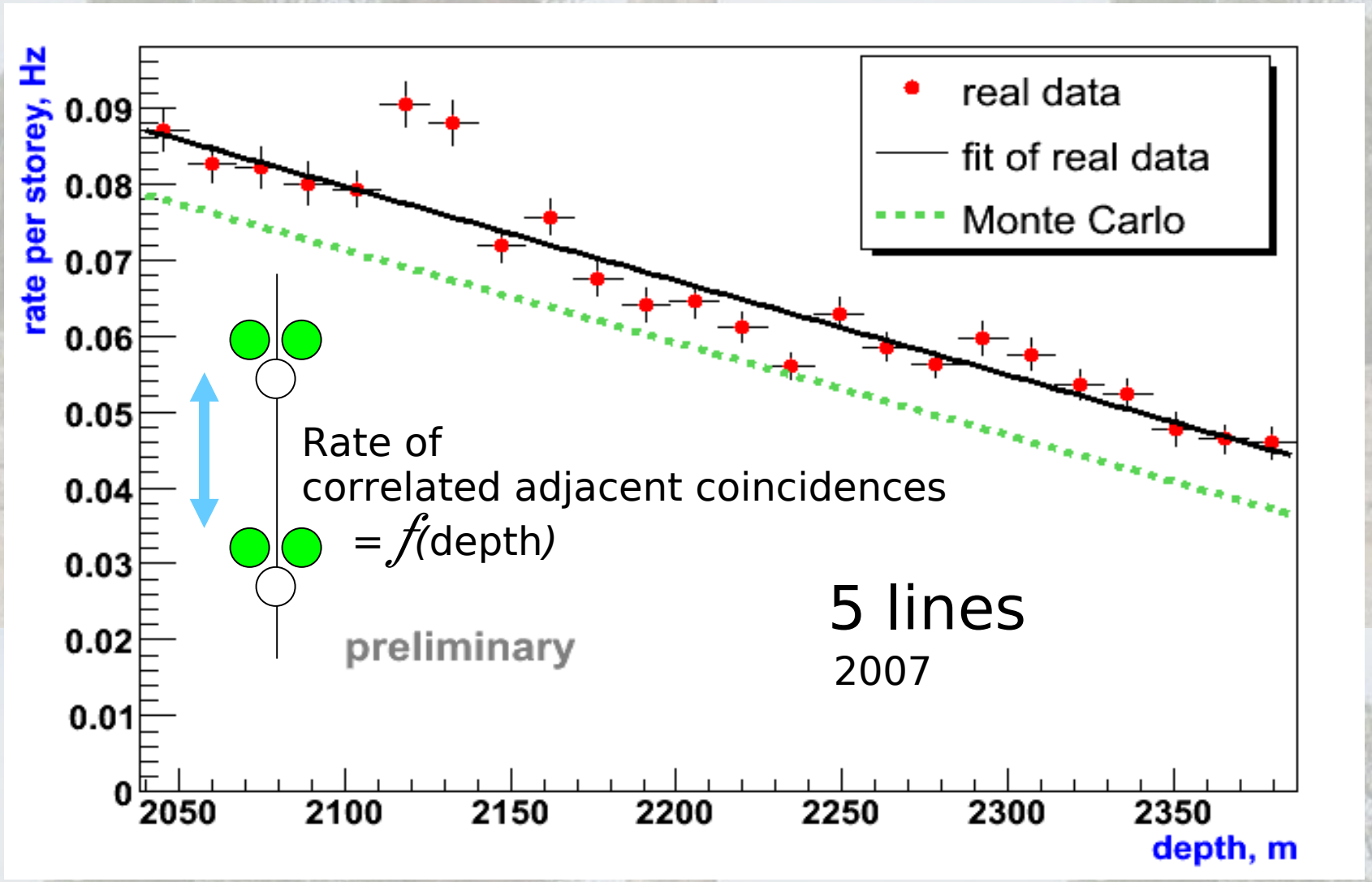


Applied quality cut : likelihood method

12 lines MC



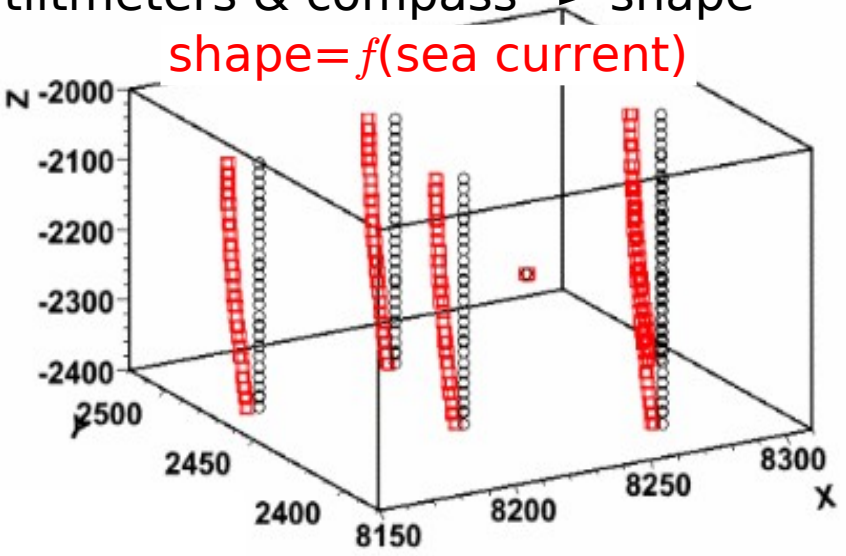
Absorption of atmospheric muons in water

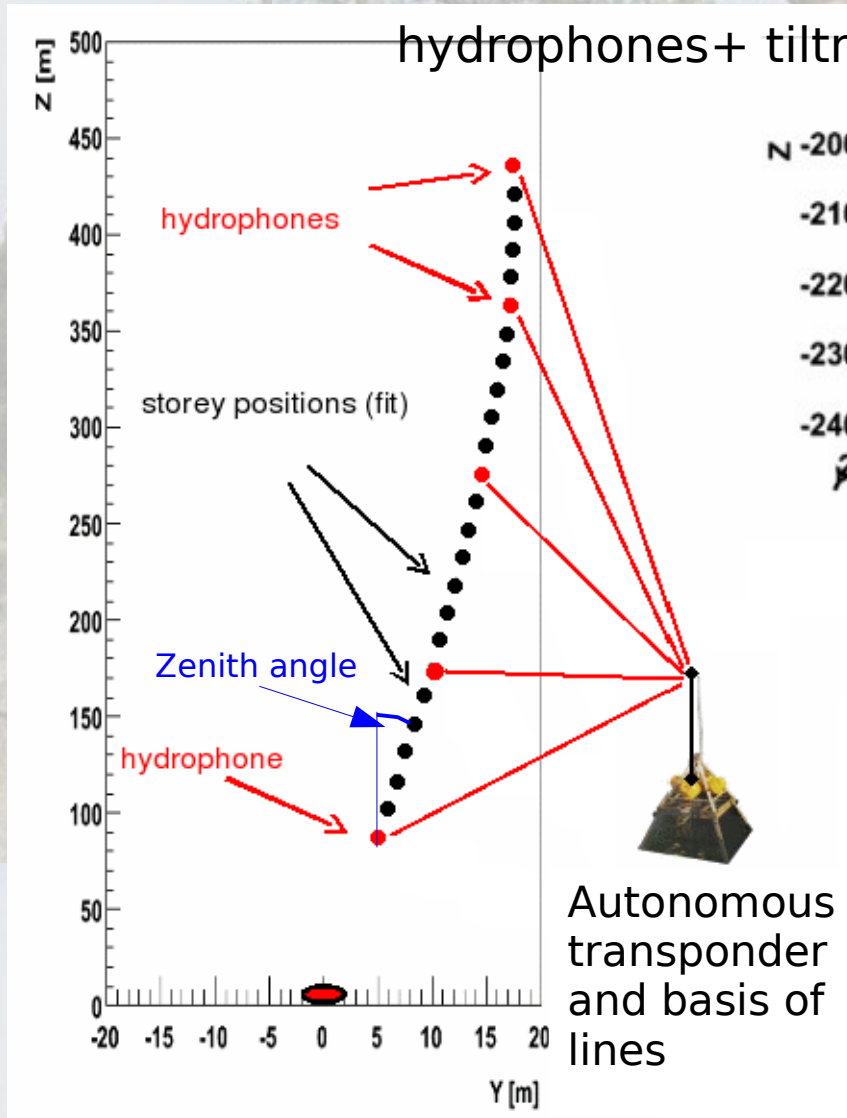


Improvement of performances : calibration (position)

hydrophones+ tiltmeters & compass → shape

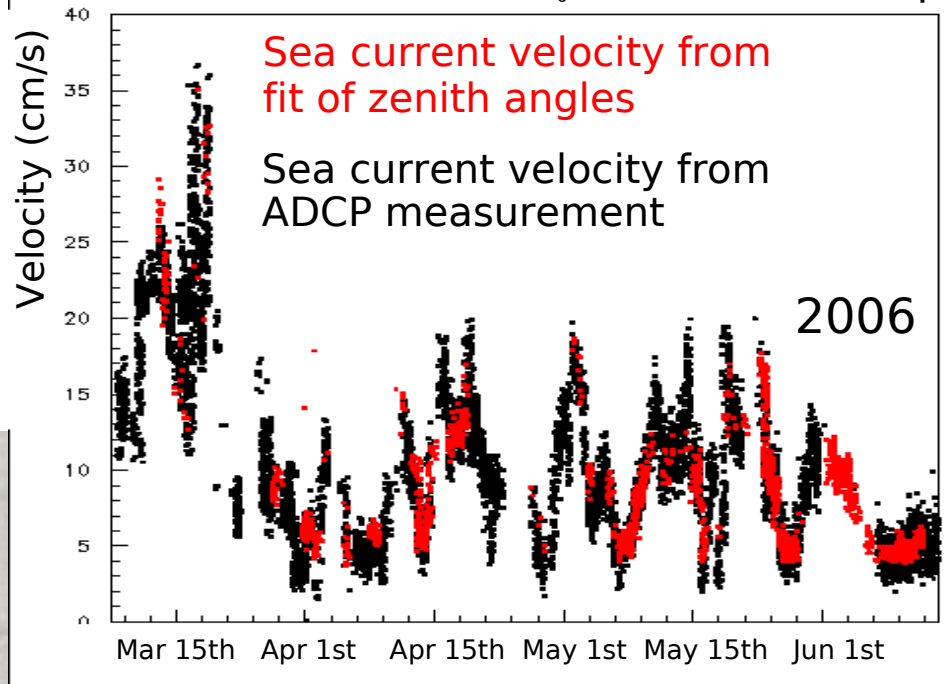
shape=f(sea current)



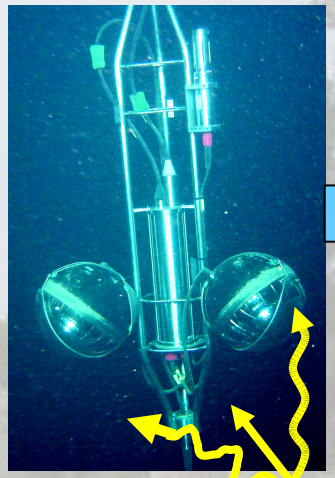


Autonomous transponder and basis of lines

Check of the Line model f used in the shape fit



Calibration/monitoring with Potassium-40



γ

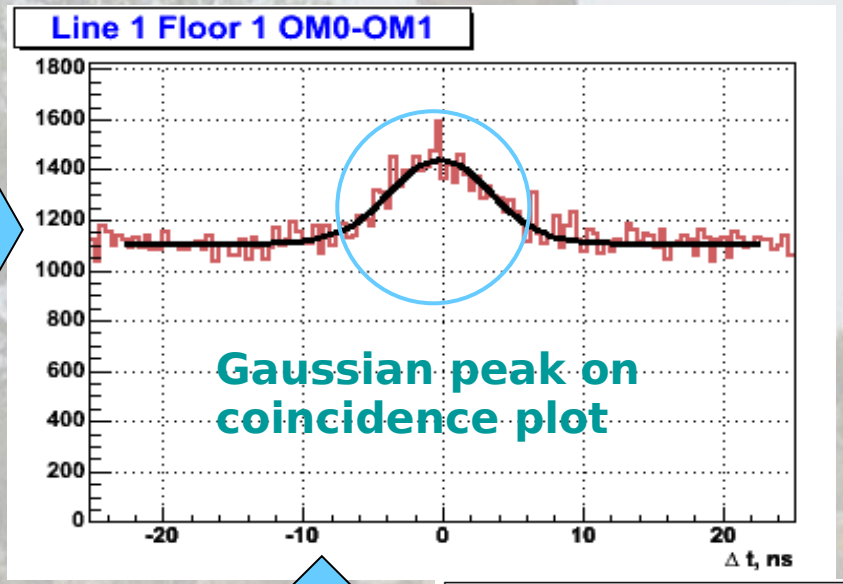
Cherenkov

γ

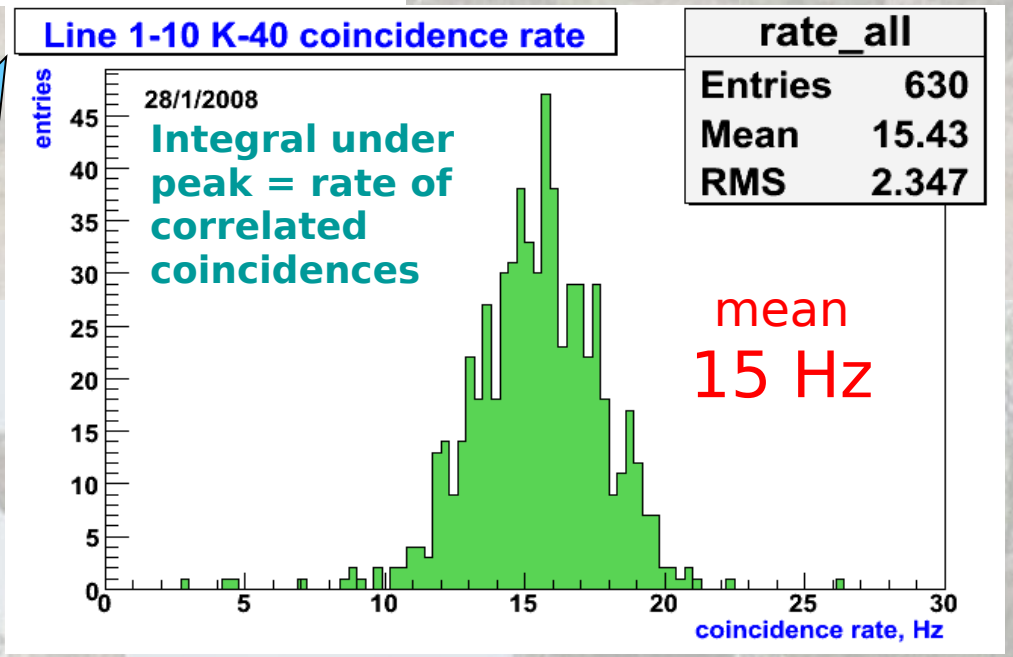
e^- (β decay)

^{40}K

^{40}Ca



High precision (~5%) monitoring of OM efficiencies



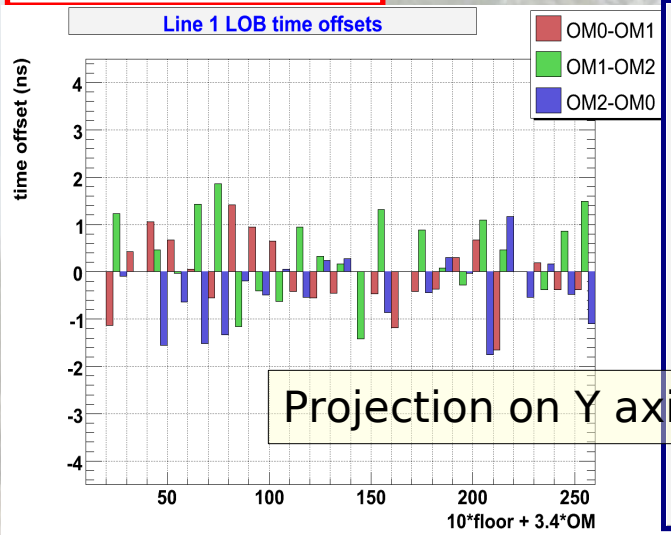
MC prediction 13+/-4 Hz
(angular acceptance to be confirmed)

D Zaborov (Moriond 2008)

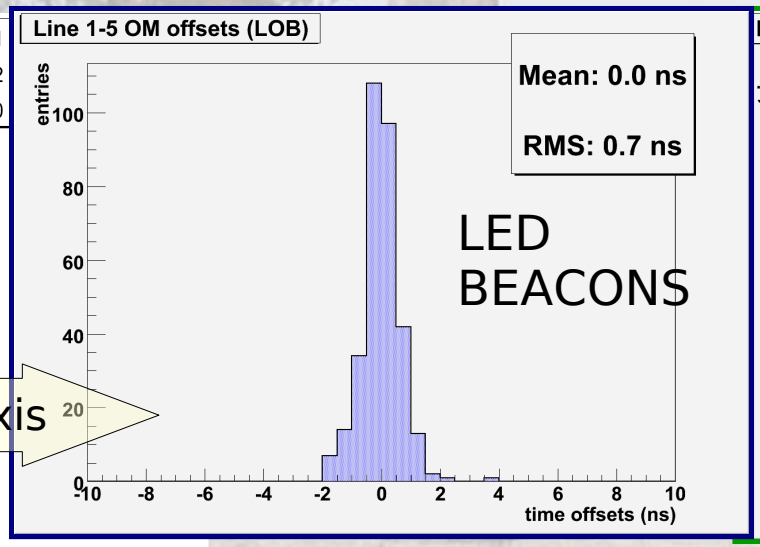
Improvement of performances : calibration (time)

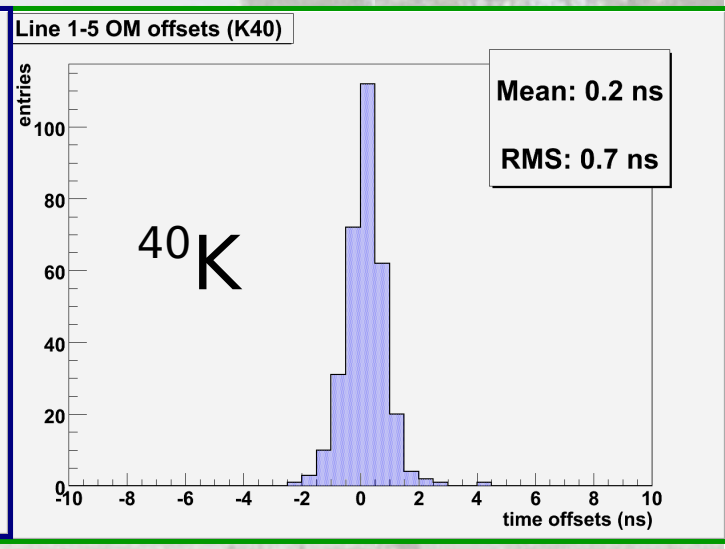
Lines 1-5

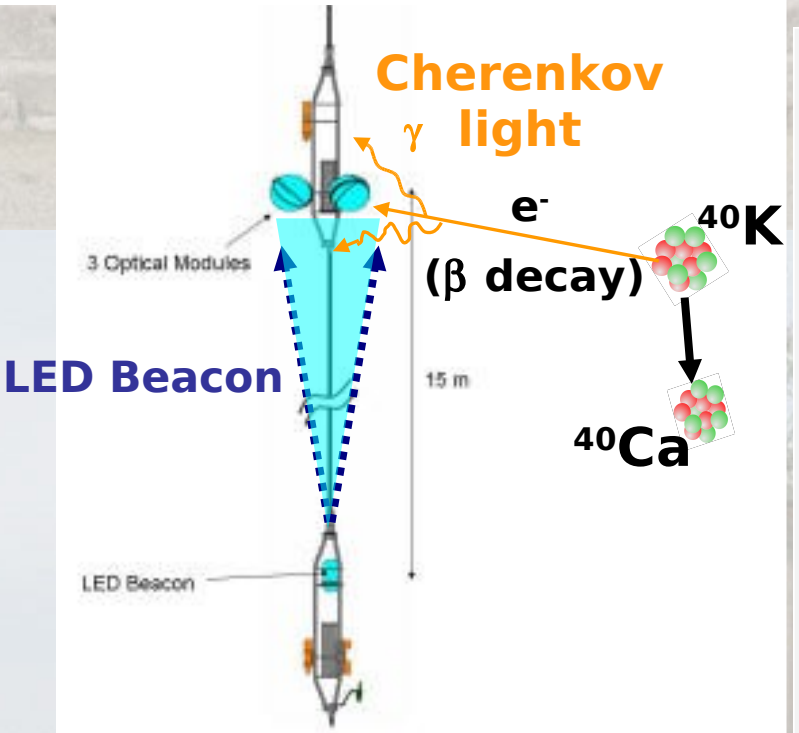
LED Beacons & K40 OM offsets

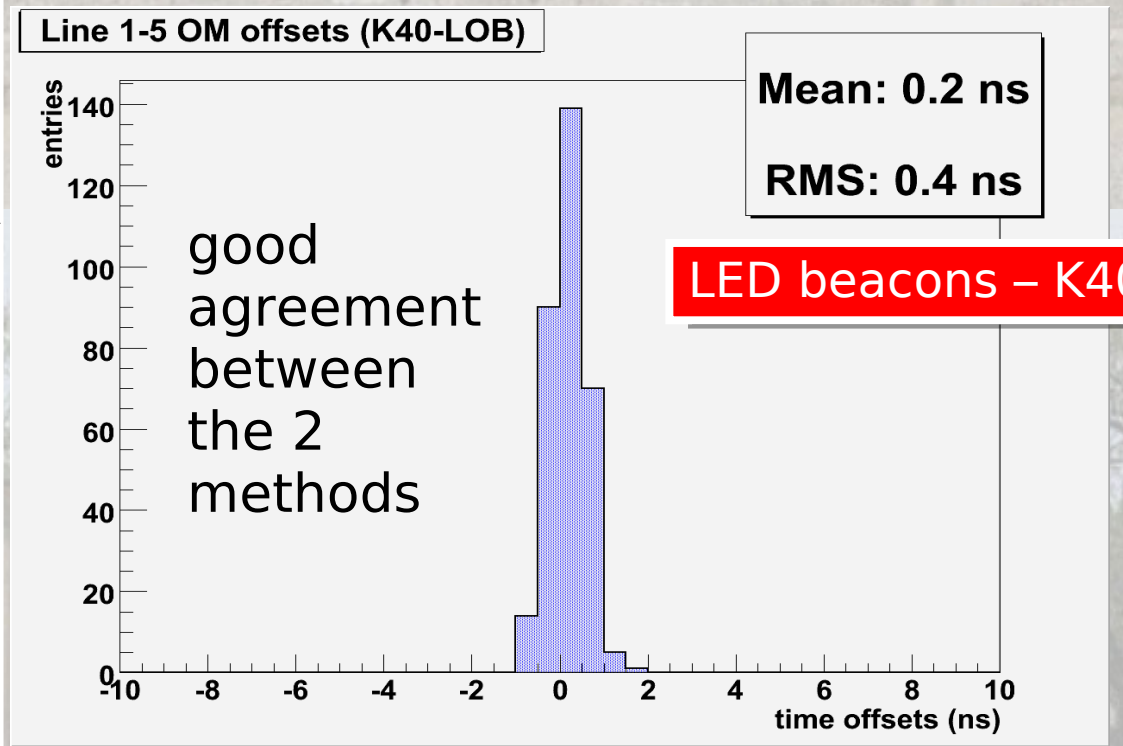


Projection on Y axis

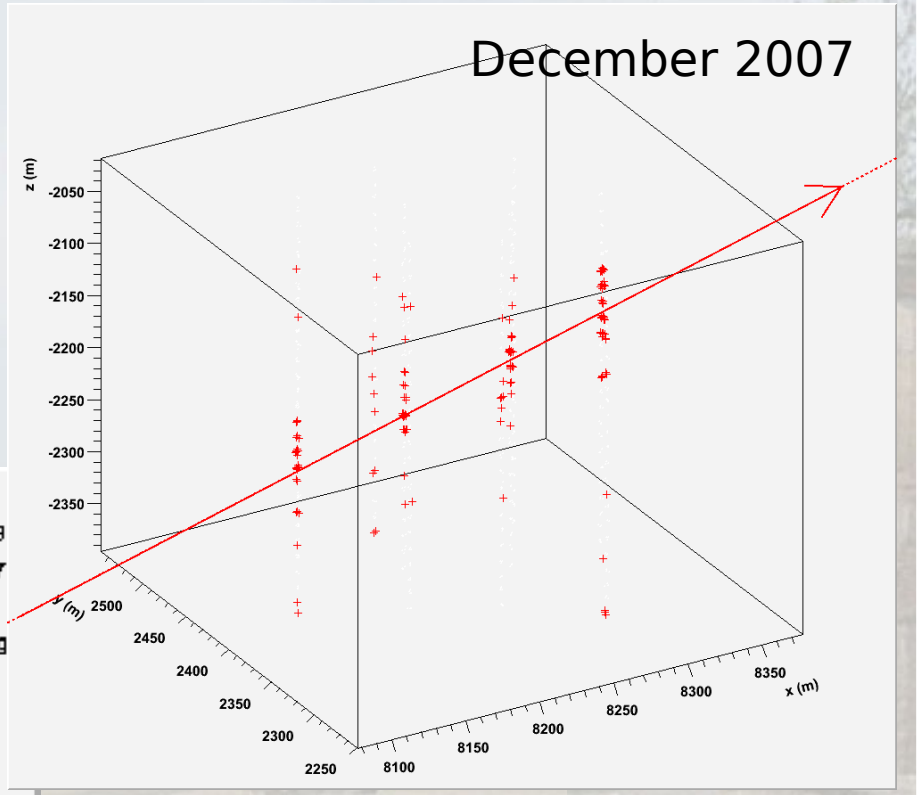


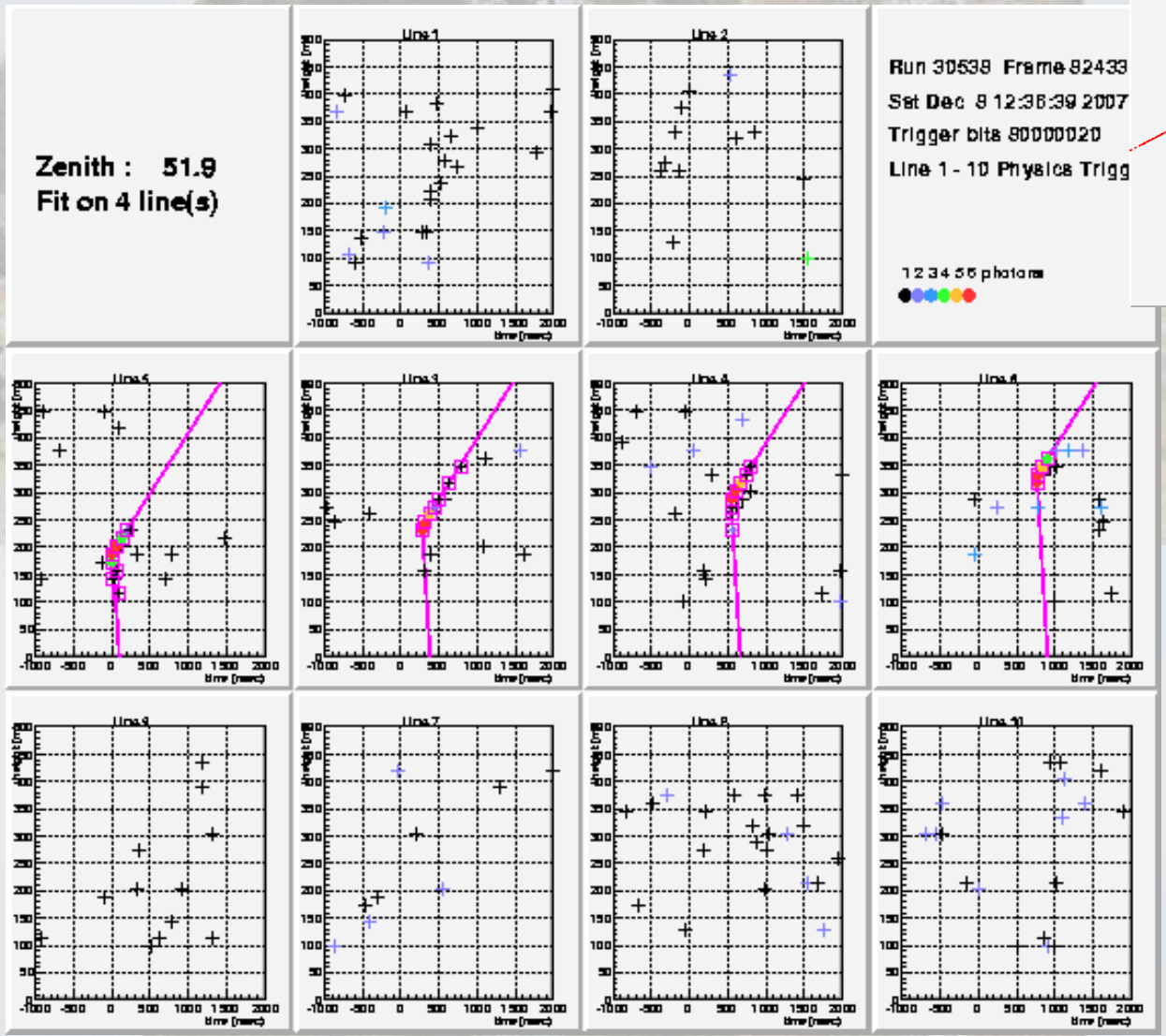






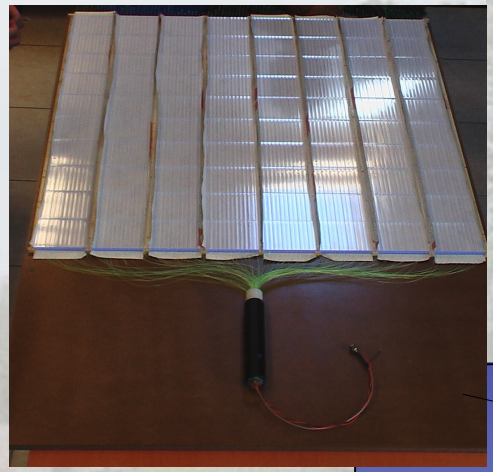
The first neutrino with 10 strings





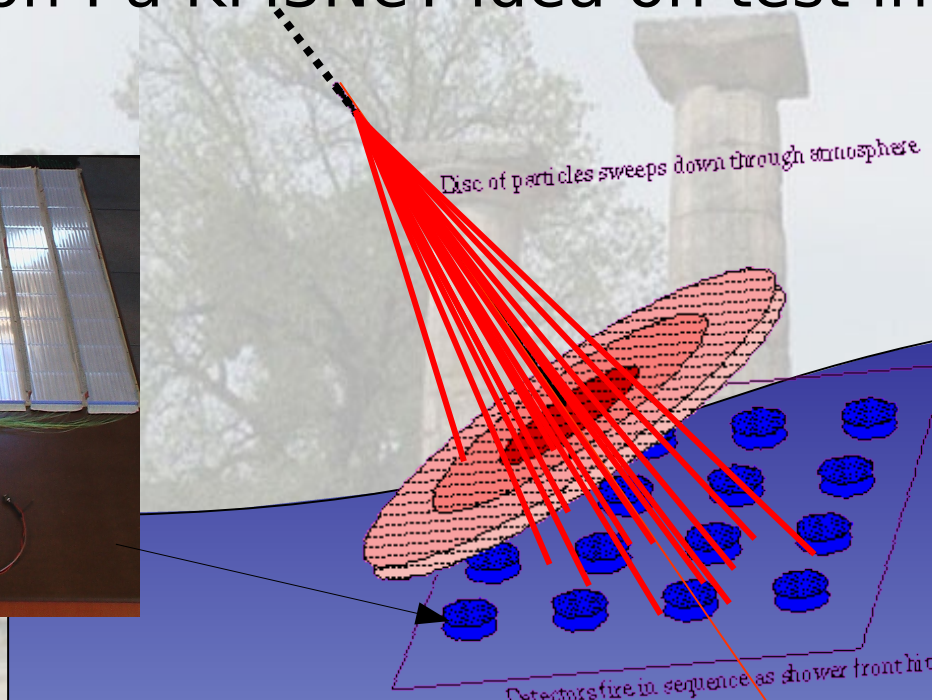
Preliminary

Calibration : a KM3NeT idea on test in ANTARES framework ?

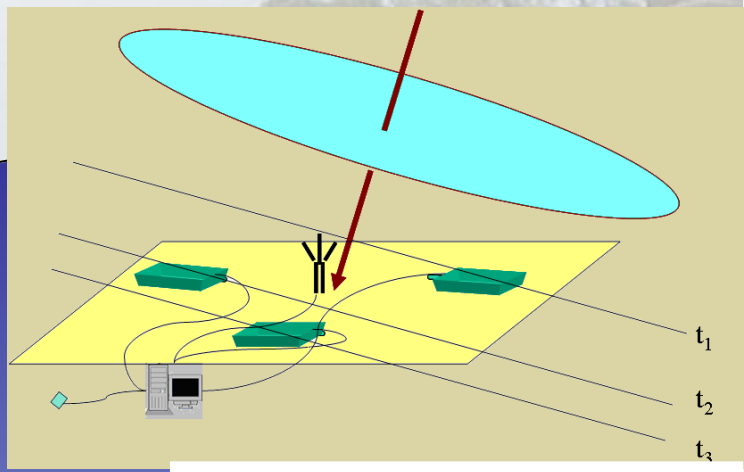


Spyros Eust. Tzamarias, Apostolos Tsirigotis et al

(HOU)



Atmospheric Muon

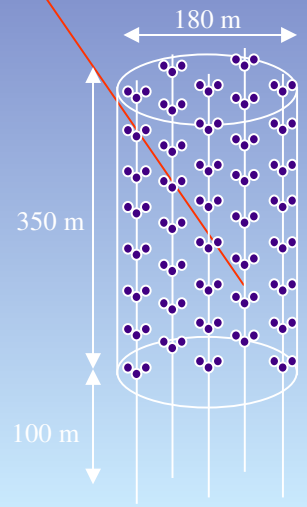


Triangulation→ ShowerDirection

GPS timestamp

to match

events



- Angular offset
- Absolute position

CONCLUSION

BAIKAL (fresh water) & AMANDA (ice) are the first high energy neutrino telescopes;
They have already proved the feasibility and interest of such devices.
The first “underwater atmospheric neutrinos” were reported in 1995 by the BAIKAL collaboration.
Reliable atmospheric neutrino results are now available.
Preliminary astrophysics results are produced.

ANTARES 5 lines data are now extensively analyzed;
The 10 line detector is running since December 2007.
In Summer 2008 ANTARES 12 lines will be completed.

NEMO phase 1 is currently on-going.

The Mediterranean sea cubic kilometer detector design is in progress, gathering all the efforts within the KM3NeT project.