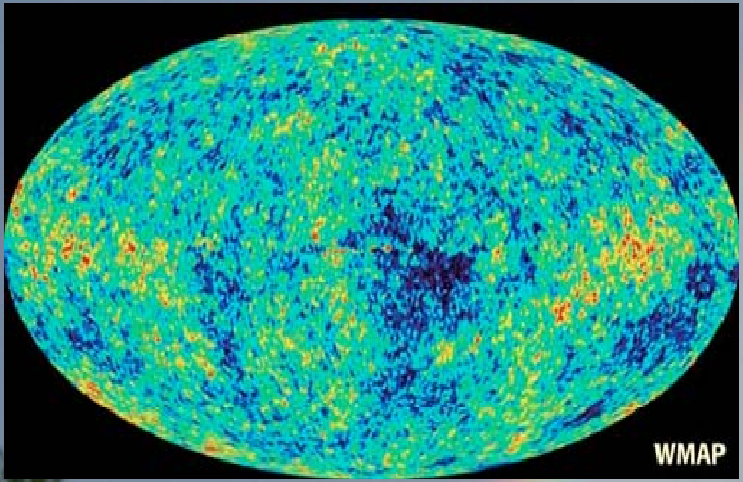
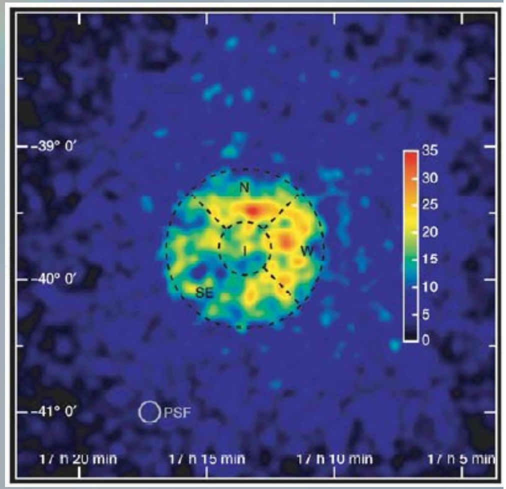
Neutrino telescopes in the deep sea

Vincenzo Flaminio

Physics Dept. & INFN-Pisa





LOMONOSOV 2007

ν^s from space: the long march

Solar neutrinos → Davis et al. 1955 – 1978

Observation of solar neutrinos confirmed later by many experiments

Thanks to these measurements, the Standard Solar Model now on a solid basis

Later → observation of ν^s from SN1978a ➔ help clarify mechanism of SNs

High Energy Cosmic ν^s

- **Understand production mechanism of HE cosmic rays**
- **Disantangle Synchrotron-Inverse Compton from Hadronic production in SNRs**
- **Study Binary systems, μQuasars**
- **Investigate the very high energy processes occurring in GRBs**
- **Search for Dark matter**
- **New probe → new observations**

A flourishing literature on cosmic ν sources

But not a single cosmic neutrino detected up to now !!!
(Like flying saucers or Gravitational Waves)

PHYSICAL REVIEW D **72,** 107301 (2005)

Note on high-energy neutrinos from active galactic nuclei cores

F. W. Stecker
NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA
(Received 20 October 2005; published 11 November 2005)

Detectable neutrino fluxes due to enhanced cosmic ray densities in the Galactic Centre region

Julián Candia
The Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, 34014 Trieste, Italy
E-mail: jcandia@ictp.it

Potential Neutrino Signals from Galactic γ-Ray Sources

Alexander Kappes
Friedrich-Alexander-University Erlangen-Nuremberg, Germany

PHYSICAL REVIEW D **74,** 063009 (2006)

High-energy neutrino yields from astrophysical sources: Weakly magnetized sources

M. Kachelrieß[1] and R. Tomàs[2]

PHYSICAL REVIEW D **74,** 063007 (2006)

Guaranteed and prospective Galactic TeV neutrino sources

Matthew D. Kistler[1,*] and John F. Beacom[1,2,†]

The cumulative background of high energy neutrinos from starburst galaxies

Abraham Loeb[1,2] and Eli Waxman[3]

PHYSICAL REVIEW D **73,** 043004 (2006)

High energy neutrinos from cosmic ray interactions in clusters of galaxies

Daniel De Marco,[*] Patricia Hansen,[†] and Todor Stanev[‡]

TeV Neutrinos from SuperNova Remnants embedded in Giant Molecular Clouds

Vincenzo Cavasinni[1,2 †], Dario Grasso[2,3 ‡], Luca Maccione[2,4 *]

October 22, 2006

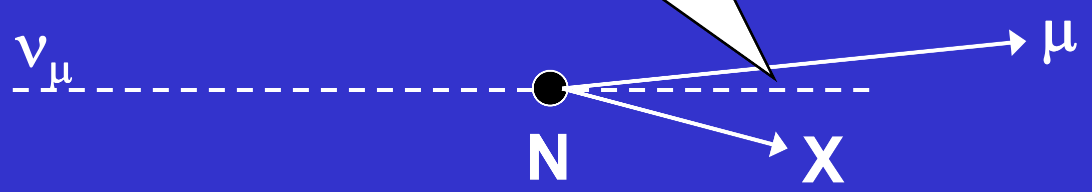
Neutrino Telescopes

- Neutral particle → points back to source (undeflected by B fields)
- Weak interaction → no absorption

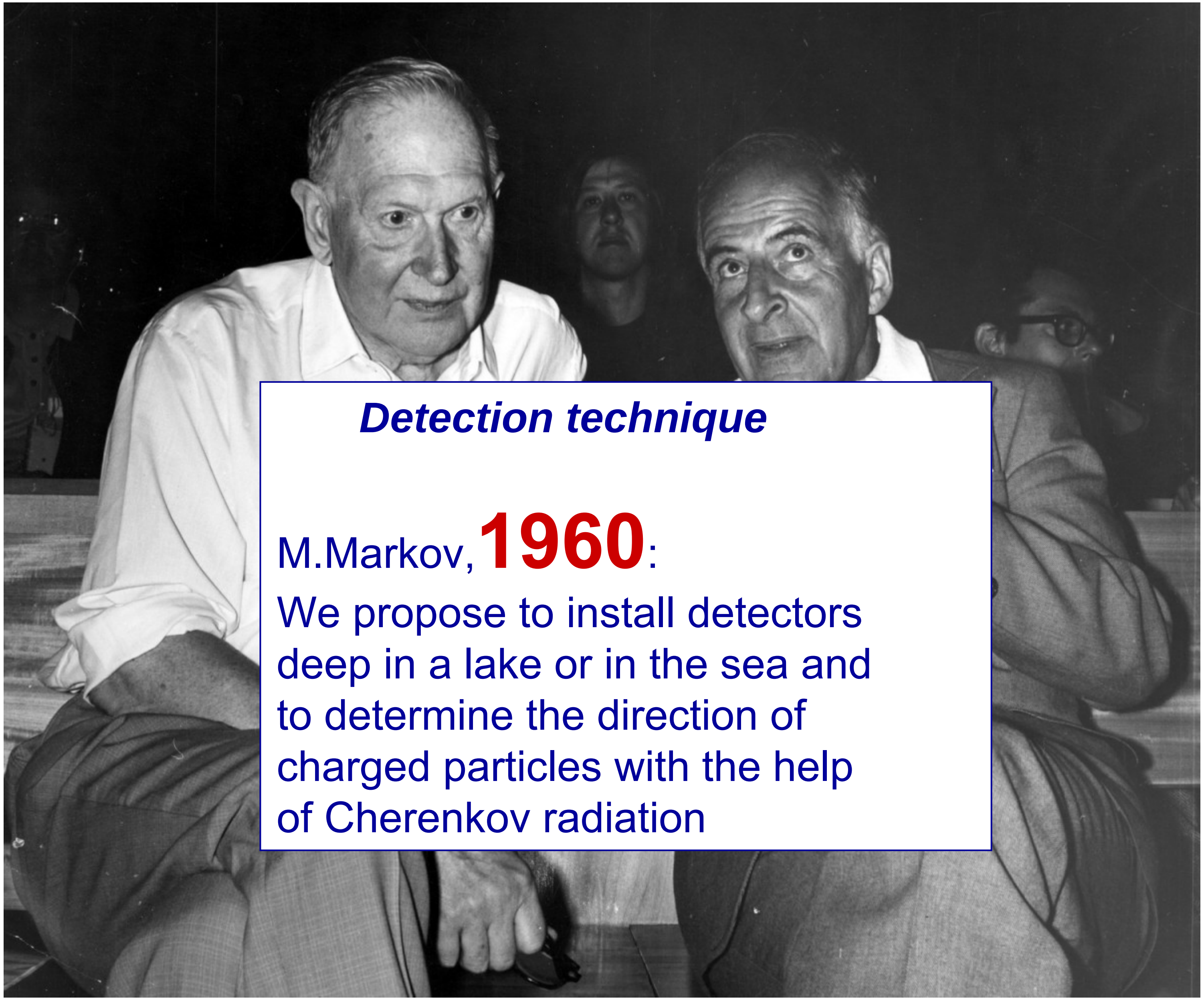
Tiny cross section
→ need huge detector

ν_μ + N → μ + hadrons
μ measures ν direction

$$\theta \leq \frac{1.5\,\text{deg.}}{\sqrt{E_\nu\,[\text{TeV}]}}$$



A little bit of history



1960 Markov's idea (1960 Rochester Conference):

Use sea water as target/detector

Detect Cerenkov light from produced muon

Muon may be produced within instrumented part of detector or outside (e.g. in underlying Earth's crust)

Range of muon : $R \cong 1\ km$ at 200 GeV

Detect Cerenkov light : $\dfrac{dN}{d\lambda\, dx} = \dfrac{2\pi\alpha}{\lambda^2} \sin^2 \theta_c$

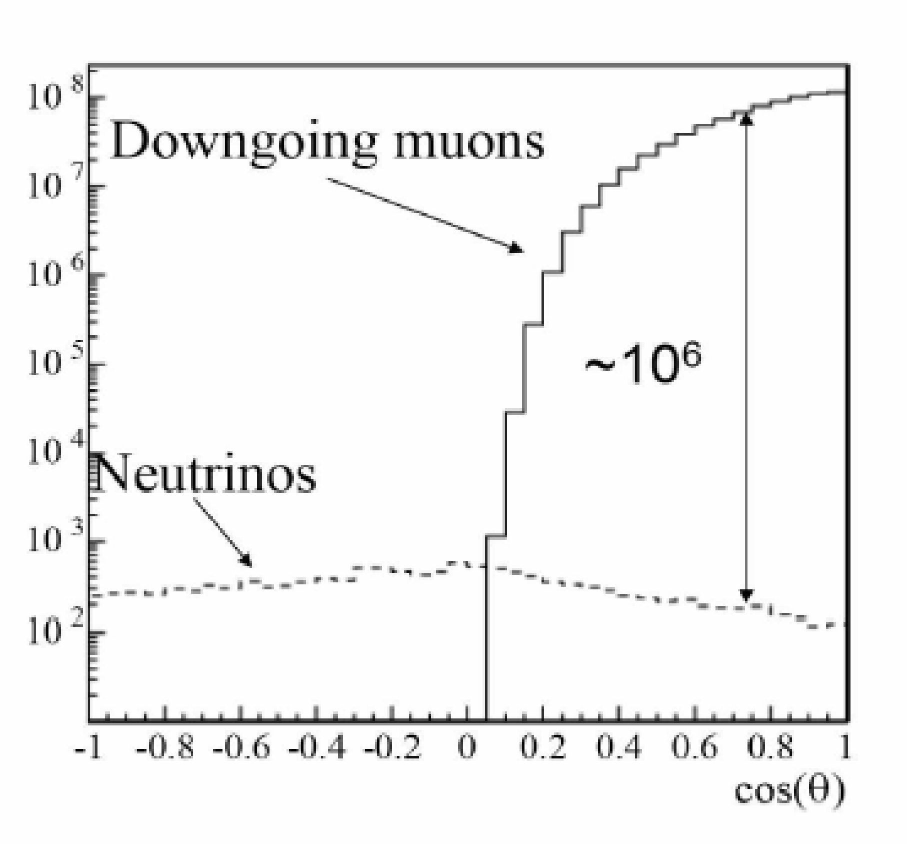
For sensitive wavelength range of PMTs $\Rightarrow 3.5 \times 10^4$ ph/m

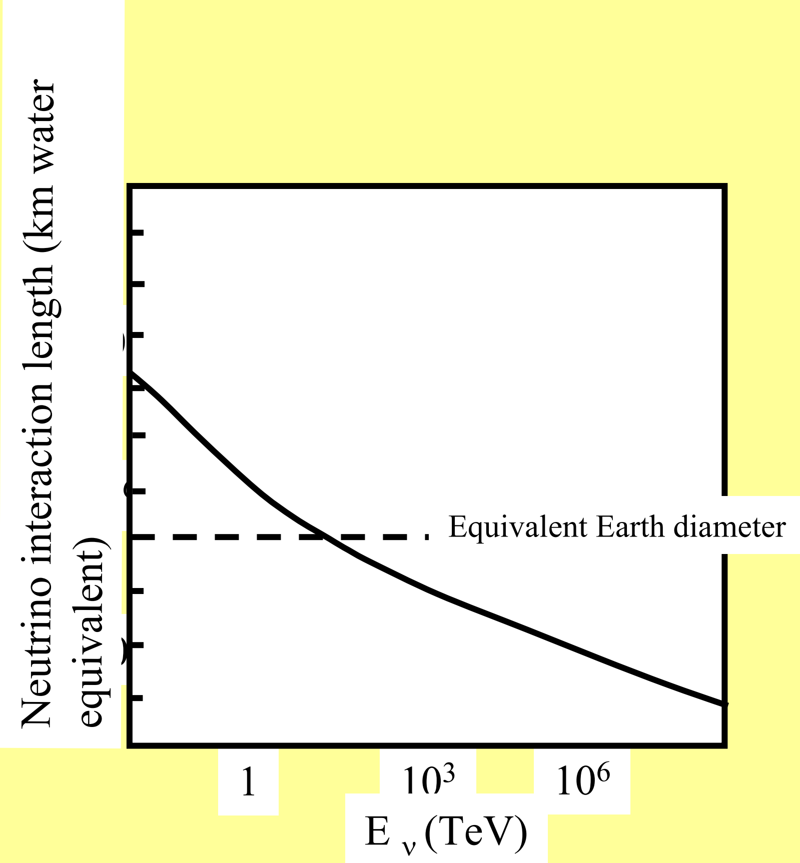
Water transparency excellent : $\lambda_{abs} \cong 60\ m$ at ANTARES site

μ

ν_μ N$\rightarrow$ μ X

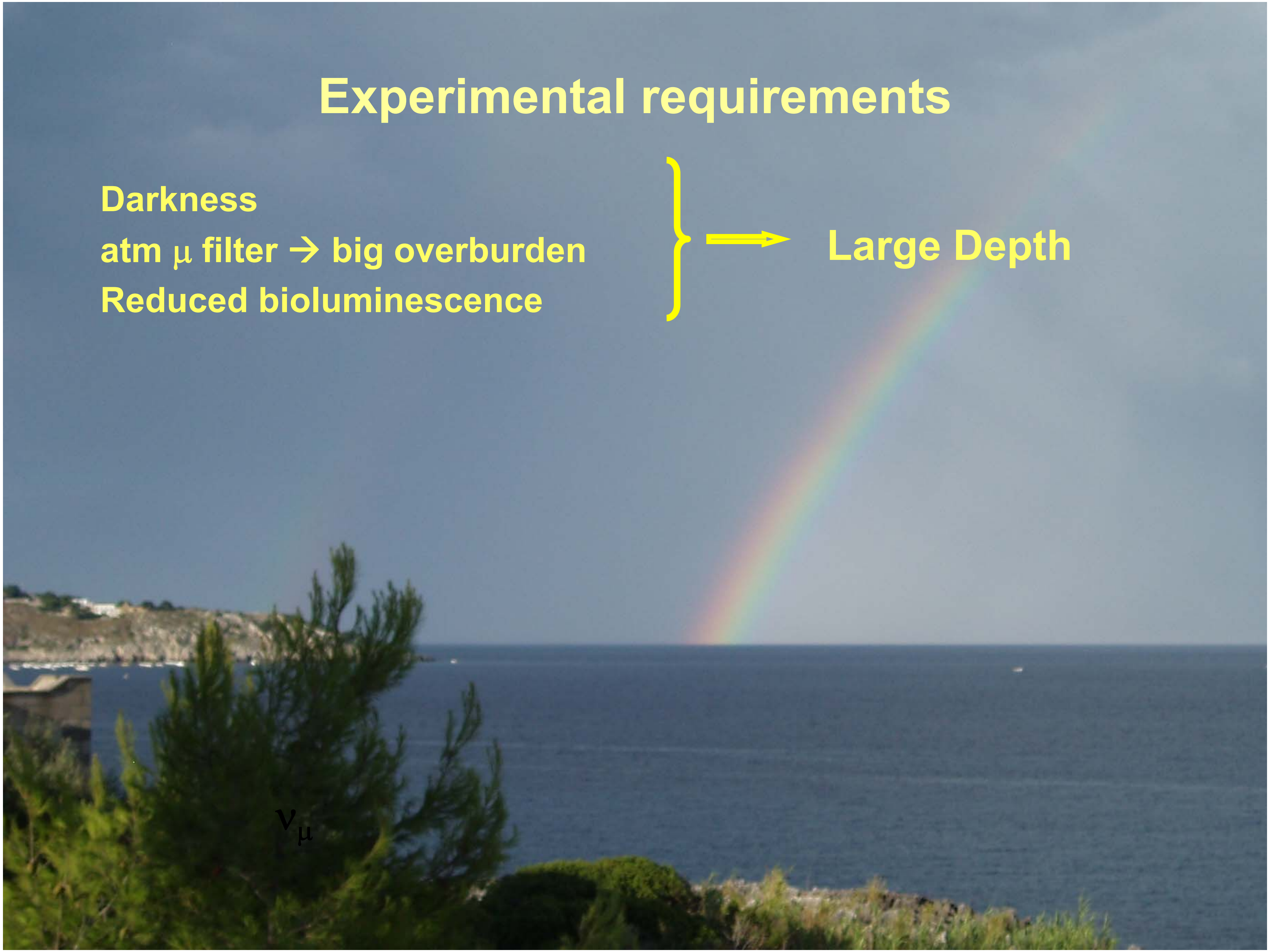
Atmospheric muon background



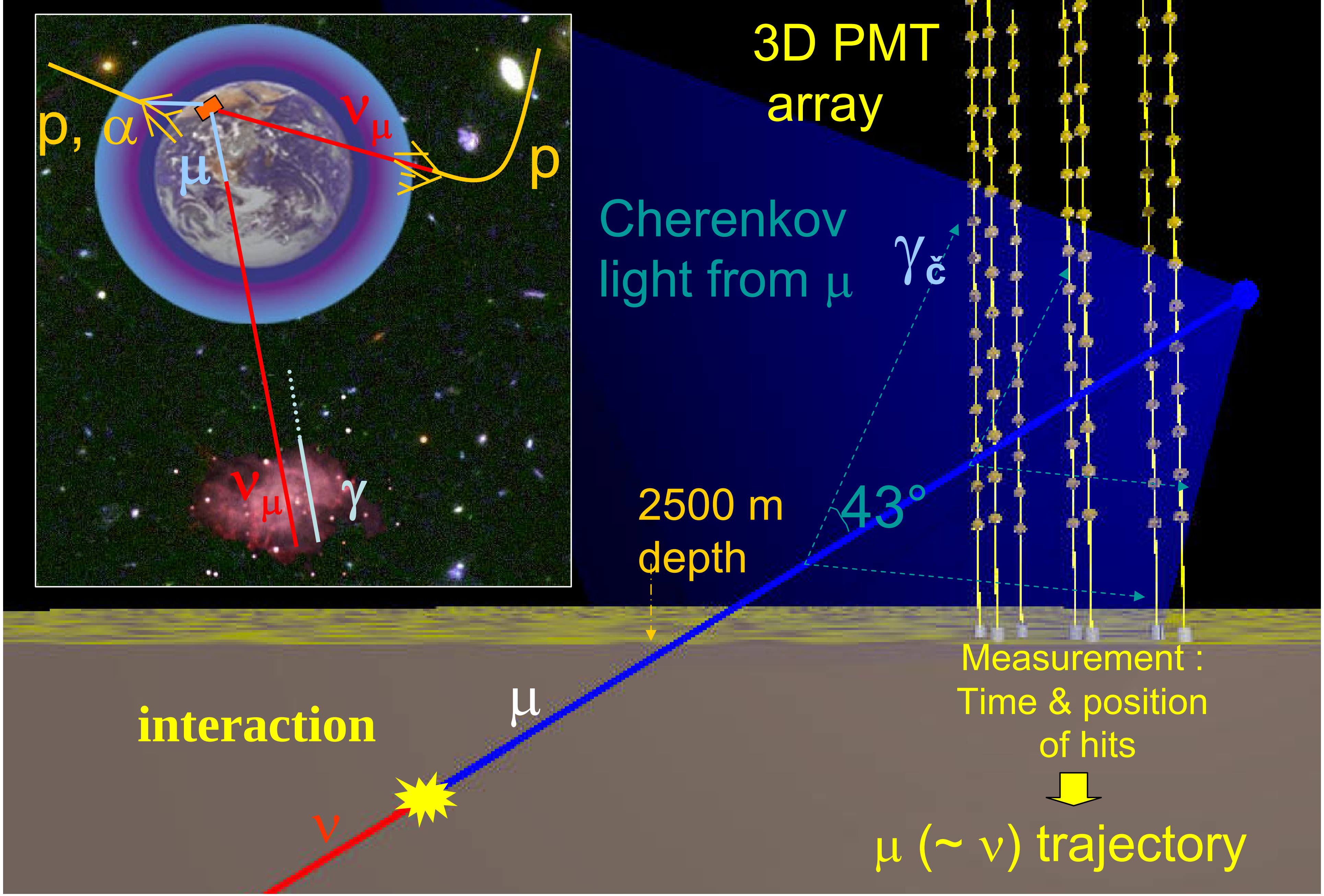


Reduced background if only events from the other side of the Earth selected

Price to pay → cutoff due to Earth


Experimental requirements
Darkness
atm μ filter → big overburden
Reduced bioluminescence
Large Depth
ν μ

Neutrino detection principle



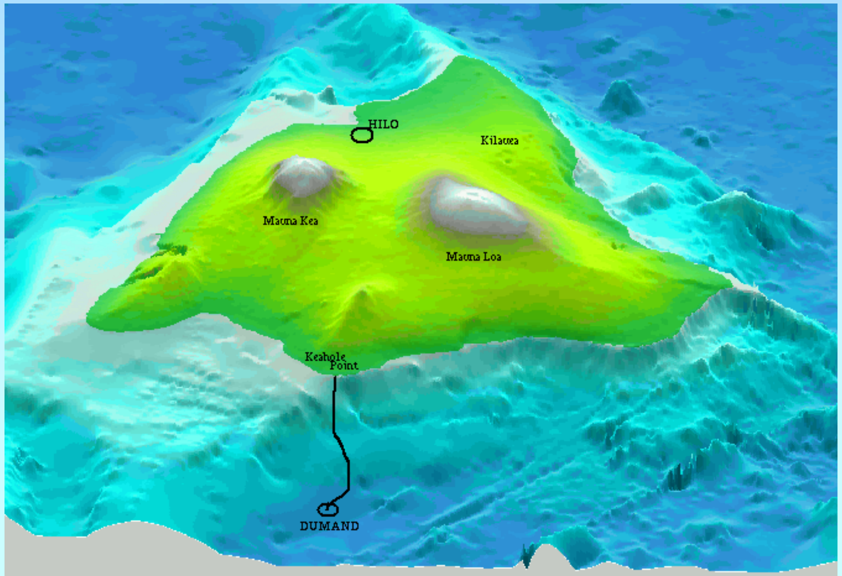
DUMAND pioneering developments

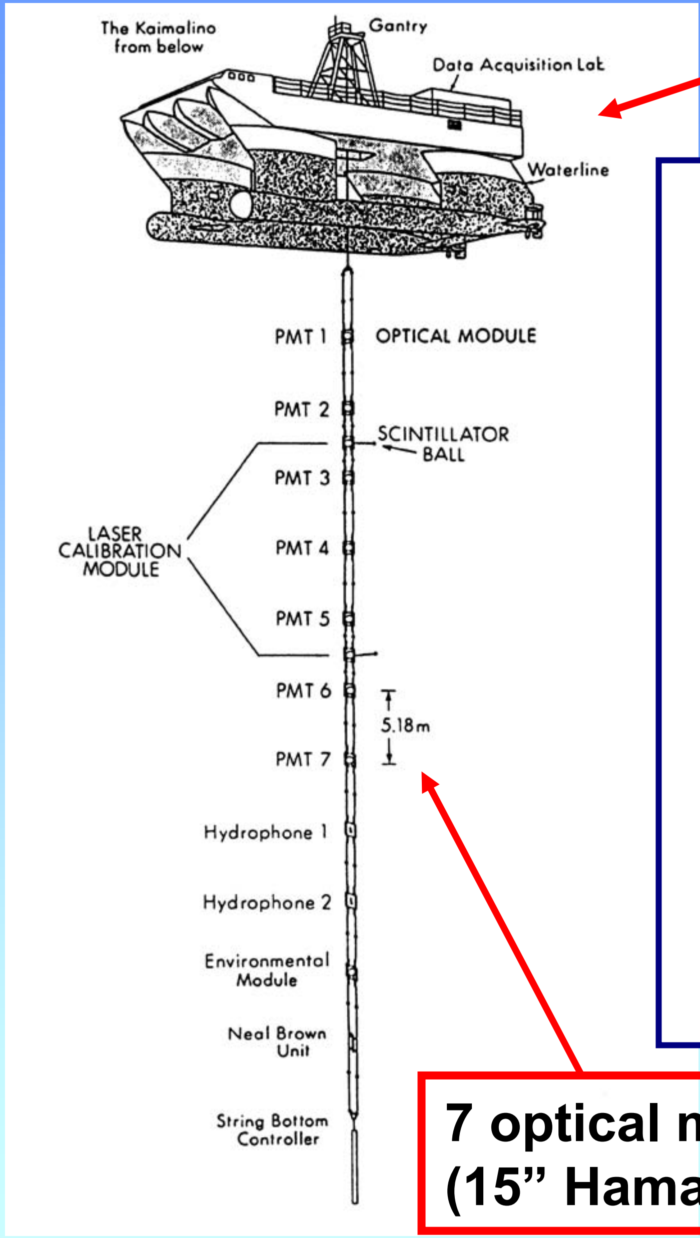
Started in 1973 (Cosmic Ray Conference in Denver)

Initial motivation: *anomalous cosmic-ray depth-intensity curves obtained by Keuffels group in Utah*
(Result later disproven)

First measurements (Short Prototype String) published in 1990 atmospheric muon measurements at various depths: (2000-4000 m) in steps of 500m

All subsequent designs have taken advantage of the DUMAND experience





S.S. Kaimalino (twin-hull ship)

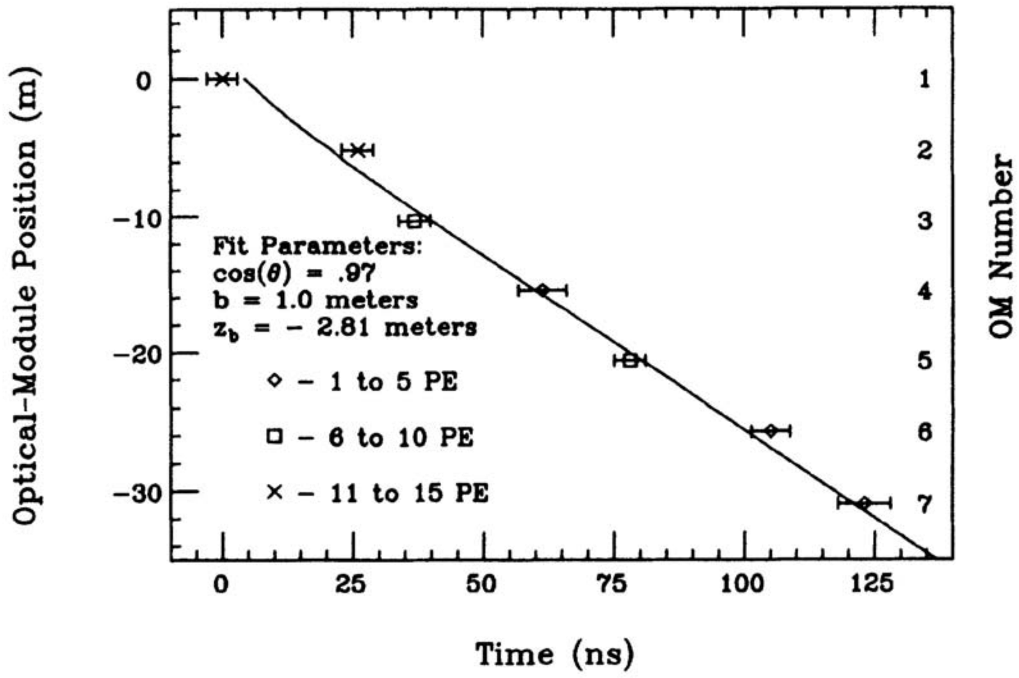


FIG. 2. Timing data and fit for typical muon event.

7 optical modules, spaced by 5.18 m (15" Hamamatsu PMTs)

Rev. Mod. Phys. 64, 259, 1992

Short Prototype String

Dumand results

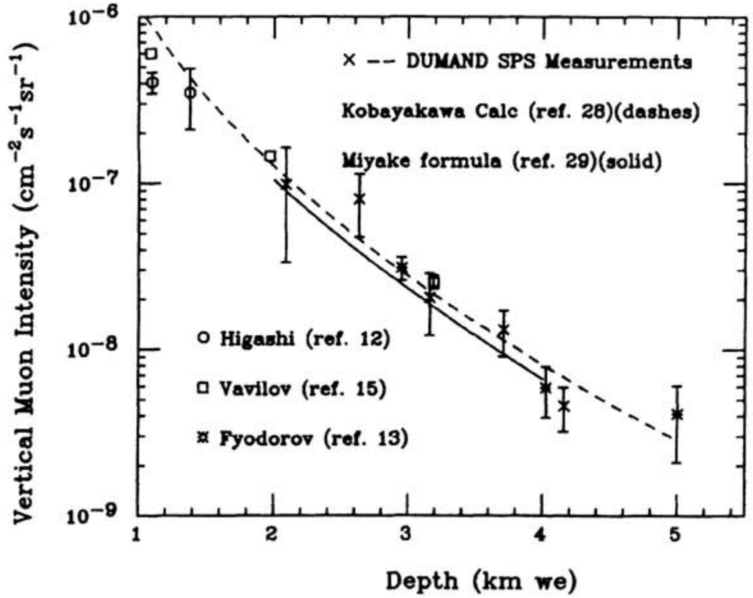
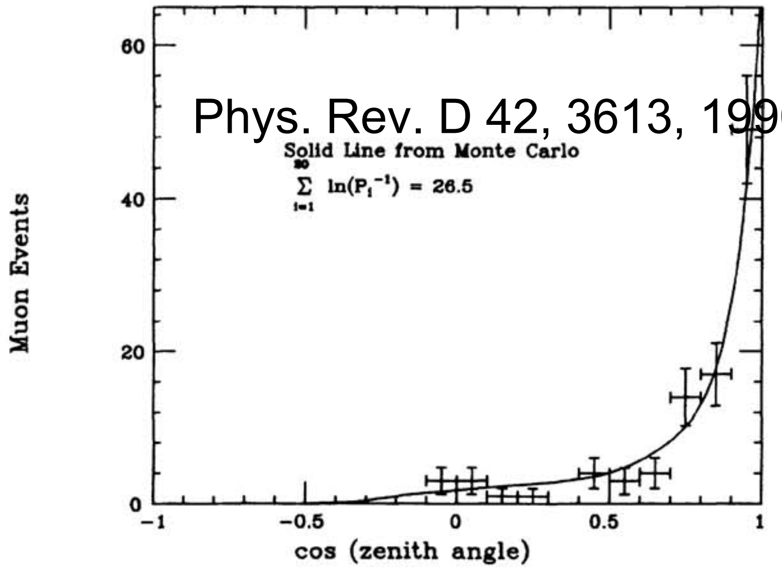


FIG. 6. Measured muon vertical intensity vs depth compared with other underwater experiments below 1000 m depth. The errors indicated are both systematic and statistical.



Phys. Rev. D 42, 3613, 1990

FIG. 7. Measured muon angular distribution at 4 km. The vertical error bars are just statistical.

μ vertical intensity vs depth

μ angular distribution at 4 km

Used a mere 17 hours of data to set the best limits (for a while) on high energy neutrinos from AGNs

(Some) reasons for the long development time

1) Lack of advanced fiber-optics technology for data transmission
2) Lack of reliable pressure-resistant underwater connectors
3) Lack of ROVs for undewater connections
4) Limited funding (funding for studies by DOE in 1980;
funding of DUMAND II in 1990 – terminated by DOE in 1996)

1-3 → Implications for deployment technique and detector layout

1-3 became gradually available (and were adopted/tested) throughout those years

Collaboration with Russian groups

A.E. Chudakov, V.S. Berezinsky, B.A. Dolgoshein, A.A. Petrukhin

Strong Russian commitment

BUT

Collaboration terminated by the Reagan administration, after the Soviet invasion of Afghanistan

[2]The severing of the Russian link was done with elegance and taste. We were told, confidentially, that while we were perfectly free to choose our collaborators as we liked, if perchance they included Russians it would be found that no funding was available for us.

A.Roberts; RMP 64, 1, 1992

In parallel → Russian initiative at lake Baikal

Initiatives in the Mediterranean

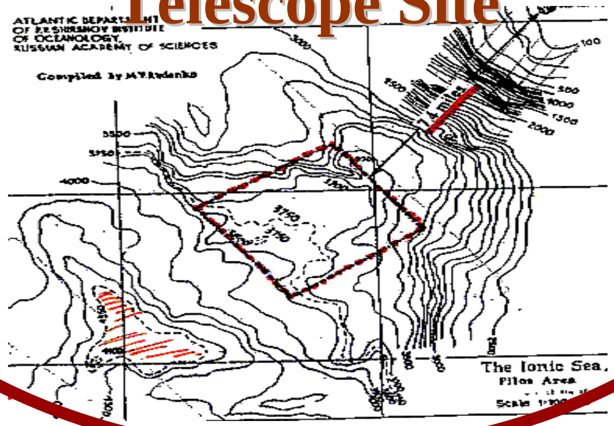
NESTOR

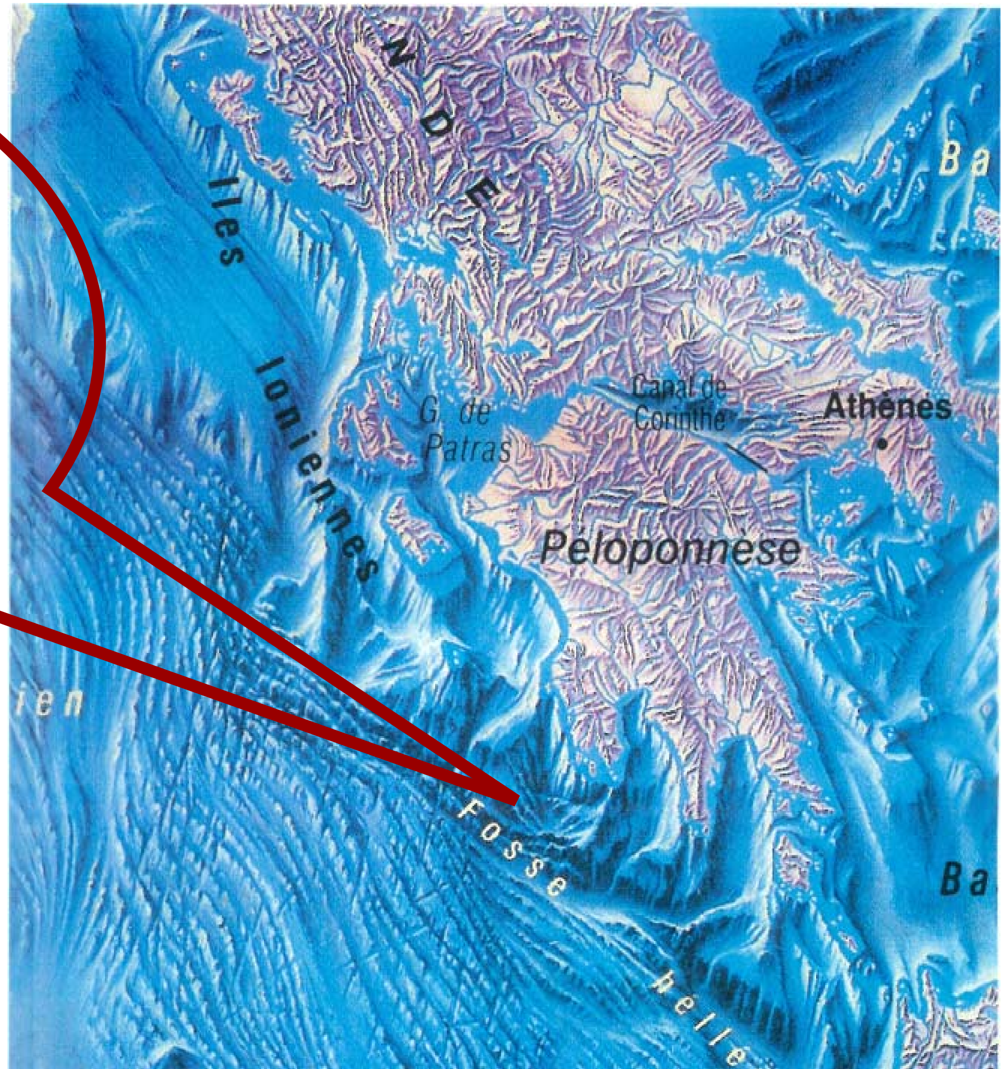
NEMO

ANTARES

…..Km3Net

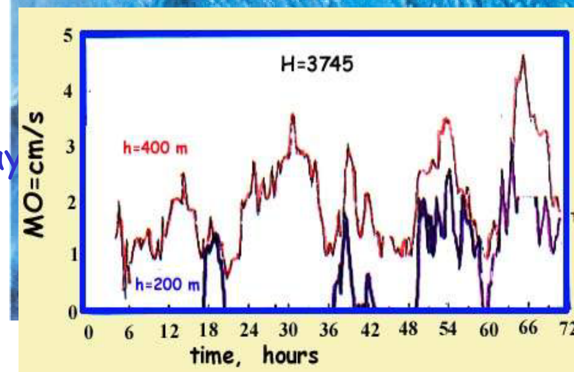
The NESTOR Neutrino Telescope Site





Site characteristics

- **a broad plateau:** 8x9 km^2 in area, 7.5 nautical miles from shore
- **depth:** ~4000m (→5200m)
- **transmission length:** 55 ± 10m at λ=460 nm
- **underwater currents:** <10 cm/s measured over the last 10 years
- **optical background:** ~50 kHz/OM due to K^{40} decay bioluminescence activity (1% of the experiment live time)
- **sedimentology tests:** flat clay surface on sea floor, good anchoring ground.

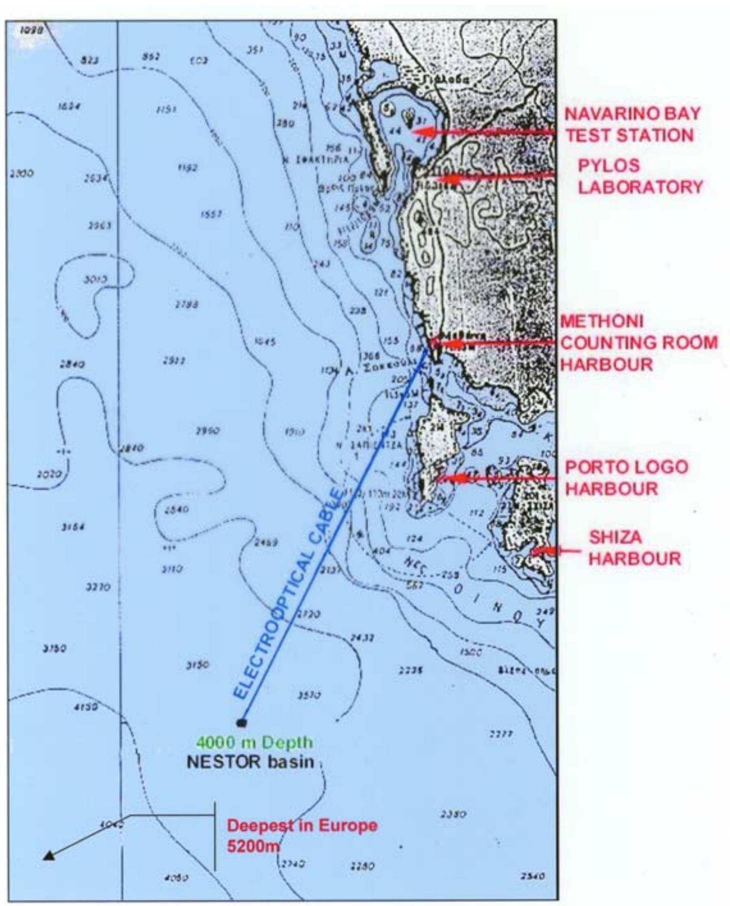


NESTOR→ first attempt in the Mediterranean

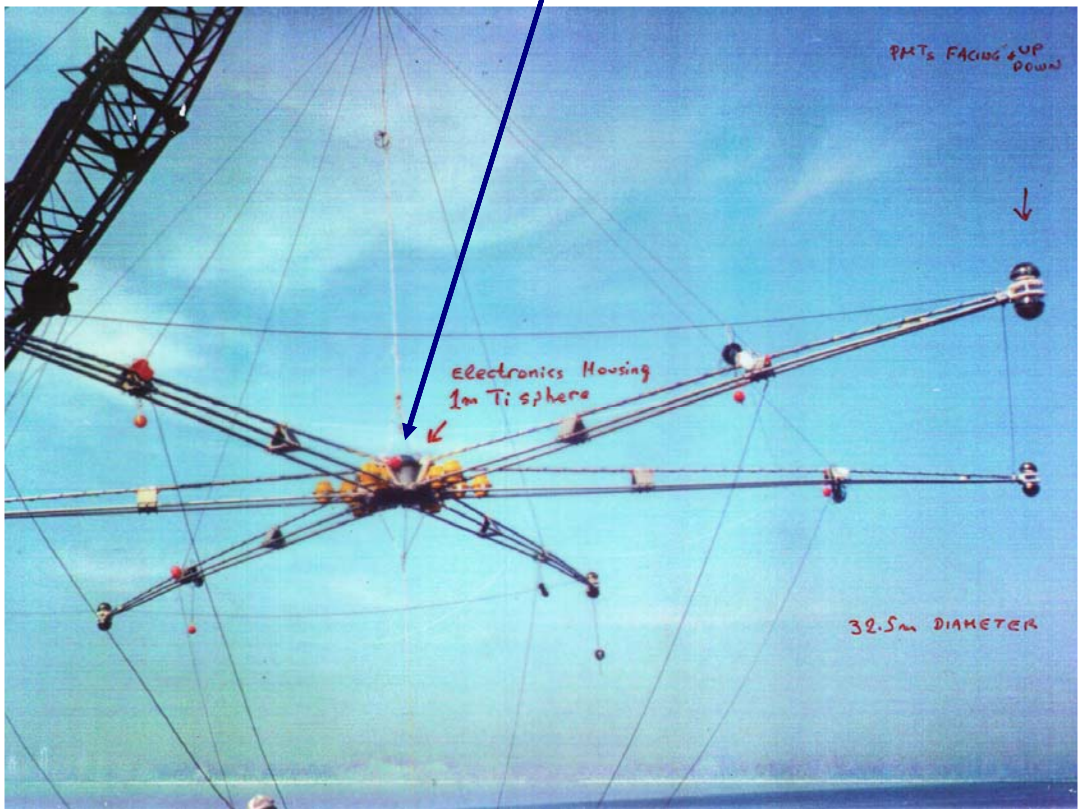
Avoid underwater connections → no use of ROV

Implications: have to recover entire detector in case of repairs
(not recommended after DUMAND experience)

32 m diameter floor (6 floors)
30 m between floors
144 15” PMTs



At the center of each floor a Ti sphere Houses the floor electronics



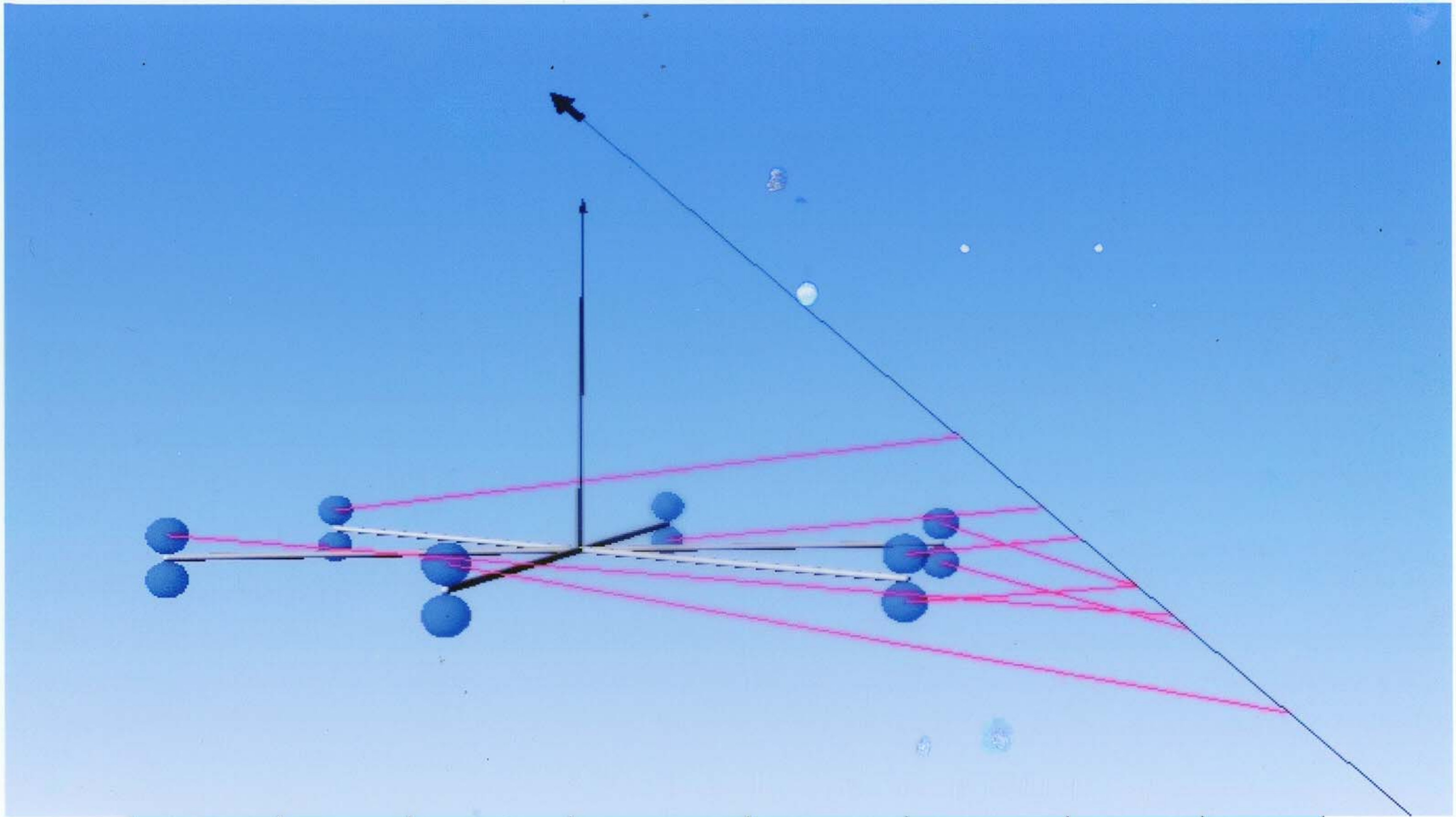
DUMAND Experience →

"….if one is not going to make ocean bottom connections, then the whole array has to be installed of a piece, a frightening thought at the level of a km^3 array….

ROVs are ever more available, being driven in development for the deep ocean at this time by the increasing depth of oil drilling operations."

"The DUMAND-II group chose to employ ROVs, so the deployment was greatly simplified from earlier plans. To our view this is the only sensible option for large arrays."

NESTOR: reconstructed event
(Data taken in 2003)



Track Candidate	Number of Hits	Number of Used Hits	Number of Degrees of Freedom	Zenith Angle (Degrees)	Azimuth Angle (Degrees)	X^2	$-\ln L_{ch}$
1	8	8	3	123 (±21)	288 (±21)	1.37	35.91

Raw Data

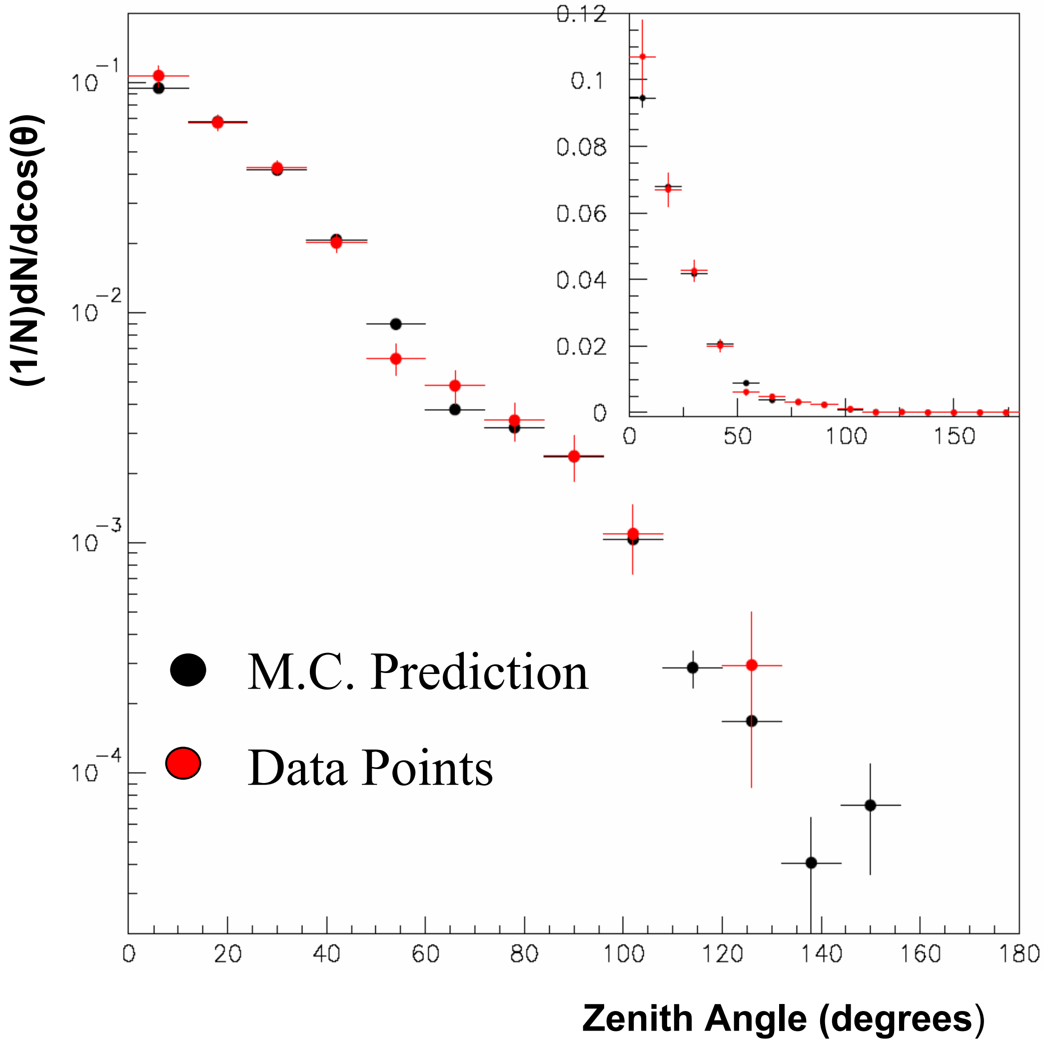
Zenith Angle Distribution

(atmospheric muons)

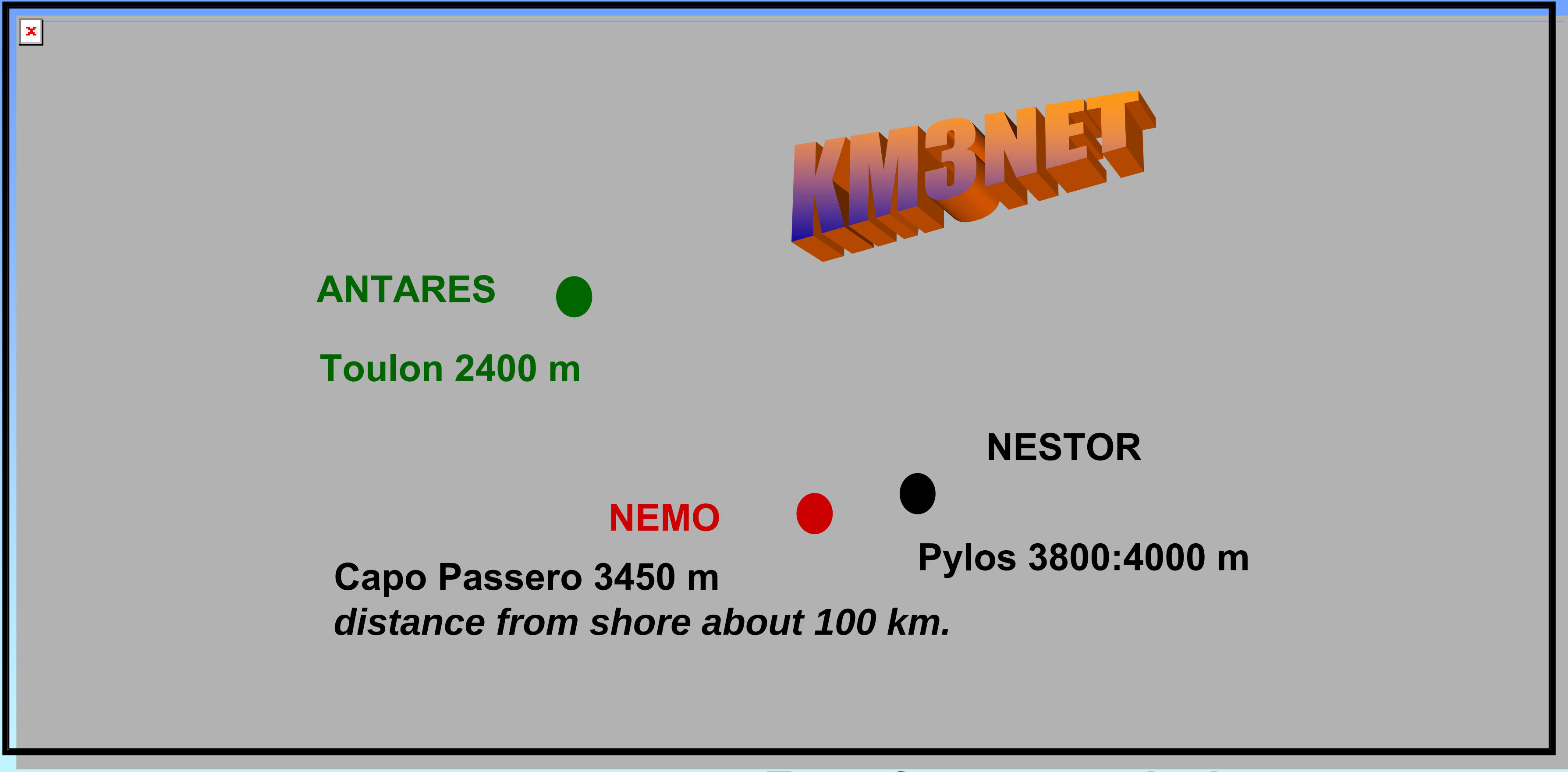
745 Data events

Comparison with Okada model

χ^2 probability: 52%



NEMO



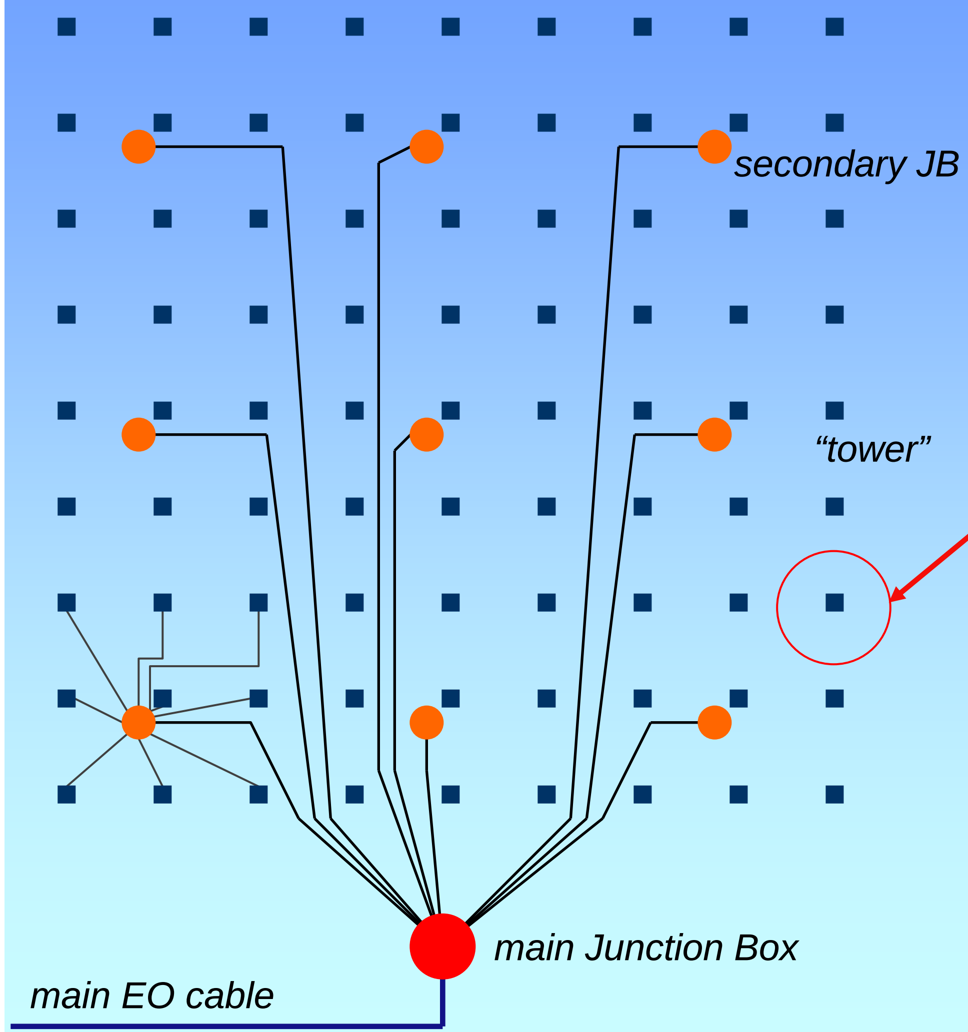
NEMO

95 Physicists from 12 Institutions

Phase1 → **Test of prototypes in deep sea**
Near Catania at 2000 m depth

Phase2 → **Construction of an infrastructure for km3**
Off Capo Passero at 3500 m depth

NEMO architecture

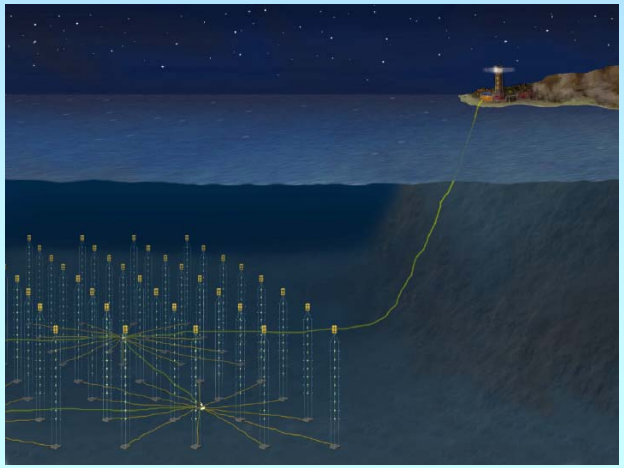


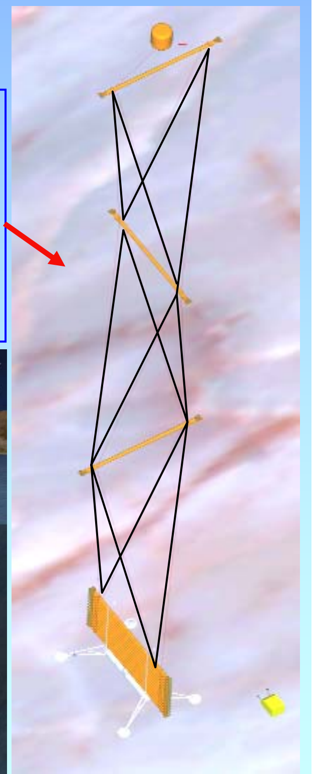
Detector architecture issues

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

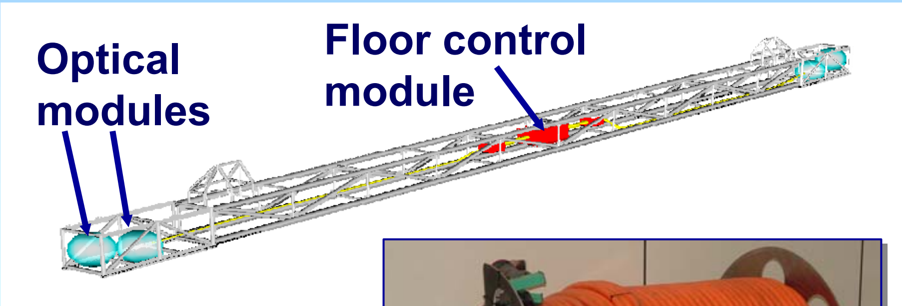
Detector modularity

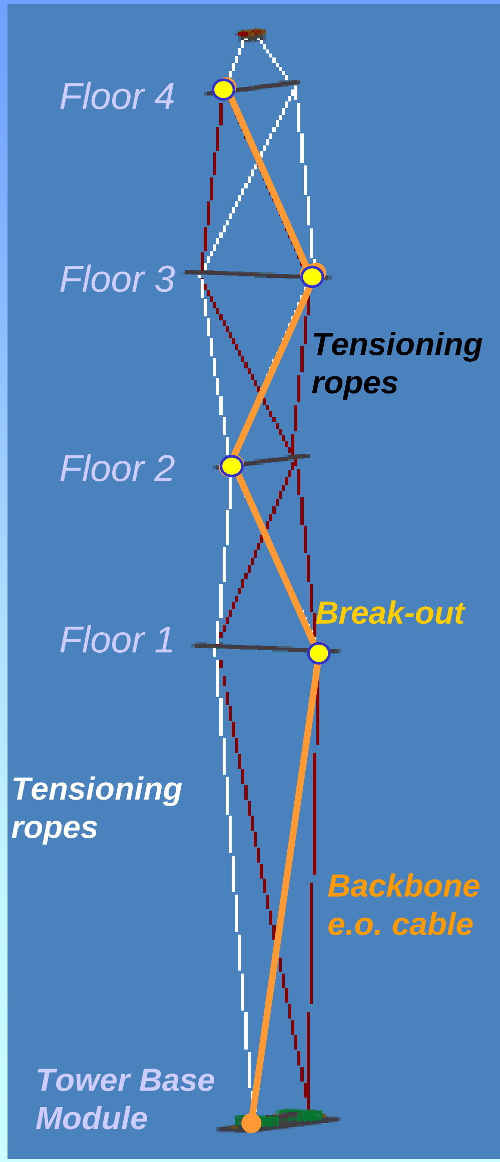
9 x 9 = 81 "Towers" with 3 dimensional and non homogeneous distribution of sensors





The Mini Tower for NEMO Phase-1

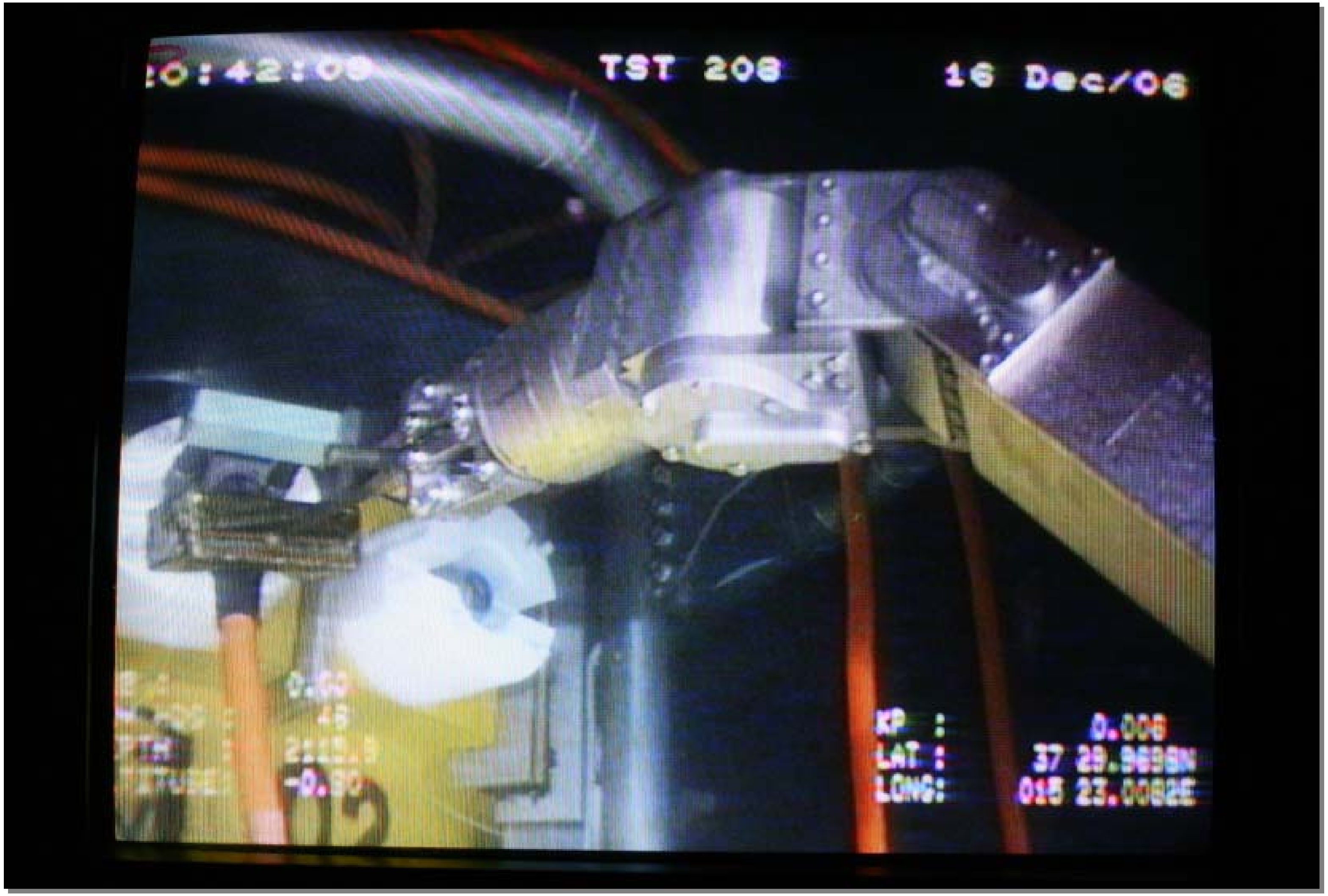




Mechanical stresses are applied only to the tensioning ropes

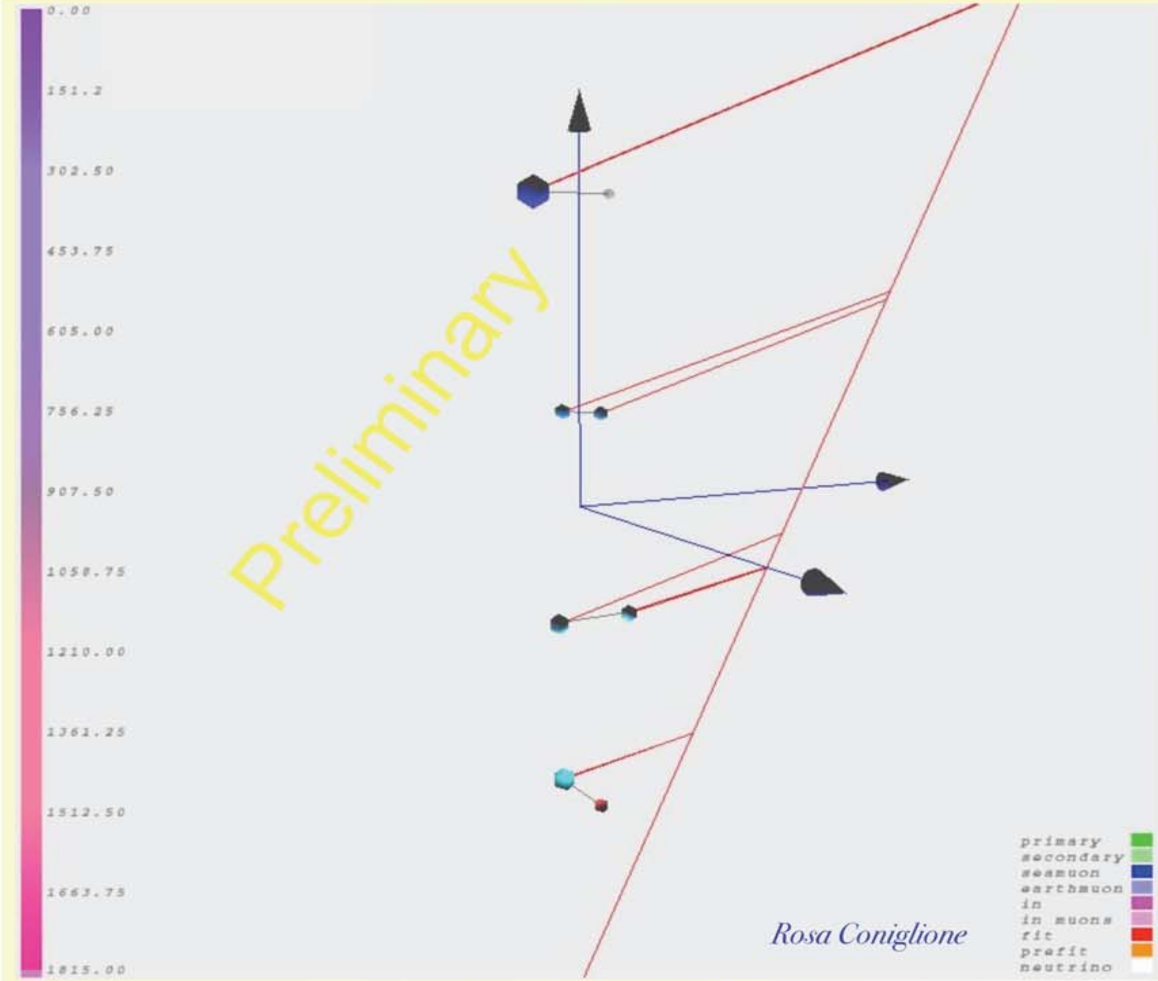
NEMO Phase-1 installation

December 16 2006 *Connection of the tower to the JB*



NEMO-Phase 1

… data contain tracks

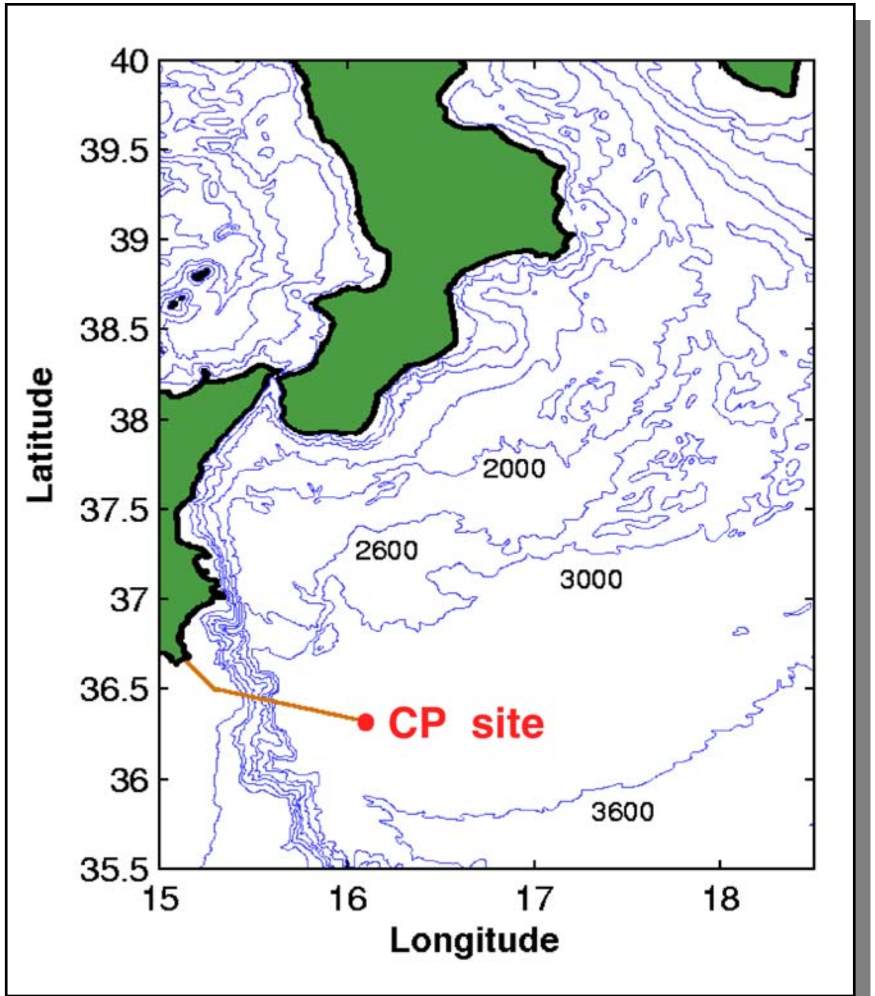


24 January 2007
Run 23 file 1
Event 189722
11 PMT involved

- Trigger local coincidence up-horizontal (Δt=20ns)
- Aart Reconstruction
- Background rejection -> causality with the highest in charge and in coincidence

Phase-2 project

A deep sea station on the Capo Passero site



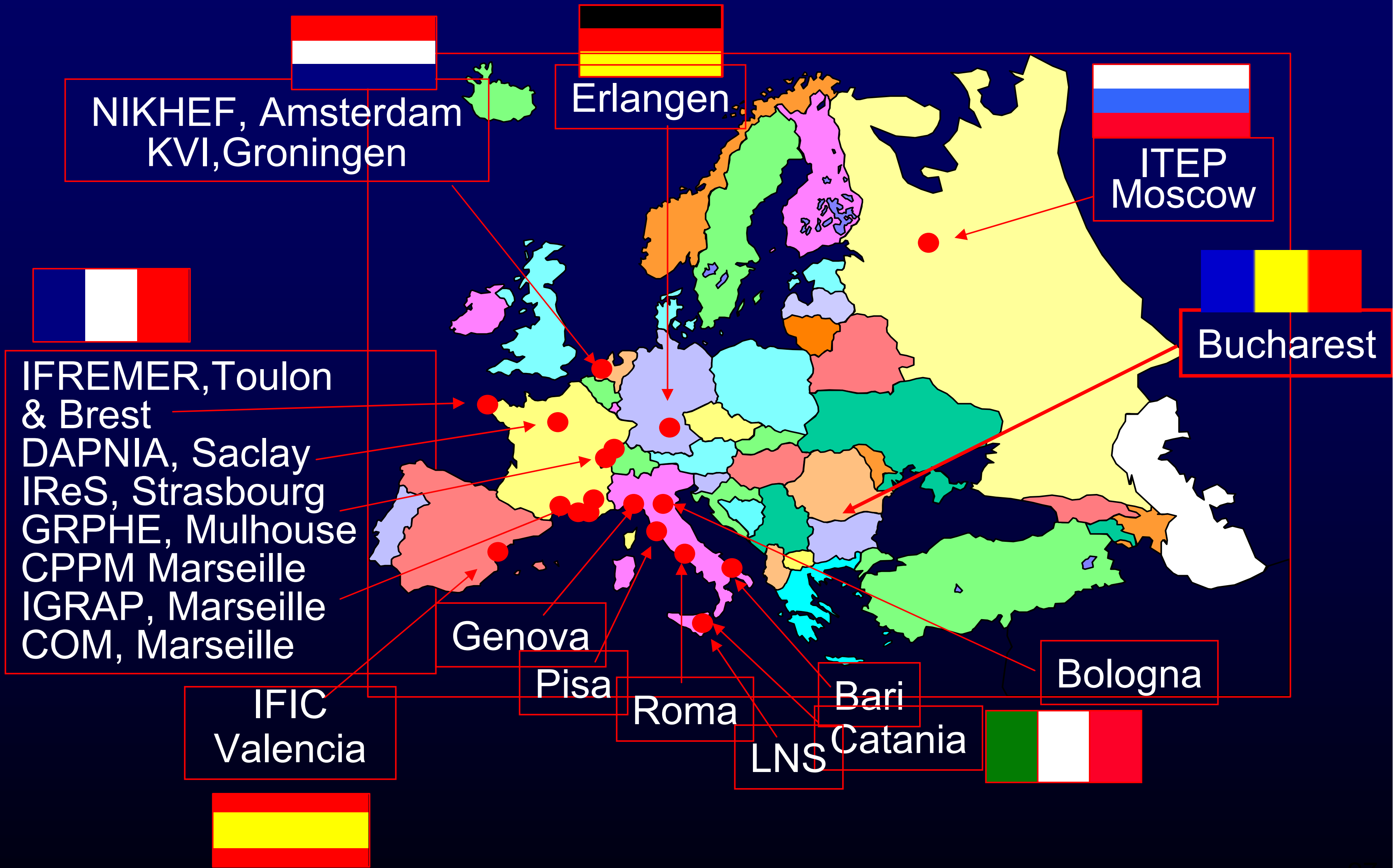
INFRASTRUCTURE UNDER CONSTRUCTION

- **Shore station in Portopalo (Capo Passero)**
- **100 km electro optical cable**
- **Underwater infrastructures**

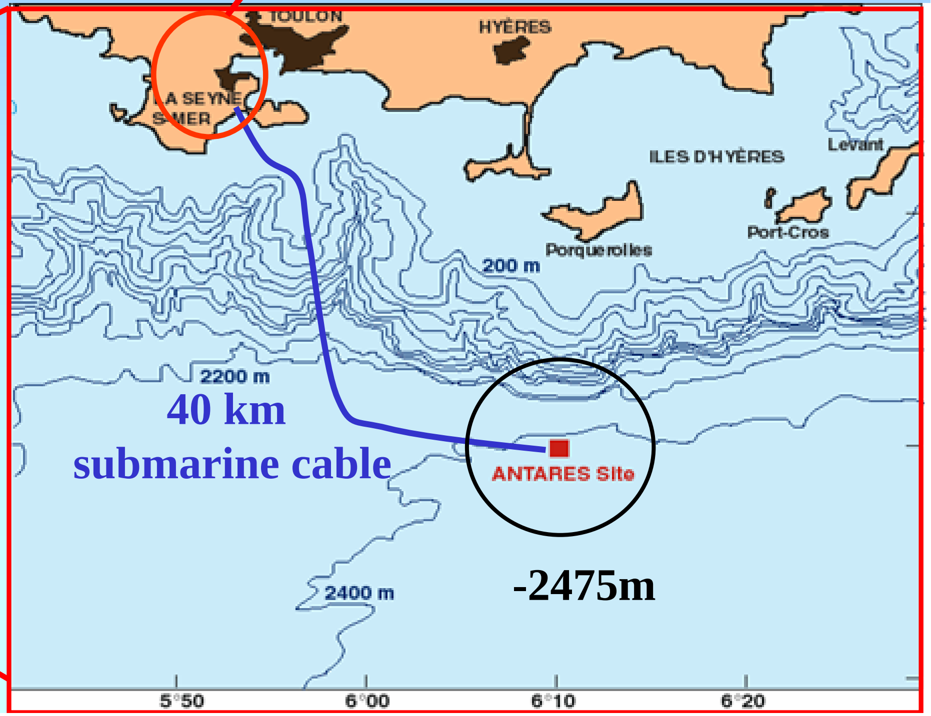
STATUS AND PLANS

- **Electro-optical cable (>50 kW, 20 fibres)**
- **Cable deployed few weeks ago**
- **Power feeding system under construction, acceptance tests december 2007**
- **Installation of cable termination frame with DC/DC converter beginning 2008**
- **Renovation of the shore station building under way. Completion beginning 2008**
- **Tower deployment foreseen for mid 2008**

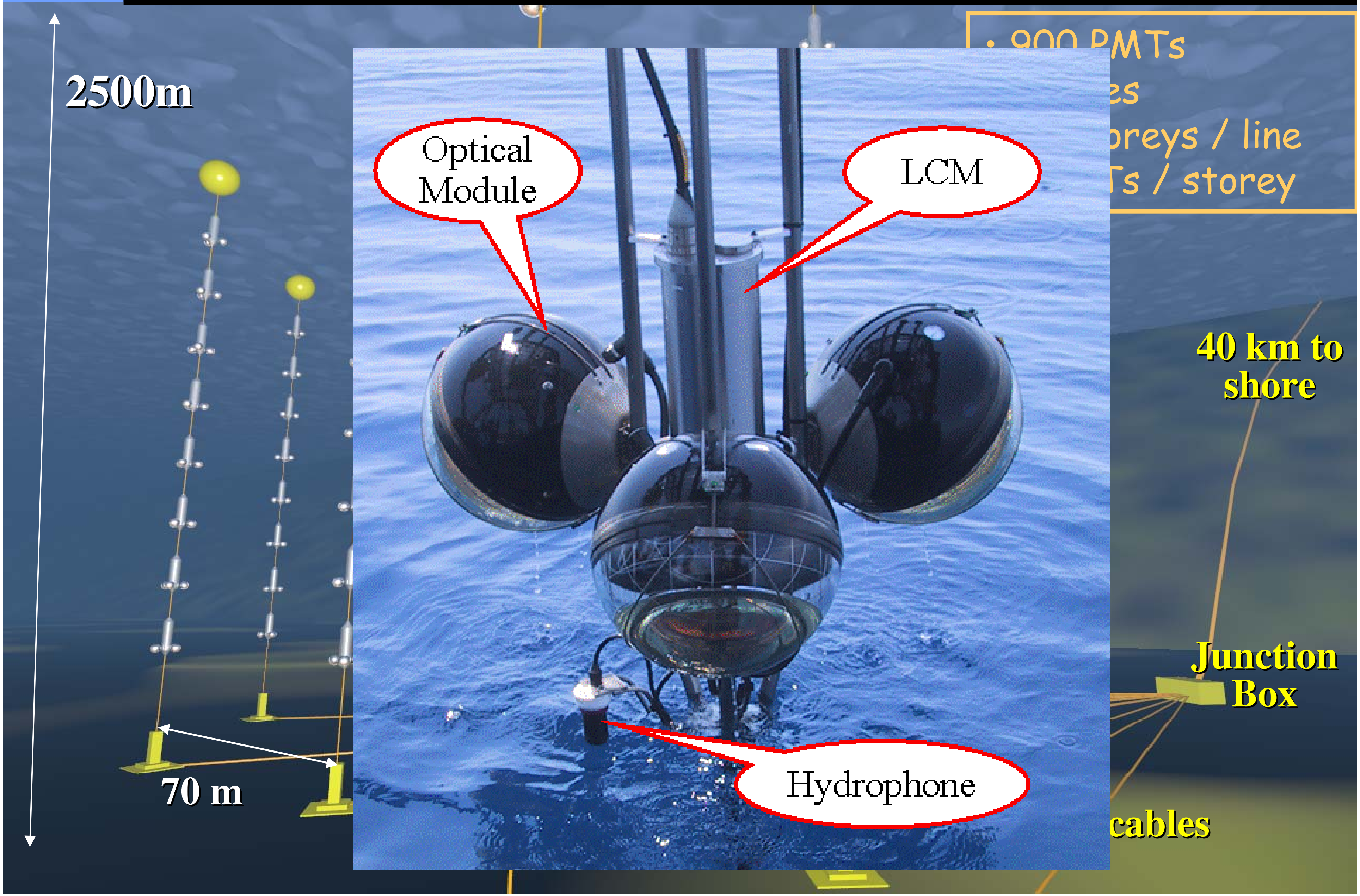
ANTARES collaboration



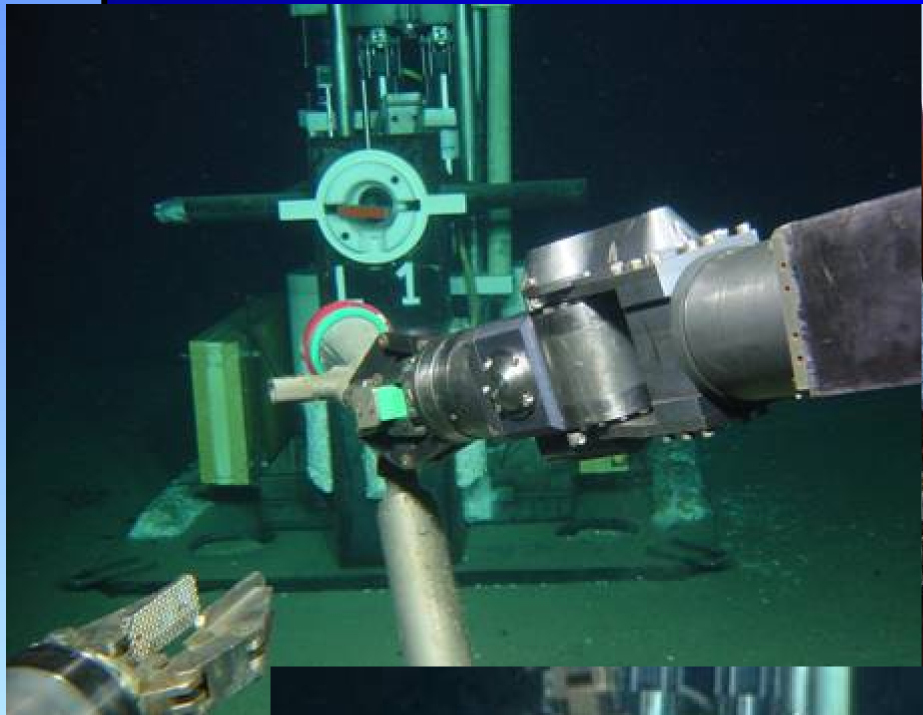
ANTARES detector site & shore station



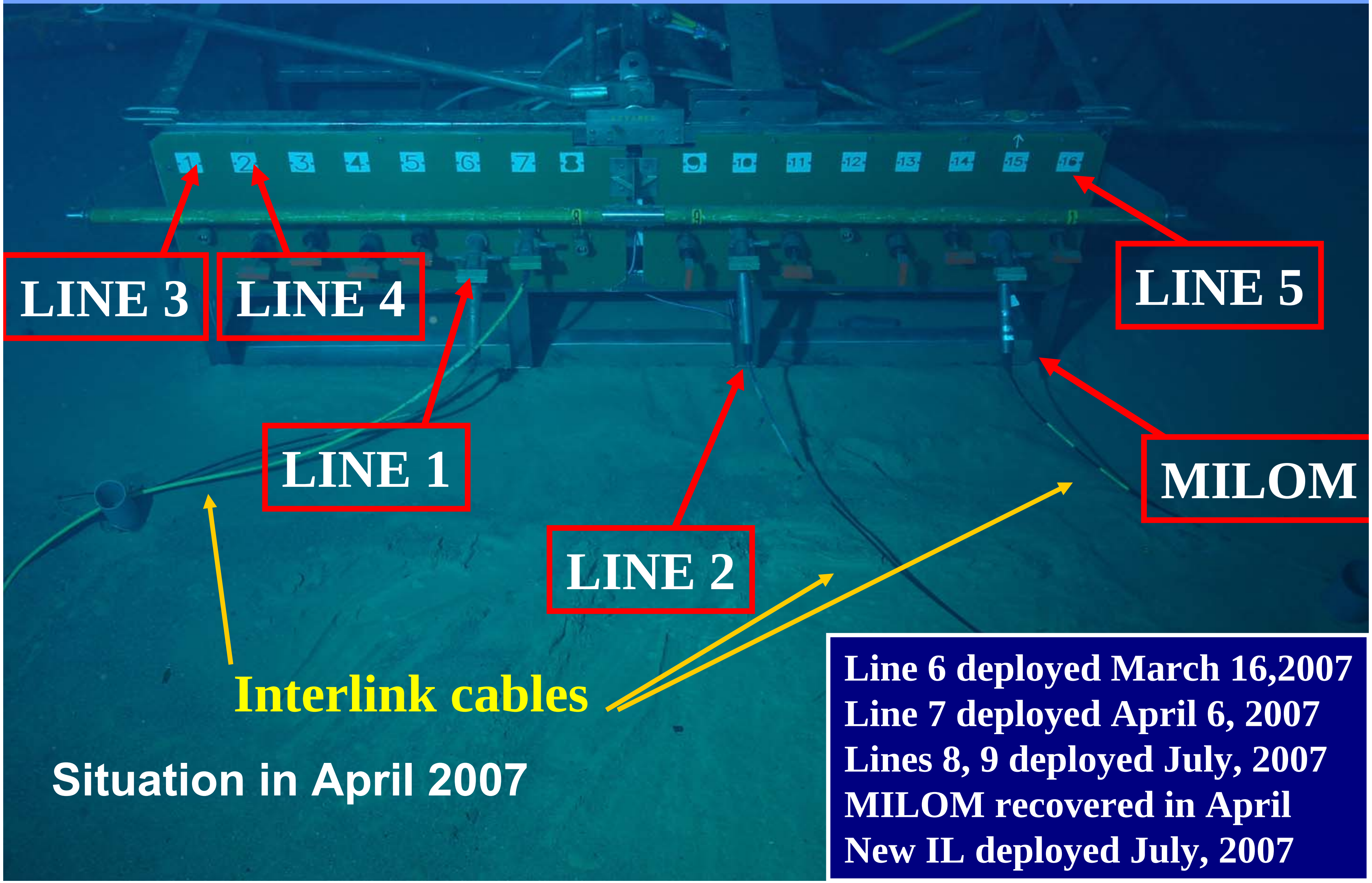
The ANTARES detector



ROV connection of Line 1 on March 2006

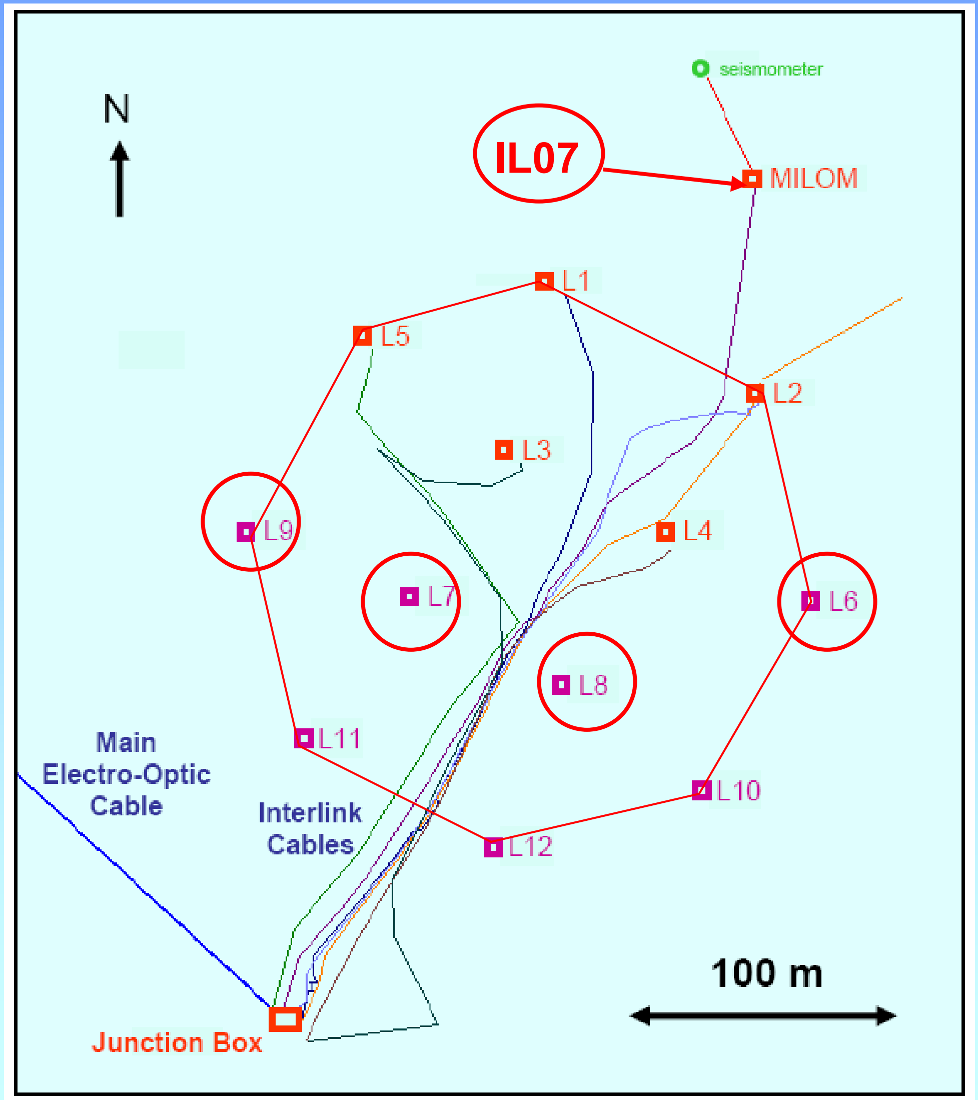


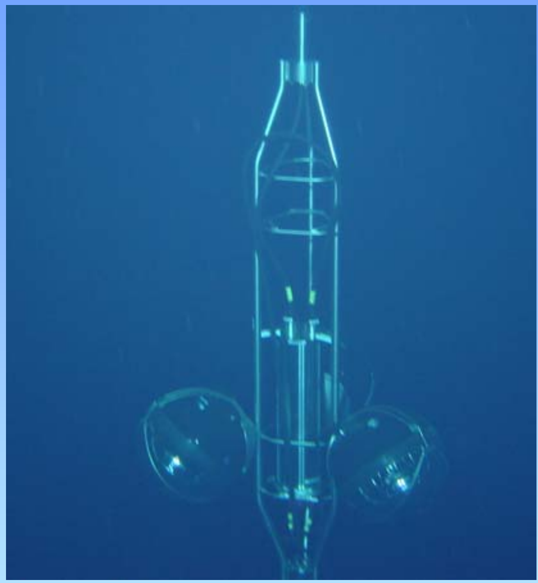
ANTARES – Junction Box connections

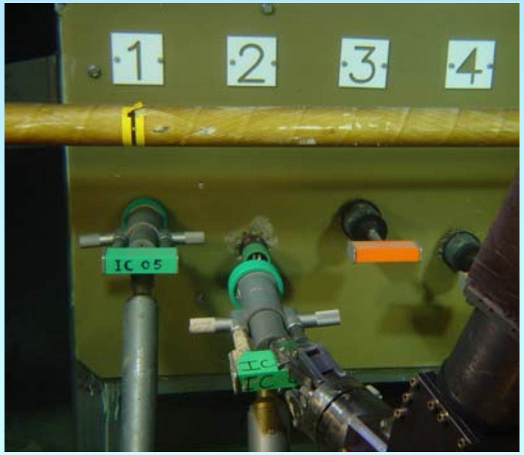


Situation in April 2007

375 PMTs now in the DAQ stream

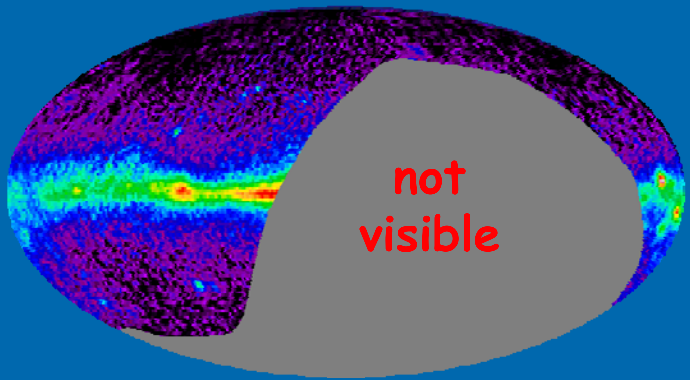






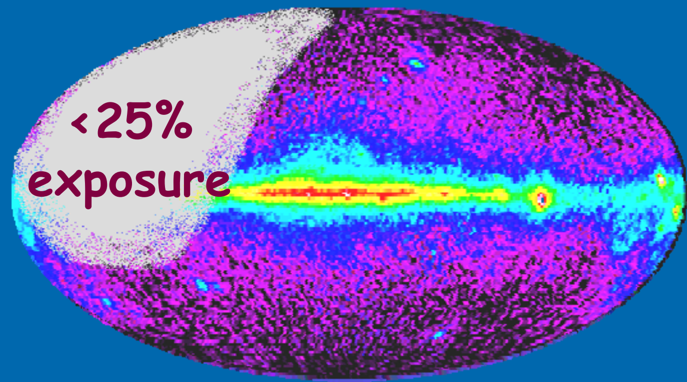
ANTARES now an operational Neutrino Telescope

South pole



Less background light

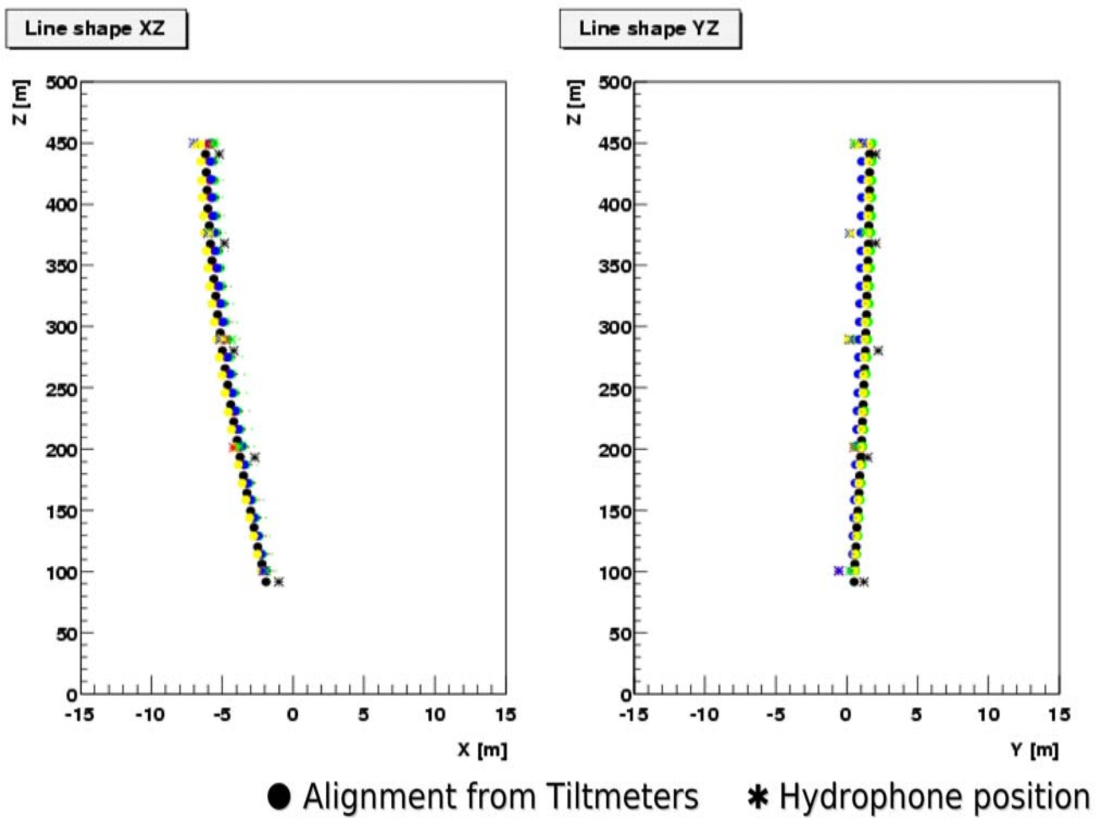
Mediterranean Sea, 43° N



Better angular resolution

ANTARES already biggest NT in Northern Hemisphere
(Effective area very similar to AMANDA)
Chance of major original discoveries

Line Alignment using tiltmeters-compasses + hydrophones

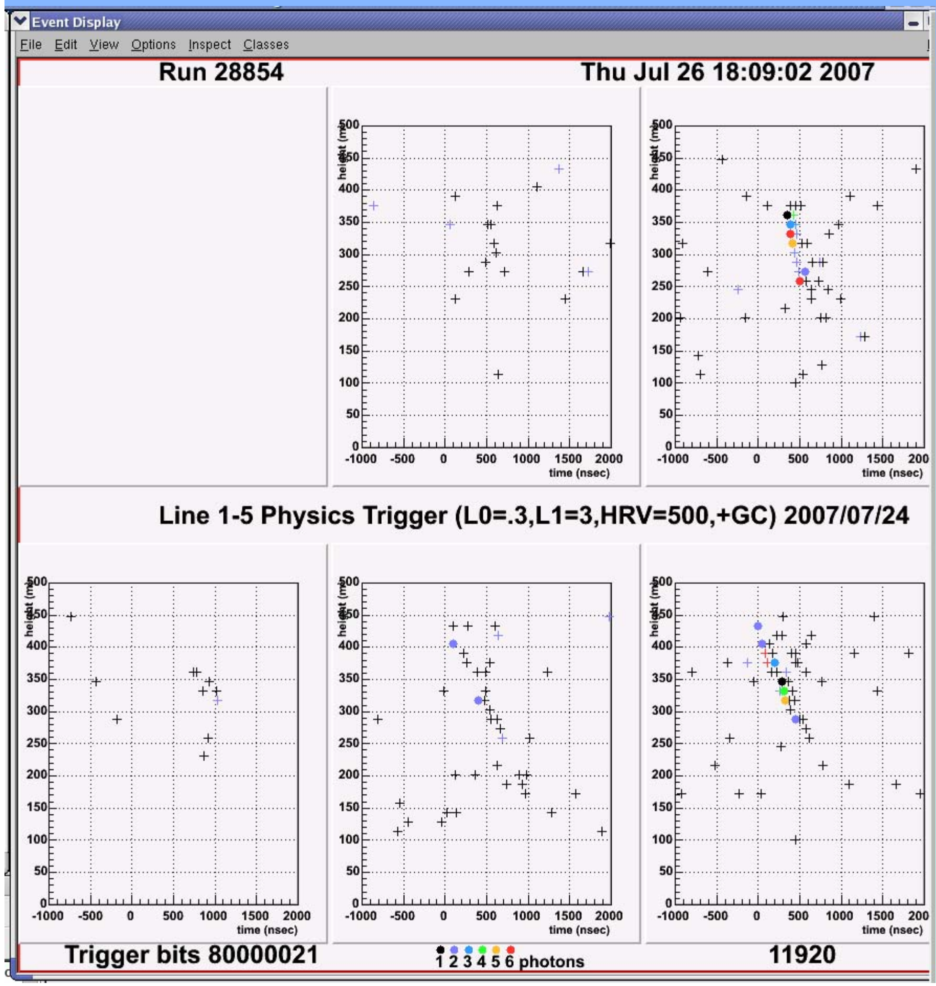


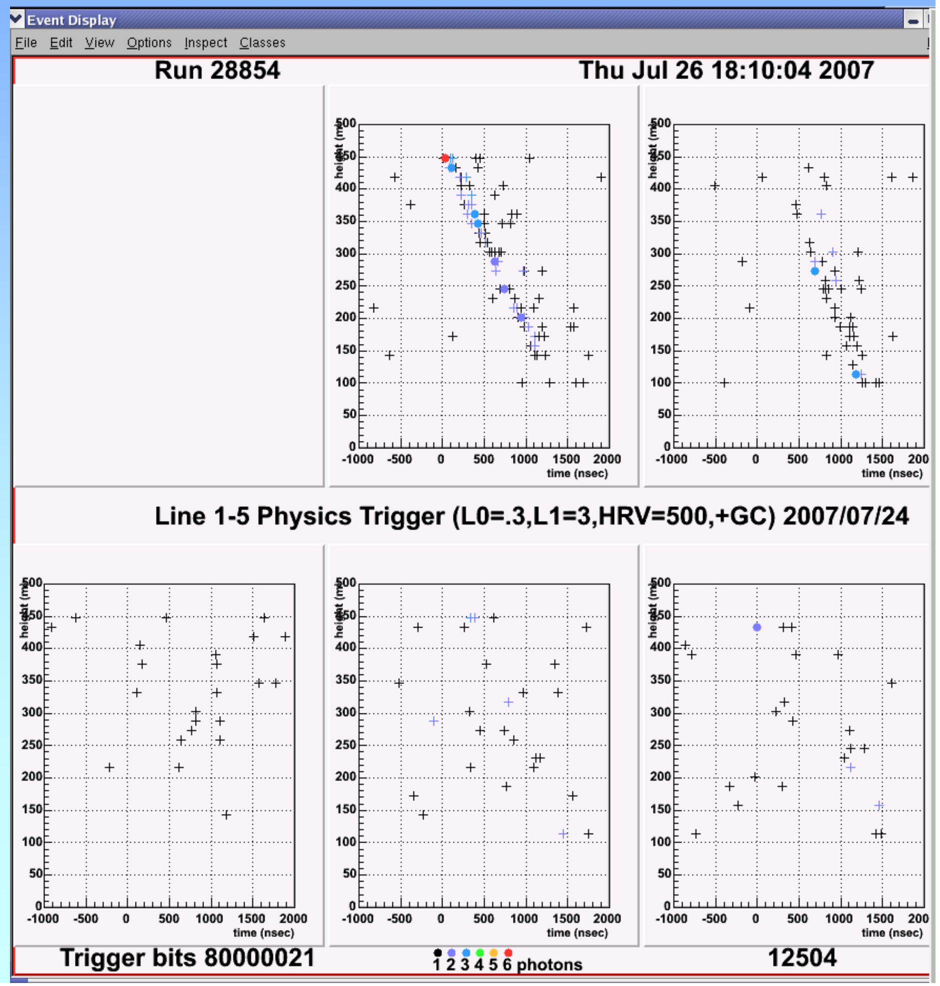
5 position sampling points

25 gradients (tiltmetre data from each storey)

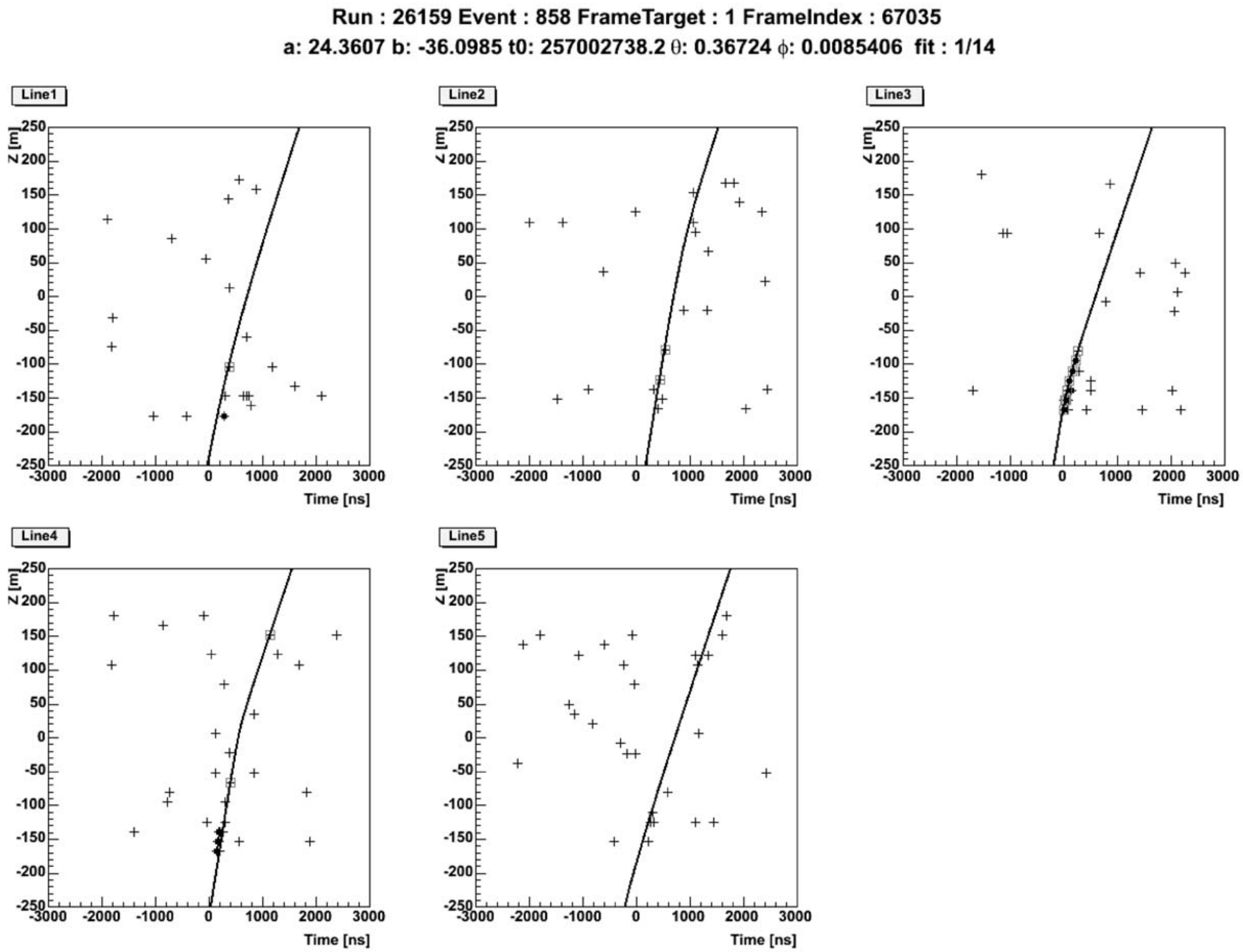
→ can reconstruct line shape

ANTARES online event display



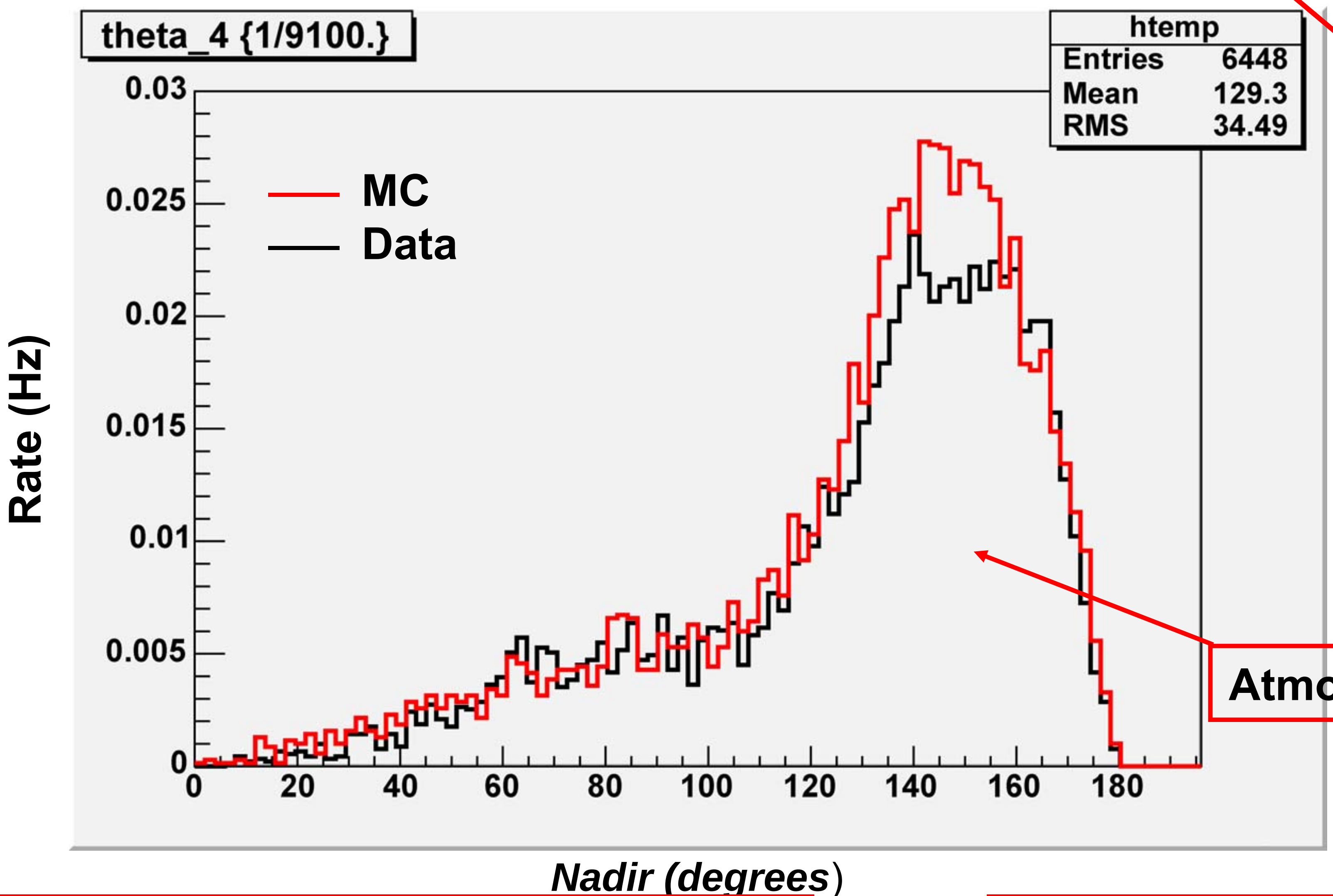


ANTARES event reconstruction



Atmospheric μ reconstruction <u>using alignements</u>

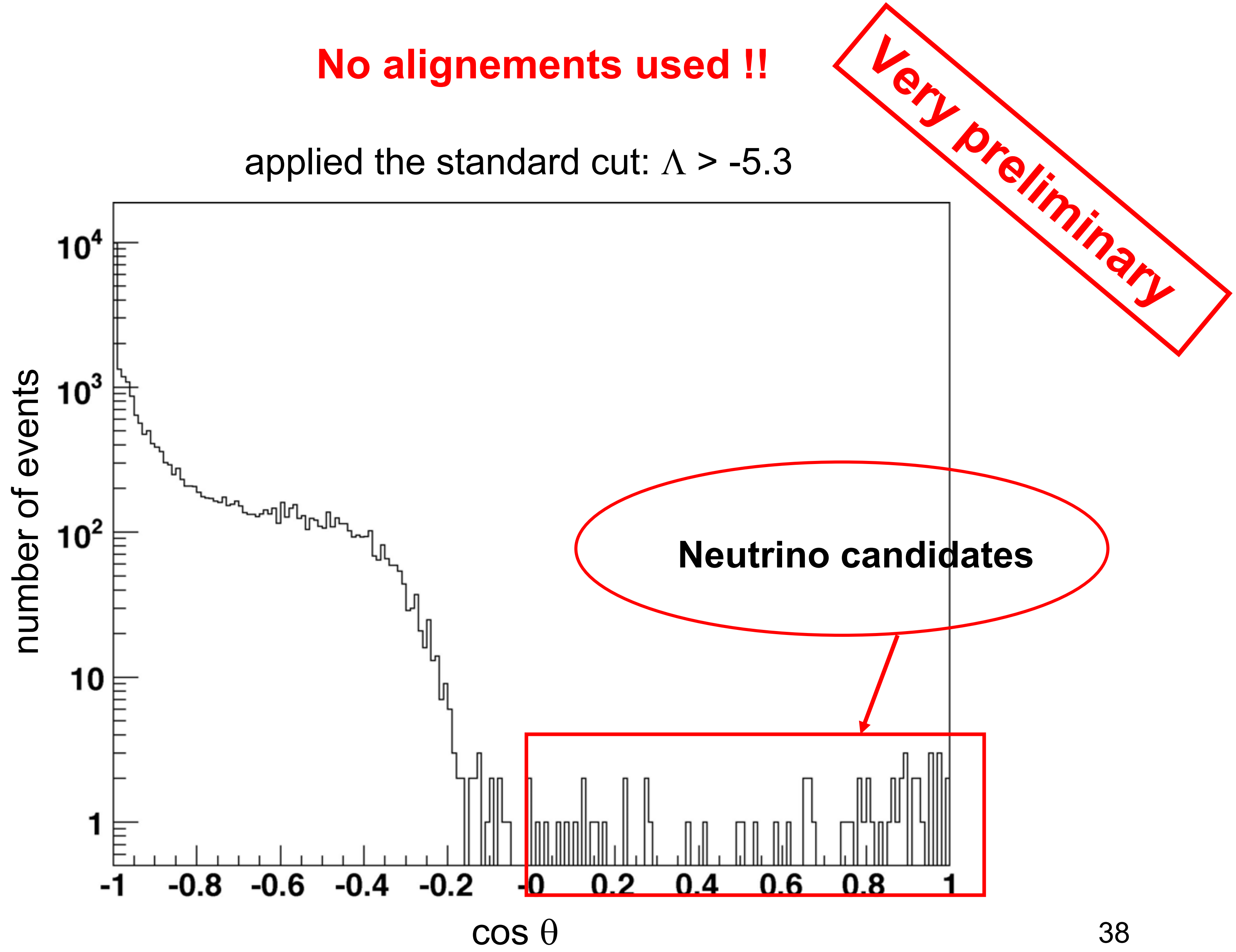
Very preliminary



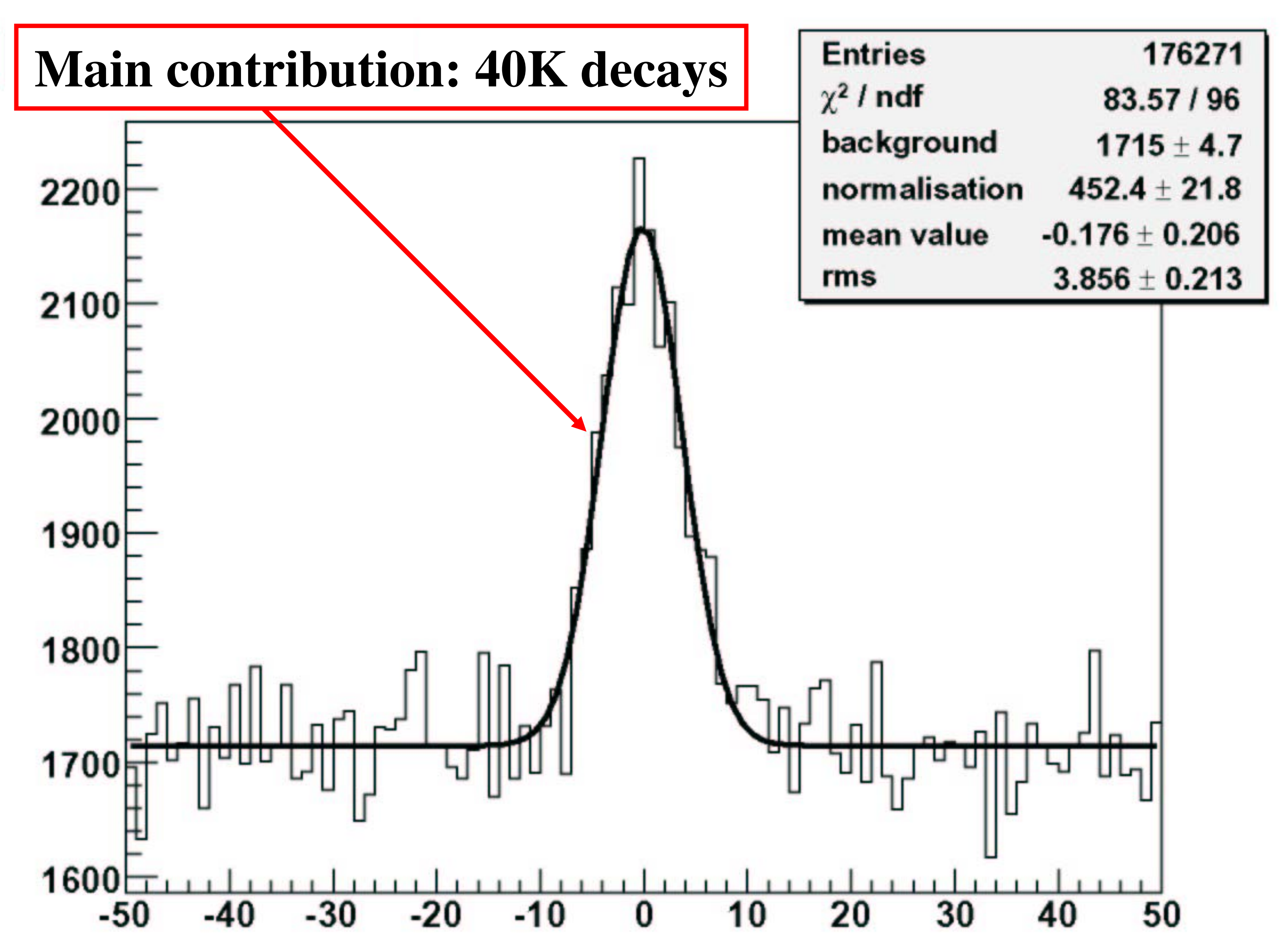
Agreement in shape
Agreement in rate to within ~10%

Integral of data: 0.71
Integral of MC : 0.79

μ zenith angle distribution after cut



Coincidence rates between adjacent PMTs



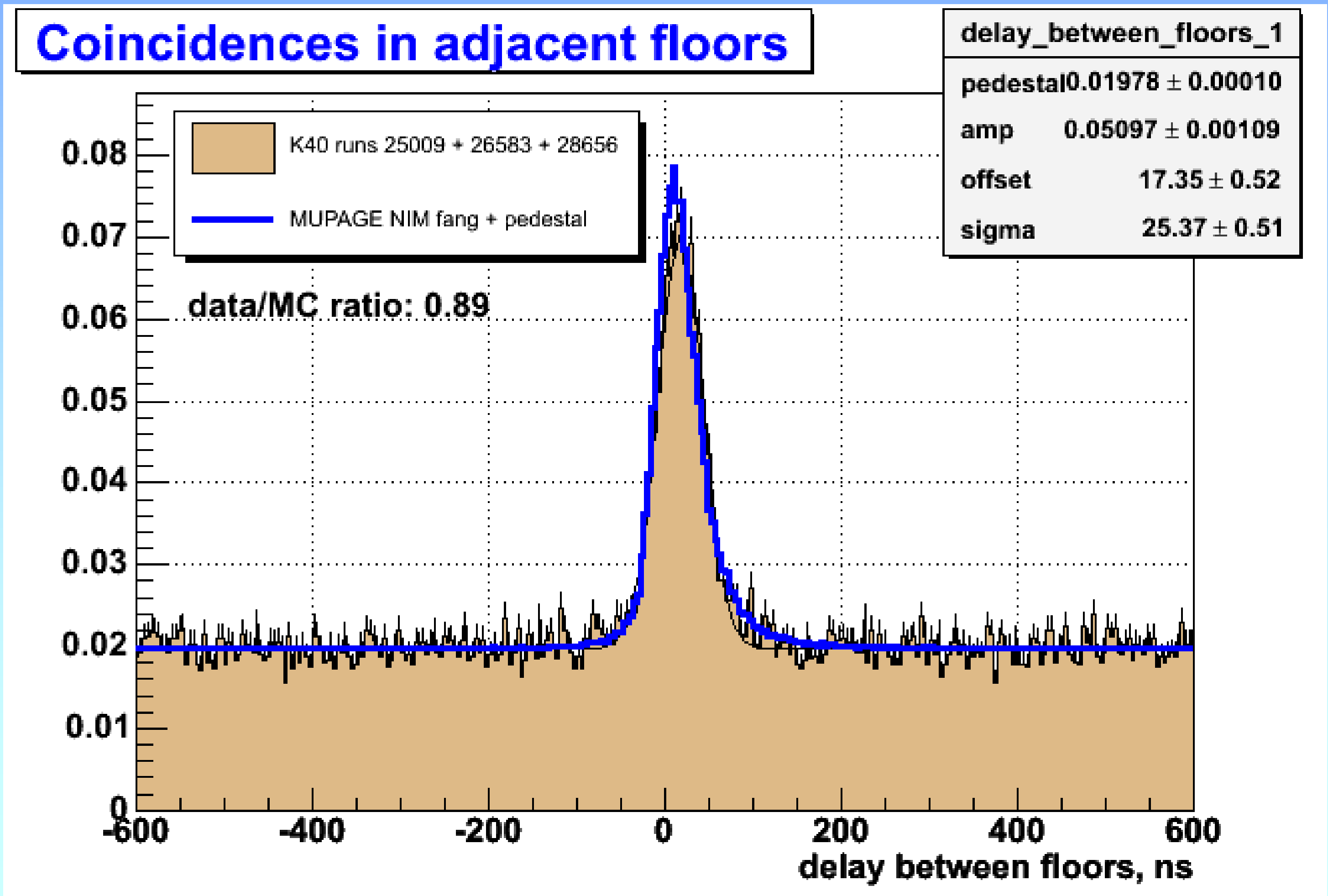
Time difference (ns)

Main contribution: 40K decays

But also atm. Muons !!!

Coincidence rates in the lines

Analysis by D. Zaborov

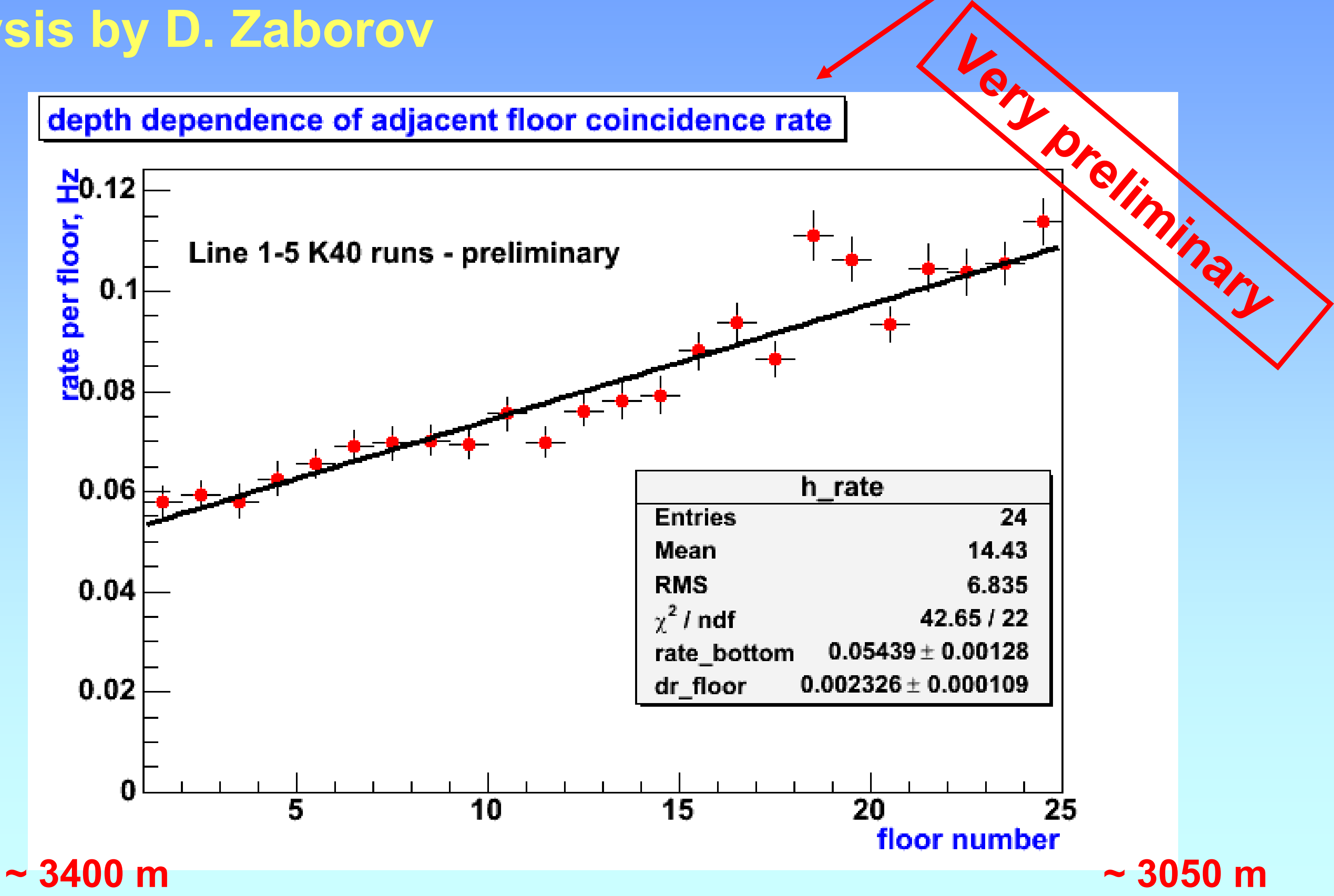


Main contribution: 40K decays

But also atm. Muons !!!

Extracting muon rate

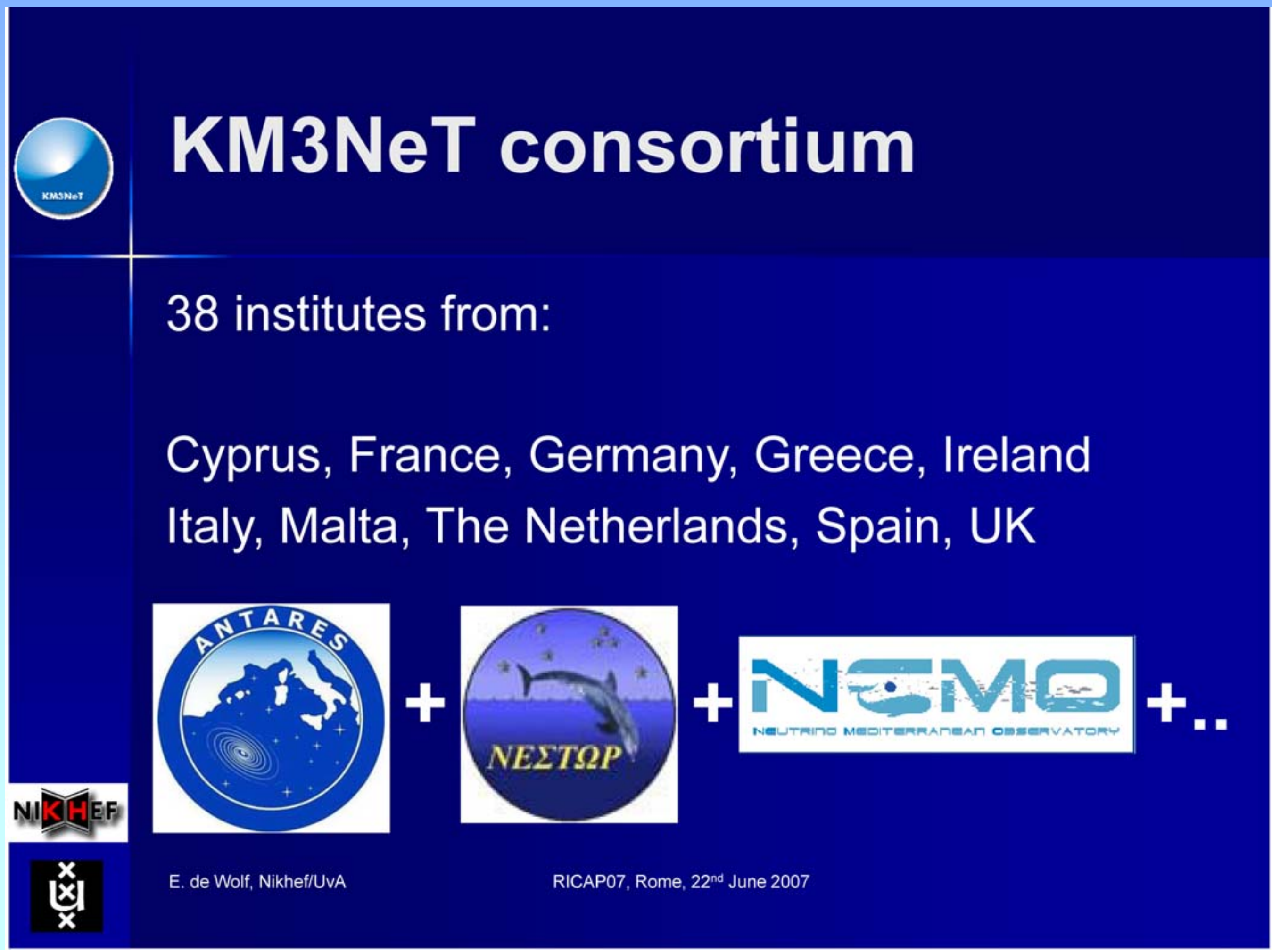
Analysis by D. Zaborov



Km3Net

- *Deep Sea Facility in the Mediterranean for*
- *Neutrino Astronomy and Associated Sciences*

Started February 2006



Km3Net

KM3NeT DS objectives

- Effective volume ≥ 1 km^3
- Angular resolution for muons: 0.1^0 (for neutrino energies ≥ 10 TeV)
- Energy threshold: few 100 GeV (~100 GeV when pointing)
- Sensitivity to all neutrino flavours, CC/NC reactions
- Field of view: close to 4π for high energies

E. de Wolf, Nikhef/UvA

Targeted budget:
M€220-250 (ESFRI roadmap)

KM3NeT Tasks

Task	Descriptive title
WP1	Management of the Design Study
WP2	Physics analysis and simulation
WP3	System and product engineering
WP4	Information technology
WP5	Shore and deep-sea infrastructure
WP6	Sea surface infrastructure
WP7	Risk assessment and quality assurance
WP8	Resource exploration
WP9	Associated science

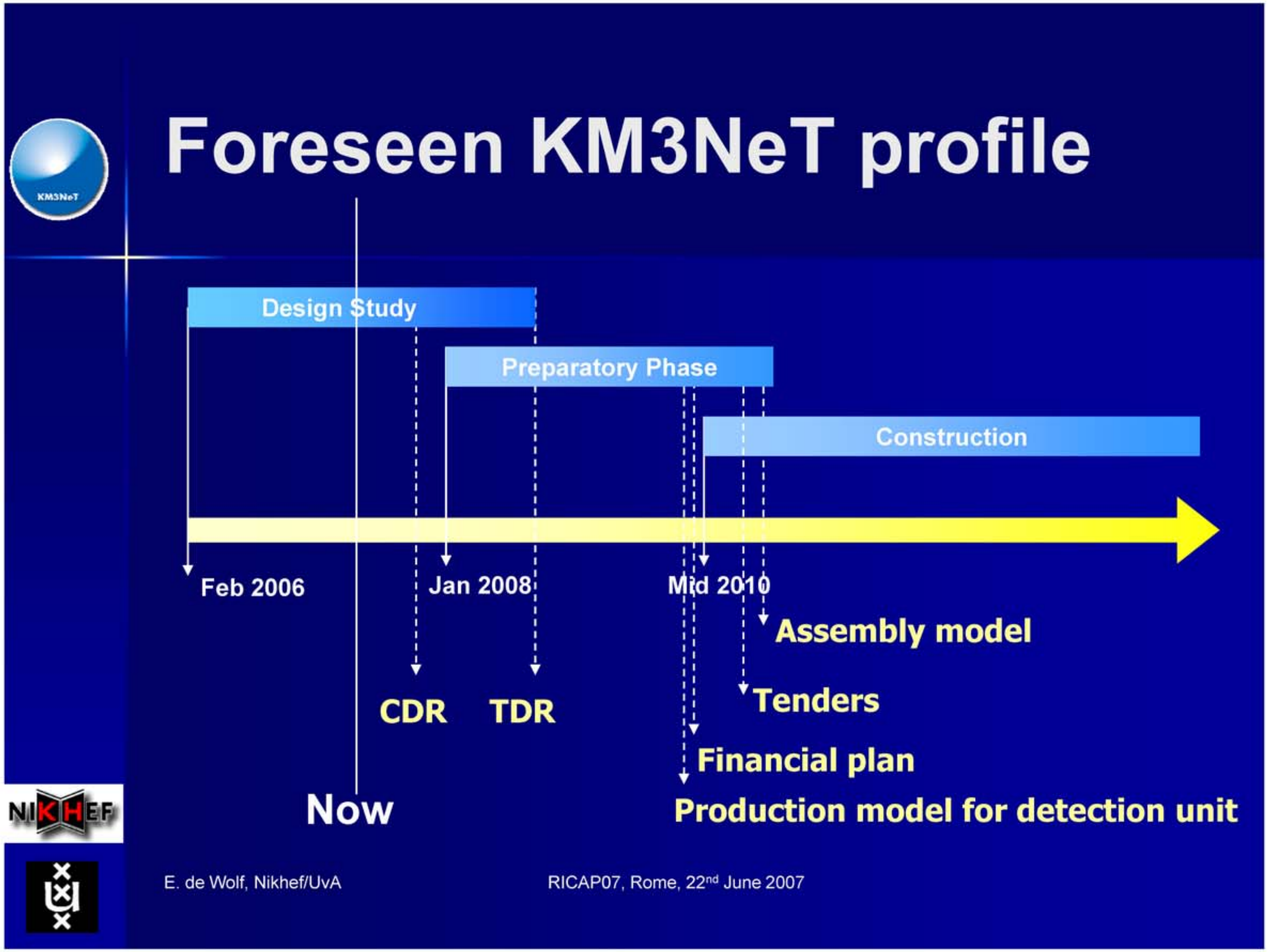
KM3NeT DS deliverables

- Conceptual Design Report: autumn 2007 (workshop in Amsterdam, November 2007)

- Technical Design Report: spring 2009

  a.o.
  - Technical description of major parts
  - QA/QC procedures
  - Optimal site-detector combinations
  - Inventory of resource opportunities

Km3Net


Foreseen KM3NeT profile
KM3NeT
Design Study
Preparatory Phase
Construction
Feb 2006
Jan 2008
Mid 2010
Assembly model
CDR
TDR
Tenders
Financial plan
Now
Production model for detection unit
NIKHEF
E. de Wolf, Nikhef/UvA
RICAP07, Rome, 22nd June 2007

Summary

- KM3NeT DS is well on its way
  - Building on experience of existing telescopes
  - CDR workshop in November 2007
- Waiting for a decision on FP7-PP proposal
  - Commitments for construction
  - Governance
  - Site selection
  - System prototype

Conclusions

- Long march towards underwater cosmic neutrino detection has undergone an acceleration
- Nestor → first serious attempt in the Medierranean → results published
- ANTARES made a major step forward during 2006-2007 and 12-lines detector with 900 OMs will be completed early 2008.
- NEMO → big effort towards capopassero site (3500 m)
  Construction of detector for NEMO PhaseI completed. Now in data-taking
  100 km electro-optical cable for NEMO PhaseII installed and shore-station building almost ready
- Joint European effort towards km3 detector in the Mediterranean now underway (Km3Net)

The End

Comparison among expts

Experiment	Connections	Power (cable)	Readout	Volume (m^3)	E_{thres} (Muons)	#PMTs	λ_{abs}
Antares (12 strings)	ROV	42 km 4.5 kV (AC-50 Hz) +sea return	T,Q (Waveform: 200 MHz-1 GHz)	10^7	50 GeV	900 (375 now)	
Baikal (NT200)	AIR	??	T,Q	10^5	15 GeV	192	
Baikal (NT200+)	AIR	??	Waveform (200 MHz)	$5x10^6$	15 GeV	228	
NEMO-II (64 Towers)	ROV	100 km 10 kV DC +sea return	Waveform (200 MHz)	$\sim 10^9$	100 GeV	5184	
NESTOR (1 Tower)	AIR	??		$2.5x10^5$		144	

Junction Box

- Effectiveness of the oil bath solution
  - Solution applied for the JB and the electronics containers of the tower
  - All power electronics under pressure in oil bath
- Importance of redundancies
  - All control channels in the JB duplicated
  - Minor failures on some control boards overcome via redundant path

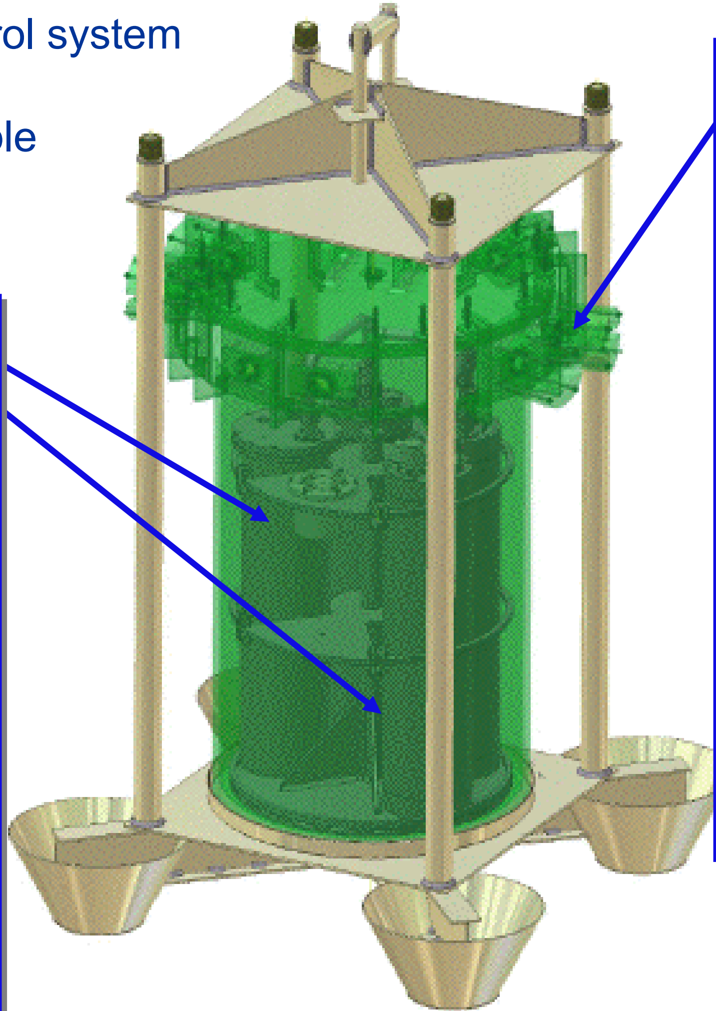
… but …

- Malfunctions due to accidental crash
  - Recovery of the JB (june 16 2007)
  - Now repaired and redeployed

The Junction Box

Data transmission electronics
Power distribution and control system
Optical fibre splitters
Innovative design to decouple the corrosion and pressure resistance problems

Electronics pressure vessels



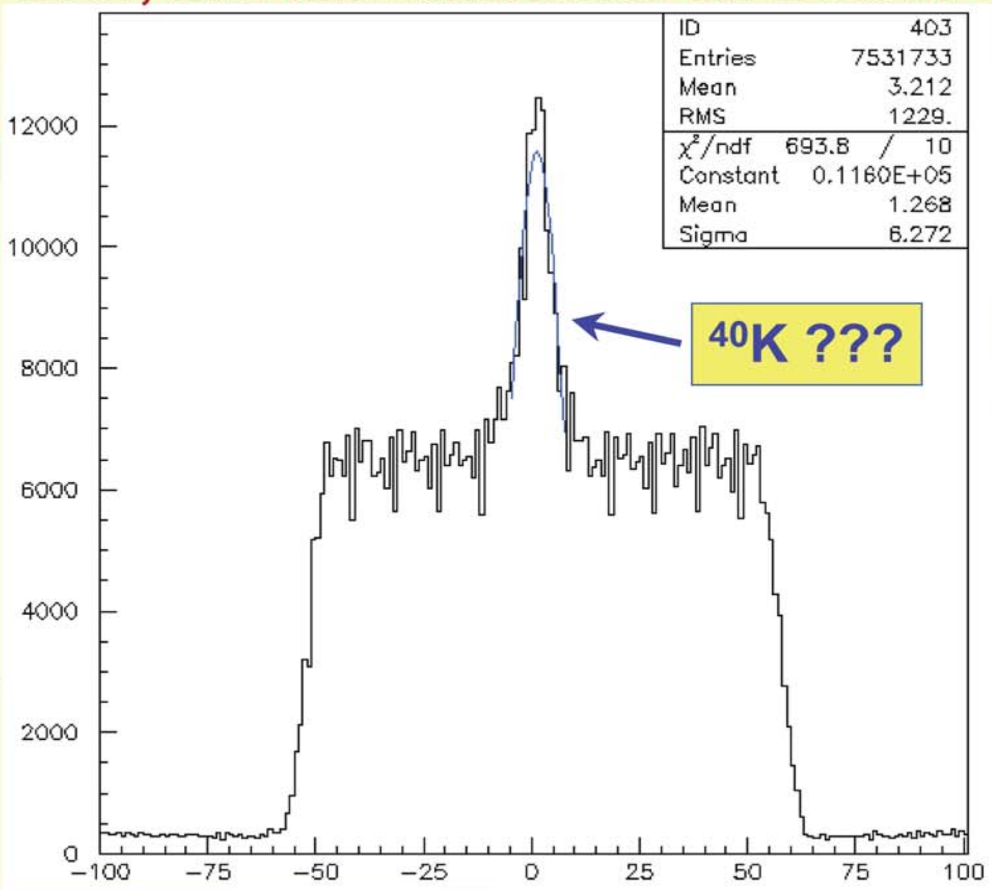
External fibreglass container

NEMO-Phase 1

Δt distribution for two close PMTs

2nd floor, hits time difference for 2 close PMTs

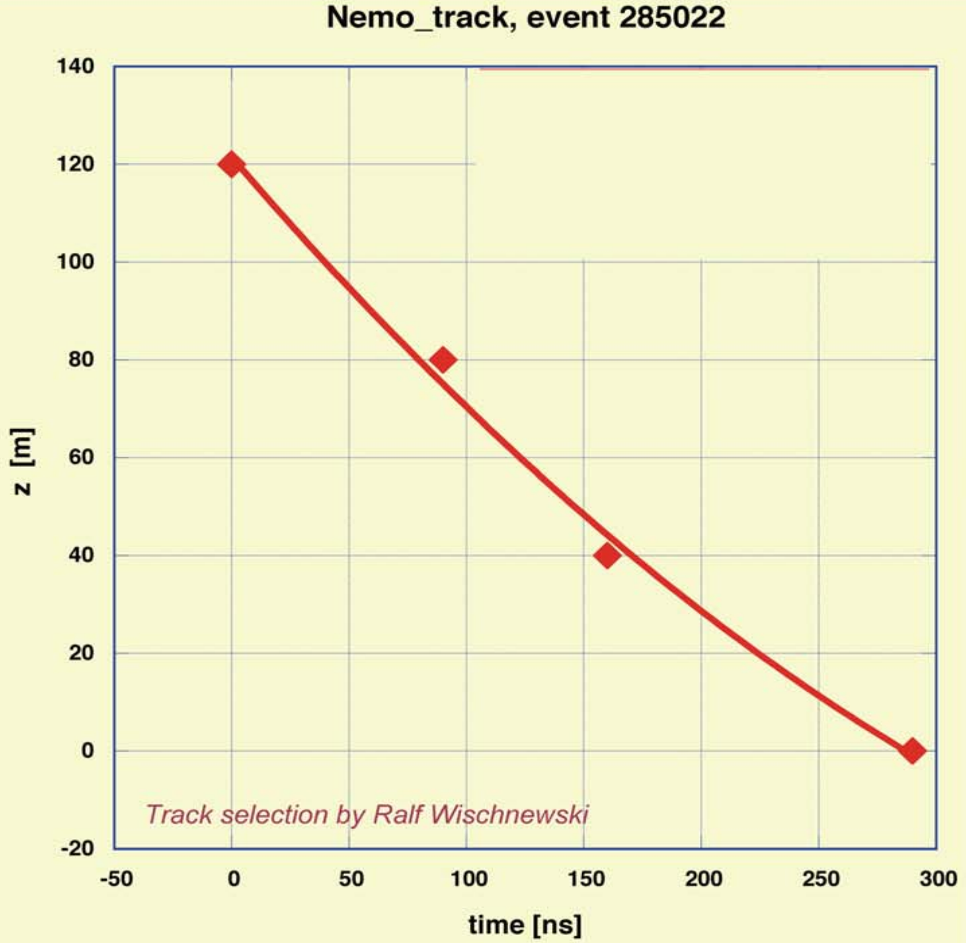
2nd floor is now close to the sea bottom, these two PMT's could "see" a small volume of water, noise is mainly coming from "close" ^{40}K decay, 2 PMT's coincidences are more evident.



t_{PMT_6}-t_{PMT_5} [ns]

NEMO-Phase 1

NEMO-Fase1 - Preliminary result

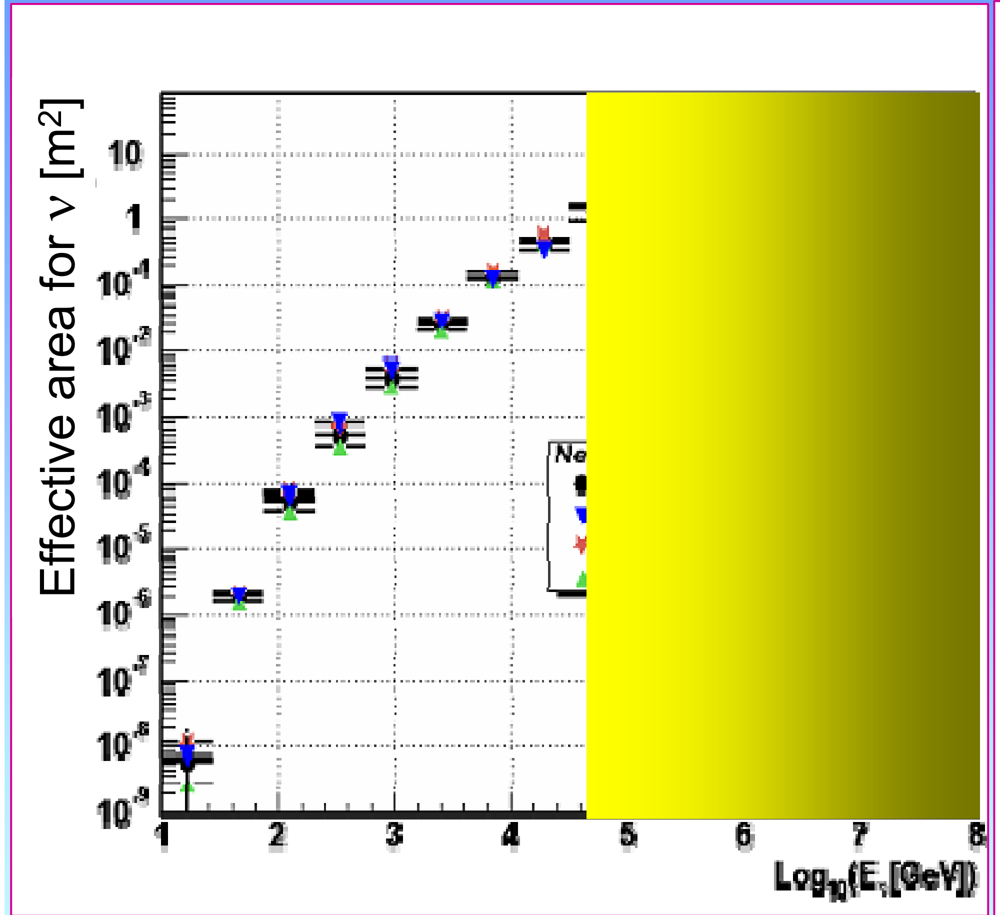


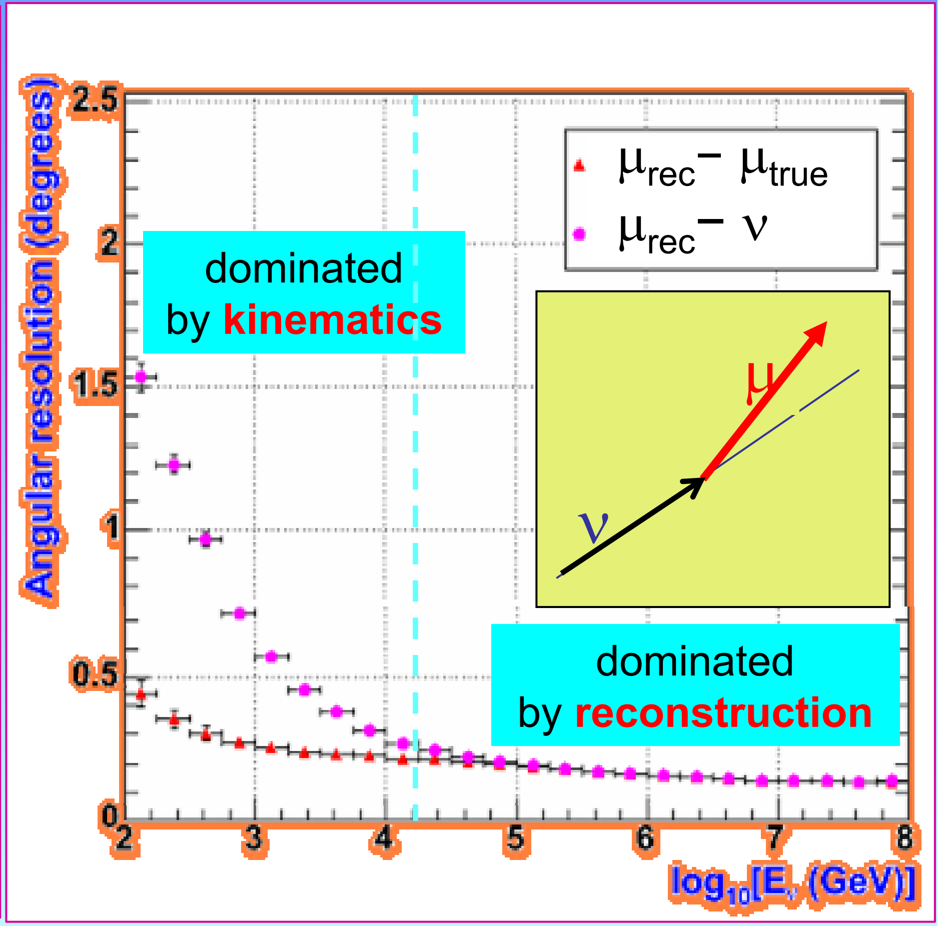
Recently the acoustic positioning system provided the knowledge of PMT position, so track finding became possible and …….

Other modifications / upgrades of the Phase-2 tower

- Full tower with 16 floors
  - Equipped with the same electronics of Phase-1, but two floors reserved for testing of new electronics (LIRA), directional OMs, …
- New DC power system to comply with the feeding system provided by Alcatel
- Optimization of the electronics and data transmission
  - Increase of the A/D conversion accuracy
  - Increase of the data bandtwidth
  - Decrease of the power consumption
- Integrate a new acoustic station

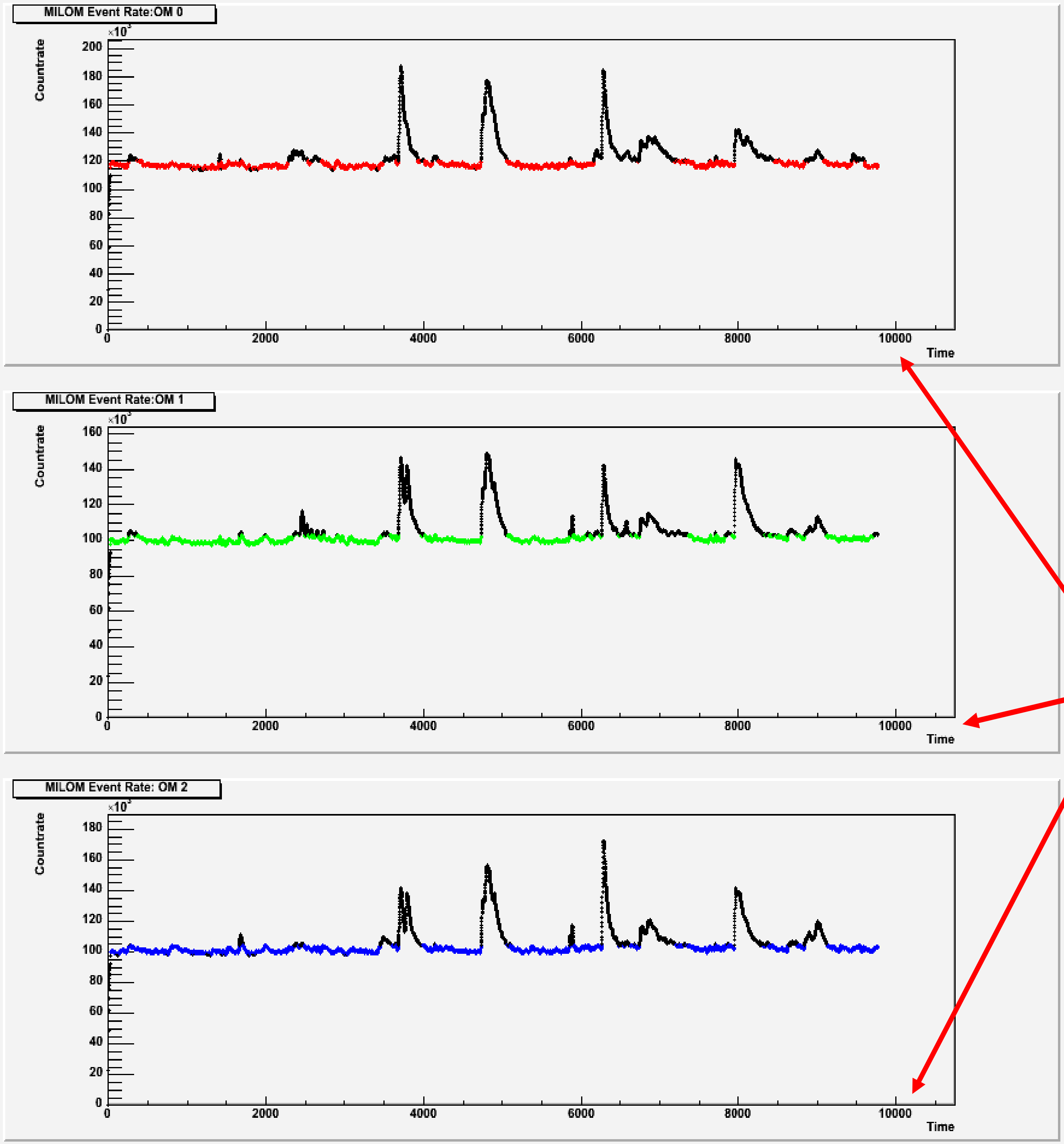
Expected performance (MC Studies)





Angular resolution better than 0.3° above a few TeV, limited by:

- Light scattering + chromatic dispersion in sea water: σ ~ 1.0 ns
- TTS in photomultipliers: σ ~ 1.3 ns
- Electronics + time calibration: σ < 0.5 ns
- OM position reconstruction: σ < 10 cm [σ < 0.5 ns]



MILOM

counting rates

July 2005 data

Baselines ~ 100 kH

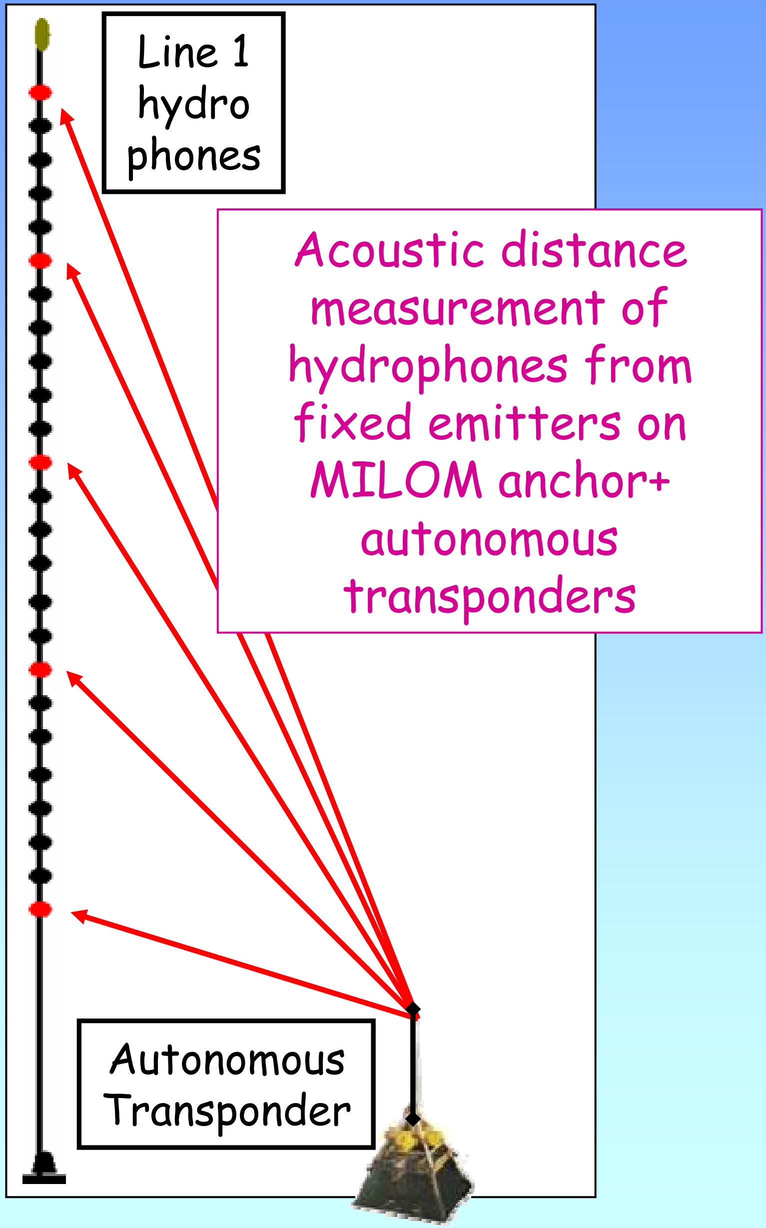
Time in seconds

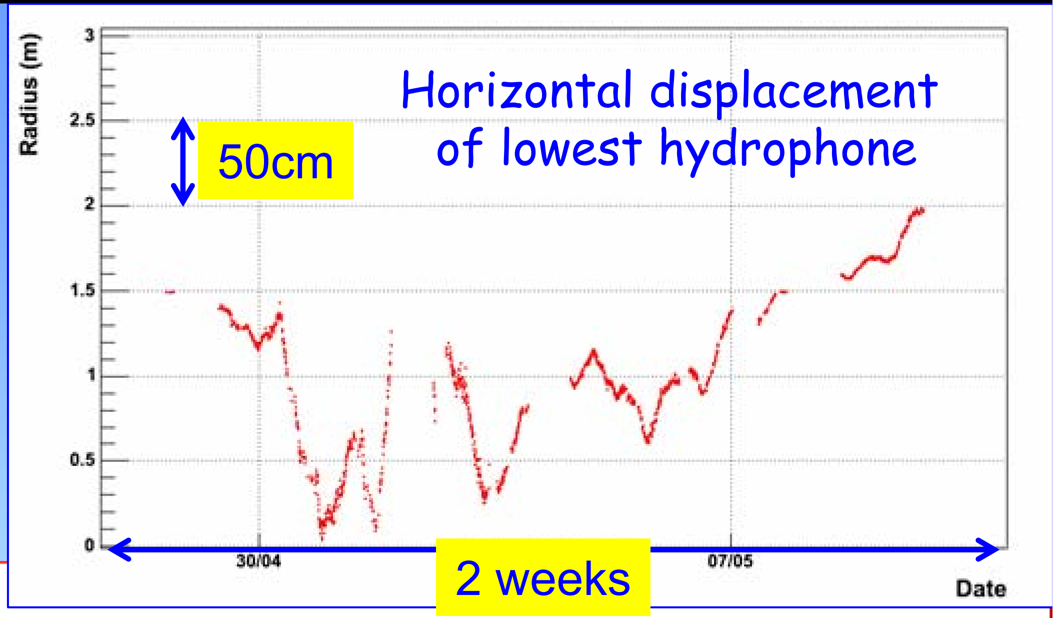
Burst-fraction =

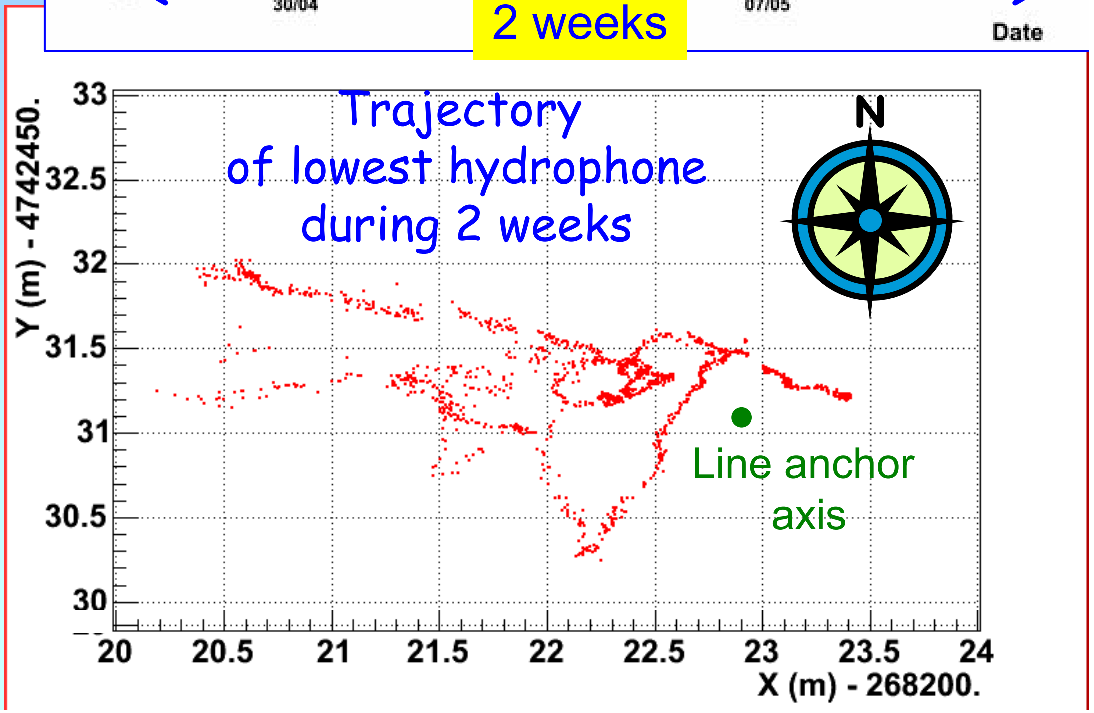
fraction of time when

rate > baseline + 20%

Acoustic triangulation of Line 1 hydrophone







Amanda vs ANTARES ν Effective areas