L.K. Resvanis
University of Athens
and
NESTOR Institute

RE - 9

NESTOR

Neutrino Extended Submarine Telescope with Oceanographic Research

Run 2003

Detector Performance & Physics Results

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A measurement of the cosmic-ray muon flux with a module of the NESTOR neutrino telescope

The NESTOR Collaboration

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Abstract

A module of the NESTOR underwater neutrino telescope was deployed at a depth of 3800 m in order to test the overall detector performance and particularly that of the data acquisition systems. A prolonged period of running under stable operating conditions made it possible to measure the cosmic ray muon flux, $I_0 \cdot \cos^{\alpha}(\theta)$, as a function of the zenith angle θ. Measured values of index α and the vertical intensity I_0

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Nuclear Instruments and Methods in Physics Research A 552 (2005) 420–439
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Operation and performance of the NESTOR test detector

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[e]*Lawrence Berkeley National Laboratory, Berkeley, CA, USA*
[f]*University of Kiel, Institute of Experimental and Applied Physics, Germany*
[g]*University of Crete, Physics Department, Greece*
[h]*University of Bern, Physikalisches Institut, Switzerland*
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Available online 27 July 2005

Abstract

NESTOR is a deep-sea neutrino telescope that is under construction in the Ionian Sea off the coast of Greece at a depth of about 4000 m. This paper briefly reviews the detector structure and deployment techniques before describing in detail the calibration and engineering run of a test detector carried out in 2003. The detector was operated for more than 1 month and data was continuously transmitted to shore via an electro-optical cable laid on the sea floor. The performance of the detector is discussed and analysis of the data obtained shows that the measured cosmic ray muon flux is in good agreement with previous measurements and with phenomenological cosmic ray models.

PACS: 95.55.Vj; 29.40.Ka; 13.15.+g

Keywords: Neutrino; NESTOR; Deep-sea; Telescope; Operation; Performance

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NESTOR

NEUTRINO EXTENDED SUBMARINE TELESCOPE WITH OCEANOGRAPHIC RESEARCH

GERMANY

Institute for Geophysics
University of Hamburg
Institute of Experimental and Applied Physics
Center for Applied Marine Sciences
Research and Technology Center West-Kueste (FTZ Buesum)
University of Kiel

GREECE

Physics Dept.
University of Athens
Institute for Geodynamics
Athens Observatory
Physics Dept.
University of Crete
Institute of Informatics and Telecommunications
NCSR DEMOKRITOS
National Science Foundation
NESTOR Institute for Deep Sea Research, Technology
and Neutrino Astroparticle Physics
Physics and Astronomy Dept.
University of Patras
School of Science & Technology
Hellenic Open University

RUSSIA

Experimental design Bureau of Oceanological Engineering
Institute for Nuclear Research
Russian Academy of Sciences

SWITZERLAND

Physics Dept.
University of Bern
CERN[a]

U.S.A.

Dept. of Physics and Astronomy
University of Hawaii[b]
Lawrence Berkeley National Laboratory[c]

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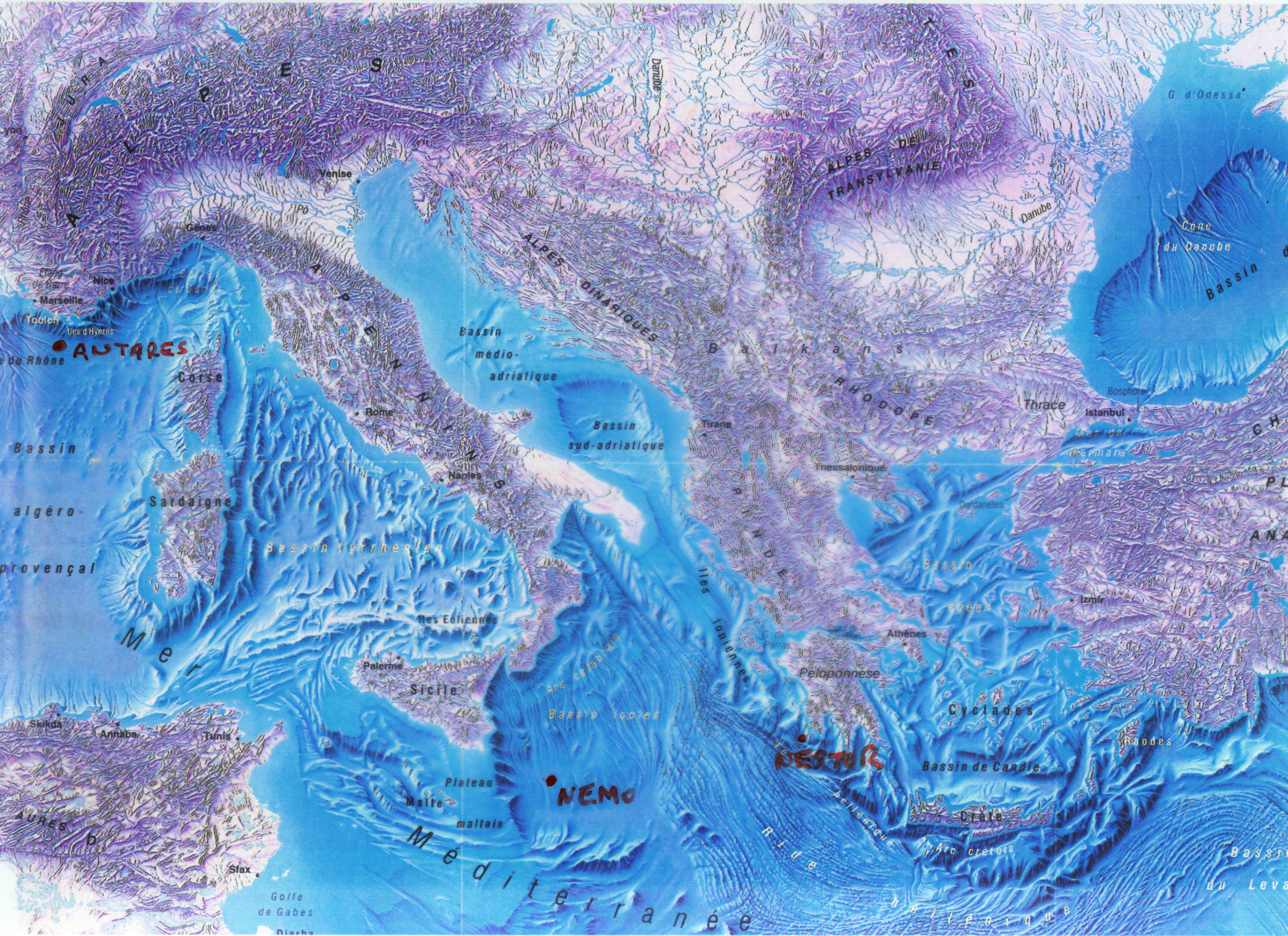
[a] Associated for Long Base Line beam studies (Recognized Experiment, RE9)
[b] Associated Institution for Ocean Technology
[c] Associated Institution for Electronics Technology



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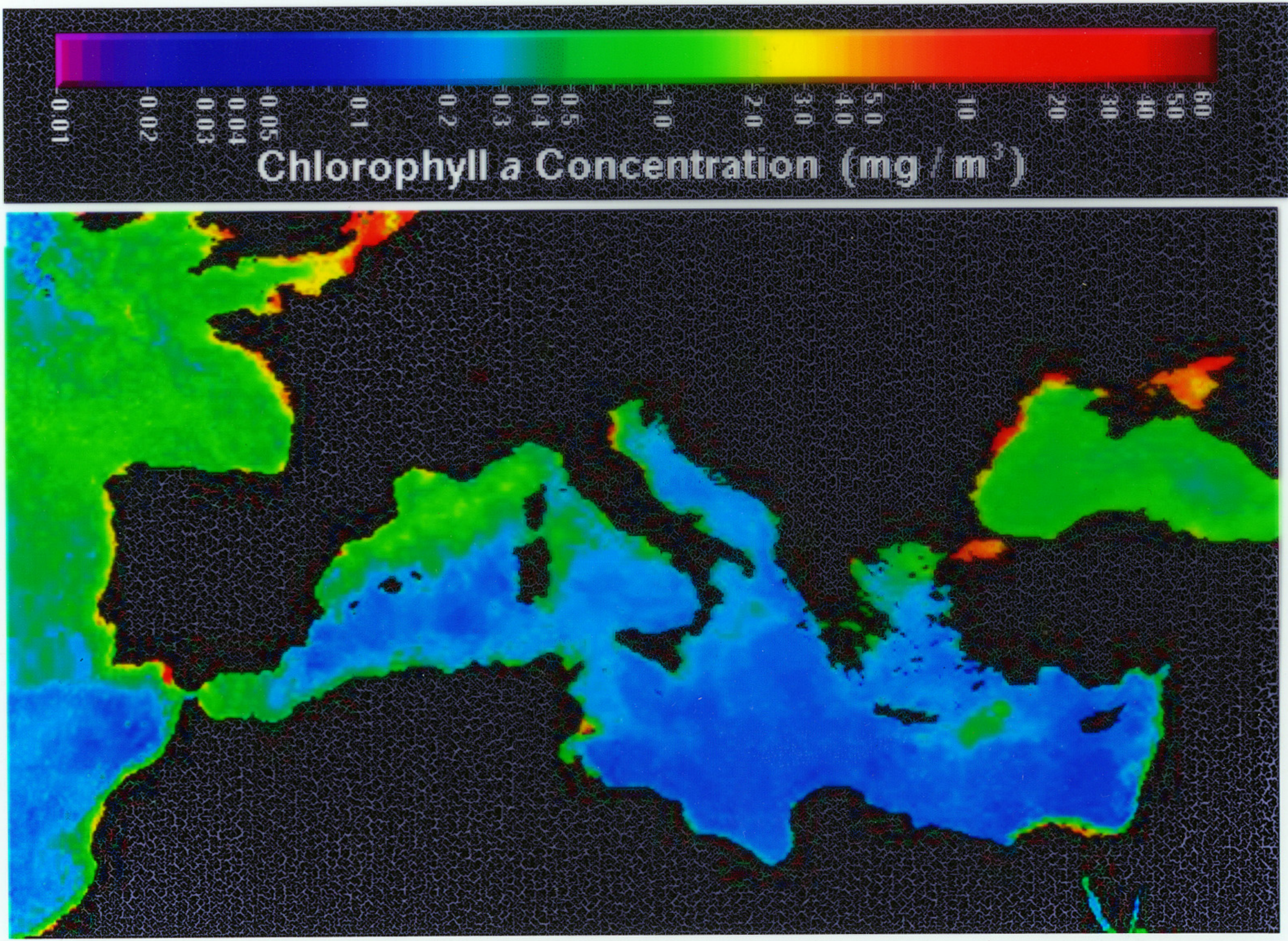
Bassin tyrrhénien
Iles Eoliennes
Iles Ioniennes
PINDE
Bassin égéen
Izmir
Athènes
Péloponnèse
Palerme
Sicile
Bassin Ionien
Cyclades
Rhodes
Bassin de Candie
Crète
Arc crétois
NESTOR
NEMO
Plateau maltais
Malte
Skikda
Annaba
Tunis
AURÈS
Sfax
Golfe de Gabès
Mer Méditerranée
Ride
Bassin du Levant


0.01
0.02
0.03
0.04
0.05
0.1
0.2
0.3
0.4
0.5
1.0
2.0
3.0
4.0
5.0
10
20
30
40
50
60
Chlorophyll a Concentration (mg / m³)

ISOBATHS

CONTOURS OF EQUAL DEPTH

~~The lighthouse of Sapientza~~
~~will be the counting room~~.
Then the data will be transmitted
to PYLOS by cable or microwave link.

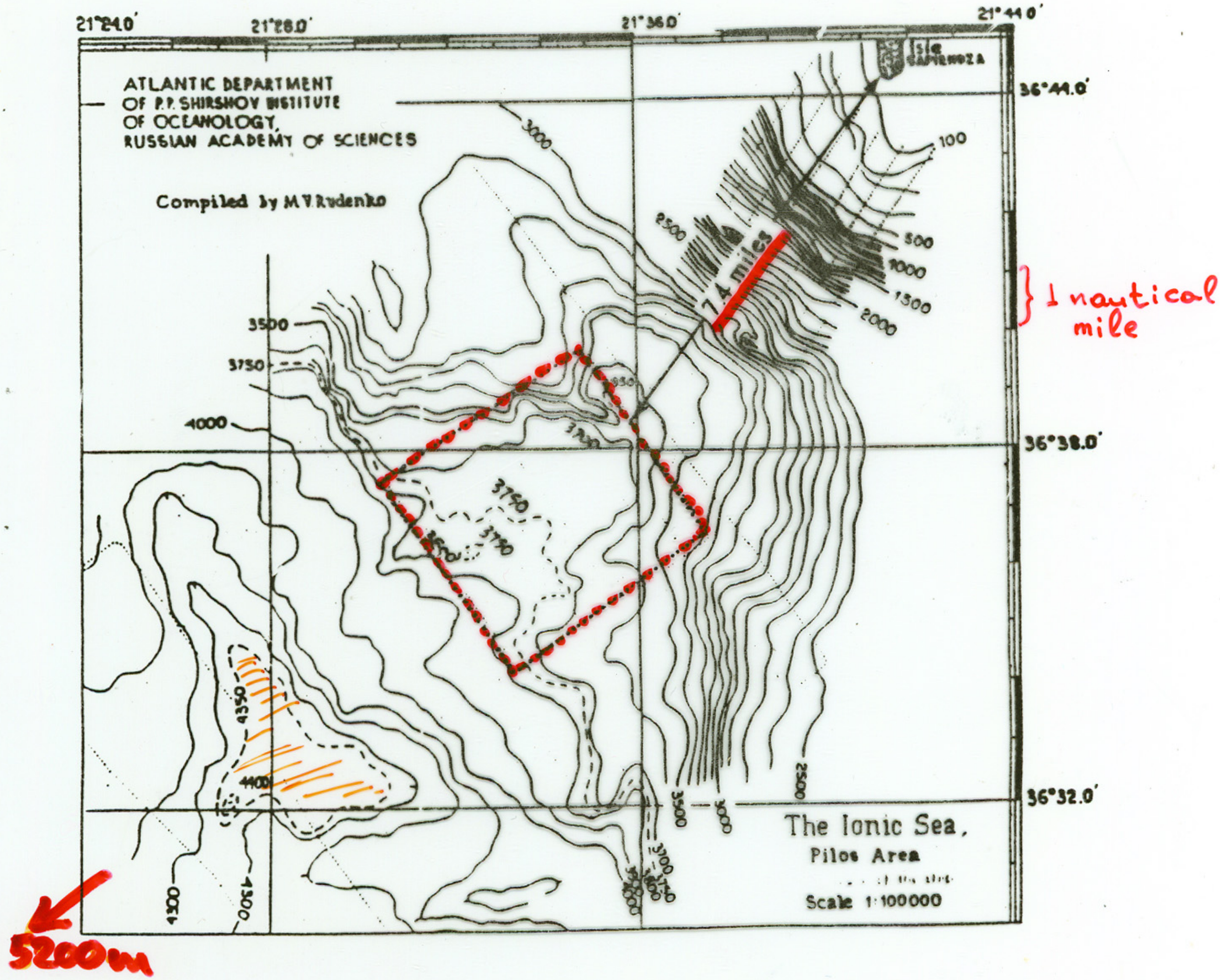
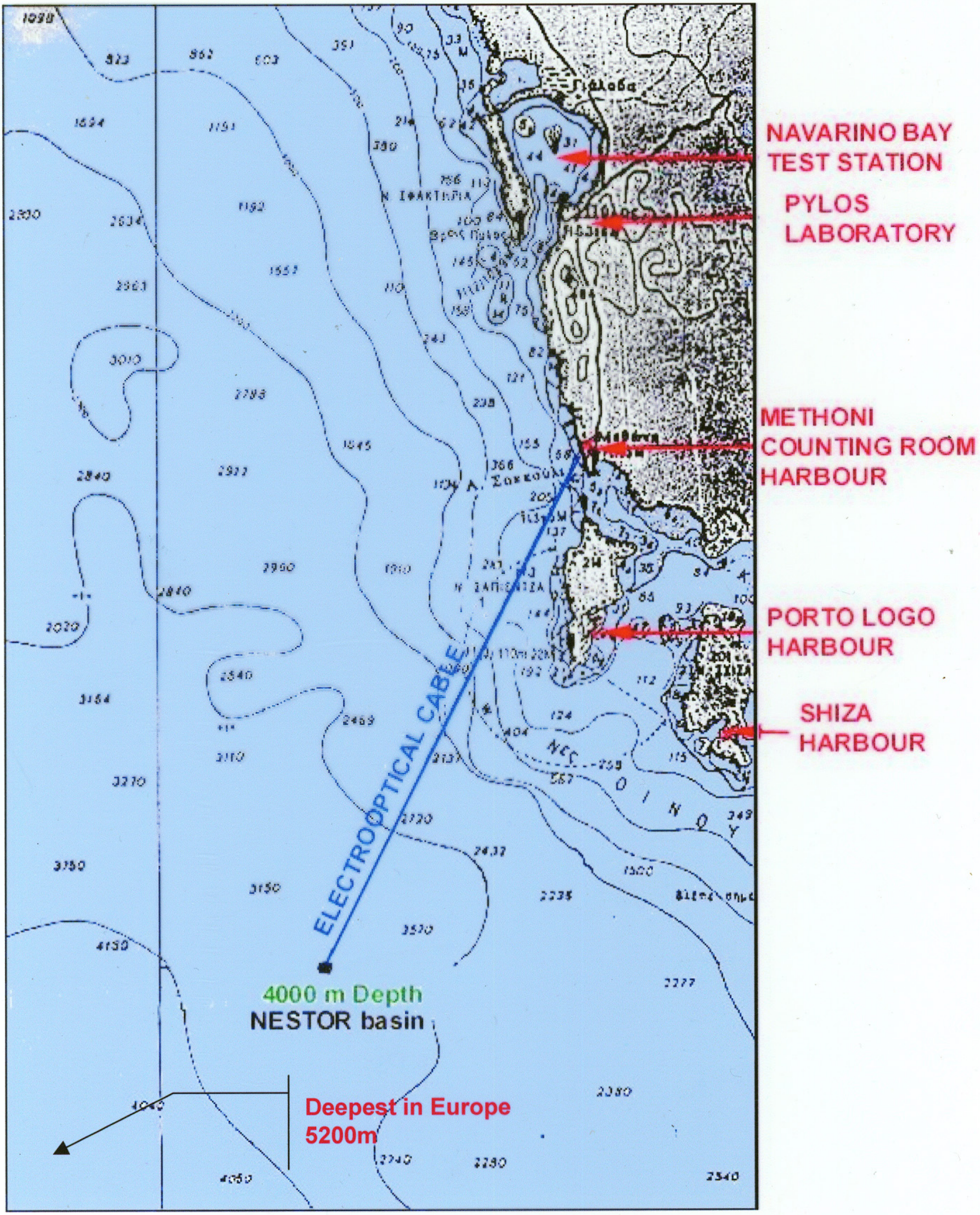
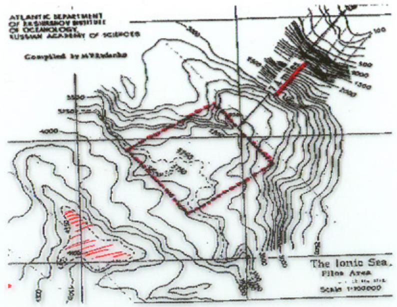


Figure 2


NAVARINO BAY
TEST STATION
PYLOS
LABORATORY
METHONI
COUNTING ROOM
HARBOUR
PORTO LOGO
HARBOUR
SHIZA
HARBOUR
ELECTROOPTICAL CABLE
4000 m Depth
NESTOR basin
Deepest in Europe
5200m

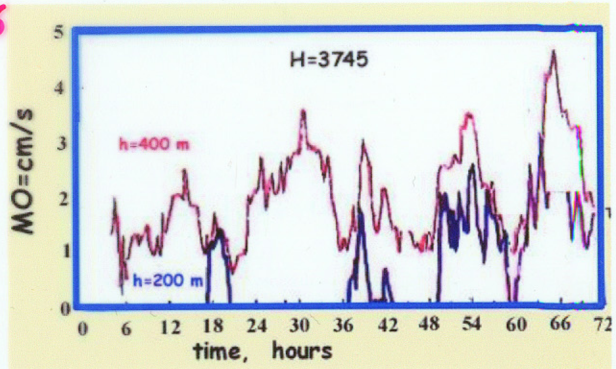
Site characteristics



- **a broad plateau:** 8x9 km^2 in area, 7.5 nautical miles from shore
- **depth:** ~4000m

N.I.M. A 349 pp 242-6

- **transmission length:** 55 $\pm$ 10m at λ=460 nm



- **underwater currents:** <10 cm/sec measured over the last 10 years
- **optical background:** ~50 kHz/OM due to K40 decay, bioluminescence activity (1% of the experiment live time)
- **sedimentology tests:** flat clay surface on sea floor good anchoring ground.

NO BOMBS !
NO SUBMARINES !

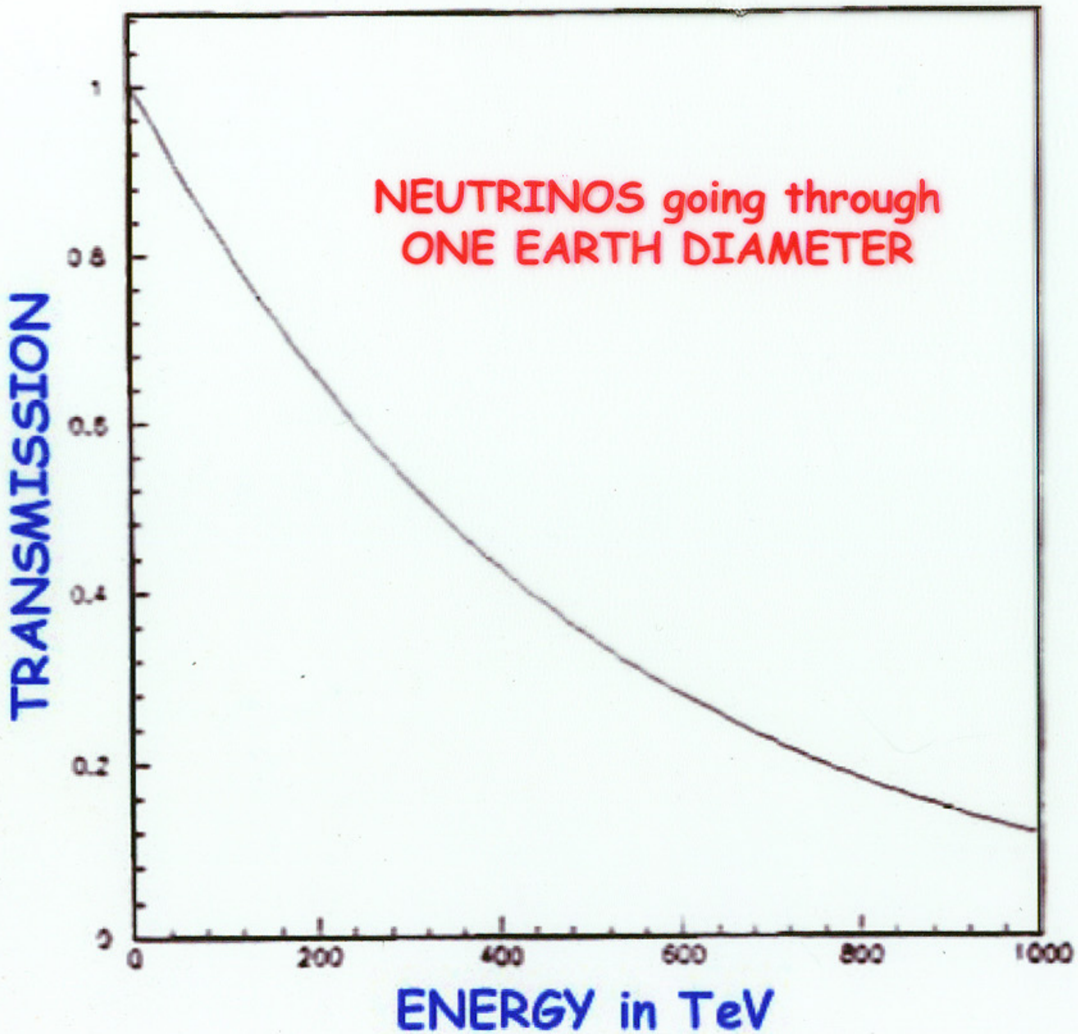

NESTOR
WORKSHOPS
NESTOR
INSTITUTE

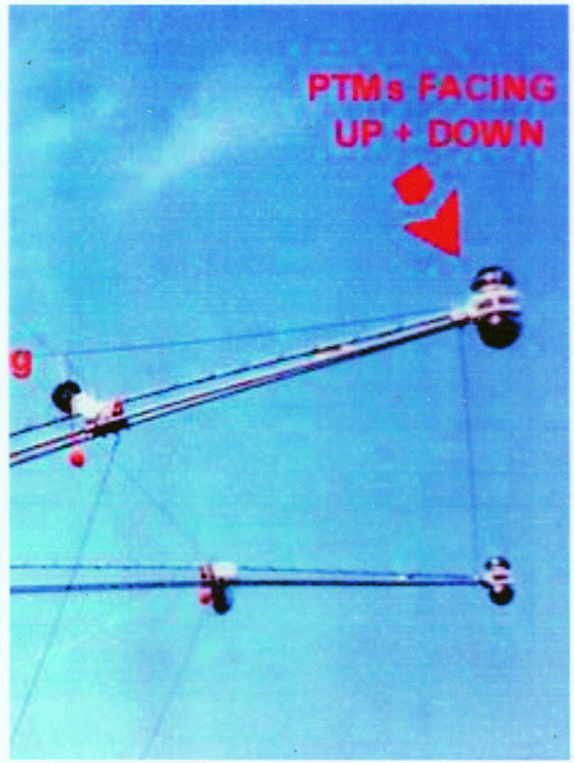

........now

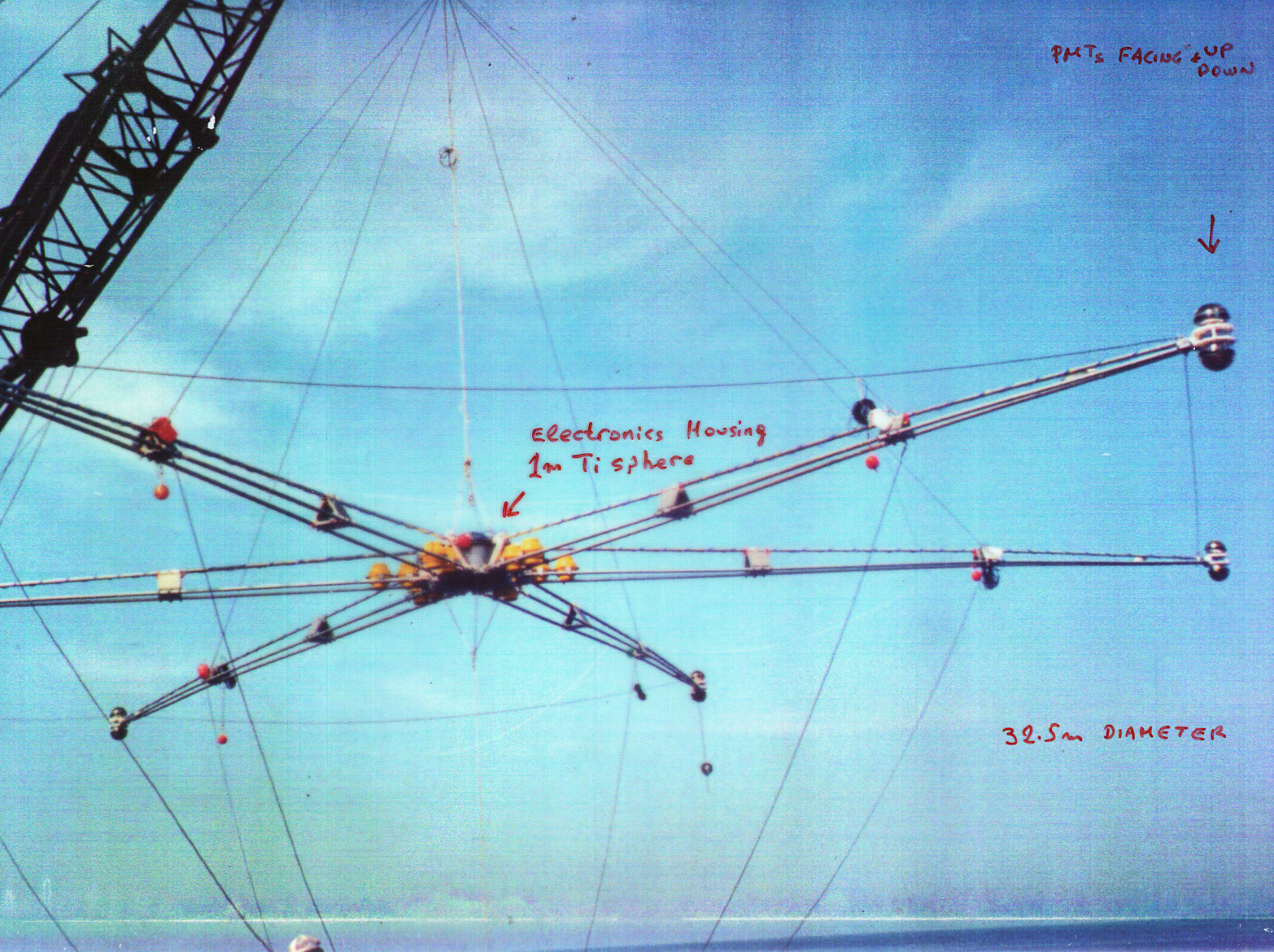
DESIGN CONSIDERATIONS

- NO BATHYSCAPHS - NO ROVs   COST + SAFETY
- NO HIGHLY SPECIALIZED SURFACE VESSELS ?
- ALL CONNECTIONS TO BE MADE IN THE AIR
- MINIMUM NUMBER OF CONNECTORS
- AS PASSIVE A SYSTEM AS POSSIBLE
  (Triggering on the shore)
- MODULAR SYSTEM WITH BUILT IN
- REDUNDANCY
- RETRIEVABLE AND EXPANDABLE

EARTH IS NO LONGER TRANSPARENT TO NEUTRINOS WITH ENERGY > A FEW HUNDREDS TeV !!!

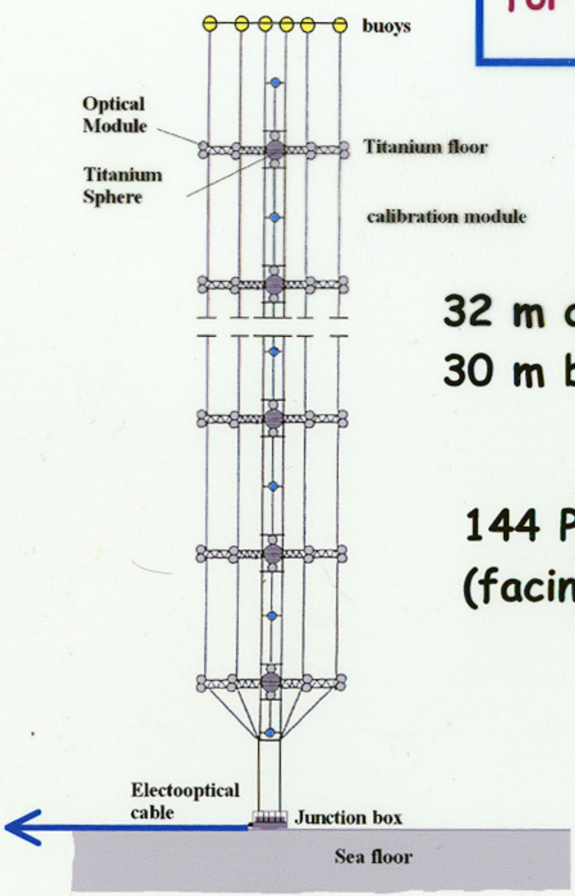





PMTs FACING UP & DOWN
Electronics Housing
1m Ti sphere
32.5m DIAMETER

NESTOR TOWER

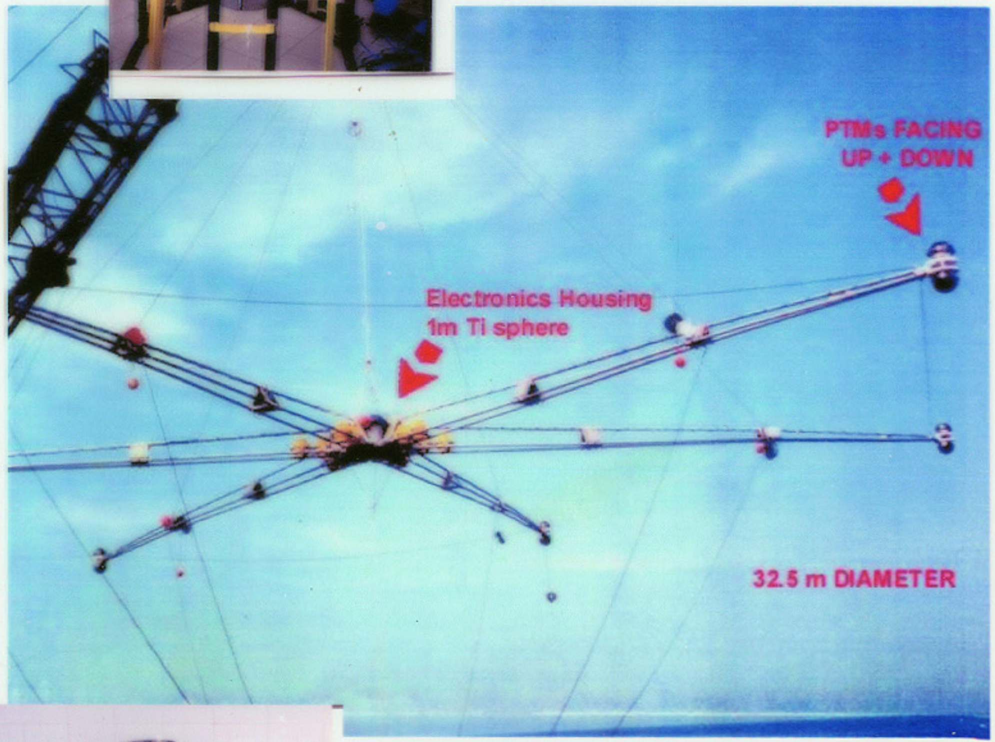
20 000 m^2
Effective Area
for E>10TeV



32 m diameter floor
30 m between floors

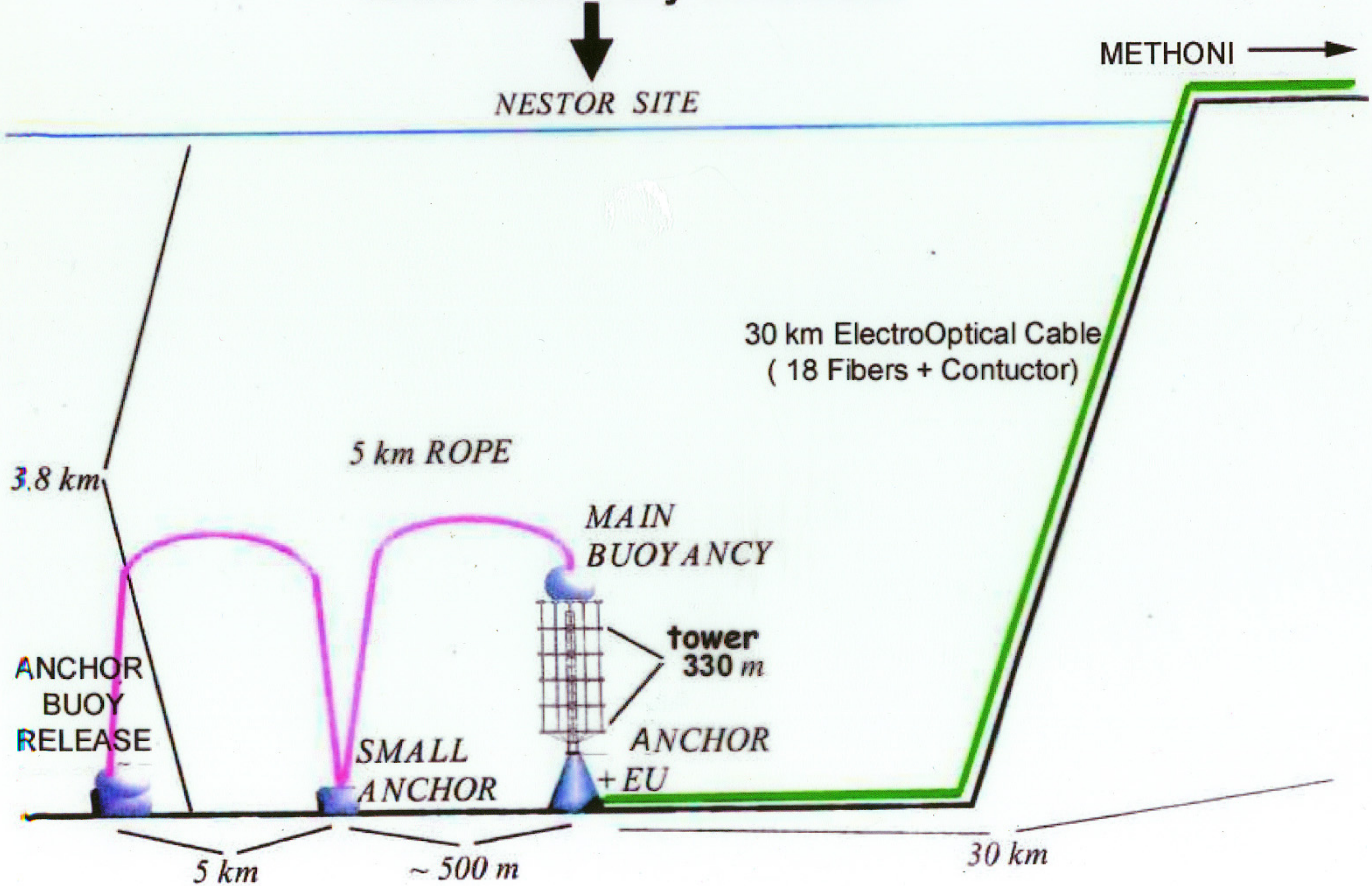
144 PMTs
(facing up & down)

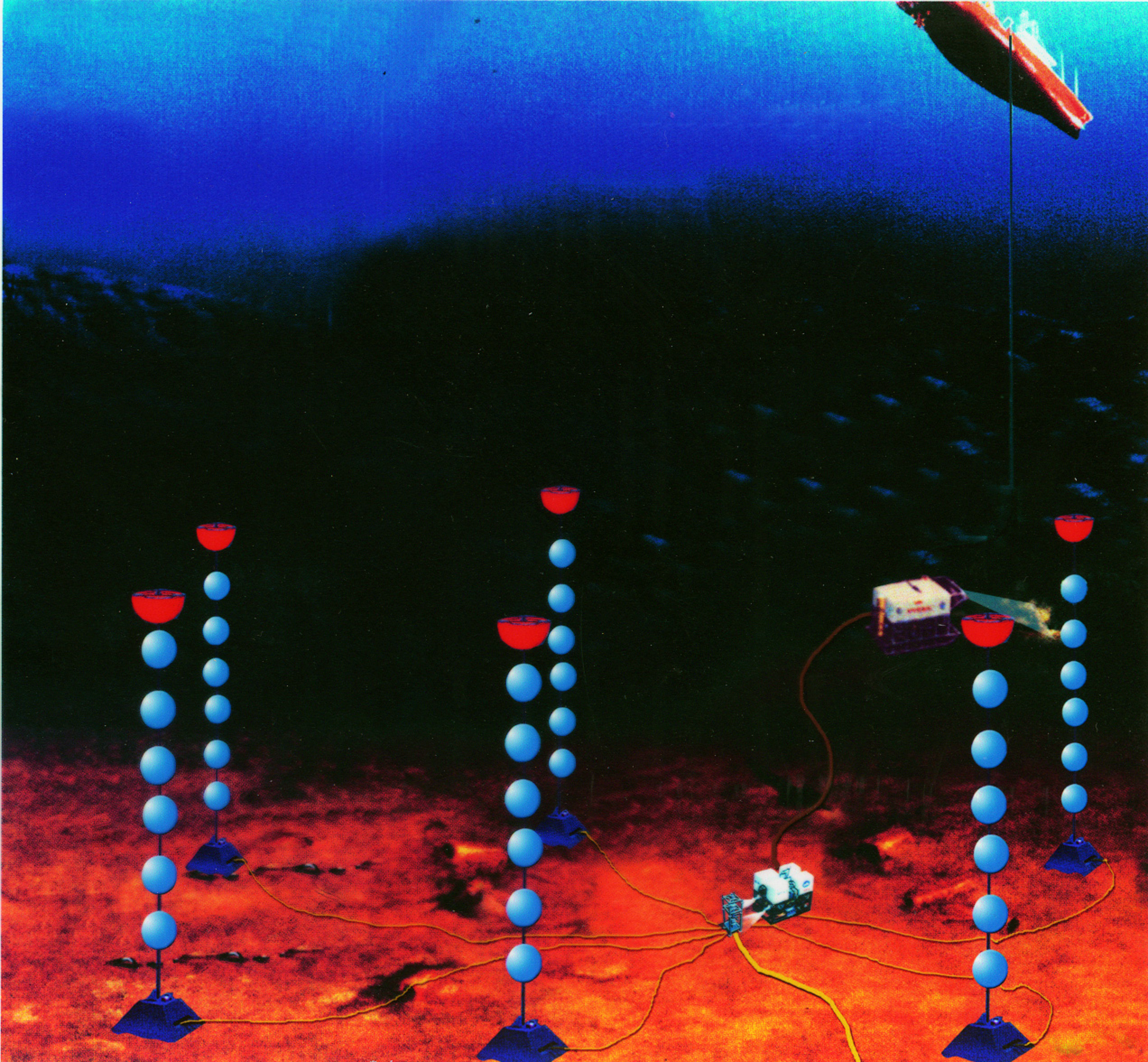
At the center of each floor, a titanium sphere houses the floor electronics



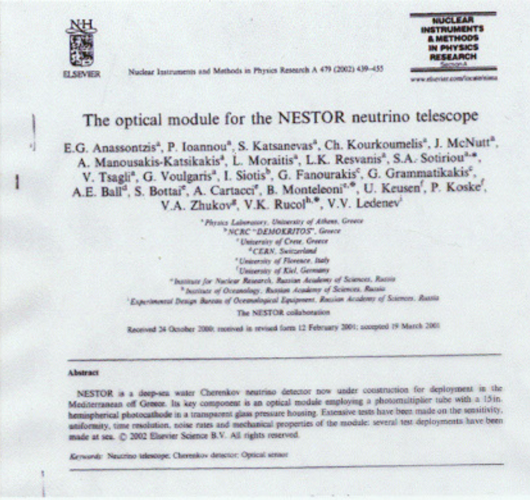
An Optical Module (i.e. a 15" PMT with a HV power supply, inside the protective glass housing)

DEPLOYMENT/ Tower Recovery Schematic





The Detector



Nuclear Instruments and Methods in Physics Research A 479 (2002) 439–455

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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The optical module for the NESTOR neutrino telescope

E.G. Anassontzis[a], P. Ioannou[a], S. Katsanevas[a], Ch. Kourkoumelis[a], J. McNutt[a], A. Manousakis-Katsikakis[a], L. Moraitis[a], L.K. Resvanis[a], S.A. Sotiriou[a,*], V. Tsagli[a], G. Voulgaris[a], I. Siotis[b], G. Fanourakis[c], G. Grammatikakis[c], A.E. Ball[d], S. Bottai[e], A. Cartacci[e], B. Monteleoni[e,*], U. Keusen[f], P. Koske[f], V.A. Zhukov[g], V.K. Rucol[h,*], V.V. Ledenev[i]

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[b] NCRC "DEMOKRITOS", Greece
[c] University of Crete, Greece
[d] CERN, Switzerland
[e] University of Florence, Italy
[f] University of Kiel, Germany
[g] Institute for Nuclear Research, Russian Academy of Sciences, Russia
[h] Institute of Oceanology, Russian Academy of Sciences, Russia
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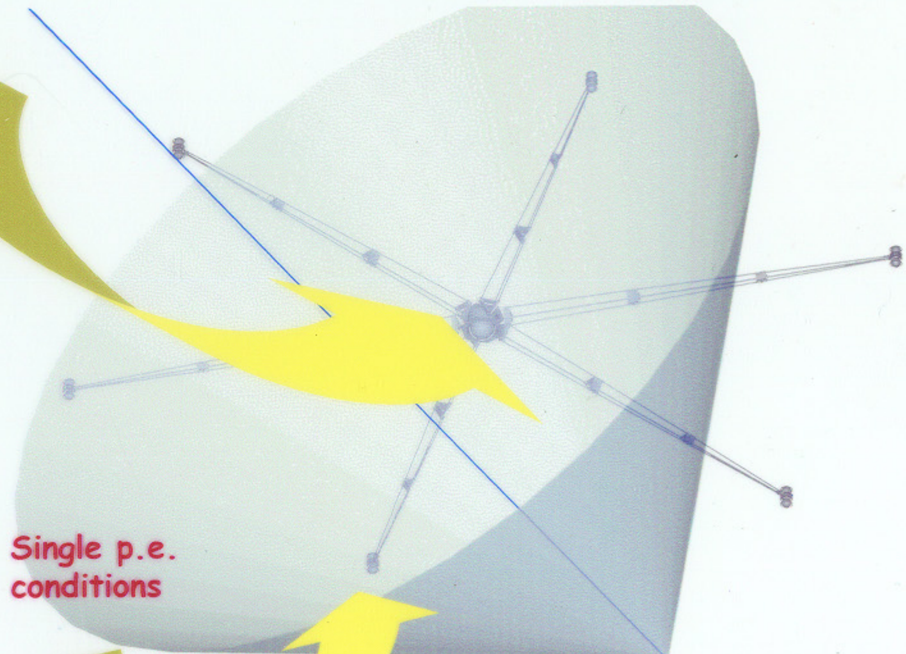
The NESTOR collaboration

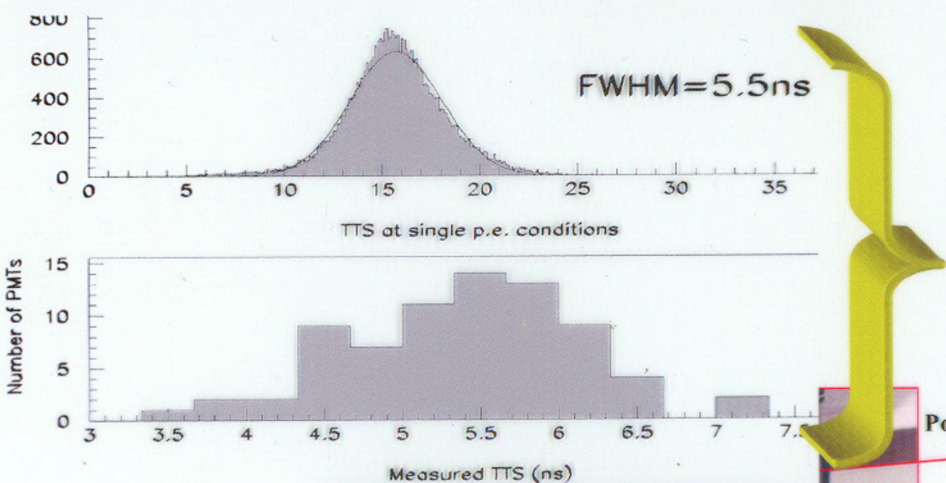
Received 24 October 2000; received in revised form 12 February 2001; accepted 19 March 2001

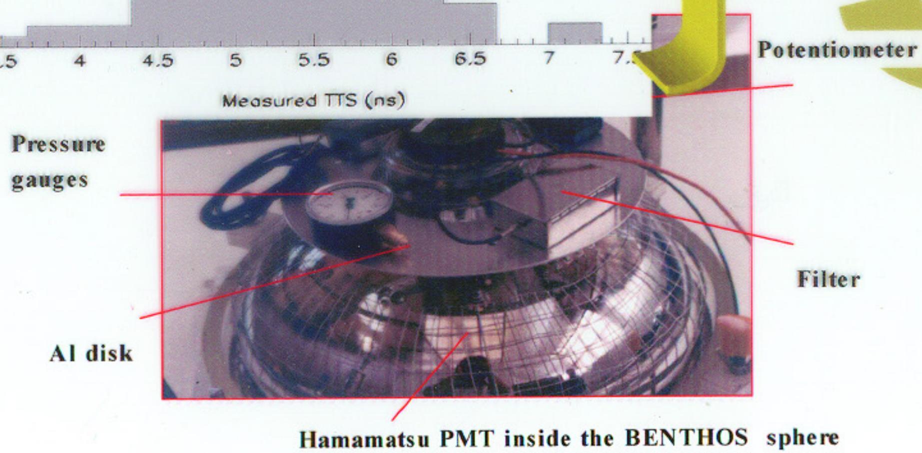
Abstract

NESTOR is a deep-sea water Cherenkov neutrino detector now under construction for deployment in the Mediterranean off Greece. Its key component is an optical module employing a photomultiplier tube with a 15 in. hemispherical photocathode in a transparent glass pressure housing. Extensive tests have been made on the sensitivity, uniformity, time resolution, noise rates and mechanical properties of the module; several test deployments have been made at sea.

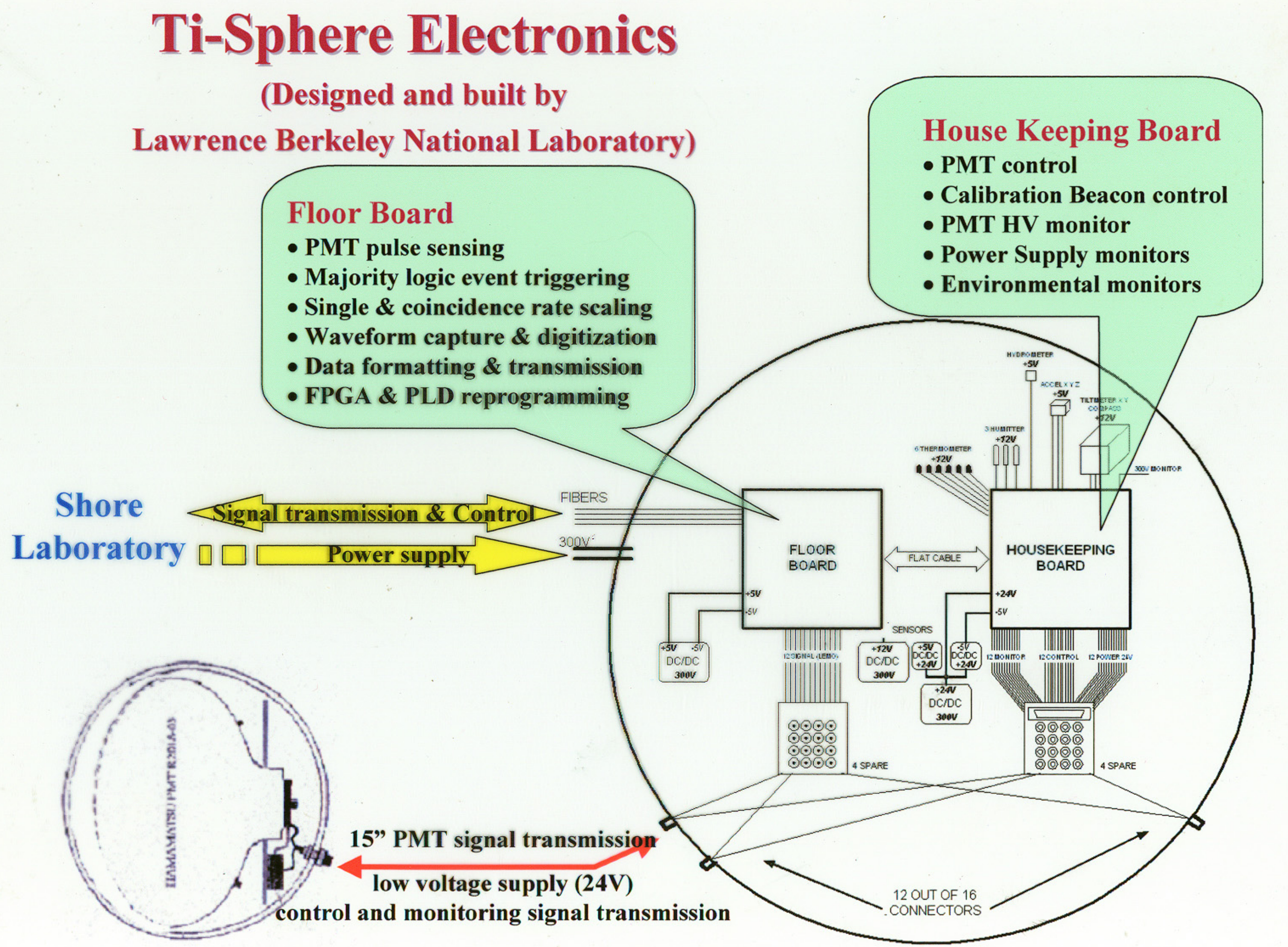
Keywords: Neutrino telescope; Cherenkov detector; Optical sensor







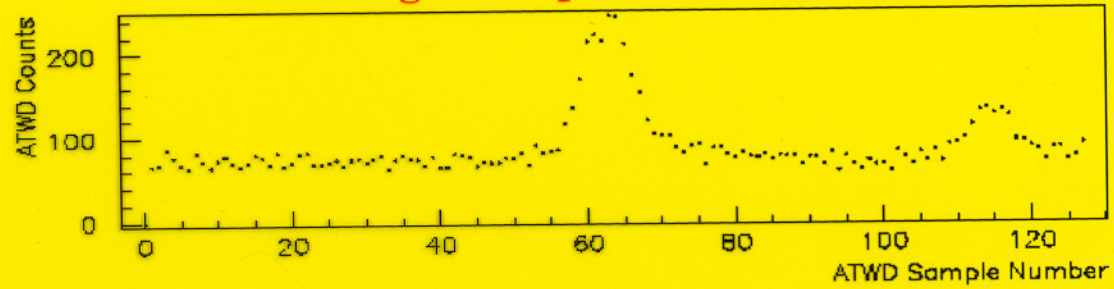
- Hamamatsu PMT R2018-03 (15")
- Benthos spheres
- μ-metal cage
- power supply


Ti-Sphere Electronics
(Designed and built by
Lawrence Berkeley National Laboratory)
Floor Board
• PMT pulse sensing
• Majority logic event triggering
• Single & coincidence rate scaling
• Waveform capture & digitization
• Data formatting & transmission
• FPGA & PLD reprogramming
House Keeping Board
• PMT control
• Calibration Beacon control
• PMT HV monitor
• Power Supply monitors
• Environmental monitors
Shore Laboratory
Signal transmission & Control
Power supply
FIBERS
300V
FLOOR BOARD
FLAT CABLE
HOUSEKEEPING BOARD
HYDROMETER +5V
ACCEL X Y Z +5V
+12V
6 THERMOMETER +12V
+12V
300V MONITOR
+5V
-5V
+24V
-5V
SENSORS
+5V -5V DC/DC 300V
+12V DC/DC 300V
+5V DC/DC +24V
-5V DC/DC +24V
+24V DC/DC 300V
12 SIGNAL (LEMO)
12 MONITOR
12 CONTROL
12 POWER 24V
4 SPARE
4 SPARE
12 OUT OF 16 CONNECTORS
15" PMT signal transmission
low voltage supply (24V)
control and monitoring signal transmission

Floor Board

- PMT pulse sensing
- Majority logic event triggering
- Single & coincidence rate scaling
- Waveform capture & digitization
- Data formatting & transmission
- FPGA & PLD reprogramming

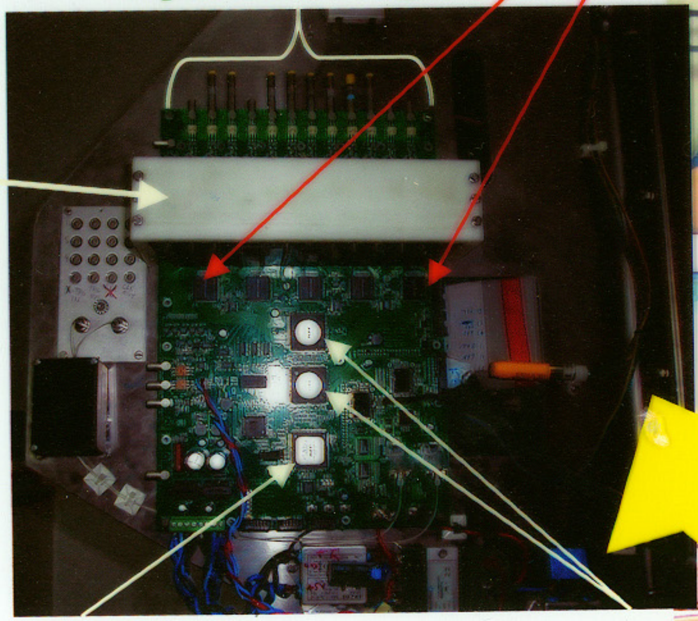
PMT Signal Capture & Digitization



5 ATWDs

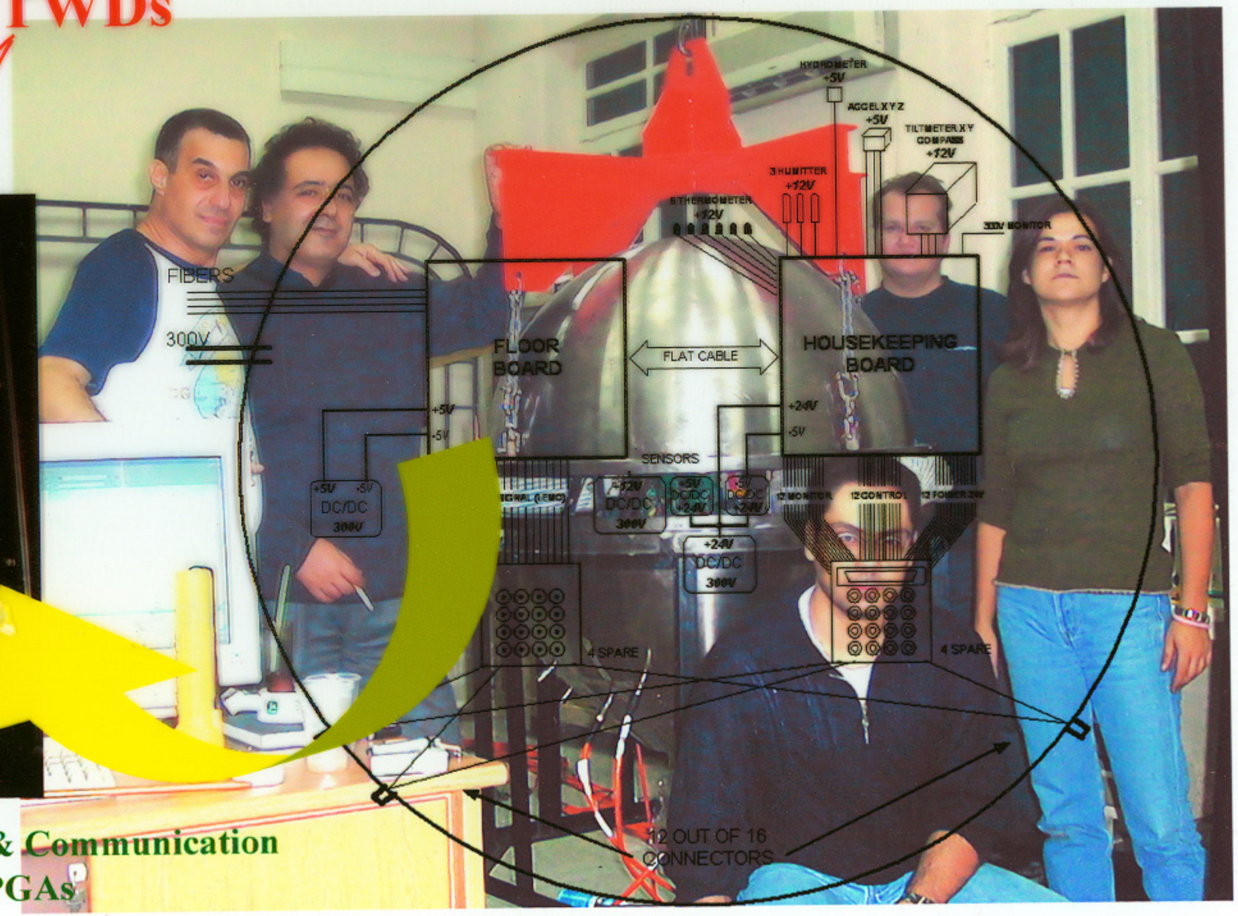
Input: 12 PMT signals

Delay lines

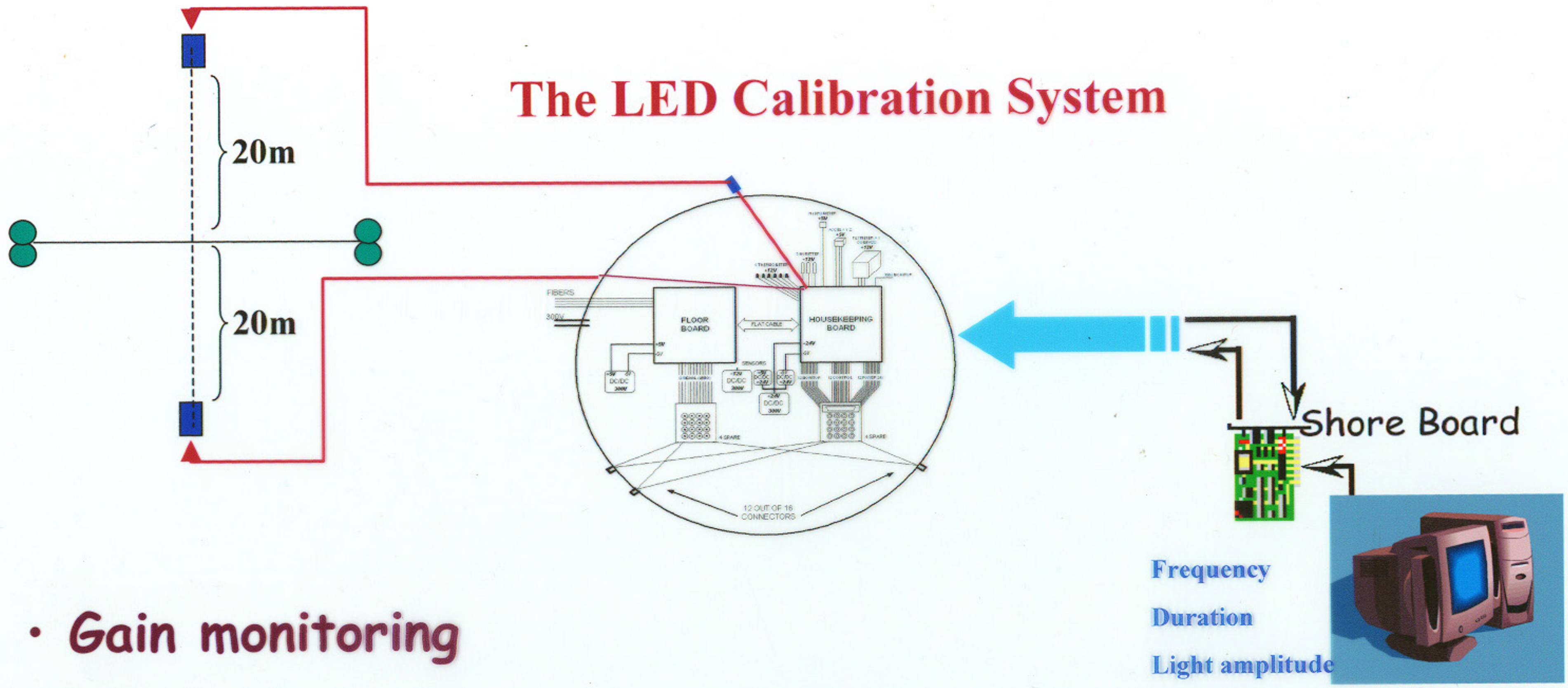


Configuration parameters
PLD

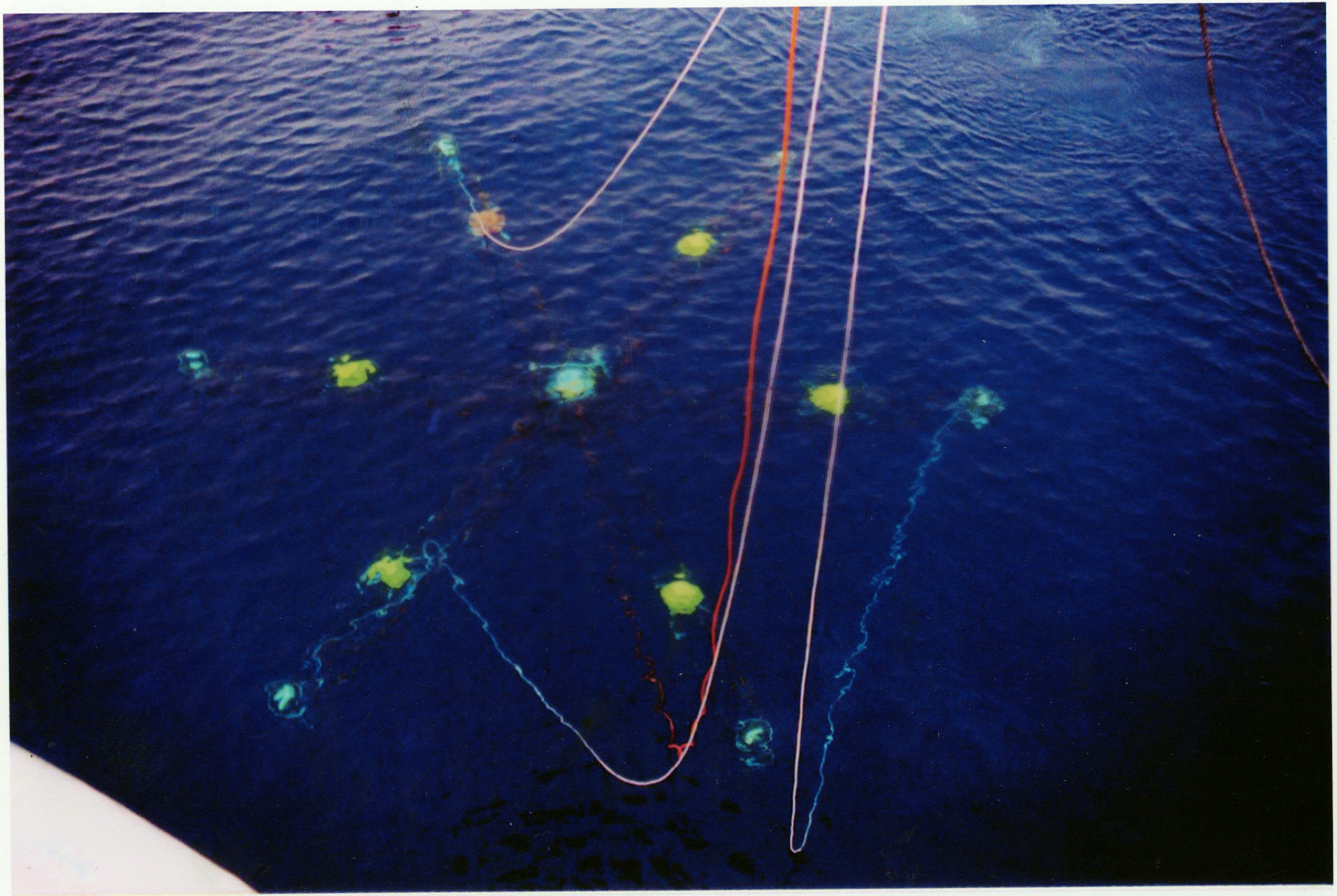
Trigger Logic & Communication
FPGAs



The LED Calibration System



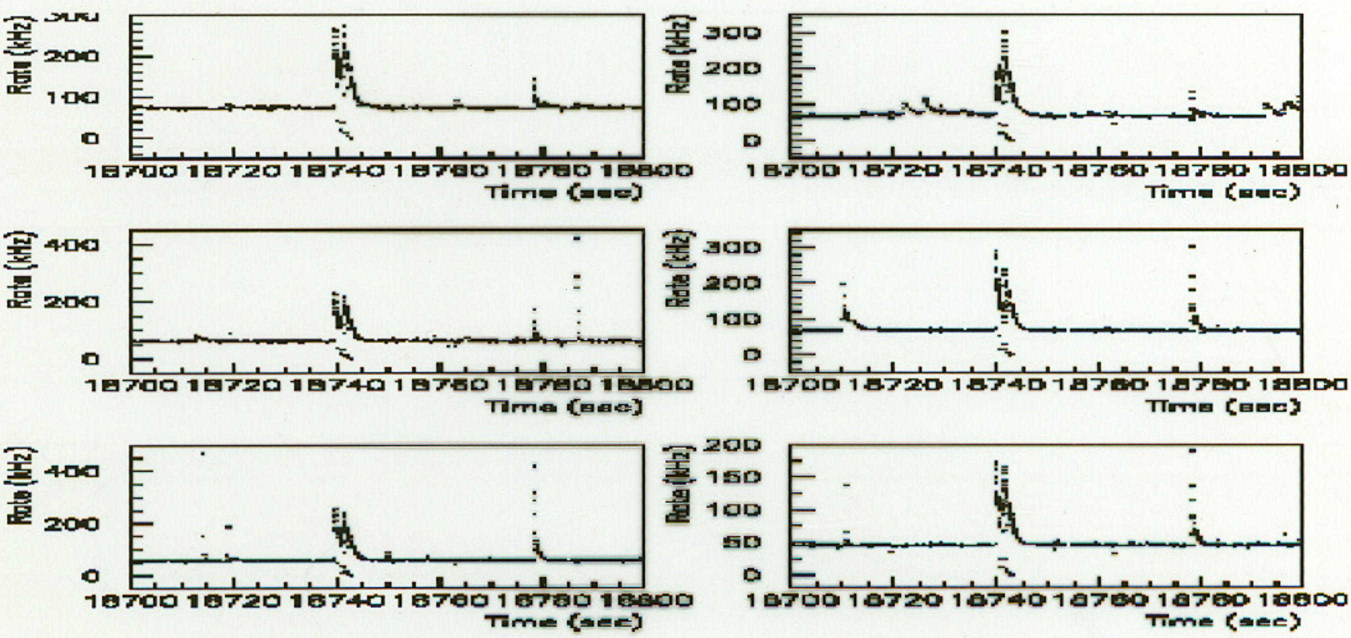
- Gain monitoring
- Timing
- Free running Calibration Trigger
- Adjustable Trigger frequency
- Adjustable LED's light output



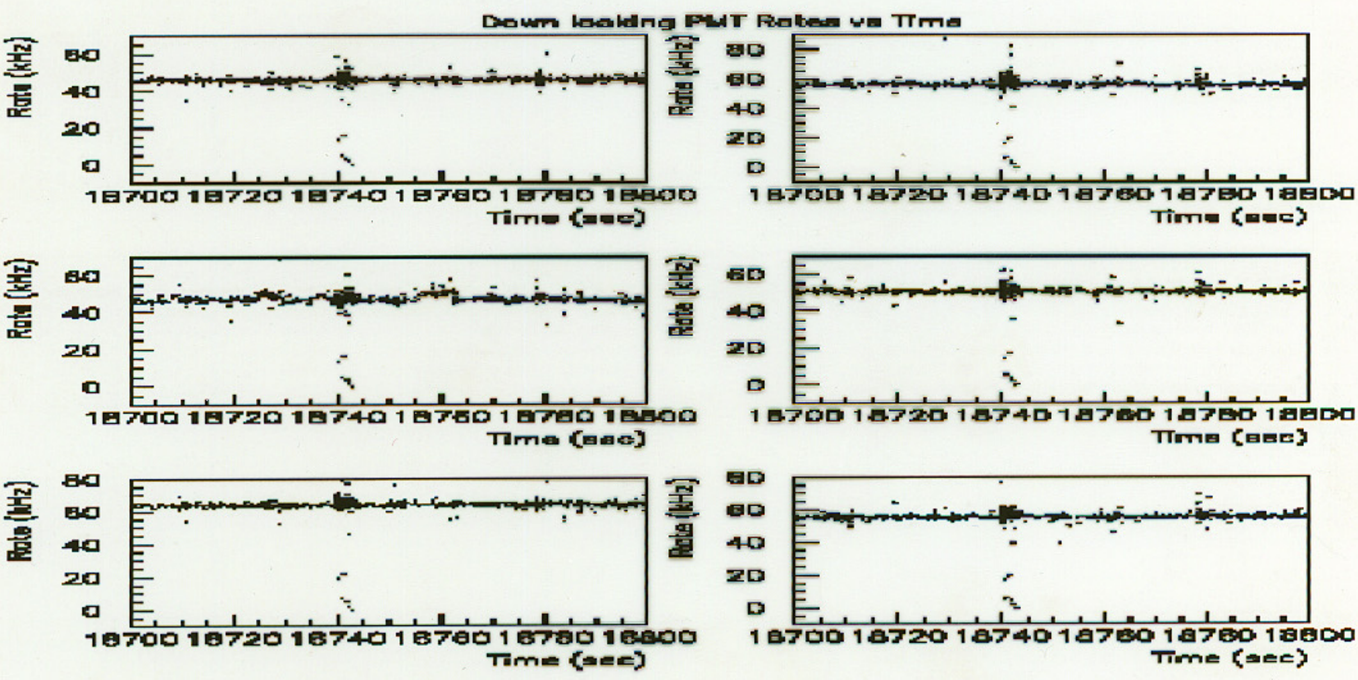
Bioluminescence Data from a depth of 4000 m

PMT Rates vs Time

Up-Looking PMTs

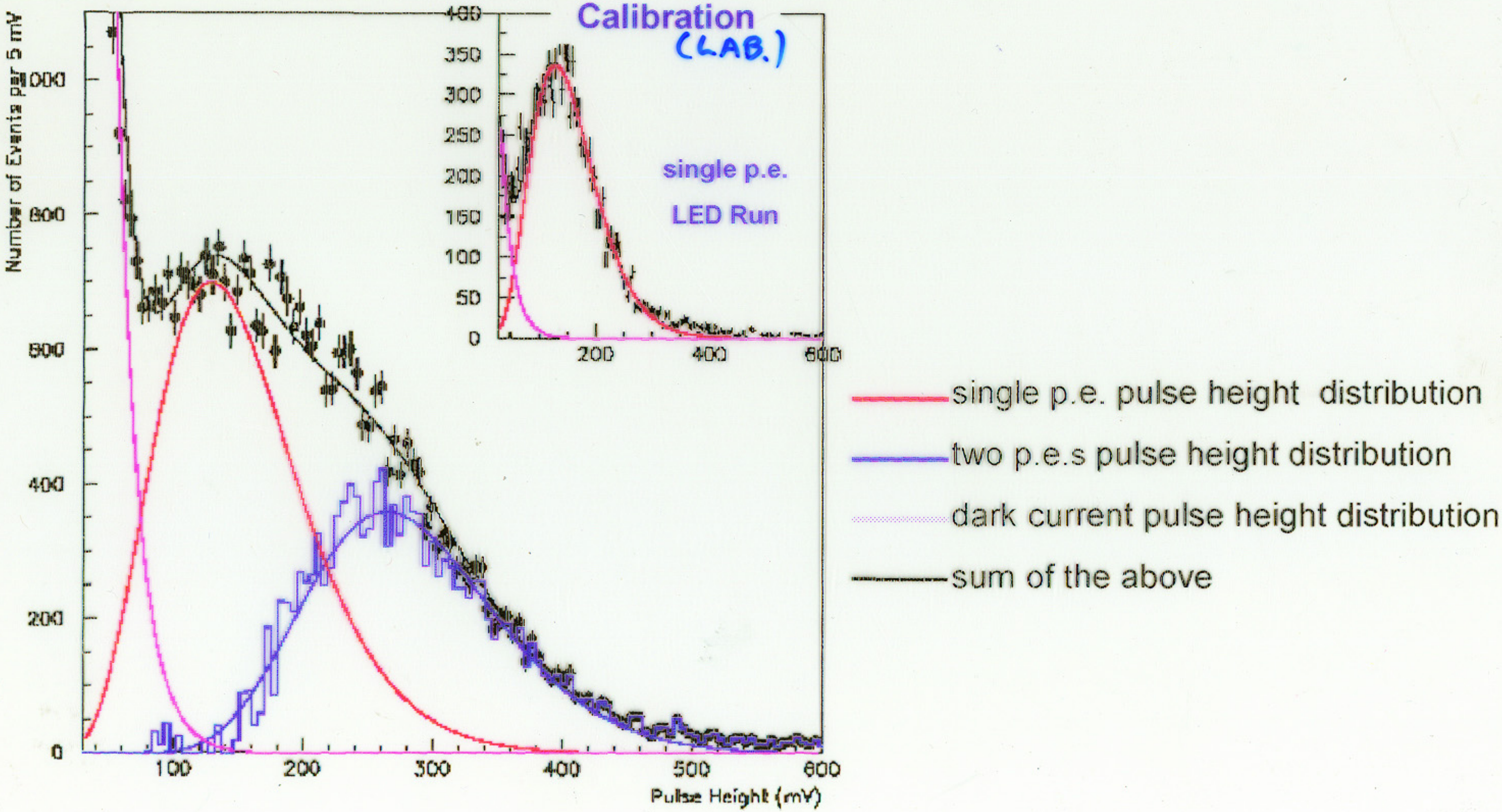


Down-Looking PMTs



Data from a depth of 4000 m

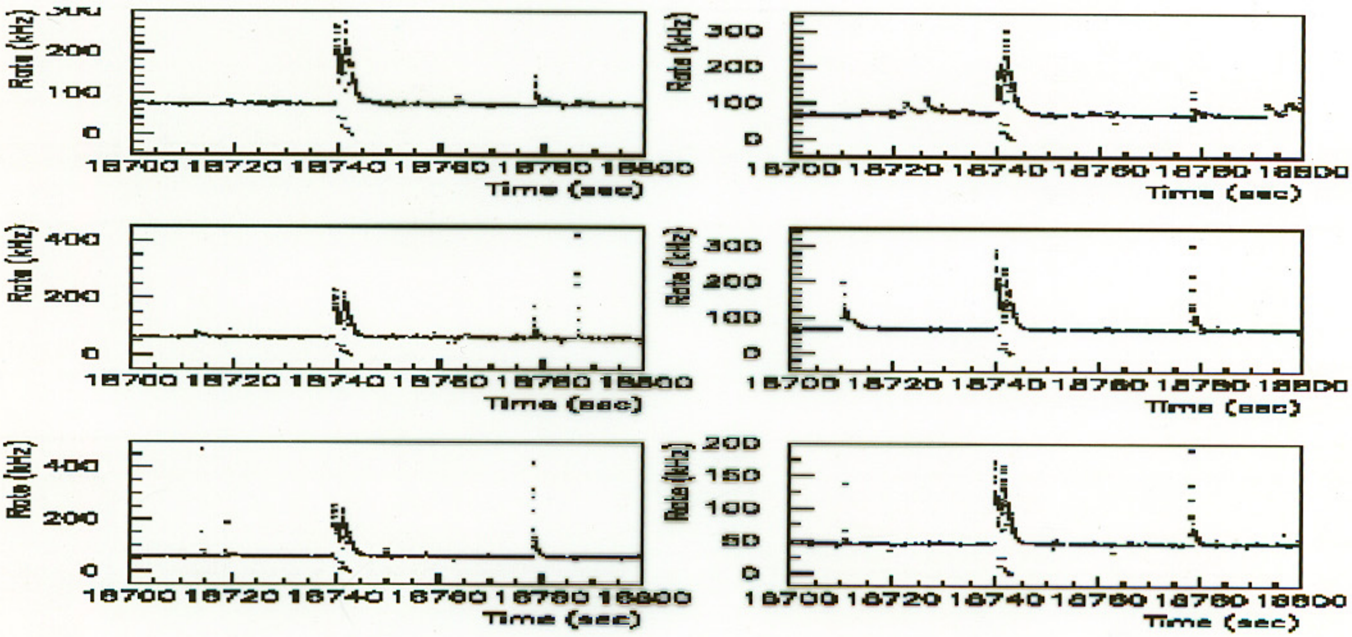
PMT Pulse Height Distribution



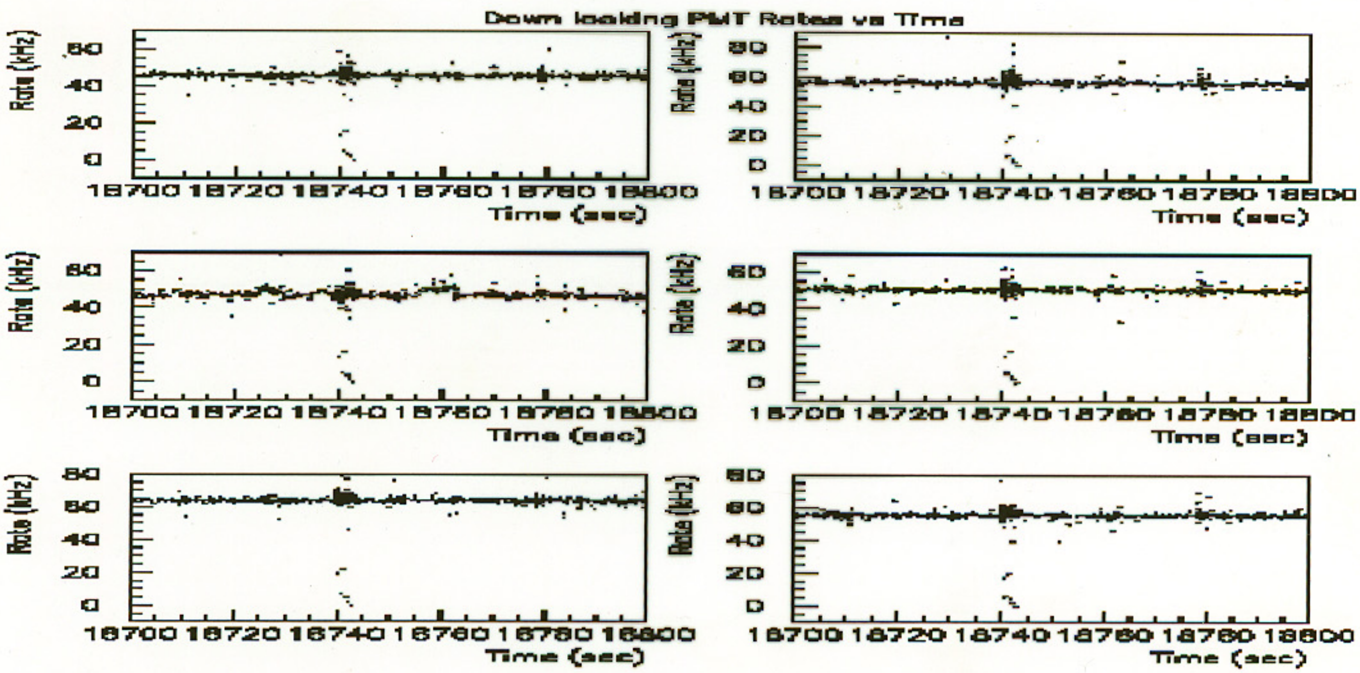
Bioluminescence Data from a depth of 4000 m

PMT Rates vs Time

Up-Looking PMTs



Down-Looking PMTs



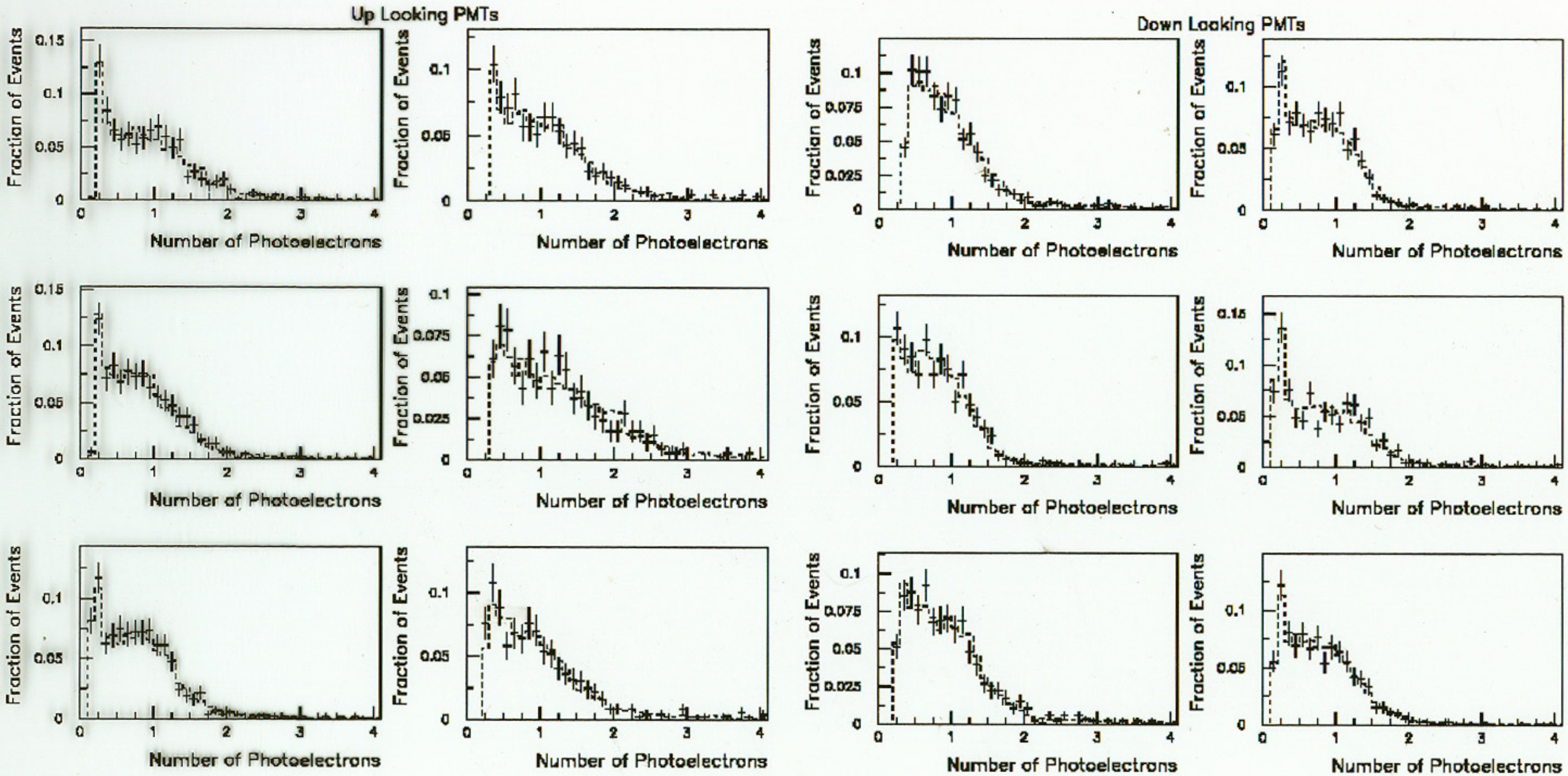
Data from a depth of 4000 m

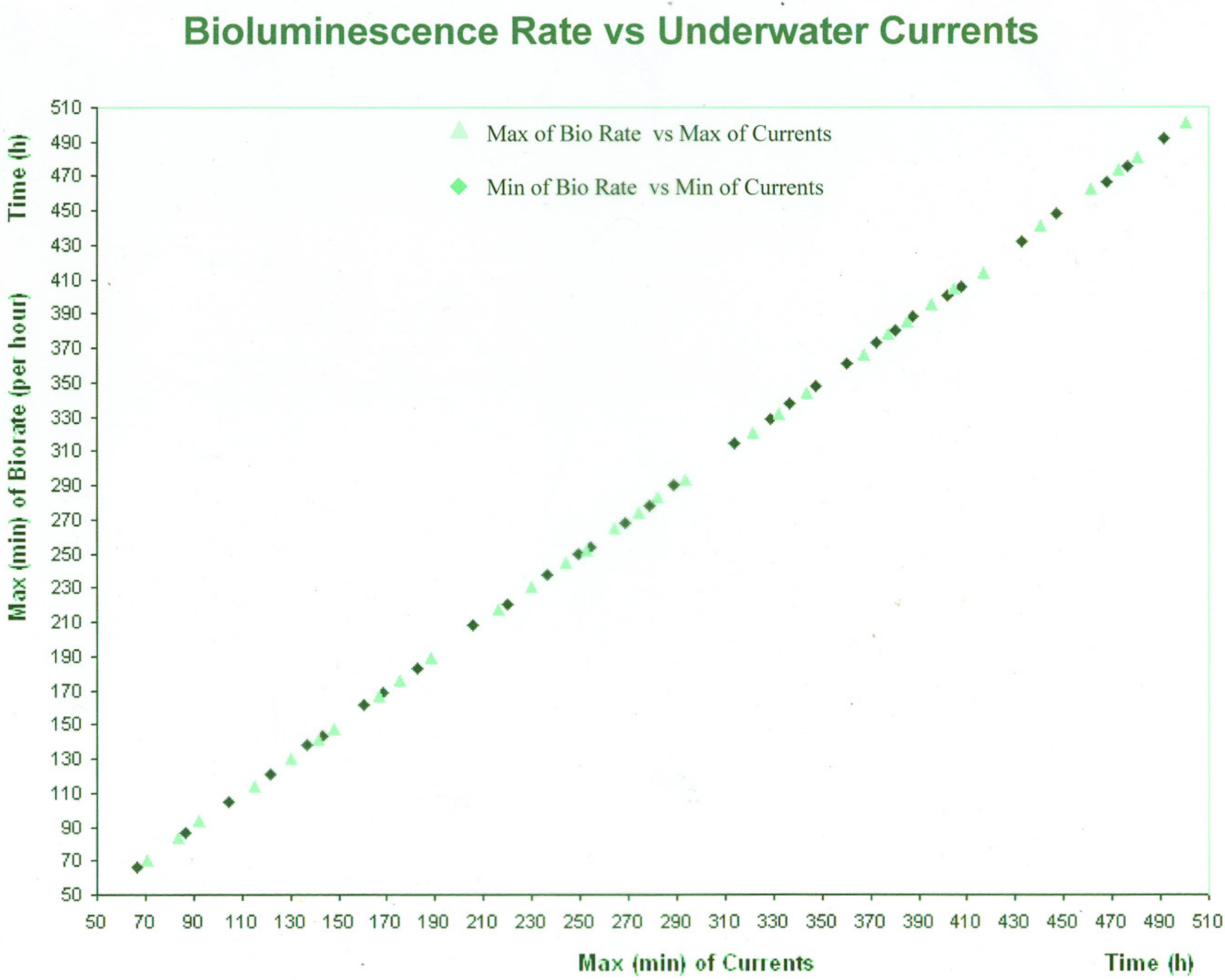
Number of Collected P.E.s

Trigger: 4fold Coincidence

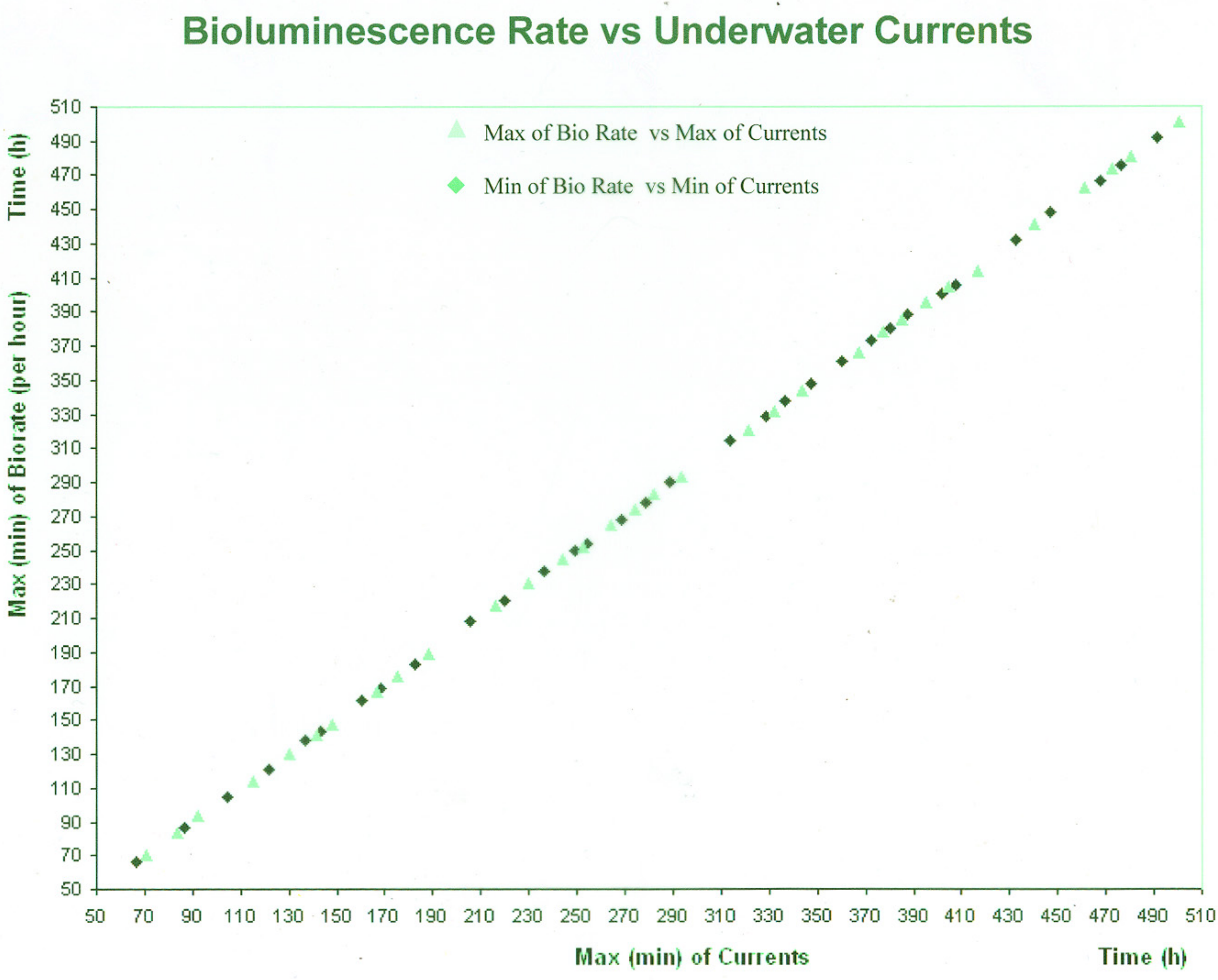
┼ During Bioluminescence Activity

— Bioluminescence Activity Excluded





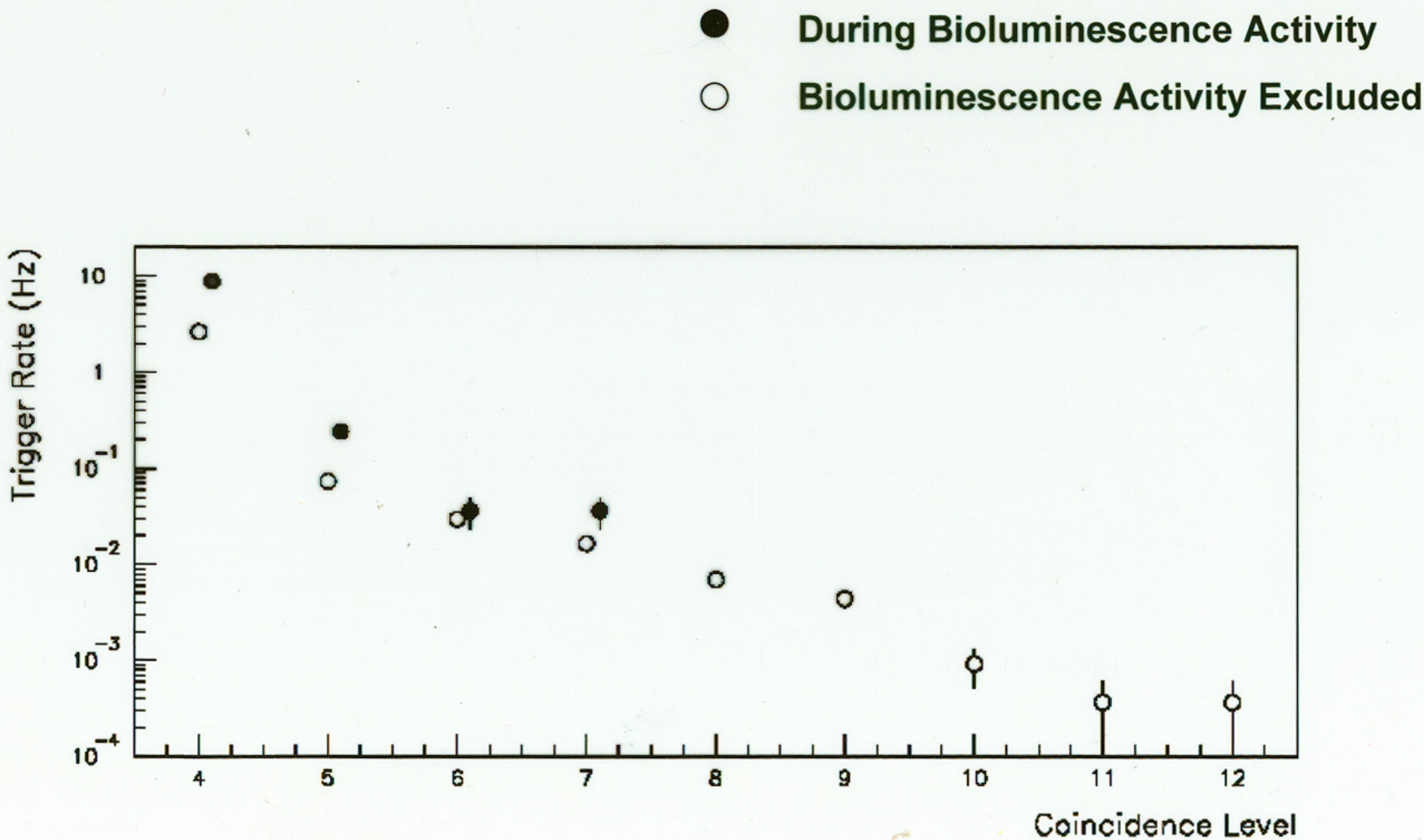
Bioluminescence Rate vs Underwater Currents
Max of Bio Rate vs Max of Currents
Min of Bio Rate vs Min of Currents
Max (min) of Biorate (per hour)
Time (h)
Max (min) of Currents
Time (h)
510
490
470
450
430
410
390
370
350
330
310
290
270
250
230
210
190
170
150
130
110
90
70
50
50 70 90 110 130 150 170 190 210 230 250 270 290 310 330 350 370 390 410 430 450 470 490 510



Bioluminescence Rate vs Underwater Currents
Max of Bio Rate vs Max of Currents
Min of Bio Rate vs Min of Currents
Time (h)
Max (min) of Biorate (per hour)
Max (min) of Currents
Time (h)
510
490
470
450
430
410
390
370
350
330
310
290
270
250
230
210
190
170
150
130
110
90
70
50
50 70 90 110 130 150 170 190 210 230 250 270 290 310 330 350 370 390 410 430 450 470 490 510

Data from a depth of 4000 m

Trigger Rates



Data from a depth of 4000 m

Bioluminescence Contribution to the Total Trigger Rates

Bioluminescence Occurs for the 1.1% ± 0.1% of the Active Experimental Time

COMPARE THIS TO 40% ELSEWHERE

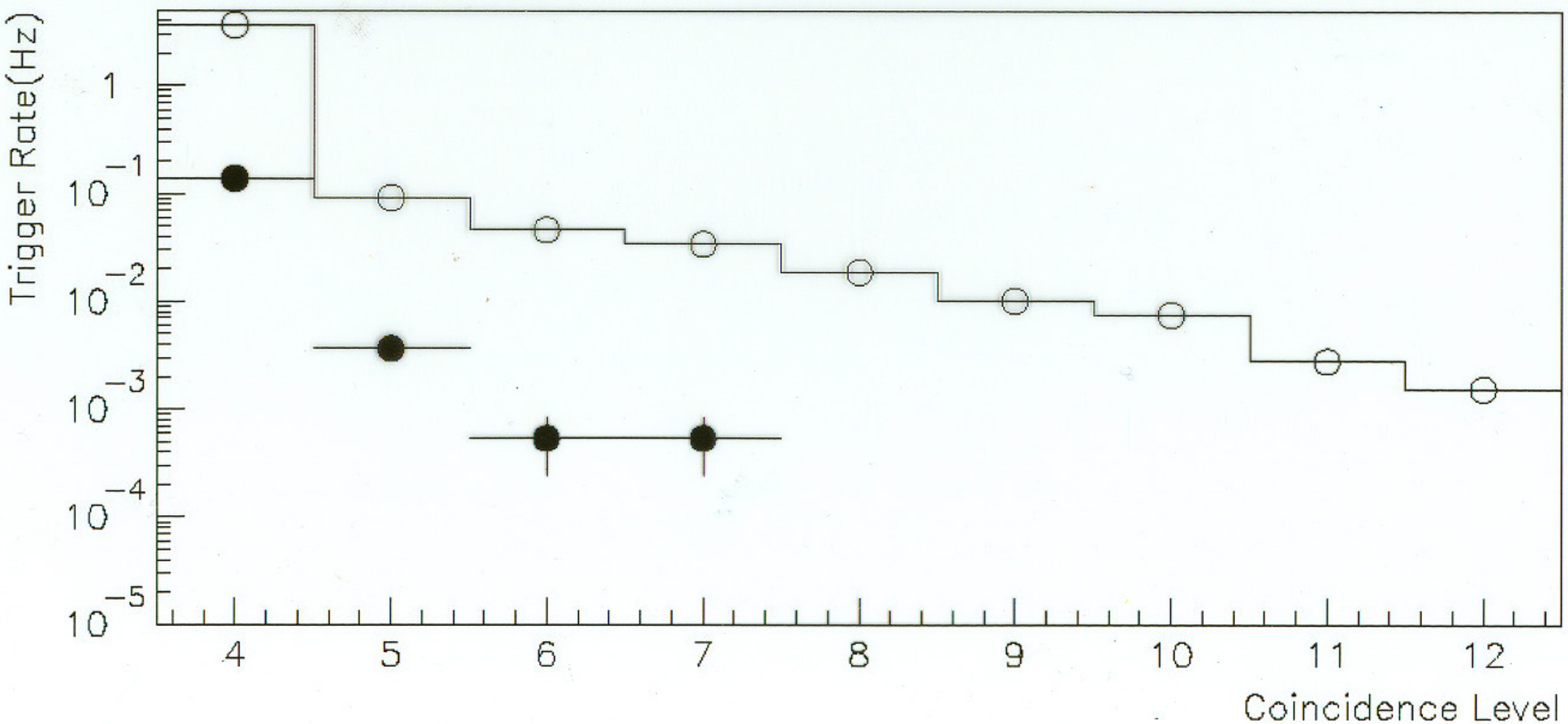
IN GOOD AGREEMENT WITH A LARGE NUMBER OF "FREE DROP" MEASUREMENTS TAKEN OVER THE LAST 6 YEARS

"SEASON INDEPENDENT"

— Total Trigger Rates

● Bioluminescence Contribution to the Total Trigger Rates

○ Experimental Trigger Rates from Periods Without Bioluminescence



Data from a depth of 4000 m

Trigger Studies

~~Preliminary~~

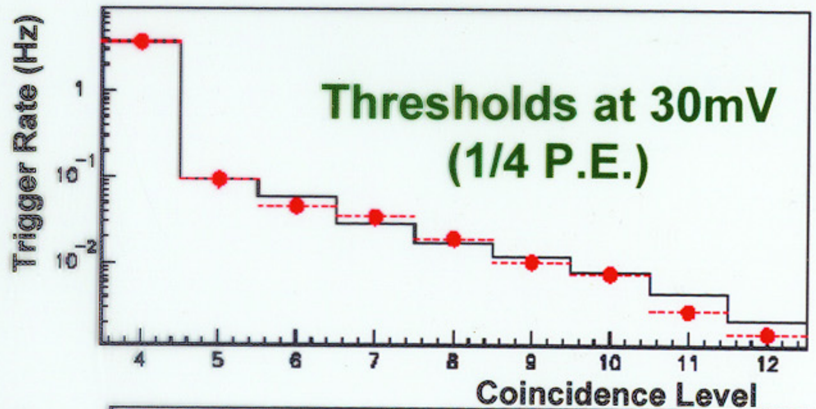
Data Collected with

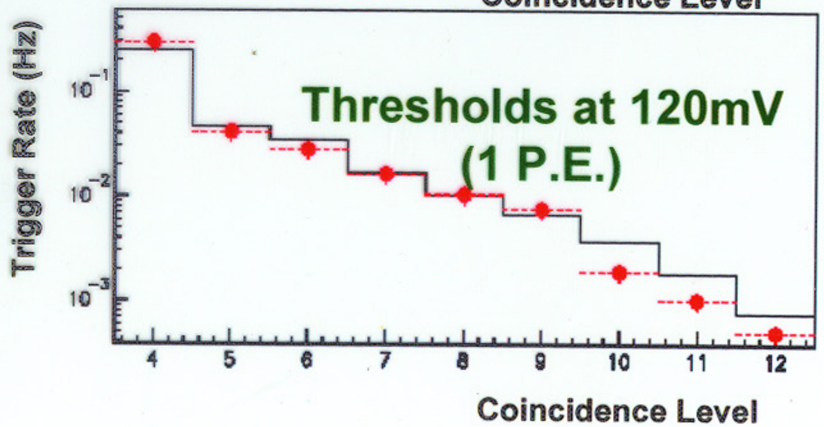
4fold Majority Coincidence Trigger

● Experimental Points

—— M.C. Estimation (Atmospheric muons + K^{40})

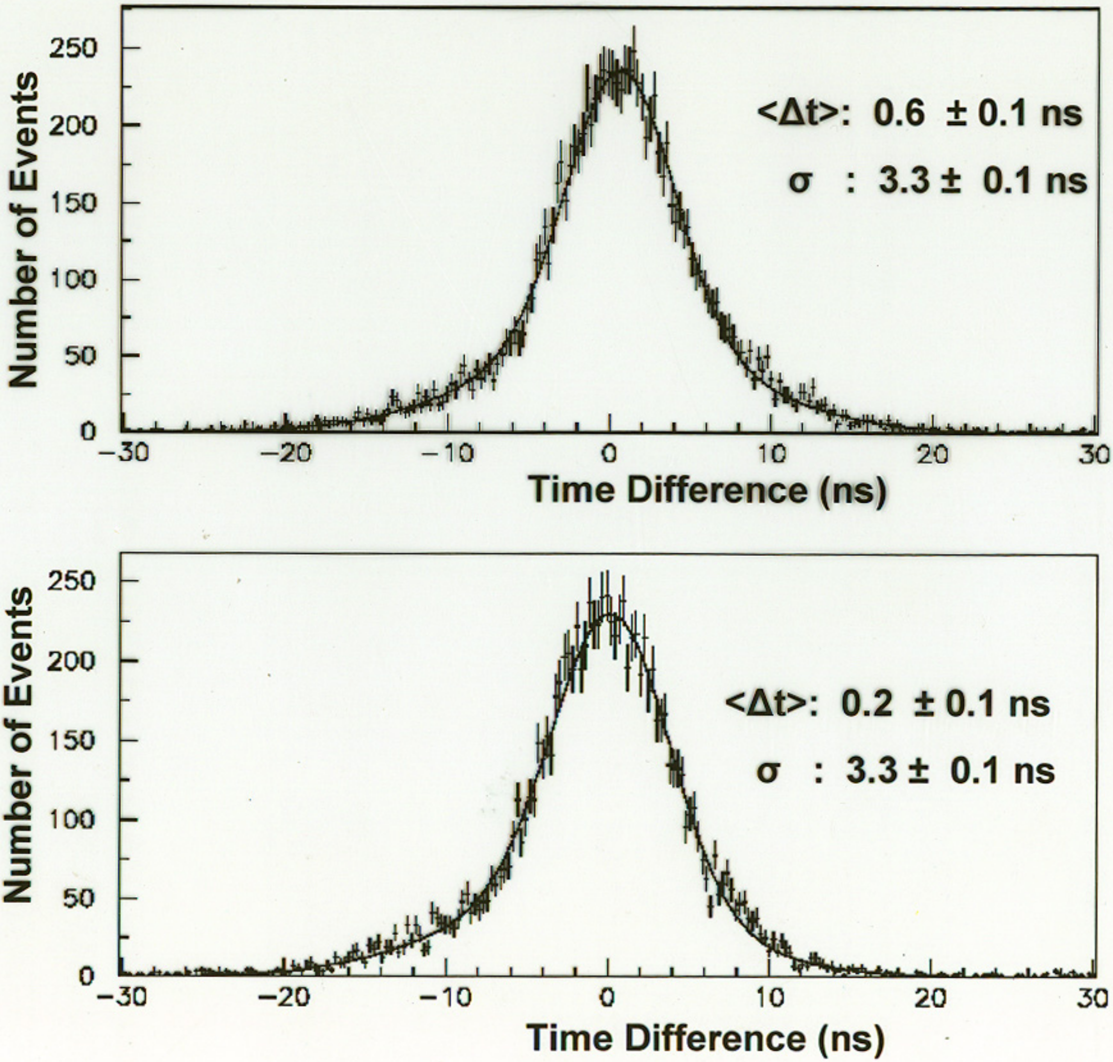
	Thresholds at 30 mV	Thresholds at 120 mV
Measured Total Trigger Rates (greater or equal to 4fold)	3.91 ± 0.08Hz	0.39 ±0.01Hz
M.C. Prediction (atmospheric muons +K^{40})	3.95 ±0.08Hz	0.38 ±0.01Hz
M.C. Prediction (atmospheric muons only)	0.26 ±0.01 Hz	0.23 ± 0.01Hz





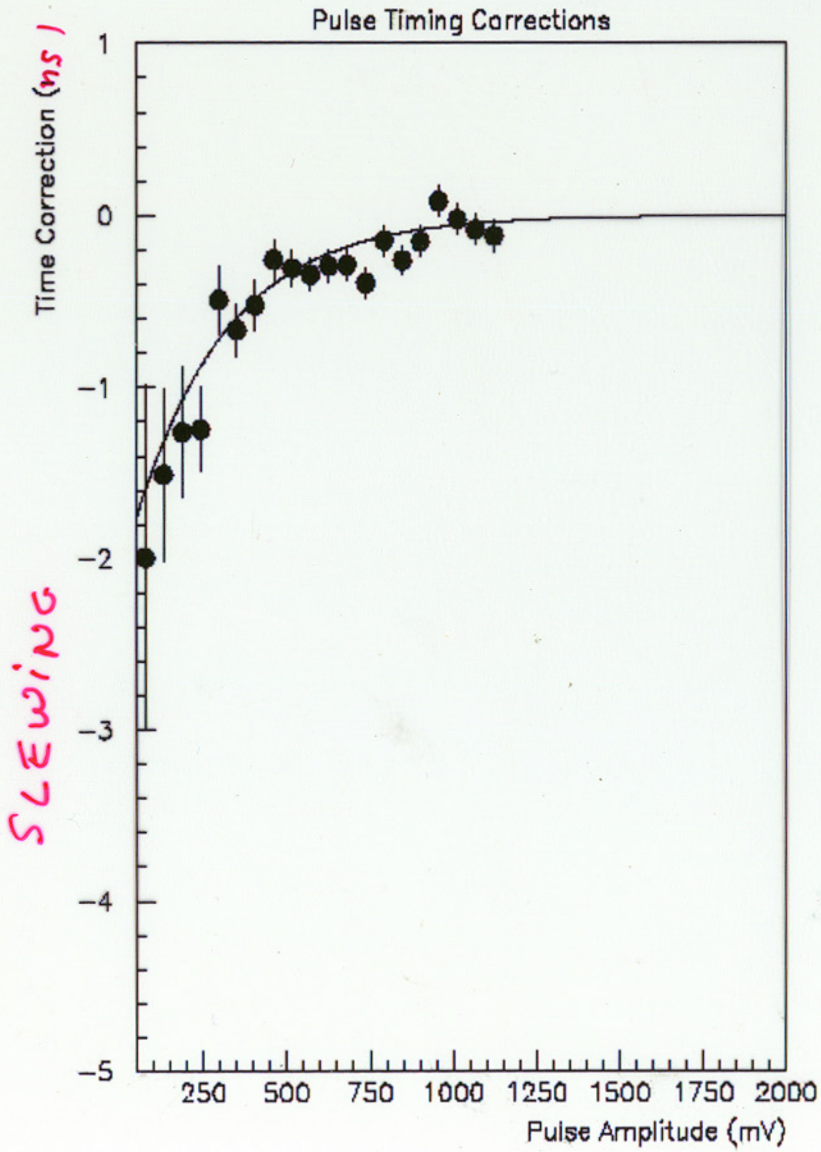
Data from a depth of 4000 m
Calibration Run

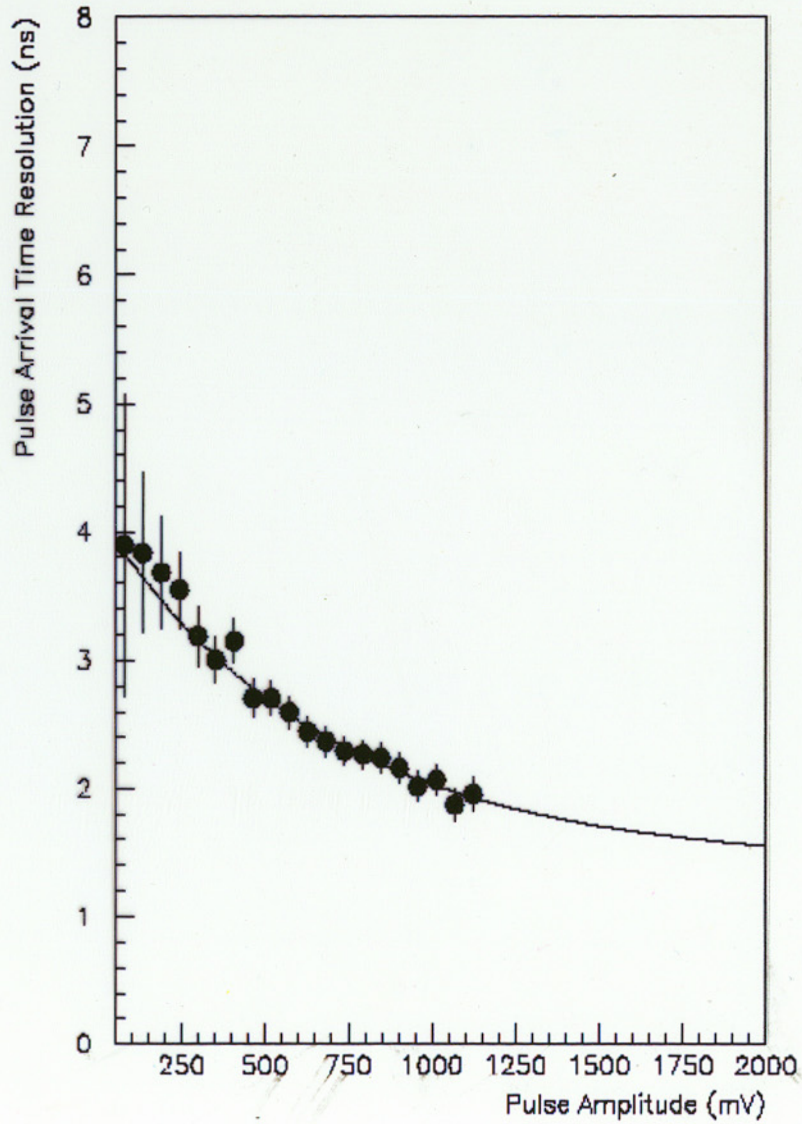
Relative Timing



Data from a depth of 4000 m

Calibration Run



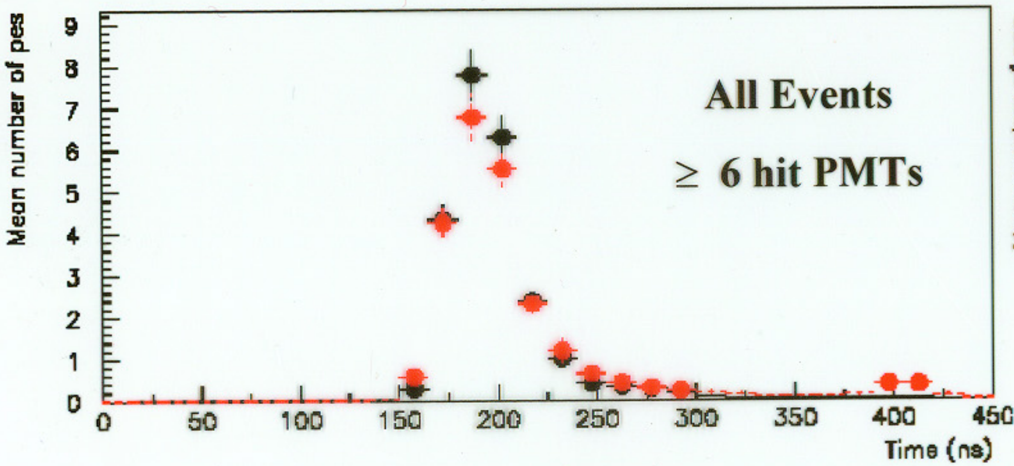


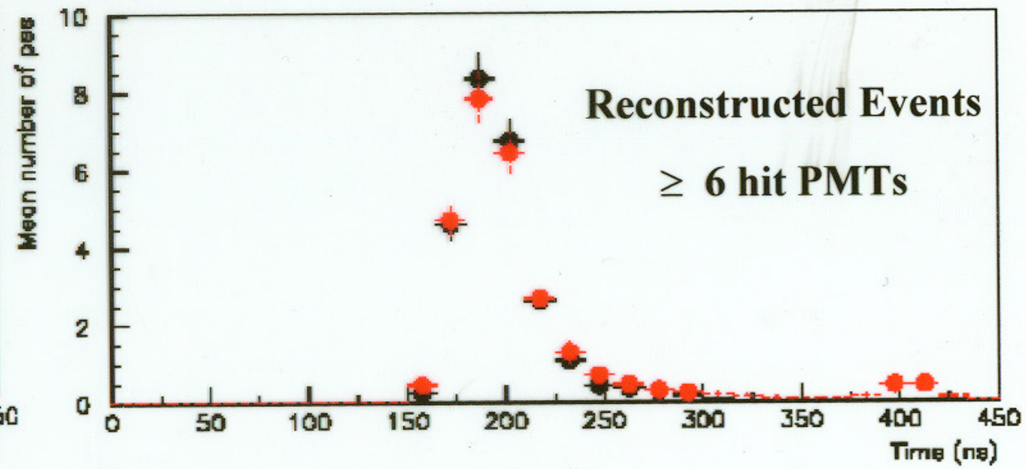
~~Preliminary~~

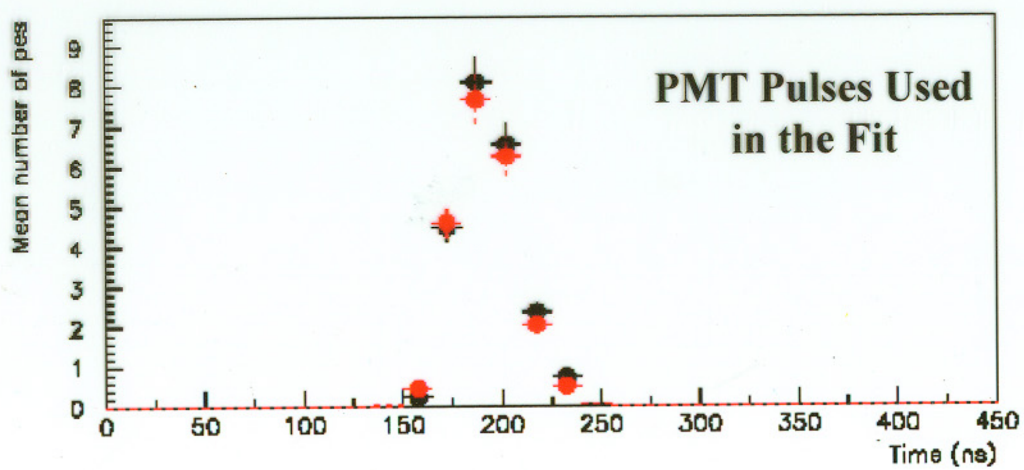
Time Distribution of the Deposited Charge

— M.C. Prediction (atmospheric muons)

● Data Points







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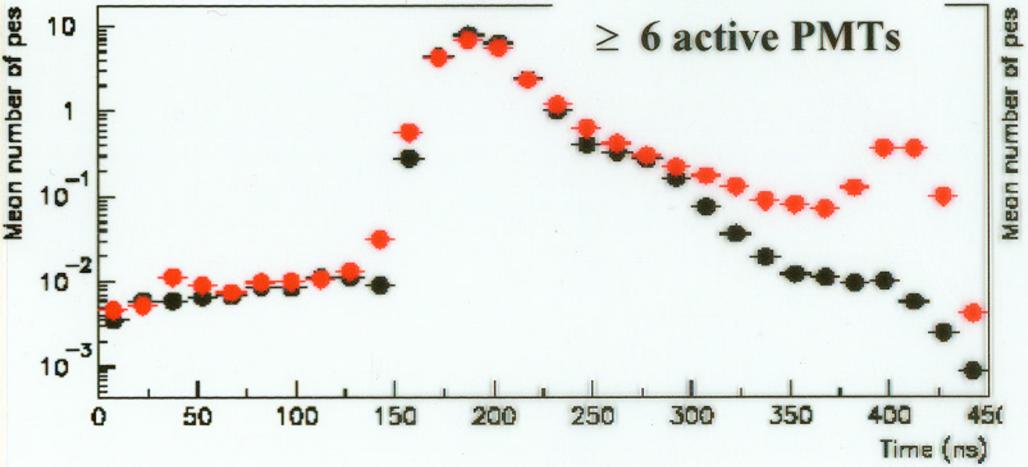
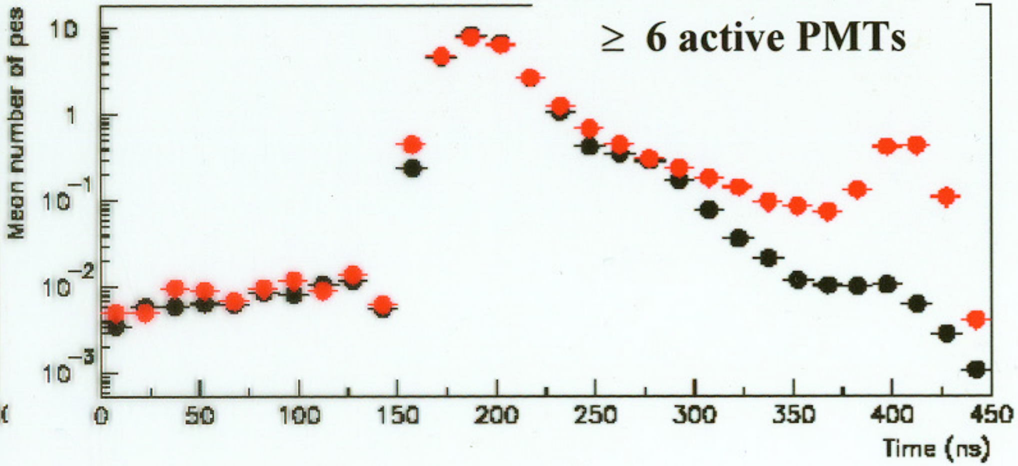
~~Preliminary~~

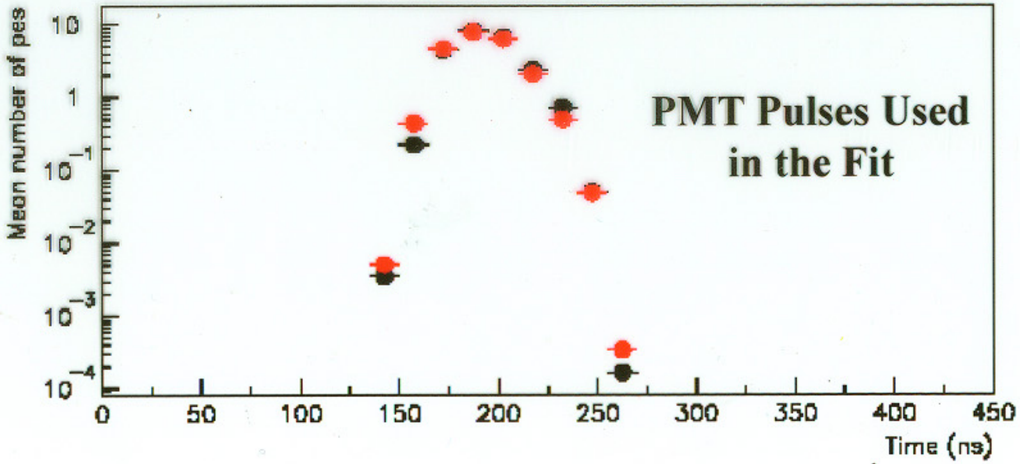
Time Distribution of the Deposited Charge

All Events



Reconstructed Events





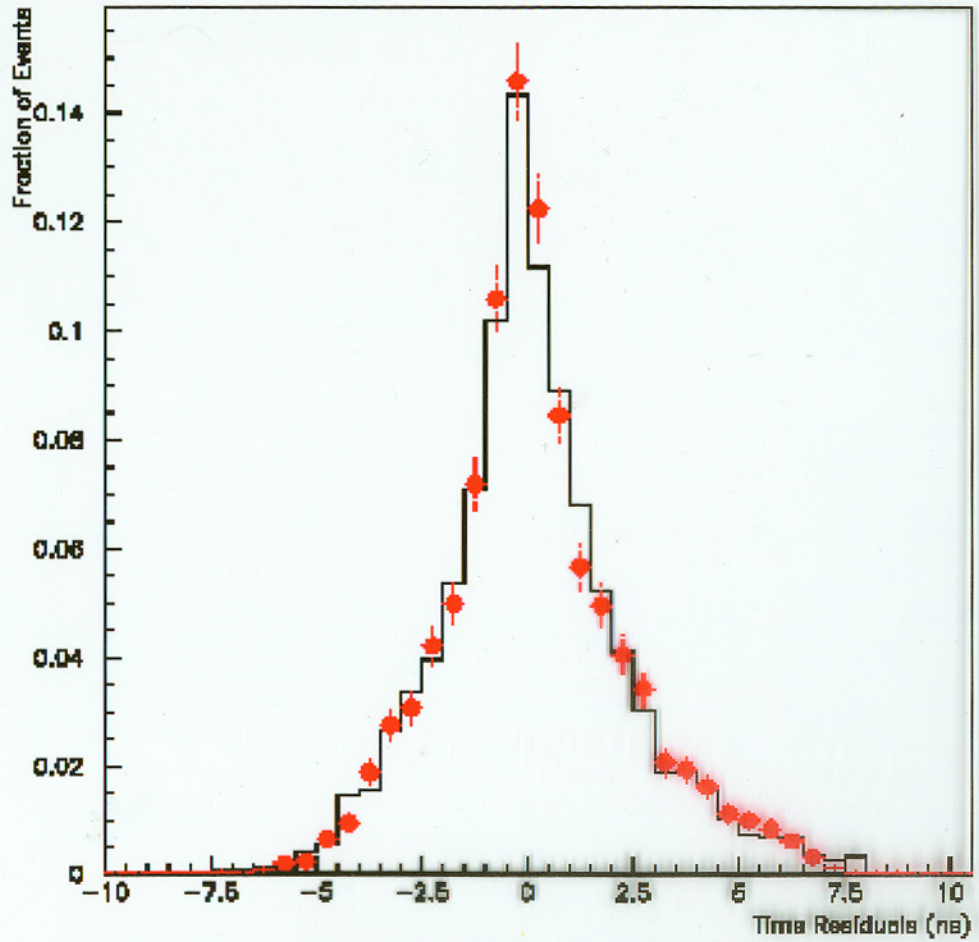
c

~~Preliminary~~

Time Residuals

— M.C. Prediction (atmospheric muons)

● Data Points



$[t_{DATA} - t_{\text{expected from fit}}]$
for each hit

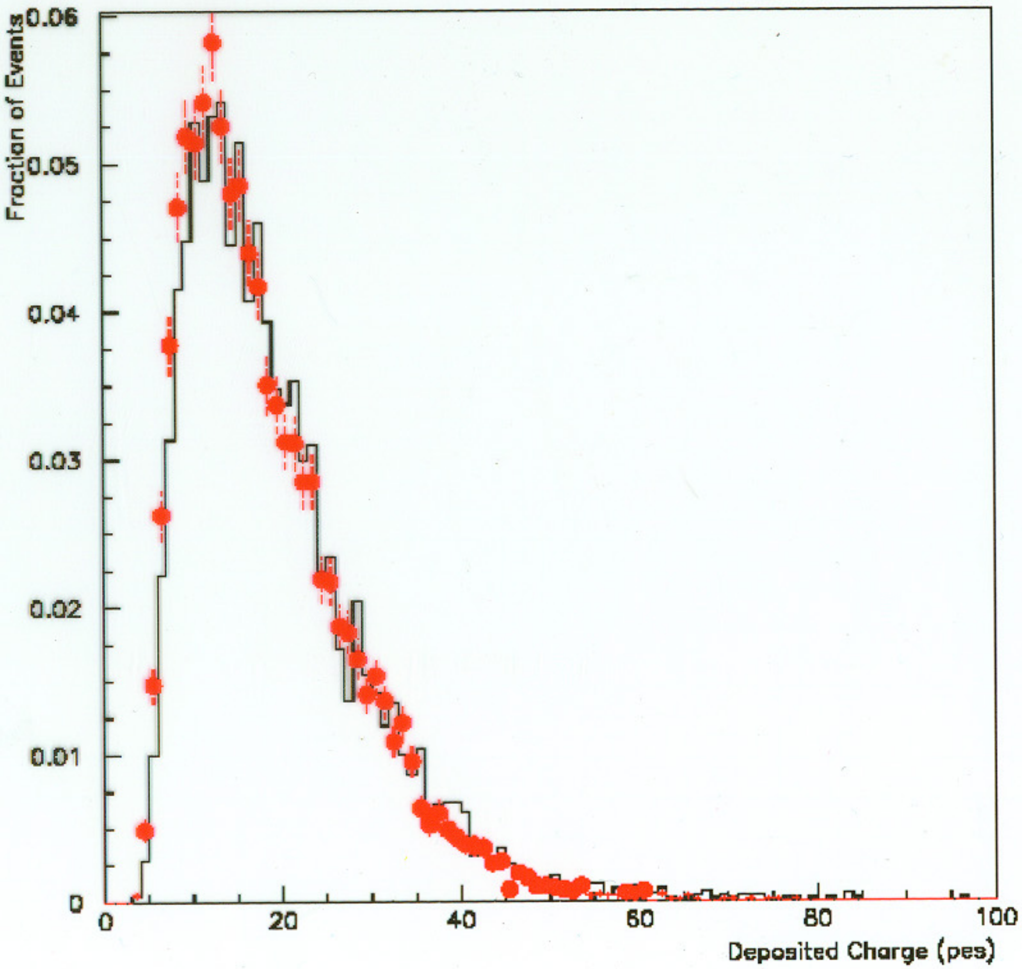
c

~~Preliminary~~

Total number of p.e.s per Track

— M.C. Prediction (atmospheric muons)

● Data Points



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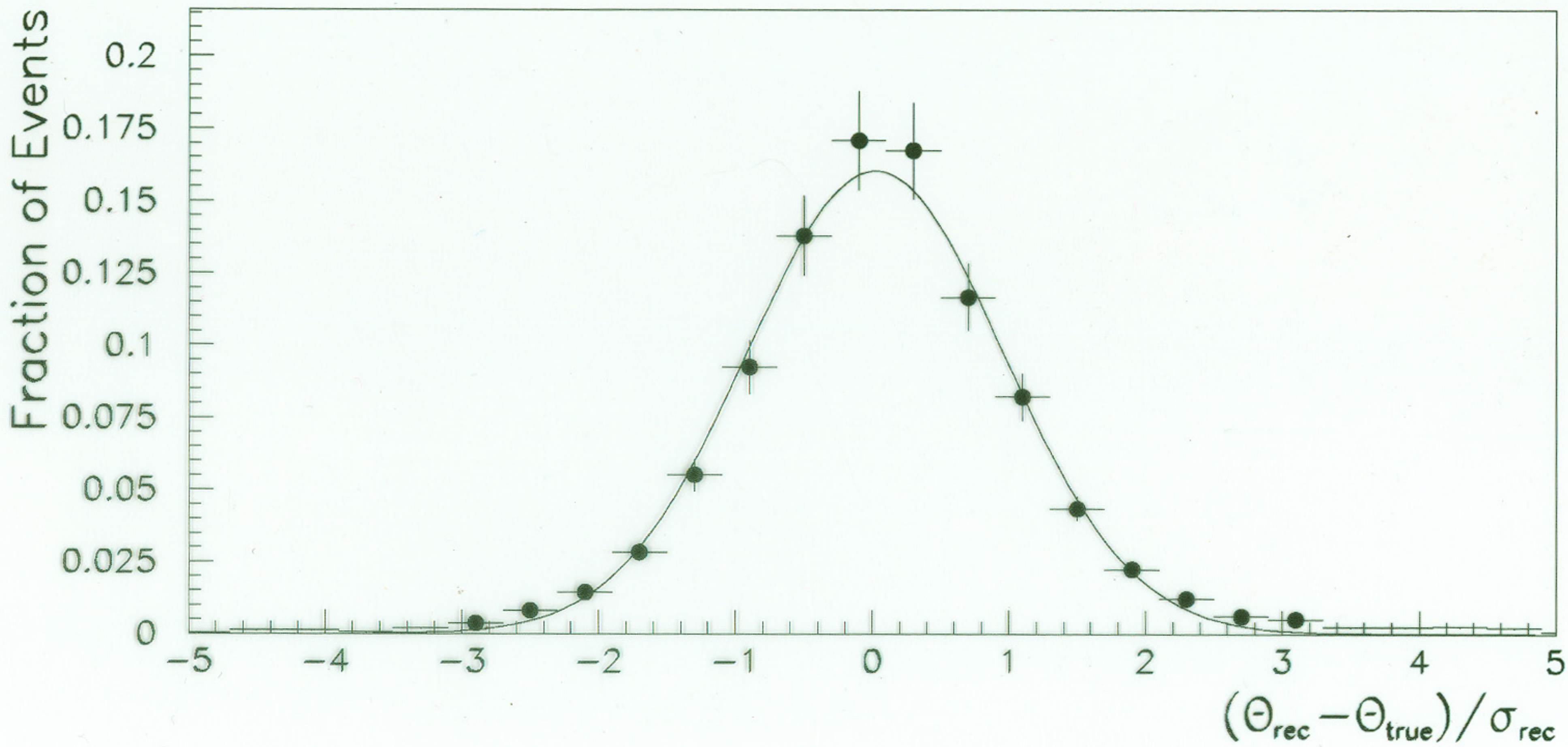
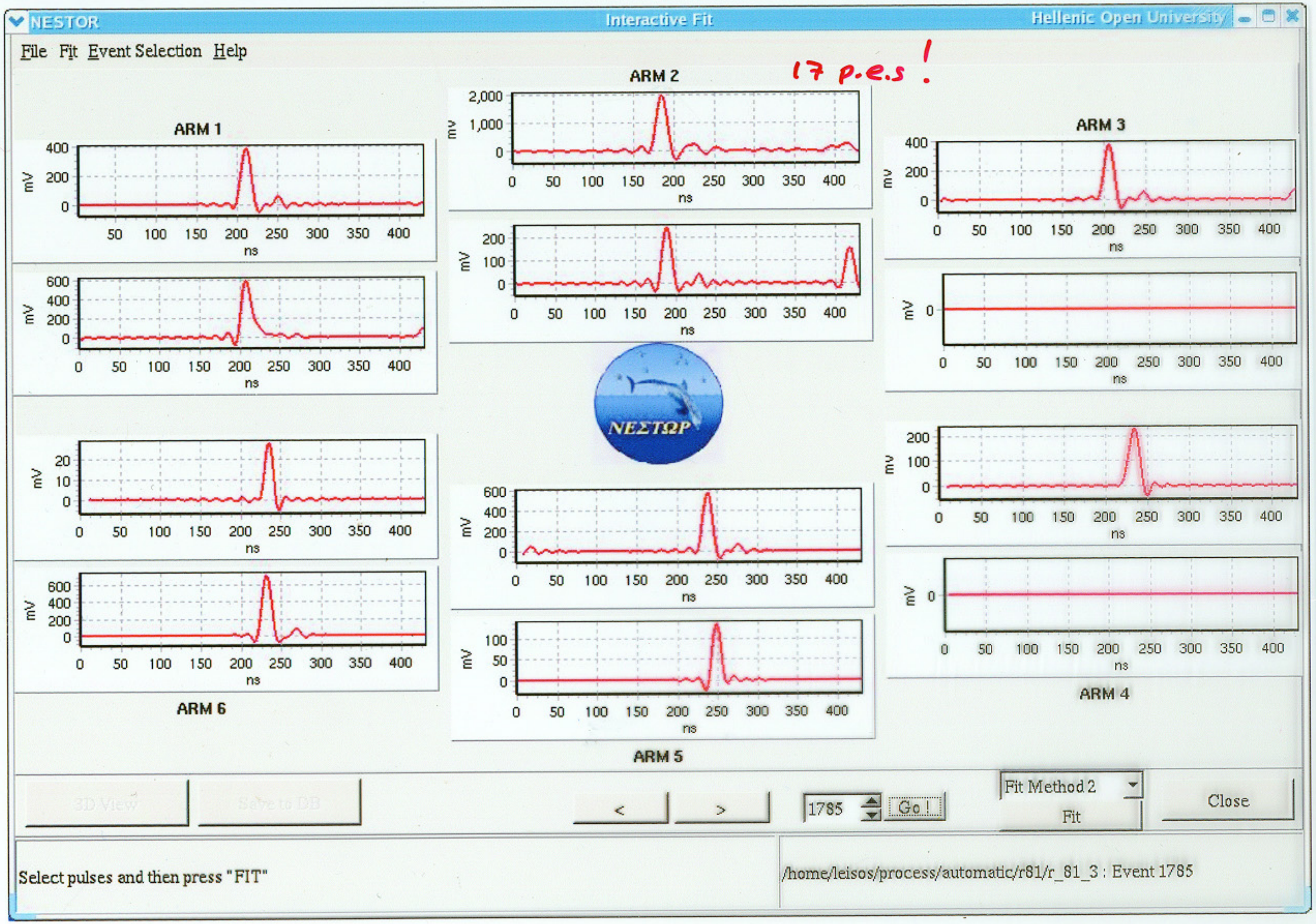
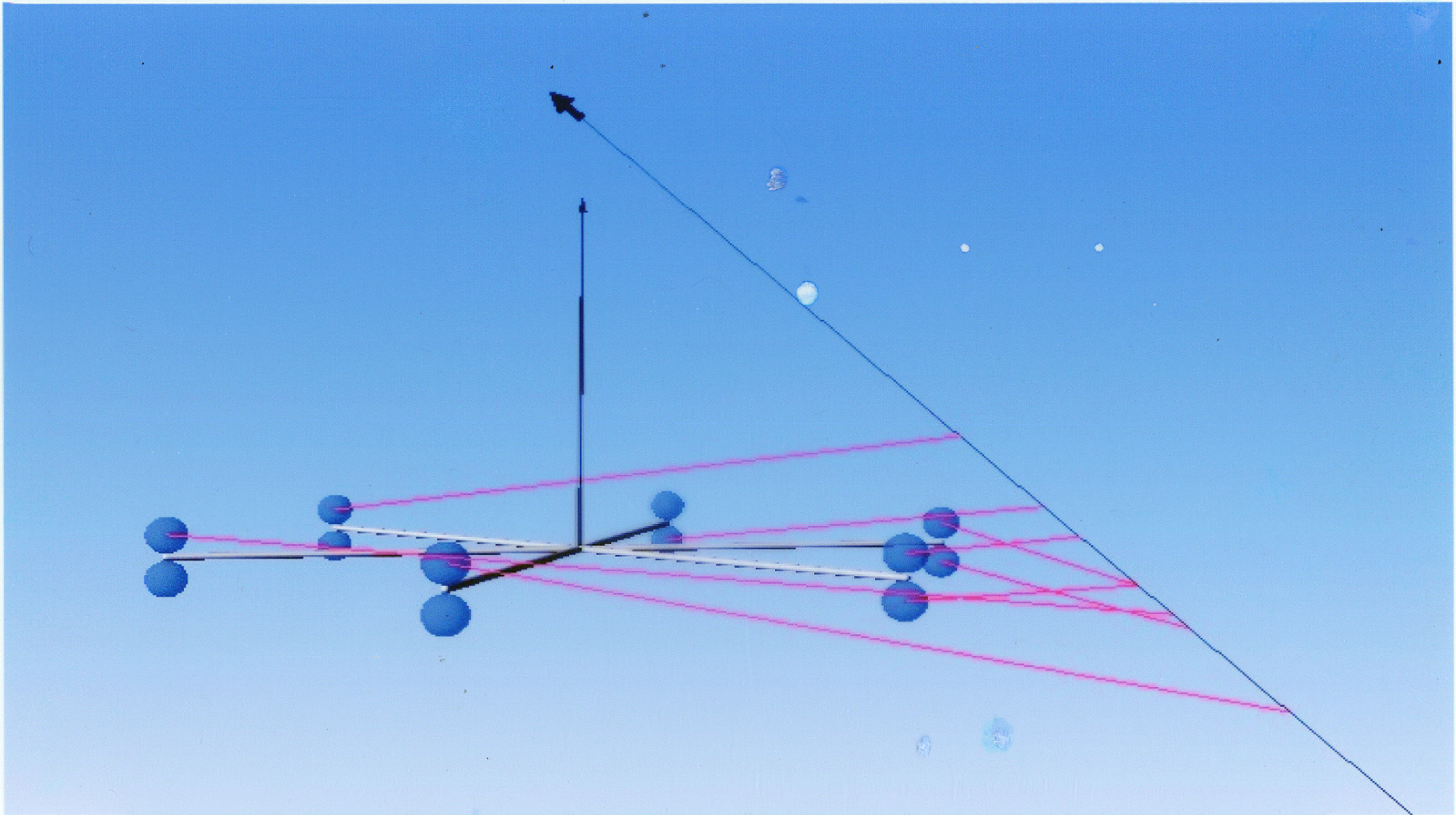


Figure 7: The pull distribution of the reconstructed zenith angles of Monte Carlo produced tracks.

Event 1785 – Run 81 – BFile 3

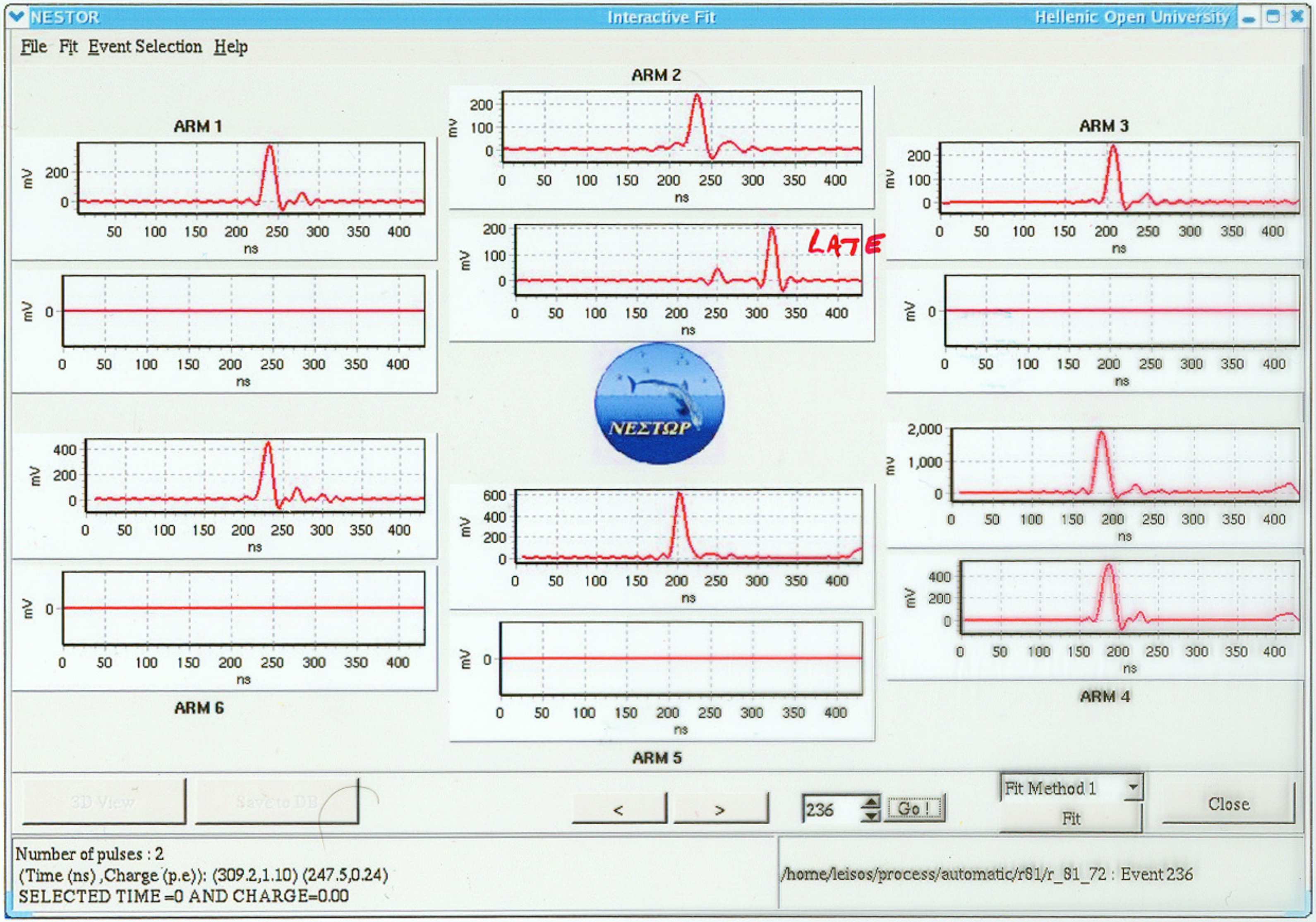


1 p.e. ≃ 120mV



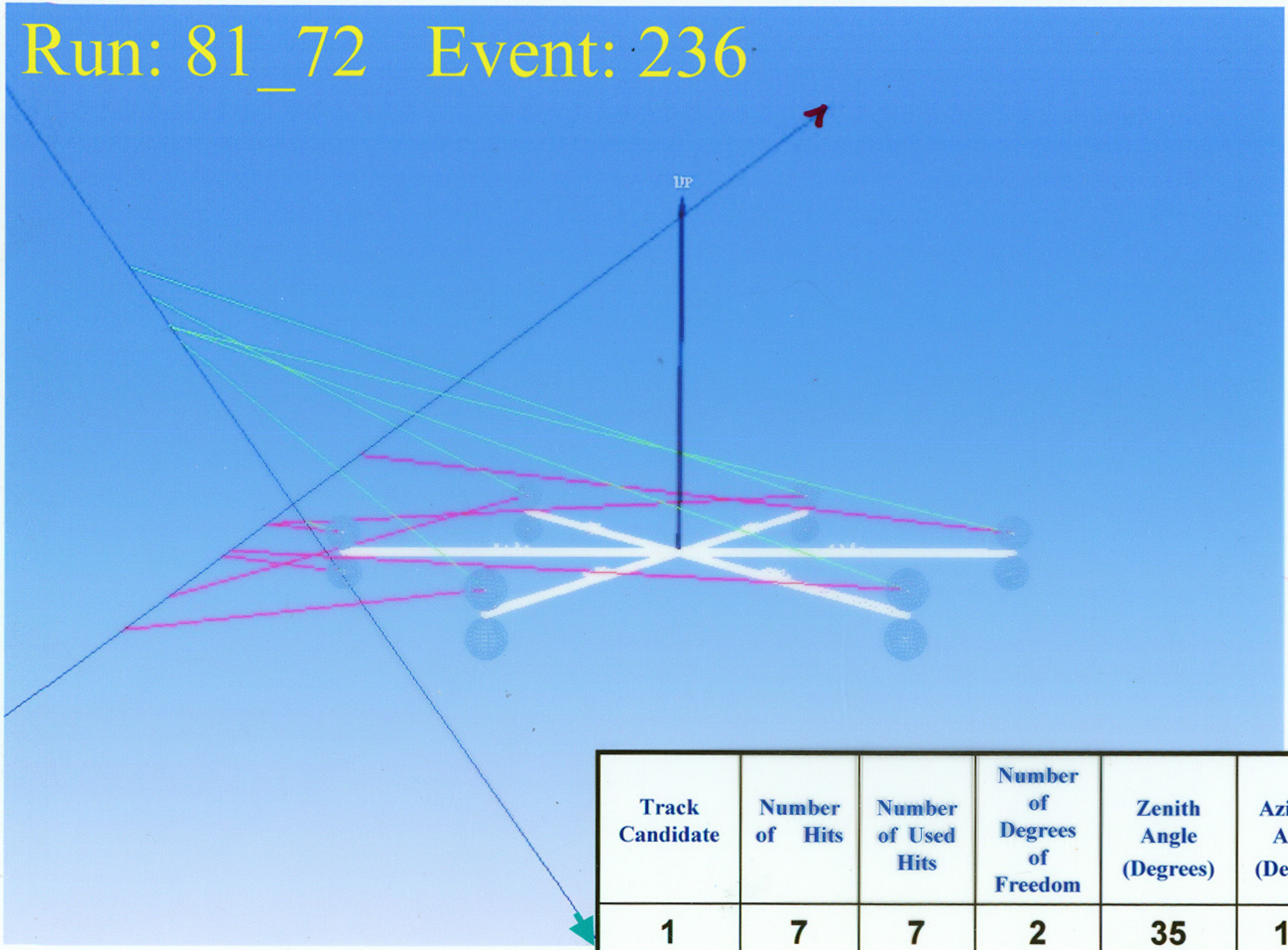
Track Candidate	Number of Hits	Number of Used Hits	Number of Degrees of Freedom	Zenith Angle (Degrees)	Azimuth Angle (Degrees)	X^2	$-\ln L_{ch}$
1	8	8	3	123 (±21)	288 (±21)	1.37	35.91

Run: 81_72 Event: 236



17 p.e.s !

c

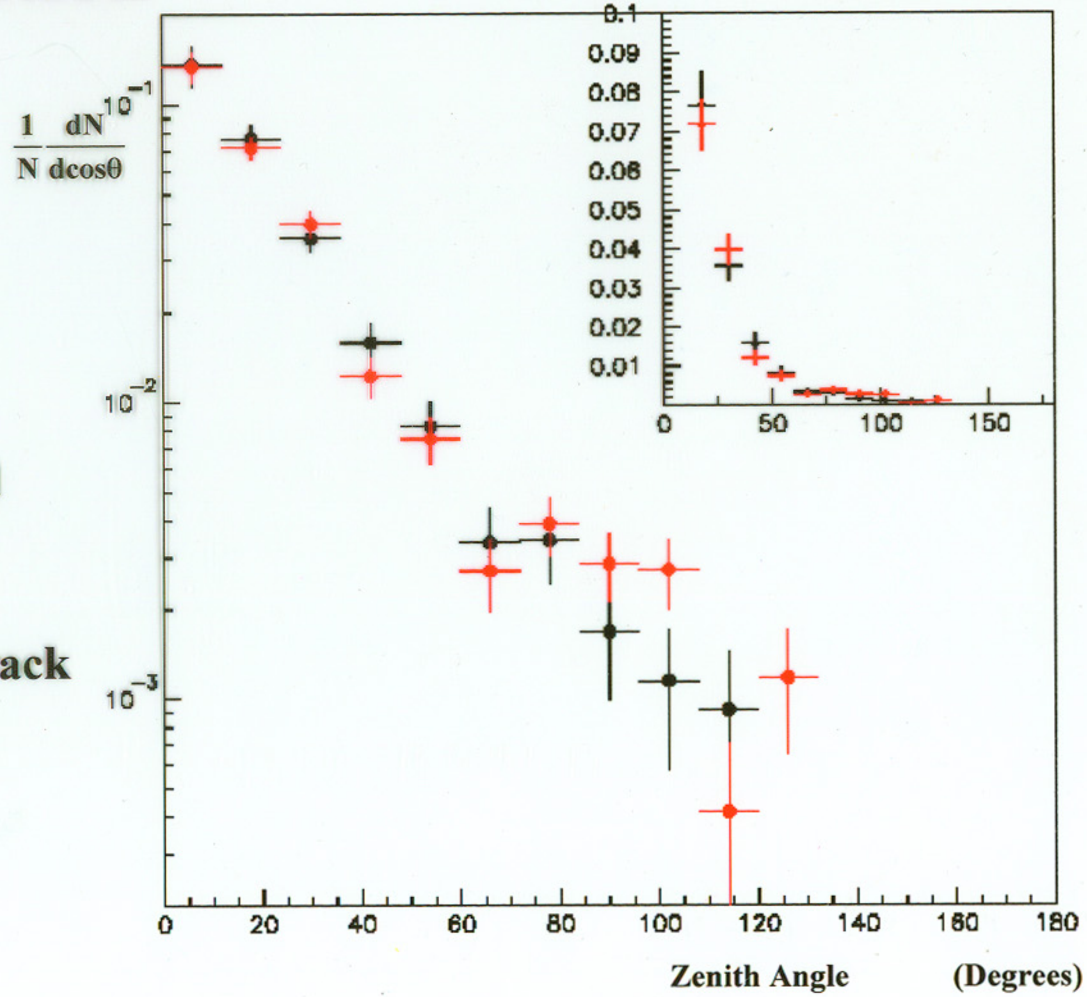


Track Candidate	Number of Hits	Number of Used Hits	Number of Degrees of Freedom	Zenith Angle (Degrees)	Azimuth Angle (Degrees)	χ^2	$-\ln L_{ch}$
1	7	7	2	35 (± 12)	172 (± 89)	3.8	35.5
2	7	7	2	126 (± 28)	181 (± 34)	2.0	28.4

~~Preliminary~~

Zenith Angular Distribution

- PMT pulse selection
- track fit
- χ^2 probability > 0.1
- track selection based on the charge-likelihood
- [track impact - 6m] > σ_{imp}
- more than [4.5 · (number of hits)] p.e.s per track

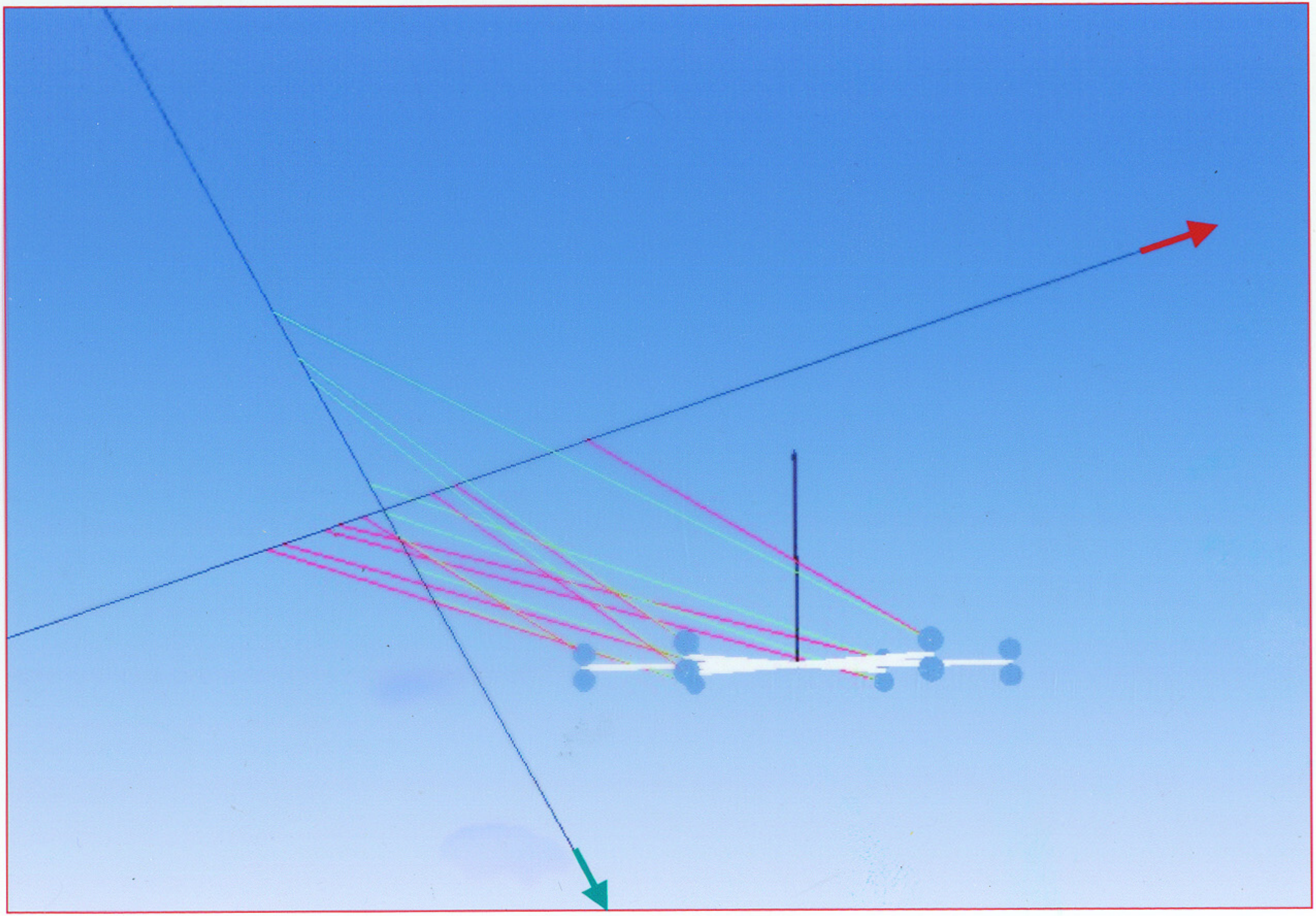


● M.C. Prediction (atmospheric muons)

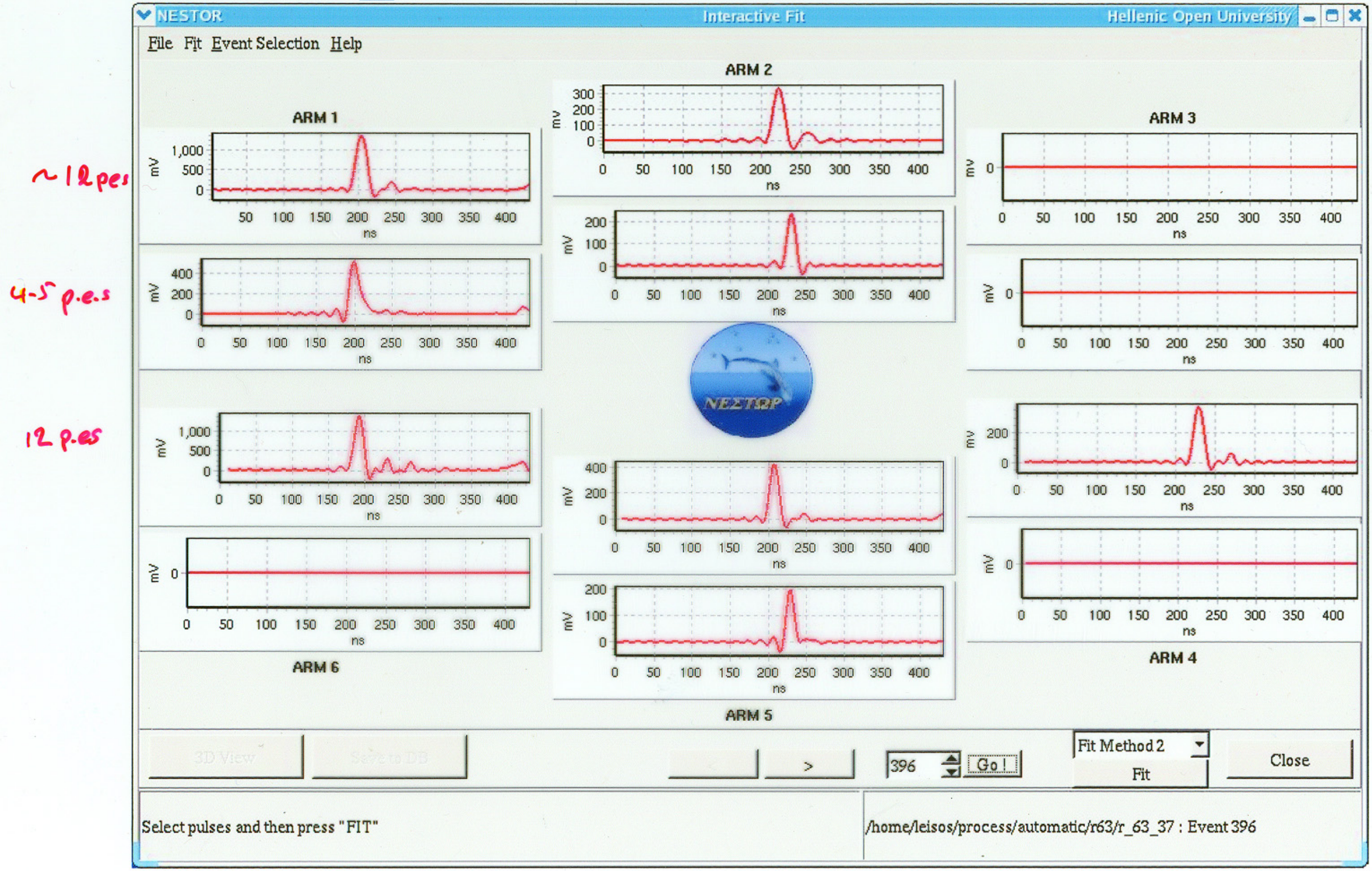
● Data Points

c

Run: 63_37   Event: 396



Run: 63_37 Event: 396



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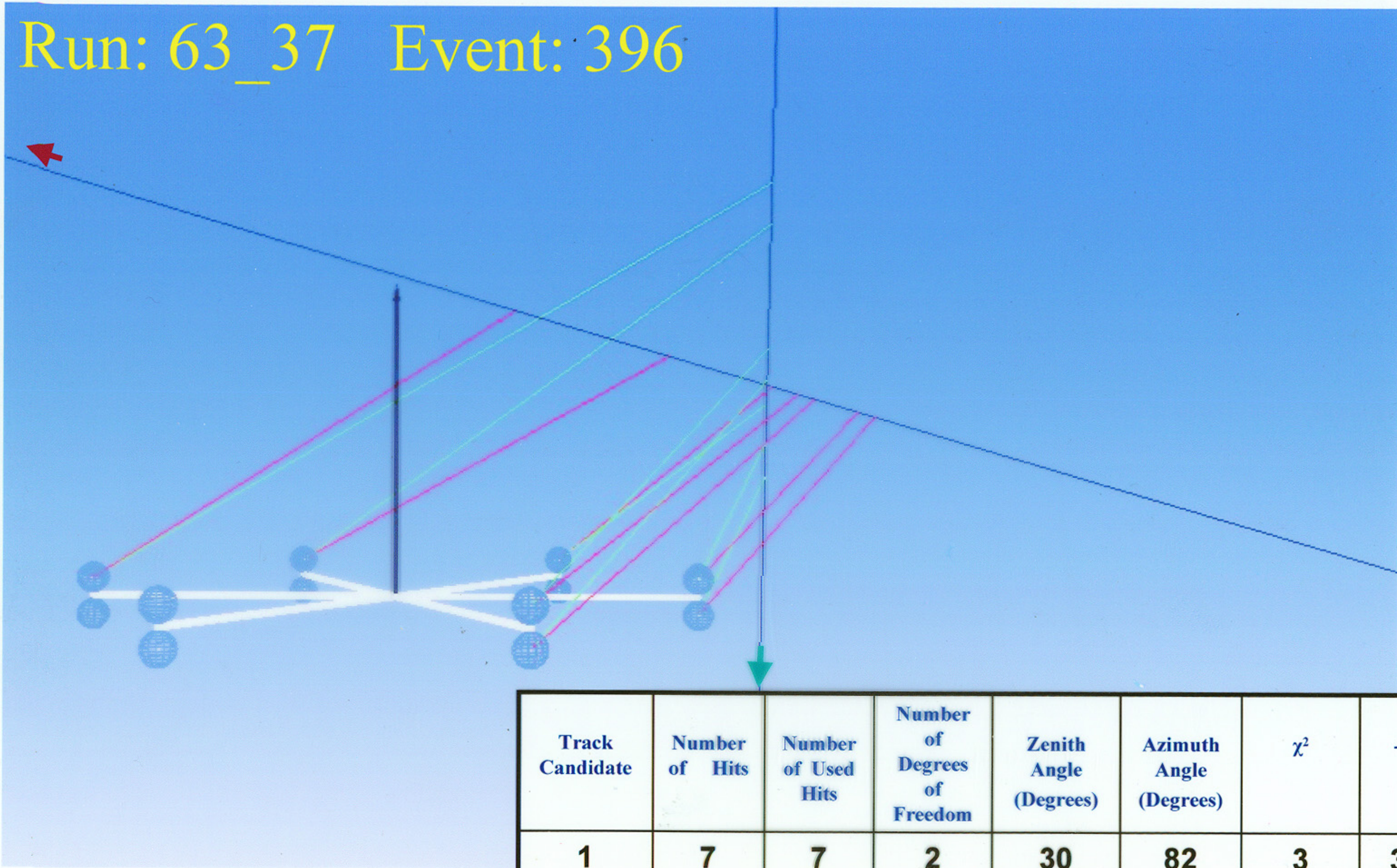
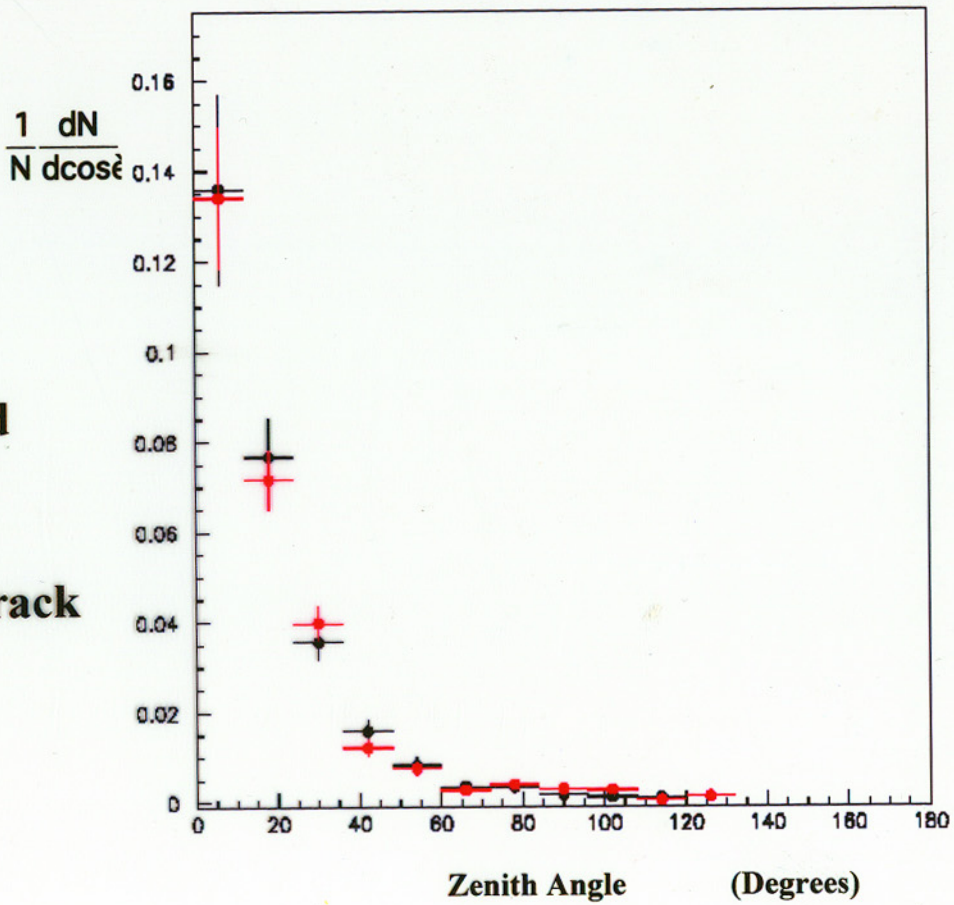


Track Candidate	Number of Hits	Number of Used Hits	Number of Degrees of Freedom	Zenith Angle (Degrees)	Azimuth Angle (Degrees)	χ^2	$-\ln L_{ch}$
1	7	7	2	30 (± 35)	82 (± 38)	3	36.5
2	7	7	2	101 (± 10)	33 (± 29)	2.7	30.3

~~Preliminary~~

Zenith Angular Distribution

- PMT pulse selection
- track fit
- χ^2 probability > 0.1
- track selection based on the charge-likelihood
- [track impact - 6m] > σ_{imp}
- more than [4.5 · (number of hits)] p.e.s per track



- ● M.C. Prediction (atmospheric muons)
- ● Data Points

Determination of Cosmic Muon Flux

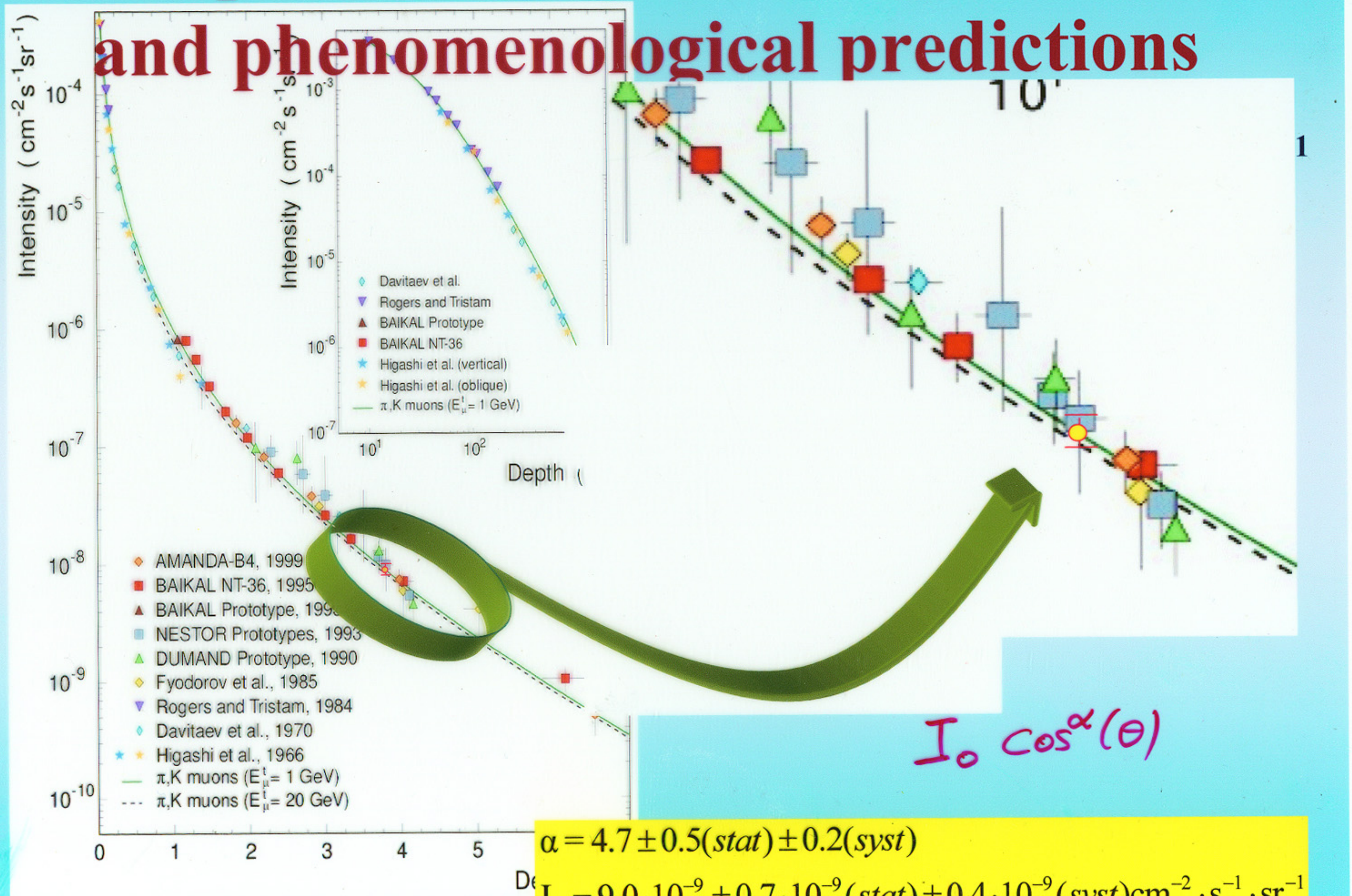
Contribution to the Systematic Errors (% of the estimation)		
Source	I_o	α
Selection criteria	2%	2%
Reweighting and binning	~0%	~0%
Energy dependance of the zenith angle distribution	3%	4%
Functional parametrization of the muon flux $\frac{dN}{d\Omega \cdot dt \cdot dS} = J_o \cdot e^{-\frac{\beta}{\cos\theta}}$	~0%	~0%

$I_o \cos^{\alpha}(\theta)$

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

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

Comparison with other experiments and phenomenological predictions



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

$$I_o = 9.0 \cdot 10^{-9} \pm 0.7 \cdot 10^{-9}(stat) \pm 0.4 \cdot 10^{-9}(syst)\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1}$$

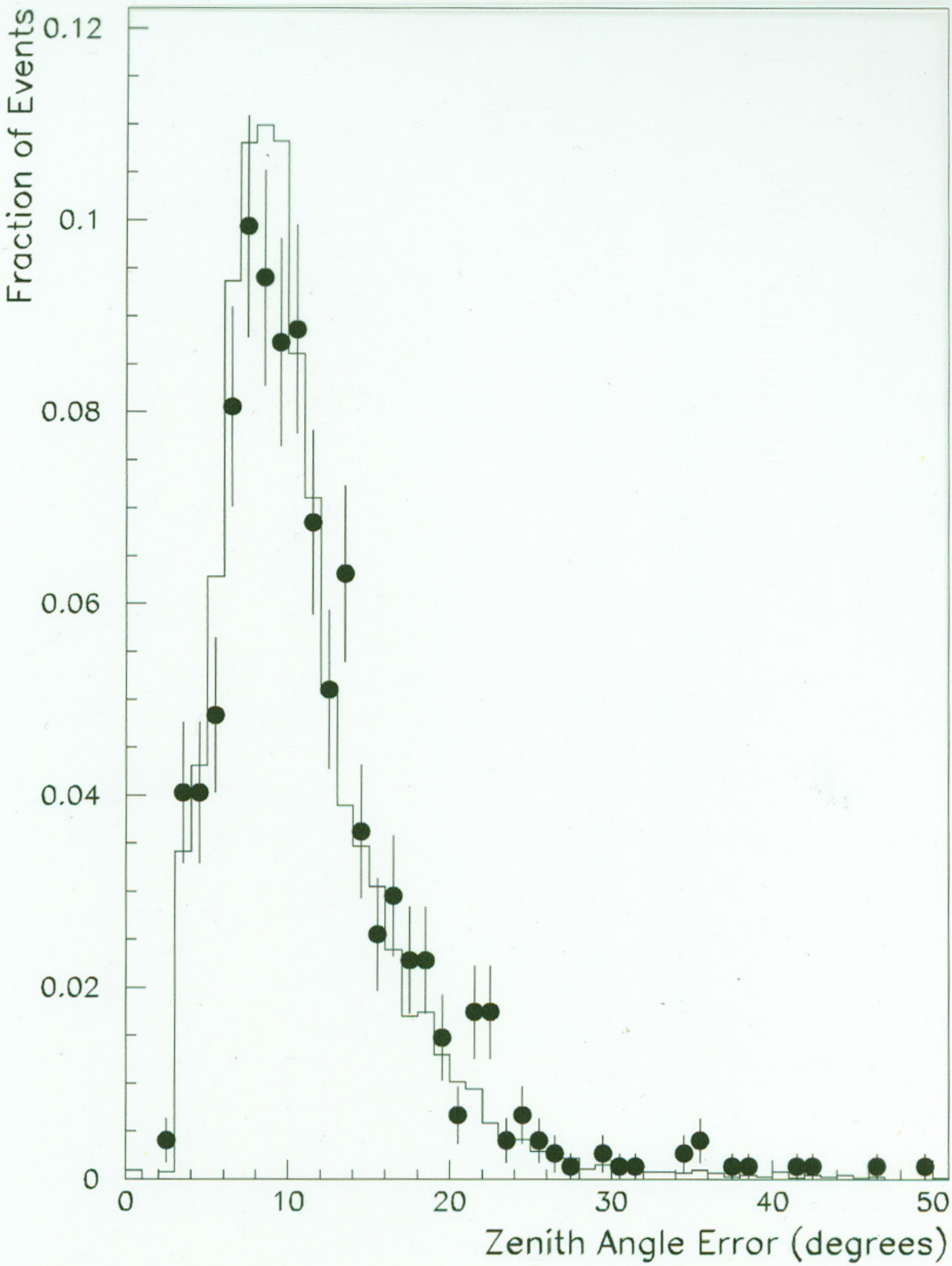


Figure 6: Distribution of the estimated errors of the reconstructed zenith angles. The solid points and the histogram correspond to the data and Monte Carlo tracks, respectively.

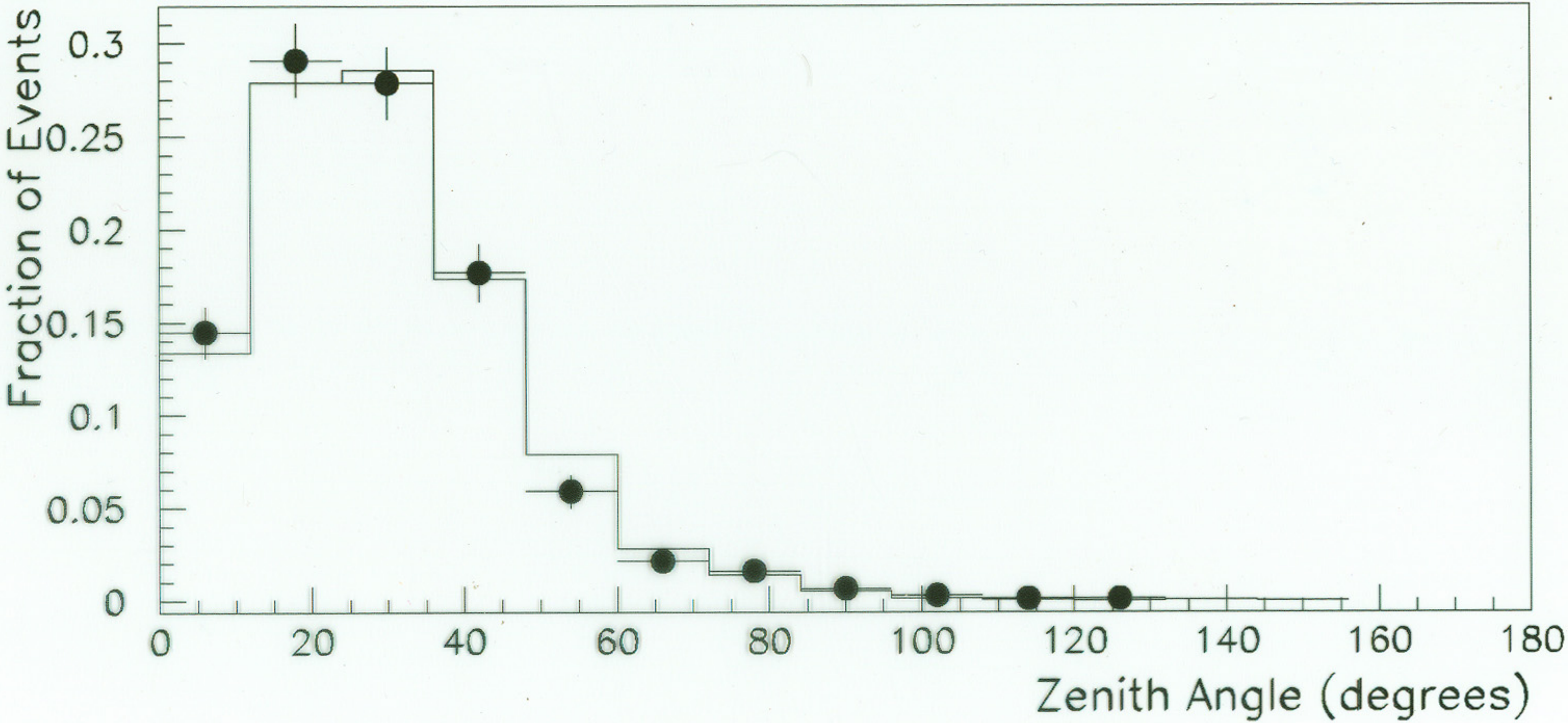


Figure 5: The zenith angle distribution of the reconstructed tracks (solid points) in comparison with the Monte Carlo prediction (histogram).

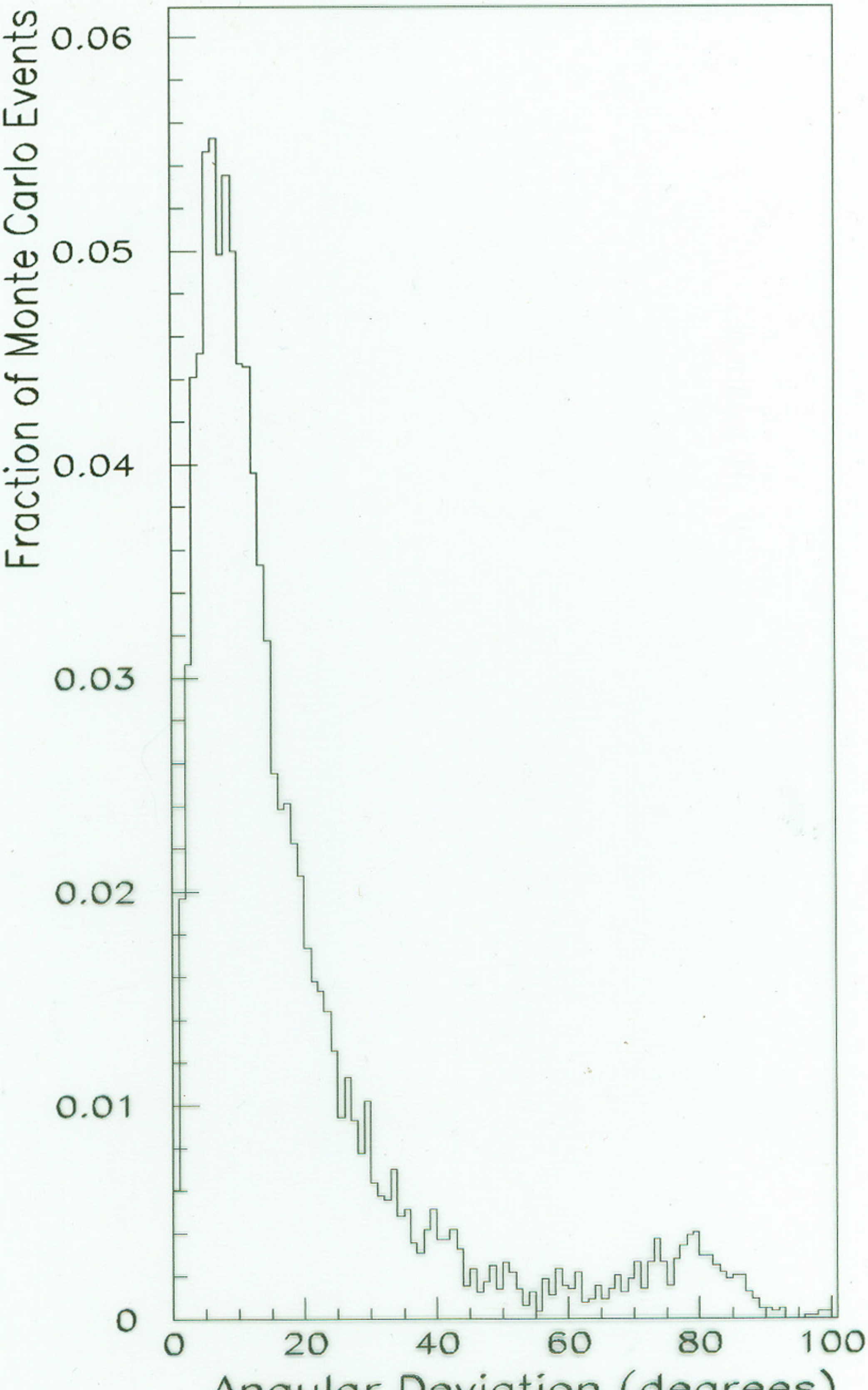


Figure 9: The three-dimensional angular deviation of Monte Carlo tracks from their true direction.

Track Fit

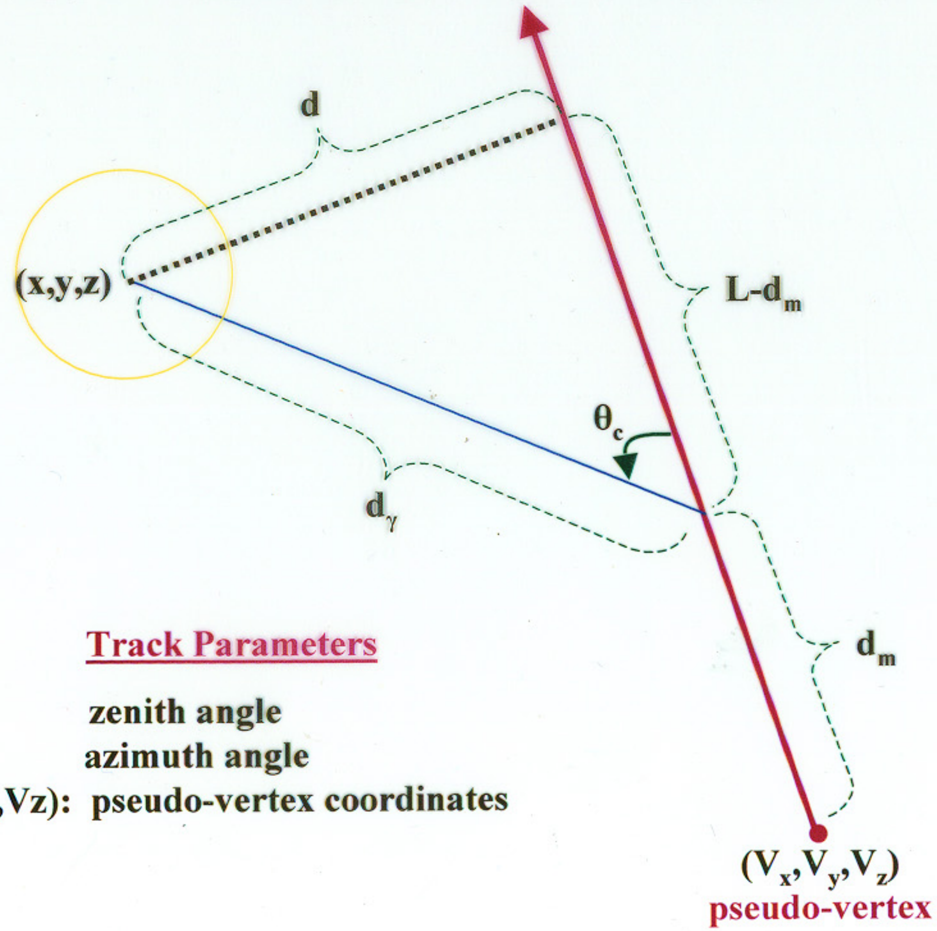
Using the Pulse Arrival Time

$$t_{exp} = \frac{d_m}{c} + \frac{d_\gamma}{(c/n)} = \frac{(L + d \cdot \tan\theta_c)}{c}$$

$$L = \cos\varphi \cdot \sin\theta \cdot (x - V_x) + \sin\varphi \cdot \sin\theta \cdot (y - V_y) + \cos\theta \cdot (z - V_z)$$

$$d = \sqrt{[(x - V_x) - L \cdot \cos\varphi \cdot \sin\theta]^2 + [(y - V_y) - L \cdot \sin\varphi \cdot \sin\theta]^2 + [(z - V_z) - L \cdot \cos\theta]^2}$$

$$t_{exp} = f(\theta, \varphi, Vx, Vy, Vz)$$



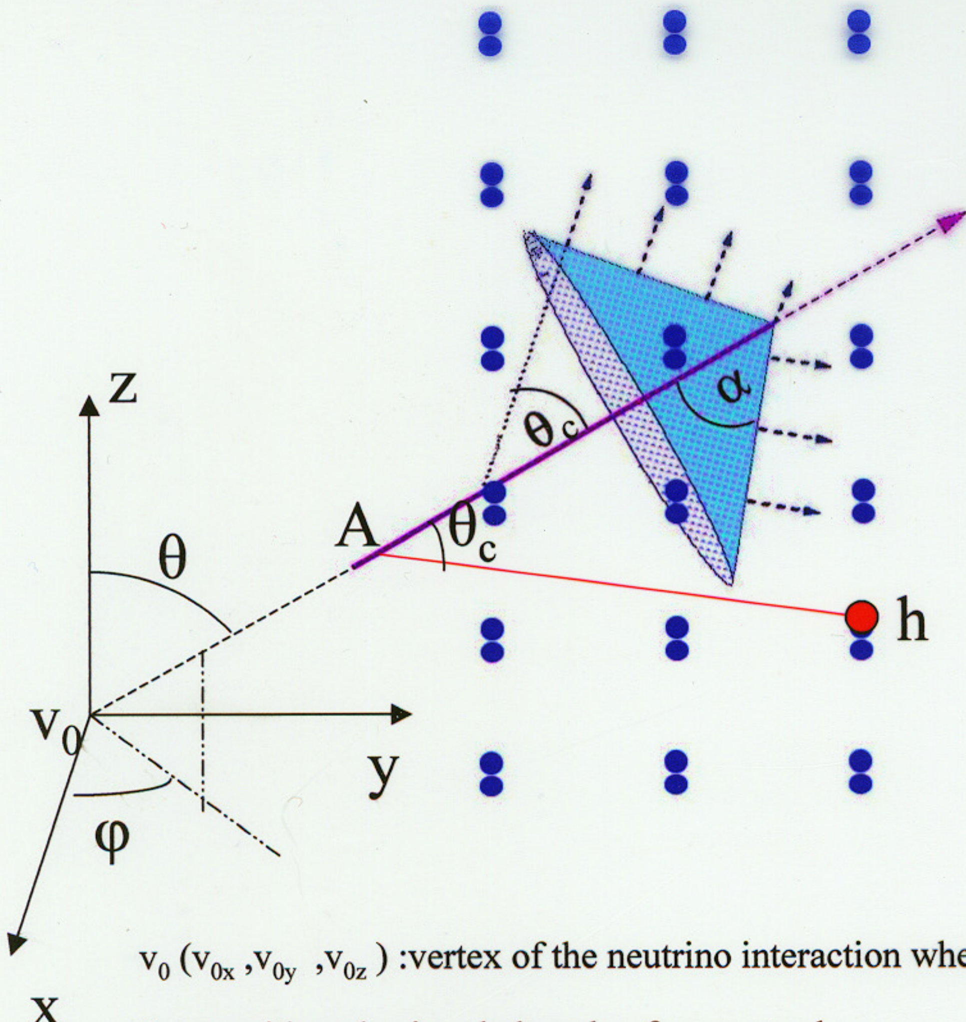
$$\chi^2 = \sum_{i=1}^{N_{hit}} \left(\frac{t_i^{exp} - t_i^{data}}{\sigma_i^{data}} \right)^2$$

Track Parameters

θ : zenith angle
φ: azimuth angle
(Vx,Vy,Vz): pseudo-vertex coordinates

c

• Track Fit & background photons (showers) reduction



For sea water the refraction index is n=1.355
so the cherenkov angle is
θc =42.4°
and
α=47.6°

v_0 (v_{0x} ,v_{0y} ,v_{0z}) :vertex of the neutrino interaction where the muon is created

θ,φ :zenith and azimuthal angle of muon track

The above five parameters of the track are estimated by minimizing the following chi-square function.

$$\chi^2 = \sum_{hit} \left(t_{hit} - t_{expected}(\vec{v}_0, \theta, \phi, \vec{v}_{hit}) \right)^2 / \sigma_{hit}^2$$

t_{hit} is the time of each hit as it is estimated from data analysis, and σ_{hit} is the estimated time uncertainty for each hit.
$t_{expected}$ is the expected time of arrival of the cherenkov photon, i.e. is the time that PMT h was hit, given that at time 0 the muon was at vertex v_0 ,i.e. is the time for the muon to travel from v_0 to A (where the photon was emitted) plus the time for the photon to travel from A to the PMT
v_{hit} is the position vector of the PMT with the corresponding hit

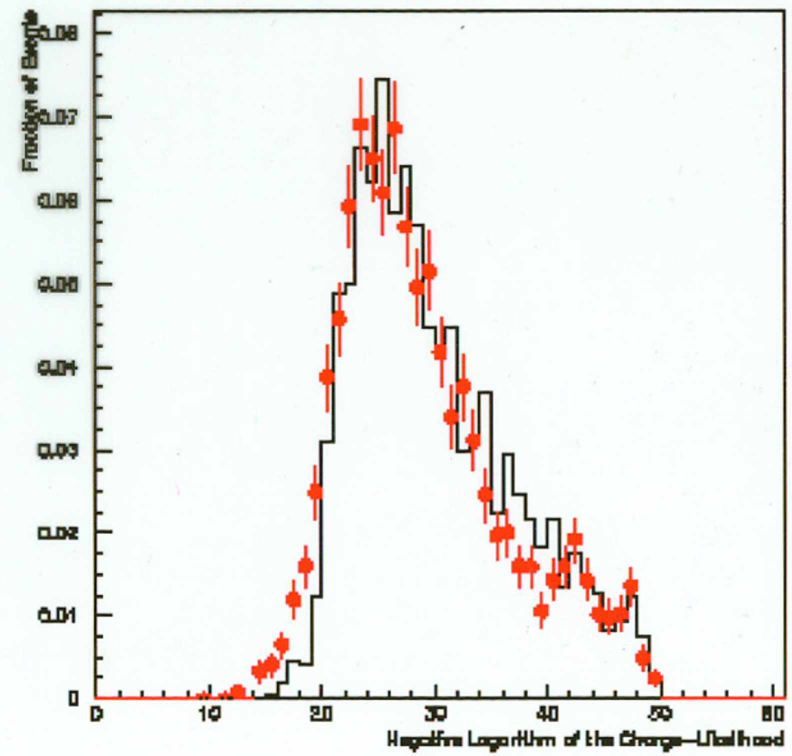
Track Selection According to the Charge-Likelihood

Charge-Likelihood $$L_{ch} = \prod_{i=1}^{N_a} P_i(Q_{exp}, Q_{meas})$$

$P_i(Q_{exp}, Q_{meas})$ is the probability the pulse height of the i^{th} PMT to be Q_{meas} while the expected mean pulse height is equal to Q_{exp}

$$P_i(Q_{exp}, Q_{meas}) = \sum_{n=1}^{\infty} \frac{(Q_{exp})^n \cdot e^{-Q_{exp}}}{n!} \cdot R_i(Q_{meas}; n)$$

Where $R_i(Q;n)$ is the (normalized to unity) pulse height distribution of the i^{th} PMT which corresponds to n photo-electrons



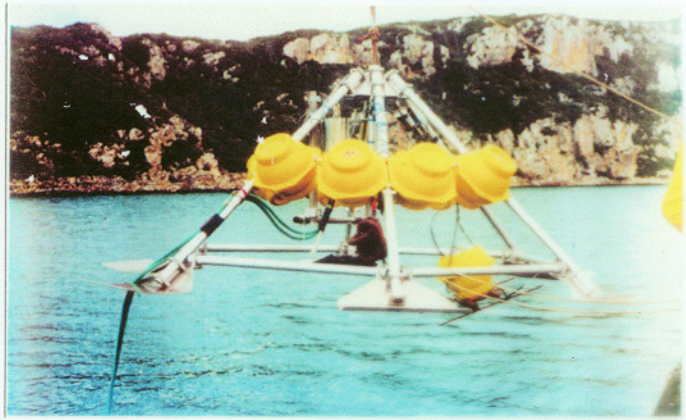
M.C. Prediction (atmospheric muons)

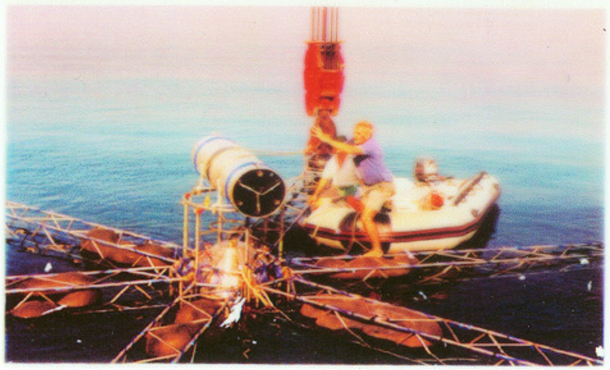
Data Points

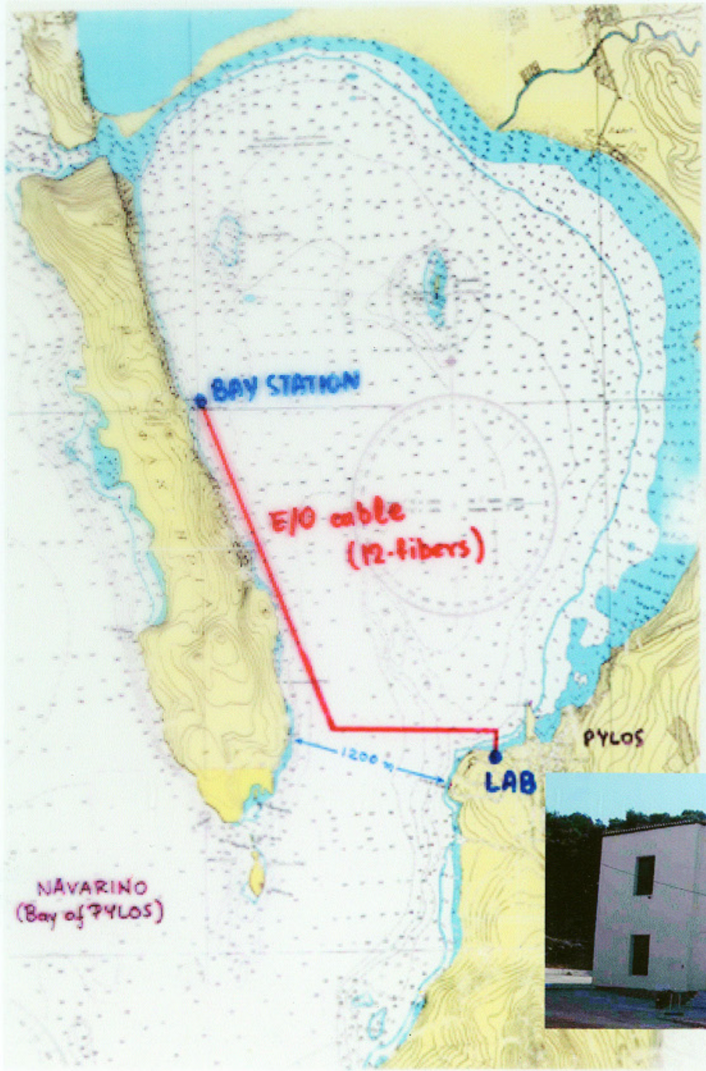
C

Detector Preparation

Bay Station Tests







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NESTOR

(NEUTRINO EXTENDED SUBMARINE TELESCOPE WITH OCEANOGRAPHIC RESEARCH)

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Neutrino Burst Experiment (NuBE)

The NESTOR collaboration
+
U.C.Berkeley/Space Sciences Lab
SUNYSB

Can we detect high energy ν in coincidence with Gamma-Ray-Bursts?

- Predict 1 km^2 detector will see more than 20 ν per year with $E_{\nu} \sim 10^{14}$eV in coincidence with GRB

(Waxman, E. and Bahcall, J. 1997, Phys. Rev. Lett. 78, 2292)

two key concepts for simple detector:

10^{14} eV => sparse detector and time signature

Coincidence with GRB => ν in time window of burst

Exploiting the ν Energy

10^{14} eV ν:

for $\nu \rightarrow \mu$ the μ Range in water > 5km
the μ is highly radiative, leading to
shower with an average of >20 times
the Ck light of single particle
all along track

for $\nu \rightarrow e$ the shower is short but intense

Exploit Coincidence with GRB

- GRB lasts few seconds to ~100 seconds
- ν can appear anywhere within this time window

Sparse Detector

- Use 4 strings of detectors surrounding NESTOR, each string ~300m from tower
- Each string is >400m long with 2 independent detector nodes per string separated by ~300m
- Each node consists of 2 clusters of 8 optical modules each with separate battery, LED, and control spheres
- All strings independent - primary data recovery through string recovery - priority data sent acoustically to NESTOR

Battery Powered Strings

- Each cluster has 3 power supplies:
  - one for the optical modules
  - one for the electronics
  - one for the acoustic system
- Power is sufficient for 1 year of operation at depth

Optical Modules

- 15” Hamamatsu PMTs
- Cockroft-Walton HV for base
- <40mw per OM
- All in 17” Benthos spheres

Cluster Controller Sphere

- 8 OM inputs
- Majority logic trigger
  - Eliminate ^{40}K and bioluminescence backgrounds
- Local oscillator
  - Stable to 1 part in 10^{11}
- Time stamp for each event
- Data storage for >1 years worth (100 GB)
- Priority events sent to acoustic readout
- <0.5W average power use

Time and Amplitude digitizing

8 channels of input for each cluster

- 3 discriminators per input channel with thresholds at 1/4 pe, 2.5 pe, and 5 pe
- Each discriminator feeds separate FIFO TDCs with 5ns sensitivity and 1.6 μs range

LED sphere

- Located ~10m below lower cluster or above upper cluster in each node
- Firing sequence controlled by cluster controller
- Light intensity variable with sufficient range to illuminate local and remote nodes and NESTOR
- For clock synchronization and position verification

Coupling to NESTOR

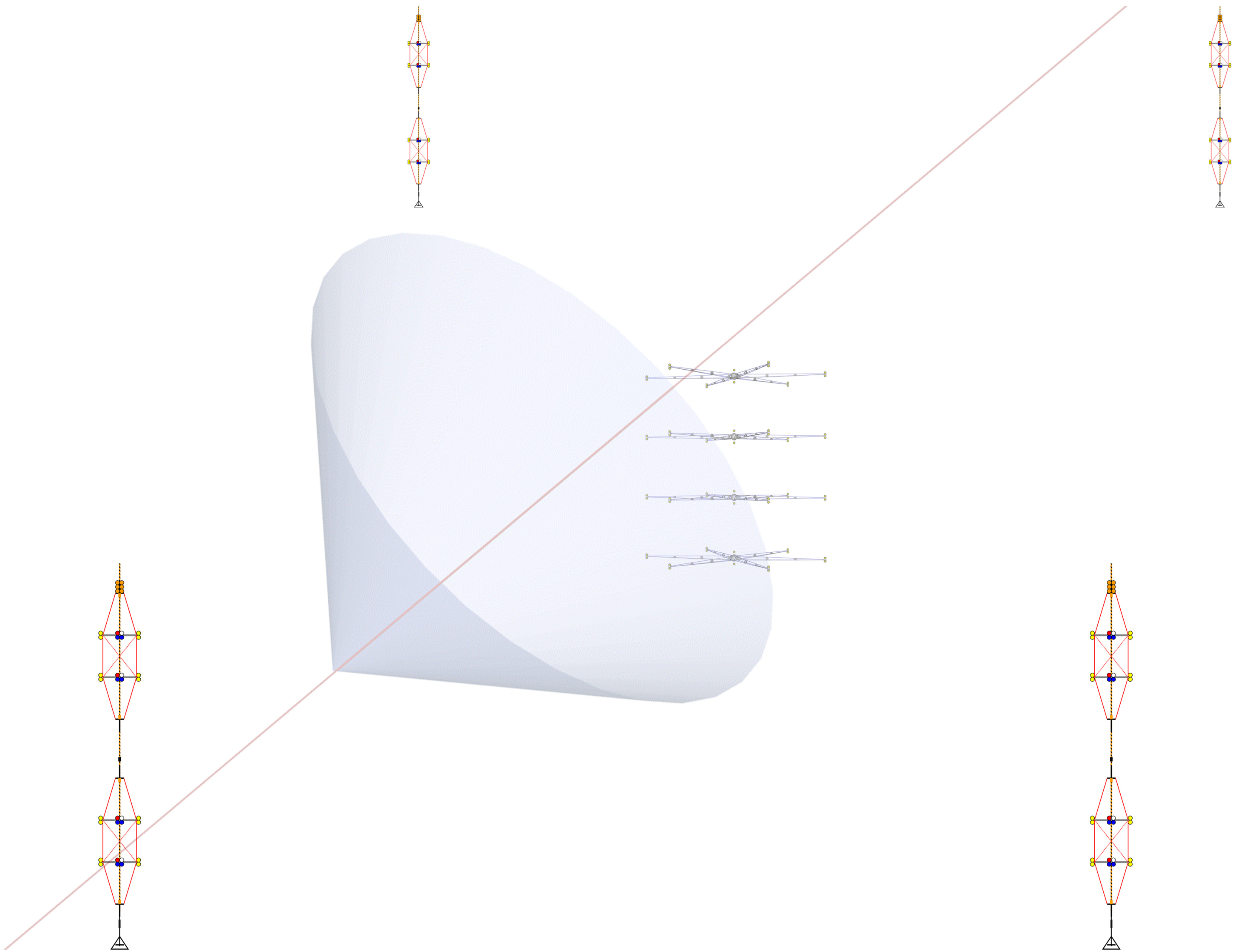
- Acoustic transceiver in each cluster communicates with NESTOR tower base unit
- NESTOR unit converts to full duplex fiber communication to shore

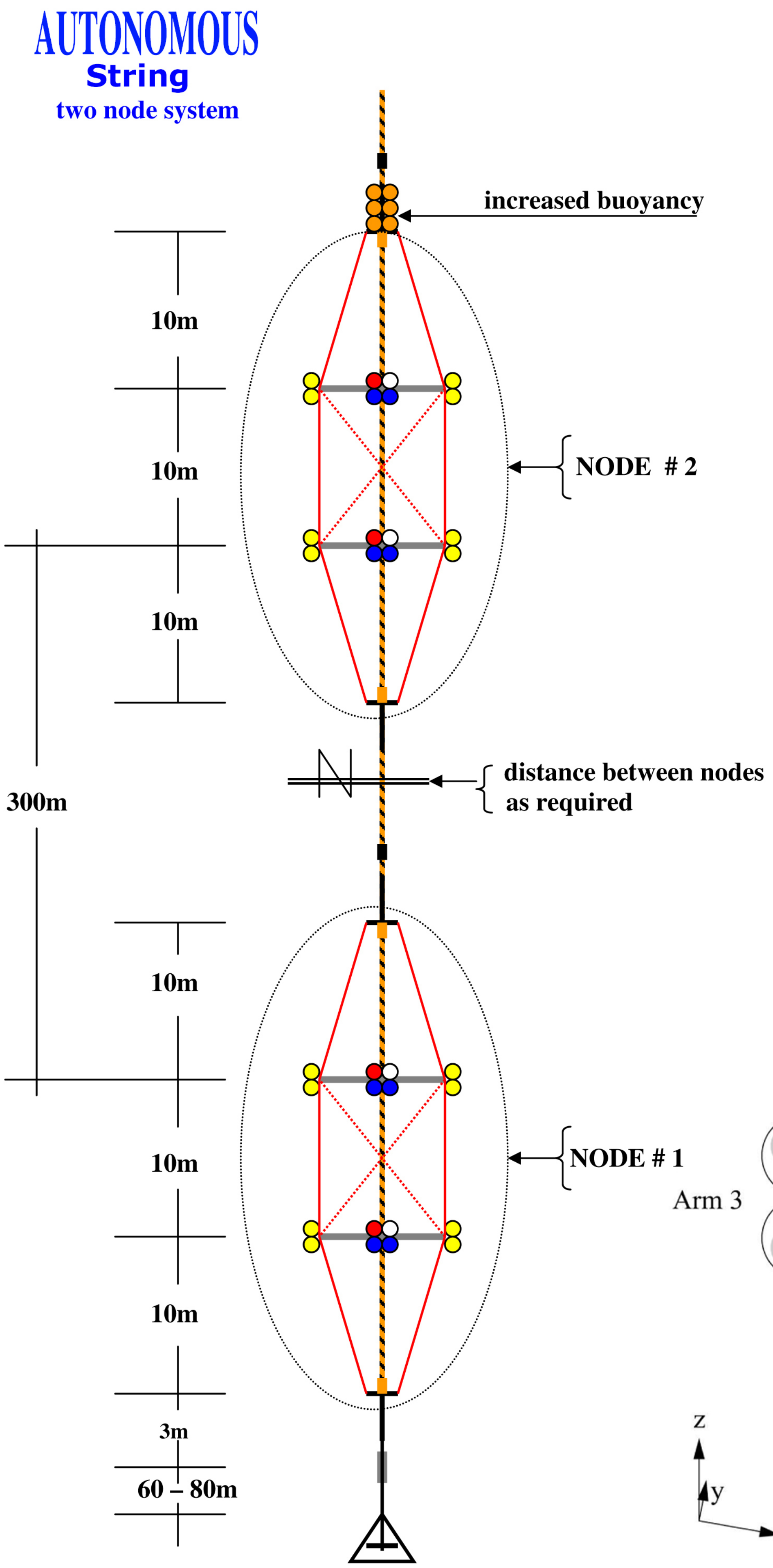
Signal analysis

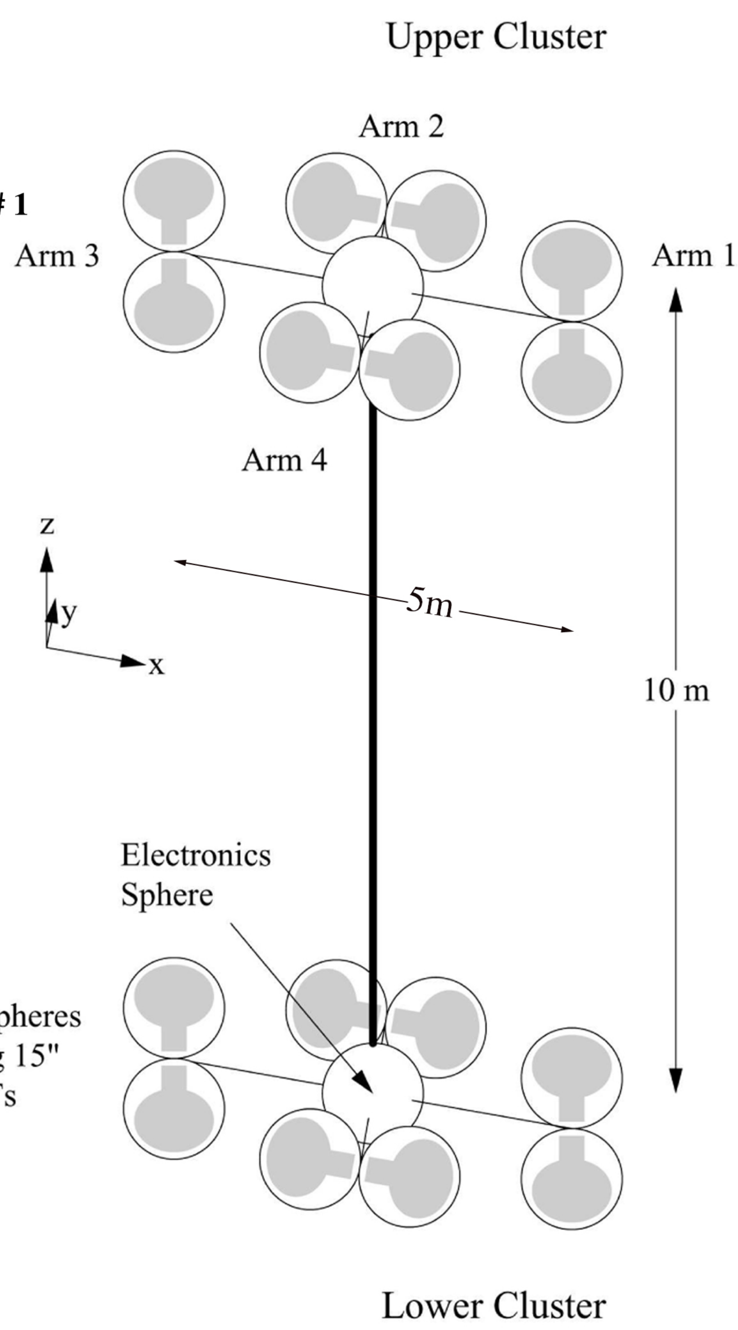
- Offline analysis
- Coincidence within node give low energy tracks for calibration
- coincidence between strings and NESTOR give high energy tracks
- Coincidence between 2 or more strings with NESTOR give highest energy tracks

Conclusions

- Can deploy strings in a series of tests to build up to 4 string array have >2km^2 effective area with NESTOR at center
- Timing comparison with satellites from detected GRB
- Rudimentary pointing accuracy from strings, excellent pointing from NESTOR, to verify GRB coincidence




AUTONOMOUS
String
two node system
increased buoyancy
10m
10m
10m
NODE # 2
distance between nodes
as required
300m
10m
10m
10m
NODE # 1
3m
60 – 80m


Upper Cluster
Arm 2
Arm 3
Arm 1
Arm 4
z
y
x
5m
10 m
Electronics
Sphere
Benthos spheres
containing 15"
PMTs
Lower Cluster

Cluster