S. E. Tzamarias
Hellenic Open University

NESTOR

Neutrino Extended Submarine Telescope with Oceanographic Research

First Results

2003 RUN

Electronics – DAQ –Data Analysis

Germany	Institute of Geophysics University of Hamburg Institute of Experimental and Applied Physics Center of 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 for Informatics and Telecommunications NCRS DEMOKRITOS National Science Foundation School of Science & Technology Hellenic Open University NESTOR Institute for Deep Sea Research, Technology and Neutrino Astroparticle Physics Physics and Astronomy Dept. University of Patras Physics Dept. University of Thessaloniki
Russia	Experimental Design Bureau of Oceanological Engineering Institute For Nuclear Research Russian Academy of Sciences
Switzerland	Physics Dept. University of Bern CERN
U.S.A.	Dept. of Physics and Astronomy University of Hawaii Lawrence Berkeley National Laboratory

NESTOR

(NEUTRINO EXTENDED SUBMARINE TELESCOPE WITH OCEANOGRAPHIC RESEARCH)

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Lawrence Berkeley National Laboratory

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National Science Foundation, Greece

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N. Arvanitis, A. Babalis, A. Darsaklis, J. Kiskiras, G. Limberopoulos, Th. Michos, J. Tsirmpas, A. Vougioukas

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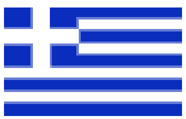
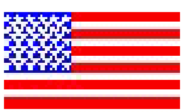
A.V. Butkevich, L.G. Dedenco, S.K. Karaevsky, A. Mironovich, N.M, Surin, I.M. Zheleznykh, V. A.Zhukov

L.M. Zacharov, A. Shnyrev

Institute For Nuclear Research

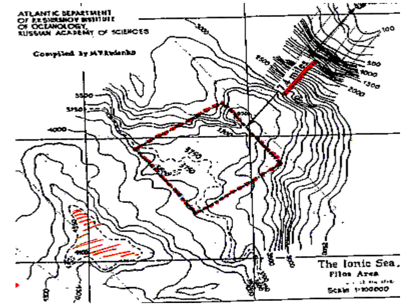
Russian Academy of Sciences

Marine Technology Collaborators

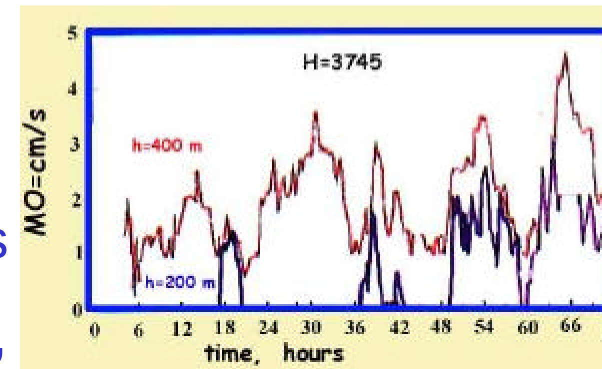
 Germany	•ALU-BAU, Buedelsdorf •GeoPro mbH •GISMA GmBH
 Greece	•Hellenic Telecommunications Organization (OTE) •Marine Technology Development Company (EANT) •National Centre Marine Research (NCMR) •Institute for Marine Biology of Crete •Kourtis Salvage Ltd •Naval Engineering Dept., Athens Technology University
 U.S.A.	•MAKAI Engineering, Hawaii •Scripps Institute of Oceanolography, La Jolla, California

The NESTOR Neutrino Telescope Site

Site characteristics

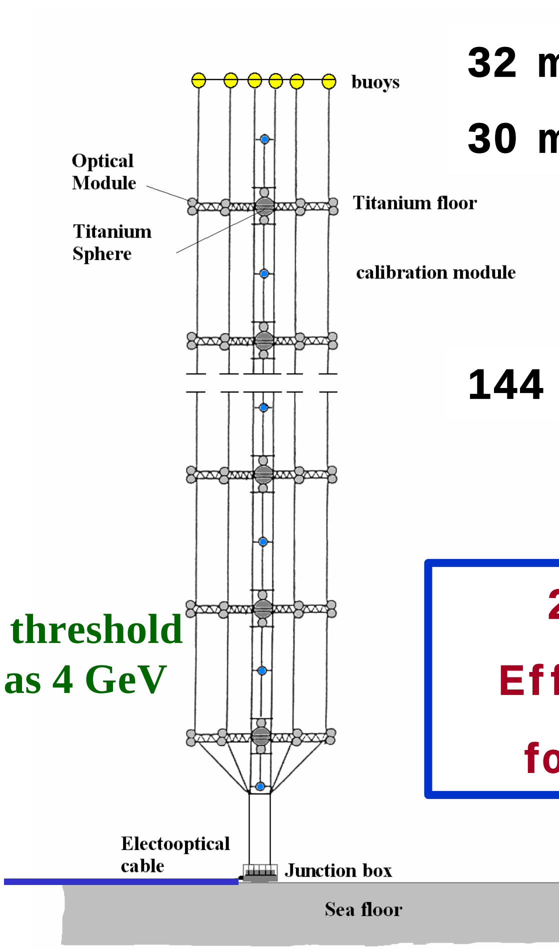


- **a broad plateau:** 8x9 km^2 in area, 7.5 nautical miles from shore
- **depth:** ~4000m
- **transmission length**: 55 $\pm$ 10m at ?=460 nm
- **underwater currents:** <10 cm/sec measured over the last 10 years



- **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.

NESTOR TOWER



32 m diameter

30 m between floors

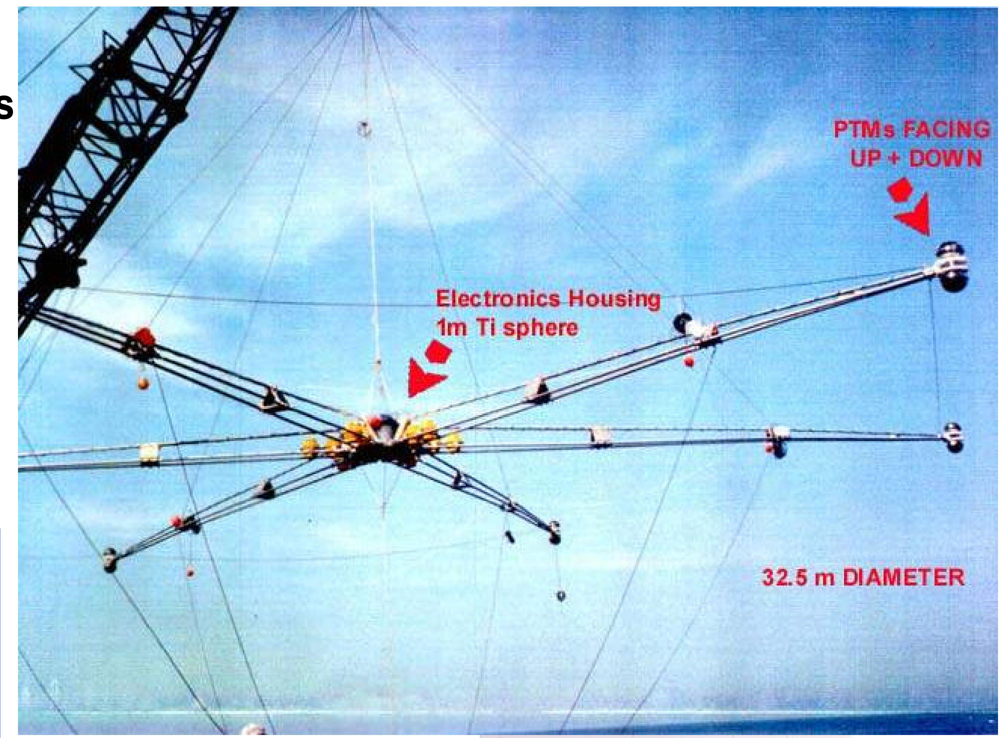
144 PMTs

Energy threshold as low as 4 GeV

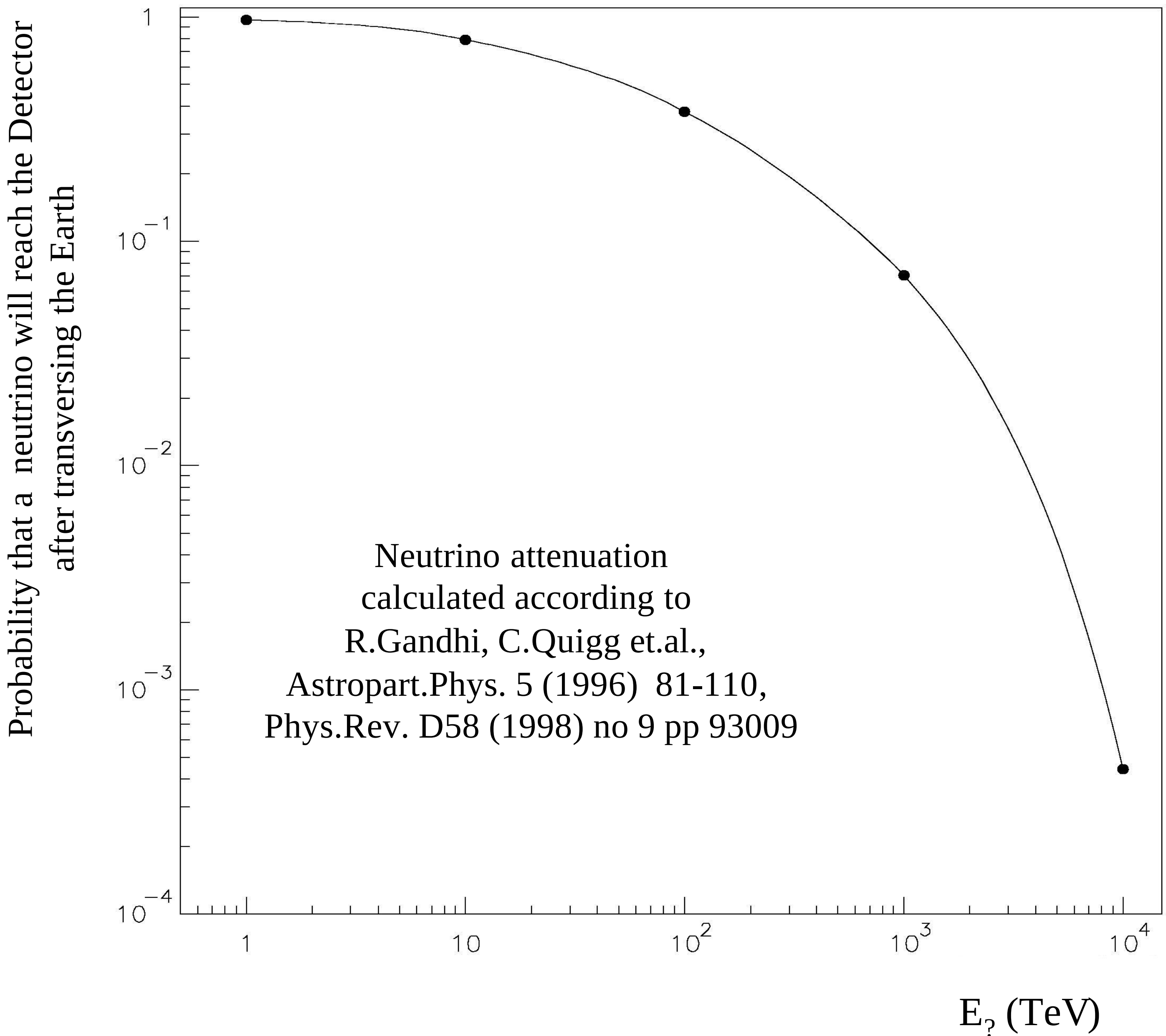
20 000 m^2

Effective Area

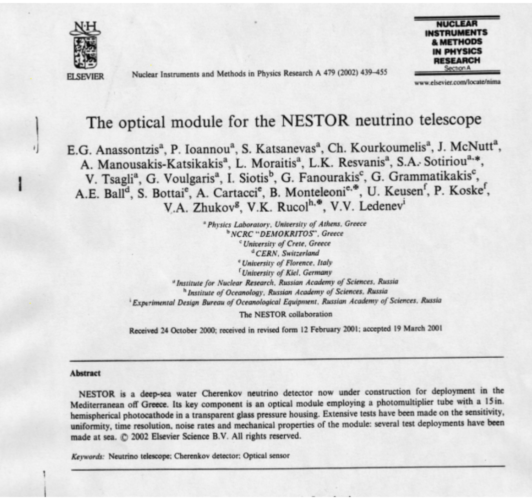
for E>10TeV



Detector looking downwards ±50º around Nadir



The Detector



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The optical module for the NESTOR neutrino telescope

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The NESTOR collaboration

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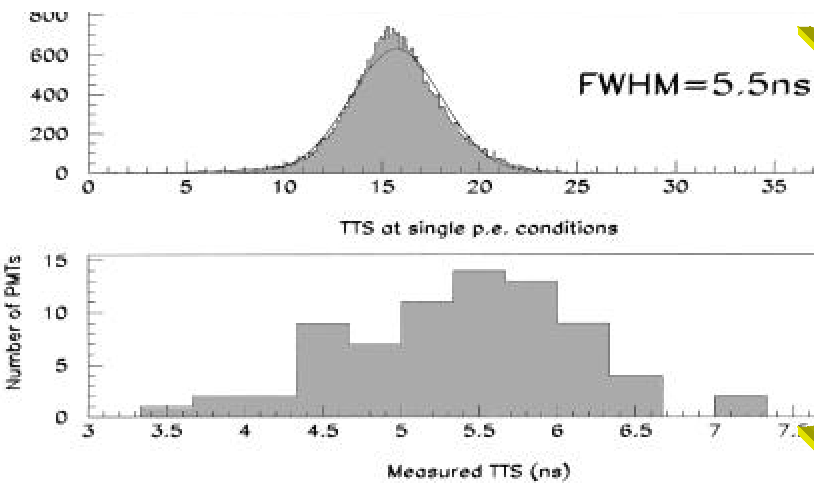
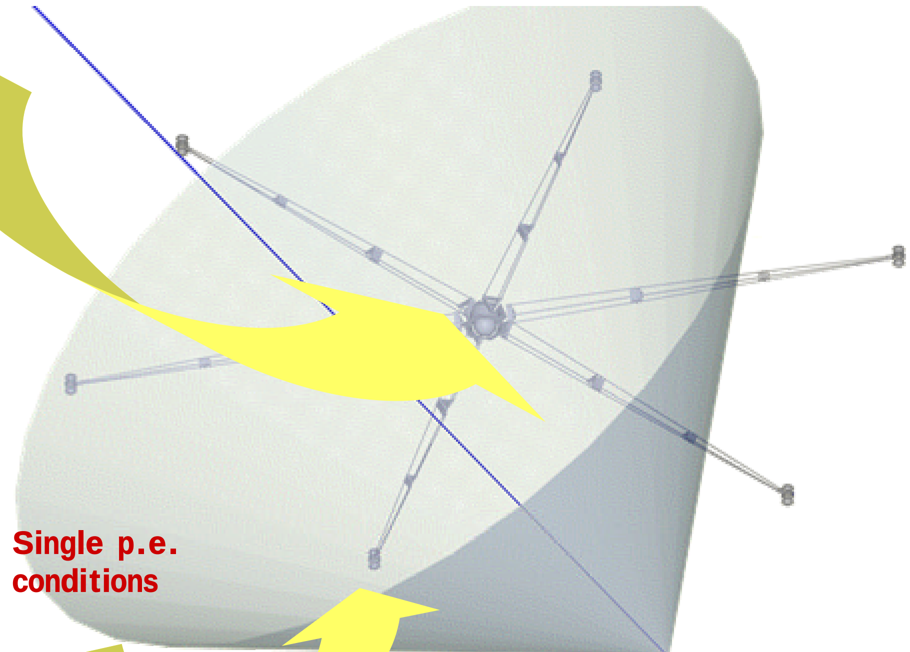
Abstract

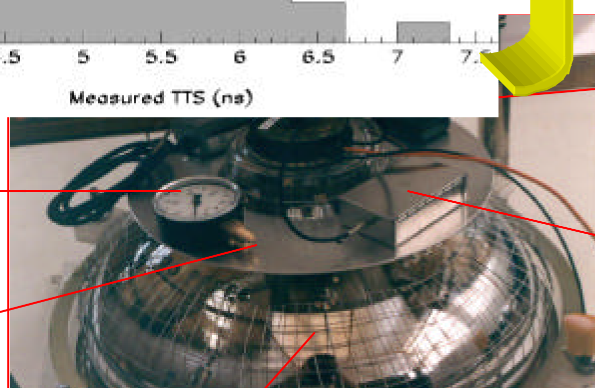
NESTOR is a deep-sea water Cherenkov neutrino detector now under construction for deployment in the Mediterranean off Greece. Its key component is an optical module employing a photomultiplier tube with a 15 in. hemispherical photocathode in a transparent glass pressure housing. Extensive tests have 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



Single p.e. conditions





Potentiometer

Pressure gauges

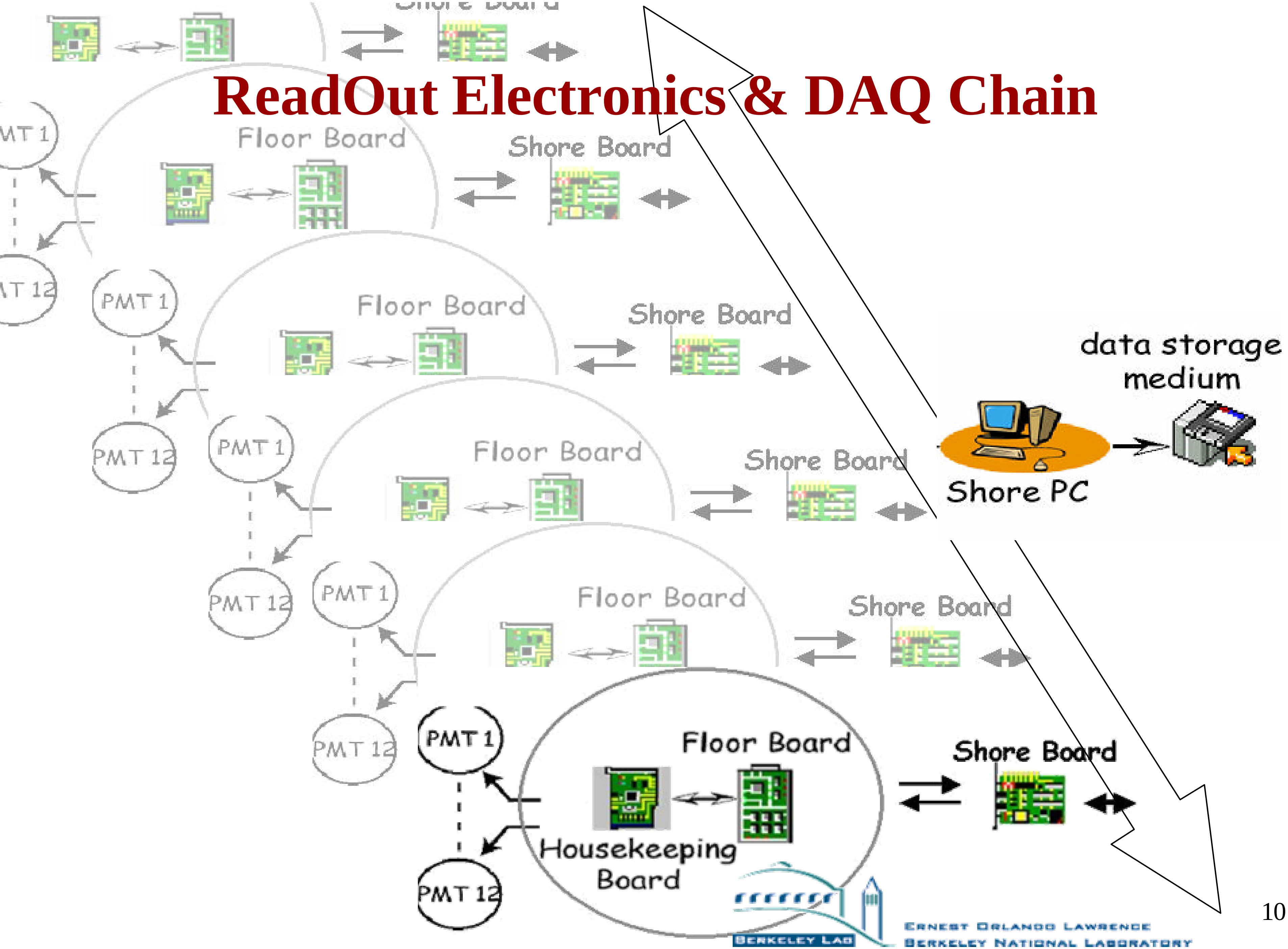
Filter

Al disk

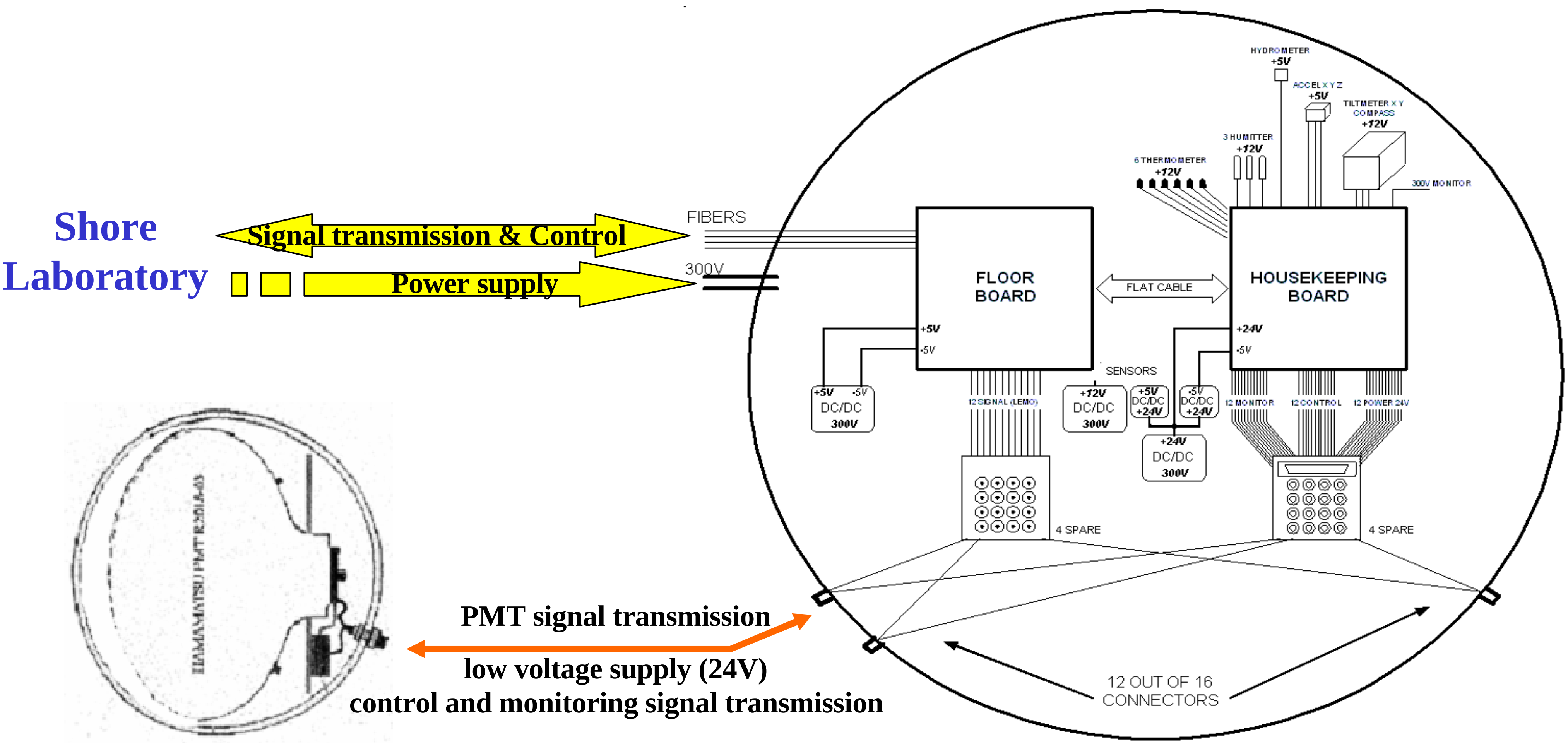
Hamamatsu PMT inside the BENTHOS sphere

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

ReadOut Electronics & DAQ Chain



Ti-Sphere Electronics



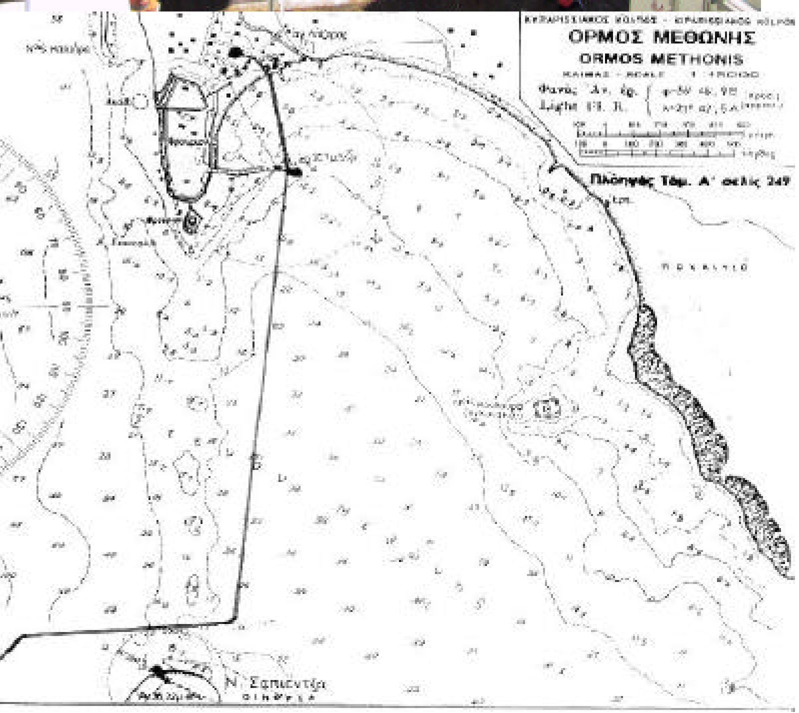
The Real Game: June 2000

ElectroOptical cable to shore (18 fibers +1 conductor)

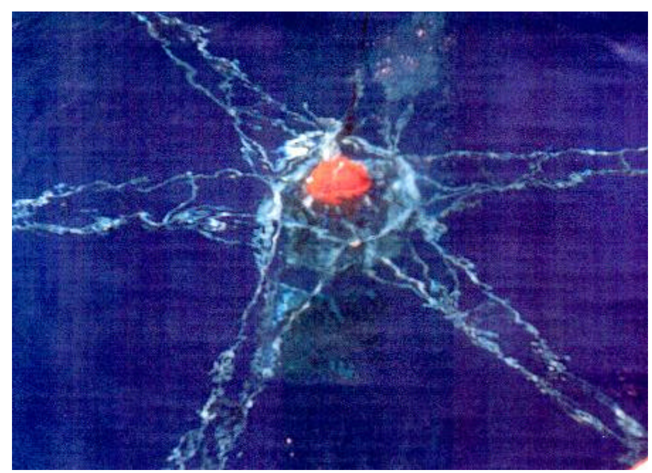
Deployed in June 2000 by the cableship MAERSK-FIGHTER (ALCATEL- TELEDANMARK)

Cable was damaged during laying because of ship’s problems. ALCATEL accepted responsibility and will repair the cable.

Cable landing has been completed and first three km have been buried 2 m inside the bottom sand.



Methoni counting room is fully operational.



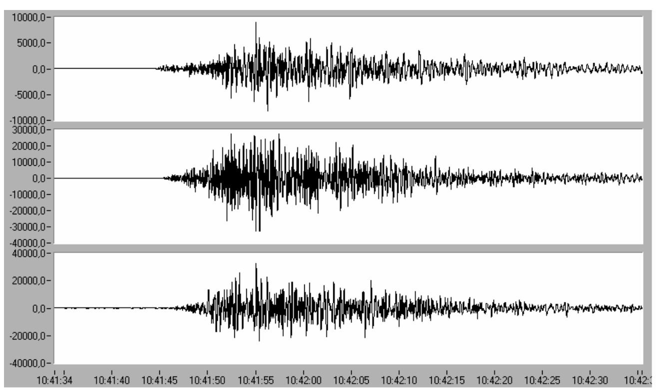
The Real Game: January 2002

ElectroOptical cable to shore (18 fibers +1 conductor)
Cable repaired in January 2002 by the cableship TENEO (TyCom)

Successful deployment of the anchor unit with environmental sensors to 4000m
A NESTOR floor deployment was postponed due to the bad weather conditions

15th of January: The first environmental data transmitted through the 35km ElectroOptical cable to the Methoni counting room

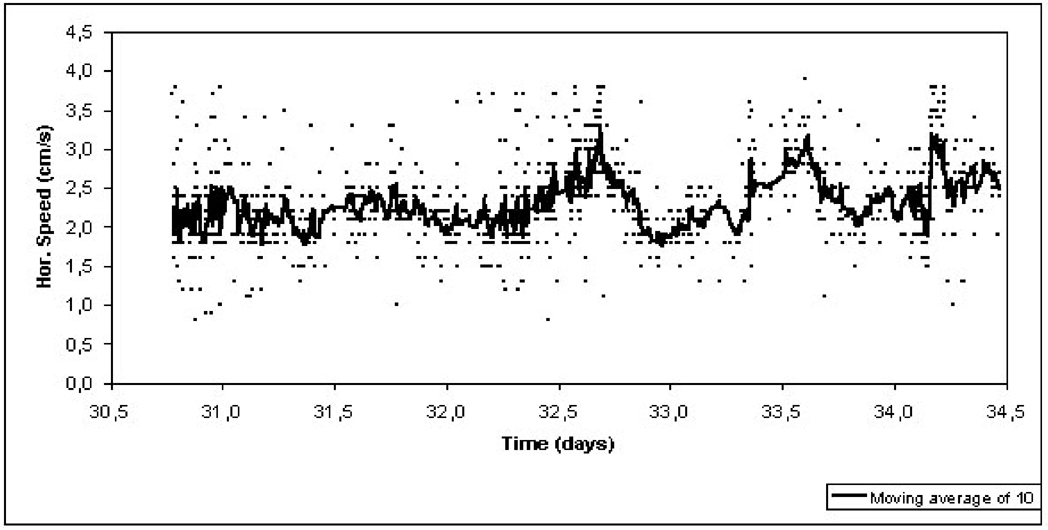
Geodynamic activity transmitted in Real Time

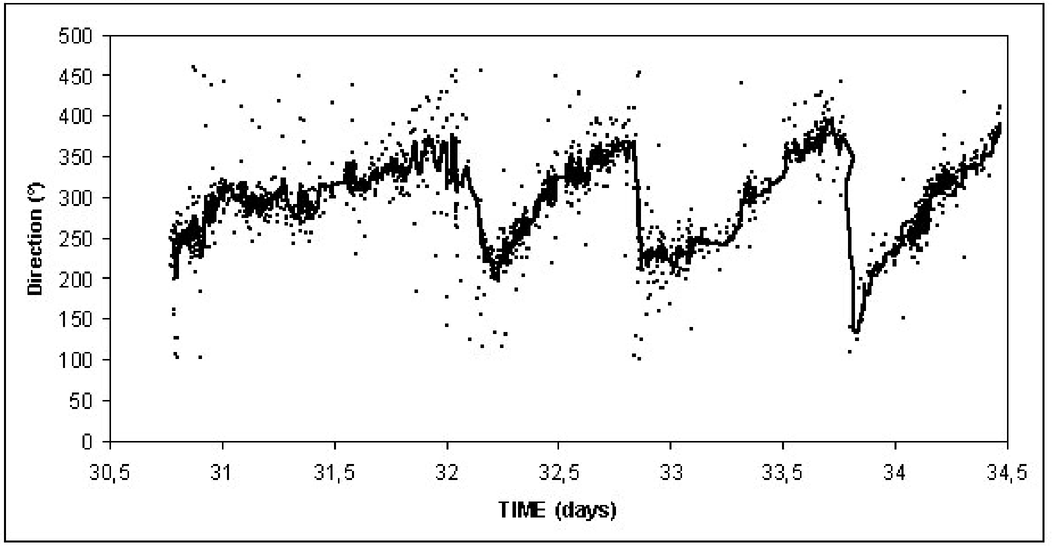


21.02.2002

Typical Current meter Data

transmitted in Real Time from the NESTOR site (4000m depth) through the 35km electrooptical cable





Our January 2002 deployment article, is published in this July issue of Sea Technology, plus, our pyramid-Bottom Station (LAERTIS) makes the cover picture of this journal.

2003

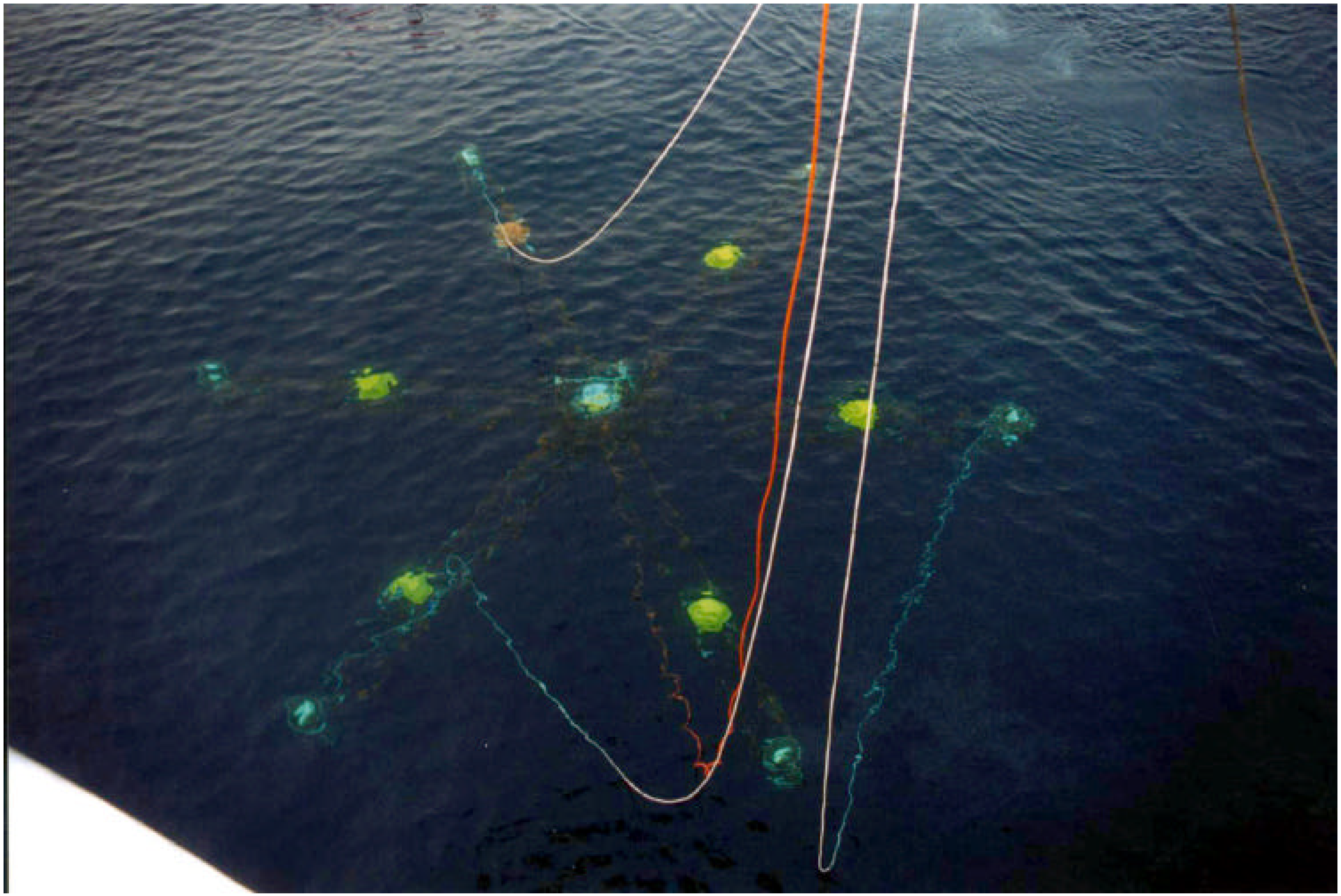
Successful deployment of one NESTOR star with 12 Optical Modules to 4000m

using the

cableship RAYMOND CROZE (FranceTelecom)

29th of March: The first deep sea muon data transmitted to shore

NESTOR Star Deployment (March 2003)



Ti-Sphere Electronics

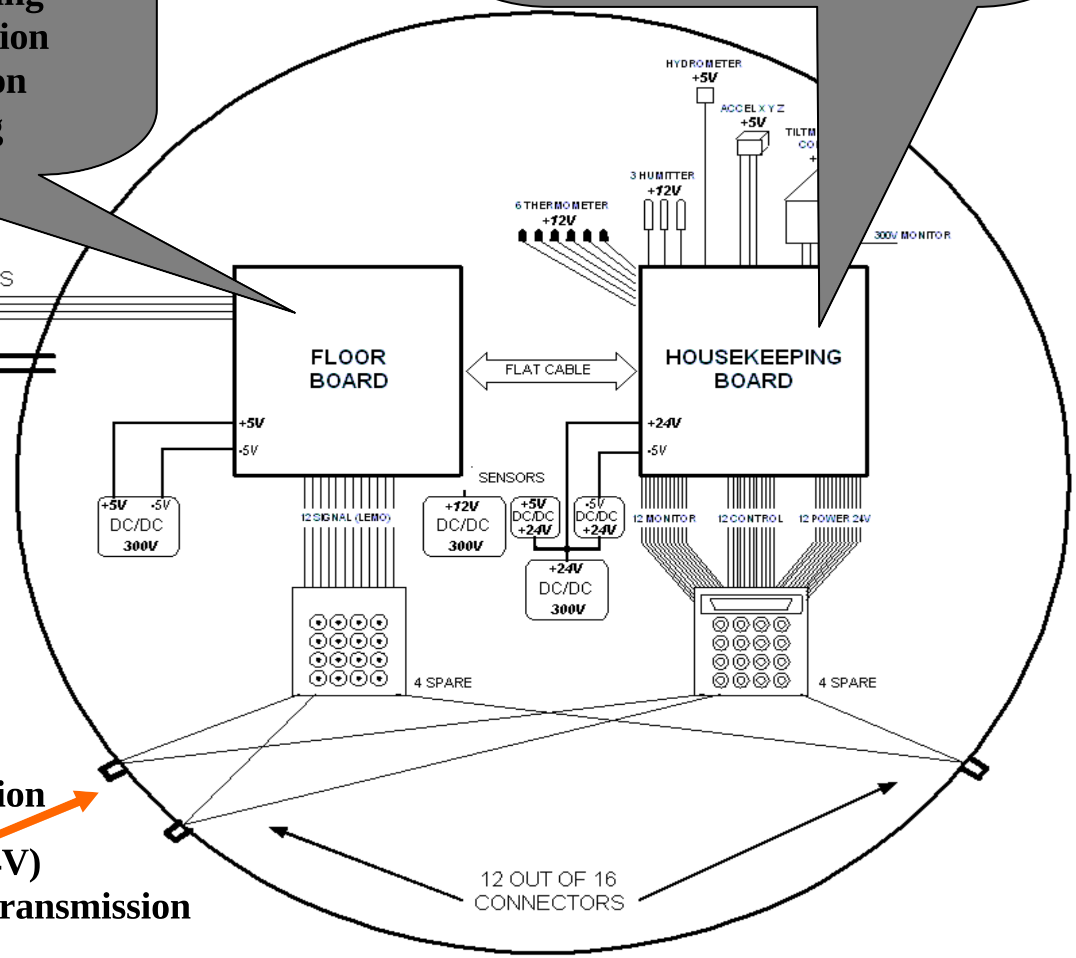
Floor Board
- PMT pulse sensing
- Majority logic event triggering
- Single & coincidence rate scaling
- Waveform capture & digitization
- Data formatting & transmission
- FPGA & PLD reprogramming

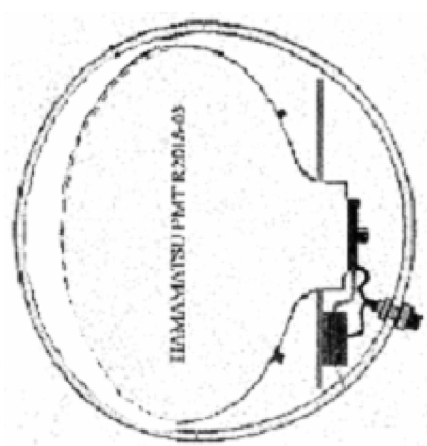
House Keeping Board
- PMT control
- Calibration Beakon control
- PMT HV monitor
- Power Supply monitors
- Environmental monitors

Shore Laboratory

Signal transmission & Control

Power supply





PMT signal transmission

low voltage supply (24V)

trol and monitoring signal transmission

Floor Board

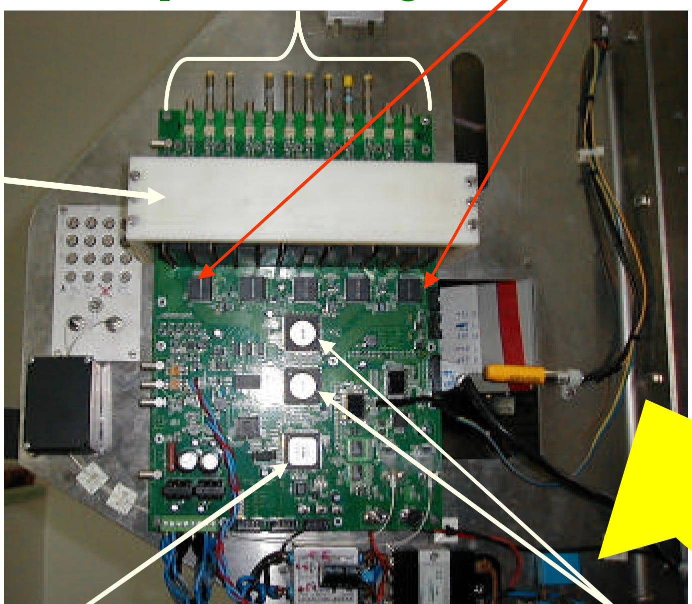
- PMT pulse sensing
- Majority logic event triggering
- Single & coincidence rate scaling
- Waveform capture & digitization
- Data formatting & transmission
- FPGA & PLD reprogramming

PMT Signal Capture & Digitization

5 ATWDs

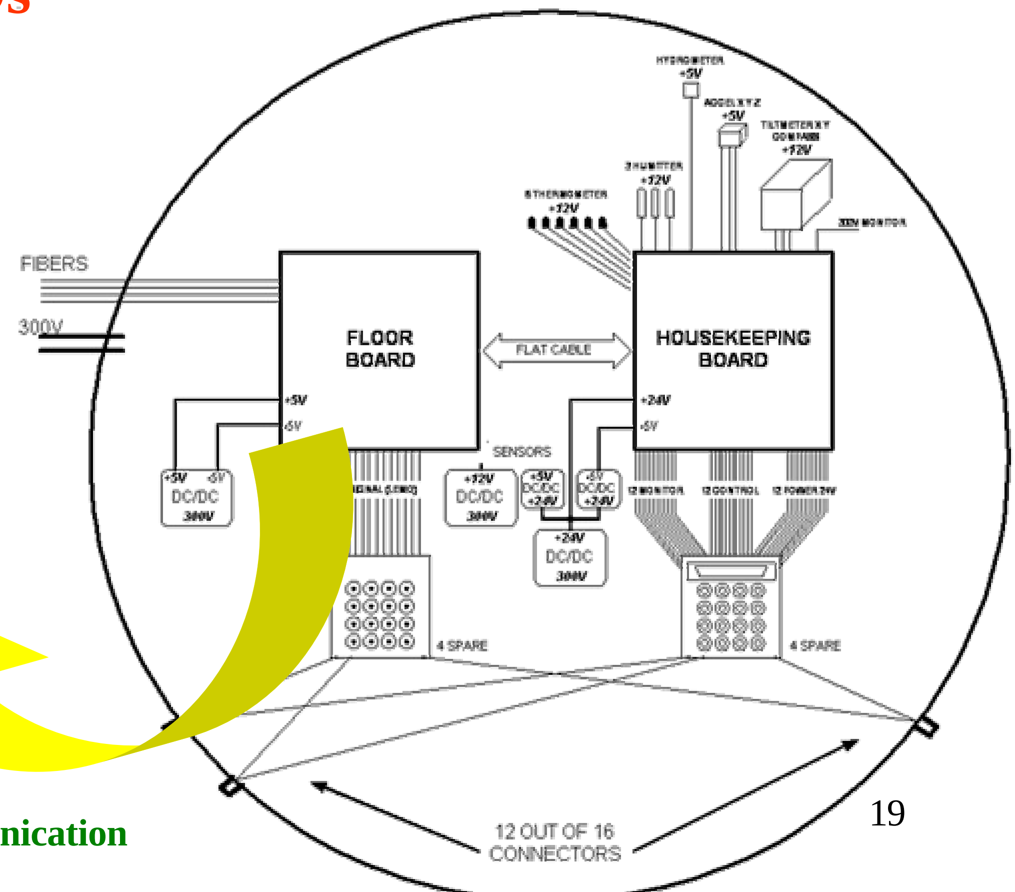
Input: 12 PMT signals

Delay lines

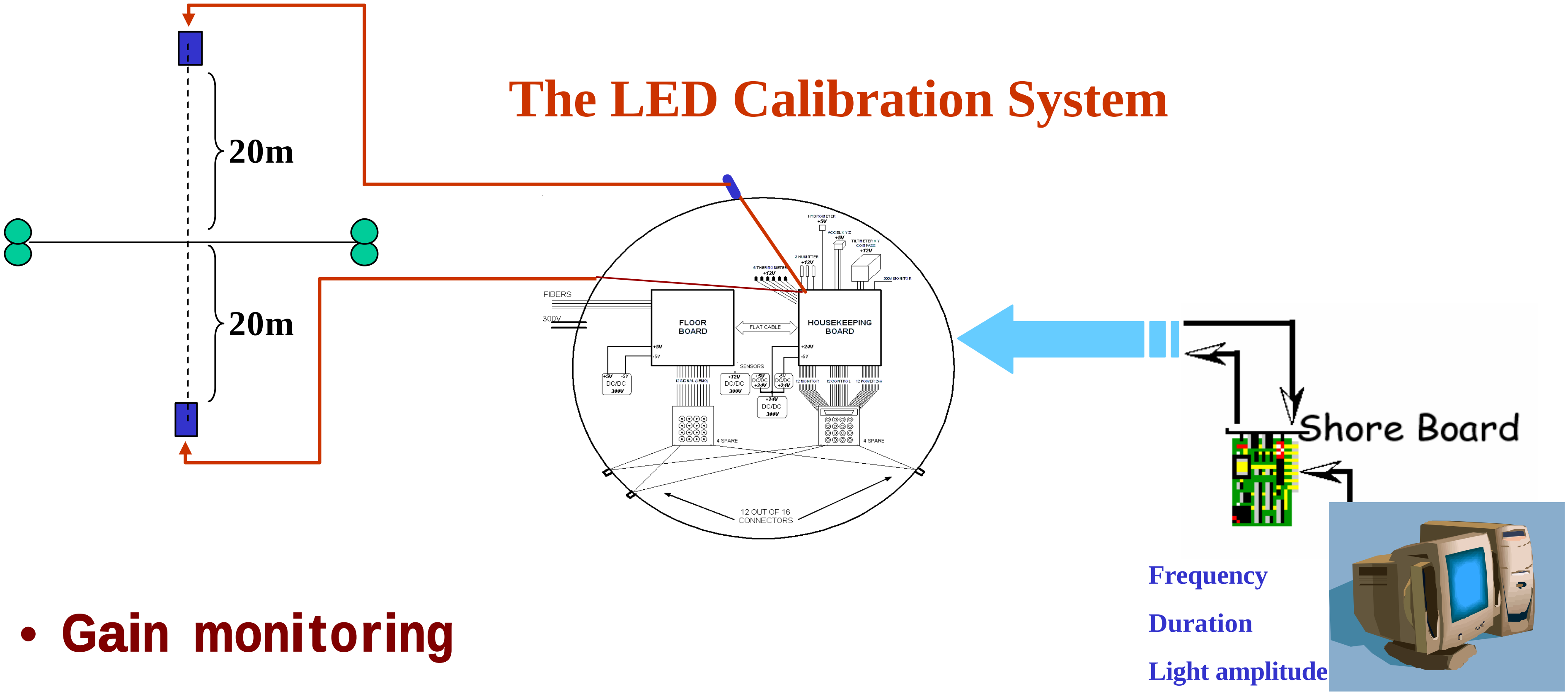


Configuration parameters
PLD

Trigger Logic & Communication
FPGAs



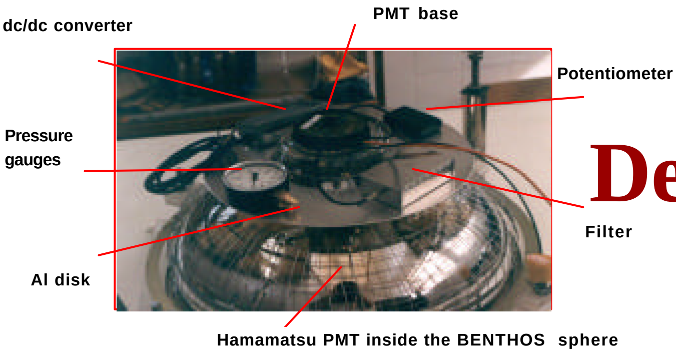
The LED Calibration System



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

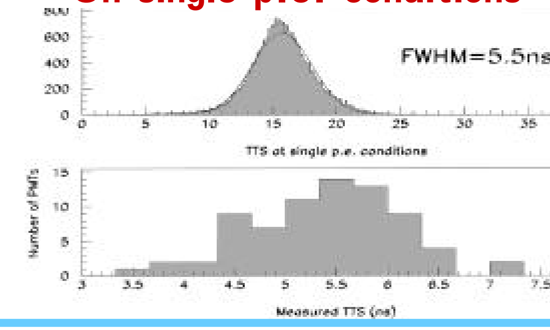
Detector Preparation

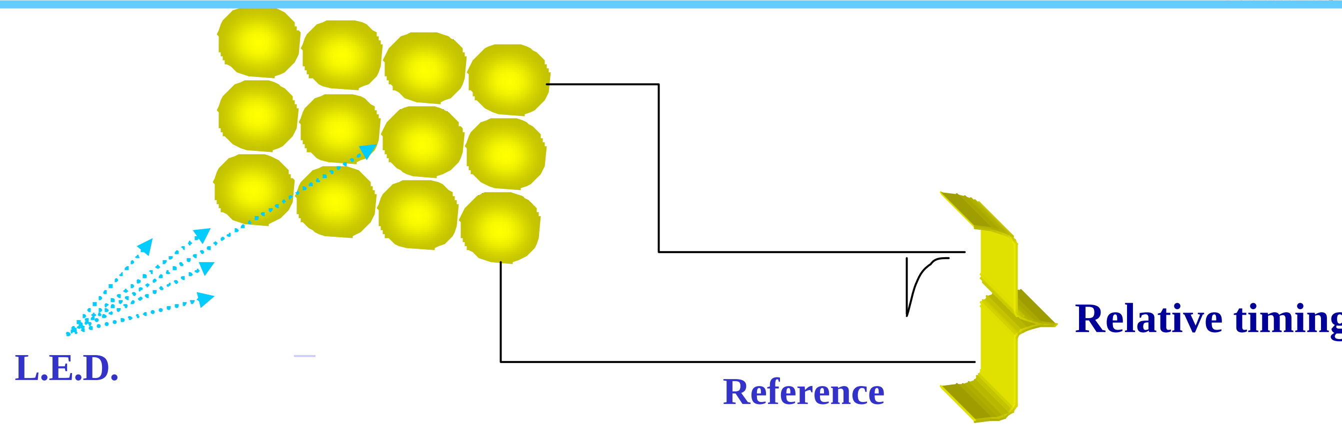
Optical Modules

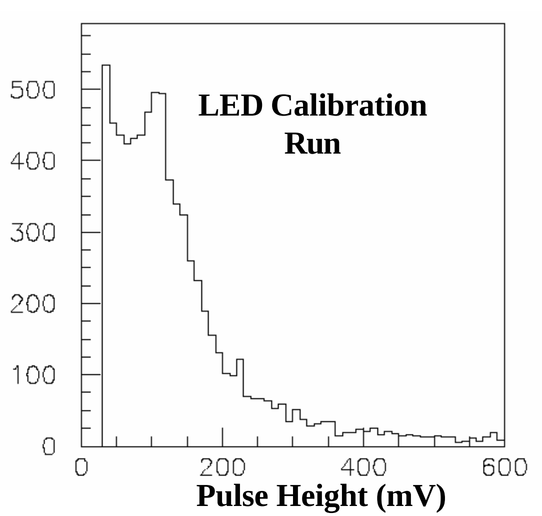


Extensive Lab tests

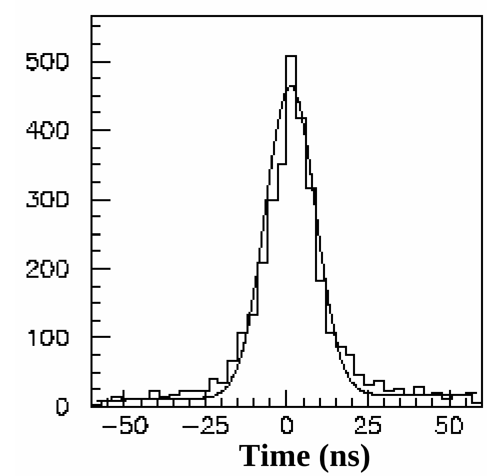
On single p.e. conditions



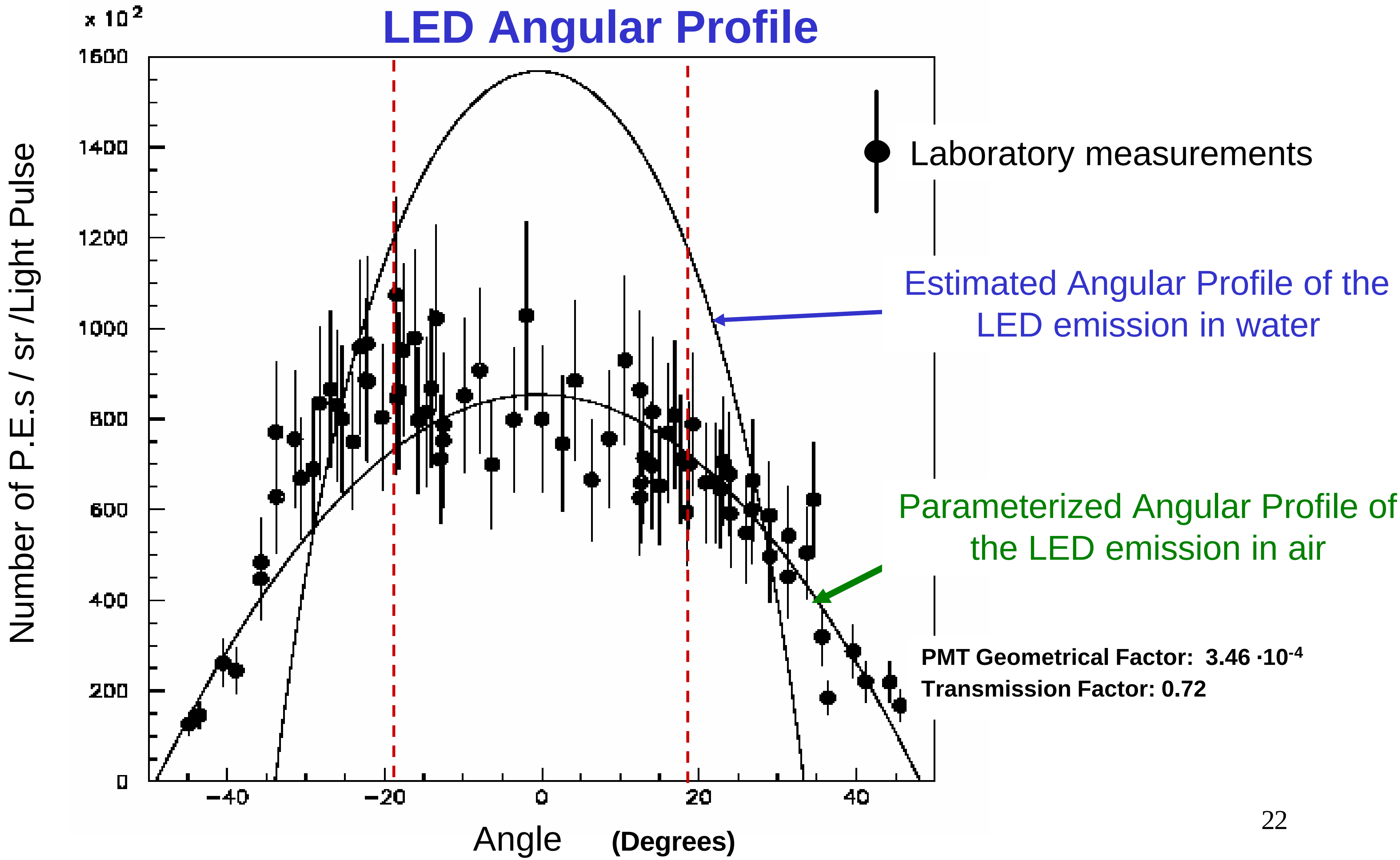




Time Difference in PMTs Response



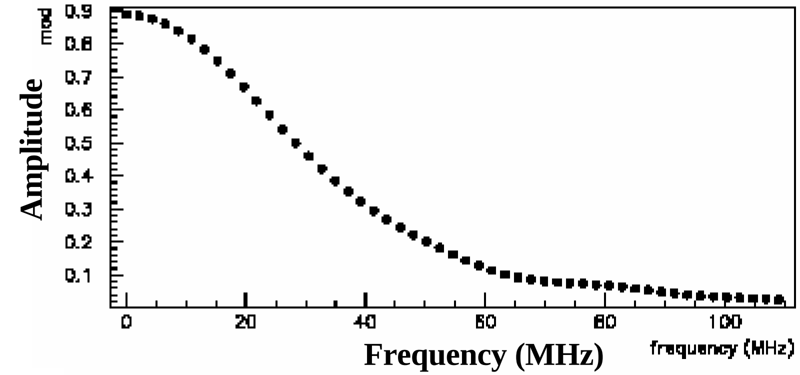
LED Angular Profile

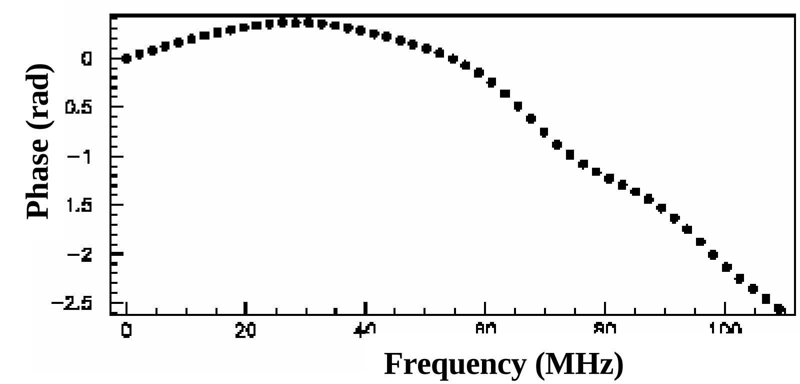


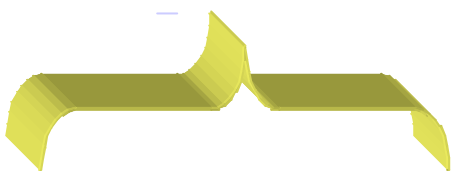
Detector Preparation

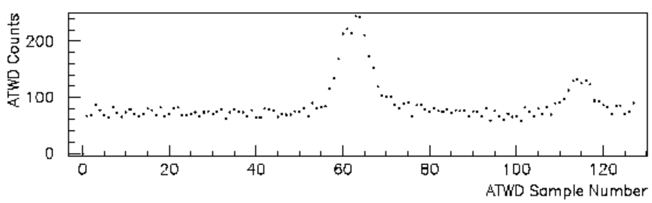
Attenuation Correction

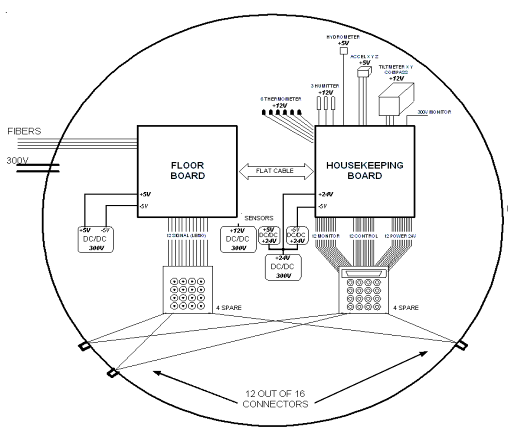
Fourier Transform-Comparison



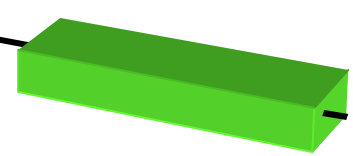


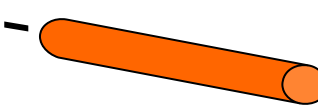






Reference waveform

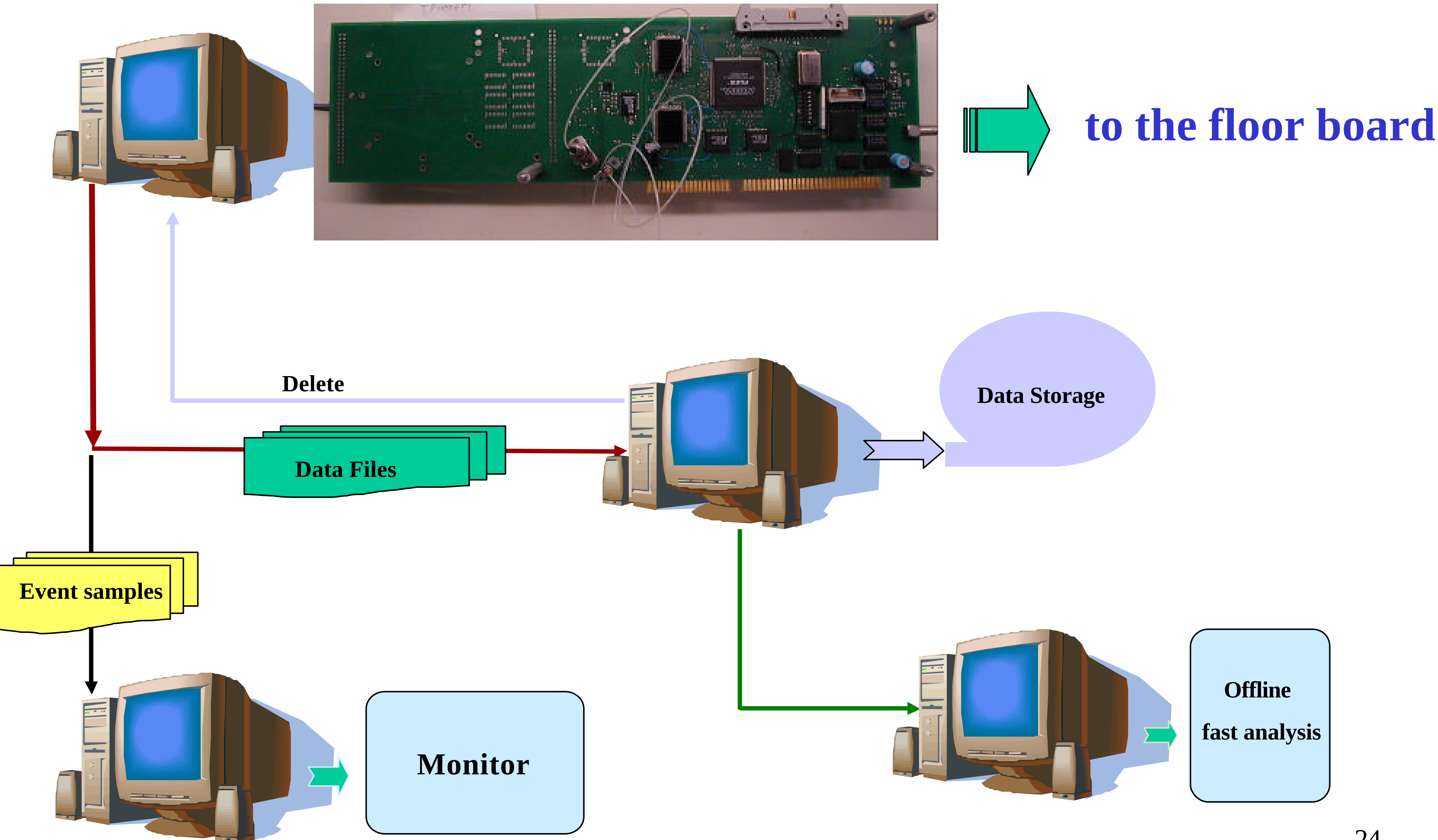


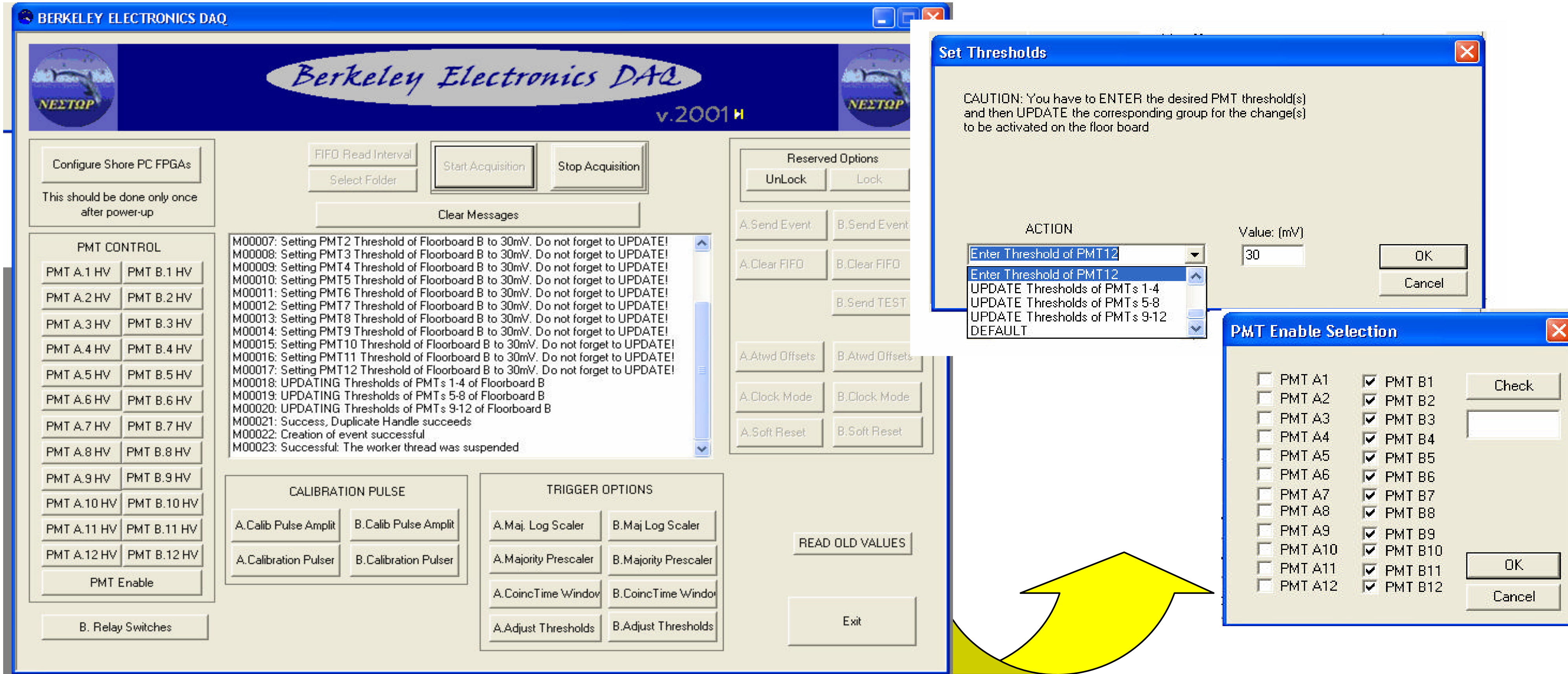


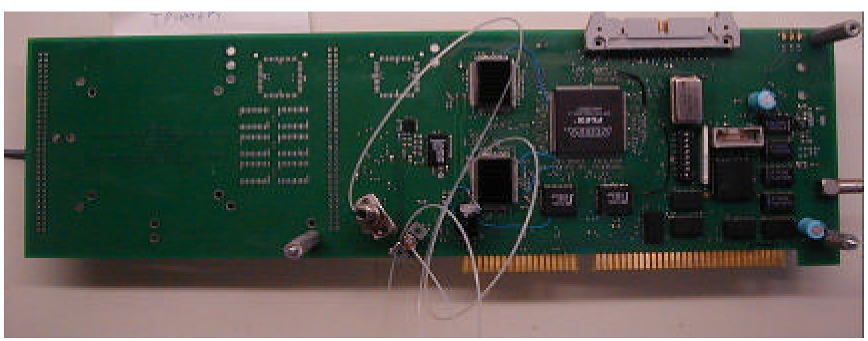
Electronic delay lines and amplifier

Coaxial cable

DAQ Architecture



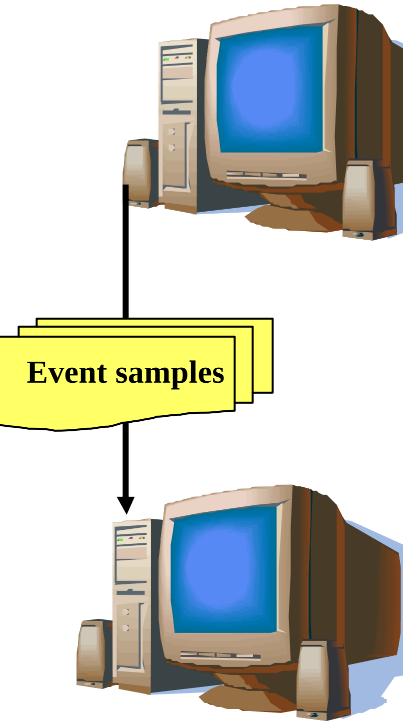


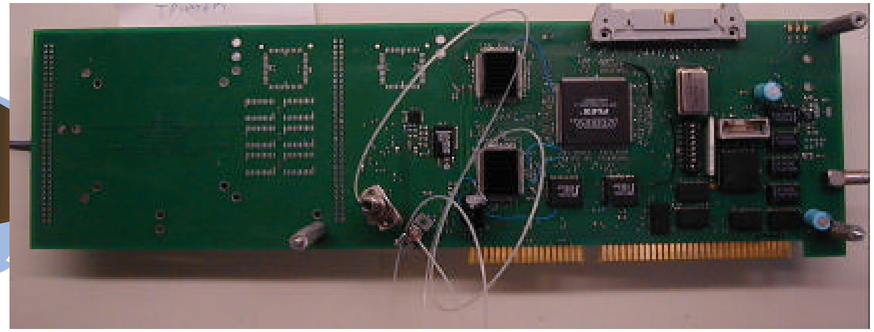


Shore Board

- Downloads the FPGAs & PLD of the Floor Board
- Broadcasts the 40Mhz clock
- Receives Data from the Floor Board
- Transmits Data to the Run Control System

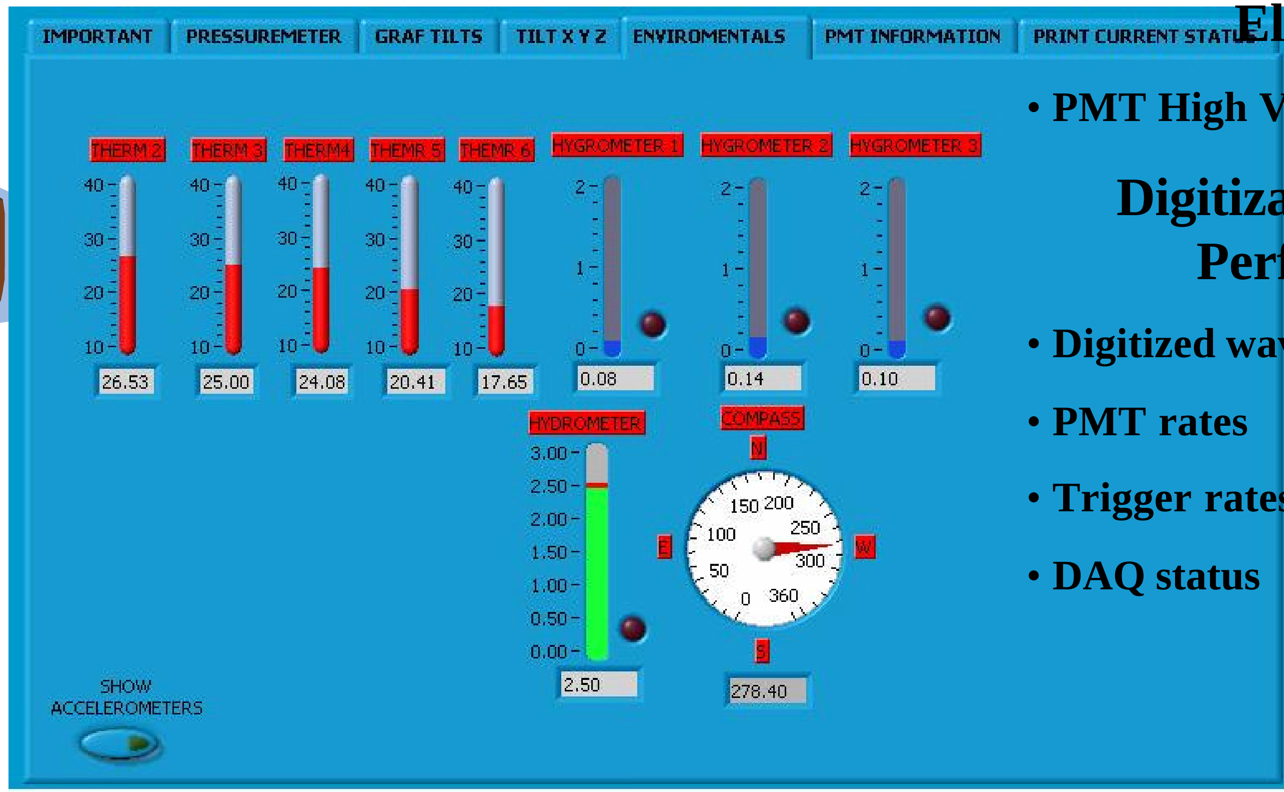
Real Time Monitor





Environmental

- Thermometers
- Hygrometers
- Compass
- Inclinometer/Accelerometer
- Pressure meter



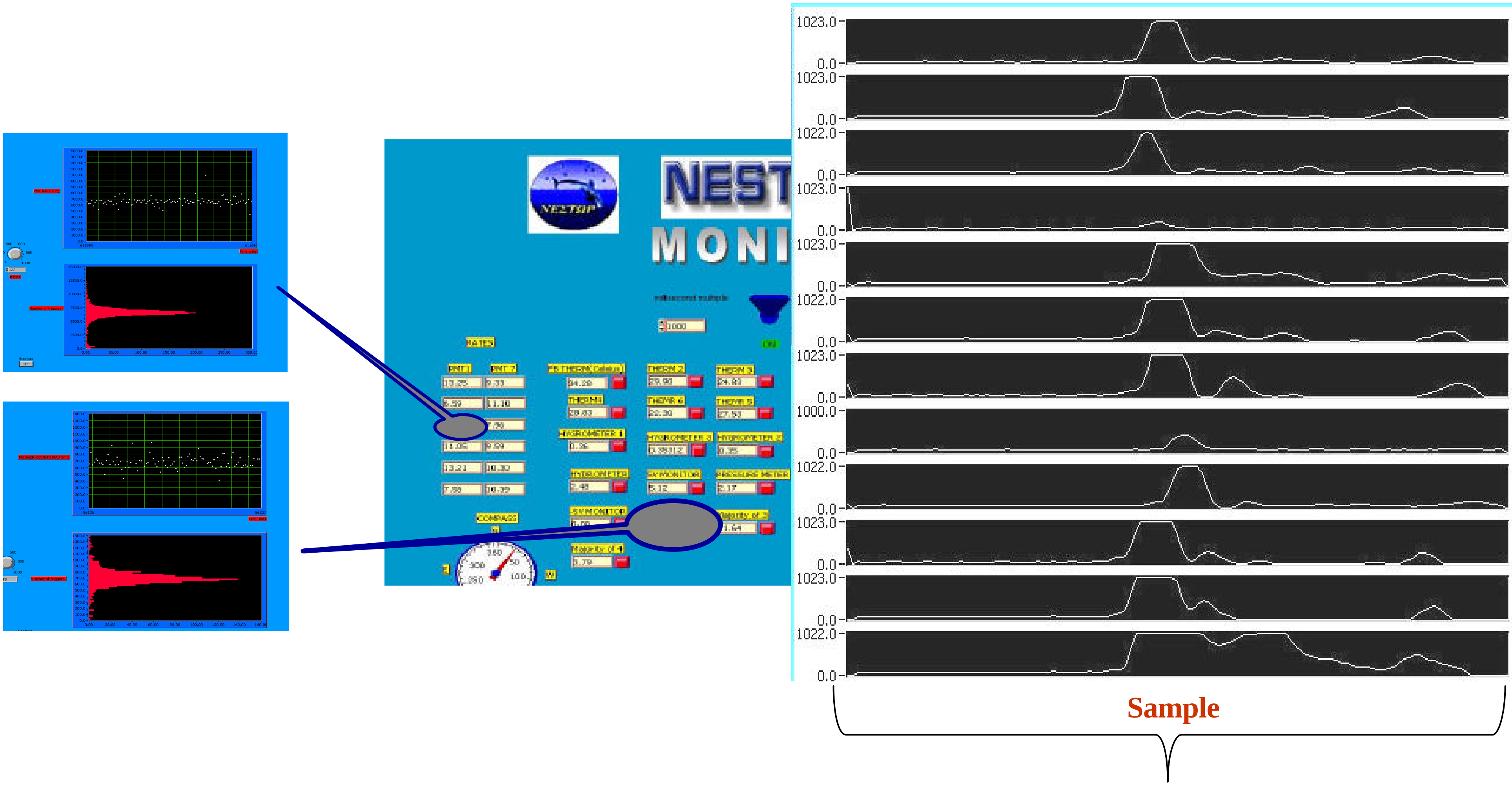
Electrical

- PMT High Voltage etc

Digitization & DAQ Performance

- Digitized waveforms
- PMT rates
- Trigger rates
- DAQ status

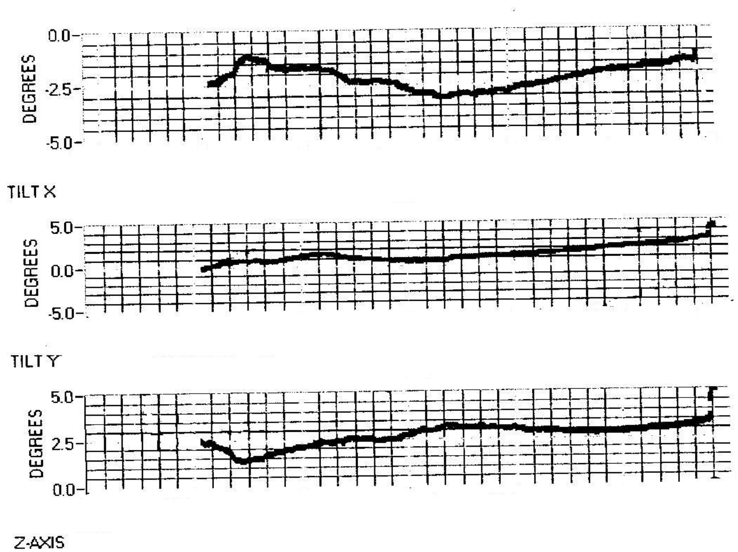
Real Time Monitors

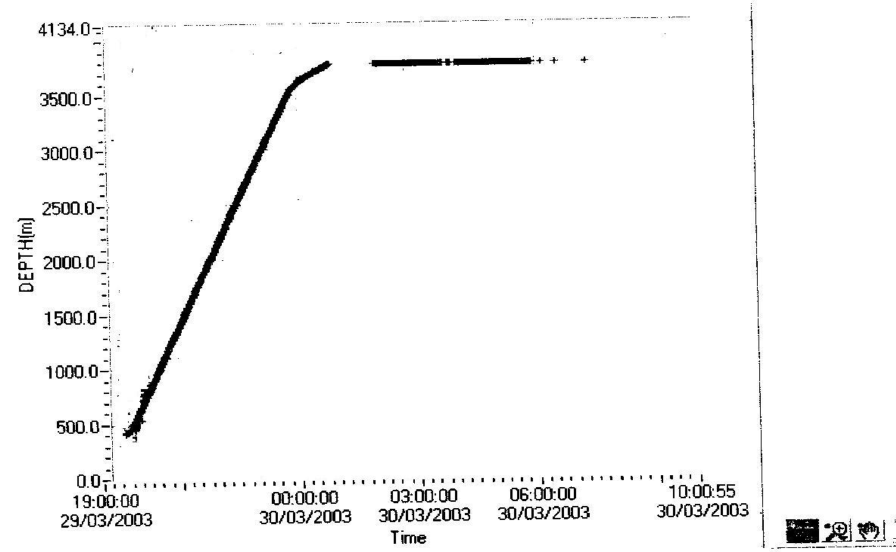


Sample

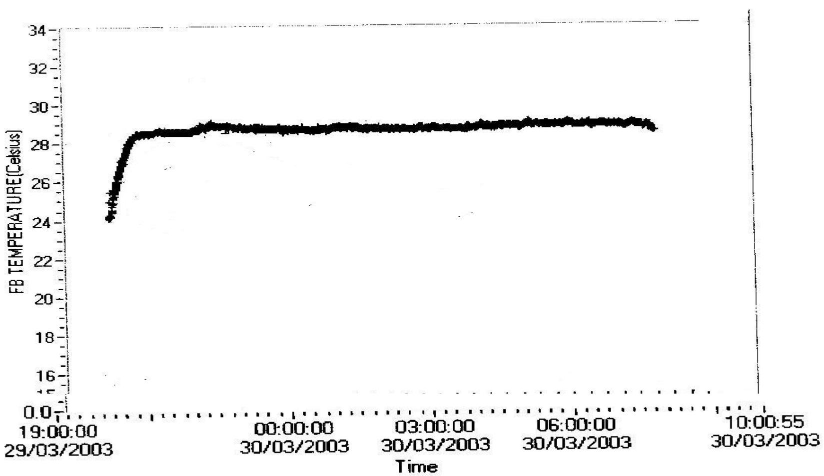
448 ns

During deployment

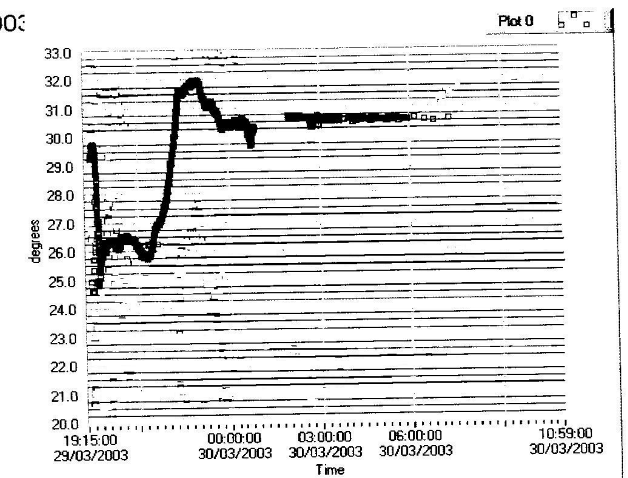




3/30/2003



3/30/20031:26 AM

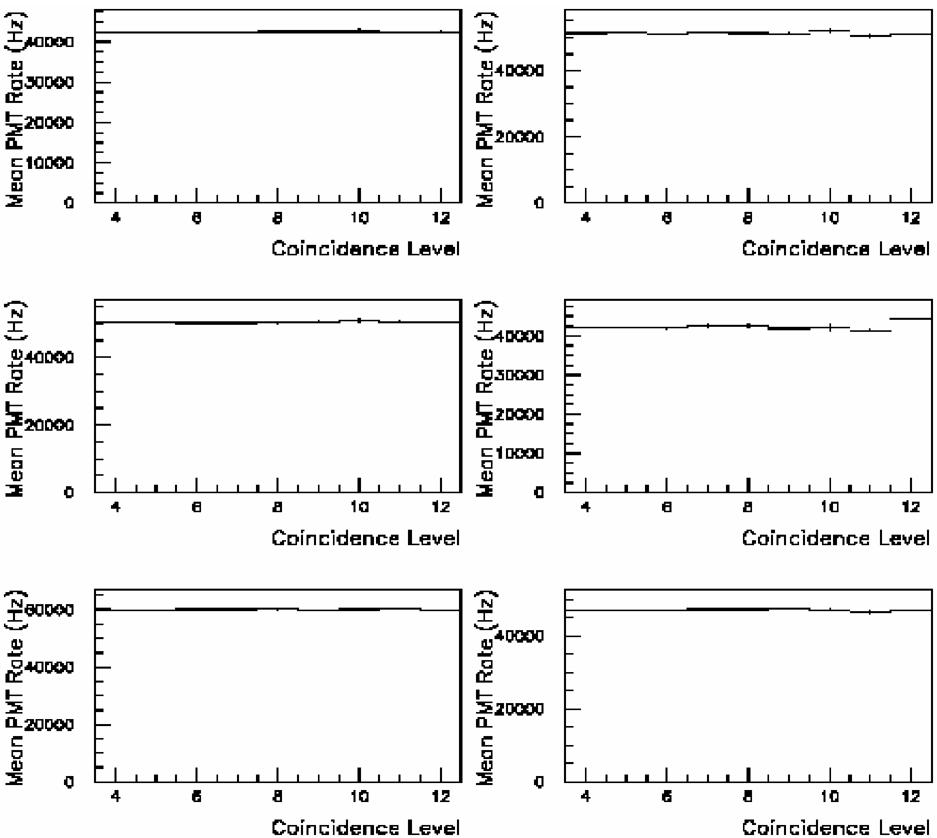


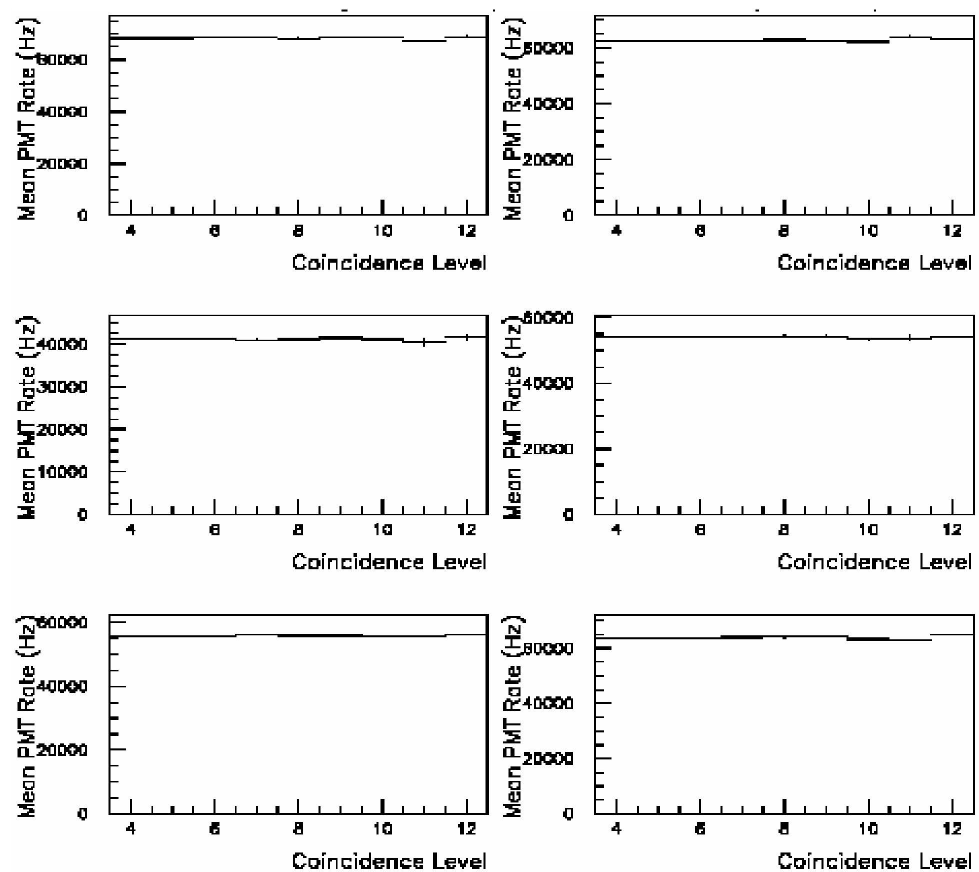
3/30/20036:58 AM

Data from a depth of 4000 m

Single PMT Rates

Trigger: =4fold Coincidence

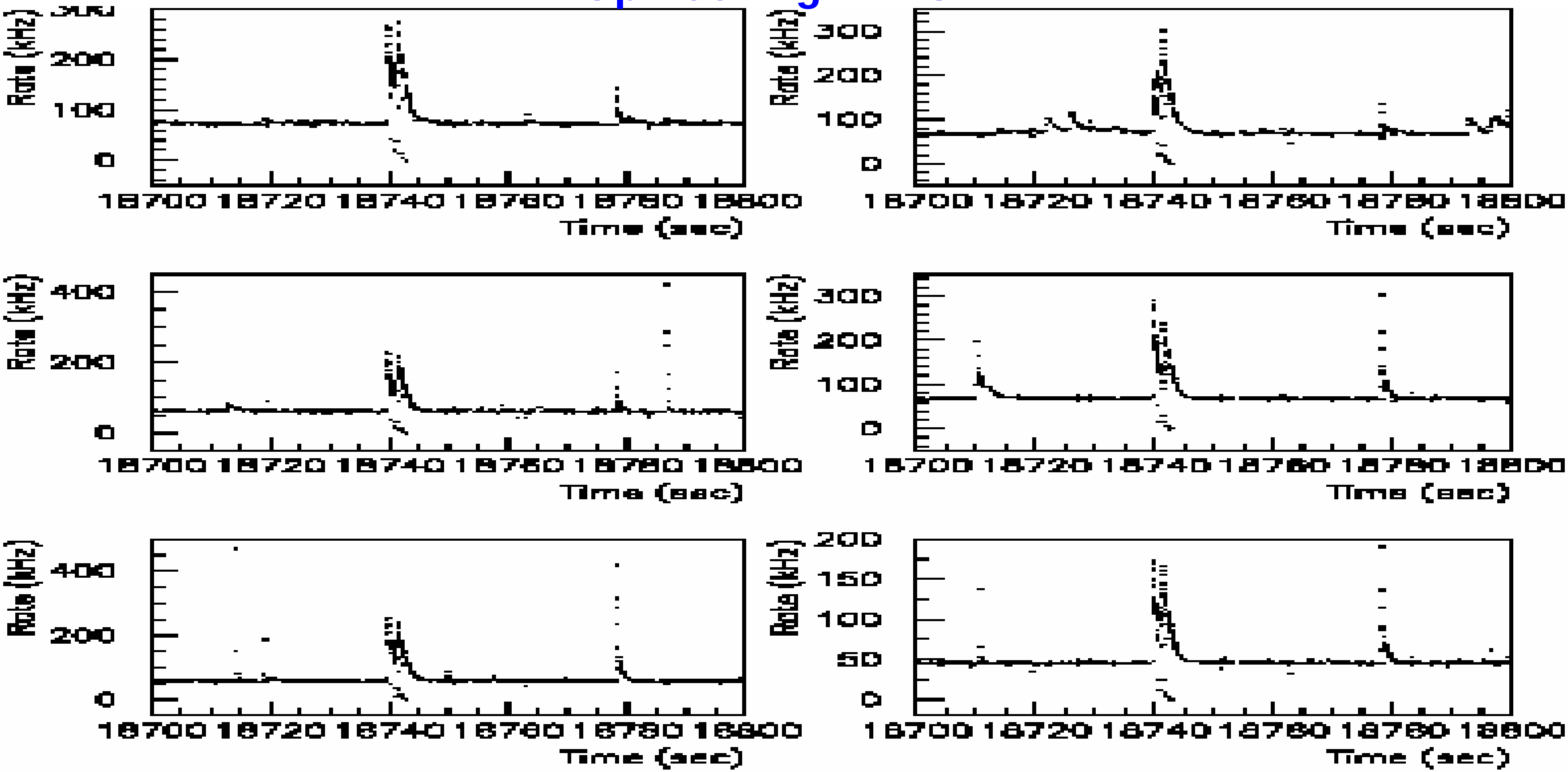




Data from a depth of 4000 m

PMT Rates vs Time

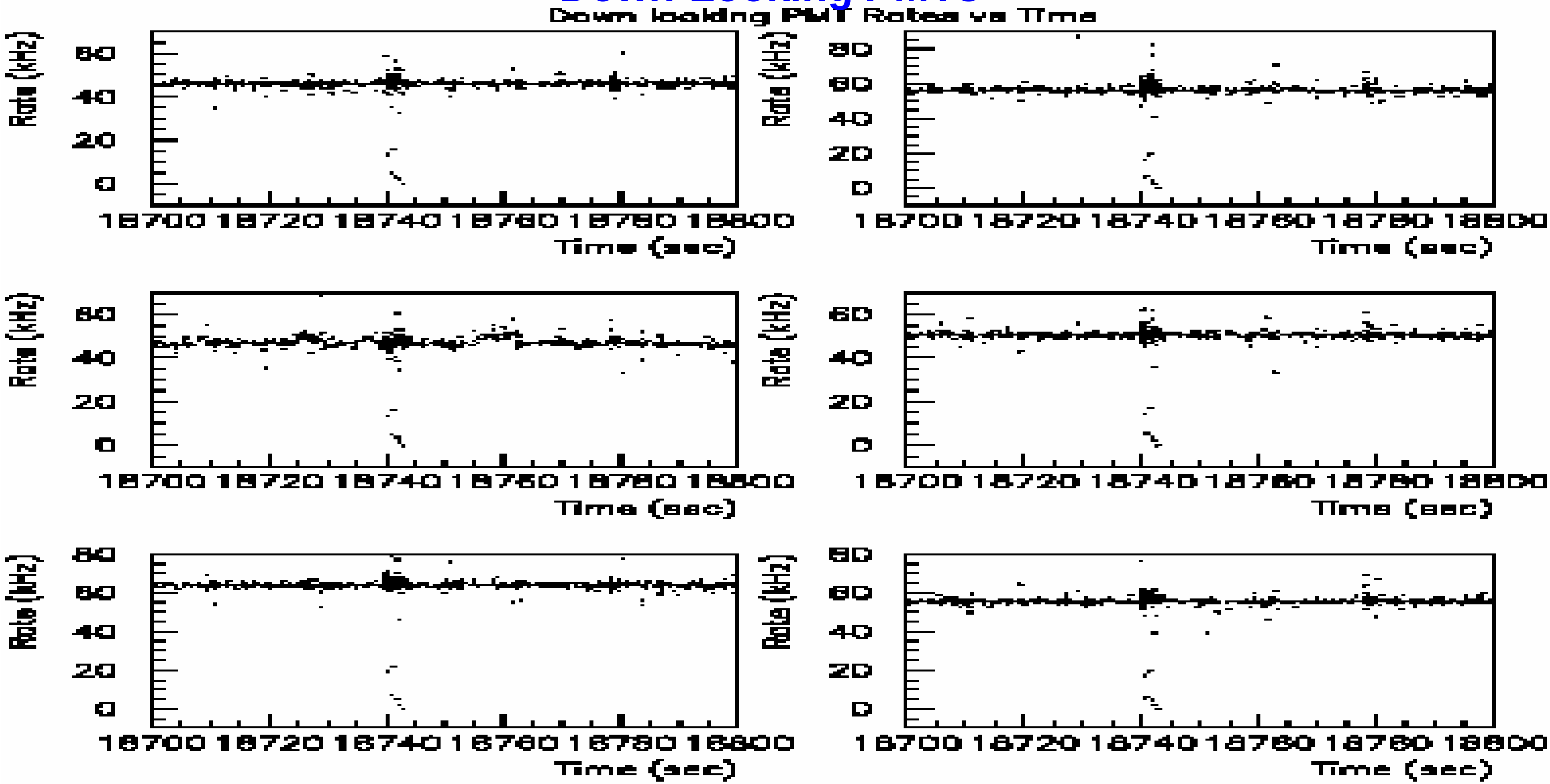
Up-Looking PMTs



Data from a depth of 4000 m

PMT Rates vs Time

Down-Looking PMTs



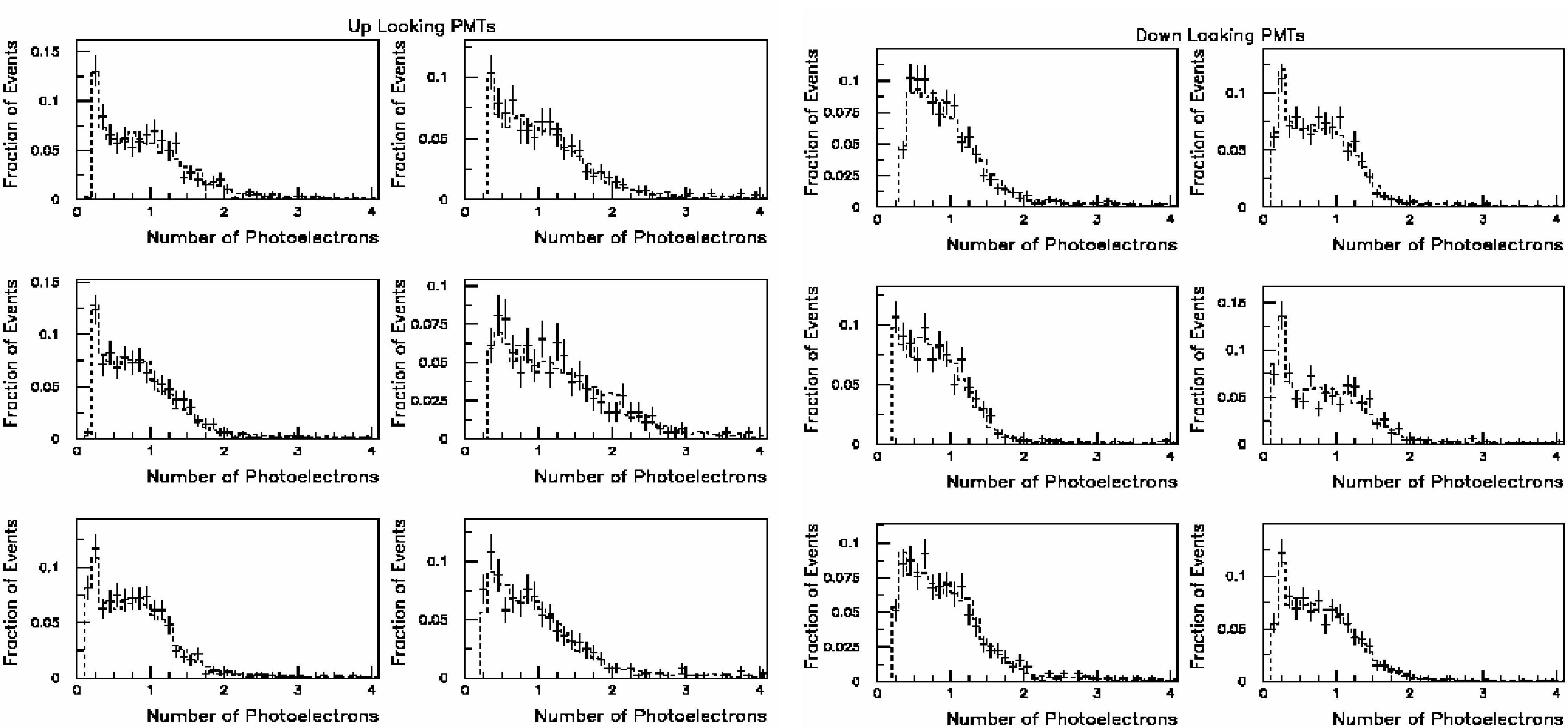
Data from a depth of 4000 m

Number of Collected P.E.s

Trigger: = 4fold Coincidence

During Bioluminescence Activity

Bioluminescence Activity Excluded



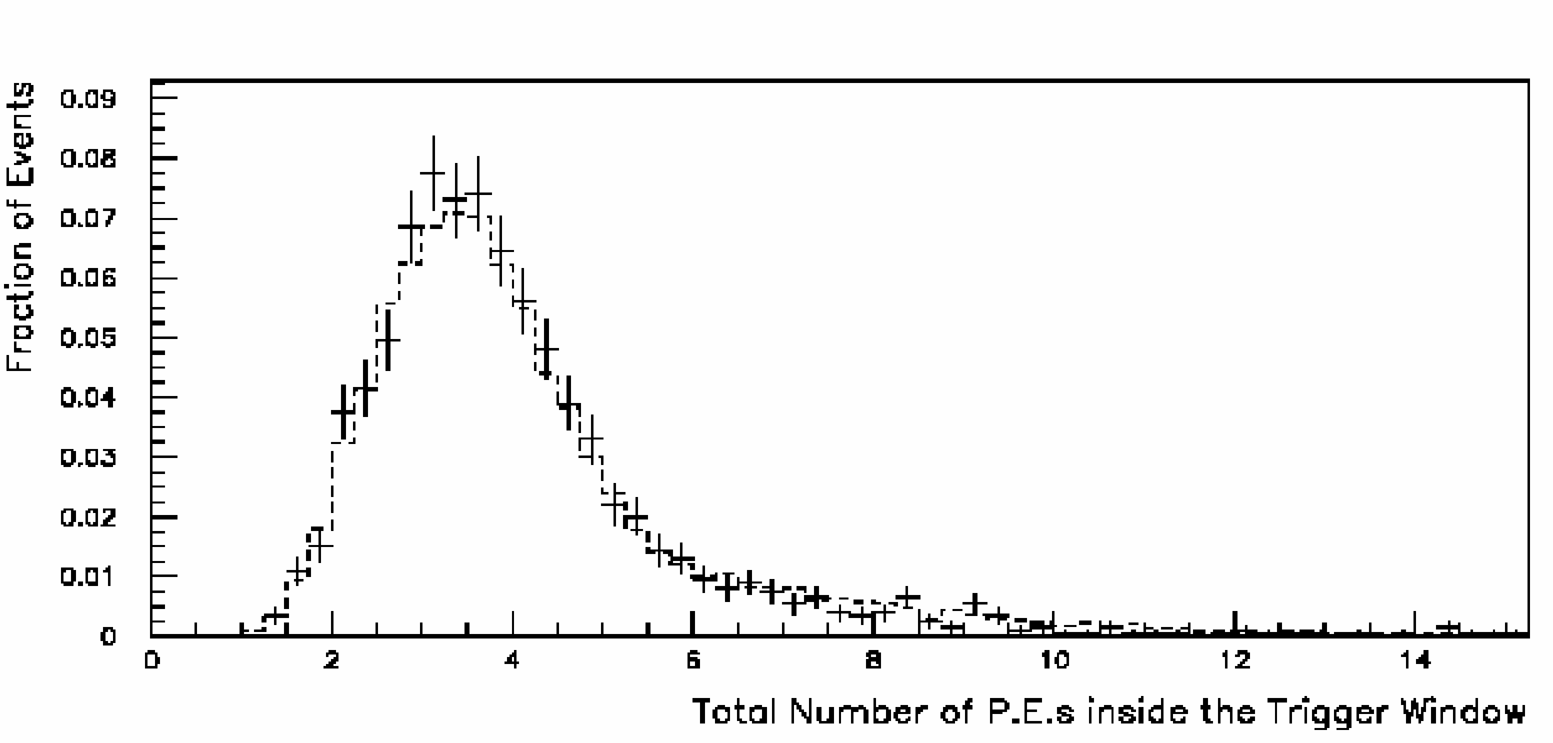
Data from a depth of 4000 m

Total Number of P.E.s Inside the Trigger Window

Trigger: =4fold Coincidence

During Bioluminescence Activity

Bioluminescence Activity Excluded



Data from a depth of 4000 m

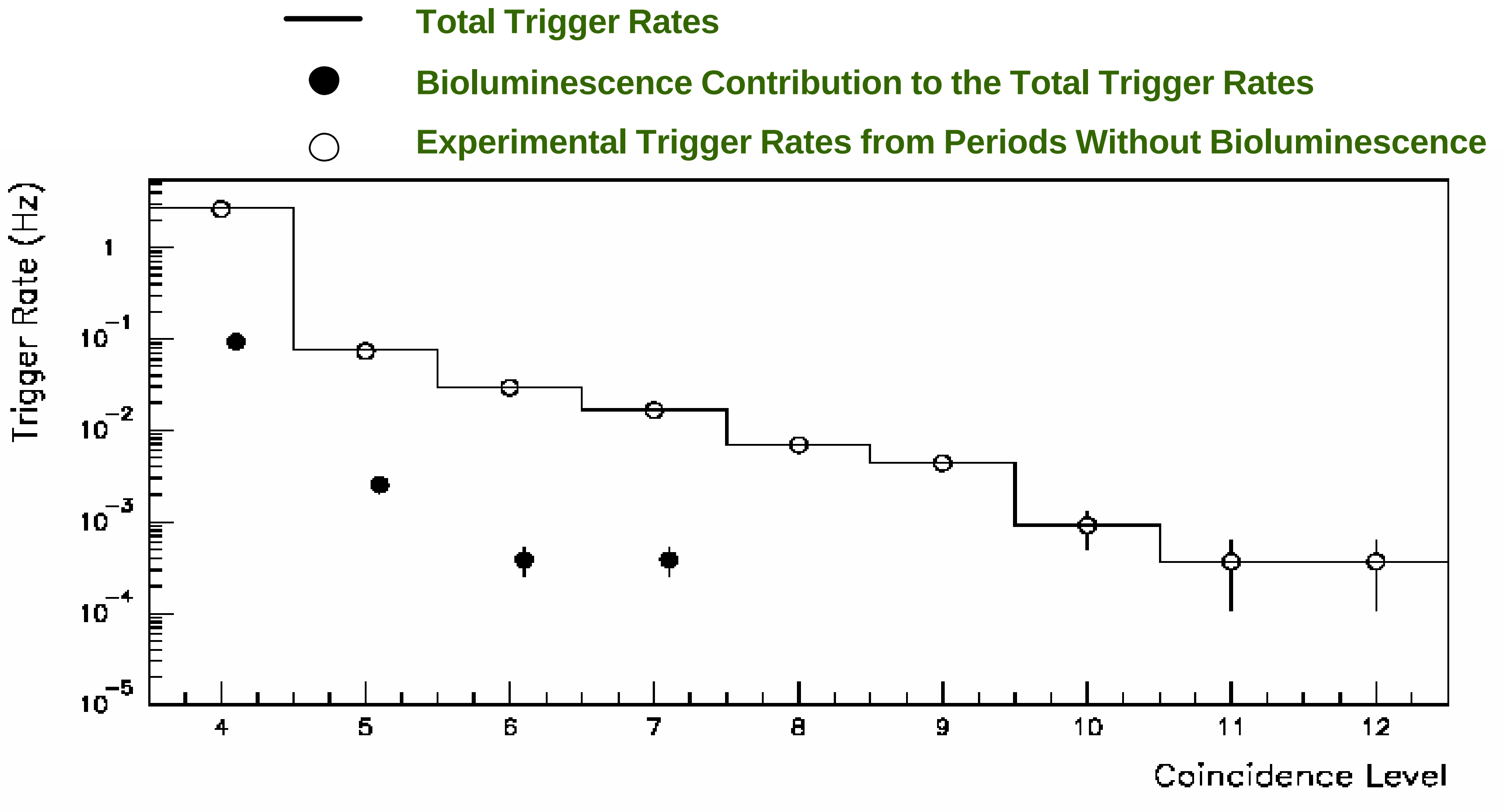
Bioluminescence Contribution to the Total Trigger Rates

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

Total Trigger Rates

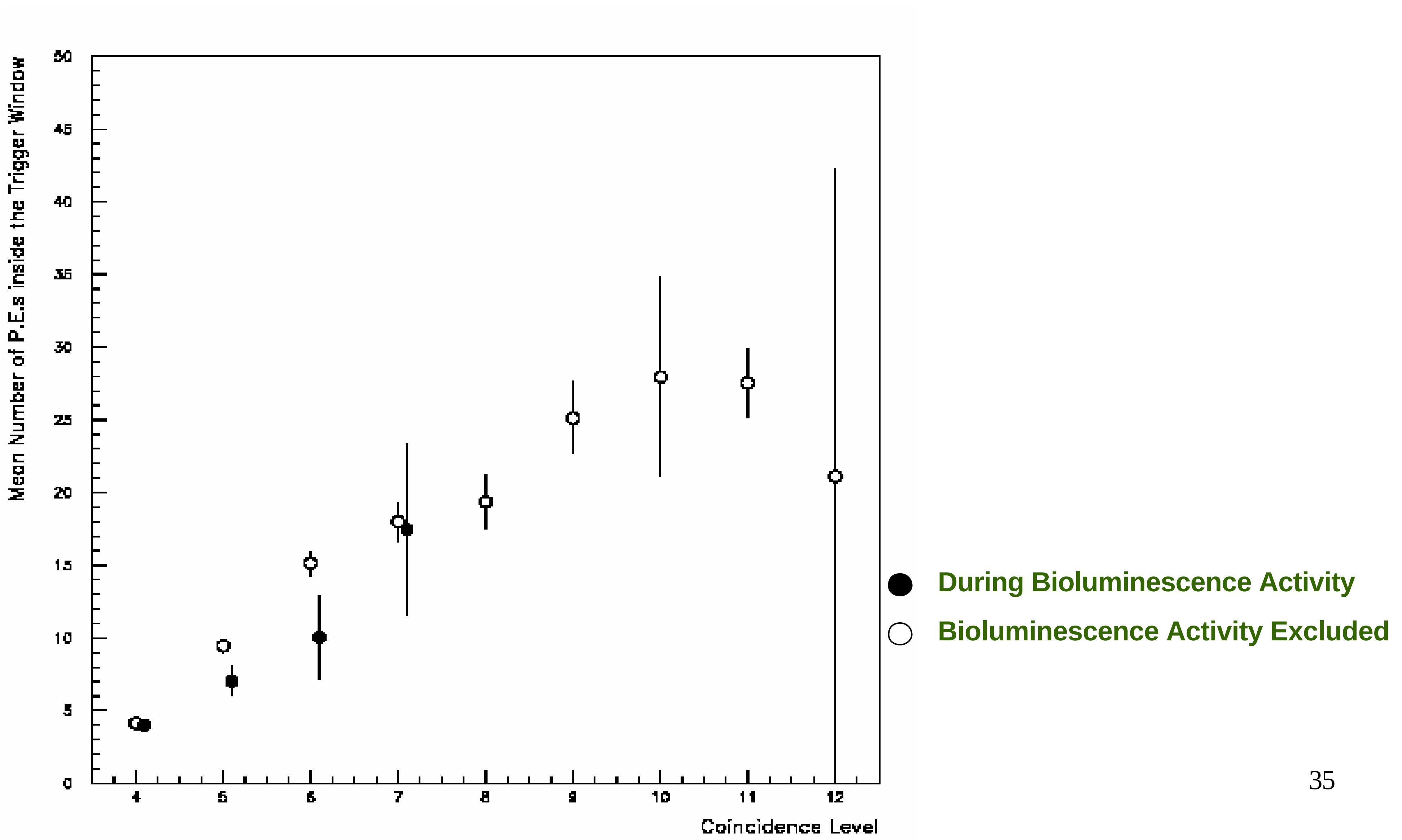
Bioluminescence Contribution to the Total Trigger Rates

Experimental Trigger Rates from Periods Without Bioluminescence

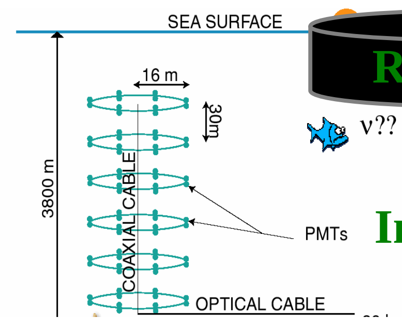


Data from a depth of 4000 m

Total Number of P.E.s Inside the Trigger Window



Data Analysis Flow



Raw Data

Interface

Software Monitor Histograms

Database
(gains, baselines,attenuation etc)

F A S T S I M

muon track generation

muon propagation & ? shower generation

Cherenkov photon emission and propagation

PMT response simulation

Digitization
ATWD &Trigger simulation

G E A N T

background noise

Waveform Reconstruction

Hit Definition

DST Production

Data Quality Histograms

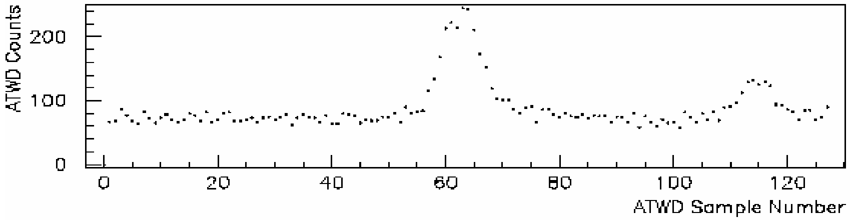
Calibration Data Analysis

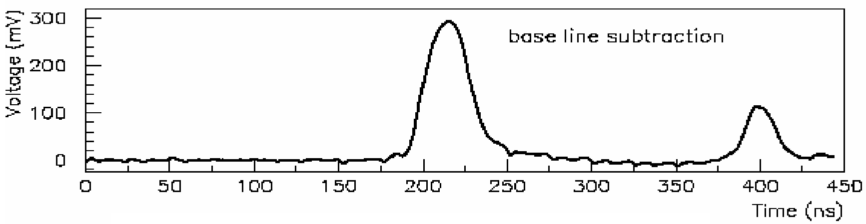
Calibration Database Quality Histograms

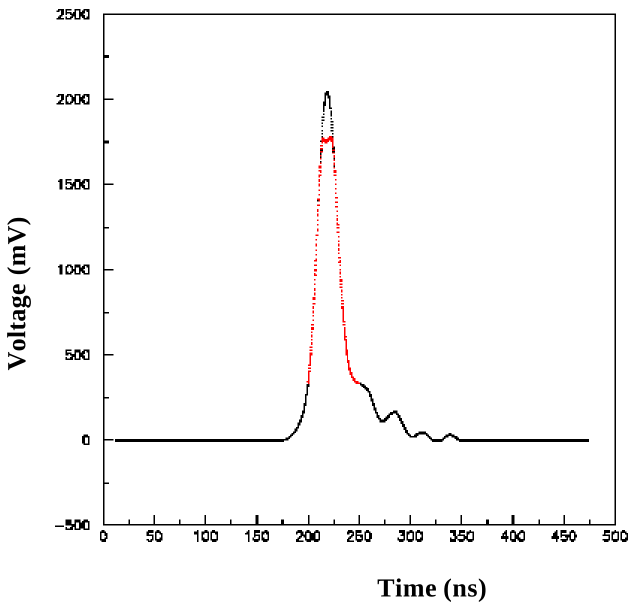
Track Reconstruction

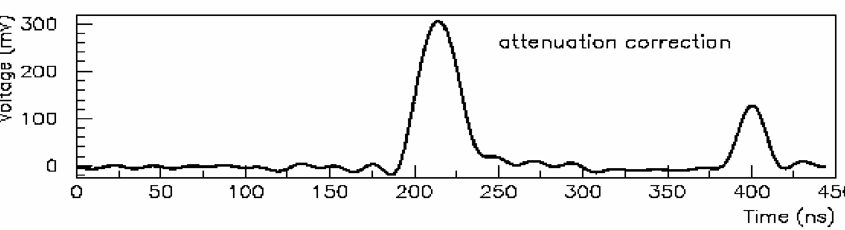
MiniDST
Ntuples & Histograms

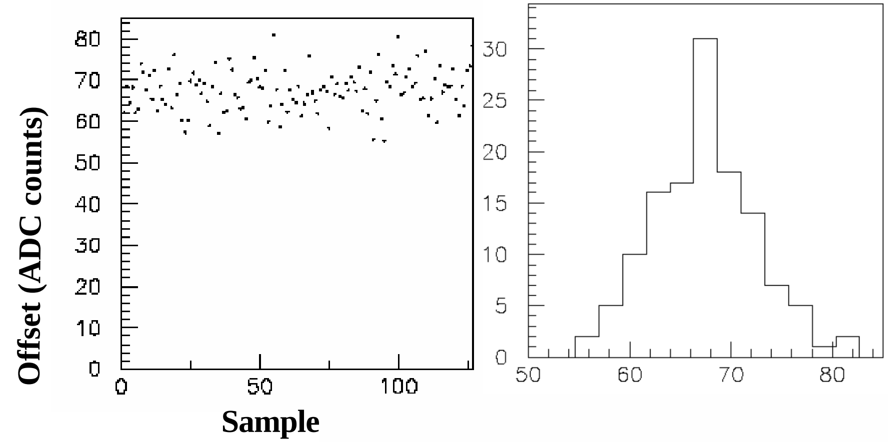
Waveform Reconstruction

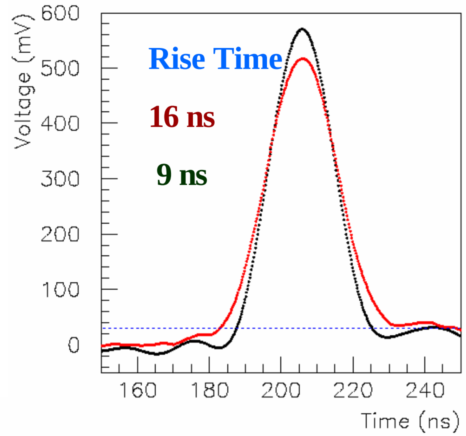


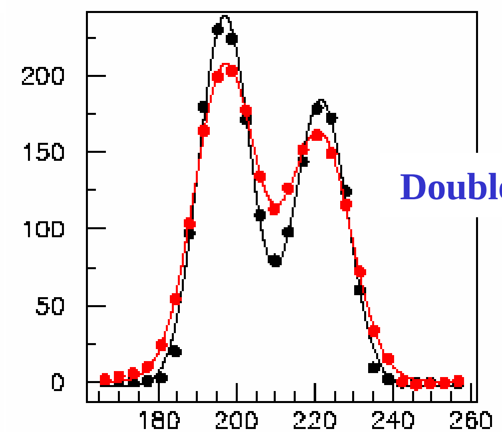












Double pulse separation

Before the F.F.T. and the attenuation corrections

After the F.F.T. and the attenuation corrections

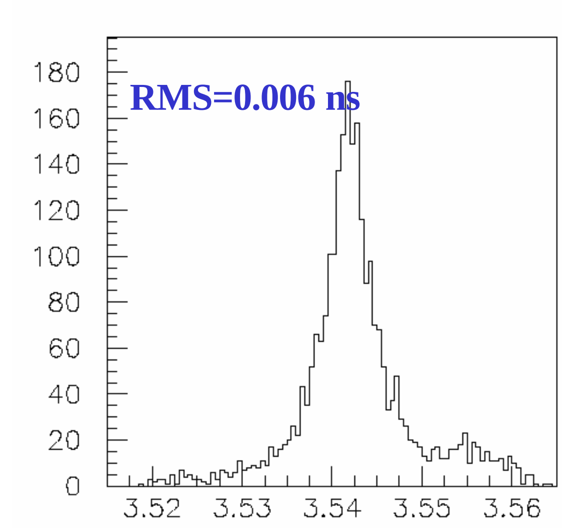
Waveform Reconstruction

Hit Definition

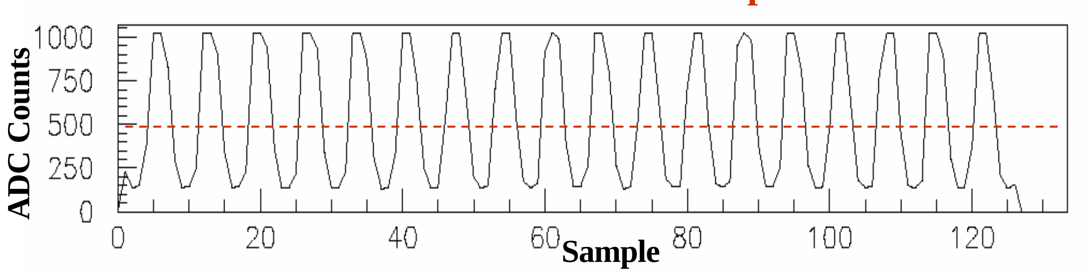
DST Production

Data Quality Histograms

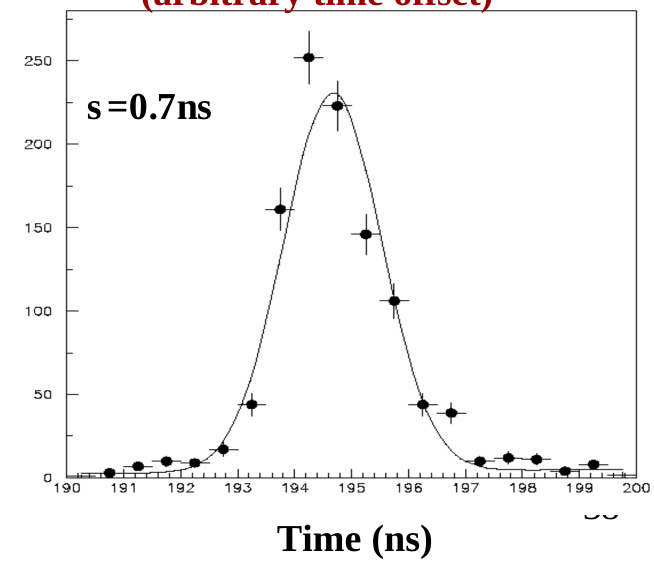
Event by Event Sampling Interval Variation (Constant Temperature)



40 MHz Clock Waveform Capture

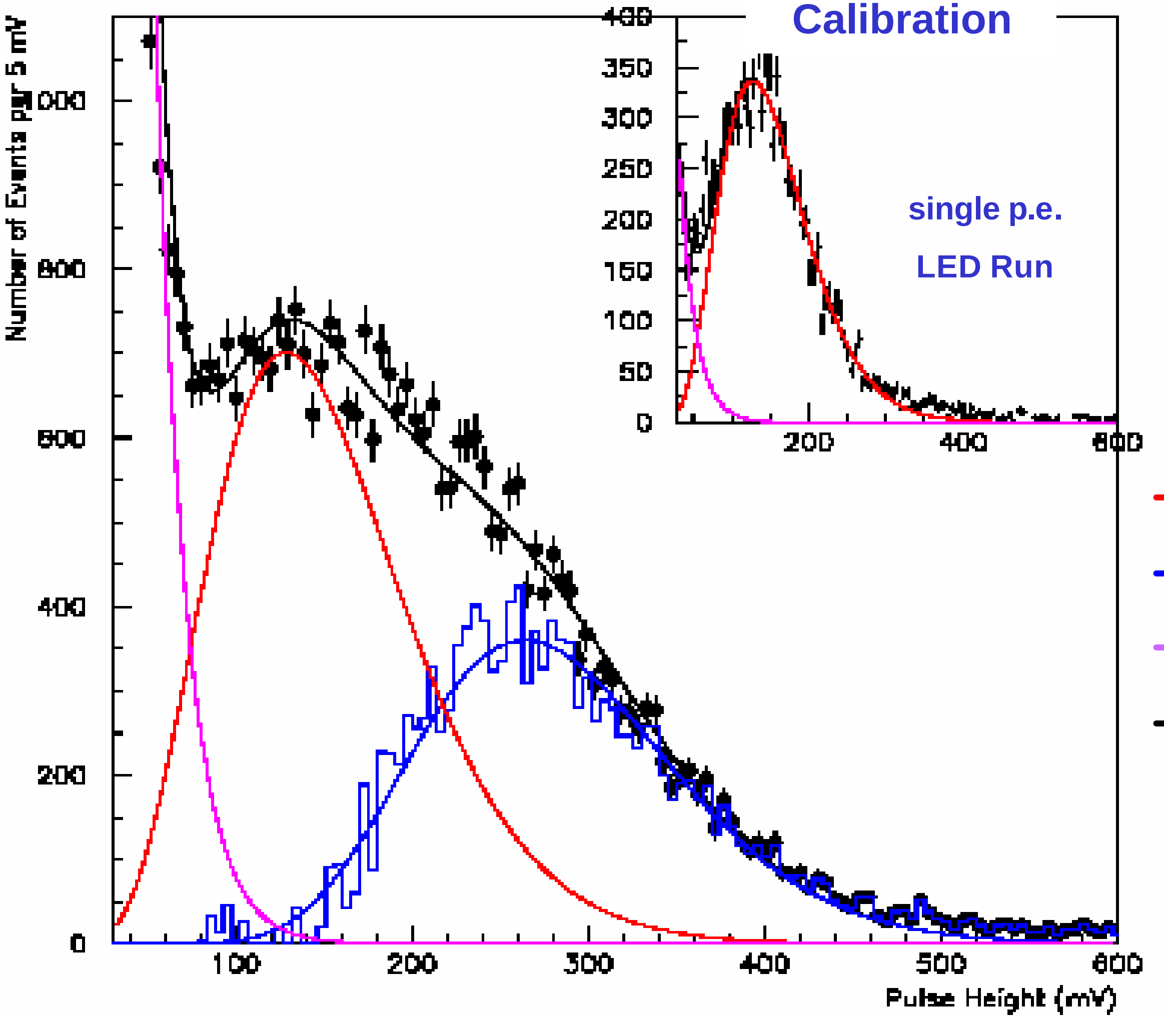


Software to Hardware Trigger Time Difference (arbitrary time offset)



Data from a depth of 4000 m

PMT Pulse Height Distribution



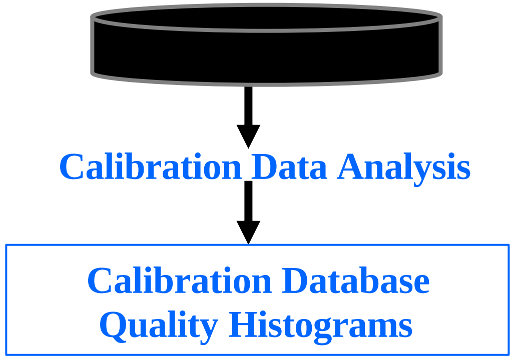
single p.e. pulse height distribution

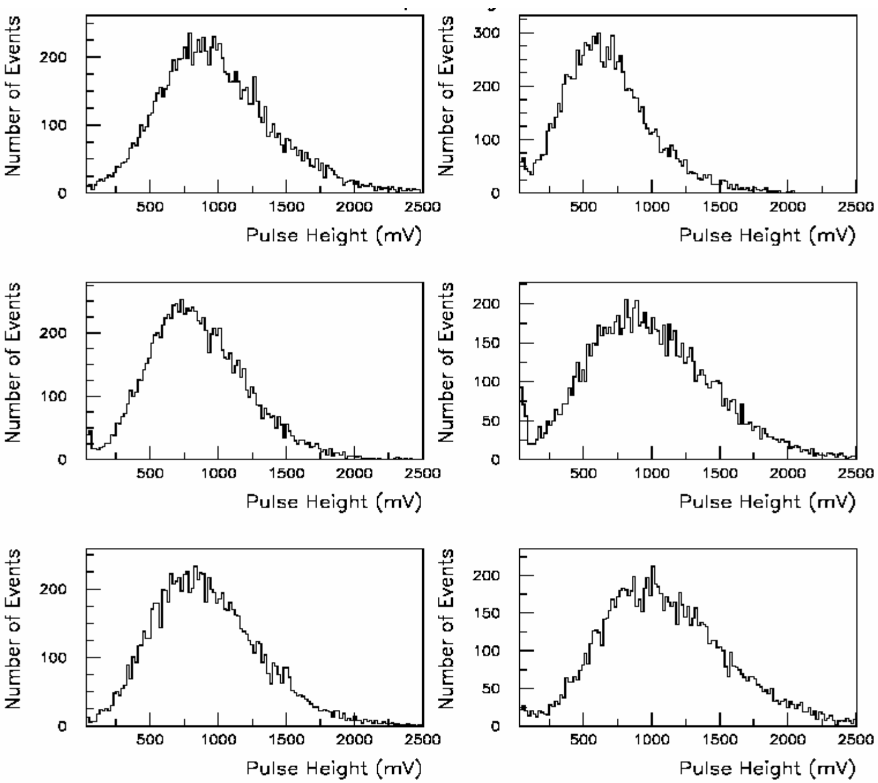
two p.e.s pulse height distribution

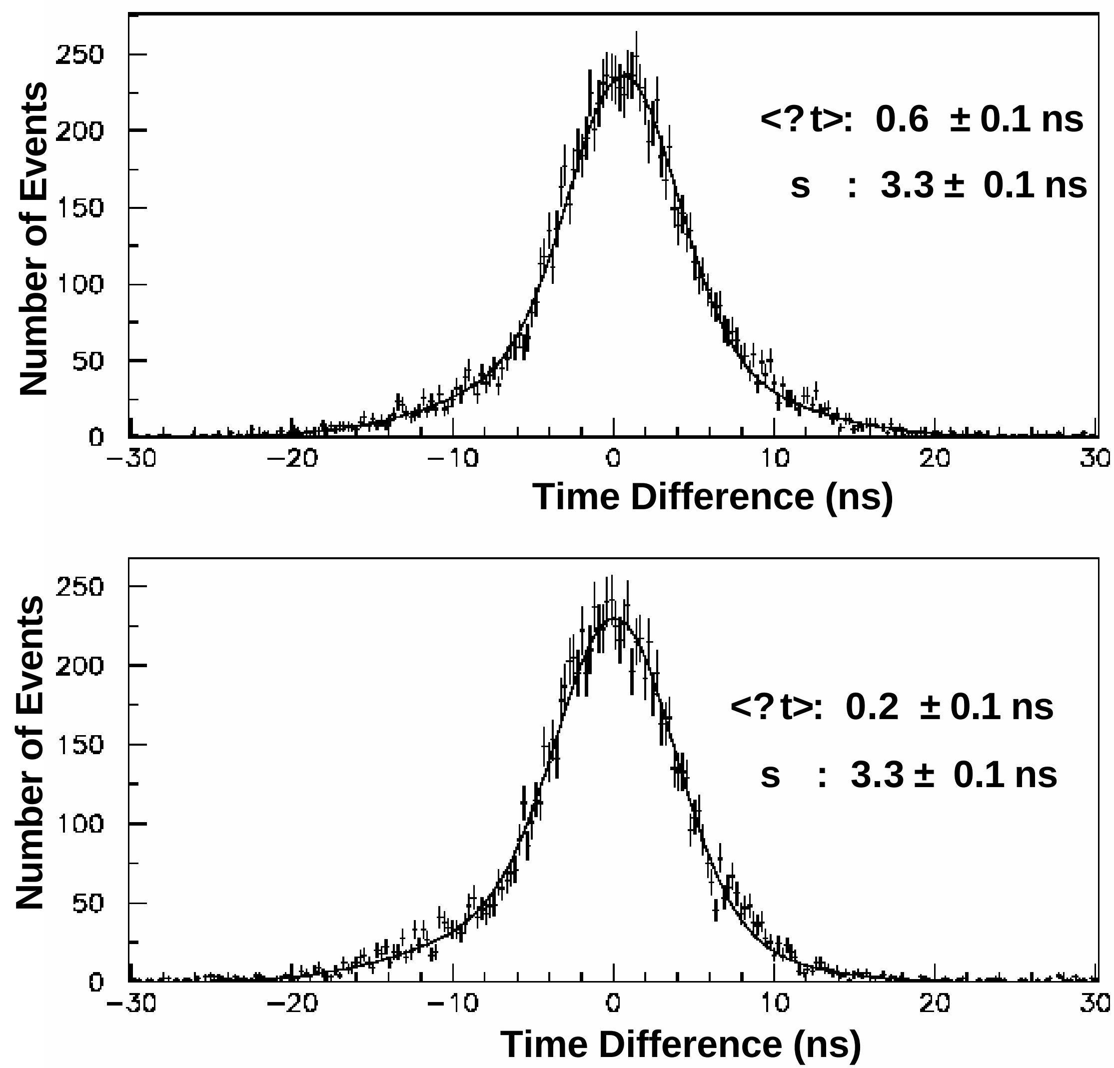
dark current pulse height distribution

sum of the above

Data from a depth of 4000 m
Calibration Run

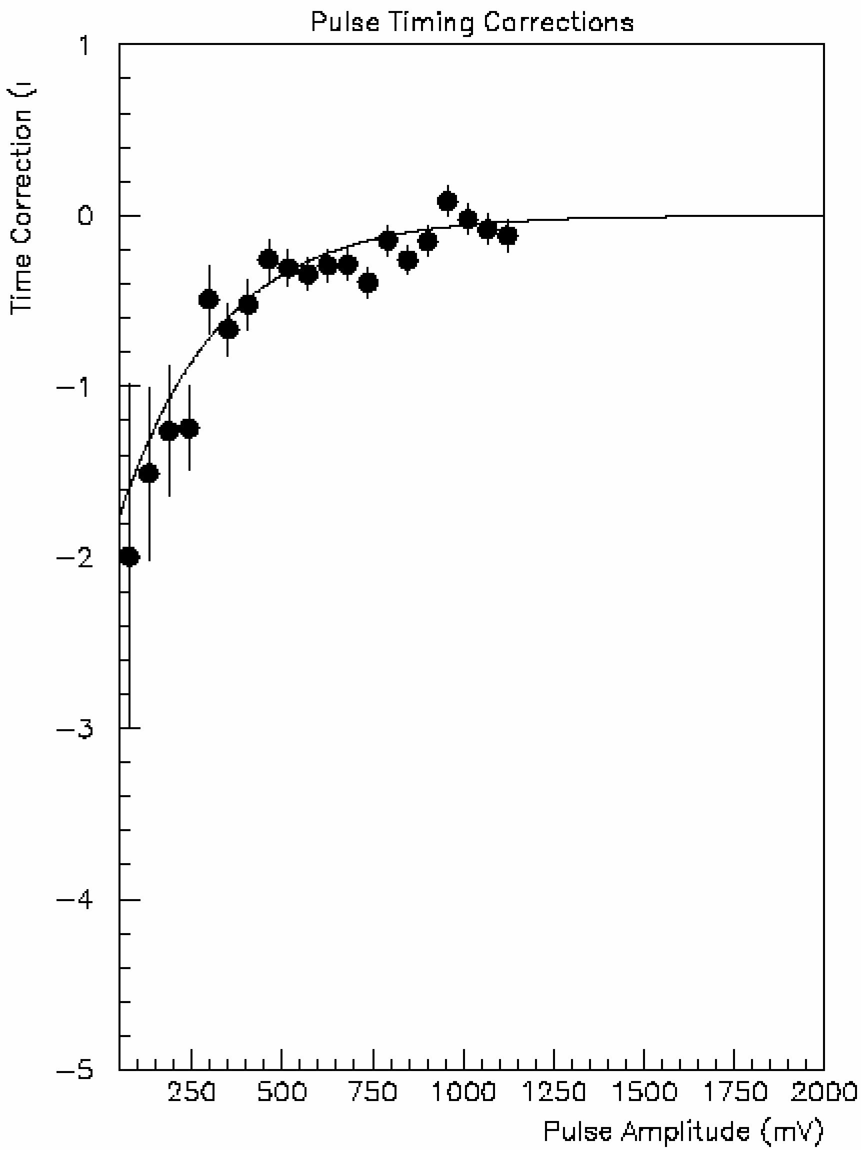


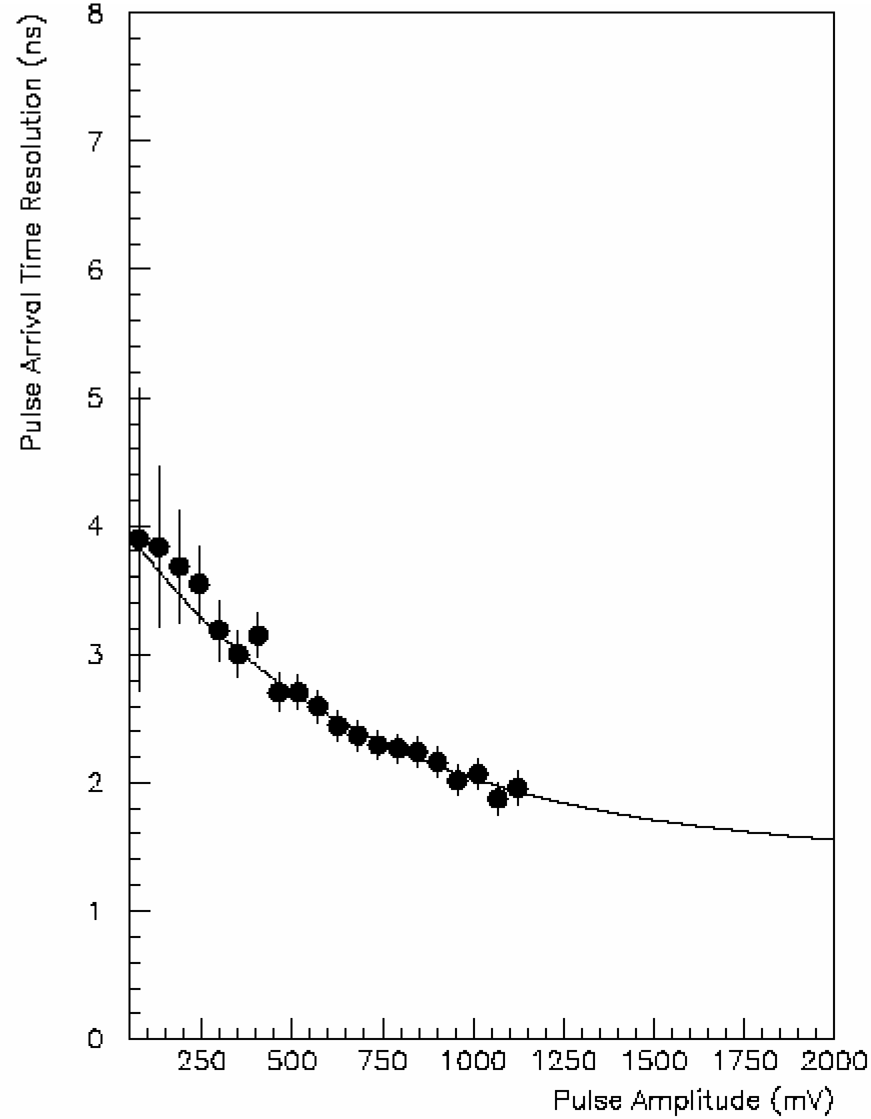




Data from a depth of 4000 m

Calibration Run





Data from a depth of 4000 m

Trigger Studies

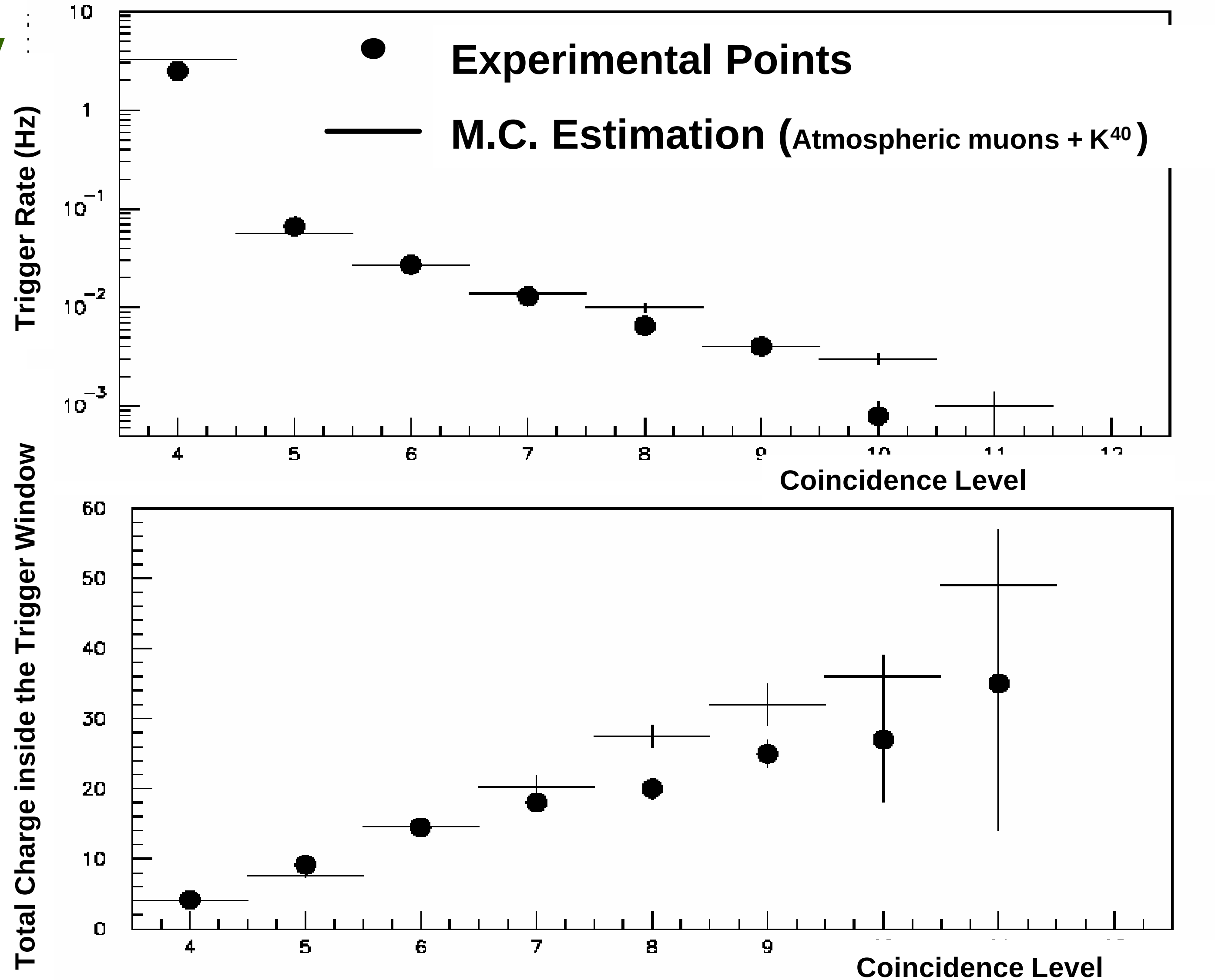
Preliminary

Data Collected with

4fold Majority Trigger

Thresholds at 30mV

(1/4 P.E.)



Data from a depth of 4000 m

Trigger Studies

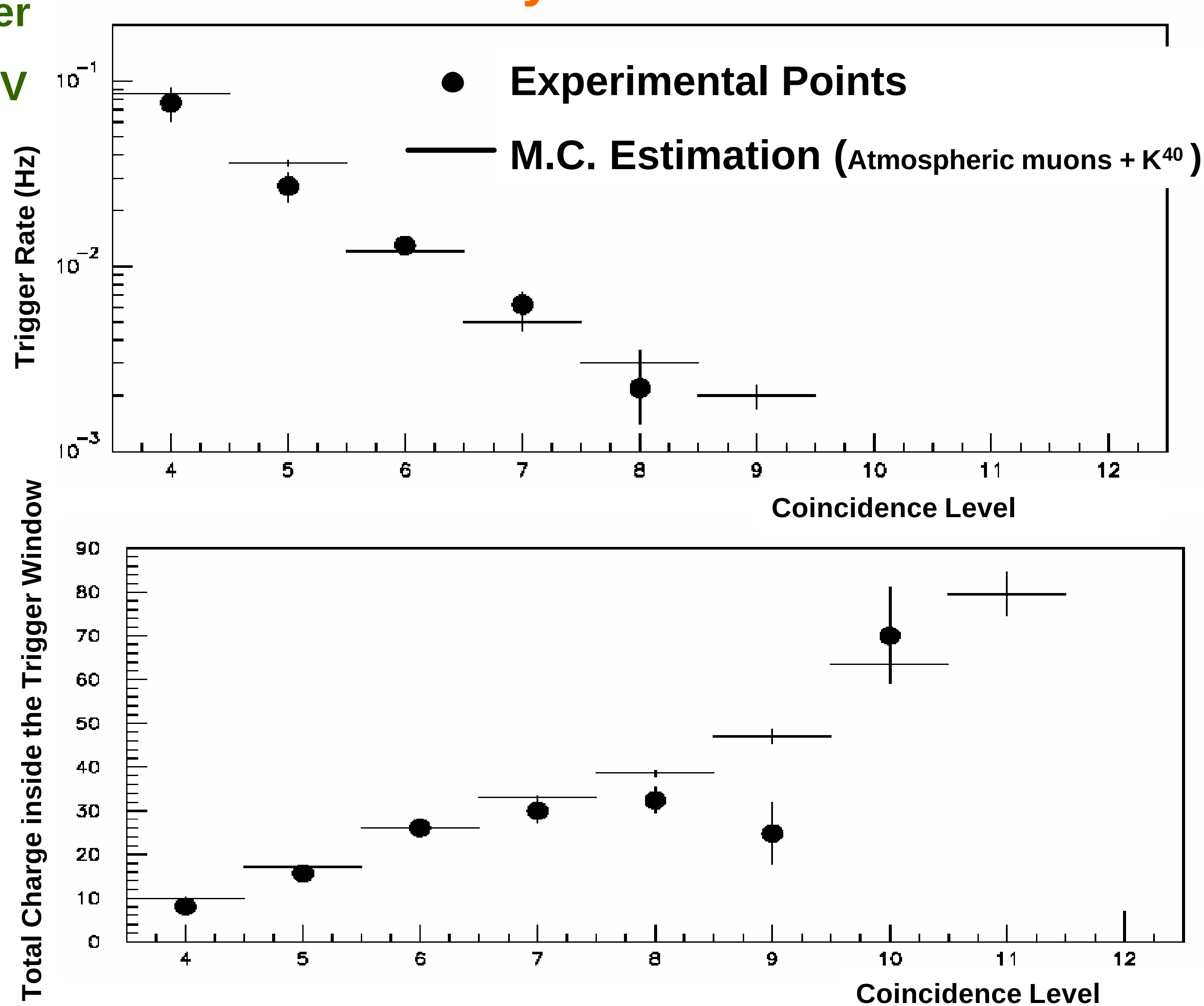
Preliminary

Data Collected with

4fold Majority Trigger

Thresholds at 120mV

(1 P.E.)



Data from a depth of 4000 m

Trigger Studies

Preliminary

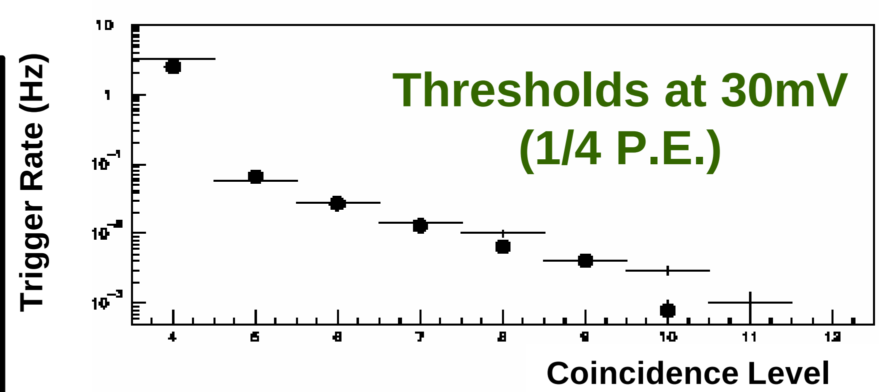
Data Collected with

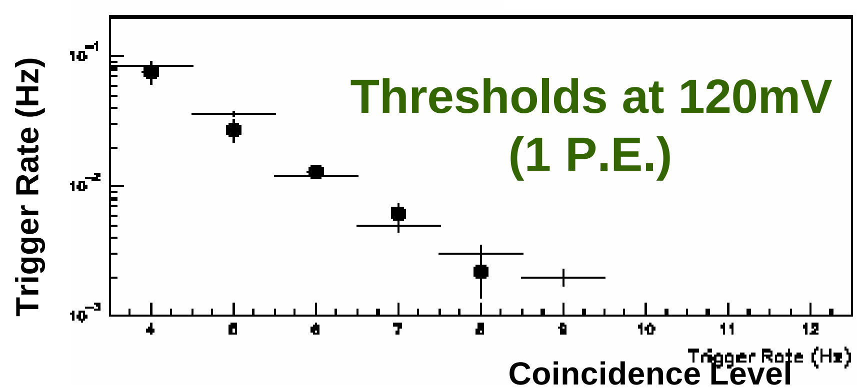
4fold Majority Coincidence Trigger

● **Experimental Points**

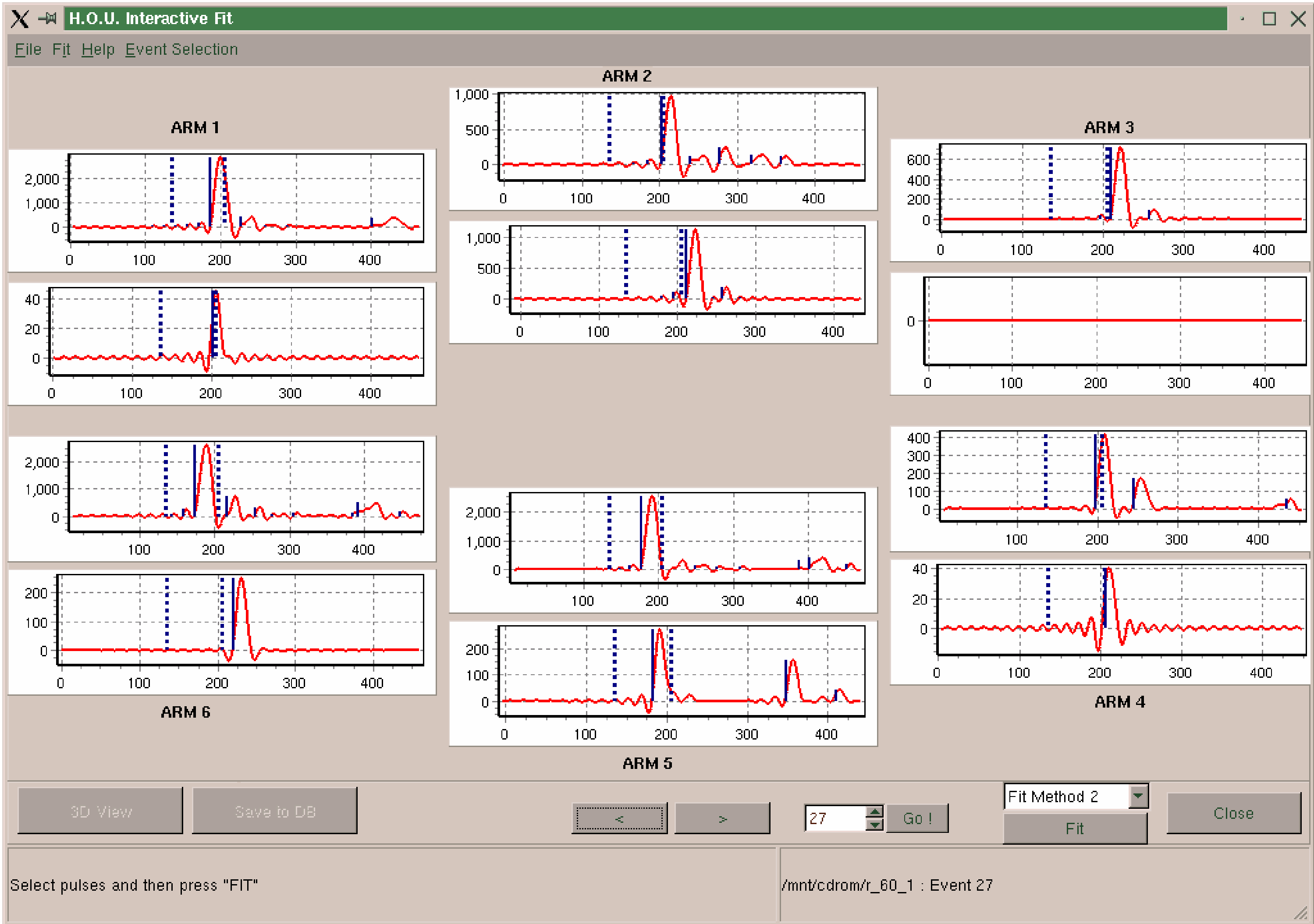
—— **M.C. Estimation** (Atmospheric muons + K^{40})

	Thresholds at 30 mV	Thresholds at 120 mV
Measured Total Trigger Rates (greater or equal to 4fold)	2.61 ± 0.02 Hz	0.12 ± 0.01 Hz
M.C. Prediction (atmospheric muons only)	0.141 ± 0.005 Hz	0.12 ± 0.01 Hz

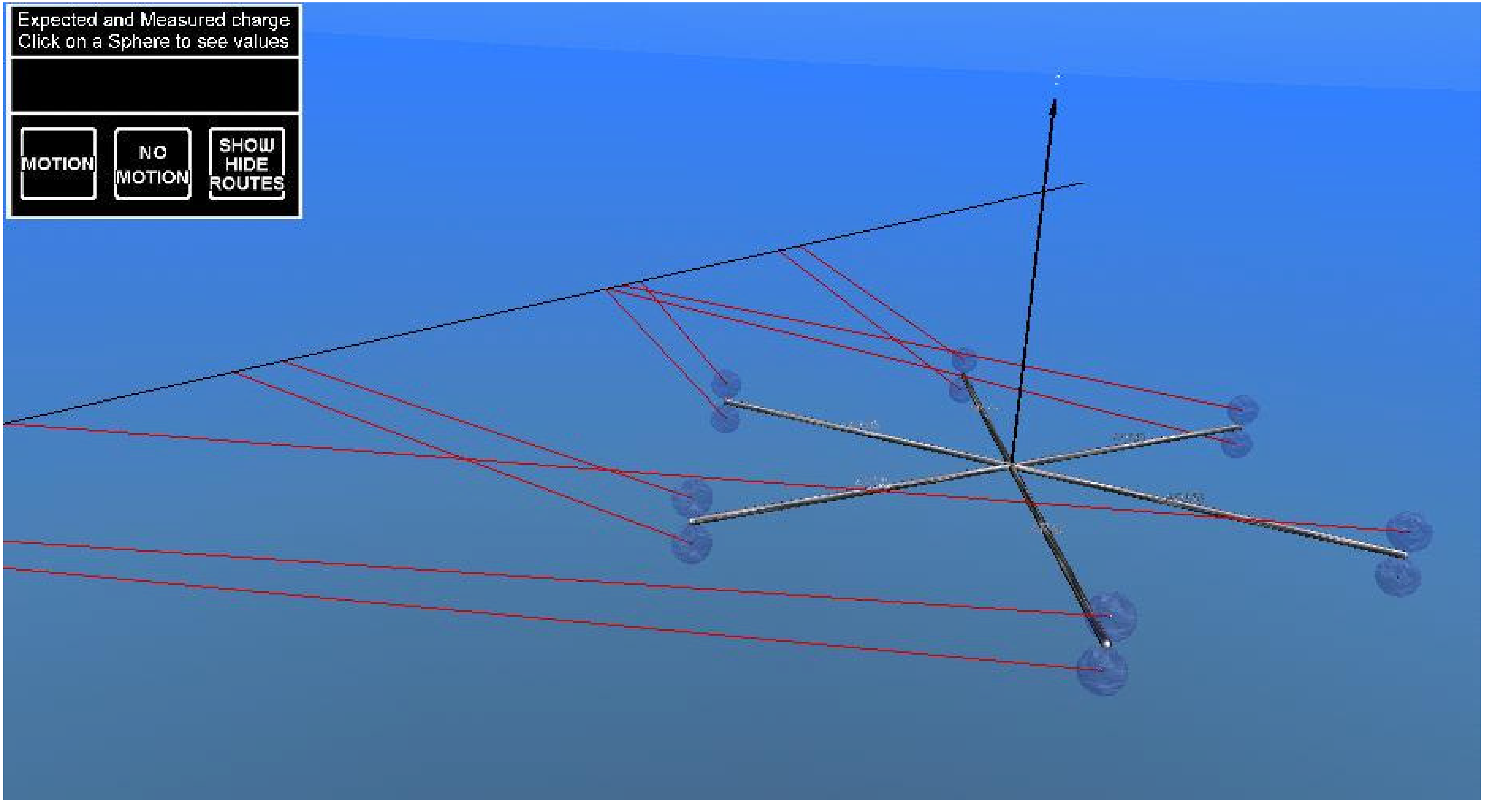




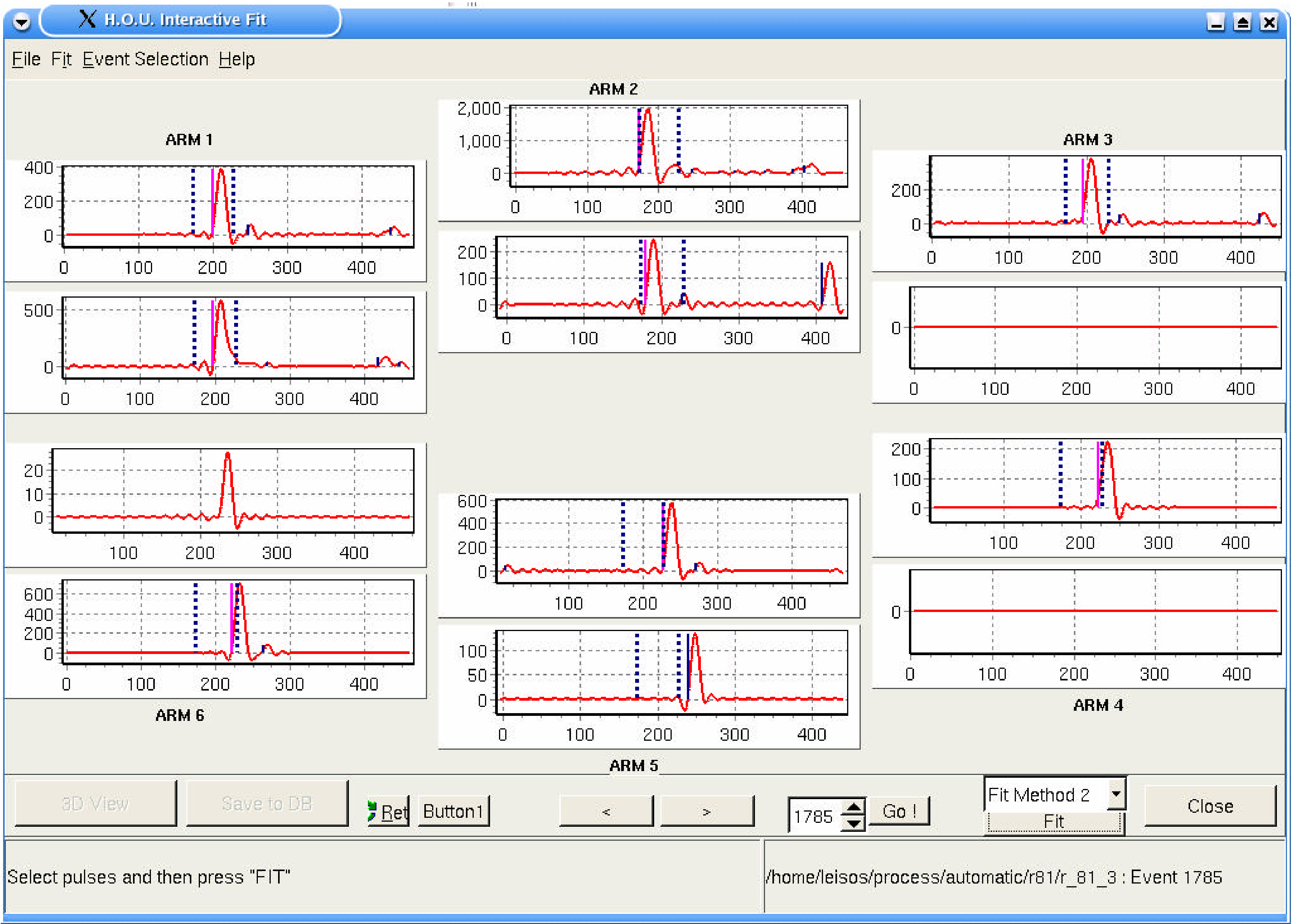
Input to the Fitter



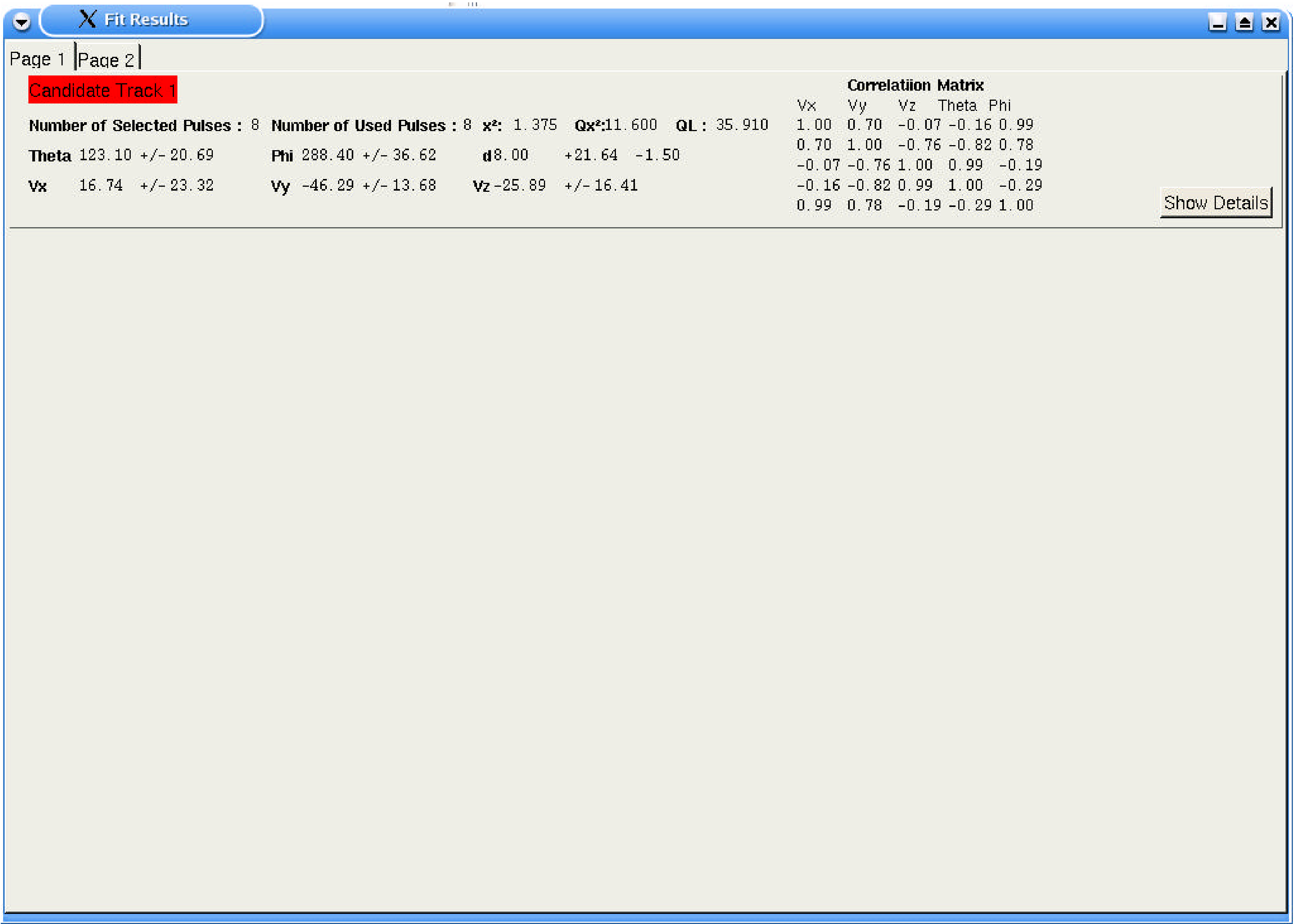
Track Reconstruction. . .



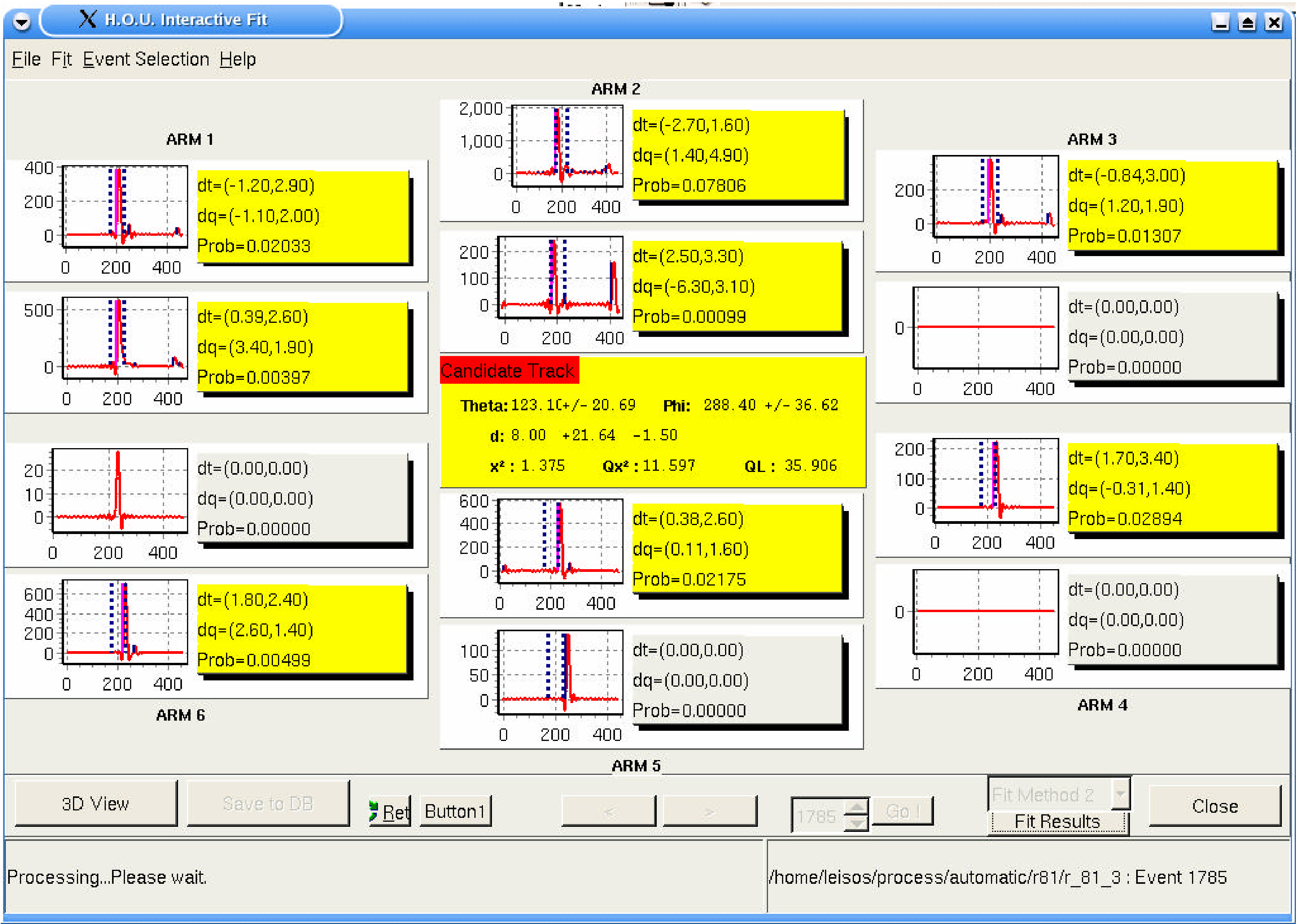
Event 1785 – Run 81 – BFile 3



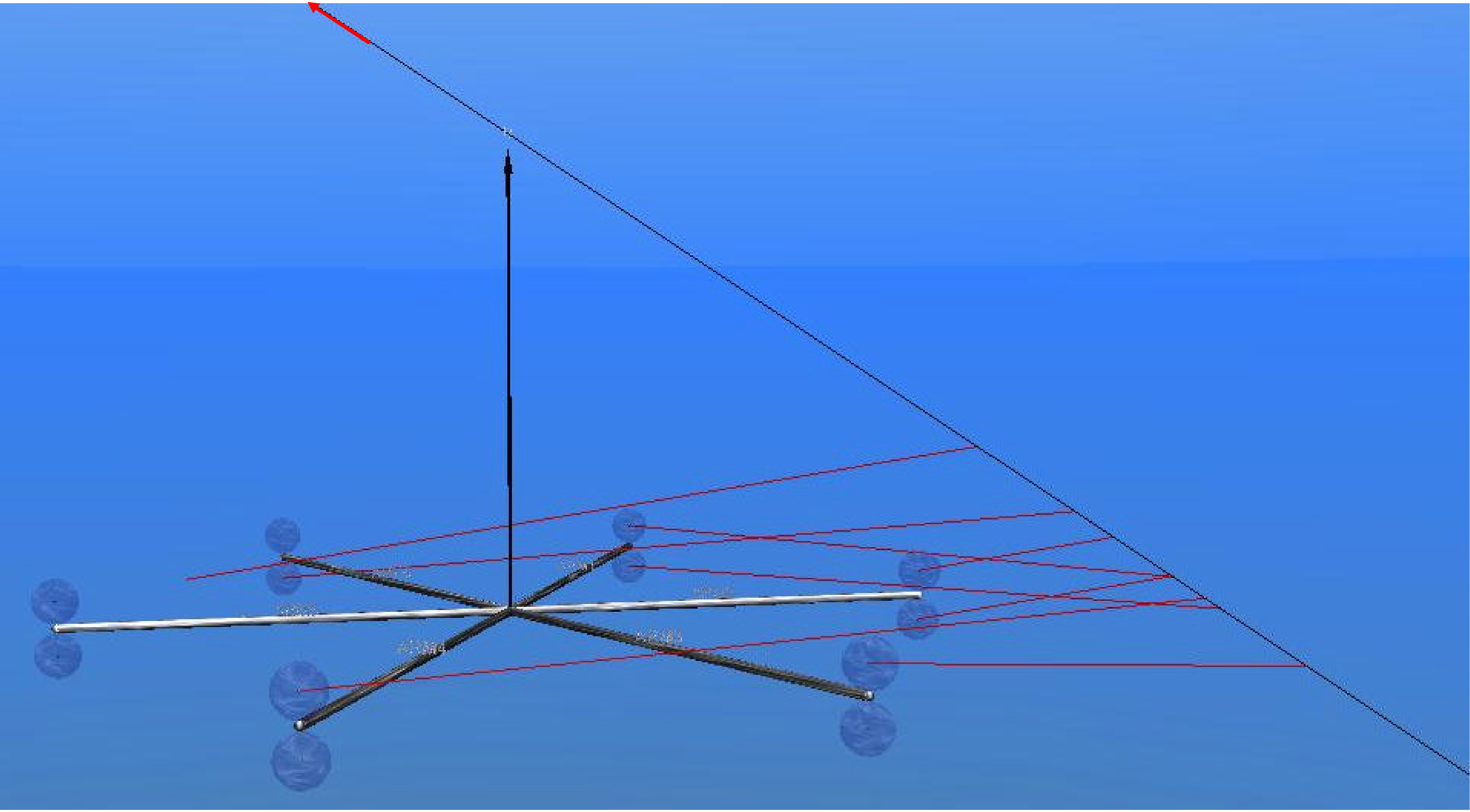
Event 1785 – Run 81 – BFile 3



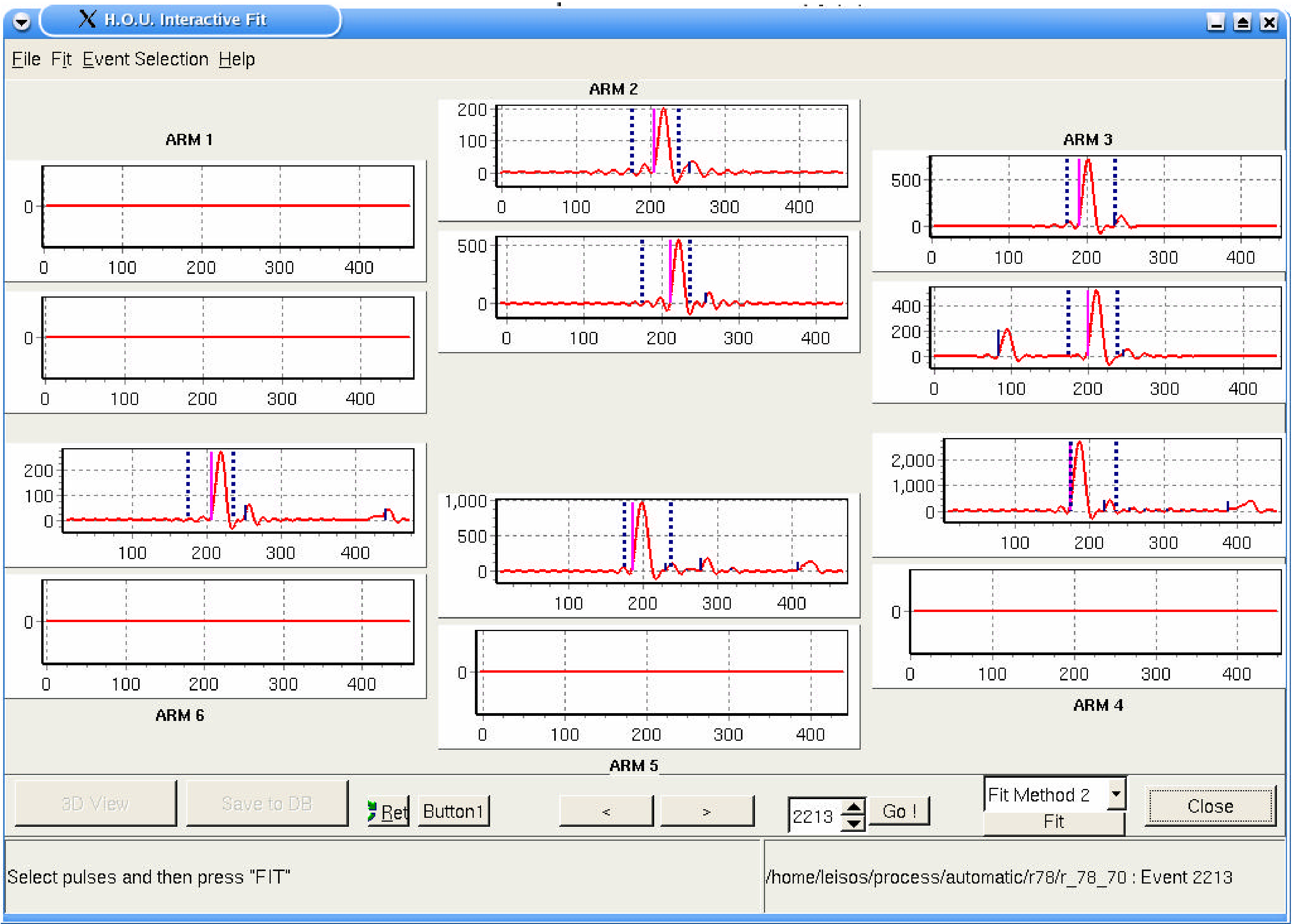
Event 1785 – Run 81 – BFile 3



Event 1785 – Run 81 – BFile 3

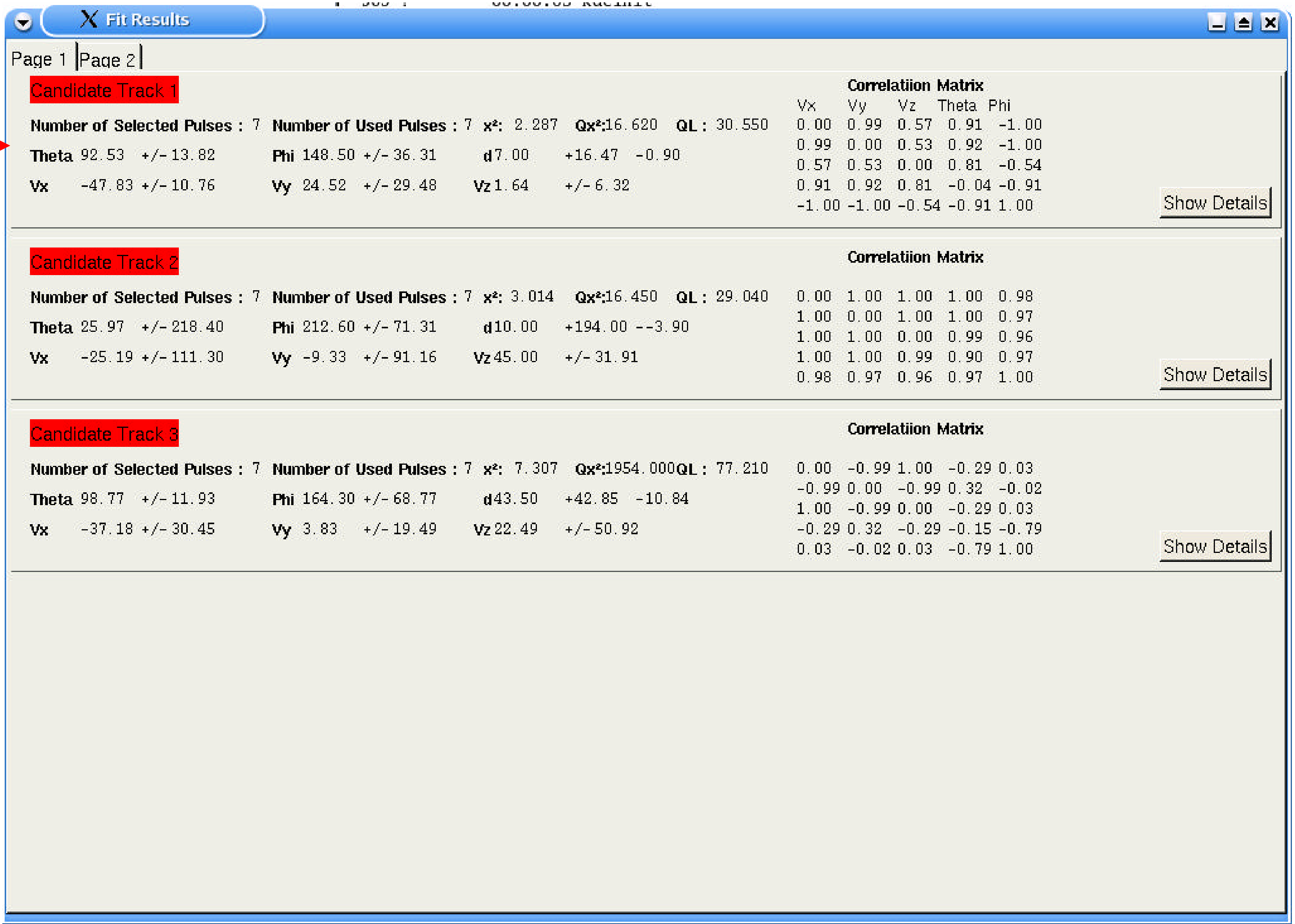


Event 2213 – Run 78 – BFile 70

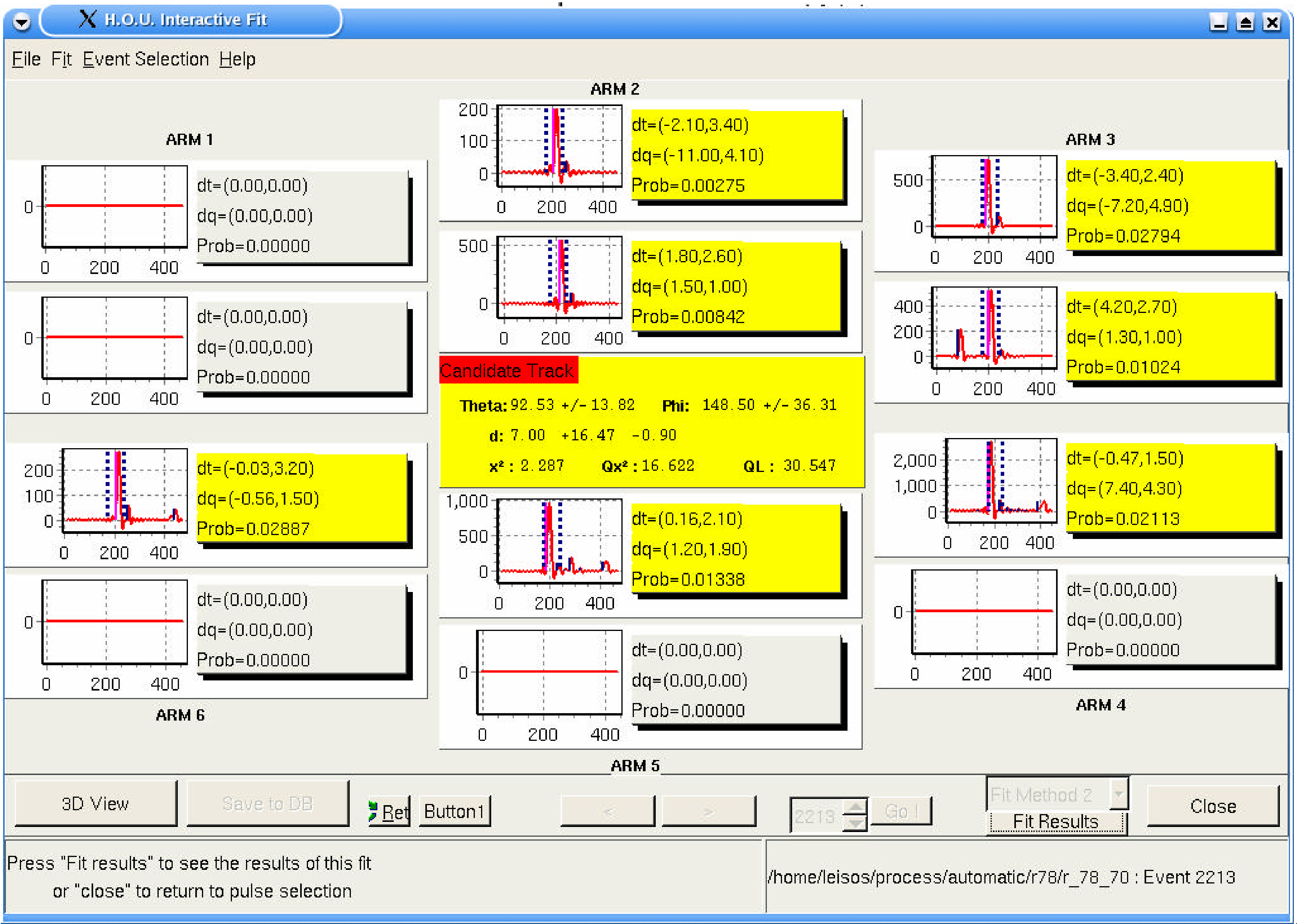


Event 2213 – Run 78 – BFile 70

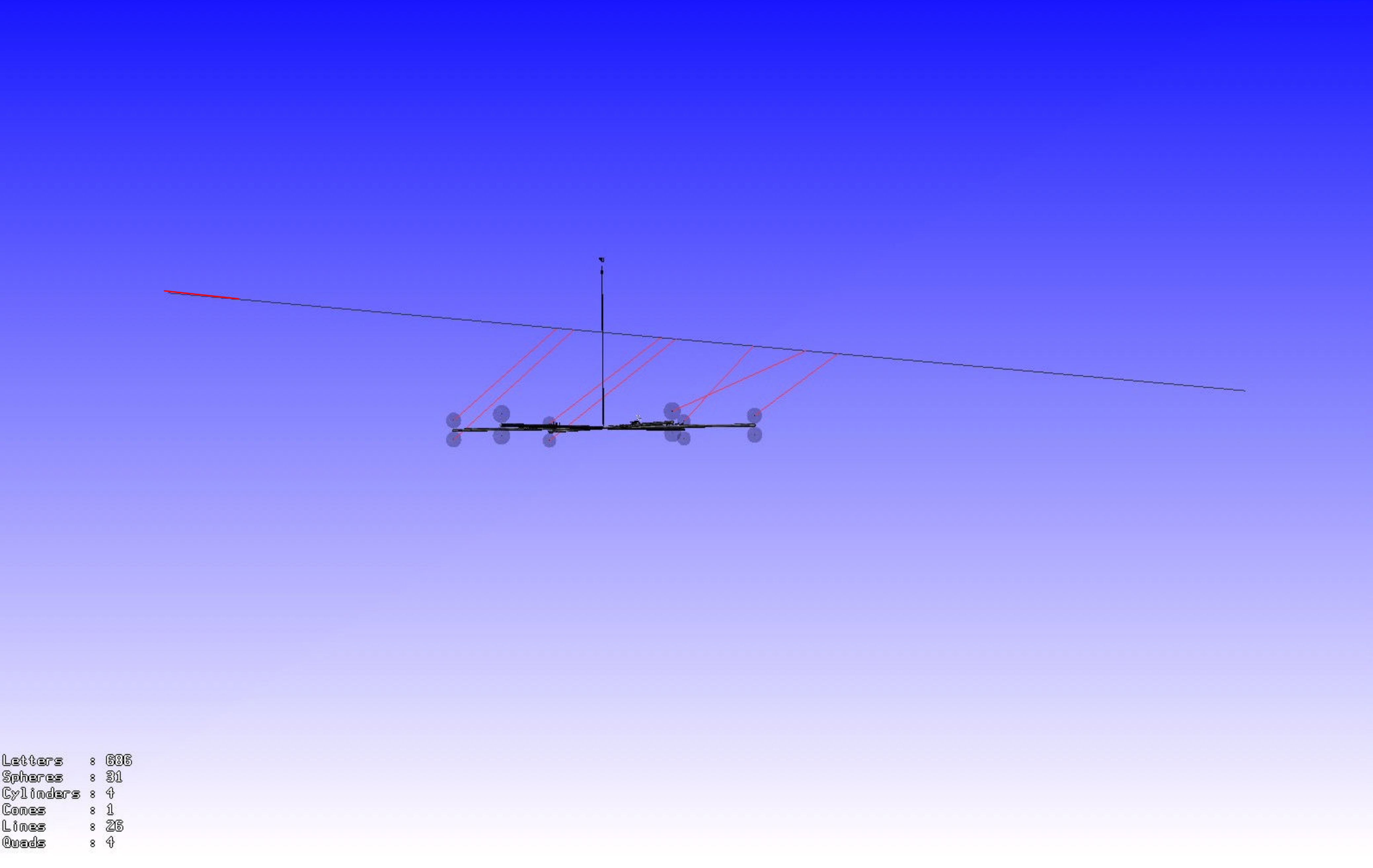
Best Fit



Event 2213 – Run 78 – BFile 70

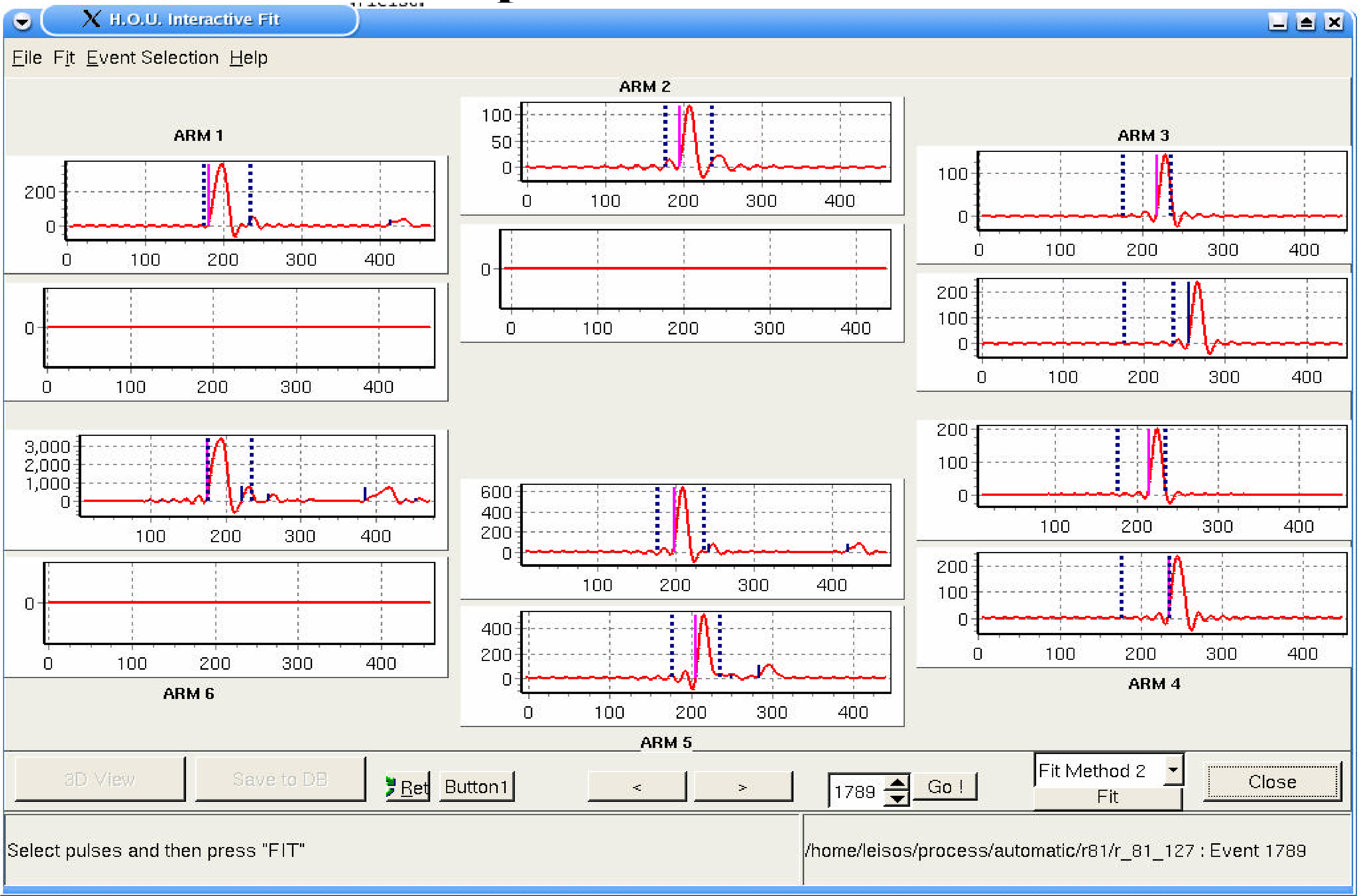


Event 2213 – Run 78 – BFile 70



Run: 81_127   Event: 1789

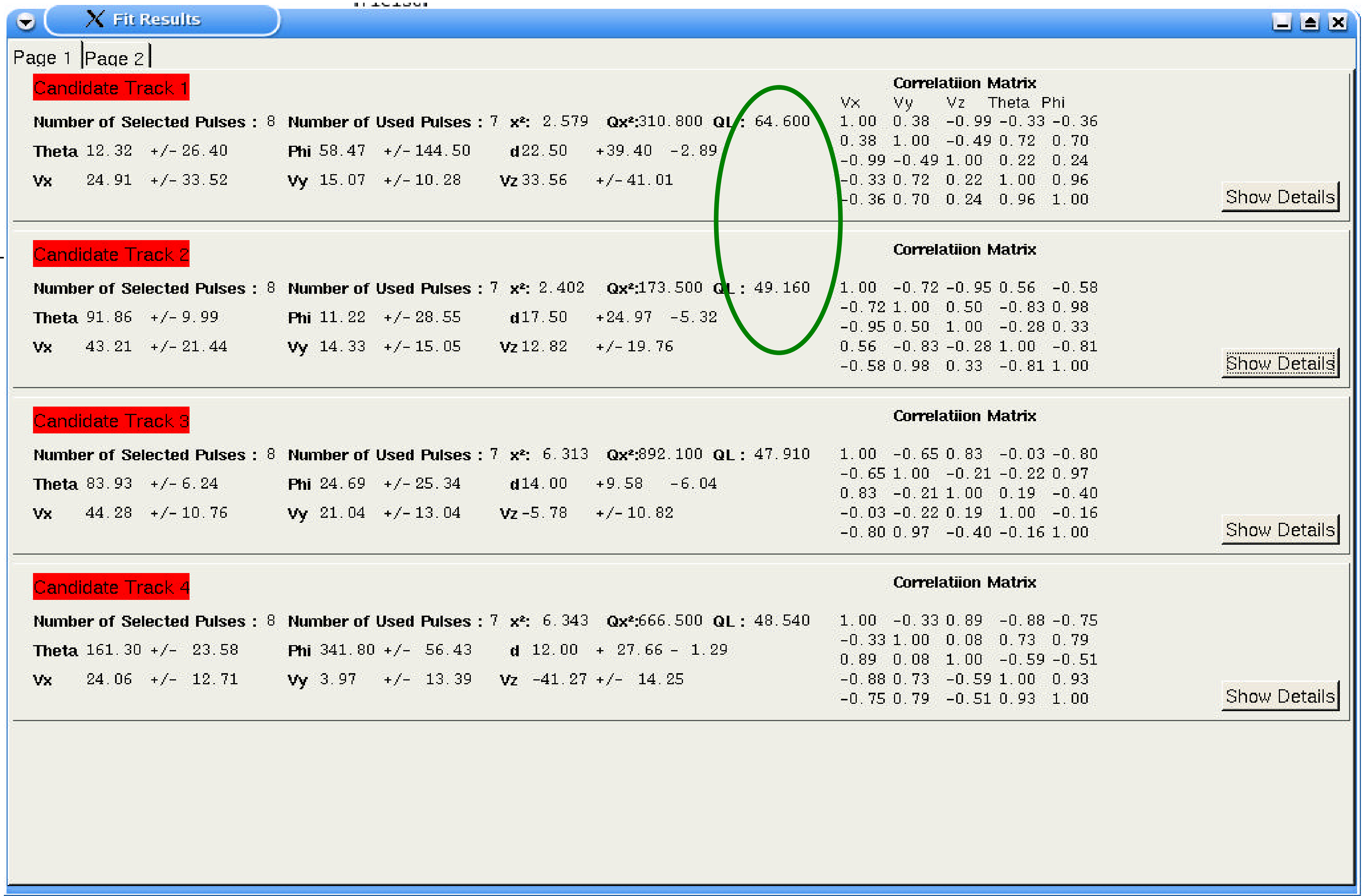
Input to the Fitter



Run: 81_127 Event: 1789

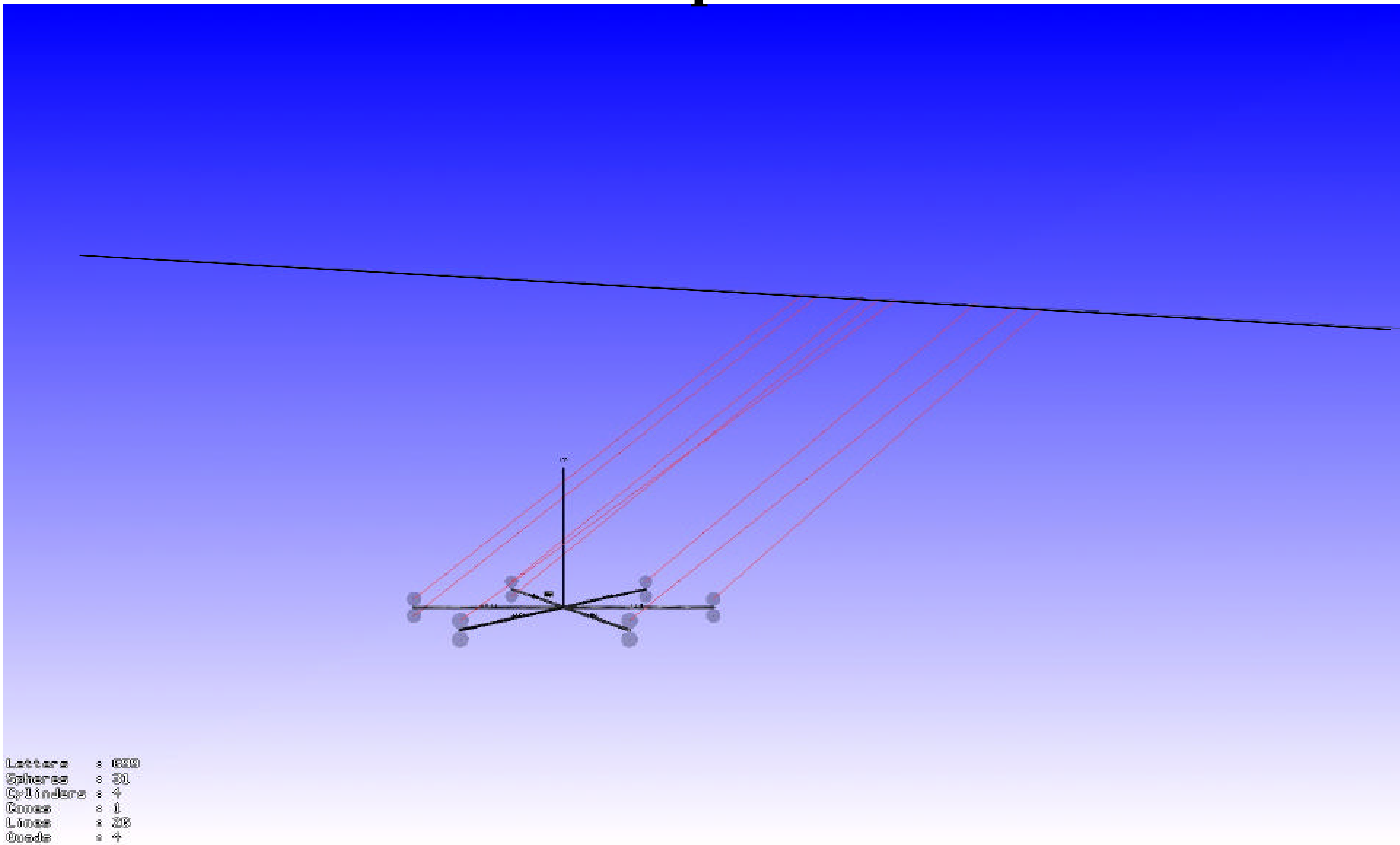
Best fit

Fit Results

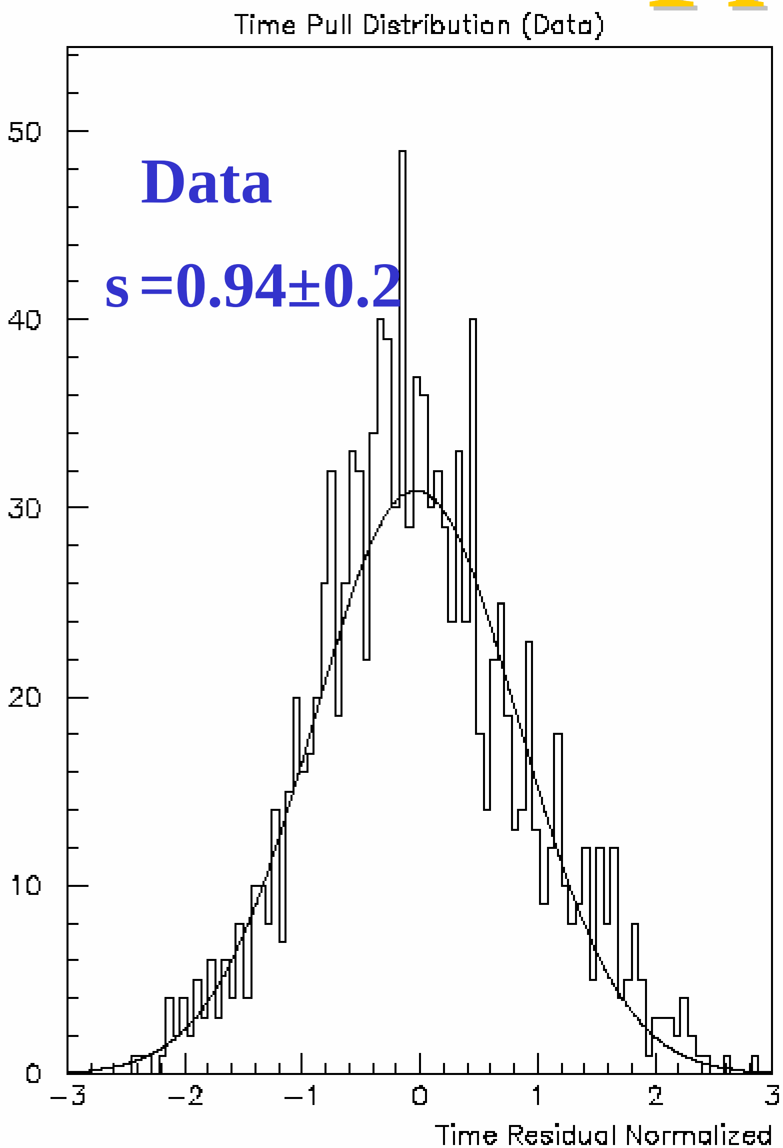


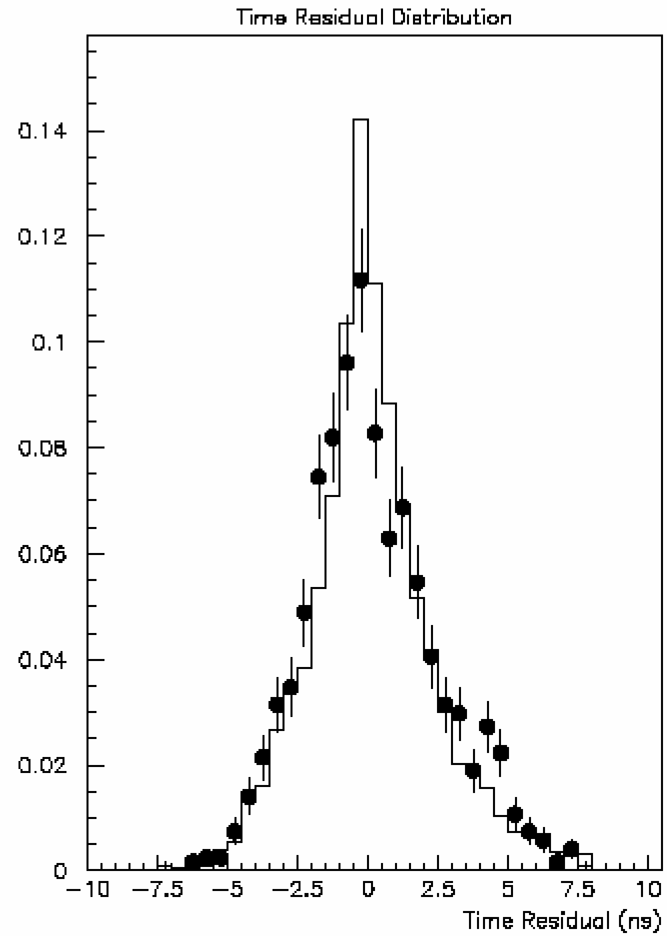
Run: 81_127   Event: 1789

Pictorial Representation



Preliminary





M.C. Prediction (atmospheric muons)

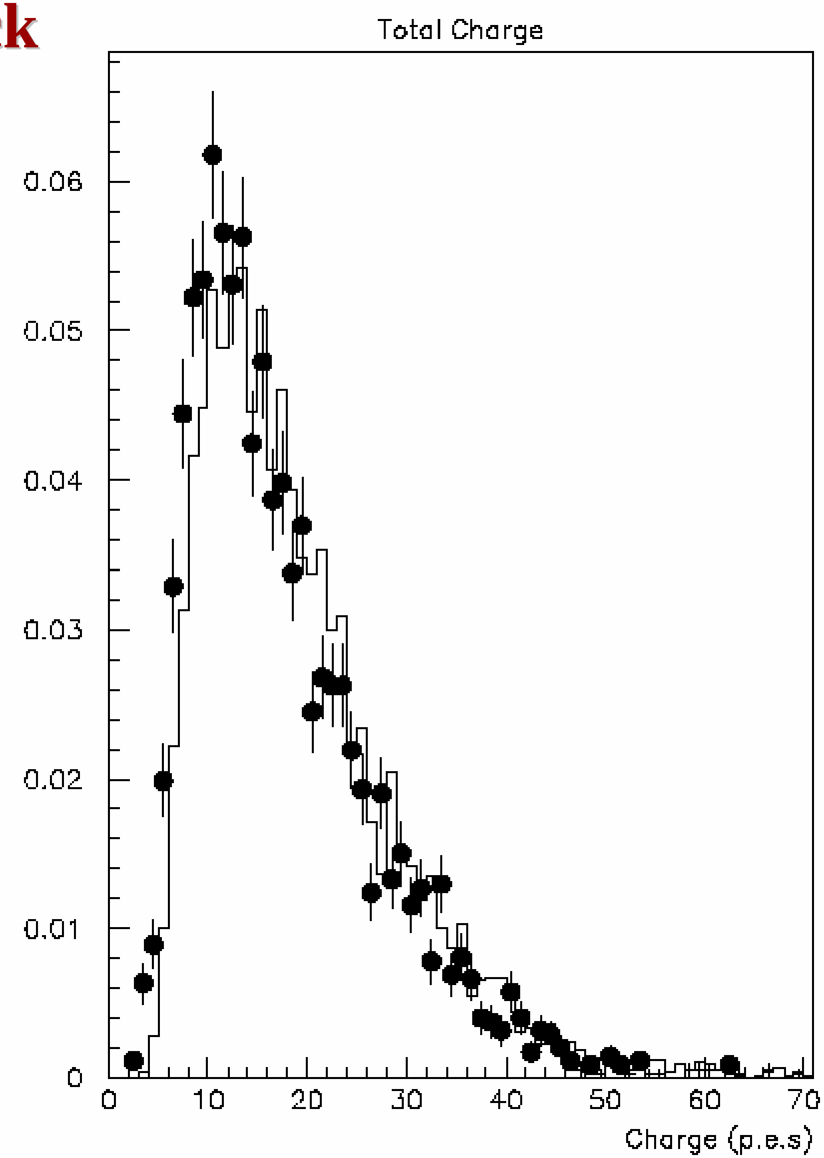
Data Points

Preliminary

Total number of p.e.s per Track

— M.C. Prediction **(atmospheric muons)**

● Data Points



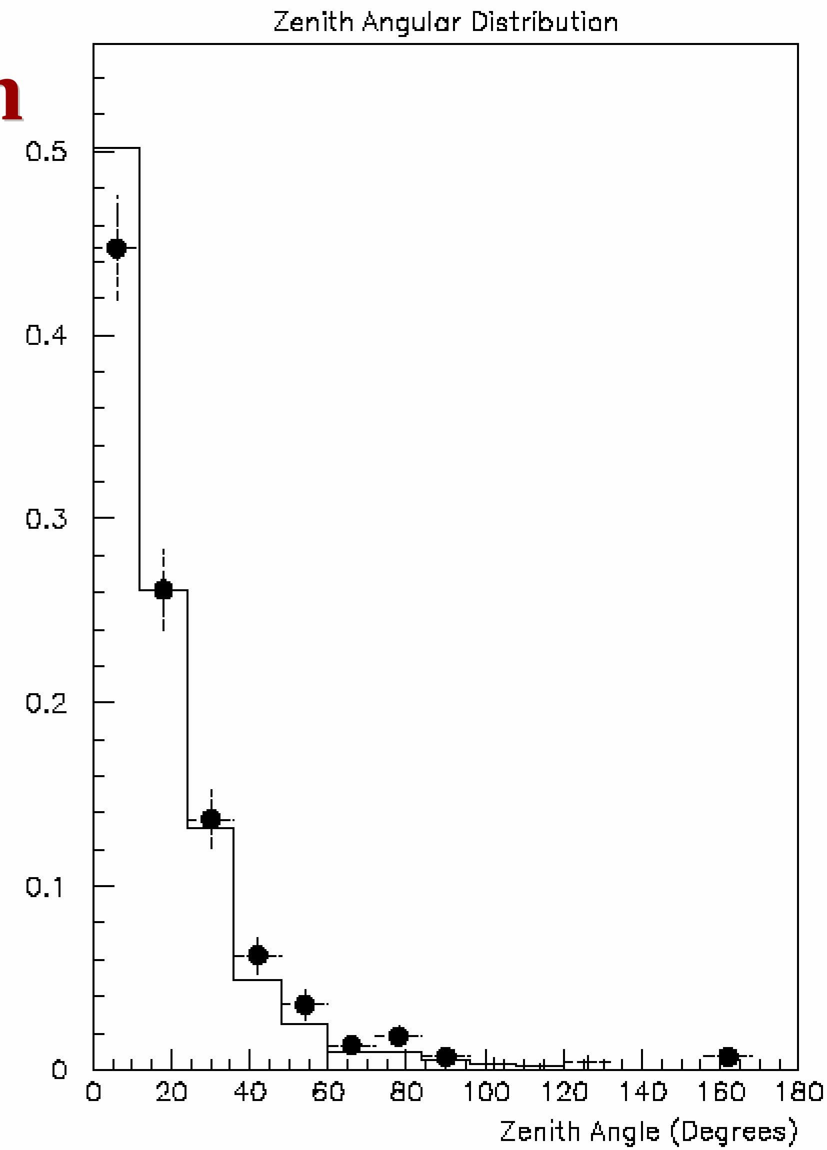
Preliminary

Zenith Angular Distribution

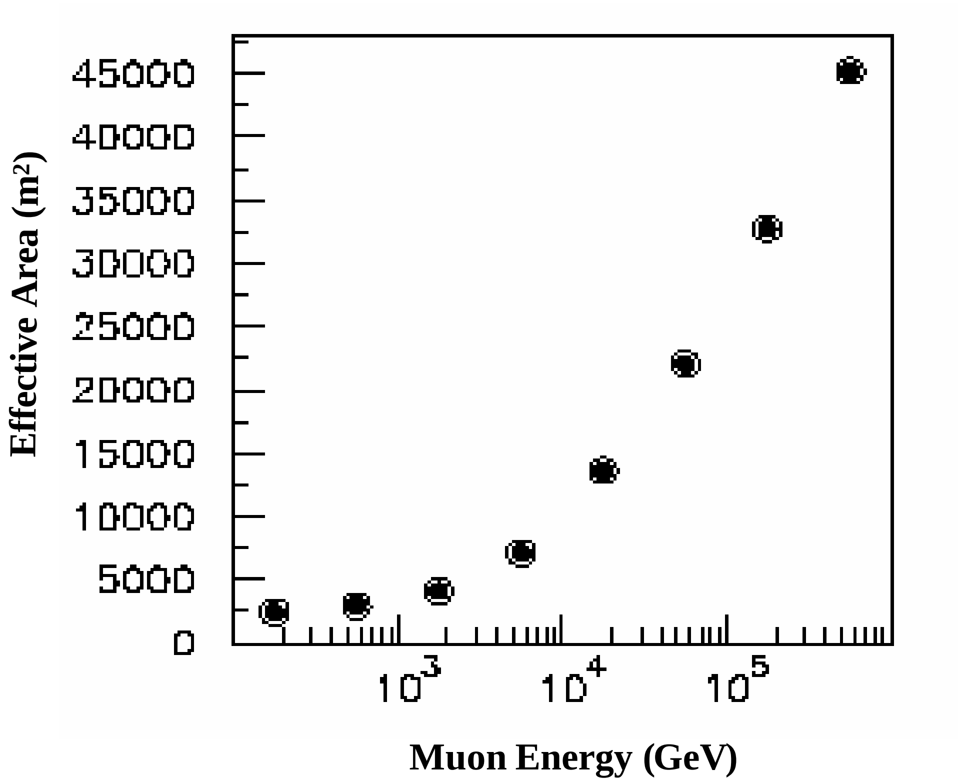
- ?^{2} probability > 0.1
- track selection according to the charge-likelihood
- more than [4.5 · (number of hits)] p.e.s per track

— M.C. Prediction **(atmospheric muons)**

● Data Points



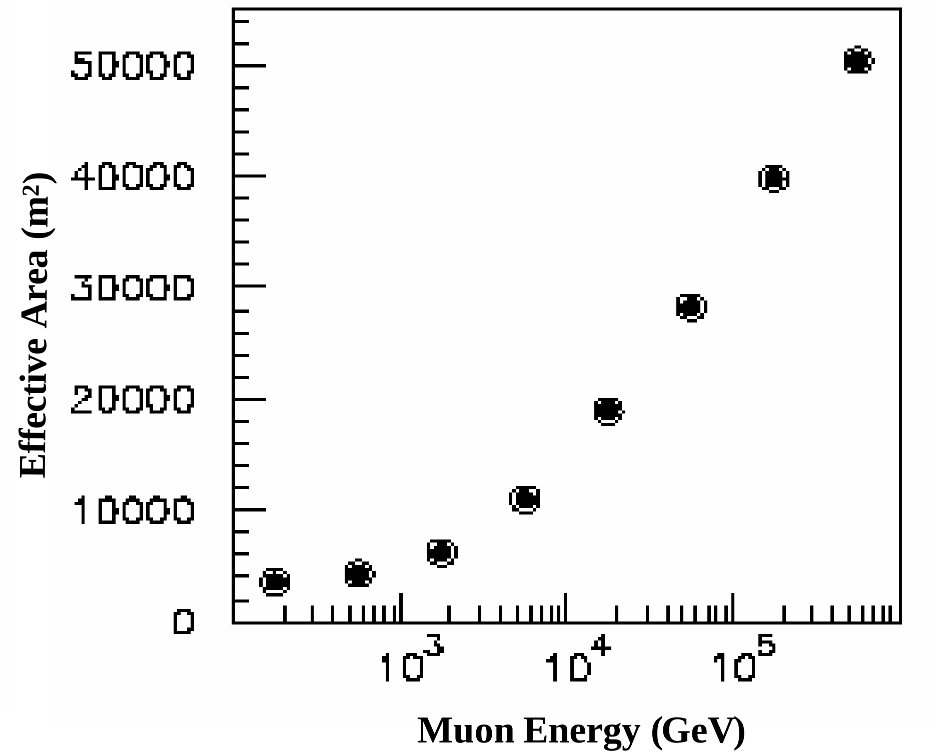
4 NESTOR Floors



10000 m^2 effective area for E>10TeV

NESTOR Tower

(12 Floors)



20000 m^2 effective area for E>10TeV