ASTRONEU
A progress report

HEP 2015 - Conference on Recent Developments in High Energy Physics and Cosmology
15-18 April 2015, Athens, Greece

Antonios Leisos
Hellenic Open University

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ASTRONEU

Development and Applications of Novel Instrumentation and Experimental Methods in Astroparticle Physics

AUTH, DEMOKRITOS, Univ. of AEGEAN and TEI PIRAEUS, Univ. Of ATHENS, HOU and Univ. of PATRAS

Principal Investigator: S.E. Tzamarias

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External Collaborators: J. Vergados I. Giomataris , Jean_Pierre Ernenwein , Ch. Nicolaou,Dr. J. Moussa, S. Pnevmaticos , E. Pierri , K. Siori ,G. Zisimopoulos

Development of innovative instrumentation, simulation tools, data analysis and experimental methodology

Research facilities as platforms for advancing educational programs for educators, students and the general public

spin-off applications of particle detector instrumentation to the environmental Sciences

- High Energy Neutrino Telescopy
- Extensive Air Shower Instrumentation
- EAS Telescopy: Operation & Reconstruction
- Low Energy Neutrino Detection

High Energy Neutrino Telescopy

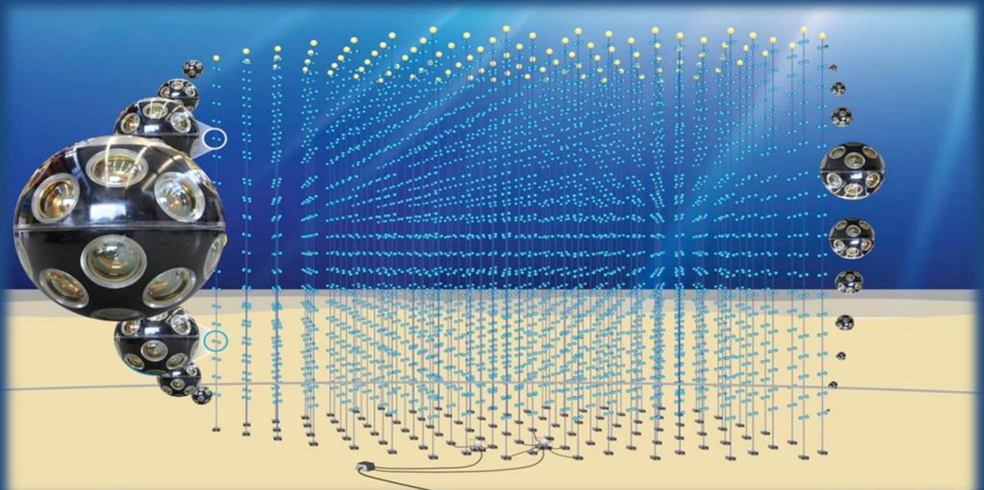
D.I.O.N.A.S. Research Infrastructure

"…The KM3NeT will be a distributed RI at three locations (Installation Sites) in the Mediterranean Sea: in South of France, South of Sicily in Italy, and in the West of Peloponnese in Greece. KM3NeT Phase-I will demonstrate the feasibility of a distributed network of neutrino telescopes in the Mediterranean Sea…"

"… **This proposal involves the development of the KM3NeT-Gr at the Greek installation site (DIONAS RI) by a consortium of 10 Hellenic research teams,** according to the results and technological solutions described in the Technical Design Report, delivered to the EC in the context of the KM3NeT Design Study…"

"…The DIONAS RI will comprise, deep sea (submarine) infrastructure, shore infrastructure, facilities for sea operation as well as several construction and assembling centers of the Detection and Calibration Units…"

"…In parallel the DIONAS RI will contribute in the multidisciplinary effort of Earth and Sea Sciences (ESS) for the monitoring and assessment of worldwide challenges, such as the climate change, providing real-time, **high bandwidth transmission of continues measurement of oceanographic, geological biological and environmental parameters from sensors installed inside the neutrino telescope detectors…"**



High Energy Neutrino Telescopy

Work published last year)

The neutrino mass hierarchy measurement with a neutrino telescope in the Mediterranean Sea: A feasibility study

A. G. Tsirigotis for the KM3NeT Collaboration

Physics Laboratory, Hellenic Open University, Greece

Detection of Extended Galactic Sources with an Underwater Neutrino Telescope

A. Leisos[*], A.G. Tsirigotis[*], D. Lenis[†] and S.E. Tzamarias[*]

[*]*Physics Laboratory, School of Science and Technology, Hellenic Open University, Tsamadou 13-15 and Ag. Andreou, Patras 26222, Greece*
[†]*INPP-NCSR Demokritos, Agia Paraskevi Attikis, Athens 15310, Greece*

A technique for measuring the sea water optical parameters with a dedicated laser beam and a multi-PMT Optical Module

A. Papaikonomou[*,‡], A. Leisos[*], I. Manthos[†], A. Tsirigotis[*] and S. Tzamarias[*] on behalf of the KM3NeT Collaboration

[*]*Hellenic Open University, Patras, Greece*
[†]*University of the Aegean, Chios, Greece*

Characterization of the KM3NeT photomultipliers in the Hellenic Open University

G. Bourlis, T. Avgitas, A. Tsirigotis and S. Tzamarias for the KM3NeT Collaboration

School of Science & Technology, Hellenic Open University, Tsamadou 13-15, Patra, Greece

Almost Completed Tasks (to be published)

A.G. Tsirigotis, A. Leisos and S.E. Tzamarias

New Developments in HOURS (HOU Reconstruction & Simulation)

Studies on: Ultra High energy cosmic neutrino detection

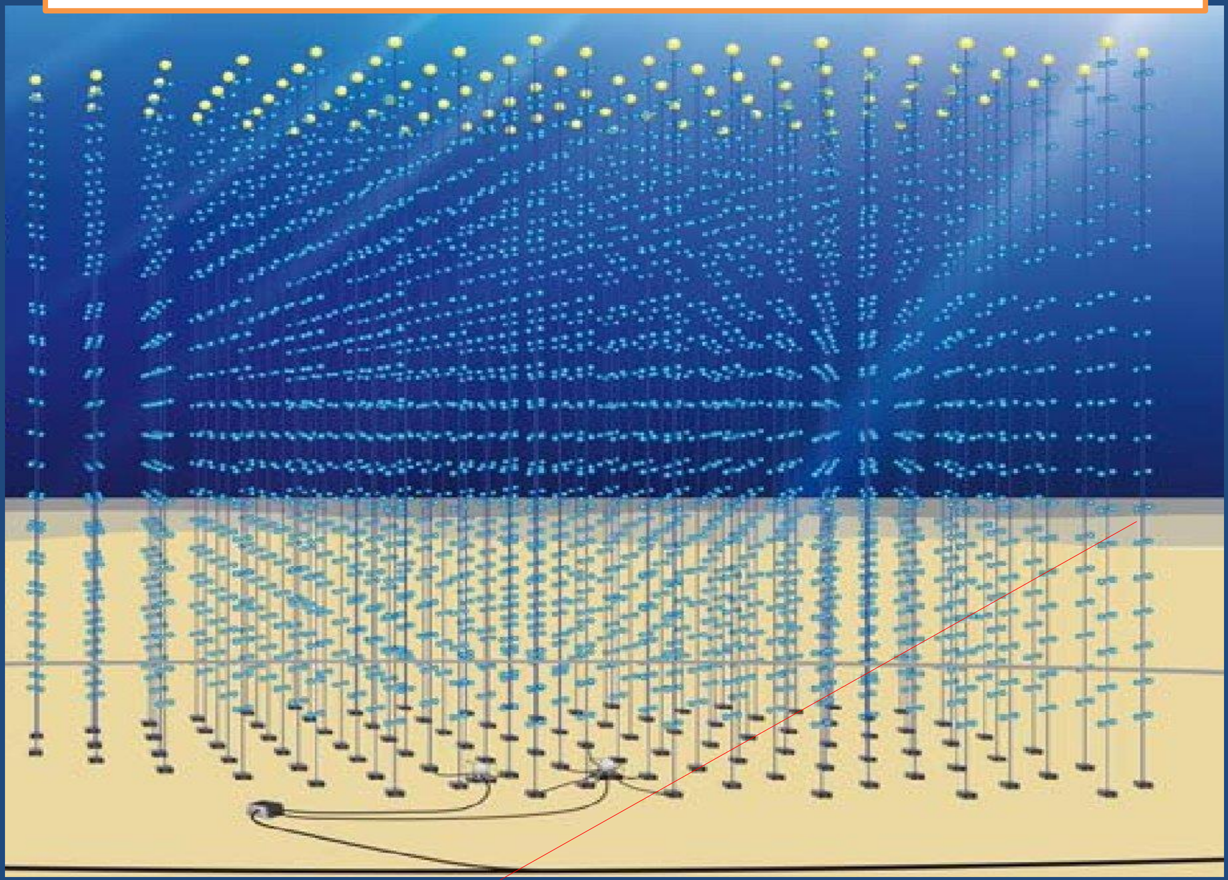
Studies on: The performance of the PPMDU to detect atmospheric muons

Developmnet of an inter-calibration technique for the estimation of the KM3NeT angular resolution

Few words for the KM3NeT lay-out

High Energy Neutrino Telescopy

KM3NeT in numbers
- 12420 DOMs
- 690 DUs
- 18 DOMs/DU
- 36 m DOM spacing
- ~700 m DU height
- 90m DU distance
- 3 km^3 volume
- 220 MEuro cost



Detection Unit (DU): mechanical structure holding DOMs, enviromental sensors, electronics,...
DU is the building block of the telescope

Digital Optical Module (DOM): 17-inch pressure resistant sphere containing 31 3-inch photo-multipliers and digitization electronics

High Energy Neutrino Telescopy

New Developments in HOURS (HOU Reconstruction & Simulation)

Few words for HOURS…

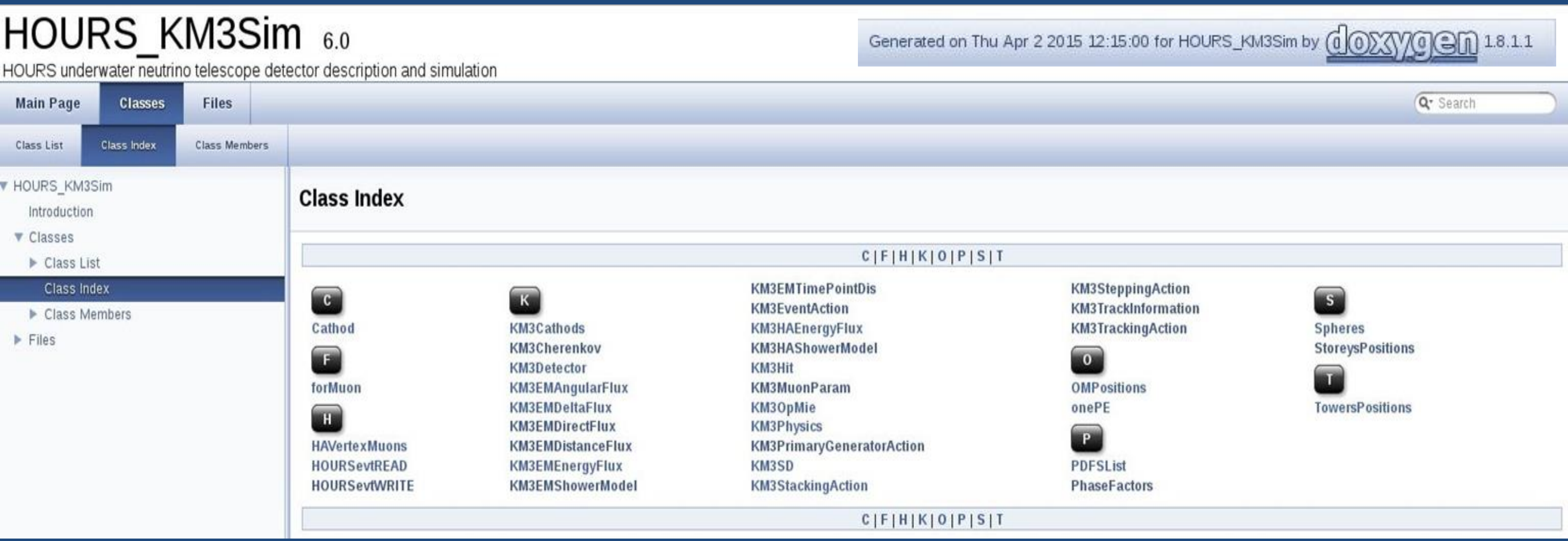
- Developed for the detailed study of the response of underwater neutrino telescopes
- Provides tools for the detector sensitivity estimation to several astrophysical neutrino sources and atmospheric neutrino oscillation parameters
- Is one of the main physics analysis packages used extensively in evaluating architectures and technologies proposed during the design study and preparatory phase of KM3NeT.

Contains

- **Physics models & Event generators**
- **Detector description (based on GEANT4)**
- **Optical background, PMT response & digitization**
- **Optical noise filtering, triggering and event reconstruction**
- **Neutrino telescope performance analysis tools**

High Energy Neutrino Telescopy

New Developments in HOURS (HOU Reconstruction & Simulation)



HOURS_KM3Sim 6.0

HOURS underwater neutrino telescope detector description and simulation

Generated on Thu Apr 2 2015 12:15:00 for HOURS_KM3Sim by doxygen 1.8.1.1

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Class Index

C | F | H | K | O | P | S | T

C
Cathod

F
forMuon

H
HAVertexMuons
HOURSevtREAD
HOURSevtWRITE

K
KM3Cathods
KM3Cherenkov
KM3Detector
KM3EMAngularFlux
KM3EMDeltaFlux
KM3EMDirectFlux
KM3EMDistanceFlux
KM3EMEnergyFlux
KM3EMShowerModel
KM3EMTimePointDis
KM3EventAction
KM3HAEnergyFlux
KM3HAShowerModel
KM3Hit
KM3MuonParam
KM3OpMie
KM3Physics
KM3PrimaryGeneratorAction
KM3SD
KM3StackingAction
KM3SteppingAction
KM3TrackInformation
KM3TrackingAction

O
OMPositions
onePE

P
PDFSList
PhaseFactors

S
Spheres
StoreysPositions

T
TowersPositions

C | F | H | K | O | P | S | T

First Release of the HOURS_KM3Sim package is ready!

Online and manual documentation is prepared →
Ready for Publication including working examples (Comput. Phys. Commun.)

High Energy Neutrino Telescopy

New studies on: Ultra High energy cosmic neutrino detection

To look for high energy (>100TeV) neutrinos we must be able to:

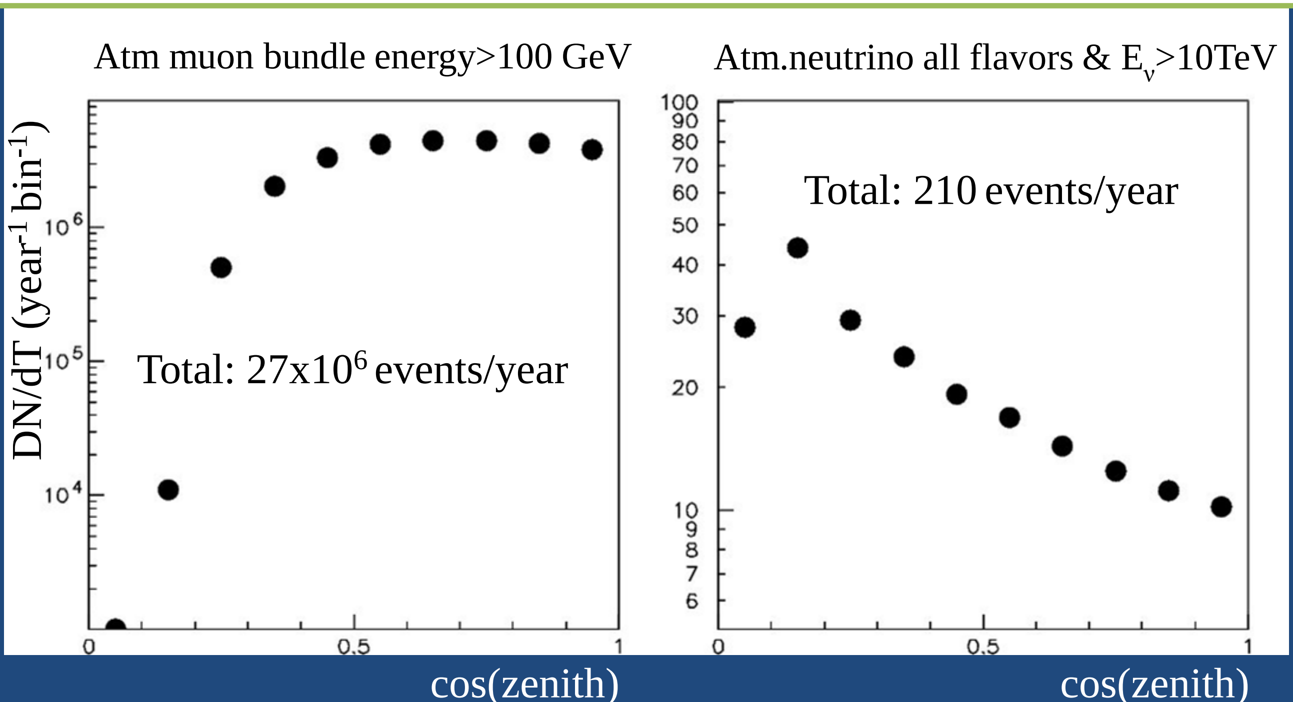
- Look for events coming from above or near the horizon (The Earth shadows ultra high energy neutrinos)
- Suppress the overwhelming noise from atmospheric cosmic ray muons and neutrinos

Signal

$E^2\Phi(E)=1.0 \times 10^{-8} \times e^{-E/3PeV}$ (GeV cm^{-2} s^{-1} sr^{-1}) diffuse flux per flavor (detected flux from ICECUBE)

Background

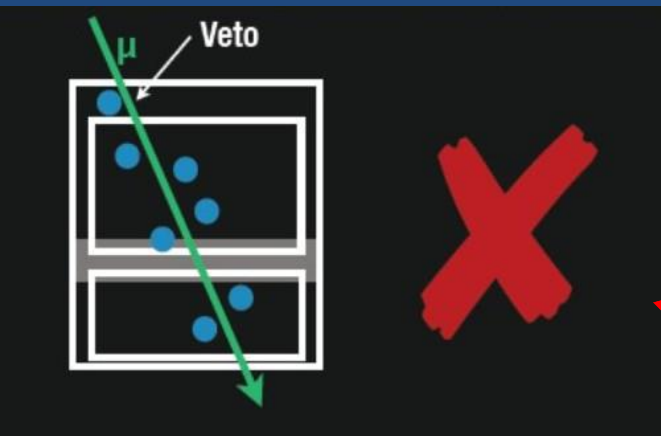
Atmospheric cosmic ray muon and neutrino events rate (1 detector block = 0.5 km^3)



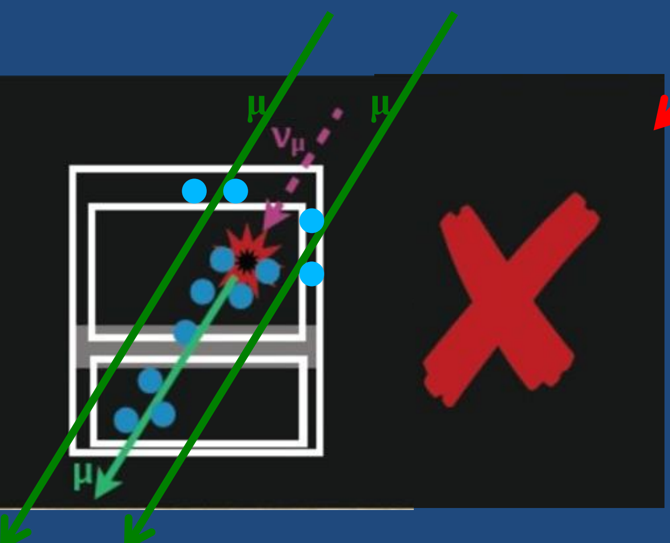
High Energy Neutrino Telescopy

Ultra High energy cosmic neutrino detection

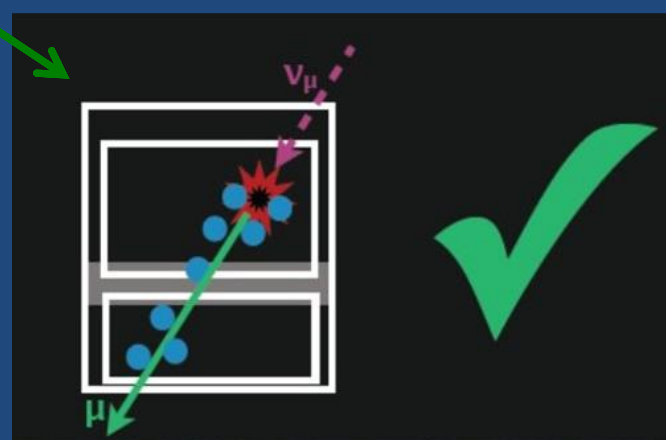
Self Veto



- Use outer Optical Module layers to veto incoming tracks
- Sacrifices a part of the detector
- Tag events as semi-contained if veto region has low hit count (for early hits), while internal detector region has high hit count (considering high energy events)
- 1- Vetos atmospheric muons
- 2- Vetos neutrino interaction events starting from outside the detector (bad energy estimation)
- 3- Vetos dowgoing atmospheric neutrino interaction events in the inner detector region due to the co-produced muons in the same shower activating the veto-region



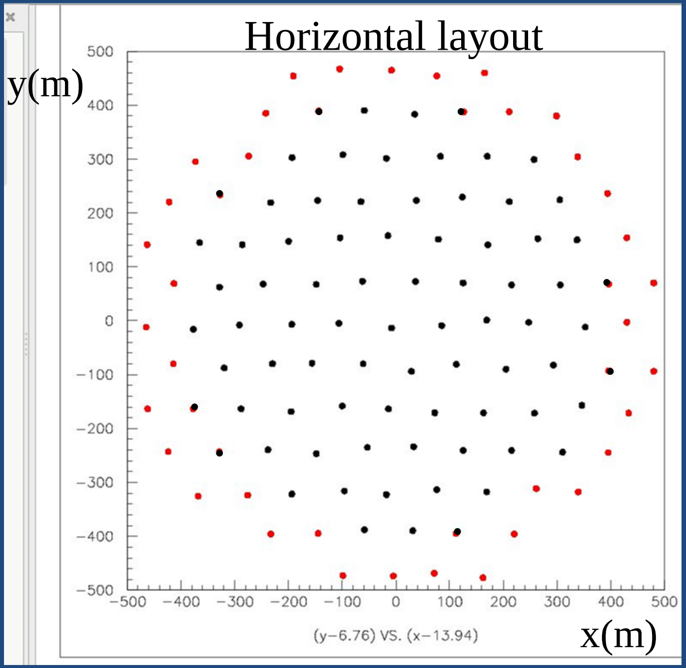
- Search for semi-contained or contained events



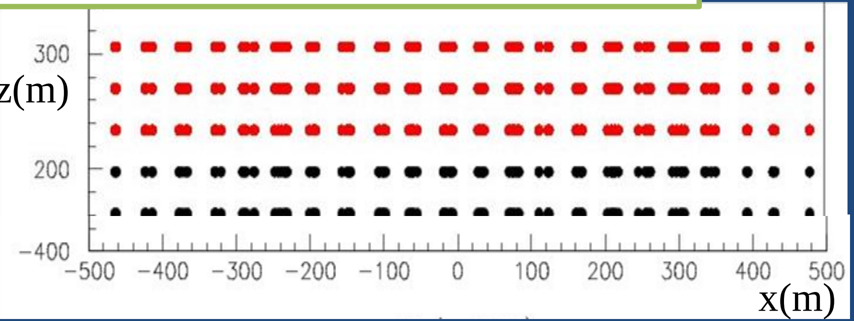
High Energy Neutrino Telescopy

Ultra High energy cosmic neutrino detection

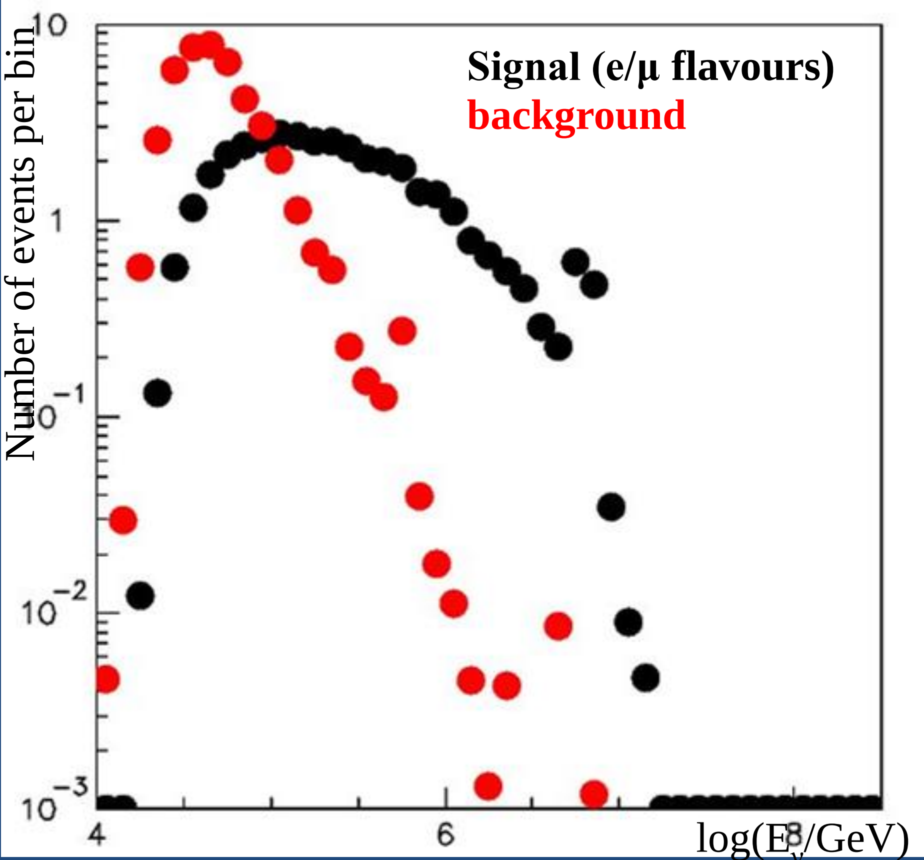
Veto setup (each building block)



Vertical layout
(only 5 upper layers of detector shown)



ONLY DOWN GOING EVENTS
SIX DETECTOR BLOCKS 3.0 km^3 3 YEARS OF OPERATION



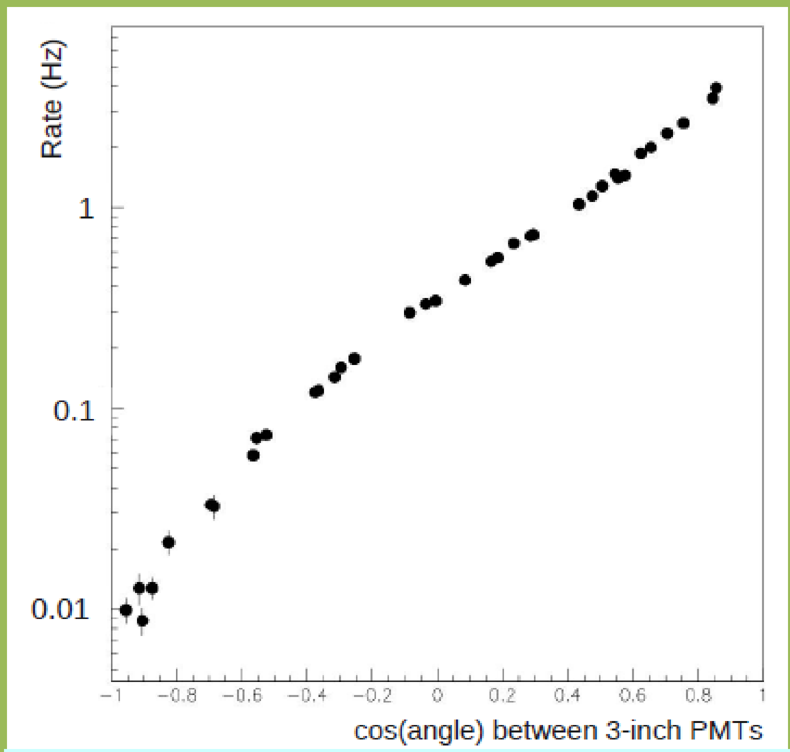
Signal: 27 events for E_ν>100TeV
Background: 5.3 events for E_ν>100TeV

High Energy Neutrino Telescopy

A Reminder on KM3NeT DOM

Optical noise from ^{40}K decays in sea water is included

- ^{40}K optical noise includes single and multiple genuine coincidence rate (up to 6-fold coincidence)
  - Noise rates per Digital Optical Module (DOM) are estimated
  - with full GEANT4 simulation of ^{40}K decays in DOM's vicinity,
  - taking into account DOM functional characteristics



The rate of double genuine coincidences versus the angle between the two 3-inch PMT axis directions

The KM3NeT DOM: 31 3" PMTs inside a 17" glass sphere

PMT response simulation

- Quantum/collection efficiency
- Time Jitter
- Single Photoelectron charge spectrum
- Waveform production

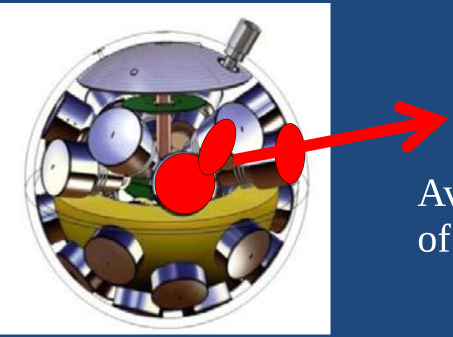
Electronics simulation

- Single Threshold ToT electronics per PMT

High Energy Neutrino Telescopy

Study of the performance of the PPMDU to detect atmospheric muons

- The Pre-Production Model of the KM3NeT Detection Unit (PPMDU) was deployed in 2014
- The PPMDU consists of 3 DOMs in a vertical structure.
- With 3 DOMs reconstruction of atmospheric muons is possible using not only the timing information of the hits but also the direction information.
- Reconstructed event rate ~ 43 h^{-1}

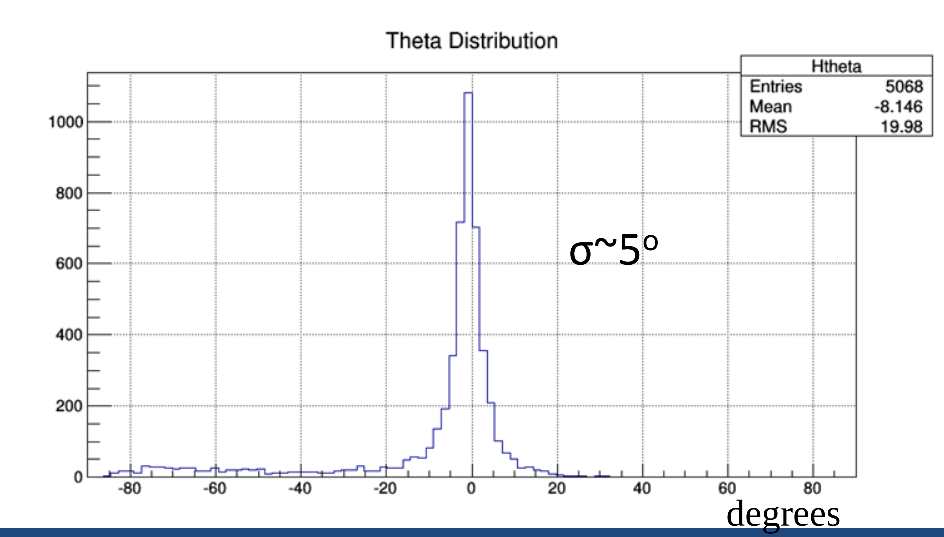


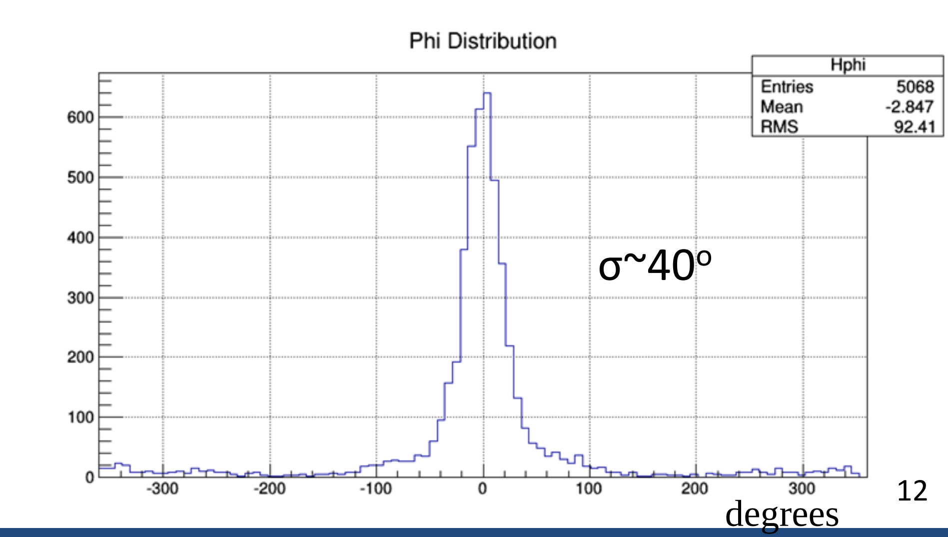
$$\hat{D} = \sum_{i=1}^{N} d_i$$

Averaged direction of active PMTs

Zenith angle difference between reconstructed and simulated direction of atmospheric muons

Azimuth angle difference between reconstructed and simulated direction of atmospheric muons



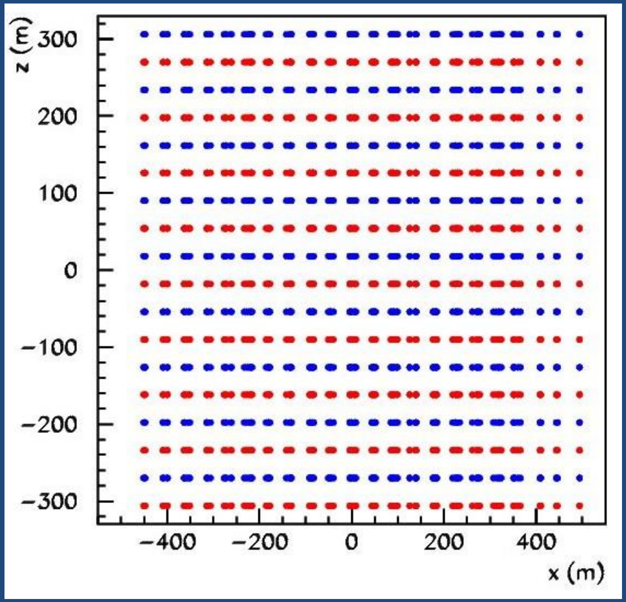


High Energy Neutrino Telescopy

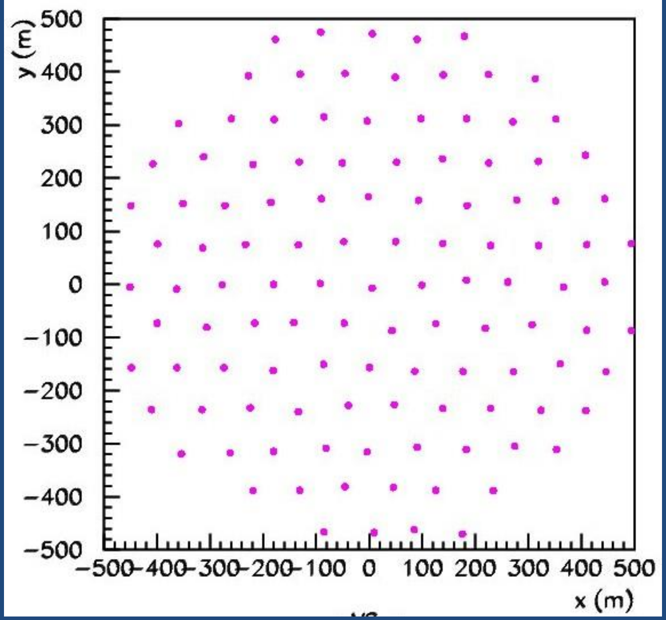
Development of an inter-calibration technique for the estimation of the KM3NeT angular resolution

- Divide the detector in two identical sub detectors
Reconstruct the same event separately using each sub detector's signal
- Compare the two reconstructed directions on a event by event basis
- The angle difference in the above comparison should be compatible with the angular resolution of each sub detector estimated with MC
- Any incompatibility can reveal systematic effects in the reconstruction techniques

Side view
Sub detector 1
Sub detector 2



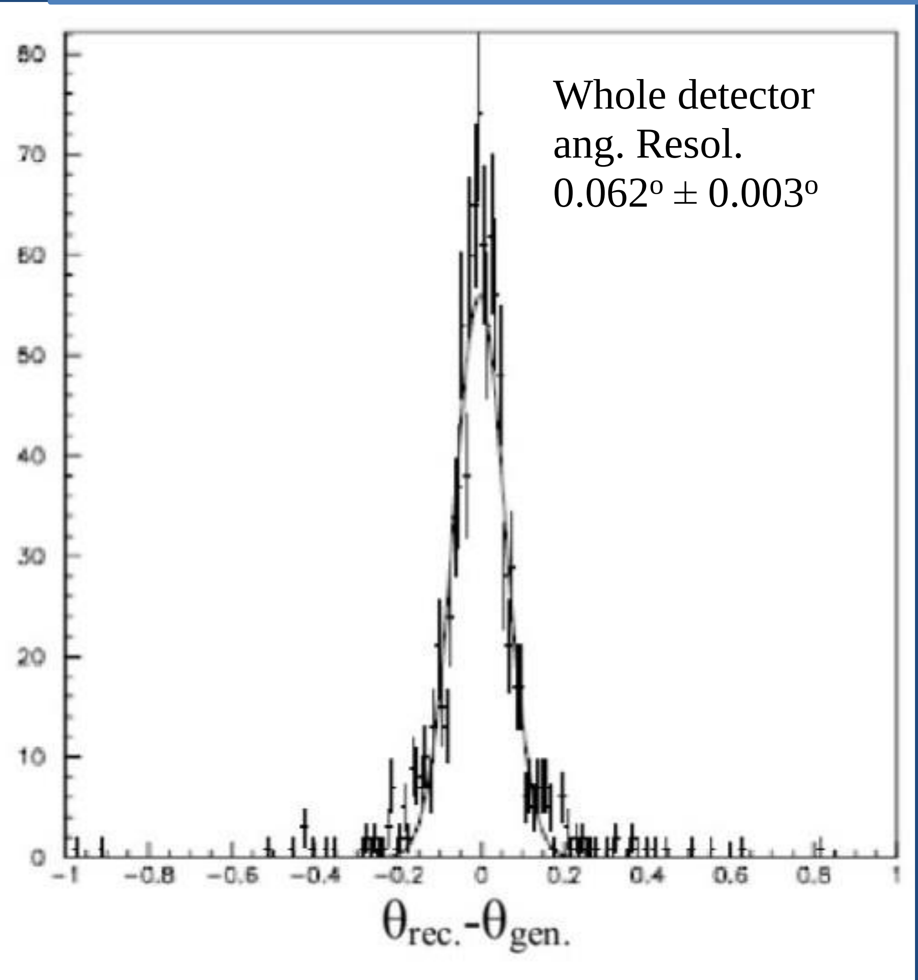
Top view

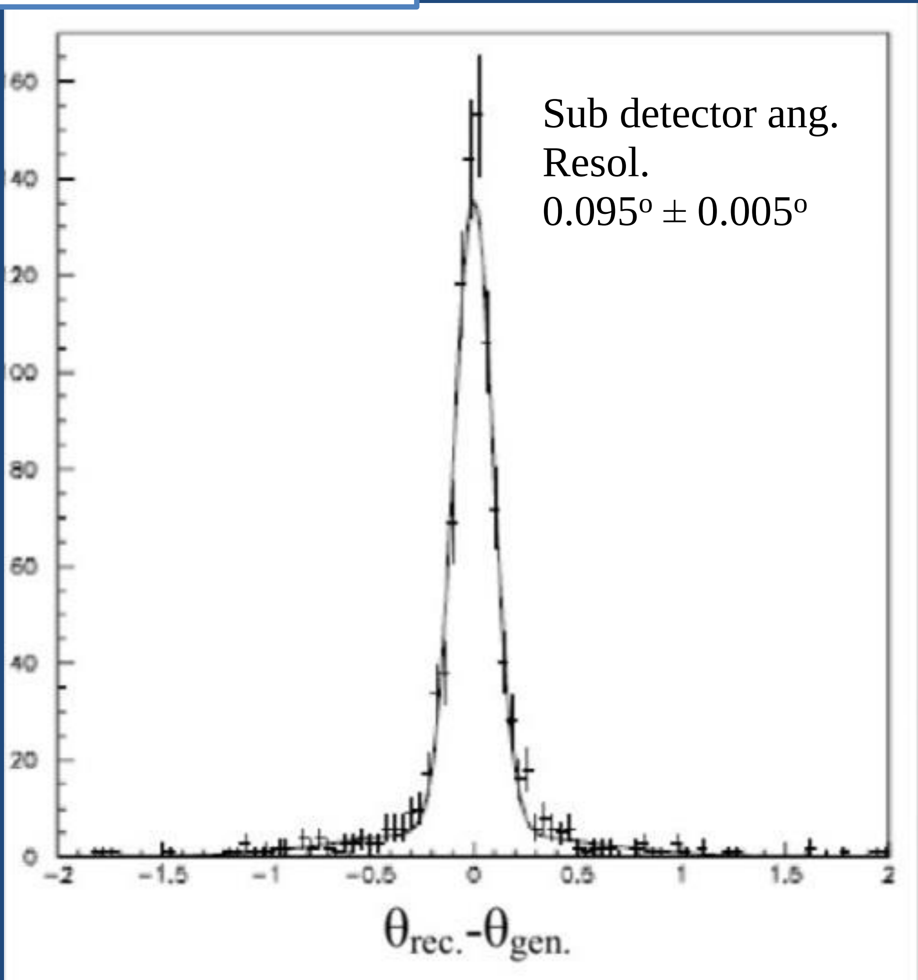


High Energy Neutrino Telescopy

An inter-calibration technique for the estimation of the KM3NeT angular resolution (preliminary results)

Detector + sub detectors' response to 1 TeV isotropically distributed muons





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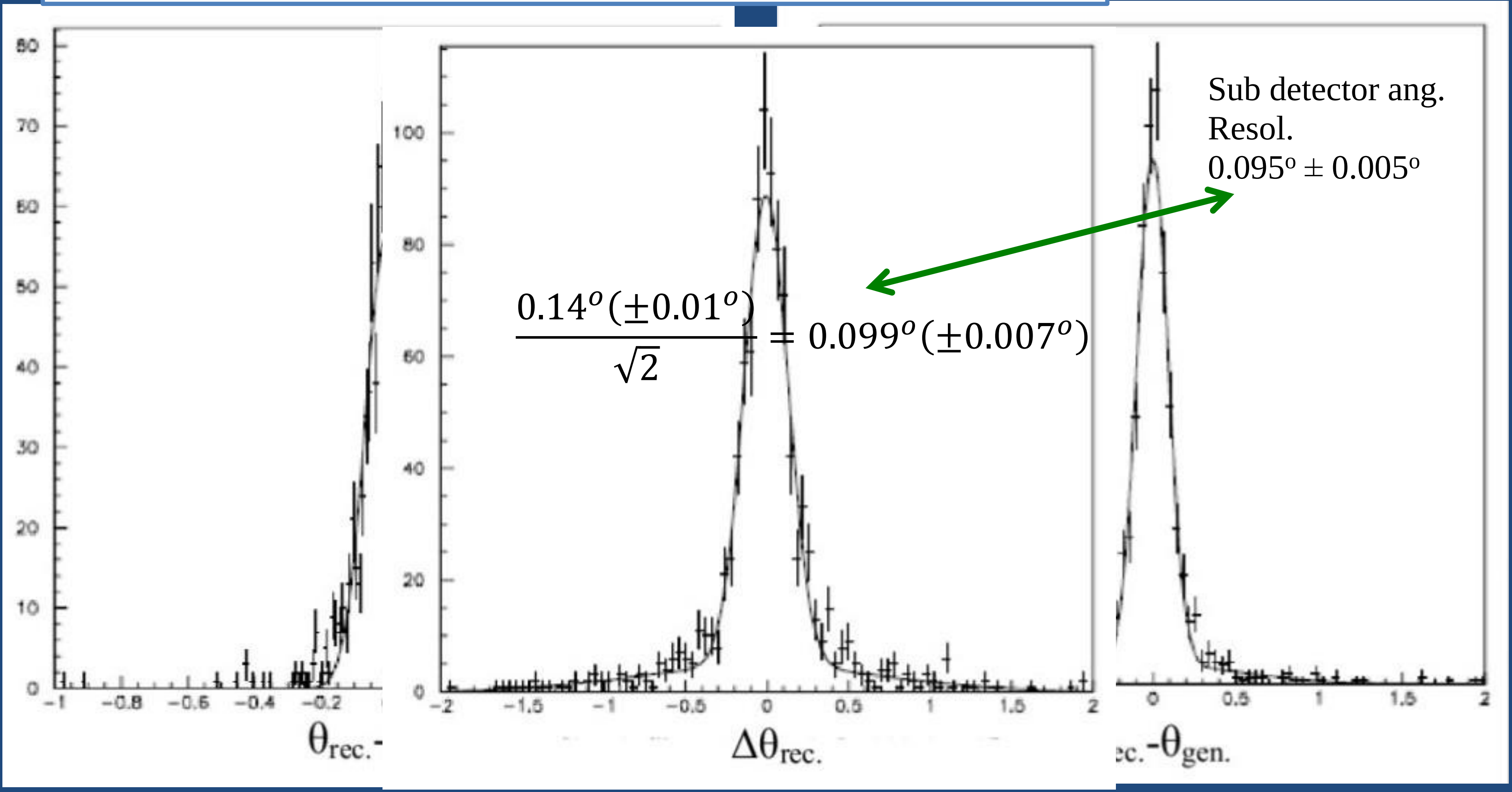


Ongoing work for the performance estimation of this technique using “realistic” signal from atmospheric muon bundles and neutrino interaction events

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

Last year achievements

This year results to be published

HOU, Demokritos, Aegean Un., TEI Peiraus, Auth

Installation and Operation of the SD system of the ASTRONEU Array

Calibration of scintillator counters and Digitization Electronics

Development of detailed Monte Carlo Simulation Software for the SD

Installation and Operation of the RF system of the ASTRONEU Array

Analysis of accumulated SD Data - Comparison with MC

Analysis of RF Data and correlation with the SD Data

Testing of MegaMicromegas detectors

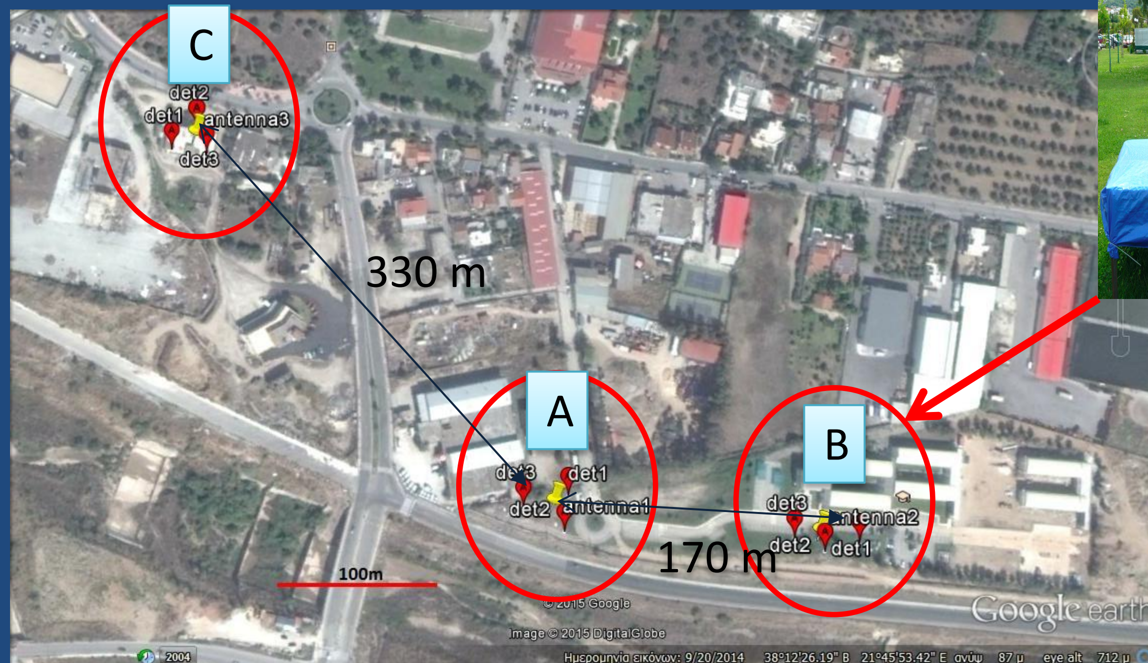
Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

The Scintillator Counters of the ASTRONEU Array

3 groups of scintillator counters (Station-A, Station-B and Station-C

Each station consists of 3 scintillator counters (~30 m spacing)



One more station deployed in the Physics Lab (3.5 km apart)

STATION

3x 1m^2 Scintillator Detectors (Protvino SC-301)

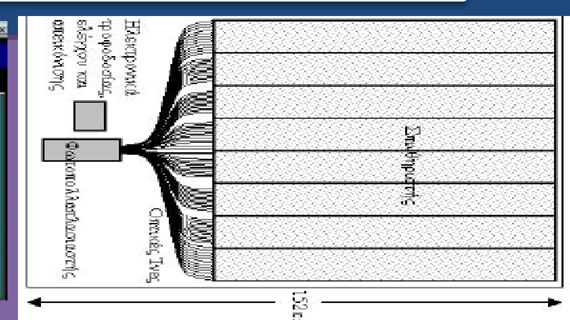
WLS Fibers (Bicron BCF91-A)

PMT Photonis XP1912

HV DC-DC Converter (EMCO CA20N)

Remote Control and Monitor of HV (NI-USB)

Quarknet – DAQ card



Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

The SD System of the ASTRONEU Array

Digitization, DAQ and Slow Control Electronics

Scintillator Counters

STATION

3x $1m^2$ Scintillator Detectors (Protvino SC-301)
WLS Fibers (Bicron BCF91-A)
PMT Photonis XP1912
HV DC-DC Converter (EMCO CA20N)
Remote Control and Monitor of HV (NI-USB)
Quarknet – DAQ card

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

The SD System of the ASTRONEU Array

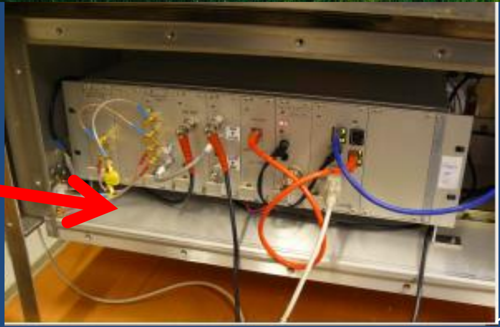
RF System

Scintillator Counters

STATION

3x 1m^2 Scintillator Detectors (Protvino SC-301)
WLS Fibers (Bicron BCF91-A)
PMT Photonis XP1912
HV DC-DC Converter (EMCO CA20N)
Remote Control and Monitor of HV (NI-USB)
Quarknet – DAQ card

Digitization, DAQ and Slow Control Electronics



Digitization: based on ToT measurement

Detectors data acquisition with the Quarknet card based on the Time over Threshold technique

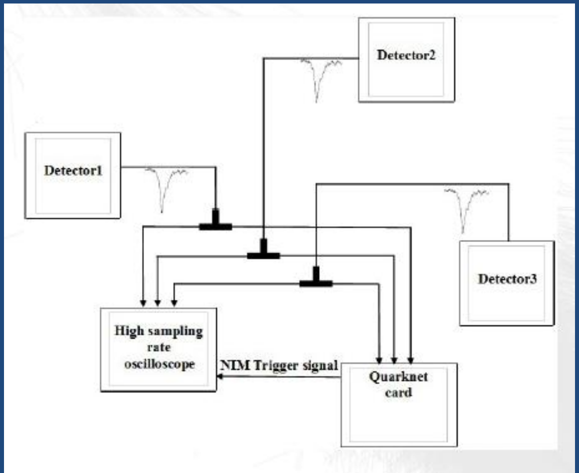
- 4 input channels
- 10x amplification of the input signals
- Performs time tagging of the crossings of the pulses with one adjustable threshold (set through the acquisition software)
- Time resolution 1.25ns
- Adjustable trigger criteria (majority, time window)
- NIM trigger out signal
- USB connection to hosting computer
- External GPS receiver provides the absolute time of the event

Extensive Air Shower Instrumentation

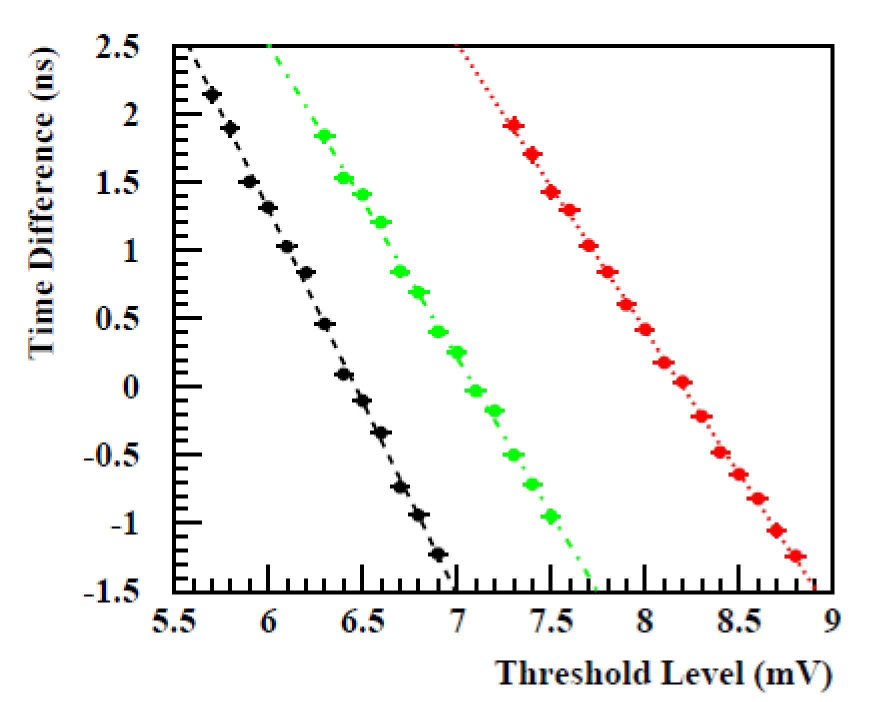
EAS Telescopy: Operation & Reconstruction

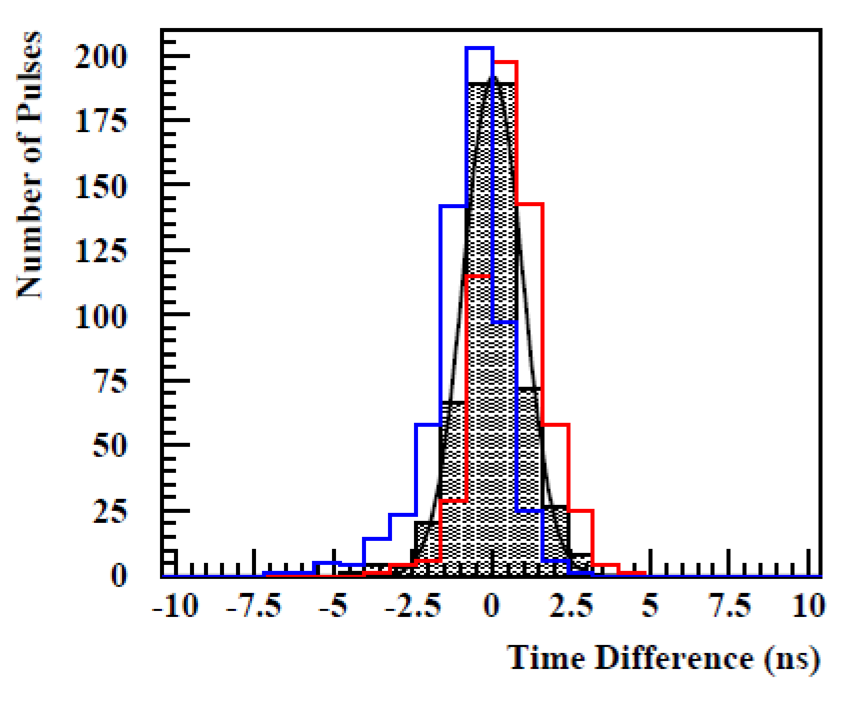
Calibration of the ToT Measurement Electronics

<u>G. Bourlis,</u> I. Manthos, S.E. Tzamarias



Employing data acquired with the Quarknet card and a high rate oscilloscope :
ToT resolution ~ 1 ns
Leading edge timing resolution ~ 0.7 ns





Extensive Air Shower Instrumentation

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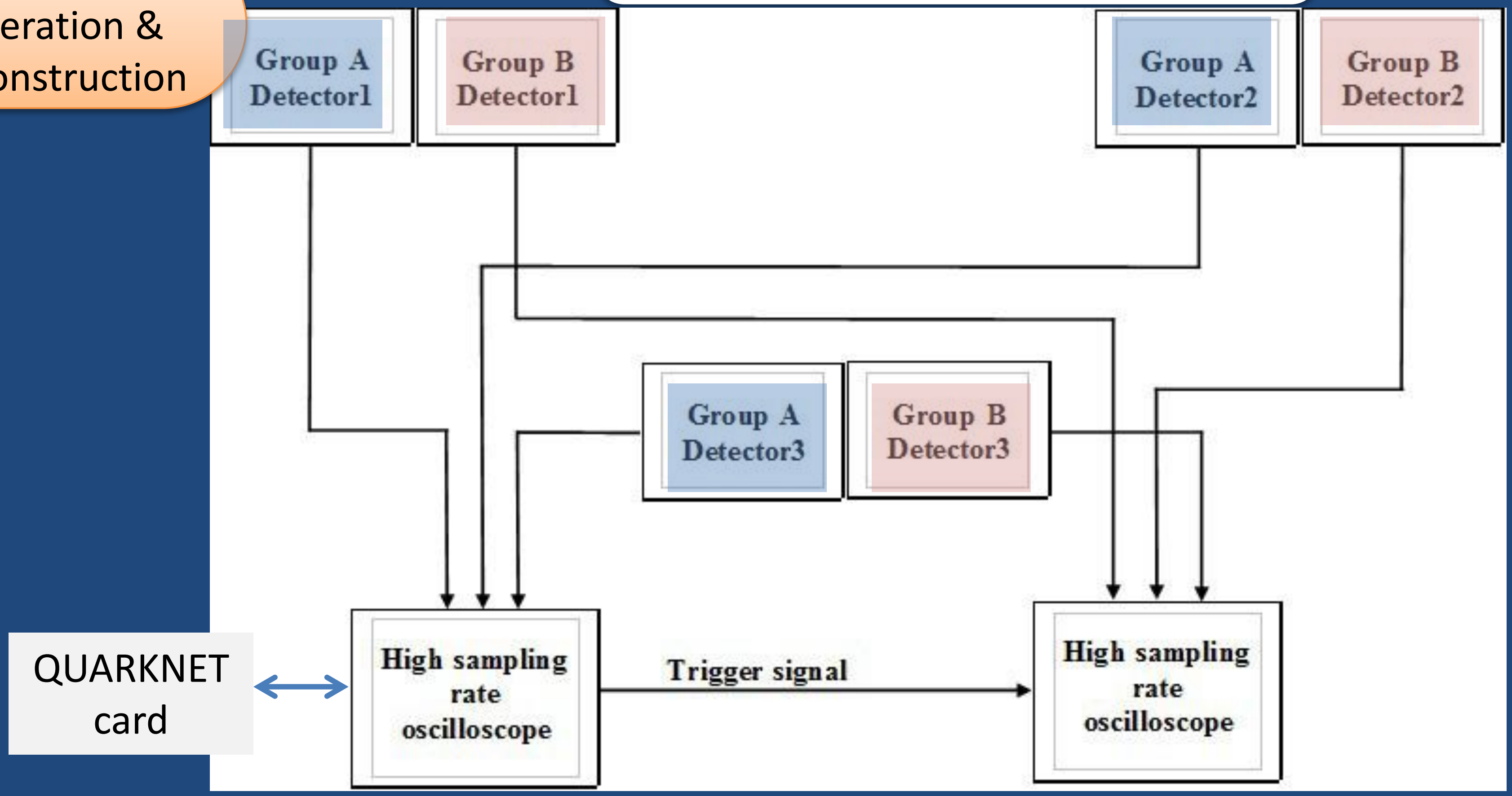
Calibration of the ASTRONEU Stations

Schematic of the Calibration Setup



- Accumulated data are used to trim Monte Carlo parameters (gains, Response of scintillator material and WLS fibers)
- Evaluation of electronics response (pulse shape characteristics vs TOT measurements)

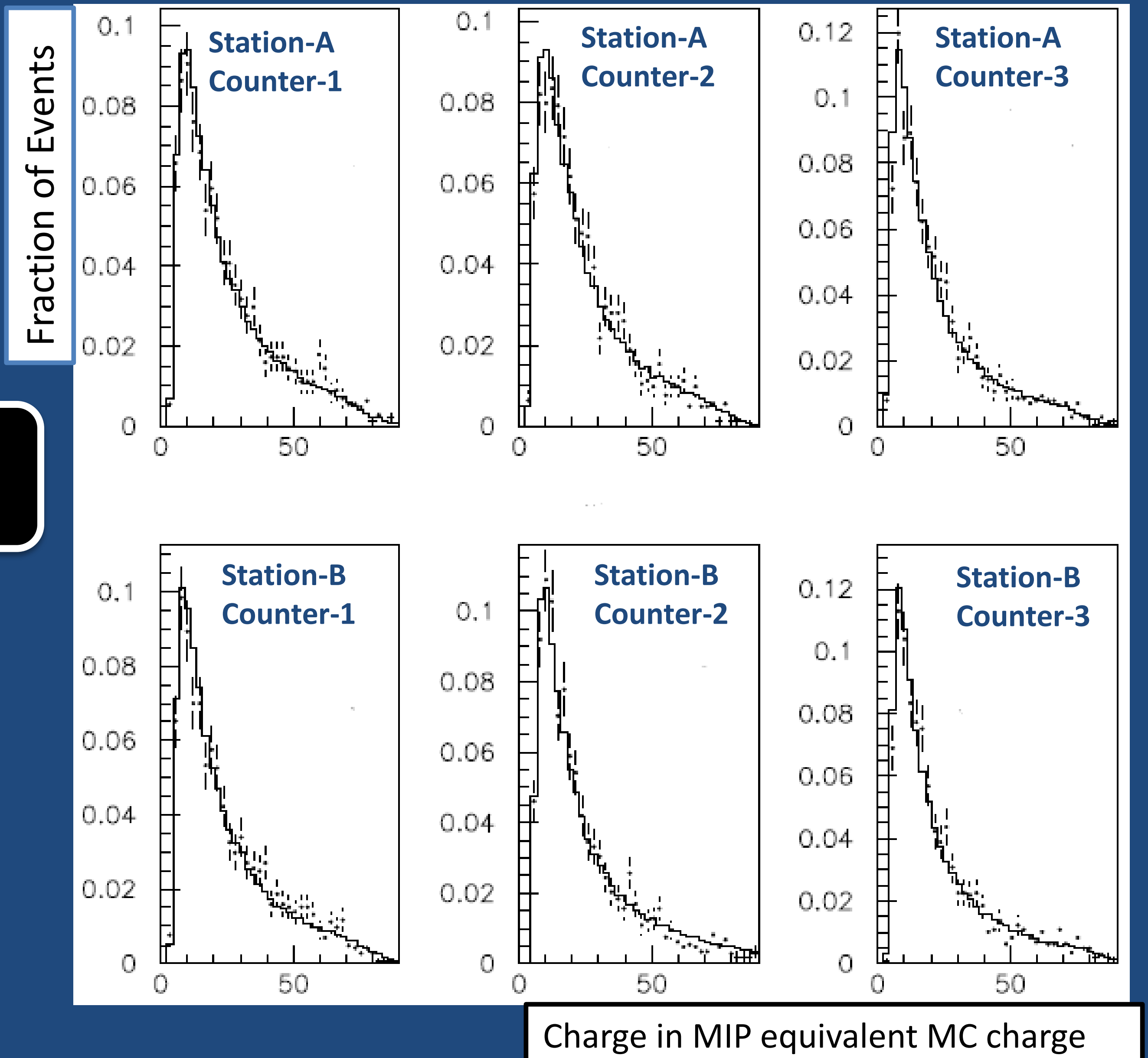
Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

Tuning HOURS using Calibration Data

A. Leisos, I. Manthos, S.E. Tzamarias

Charge Distribution 1/2



Trigger Condition

6-fold coinidensce @ 12.7 mV threshold

Histogram: MC
Points : Data

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

Tuning HOURS using Calibration Data

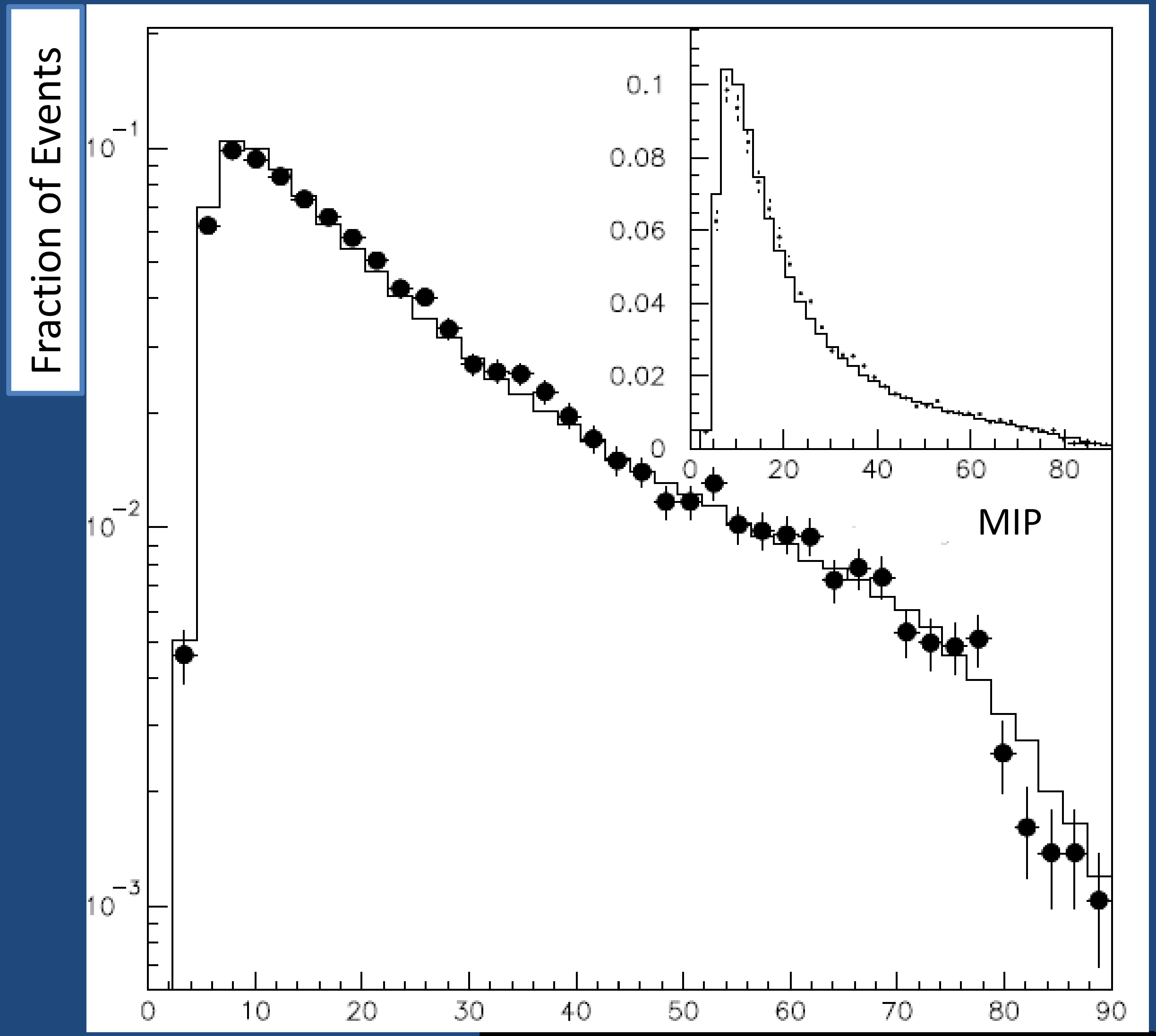
A. Leisos, I. Manthos, S.E. Tzamarias

Charge Distribution 2/2

Trigger Condition

6-fold coinidensce @ 12.7 mV threshold

Histogram: MC
Points : Data

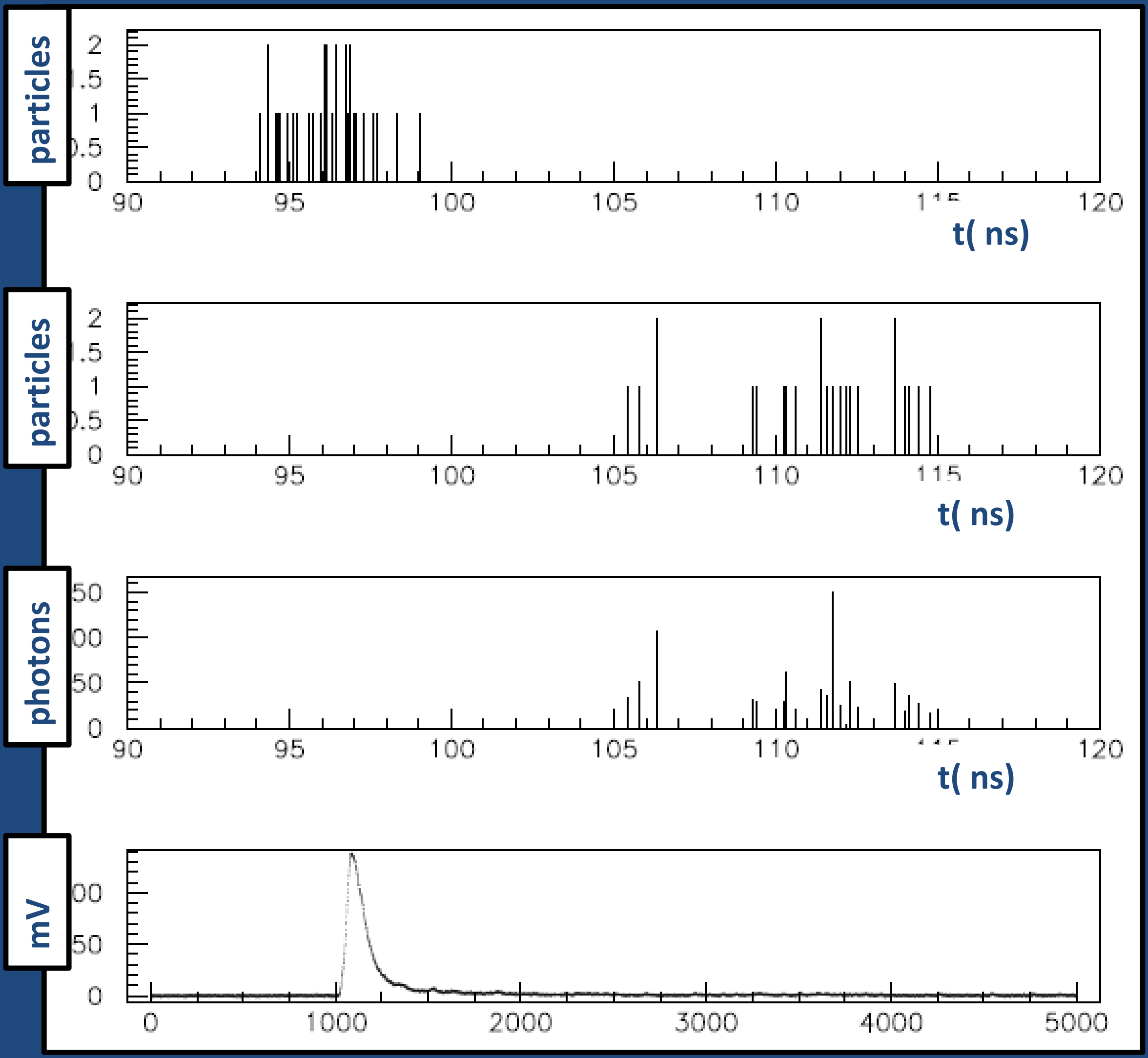


Average Charge in MIP equivalent MC charge

Tuning HOURS using Calibration Data

A. Leisos,, S.E. Tzamarias

Pulse Simulation1/2



Corsika→ timing of particles entering the detector

HOURS→ timing of particles according to their impact point on the counter

HOURS→ timing of photons produced

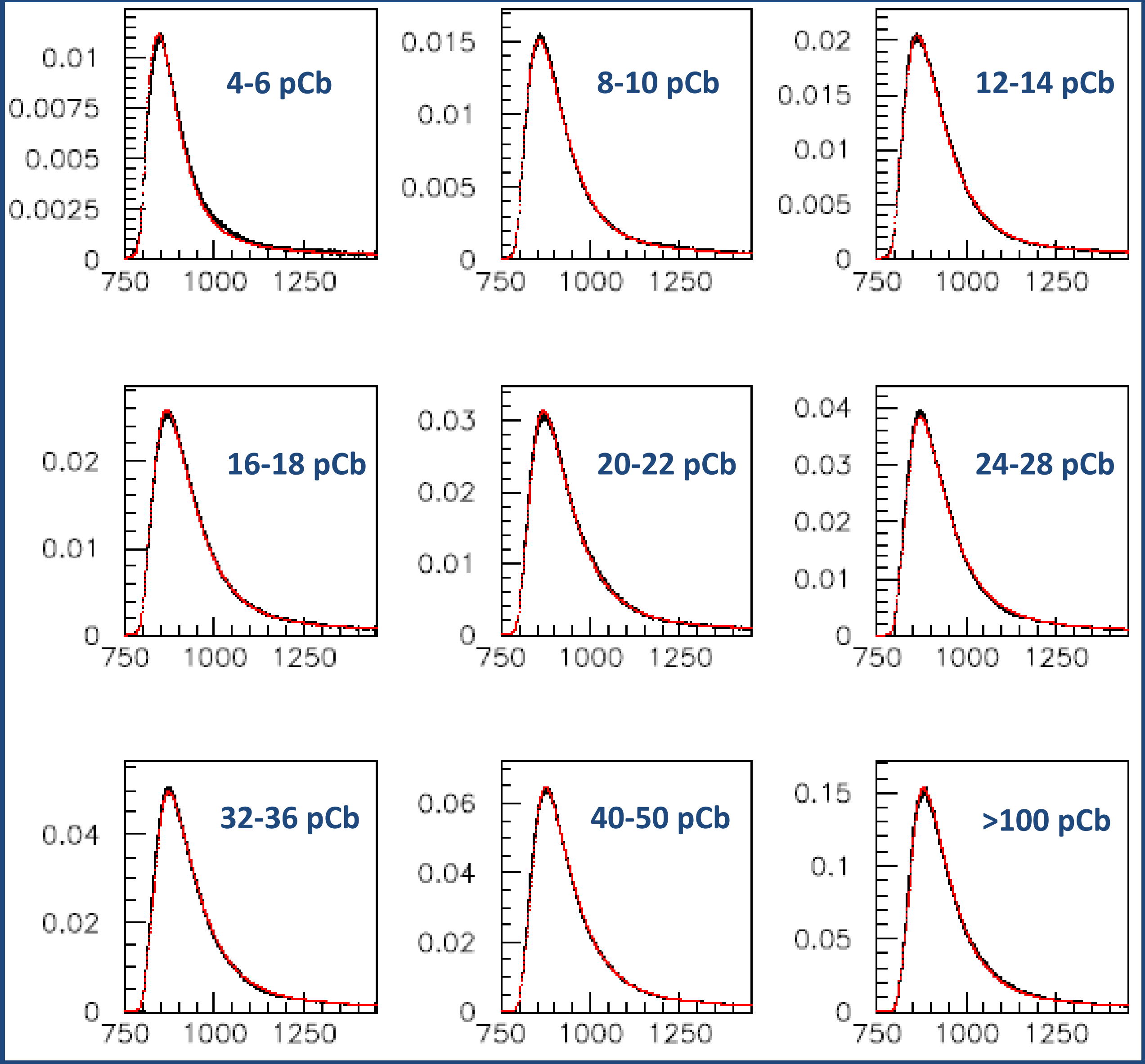
HOURS→ superimposed pulse from each pe

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

Tuning HOURS using Calibration Data

A. Leisos,, S.E. Tzamarias



Red: MC
Black: Data

Pulse Simulation2/2

Tuning HOURS using Calibration Data

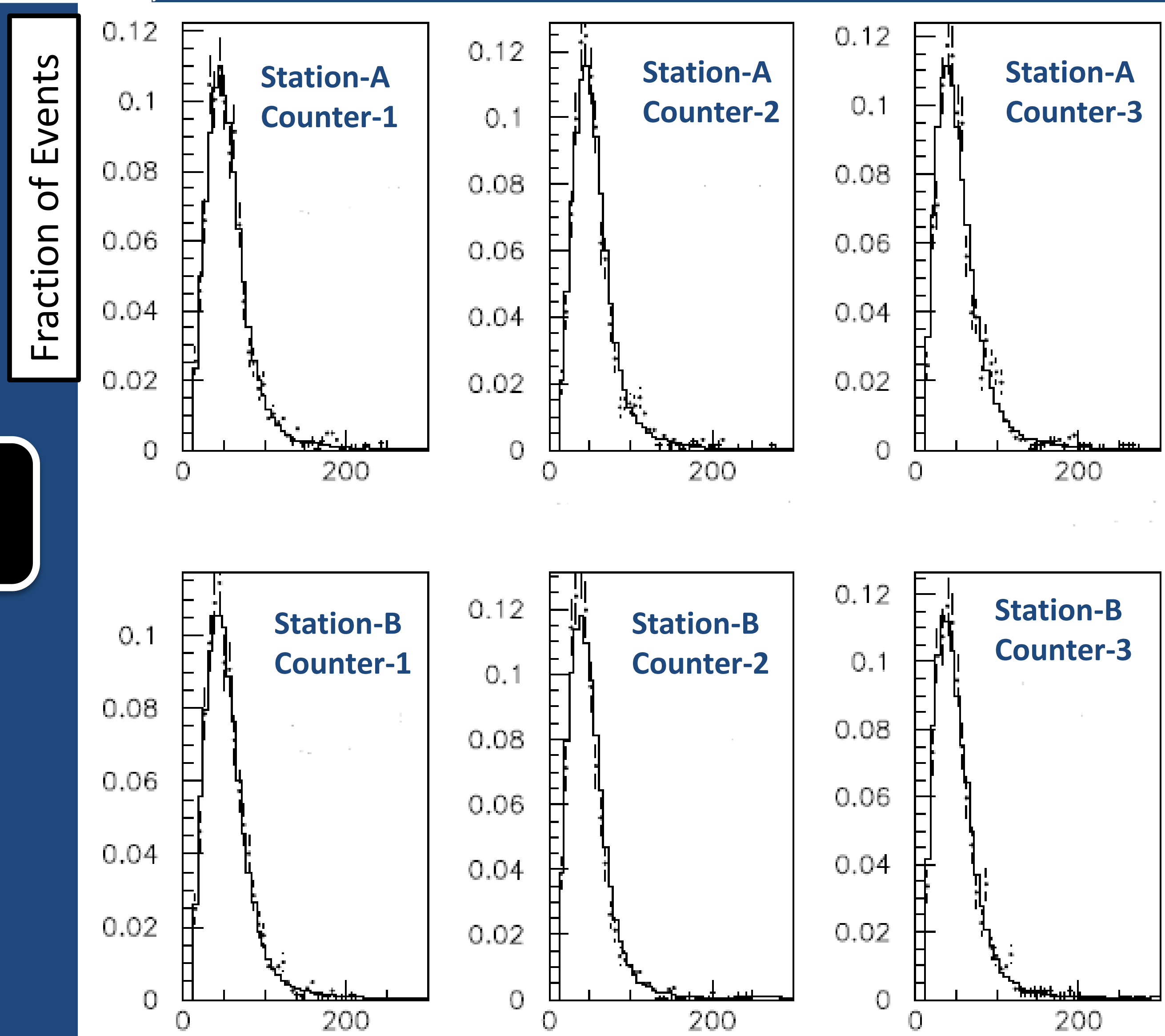
A. Leisos,, S.E. Tzamarias

ToT Distribution 1/2

Trigger Condition

6-fold coinidensce @ 12.7 mV threshold

Histogram: MC
Points : Data



TOT @ 9.7 mV

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

Tuning HOURS using Calibration Data

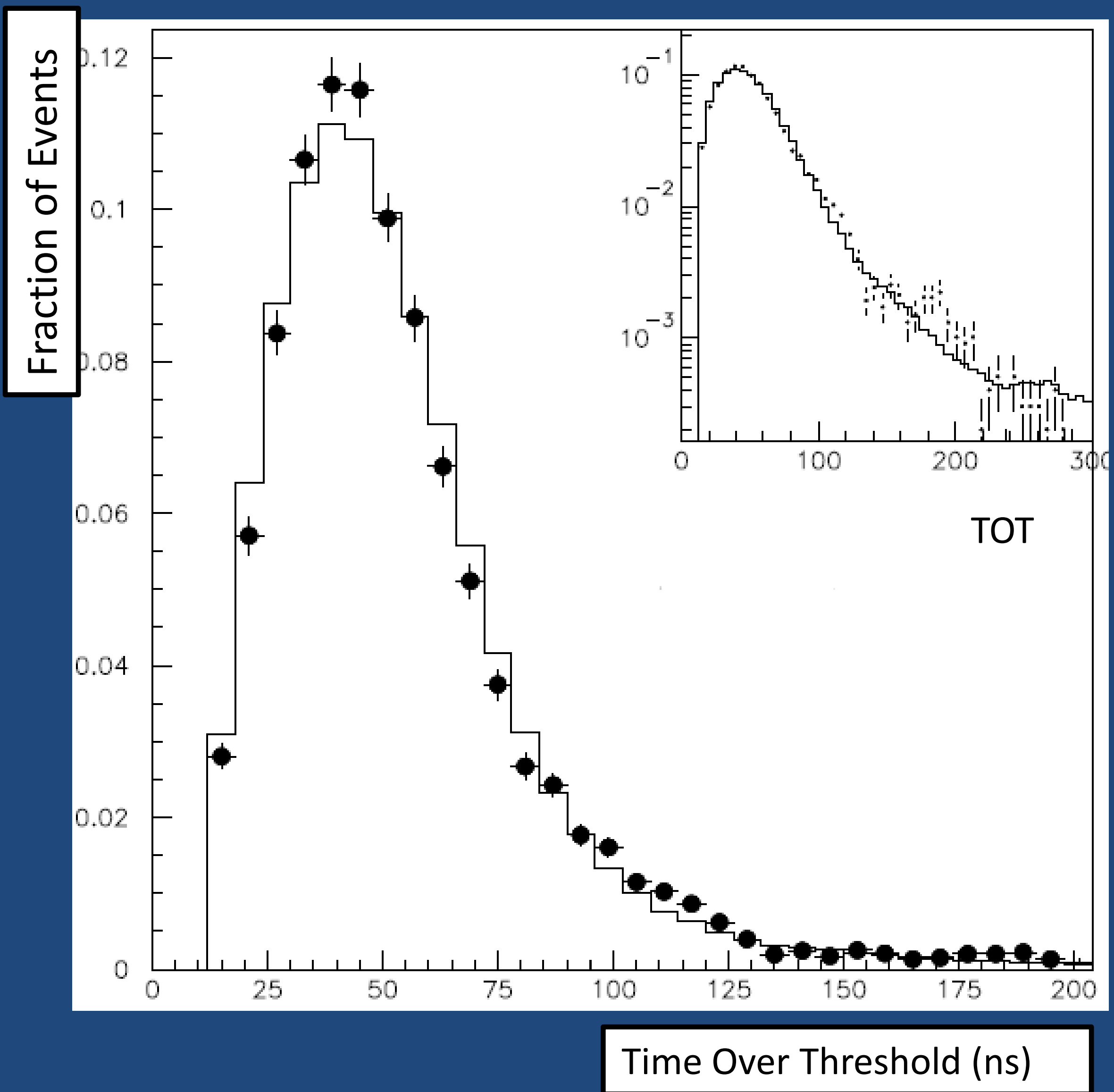
A. Leisos,, S.E. Tzamarias

ToT Distribution 2/2

Trigger Condition

6-fold coinidensce @ 12.7 mV threshold

Histogram: MC
Points : Data



Extensive Air Shower Instrumentation

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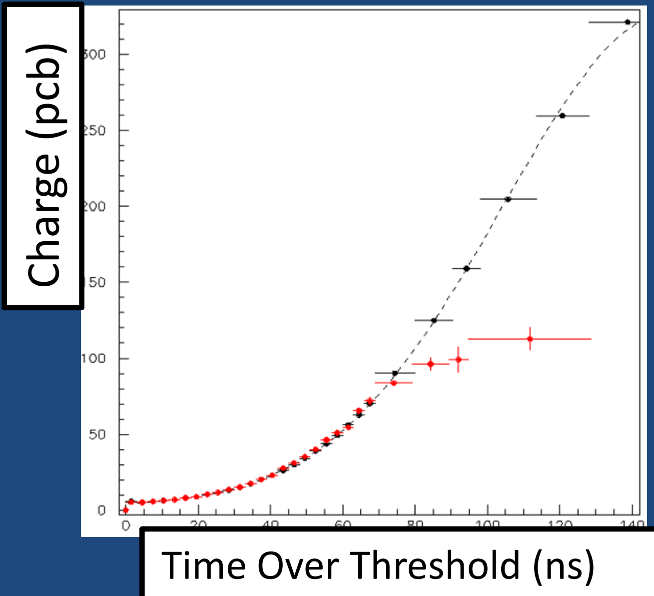
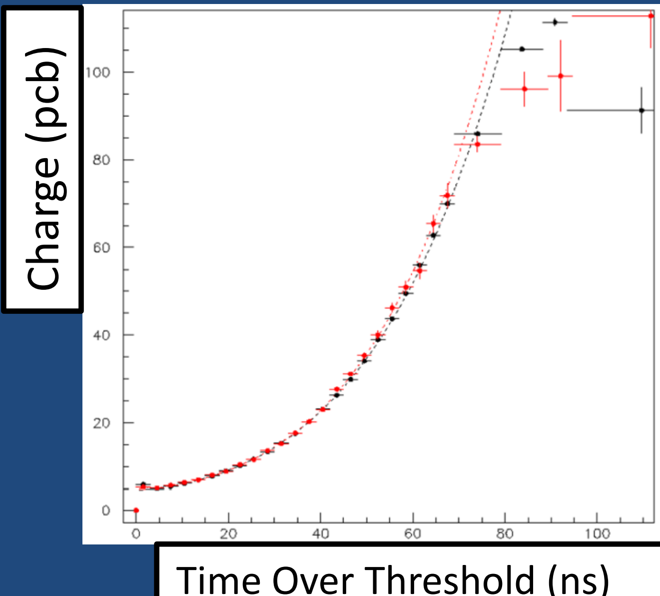
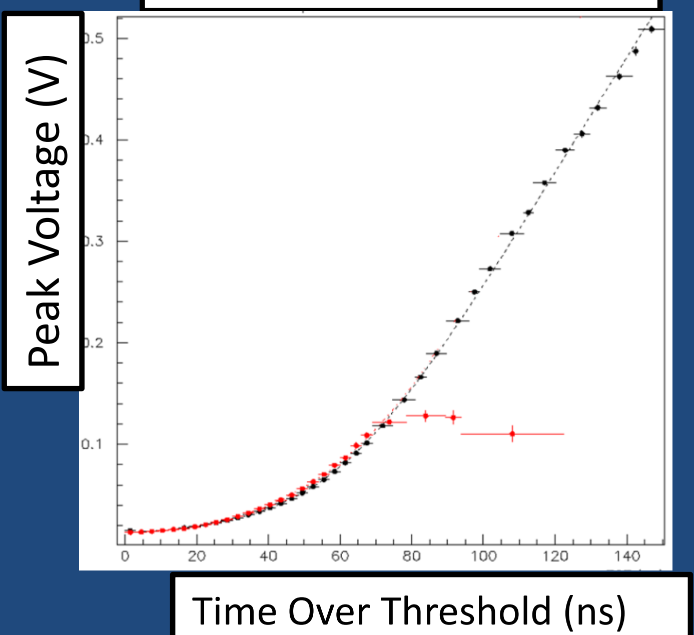
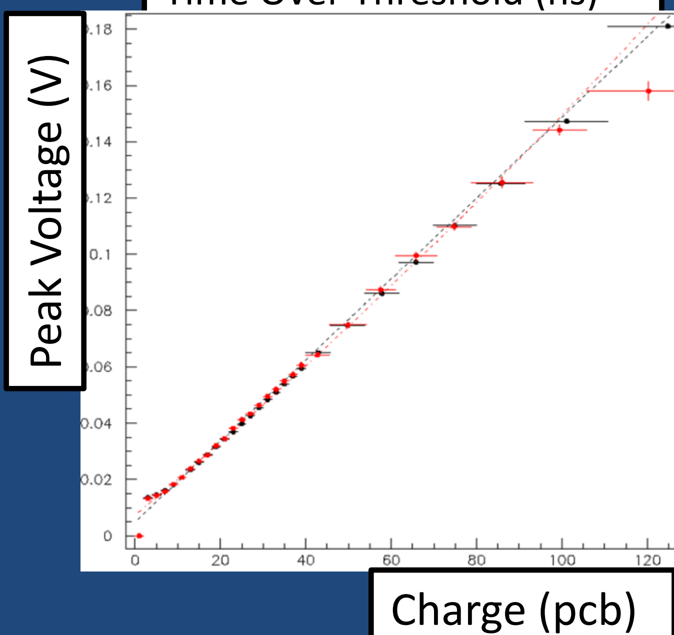
A. Leisos,, I. Manthos S.E. Tzamarias





Parameterizations





ToT Analysis threshold@ 9.7 mV

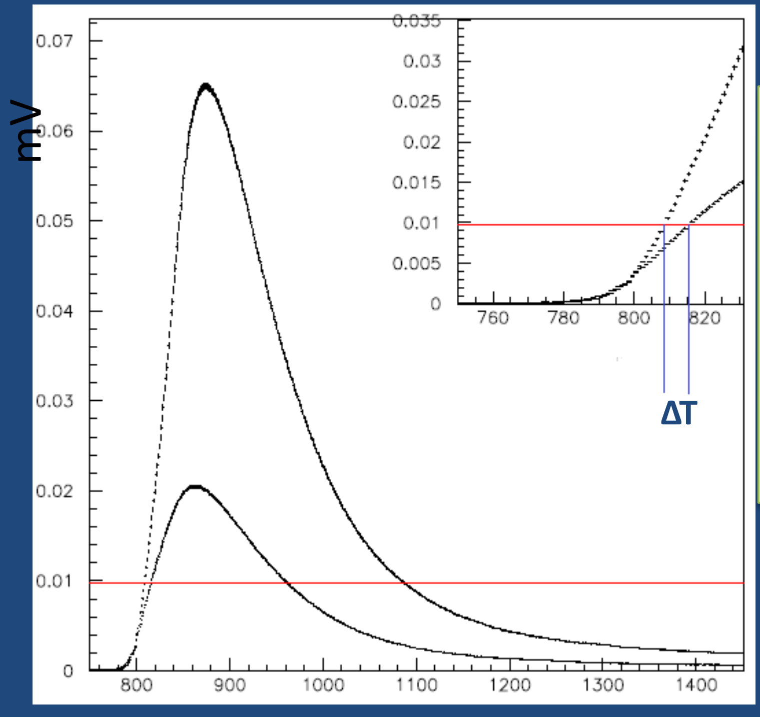
Black: MC
Red: Data

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

Slewing Correction

G. Bourlis,, I. Manthos A. G. Tsirigotis S.E. Tzamarias



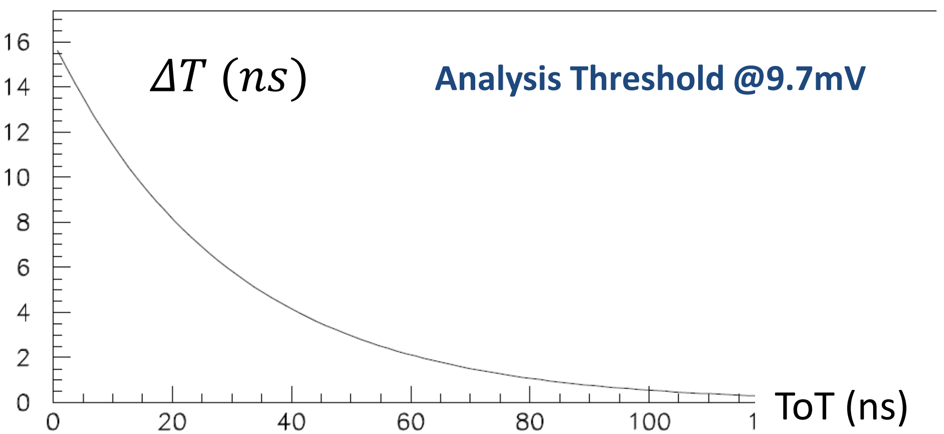
- Accumulate data from showers recorded by both stations
- Model of slewing correction and associated error as:

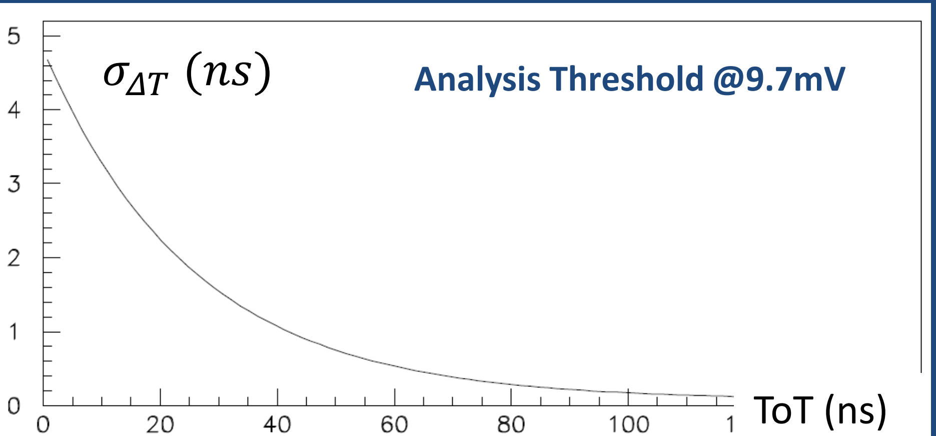
$$\Delta T = a \cdot e^{-b \cdot TOT} \qquad \sigma_{\Delta T} = c \cdot e^{-d \cdot TOT} + f$$

- Minimize

$$\chi^2 = \sum \frac{\left((t_1 - \Delta T_1) - (t_2 - \Delta T_2) \right)^2}{\left(\sigma_1^2 + \sigma_2^2 \right)^2}$$

Estimated values @ 9.7 mV
α=16.04, b=0.03375, c=4.74, d=0.039, f=0.076



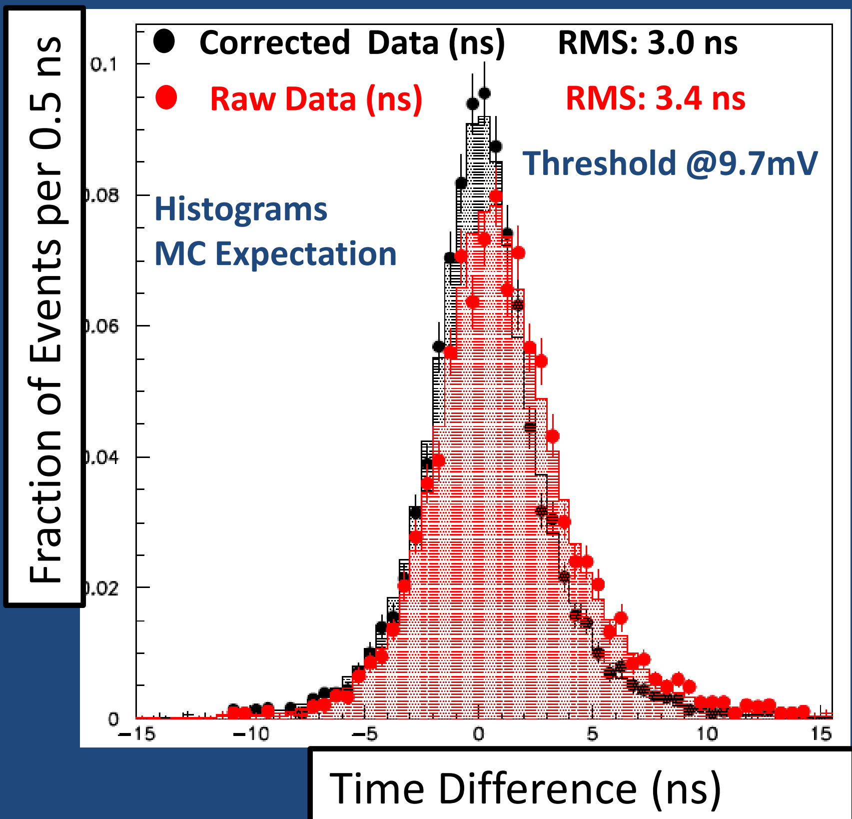


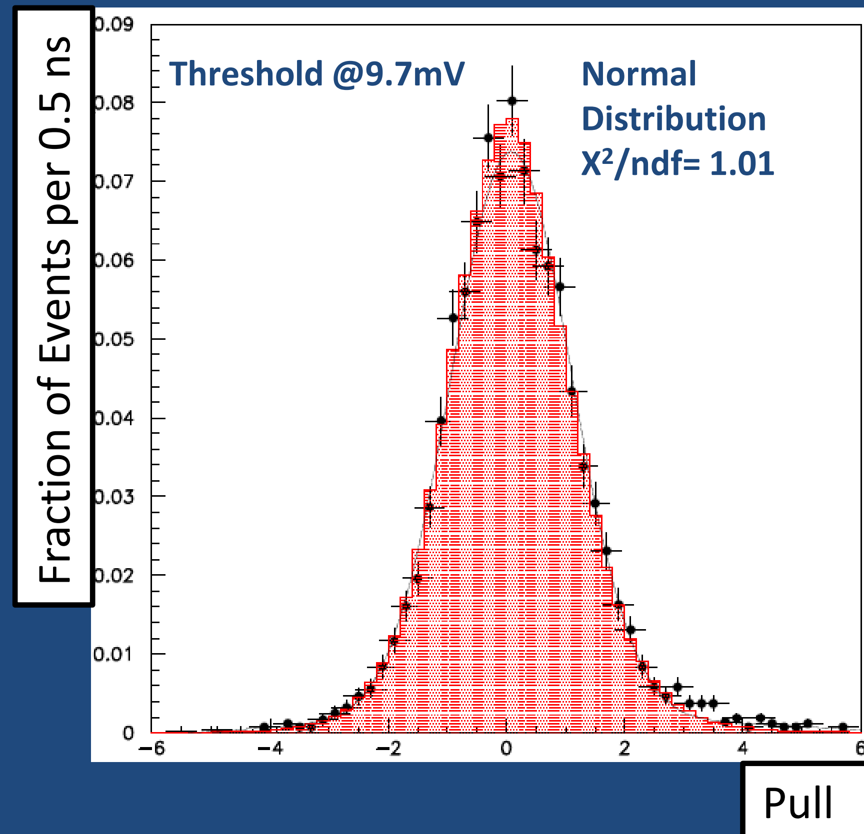
Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

Slewing Correction

G. Bourlis,, I. Manthos A. G. Tsirigotis S.E. Tzamarias





Histogram: MC
Points : Data

Time difference (ns) distribution of a pair of counters agree with the MC prediction

Correction and its Resolution is consistent

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

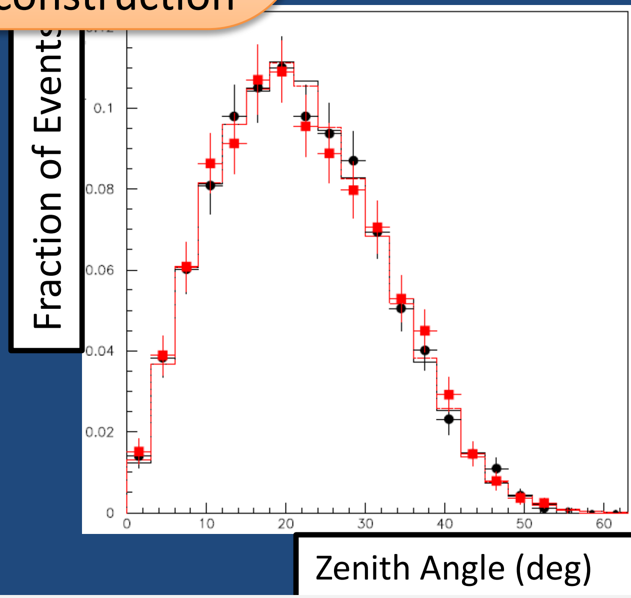
EAS Reconstruction with the Calibration Setup

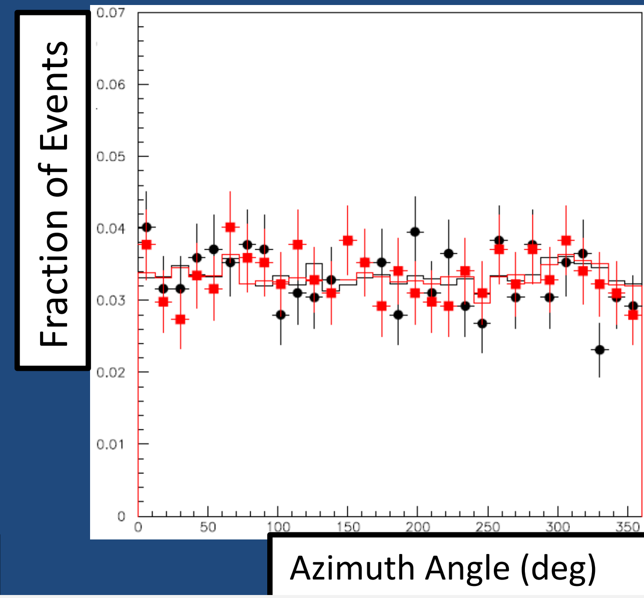
A. Leisos,, G. Bourlis, S.E. Tzamarias

Shower Reconstruction1/2

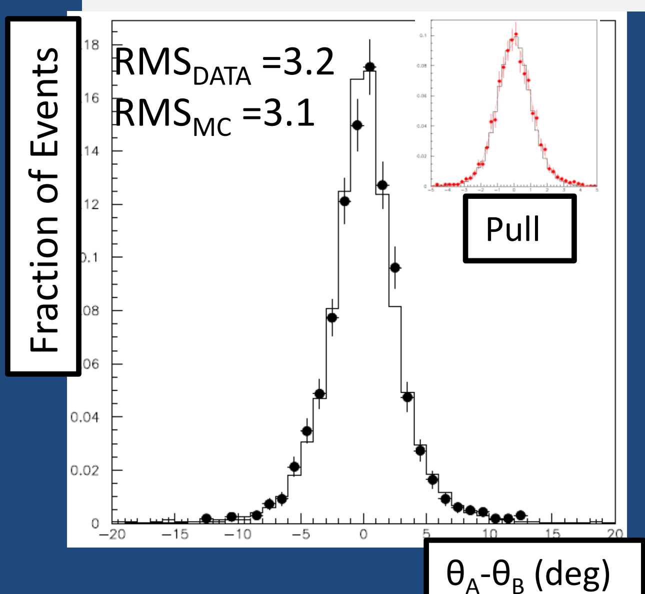
Analysis Threshold@ 7.7 mV
Trigger Threshold@12.7mV
Osc-Osc Int. Run

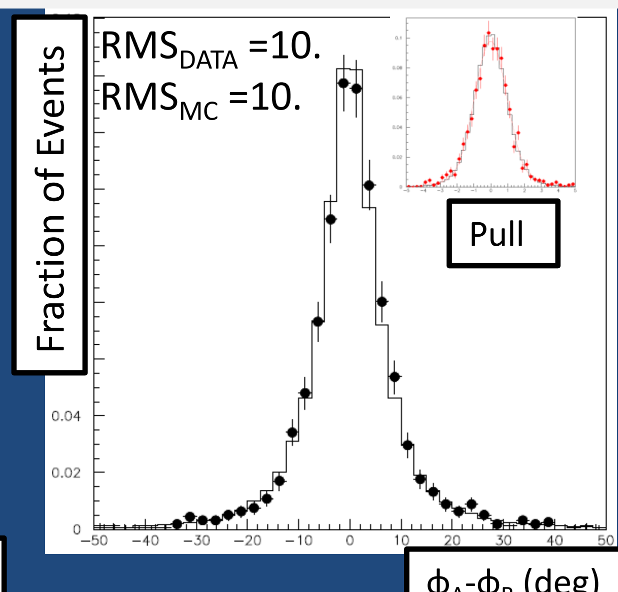
Histogram: MC
Points : Data

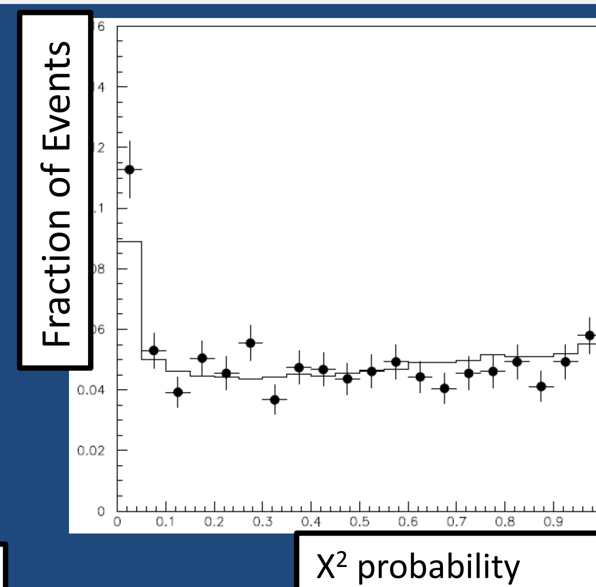




Station A – Station B Comparison







Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

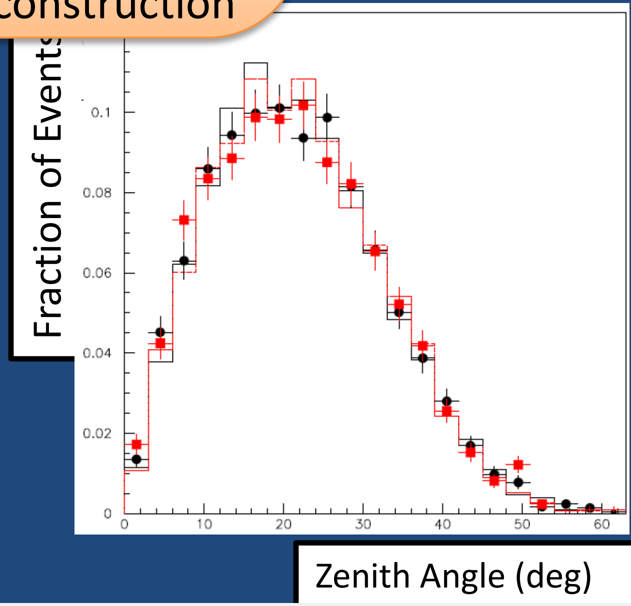
EAS Reconstruction with the Calibration Setup

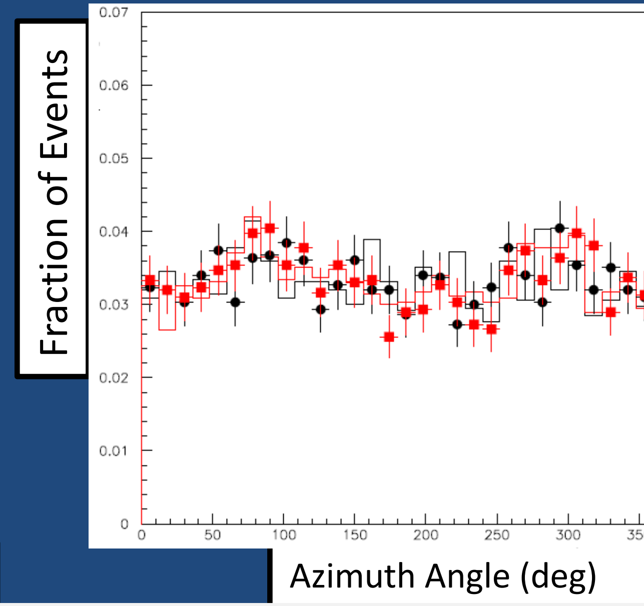
A. Leisos,, G. Bourlis, S.E. Tzamarias

Shower Reconstruction2/2

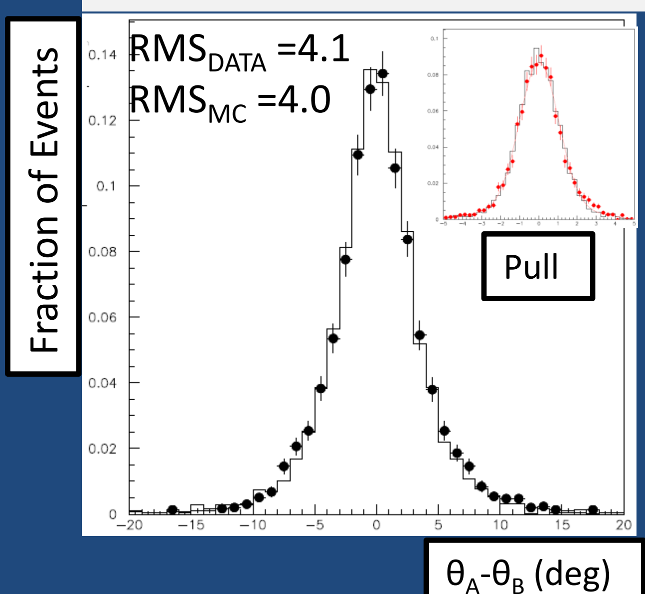
Analysis Threshold@ 4.7 mV
Trigger Threshold@7.7mV
Qnet-Onet Int Run

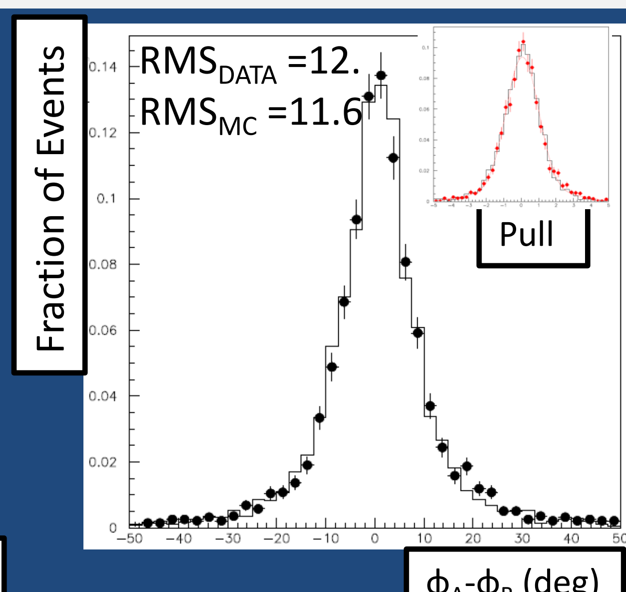
Histogram: MC
Points : Data

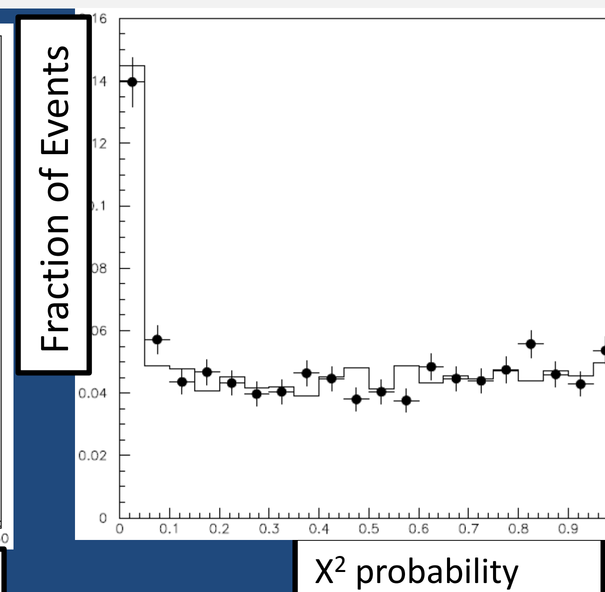




Station A – Station B Comparison







Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

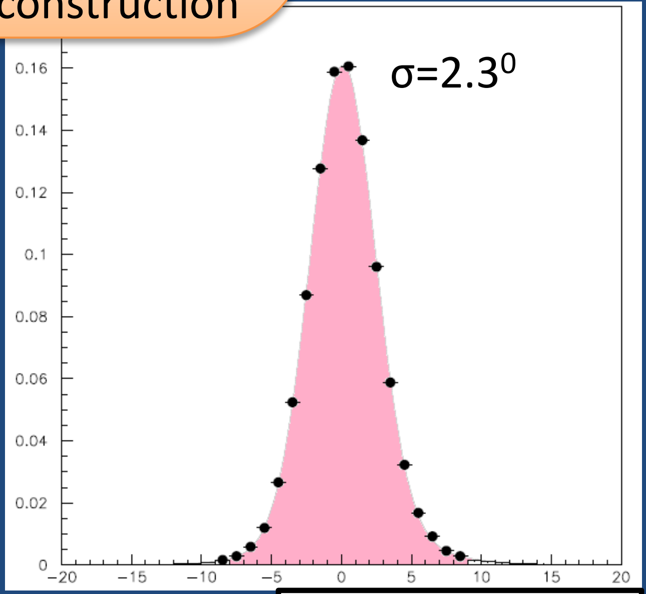
EAS Reconstruction MC Studies

A. Leisos,, I. Manthos, S.E. Tzamarias

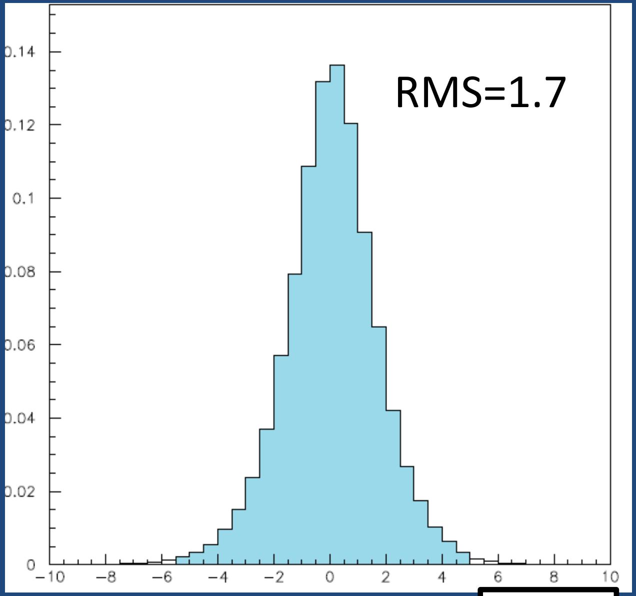
Single Station Resolution

Analysis threshold @ 9.7 mV
Monte Carlo Simulation

Histogram: MC
Points : Data

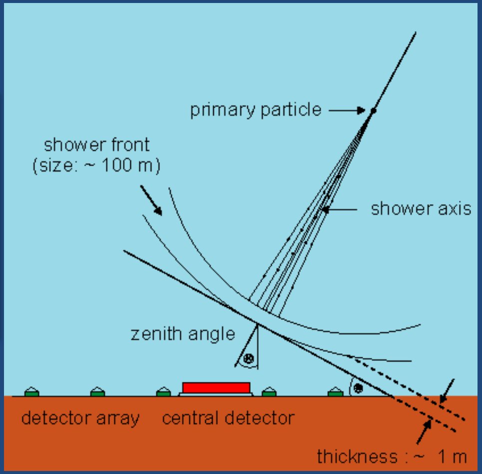


θ_{REC}-θ_{TRUE} (deg)



Pull

Plane Particle Shower Front is an approximation due to Shower Thickness and Curvature
Shower Thickness and Curvature depend on the distance from the shower core , primary energy and primary particle
Deviations can be parametrized with Charge density of detected particles

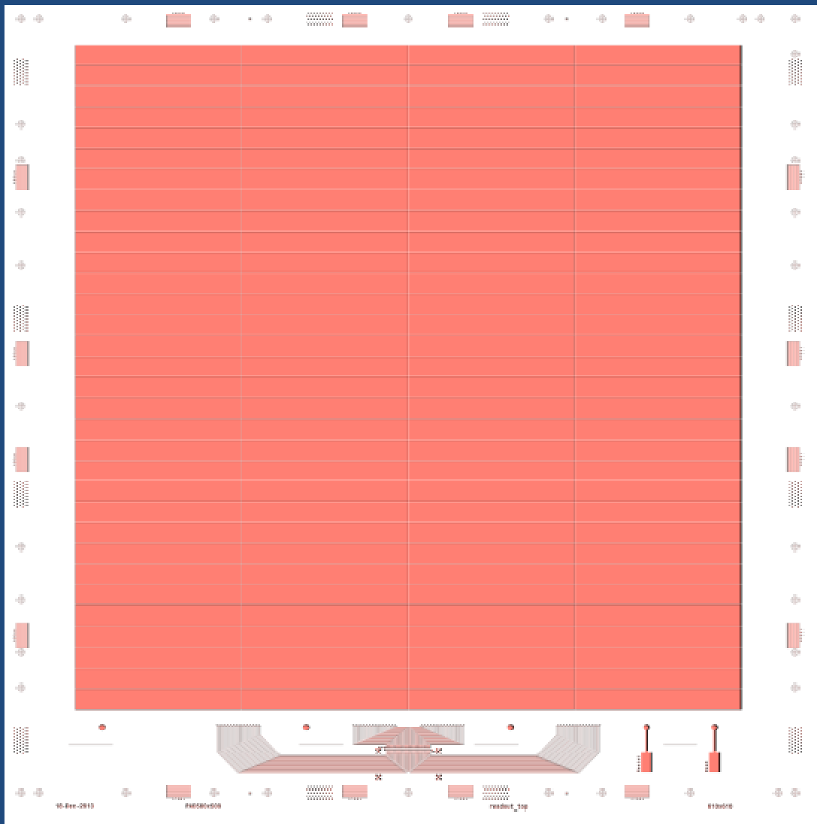


Extensive Air Shower Instrumentation

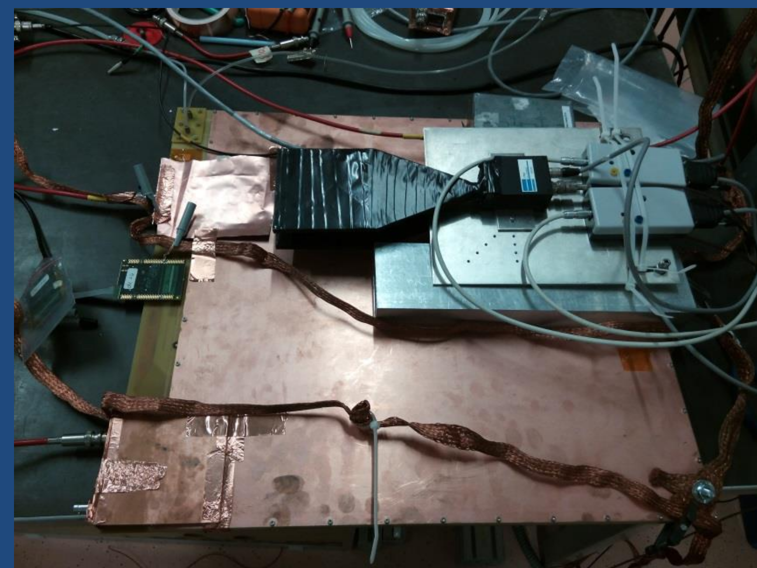
EAS Telescopy: Operation & Reconstruction

EAS ARRAY WITH MICROMEGAS

G. Fanourakis, G. Bourlis, S.E. Tzamarias



G. Fanourakis design, constructed at CERN
4 columns of 32 pads each
1.5 x 12.5 cm^2 per pad



Tested at CERN and DEMOKRITOS using Sr source and cosmics

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

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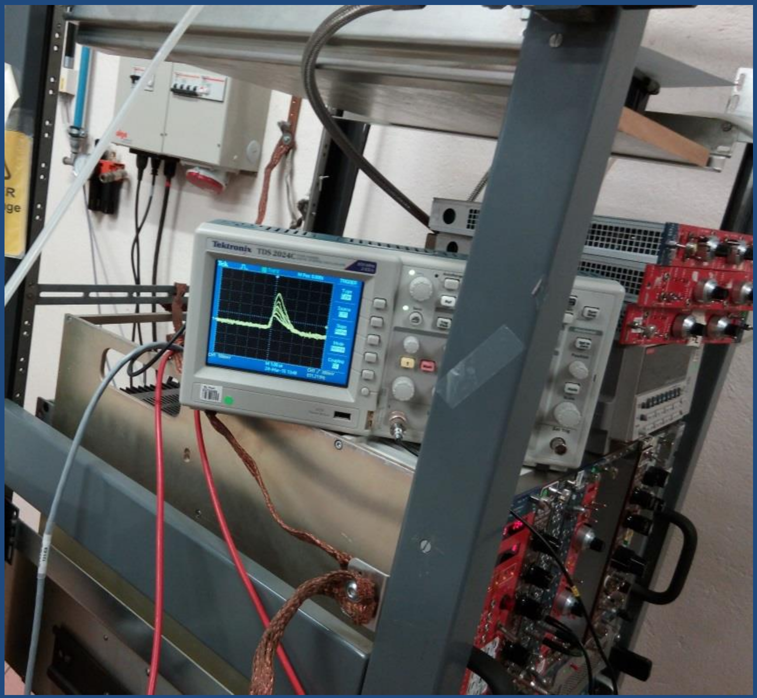
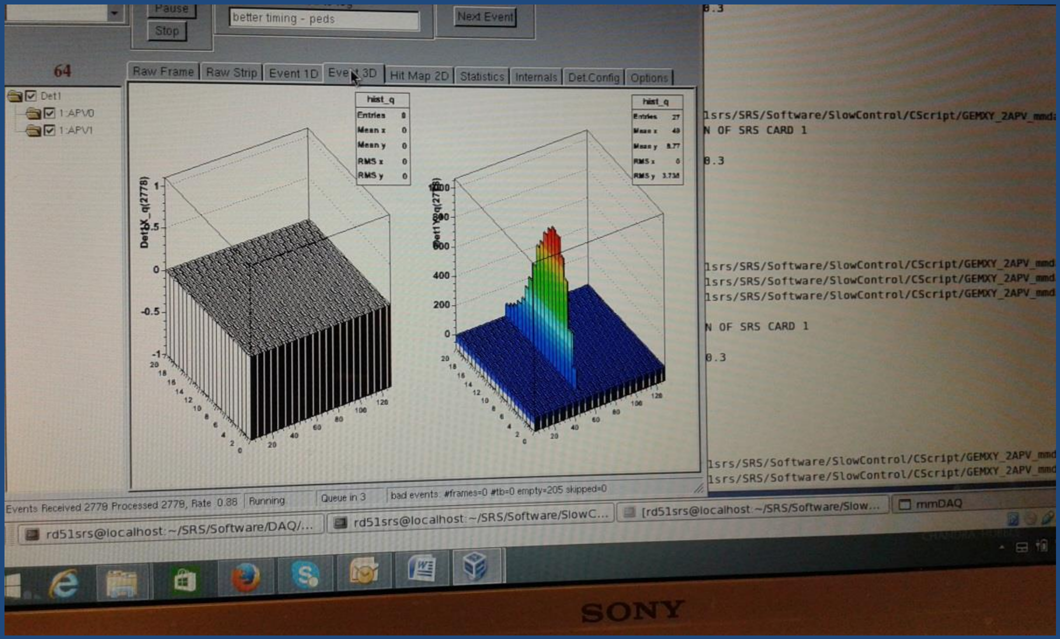


Reading the mesh
(signal preamplified and shaped)

Signal accumulated using the APV electronics and SRS (Scalable Readout System)

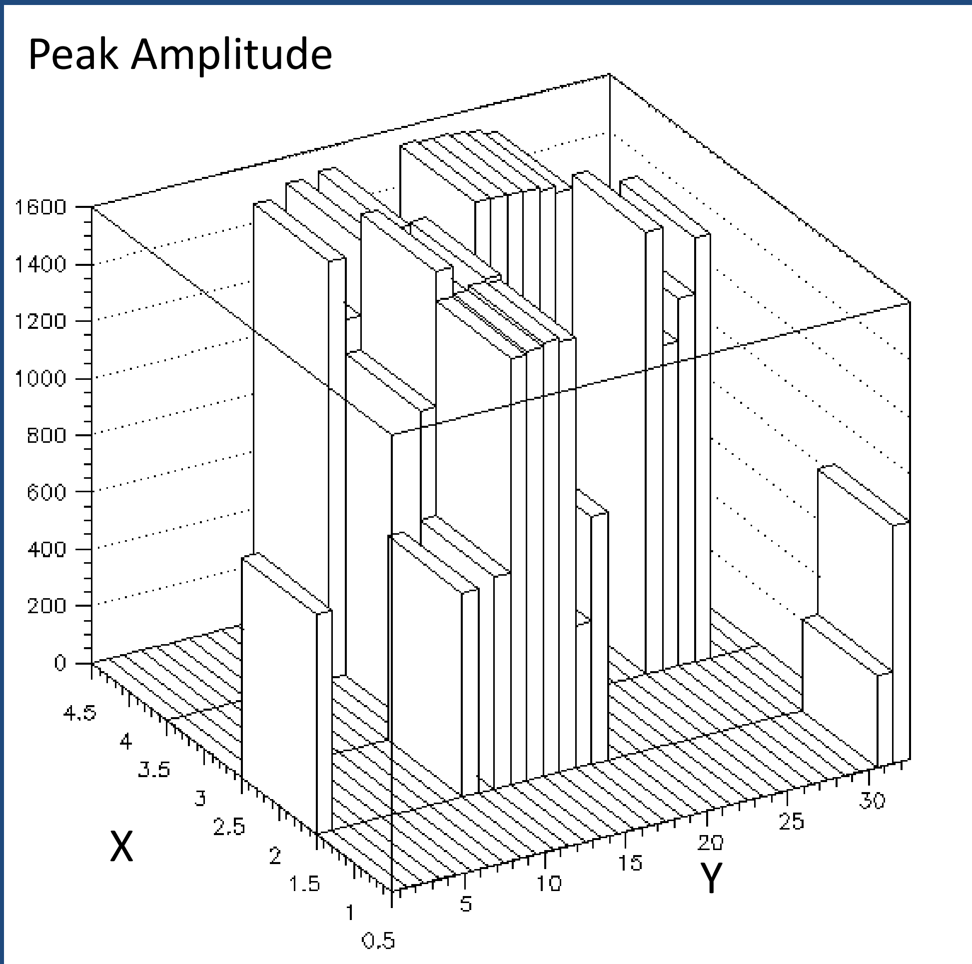


Extensive Air Shower Instrumentation

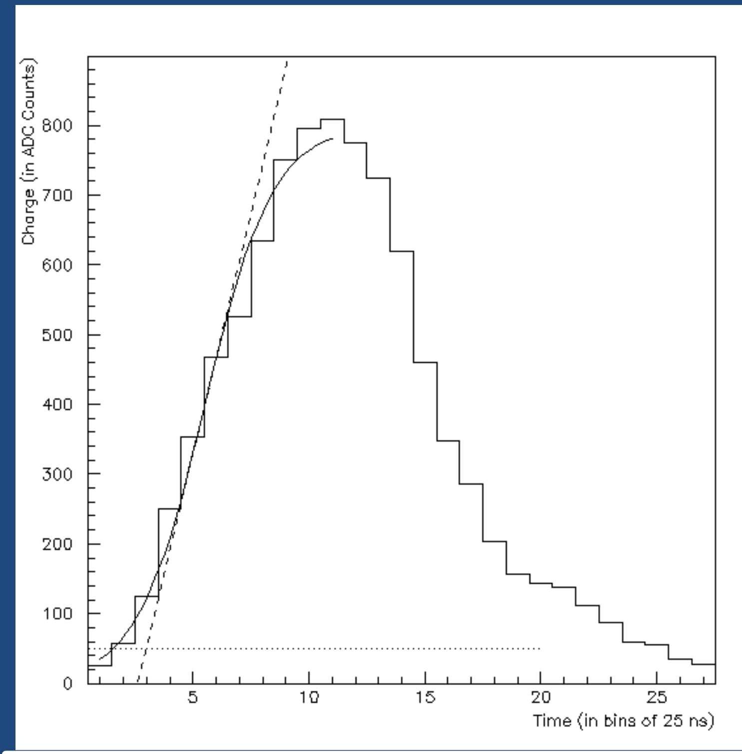
EAS Telescopy: Operation & Reconstruction

EAS ARRAY WITH MICROMEGAS

G. Fanourakis,, S.E. Tzamarias



A Shower Event



Digitization of a pad's signal
(the lines are used to define timing)

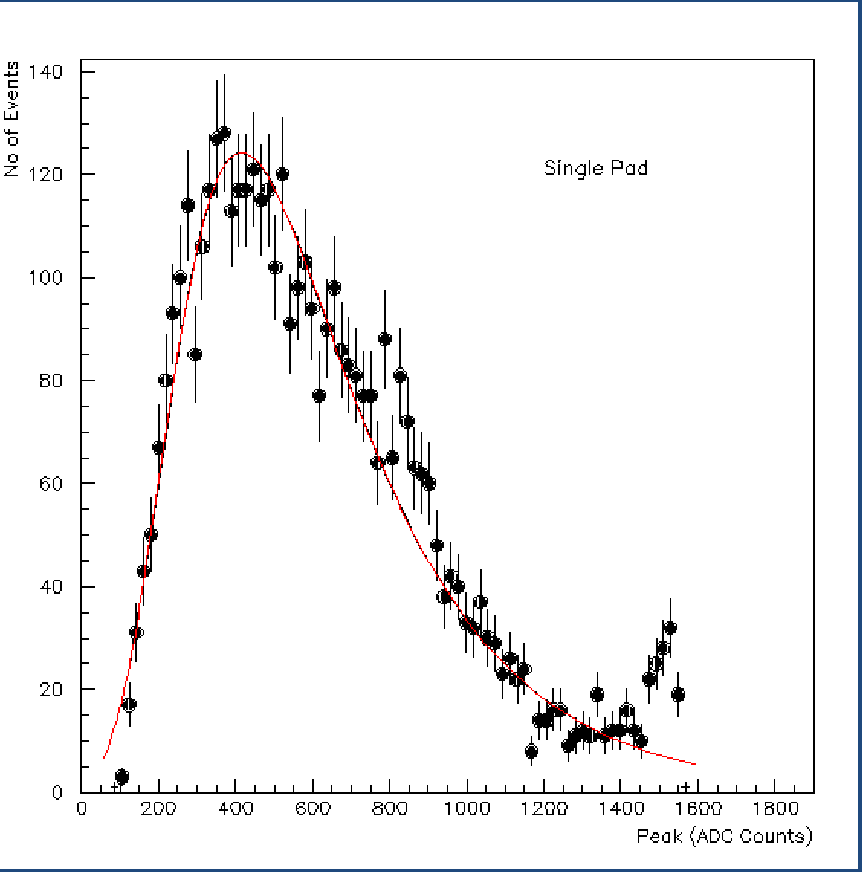
Extensive Air Shower Instrumentation

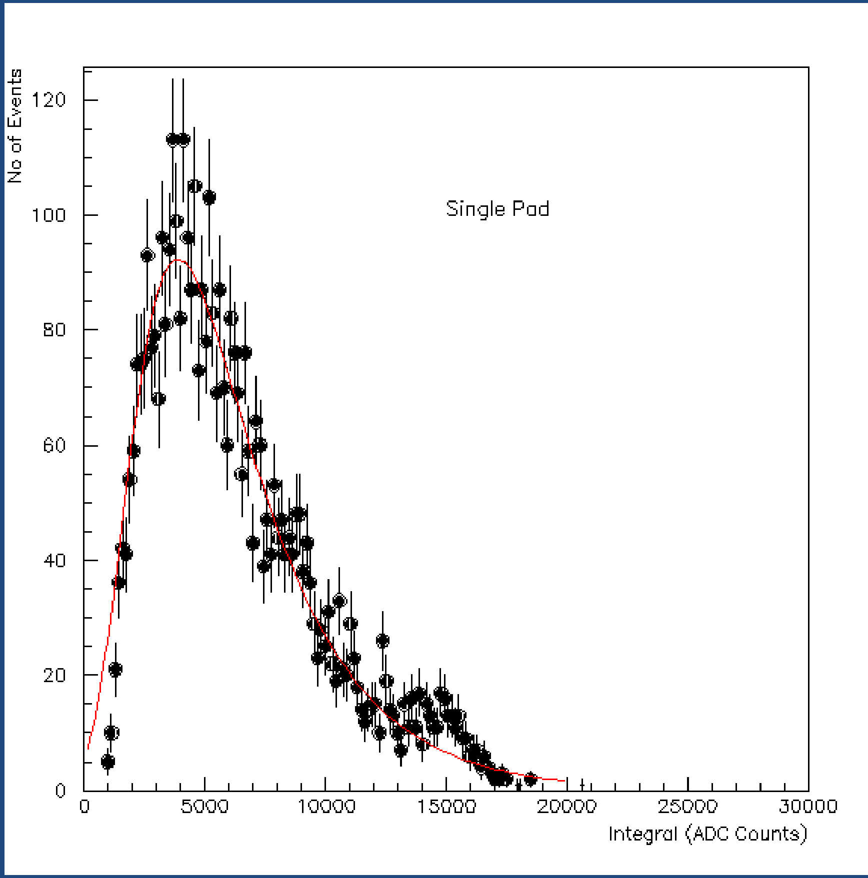
EAS Telescopy: Operation & Reconstruction

EAS ARRAY WITH MICROMEGAS

G. Fanourakis,, S.E. Tzamarias

Single muons charge distribution





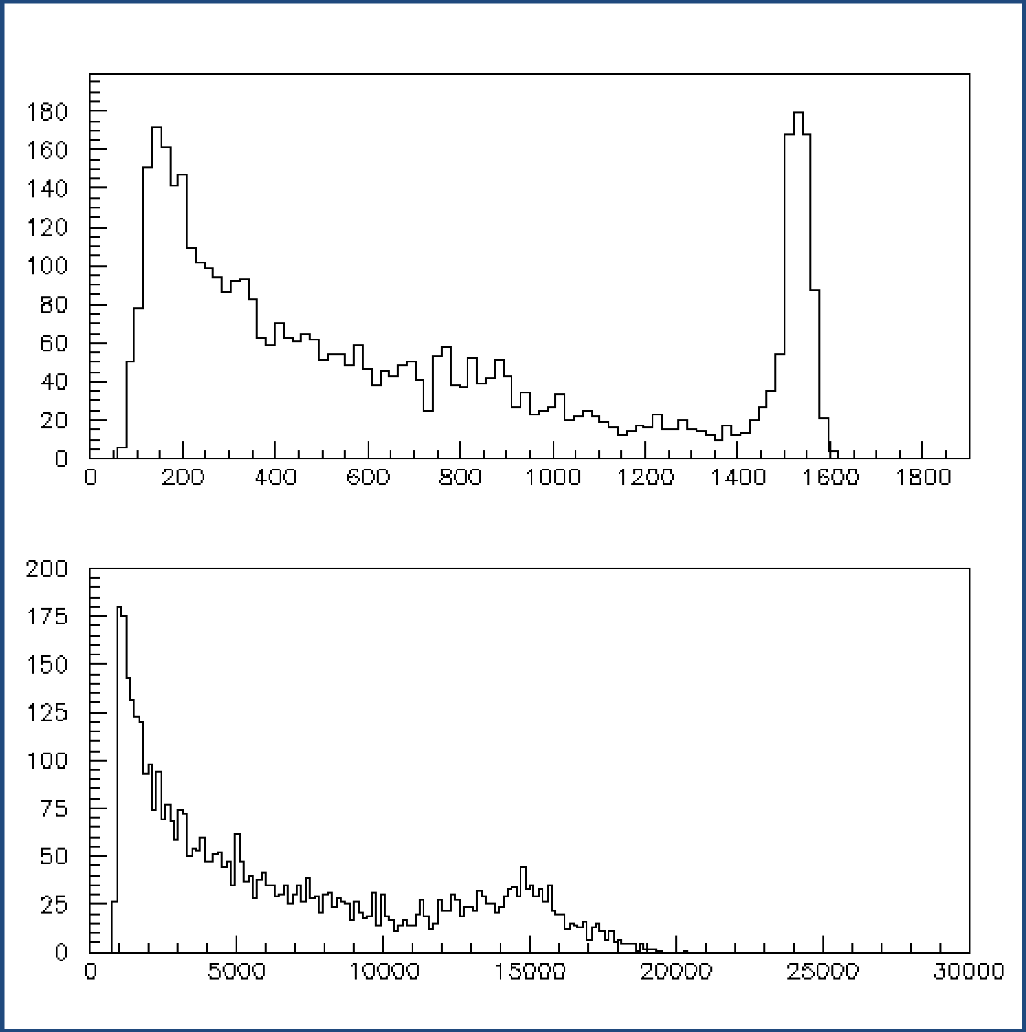
Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

EAS ARRAY WITH MICROMEGAS

G. Fanourakis,, S.E. Tzamarias

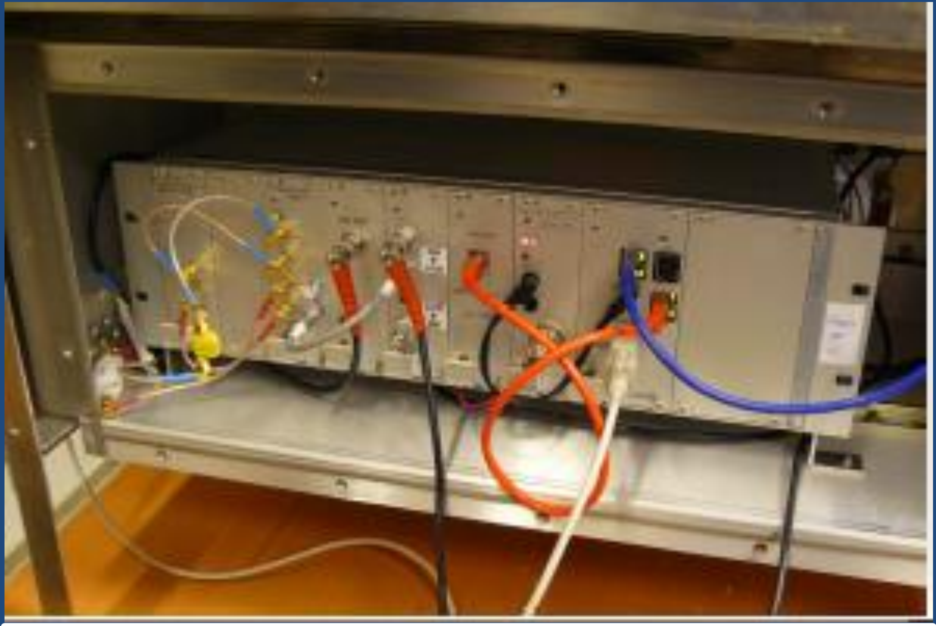
Multiple muons (shower?) charge distribution



EAS RF Detection System

- 4 CODALEMA antenna systems are operating in Tandem with the scintillator counters of the ASTRONEU EAS array.
- 2 more are tested in the Lab and are ready for operation.


CODALEMA Antenna


CODALEMA Antenna Electronics

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

The RF System of the ASTRONEU Array

G. Bourlis, I. Manthos, K. Zachariadou, K. Prekas, A. Papaikonomou, I. Gkialas,, S.E. Tzamarias
In collaboration with the CODALEMA Group

Trigger+Analysis

- Each Station and RF antenna have their own GPS system
- The antenna is triggered by the Station when a triple coincidence between the scintillation counters occurs
- Each triggered station and antenna are independently read out.
- The antenna has a 2560 ns buffer
- Coincidences between stations are found by Offline analysis.

Data Period : June 2014 through February 2015

Station-A :	148345
Station-B:	77594
Station-C :	174567
Double coincidence A,B :	**1232**
Double coincidence B,C :	21
Double coincidence A,C :	169
Triple coincidence :	**19**

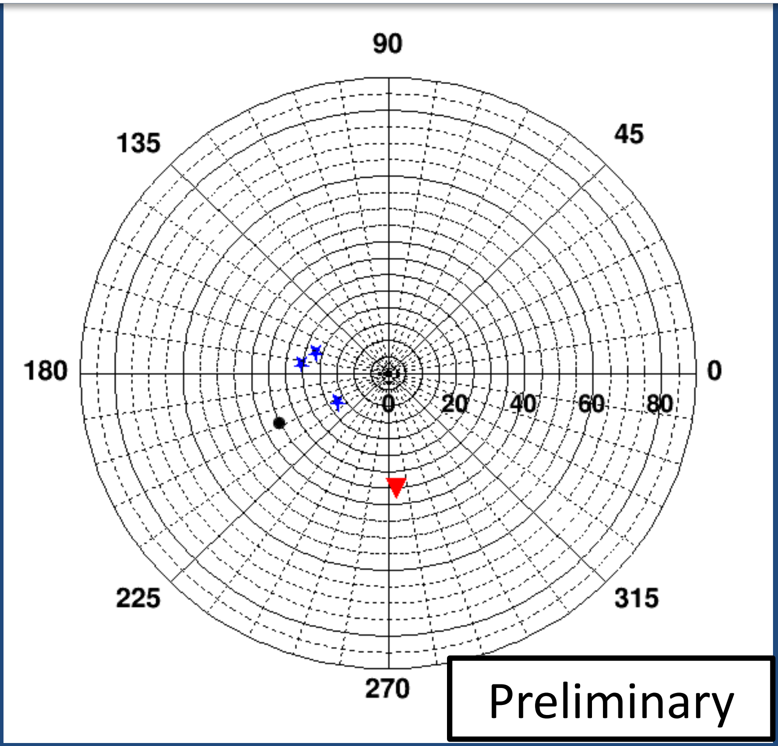
Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

A. Papaikonomou, I. Gkialas, I. Manthos, G. Bourlis
In collaboration with the CODALEMA Group

An example of a good event
Shower Direction (SC, antennas)

Θ,ϕ polar diagram



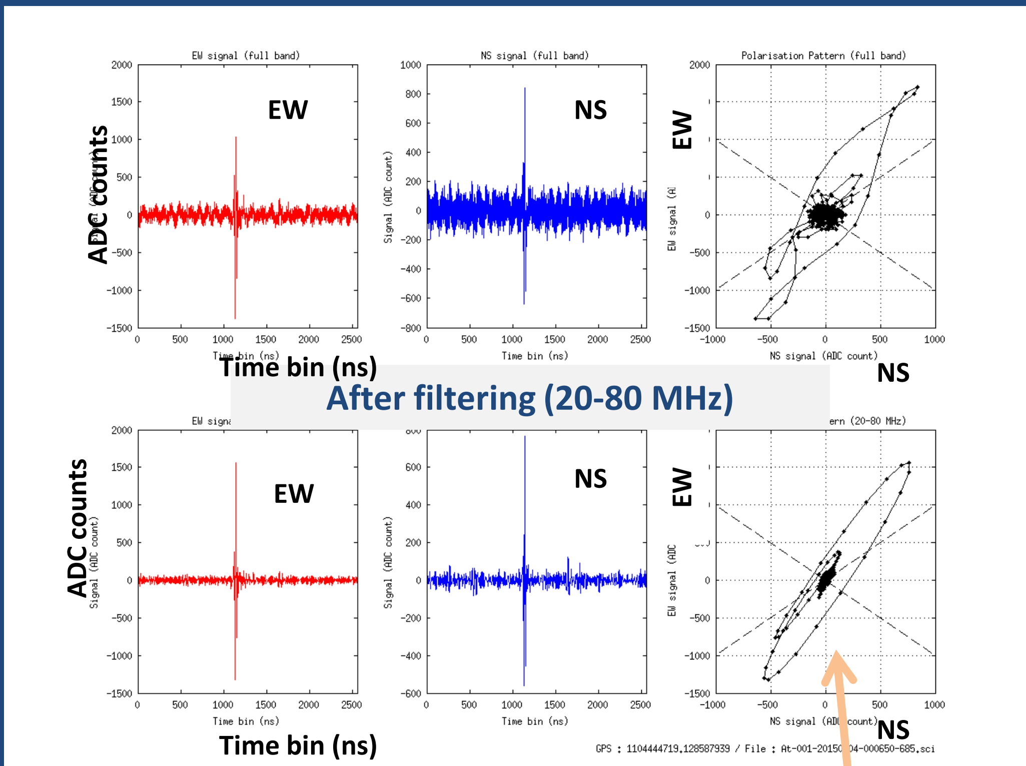
- 3 stations reconstruct θ,ϕ independently (blue stars). Reasonable agreement for 8 triple coincidence events (out of 19 available events)
- Also the 3 antennas reconstruct θ,ϕ (black circle).

Extensive Air Shower Instrumentation

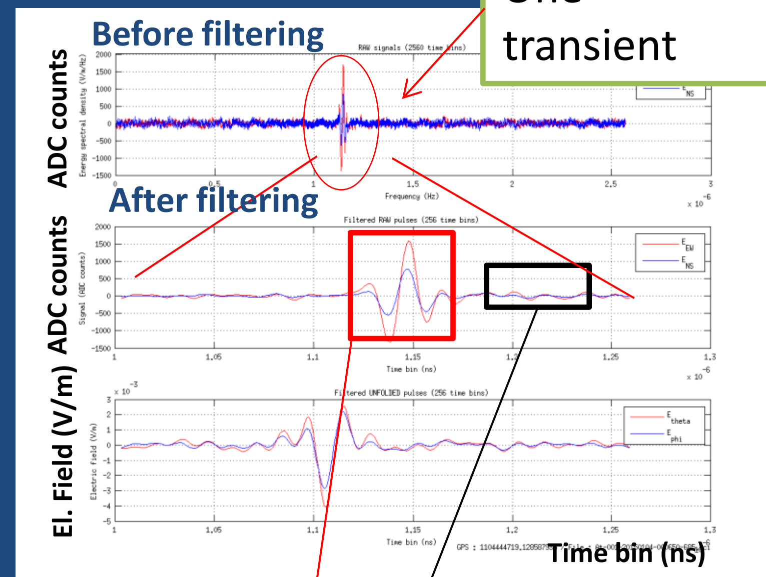
EAS Telescopy: Operation & Reconstruction

The RF System of the ASTRONEU Array

A. Papaikonomou, I. Gkialas, I. Manthos, G. Bourlis
In collaboration with the CODALEMA Group

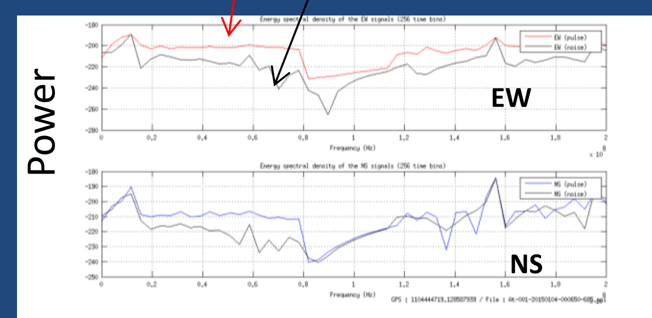


Good polarisation



One transient

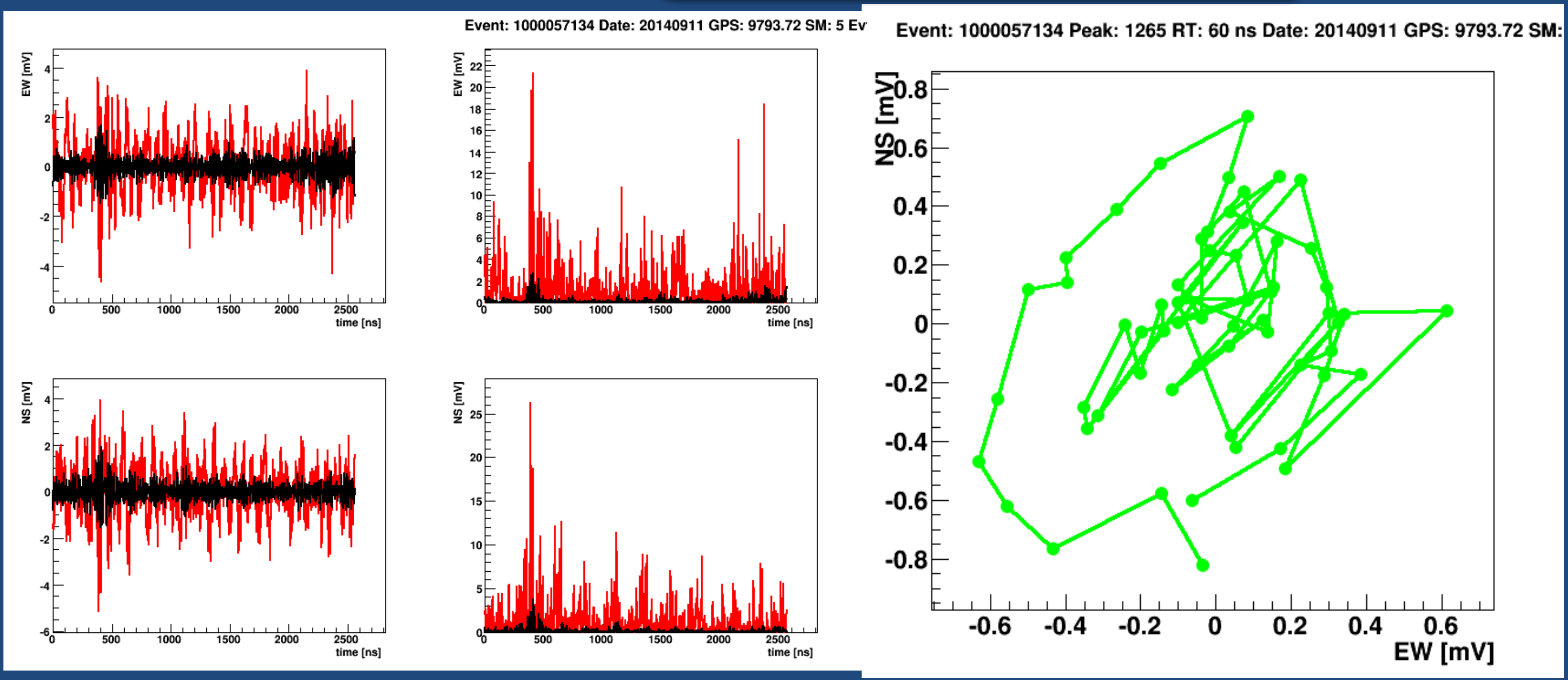
Red: Signal spectrum
Black: Background spectrum



Many thanks for the help from Codalema colleagues

- Lilian Martin
- Didier Charrier

A background event



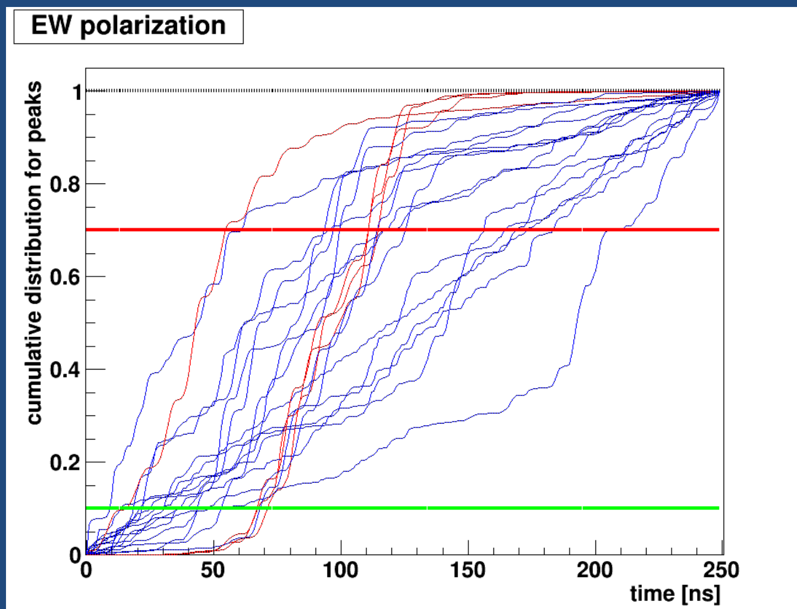
- More peaks
- Lack of polarization between NS and EW

Extensive Air Shower Instrumentation

EAS Telescopy: Operation & Reconstruction

The RF System of the ASTRONEU Array

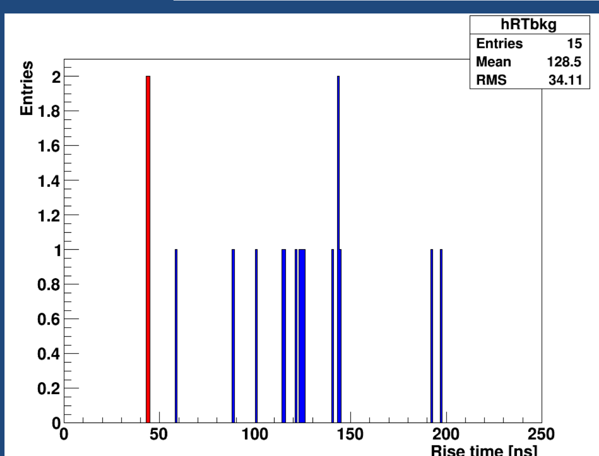
Rise Time

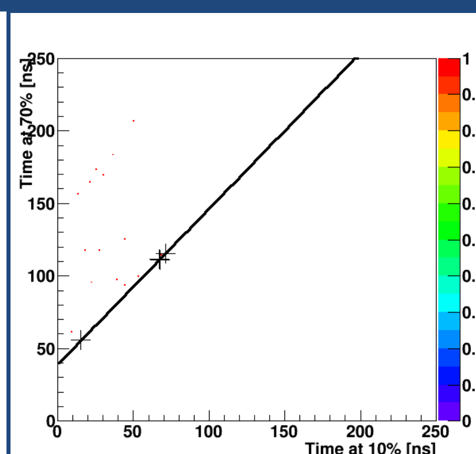


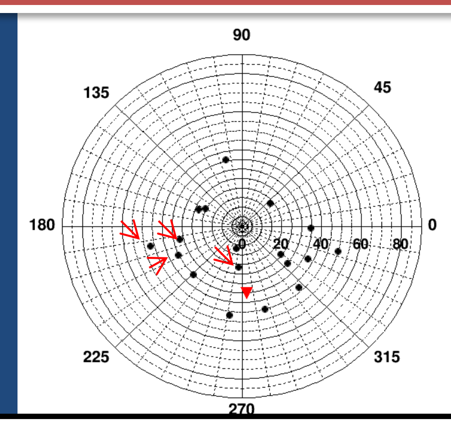
- In cosmic events, all activity happens in a few ns, so fast risetimes (<50 ns)
- Background signals accumulate activity through the complete time window so the they are slow (Risetime = (t_70-t_10) >50 ns)

RADIO SIGNAL RECONSTRUCTION

19 Triple Coincidencies







Red arrows showing the 4 low risetime events

Radio cosmic signals selection criteria

- Direction reconstruction agreement between SC and antennas (we would like to select eventually based on antennas only)
- Check for transients
- Rise time cut
- Polarization check

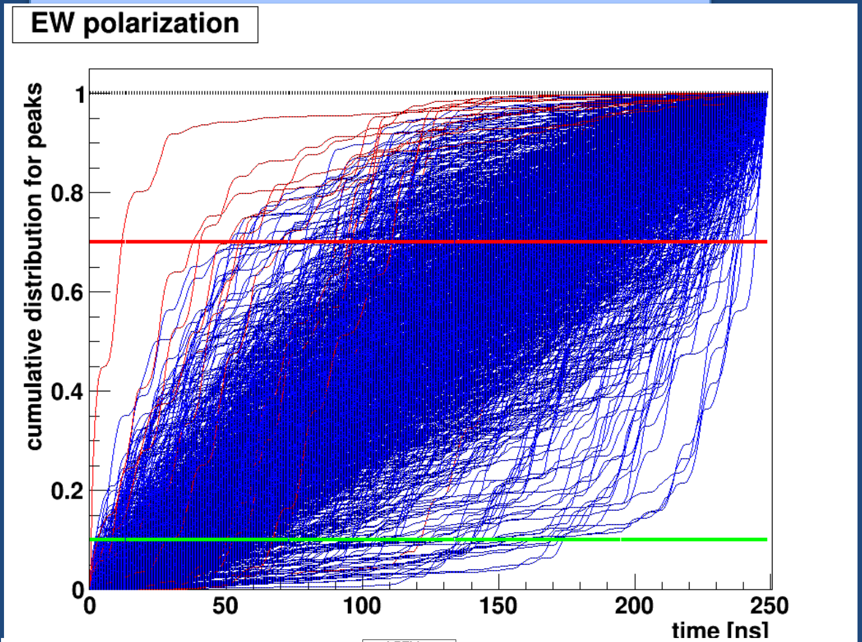
Extensive Air Shower Instrumentation

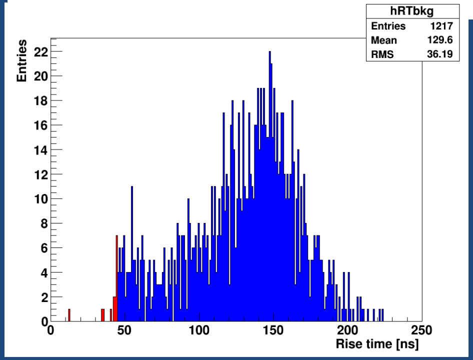
EAS Telescopy: Operation & Reconstruction

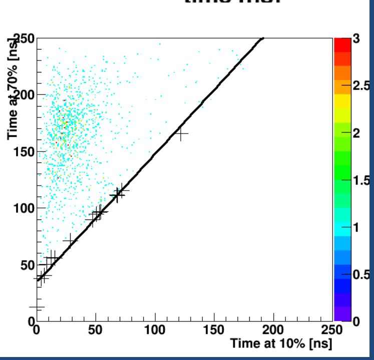
The RF System of the ASTRONEU Array

Double (2 stations) coincidences

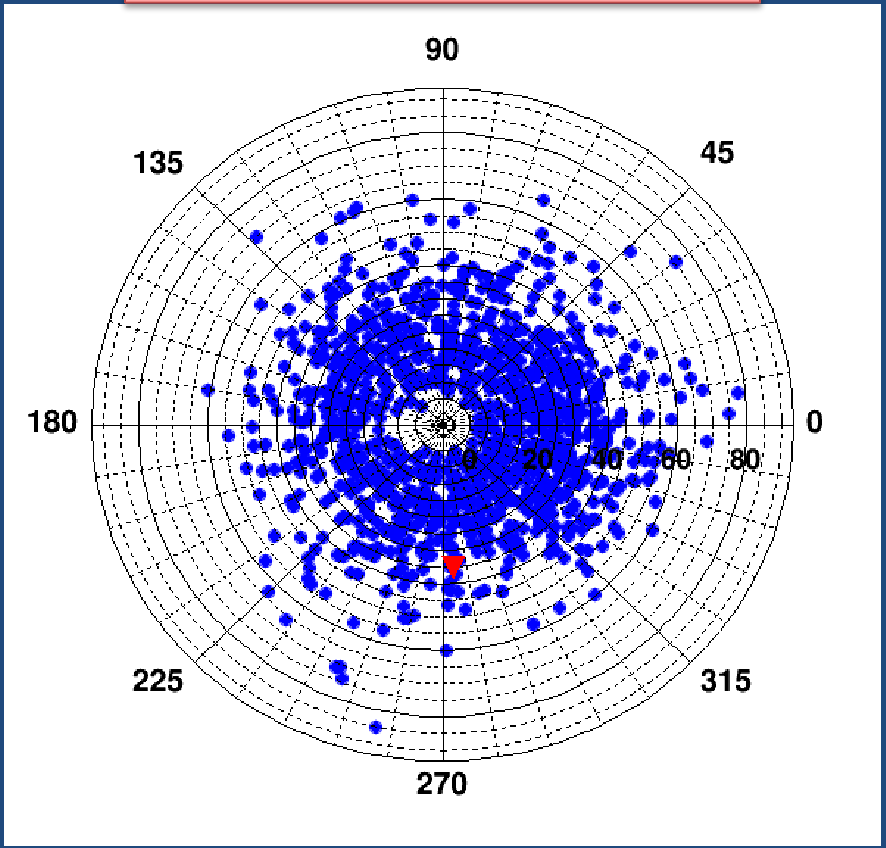
- 1232 events
- Risetimes from one antenna







Θ,ϕ Reconstruction from one station (3 SC)



Work in progress

Summary

Present

- We have learnt how and we have operated successfully the antennas triggered by the scintillator stations.
- We select data routinely
- Event analysis in progress

Immediate future (by September 2015):

- Finalize the HOURS-RF Simulation Software Package (Corsika based COREAS, SELFAS2)
- Complete the Analysis of RF Data collected with Double-Station as well as Single-Station trigger.
- Publish results.

Medium future (by Spring 2016)

- Deploy 2 more RF Systems
- Use a fast micromegas chamber as a triggering system to the antennas

Low Energy Neutrino Detection

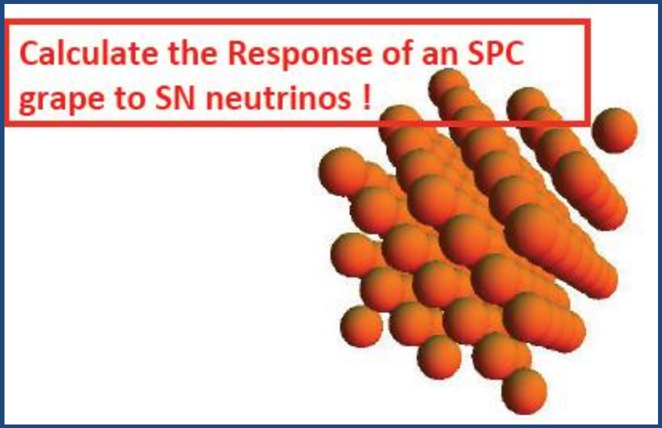
The ASTRONEU Spherical Proportional Counter

Low energy ion detection capabilities

I. Katsioulas[a], I.Savvidis[a], C. Eleftheriadis[a], I. Giomataris[b], T.Papaevangelou[b]

1) **Low Radioactivity Measurements**
2) **SuperNova neutrino detection**
3) **WIMP searches**

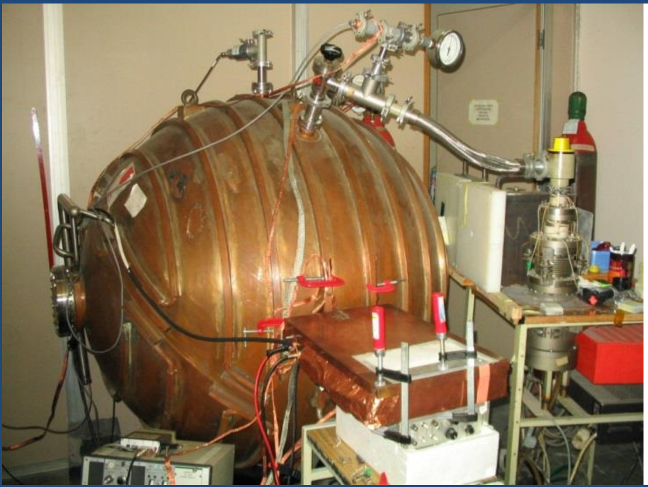
A feasibility study for the detection of SuperNova explosions with an Undersea Neutrino Telescope, A. Leisos et al, Nucl.Instrum.Meth. A725 (2013) 89-93

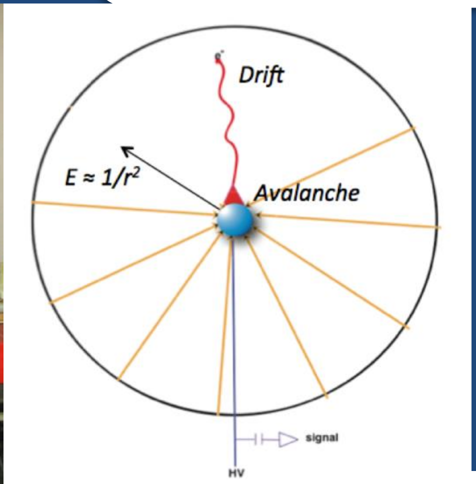


Low Energy Neutrino Detection

The ASTRONEU Spherical Proportional Counter

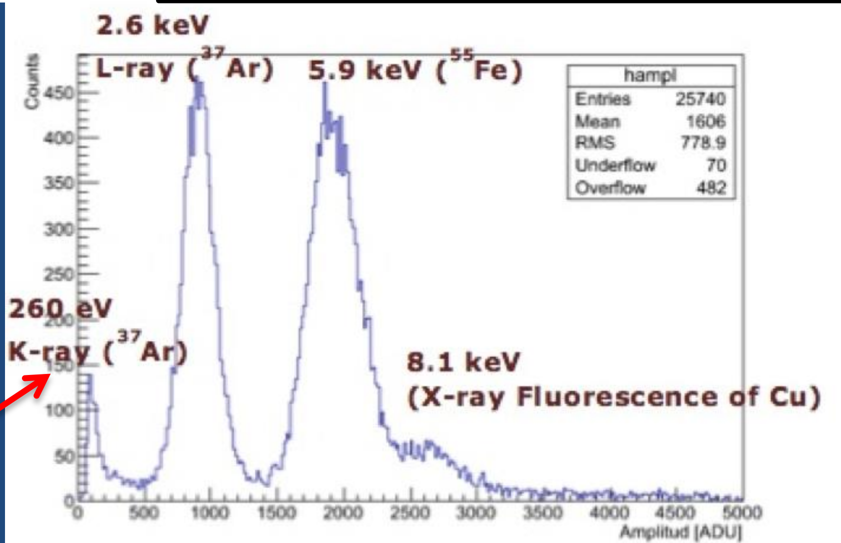
The Spherical Proportional Counter (SPC)





- Flexibility
  - Pressure < 10 atm
  - Gas: Ar, Xe, Ne, He ...
  - Radius: 20 cm -65 cm

arXiv:1412.0161 [astro-ph.IM]



- Very low noise
- Large Amplification capability
- Strong background rejection
- Very low energy threshold ~100eV

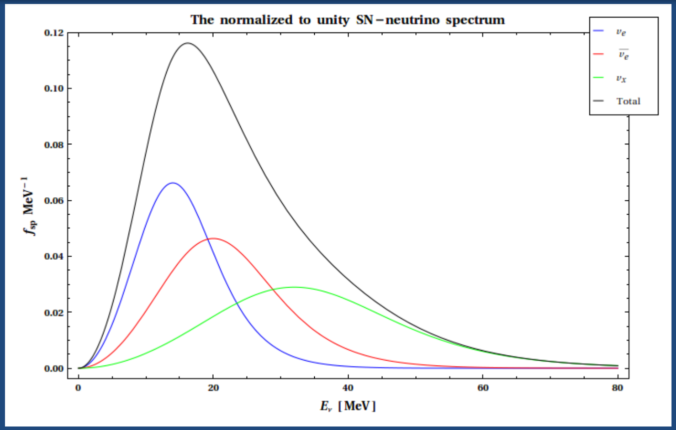
K-ray ^{37}Ar at 260 eV

Low Energy Neutrino Detection

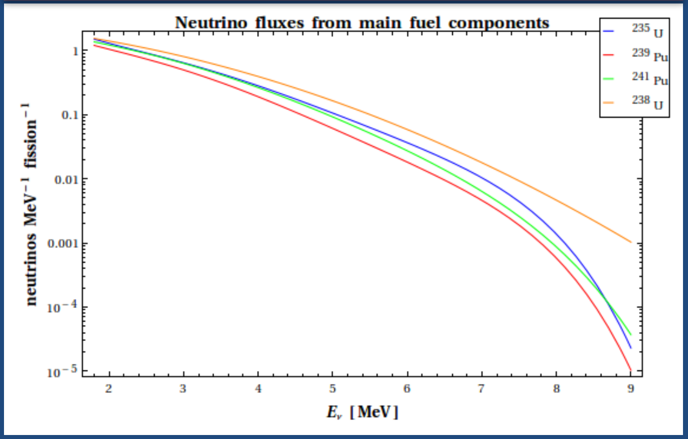
The ASTRONEU Spherical Proportional Counter

Possible Low energy threshold applications

Supernona Neutrino Detection



Reactor Neutrinos

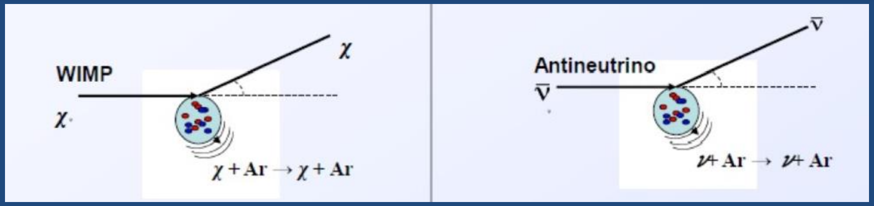


Dark Matter searches

Low energy neutrinos <100 MeV

- Geoneutrino detection
- Solar neutrino detection
- Neutrino from terrestrial sources

Direct detection through detecting the low energy nuclear recoil (E < 1keV) after scattering !



The ASTRONEU Spherical Proportional Counter

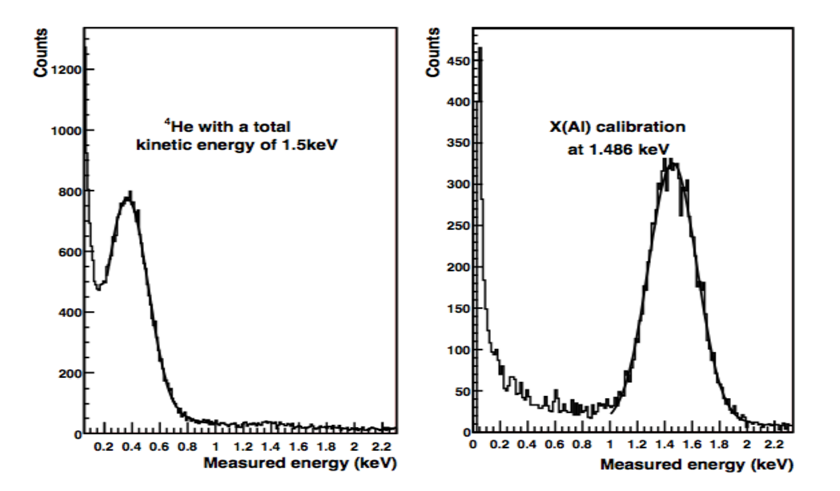
Ionizing Quenching factor

The big drawback

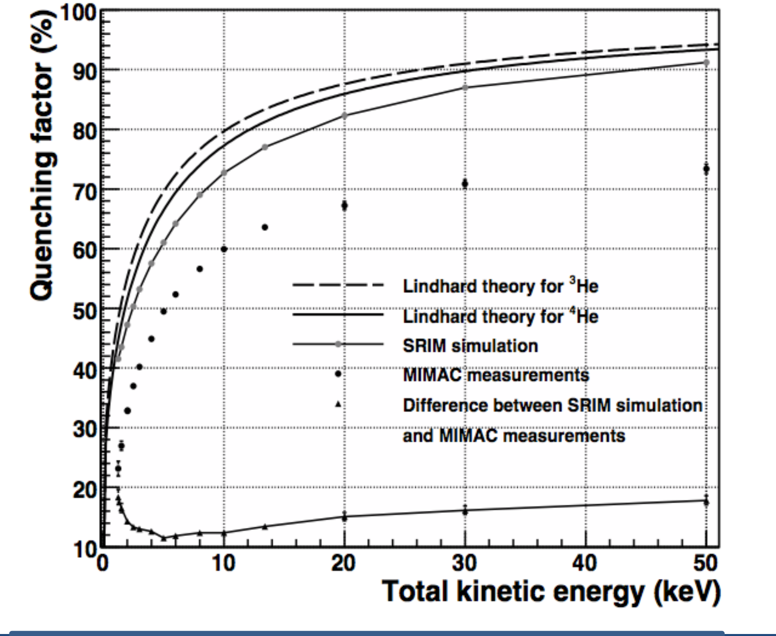
- Ionizing Quenching factor
  - The fraction of energy released through ionization by a recoil compared to its kinetic energy

Problems

- **Very few experimental measurements**
- **Not well described by theory (*Lidhard et al)***



arXiv:0810.1137 [astro-ph]



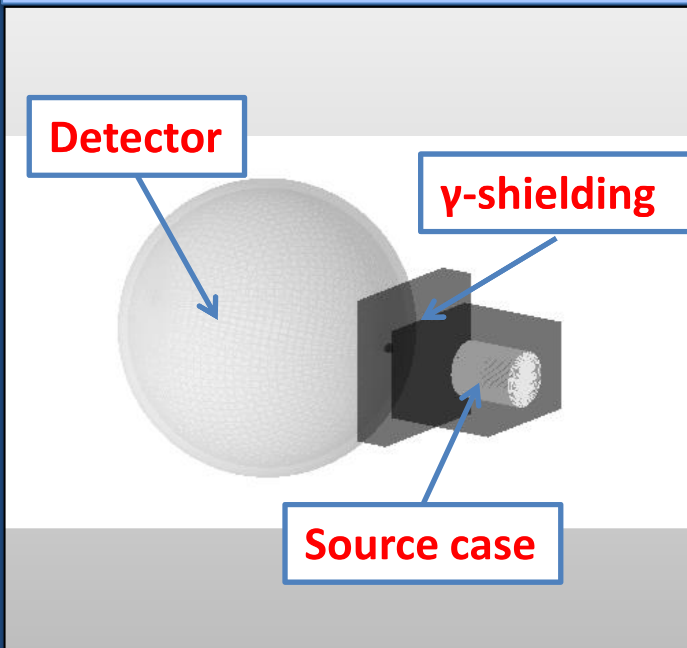
Being measured for Argon at LPSC Grenoble by Giomataris et al

Low Energy Neutrino Detection

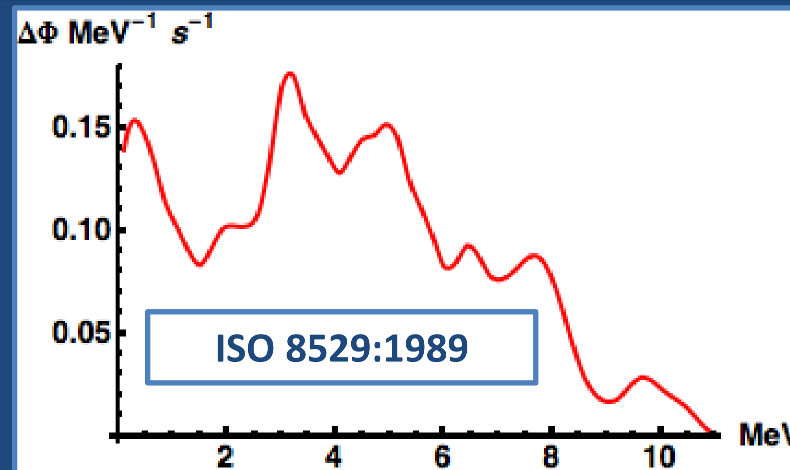
The ASTRONEU Spherical Proportional Counter

Experimental detection of low energy nuclear recoils

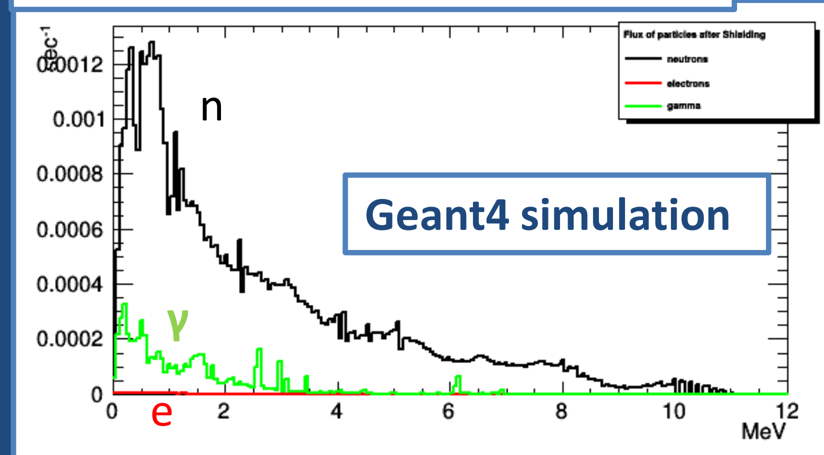
Producing Ar recoils with an Am-Be source



Total neutron flux : 6.0×10^{4} n/sec ≅ γ ray activity of the source



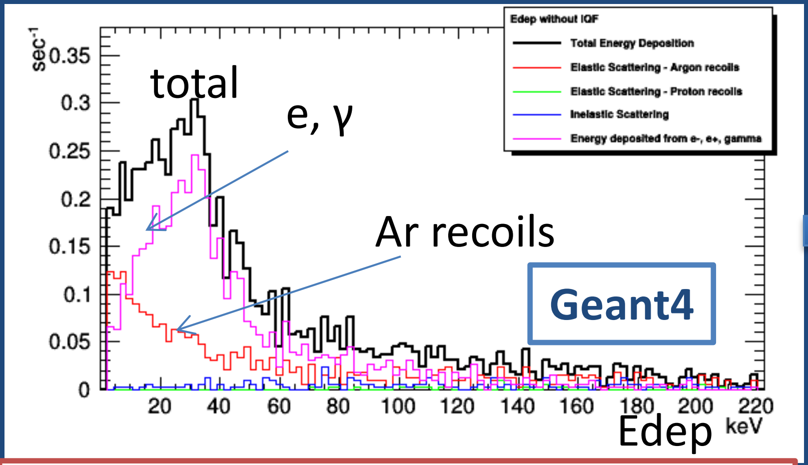
Flux of particles after shielding



1. Glass Shell (thermal neutron shielding) (1.5 cm thick)
2. Gas, 98%Ar +2%CH_4 at 500mbar
3. γ-shielding (Pb ~12 cm)
4. AmBe source

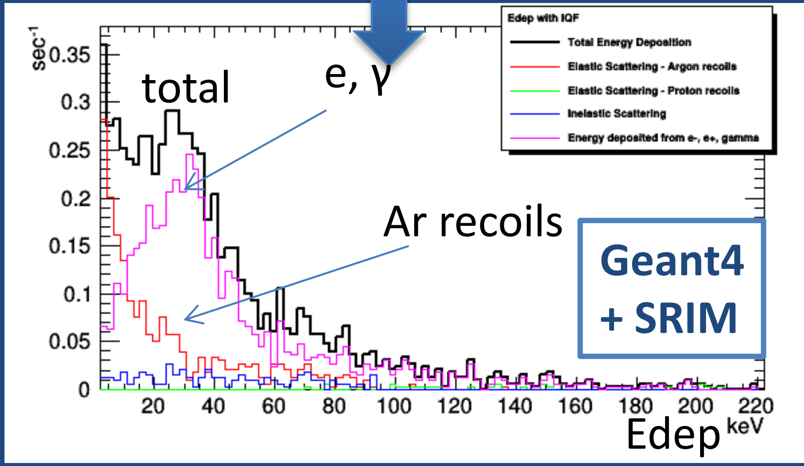
The ASTRONEU Spherical Proportional Counter

Simulation with Geant4



Remember the IQF
we introduce it
and there is a big difference…

The IQF is calculated with SRIM



FACTS

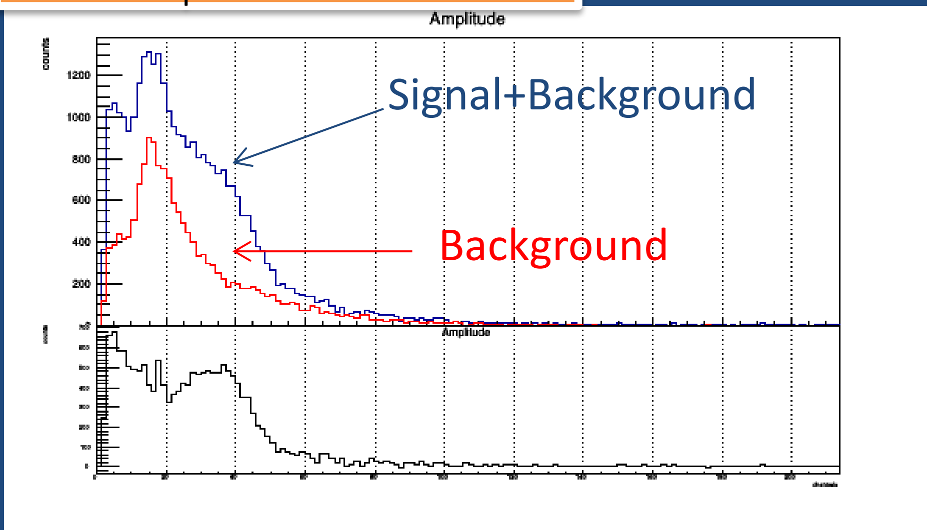
- **Neutrons react with the detector materials causing lots of background**
- **The γ-rays from source are negligible**
- **The IQF pushes the recoil spectrum at lower energies leaving the rest unaffected**

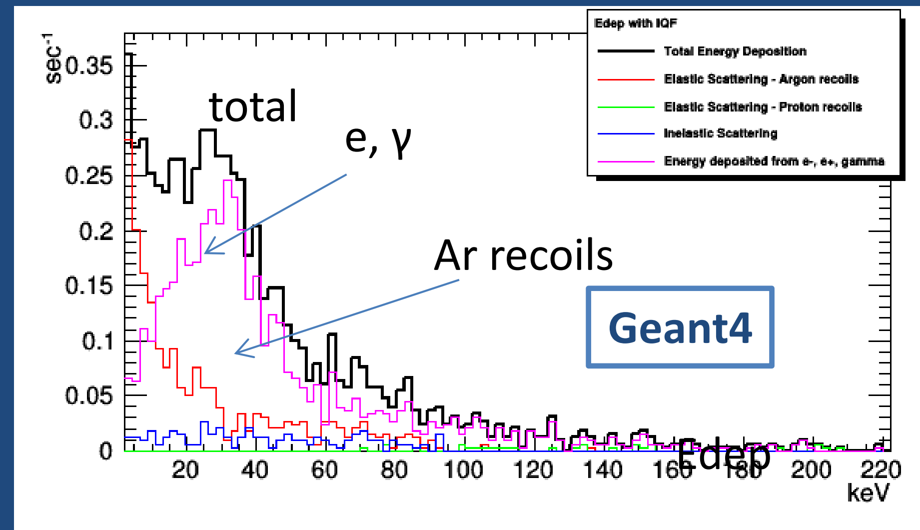
Low Energy Neutrino Detection

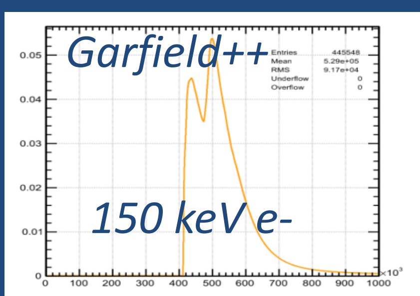
The ASTRONEU Spherical Proportional Counter

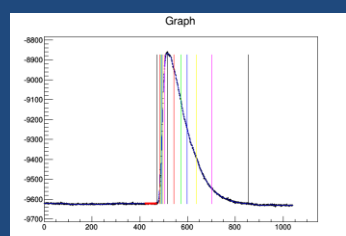
Experimental Results and Pulse Shape Discrimination

Experimental Data

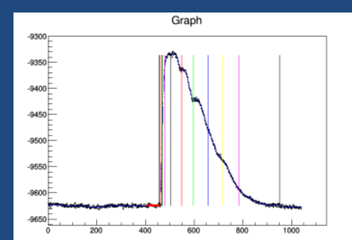






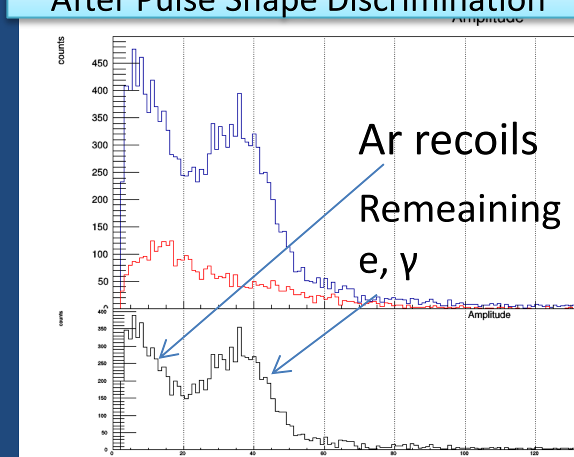


Argon Recoil Pulse



No recoil pulse

After Pulse Shape Discrimination



Multiple Peak events are mainly due to μ,e
Big Rise Times (>20μs) are due to μ

Low Energy Neutrino Detection

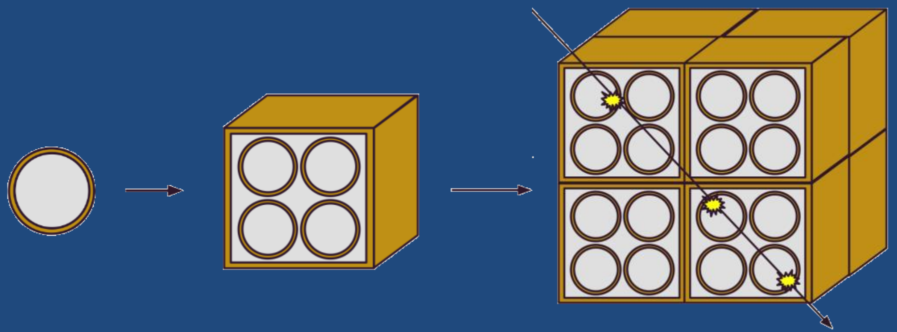
The ASTRONEU Spherical Proportional Counter

Nuclear reactor neutrinos

- Run the SPC to a nuclear reactor radiation environment (n, γ)
  - Develop appropriate shielding and background rejection techniques especially for the ~100 eV – 1 keV energy region

Supernova neutrino detection

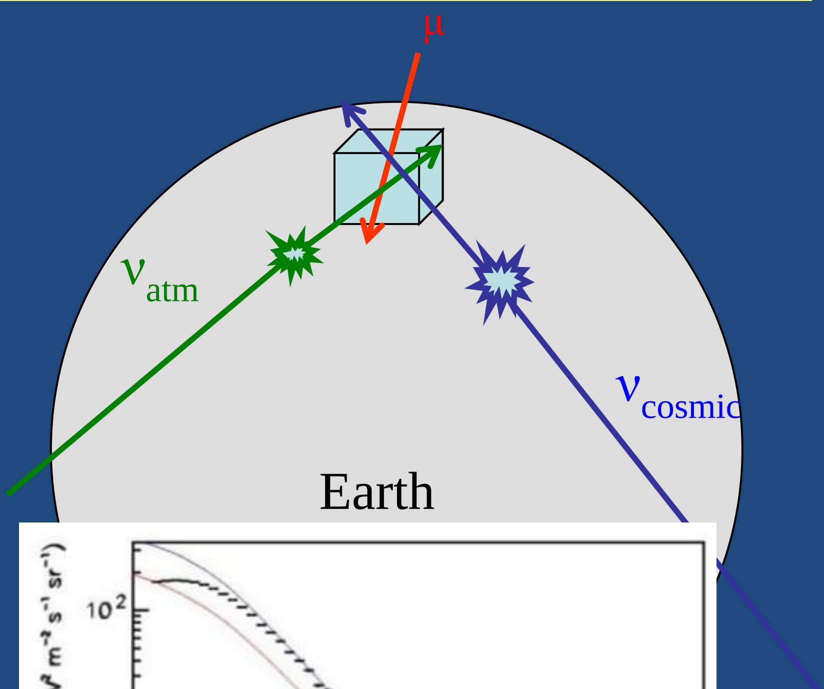
- Finalize the SPC response calculations of an undersea “grape” installation to a “typical” SN neutrino spectrum. Evaluate or/and decide on:
  - the appropriate gas mixture (improving threshold, increasing rate…)
  - the underwater background level (^{40}K, muons …)
  - *the appropriate critical mass needed for SN discovery*
  - *The installations geometrical and operational parameters (size of a module, pressure, high voltage…)*



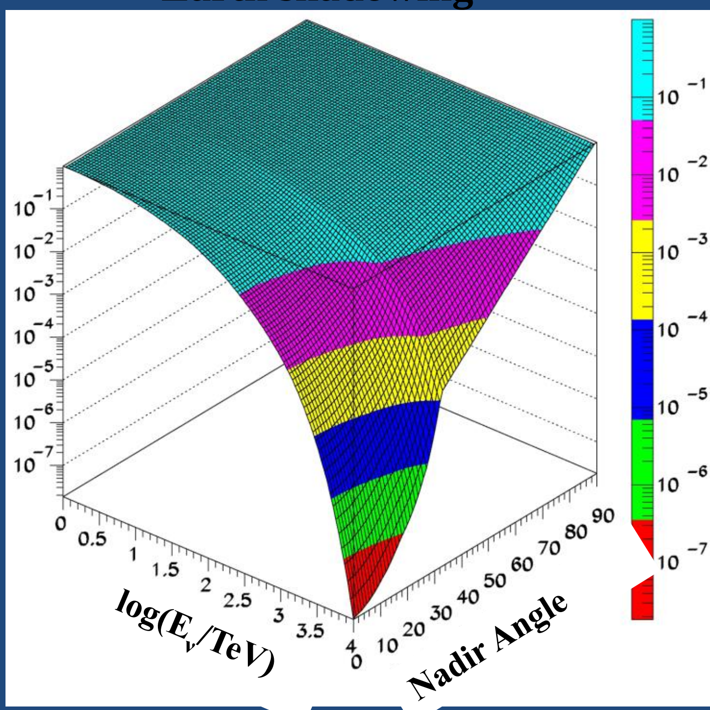
BACK UP

Physics models & Event generators

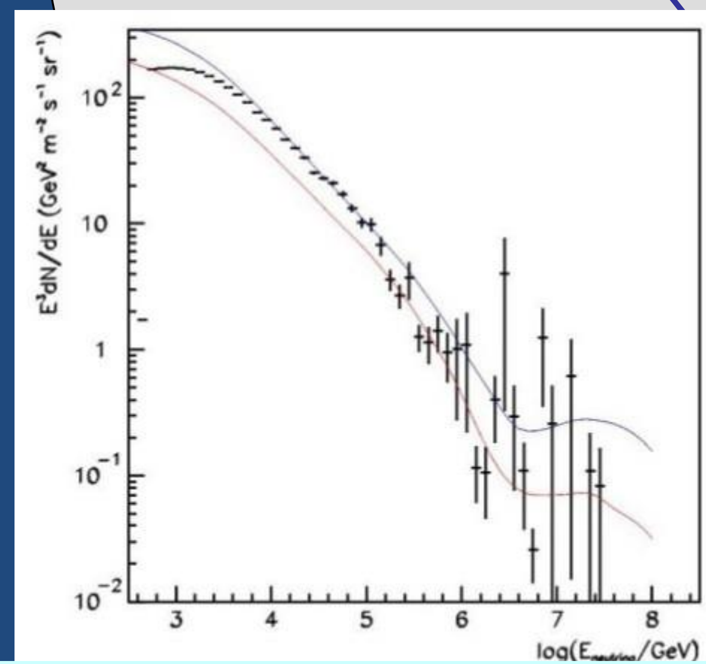
- Atmospheric Muon Generation (based on CORSIKA)
- Neutrino Interaction Events (using PYTHIA/GENIE)
- Atmospheric Neutrinos
  - Models (Conventional Flux+Neutrinos from charm+ Neutrino oscillations)
  - Down coming with accompanying atmospheric muons
- Cosmic Neutrinos (AGN – GRB – GZK – SNRs and more)



Earth shadowing



The probability of a ν_μ to cross the Earth and reach the detector vs energy and nadir angle.



Vertical atmospheric ν_μ flux from generator compared to semi-analytical calculations using SYBILL (blue line) or QGSJET01 (red line) high energy hadronic interaction models (Eun-Joo Ahn et. al. Proceedings of 33 ICRC).

Detector description (based on GEANT4)

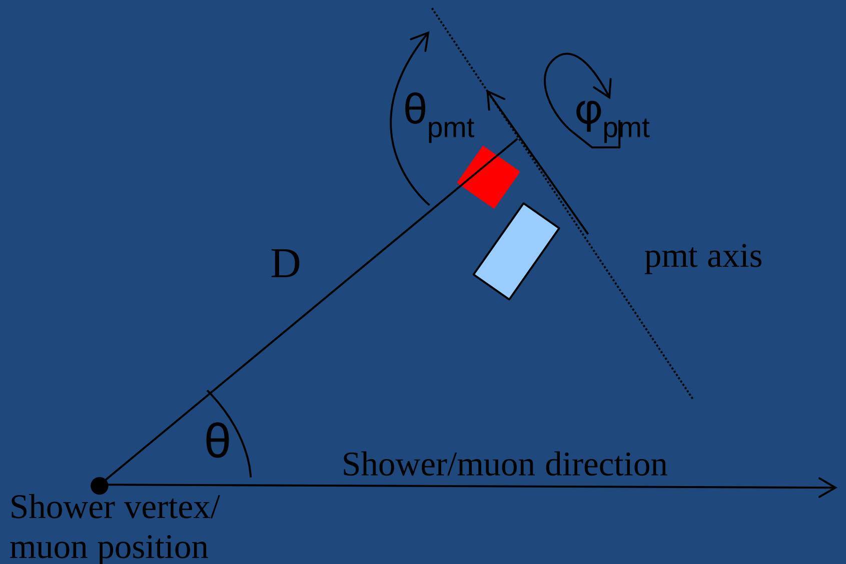
- Any detector geometry is described in a effective way
- All the relevant physics processes are included in the simulation

Full GEANT4 simulation → SLOW

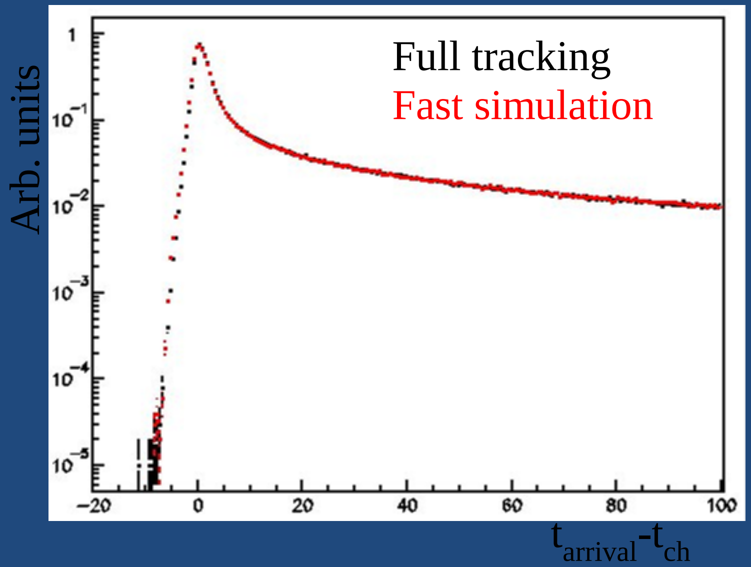
Fast Simulation → 2 to several thousand times faster than full simulation (depending on neutrino energy)

Fast simulation: Parametrizations for:

- EM showers (from e-, e+, γ)
- HA showers (from long lived hadrons)
- Low energy electrons (from ionization)
- Direct Cherenkov photons (from muon)



Arrival time profiles comparison ($\theta = 90^o$,all D)



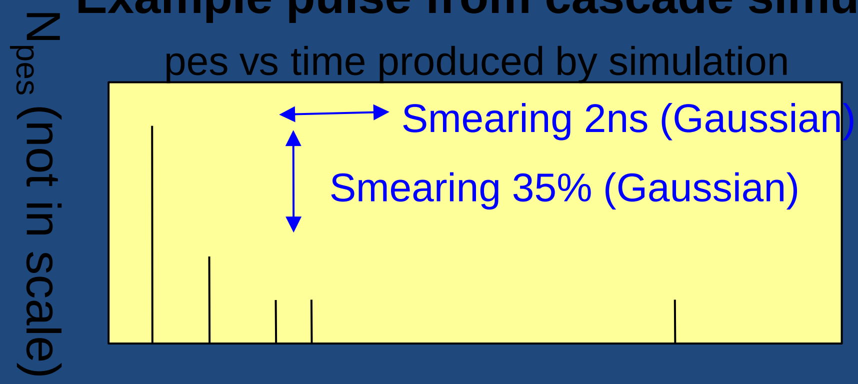
Each parametrization describes the number and time profile of photons arriving on a PMT in bins of:

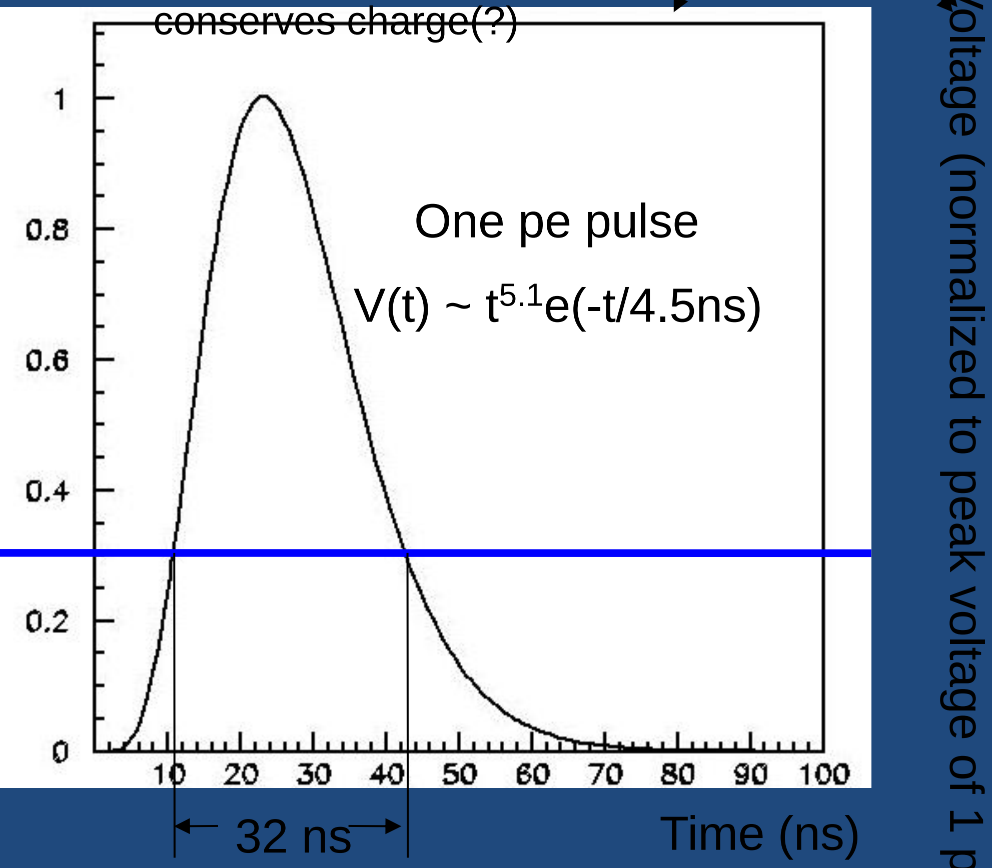
- Shower energy (E) (EM and HA showers)
- PMT position (D,θ) relative to shower
- vertex/muon position,
- PMT orientation (θ_{pmt},φ_{pmt})

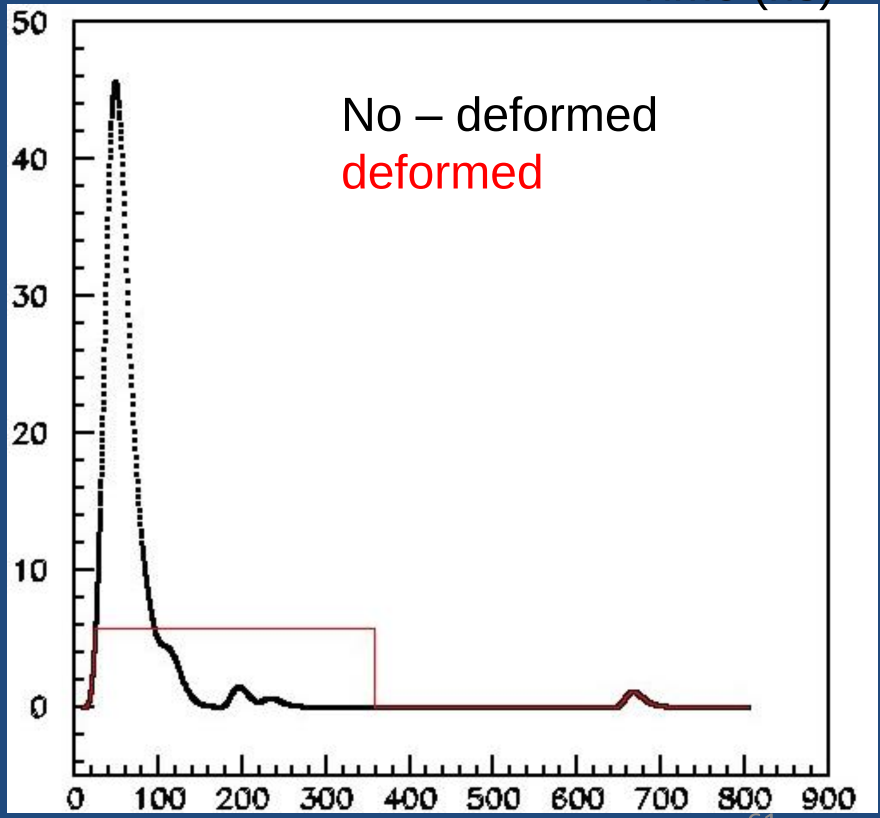
Pulse creation (including preamplifier saturation)

- pes produced at the photocathode:
  - Apply smearing 2 ns (TTS)
  - Apply smearing 35% on the pulse high of each pe (pmt charge resolution)
- Add all waveforms for each pe on the same pmt
- Deform pulse so that ΔToT/Δpe=4.5 ns/pe for many pes
  - Assumption: The deformation conserves charge(?)

Example pulse from cascade simulati







Optical noise filtering, triggering & event reconstruction

Filtering and Triggering based on:

- Single vs multi-photon hit separation capability of the DOM design (multiple coincidences in the same DOM)
- 99.7% of the hitted DOMs in an event have only one active PMT due to ^{40}K decays

Energy reconstruction based on:

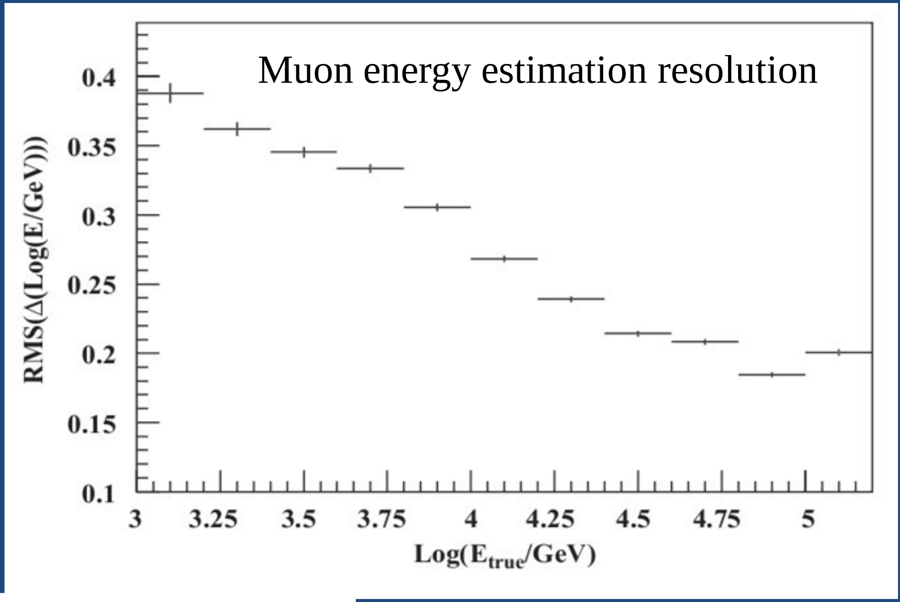
- Charge likelihood (>1TeV muons)

$$L(E) = \ln\left(\prod_{i=1}^{N_{hit}} P\left(Q_{i,data}; E, D, \theta\right) \prod_{i=1}^{N_{nohit}} P(0; E, D, \theta)\right)$$

$Q_{i,data} \equiv$ Hit charge normalized to the Charge of a single photoelectron pulse

Probability to observe charge $Q_{i,data}$ on a DOM depends on:

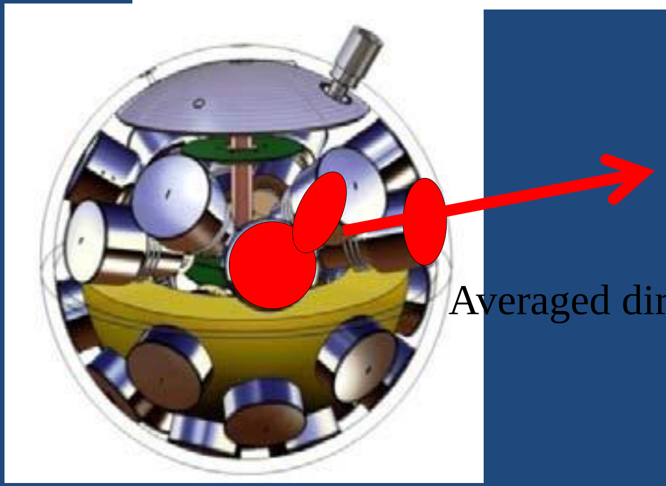
- muon energy, E,
- DOM distance from track, D,
- DOM orientation with respect to the Cherenkov wavefront, θ



- Muon track length estimation
- (<1TeV contained muon events)

Event direction reconstruction based on:

- Likelihood fit using the time and
- direction information of the hits
- Combination of χ^2 fit and
- Kalman Filters

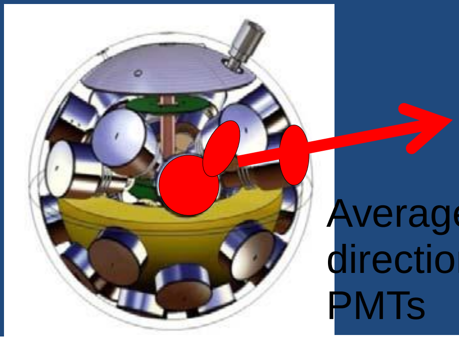


$$\hat{D} = \sum_{i=1}^{N} d_i$$

Averaged direction of active PMT

Study of the performance of the PPMDU to detect atmospheric muons

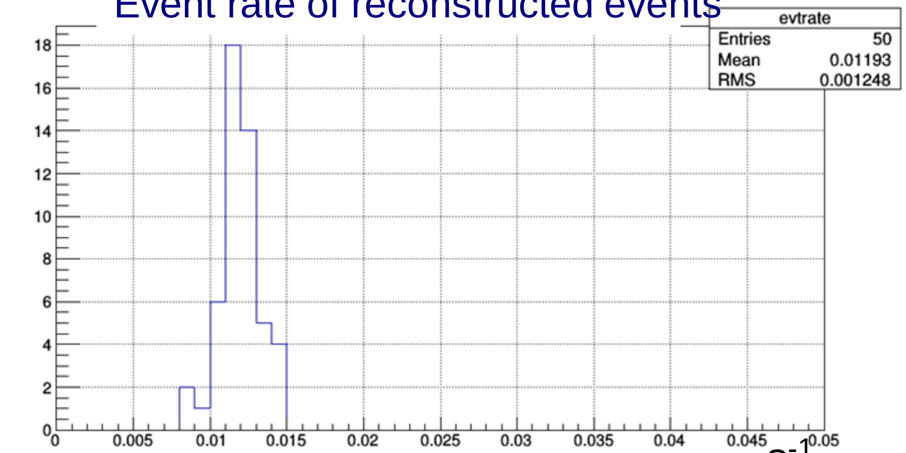
- The Pre-Production Model of the KM3NeT Detection Unit (PPMDU) was deployed in 2014
- The PPMDU consists of 3 DOMs in a vertical structure.
- With 3 DOMs reconstruction of atmospheric muons is possible using not only the timing information of the hits but also the direction information.



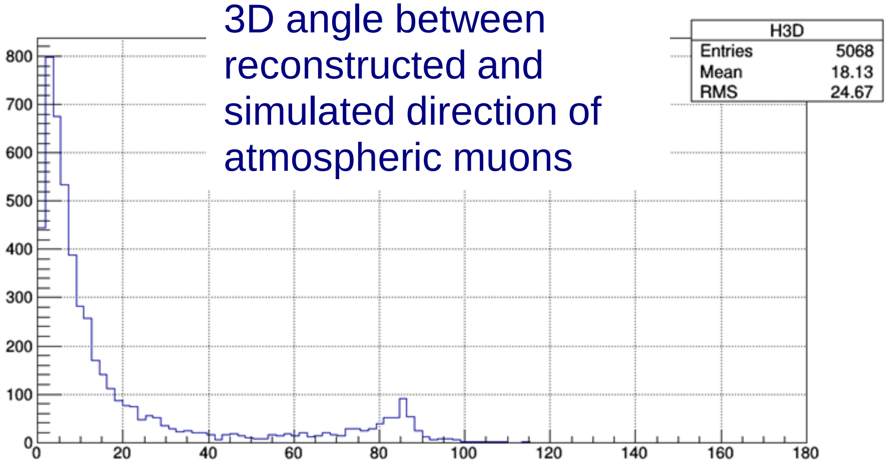
$$\hat{D} = \sum_{i=1}^{N} d_i$$

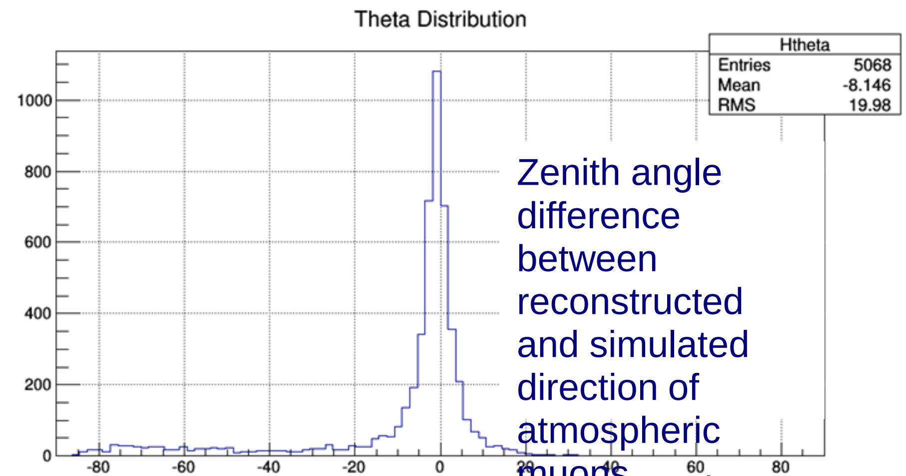
Averaged direction of active PMTs

Event rate of reconstructed events

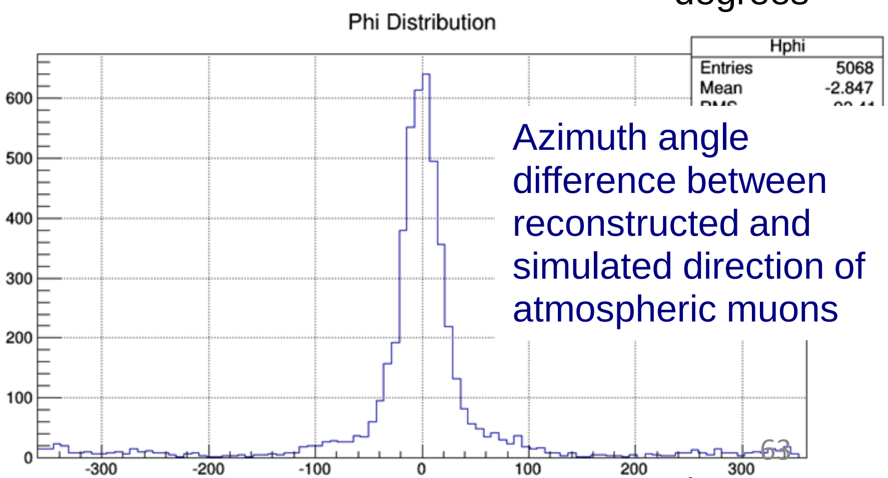


3D angle between reconstructed and simulated direction of atmospheric muons





Zenith angle difference between reconstructed and simulated direction of atmospheric muons

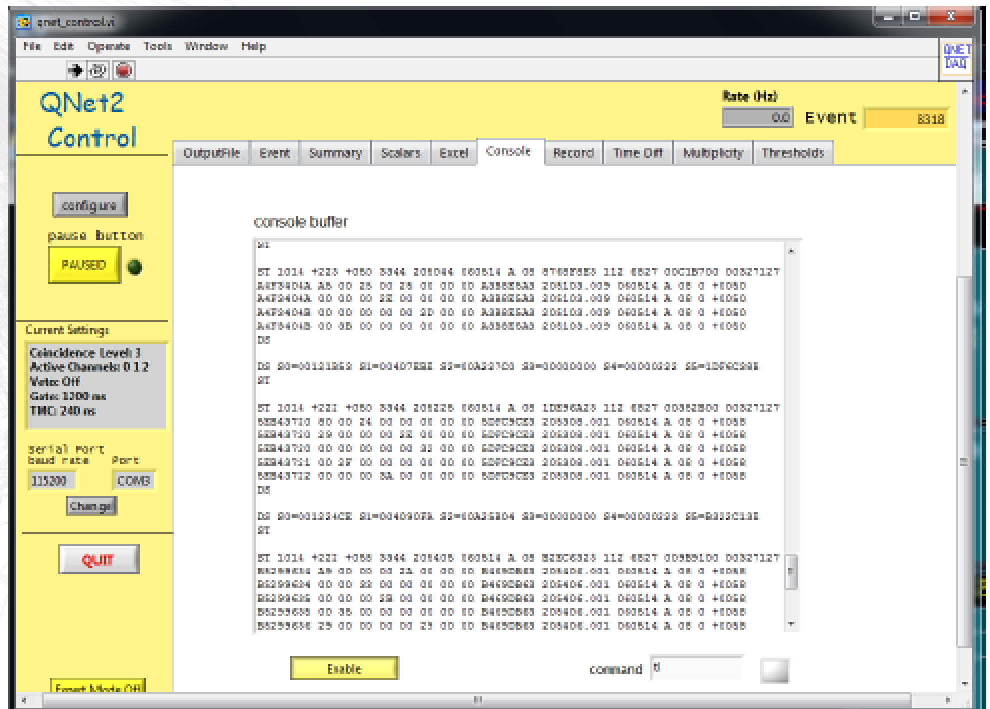


Azimuth angle difference between reconstructed and simulated direction of atmospheric muons

Data Acquisition
Quarknet

Quarknet card acquisition software developed in LabVIEW

- Set acquisition parameters (majority, threshold level for each input channel, coincidence window)
- Monitor acquisition (counters, rates, time)
- Monitor status registers and environmental sensors values (temperature, barometric pressure)
- Event data (timing of the threshold crossings, GPS data) packed and saved
- Periodically saves the status registers and environmental sensors values



HOURS-EAS

Hellenic Open University Reconstruction and Simulation of Extended Air Showers

Initialization

CORSIKA Particle Information on the Detector Level

Fast Simulation of Scintillation & WLS Processes

Generation Of PMT Photoelectrons

PMT Response Pulse

Signal Transmission and Digitization

Detector Database

Counter Positions & Orientations,
Counter characteristics,
PMT characteristics,
Cable Calibration,
Digitization Parameters

Initialization

Signal Processing

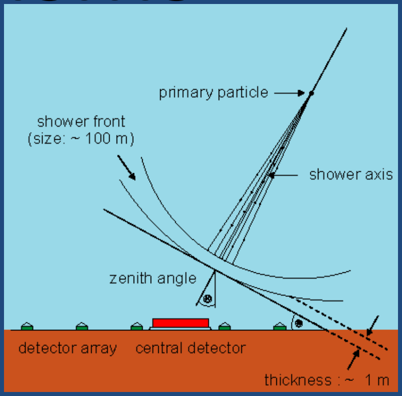
Data Quality

Shower Reconstruction

Raw Data Creation

Performance Plots

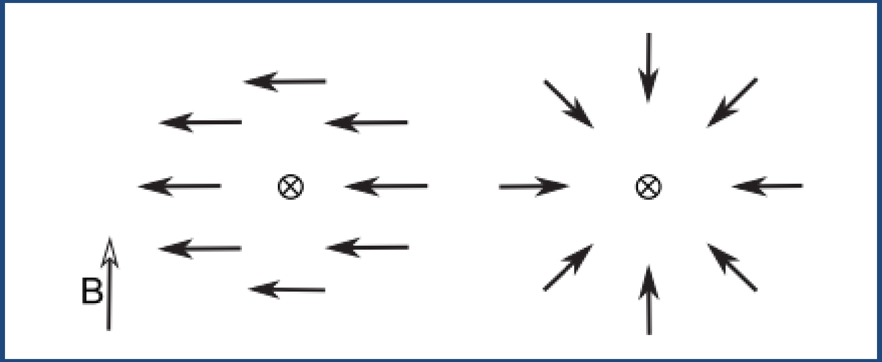
EAS development-
Radiation production mechanisms



- **Geomagnetic Effect (Kahn, Lerche, 1966)** . Transverse currents in pancake, boosted to ground reference frame
- **Charge Excess mechanism (Askaryan, 1962)** . Cerenkov radiation of electron excess in shower development
- **Sudden Death mechanism (B. Revenu, V. Marin, 2013)**. Radiation from sudden deceleration on impact to ground.

Electric field - Geomagnetic effect

Electric field – Charge Excess effect



Geomagnetic effect is dominant (Codalema 2005, Lopes 2005)

Superimposed effect of charge excess mechanism (Codalema 2011)