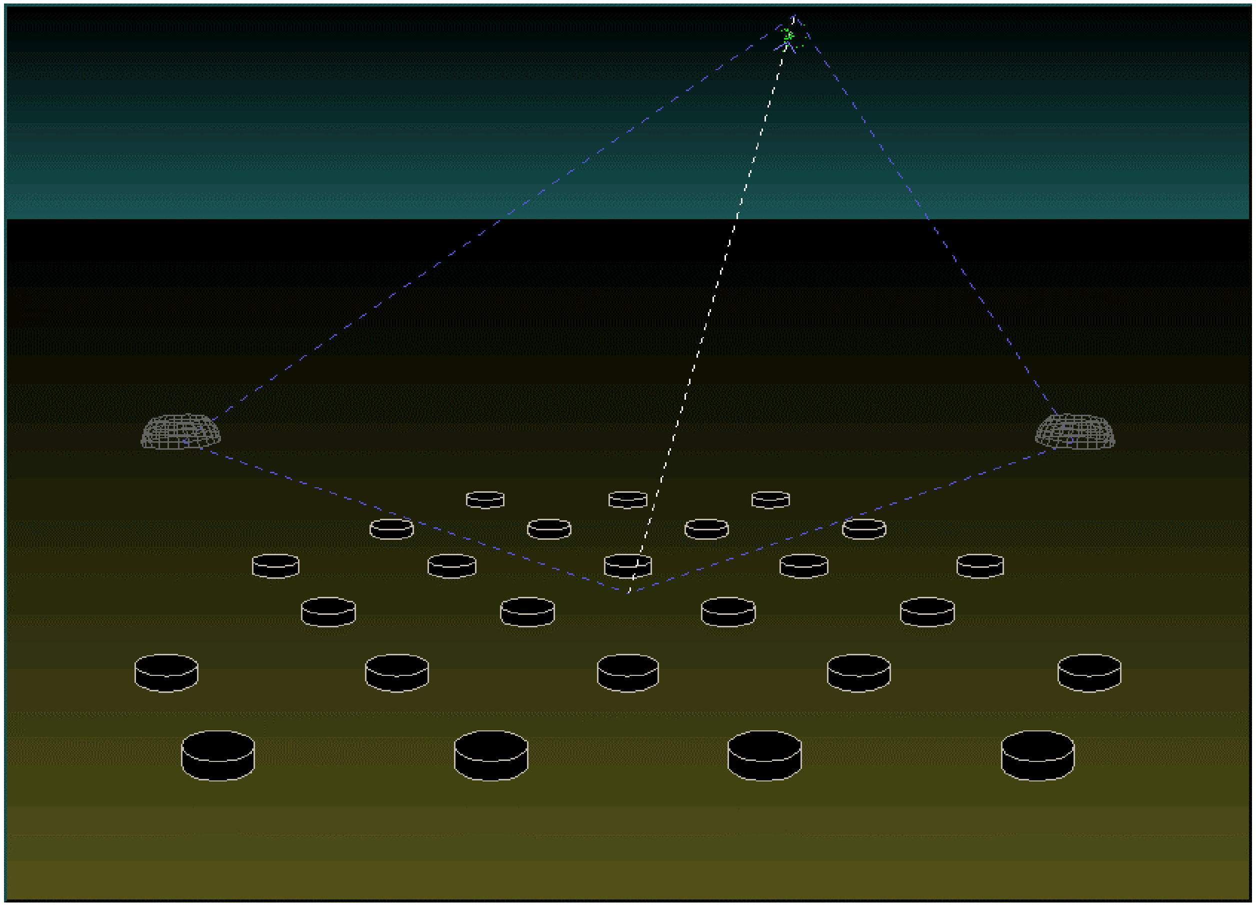
The Pierre Auger Observatory

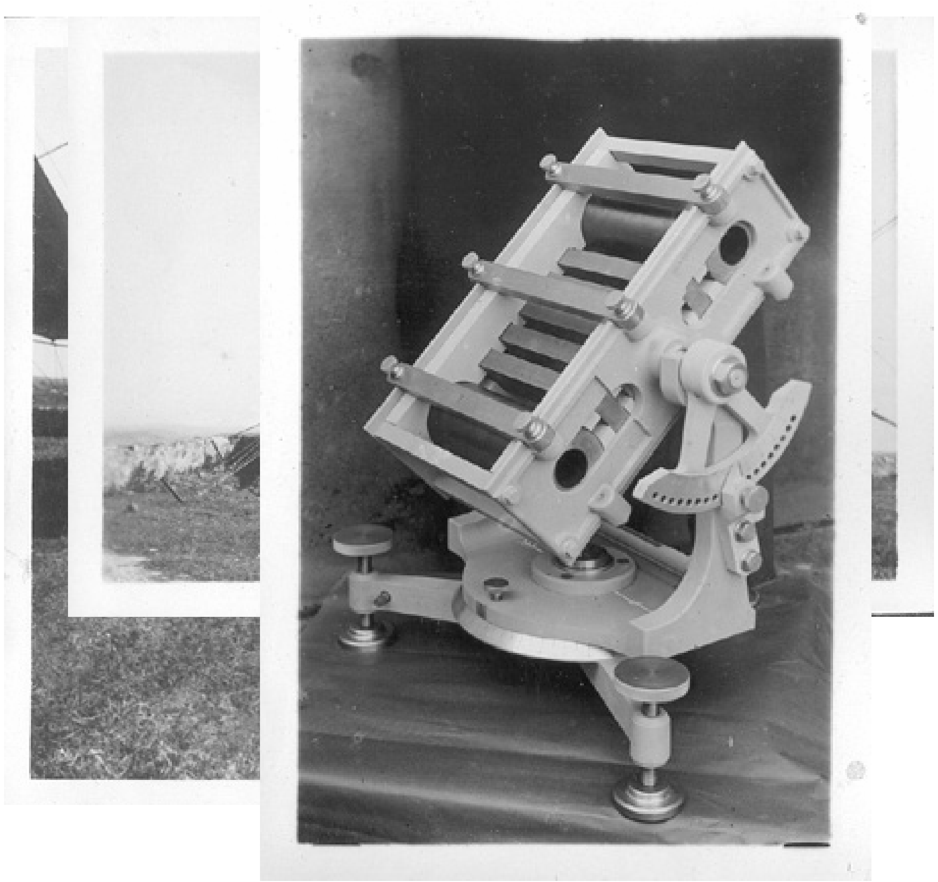
Hunting the Highest Energy Cosmic Rays

II – EAS Detection at the Pierre Auger Observatory

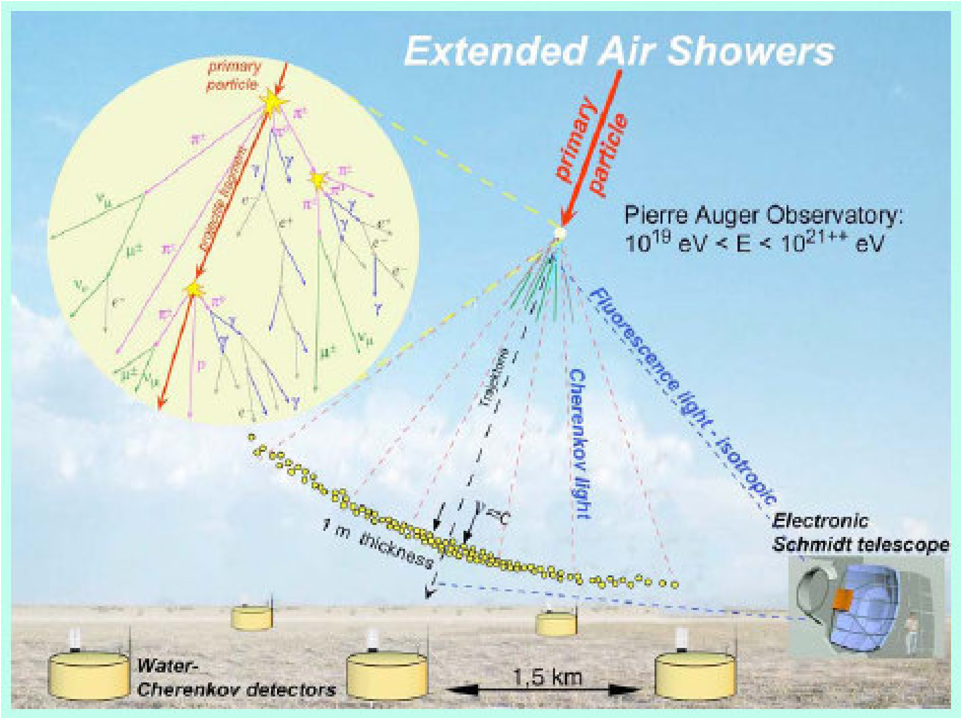
EAS – The Movie

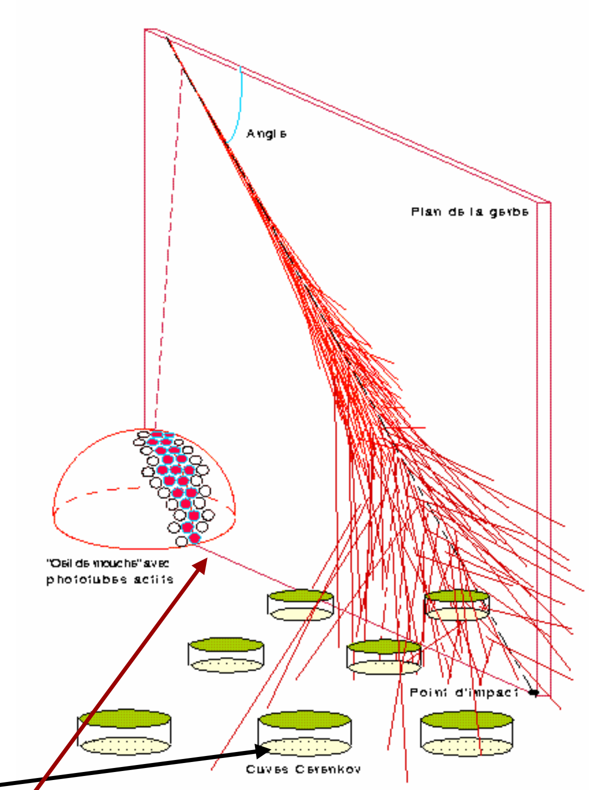


EAS – Early History



The Hybrid Concept





SD: Sampling Lateral Profile at ground

FD: Measuring E_{tot} & Longitudinal Profile

Geography - I

Very flat region   "Pampa Amarilla"
Malargüe (Argentina)

35º S latitude   69º W longitude

≈ 1400 m height

≈ 875 g/cm^2

Very low population density (< 0.1 /km^2)

Good atmospheric conditions (clouds, aerosol, light…)

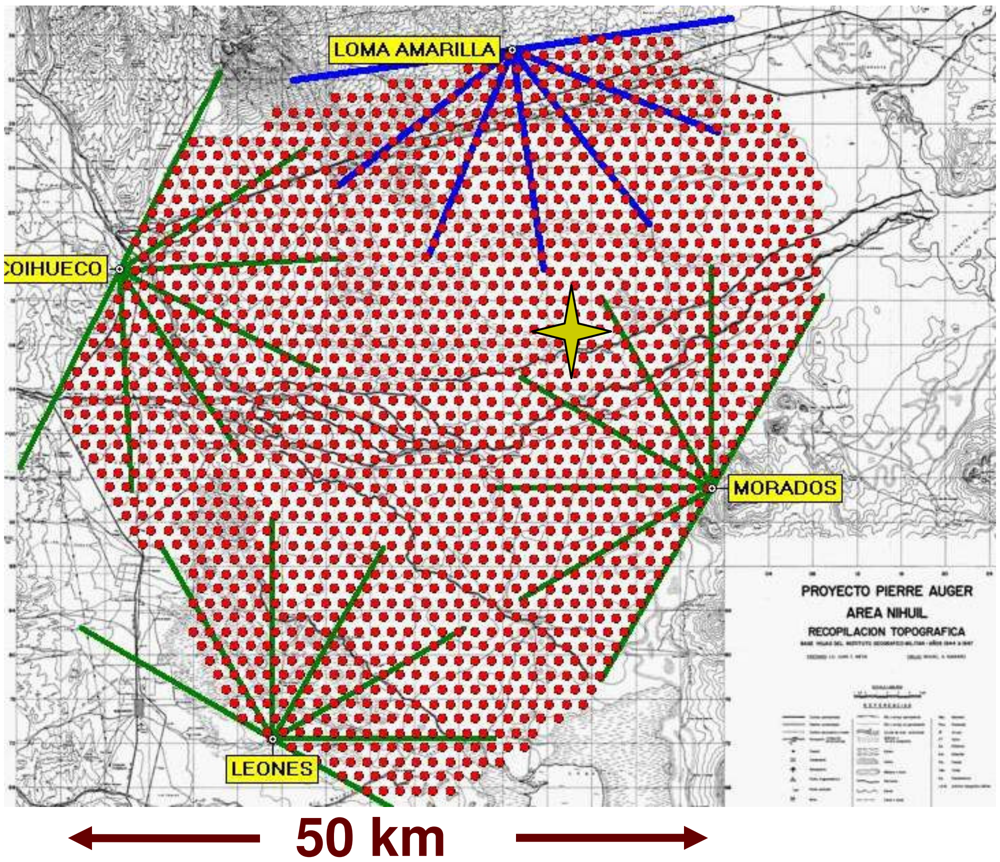
Geography - II

The South Site

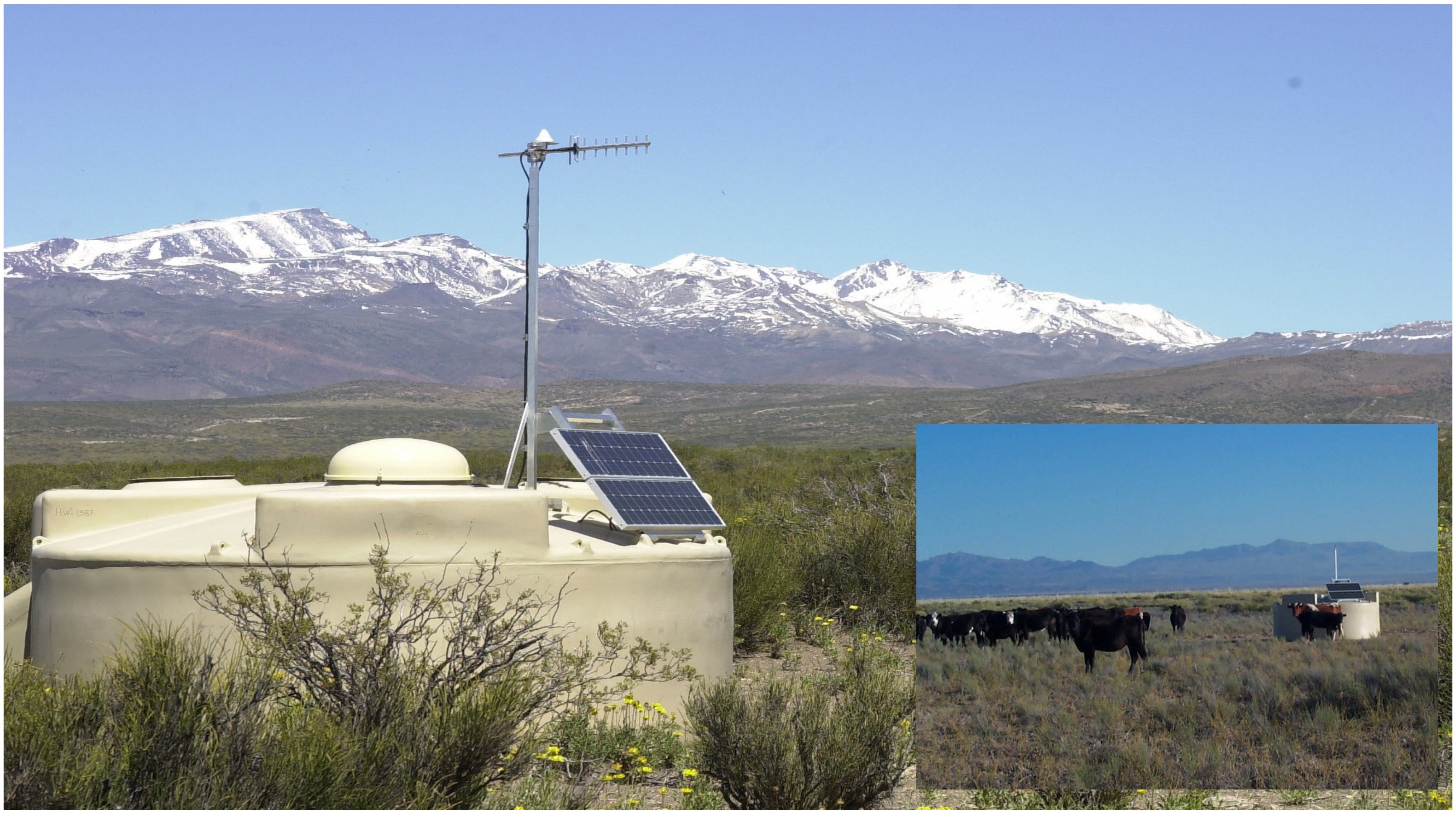
Total area ~3000 km^2

1600 Surface detectors ("water tanks")

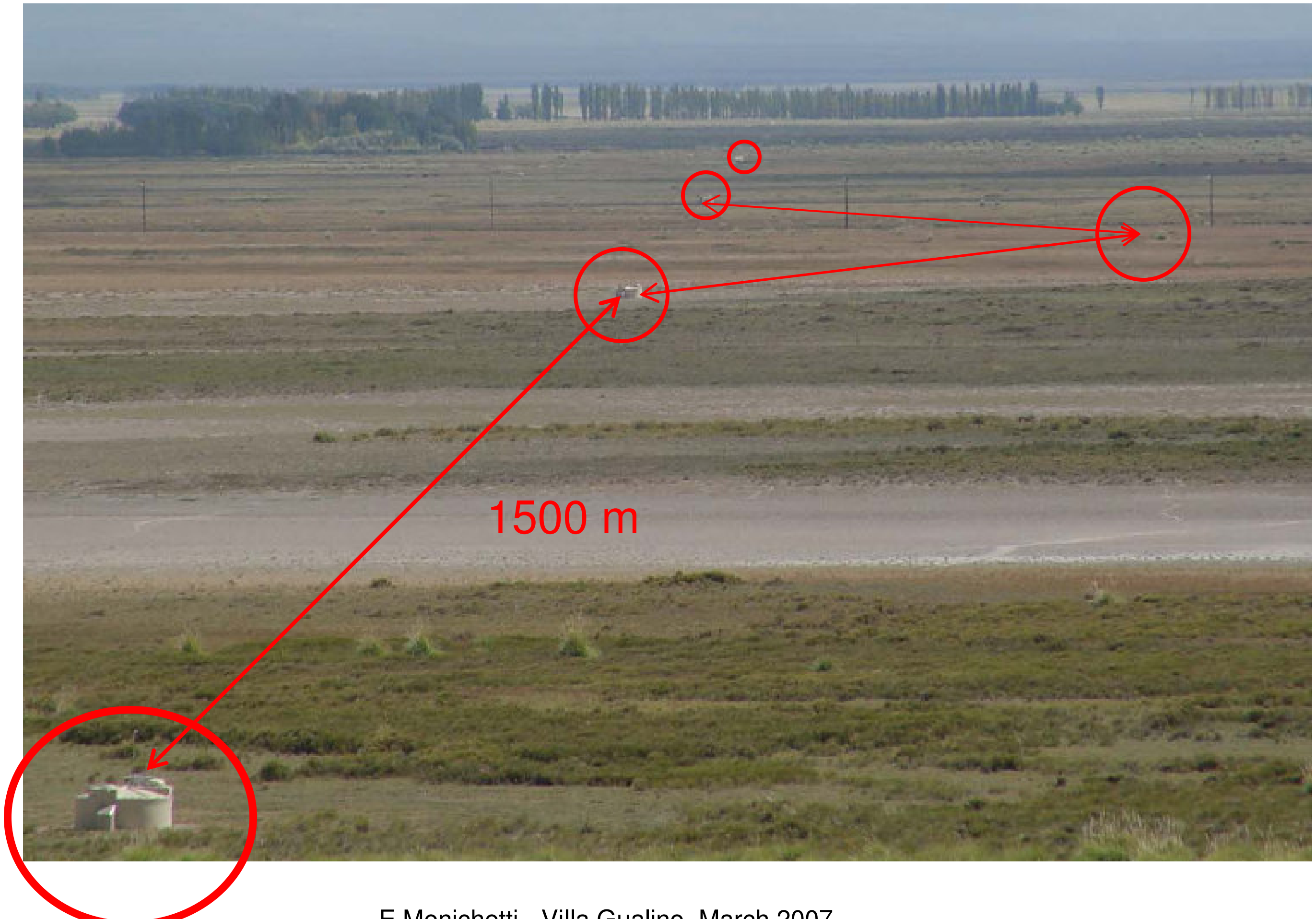
24 fluorescence telescopes
6 in each of 4 buildings



Advertisement - I

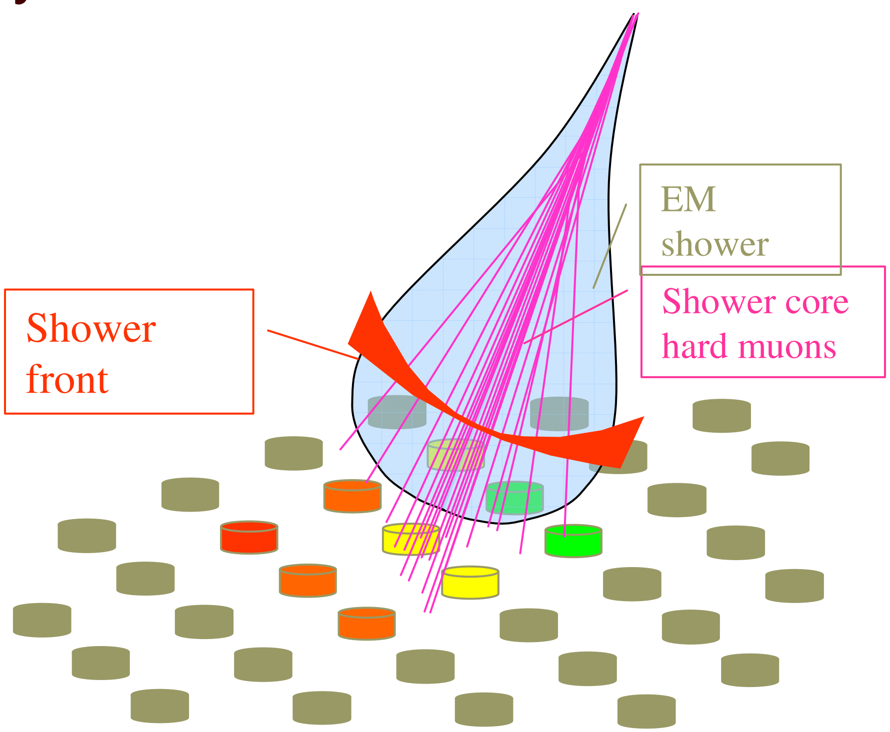


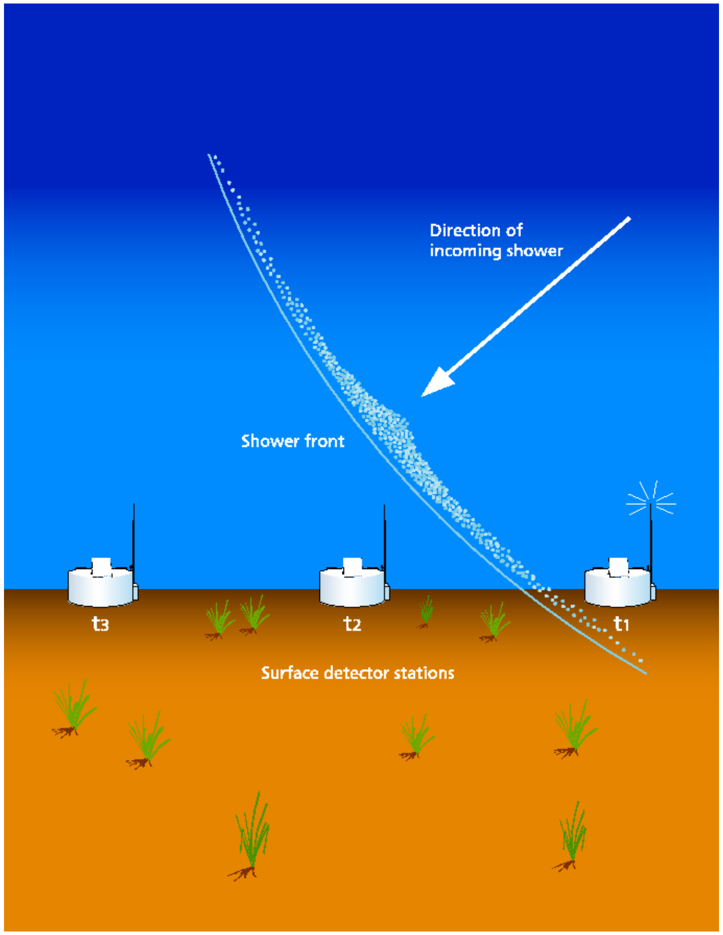
Topography



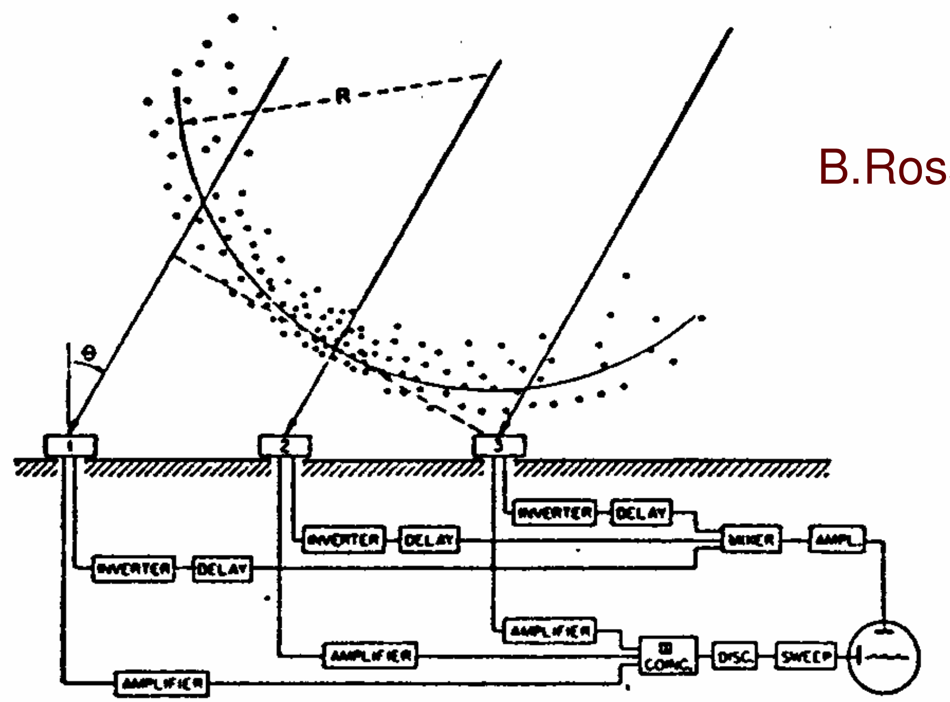
Ground Array

EAS sampled at ground
by a number of detector stations





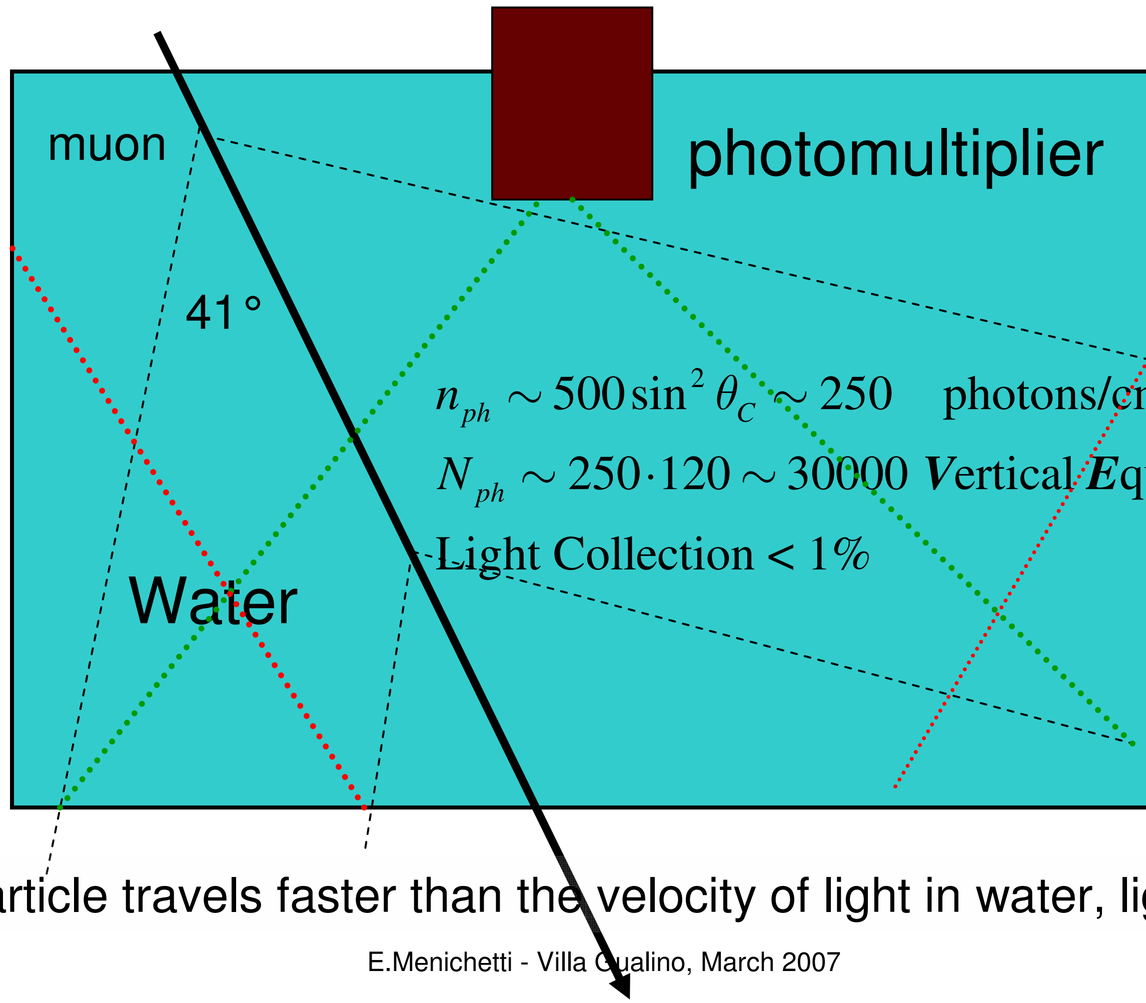
EAS Direction from Timing



B.Rossi, 1953

FIG. 2. Block diagram of the apparatus with a schematic representation of an air shower about to strike the counters. The counters are in arrangement II.

Light Emission by Muons



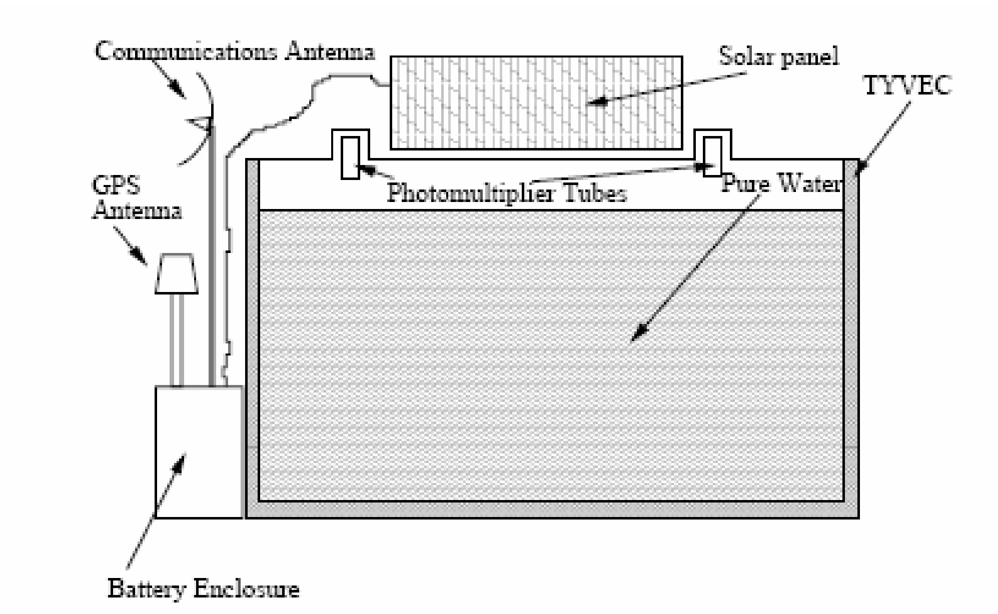
$n_{ph} \sim 500 \sin^2 \theta_C \sim 250$ photons/cm

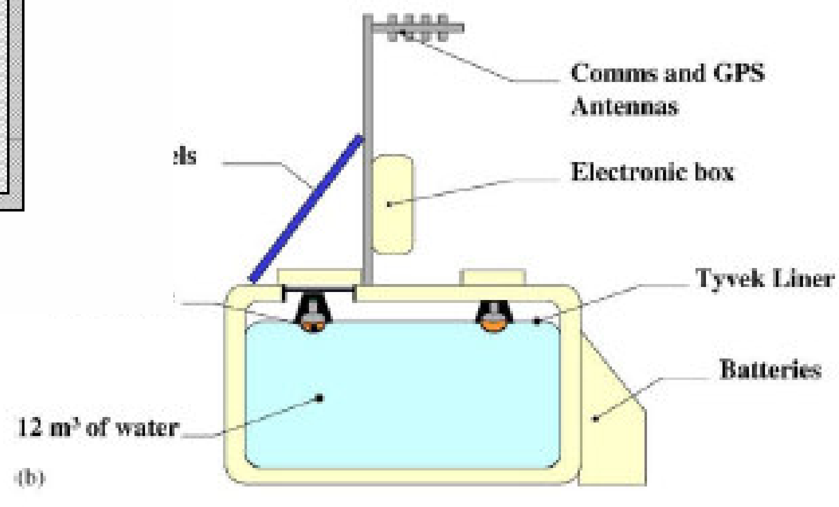
$N_{ph} \sim 250 \cdot 120 \sim 30000$ ***V**ertical **E**quivalent **M**uon*

Light Collection < 1%

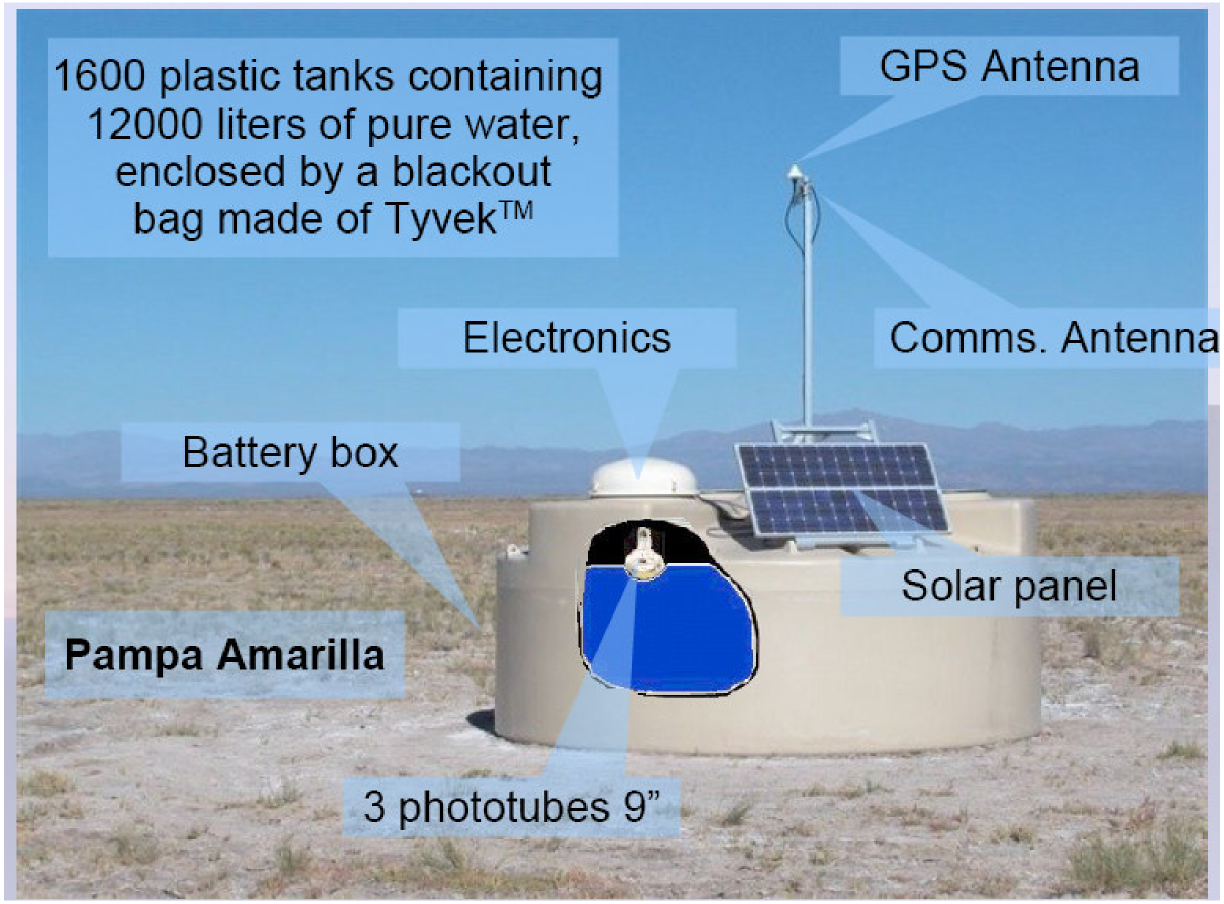
When a particle travels faster than the velocity of light in water, light is emitted

Tank Details



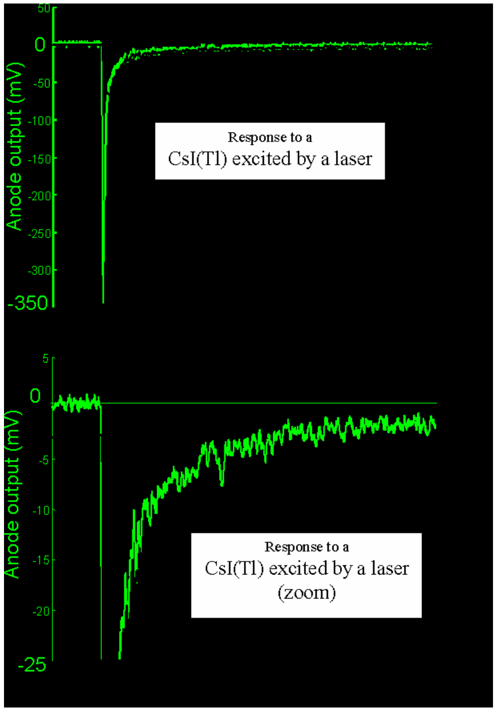


From Design to Reality



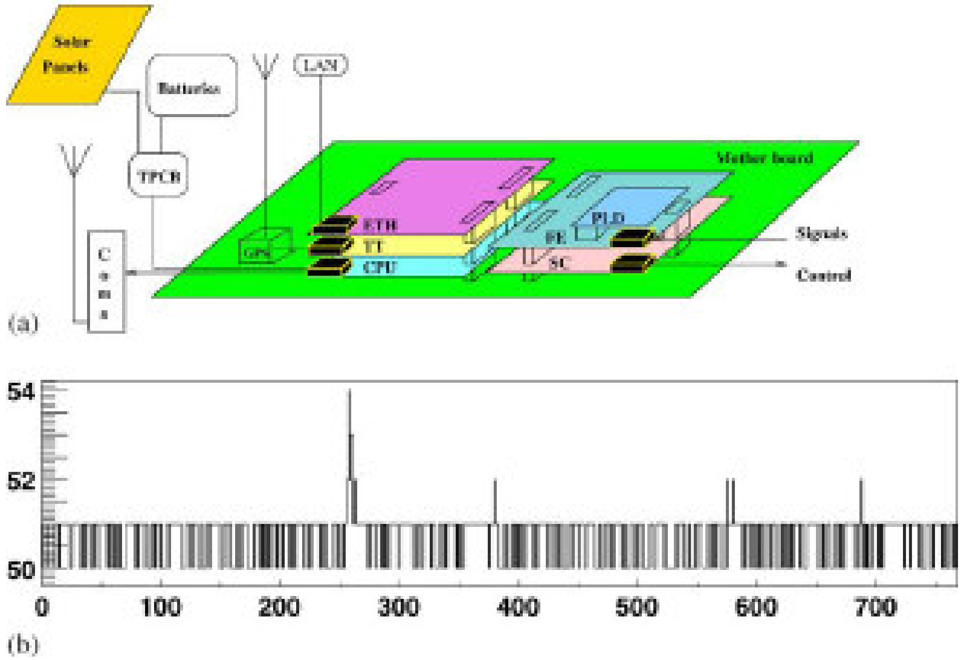
PM and HV Voltage Divider

Photonis
XP1805/D1



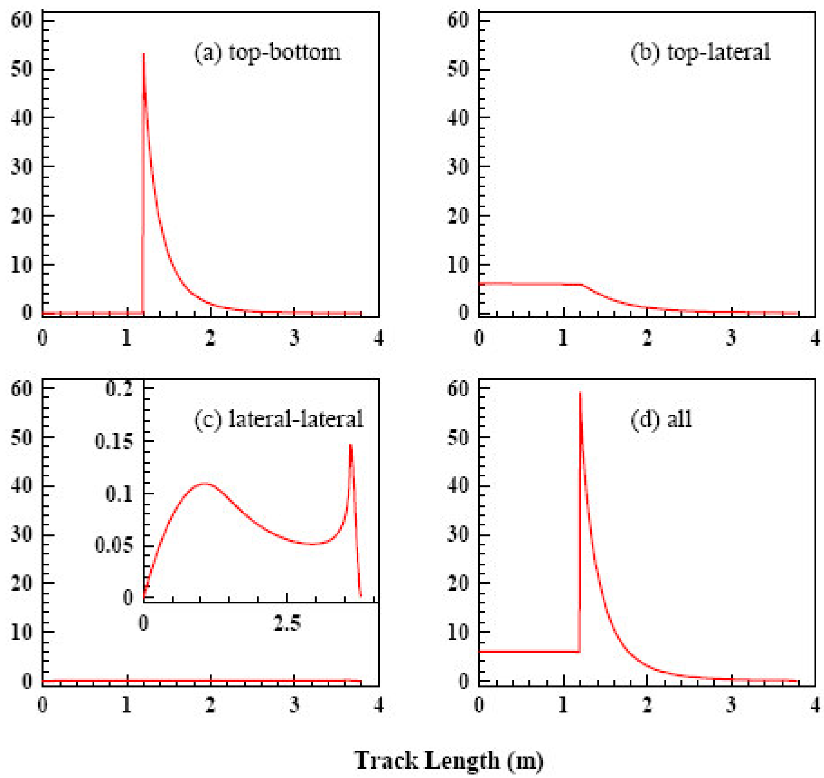
9” PM from Photonis
HV made on board

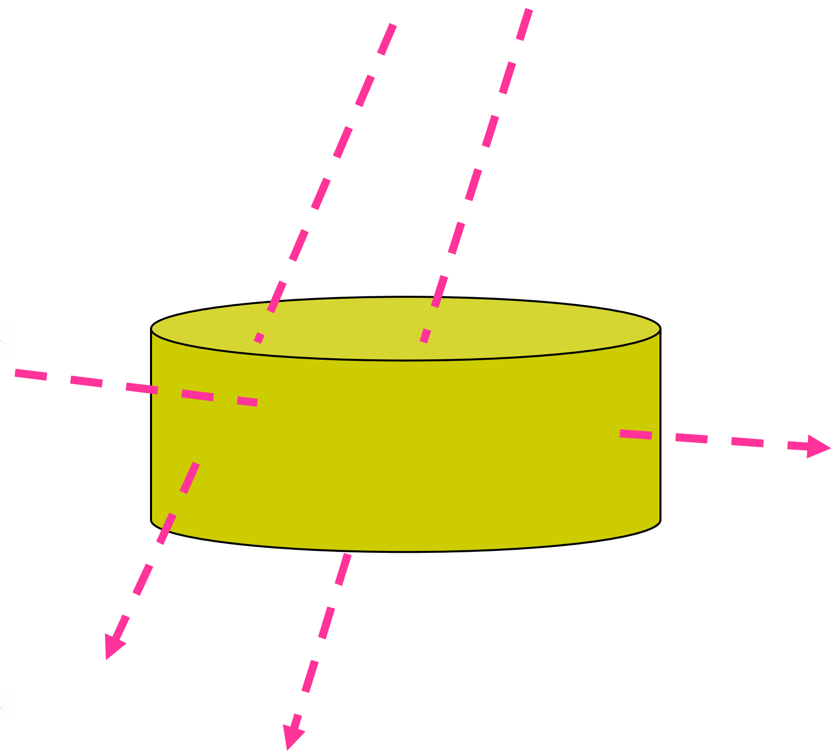
Mechatronics, Pedestals



Solar Panels, Antennas

SD Pulse Height from Muons



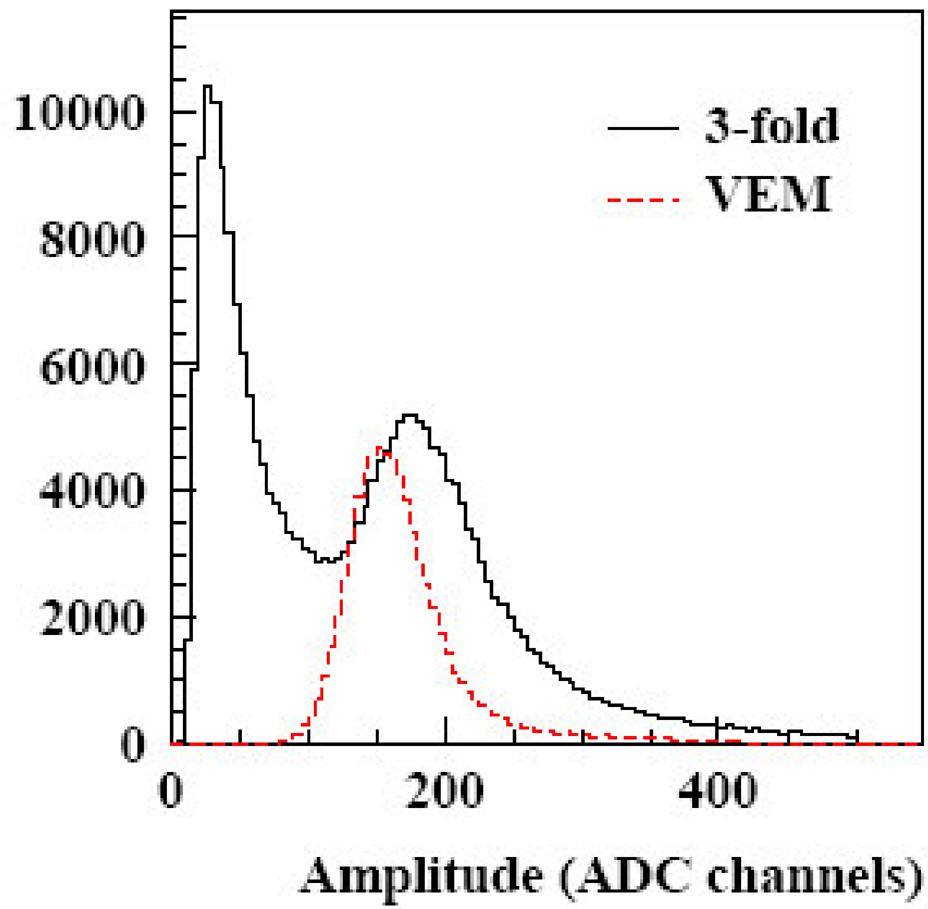


Signal unit ~ 1 VEM ~ 94 ph.e.

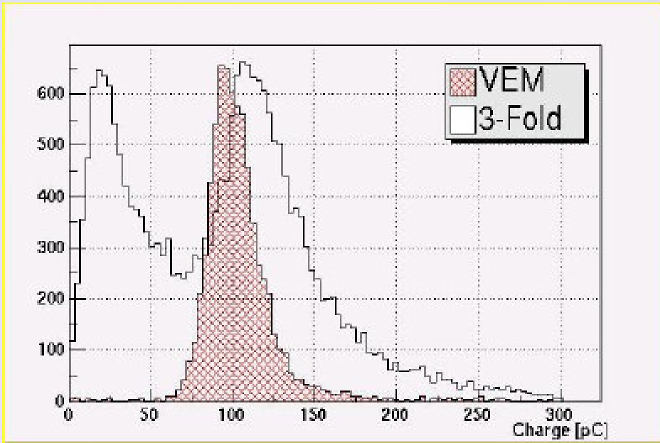
SD P.H. Spectrum for Calibration

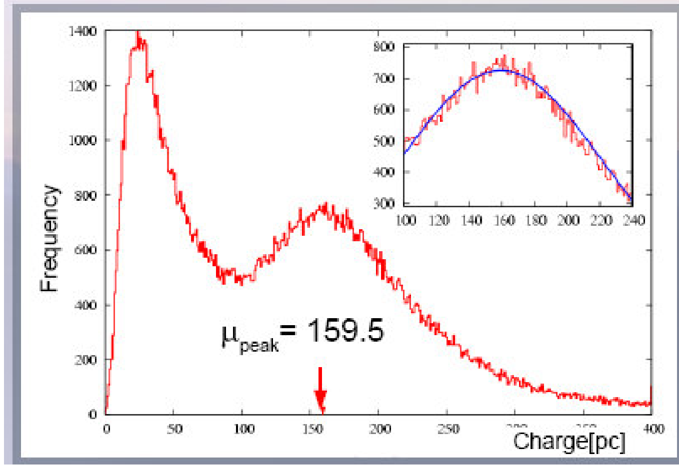
Most frequent signals ~ atmospheric muons . . We measure muon lifetime

A/D ratio - sliding average over 3 min of signals > 512



SD Muon Calibration



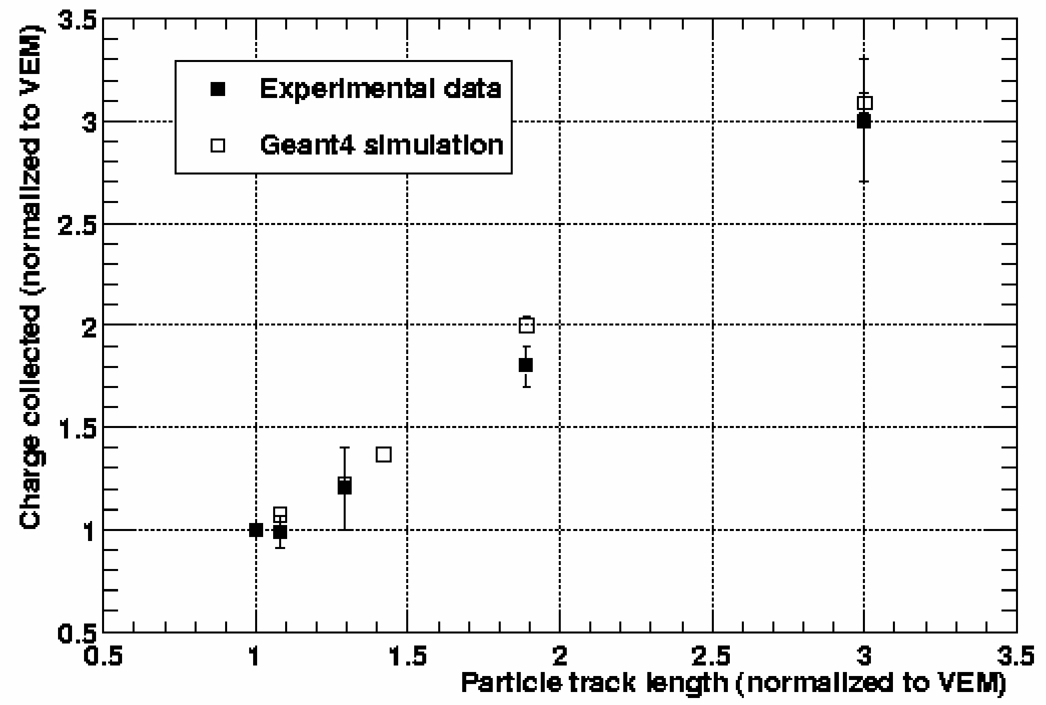


- **V**ertical **E**quivalent **M**uon
  The average charge deposited by a vertical and central muon.
- Shift due to muon track distribution:

$$S_{VEM} \propto \iint TL[zenith, x, y]\,dS \propto V$$

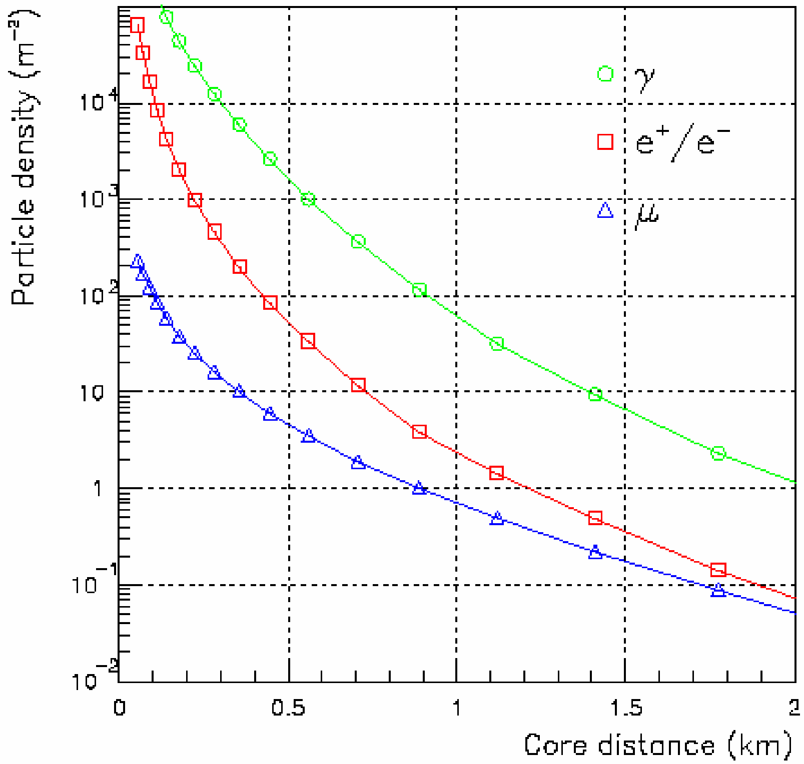
  and photo-statistics.
- μ_{Peak} = 1.05 VEM

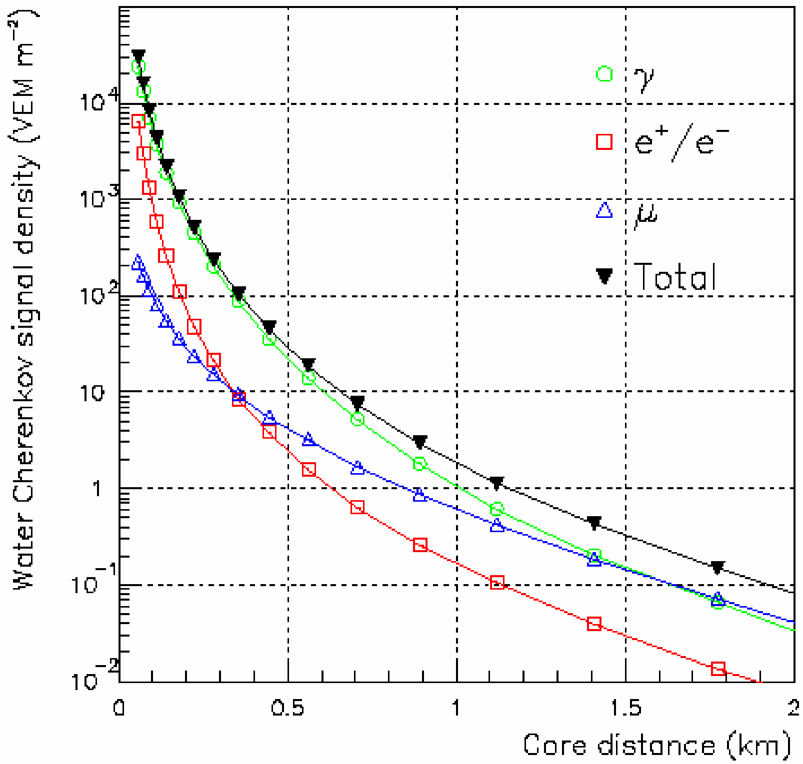
SD Linearity (Low Signals)



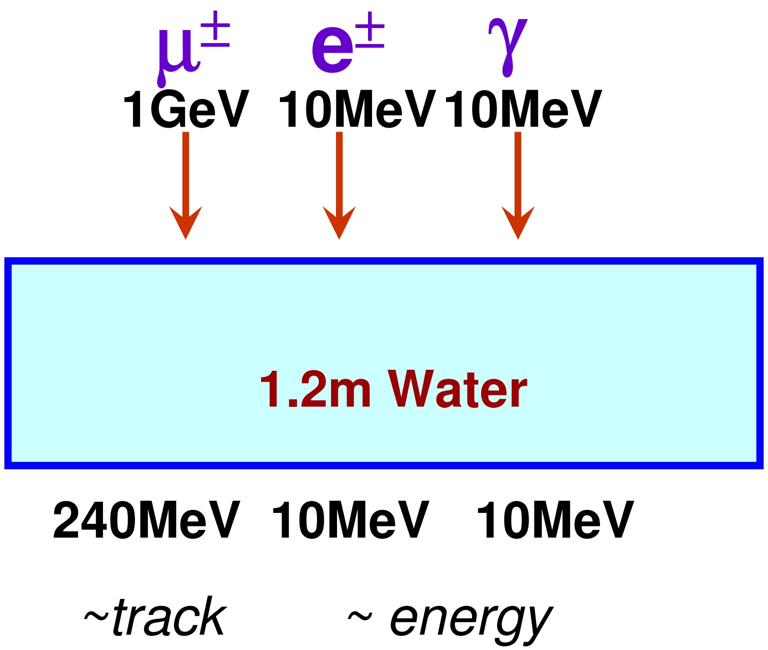
SD: Signal Components

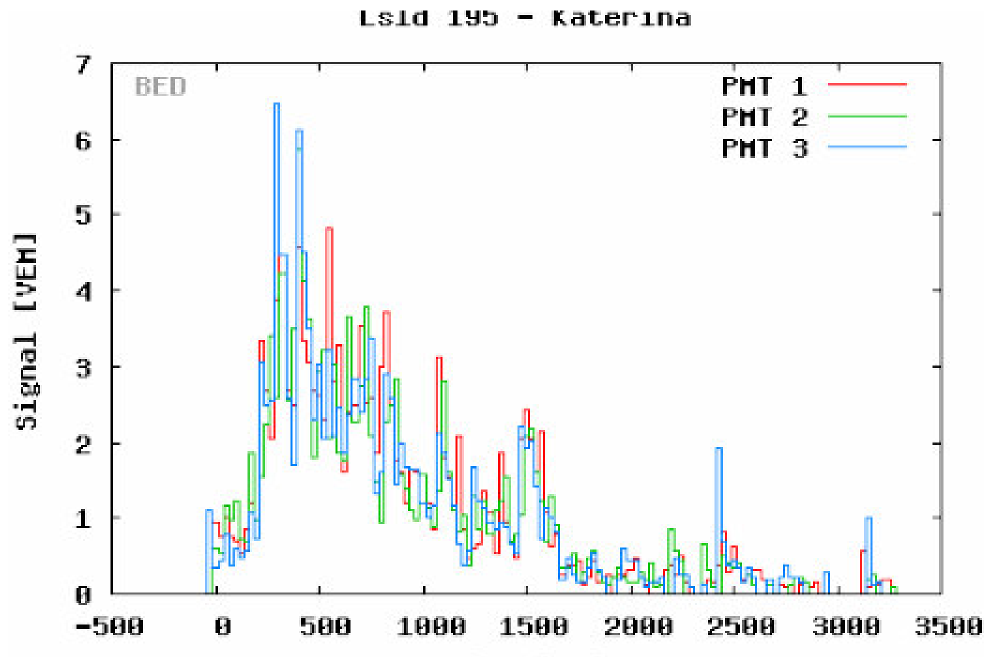
Simulation





SD FADC Traces



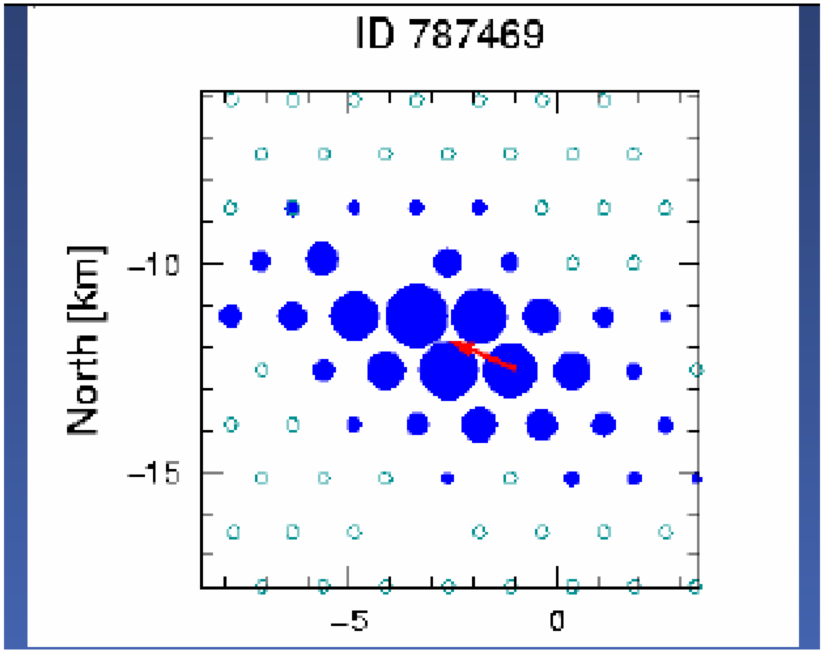


Time (ns)

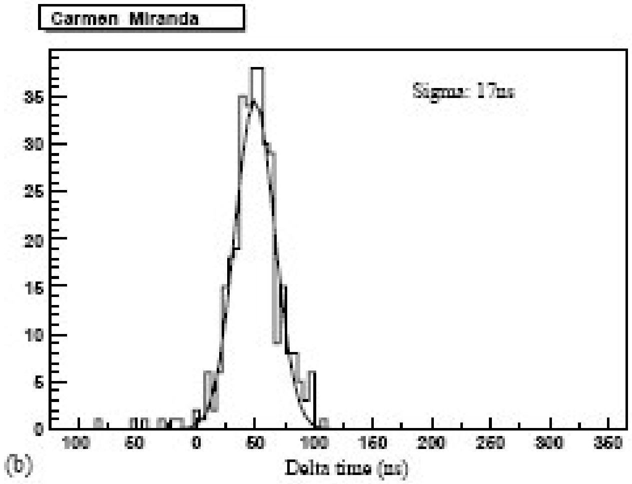
SD - Hunting the Shower I

Concept: ***Energy from Lateral Distribution !***

1) EAS direction from tank timing, position

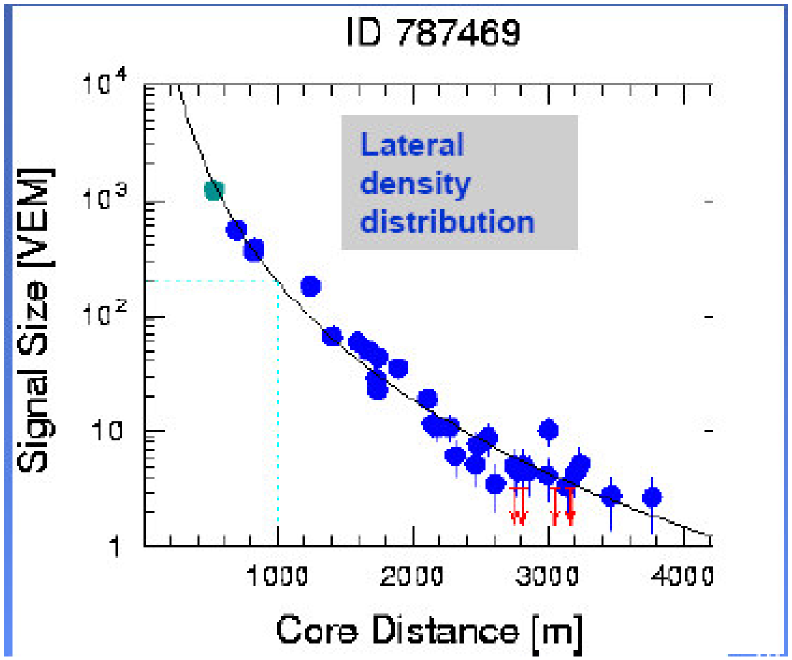


SD Twin Tanks



Good to check timing resolution

SD - Hunting the Shower II



2) Reconstruct LDF
Fit to empirical formula

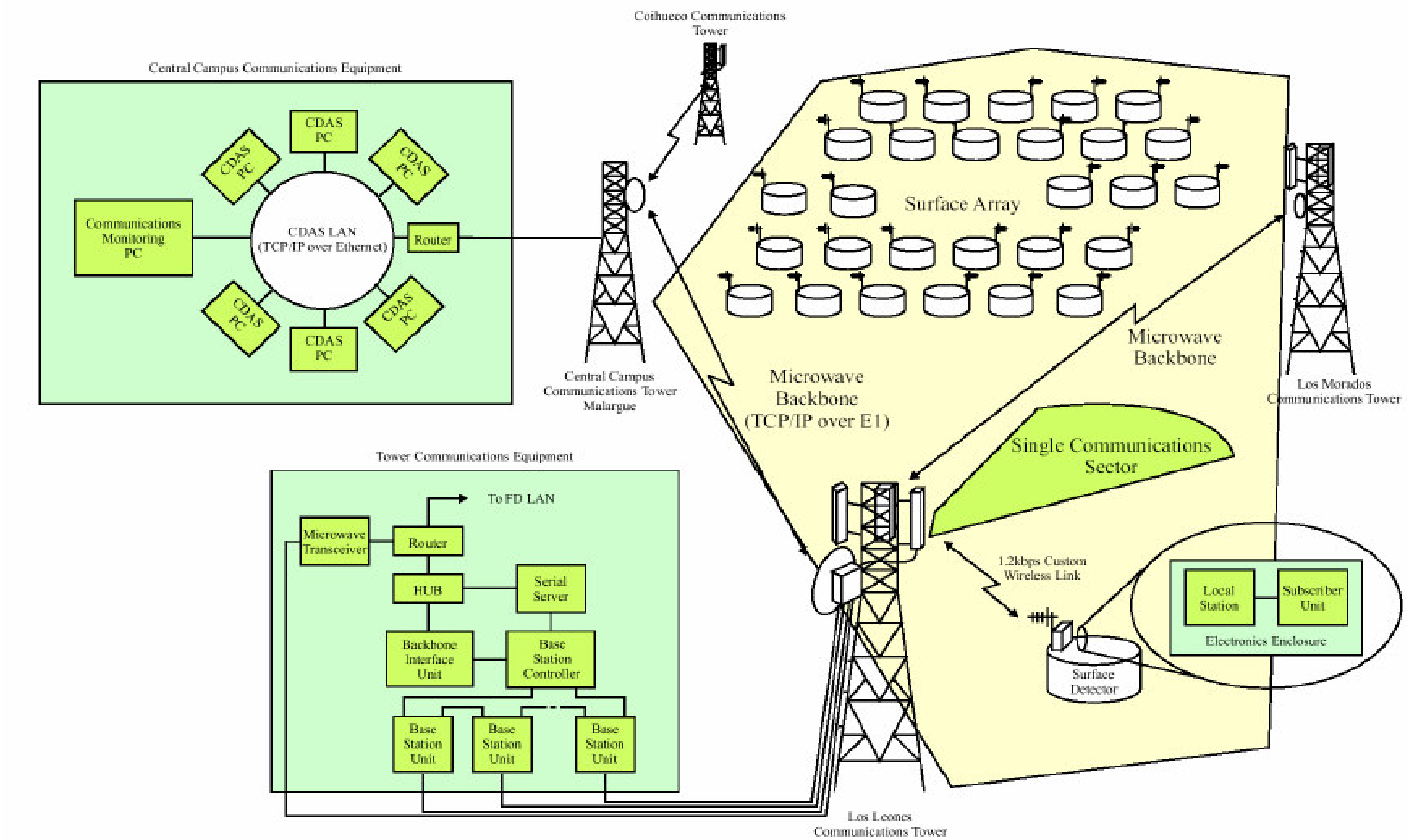
3) Get *S(1000)*
Detector signal at ground, 1 km off the core

4) Correct for slant depth→ $S_{38}(1000)$
Constant Intensity Cut→Take 38^0 Zenith as a Reference

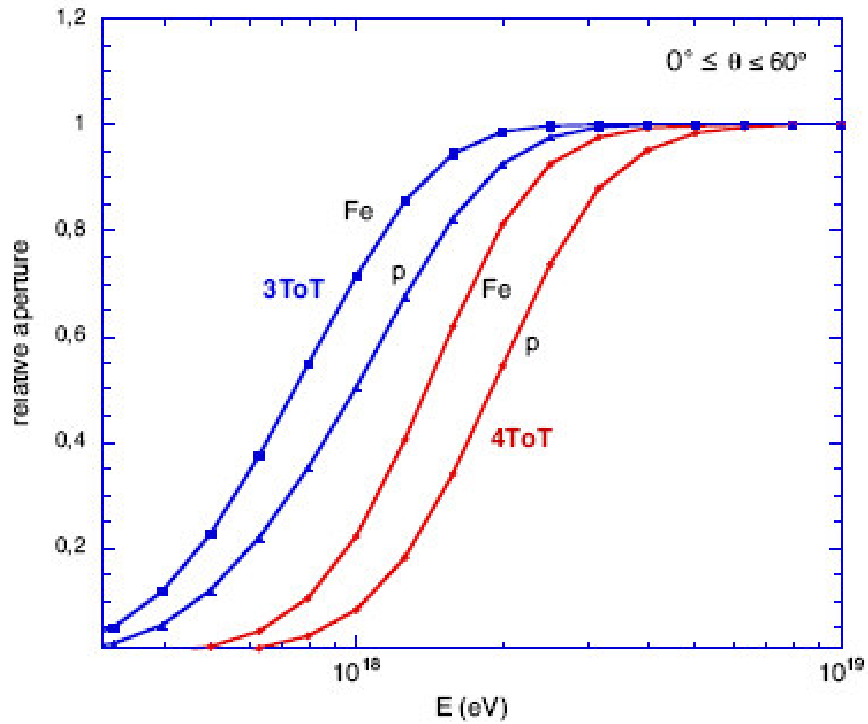
Previous experiments, MCarlo: E = k $S_{38}(1000)$

AUGER Unique Capability**: Get k constant from FD**

Communications Network

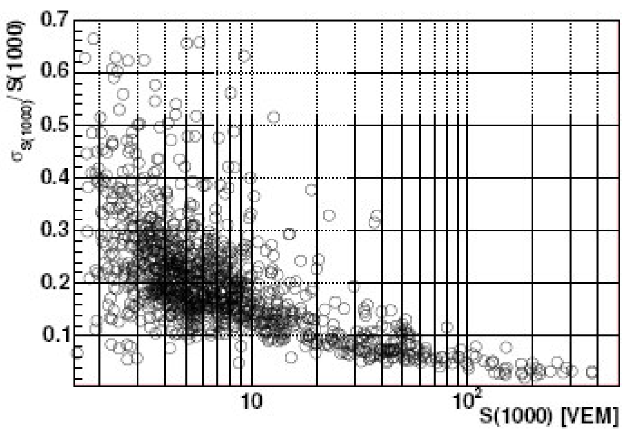


SD Aperture

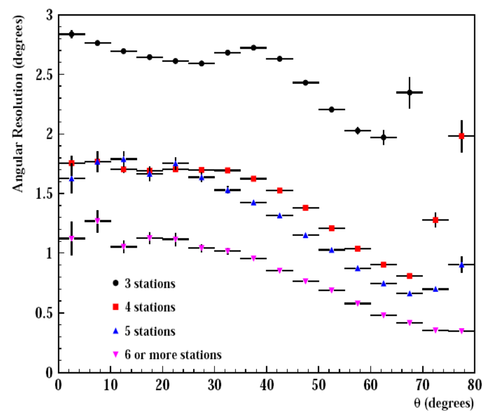


Relative aperture (trigger included) vs. Energy
Full efficiency above 3 EeV

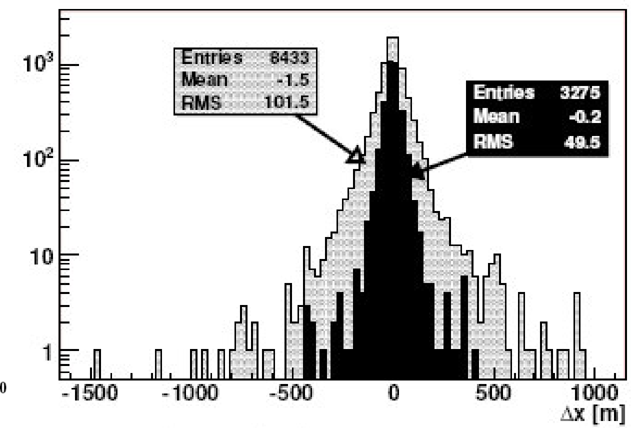
SD – Resolution



S(1000)



Zenith



Core Position

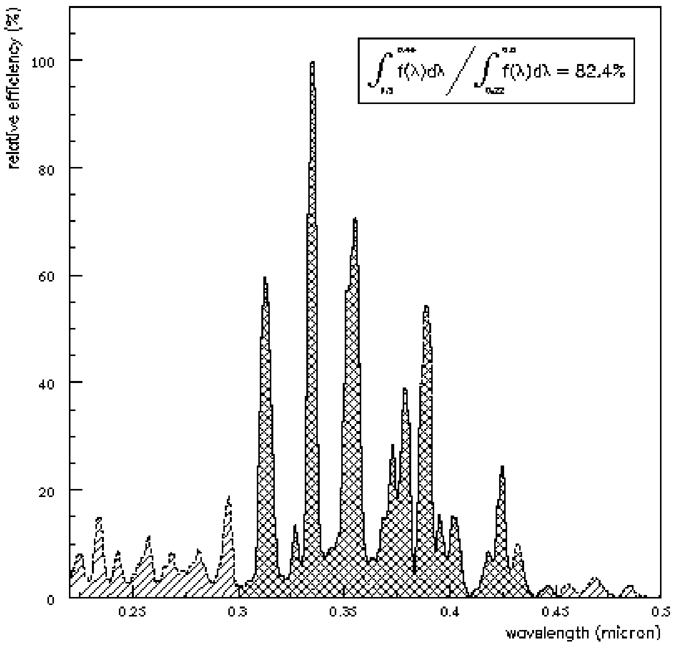
S(1000)>30VEM

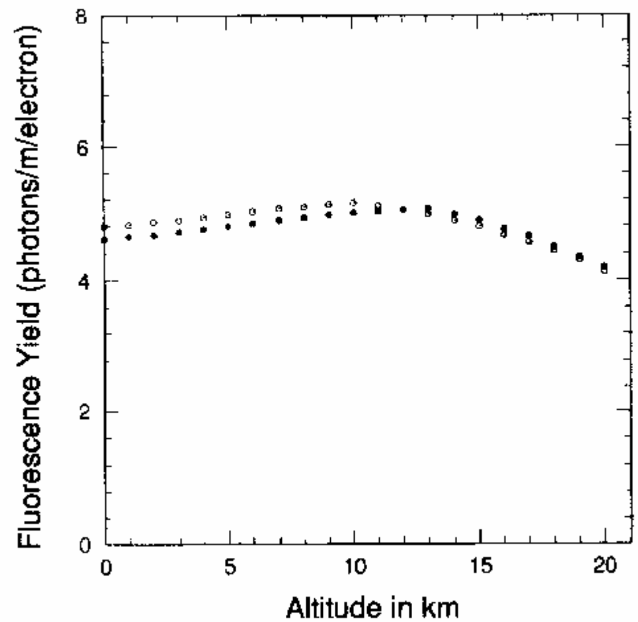
Several sources of systematic uncertainty

1. *VEM calibration*
2. *Timing*
3. *S(1000) slant depth effects (CIC)*

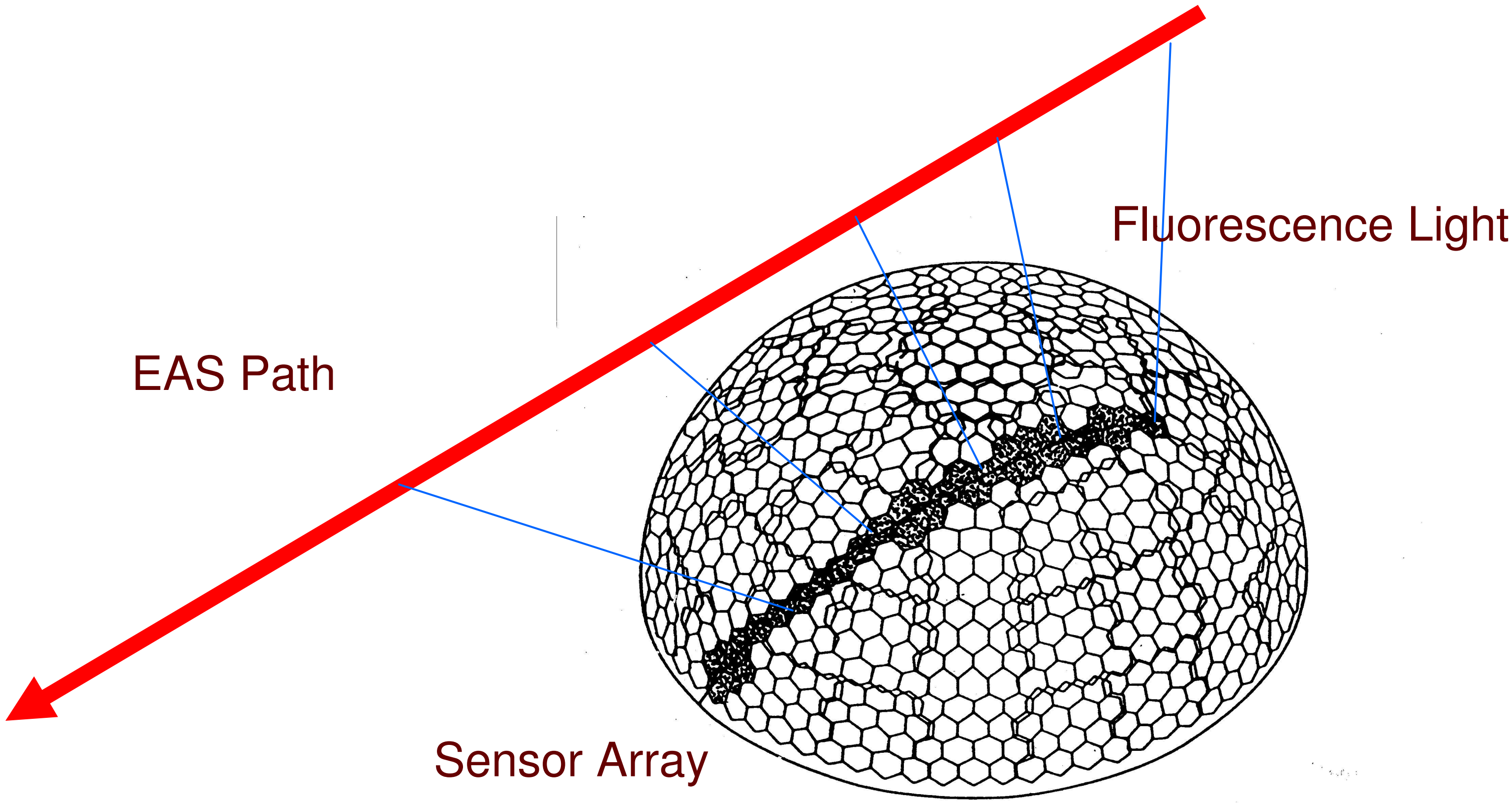
FD – Fluorescence Yield

Atmosphere working as a large scale calorimeter

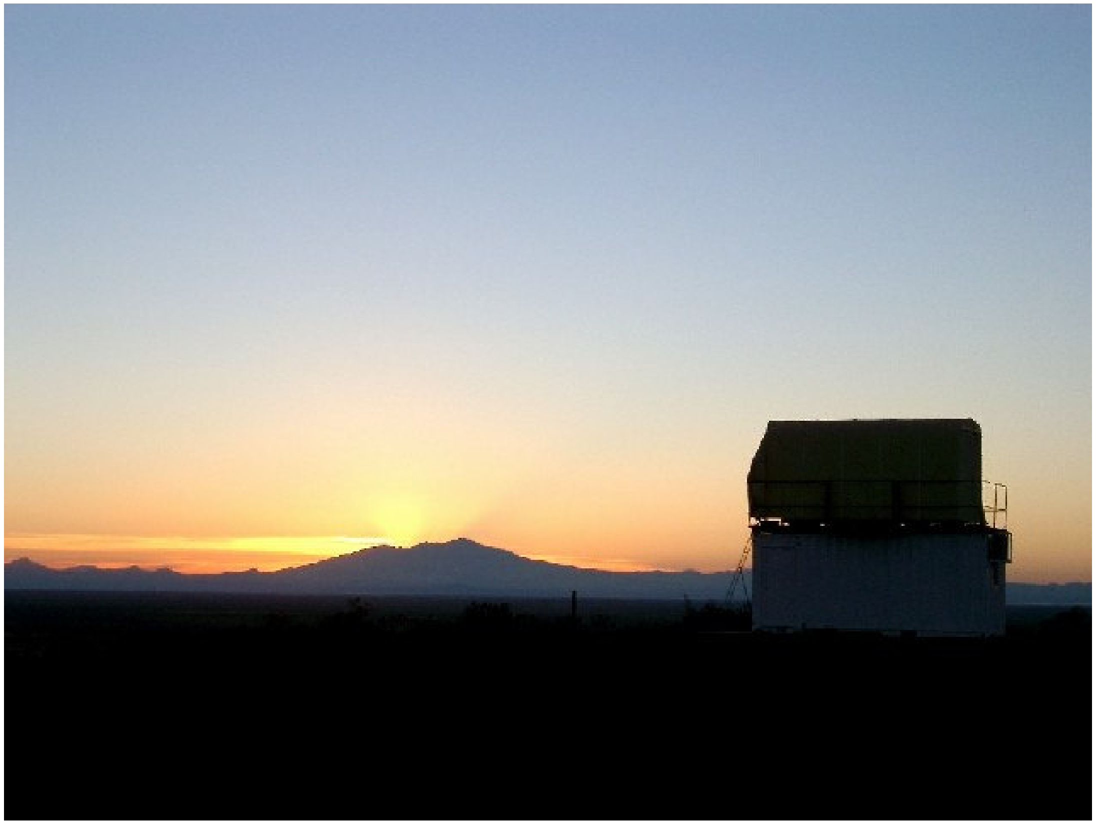




FD – The Fly's Eye Concept

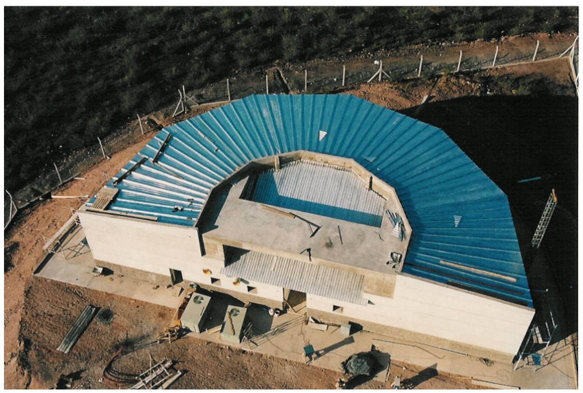


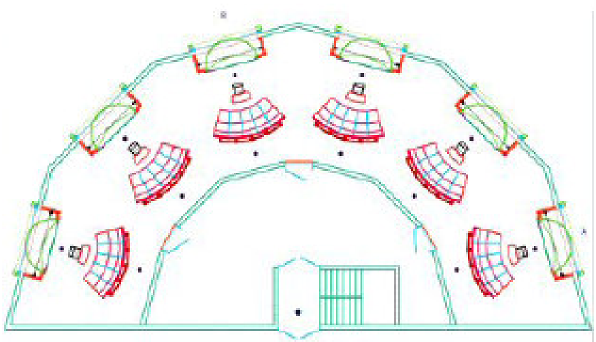
Advertisement - II

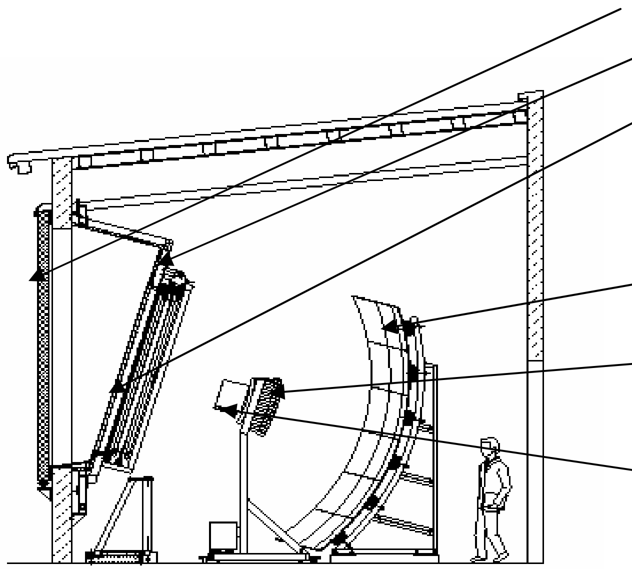


FD – Telescope

Four FD Eyes   6x4=24 Telescopes



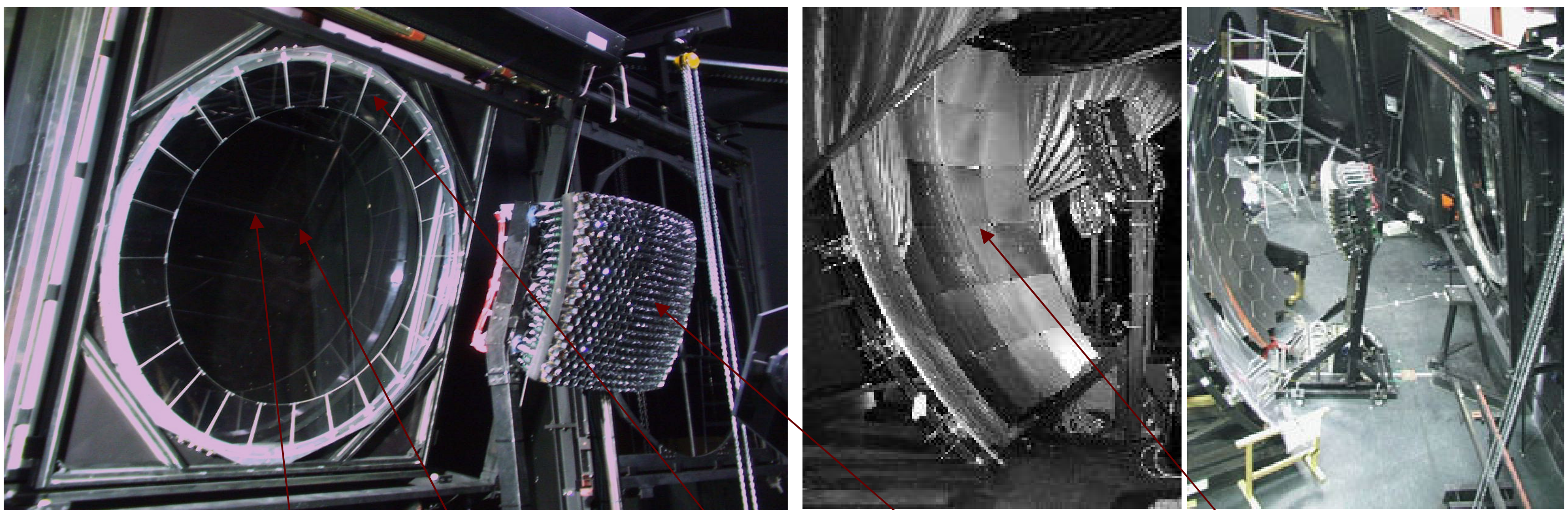




Shutter
Corrector Ring
Optical UV Filter

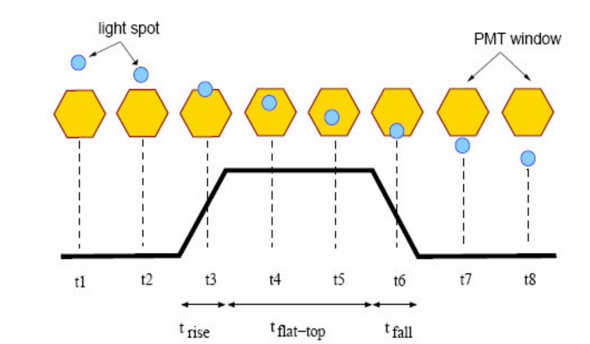
Mirror
Pixel Camera
  Light Collectors,440 PM
Electronics
  Analog Chain, FADC
  12 bit, 10 MSPS

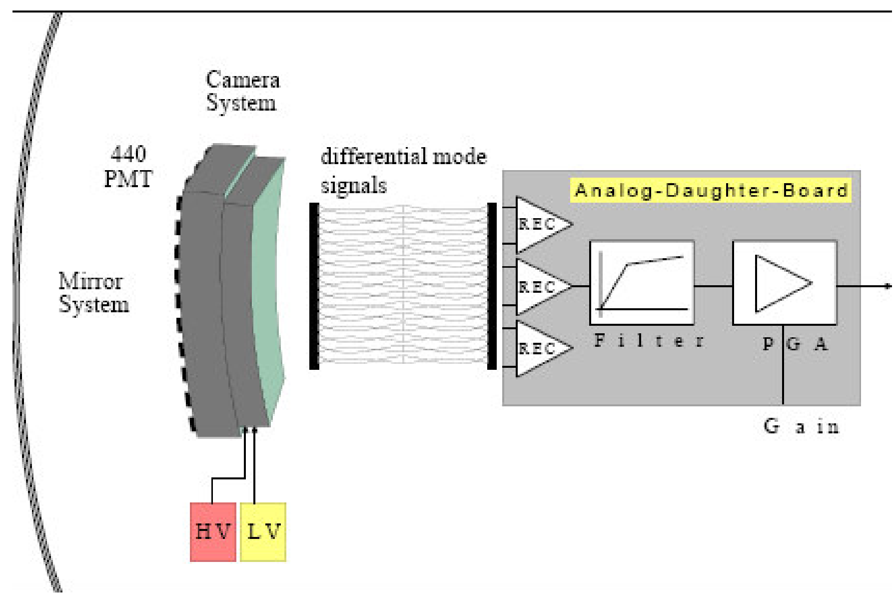
FD – Telescope



Aperture, UV Filter, Corrector Ring, Pixel Camera, Mirror

FD – Electronics





Signal Formation

Front-End Electronics

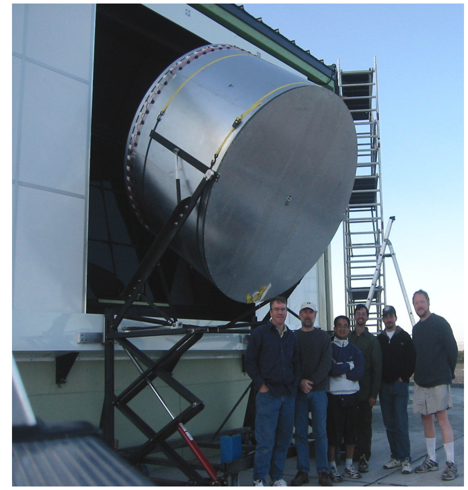
FD – Calibration

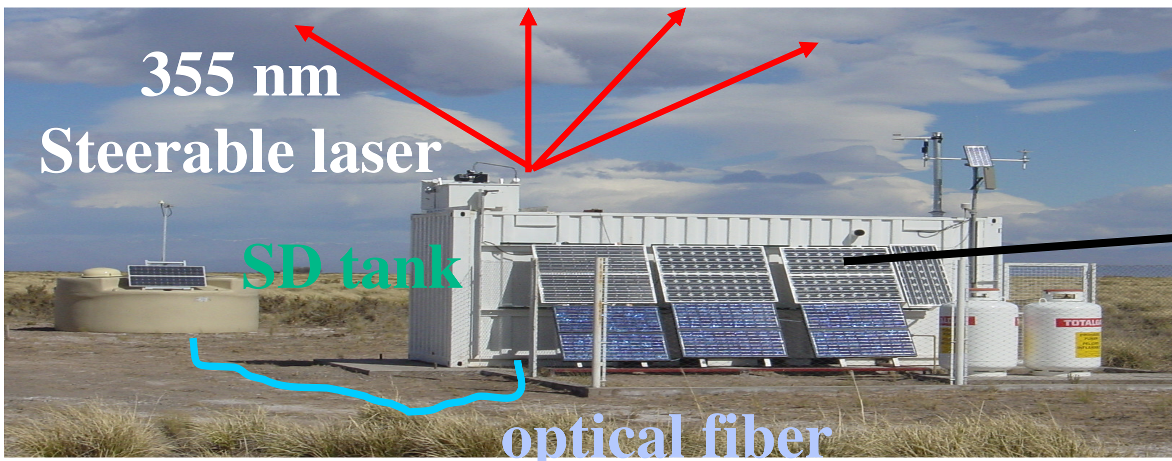
Drum

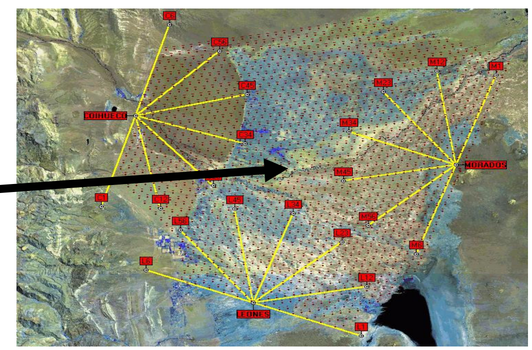
Diffuse, uniform camera illumination

Central Laser Facility

AUGER “Test Beam”





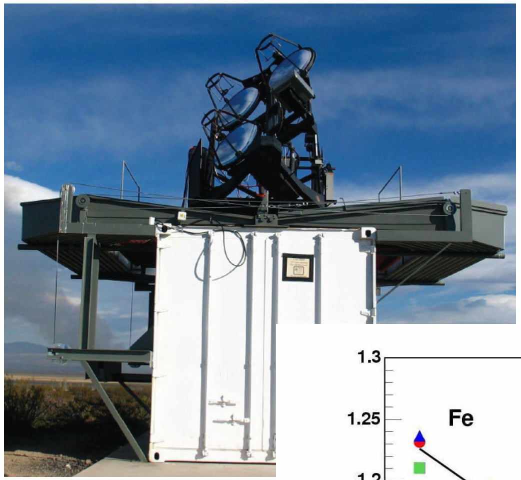


FD – Corrections

Atmospheric Monitoring: Density, Transparency, Aerosols

Several Gadgets:

Horizontal Attenuation Monitor
Balloon Radiosondes
CLF
LIDAR
Phase Function Monitor



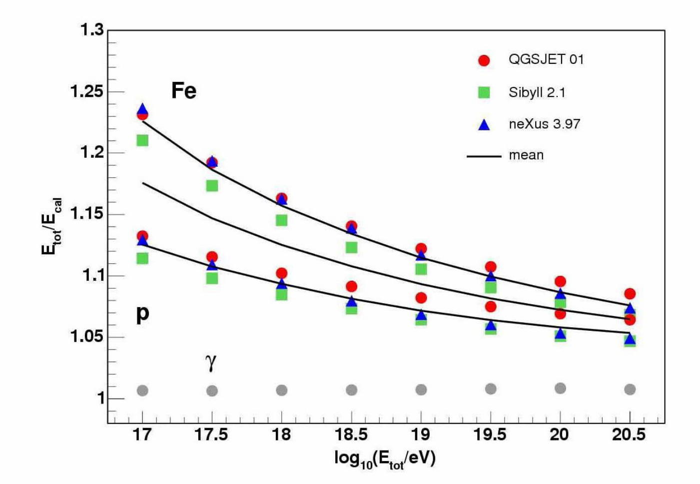
Cerenkov subtraction

Based on track geometry, iterative

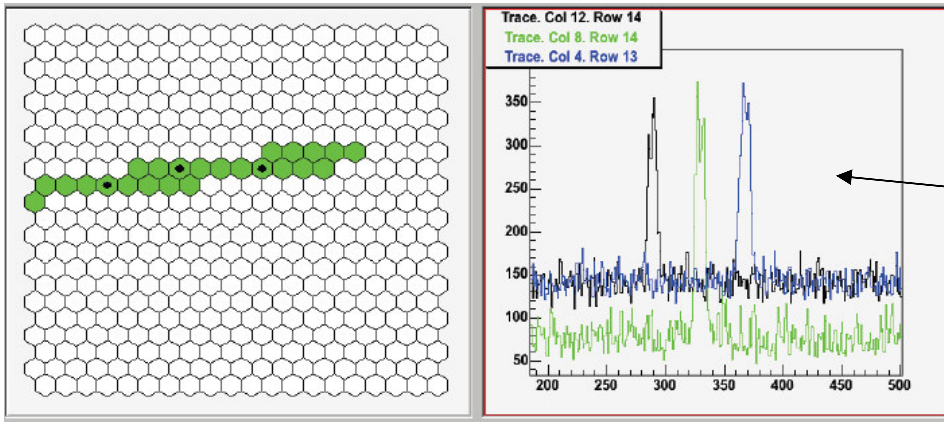
Unseen Energy

Neutrinos, …

MCarlo: ~ 10 % @ 10 EeV

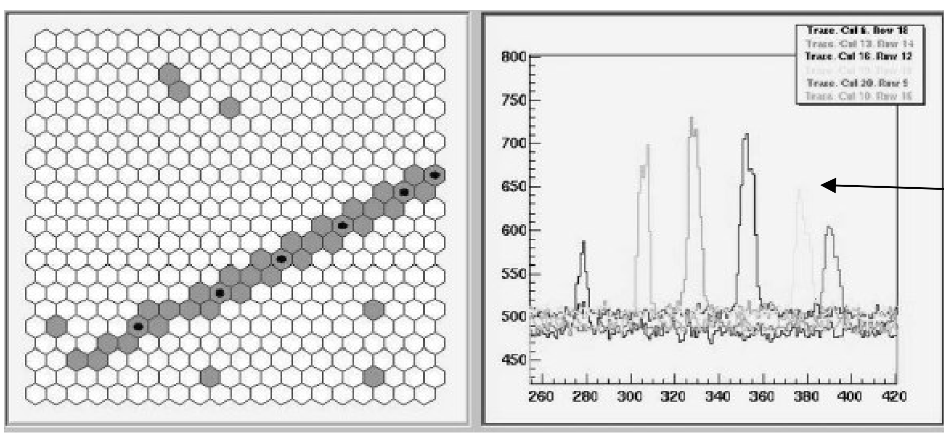


FD – From Shower to Data



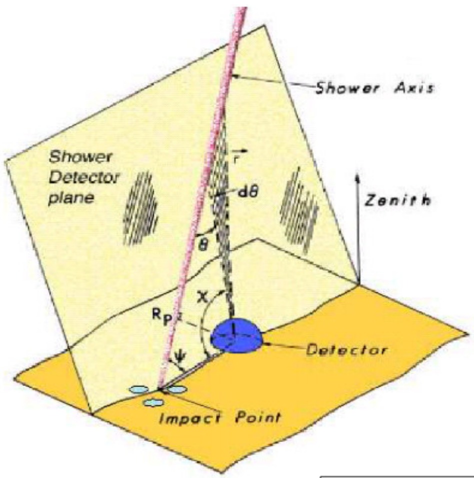
FADC Traces

Pixel signals – CLF
~Uniform amplitude



Pixel Signal – EAS
Longitudinal profile

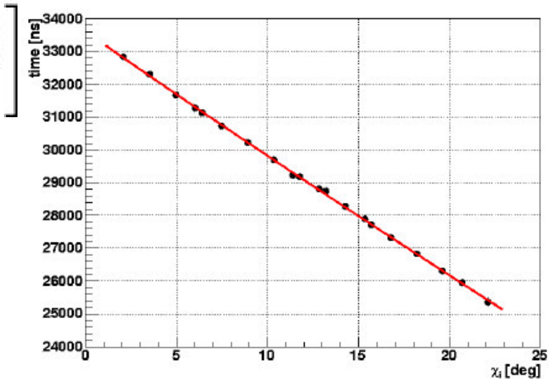
FD – Geometry, Energy, Profile

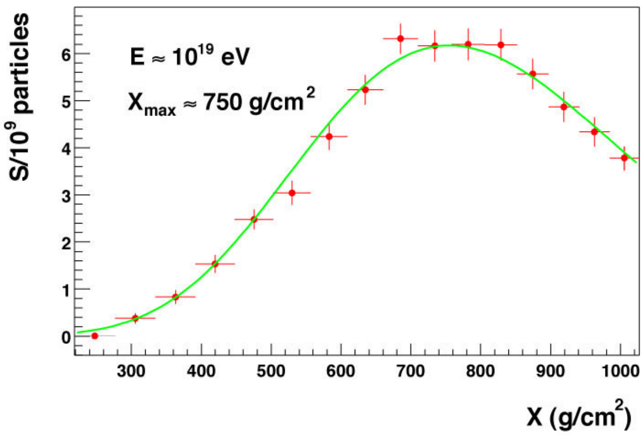


SDP: Time fit…..and its problems for 1-eye evts

$$t(\chi) = T_0 + \frac{R_p}{c} \tan\left[\frac{(\chi_0 - \chi)}{2}\right]$$

$$\chi_0 = 180° - \psi$$





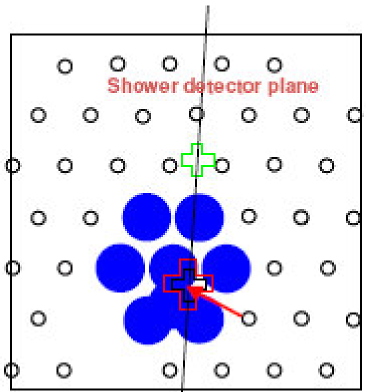
Abs. Calib. ~ ***5 γ/ADC count***
FY ~ ***4.2 γ/m*** ***Electron Track***

But: New results expected soon
AIRFLY (LNF, Argonne, ..)
FLASH (SLAC)

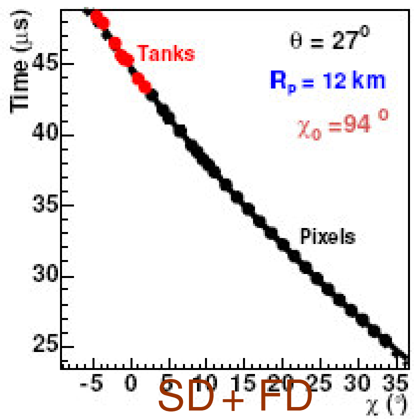
σ_{Xmax} ~ ***30 g cm^{-2}***

Hybrid Reconstruction

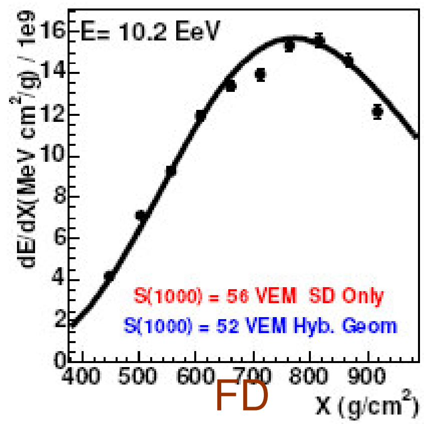
Typical



SD

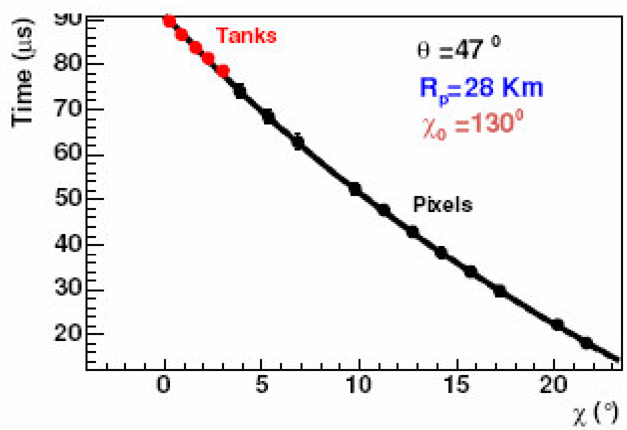


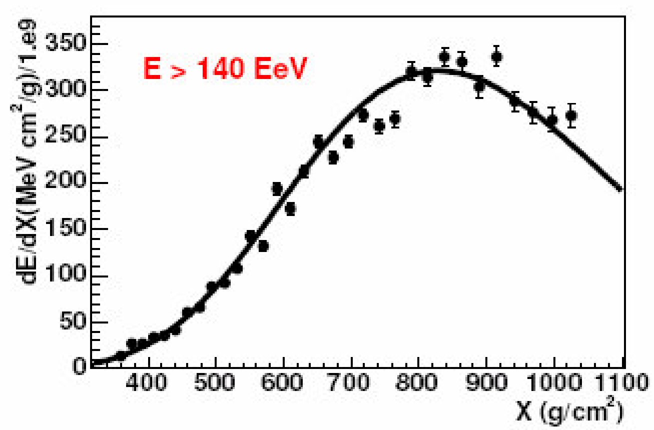
SD+FD



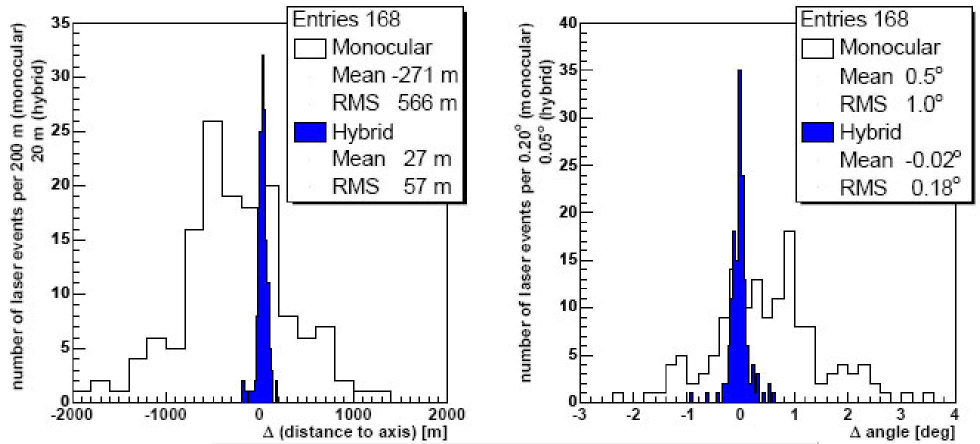
FD

Top Hybrid…
Not included
in the sample

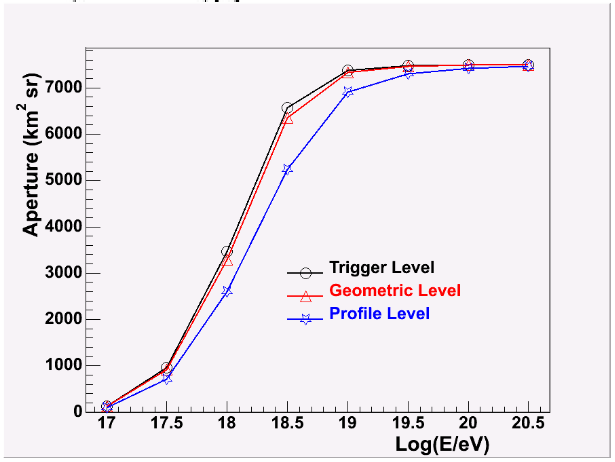




Hybrid Performance



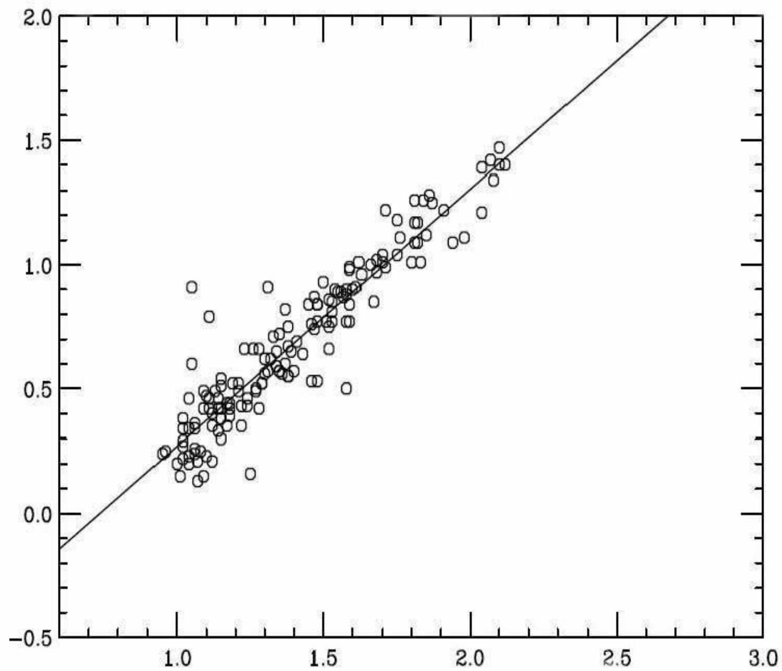
From Laser Shots



Effective Aperture

Energy Calibration with Hybrids

log$_{10}$ E_{FD} (EeV)



log$_{10}$ S_{38}(1000)

E Systematics Budget (projected)

FD

Fluorescence Yield 15% (↓ 8%)
Abs/Rel Calibration 12%
Atmosphere 11 % (↓ 6%)
Other 12 %

Total ***25 %*** *(↓ 17%)*

SD

Detector calibration 10%
S_{38}(1000) 8 %
Other 7 %

Total ***16 %***

Overall Energy Scale

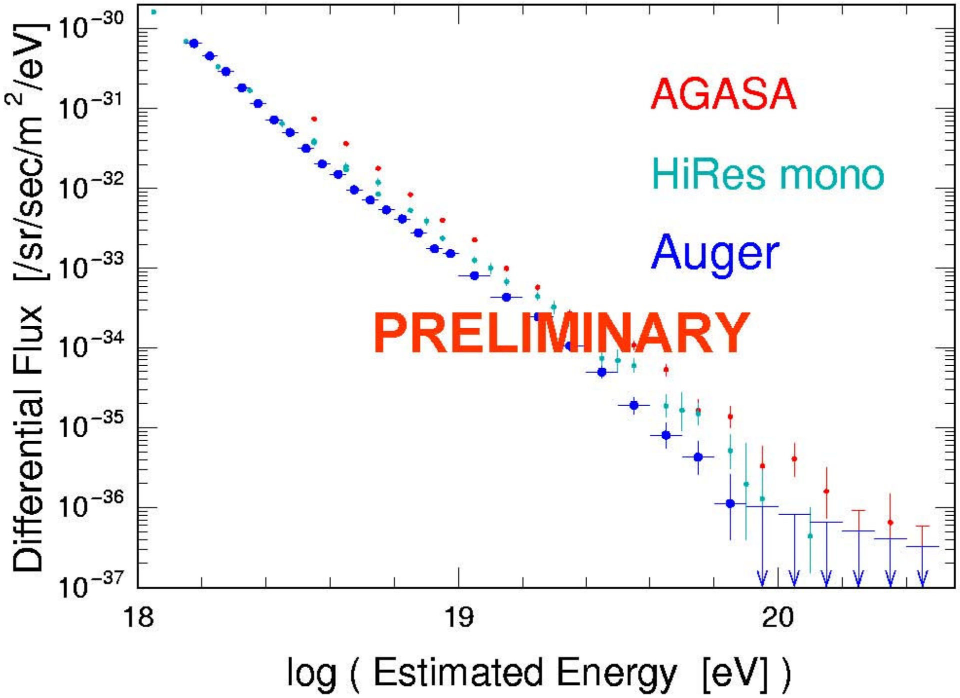
(Includes Hybrid Statistics)

E dependent **30÷50 %**

Expected to ↓ to 25 ÷ 35 %

Spectrum

This Statistics: ~ ½ Year of Full Observatory (~7000 km^2 sr yr)



(NB: AGASA pre-Vulcano)

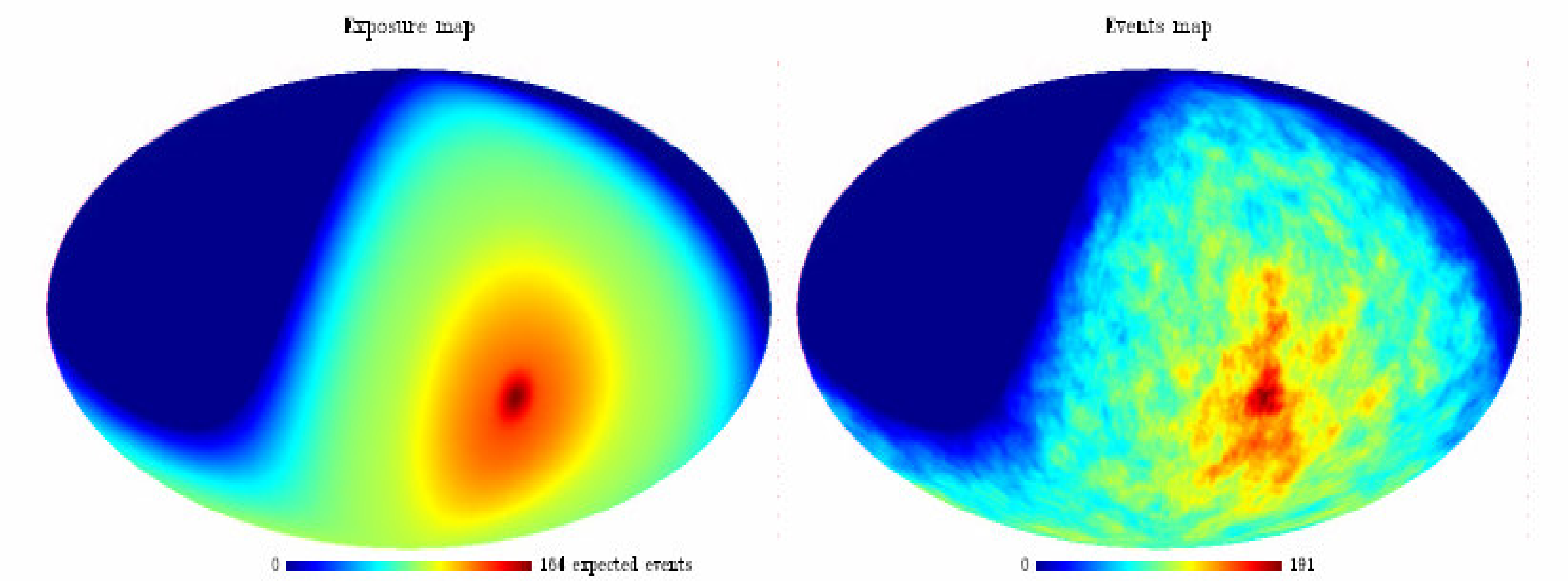
Still investigating systematics (e.g.Energy scale still uncertain)

Preliminary:
Data difficult to reconcile with AGASA (pre/post-Vulcano)

But:
Wait for statistics, reduced systematics

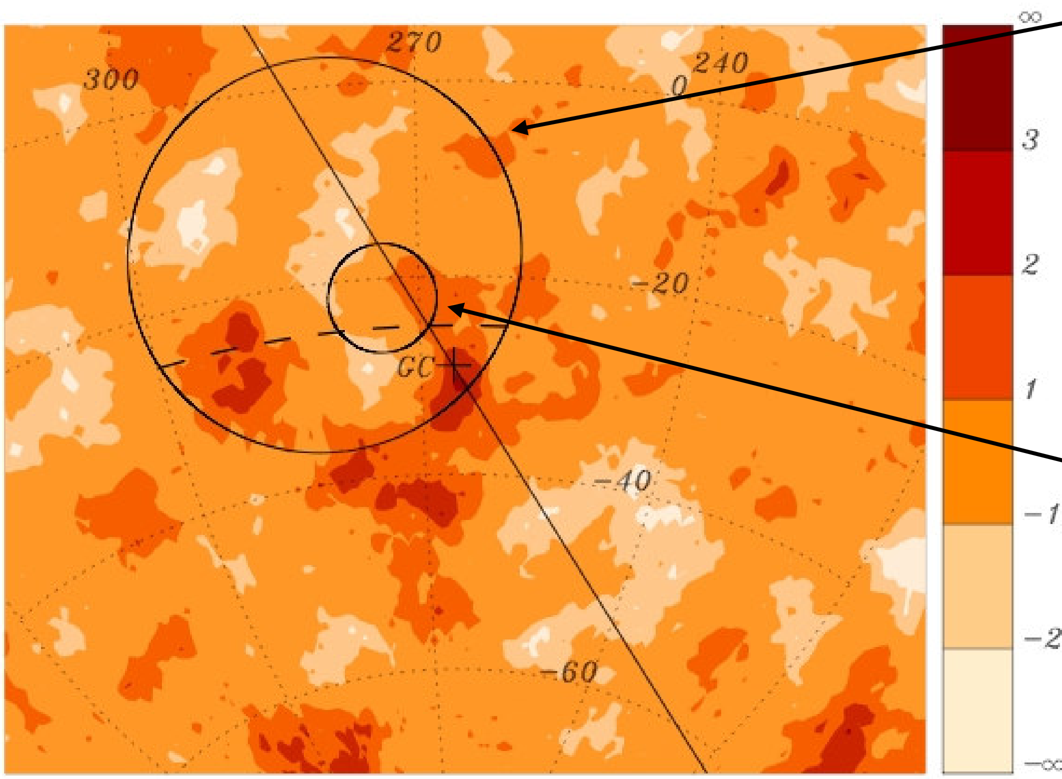
Energy: Systematics ~ ±30-50 %; Statistical Error ~15 - 10%
Efficiency =100% above 3 EeV
A few high energy events

Anisotropies: Exposure, Rates



Galactic Coordinates; E=1÷5 EeV

Anisotropies: AGASA, SUGAR



AGASA

Angular range: 20°
Energy interval (1.0 – 2.5 EeV)

2116 / 2159.5
ratio = 0.98 ± 0.02 ±0.0
(22% excess projection:
2634 evts, 10-σ effect)

SUGAR

Angular range 5°
Energy interval (0.8 – 3.2 EeV)

286 / 289.7
ratio = 0.98 ± 0.06 ± 0.
(85% excess projection:
536 evts, 14.5-σ effect)

Next Step: The North Site