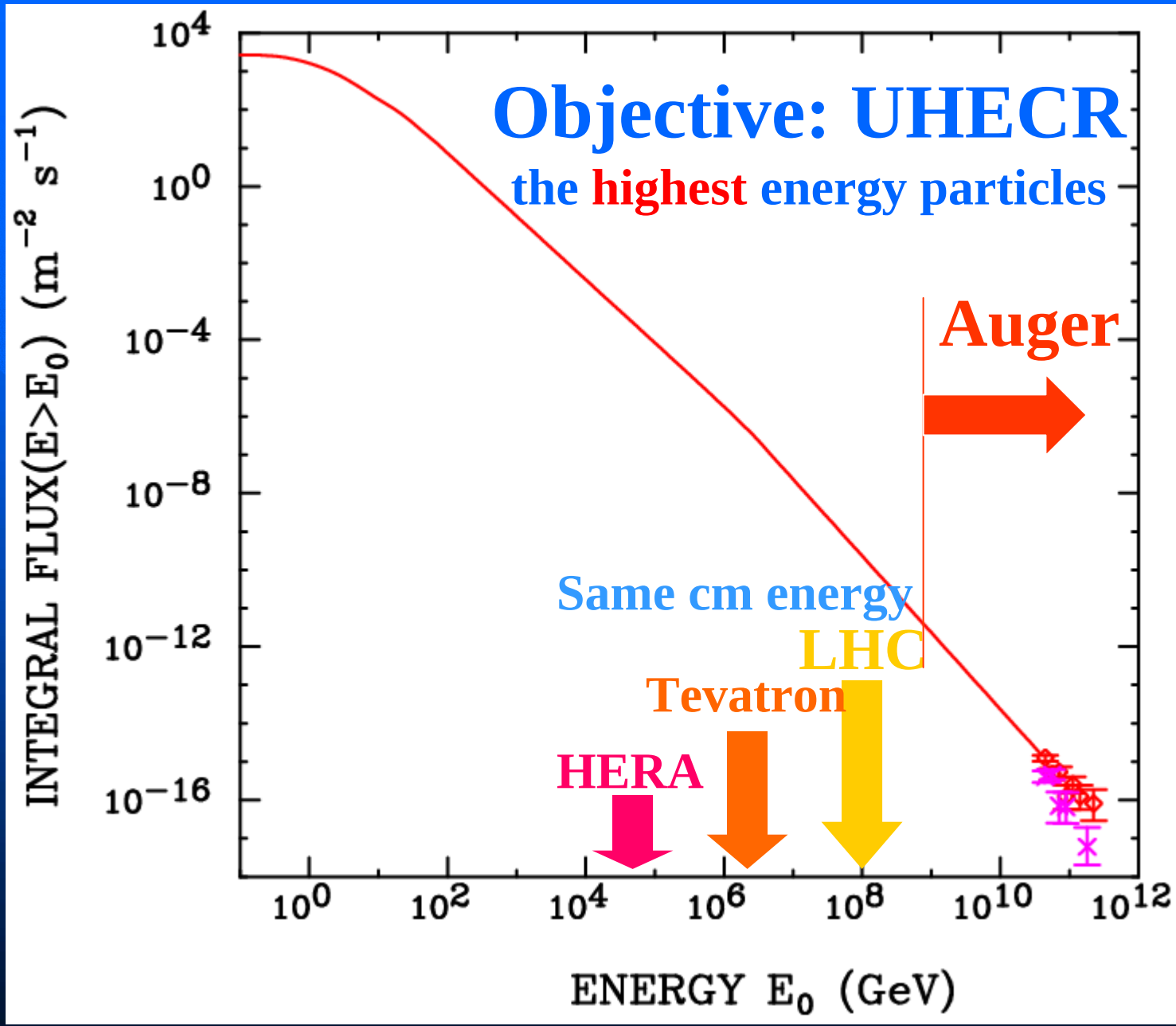
Status and First Results of the Largest UHECR Observatory

The Auger Collaboration

16 Countries **60+ Institutions** **350+ Scientists**

Argentina
Australia
Bolivia(*)
Brazil
Czech Republic
France
Germany
Greece
Italy
Mexico
Netherlands
Poland
Slovenia
Spain
United Kingdom
USA
Vietnam(*)

(*) Associate countries


Objective: UHECR
the highest energy particles
Auger
Same cm energy
LHC
Tevatron
HERA
INTEGRAL FLUX(E>E0) (m-2 s-1)
ENERGY E0 (GeV)
10^4
10^0
10^-4
10^-8
10^-12
10^-16
10^0
10^2
10^4
10^6
10^8
10^10
10^12

Ultra High Energy

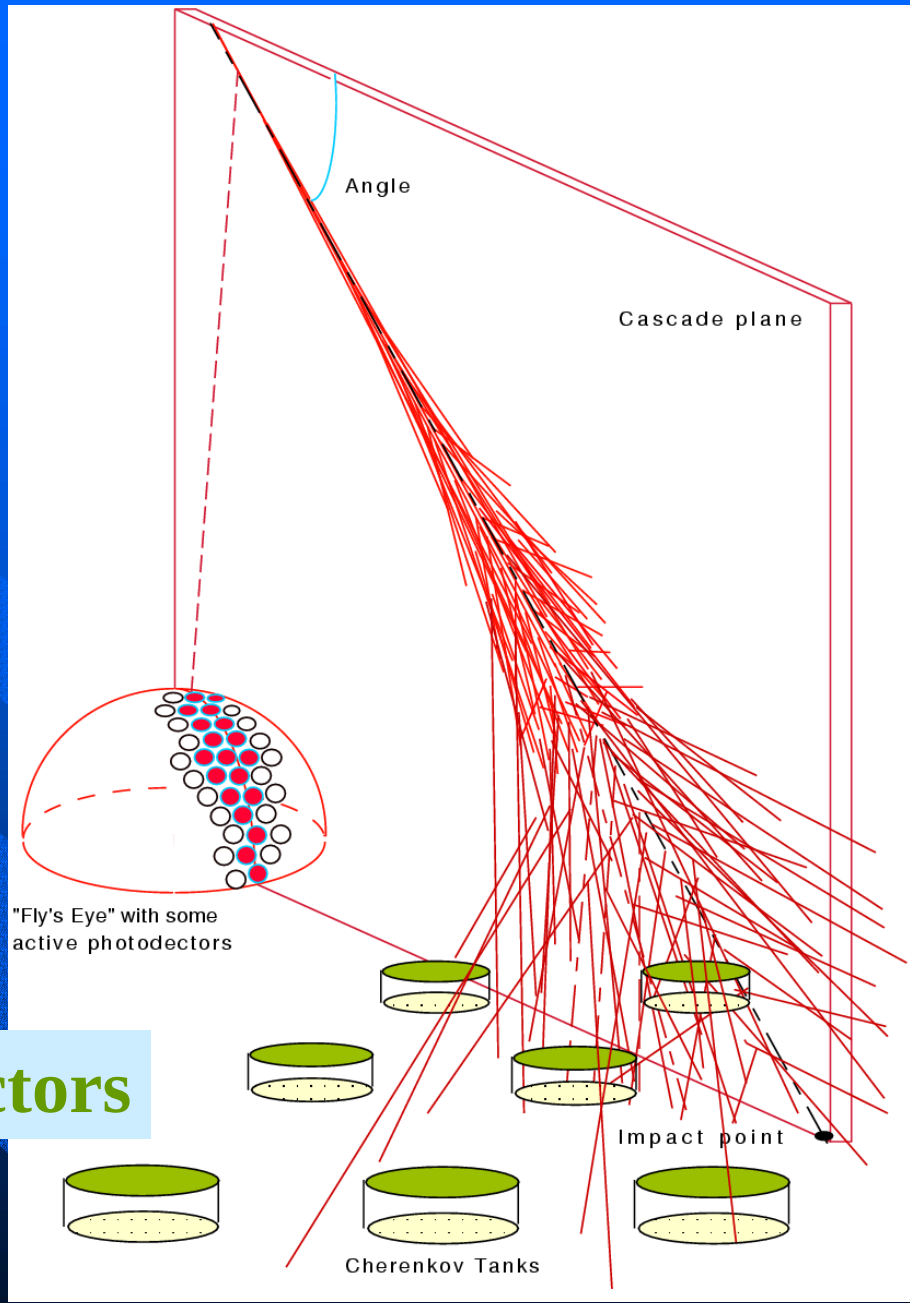
2-fold motivation

- Particle Physics
  - » Test interactions at the highest energies
  - » Test forward region
  - » Neutrino detection
- Astrophysics
  - » Origin: Still an unresolved puzzle
  - » Posibility to:
    - do astronomy
    - learn about B fields

Two succesful techniques

Fluorescence

Array of particle detectors



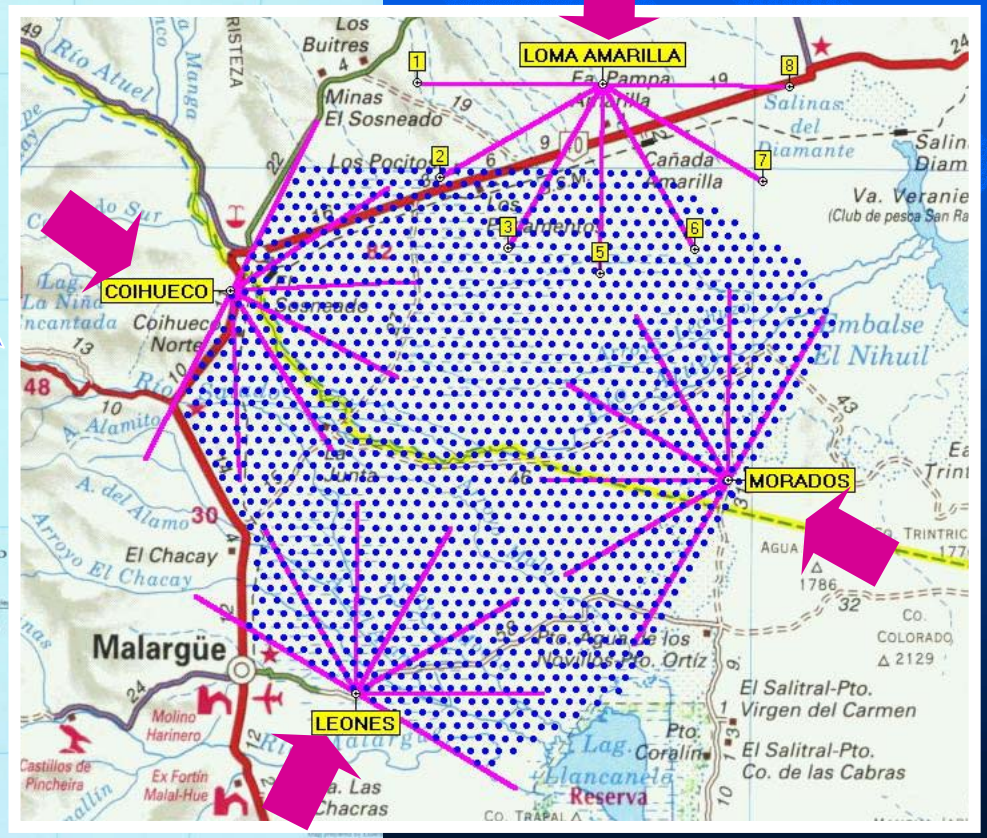
Auger Science Objectives

- **Uniform Exposure** — North & South Observatories
- **Improve statistics** — 2 x 3000 km^2 Surface Array
  - 1600 particle detectors
  - hexagonal array: 1.5 km spacing
- **Intercalibration** — Combine Fluorescence
  - 4 Enclosures ("Eyes") each with:
    6 Telescopes (3.4 m diameter) &
    Cameras (440 PMTs each)
- **Composition** — FADC traces
  GPS timing
  Hybrid, stereo modes ...

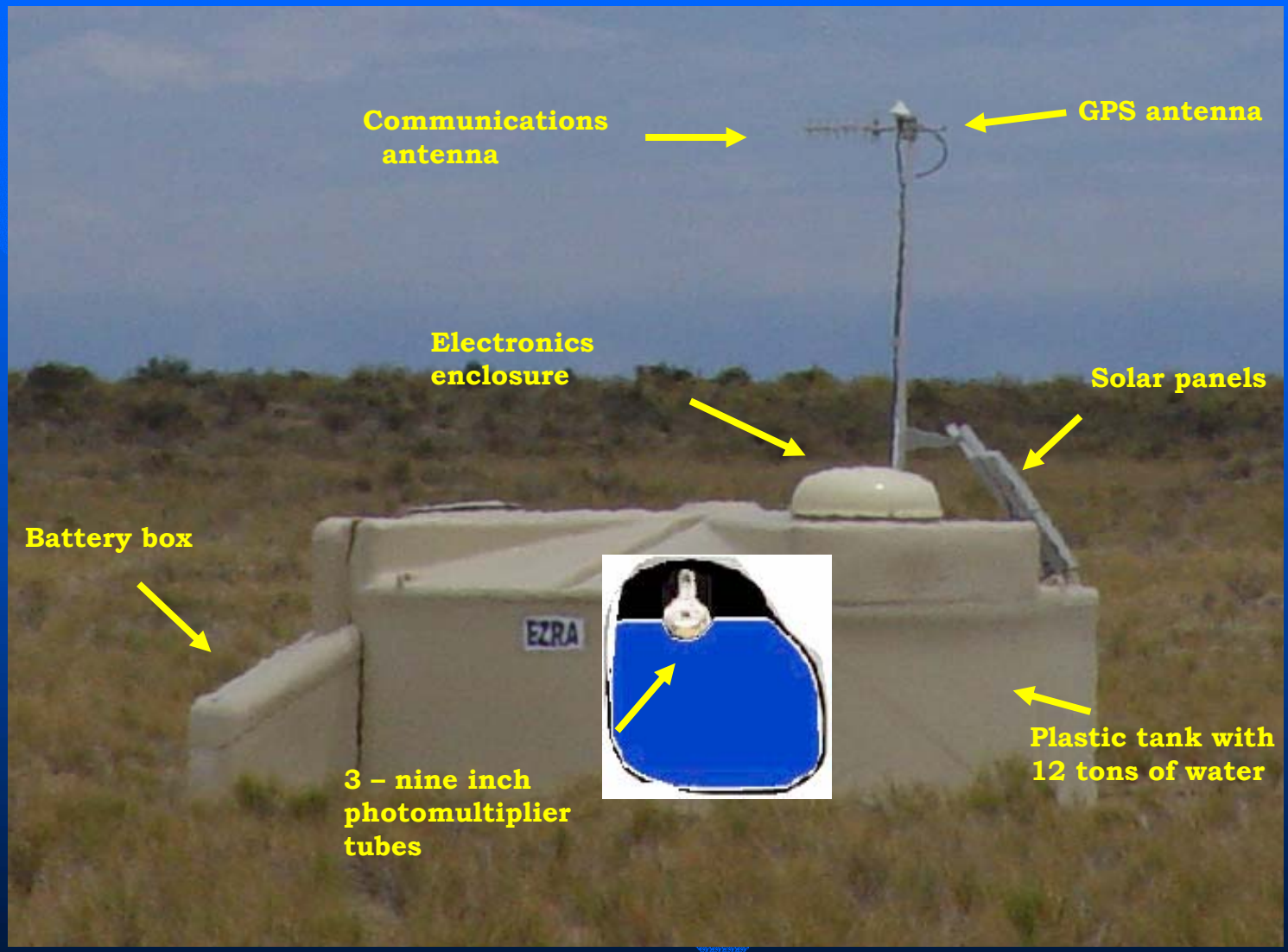
Auger Southern Observatory: Malargüe Mendoza (Argentina)

- 1600 tanks

➡ 4 Eyes



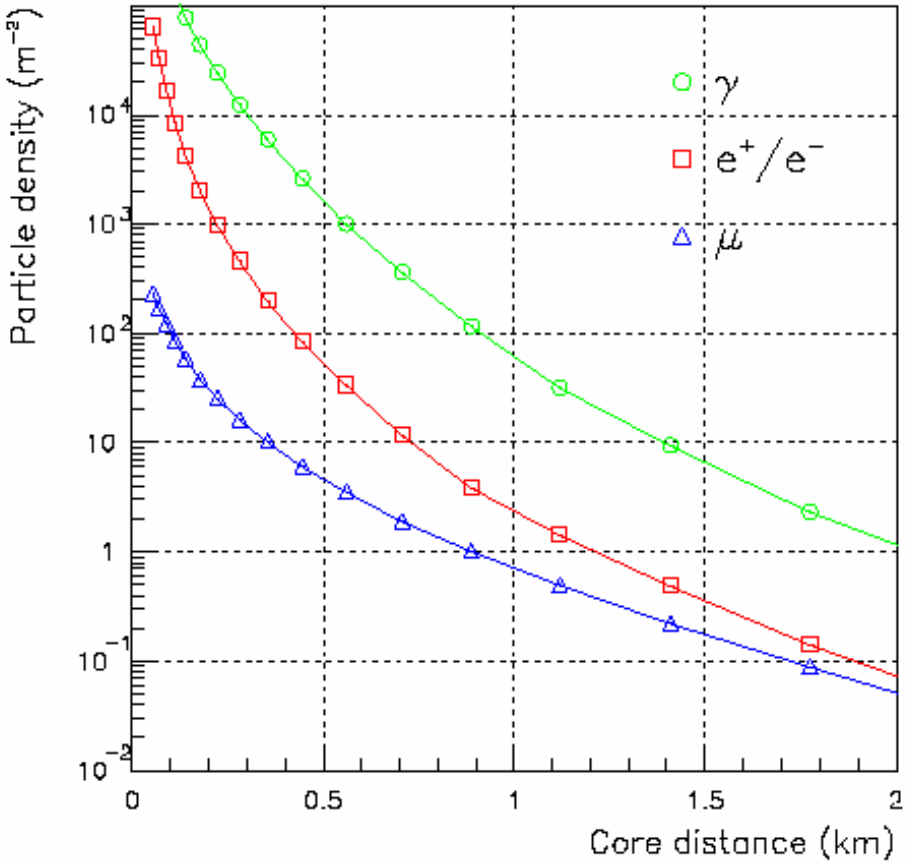
The Surface Detectors

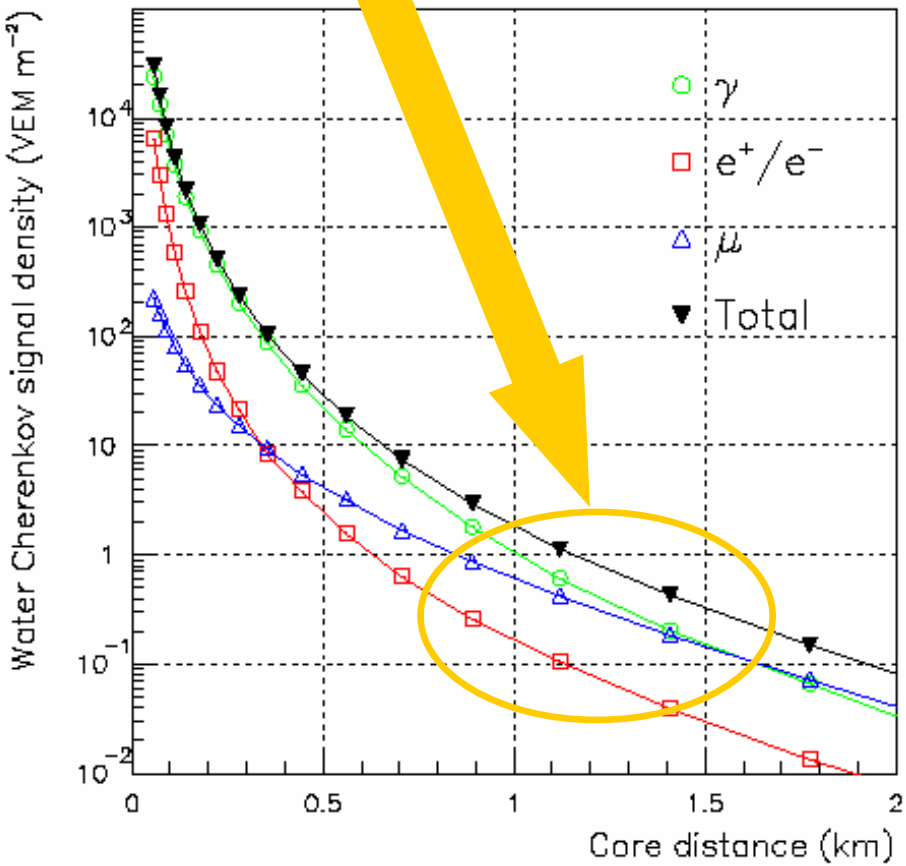


- μ-response α track
- e/γ-response α energy

Inclined: μ/em UP

μ-signal of order em-signal





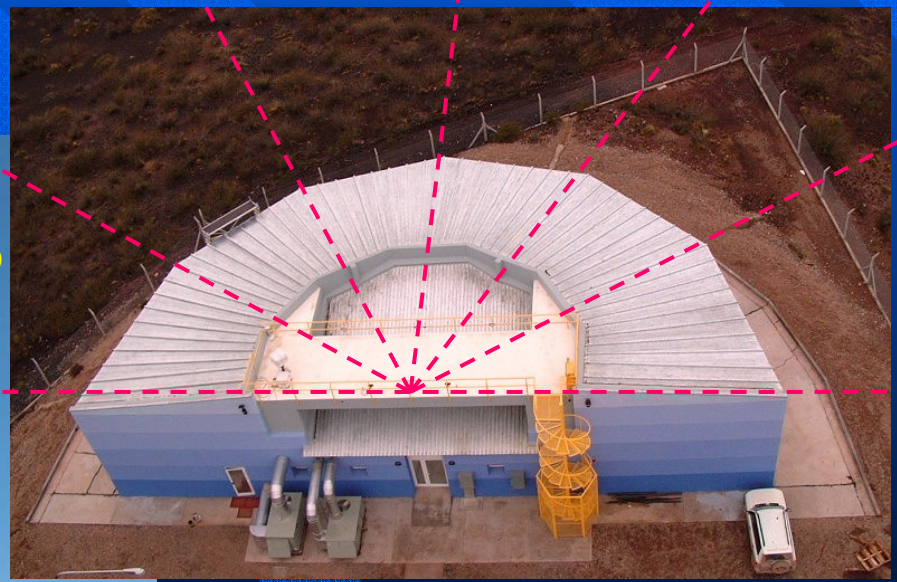
The Fluorescence Detector:

4 Eyes at the perimeter

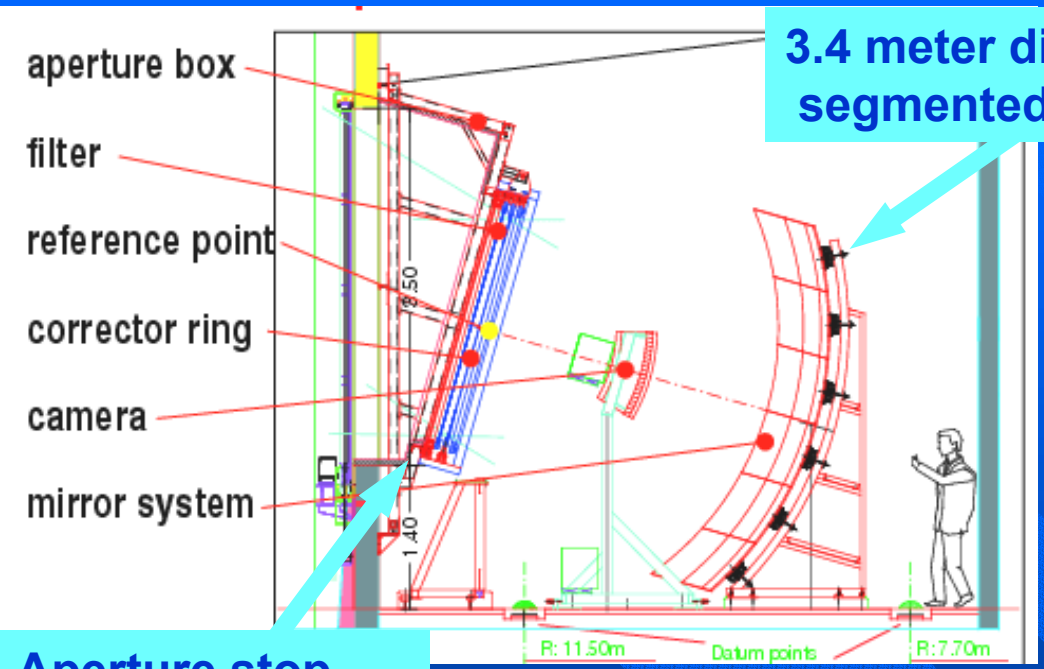
Each has 6 Telescopes (Schmidt optics):

- ✓Spherical mirror, 3.4 m radius of curvature
- ✓2.2 m diameter diaphragm, corrector ring
- ✓30ºx30º FOV, 15 mm diameter spot

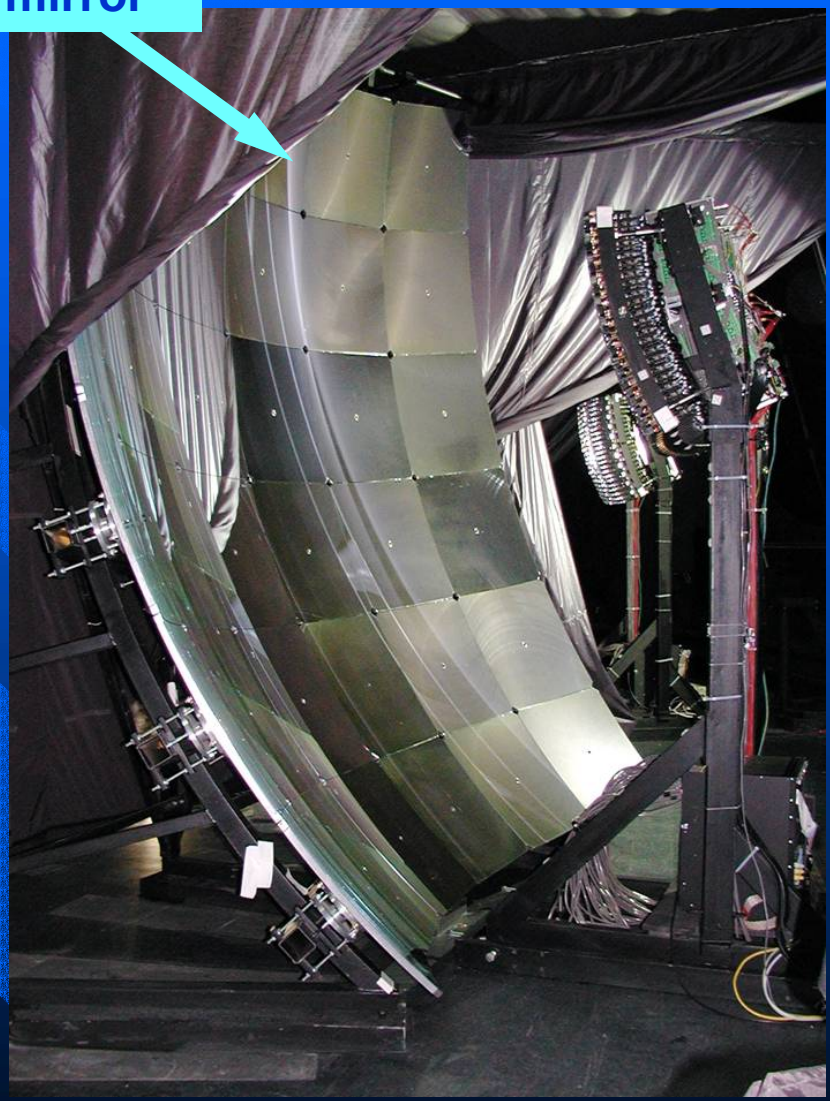
Los Leones



A Fluorescence Telescope

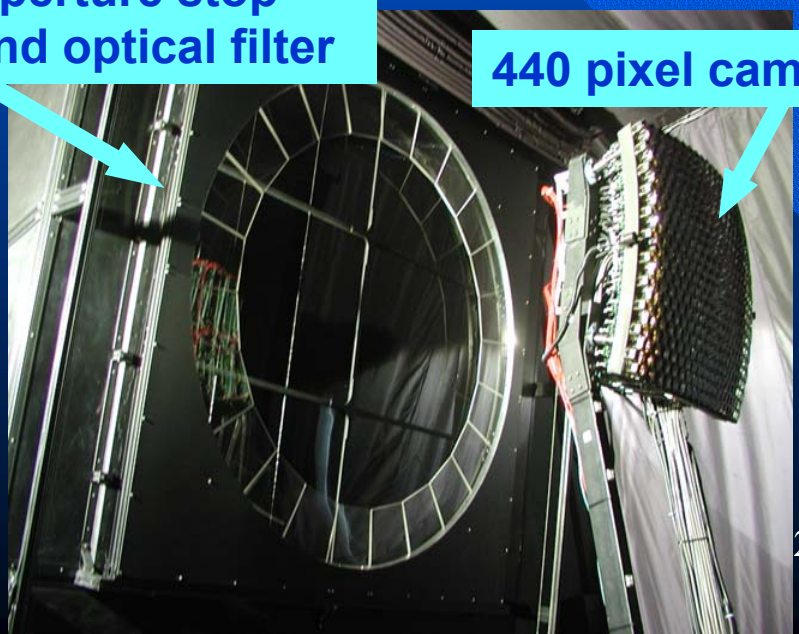


3.4 meter diameter segmented mirror



Aperture stop and optical filter

440 pixel camera



Atmospheric Monitoring & Calibration

Central Laser Facility

Atmospheric Monitoring

Lidar at each fluorescence eye

Absolute Calibration

Drum for uniform camera illumination – end to end calibration .

Status August 2005

905 surface detector stations deployed >800 operating

Three fluorescence buildings complete each with 6 telescopes

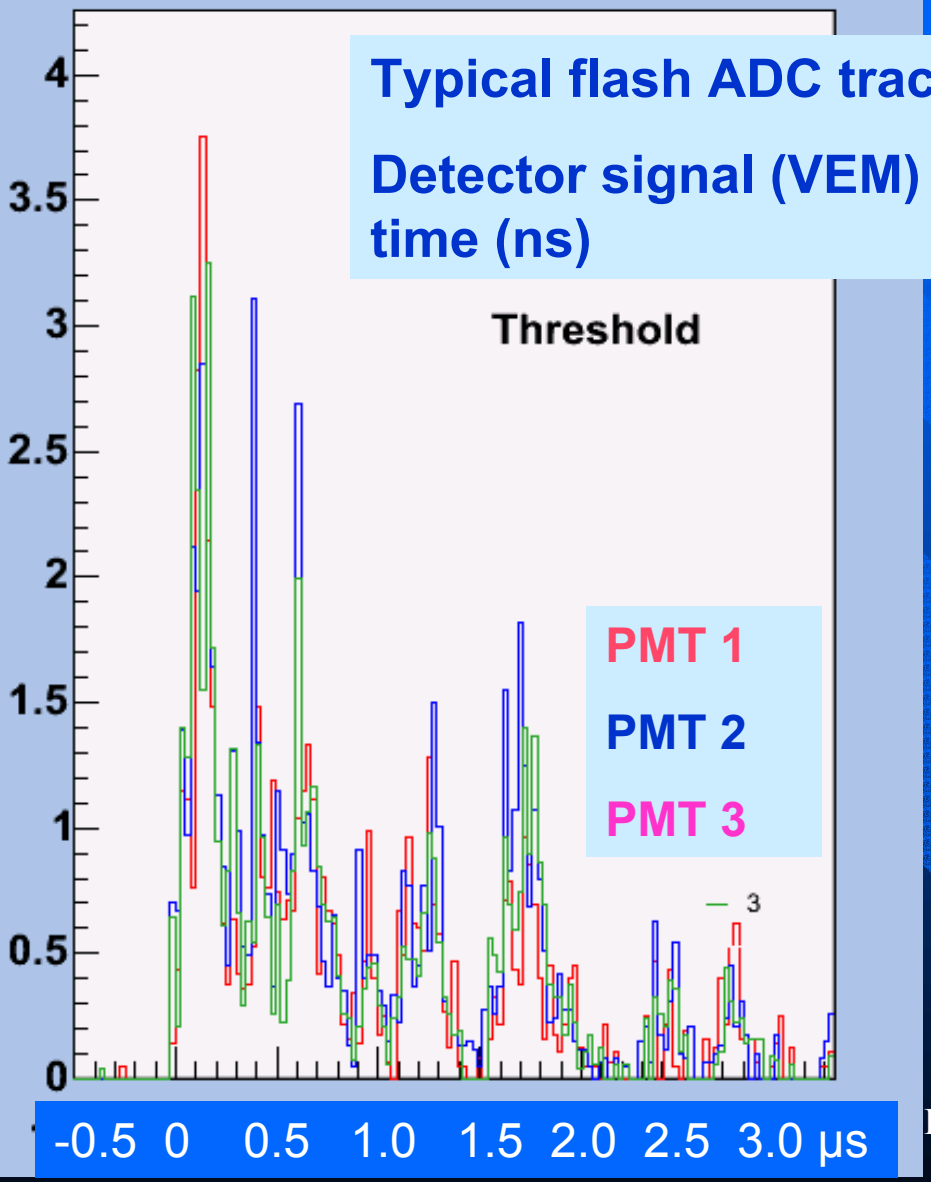
SD Reconstruction:

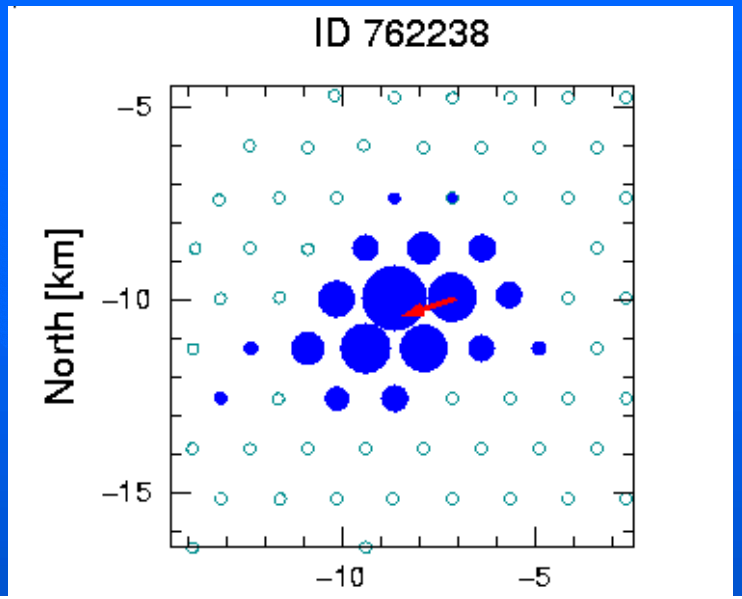
Timing => Direction

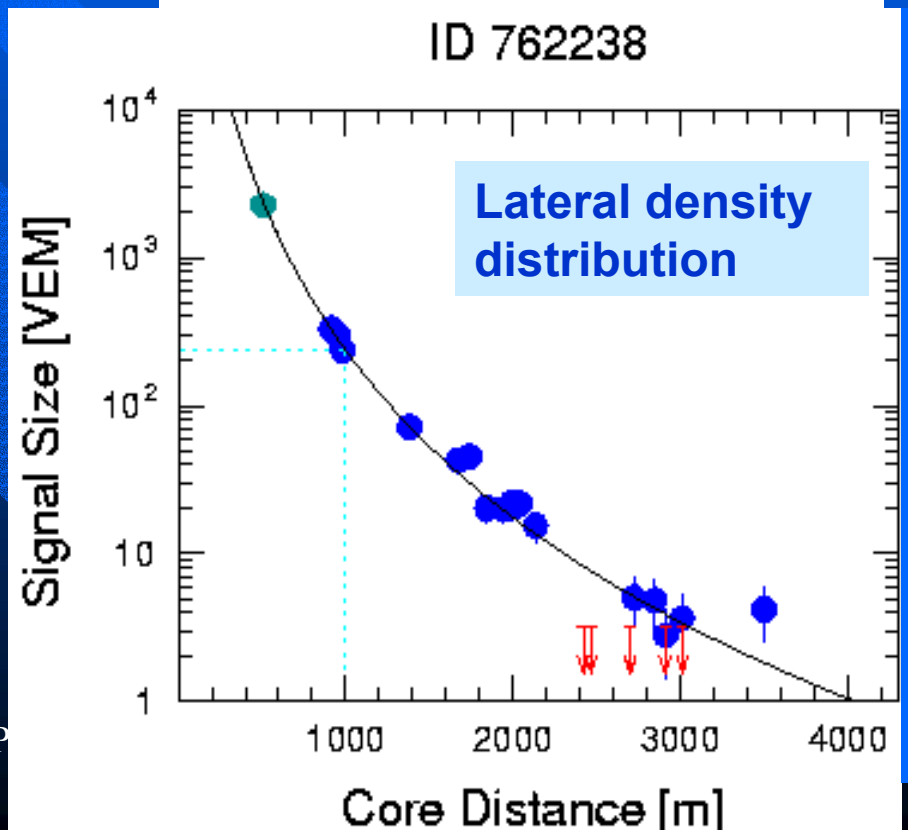
Signal => Energy

Obtain S(1000)

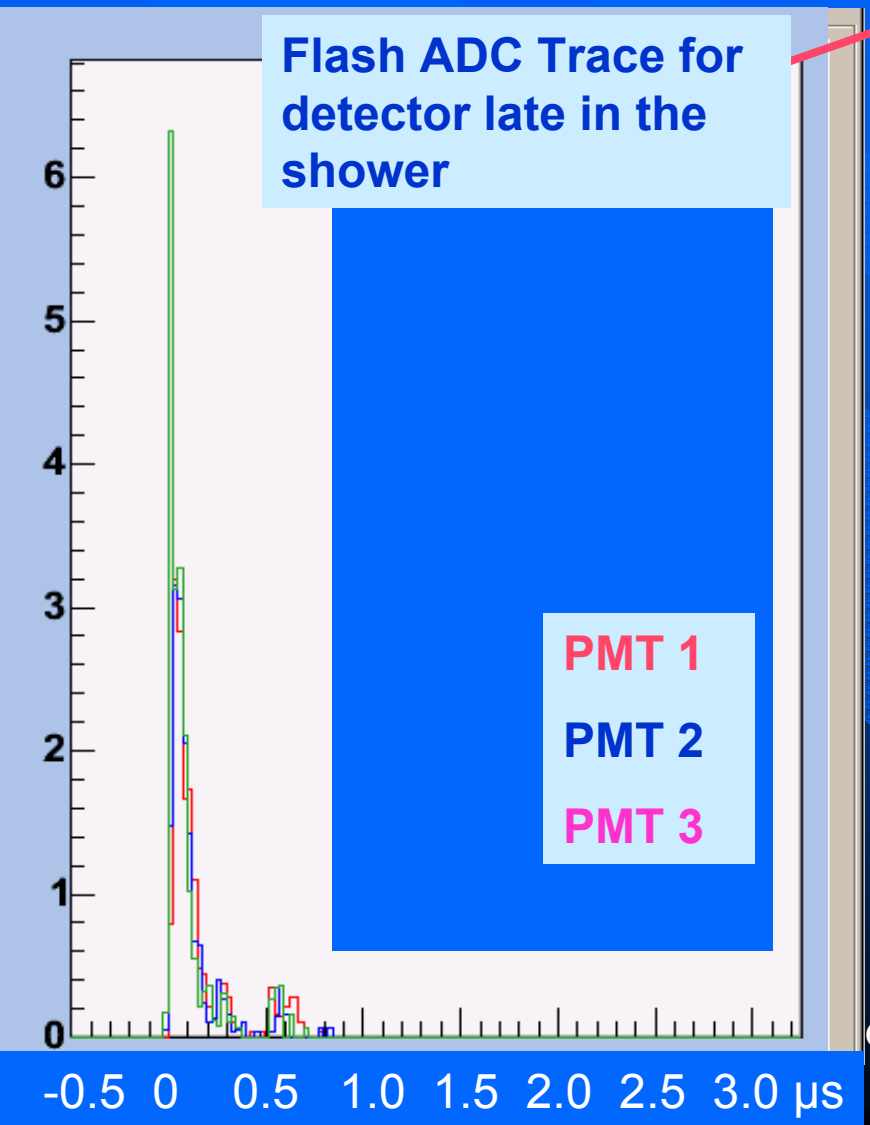
θ~ 48º, ~ 70 EeV

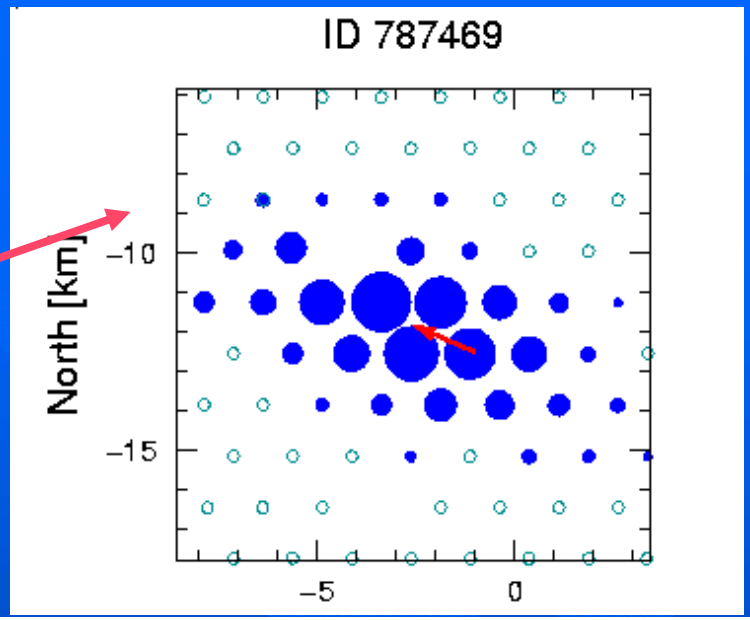

Typical flash ADC trace
Detector signal (VEM) vs time (ns)
Threshold
PMT 1
PMT 2
PMT 3
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5 0 0.5 1.0 1.5 2.0 2.5 3.0 μs

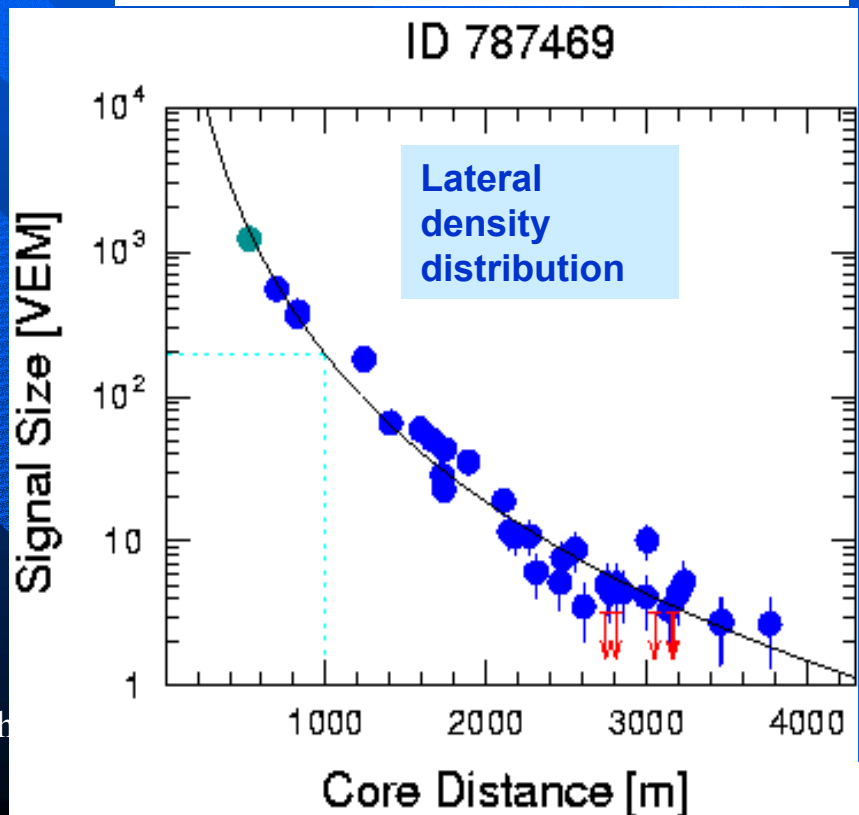

ID 762238
North [km]
-5
-10
-15
-10
-5


ID 762238
Lateral density distribution
Signal Size [VEM]
10^4
10^3
10^2
10
1
1000
2000
3000
4000
Core Distance [m]

θ~ 60º, ~ 86 EeV

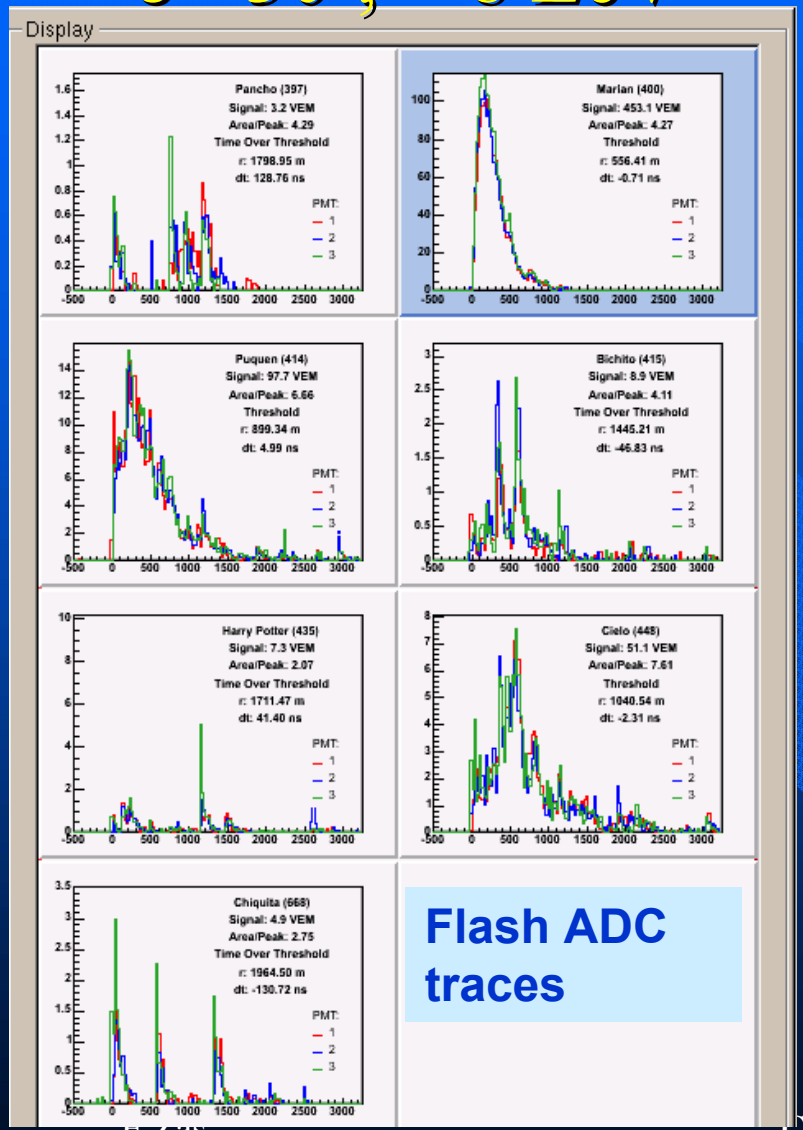


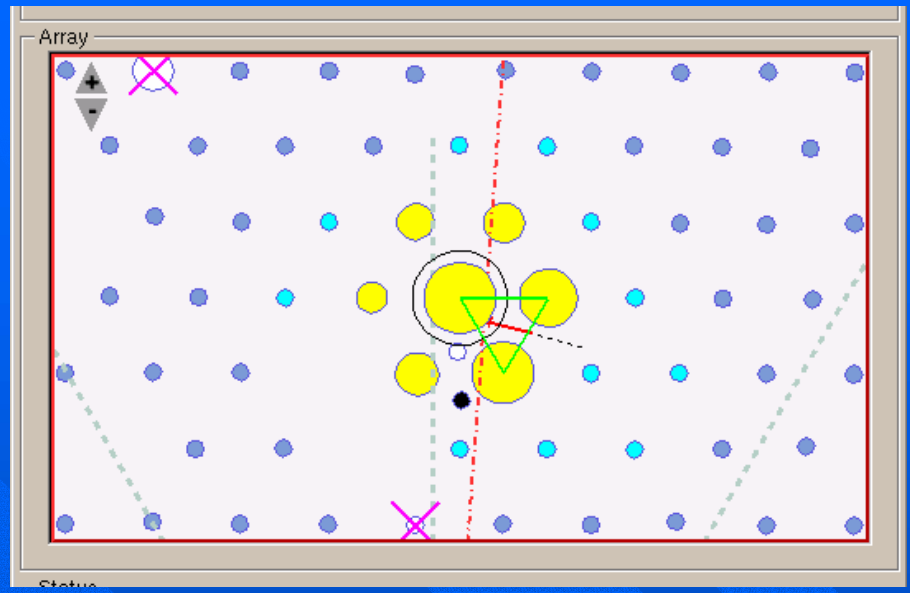


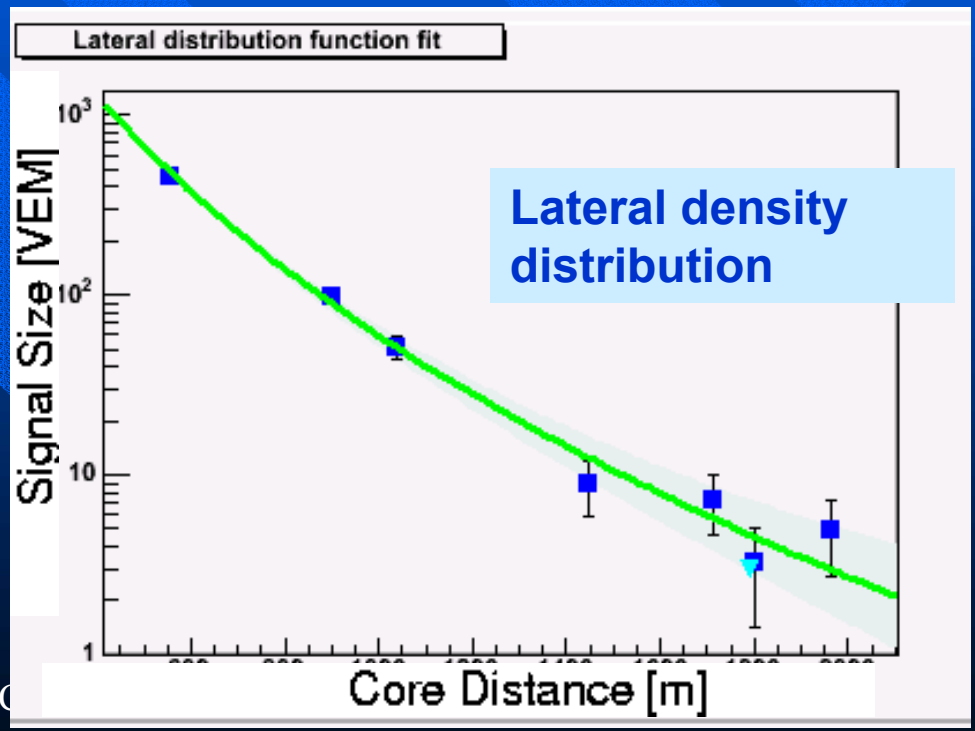


CR Prah

Hybrid Event
θ~ 30º, ~ 8 EeV







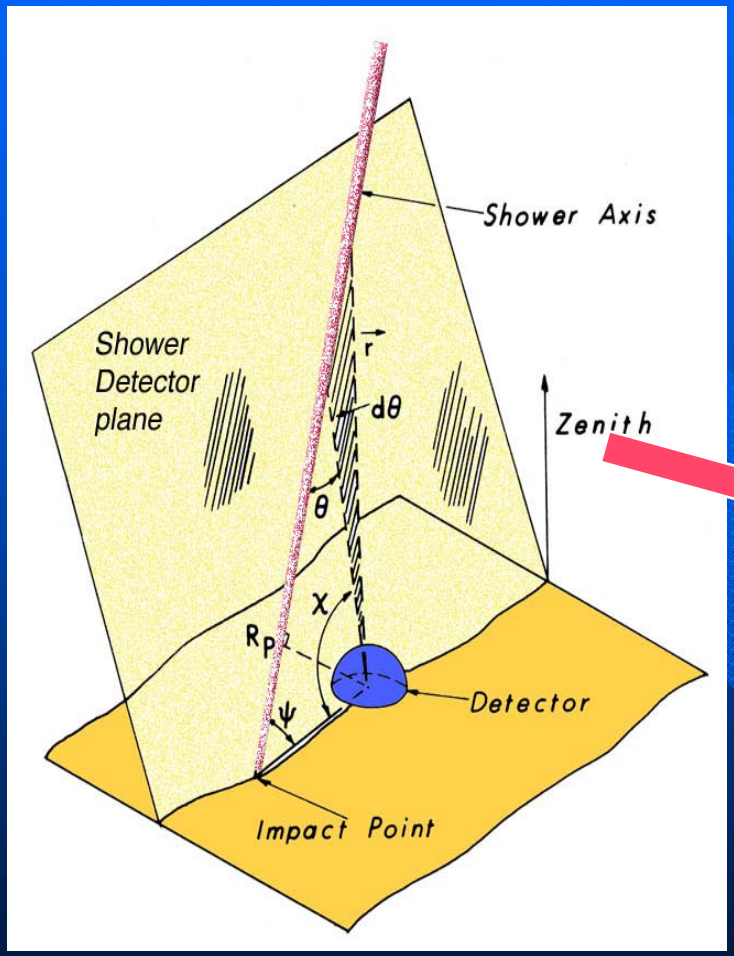
FD Reconstruction:

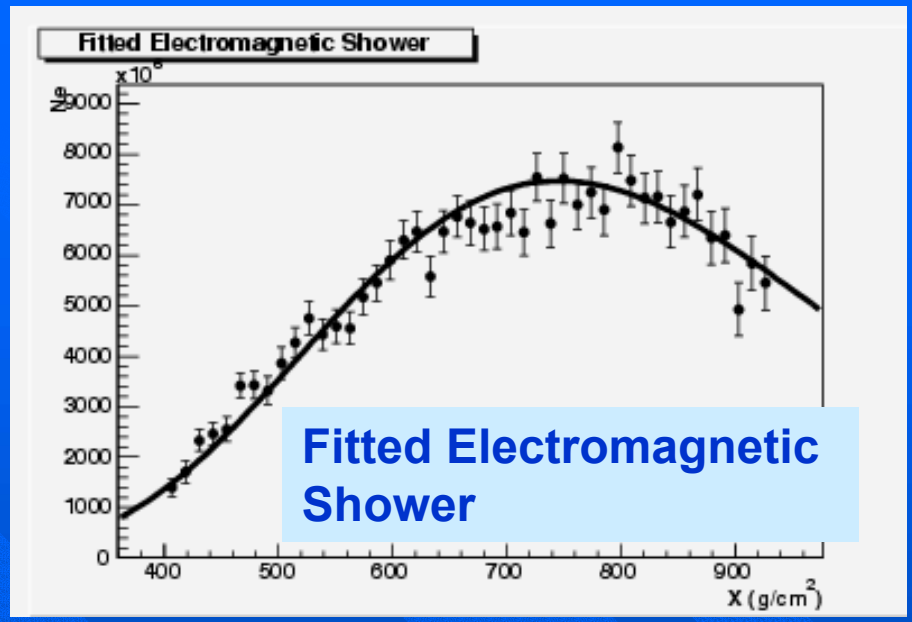
Pixel Geometry => Shower Plane

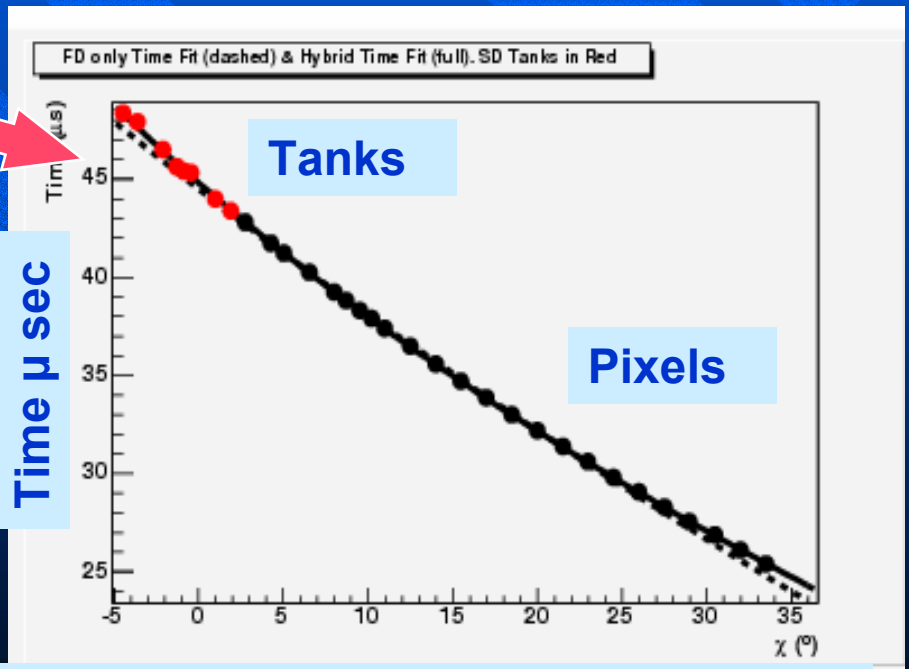
Timing => Direction

Signal+direction => Energy

Same Hybrid Event
θ~ 30º, ~ 8 EeV





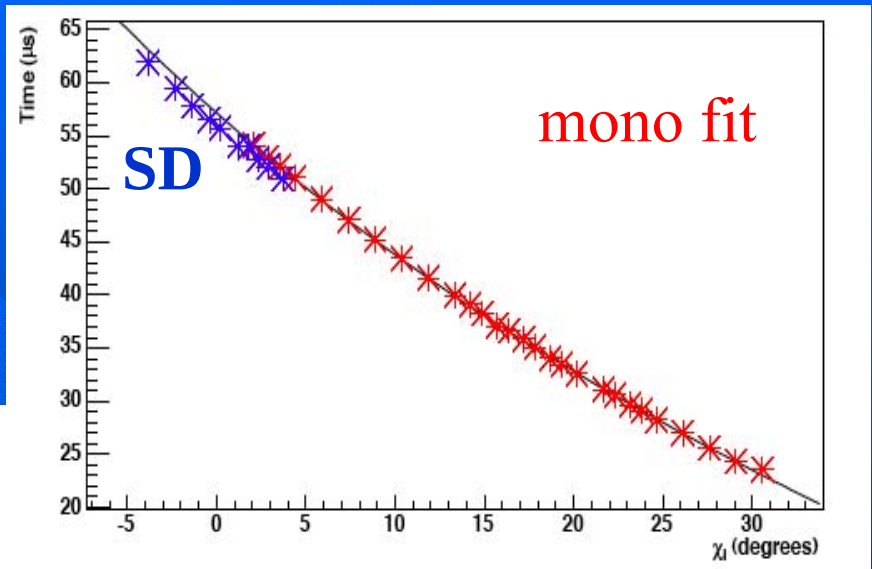


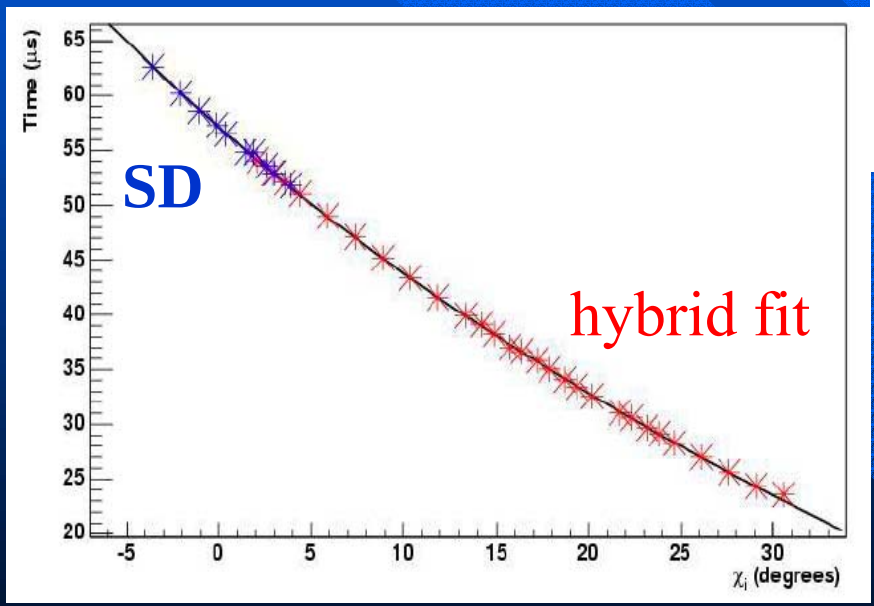
Angle X in the shower-detector plane

E Zas

Hybrid at work:
Improve θ ϕ reconstruction using SD

Improved geometric reconstruction
***Extra* points accurately positioned**
degeneracy is completely broken



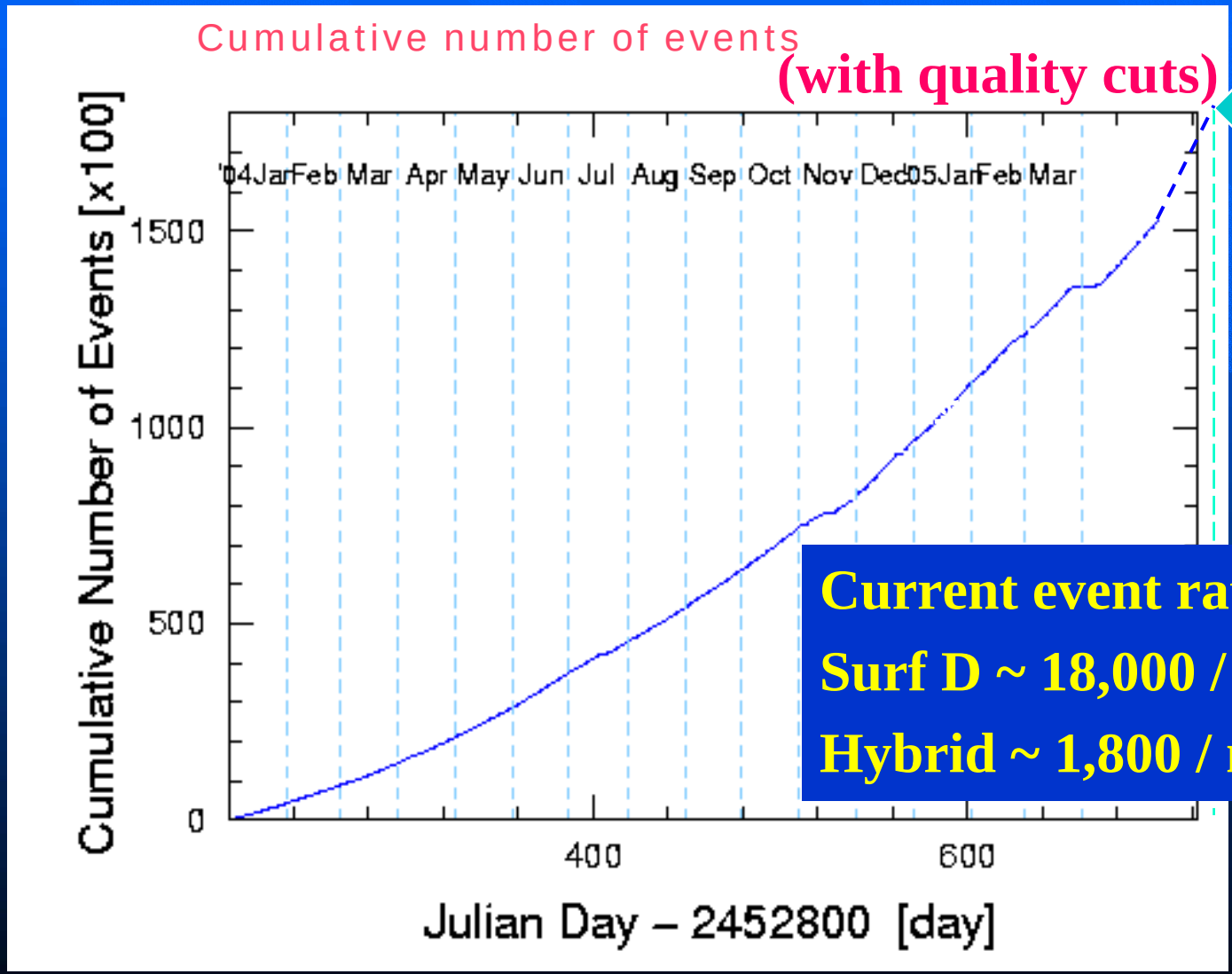


$\Delta\phi \sim 0.6^0$

including SD times

The First Data Set (29 ICRC Pune)

θ [0º,60º] 1 Jan 2004 - 5 Jun 2005 Acceptance ~ 1750 km^2 sr yr



June 05 ~ 180,000
Hybrid ~ 18,000

Current event rates

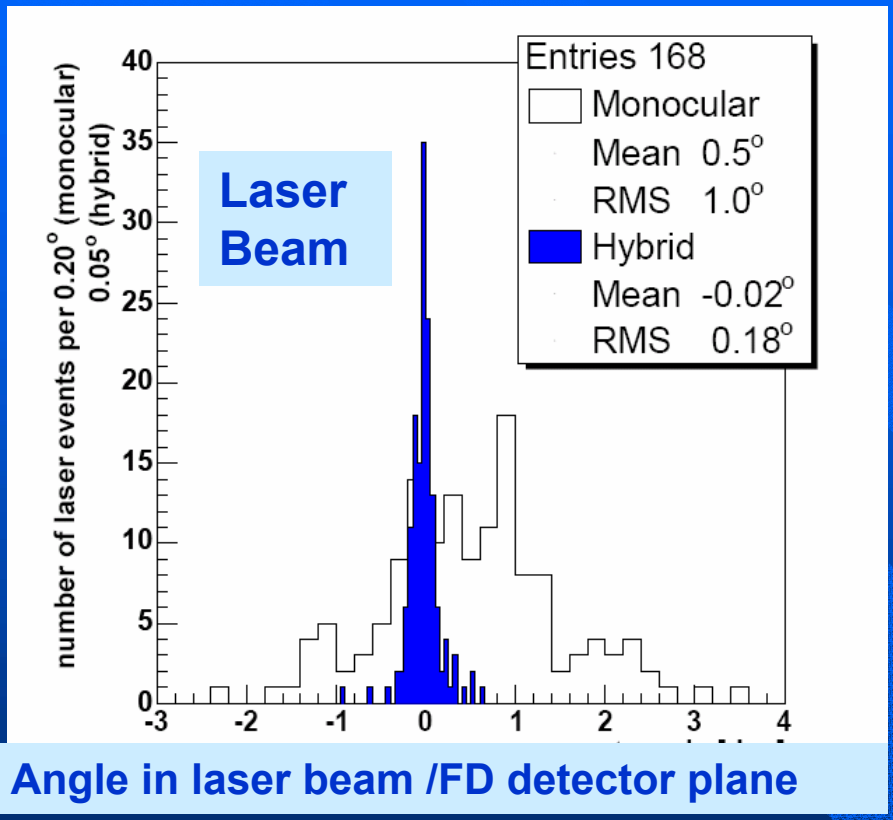
Surf D ~ 18,000 / month

Hybrid ~ 1,800 / month

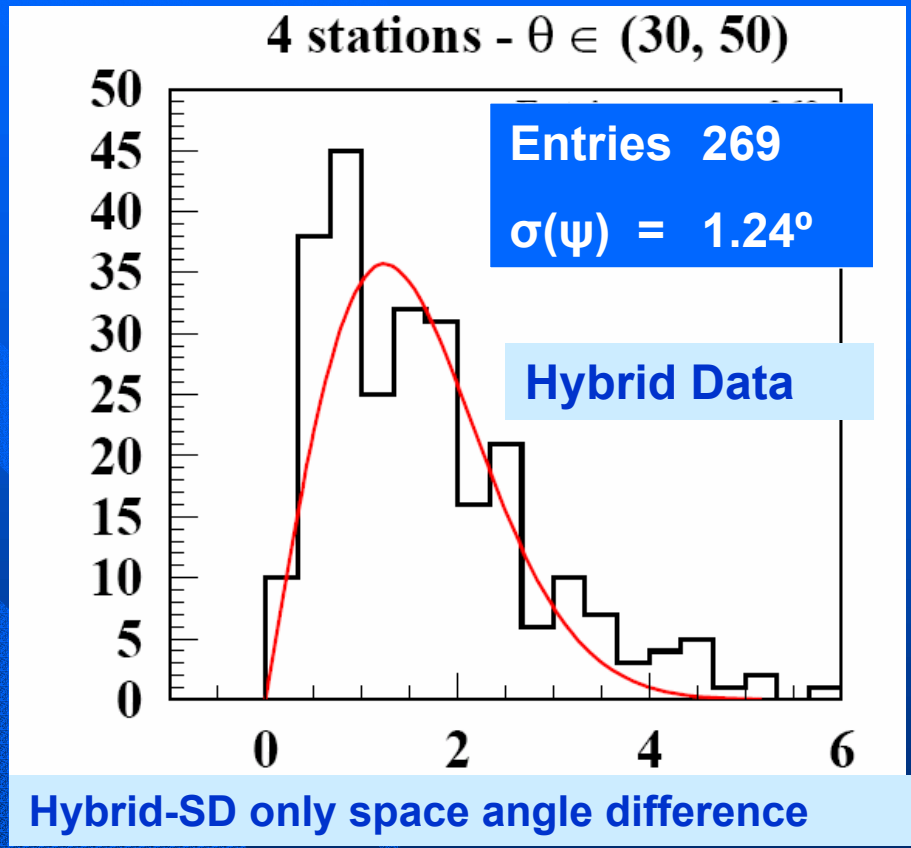
Exploit full power of Hybrid

- SD uncertainties from hybrid data
- Spectrum: Constant intensity method
- Energy calibration from hybrid
- Use hybrid for compostion studies

Performance: *Angular Resolution*



Angle in laser beam /FD detector plane



Hybrid-SD only space angle difference

Hybrid Angular resolution (68% CL)

0.6 degrees (mean)

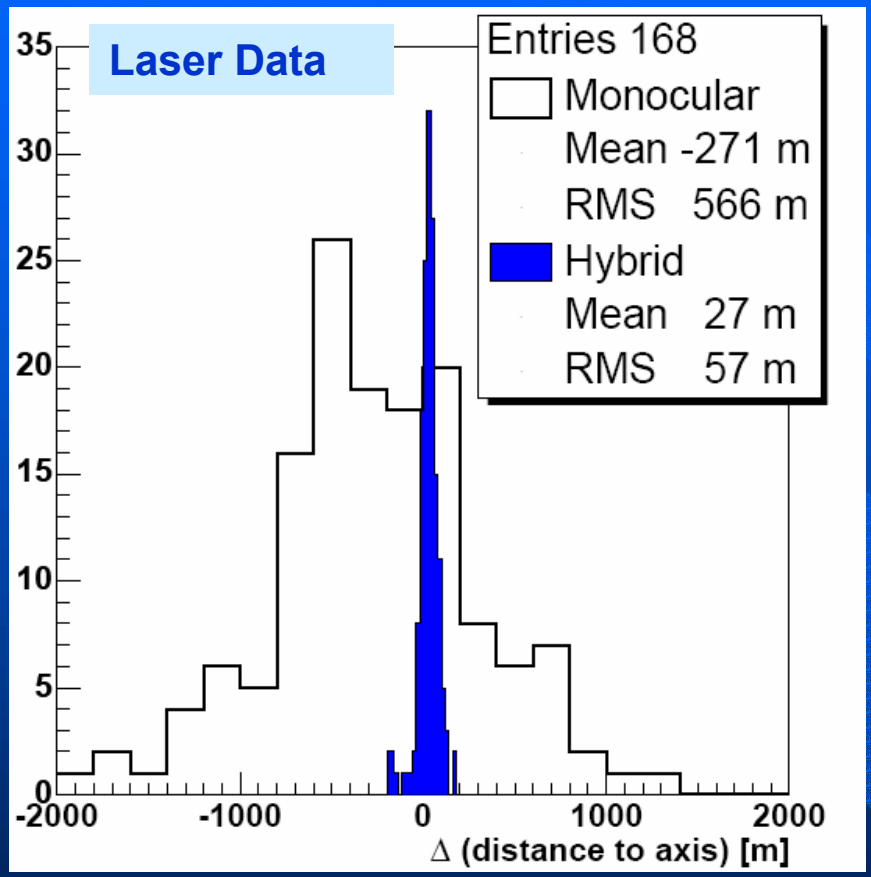
Surface array Angular resolution (68% CL)

< 2.2° for 3 station events (E< 3EeV, θ < 60°)

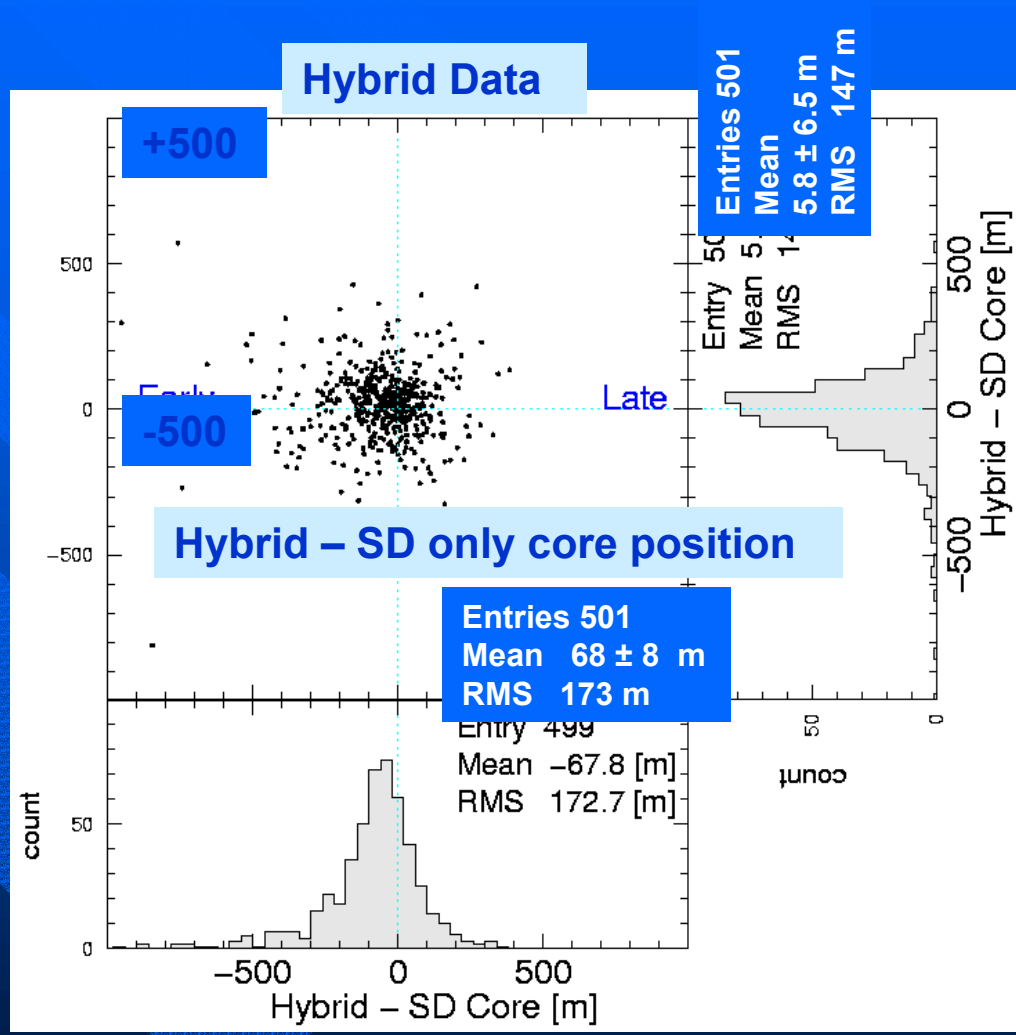
< 1.7° for 4 station events (3<E<10 EeV)

< 1.4° for 5 or + station events (E>10 EeV)

Performance: *Resolution of Core Position*

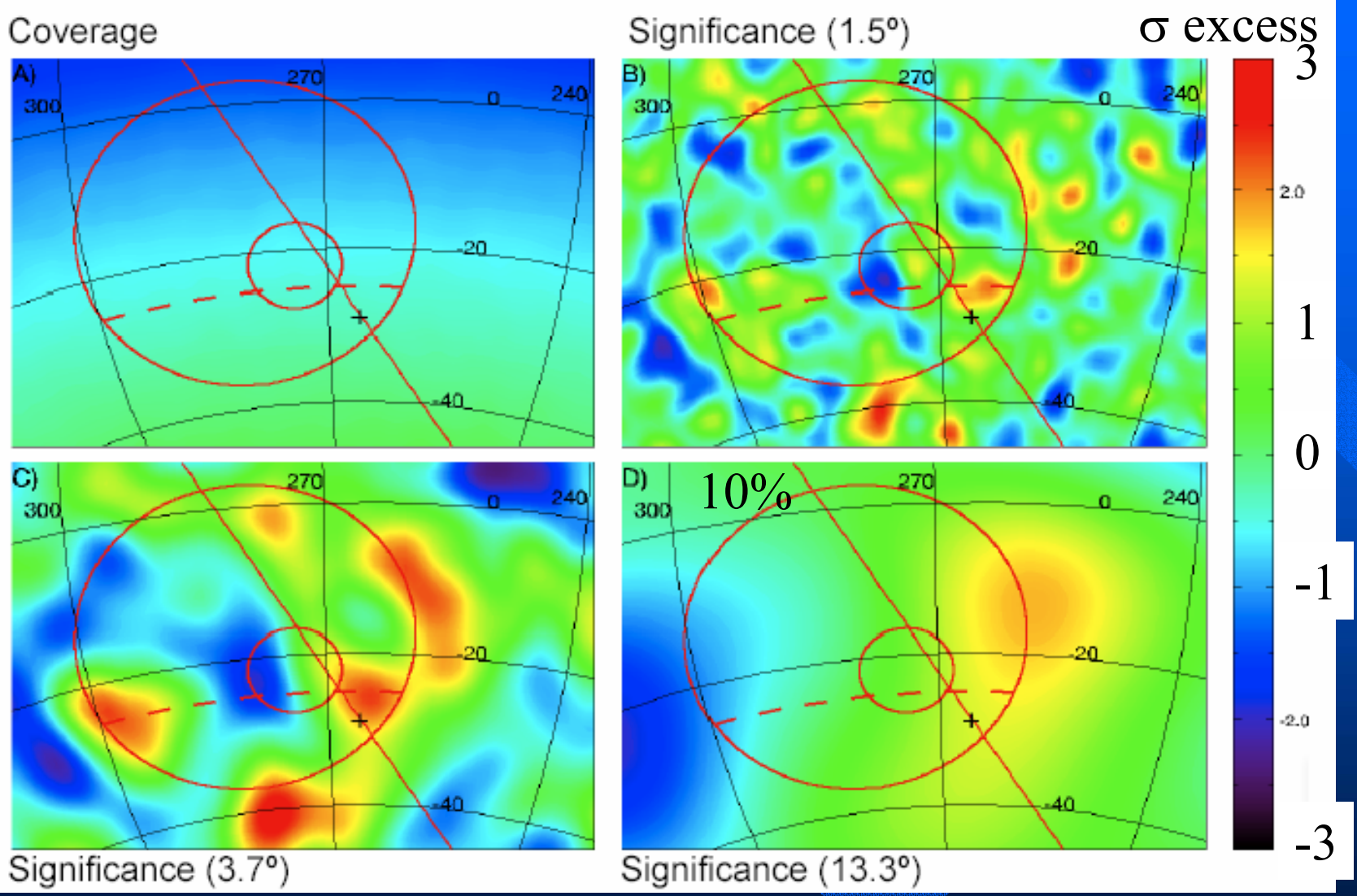


Laser position – Hybrid and FD only (m)



Core position resolution Surface array: *~150 m*

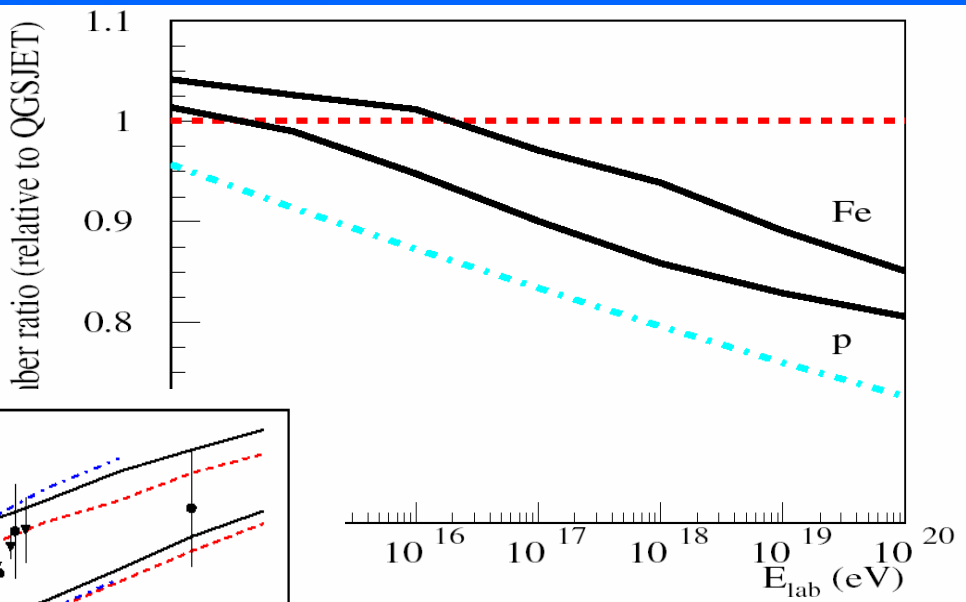
No significant excesses: Galactic Center

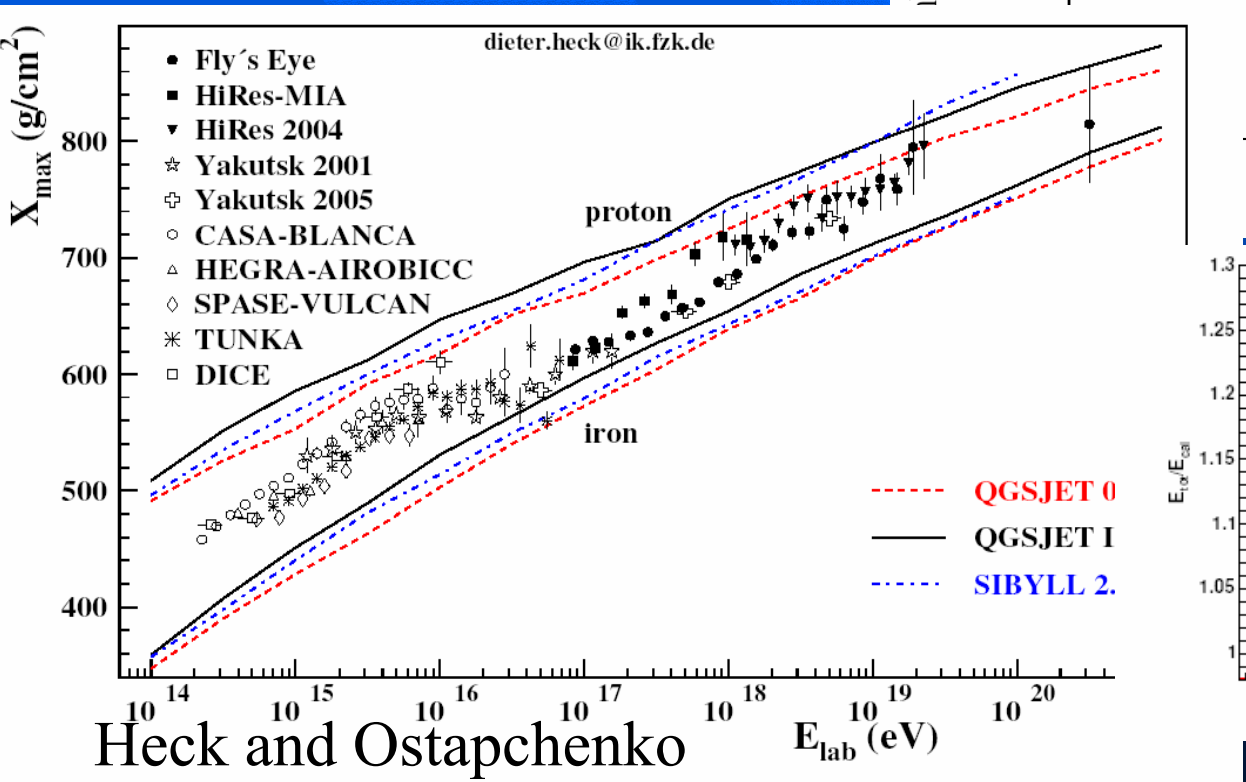


Top hat 20° [1-2.5EeV] AGASA results =>7.5 σ

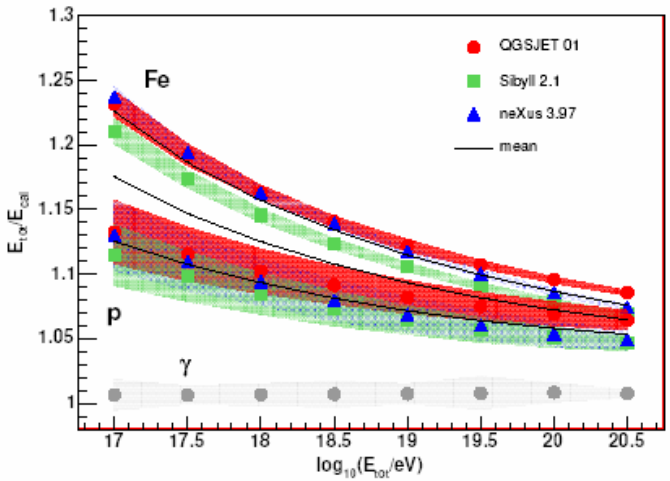
Top hat 5° [0.8-3.2EeV] SUGAR results =>10.5 σ

UHECR studies depend on simulation
- Hadronic Models
-Composition
(Ostapchenko, Pierog, Meurer...)





Heck and Ostapchenko

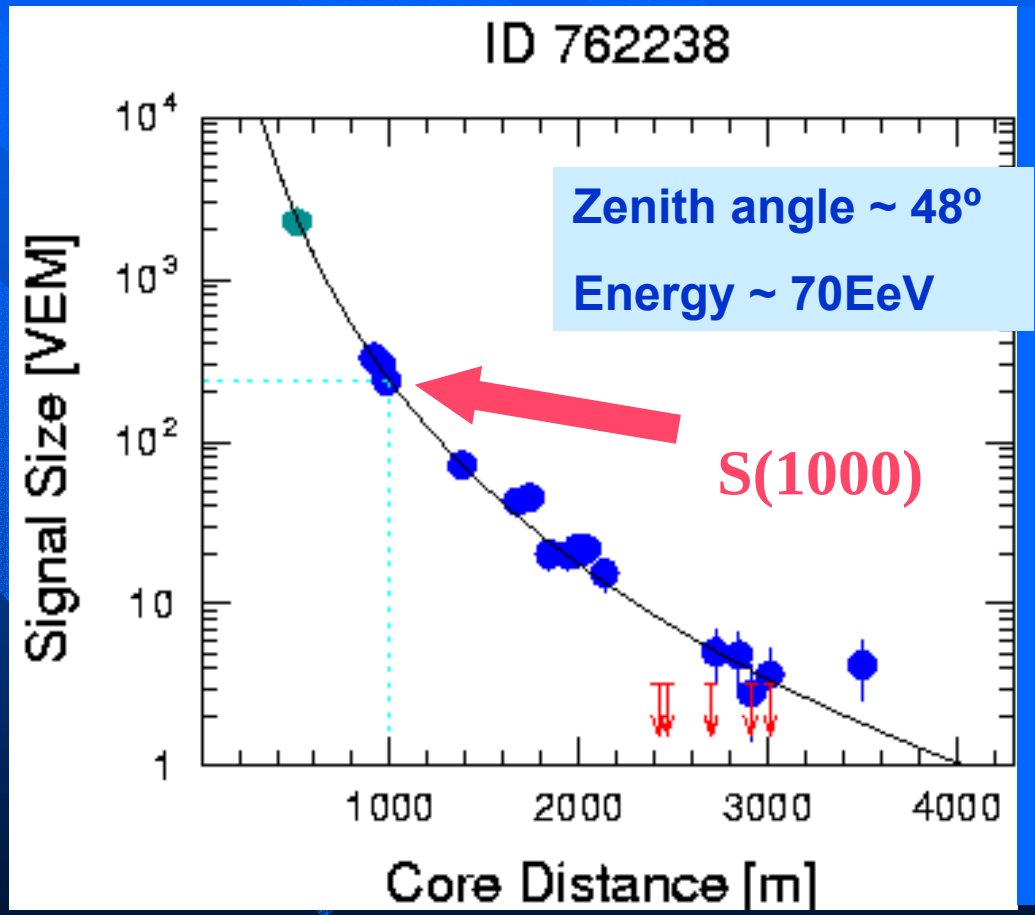


But AUGER Energy Determination

Energy calibrated by fluorescence:
No reliance on interaction models
nor on composition assumptions.

Use S(1000) as SD
Energy estimator

- for each SD event
- Fit lateral density function
- Read S(1000)
- S(1000) α Energy



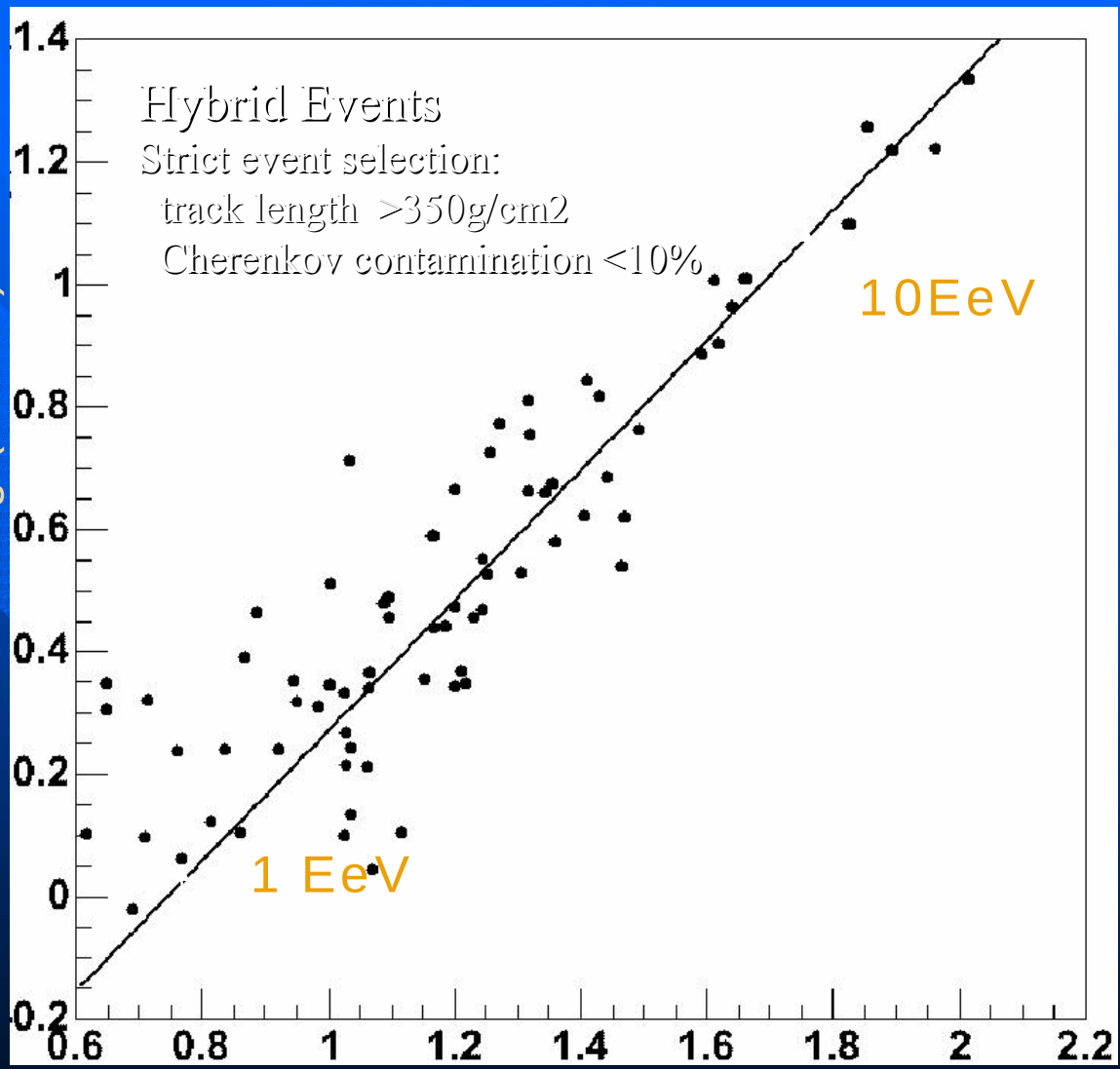
Energy determination and Spectrum

The energy converter:

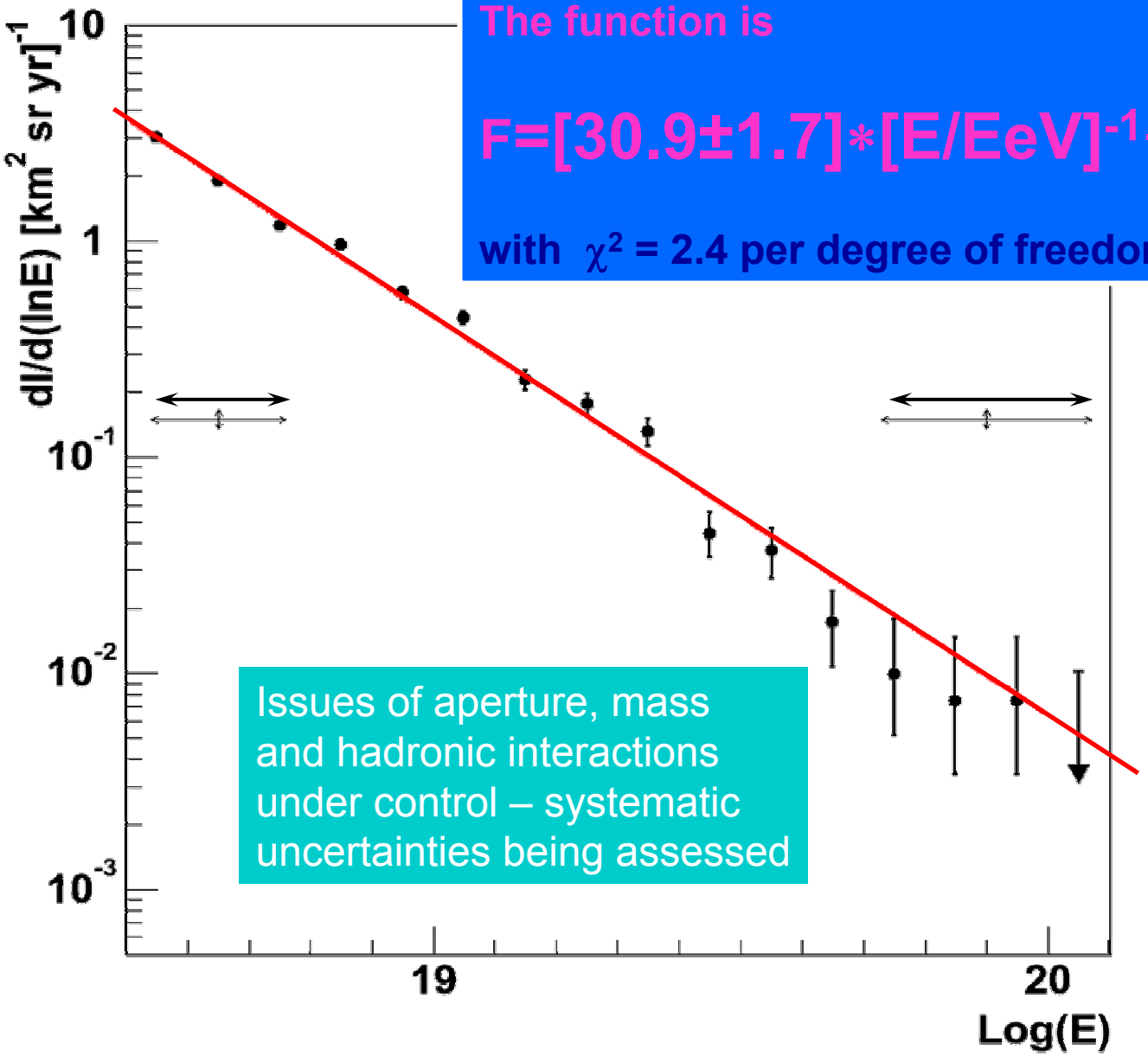
S(1000) α FD Energy

Use for SD events

Uncertainty in scale is Statistics limited



Auger Energy Spectrum



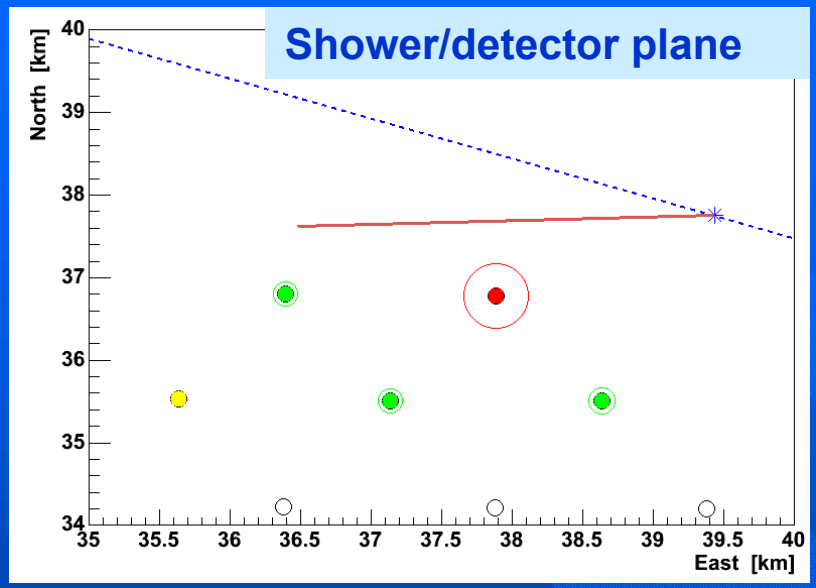
The function is

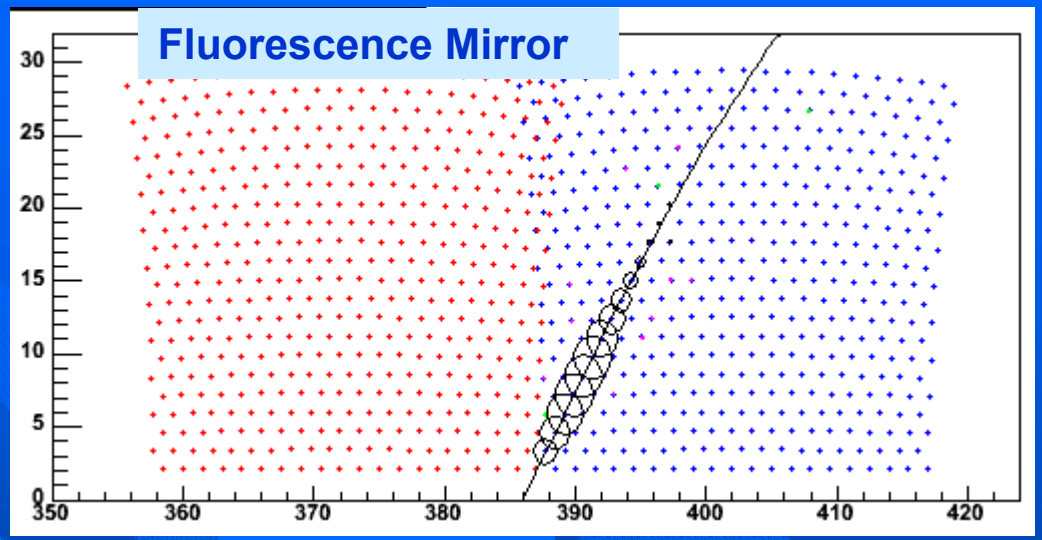
$F=[30.9\pm1.7]*[E/EeV]^{-1.84\pm0.03}$

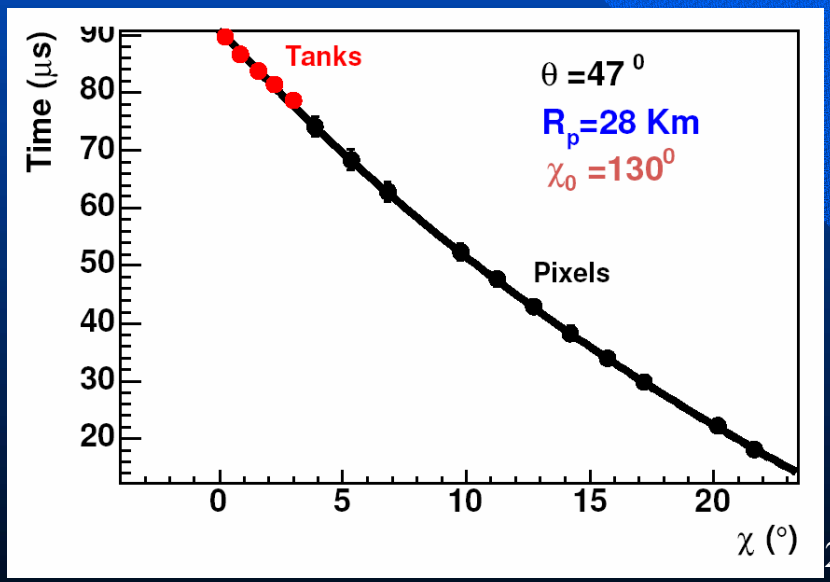
with χ^2 = 2.4 per degree of freedom

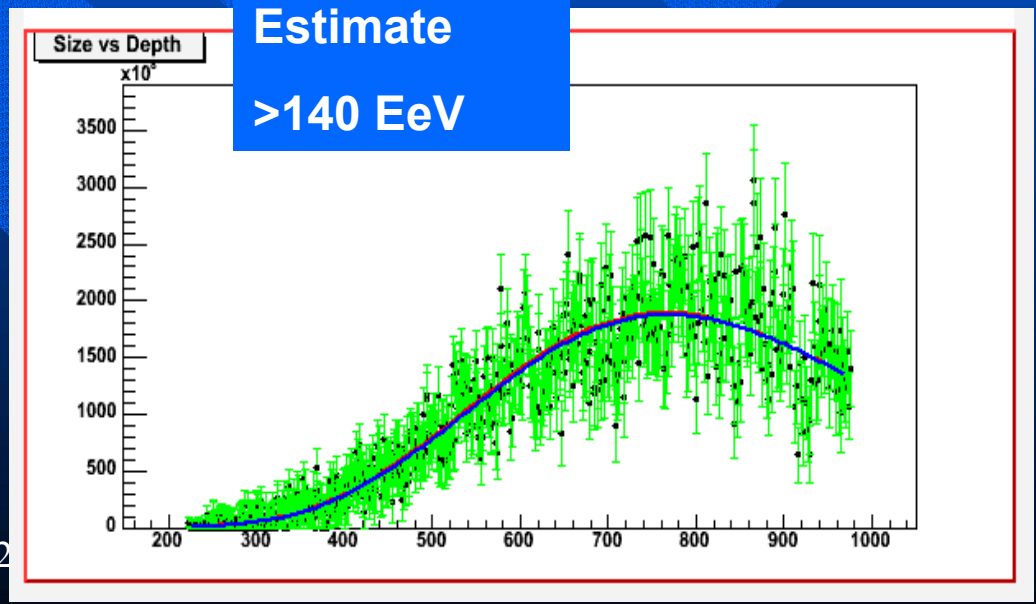
Issues of aperture, mass and hadronic interactions under control – systematic uncertainties being assessed

A Big Event - *One that got away!*

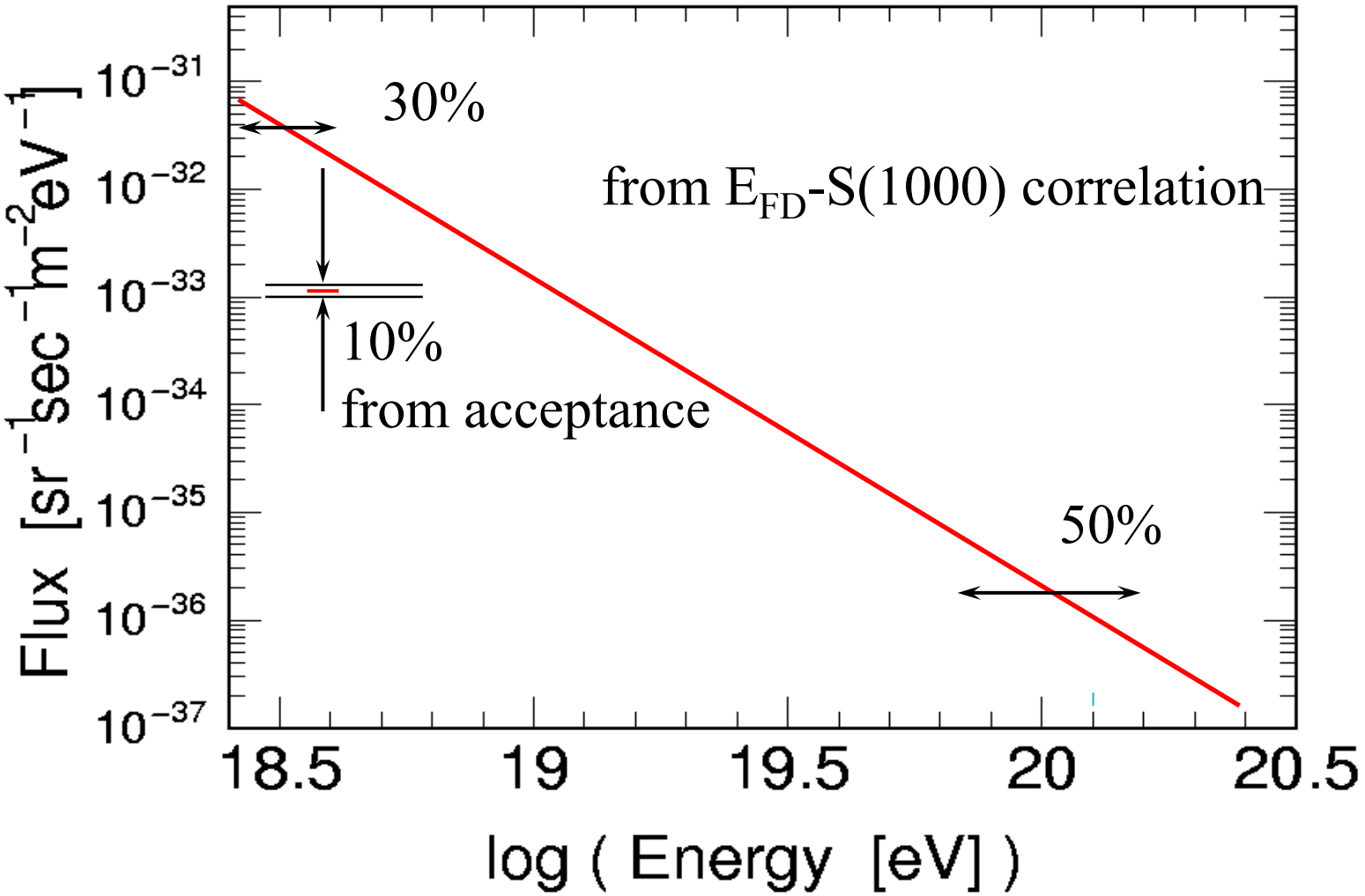








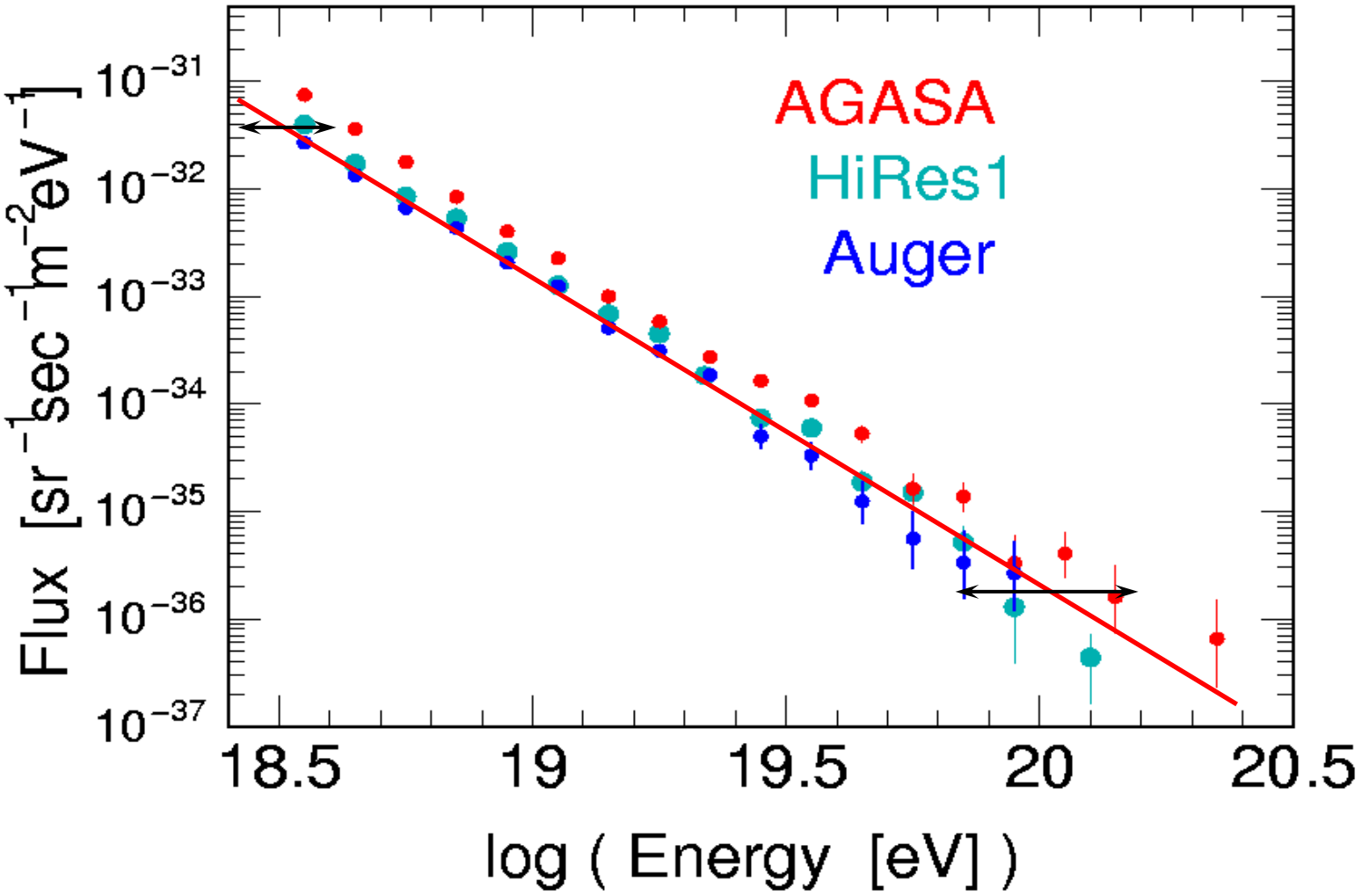
Uncertainties



1) M. Takeda *et al.* Astroparticle Physics 19, 447 (2003)

2) R.U. Abbasi *et al.* Phys Lett B (to be published)

Comparison with HiRes1, AGASA



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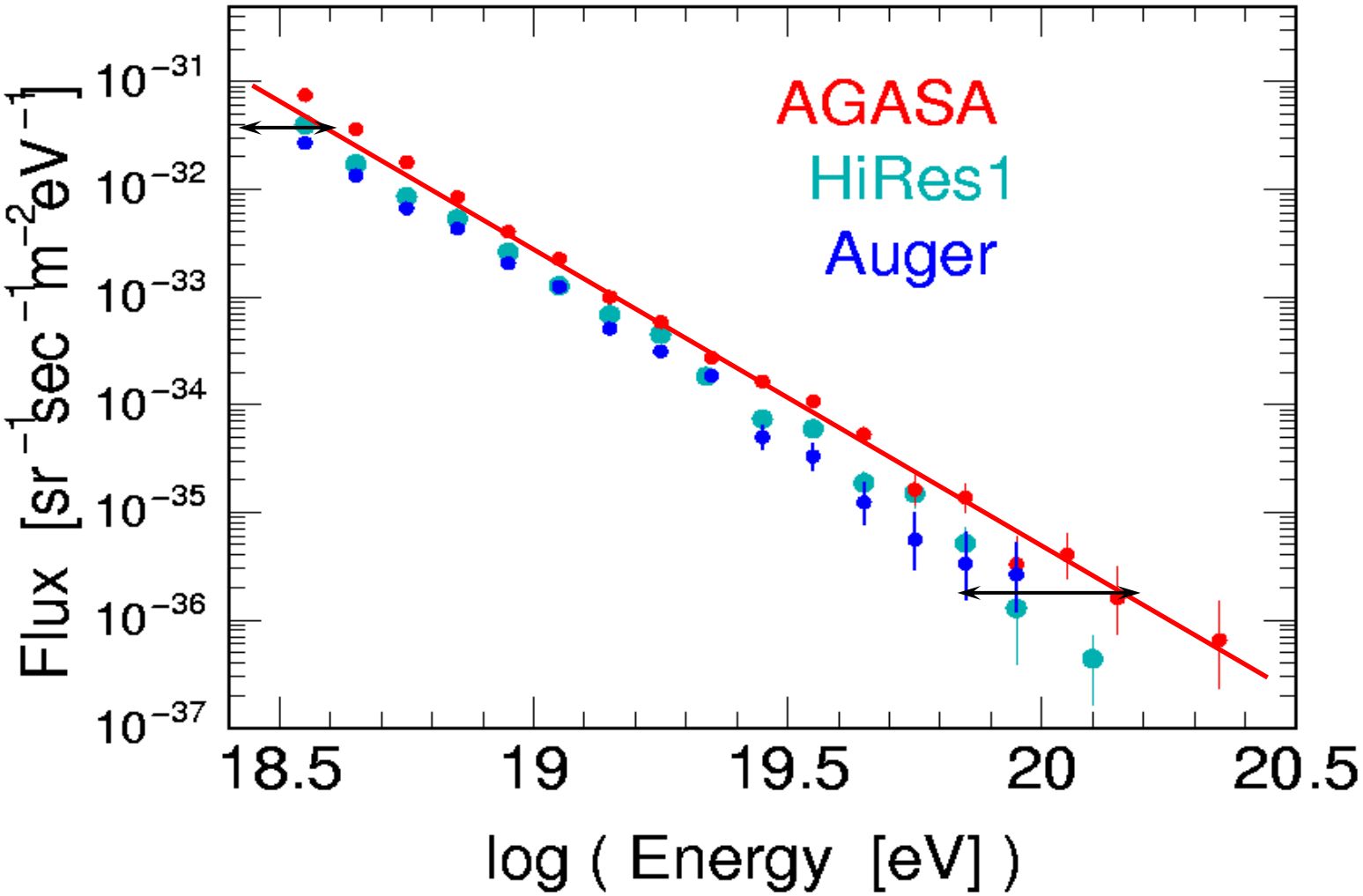
Comparison with HiRes1, AGASA



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Methods of Inferring the Primary Mass

(i) Variation of Depth of Maximum with Energy

Elongation Rate (Linsley 1977, Linsley and Watson 1981)

$dX_{max}/ d\log E < 2.3X_o$ g cm^{-2} /de

from Heitler mod

$\ln \varepsilon_c$)/ ln 2

HADRONIC MODELS REQUIRED FOR INTERPRETATION

(ii) Muon C

$A\varepsilon_\pi)p$ (depends on

$N\mu(>1\ GeV) = 2.8A(E/A\varepsilon_\pi)^{0.86} \sim A^{0.14}$

So, more muons in Fe showers

Summary:

- **Over 50% of the Auger detector is taking data**
- **Integrated acceptance obtained similar to AGASA**
- **Auger has measured a spectrum quasi-independent of compostion and simulations**
- **Much redundancy and improvement is expected with more hybrid data and more SD statistics, will obtained soon**
- **But composition studies will rely heavily on simulation**