Status of the Auger Observatory and First Results

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Madrid 23 June 2006

PIERRE AUGER OBSERVATORY

Summary:

- Cosmic Rays: goals and motivations
- The Auger Observatory: Status
- Reconstruction of Showers
  - Surface Array
  - Fluorescence Detectors
- First Results:
  - Clustering
  - Photon abundances
  - Energy Spectrum
- Conclusions

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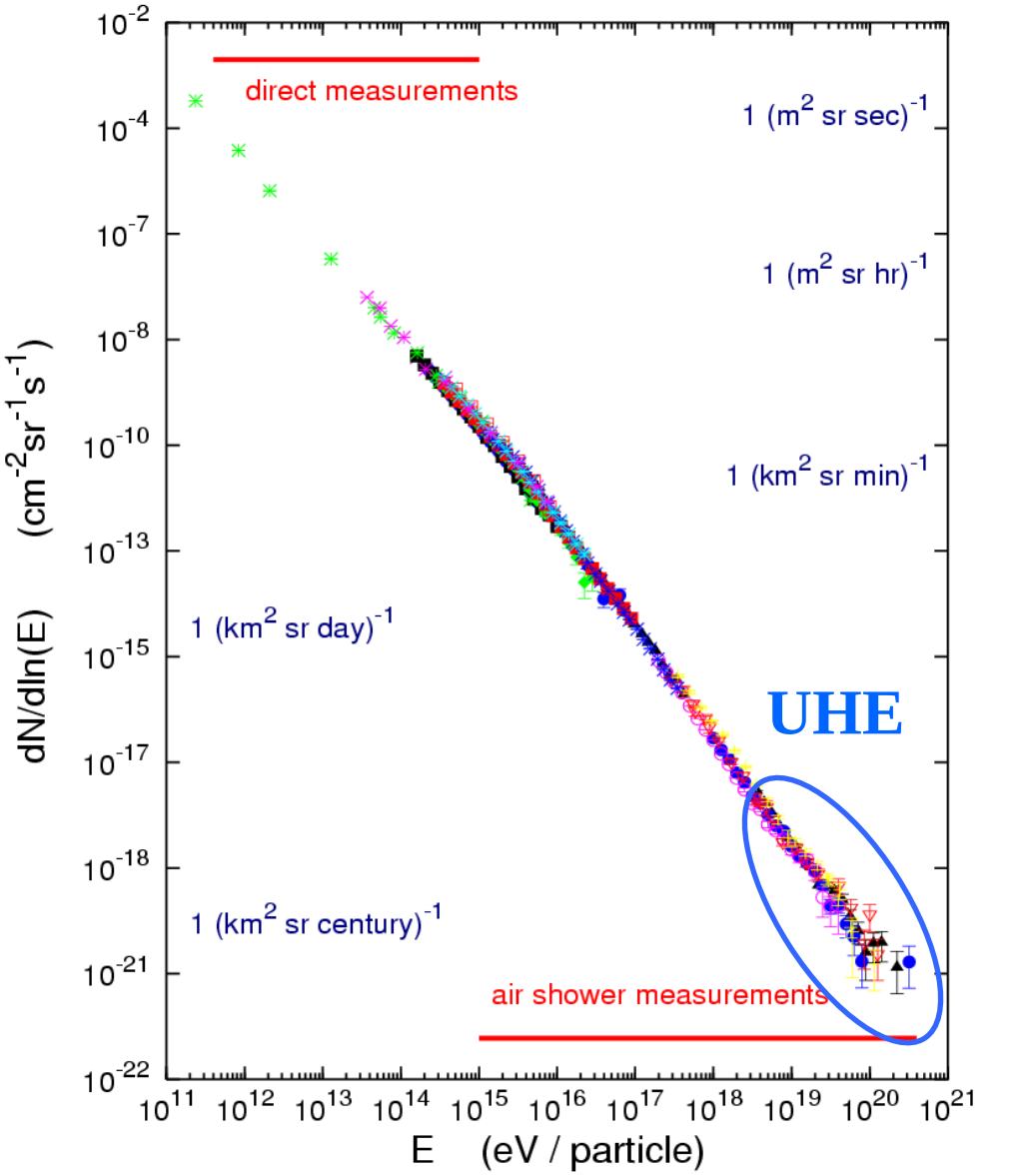
CR Spectrum



Air Showers

- Produced by all known cosmic particles
- Predominantly by CR
- The atmosphere is just the right depth
- Dominated by low energy physics (similar)
  - Hadronic
  - Electromagnetic
- Inclined Sowers are different

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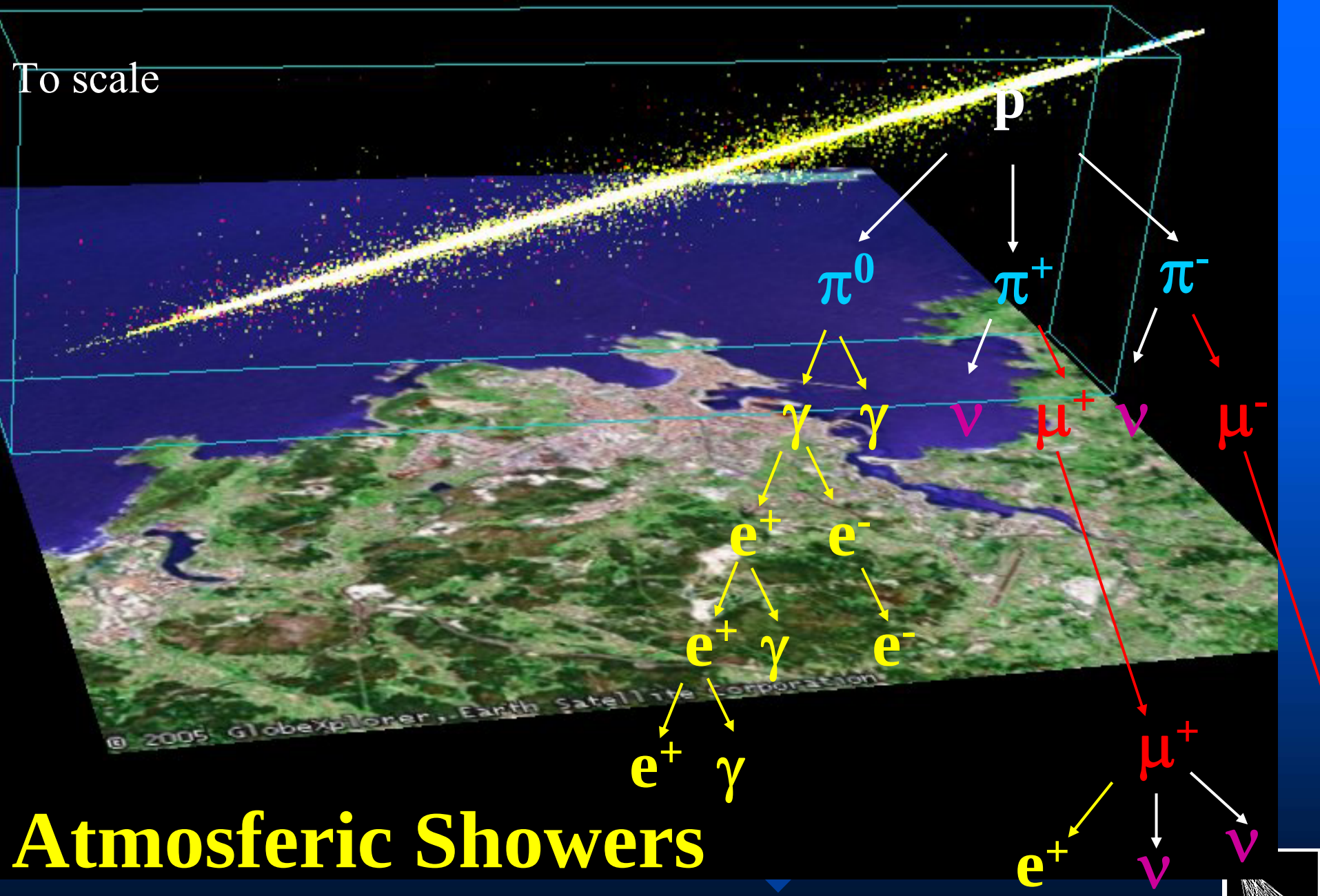

Atmosferic Showers

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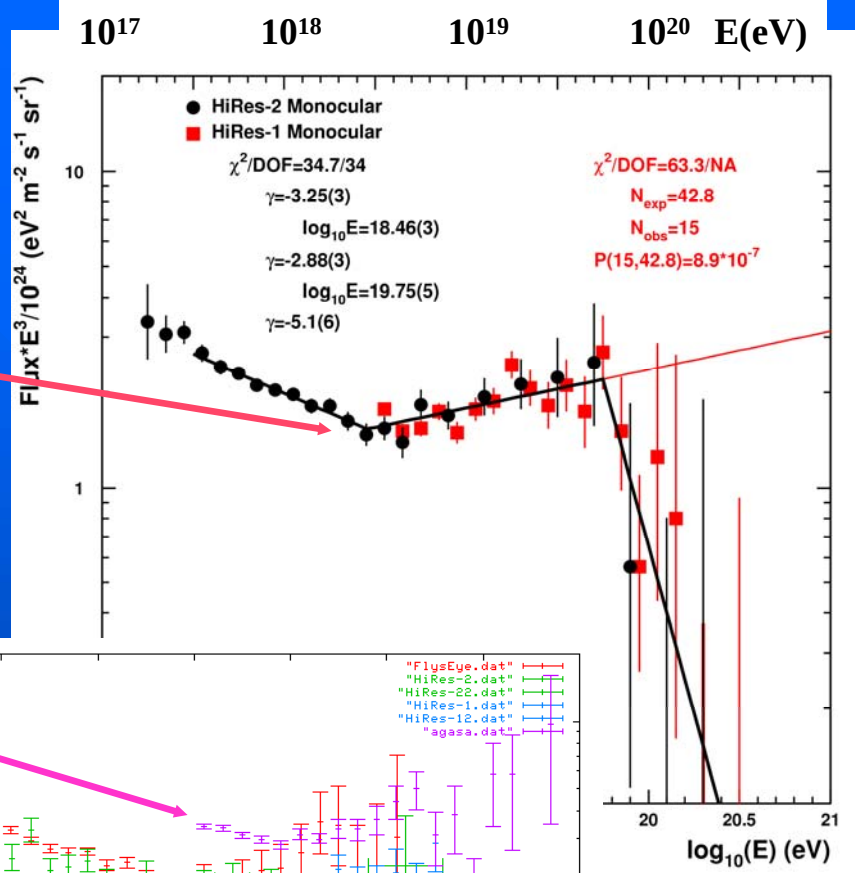
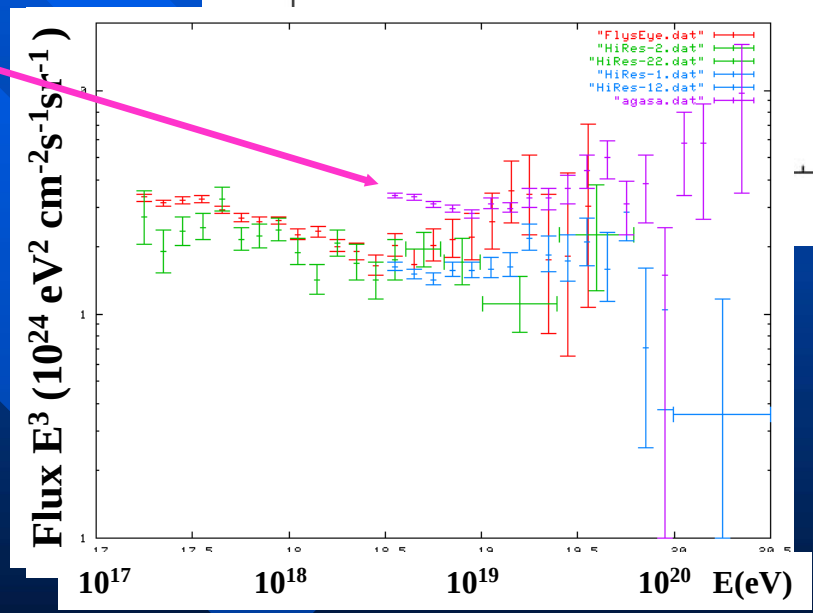
UHECR Data

- Fluorescence
  - Suggests GZK cutoff
  - No clustering evidence
- Surface array
  - No GZK cutoff seen
  - Marginal clustering?
- But BOTH
  - Detect events E>10^{20} eV
  - Agree at 2σ level
  - Rely on simulation





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Auger Science Objectives

- **Cosmic ray spectrum >10^{19} eV:** ***GZK feature (?)***
- **Arrival direction distribution:** ***point sources (?)***
- **Composition:** ***Light, heavy, γ, ν, exotics(?)***

Design (After 6 month design study at FNAL)

- **Uniform Exposure** — **North & South Observatories**
- **Improve statistics** — **2 x 3000 km2 Surface Array**
  - **1600 particle detectors**
  - **hexagonal array: 1.5 km spacing**
- **Intercalibration** — **Combine Fluorescence**
  - **4 Enclosures ("Eyes")**

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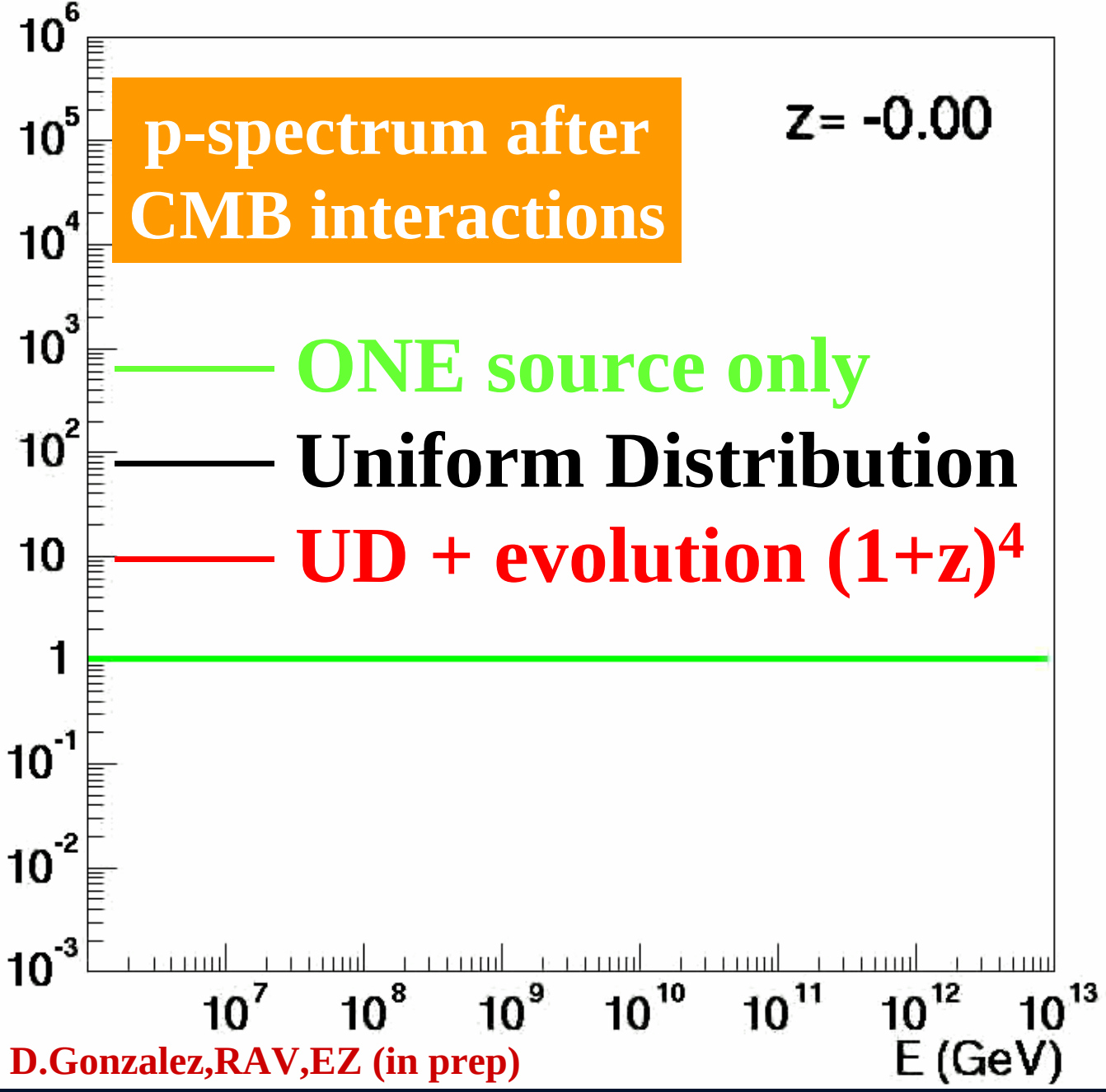
CR Flux / Reference Flux

E^{-2}



D.Gonzalez,RAV,EZ (in prep)

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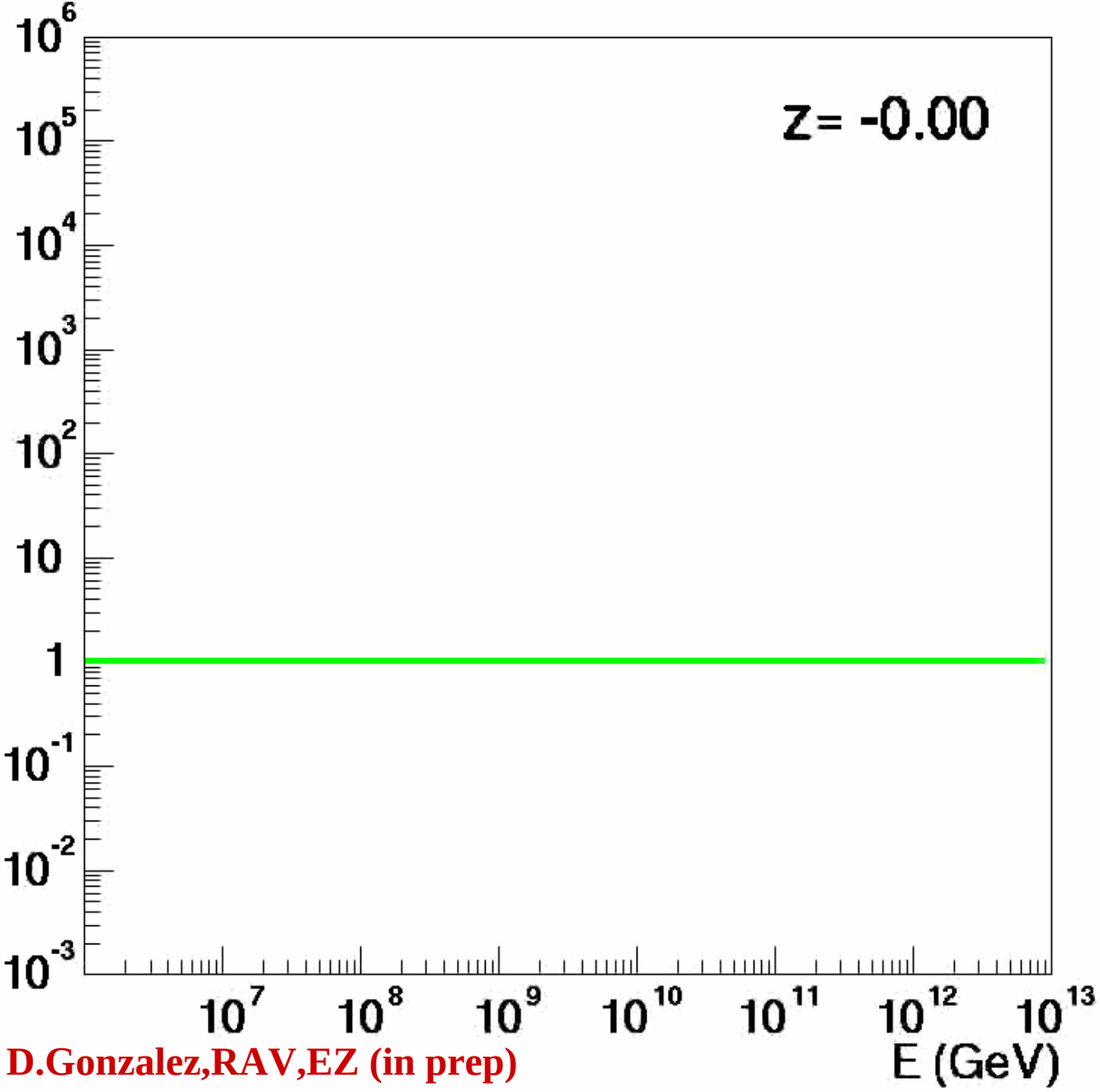
CR Flux / Reference Flux



D.Gonzalez,RAV,EZ (in prep)

E^{-2}

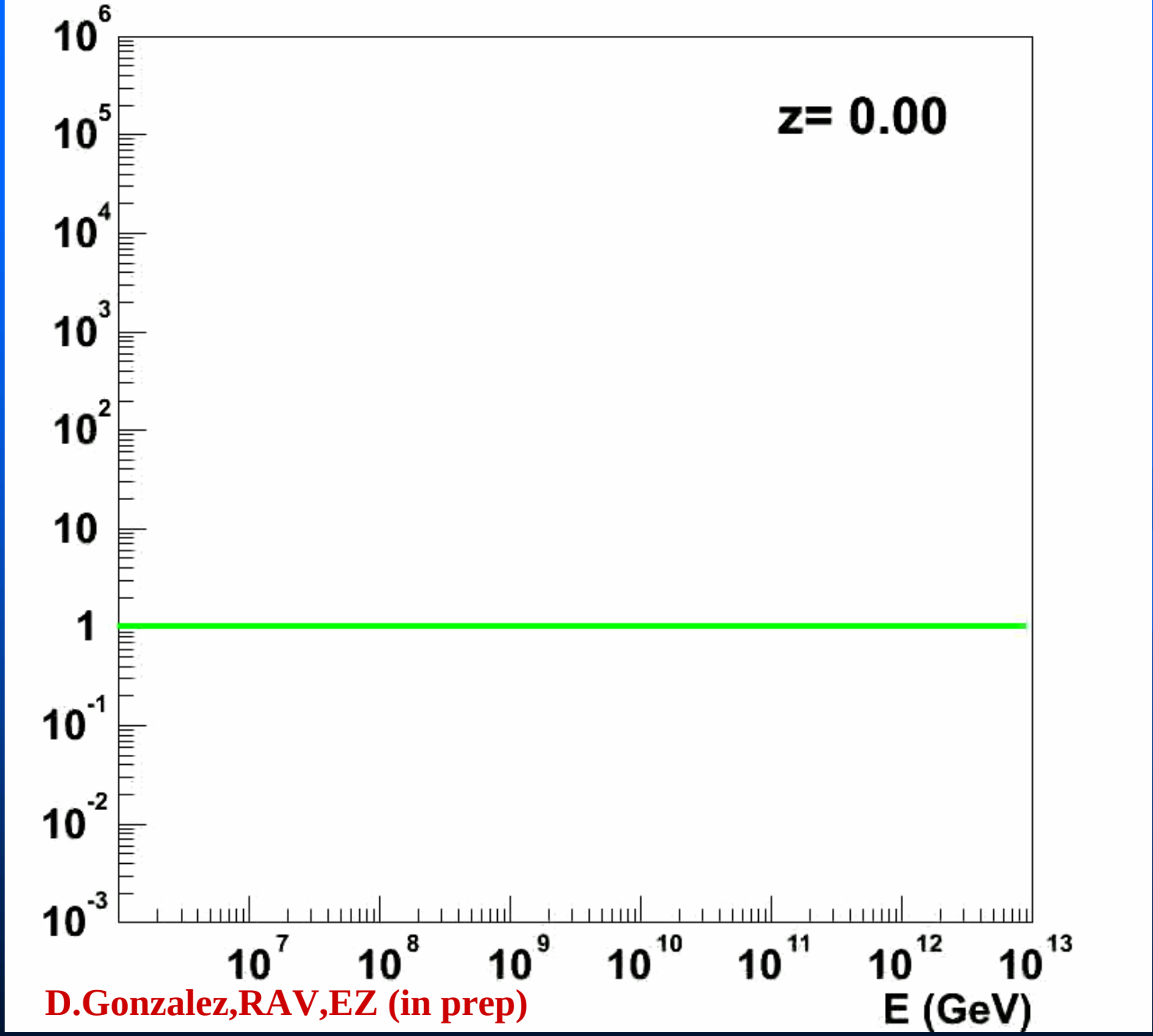
U Dis+evol

Unif Distr

one source

PIERRE AUGER OBSERVATORY

P & ν-Flux / Reference Flux



D.Gonzalez,RAV,EZ (in prep)

E^{-2}

U Dis+evol

Unif Distr

one source

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Ultra High Energy

2-fold motivation

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

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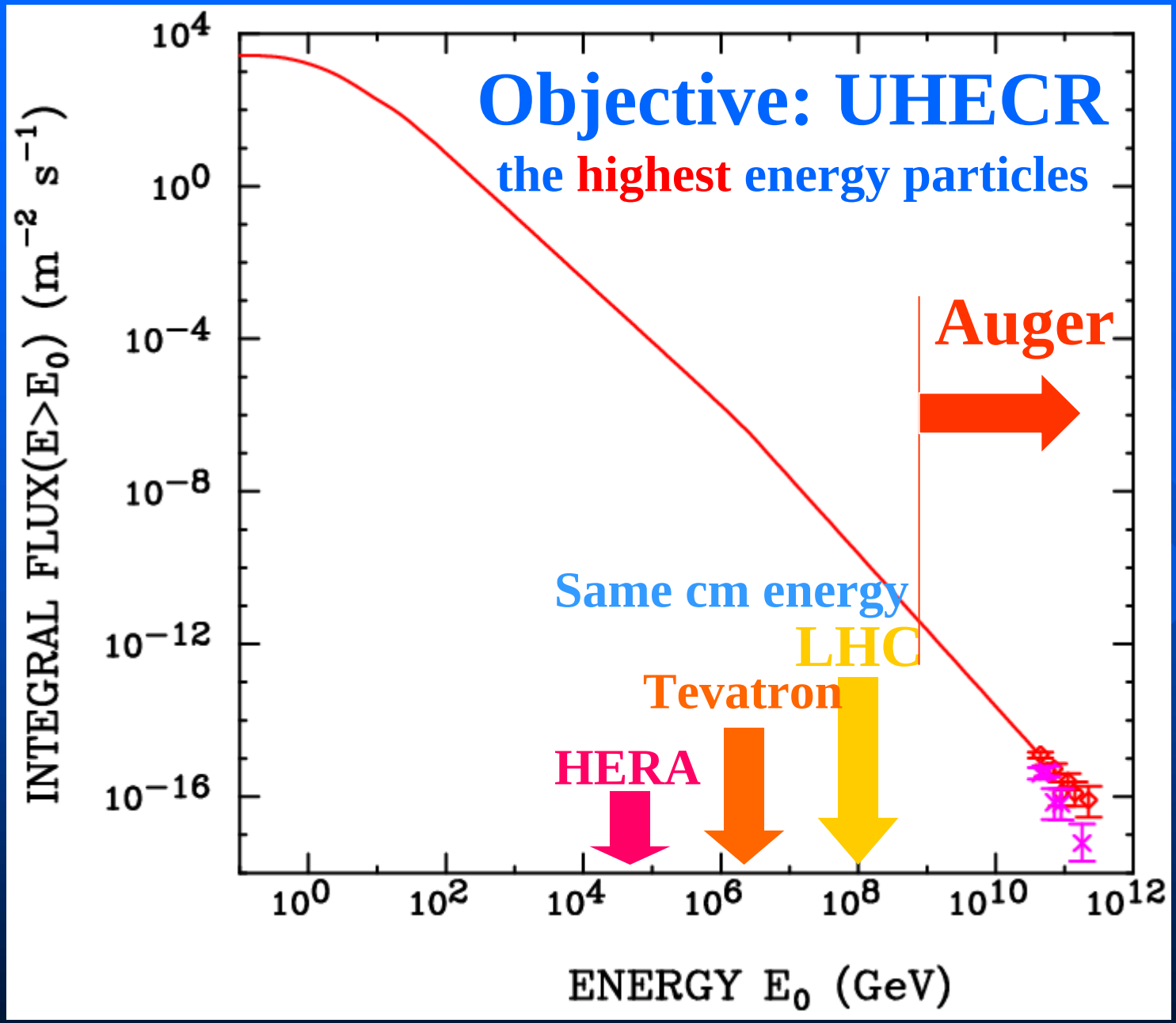

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The Auger Collaboration

17 Countries **70+ Institutions** **350+ Scientists**

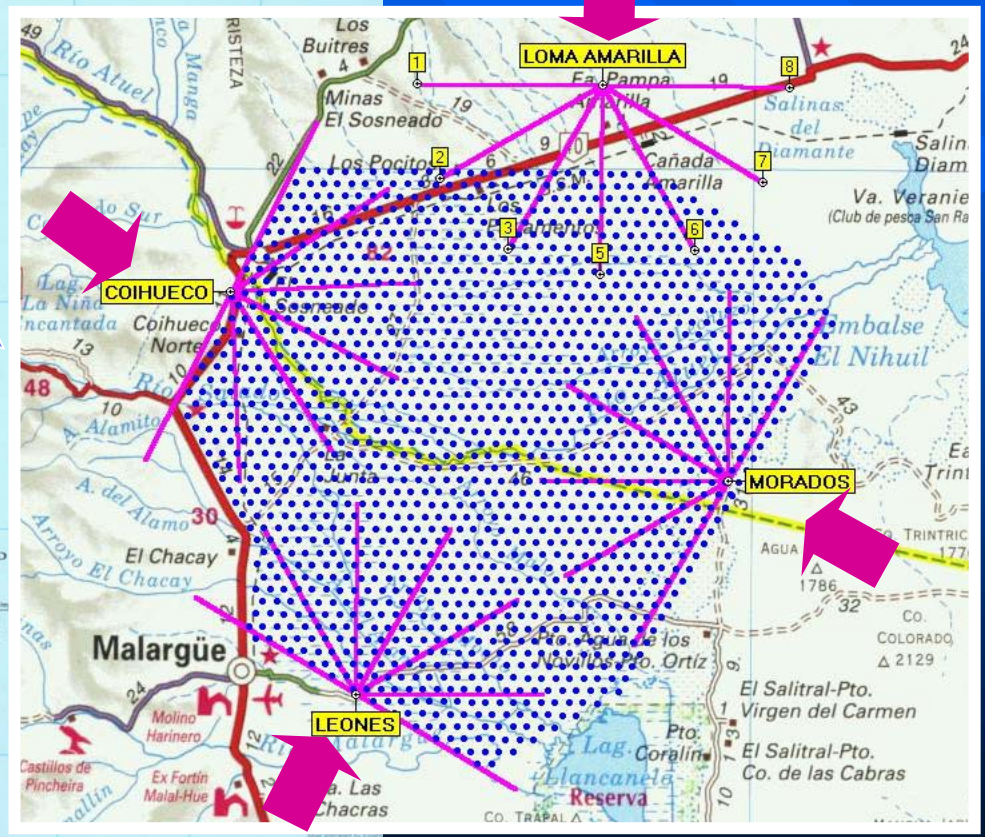
Argentina
Australia
Bolivia(*)
Brazil
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
United Kingdom
USA
Vietnam(*)

(*) Associate countries

Auger Southern Observatory: Malargüe Mendoza (Argentina)

- 1600 tanks

➡ 4 Eyes



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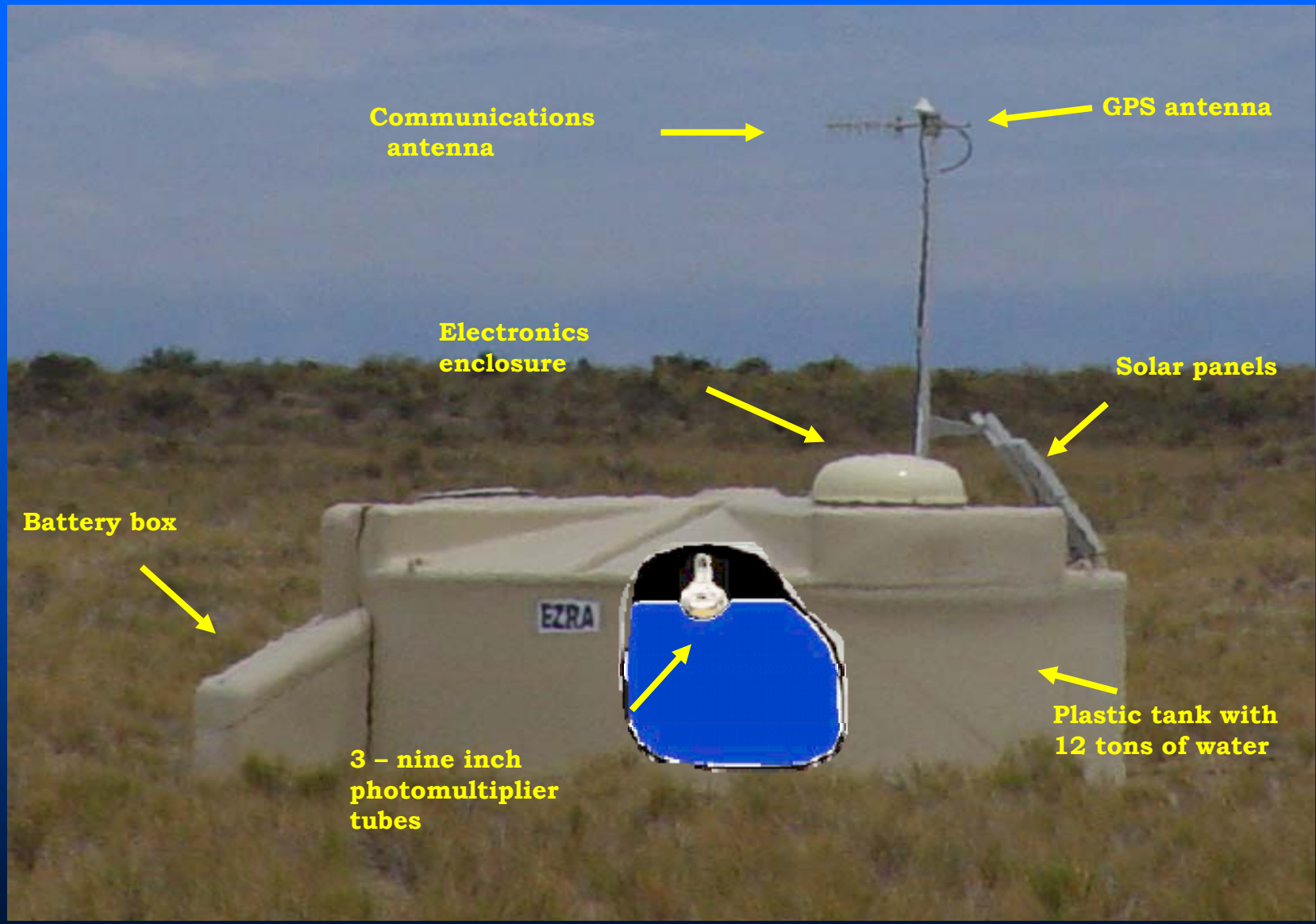
The Surface Detectors



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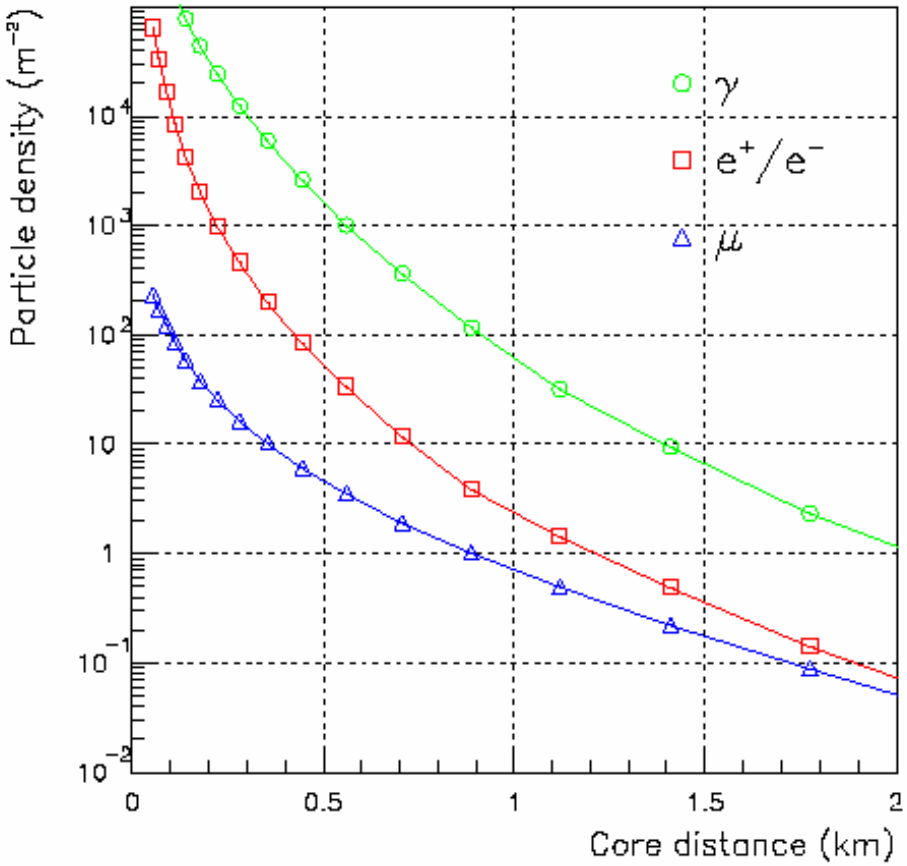
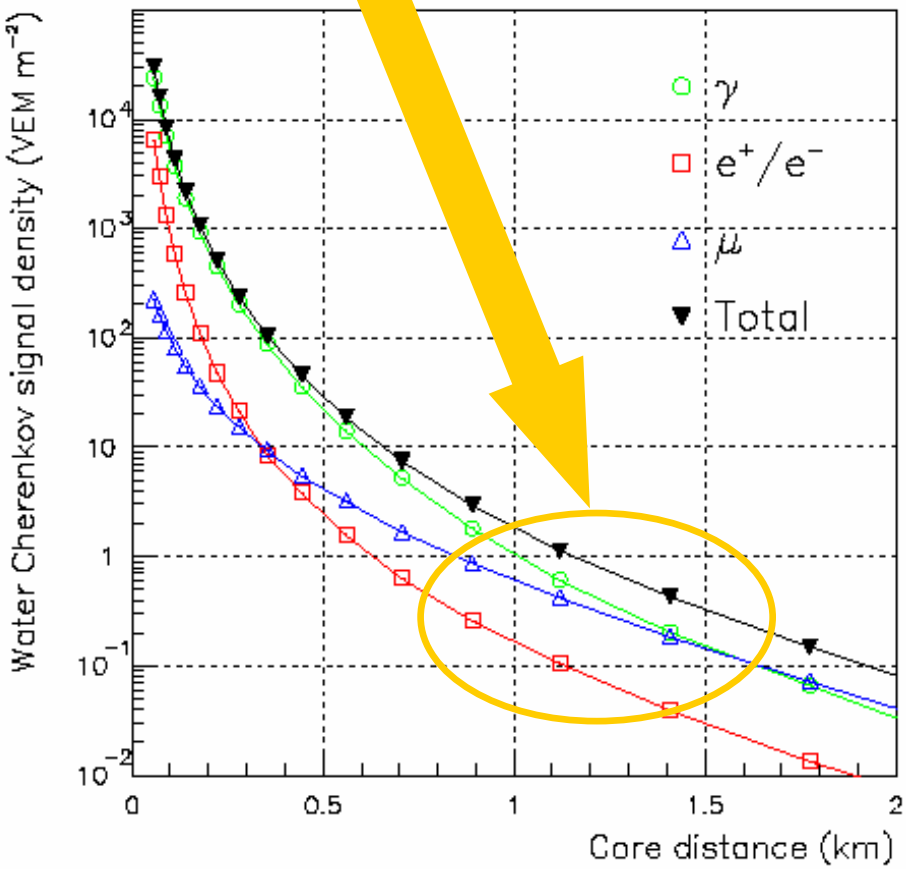
- μ-response α track
- e/γ-response α energy

➡ Inclined: μ/em UP

μ-signal of order em-signal





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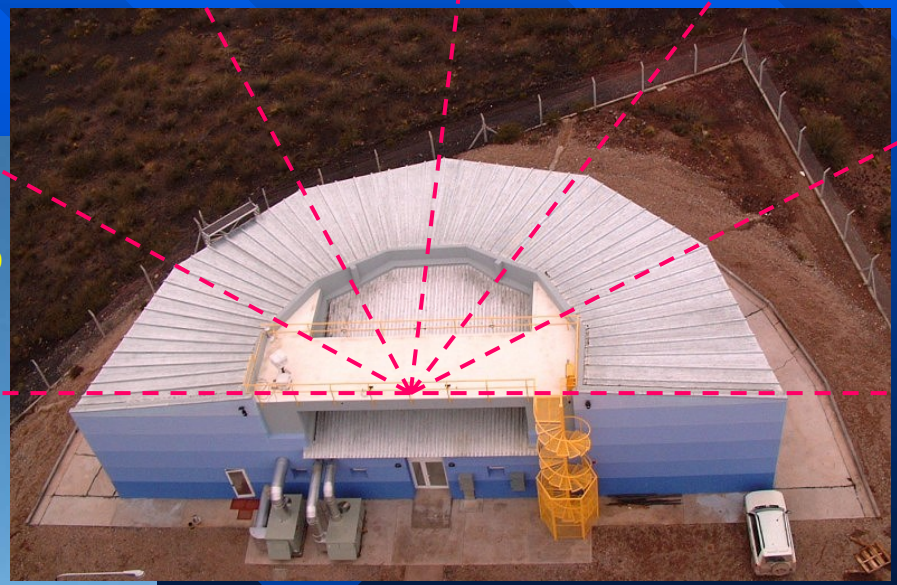
The Fluorescence Detector:

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



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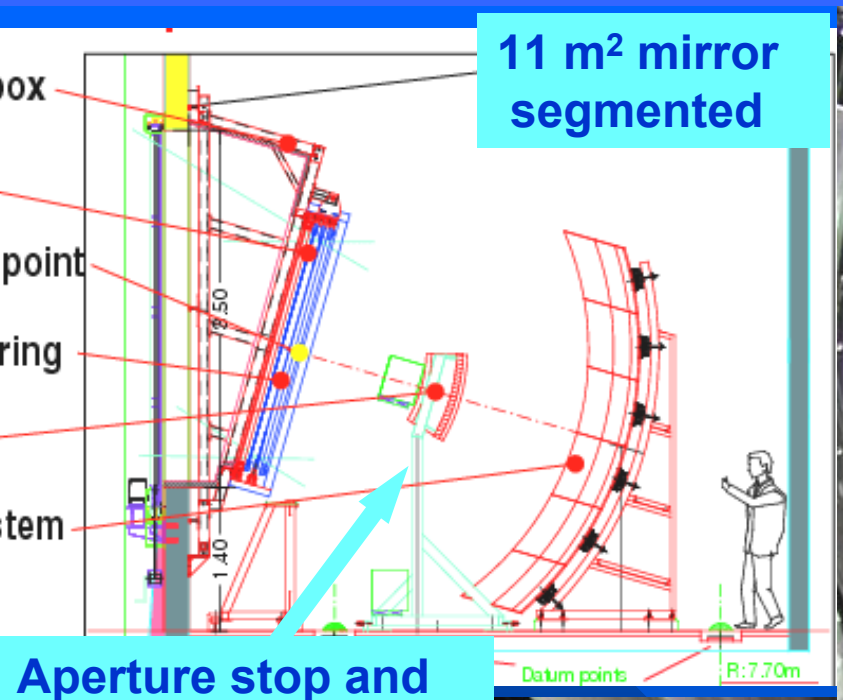
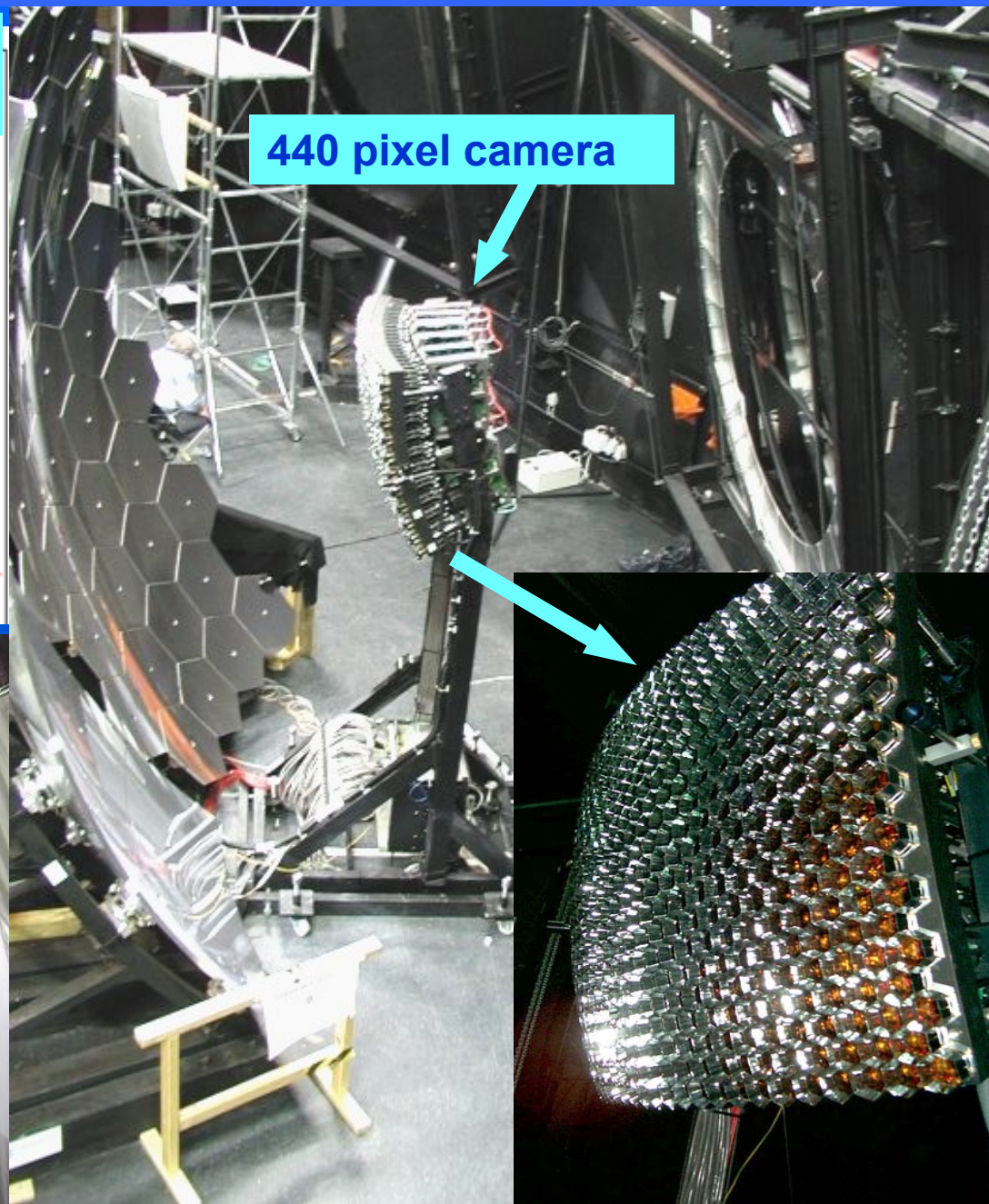
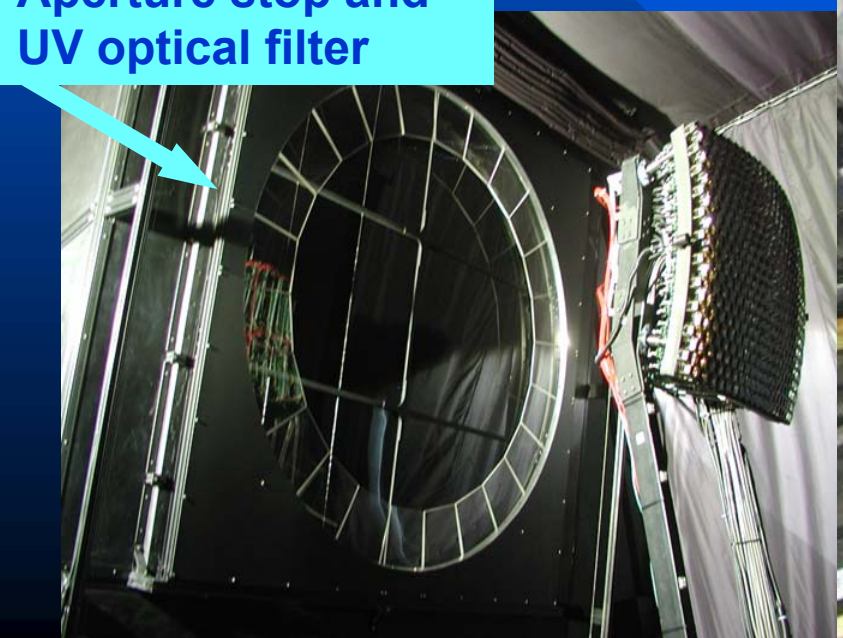
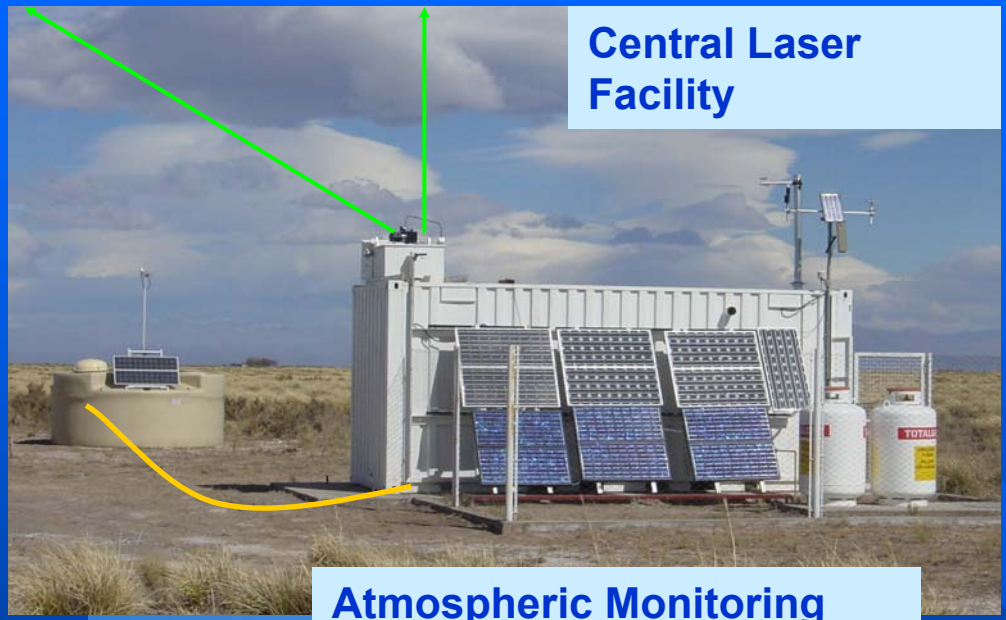
A Fluorescence Telescope







Atmospheric Monitoring & Calibration

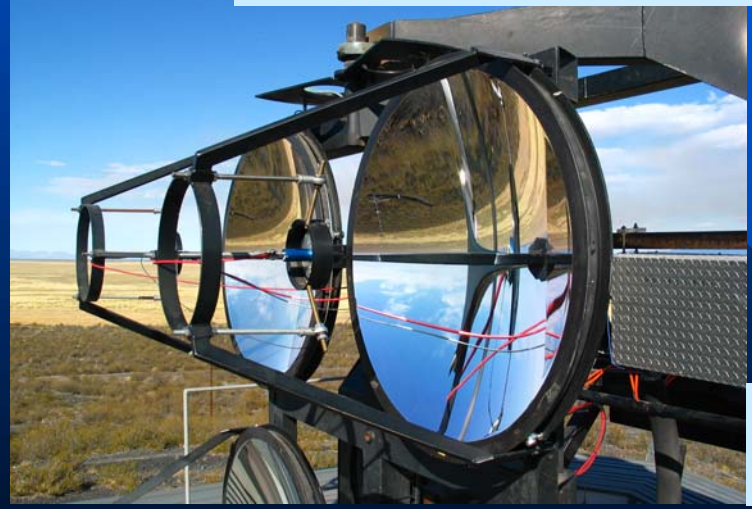


Central Laser Facility

Absolute Calibration

Drum for uniform camera illumination – end to end calibration .

Atmospheric Monitoring



Lidar at each fluorescence eye

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Status June 2006

1152 surface detector stations deployed
930 operating

Three fluorescence buildings complete each with 6 telescopes

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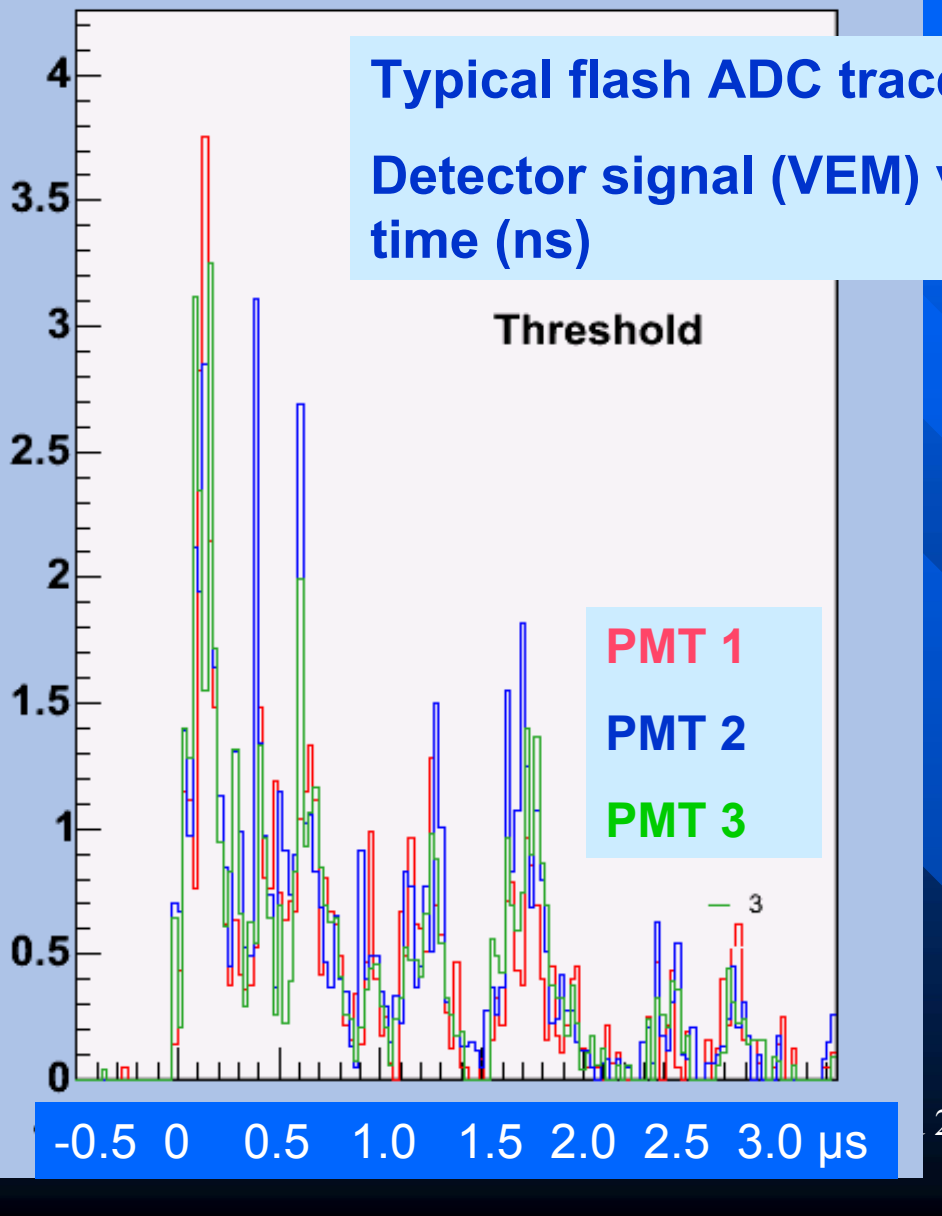
SD Reconstruction:

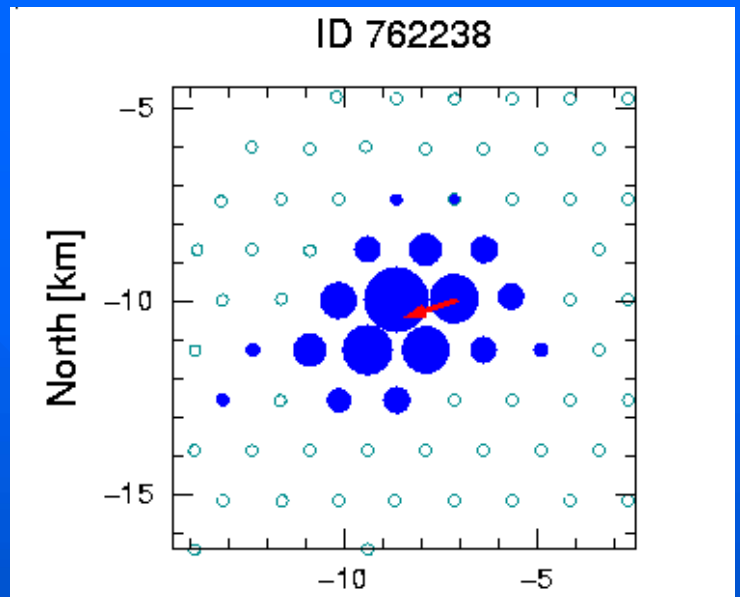
Timing => Direction

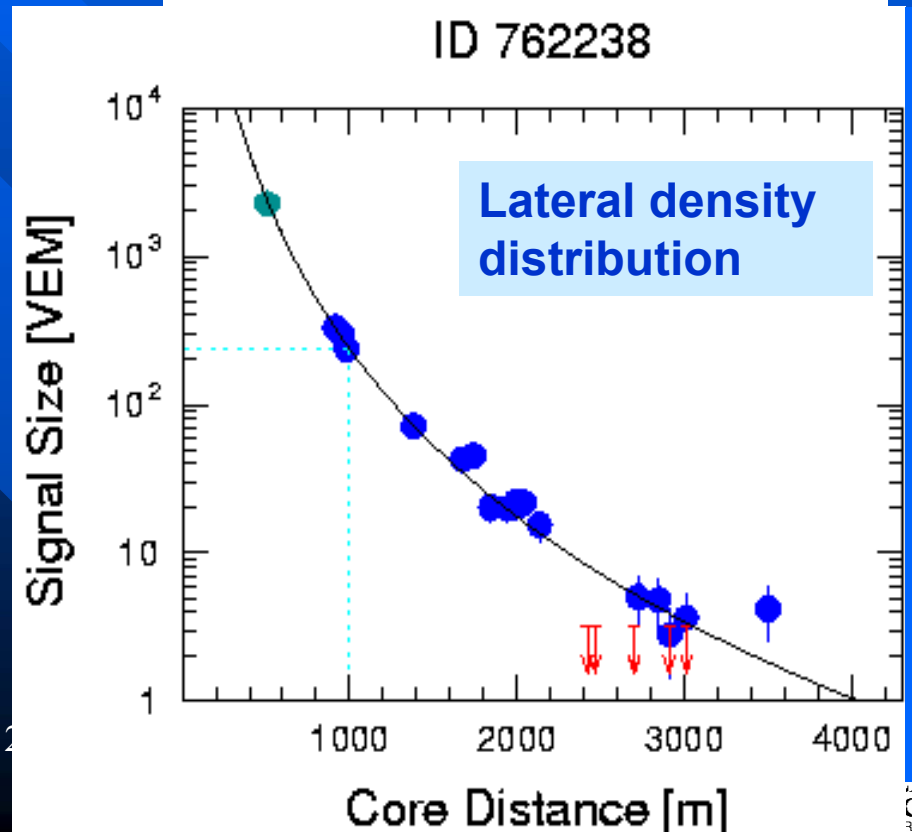
Obtain Signal in VEM at 1000 m

S(1000) => Energy

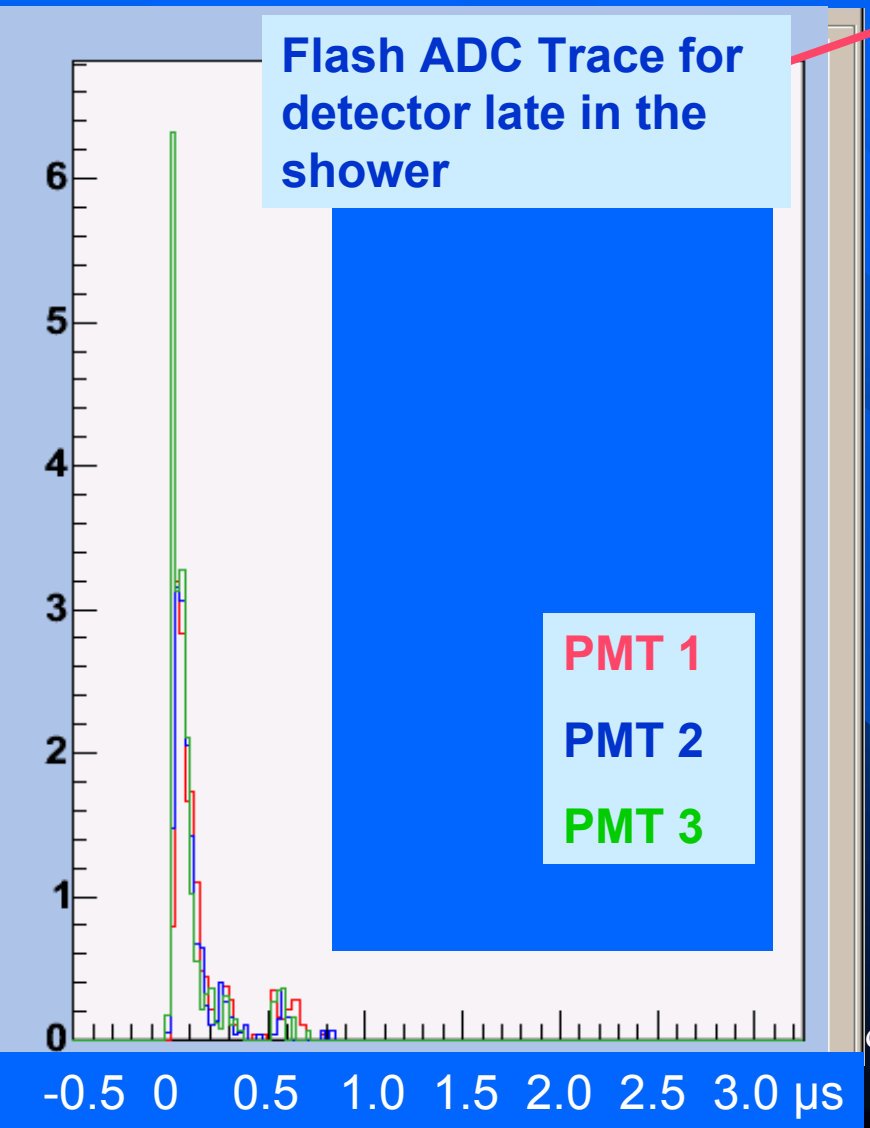
θ~ 48º, ~ 70 EeV

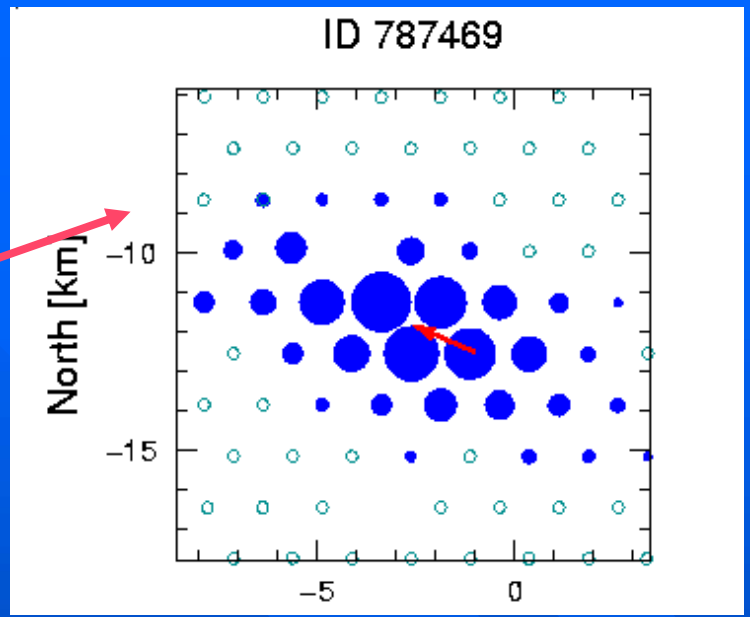

Typical flash ADC trace
Detector signal (VEM) vs time (ns)
Threshold
PMT 1
PMT 2
PMT 3
0
0.5
1
1.5
2
2.5
3
3.5
4
-0.5 0 0.5 1.0 1.5 2.0 2.5 3.0 μs

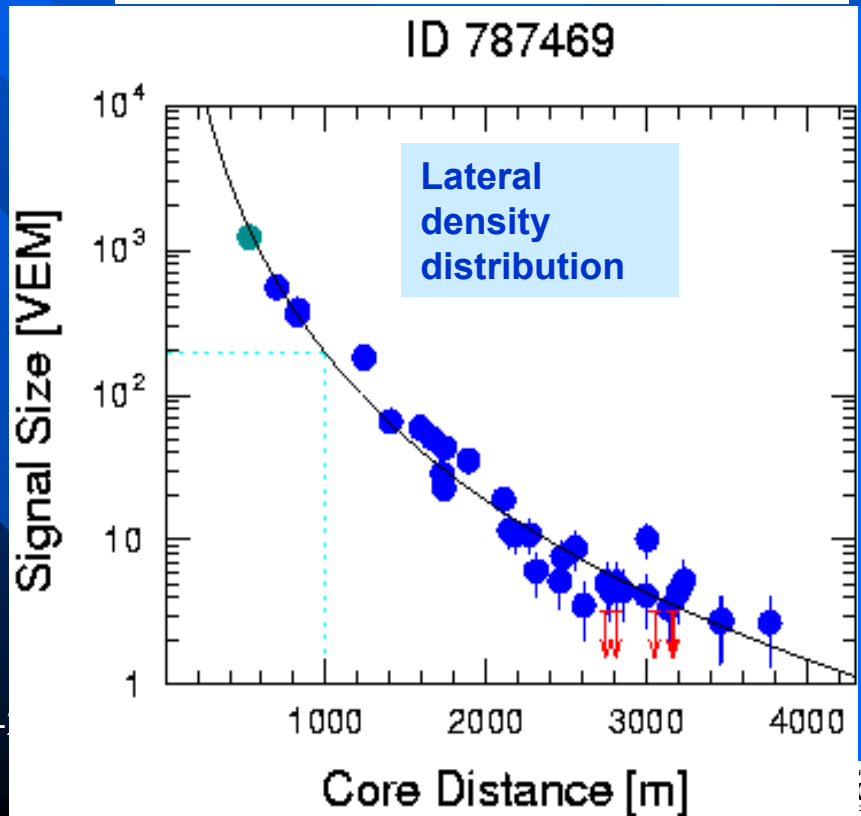

ID 762238
North [km]
-5
-10
-15
-10
-5


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

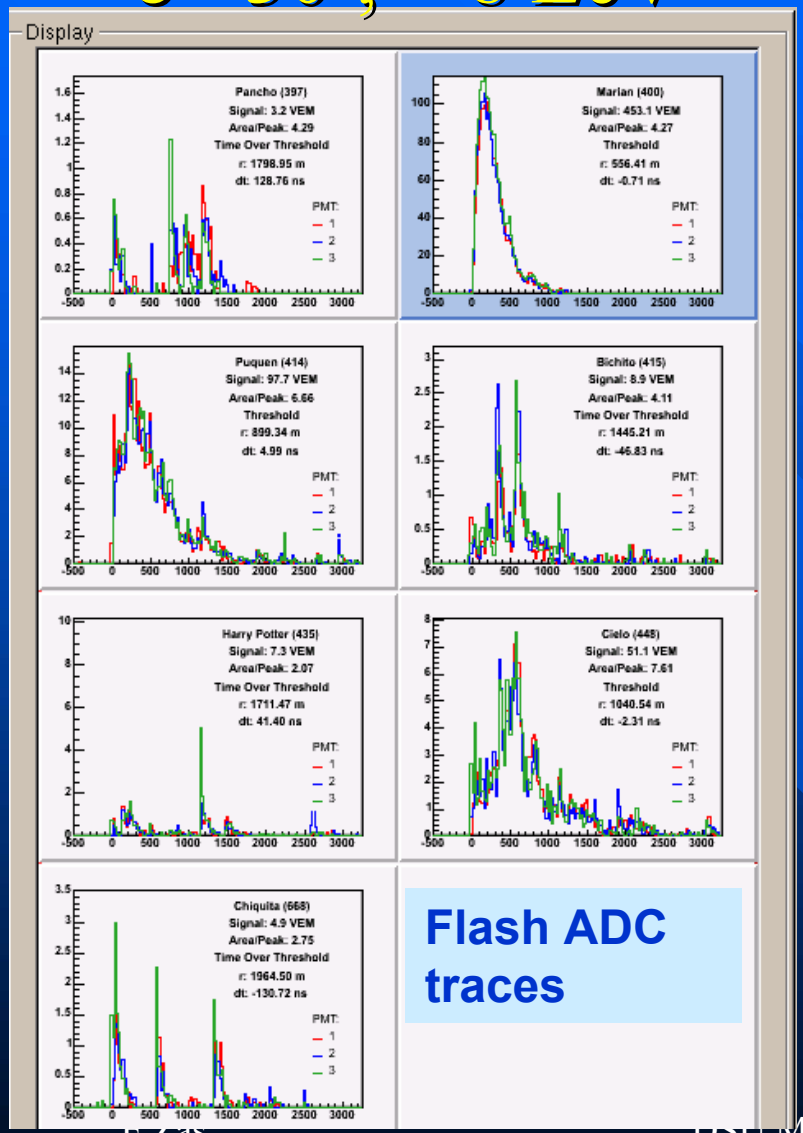
θ~ 60º, ~ 86 EeV

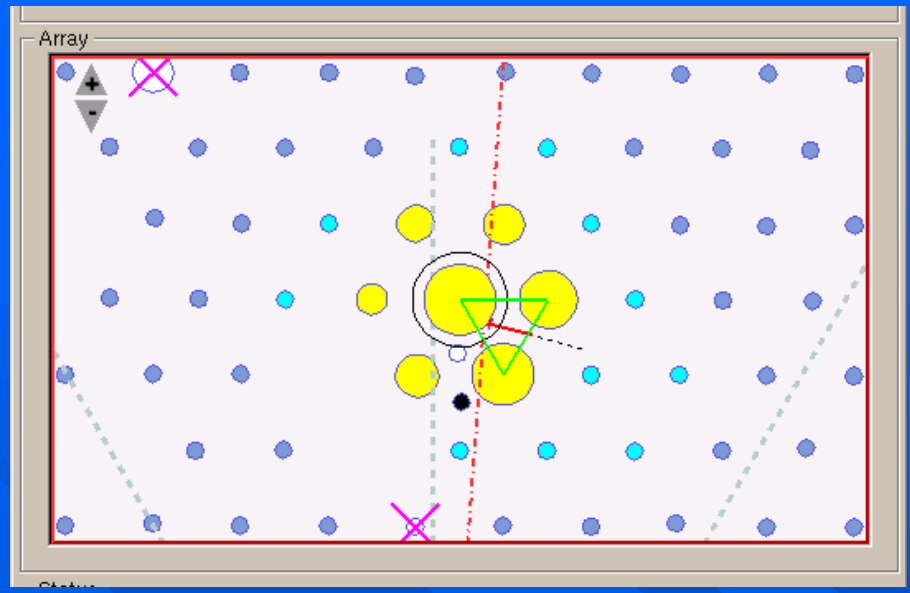

Flash ADC Trace for detector late in the shower
PMT 1
PMT 2
PMT 3
0
1
2
3
4
5
6
-0.5 0 0.5 1.0 1.5 2.0 2.5 3.0 μs

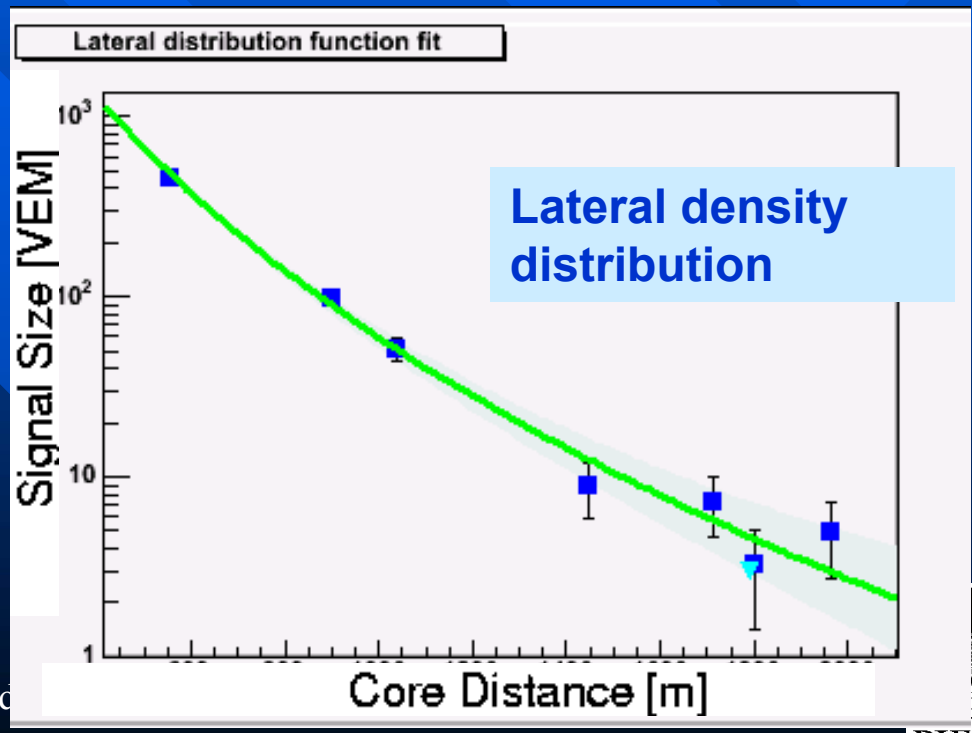

ID 787469
North [km]
-10
-15
-5
0


ID 787469
Lateral density distribution
Signal Size [VEM]
10^4
10^3
10^2
10
1
1000
2000
3000
4000
Core Distance [m]

Hybrid Event
θ~ 30º, ~ 8 EeV







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FD Reconstruction:

Pixel Geometry => Shower Plane

Timing => Direction

Signal+direction => Energy

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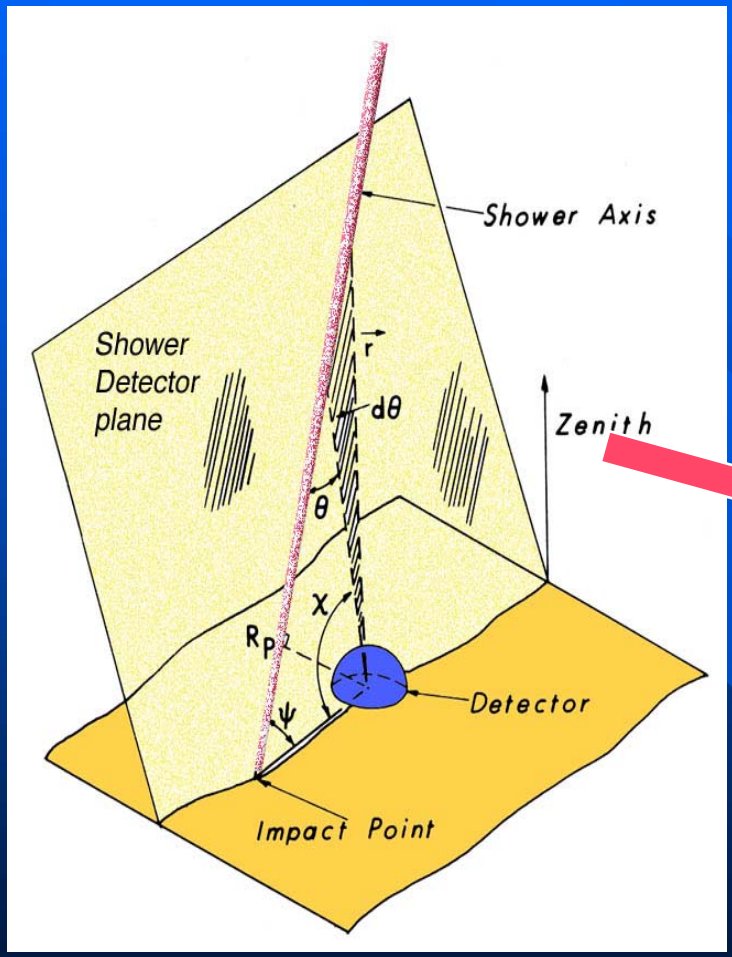
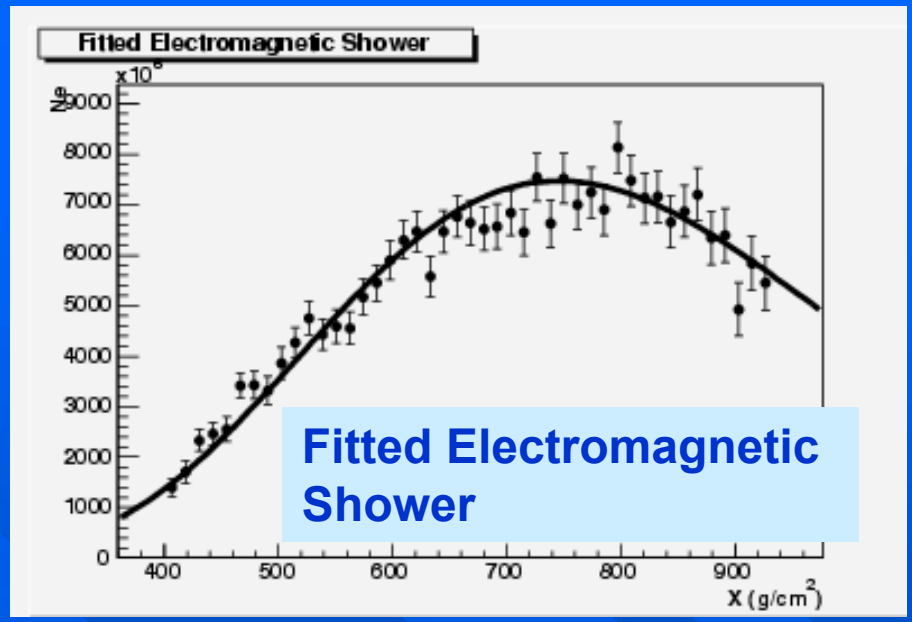
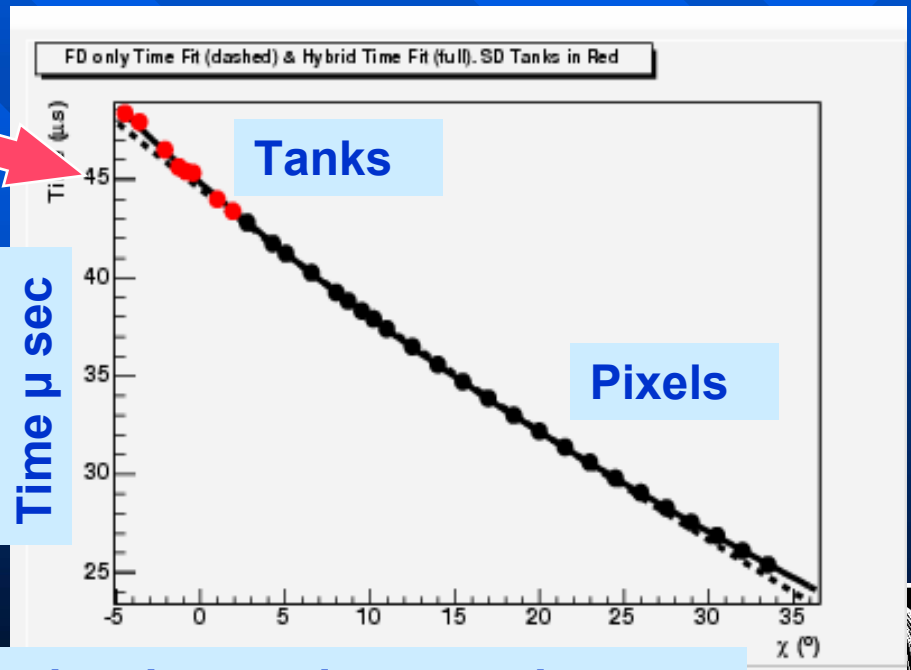
Same Hybrid Event
θ~ 30º, ~ 8 EeV







Angle χ in the shower-detector plane

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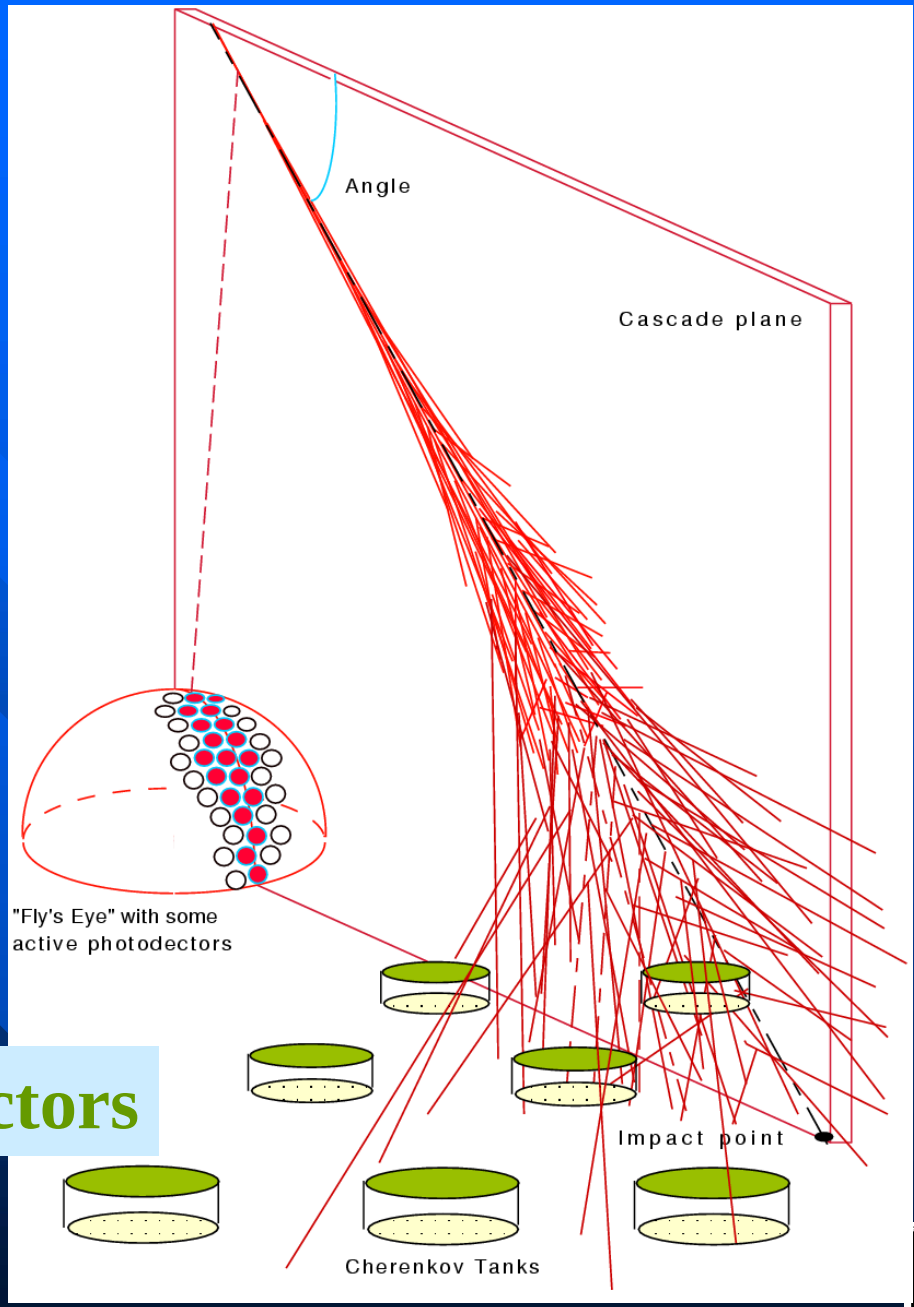
HYBRID:

Combine the two succesful techniques

powerful approach:

- **Angular accuracy**
- **Energy calibration**
- **Uncertainty tests**
- **Redundancy**
- **...**

Fluorescence



Array of particle detectors

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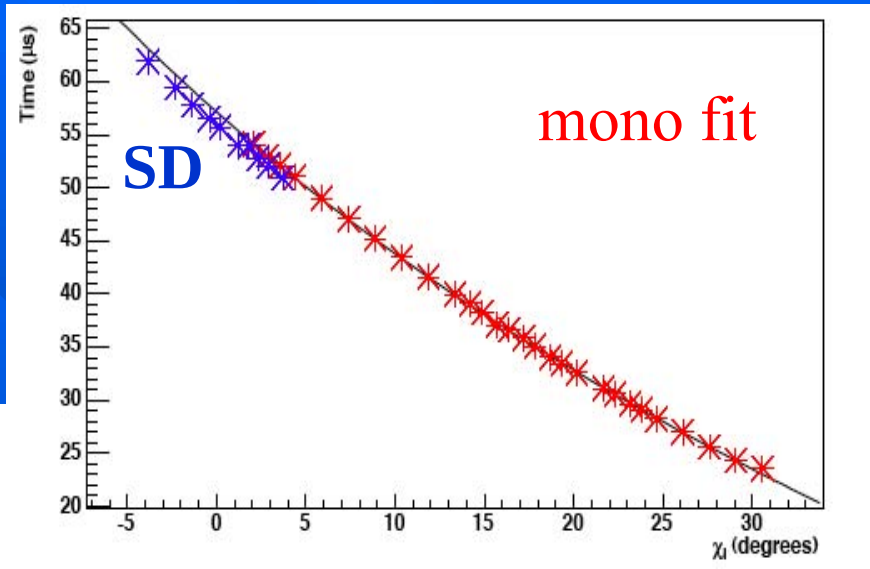
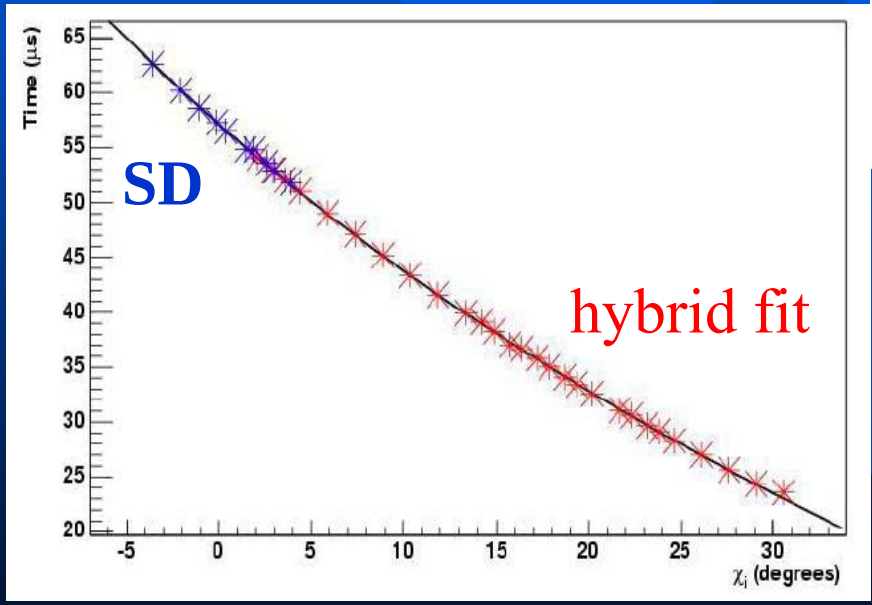
Hybrid at work:
Improve θ ϕ reconstruction using SD

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





$\Delta\psi \sim 0.6^0$

including SD times

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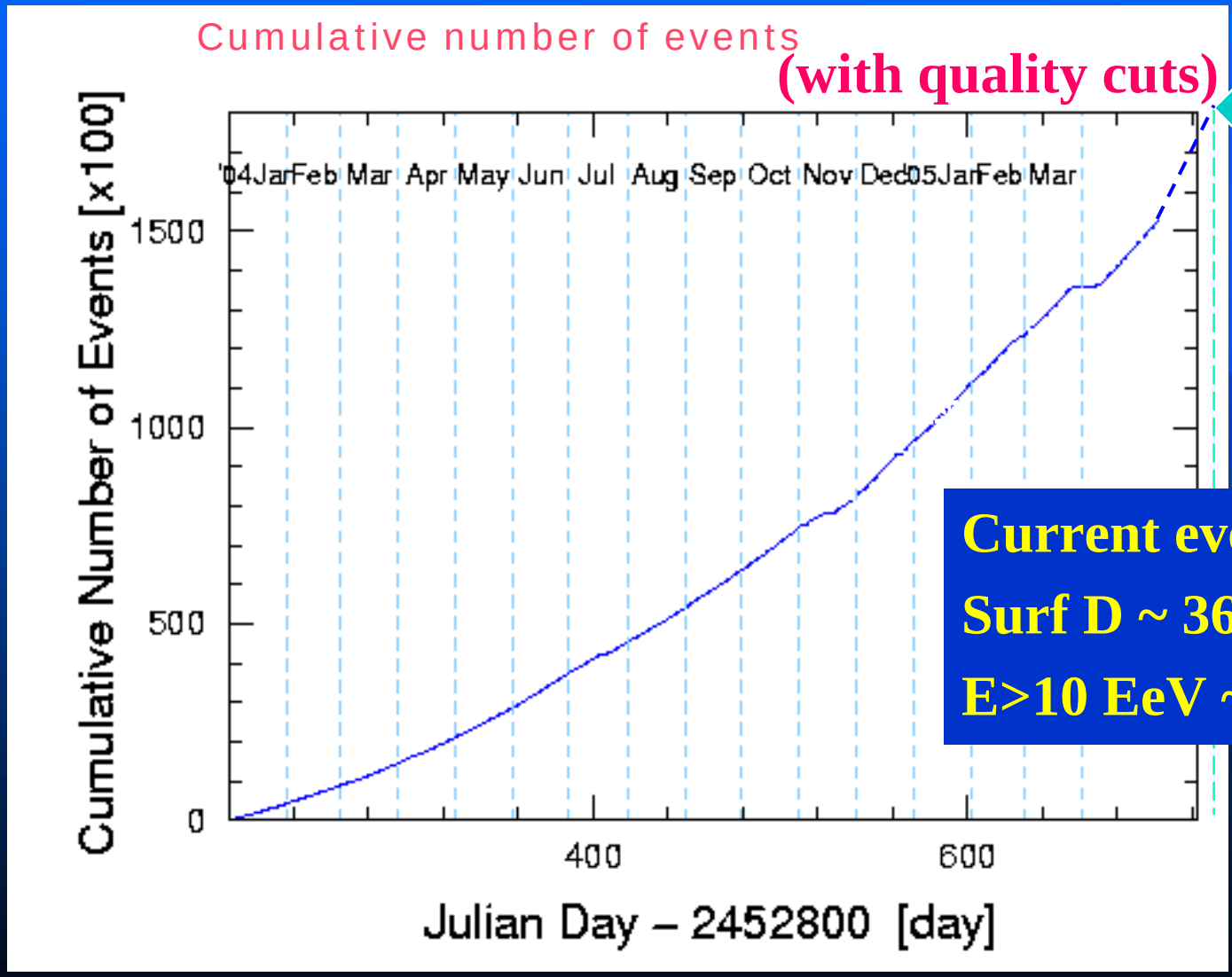
The First Data Set (29 ICRC Pune)

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 ~ 36,000 / month

E>10 EeV ~ 60 / month

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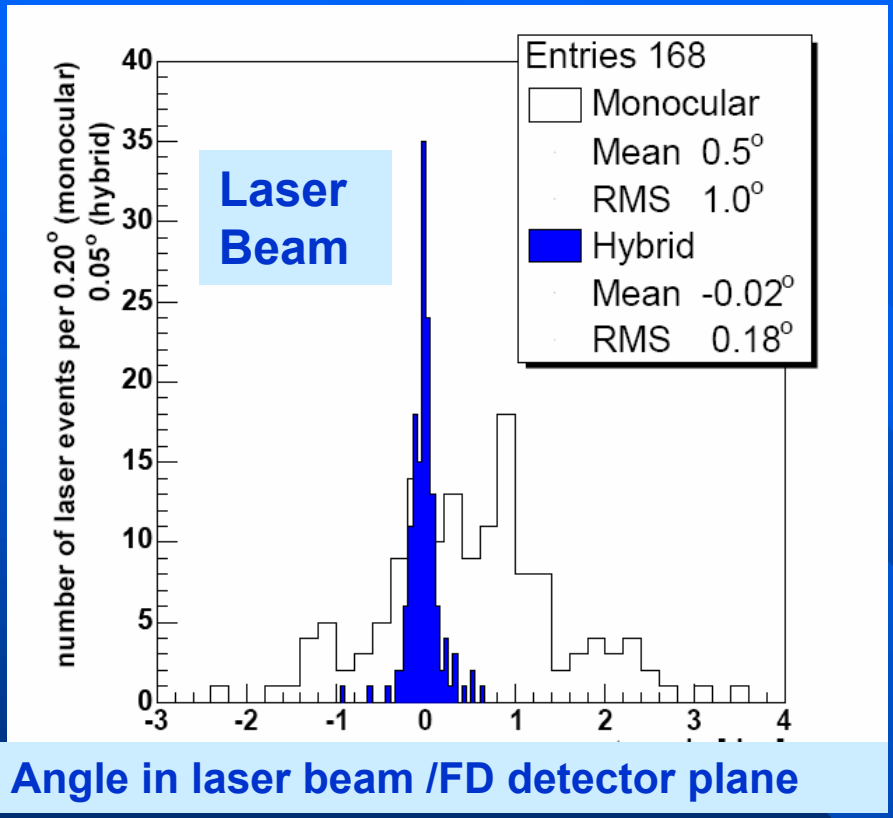
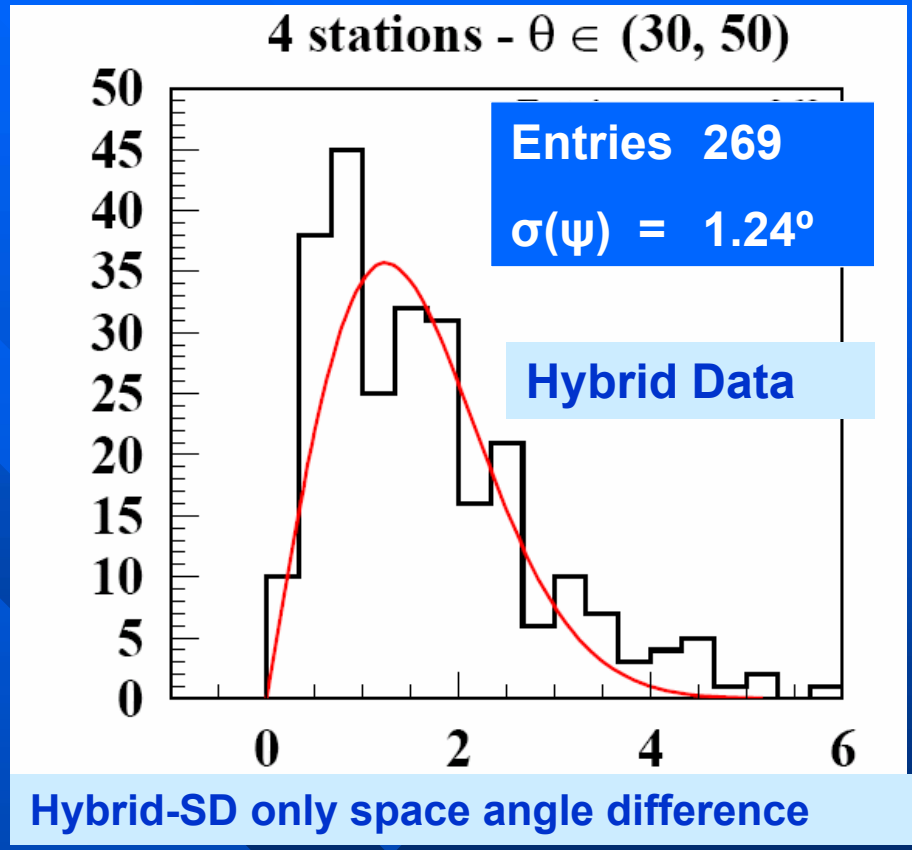
Performance: *Angular Resolution*



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)

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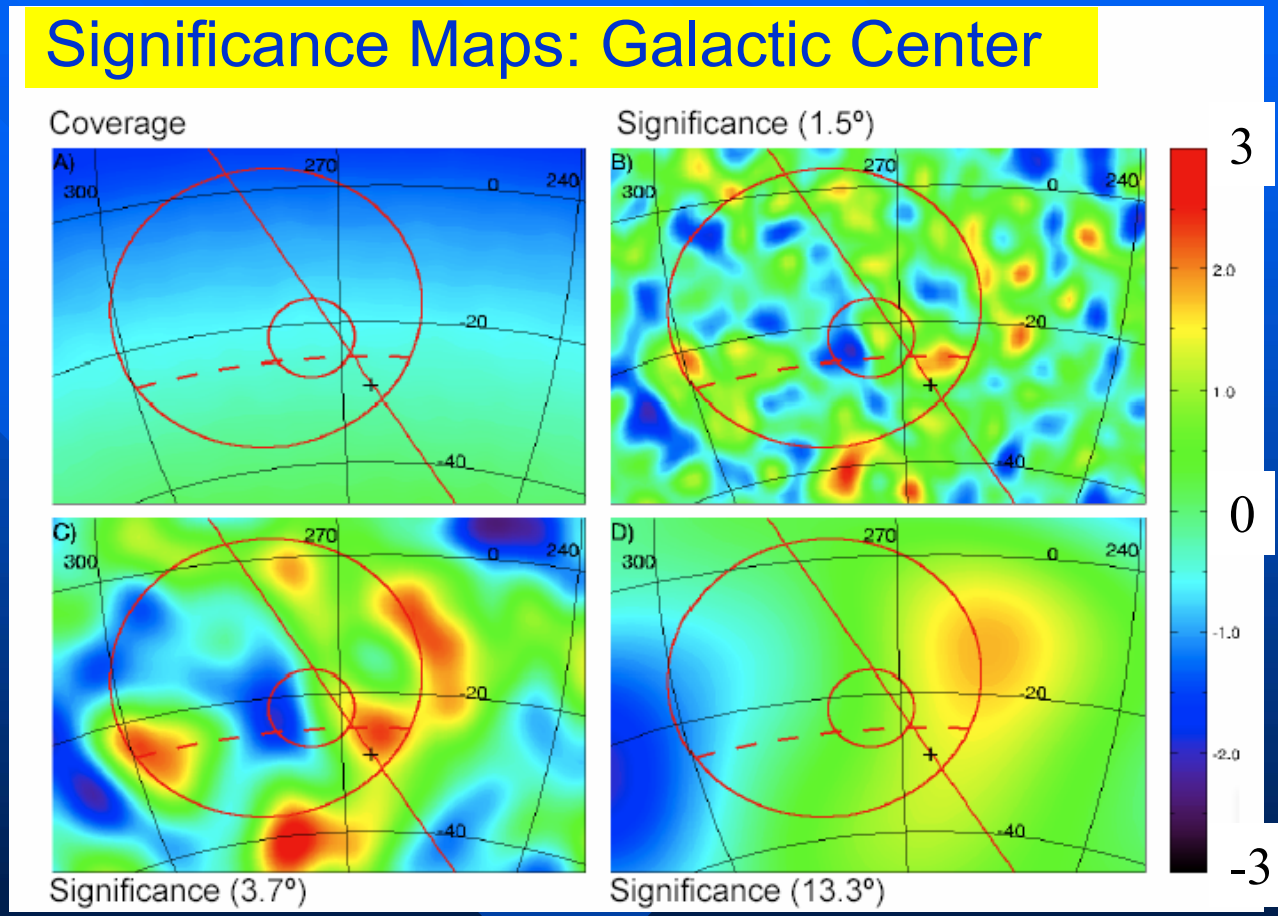
ANISOTROPY SEARCHES: No evidence of Clustering

- Top hat 5° [0.8-3.2EeV] SUGAR results =>10.5 σ
- Top hat 20° [1-2.5EeV] AGASA results =>7.5 σ



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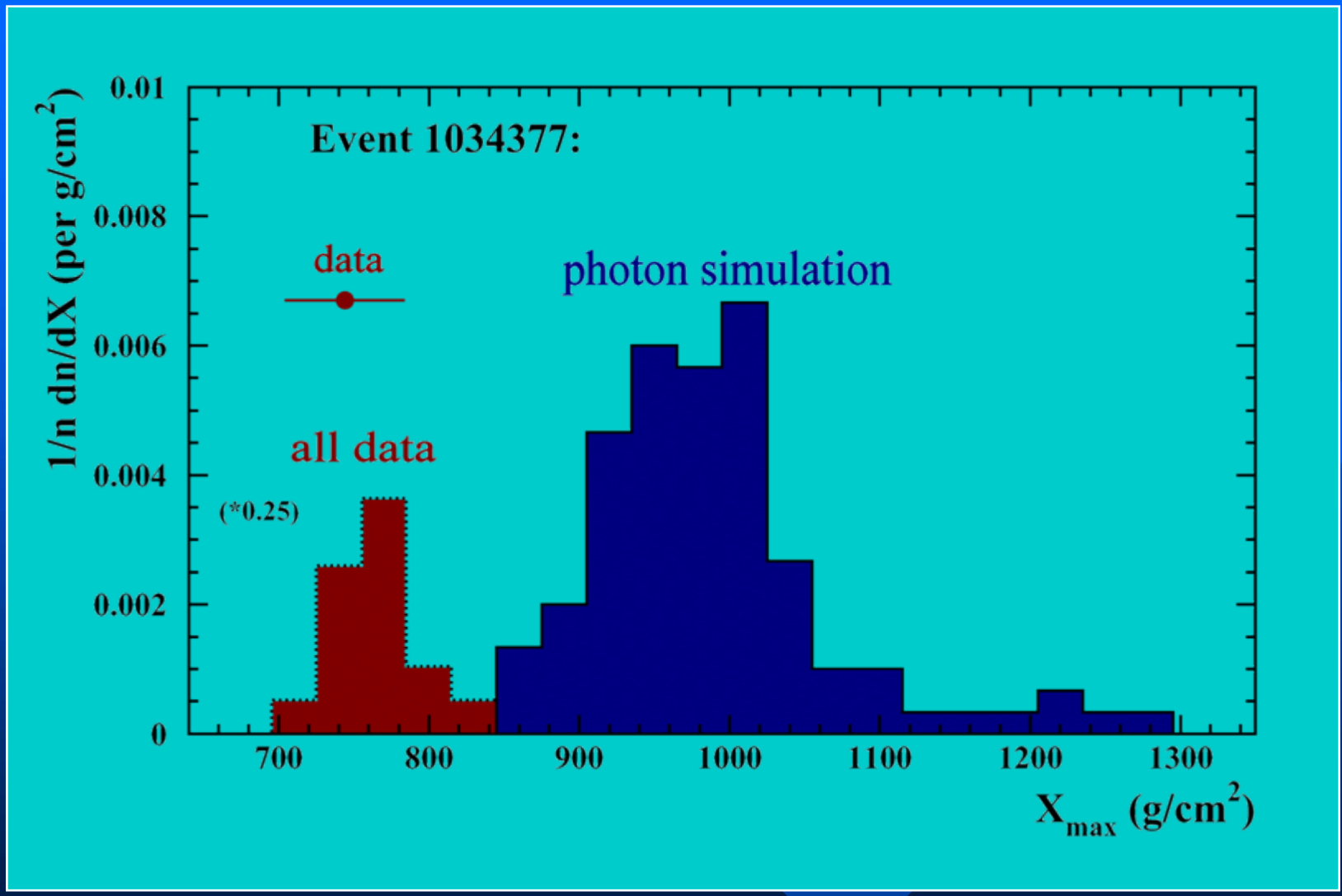
NEW PHOTON LIMIT:



Xmax distributions of selected sample of 28 hybrid events

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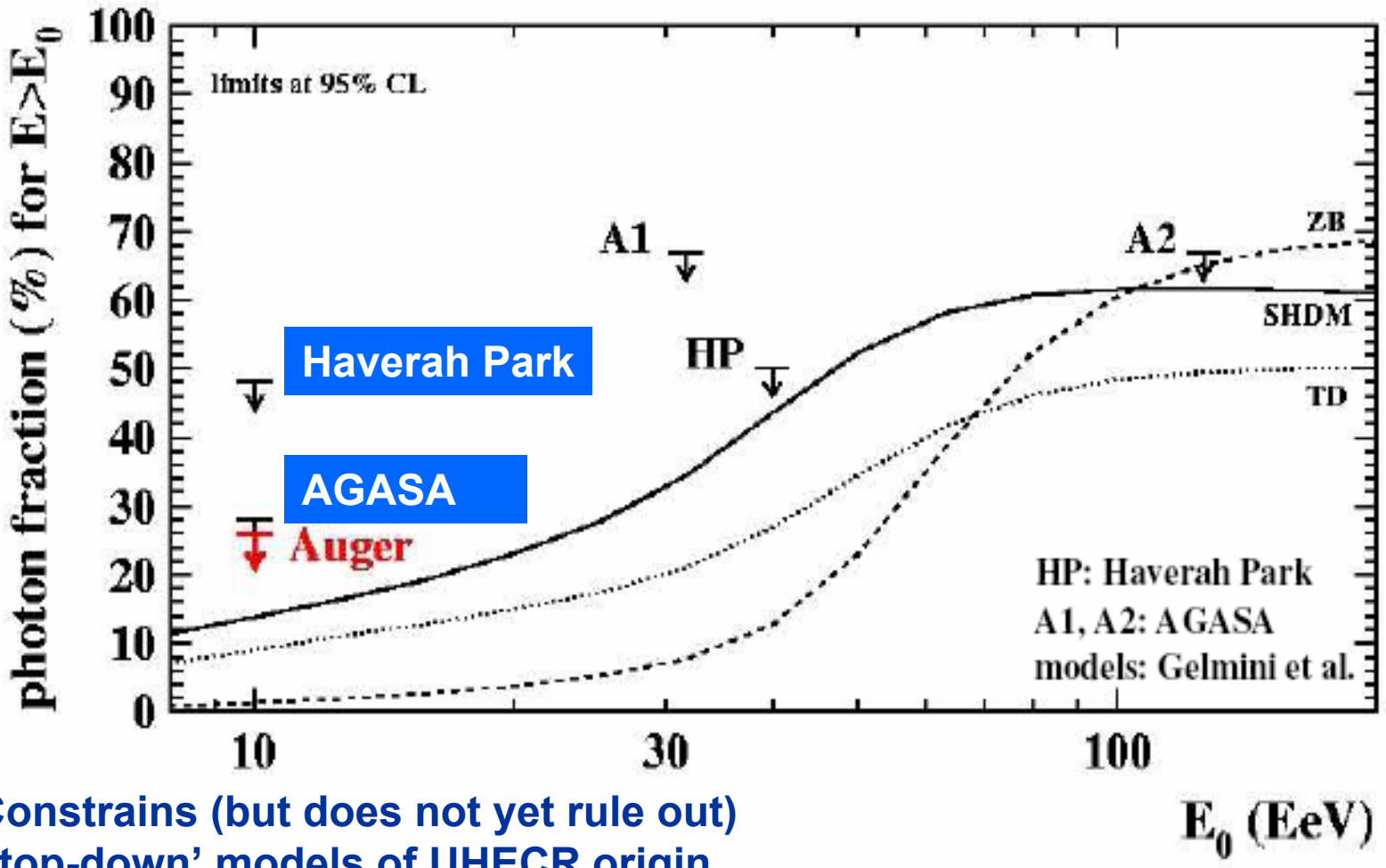
New upper limit



Constrains (but does not yet rule out) 'top-down' models of UHECR origin

- **26% upper limit** (95% CL) on cosmic-ray photon fraction

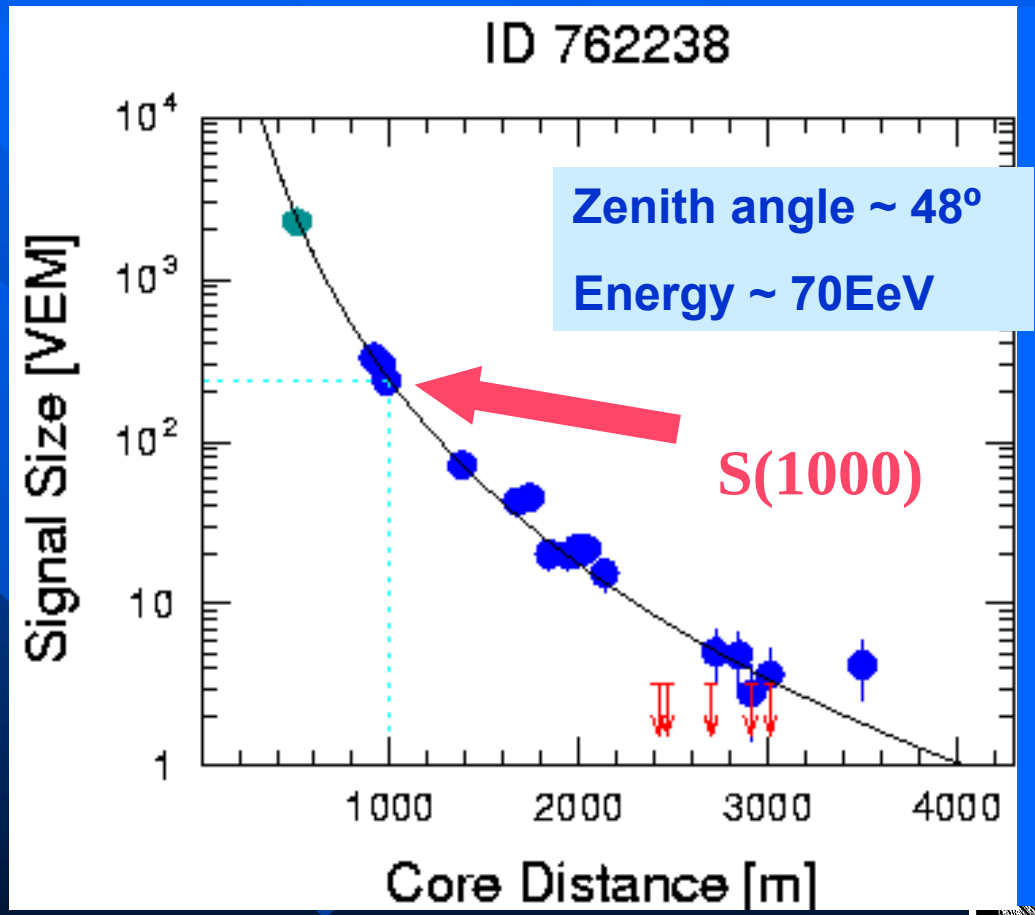
PIERRE AUGER OBSERVATORY

AUGER Energy Determination

Energy calibrated by fluorescence:
Insensitive to interaction models
and composition assumptions.

Use S(1000) as SD
Energy estimator

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

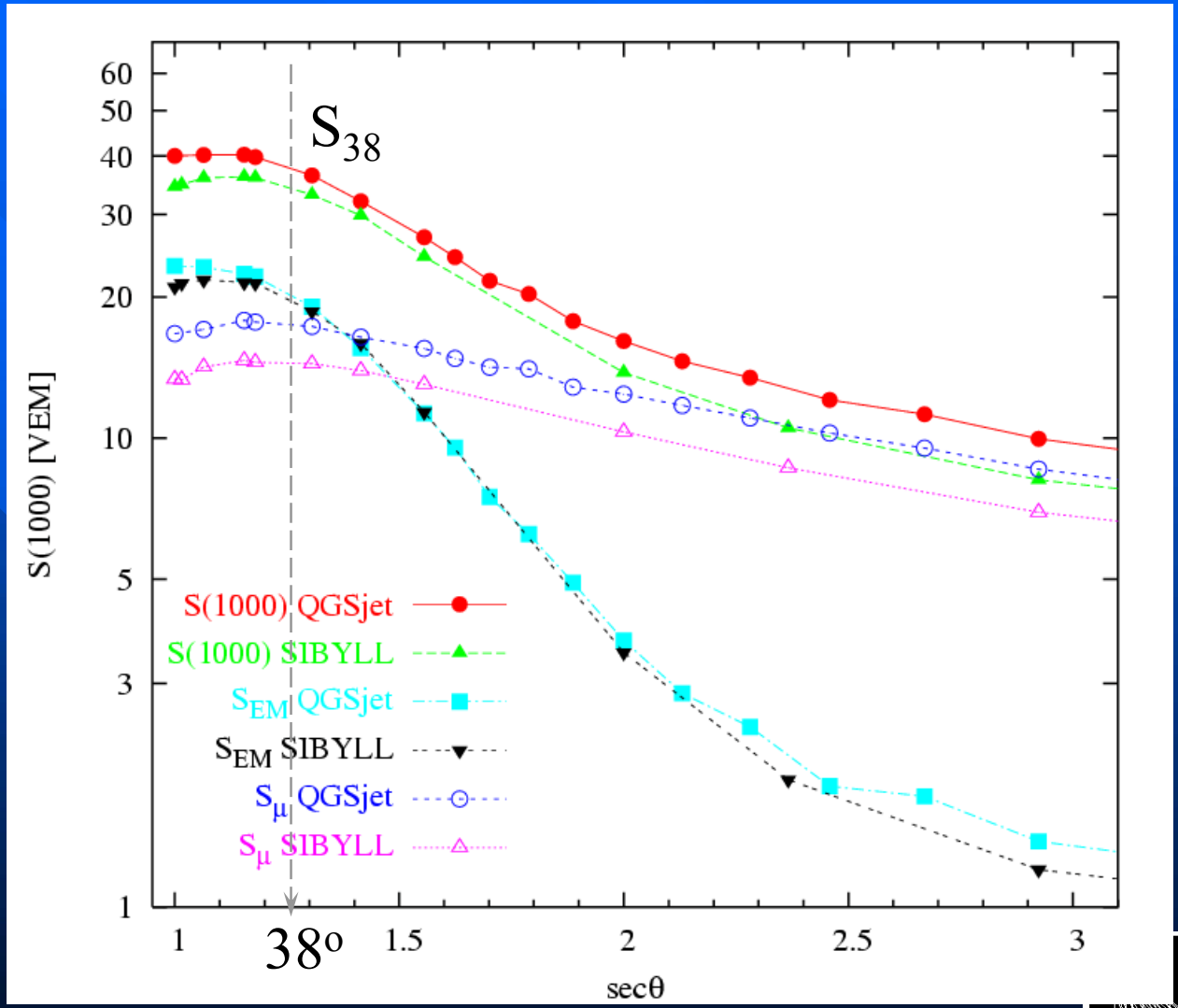


PIERRE AUGER OBSERVATORY

S(1000) hadronic model dependence

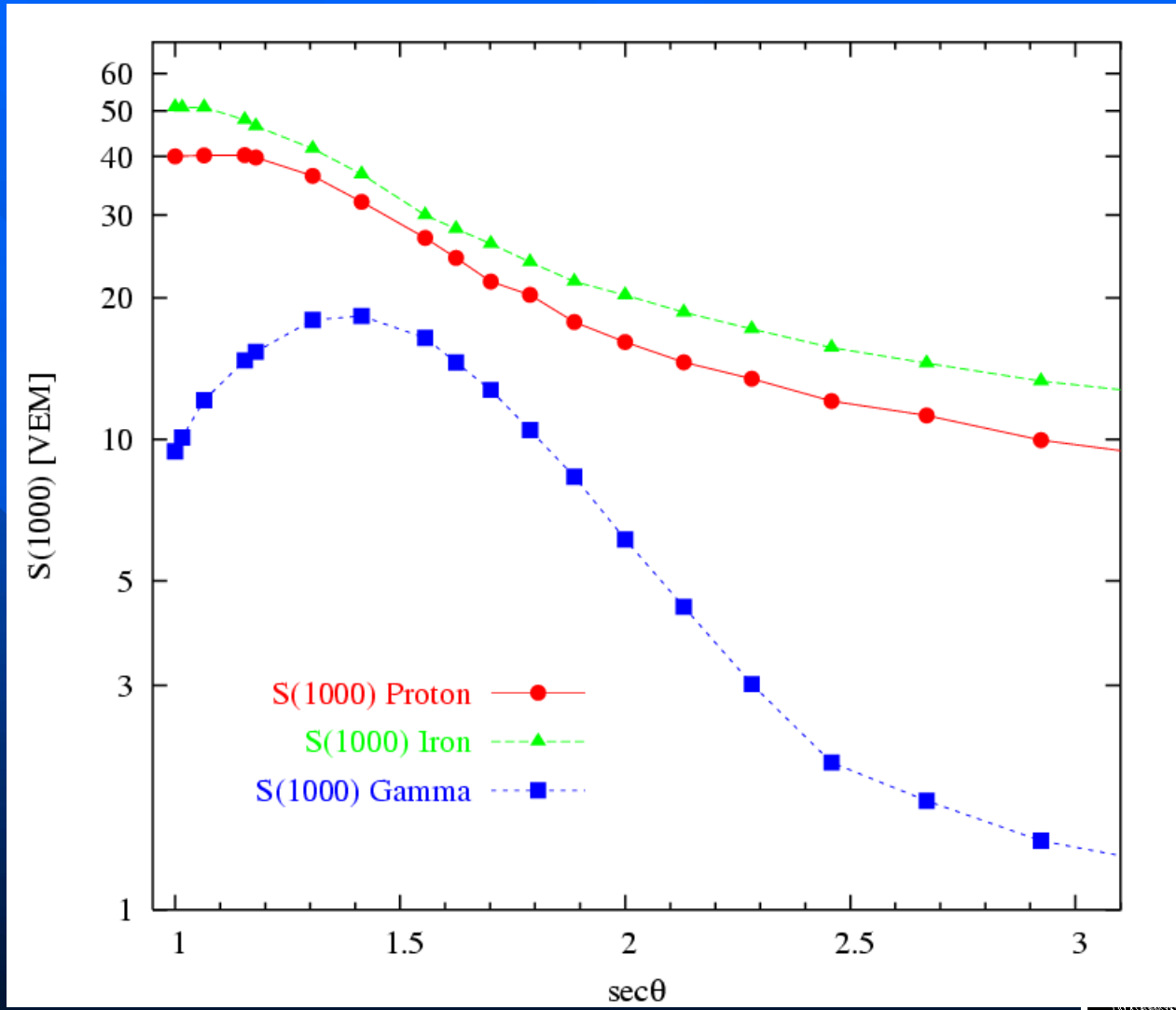
S(1000) @ secθ =1

QGSjet	SIBYLL
40.02	34.49



PIERRE AUGER OBSERVATORY

S(1000) composition dependence



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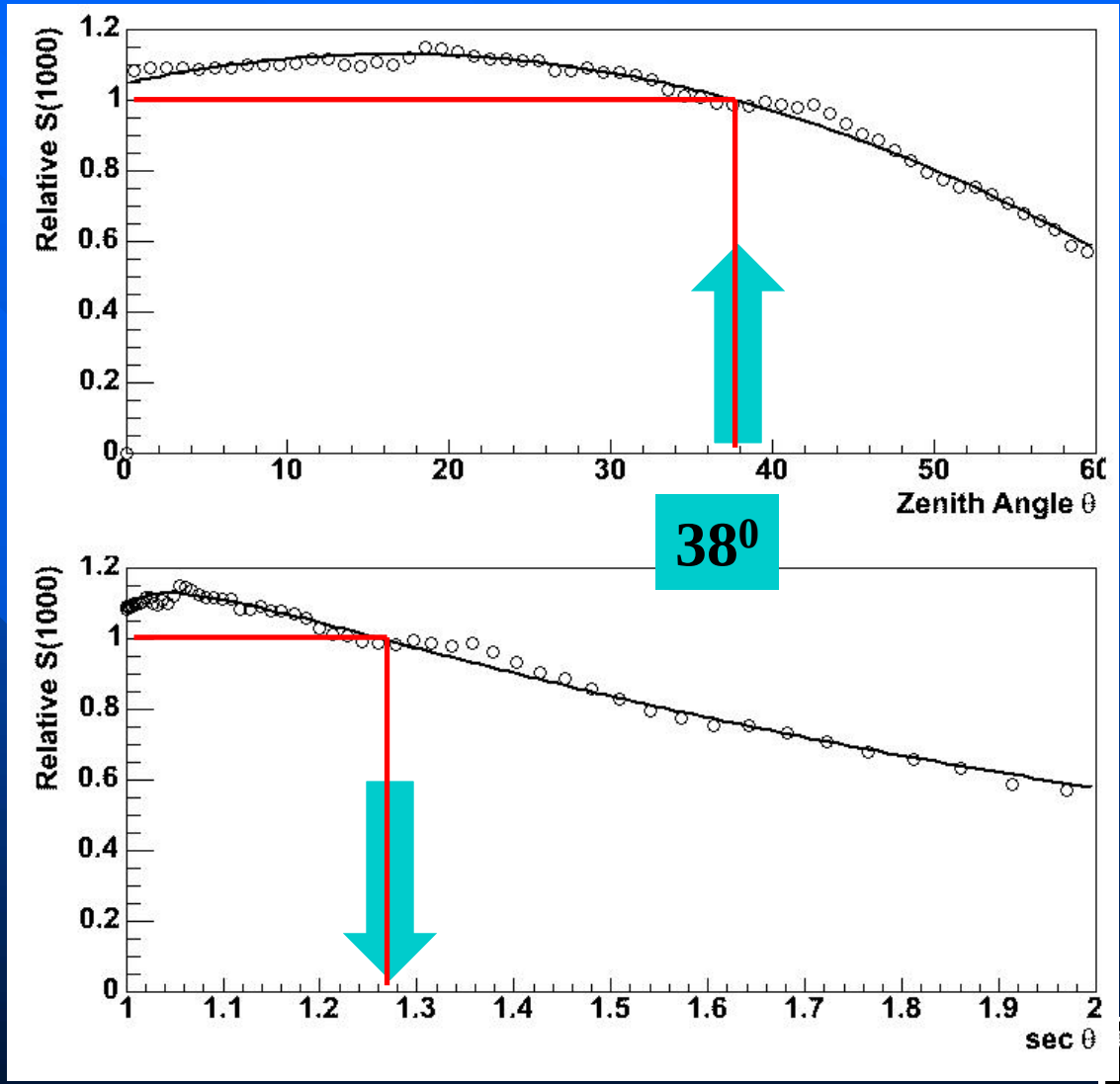
Use constant Intensity Cut method:

Relative S(1000) values for different zeniths are obtained from data assuming isotropic flux

Reference at 38^0: the median of the $0^0<\theta<60^0$ distribution



PIERRE AUGER OBSERVATORY

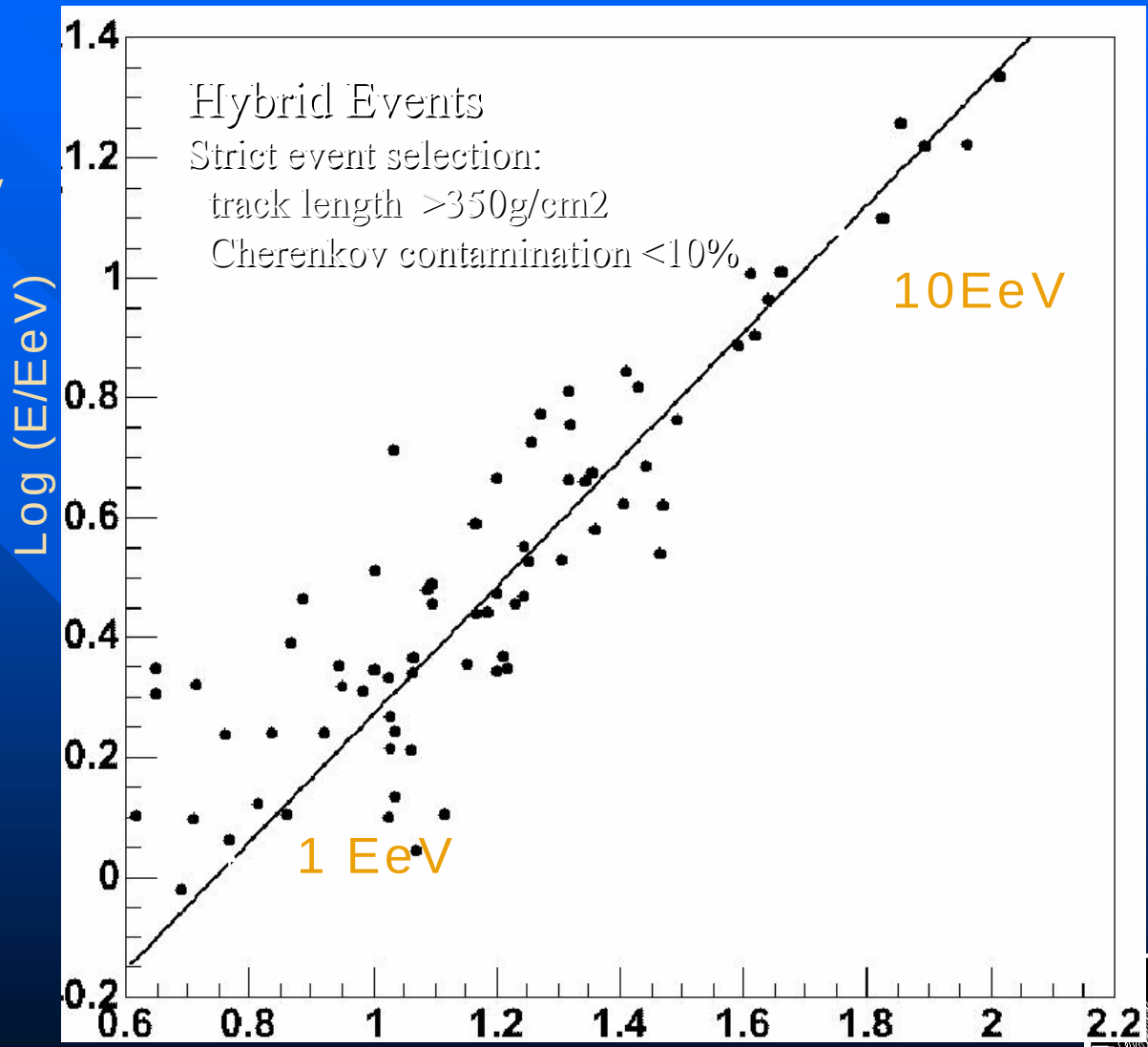
Energy determination and Spectrum

The energy converter:

S38(1000) α FD Energy

Use for SD events

Uncertainty in scale is Statistics limited



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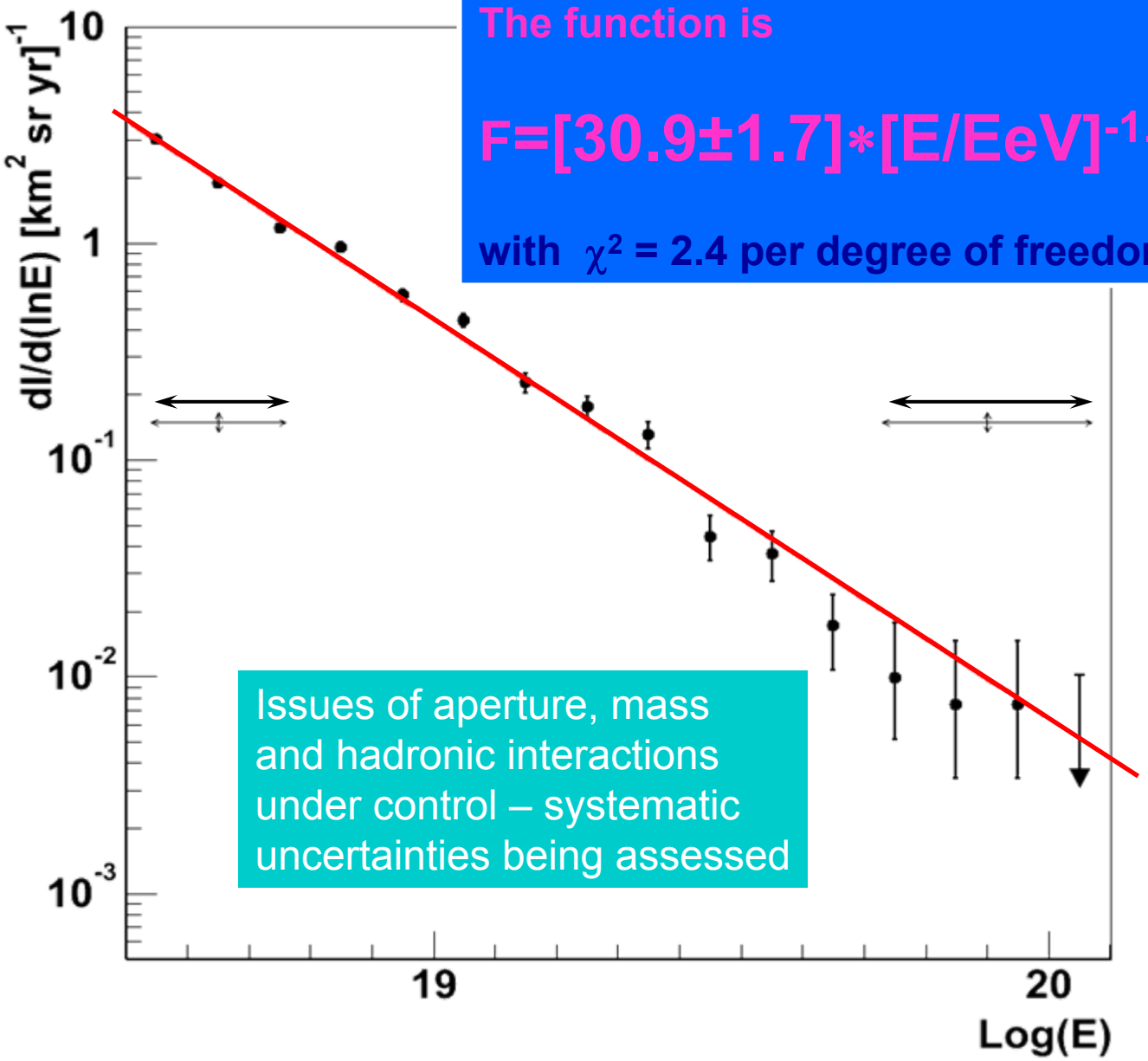
Auger Energy Spectrum



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

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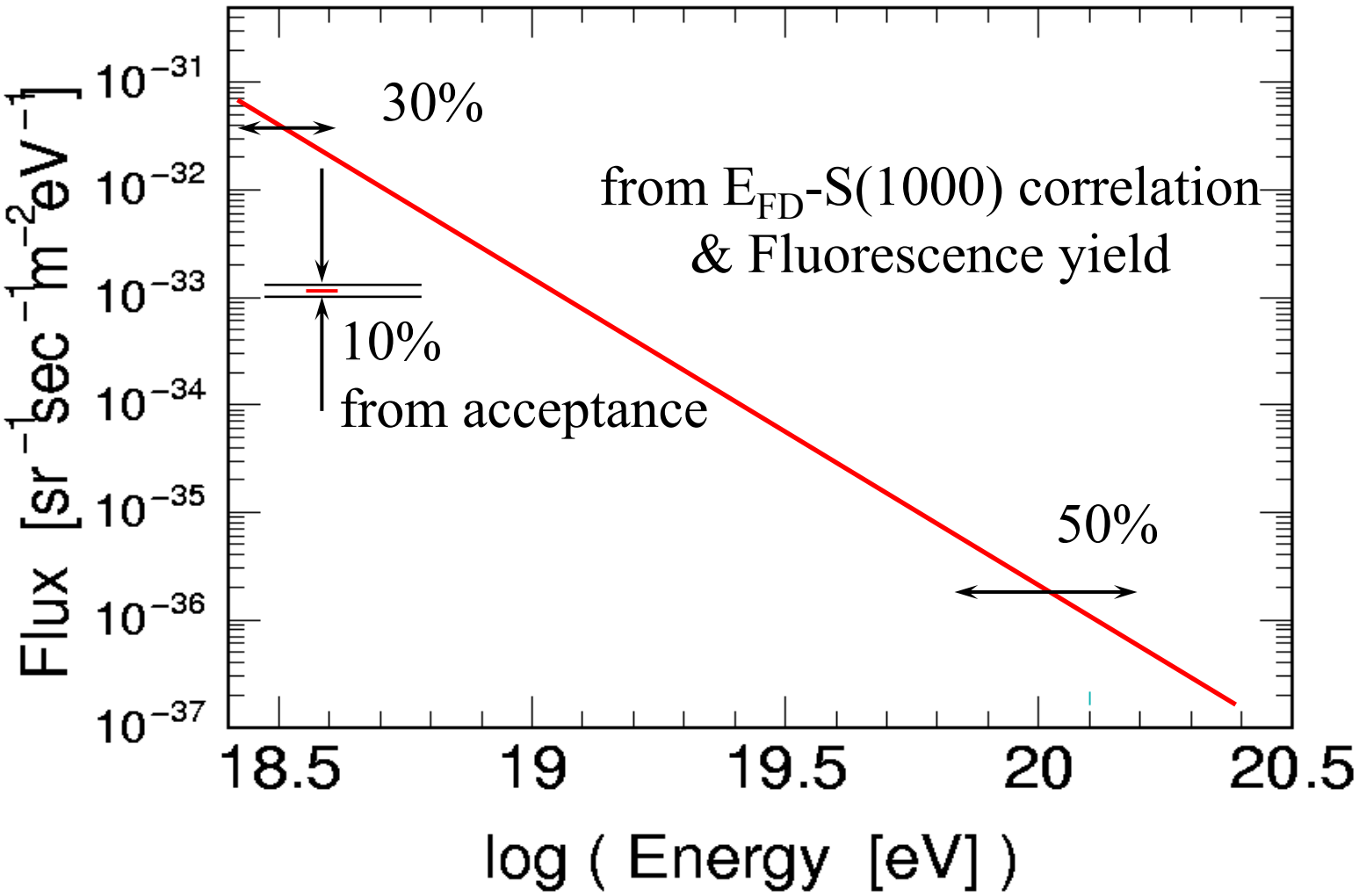
Uncertainties



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

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

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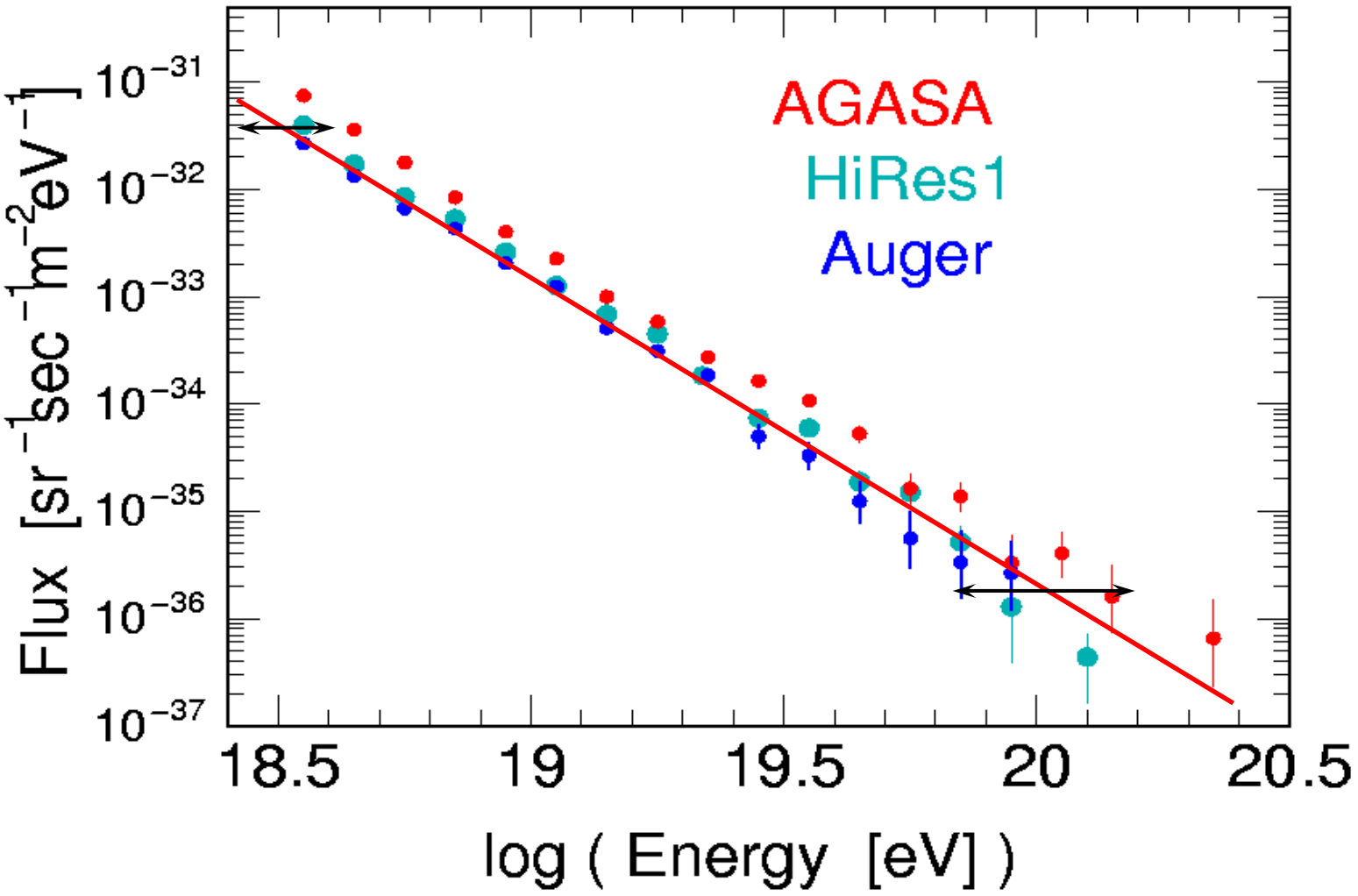
Comparison with HiRes1, AGASA



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

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

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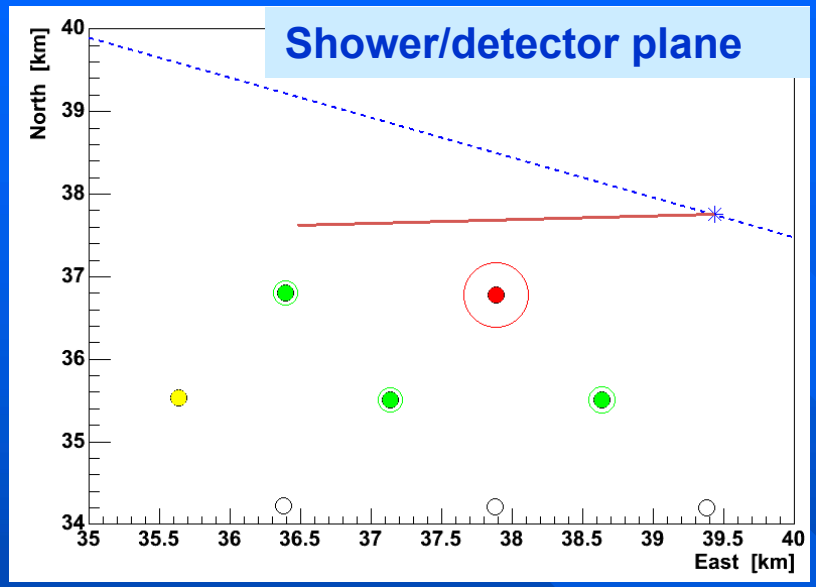
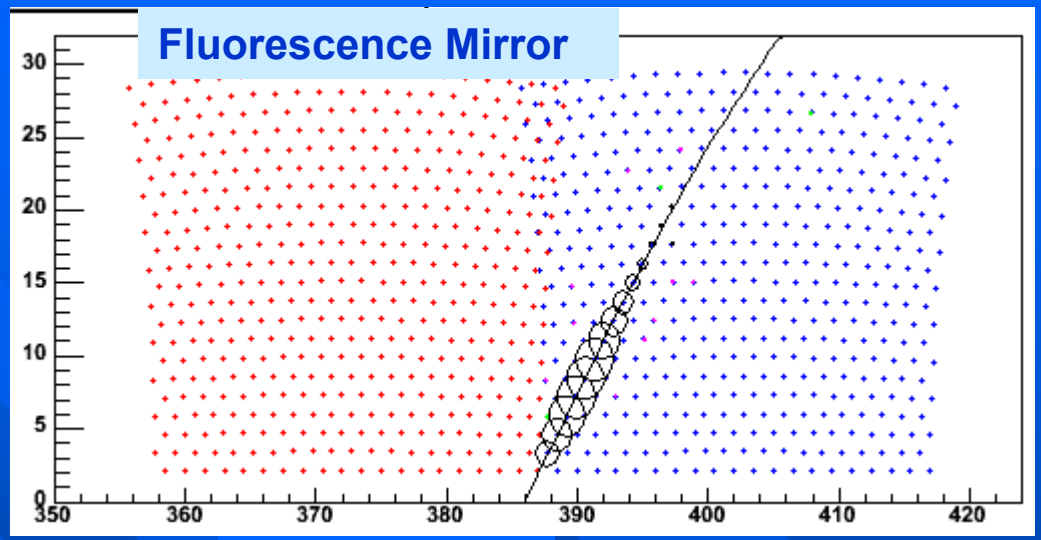
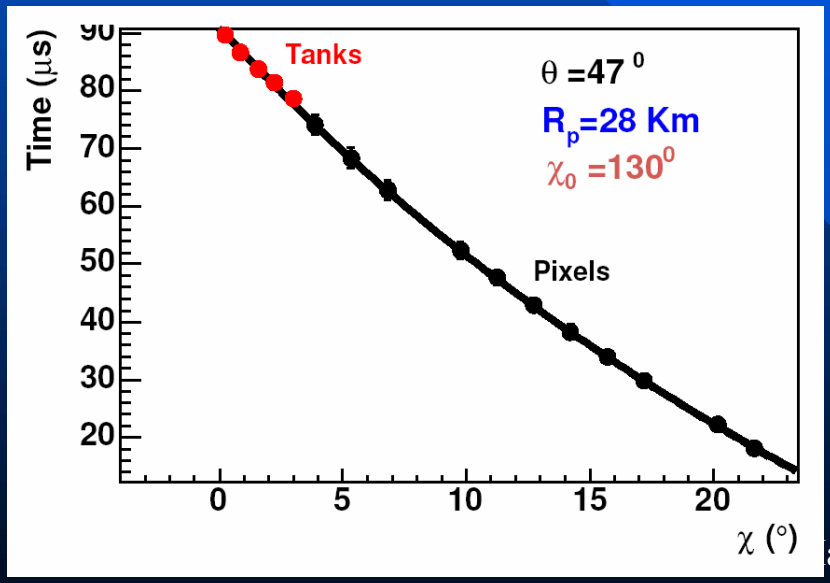
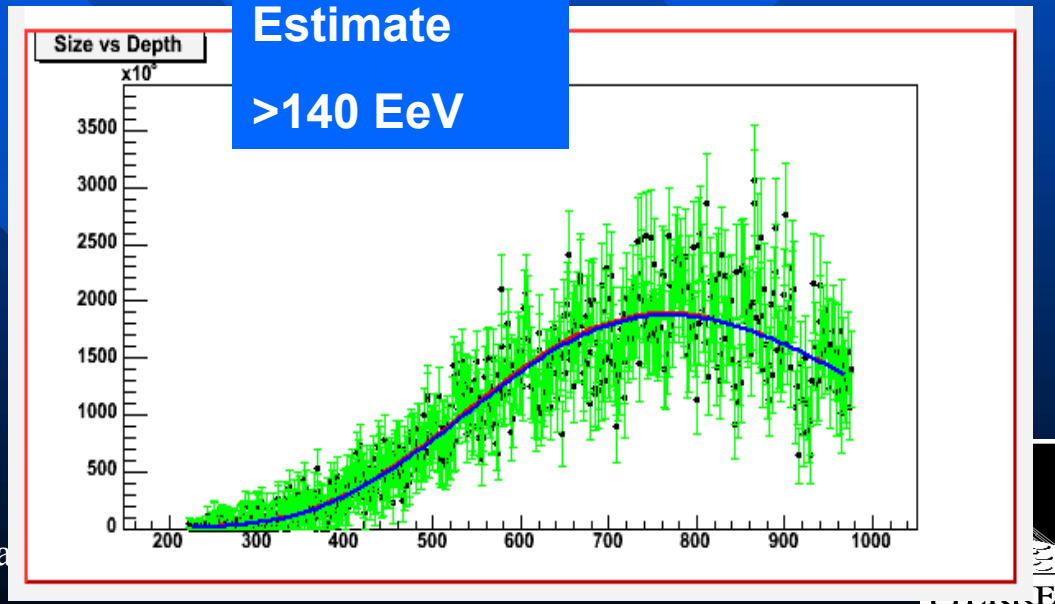
A Big Event - *One that got away!*





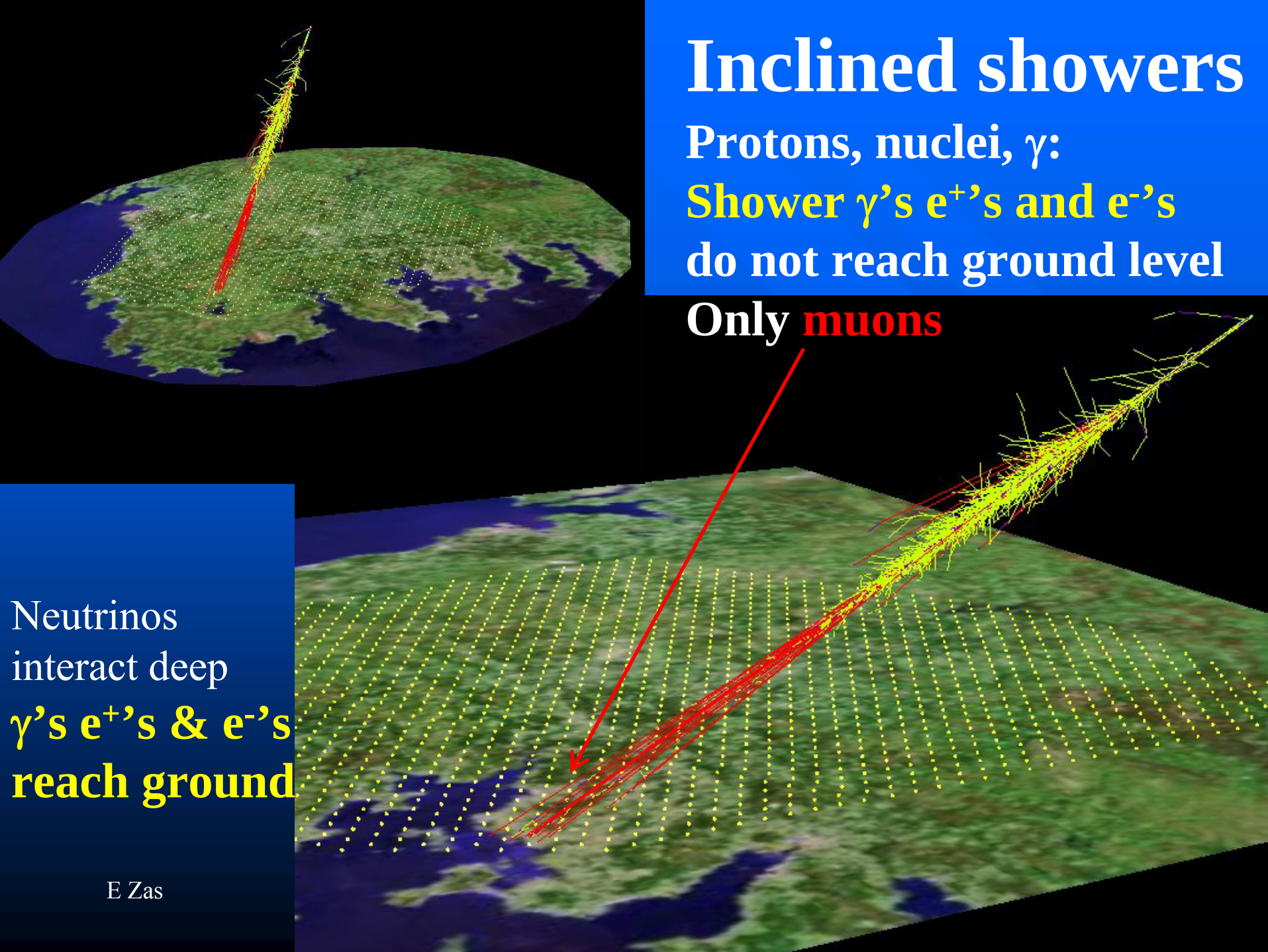




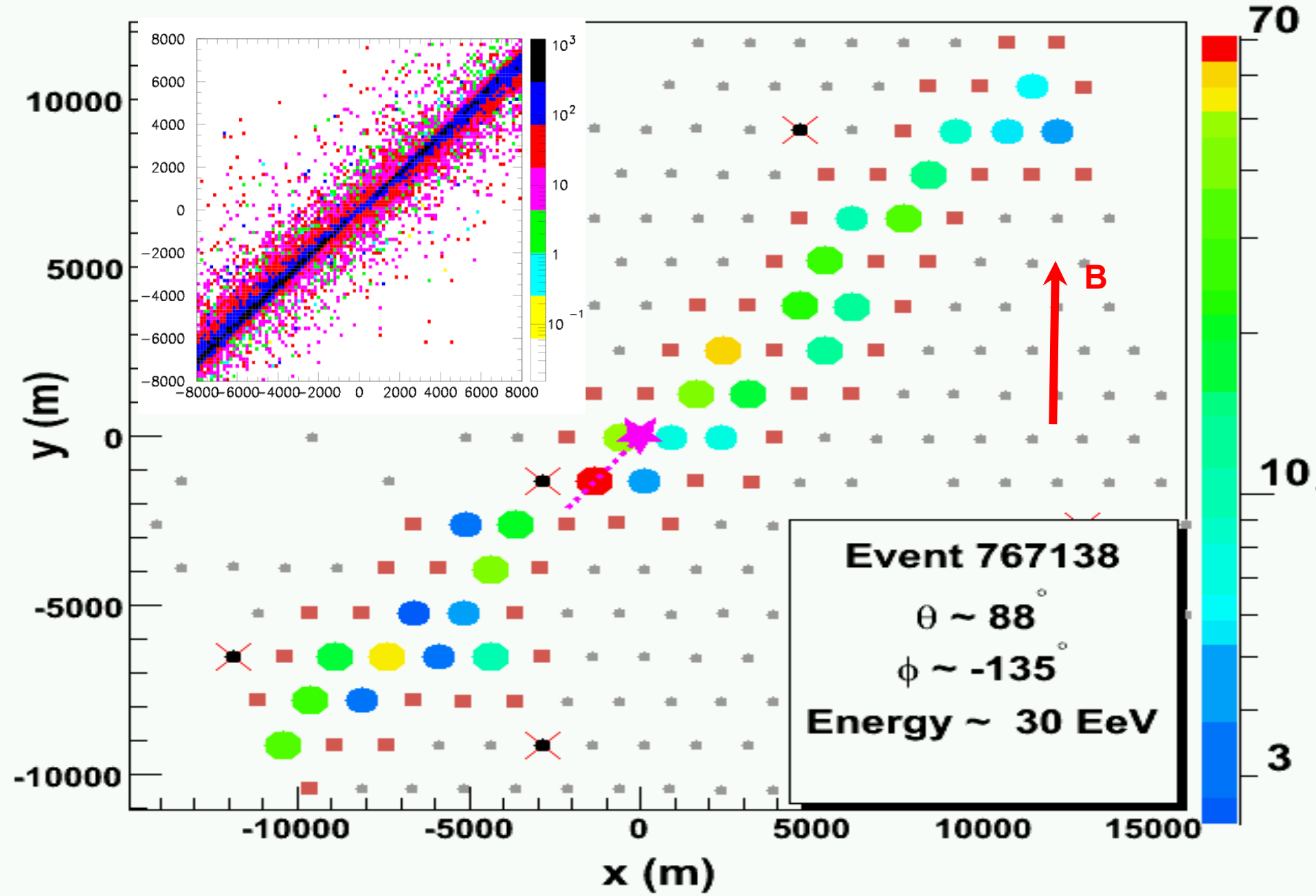
Inclined Air Showers

Can be induced by:

- Neutrinos
  - Down-going neutrinos interacting with the atmosphere
  - Earth skimming neutrinos interacting just below groud level
- Cosmic Rays
  - Measure different component: Muons => Composition
  - Background for neutrinos
- Hard muon processes: mainly muon bremsstrahlung
  - Sensitive to the prompt muon flux
  - Background for neutrinos
- Exotic particles?


Inclined showers
Protons, nuclei, γ:
Shower γ's e+'s and e-'s
do not reach ground level
Only muons
Neutrinos
interact deep
γ's e+'s & e-'s
reach ground
E Zas

Spectacular inclined events routinely seen

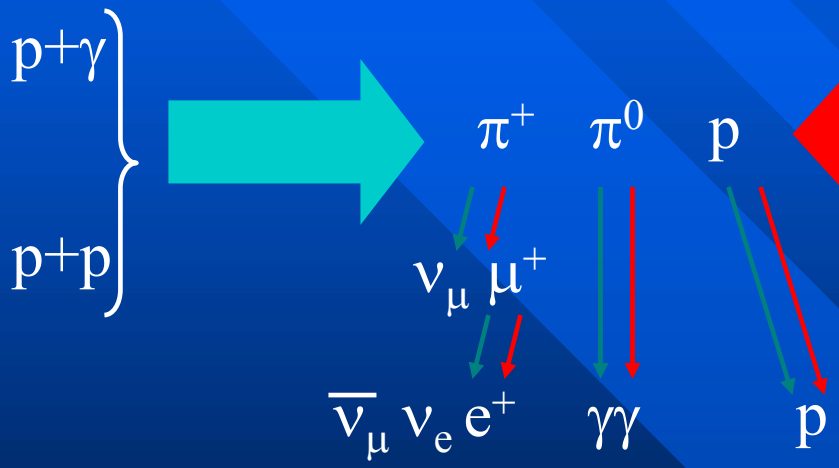


Conclusions:

- **First results (2005) (integrated acceptance AGASA)**
- **Auger has measured a spectrum quasi-independent of compostion and simulations**
- **No clustering evidence**
- **New limit of 16% photon abundance (in press)**
- **Much redundancy and improvement is expected with more hybrid data, more SD statistics, inclined events, soon (now we have > 2 x AGASA exposure)**
- **Hadronic Models will be needed for interpretation**

ν: UHECR source classification

- **Acceleration**
- **Fragmentation**



$q\bar{q} \leftarrow X$

p : π^0 : $\pi^{+/-}$
0.03 : 0.3 : 0.65

p : ν
1 : 3

γ : $\bar{\nu}_\mu$: ν_e : ν_μ : $\bar{\nu}_e$
2 : 2 : 1 : 2 : 1

p : γ : ν
0.09 : 2 : 6

Δ threshold

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A *heavy* task : Primary Composition

reduced fluctuations

- Xmax fluctuations ↓

- Xmax **(elongation rate)** ↓
- Time delay ↓
- Risetime ↓
- Lateral distribution **(flatter)**

Heavy

early

more μ

- μ / (γ e) ratio ↑
- Inclined shower rate ↑

(Also for γ's)

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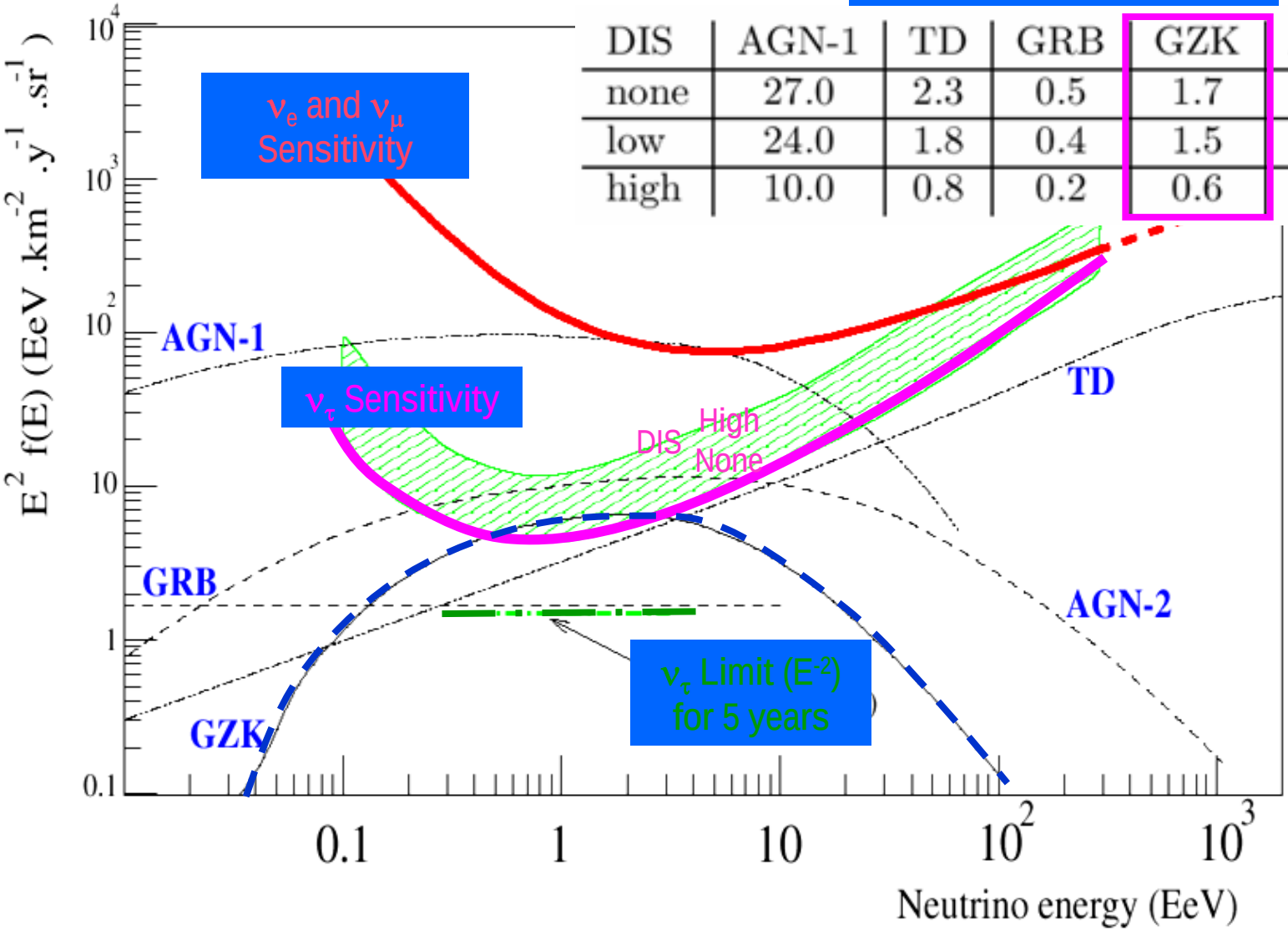
Neutrino Sensitivities

Expected no. per year

DIS	AGN-1	TD	GRB	GZK	AGN-2
none	27.0	2.3	0.5	1.7	2.9
low	24.0	1.8	0.4	1.5	2.5
high	10.0	0.8	0.2	0.6	1.1



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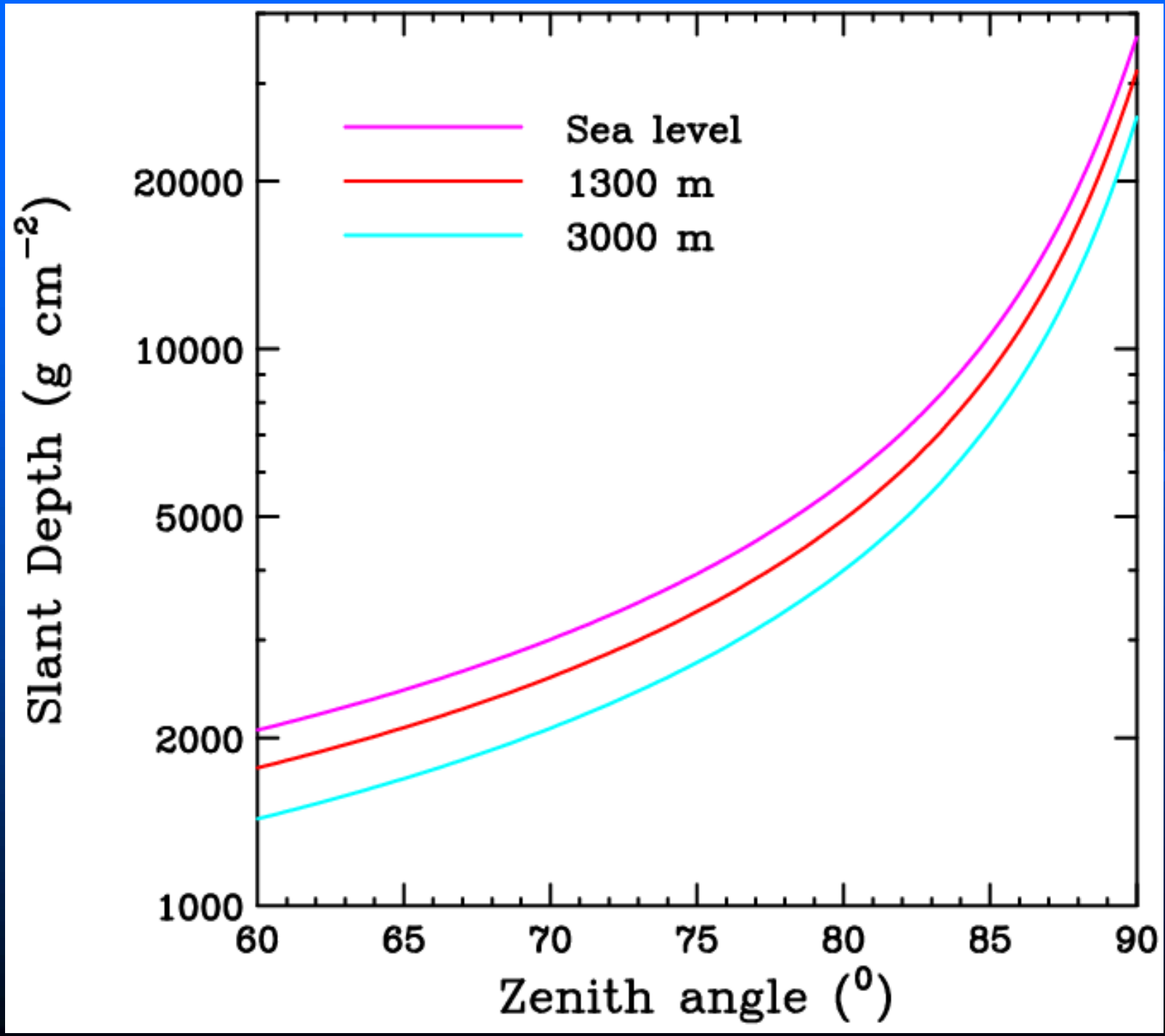

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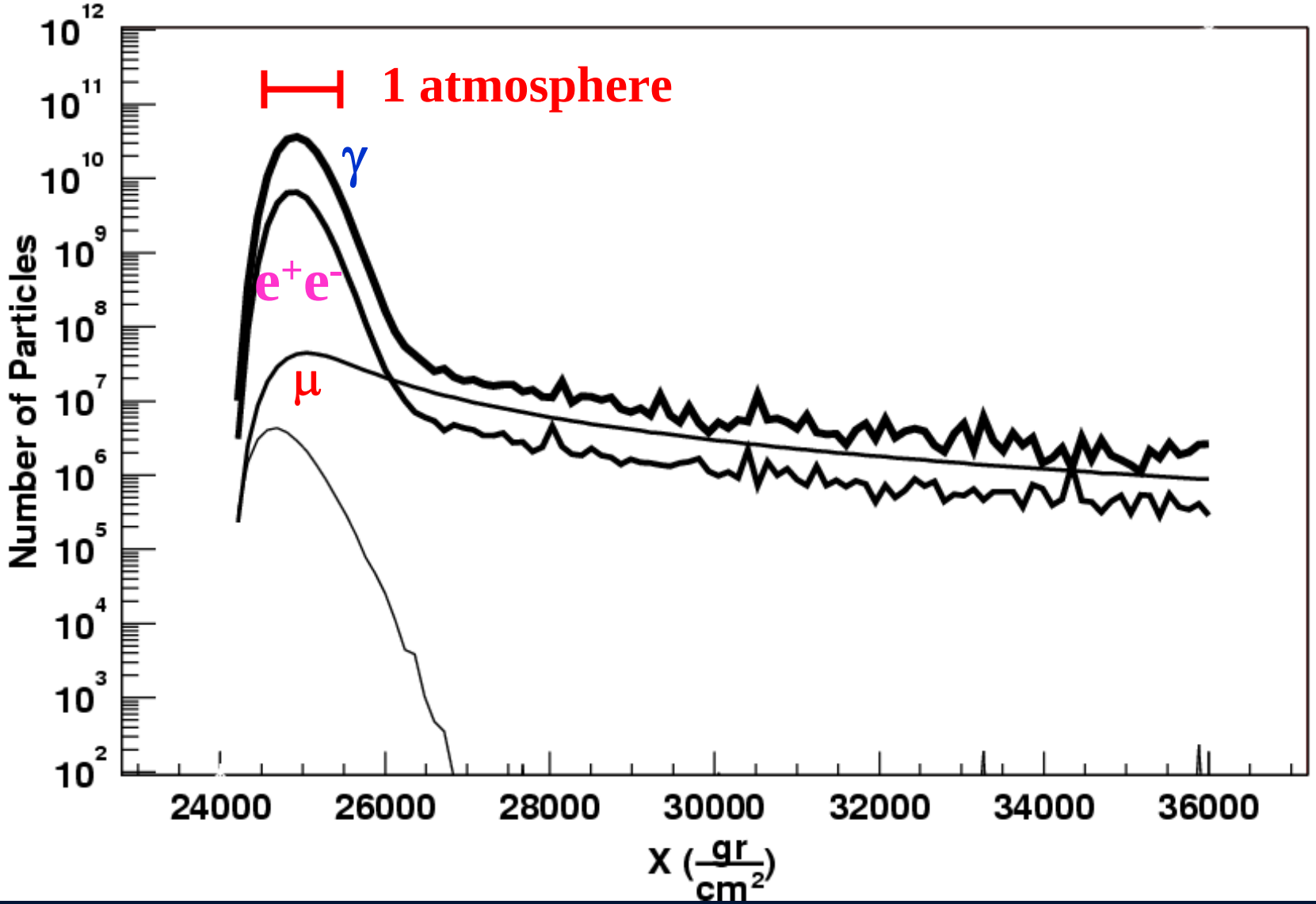

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