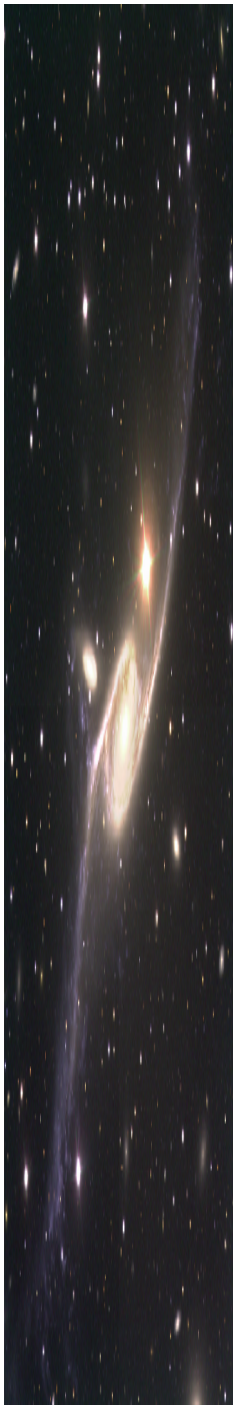
Ultra High Energy Cosmic Rays

Rosanna Cester – University of Torino

1. The Physics Case
2. Experimental Overview



Open issues:

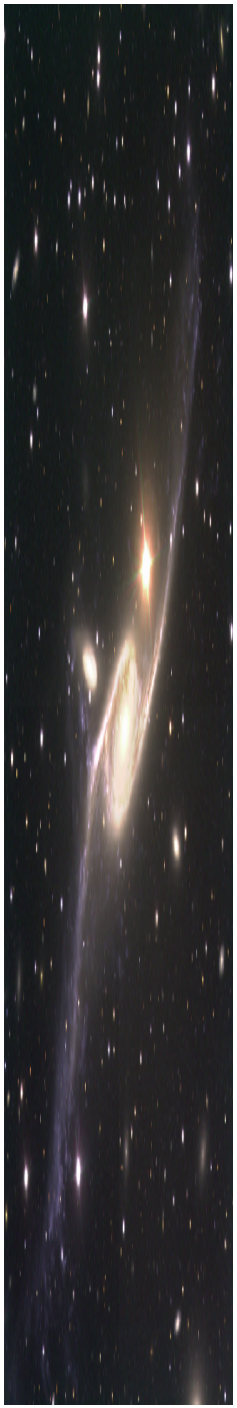
- Is there a cutoff at E ~ 10^{20} ?

→ GZK mechanism

→ No sources

- Is there correlation of CR direction with known sources ?
- What is the mass of incoming CR primaries?
- Are there photons and neutrinos?

.....

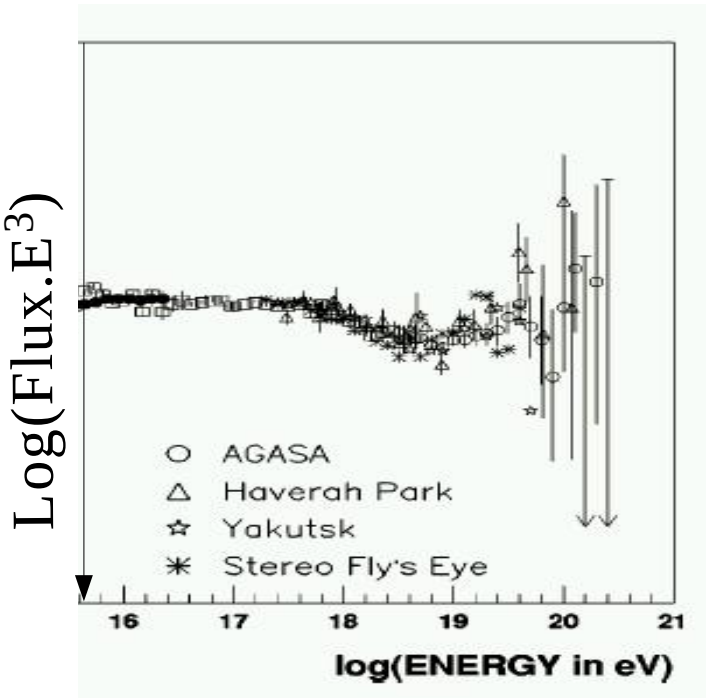


Outline

- First Generation of Experiments to detect

UHECR

- The new generation : HIRES – AUGER – TA
- UHECR s from space: EUSO ...



Early Experiments

Experiment	Exposure	Detector	Area (Km2)	Events E > 40 EeV	Events E >100 EeV
Volcano Ranch	0.2	Scintillator m detector	8	6	1
SUGAR	?	m detector	8	?	0
Haverah Park	0.87 (0.73)	H2O Cer.	12	27	4
Yakutsk	1.35	Scintillator Air Cer.	18	12	0
AGASA	3.1	Scintillator	100	47	7
Fly's Eye	2.6	m detector	50	24	**11** 1
		Fluoresc.			

Experiments have different exposures (in 10^{16} m^2 sec sterad) for Energies > 10^{20}

Energy Calibration :

→ All experiments agree with each other to within 15% in the energy calibration

→ Anomaly in the position of the ankle in Fly's Eye

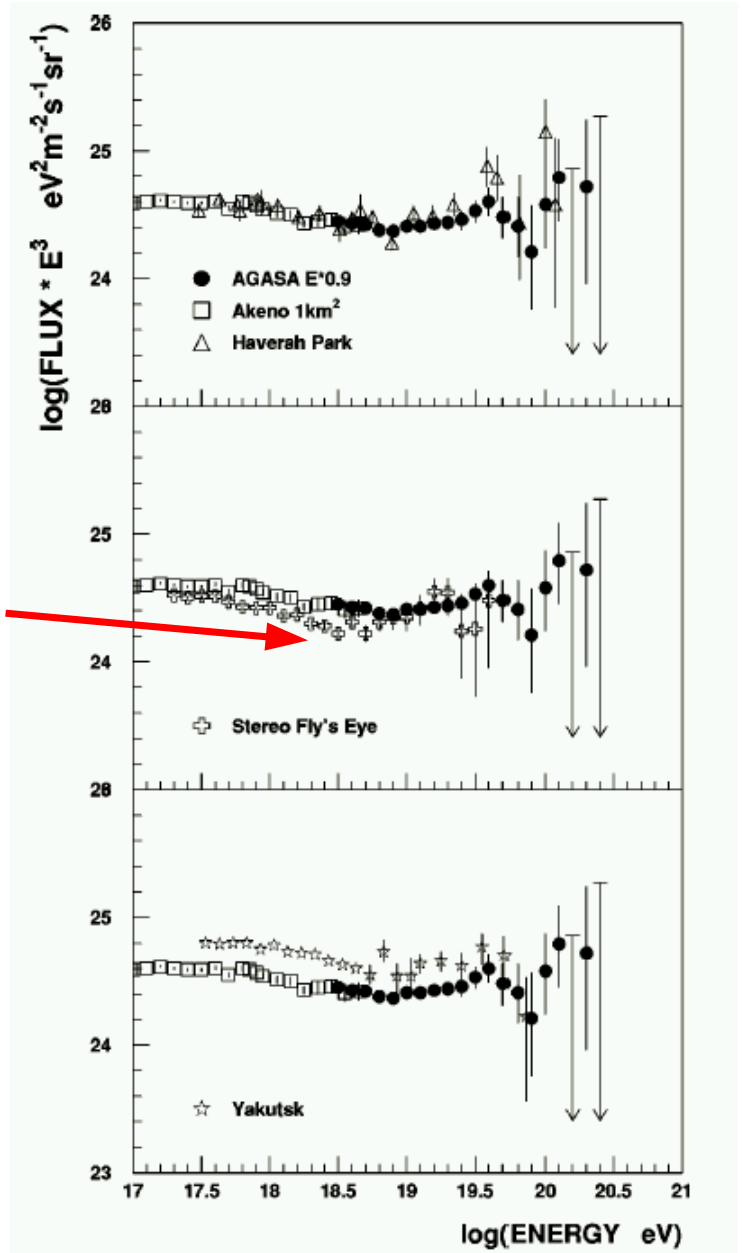
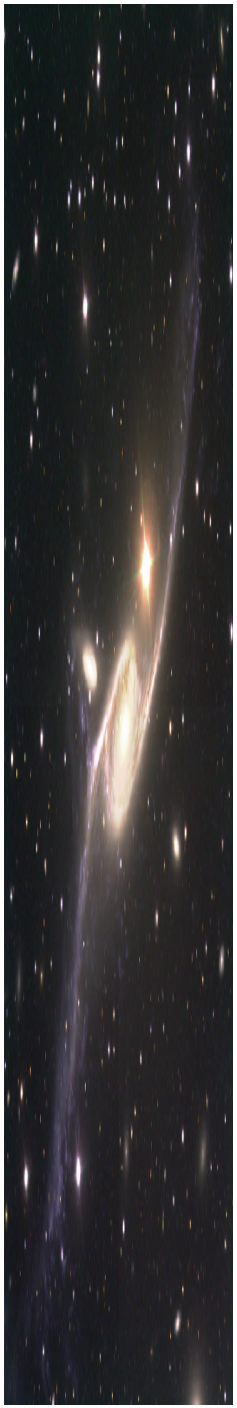
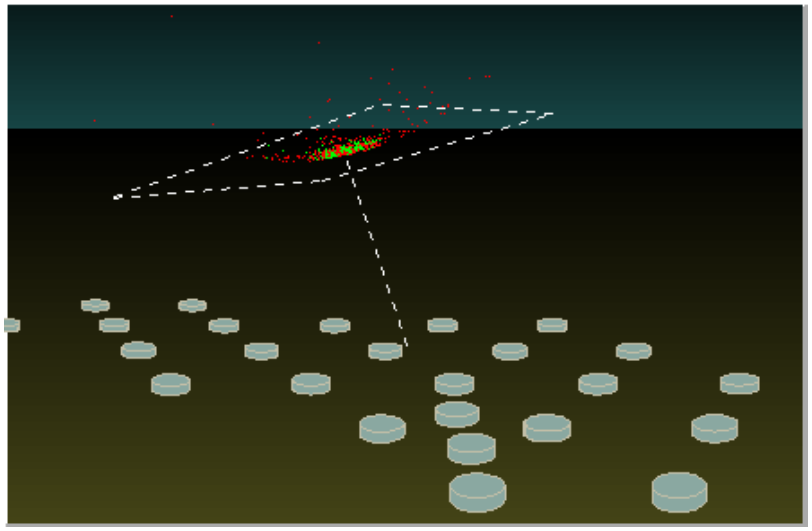
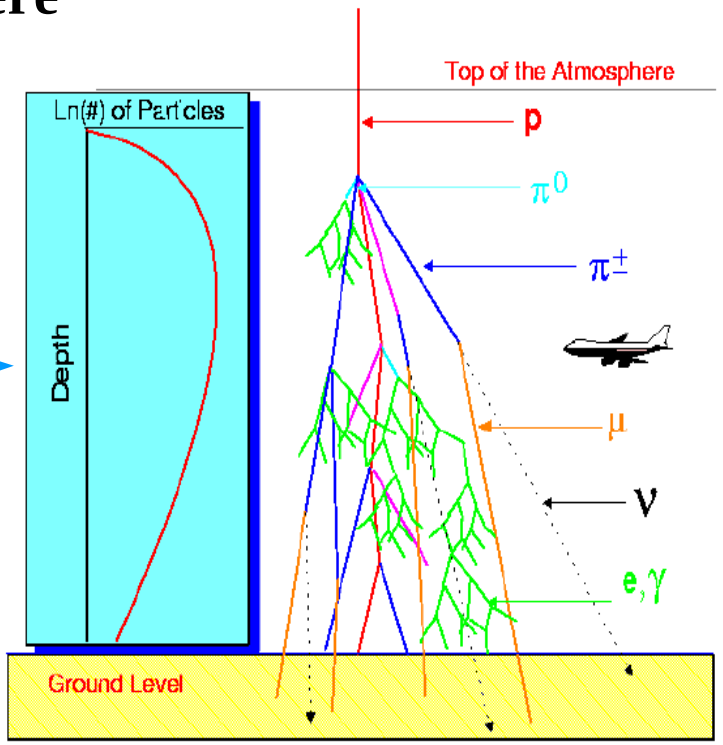


FIG. 23. Differential energy spectra determined by Haverah Park, Yakutsk, and Fly's Eye, compared with those determined by AGASA.



EAS development in the atmosphere





Fluorescernce Detector

Shower longitudinal profile:

Number of shower particles as a function of atmospheric depth

Ground Arrays (SD)

Lateral distribution profile:

Lateral distribution of shower particles density at ground

- Electromagnetic component is 99% of shower particles and dissipates 85% of initial energy
- Remaining 1% is compound of μ (10% of Energy), p (4% of Energy), neutrinos and barions.

Typology of experiments and detector characteristics

- **Fluorescence Detectors** (Fly's Eye)

Measurement of shower Energy Profile as it developes

Low level of light detected hence strong dependence on environement and low duty-cycle

- **Ground Arrays**:

→ 100% duty-cycle

→ Insensitive to environement

→ Identical modules (for large areas ⟶ simple, low-cost and stable:

scintillators or Cerenkov H_2O detectors)

Snapshot of shower when it hits ground : results depend heavily on simulation

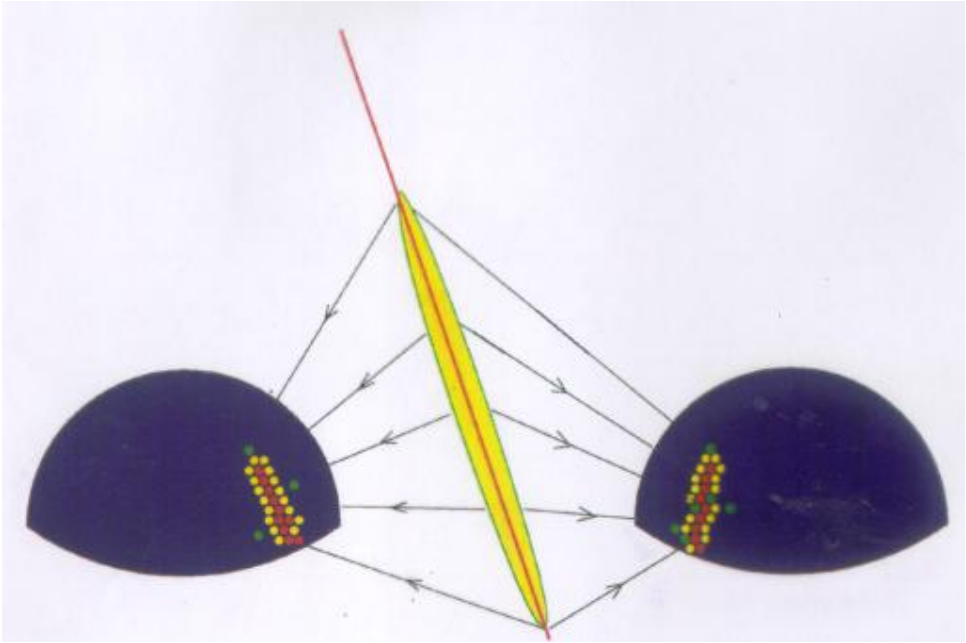
New generation of experiments

Experiment	Detector	Area (Km^2)	E_{thresh} (EeV)	Events	/year*
HiRes (data taking)	Fluorescence stereo		1		10
Telesc. Array (construction)	Hybrid	900 km^2	0.1		20
Auger (construction)	Hybrid (2 sites)	3000 km^2 (each site)	0.5		60
EUSO (R&D)	Fluorescence	(in orbit)	40		1000

*** Based on Agasa Rate**

Stereo Fluorescence Detectors

HIRES



4 events with E > 50 EeV

Exposure ?

HIRES 1

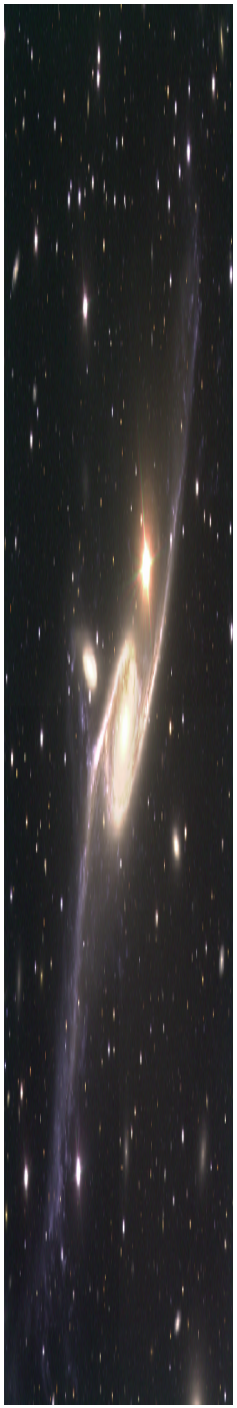
Has been taking data from 1997 to 2003 with optics acceptance: 3° to 17° full azimuth

HIRES 2

Taking data since 1999

Will take data for 2 years more

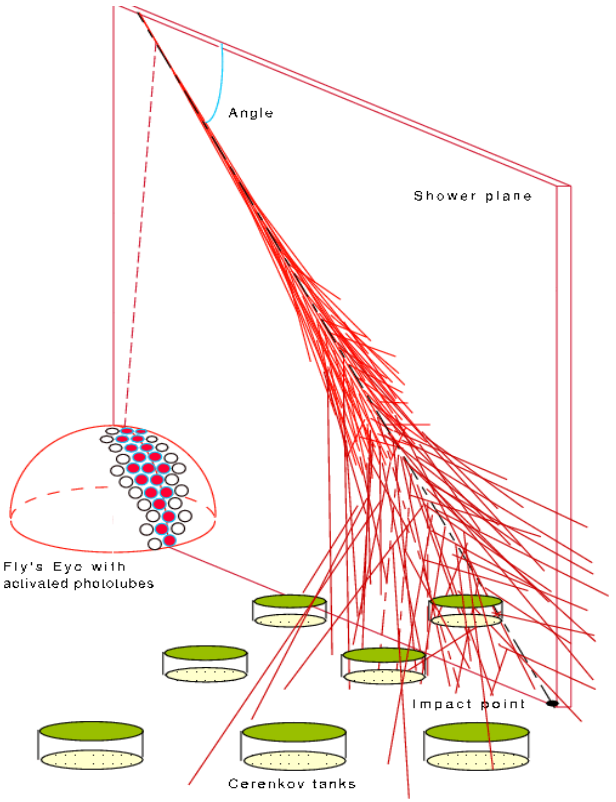
In stereo mode since Dec. 2003



The Hybrid Concept (Auger and TA)

- The Ground Array (SD) defines the aperture, with a 100% duty cycle
- Fly's Eye (FD) detects events within the SD area, with a 10% duty cicle

(**Hybrid events**).

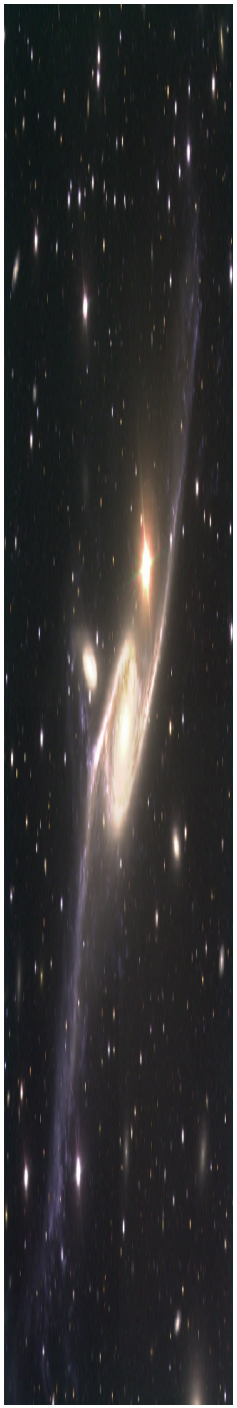


Energy cross-calibration:

1. FD determines energy from the shower longitudinal light- profile
2. SD measures the lateral particle density profile 1000 m far from the shower core

Two independent estimates of the mass of the primary:

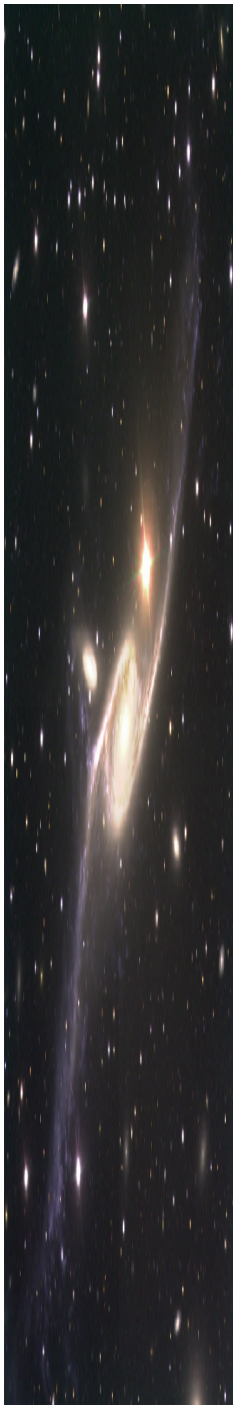
1. FD estimates primary mass from Xmax measurement
2. SD estimates primary mass from fractional muon content



The Pierre Auger Observatory

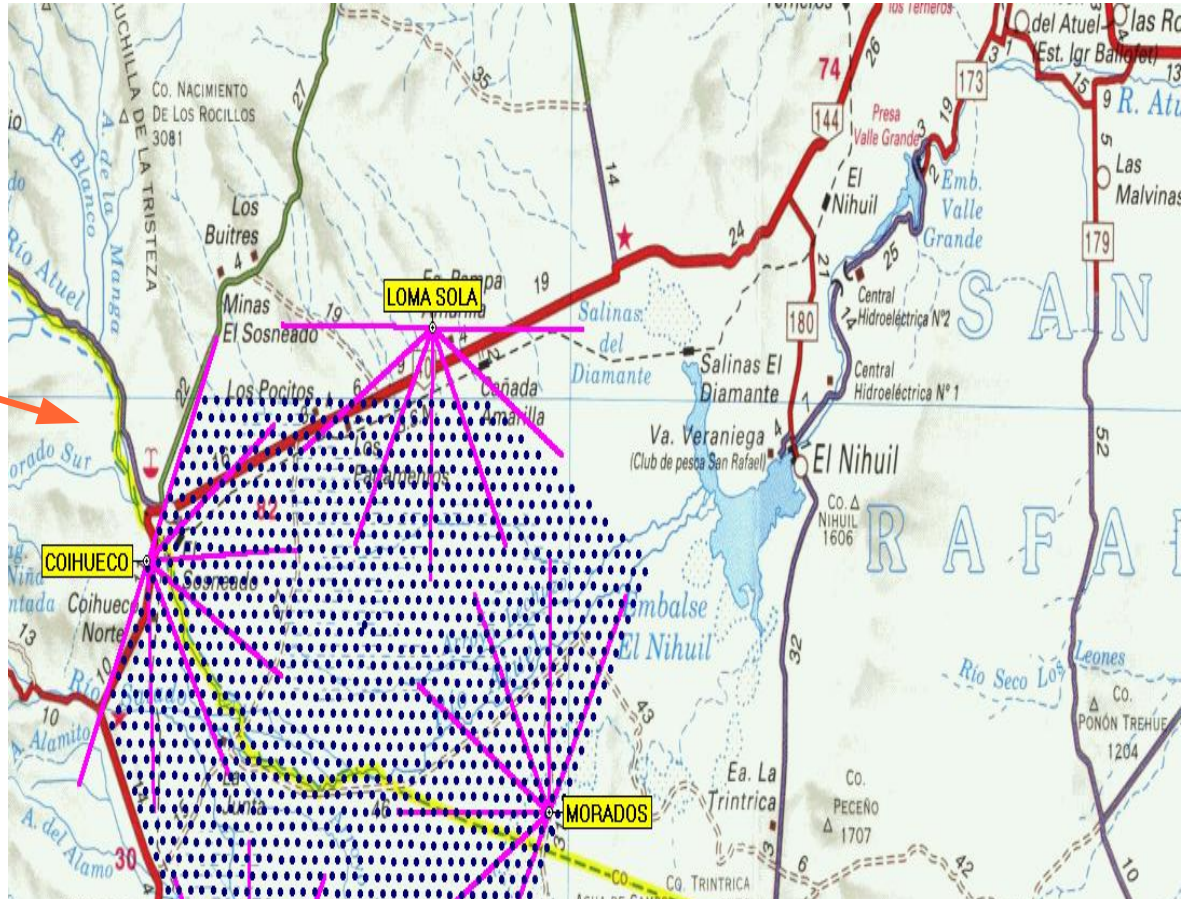
- Two sites, one in the southern emisphere, 35°S (Argentina),
  in construction and taking data,
  the other in the northern emisphere : (USA)
- 6000 Km^2
- Full coverage of the sky with uniform exposure
- Hybrid detector
- One Year Exposure $\simeq 23 \cdot 10^{16}$ m^2 sr sec in each emisphere
- 6000 events/year above 10^{19} eV
- 60 events/year above 10^{20} eV (based on Agasa flux)

SD events



The southern site of Pierre Auger Observatory

1600 **water cherenkov detectors**, with 1.5 km spacing covering an area of 3000 km2 and 4 fluorescence eyes, each with 6 telescopes overlooking the Ground Array

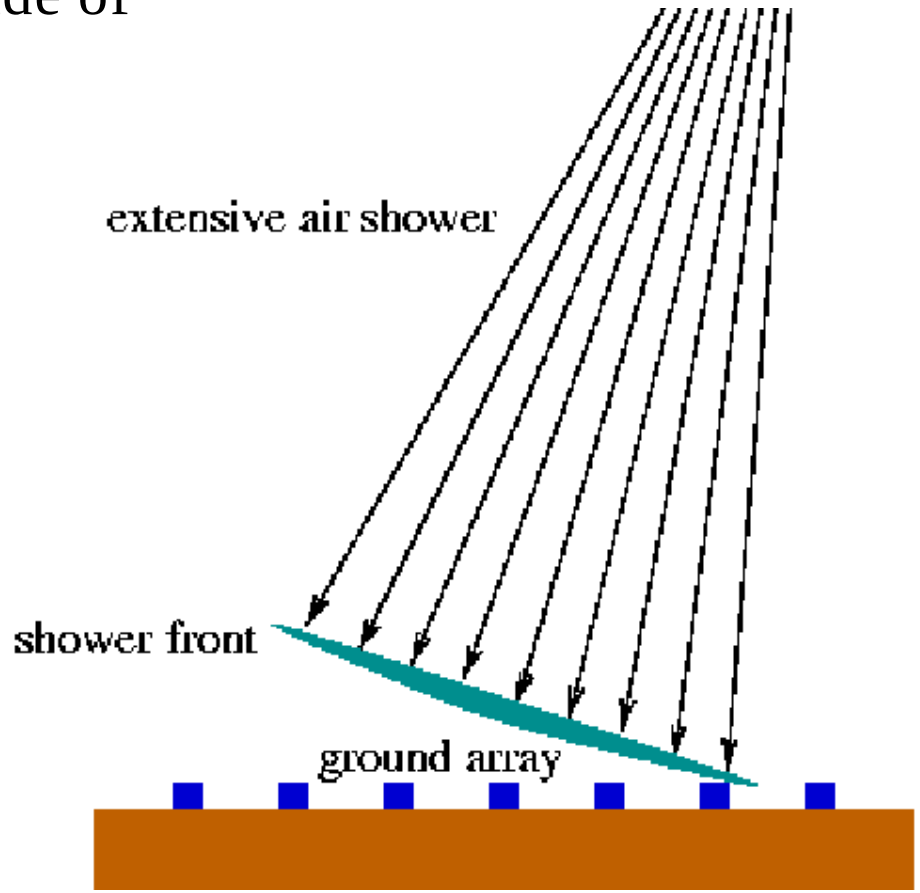


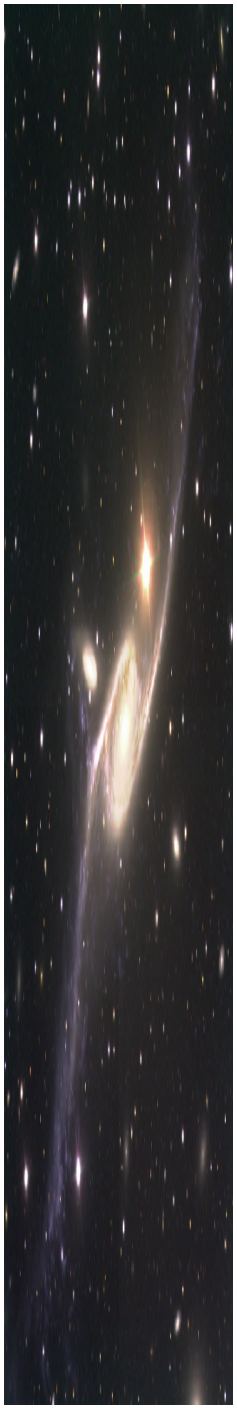
SD tanks deployment

H_2O Cerenkov detectors

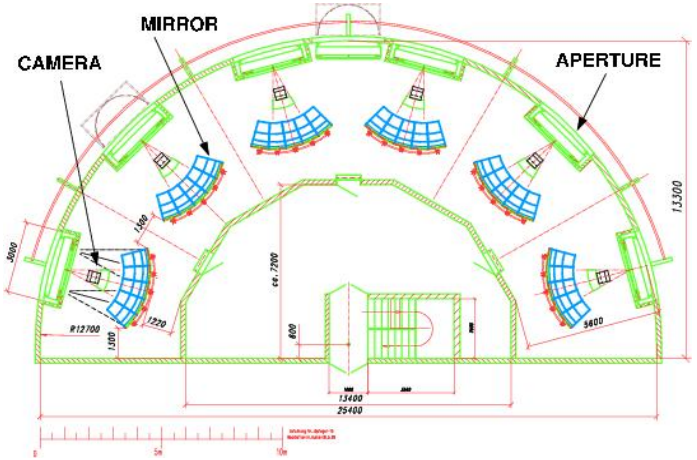
SD reconstruction

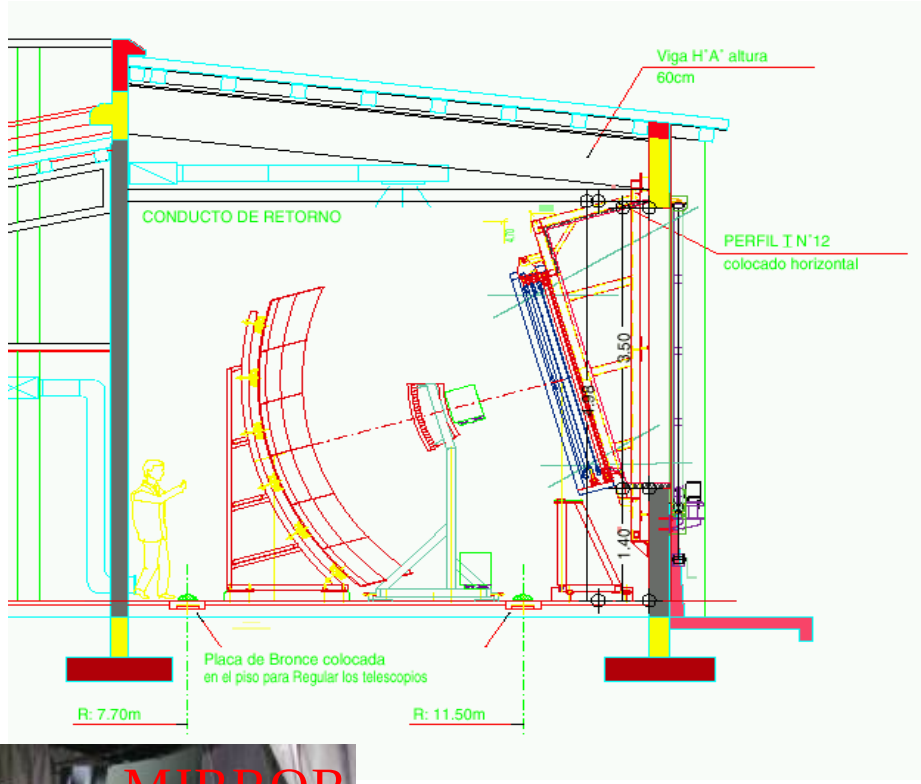
→ Impact point from signal amplitude of trigered stations
→ Energy from r(1000)
→ Direction from time of arrival at detectors





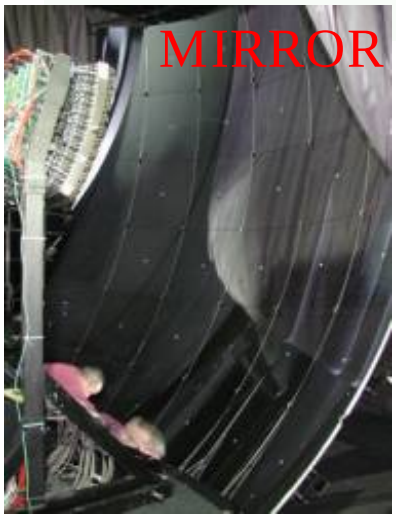
The Pierre Auger Fluorescence Detector





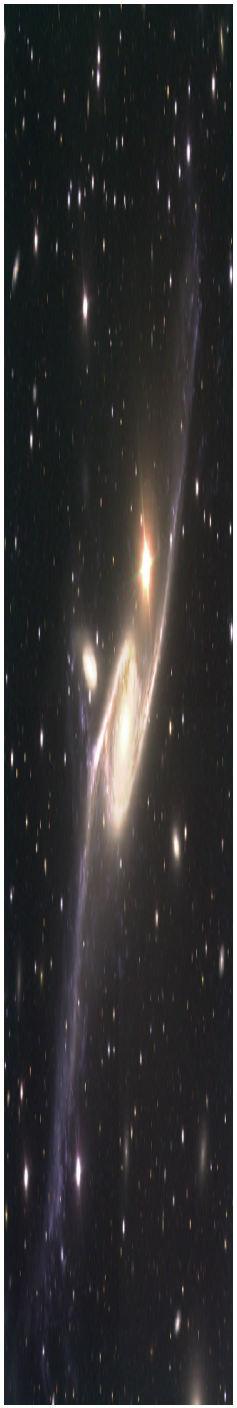
Spherical surface: radius 1.743 m

20 X 22 PMTs
each 1.5º X 1.5º FOV



Spherical mirror: Rc
1.743 m

30º X 30º F.O.V



Light emission by shower particles in atmosphere

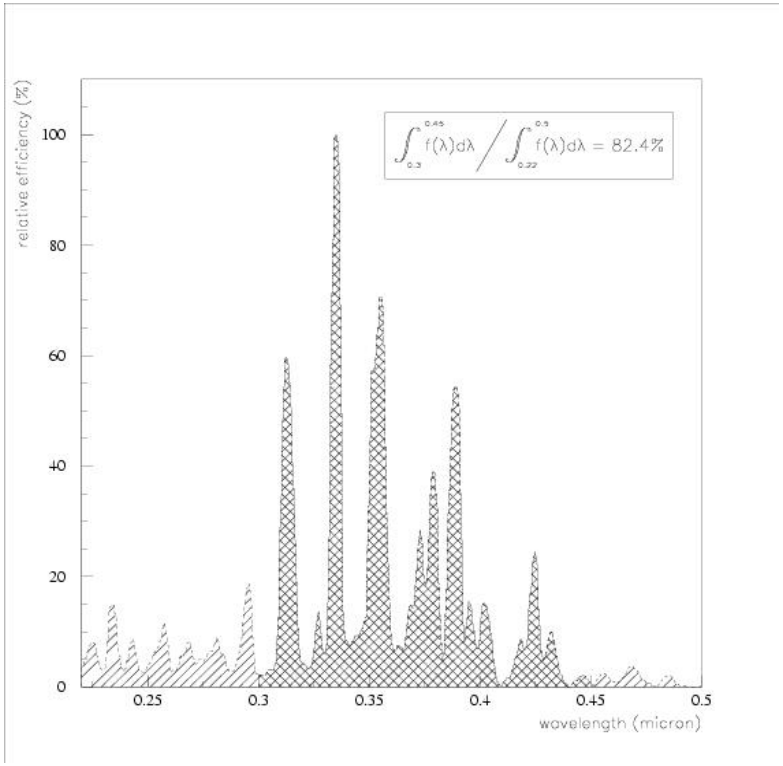
The atmosphere acts as a calorimeter !

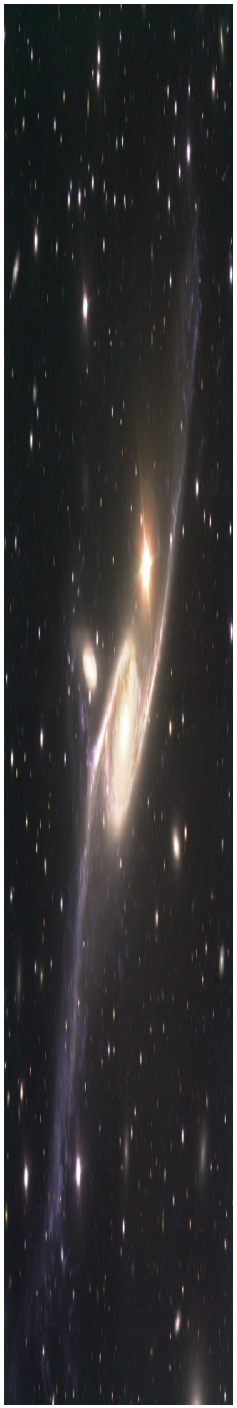
Fluorescence light emission

- EAS charged particles excite N_2 molecules and N_2^+ ions in the troposphere
- Emission of fluorescence light by de-excitation of N_2 and N_2^+
- → Light emitted proportional to particles energy loss

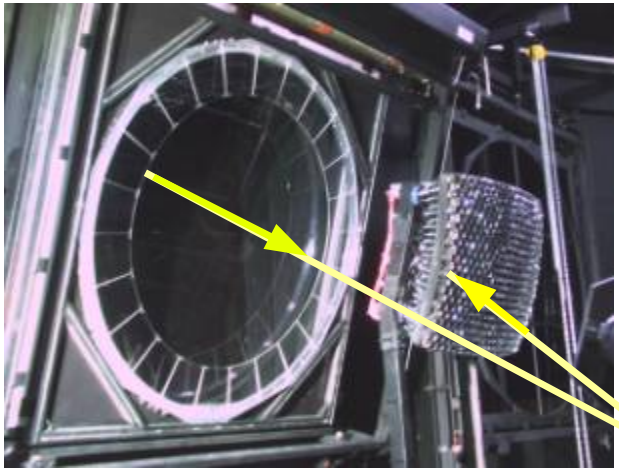
Low light yield -
Optical Filters to reduce sky-light background;

Cerenkov Light subtracted

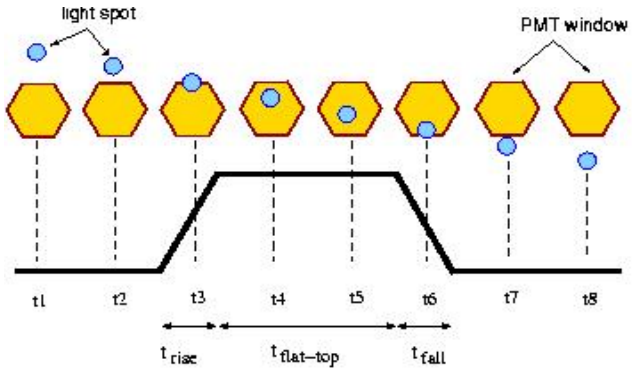


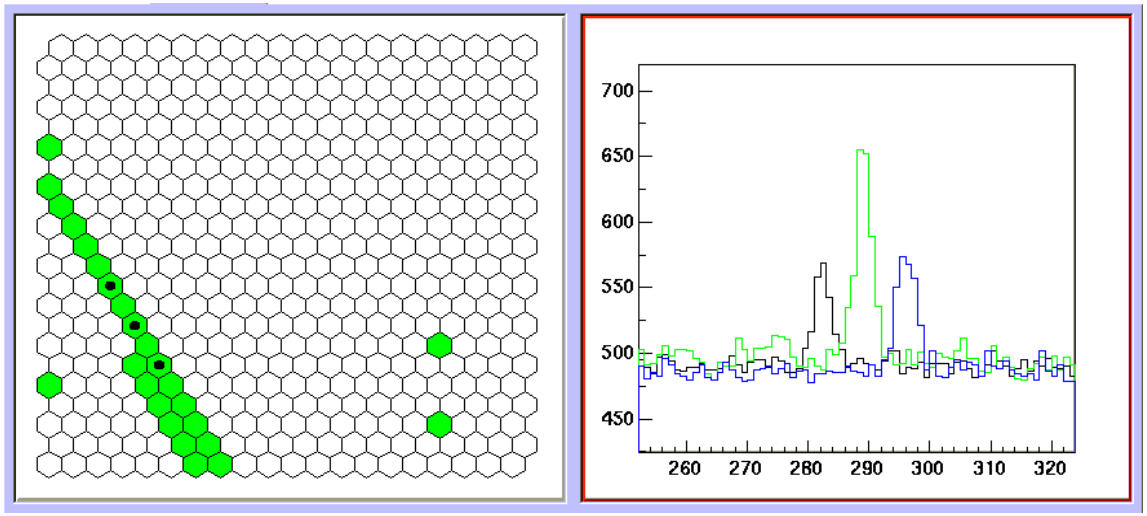


The Pierre Auger Fluorescence Detector



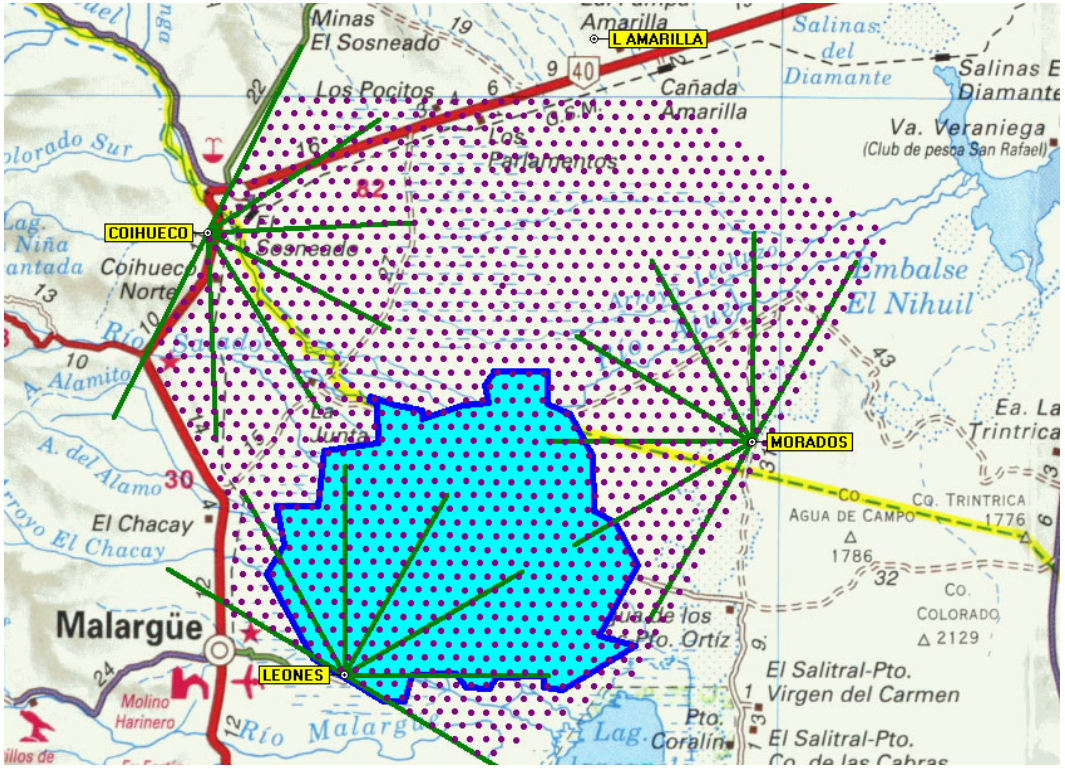
Angular motion of the spot depends both on distance and orientation of shower axis

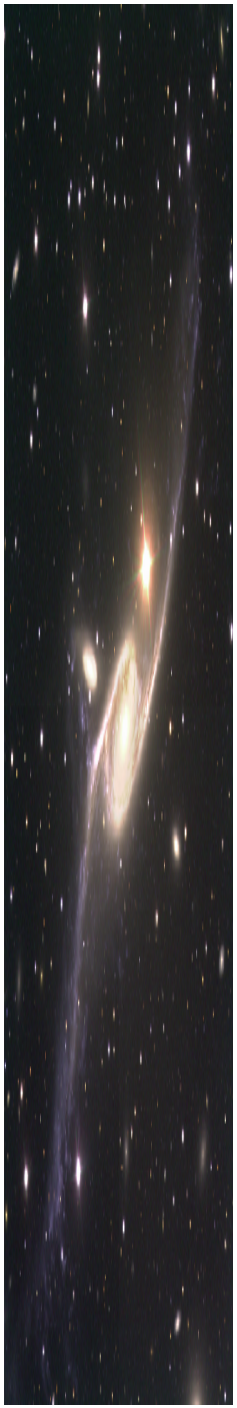




From each PMT triggered read amplitude and timing of the signal

Current Status





Current Status

SD ARRAY

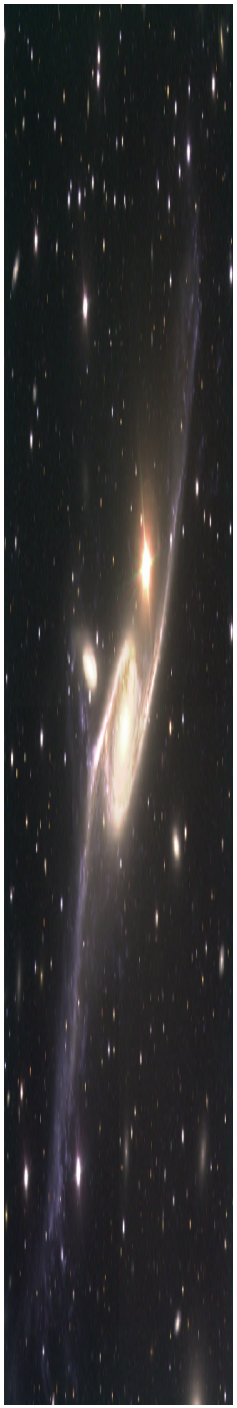
416 detectors deployed: >700 km^2, >25% of array!

- **384 detectors filled with water**
- **350 detectors with electronics (> 600 km^2)**
- **+ 45 detectors assembled but not yet deployed (in AB yard)**

FD TELESCOPES

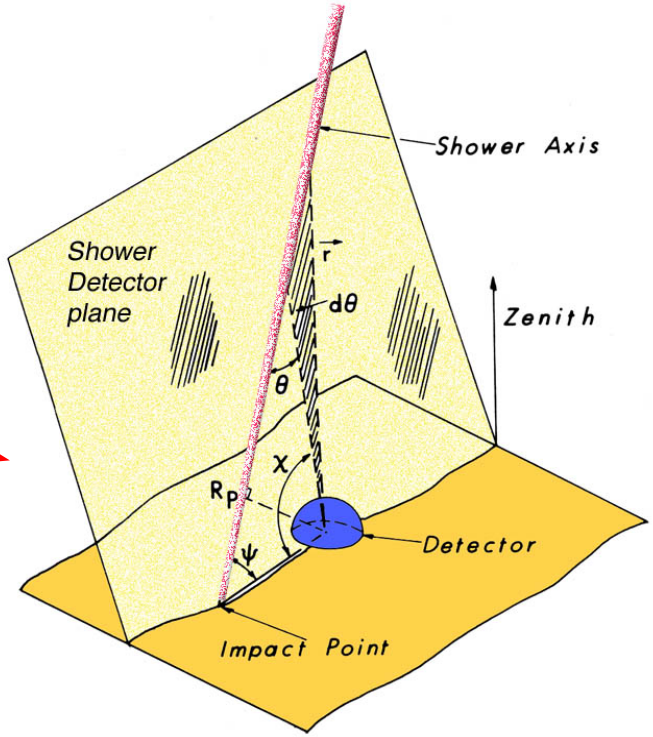
2 of the 4 sites – (12 telescopes) fully instrumented and taking data . 3rd site will be fully operational beginning 2005

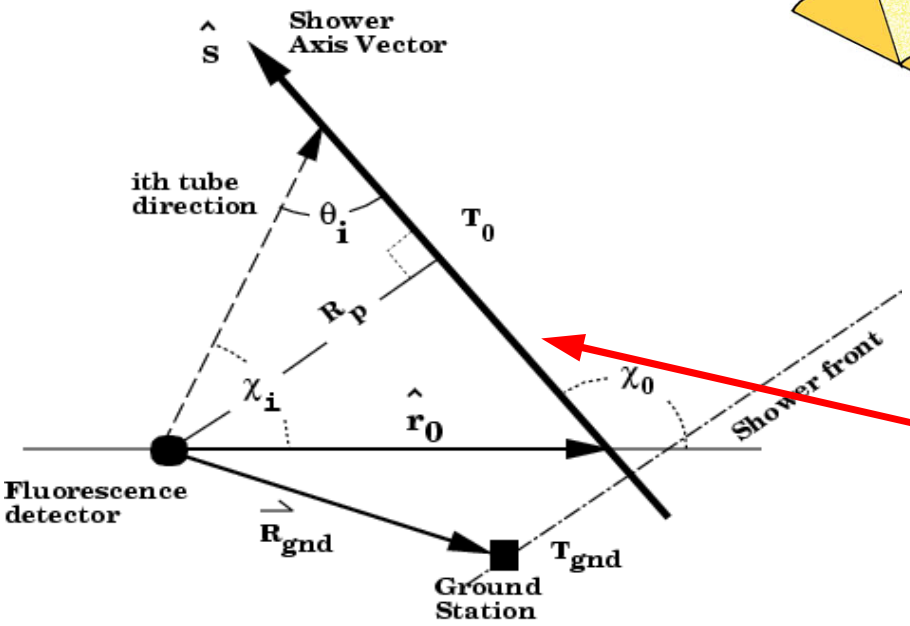
August 6 2004 : 400 detectors operational



Event Reconstruction (FD)

Finds the shower detector plane

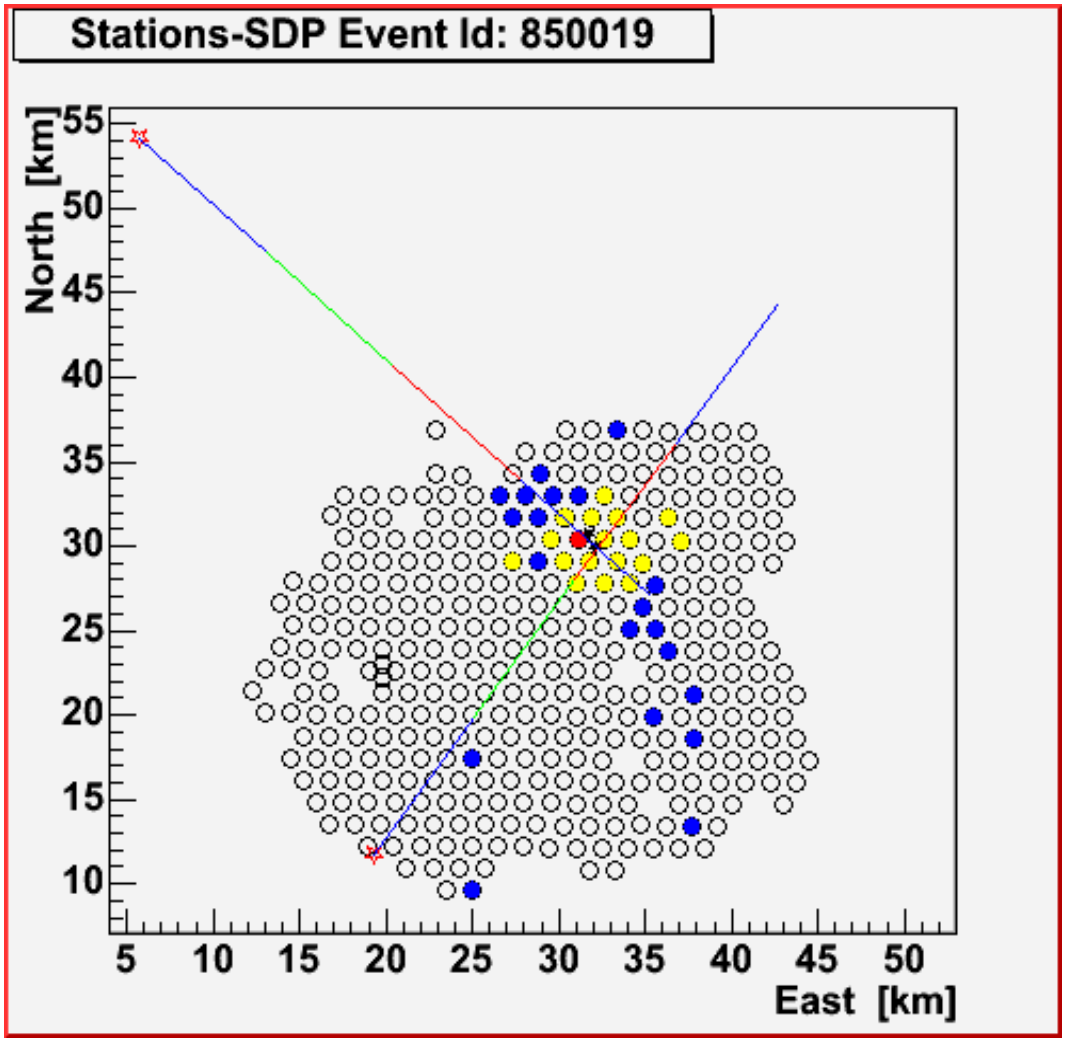


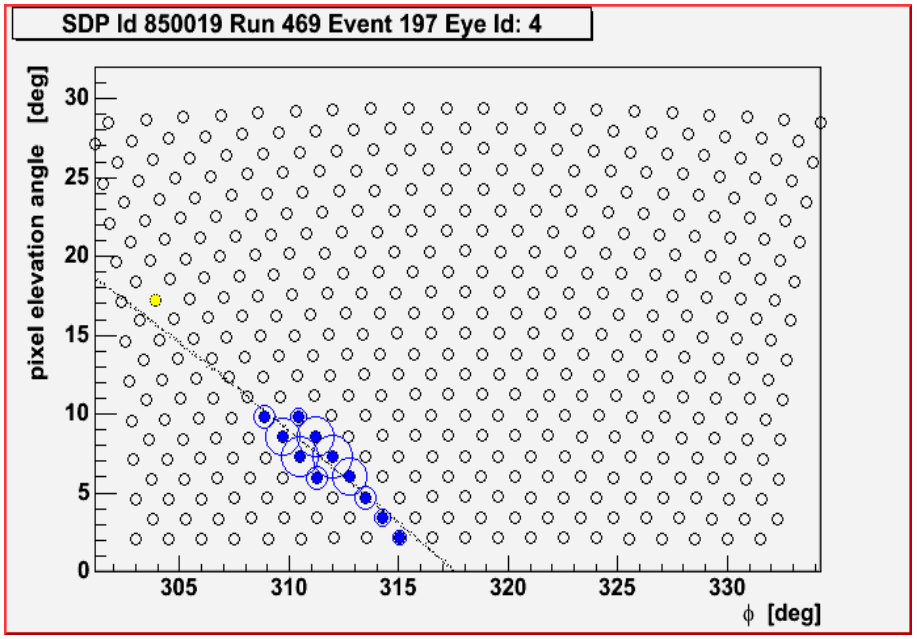


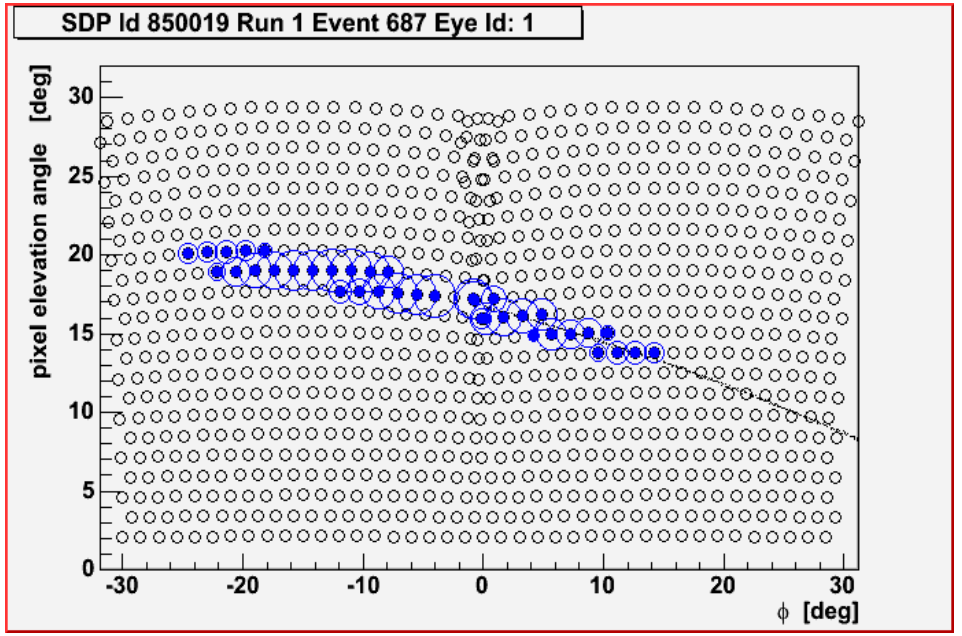
Find the shower axis

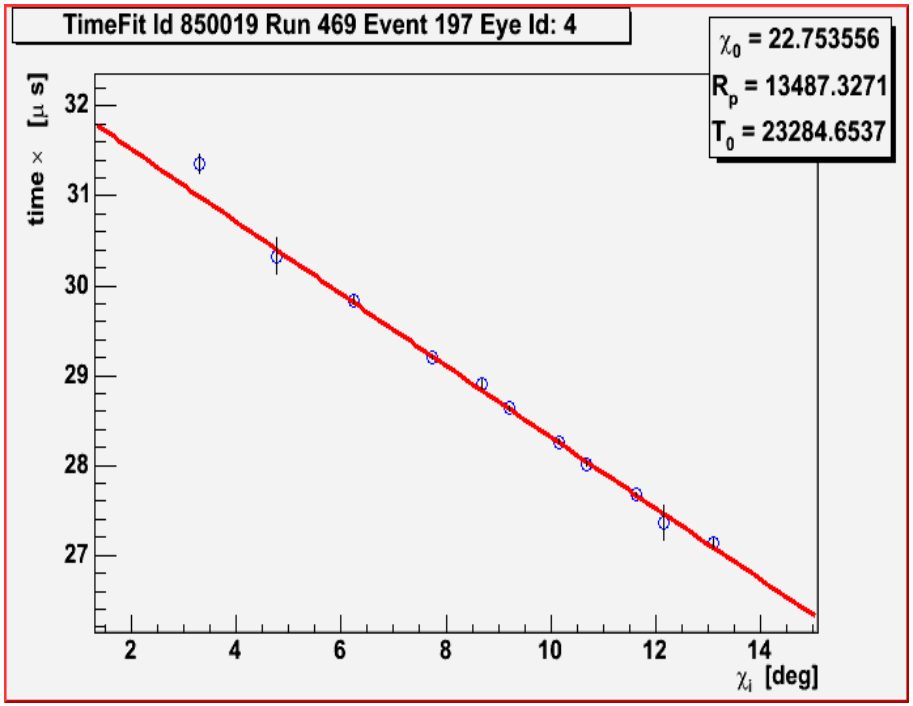
1985

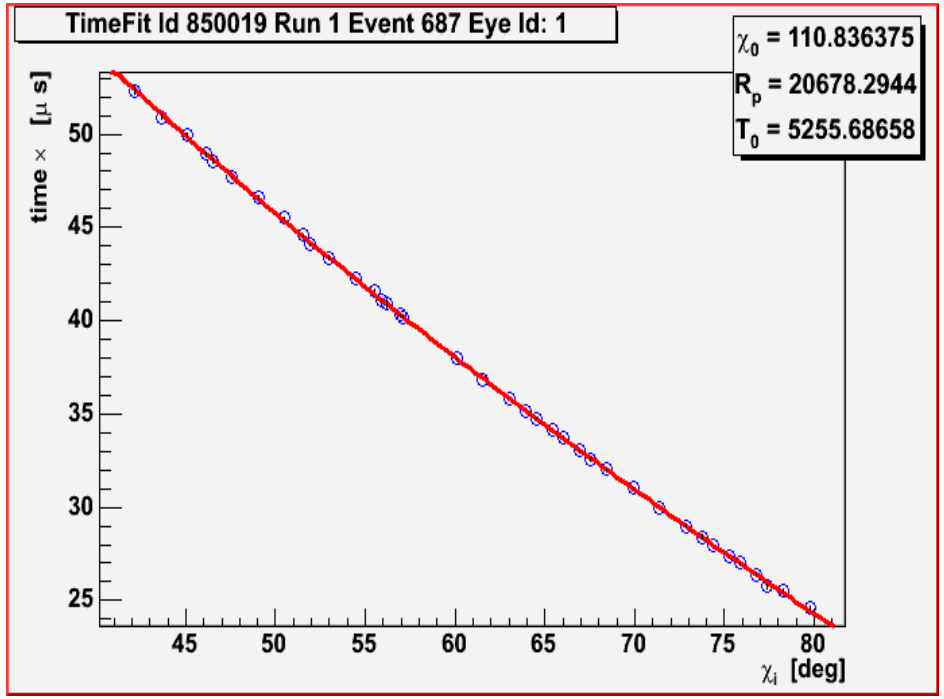
- An example of an event seen by Los Leones and Coihueco FD eyes, and the SD
- June 26 2004
- by definition high energy (to be seen by Coihueco)
- preliminary analyses
- geometry now, energy later



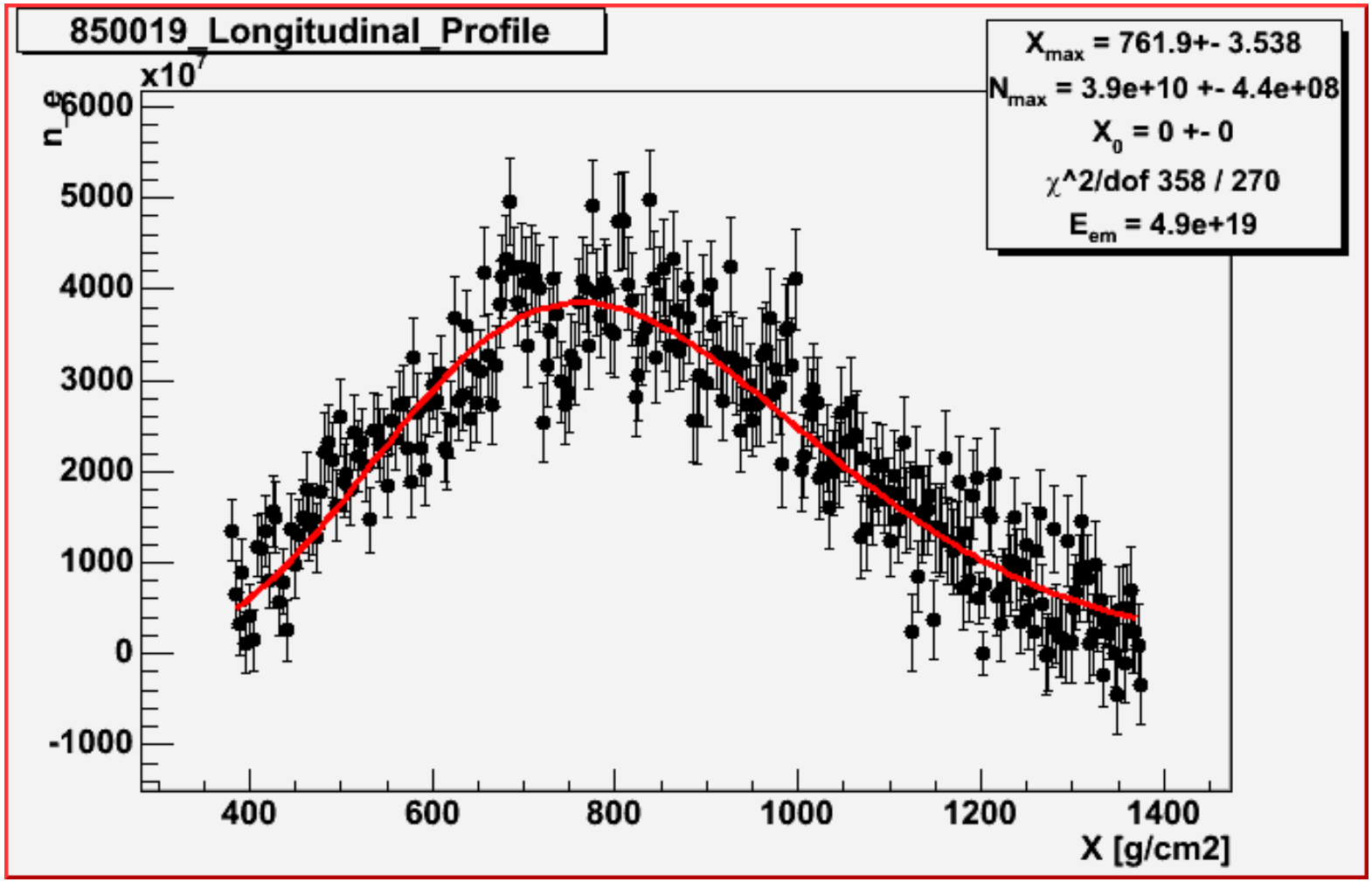

SDP Id 850019 Run 469 Event 197 Eye Id: 4
pixel elevation angle [deg]
30
25
20
15
10
5
0
305
310
315
320
325
330
ϕ [deg]


SDP Id 850019 Run 1 Event 687 Eye Id: 1
pixel elevation angle [deg]
30
25
20
15
10
5
0
-30
-20
-10
0
10
20
30
ϕ [deg]

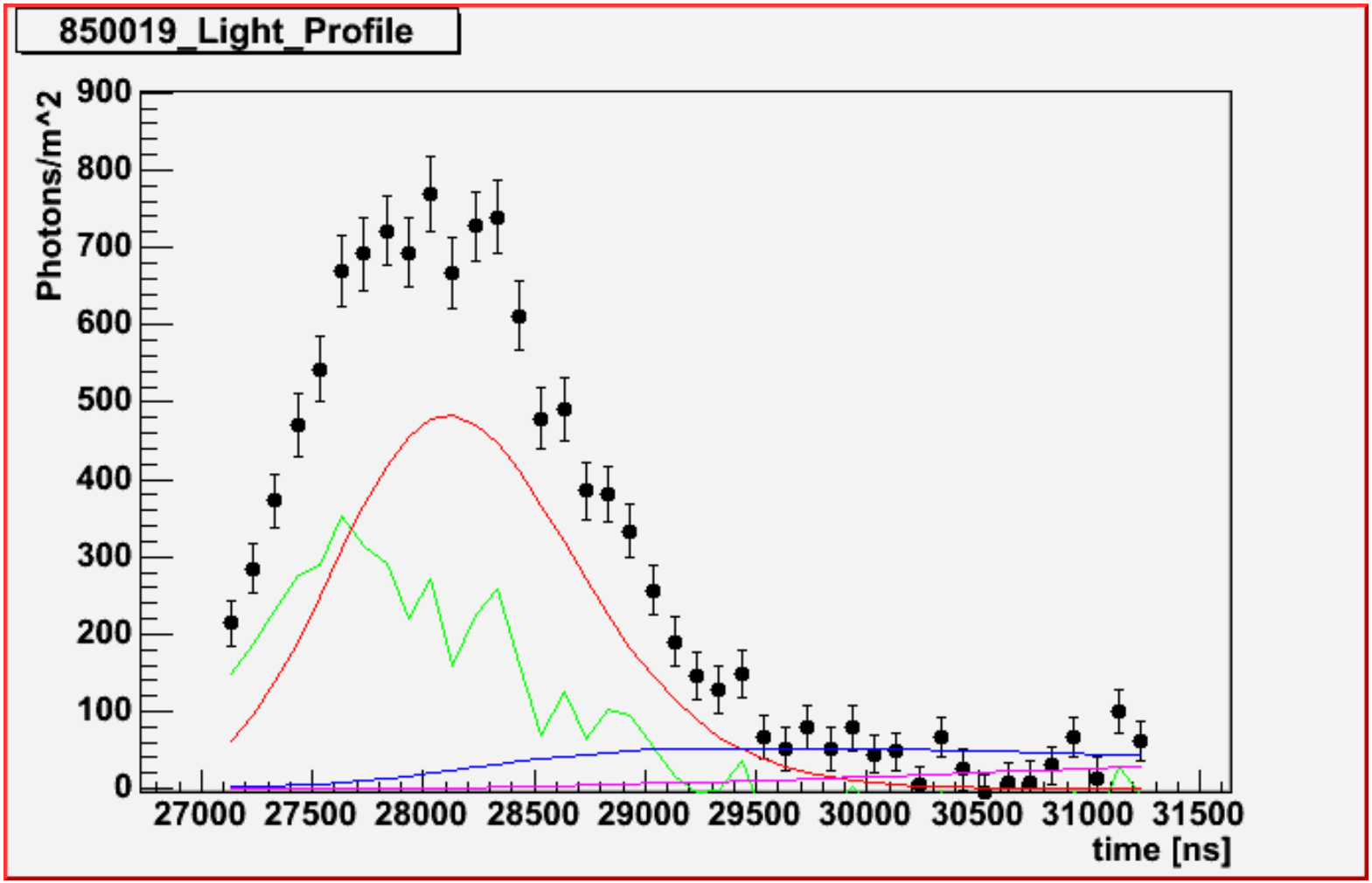

TimeFit Id 850019 Run 469 Event 197 Eye Id: 4
χ0 = 22.753556
Rp = 13487.3271
T0 = 23284.6537
time × [μ s]
32
31
30
29
28
27
2
4
6
8
10
12
14
χi [deg]

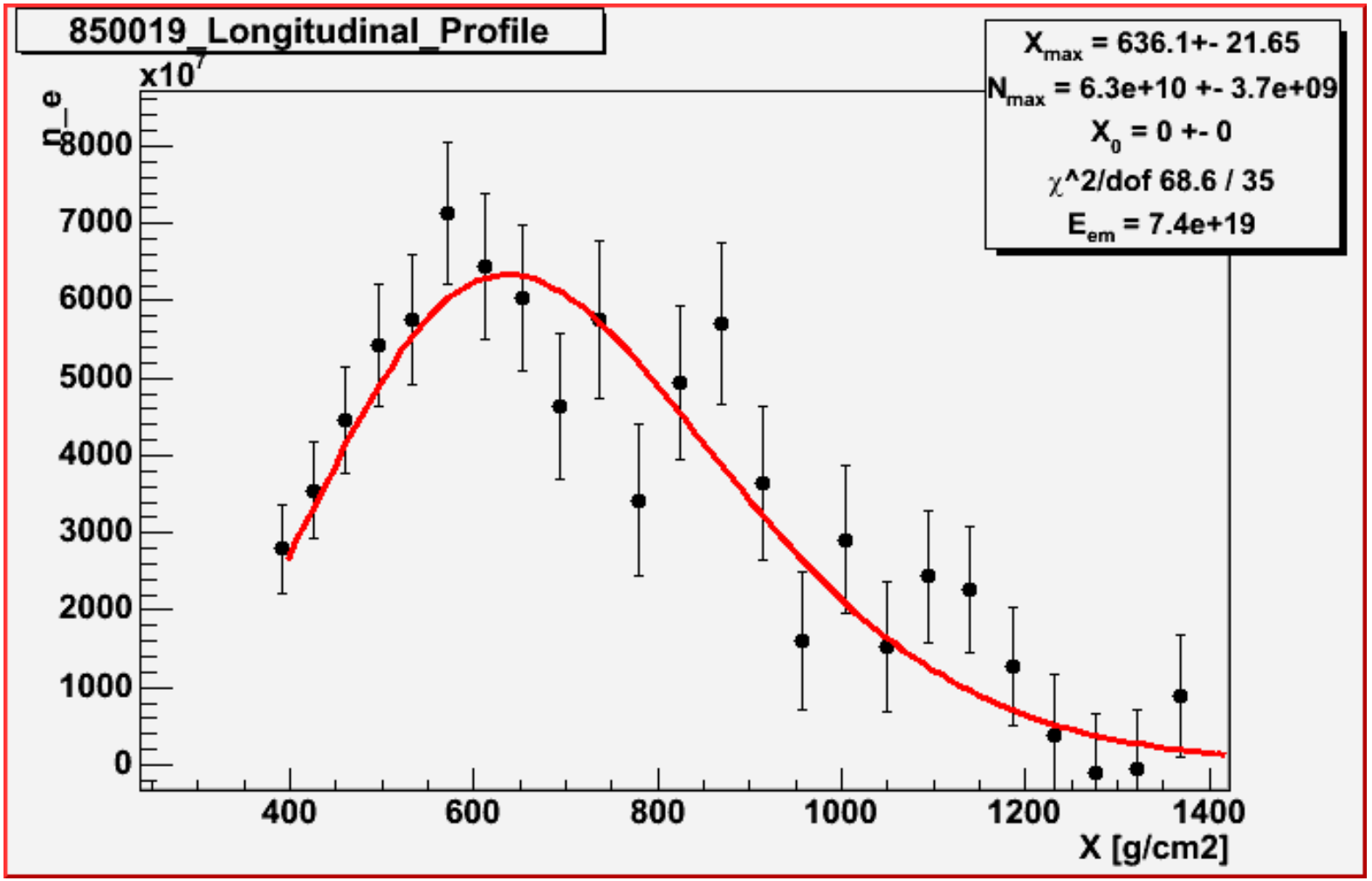

TimeFit Id 850019 Run 1 Event 687 Eye Id: 1
χ0 = 110.836375
Rp = 20678.2944
T0 = 5255.68658
time × [μ s]
50
45
40
35
30
25
45
50
55
60
65
70
75
80
χi [deg]

Los Leones

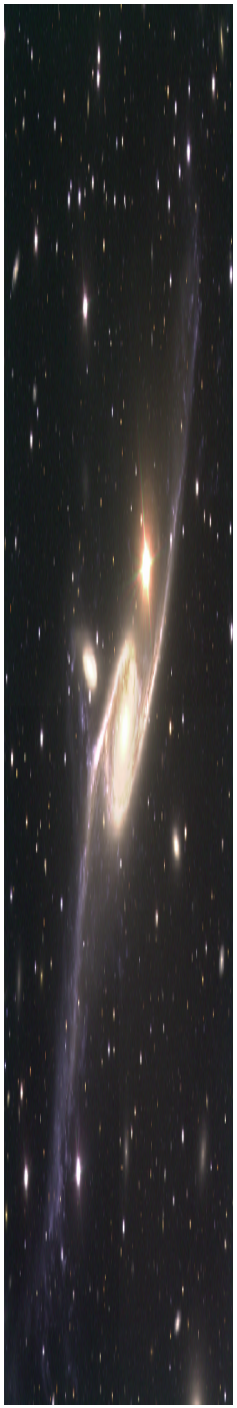

850019_Longitudinal_Profile
x10^7
dE/dX
6000
5000
4000
3000
2000
1000
0
-1000
400
600
800
1000
1200
1400
X [g/cm2]
X_max = 761.9+- 3.538
N_max = 3.9e+10 +- 4.4e+08
X_0 = 0 +- 0
χ^2/dof 358 / 270
E_em = 4.9e+19

Coihueco

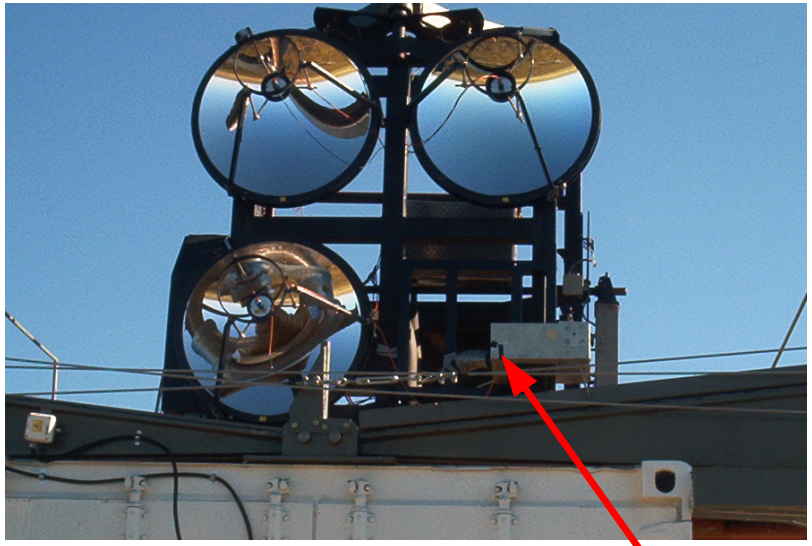

850019_Light_Profile
Photons/m^2
900
800
700
600
500
400
300
200
100
0
27000
27500
28000
28500
29000
29500
30000
30500
31000
31500
time [ns]

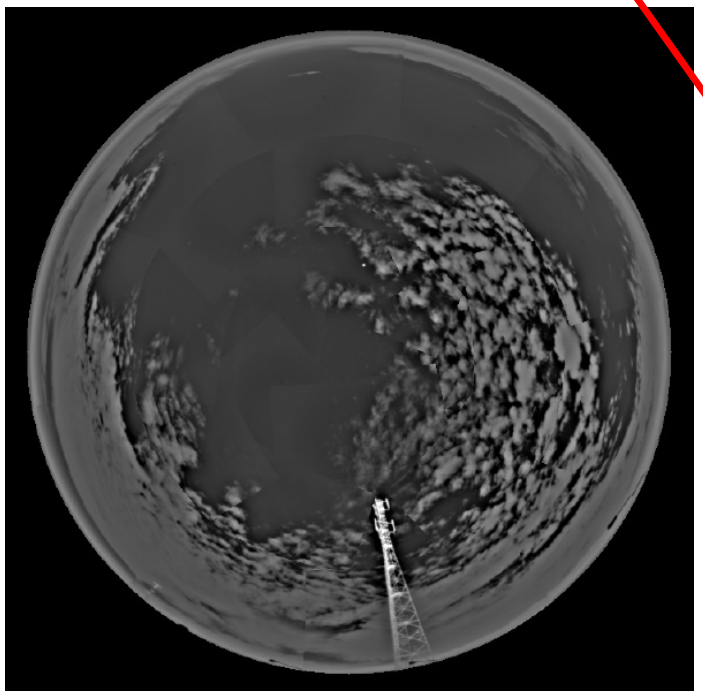

850019_Longitudinal_Profile
x10^7
dE/dX
8000
7000
6000
5000
4000
3000
2000
1000
0
400
600
800
1000
1200
1400
X [g/cm2]
X_max = 636.1+- 21.65
N_max = 6.3e+10 +- 3.7e+09
X_0 = 0 +- 0
χ^2/dof 68.6 / 35
E_em = 7.4e+19

Atmospheric Monitoring for the Auger Observatory



Atmospheric Monitoring for the Auger Observatory





Shoot the shower !

Telescope Array

Hybrid Detector:

600 SD detectors (scintillators); 1.2 Km spacing ⟶ 9 times Agasa

Detectors: Scintillator - Fe - scintillator

3 Fluorescence Detectors

Construction just started

Data taking 2007

The EUSO experiment

2 10^{12} tons target for neutrinos

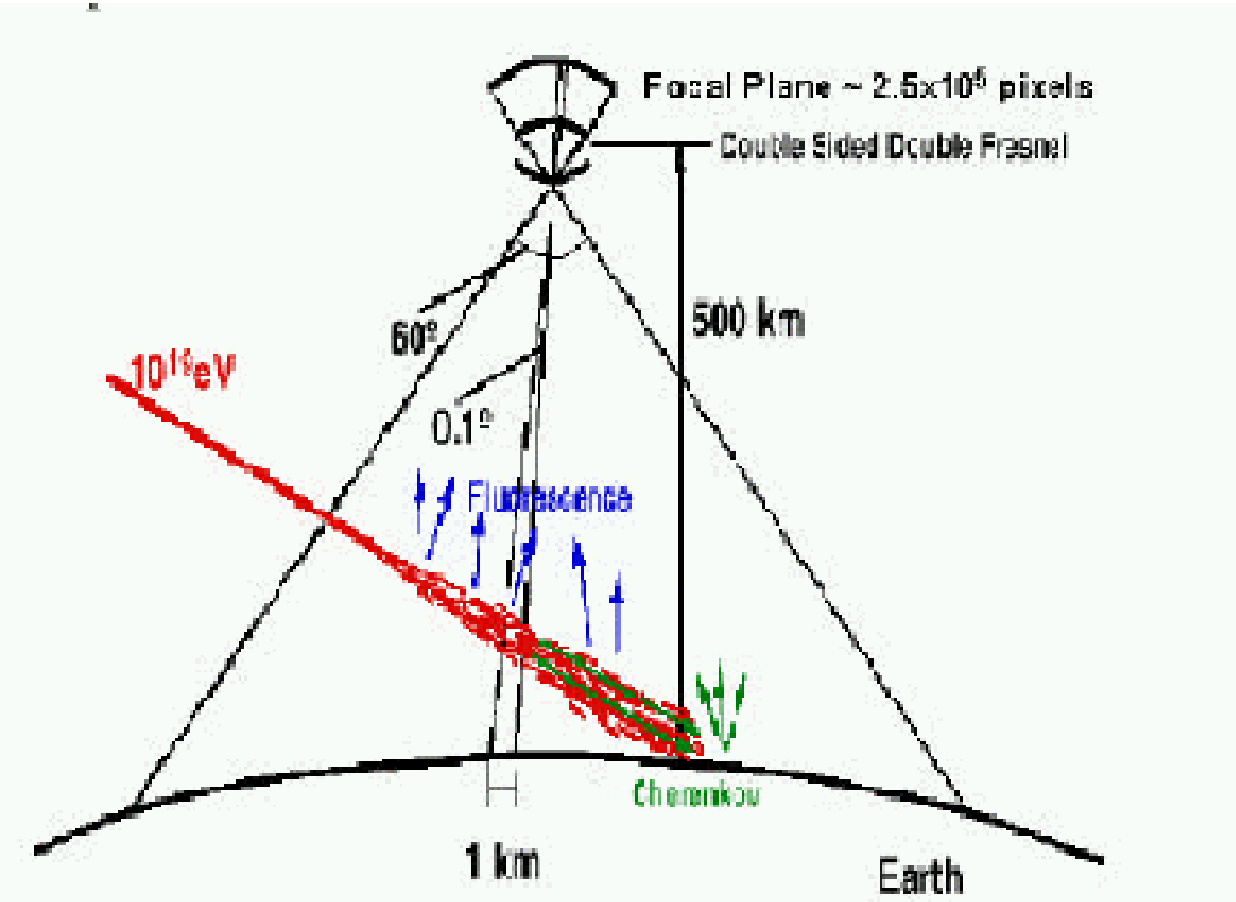


Fig.1.3 – Orientation of the fluorescence (left) and Cherenkov (right) lights for detection by the ***EUSO*** satellite (not on scale).