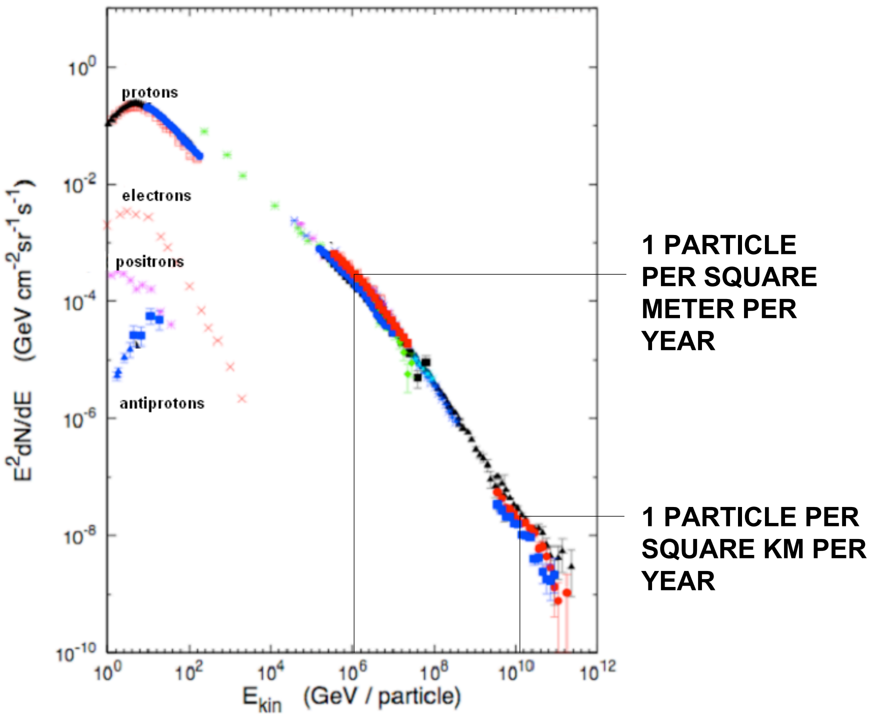
Astrofisica e particelle elementari

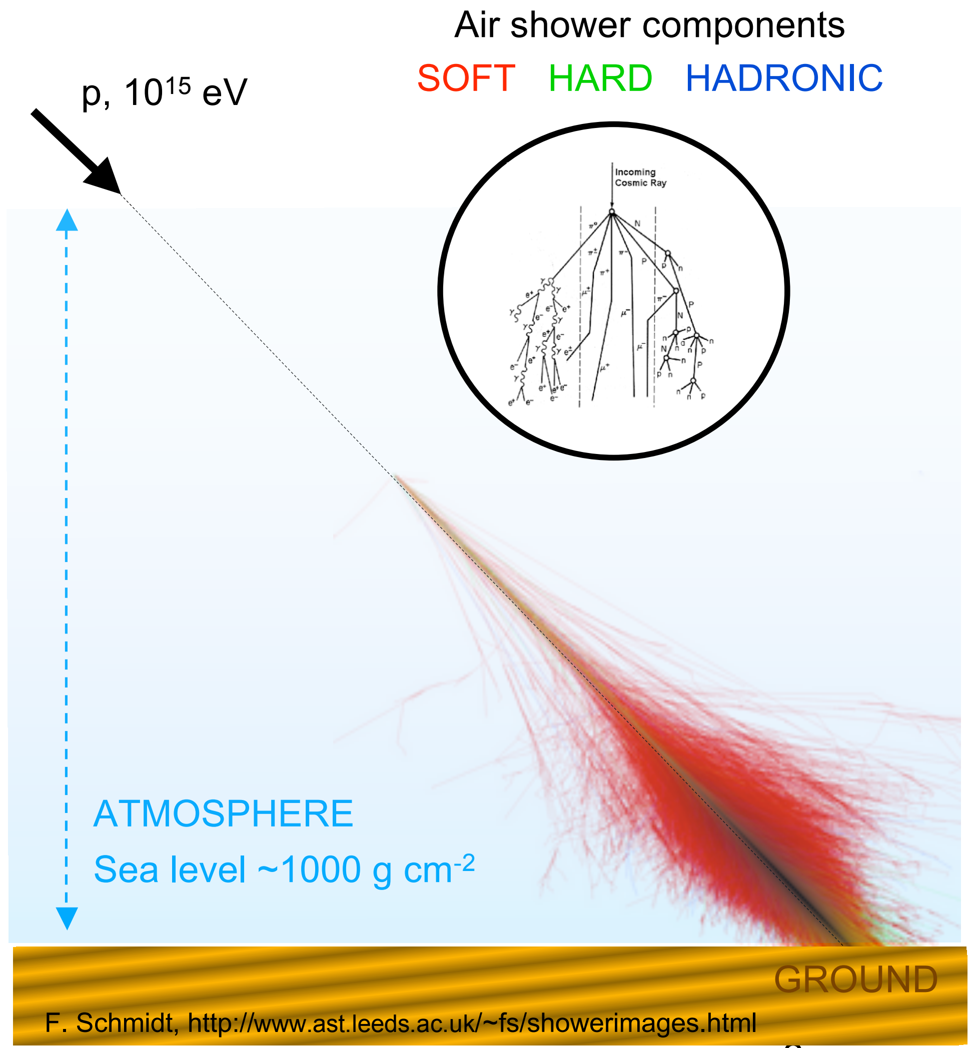
aa 2007-08

Lezione 9

Bruno Borgia

Misure indirette dei RC





- large detection areas for significant statistics
- ground based detectors:

  → Extensive Air Showers

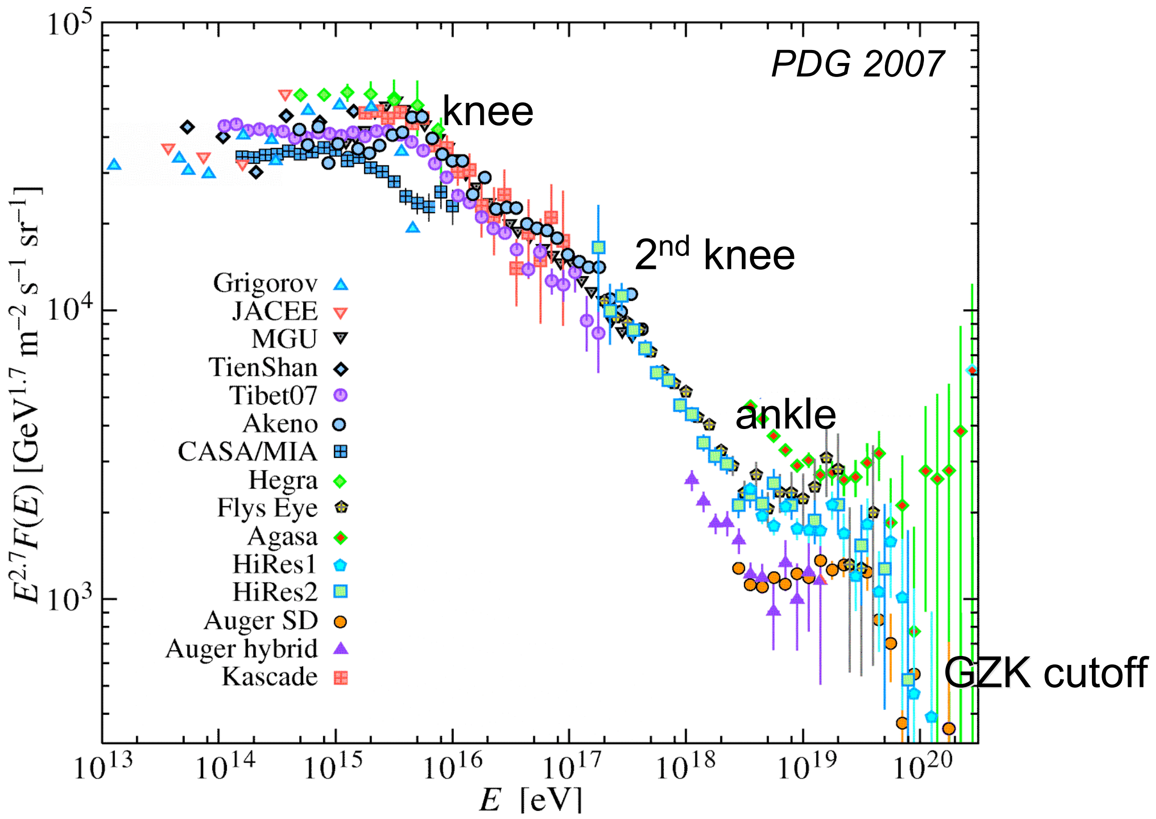
La fisica dei raggi cosmici UHE

ASTRO -

- quali sono le sorgenti?
- quanto distanti e come distribuite?
- meccanismi di accelerazione?
- propagazione?

- PARTICLE

- interazioni di particelle ad energie superiori delle macchine acceleratrici?



Misure:

- distribuzione di energia
- composizione chimica
- direzione di arrivo
- verifica modelli di interazione ad alta energia

EAS

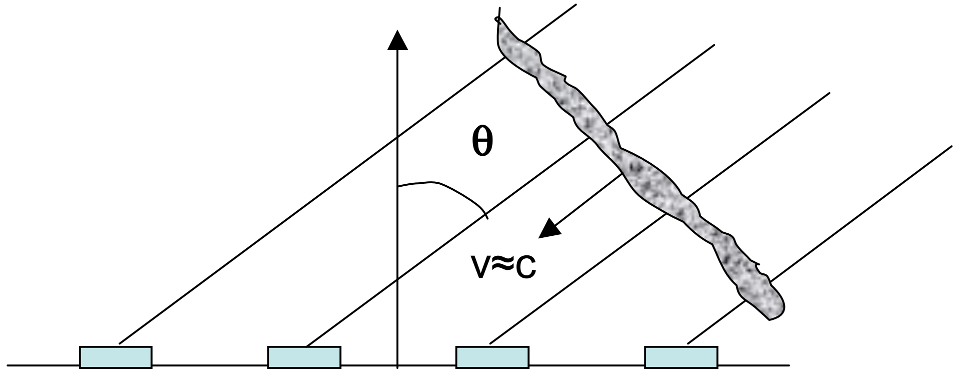
Estensive Air Shower

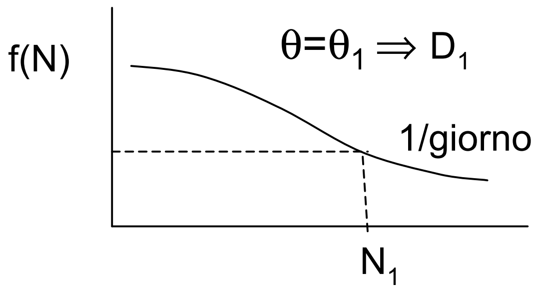
Le particelle cariche dello sciame possono provocare anche la fluorescenza dell'azoto atmosferico, generando circa 5000 fotoni per km di traccia, nella regione del blu. La luce di fluorescenza è emessa isotropicamente.

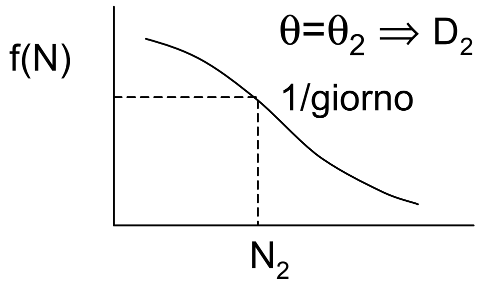
Particelle secondarie generate negli sciami iniziati da protoni o nuclei di alta energia possono arrivare a terra senza perdere tutta la loro energia nell'atmosfera. Per rivelare tali sciami si impiegano rivelatori di dimensioni limitate ma in gran numero distribuiti su una grande superficie. Il solo fatto di osservare a terra 10^6 o più particelle relativistiche ci dice che il primario deve aver avuto una energia molto grande.Per stimare l'energia si modella lo sviluppo di sciami adronici per mezzo di montecarli confrontando i risultati con le misure eseguite da una collaborazione US-Giappone sul Monte Chacaltaya in Bolivia a 5200 m di quota. A questa altezza la densità atmosferica sopra il rivelatore è circa la metà essendo 520 g/cm^2. Si misura quindi il numero di particelle in funzione dell'angolo zenitale θ e quindi si studia lo sviluppo dello sciame per profondità variabili. L'angolo θ si ottiene dai tempi di arrivo delle particelle nei vari rivelatori, tenendo conto che lo spessore delle particelle che arrivano è dell'ordine di qualche metro. Inoltre si assume che sciami che arrivano da angoli diversi ma che hanno la stessa frequenza siano iniziati da primari della stessa energia. In definitiva si può quindi ottenere una distribuzione di numero di particelle per spessori variabili dell'atmosfera a energia fissata,

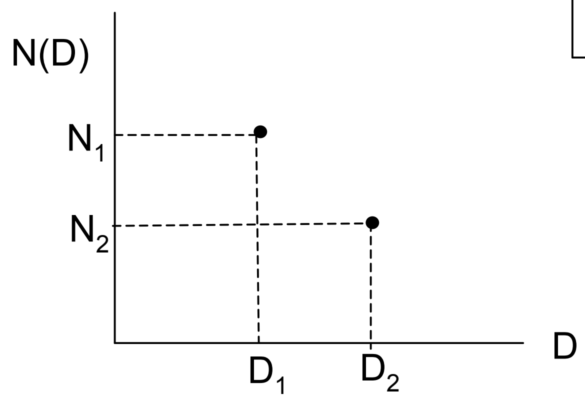
Esistono altri metodi per calibrare gli sciami estesi.

EAS









UHE e EHE CR

Lo spettro dei RC si estende fino a 10^{20} eV e i dati provengono da esperimenti con rivelatori distribuiti su grandi superfici. AGASA in Giappone ha un'estensione di 100 km^2. Auger si estende su 3000 km^2 e potrà misurare ≈50 eventi/anno con E≈10^{20} eV.
Greisen, Zatsepin e Kuzmin mostrarono che a quelle energie l'universo diventa opaco a causa della fotoproduzione di pioni alla risonanza Δ^{++} nell'urto di protoni contro i fotoni della radiazione cosmica di fondo:

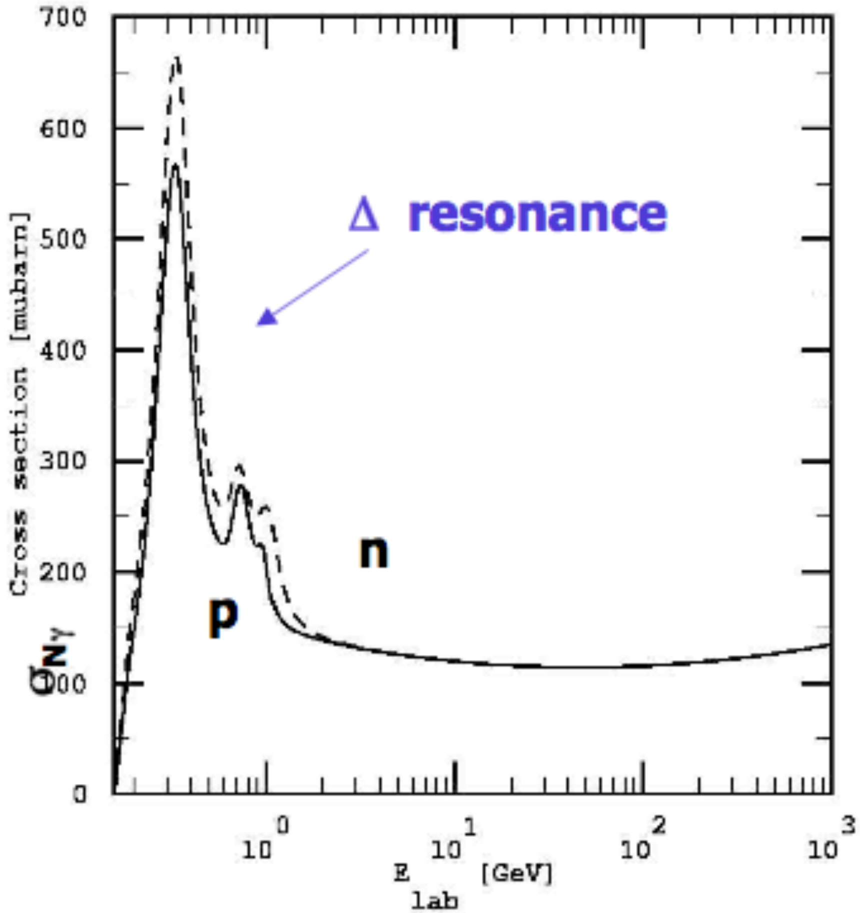
$$p+\gamma\rightarrow\Delta^{++}\rightarrow p+\pi^0$$

$$p+\gamma\rightarrow\Delta^{++}\rightarrow n+\pi^+$$

La sezione d'urto per questa reazione è $\sigma \approx 2\ 10^{-28}$ cm^2
La densità della radiazione di fondo è ρ = 400 fotoni/cm^3
Il cammino libero medio è quindi $\lambda = 1/\rho\sigma \approx 10^{25}$ cm = 5 Mpc (dimensione di un cluster di galassie)
I protoni con energia $E_p \approx 10^{19}$ sono sopra soglia per la produzione di Δ^{++}.
Questo limite è noto come limite GZK.
A queste energie i protoni non sono confinati nella nostra Galassia.

{calcolare il raggio di curvatura nel campo magnetico galattico}

LIMITE GZK



$$protone: (\vec{p},E); \quad fotone_{CMB}: \quad (\vec{q},qc)$$

$$s = E_{cm}^2 = (E+q)^2 - (\vec{p}+\vec{q})^2 = M^2 + 2q(E - |\vec{p}|\cos\theta)$$

$$s \ iniziale > s \ a \ soglia$$

$$M^2 + 2q(E - |\vec{p}|\cos\theta) > M^2 + m_\pi^2 + 2Mm_\pi$$

$$protone \ relativistico$$

$$E \approx p$$

$$urto \ centrale$$

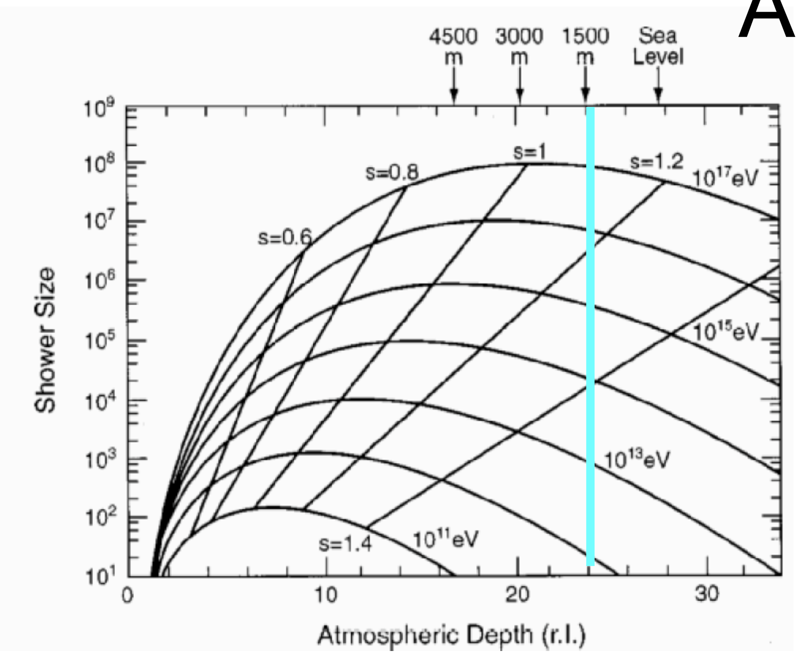
$$(1-\cos\theta) = 2$$

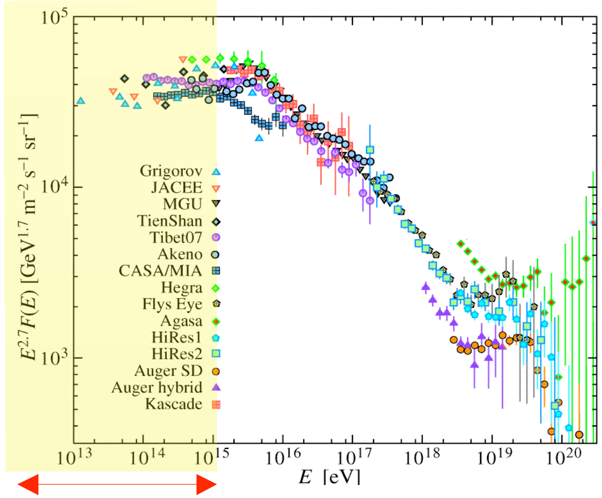
$$E_{soglia} = m_\pi \frac{M + m_\pi/2}{2q}$$

$$fotoni \ CMB: \ T = 2.74K; \quad qc = kT = 2.35\times10^{-4}\,eV$$

$$E_{soglia} = (4.3/z)\times10^{20}\,eV \qquad con \ \ qc = zkT$$

ARGO-YBJ

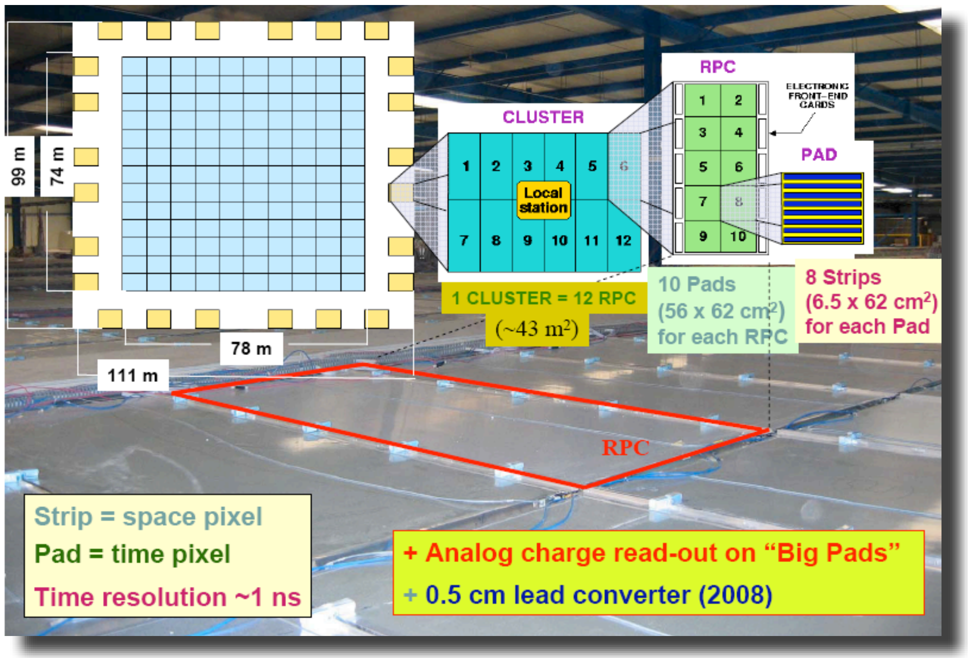




10^{12} - 10^{15} eV

To lower the energy threshold:

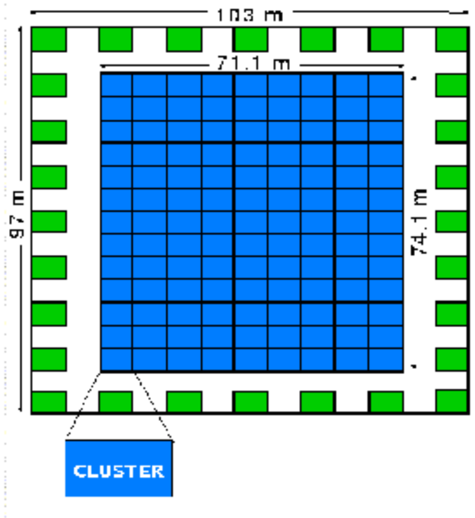
- go to high altitude!
- reduce the spacing between particle detectors



ARGO

ARGO

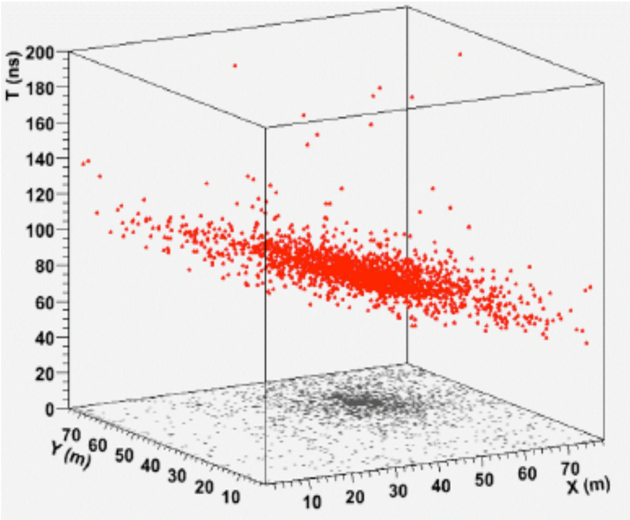
Area 5.200 m^2 (full coverage)
(10.000 m^2 with guard ring)
Field of view ~ 1 sr
E = 50 GeV - 50 TeV
Location: Tibet 4300m alt.
Scheduled 2002 (final conf.)

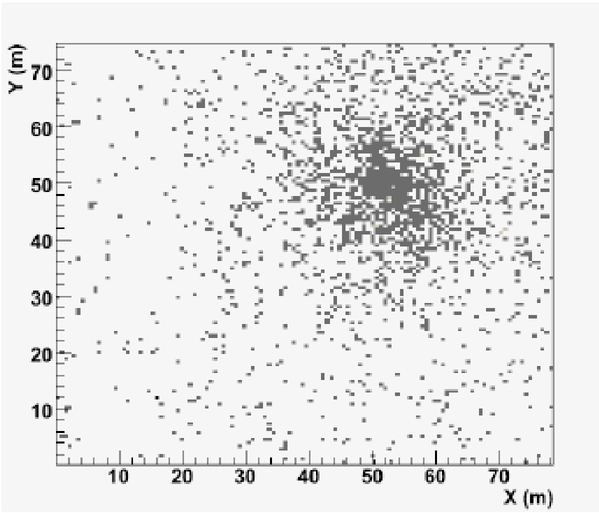


17400 Pads 56 by 60 cm^2 each of Resistive Plate Chamber (RPC).
Each pad subdivided in pick-up strips 6 cm wide for the space pattern inside the pad.
The CLUSTER is made of 12 RPCs Pads

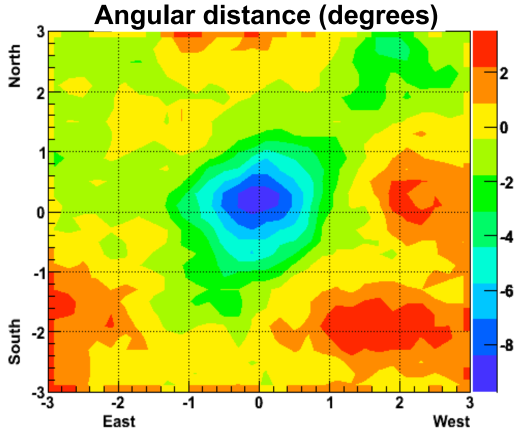
Risultati ARGO-YBJ (I)

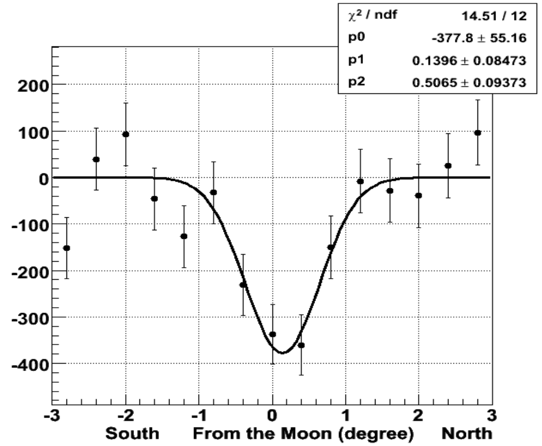
High space-time granularity

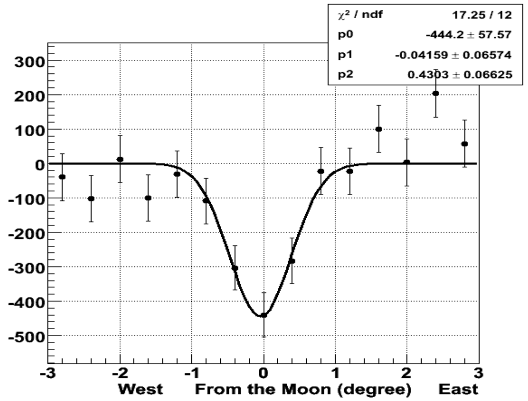




Moon Shadow



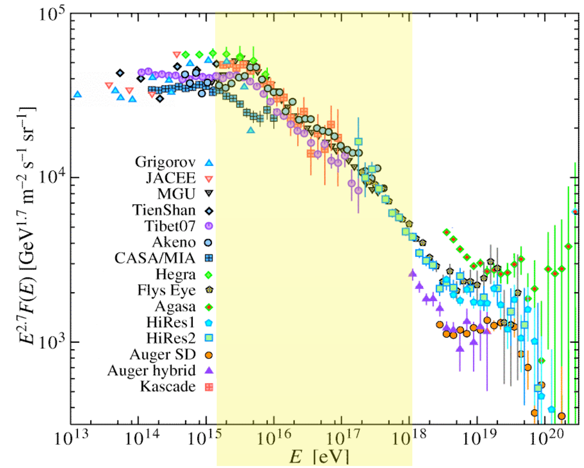




- 560 h of Moon observation with $\vartheta<45°$
- $N_{pad} > 500$ (median energy ~ 5 TeV)
- only events with core reconstructed inside the array

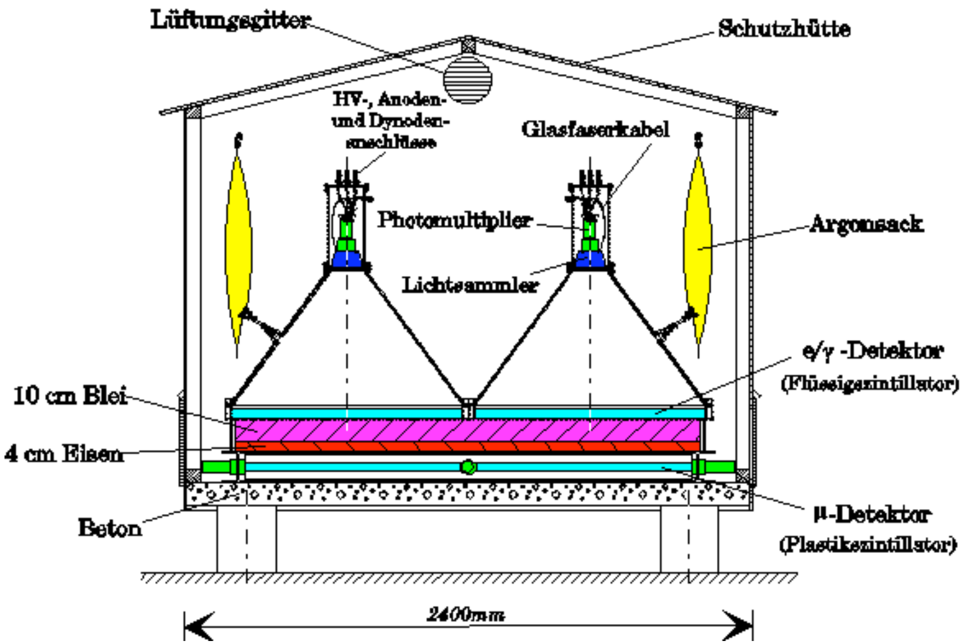
Deficit significance ~10 σ
Angular shift with respect to the Moon position :
0.04° westward
0.14° northward

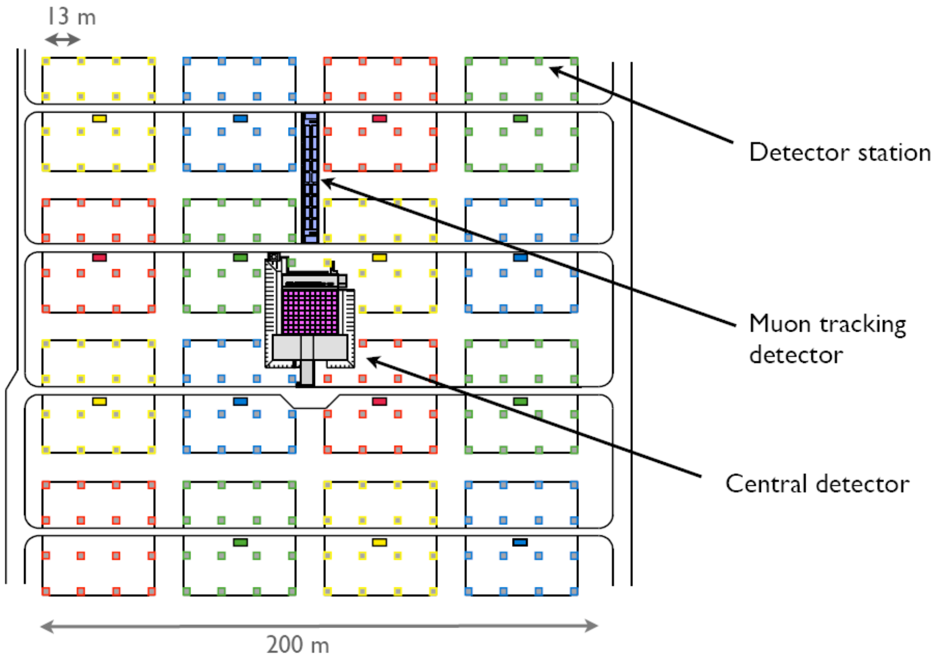
Karlsruhe Shower Core Array DEtector



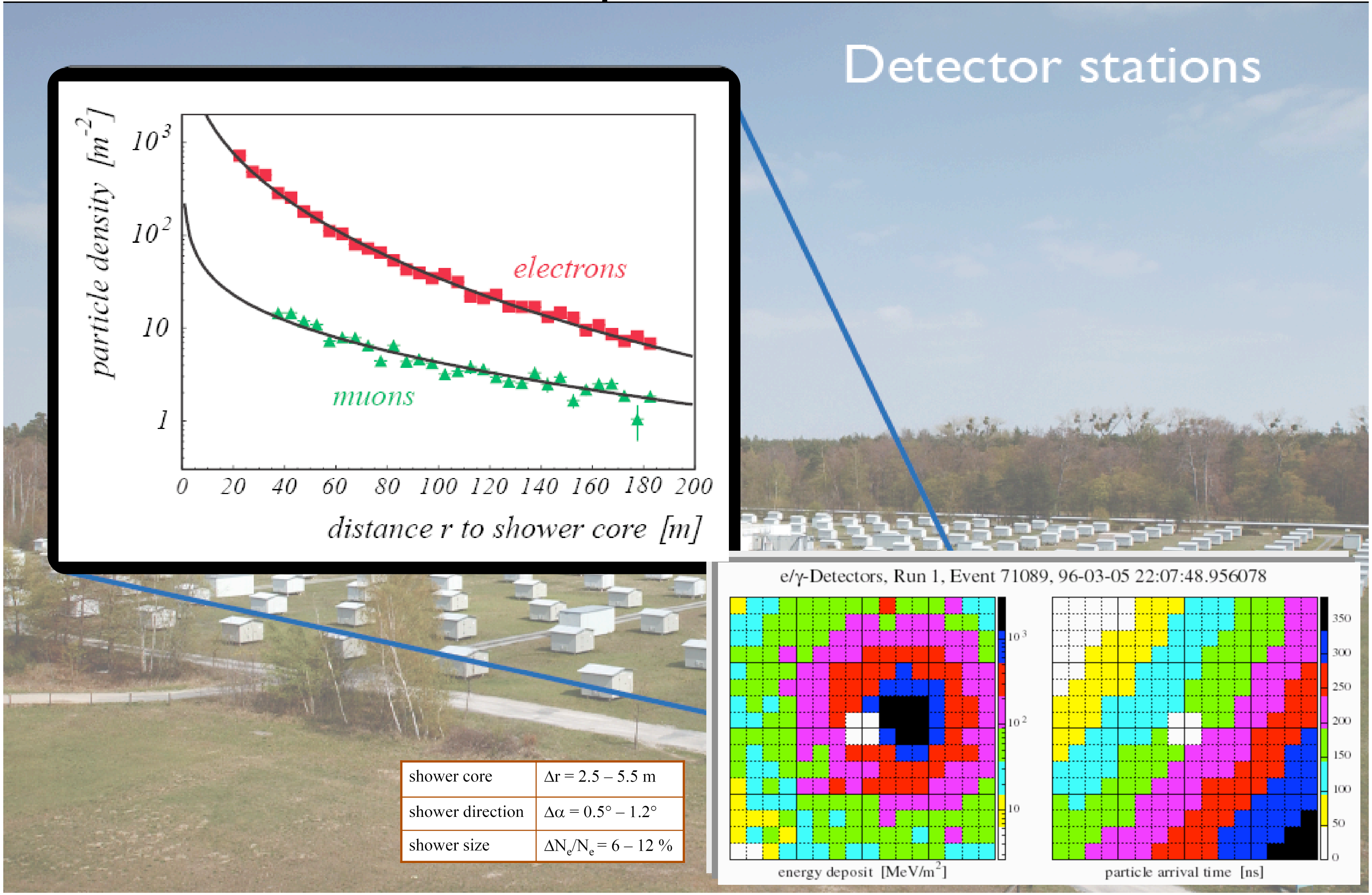
Simultaneous measurement of the shower components:

- electromagnetic
- muonic
- hadronic



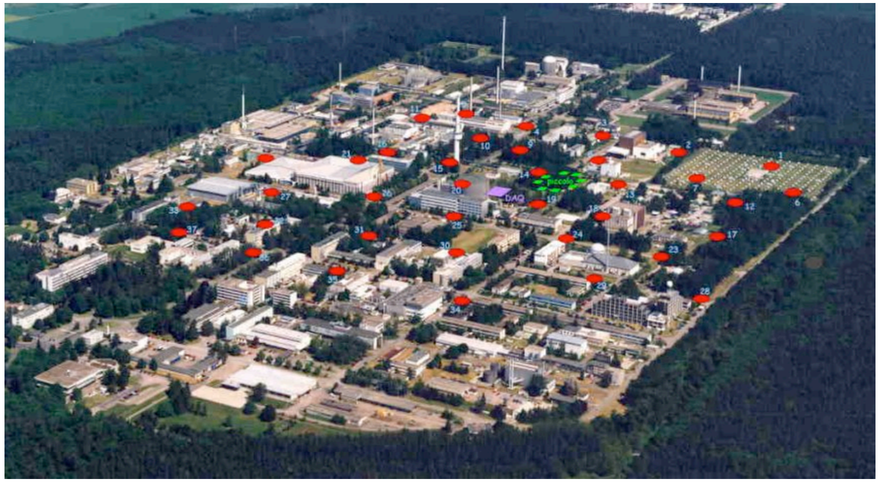


KASCADE e/γ and muon detector



shower core	$\Delta r = 2.5 - 5.5$ m
shower direction	$\Delta\alpha = 0.5° - 1.2°$
shower size	$\Delta N_e/N_e = 6 - 12$ %

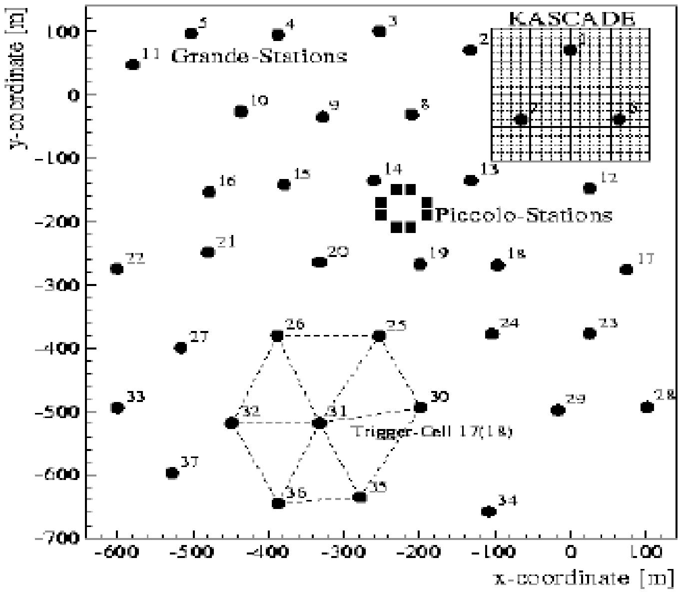
KASCADE-Grande

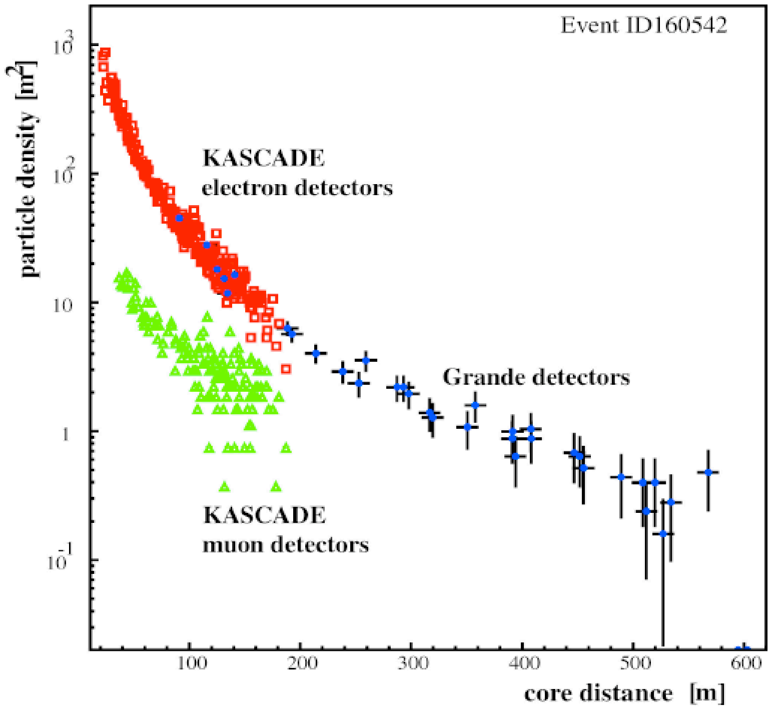


Using scintillators from EAS-TOP, the Instrumented area is increased of more than a factor 10:

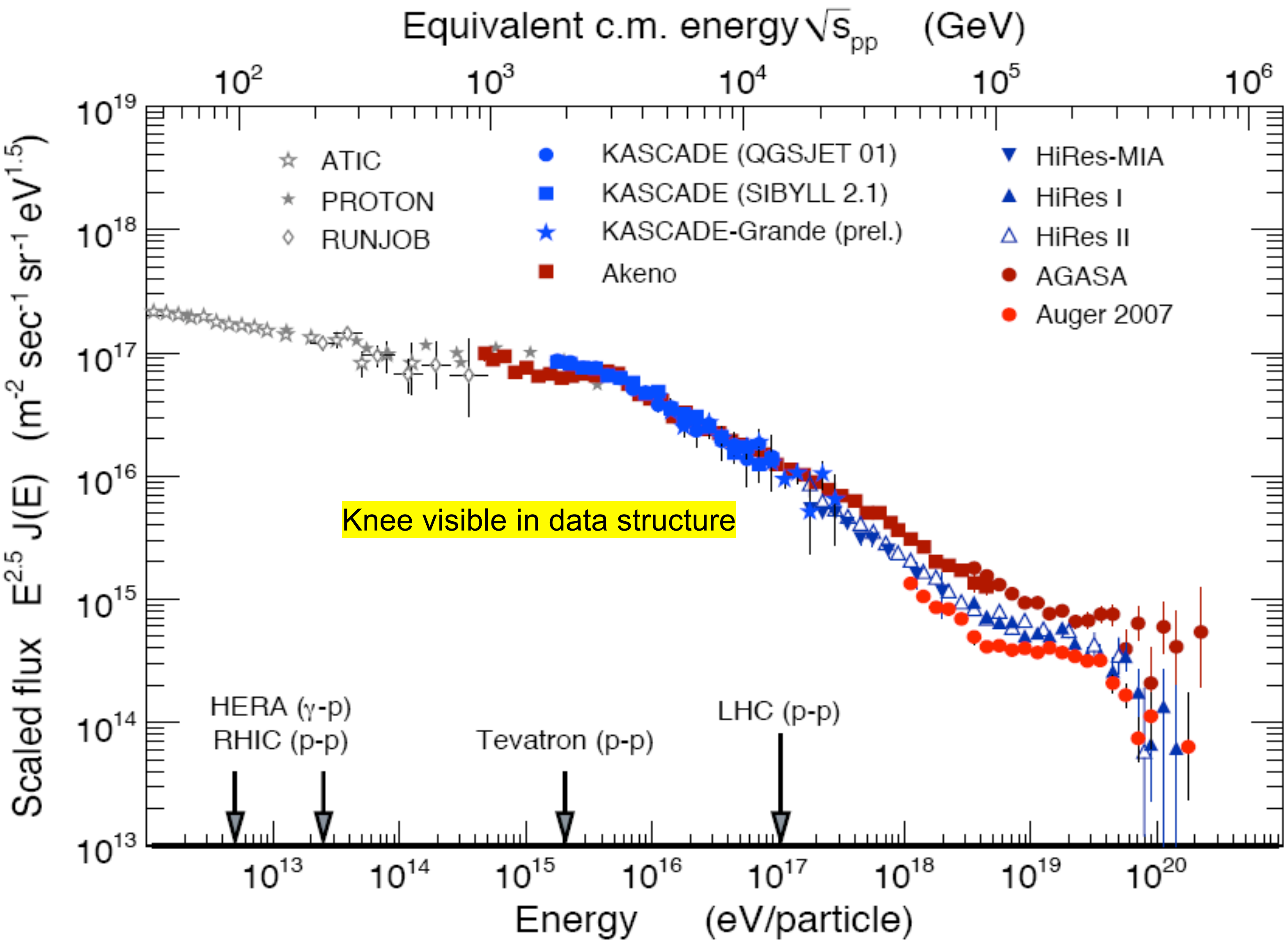
$0.04 \rightarrow 0.5\ km^2$

Energy range extended to 1 EeV

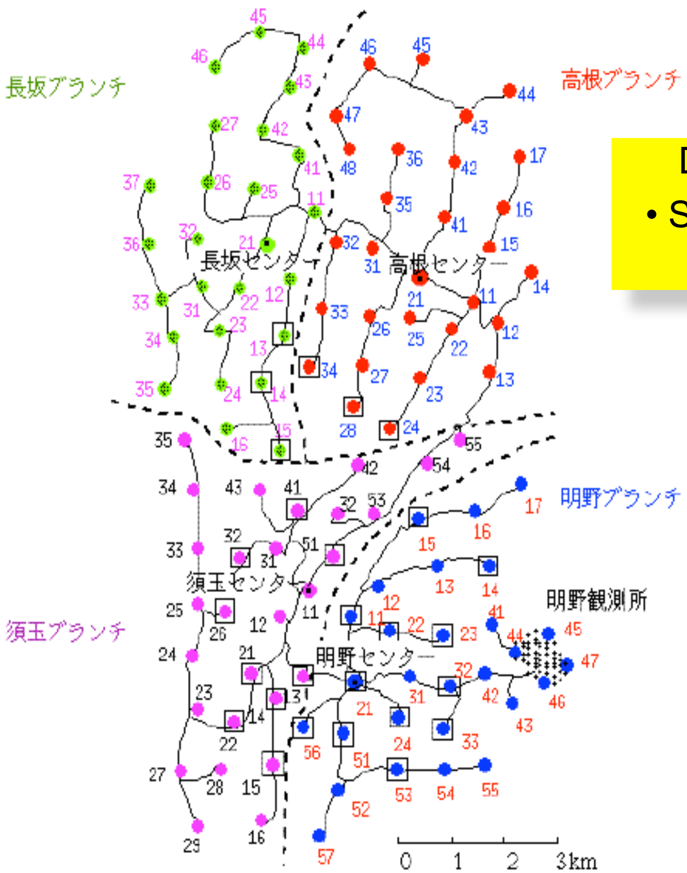




KASCADE all-particle spectrum

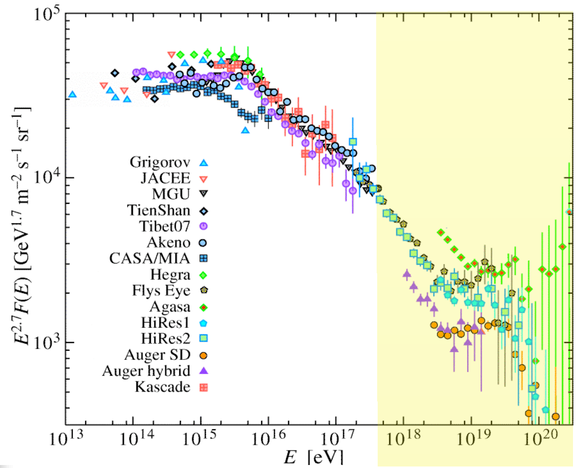


La regione delle alte energie

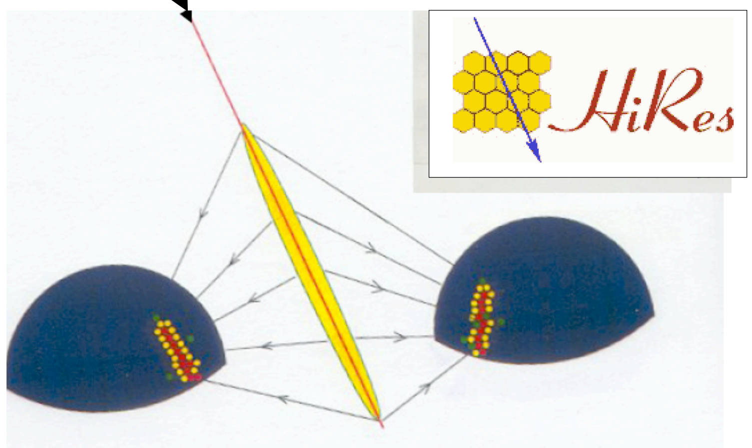


AGASA (Akeno, Japan)
100 km^2 array
1990-2003

Due tecniche di rivelazione:
- Surface particle detector array
- Fluorescence telescopes

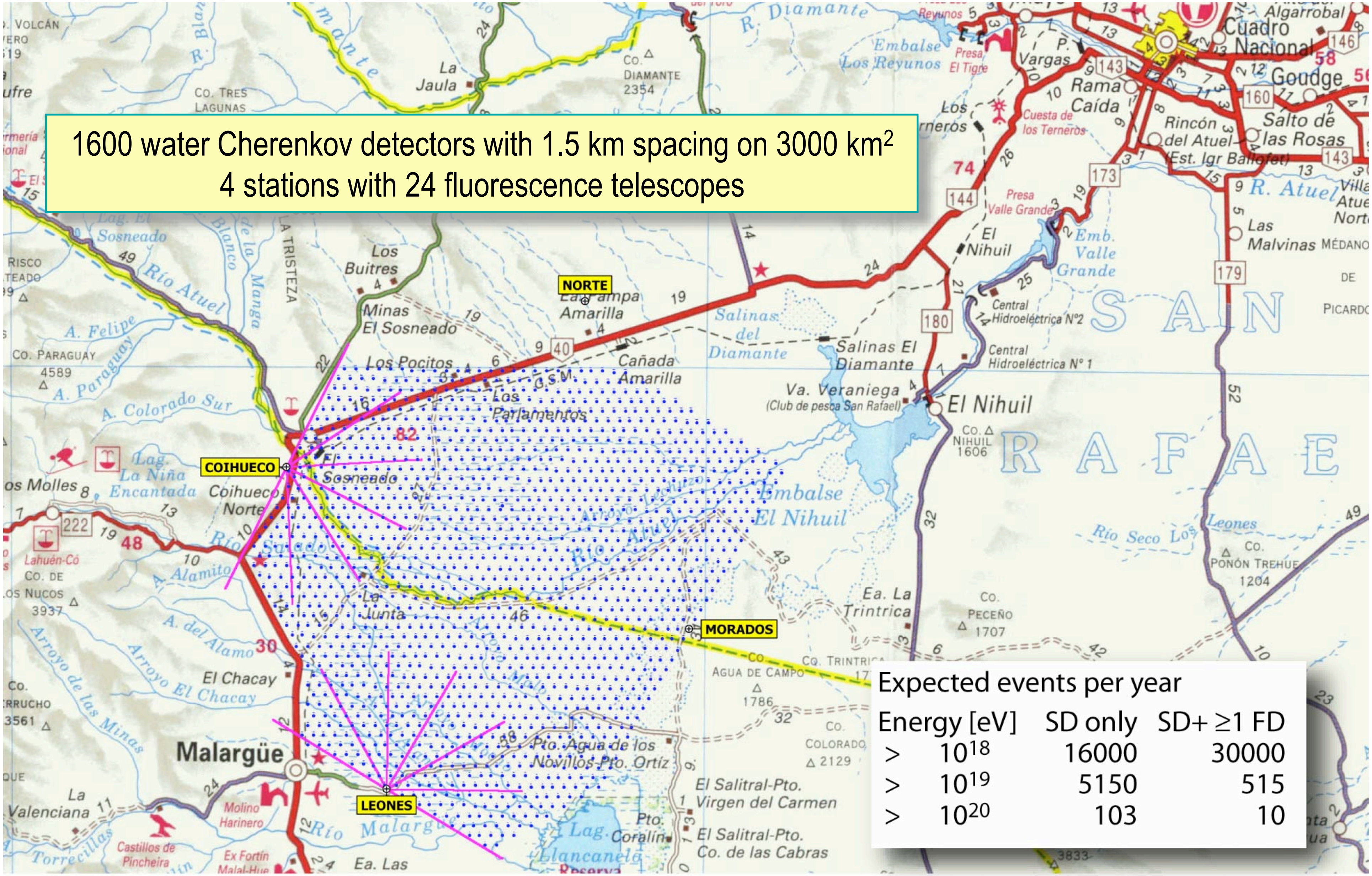


Utah
Stereo FD
1997-2006



- Fluorescence UV photons imaged with a pixel detector
- Track the longitudinal profile

AUGER



1600 water Cherenkov detectors with 1.5 km spacing on 3000 km^2
4 stations with 24 fluorescence telescopes

Expected events per year

Energy [eV]	SD only	SD+ ≥1 FD
> 10^{18}	16000	30000
> 10^{19}	5150	515
> 10^{20}	103	10

Auger: il metodo ibrido

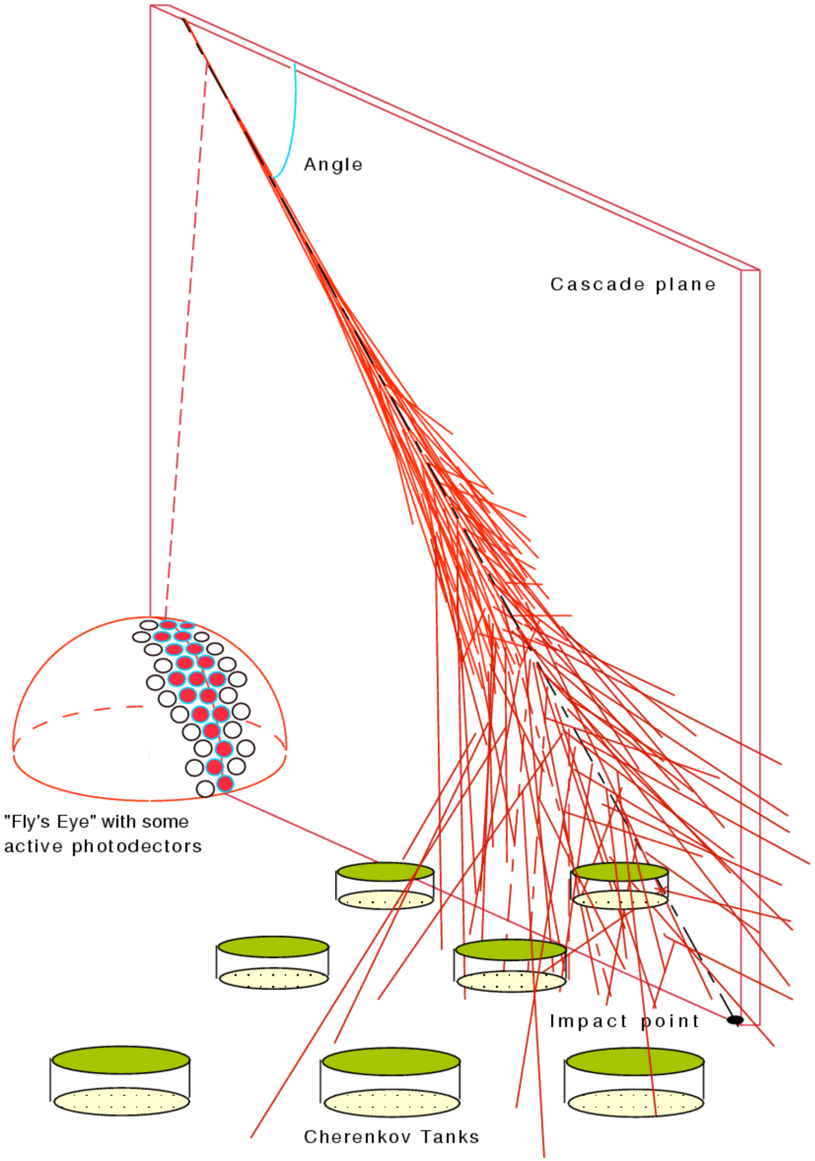
L'Osservatorio Pierre Auger
combina le due tecniche

FLUORESCENCE DETECTOR (FD)

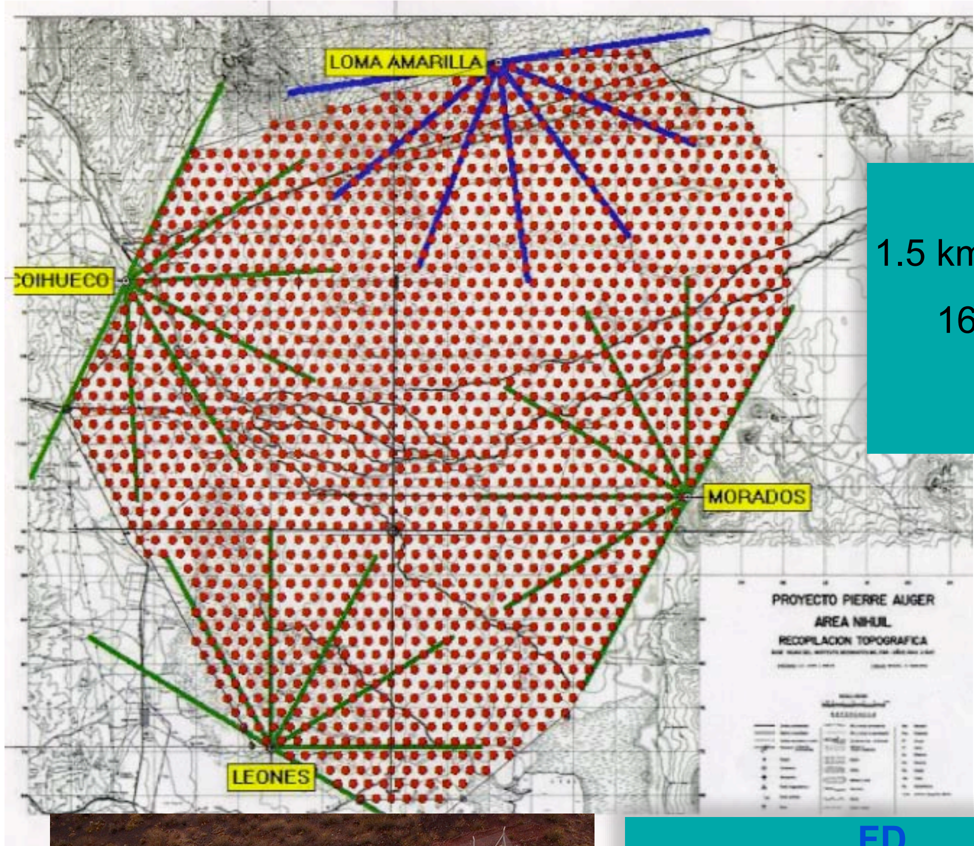
• calorimetric measurement of the energy

SURFACE DETECTOR (SD)

• large collection area, 100% duty cycle



The Pierre Auger Observatory Southern Site



SD

1.5 km spacing, triangular grid

1600 water Cherenkov stations

~ 3,000 km

PIERRE AUGER OBSERVATORY

FD

4 telescope enclosures

6 telescopes x 4 FD sites

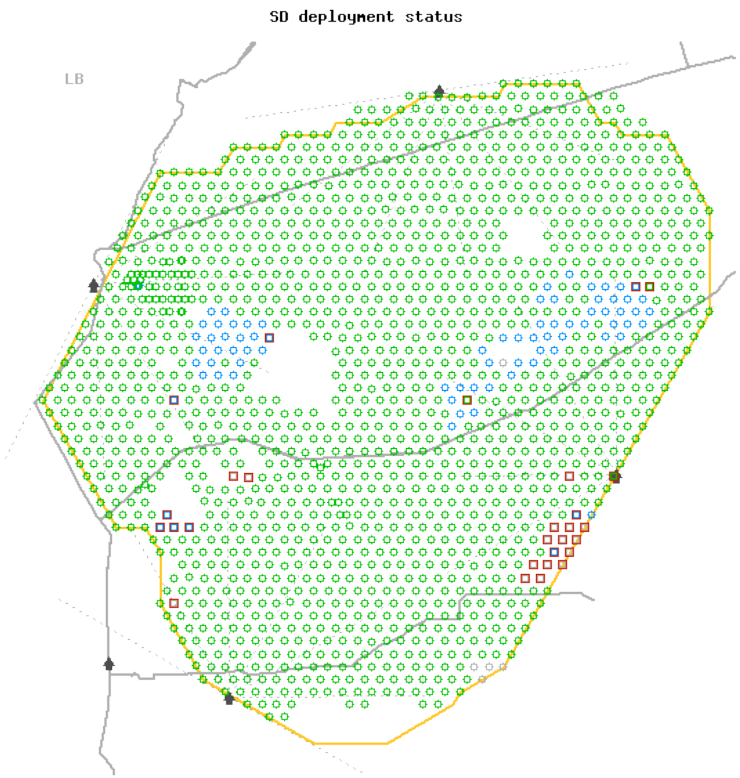
Pampa Amarilla, Argentina

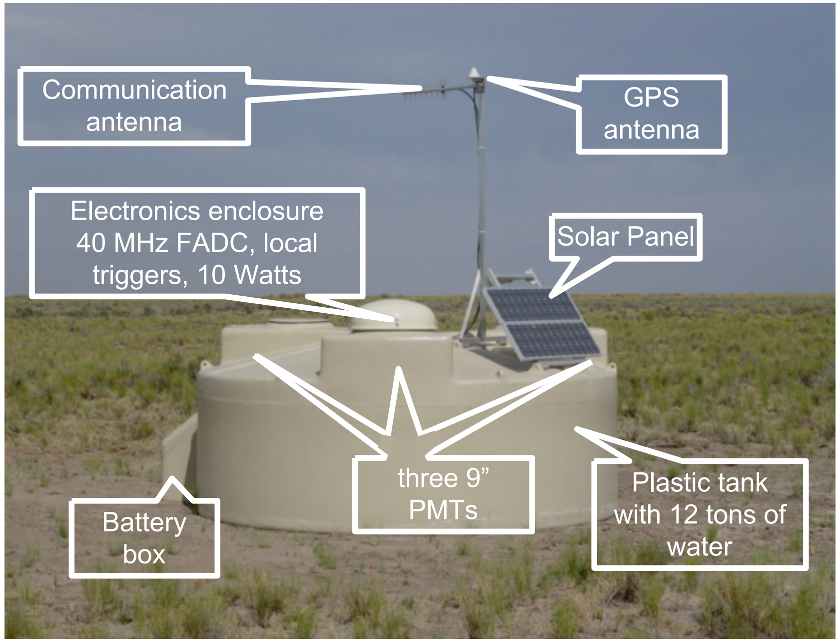
35° S,   69° W

≈ 1400 m a.s.l

≈ 880 g/cm^2

Surface Detector

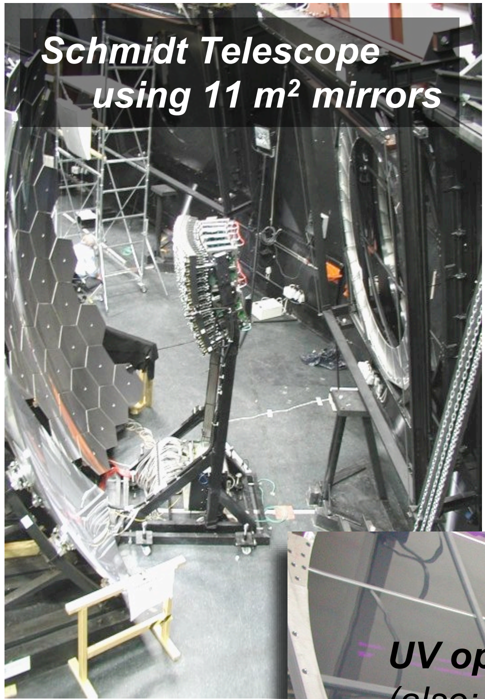


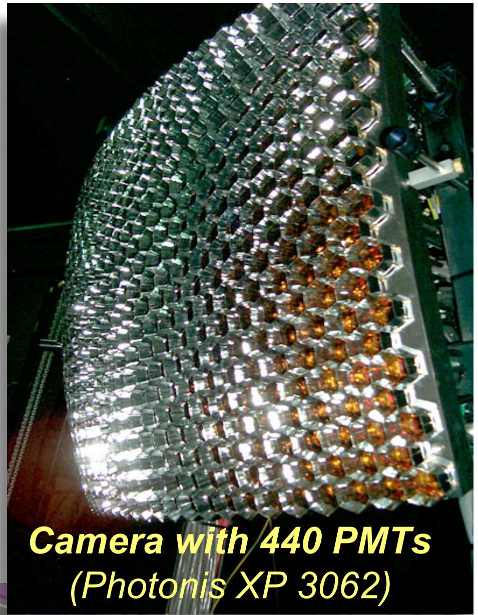


L. Perrone, Aspen 2007

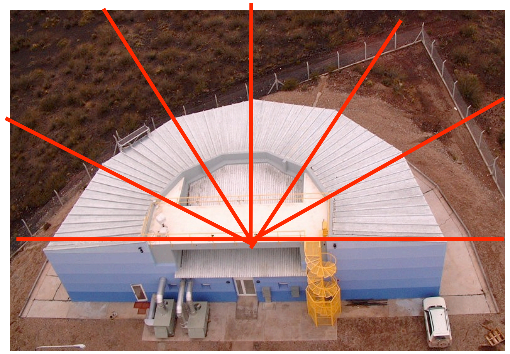
- Stable data taking started in January 2004
- Deployment status: completed!

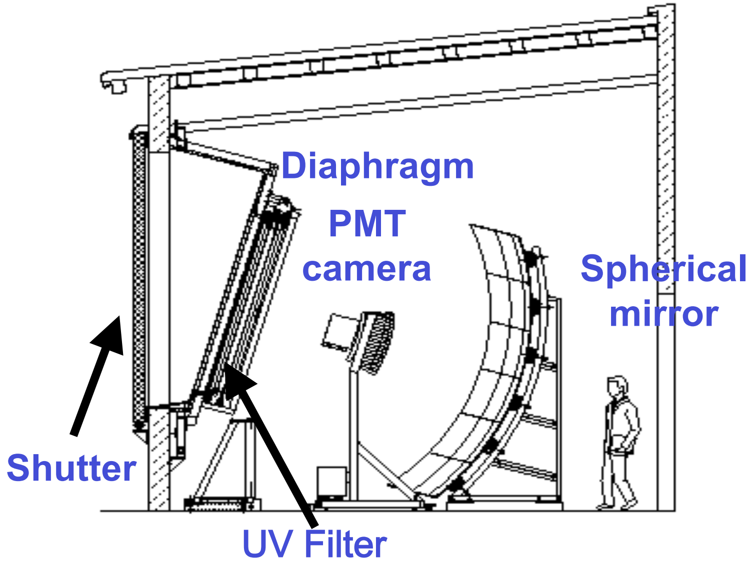
Fluorescence detector





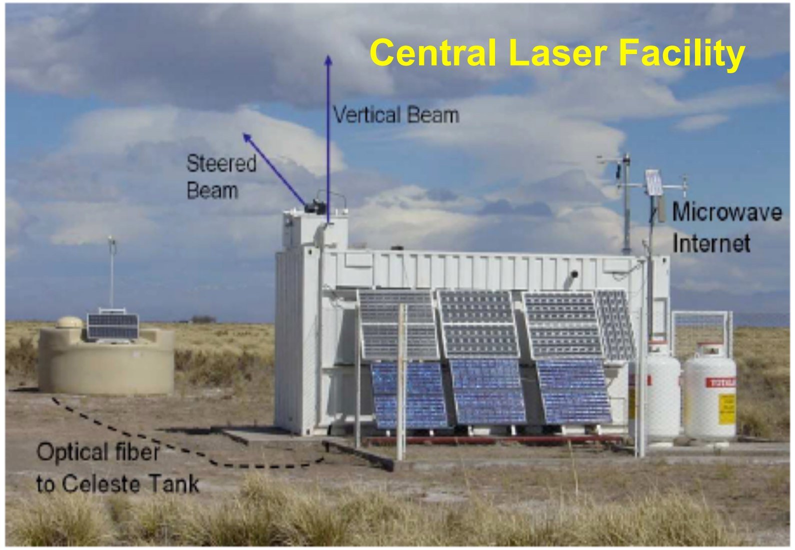
FD completed one year ago



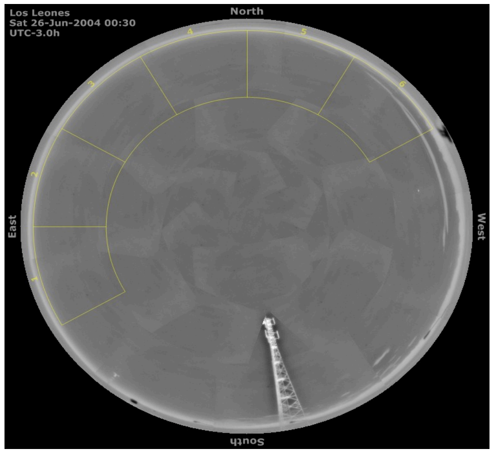


FOV : 30° x 30°

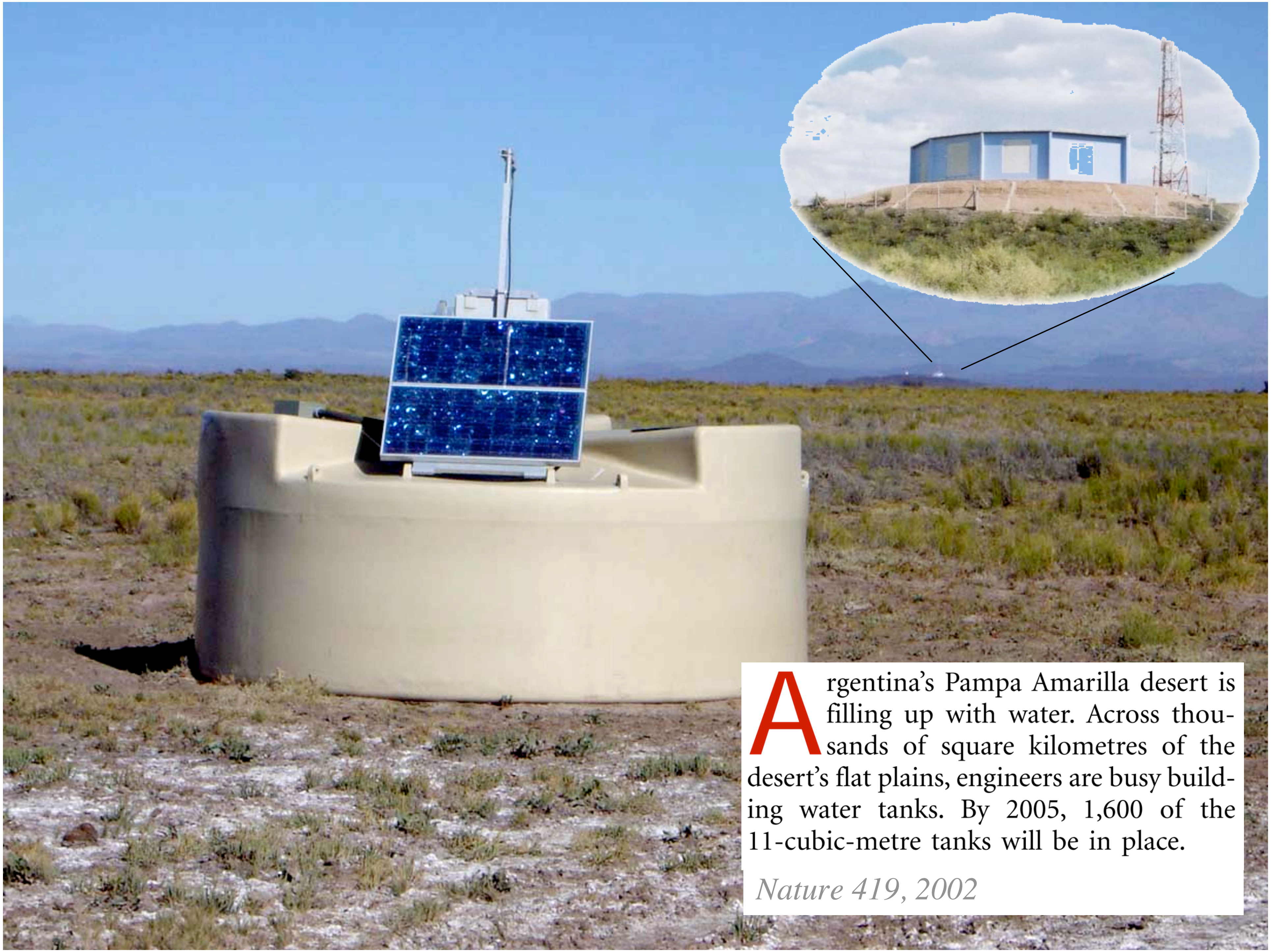
Monitor atmosfera



Radio Soundings with balloons equipped with T,P, wind, humidity sensors



Cloud Camera (one per FD site)

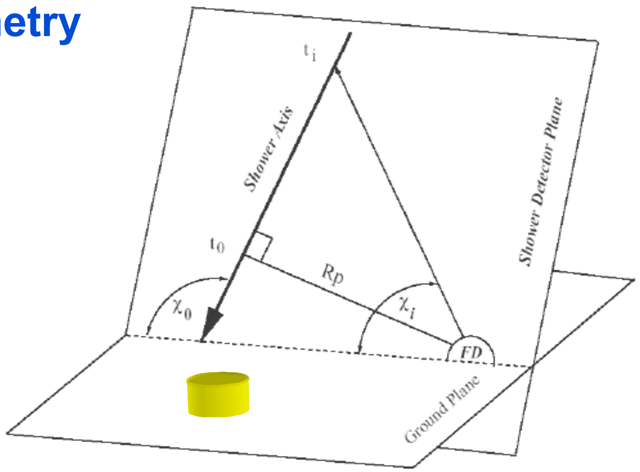


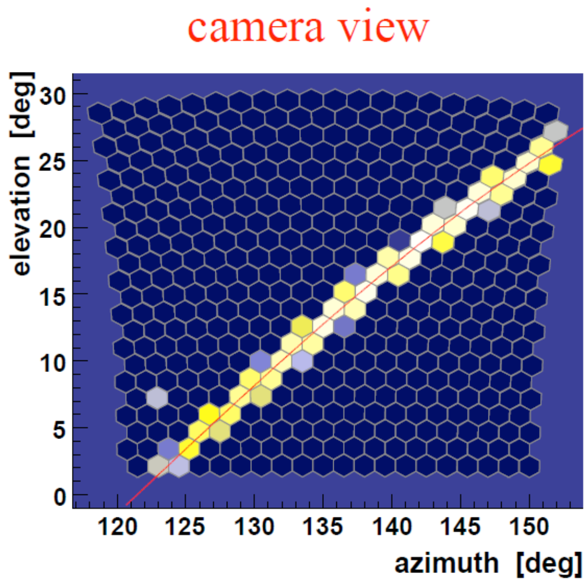
Argentina's Pampa Amarilla desert is filling up with water. Across thousands of square kilometres of the desert's flat plains, engineers are busy building water tanks. By 2005, 1,600 of the 11-cubic-metre tanks will be in place.

Nature 419, 2002

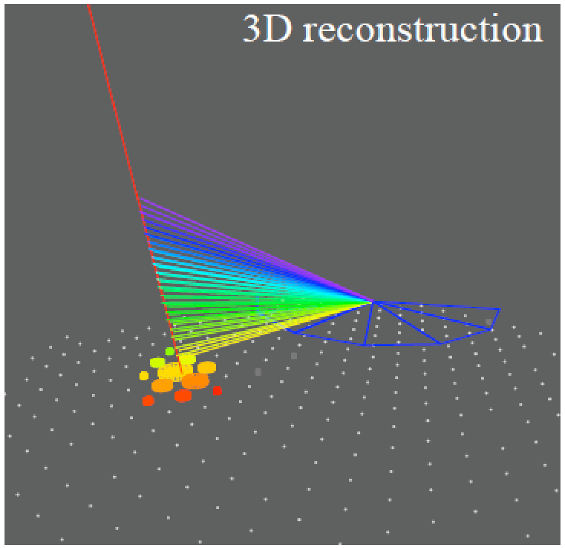
Ricostruzione con FD (hybrid)

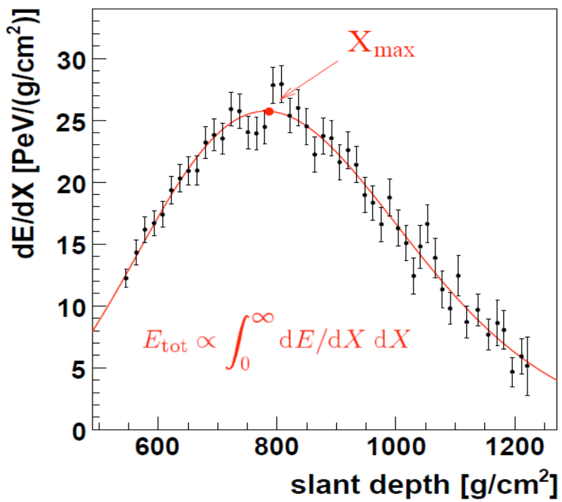
Geometry



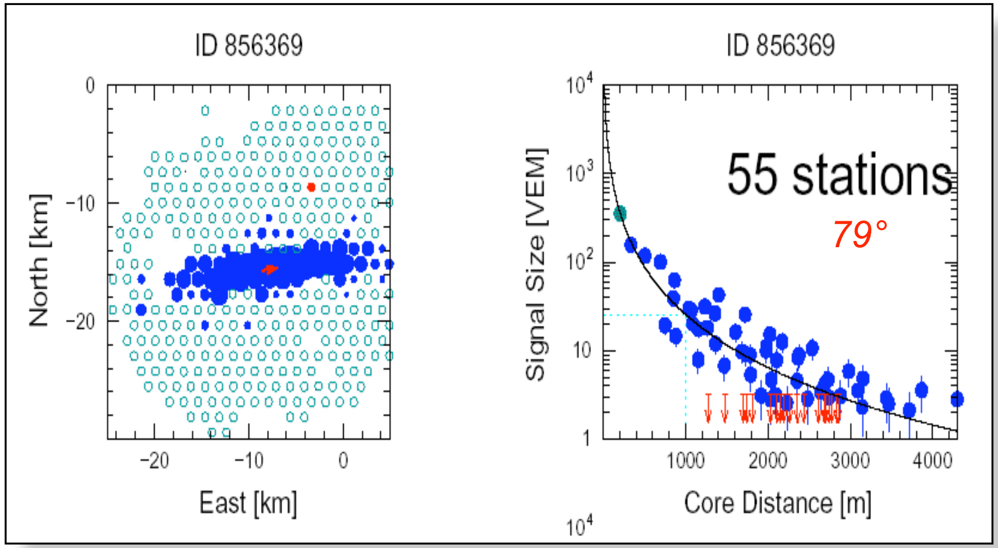


Energy and X_{max}

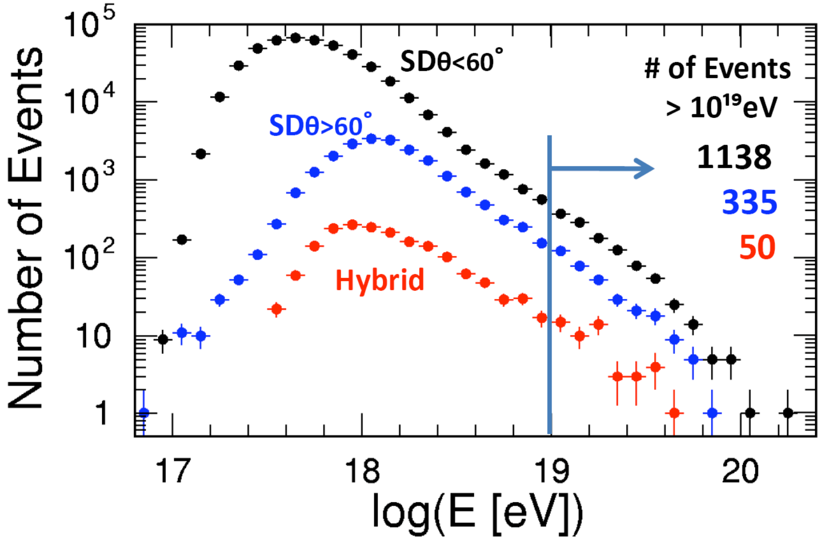




Auger spettro RC: SD, SD-inclined and hybrid

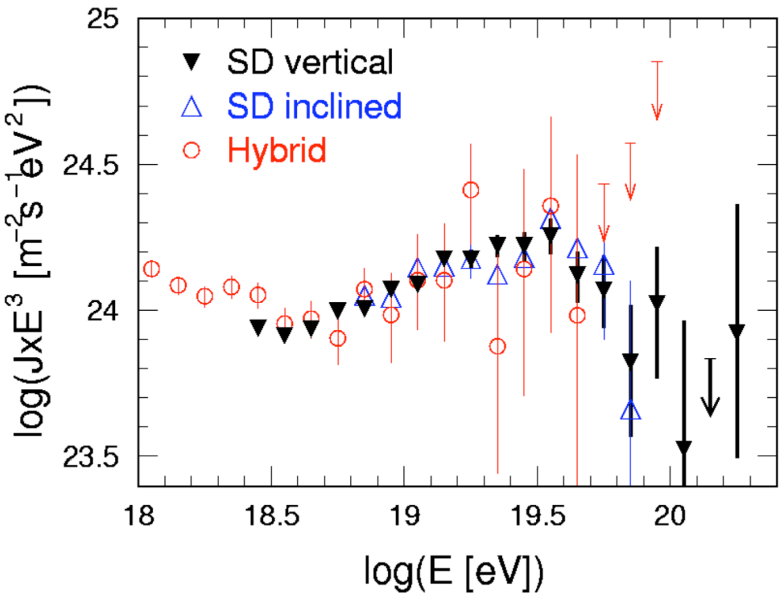


VEM: Vertical Equivalent Muon



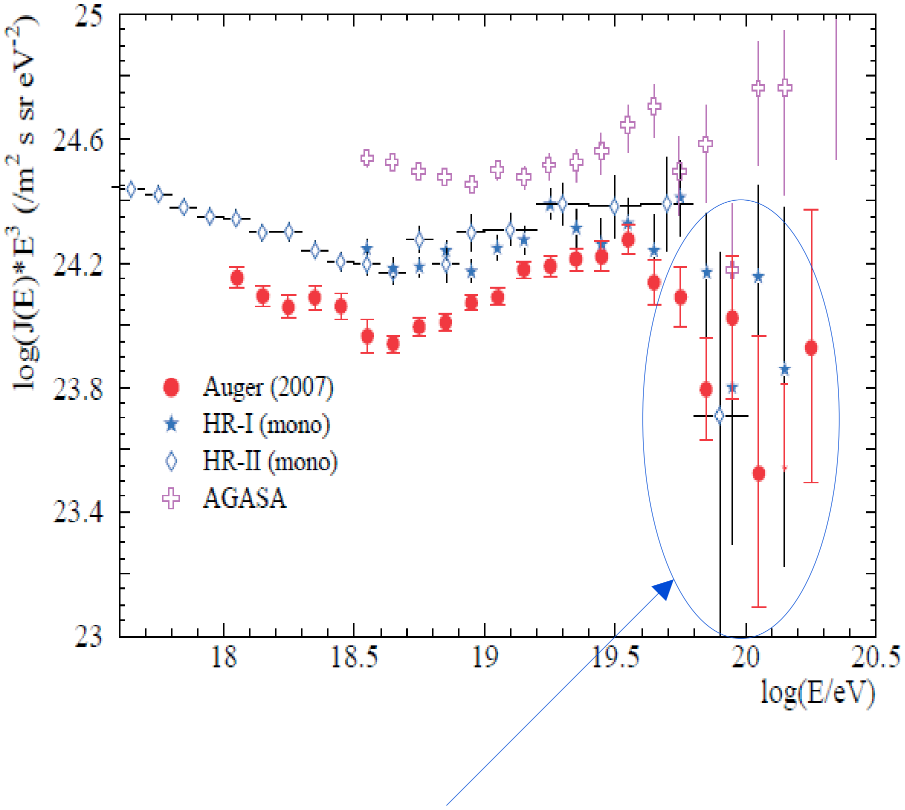
Energy scale is measured with Hybrid Observation

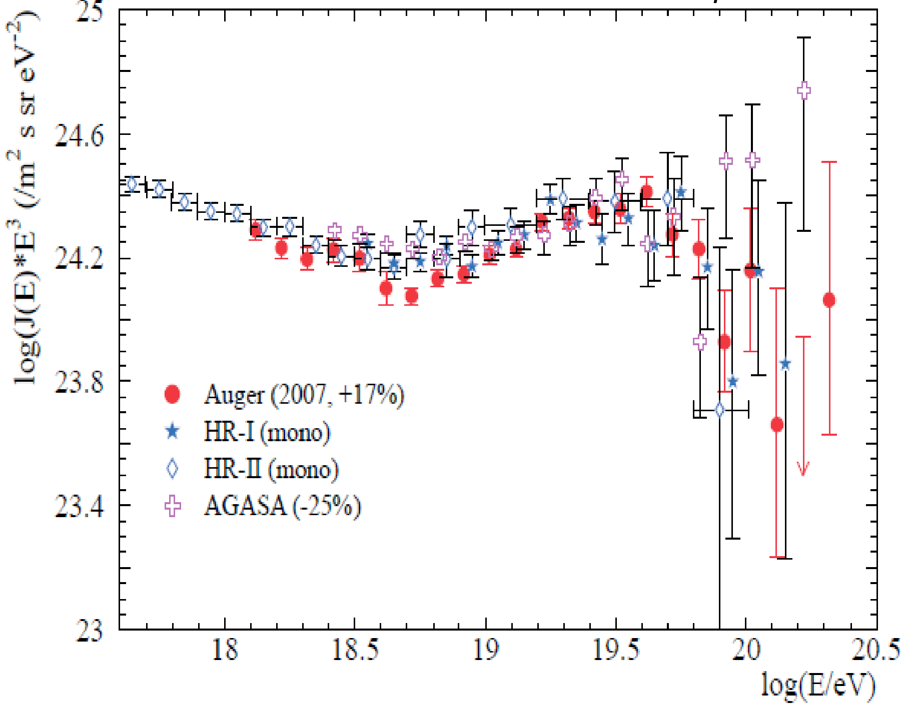
Good agreement between the three spectra



Sommario spettro UHECR

From K.H. Kampert





GZK cutoff?

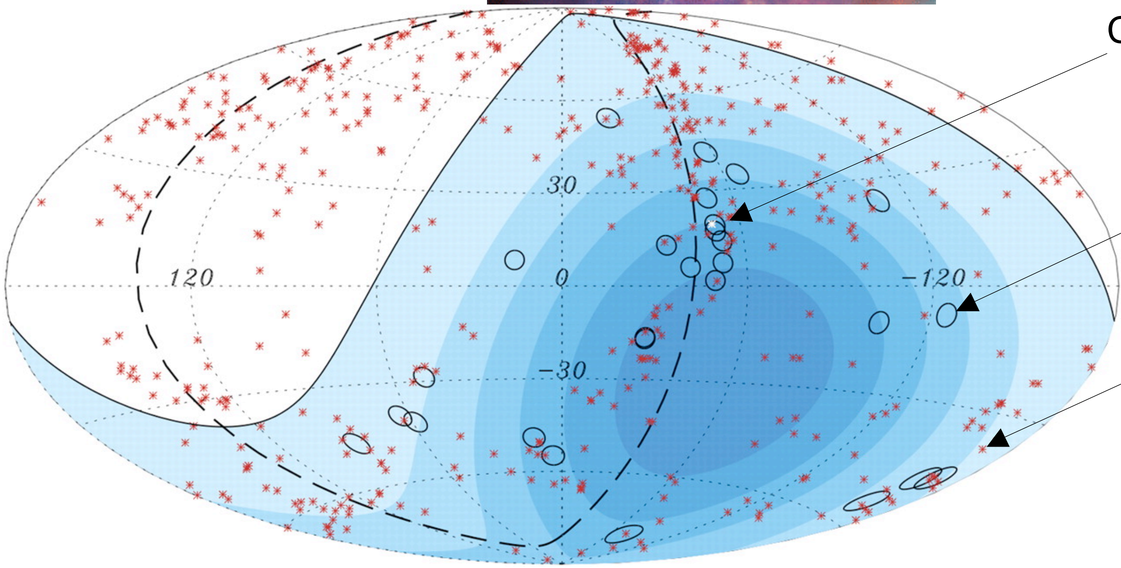
Acceleration limit?

Drop off of lighter elements?

Energy scale problem !

Correlation with nearby AGNs (I)

Pierre Auger Coll., 9 Nov 2007



Centaurus-A (4 Mpc)

3.1° circles around the direction of observed events (E> 57 EeV)

AGNs with z<0.018 from the 12° Veron-Cetty & Veron catalogue

Data set 1Jan 2004 – 31 Aug 2007

20 of 27 events with E>57 EeV are within 3.1 degrees of an AGN at a distance of less than ~75 Mpc

also J.Abraham et al., Astroparticle Physics 29 (2008) 188-204

UHECR summary

•**SPECTRUM**

• Hi-Res and Auger measure a flux suppression above ~4 10^{19} eV with 5 and 6 σ significance level (AGASA data are being reanalised)

• GZK cutoff?

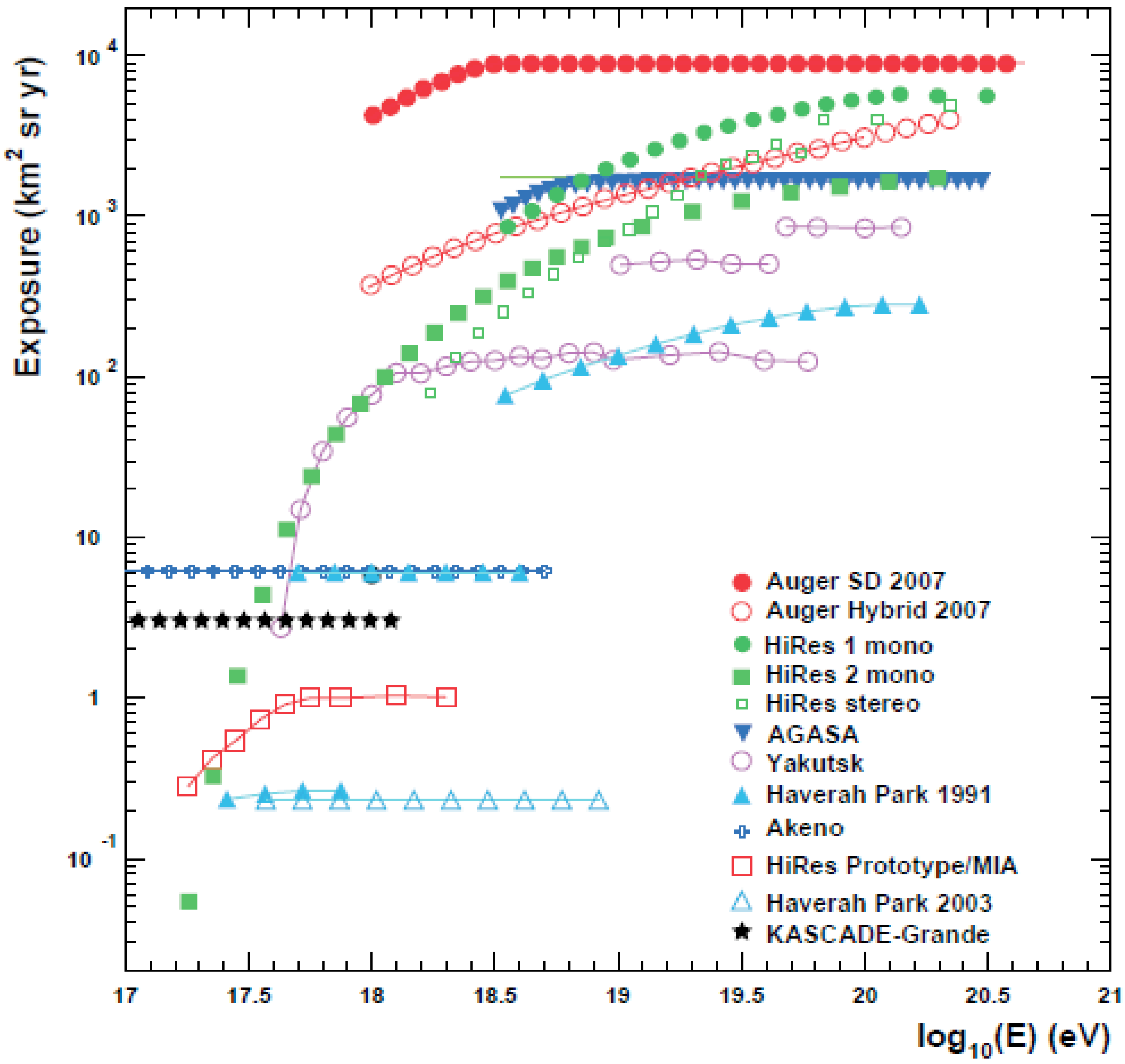
•**ARRIVAL DIRECTION**

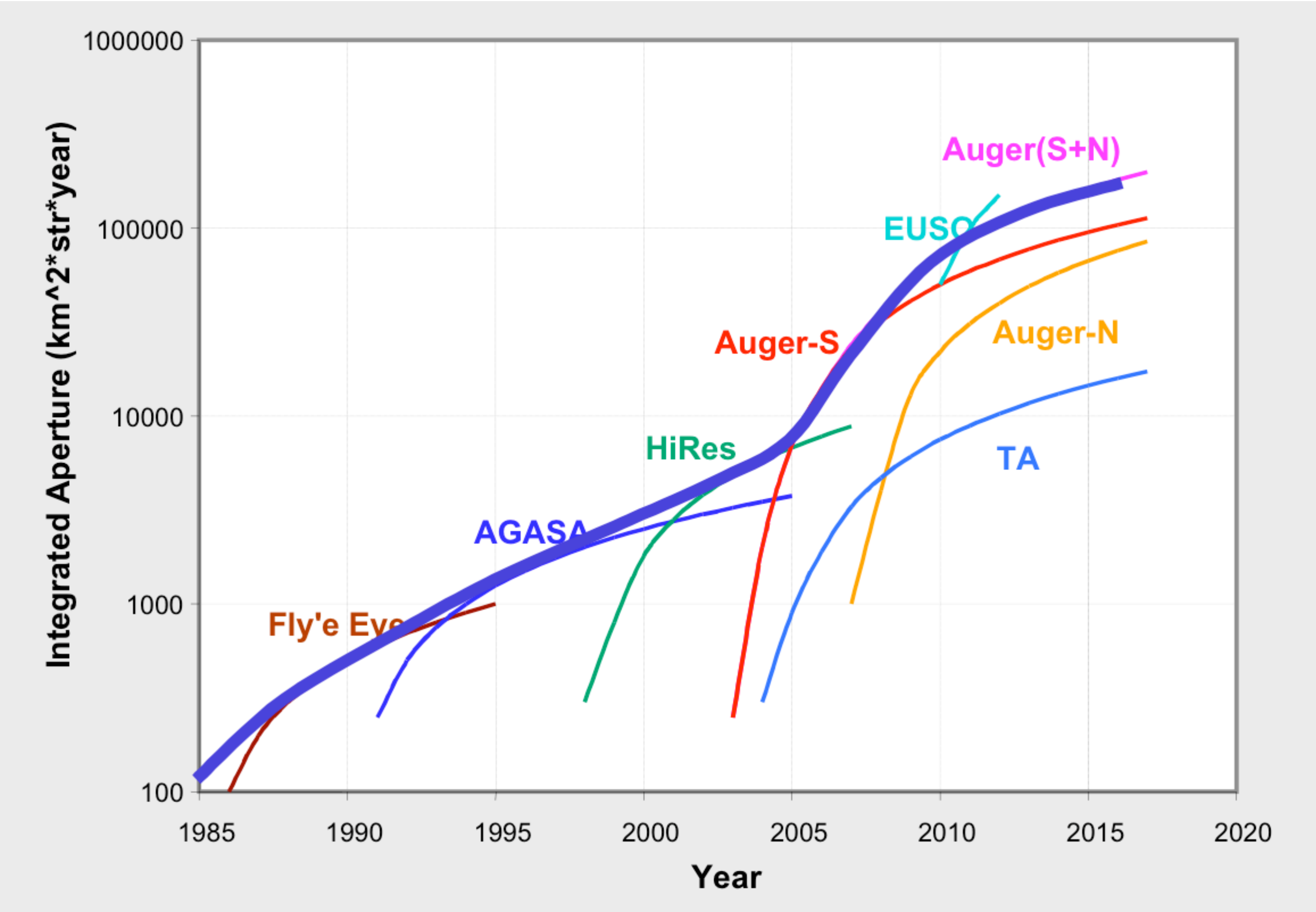
• Auger sees a correlation of highest energy events with nearby AGNs, not confirmed by Hi-Res

•**MASS COMPOSITION**

• no neutrino or photon detected so far

• Xmax analysis suggests mixed composition


Exposure (km² sr yr)
10⁴
10³
10²
10
1
10⁻¹
17
17.5
18
18.5
19
19.5
20
20.5
21
log10(E) (eV)
Auger SD 2007
Auger Hybrid 2007
HiRes 1 mono
HiRes 2 mono
HiRes stereo
AGASA
Yakutsk
Haverah Park 1991
Akeno
HiRes Prototype/MIA
Haverah Park 2003
KASCADE-Grande


Integrated Aperture (km^2*str*year)
1000000
100000
10000
1000
100
1985
1990
1995
2000
2005
2010
2015
2020
Year
Auger(S+N)
EUSO
Auger-S
Auger-N
HiRes
TA
AGASA
Fly'e Eye