

Astrofisica e particelle elementari

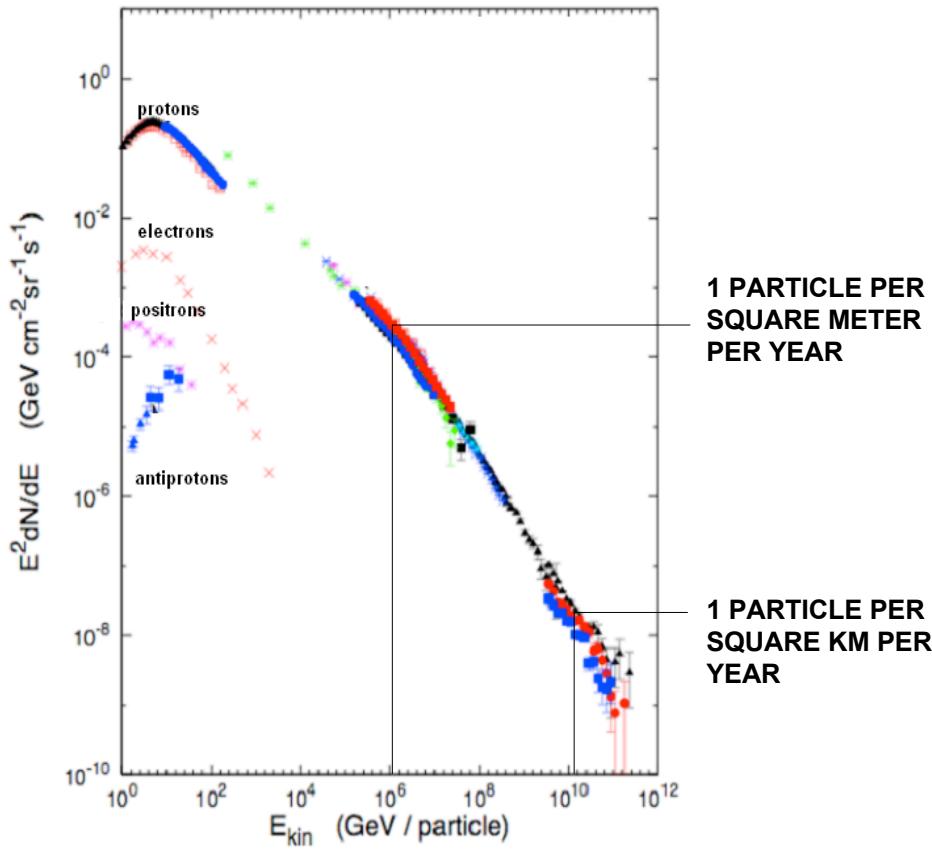
aa 2009-10

Lezione 7

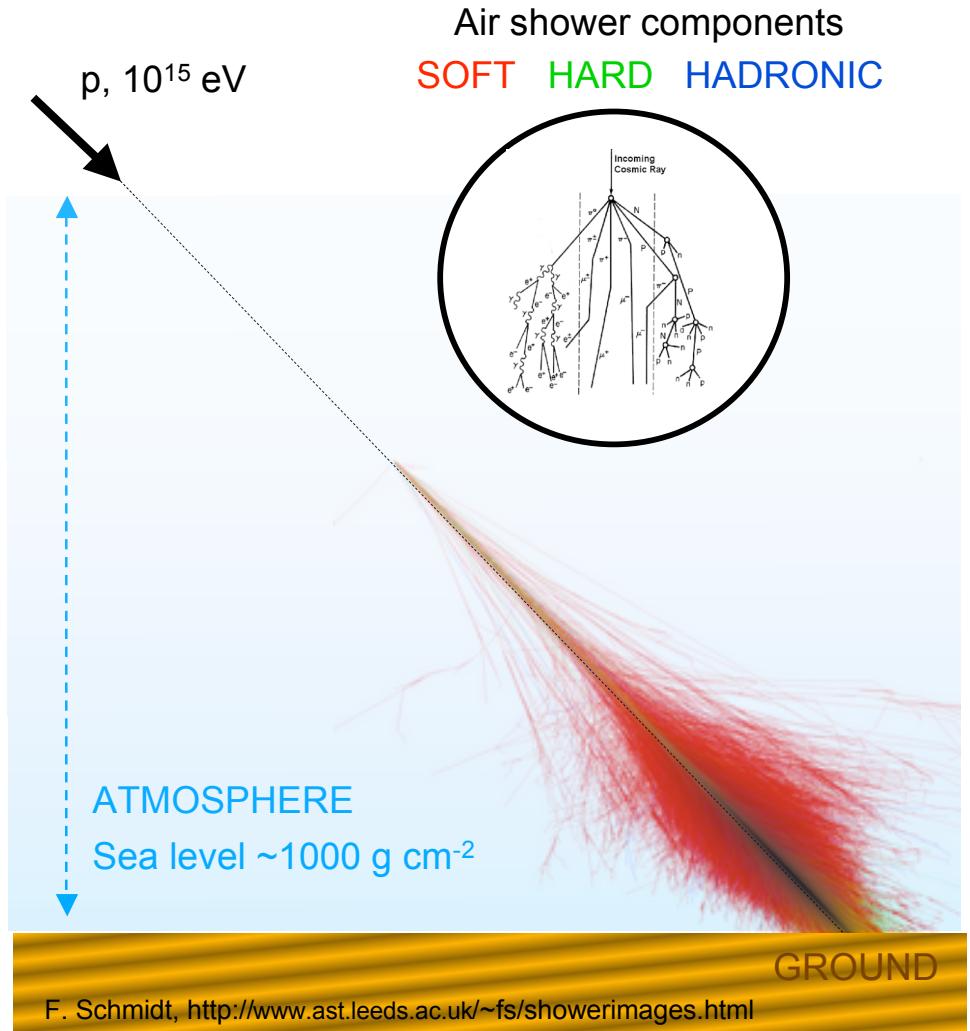
- UHECR/EAS
- Effetto GZK
- ARGO
- KASCADE
- AGASA
- AUGER
- Sommario

Bruno Borgia

Misure indirette dei RC



- large detection areas for significant statistics
- ground based detectors:
→ Extensive Air Showers



La fisica dei raggi cosmici UHE

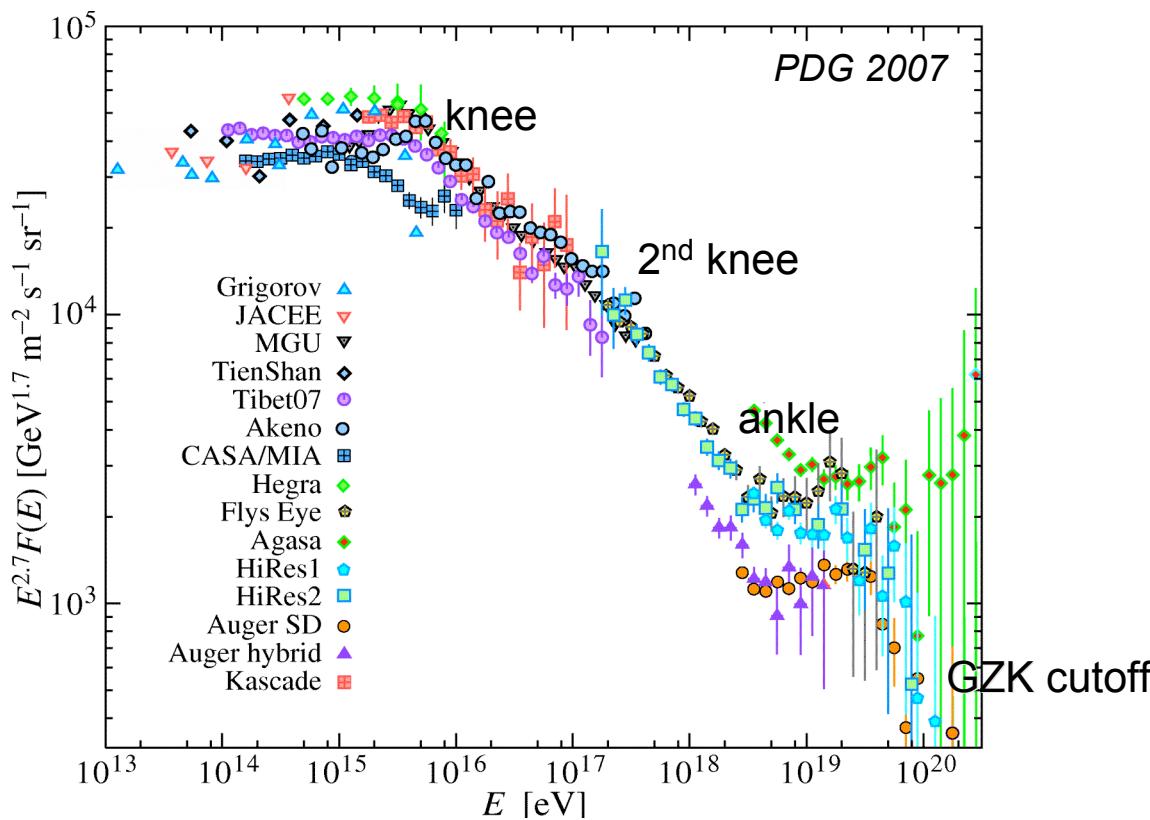
ASTRO -

- 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

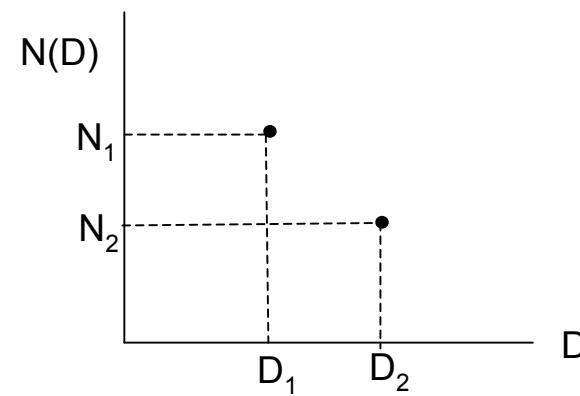
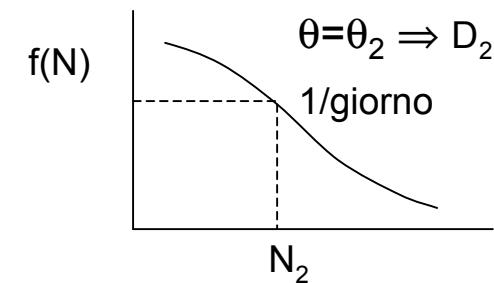
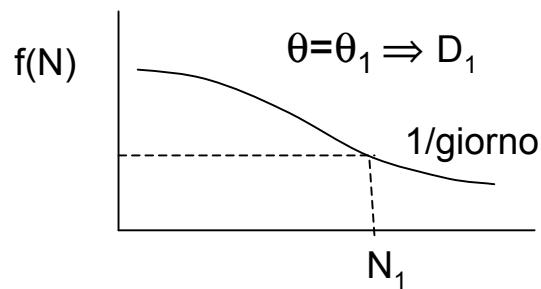
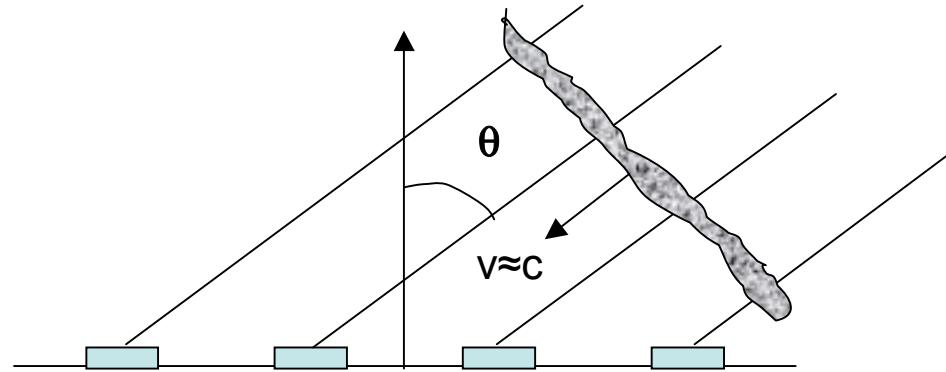
Estensive Air Shower

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.

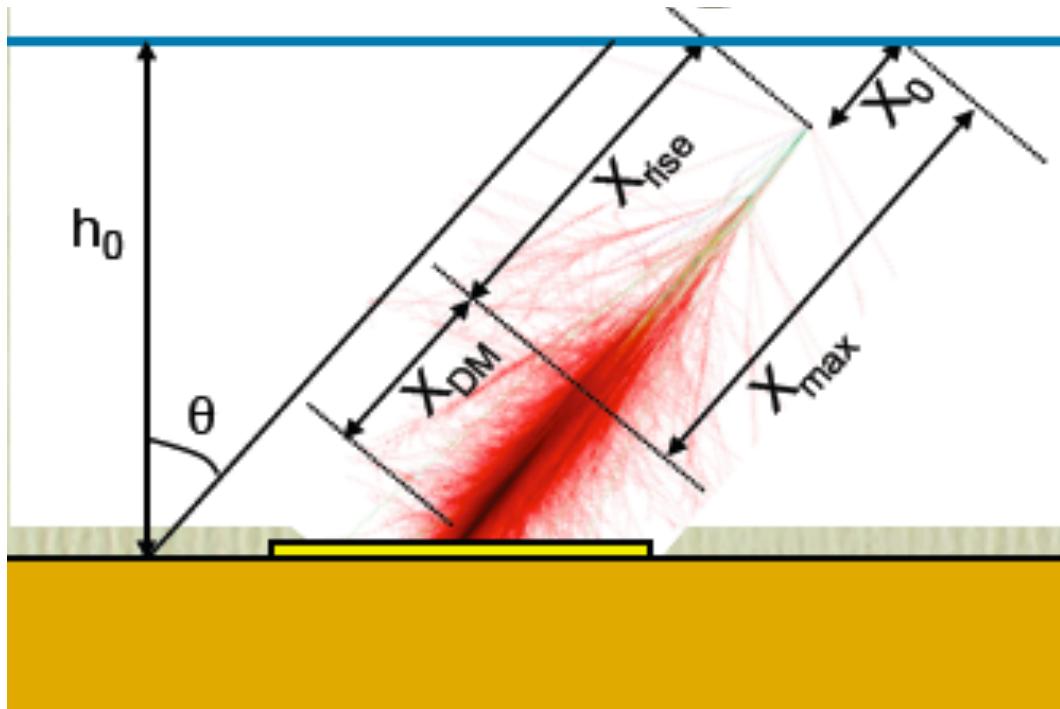
Particelle secondarie generate negli sciami iniziati da protoni o nuclei di alta energia possono arrivare a terra senza perdere tutta la loro energia nell'atmosfera. Per rivelare tali sciami si impiegano rivelatori di dimensioni limitate ma in gran numero distribuiti su una grande superficie. Il solo 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



σ (p - aria)

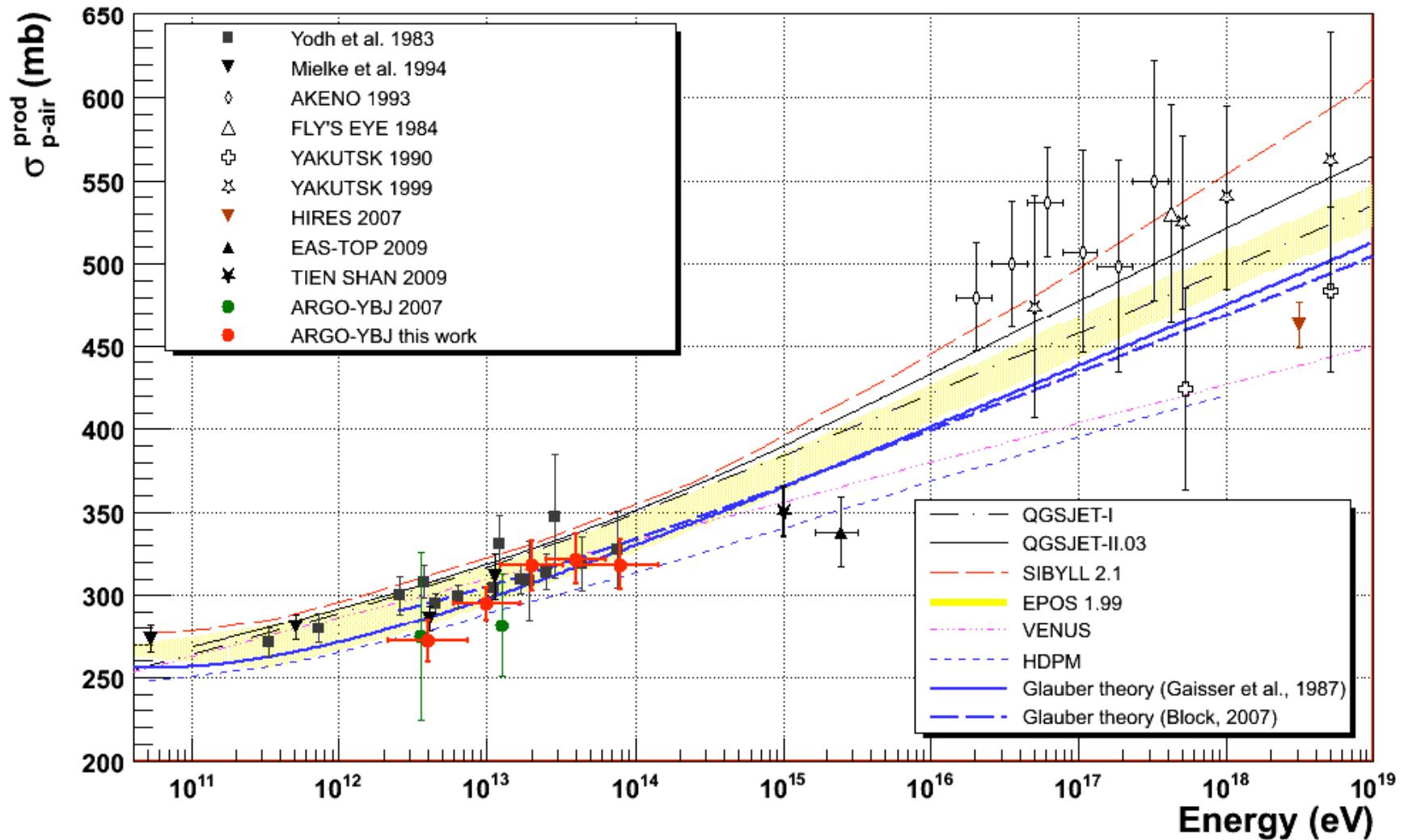


$$R(\theta) \sim \exp\left[-\frac{h_0}{k\lambda_{p-atm}} (\sec \theta - 1) \right]$$

$$\lambda_{p-atm} = 2.41 \cdot 10^4 / \sigma_{p-atm} \quad (\text{g/cm}^2)$$

k è un fattore di correzione che dipende dalla particella primaria

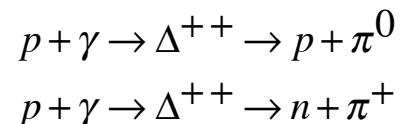
Sezione d'urto p-aria



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 $E \approx 10^{20}$ 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:



La sezione d'urto per questa reazione al di là della risonanza è $\sigma \approx 2 \cdot 10^{-28} \text{ cm}^2 = 200 \mu\text{barn}$ ($1\text{barn} = 10^{-24}\text{cm}^2$)

La densità della radiazione di fondo è $\rho = 400$ fotoni/ cm^3

Il cammino libero medio è quindi $\lambda = 1/\rho\sigma \approx 10^{25} \text{ cm} = 5 \text{ Mpc}$ (dimensione di un cluster di galassie)

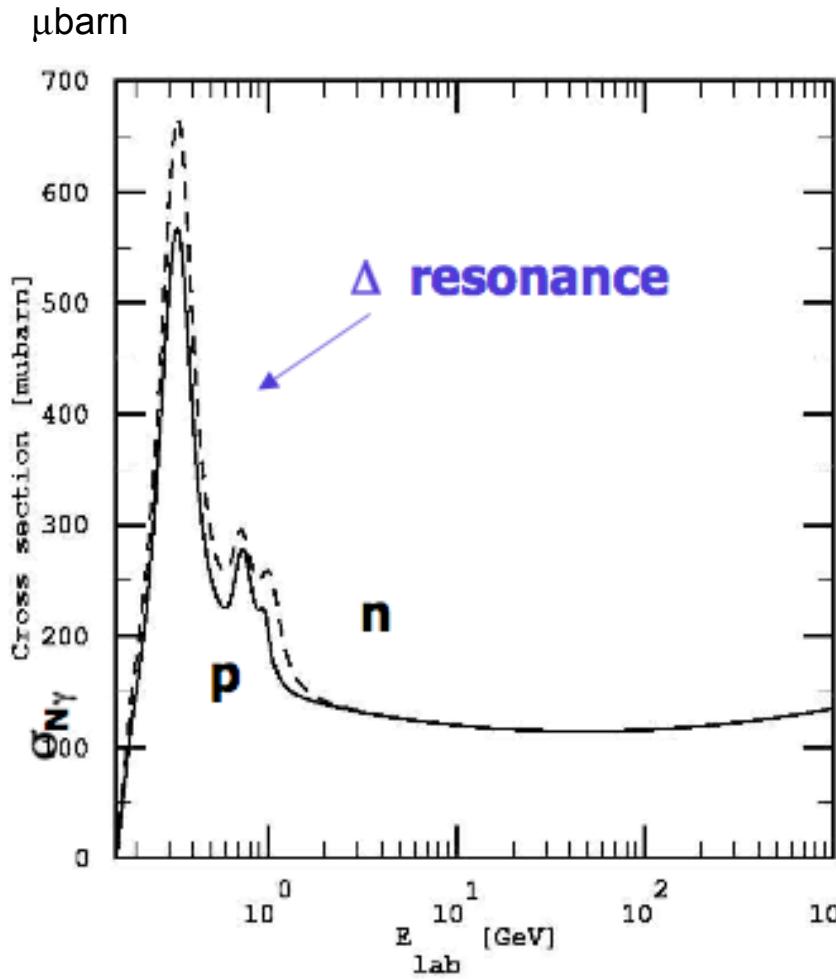
I protoni con energia $E_p \approx 10^{19}$ eV sono sopra soglia per la produzione di Δ^{++} .

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) ; fotone_{CMB} : (\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

$$E \approx p$$

$$2qE(1 - \cos \theta) > m_\pi^2 + 2Mm_\pi$$

urto centrale

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

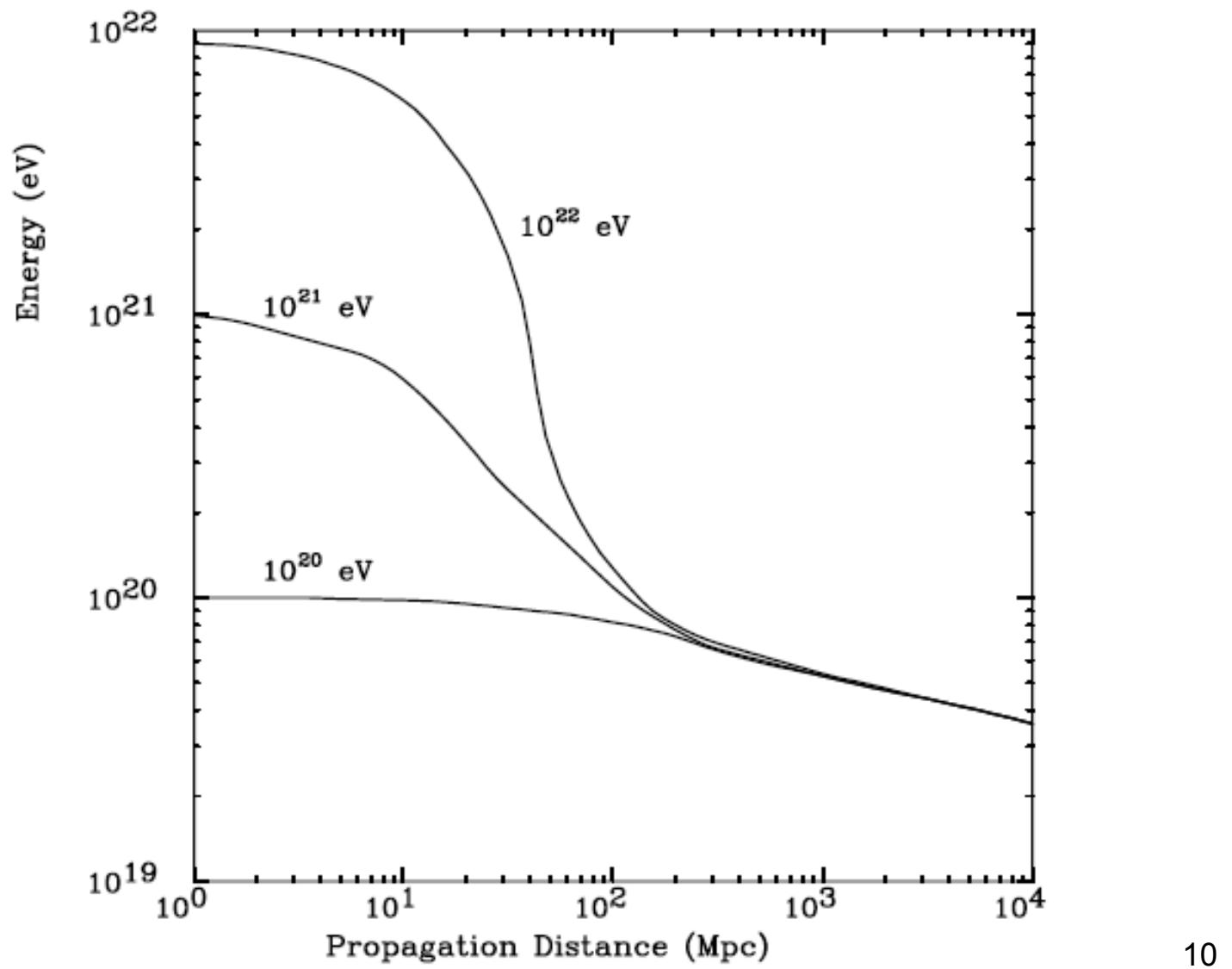
$$E_{soglia} = m_\pi \frac{M + m_\pi / 2}{2q}$$

fotoni CMB : $T = 2.74 K$; $qc = kT = 2.35 \times 10^{-4} eV$

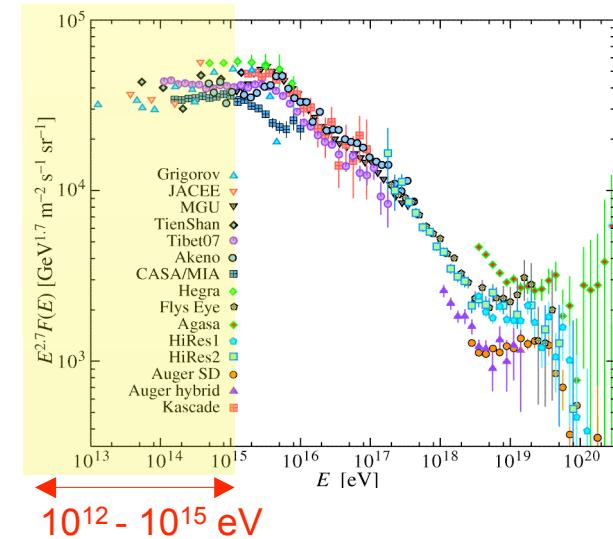
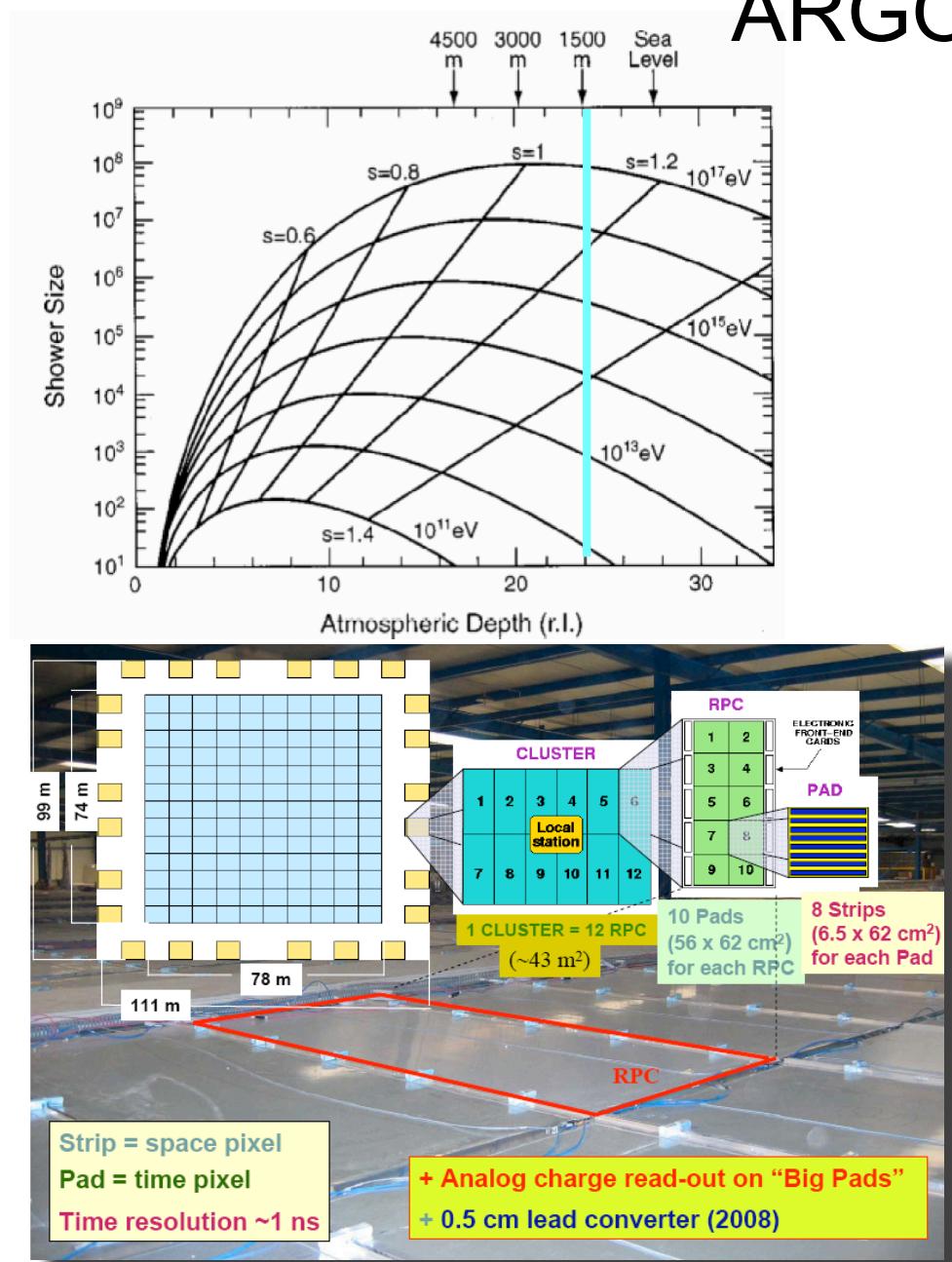
$$E_{soglia} = (4.3 / y) \times 10^{20} eV \quad \text{con } qc = ykT$$

dove y da la coda dello spettro

Propagazione protoni nel CMB



ARGO-YBJ



To lower the energy threshold:

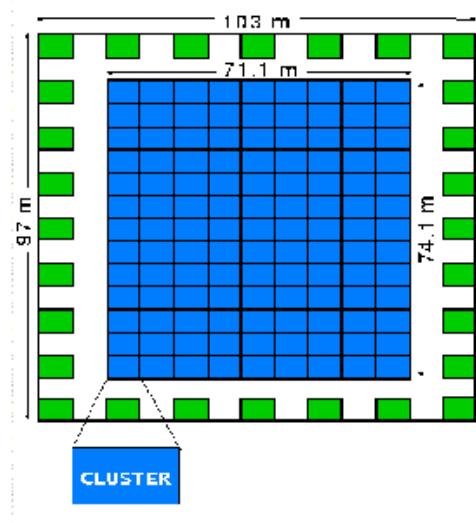
- go to high altitude!
- reduce the spacing between particle detectors



ARGO

ARGO

Area 5.200 m² (full coverage)
(10.000 m² with guard ring)
Field of view ~ 1 sr
 $E = 50 \text{ GeV} - 50 \text{ TeV}$
Location: Tibet 4300m alt.
Scheduled 2002 (final conf.)

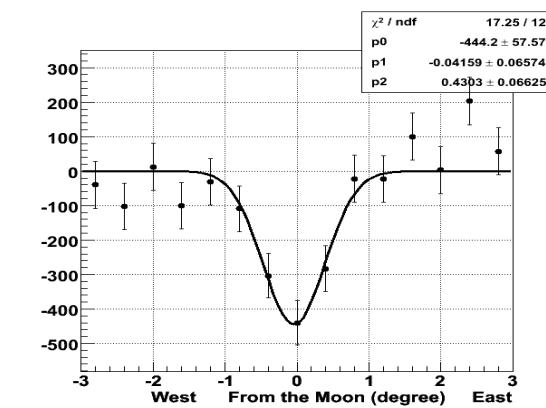
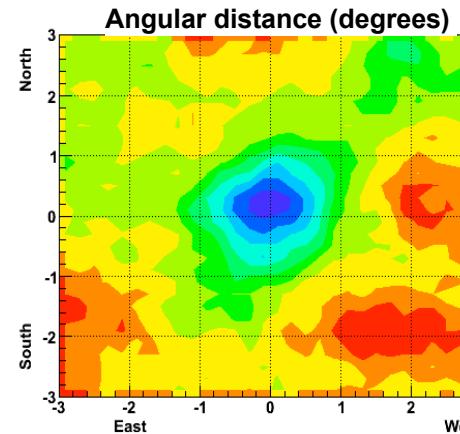
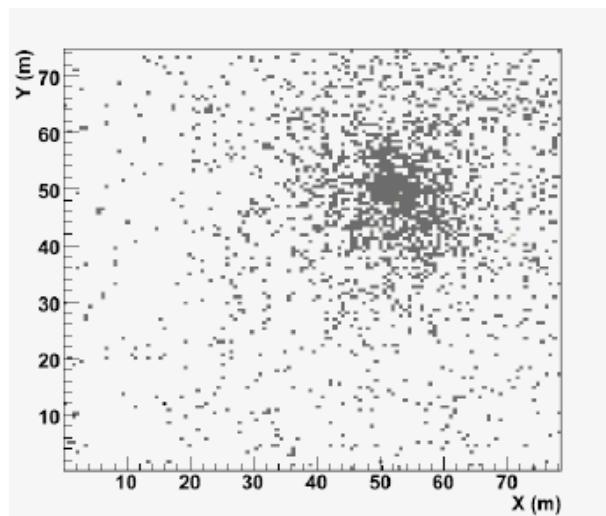
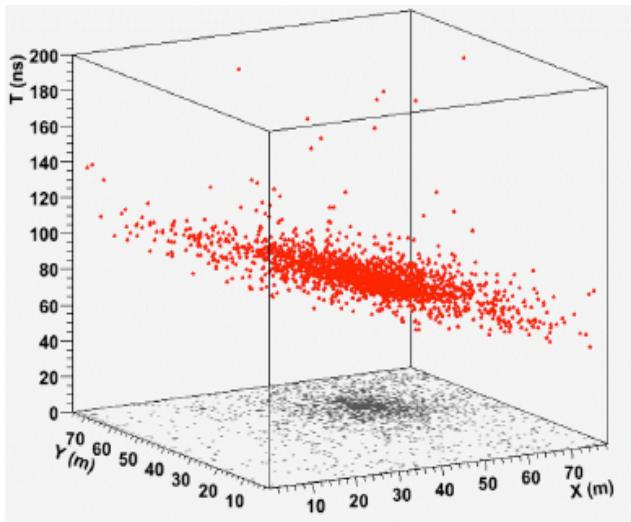


17400 Pads 56 by 60 cm² each of Resistive Plate Chamber (RPC).
Each pad subdivided in pick-up strips 6 cm wide for the space pattern inside the pad.
The CLUSTER is made of 12 RPCs Pads

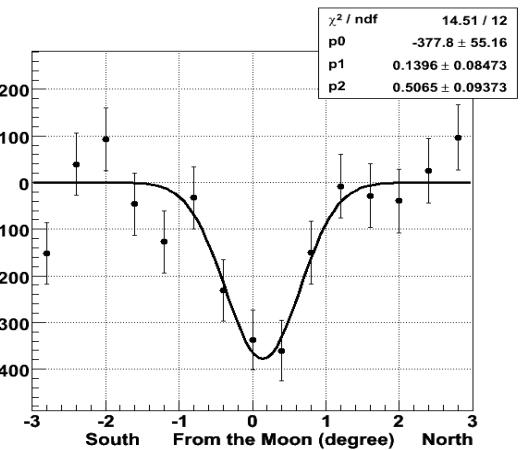


Risultati ARGO-YBJ (I)

High space-time granularity



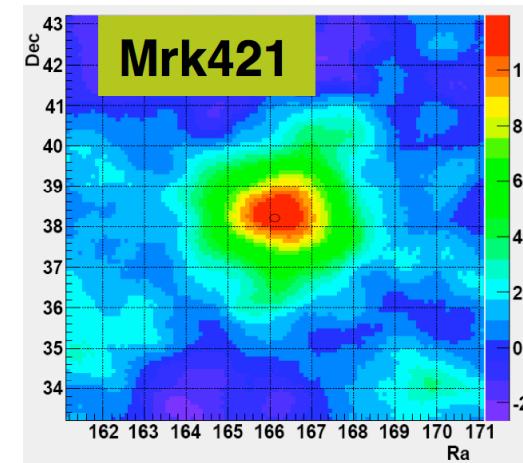
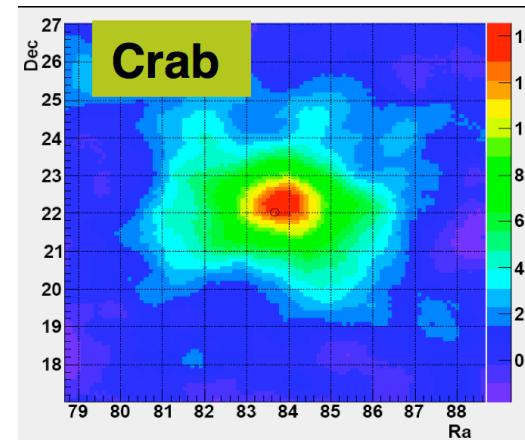
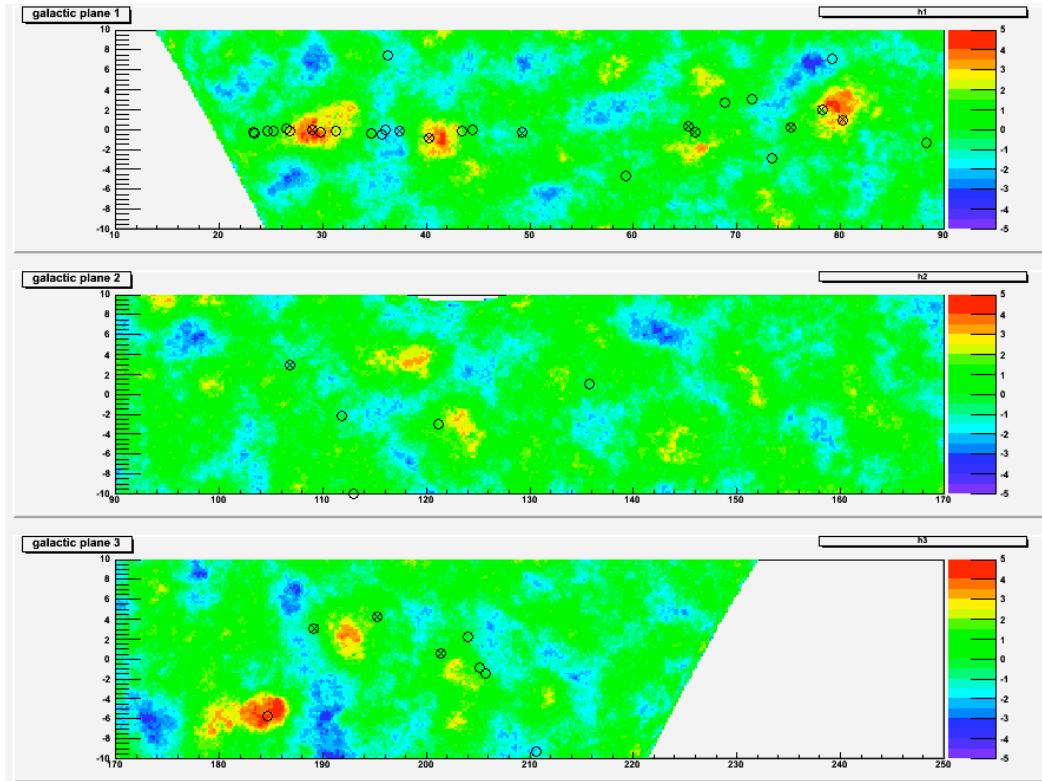
Moon Shadow



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

Deficit significance $\sim 10 \sigma$
 Angular shift with respect to the Moon position :
 0.04° westward
 0.14° northward

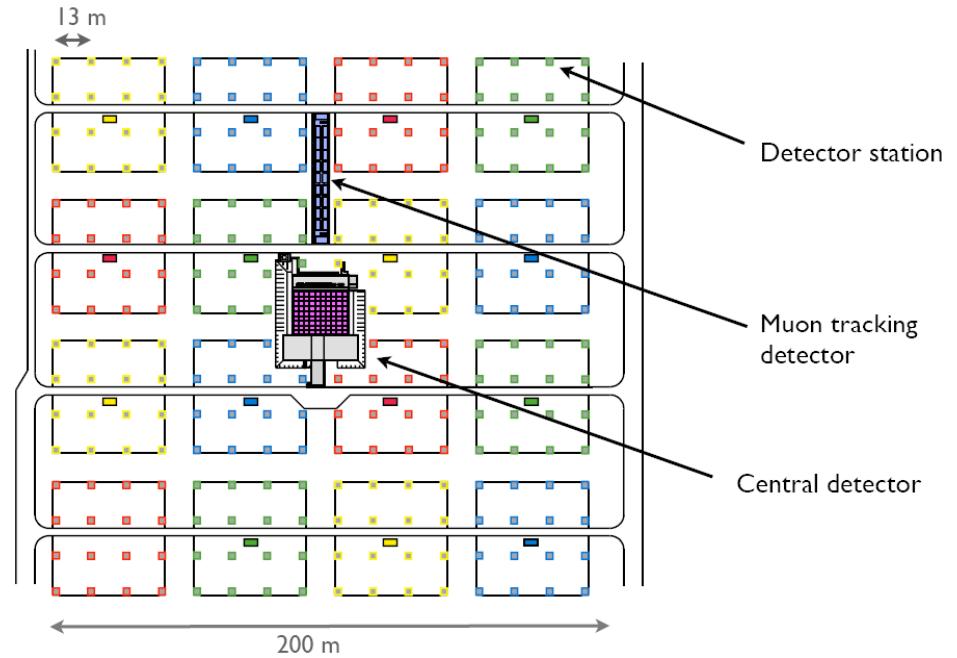
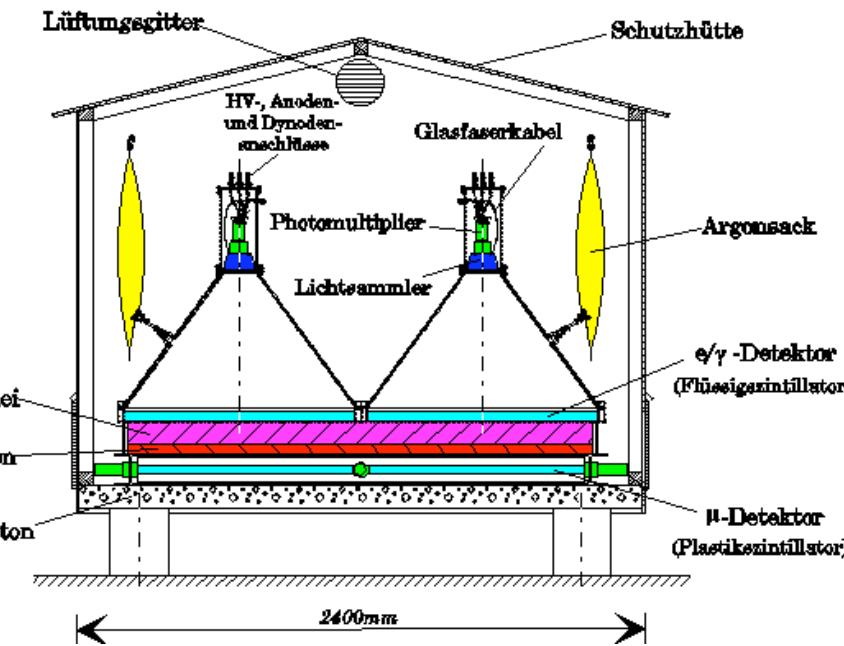
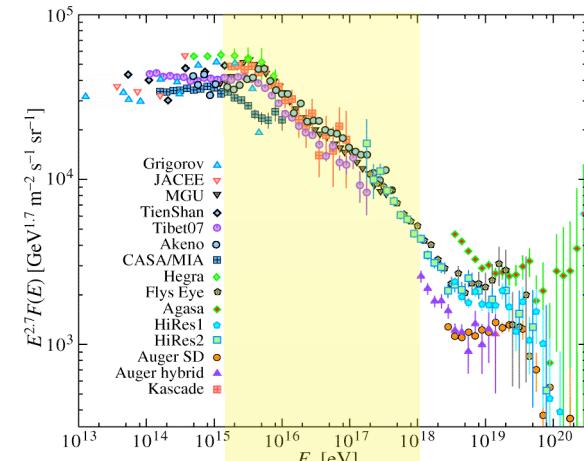
Sorgenti osservate da Argo



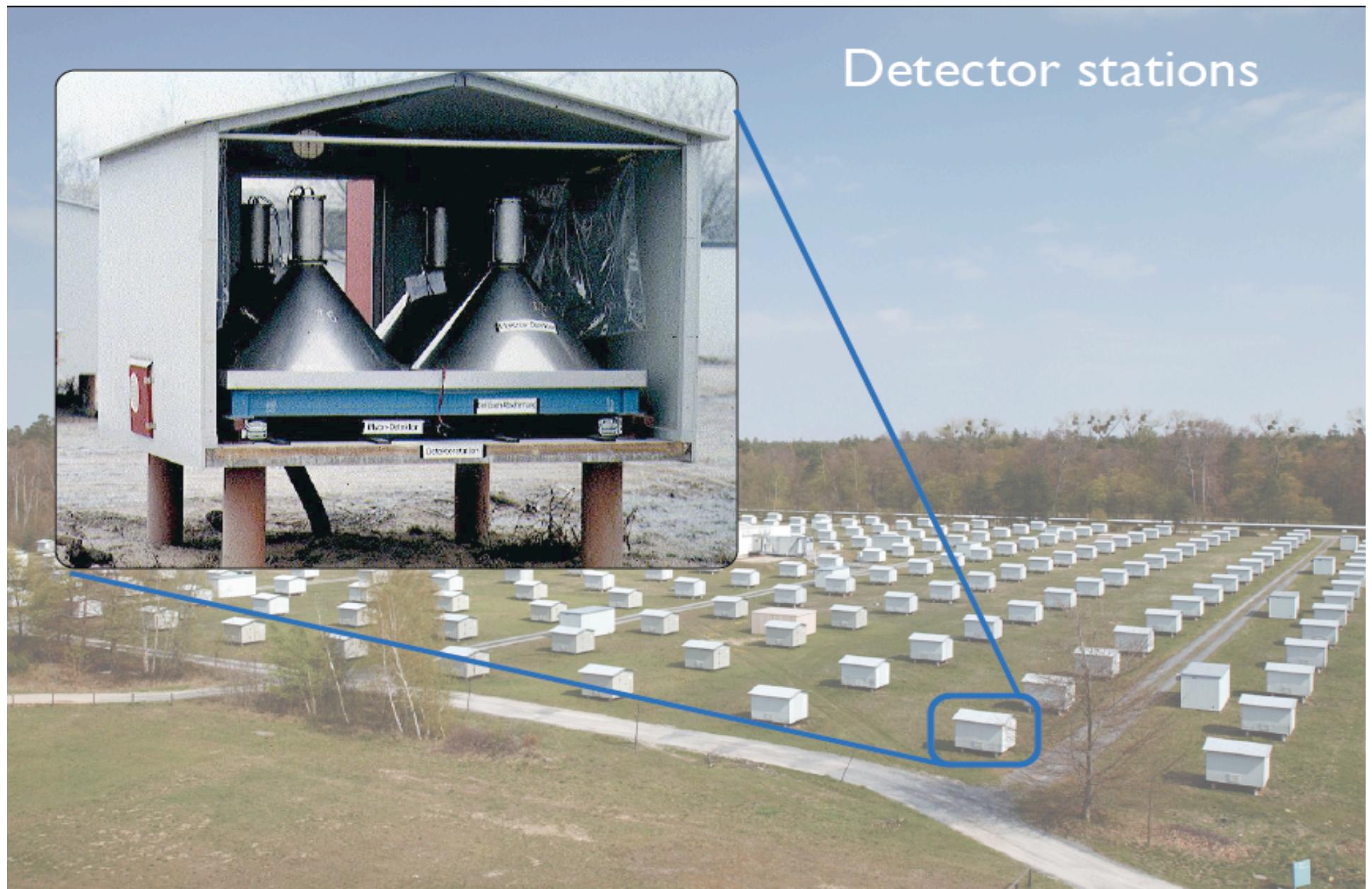
Karlsruhe Shower Core Array DEtector

Simultaneous measurement of the shower components:

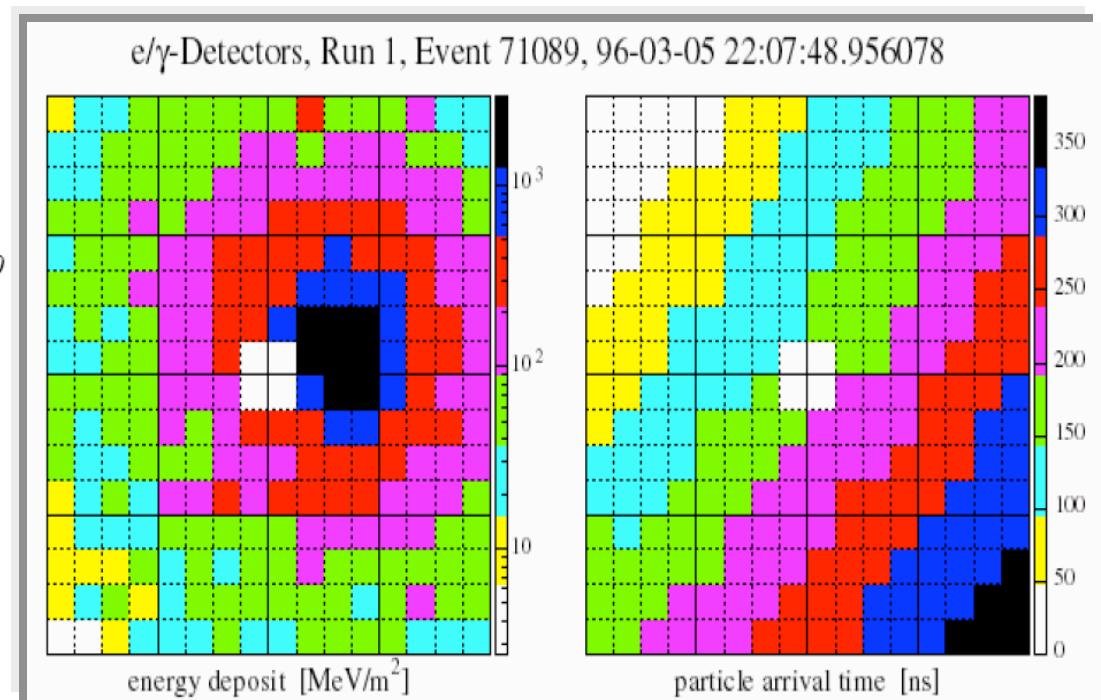
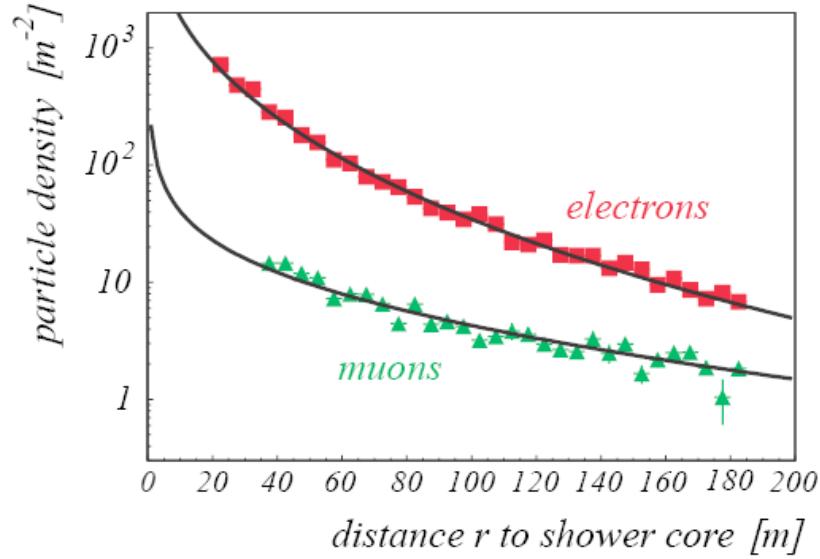
- electromagnetic
- muonic
- hadronic



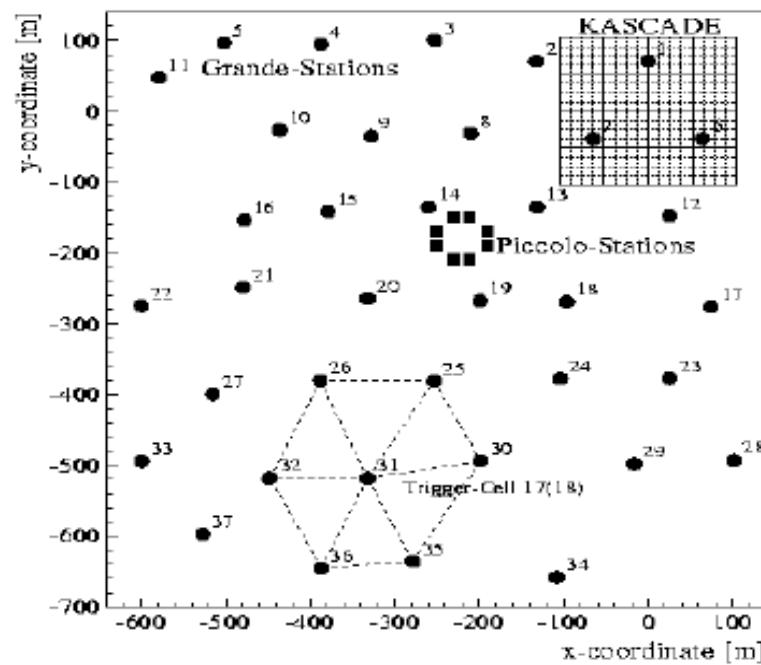
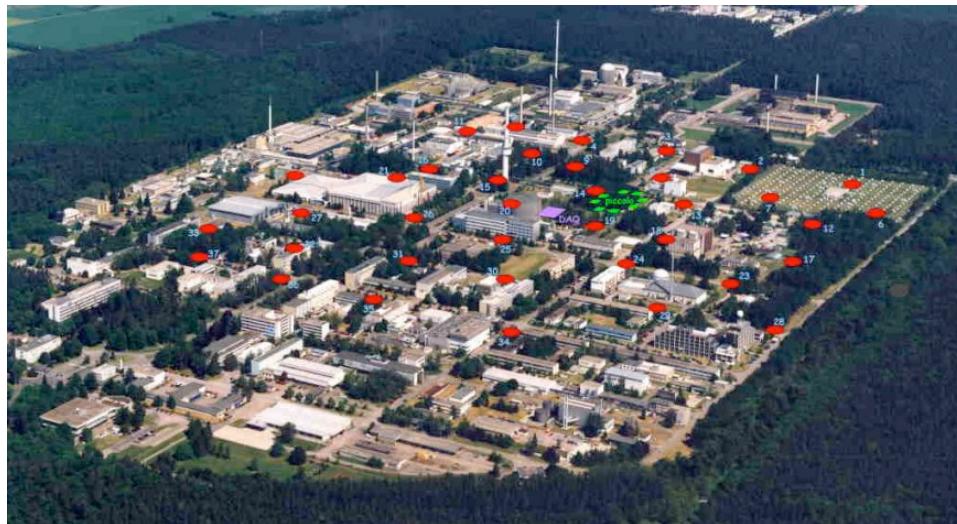
KASCADE e/ γ and muon detector



KASCADE



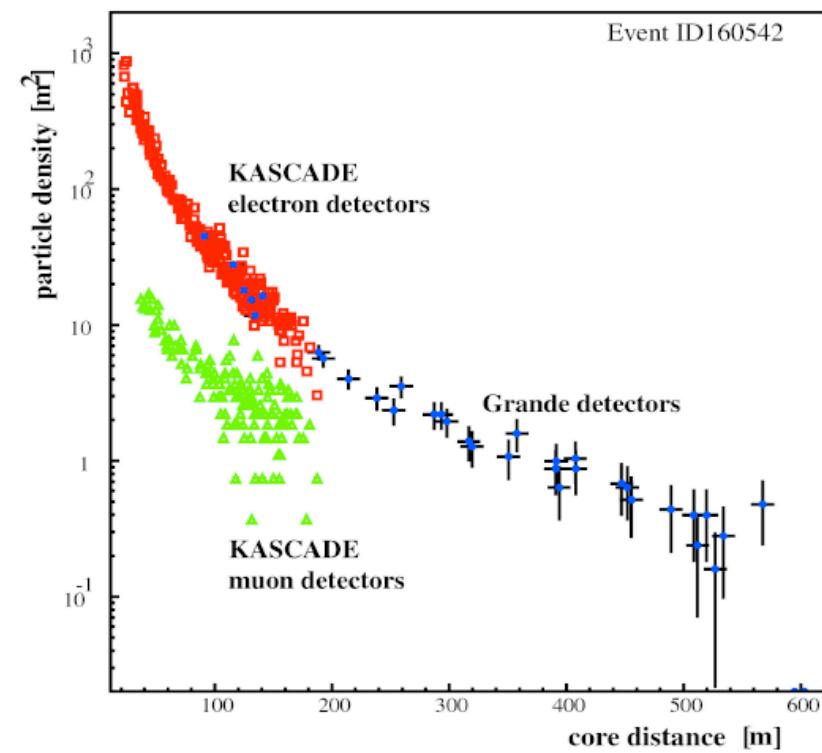
KASCADE-Grande



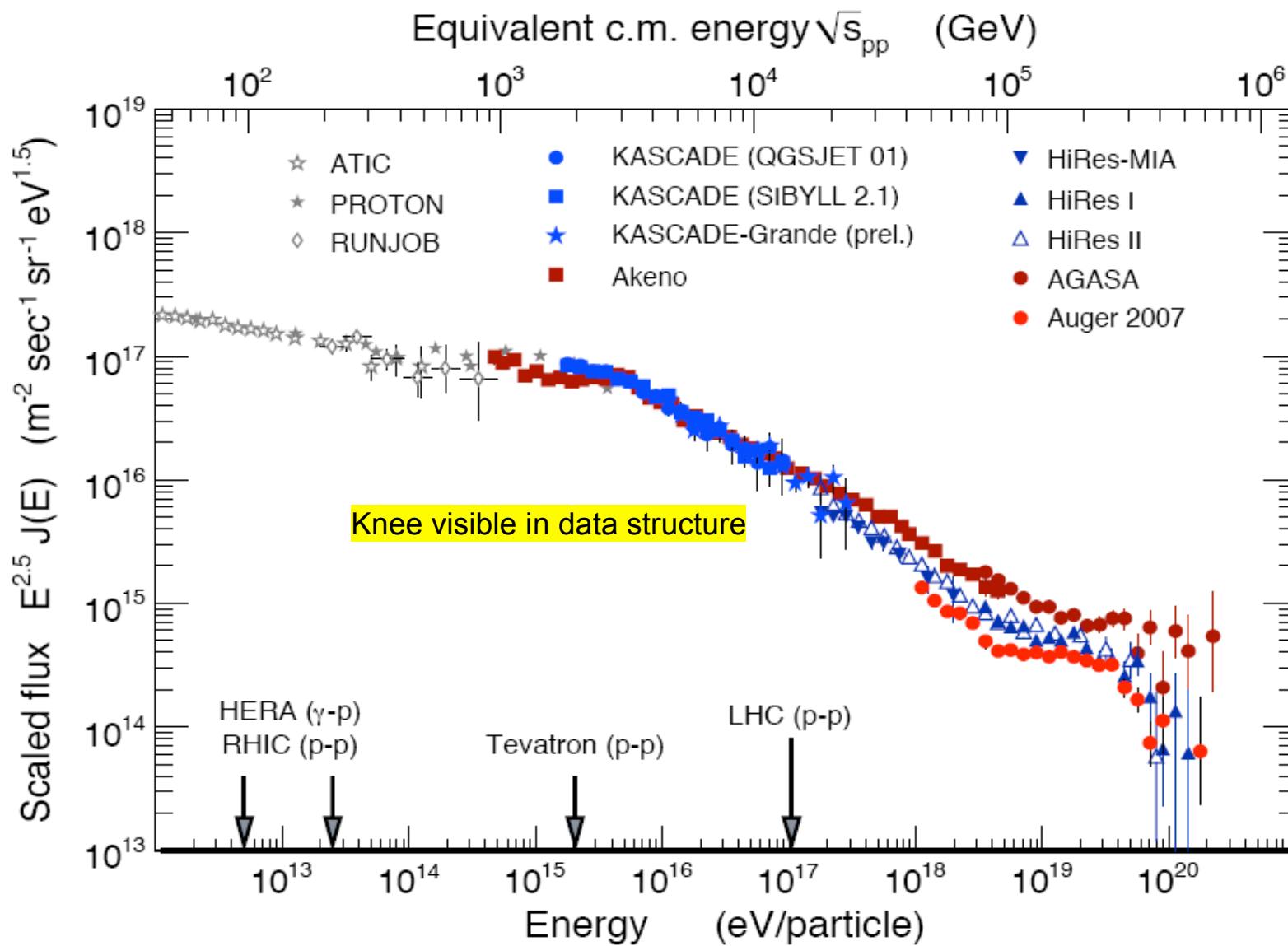
Using scintillators from EAS-TOP, the
Instrumented area is increased of more
than a factor 10:

$$0.04 \rightarrow 0.5 \text{ km}^2$$

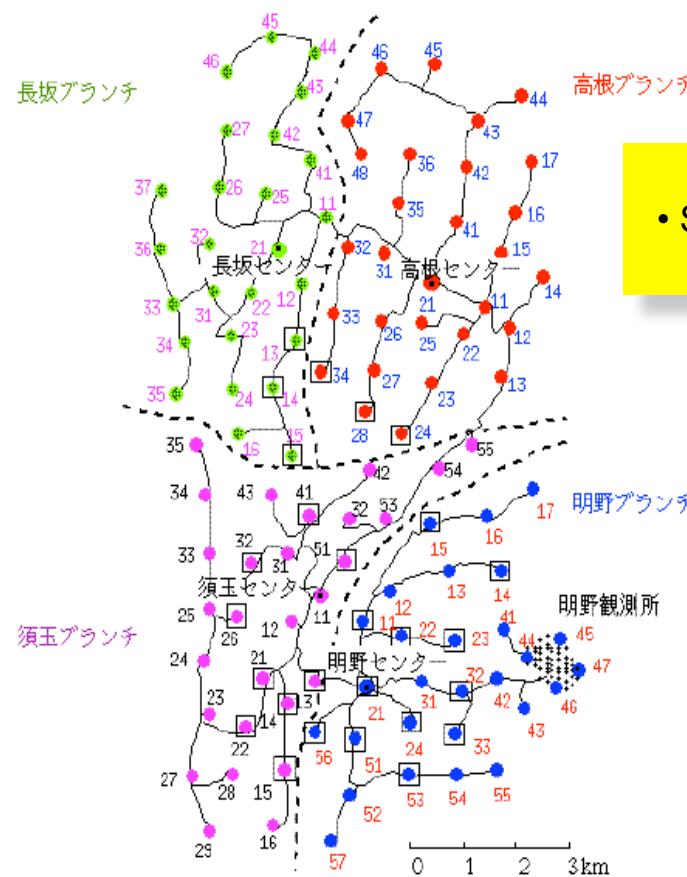
Energy range extended to 1 EeV



KASCADE all-particle spectrum

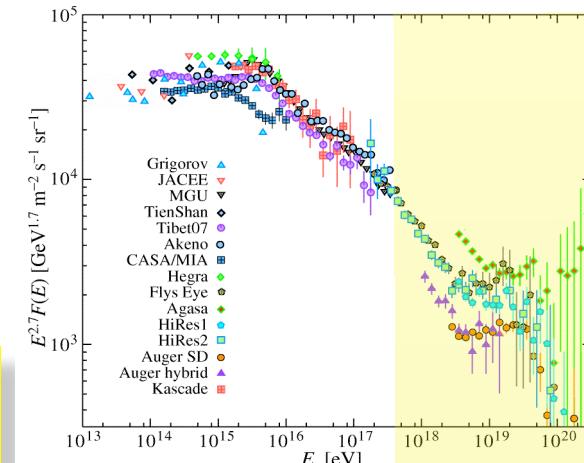


La regione delle alte energie

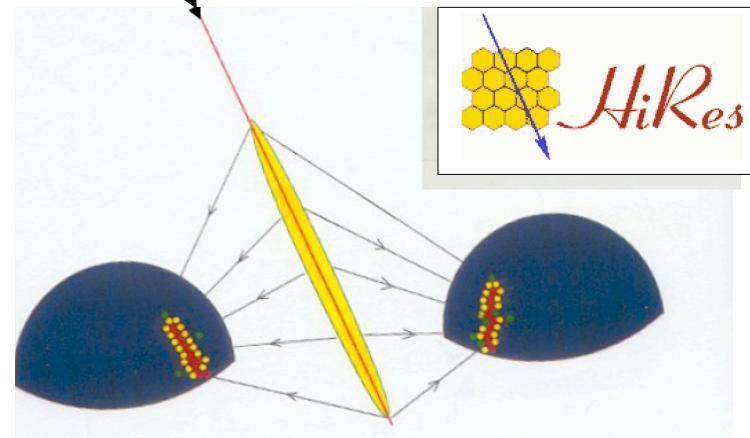


AGASA (Akeno, Japan)
100 km² array
1990-2003

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

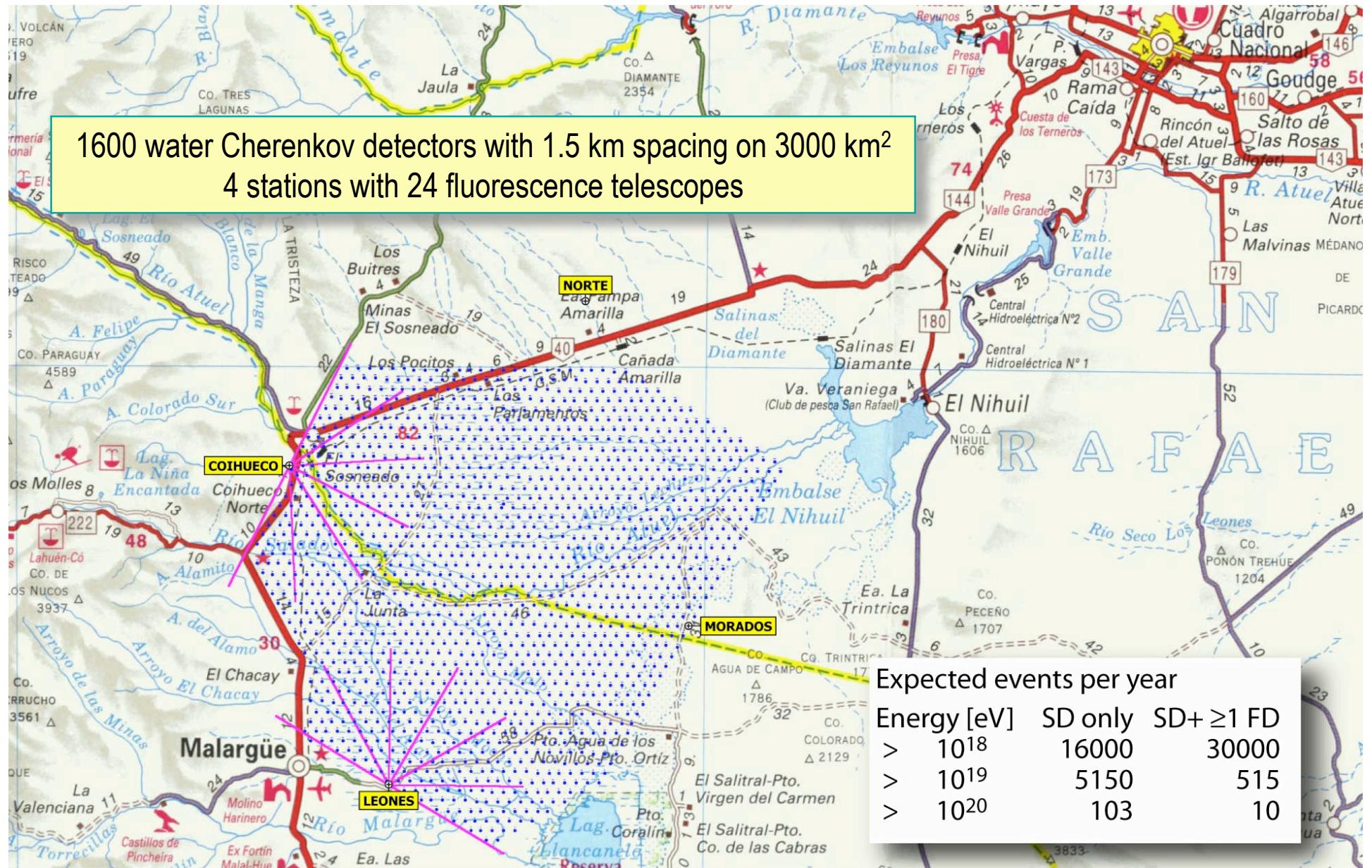


Utah
Stereo FD
1997-2006

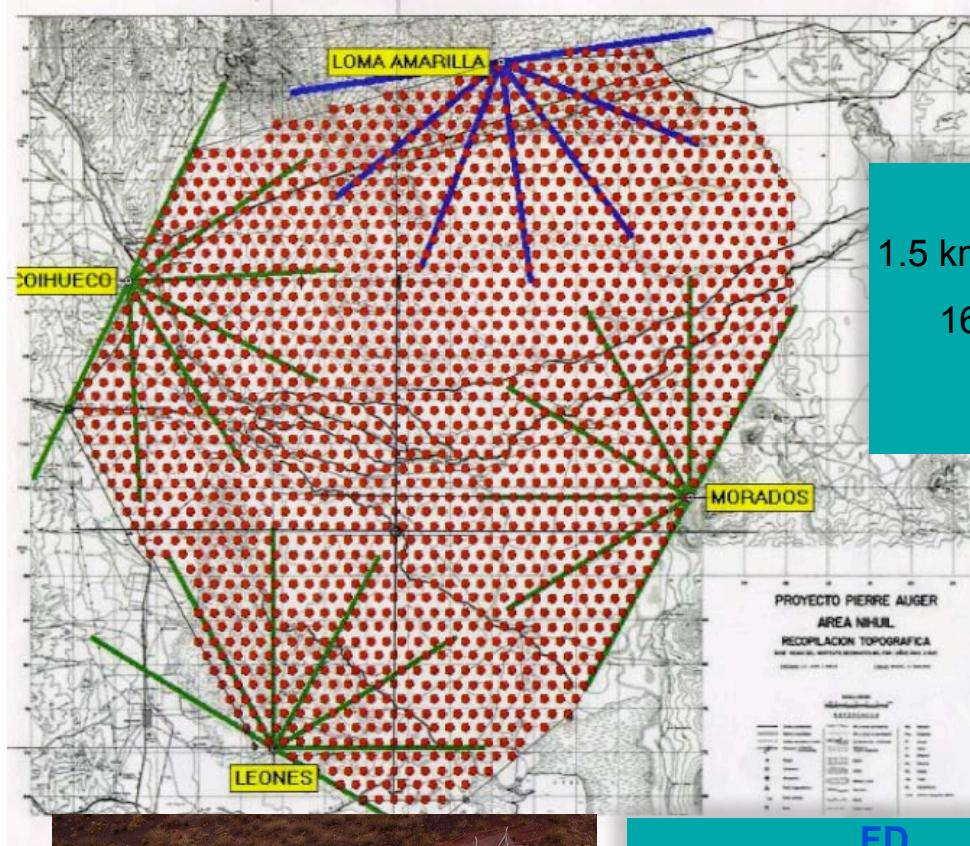


- Fluorescence UV photons imaged with a pixel detector
- Track the longitudinal profile

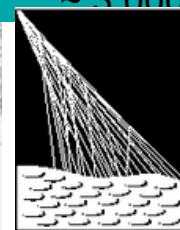
AUGER



The Pierre Auger Observatory Southern Site



SD
1.5 km spacing, triangular grid
1600 water Cherenkov stations
 $\sim 3,000$ km



PIERRE AUGER OBSERVATORY



FD
4 telescope enclosures
6 telescopes x 4 FD sites

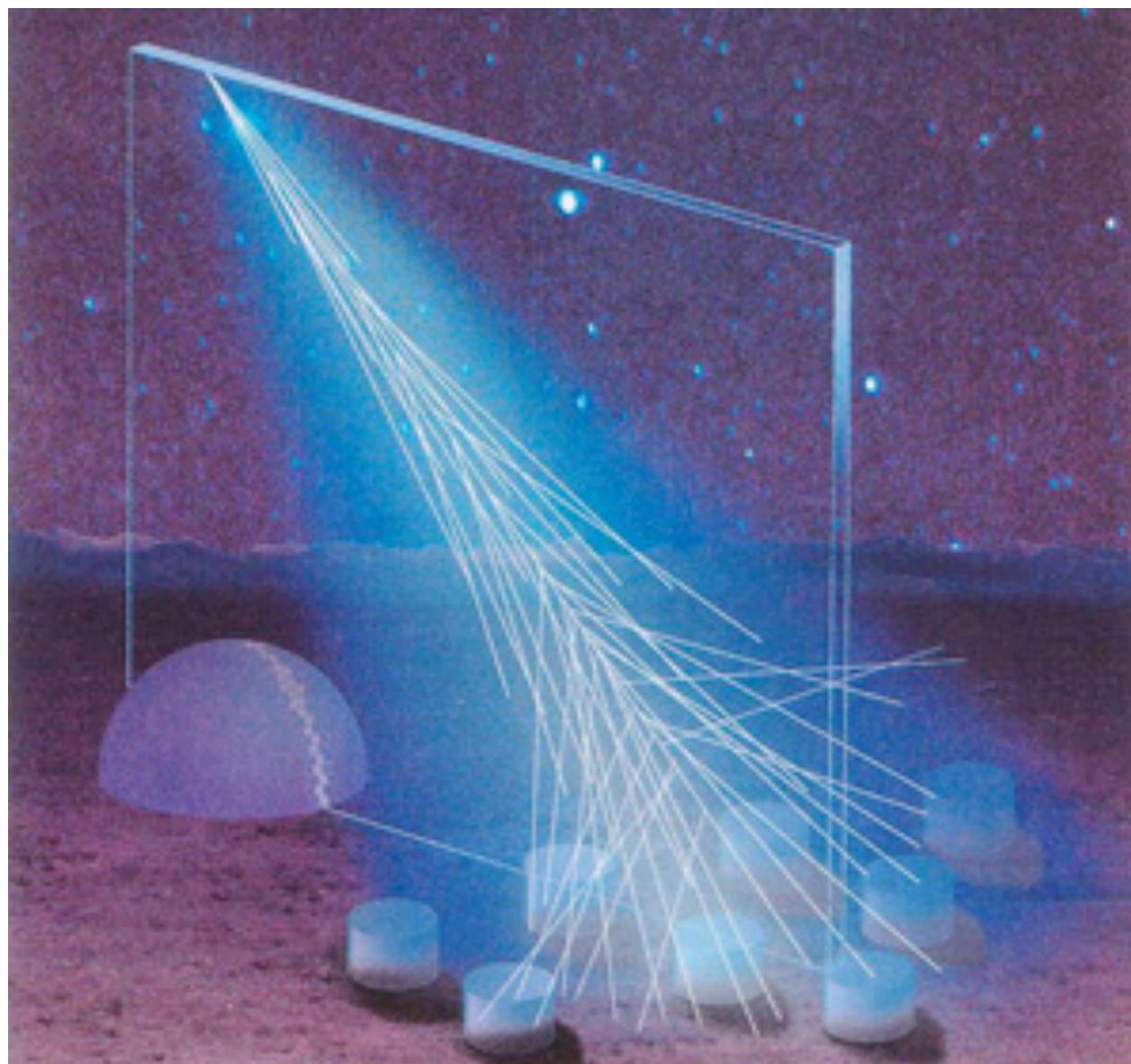


Pampa Amarilla, Argentina
 35° S, 69° W
 ≈ 1400 m a.s.l
 ≈ 880 g/cm²

AUGER SEEN WITH GOOGLE Los Leones



AUGER

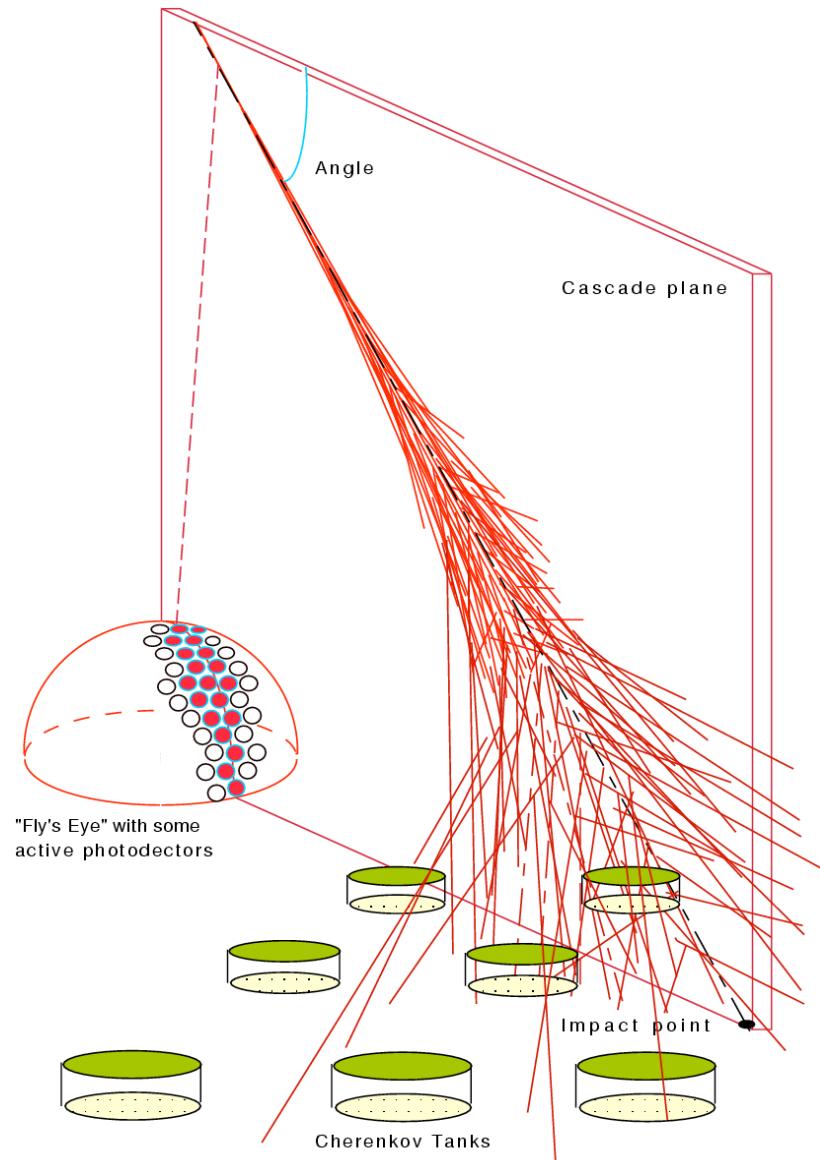


Auger: il metodo ibrido

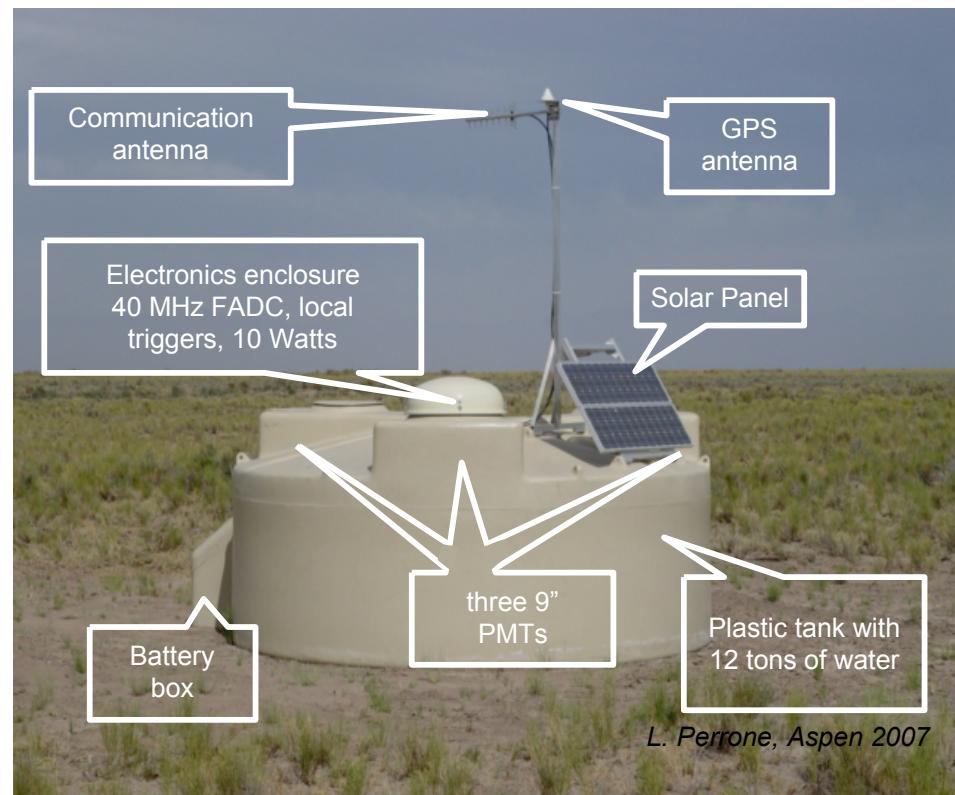
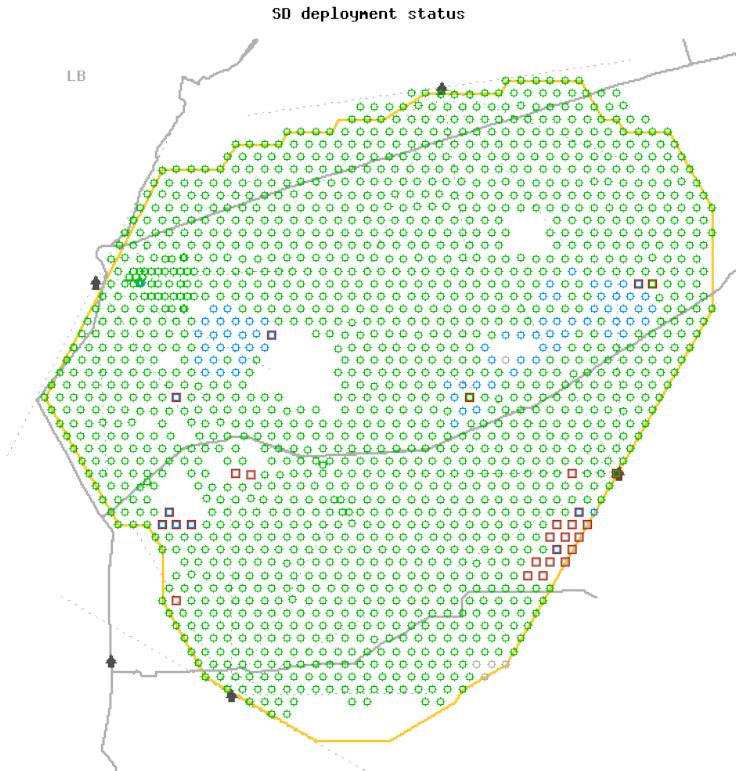
L'Osservatorio Pierre Auger
combina le due tecniche

FLUORESCENCE DETECTOR (FD)
• calorimetric measurement of the energy

SURFACE DETECTOR (SD)
• large collection area, 100% duty cycle

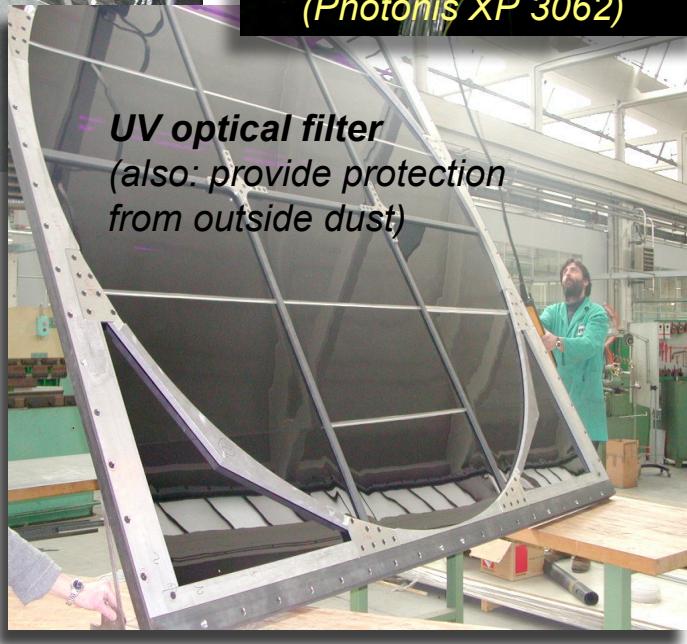
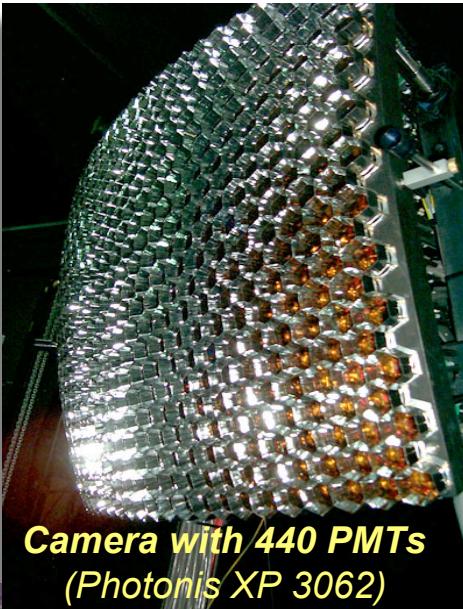
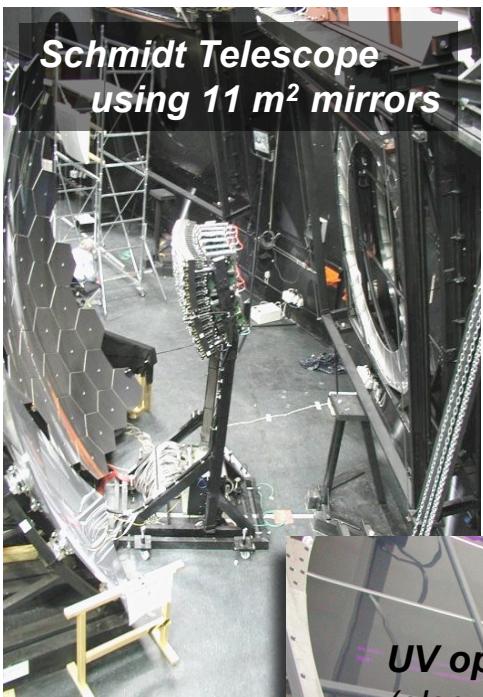


Surface Detector (SD)

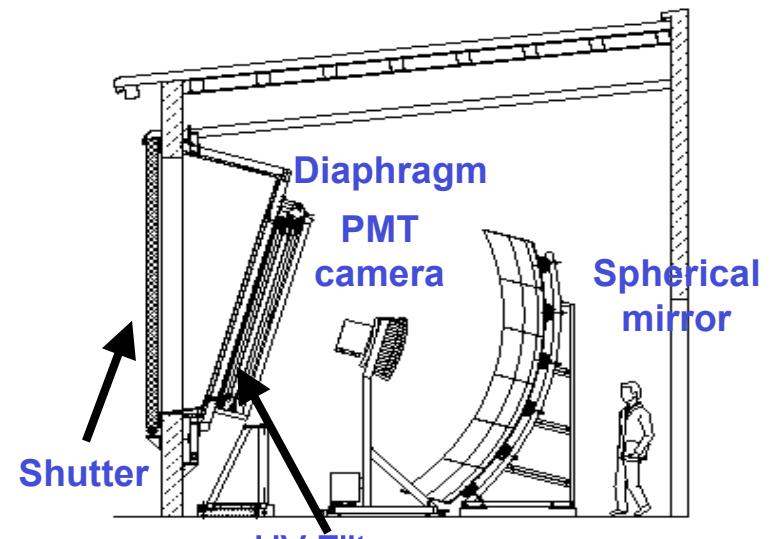
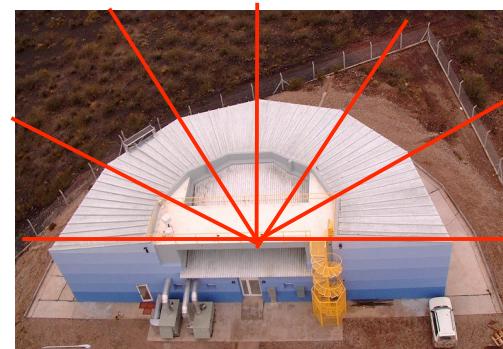


- Stable data taking started in January 2004
- Deployment status: completed!

Fluorescence detector (FD)

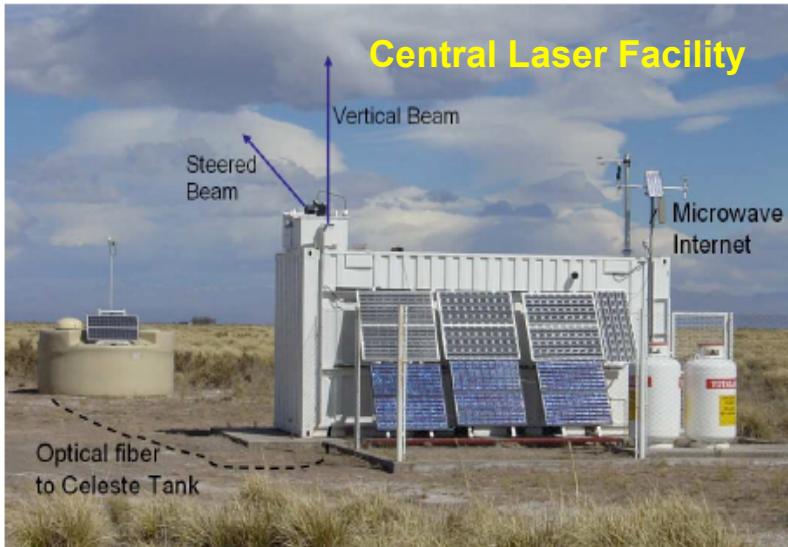


FD completed one year ago

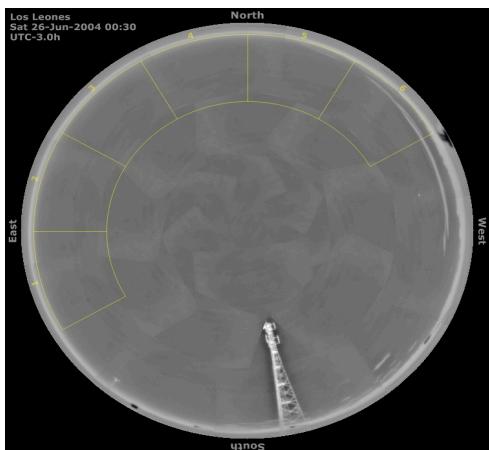


FOV : 30° x 30°

Monitor atmosfera



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



Cloud Camera
(one per FD site)



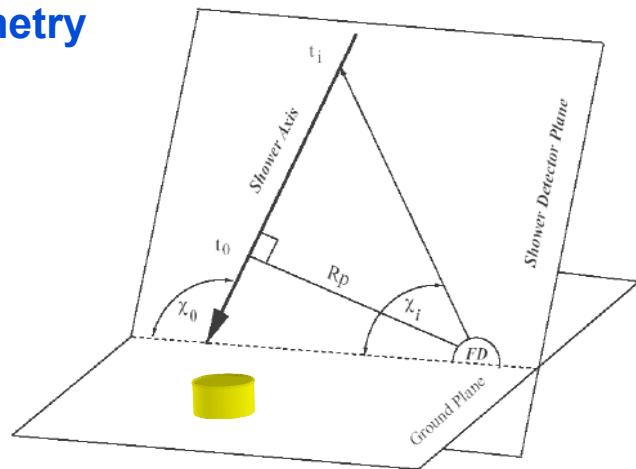


Argentina's Pampa Amarilla desert is filling up with water. Across thousands of square kilometres of the desert's flat plains, engineers are busy building water tanks. By 2005, 1,600 of the 11-cubic-metre tanks will be in place.

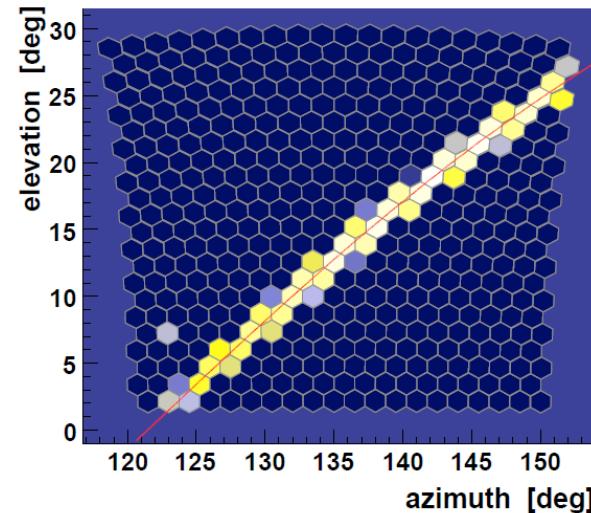
Nature 419, 2002

Ricostruzione con FD (hybrid)

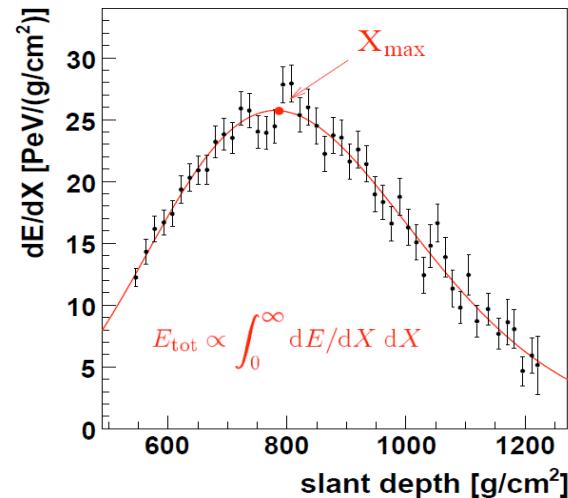
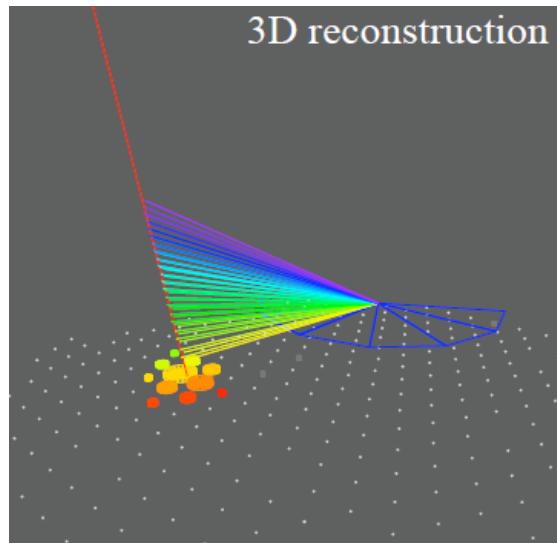
Geometry



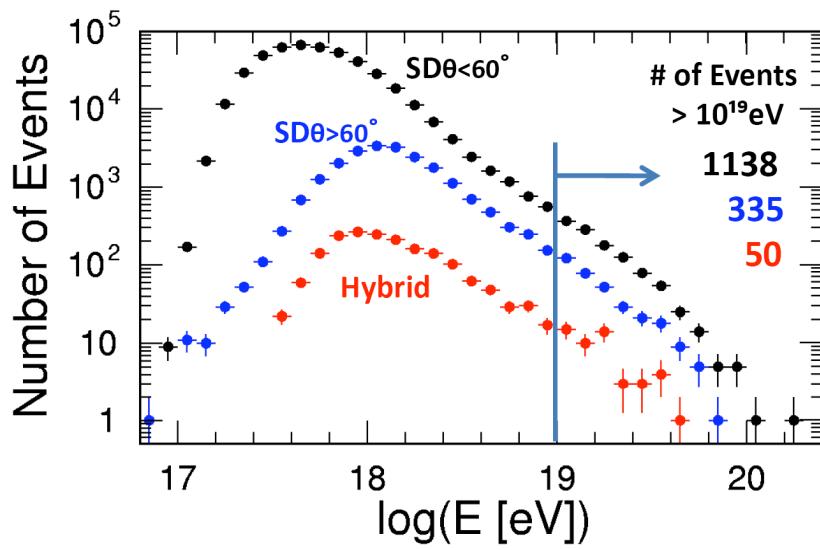
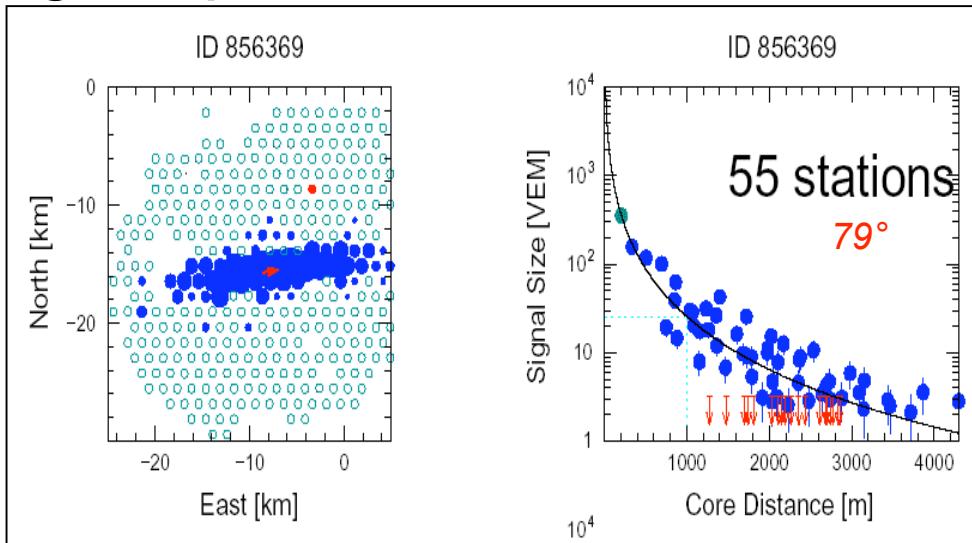
camera view



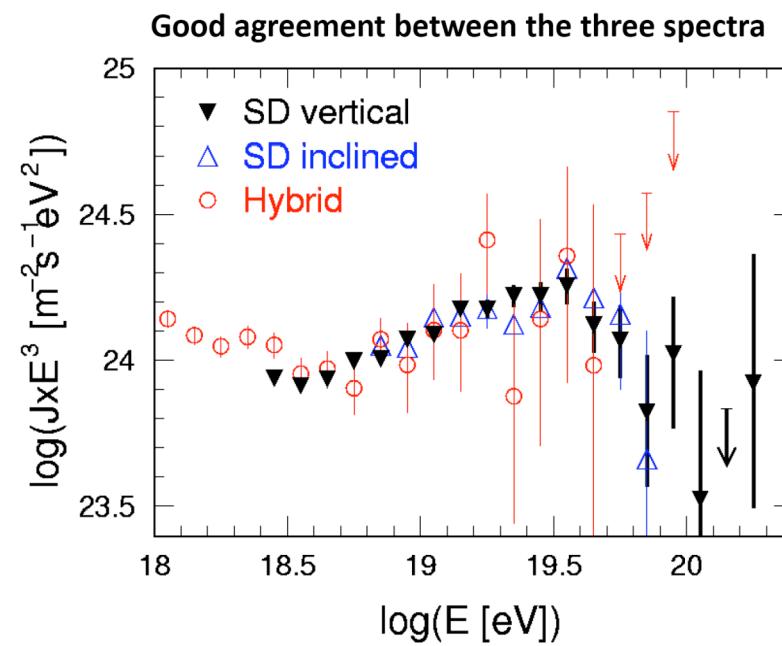
Energy and X_{\max}



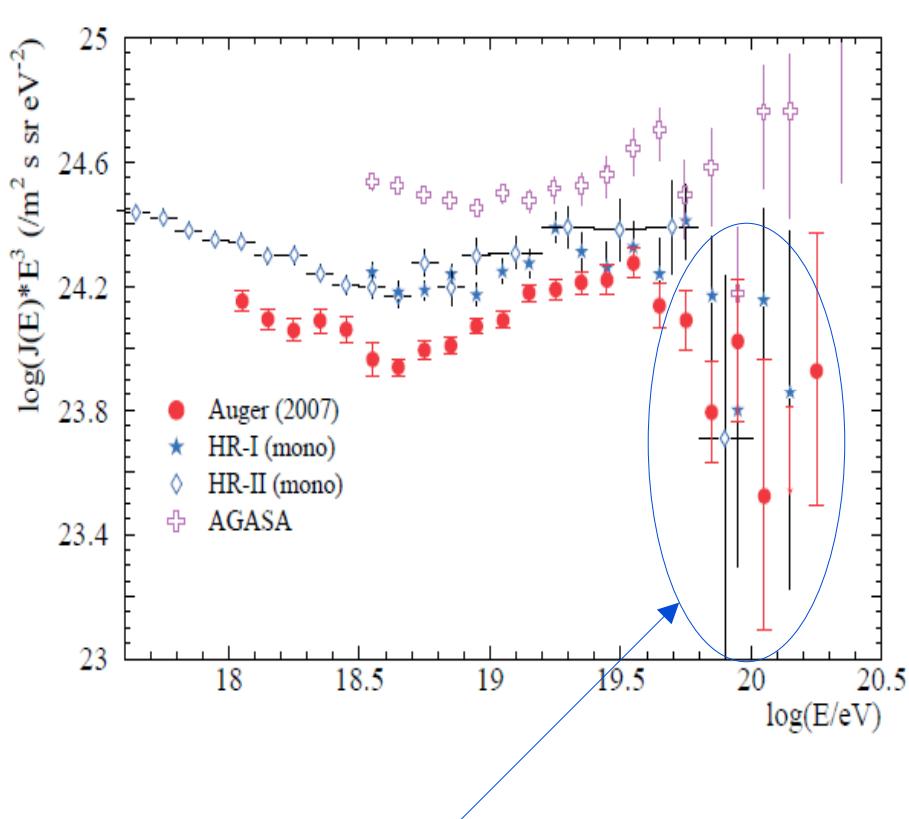
Auger spettro RC: SD, SD-inclined and hybrid



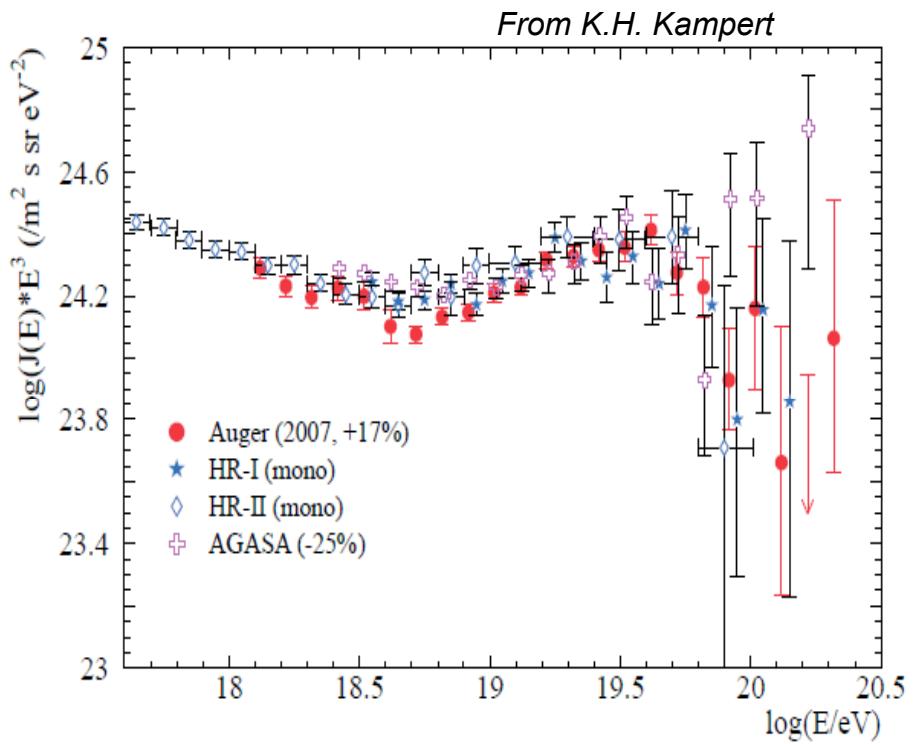
Energy scale is measured with Hybrid Observation



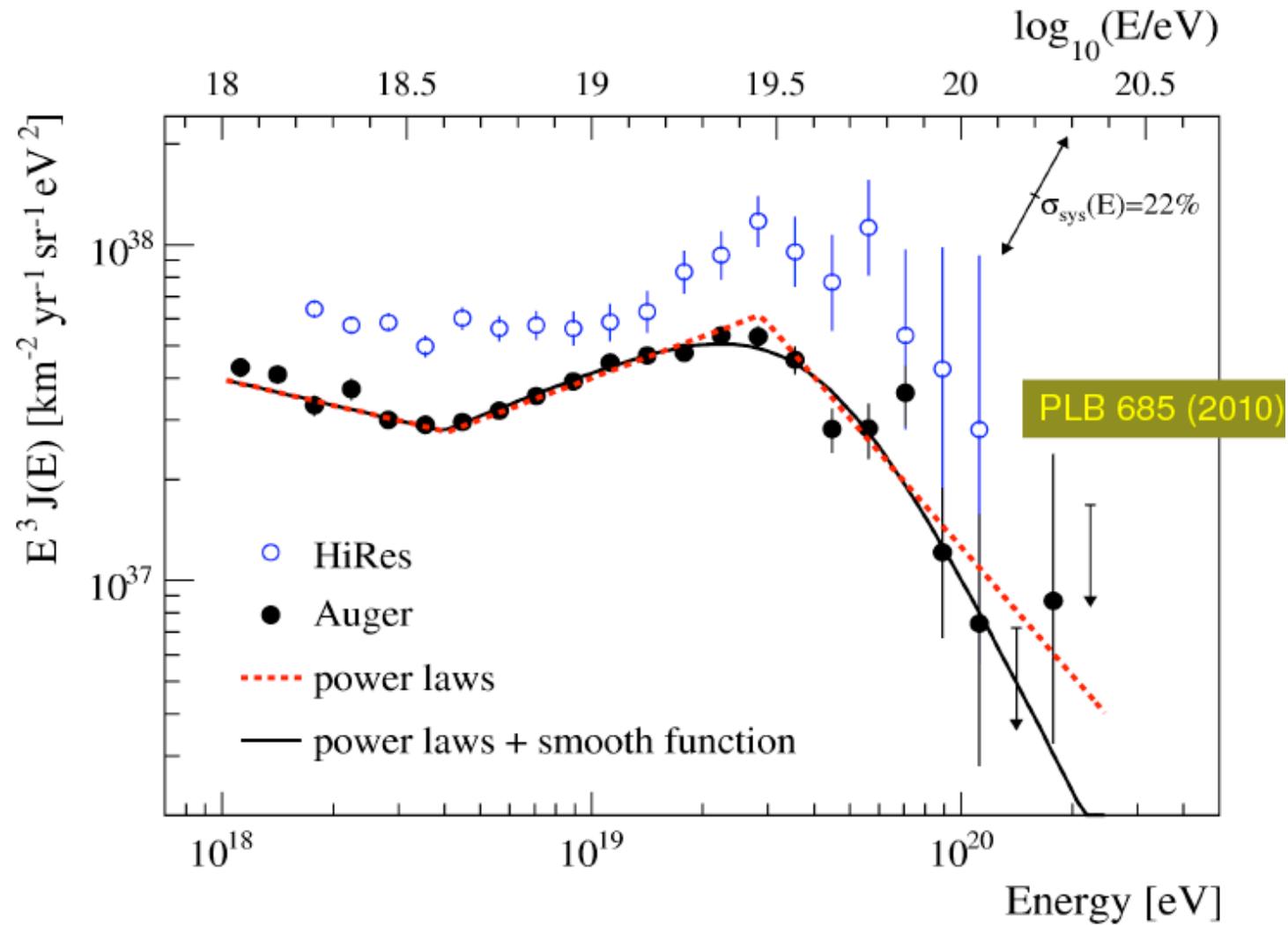
Sommario spettro UHECR



Acceleration limit?
Drop off of lighter elements?

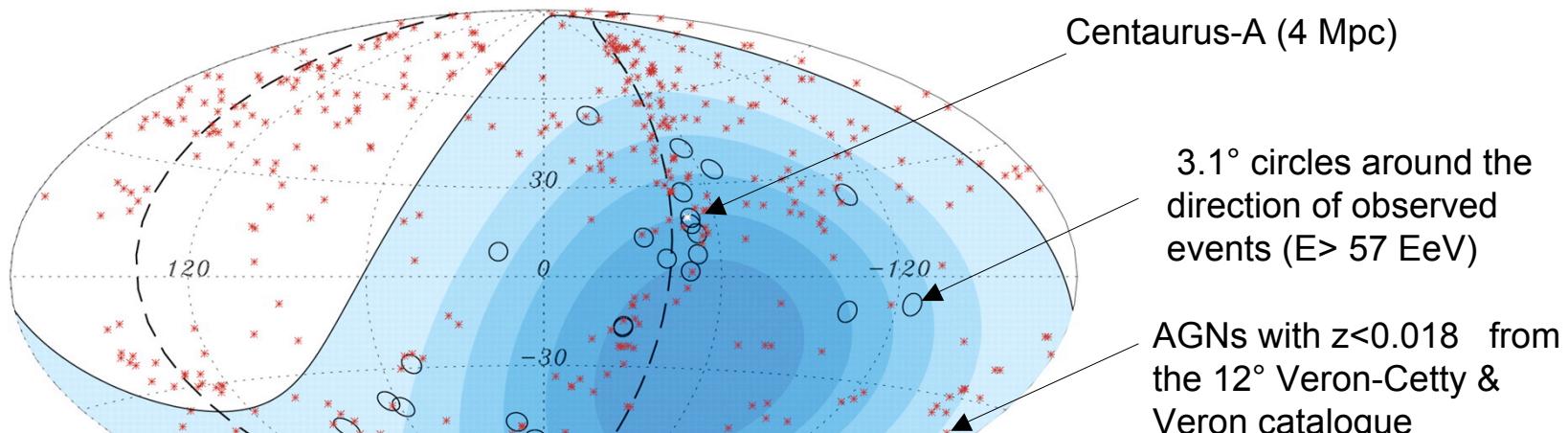


Auger



Correlation with nearby AGNs (I)

Pierre Auger Coll., 9 Nov 2007



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

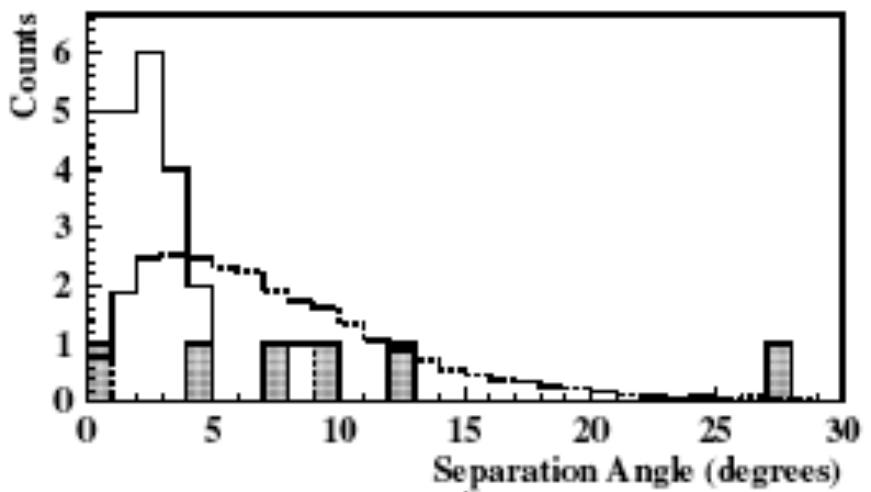
Correlazione attuale: 21/55 (38±6)%
attesa: 21%
Era 69%

UHECR e AGN

Correlation of the highest-energy cosmic rays
with the positions of
nearby active galactic nuclei

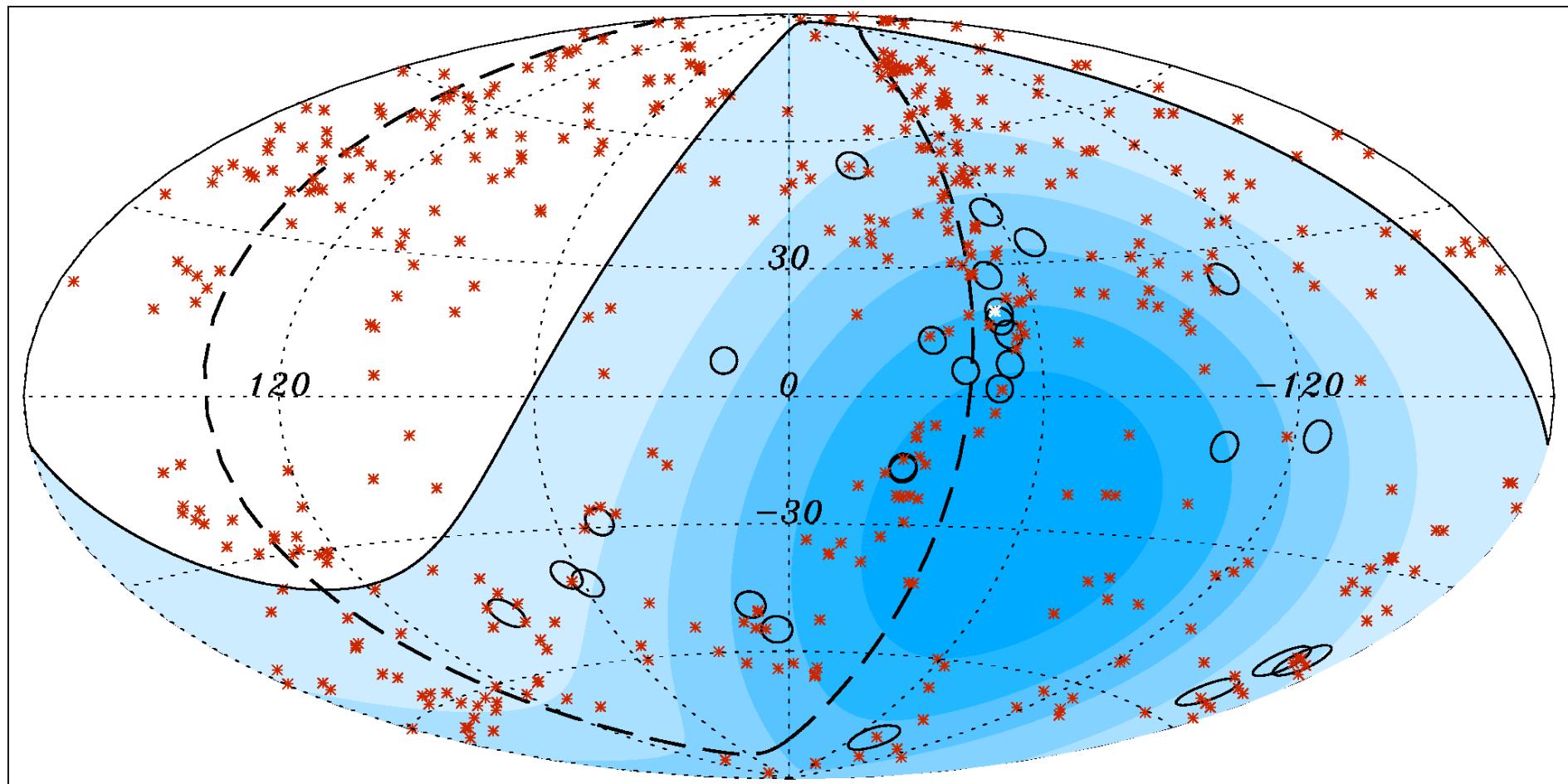
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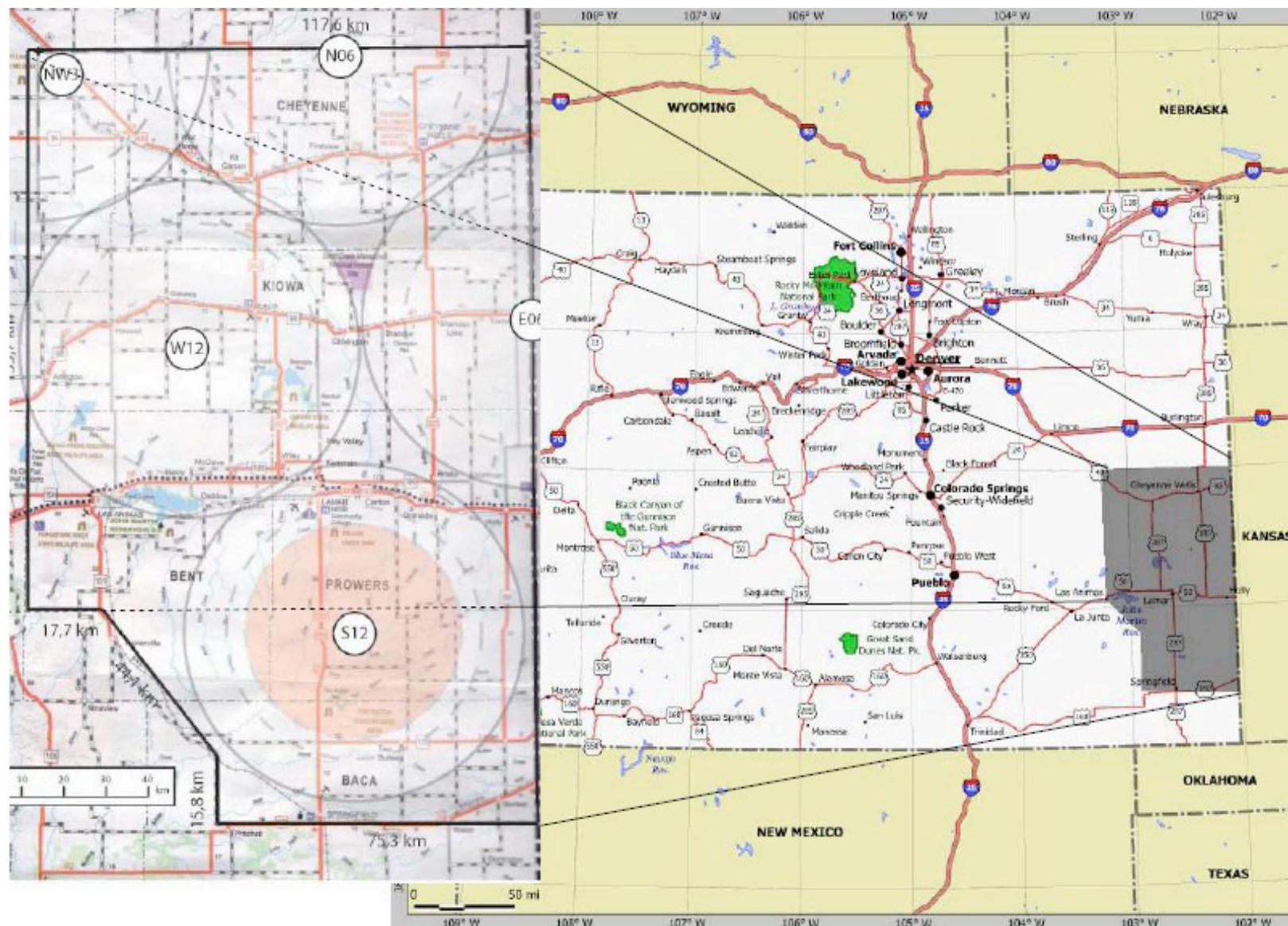


Distribuzione della separazione angolare di
27 eventi di energia più alta con la posizione
del vicino AGN a distanza < 71 Mpc.
I 6 eventi plottati in grigio hanno una latitudine
galattica $|b| \leq 12^\circ$

AUGER: sorgenti UHECR



Auger Nord



UHECR sommario

- **SPECTRUM**

- Hi-Res and Auger measure a flux suppression above $\sim 4 \cdot 10^{19}$ 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

