Pierre Auger Observatory

studying the universe's highest energy particles

L'Osservatorio Pierre Auger
What Next?

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Il progetto Pierre Auger: range di operatività

Studio della radiazione cosmica di altissima energia

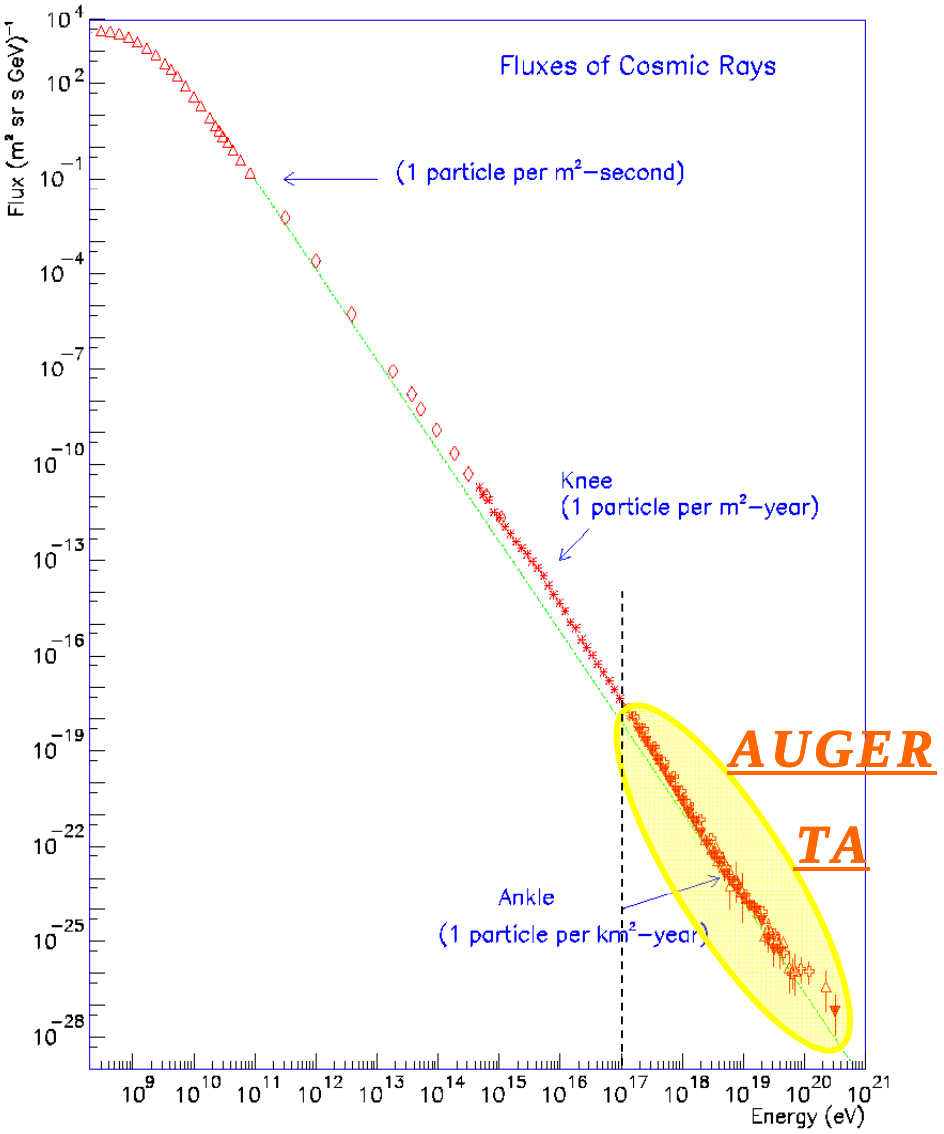
(10^{17}-10^{21}) eV

Flusso ad E>$10^{19.5}$ eV molto basso

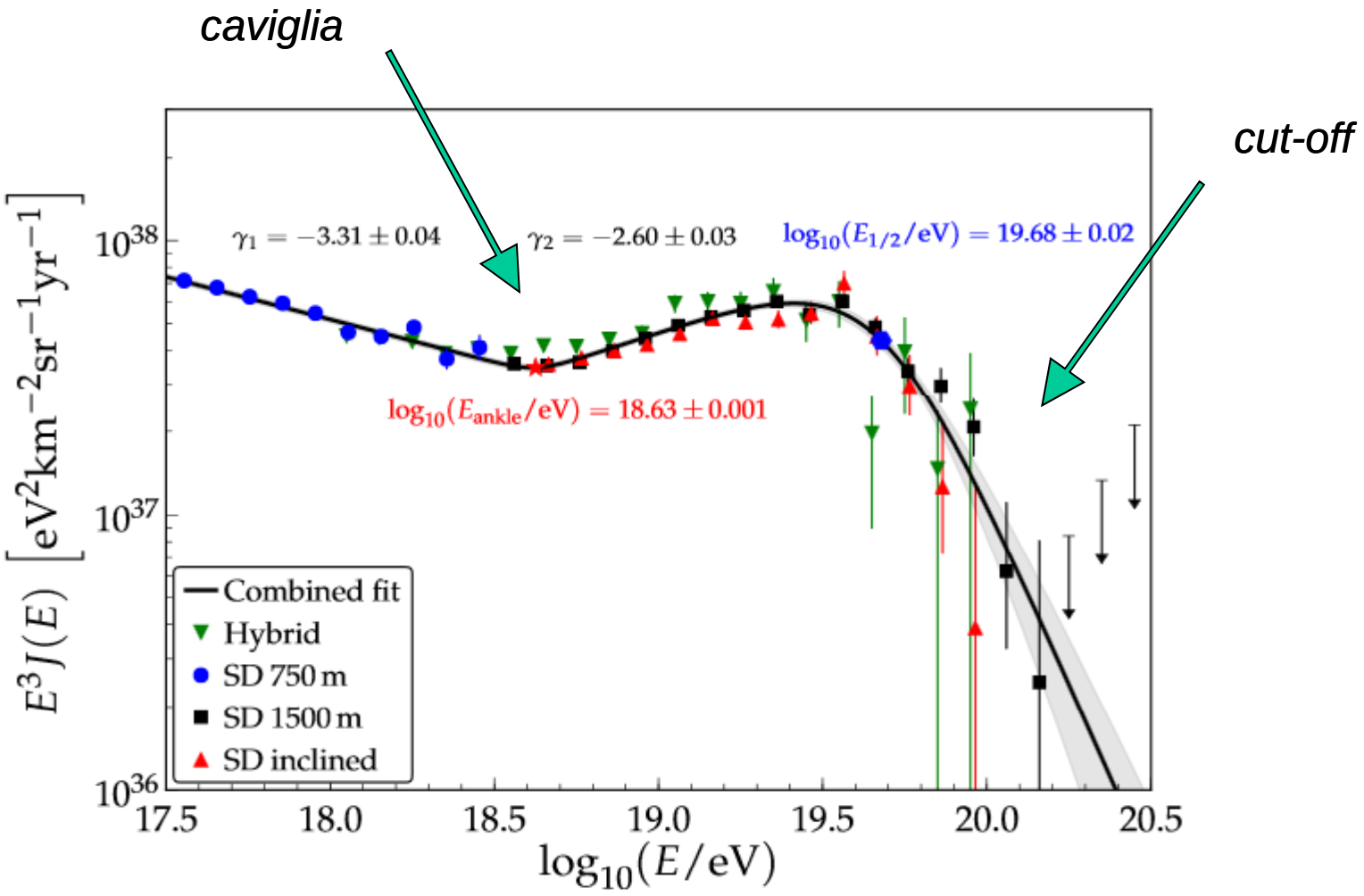
1 particella/(km² sr secolo)

Apparato di grandi dimensioni: 3000 km² (Auger)

30 eventi/anno



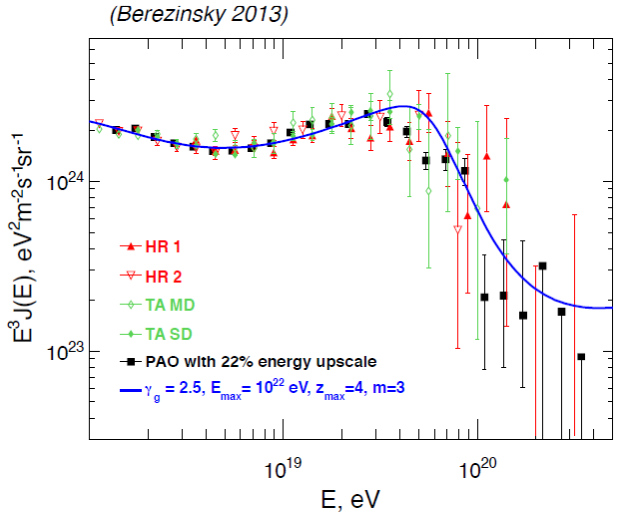
Spectrum

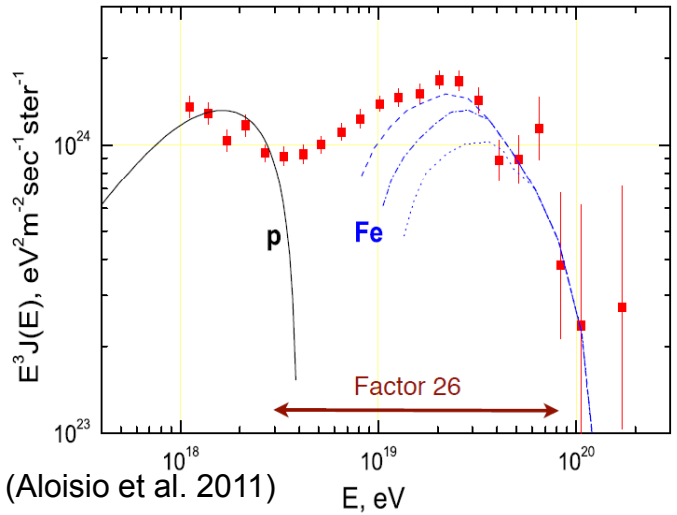


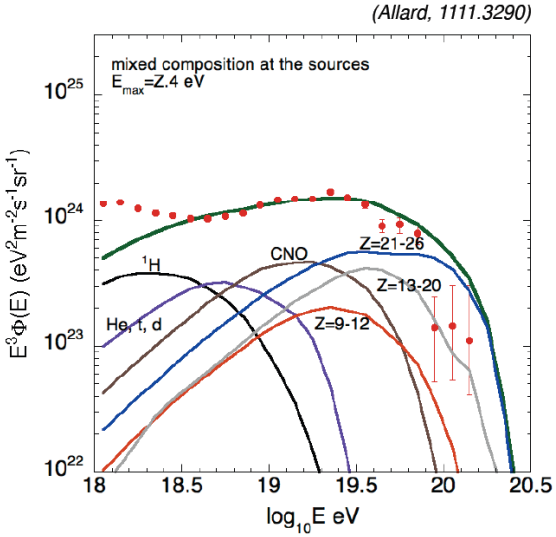
Universalmente accettato che esiste un *cut-off* nel flusso dei Raggi Cosmici.
Universalmente accettato che esiste una *caviglia*.

Spectrum: implications

Suppression established ($E > 4 \cdot 10^{19}$ eV)
Ankle observed at about $4 \cdot 10^{18}$ eV







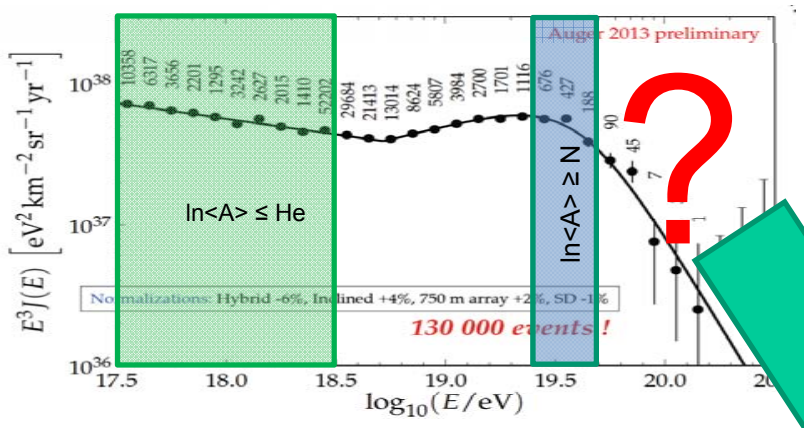
- ✓UHECR are Protons
- ✓GZK effect produce the cut off
- ✓Natural explanation for the ankle

- ✓UHECR Rigidity dependent composition of Extragalactic origin
- ✓GZK effect not needed
- ✓ Transition from galactic to extragalactic at lower energy (2nd knee)

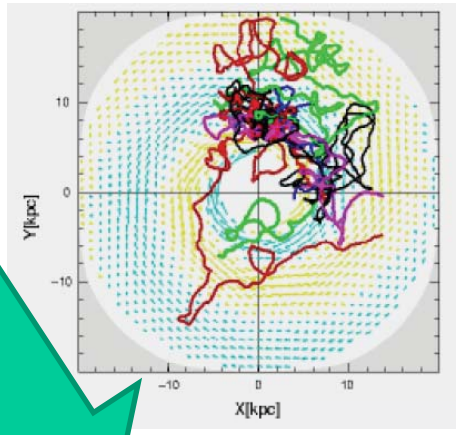
- ✓UHECR Mixed composition at the sources (Extragalactic origin)
- ✓GZK effect but for Heavy Elements
- ✓ Ankle due to transition between Galactic and Extragalactic spectrum.

Do not resolve between different scenario.
Also the galactic origin is not excluded.

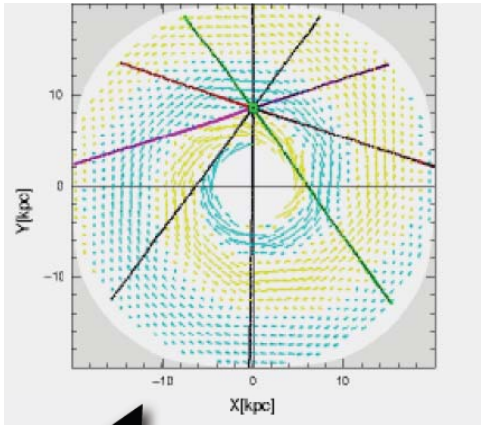
Anisotropy



Proton 10^{18} eV



Proton 10^{20} eV



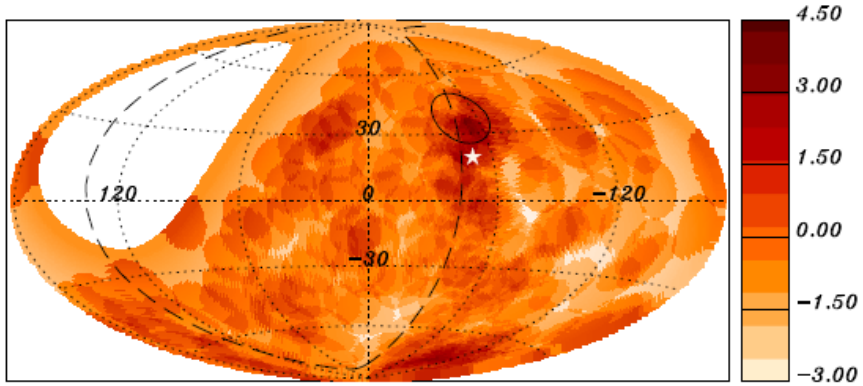
Deflessione P <3° ; Deflessione Fe 15°-20°

Eventi con energia maggiore di 54.8 EeV. Angolo di selezione 3.1°. Catalogo di riferimento VCV con z<0.018.

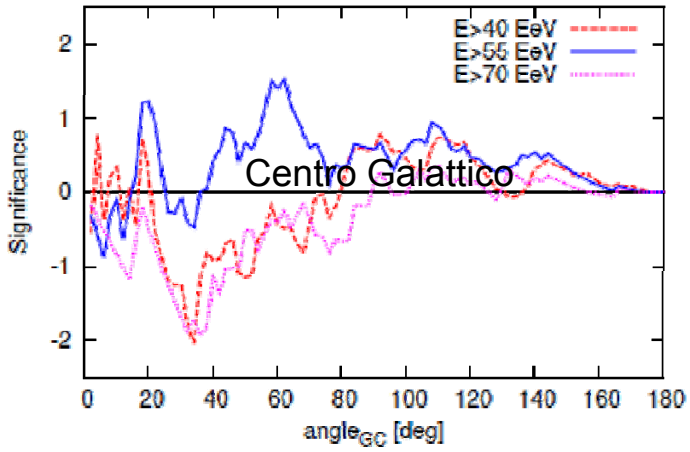
146 eventi rivelati, 41 correlano con AGN nel catalogo. La frazione di eventi che correlano è $28.1^{+3.8}_{-3.6}$ % l'attesa per un flusso isotropo è 21%. Il segnale è solo 2 sigma sopra l'isotropia.
Anche TA presenta un risultato analogo.

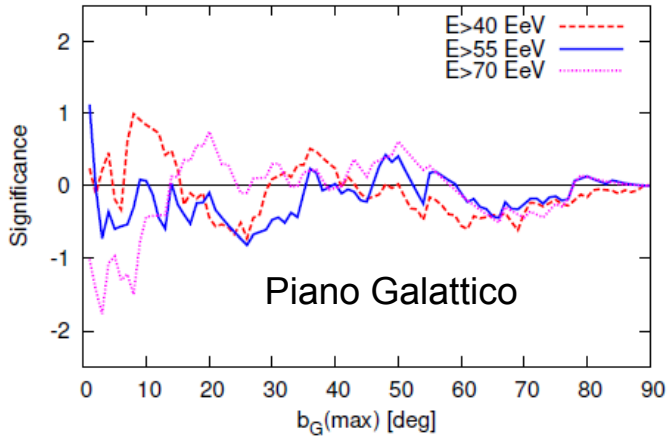
Science 318, 938 (2007)
Frazione correlati 61%

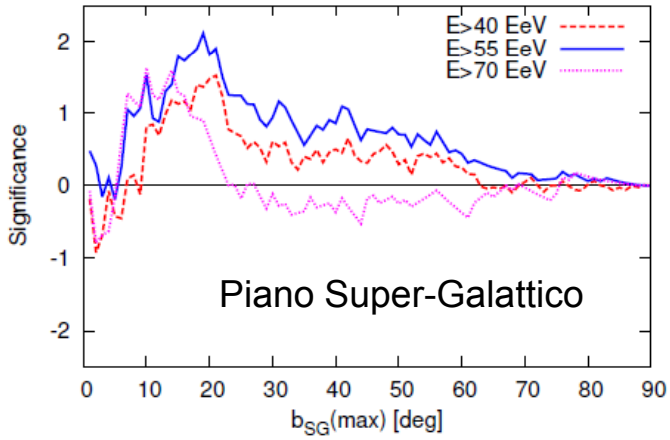
Anisotropy



Li-Ma R=12˚ , E>54 EeV
Massimo eccesso P=1.4% in prossimità di Cen A





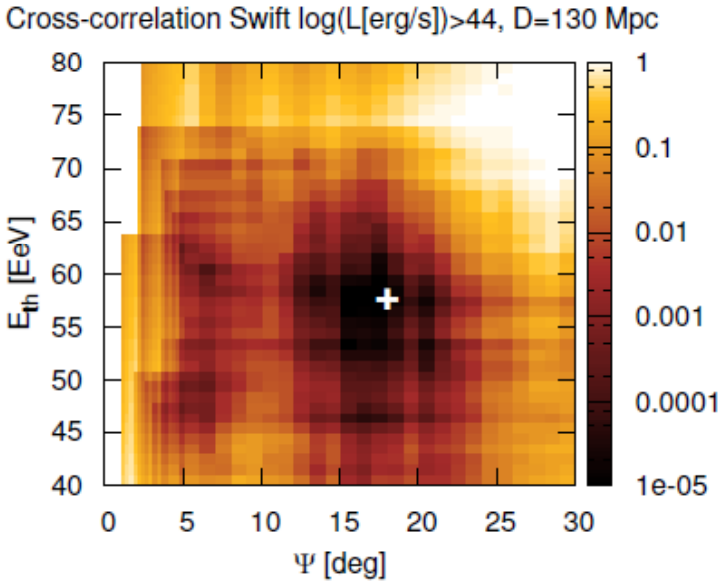


10 anni di dati: 602 eventi E>40EeV θ<80º

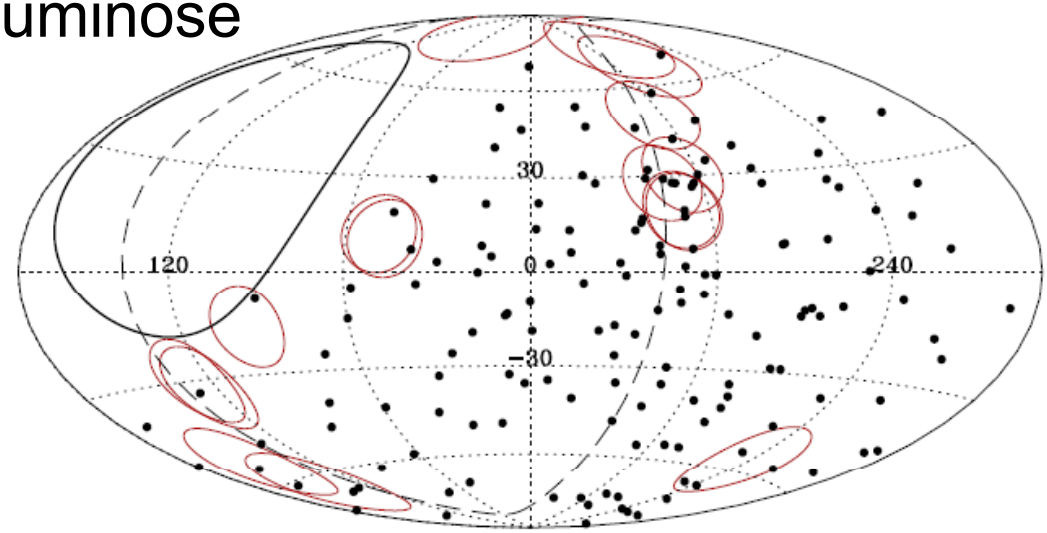
Submitted Astrop. J.

Anisotropy

AGN più luminose

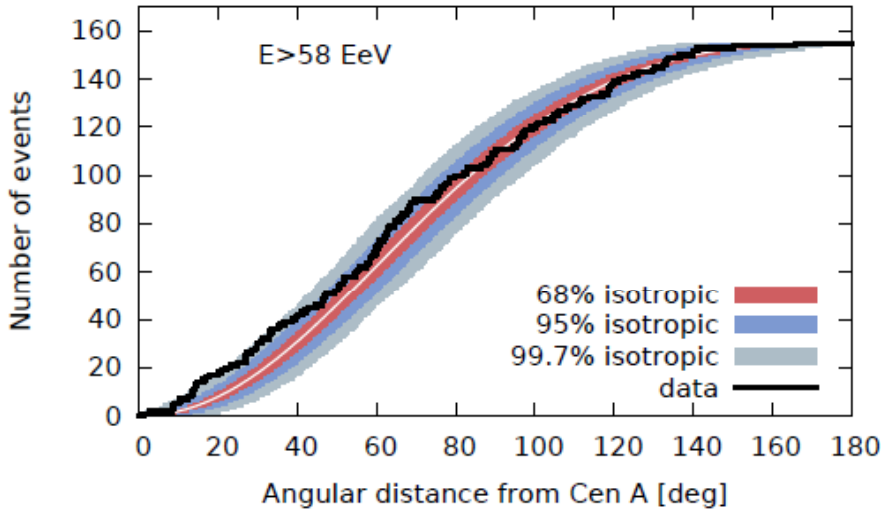


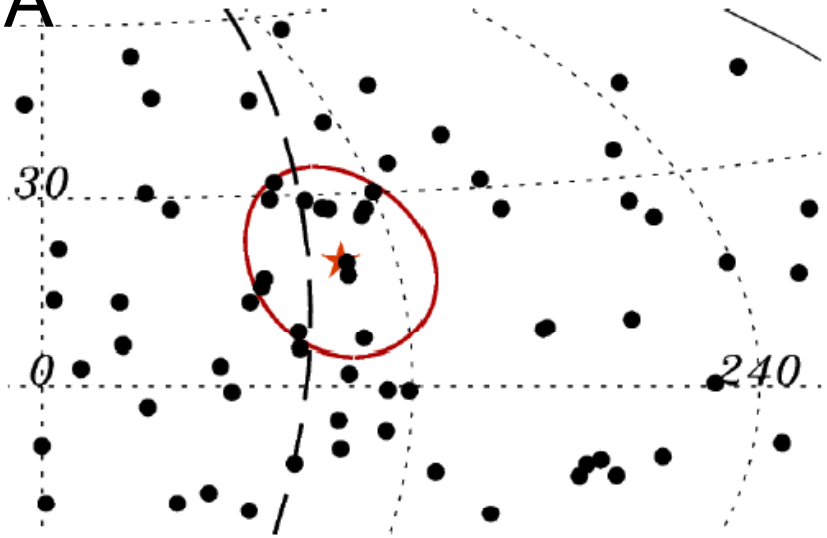
Scanning in funzione della luminosità. Swift



Probabilità post trial 1.8%

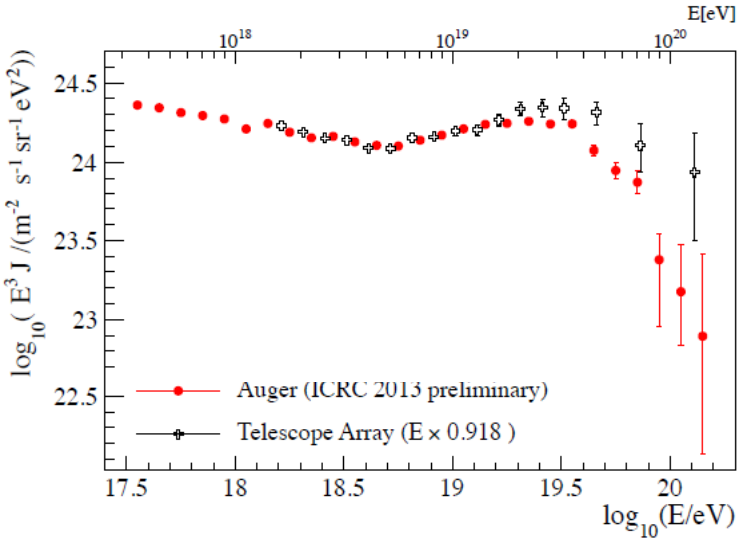
Cen A

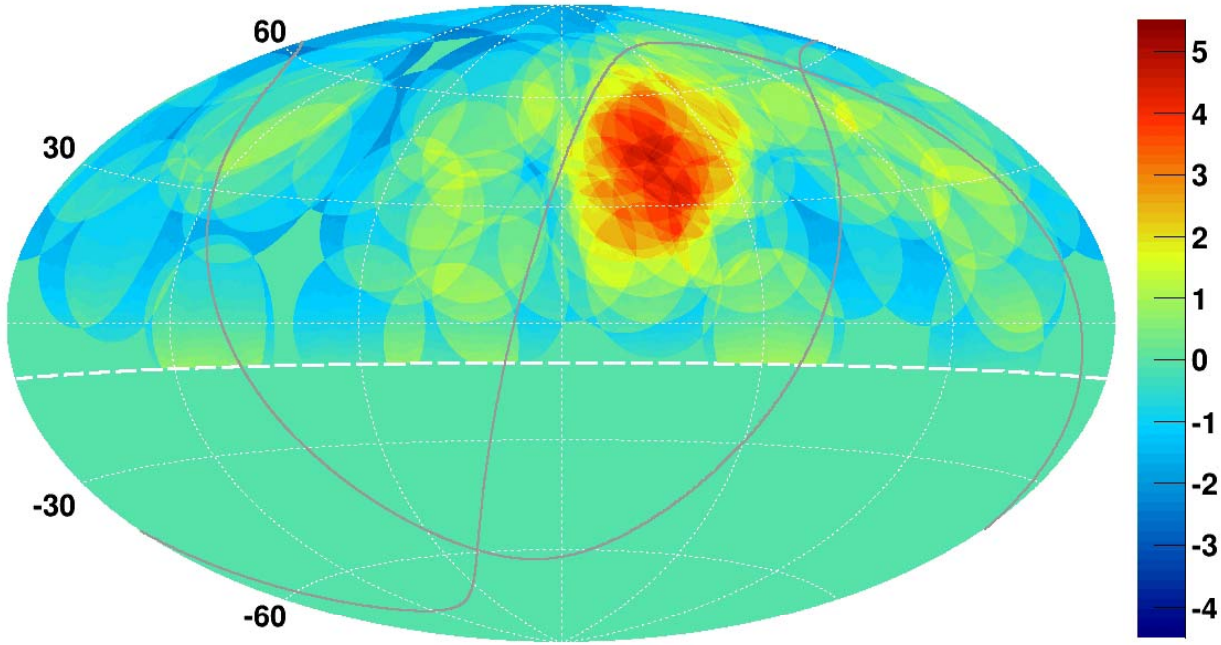




Minimo per E>58 EeV, R=15° P=1.4%

Anisotropy



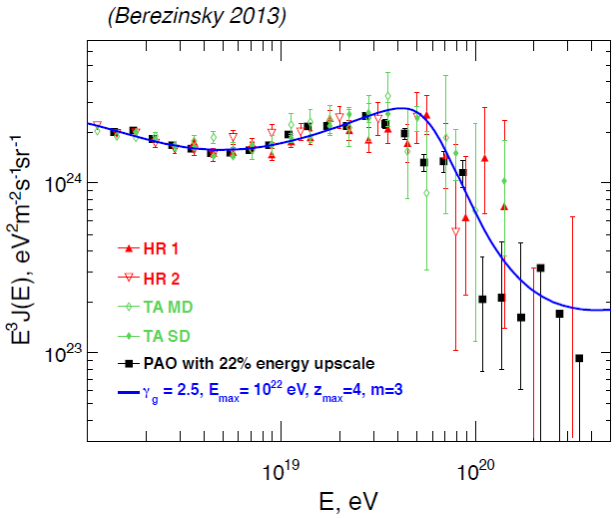


TA ha annunciato l'evidenza di un hot spot . Non coincide con l'hot spot di Auger.

ApJ 790 L21 (2014)

Anisotropy: implications

The UEHCR flux is isotropic
Lower energy events, if protons, has to be extragalactic



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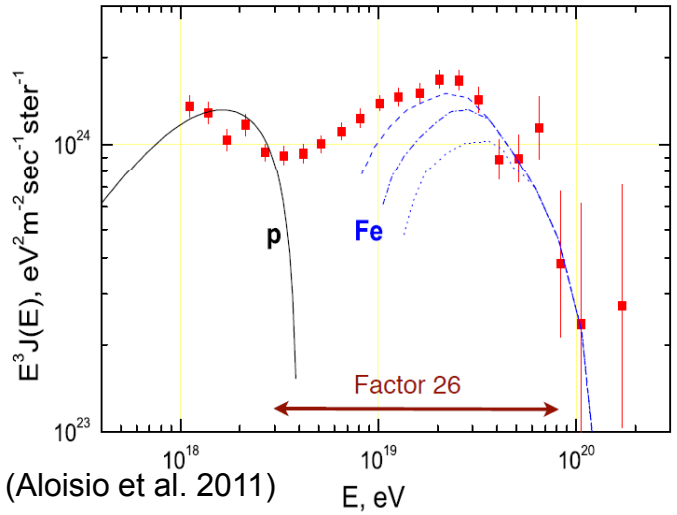

(Aloisio et al. 2011)

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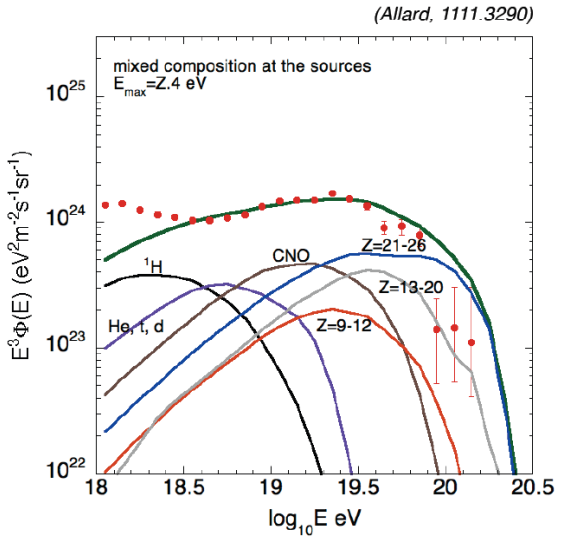

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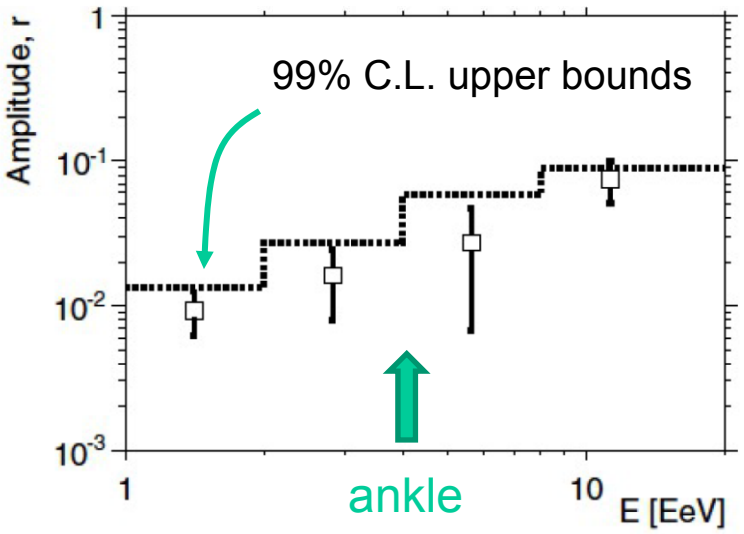
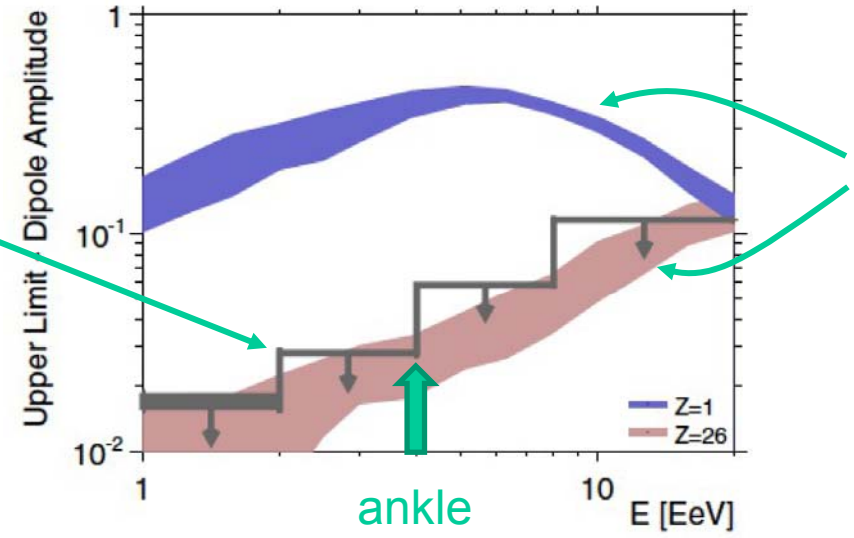
Anisotropy



Above 1 EeV anisotropies could be imprinted in the distribution of arrival directions as the result of the escape of UHECRs from the Galaxy up to the ankle energy.

If UHECRs have already a predominant extragalactic origin their angular distribution is expected to be isotropic to a high level.

99% C.L. upper limits



Model prediction for an uniform distribution of sources in the galaxy and different compositions

ApJL, 762 (2013) L13

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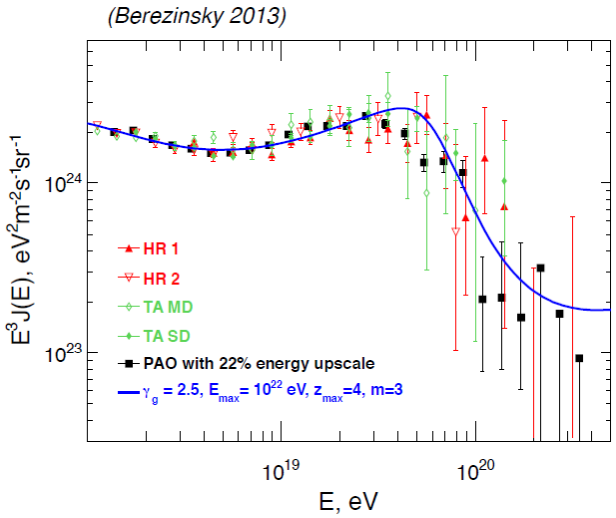

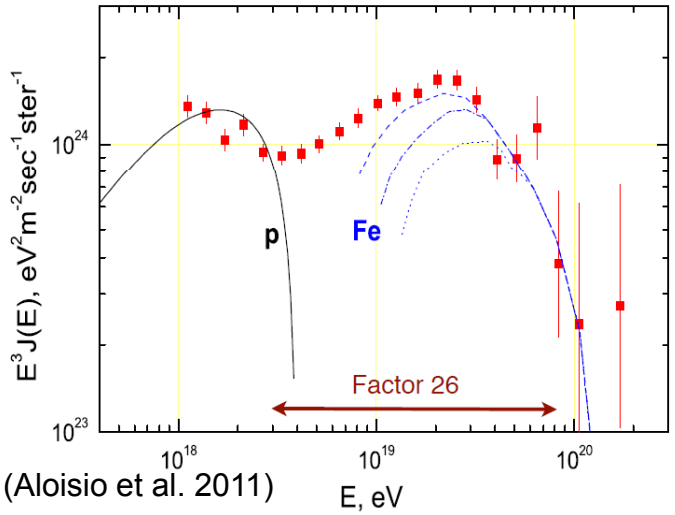

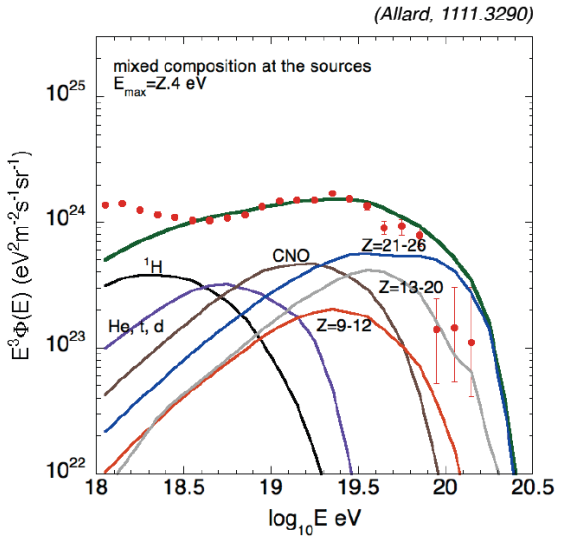

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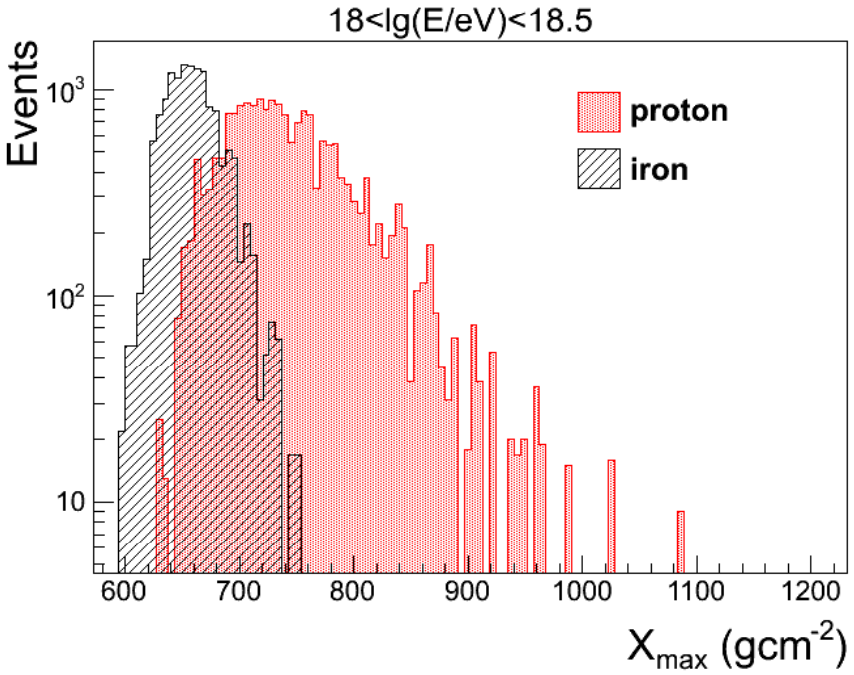
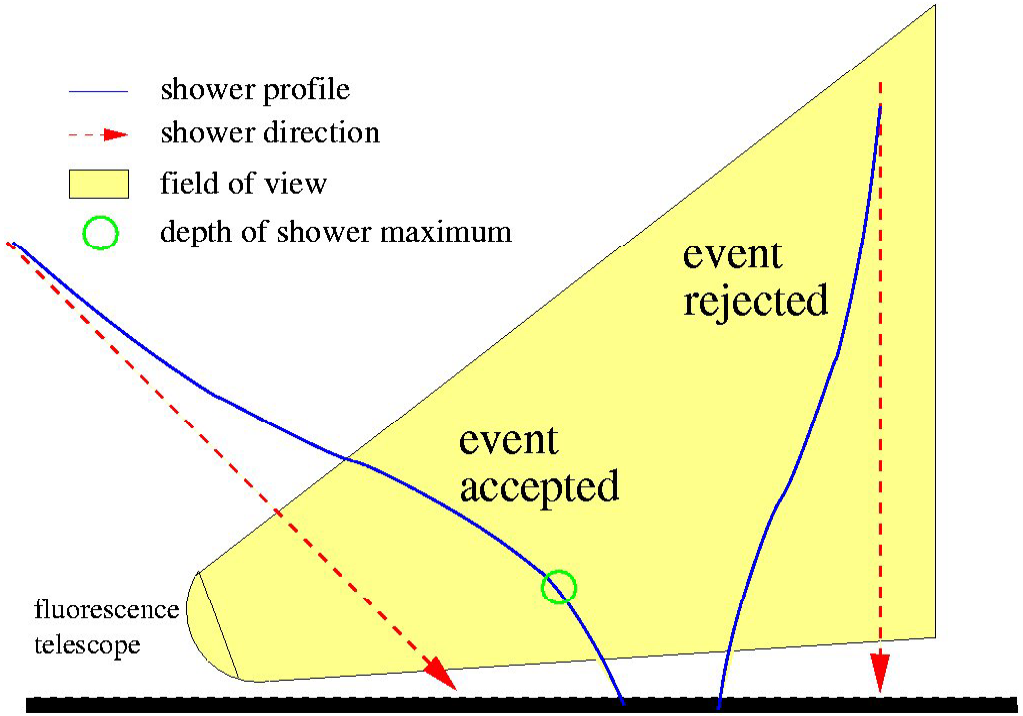
- Need an ad-hoc component

Mass Composition

The main instrument of analysis is the Fluorescence Detector, but also the Surface Array can be used.

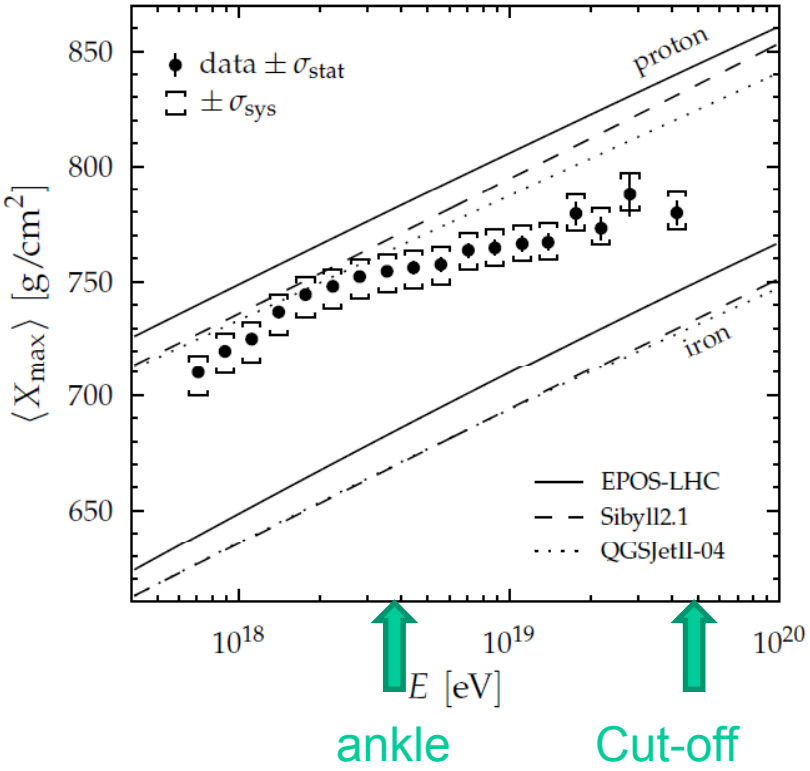


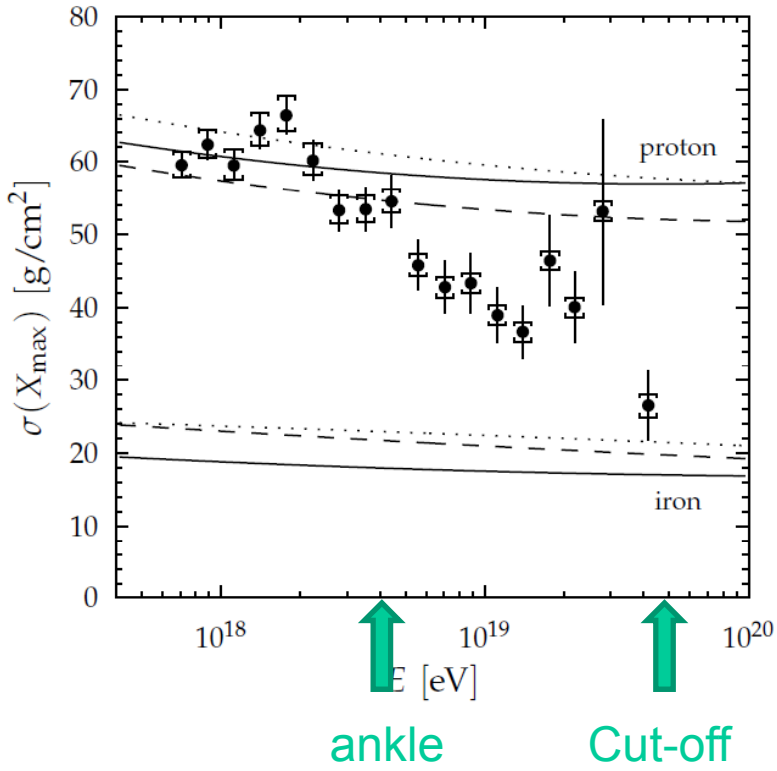


$<X_{max}>$ and its RMS sensitive to mass composition
Key observables for composition studies

Filed of View and Anti-Bias cut used to obtain detector independent results

Mass Composition





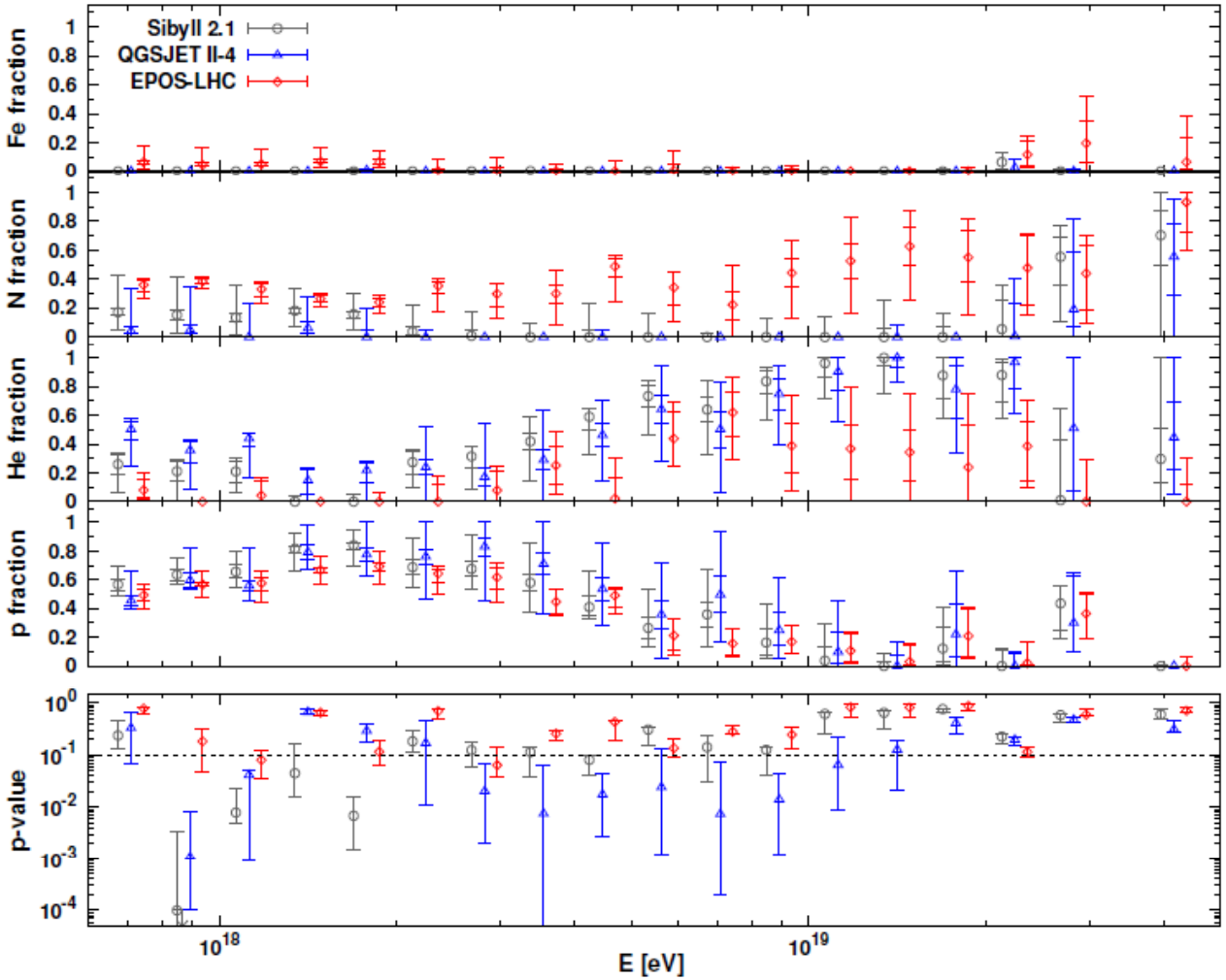
$<X_{max}>$ became lower with energy

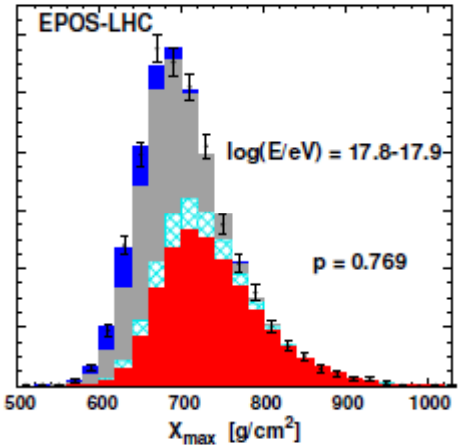
X_{max} distributions become narrower with energy

Increase of the mean mass with the energy? Inadequate interaction models?

Submitted PRD

Composition

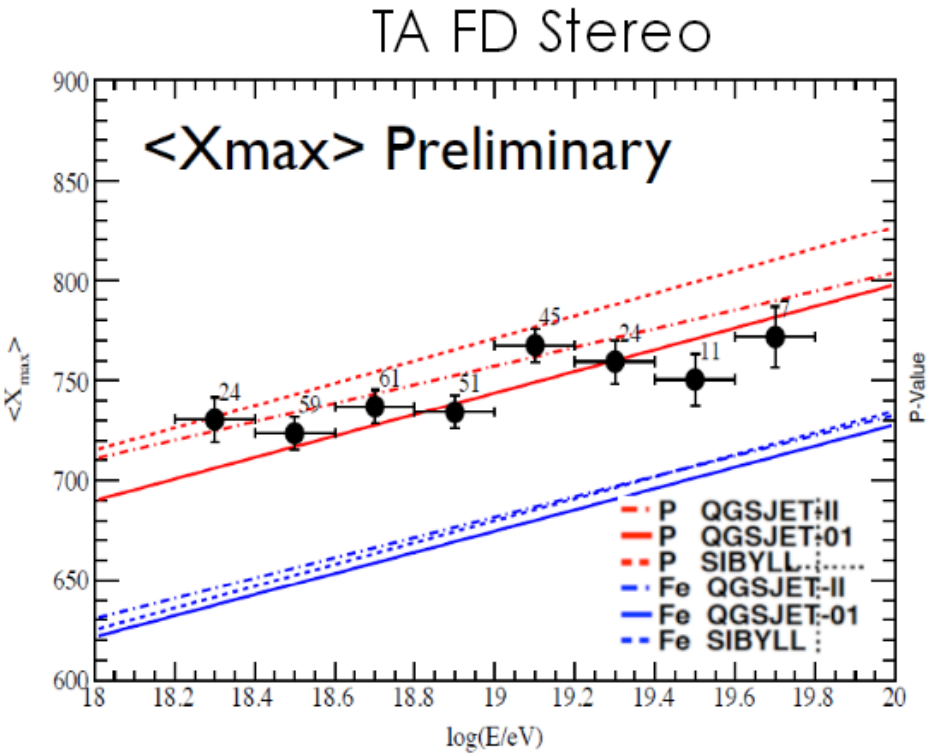


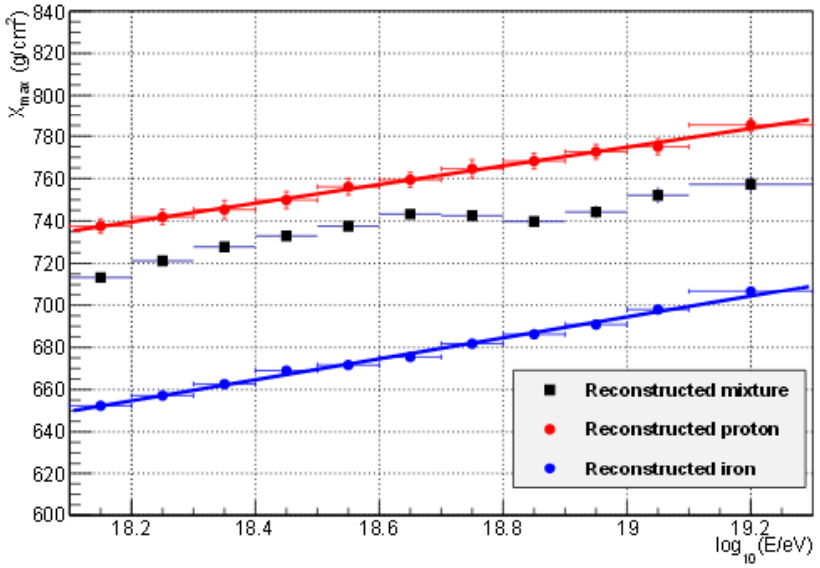


Submitted PRD

Composition

TA results





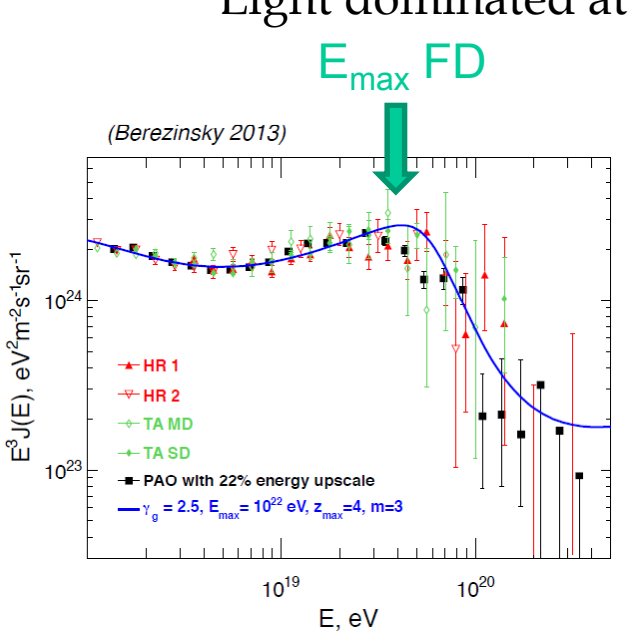
ICRC 2013

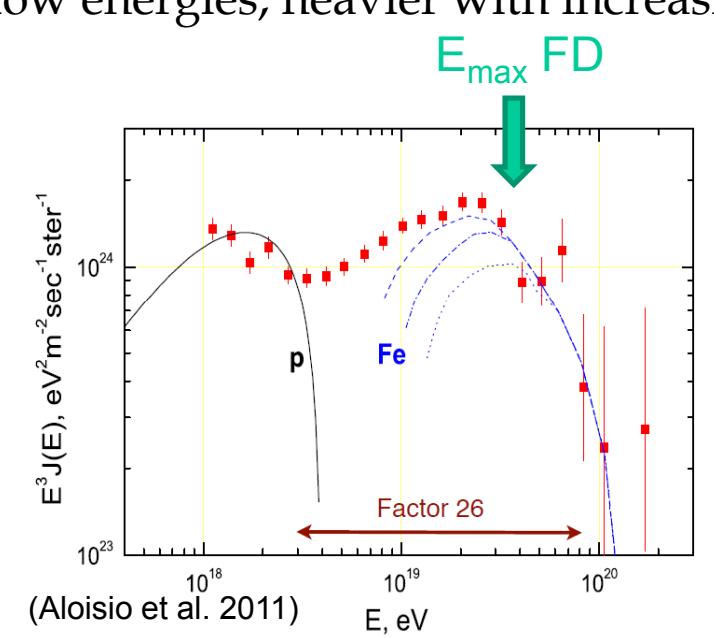
Metodologia di analisi completamente diversa.

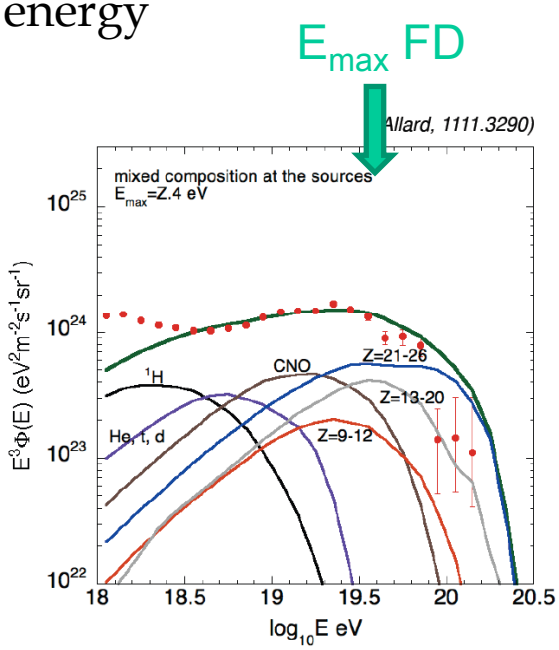
Work in progess…

Mass Composition: implications

AUGER results:
Light dominated at low energies, heavier with increasing energy







✓ AUGER Excluded? Still possible if new physics is responsible of the change in the $\langle X_{max} \rangle$ and RMS(X_{max}) distributions.

✓ Not in contradiction with Auger Mass Composition Data.

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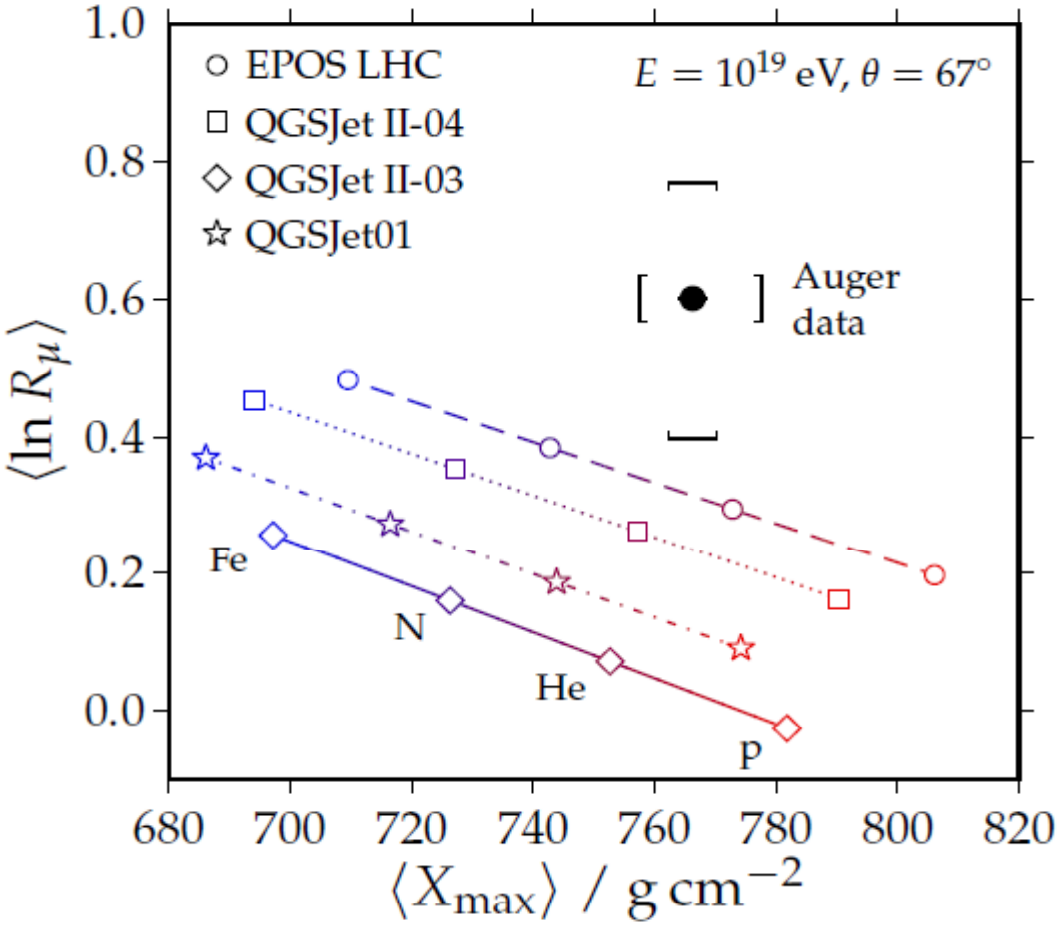
✓Need an ad-hoc component

Hadronic Interaction



$$\rho_\mu(\vec{r}) = N_{19}\ \rho_{\mu,19}(\vec{r};\theta,\phi),$$

Submitted PRD

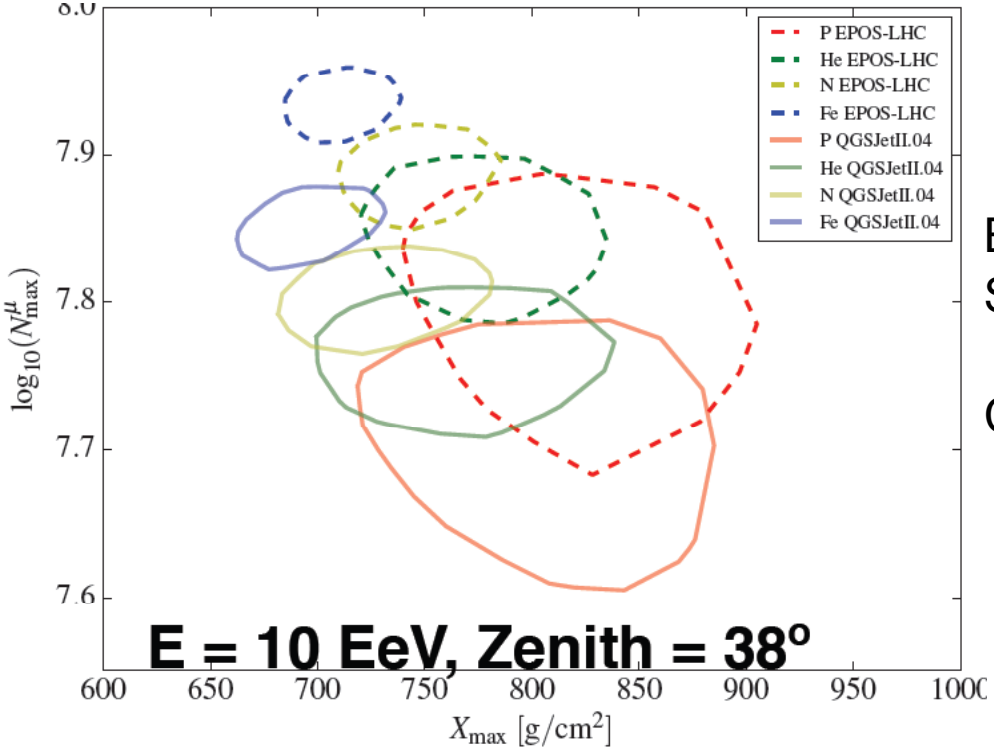
The upgrade Science Case

1) The primary objective of the upgrade of the Auger Observatory is to elucidate the origin of the flux suppression and the mass composition at the highest energies…

2) The search for a flux contribution of protons up to the highest energies will be the second key science objective. We aim to reach a sensitivity to a contribution as small as 10%. …

3) …Estimating the number of muons in air showers from Auger data, a discrepancy between the observed and expected muon numbers is found. Therefore the third key science objective will be the study of extensive air showers and hadronic multiparticle production….

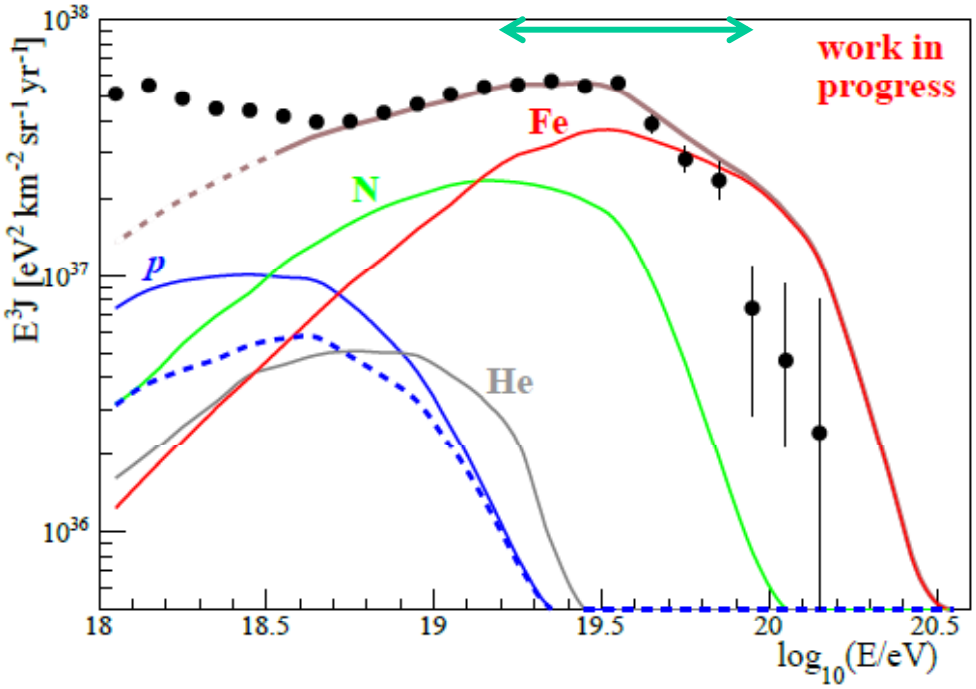
The origin of the flux suppression



We need to estimate at least X_{max} and N_{μ}, but also other parameters are useful.

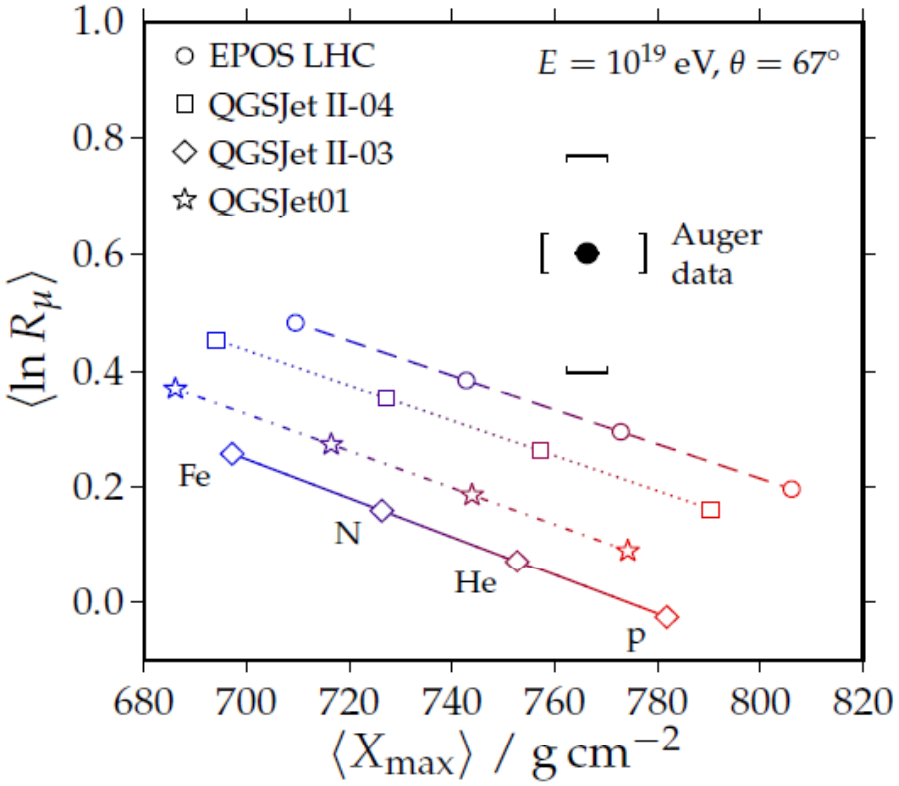
Best technique: global fit of data with propagation.
Spectrum, X_{max}, RMS(X_{max}), N_{mu}, Anisotropy, …

Comparison with MC



Strong correlations between different energy regions

The hadronic interaction



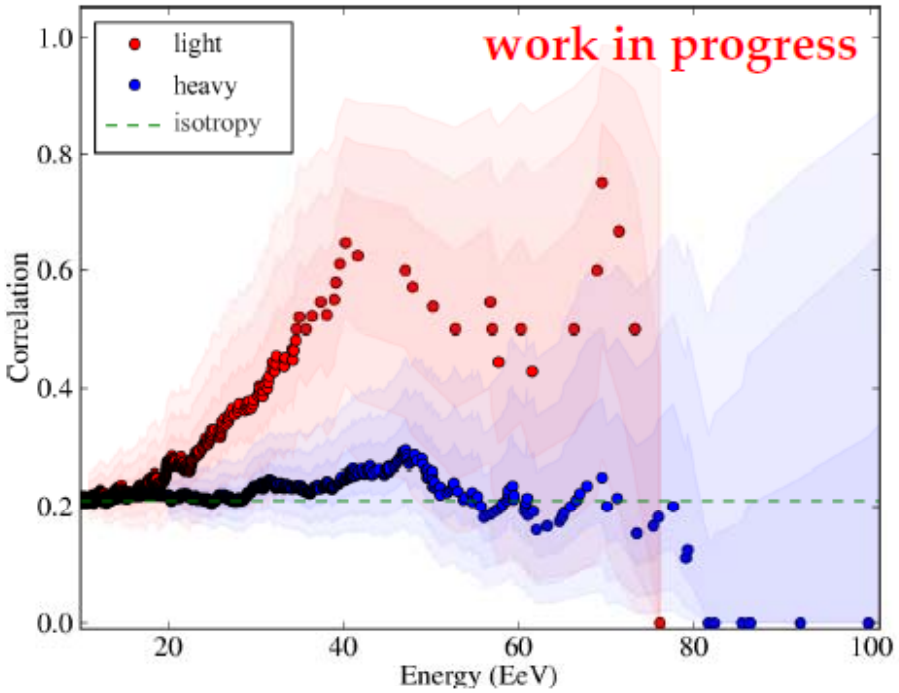
X_{max} can be measured only by FD! → We can not "answer" to this question at energy larger that few 10^{19} eV.

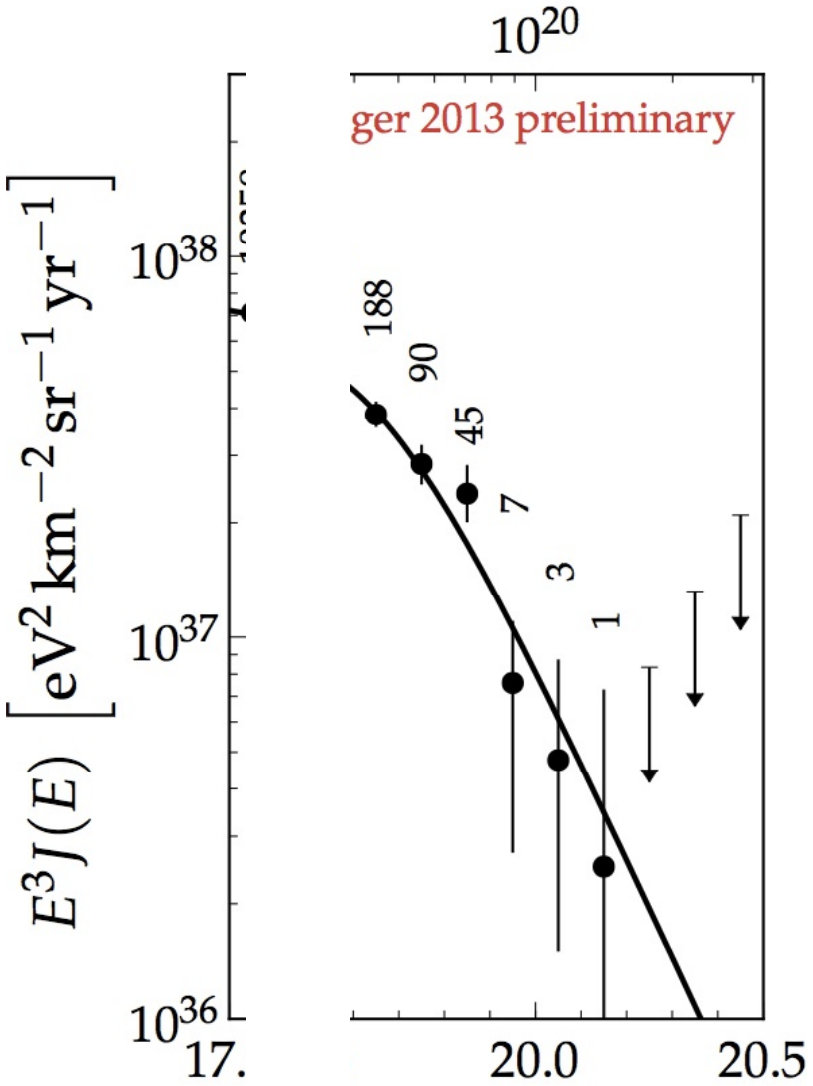
Necessary to increase the FD statistics.
Necessary a direct measurement of the muonic component.

The fraction of proton

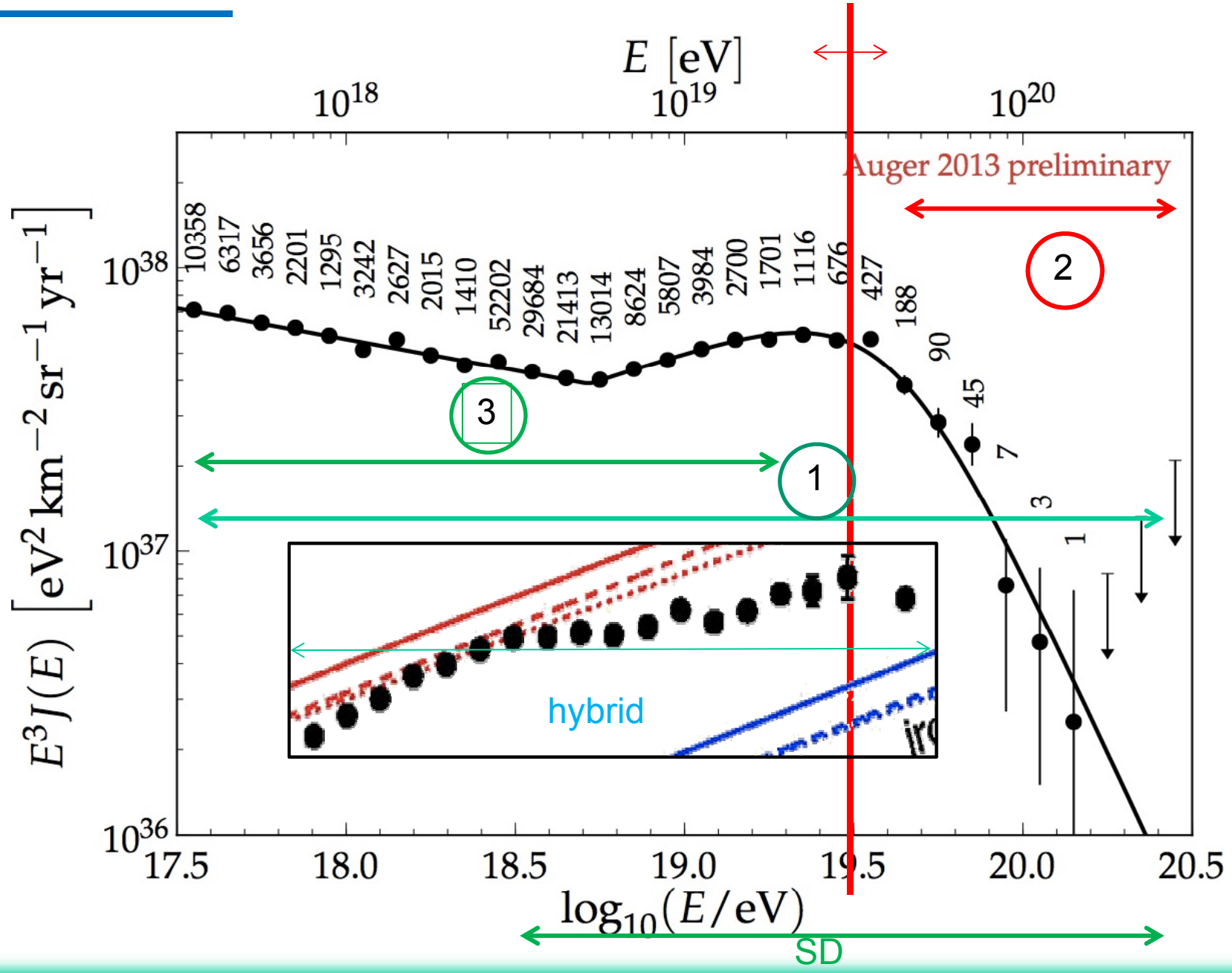
It is necessary a event-by-event mass identification.

We need a 3000 km^2 detector (maybe more…)





Science case and Spectrum



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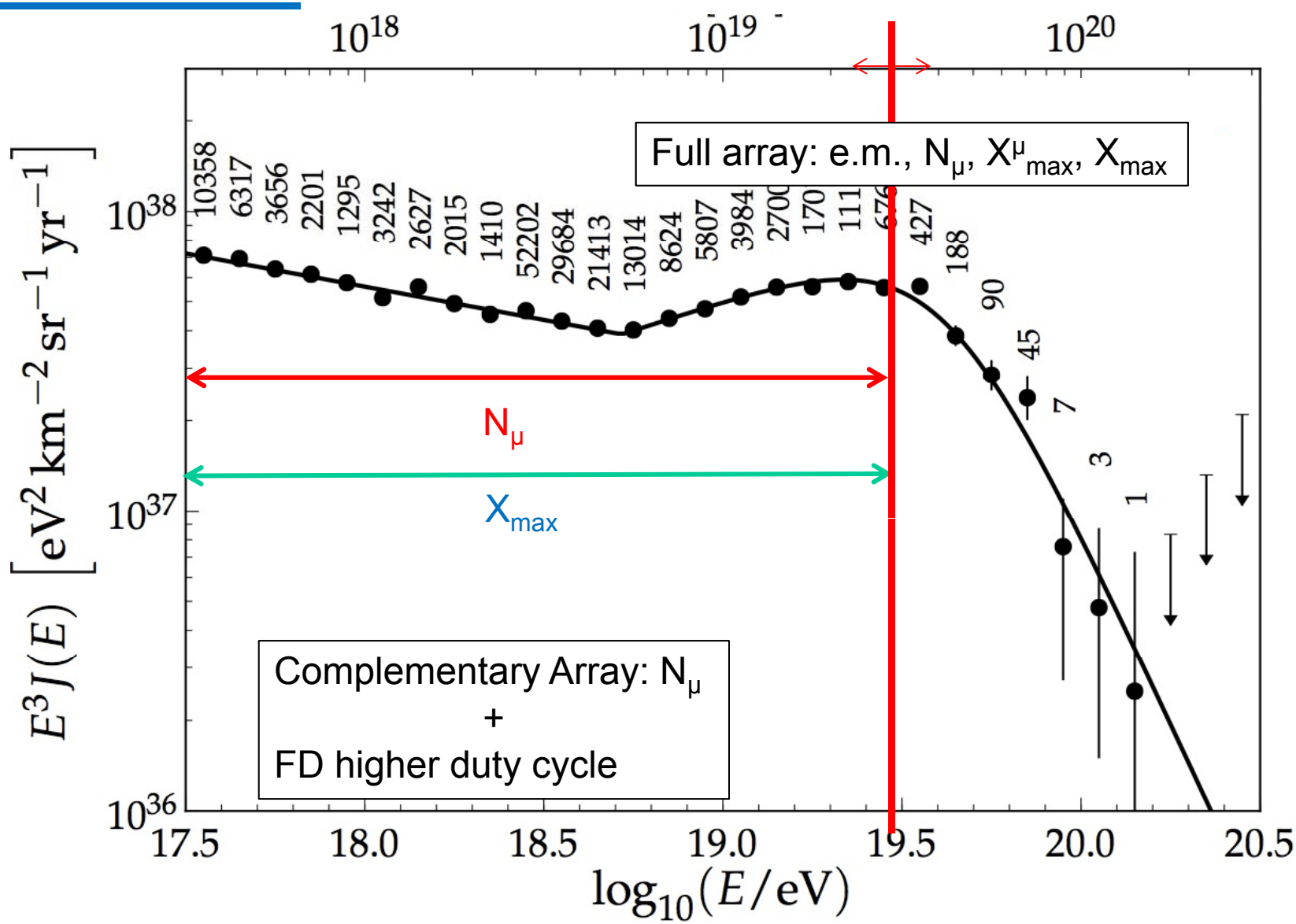
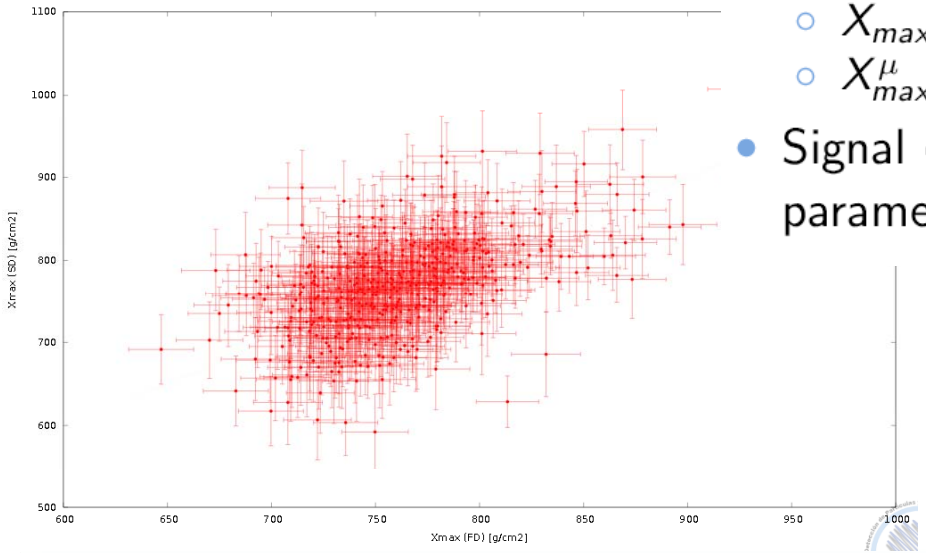
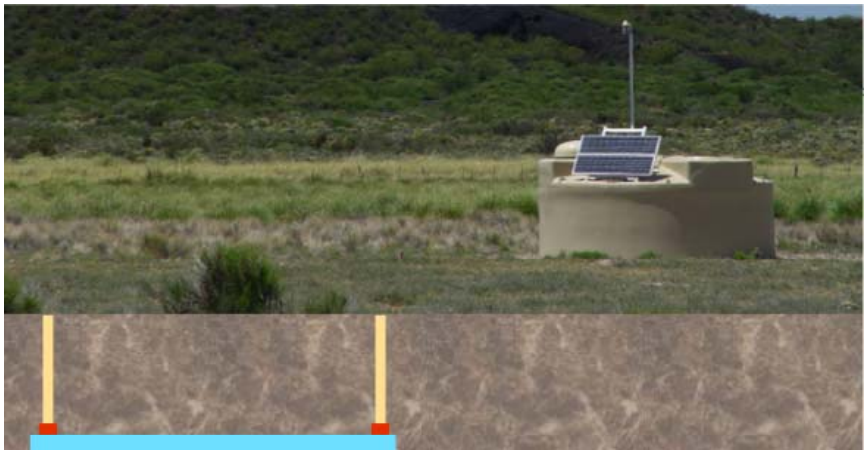


Full Array ASCII & Universality

- Based on the Universality:
- EAS sum of 4 components:
  - pure EM
  - Muons
  - EM from muon decays
  - EM from direct pion jets
- EAS described by macro parameters:
  - Geometry
  - Energy
  - N_μ
  - X_{max}
  - X^{μ}_{max}
- Signal (both integral and time structure) dependence on these parameters derived from MC (QGSJetII-03 and EPOS-1.99)

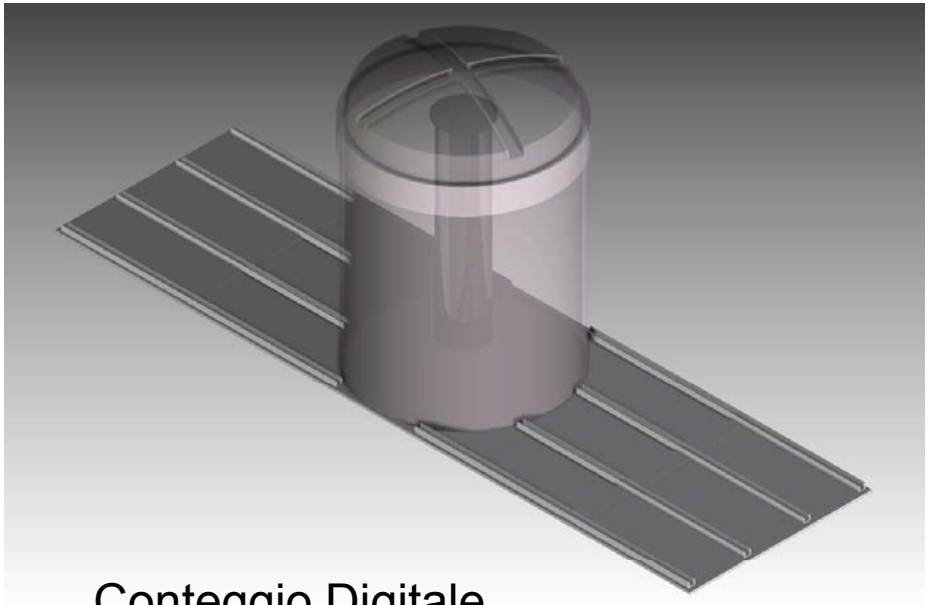


Complementary Array



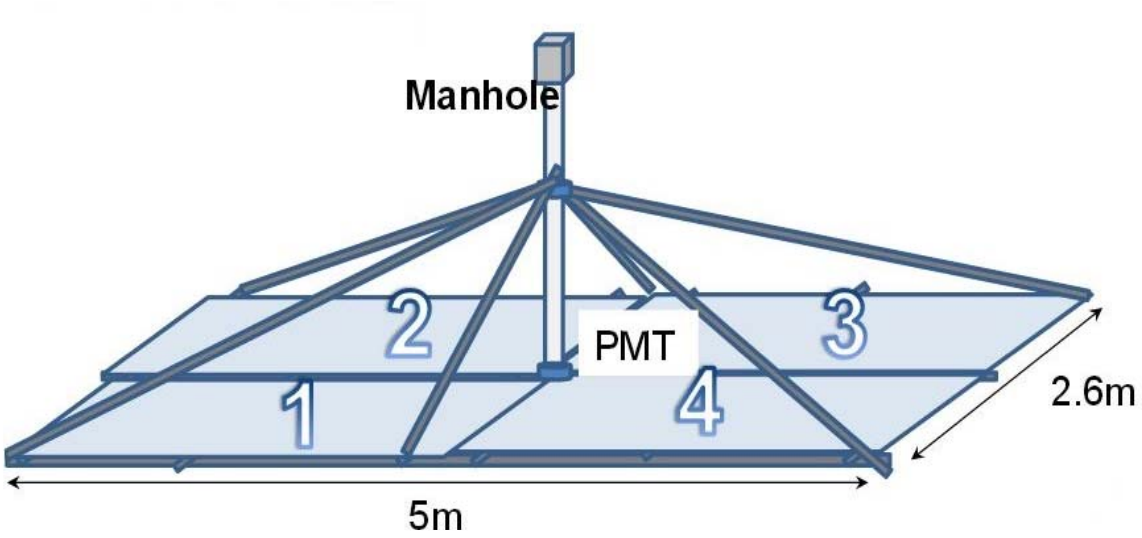
SCINTILLATORI UNDERGROUND

AMIGA-Grande



Conteggio Digitale

TOSCA

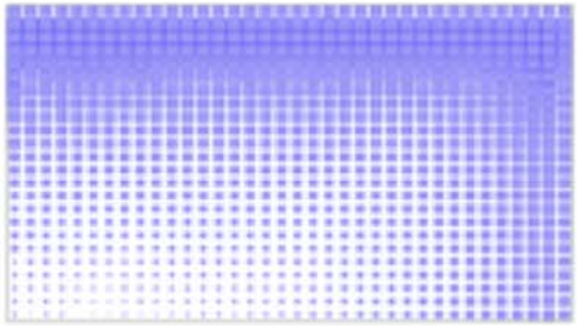


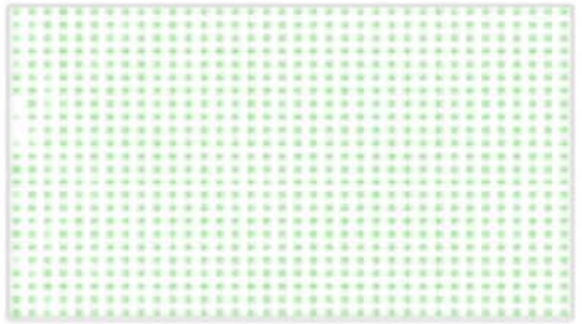
Conteggio Integrale

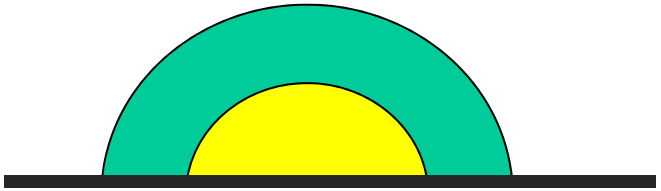
NEXT?

Array di Superficie

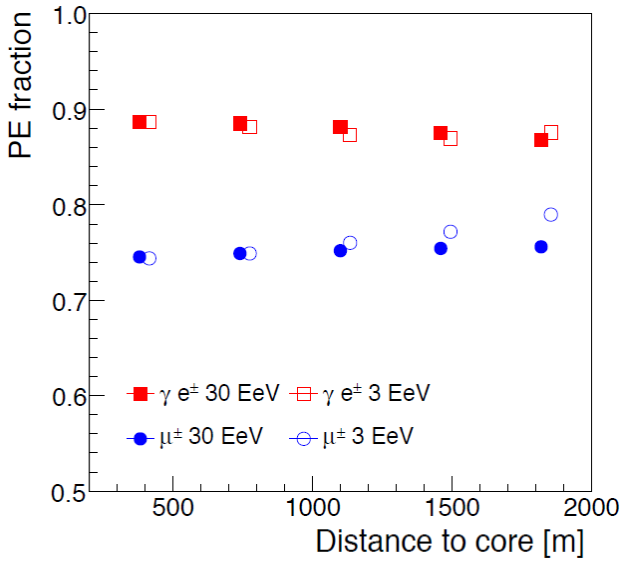
Misura simultanea del segnale dovuto alla componente e.m. e muonica dello sciame

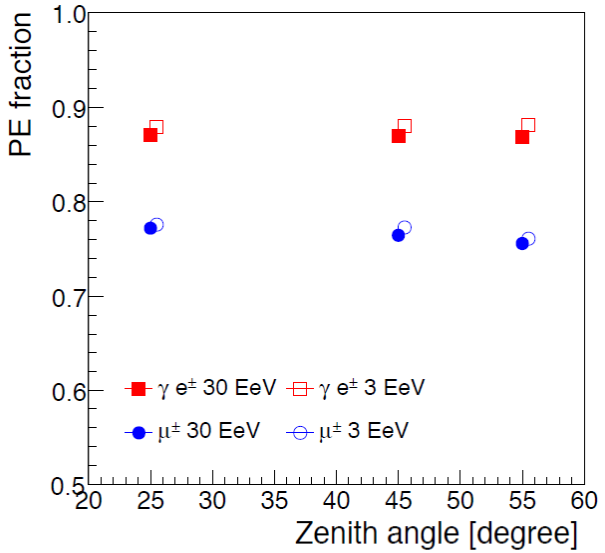






$$\begin{pmatrix} S_{top} \\ S_{bot} \end{pmatrix} = \begin{pmatrix} a & b \\ 1-a & 1-b \end{pmatrix} \begin{pmatrix} S_{em} \\ S_{\mu} \end{pmatrix}$$



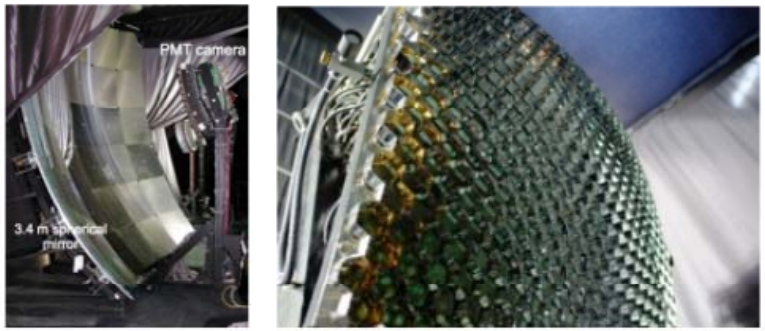


A. Letessier-Selvon et al.

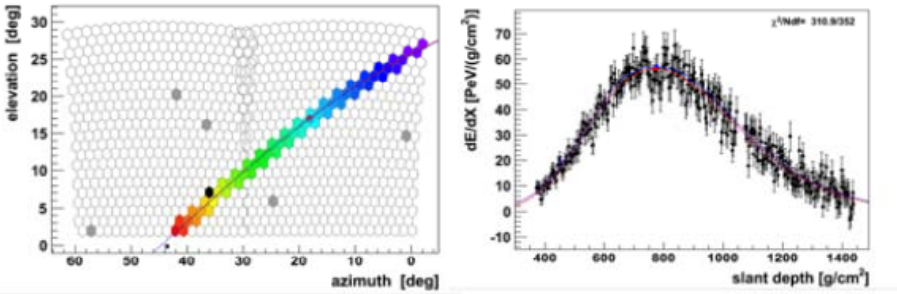
Fluorescenza

- Target : > $10^{19.5}$ eV, UHE nuclei and neutral particles
- Huge target volume ⇒ Fluorescence detector array

Fine pixelated camera

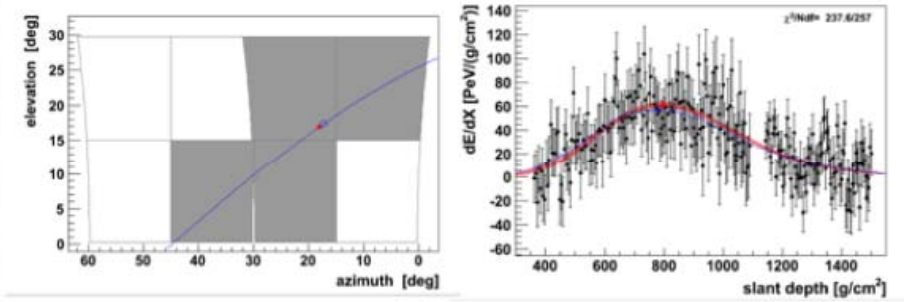


Too expensive to cover a large area



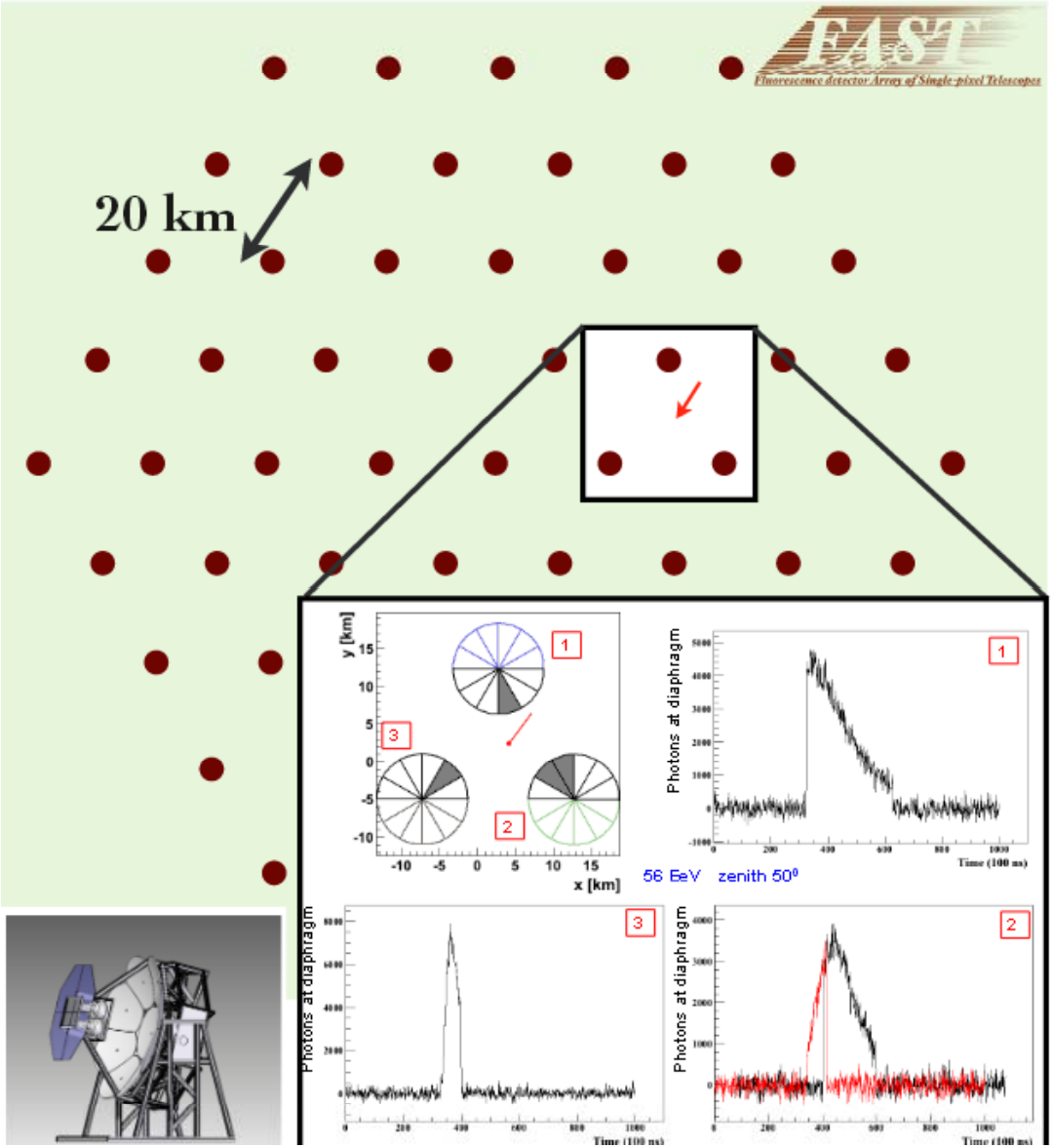
Low cost single pixel telescope (FAST)

Shower profile reconstruction by given geometry



FAST P. Privitera et al.

Fluorescenza



- Reference design: 1 m^2 aperture, 15°×15° FoV per single PMT
- 12 Telescope, 48 PMTs, 30°×360° FoV in each station.
- If 127 stations are installed with 20 km spacing, a ground coverage is ~ 40,000 km^2
- Geometry: Radio, SD or three coincidence of FAST.