



# Cosmic Rays

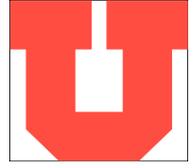
Miguel Mostafa

Aspen Winter Conferences

Particle Physics

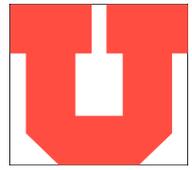
January 13-19, 2008





# Outline

- Brief **history** of UHECRs
- *Particle Astrophysics*
- Observation **techniques**
- **Auger** latest **results**
- **Auger** **current** analysis
- Conclusions and **Prospects**



# History

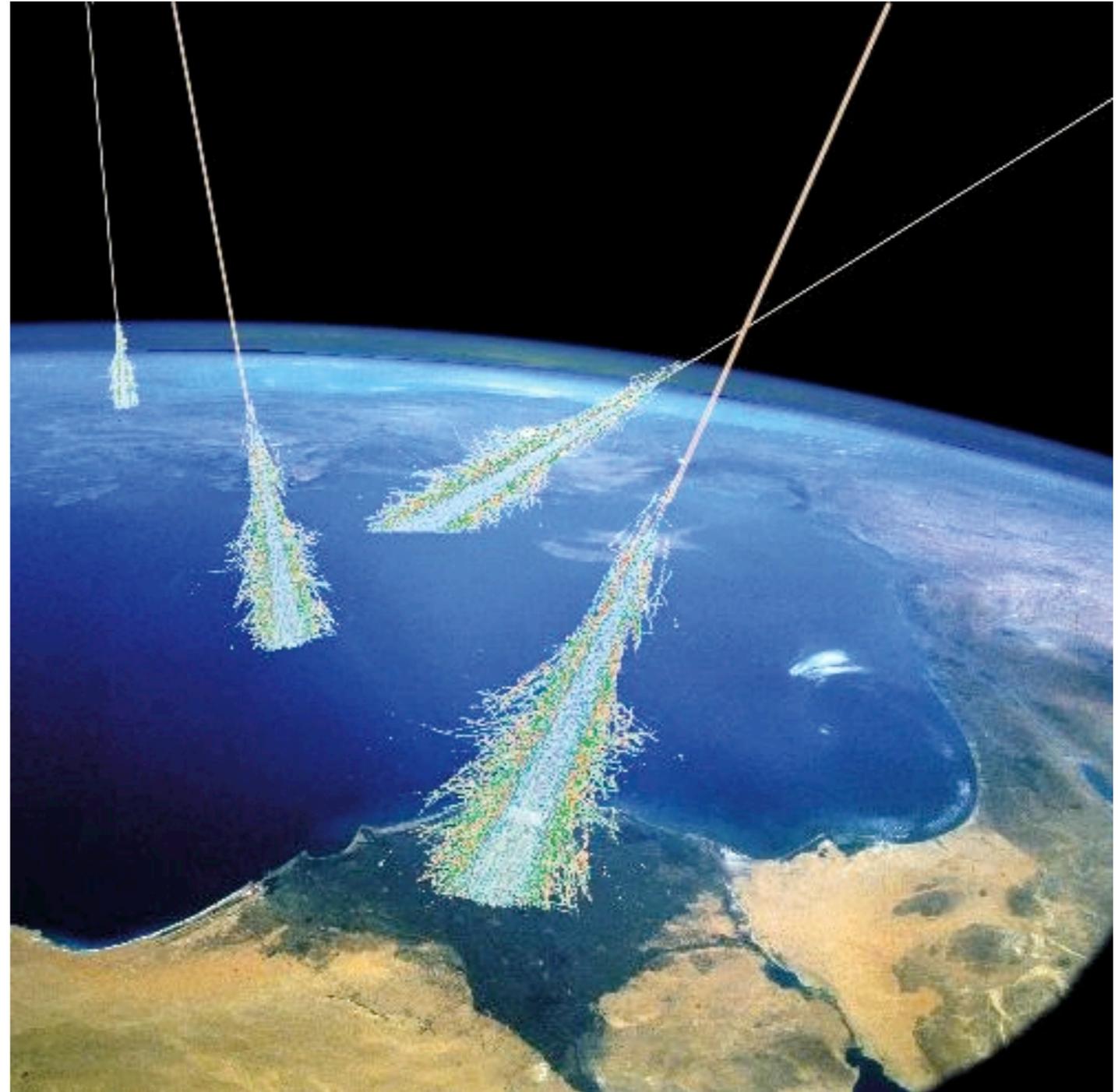
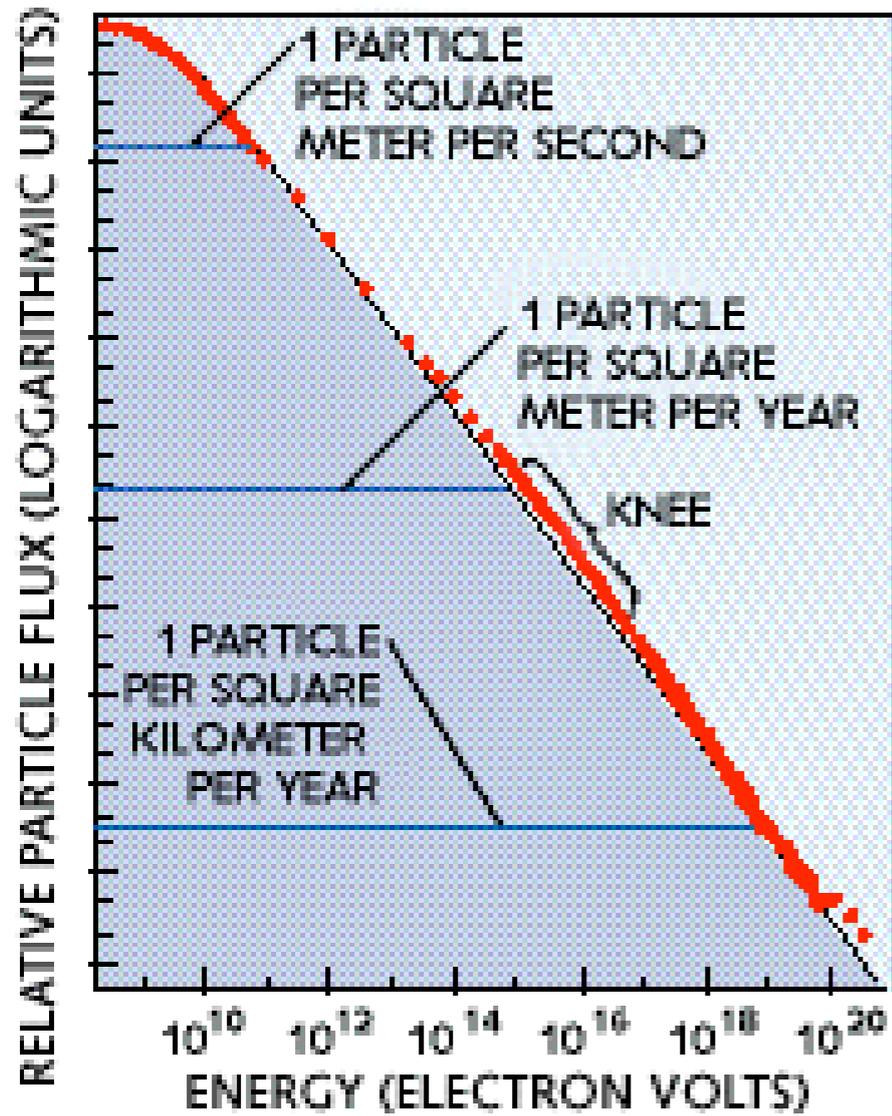
- 1912: **Victor Hess** discovers cosmic rays

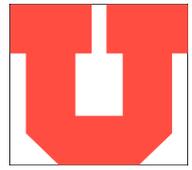




# History

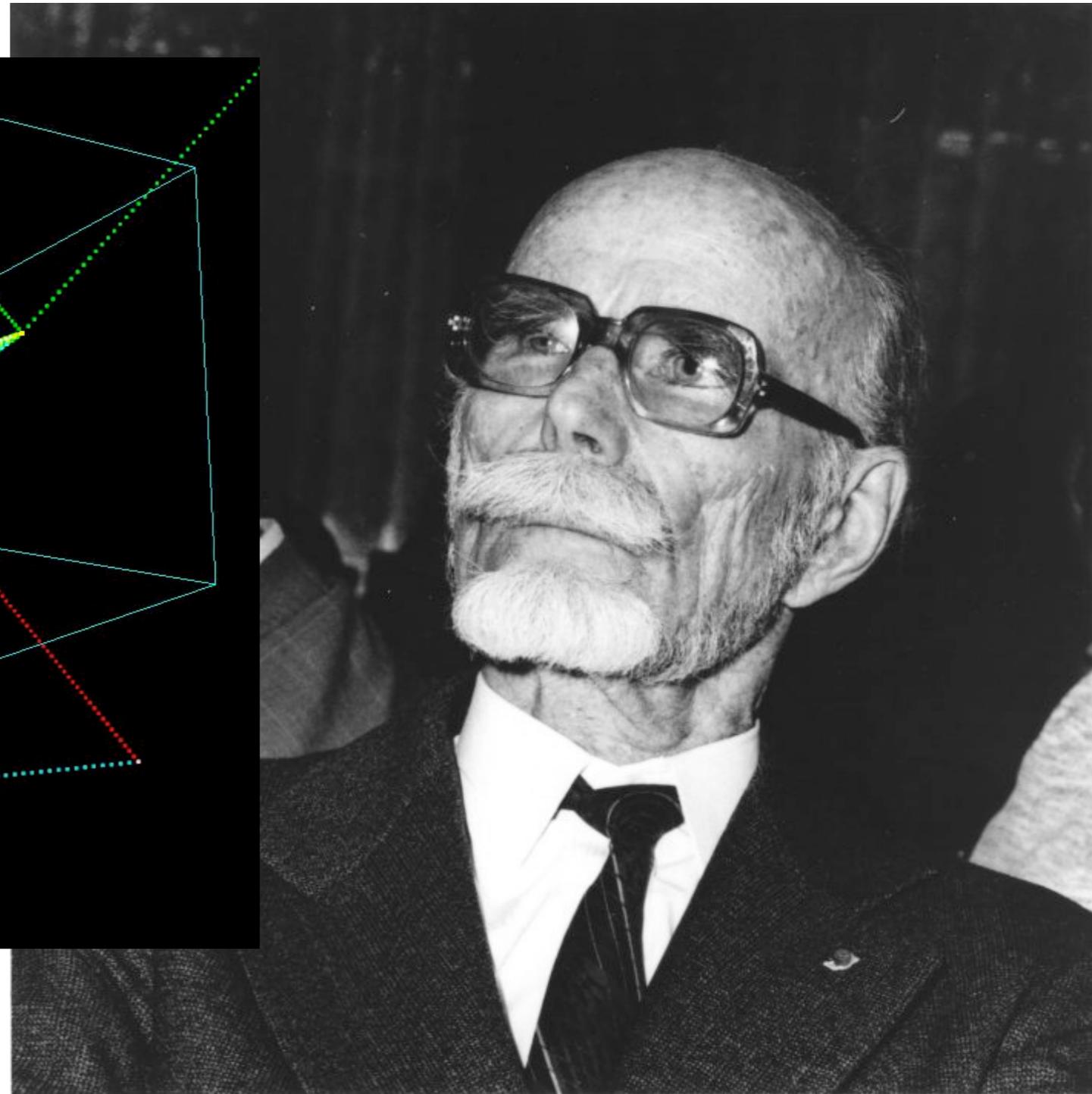
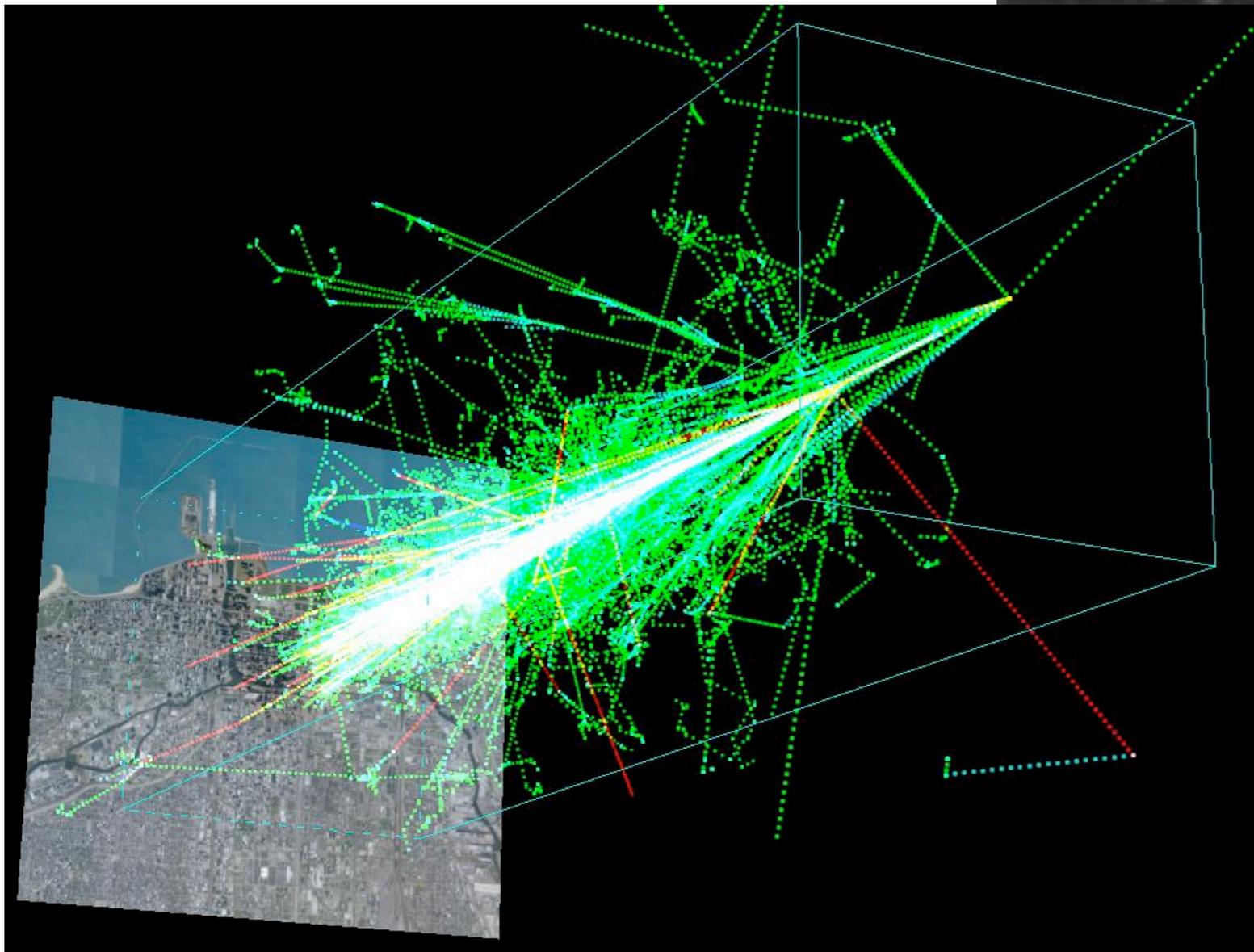
- What are Cosmic Rays?

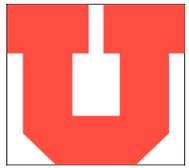




# History

- 1938: **Pierre Auger** saw Extensive Air Showers

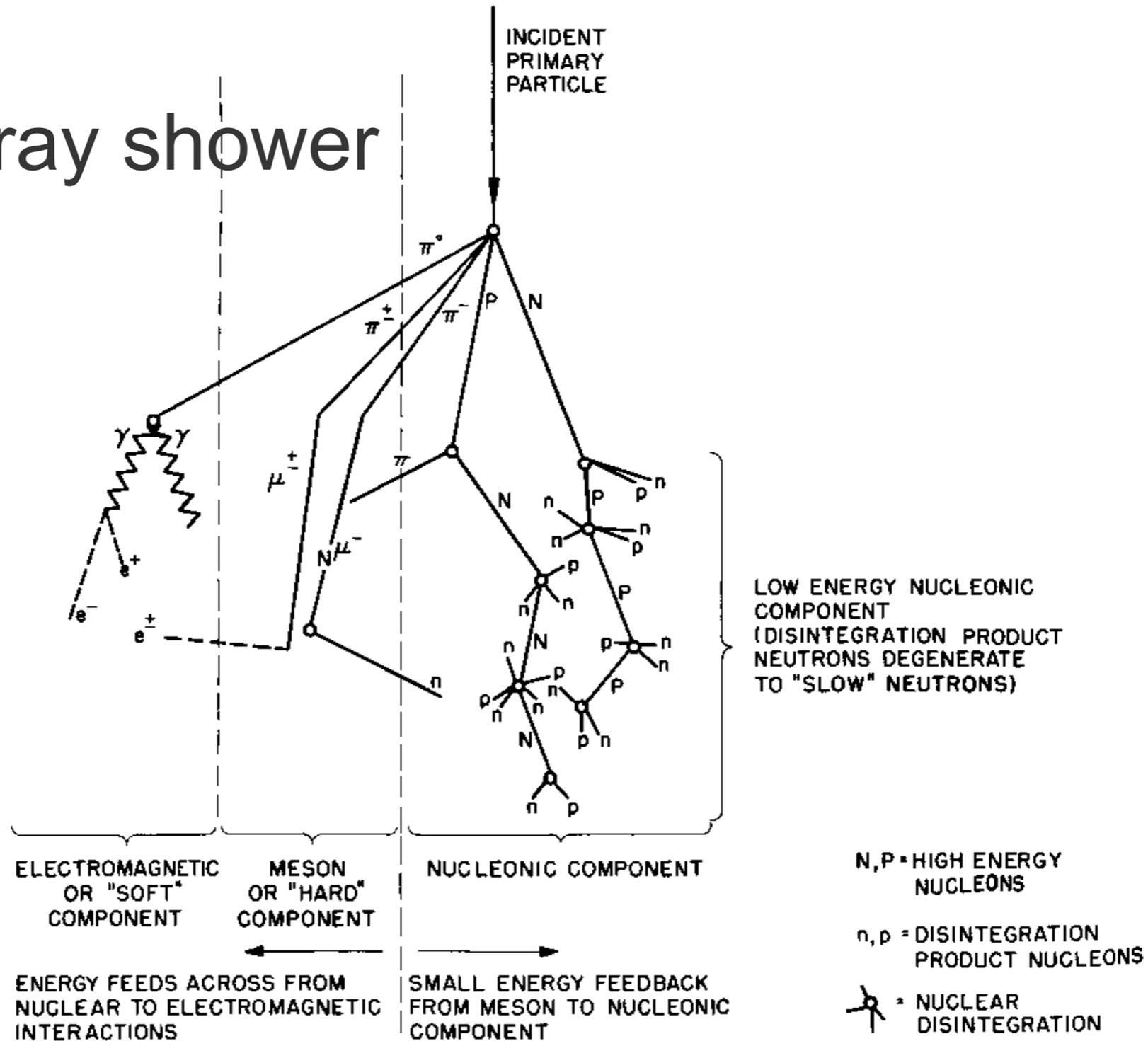


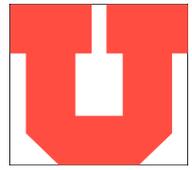


# History - Science

## ■ Cosmic ray shower

Top of the at

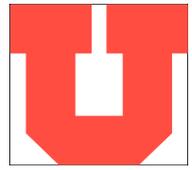




# History

- 1946: **Rossi & Zatsepin** build *first* array





# History

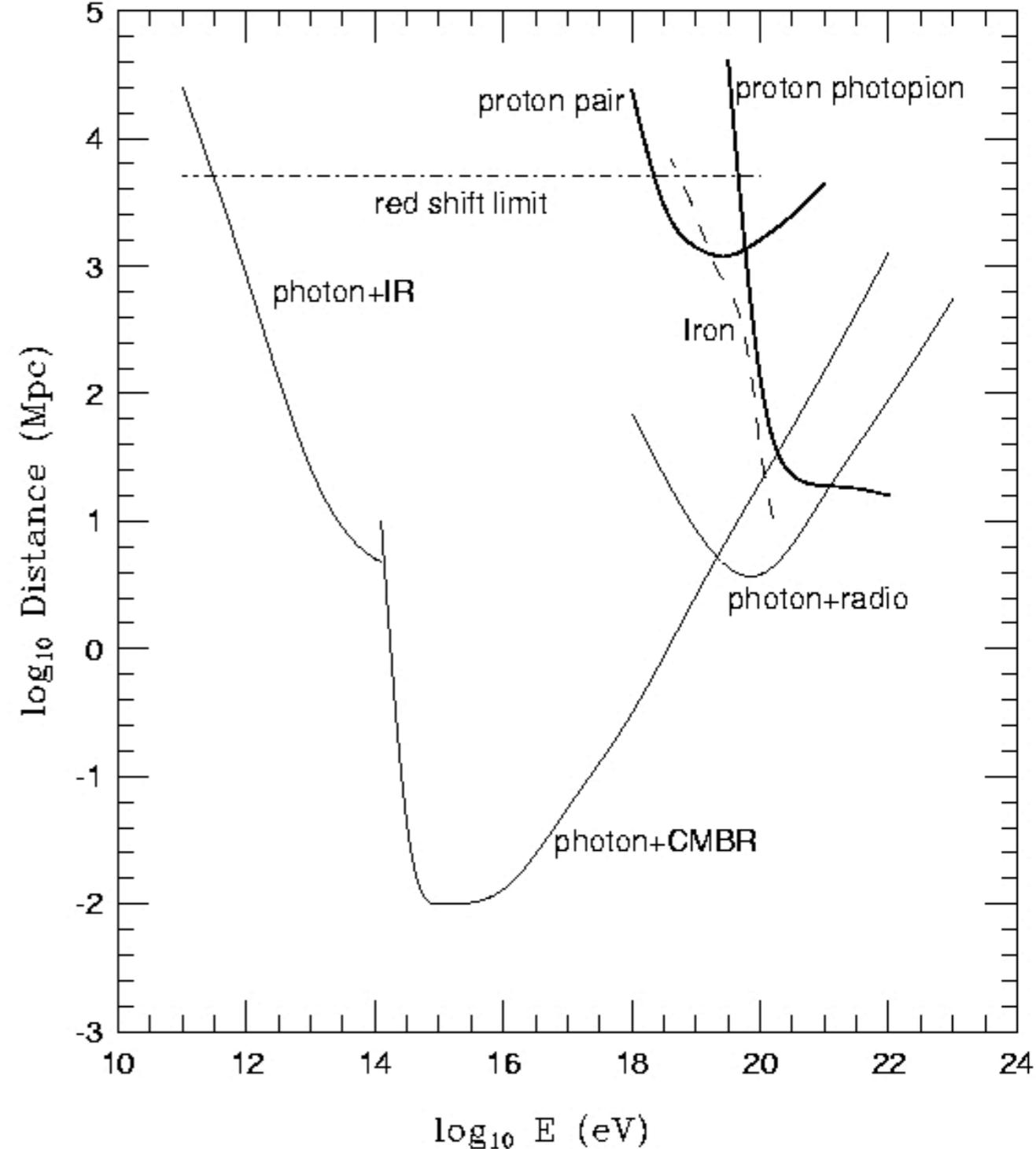
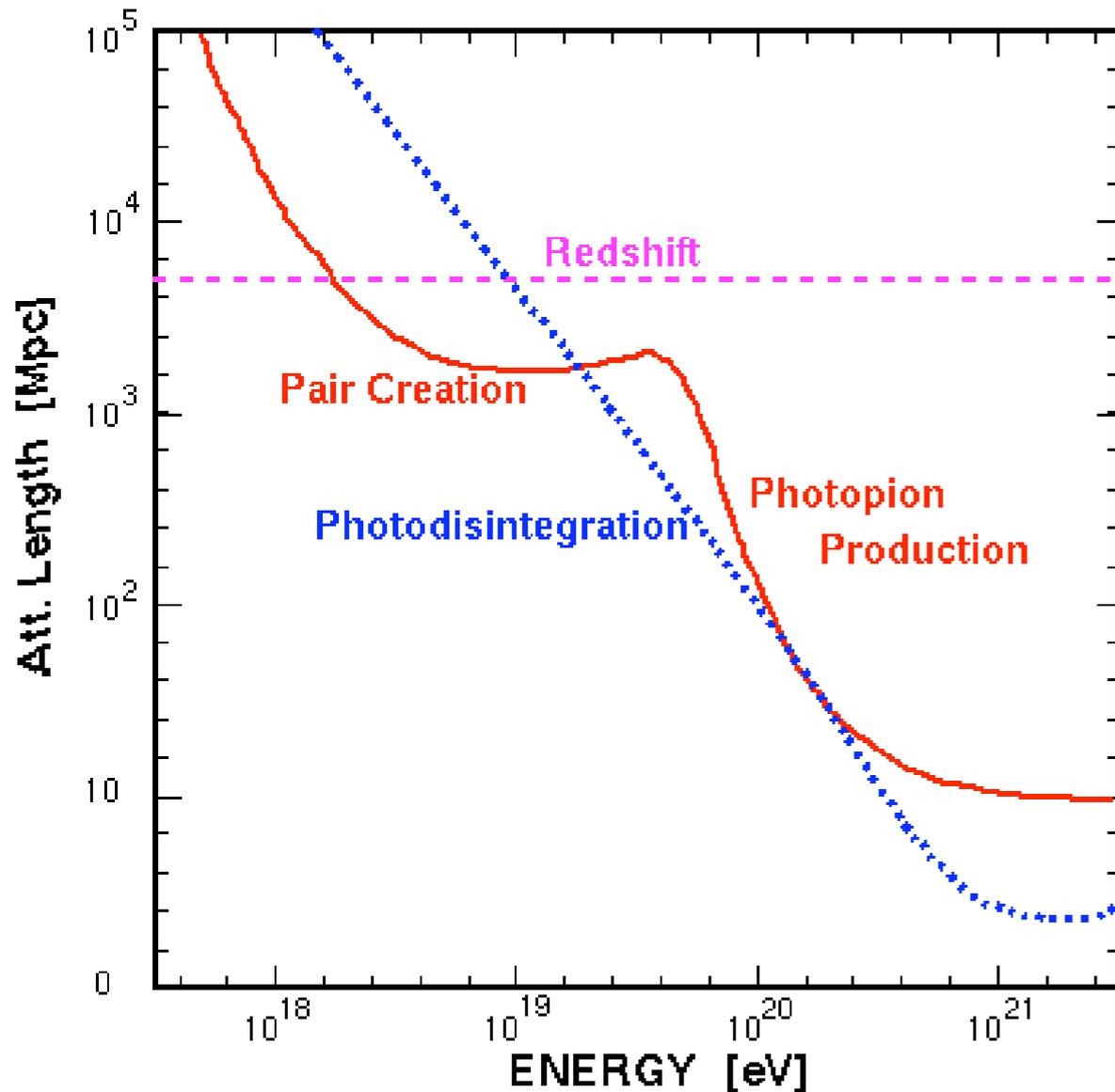
- 1962: *Linsley et al.* see 1<sup>st</sup> event  $E > 10^{20}$  eV

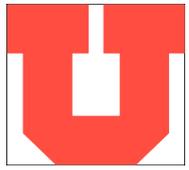




# History - Science

- 1966: Greisen, Zatsepin, & Kuzmin predict the GZK *suppression*

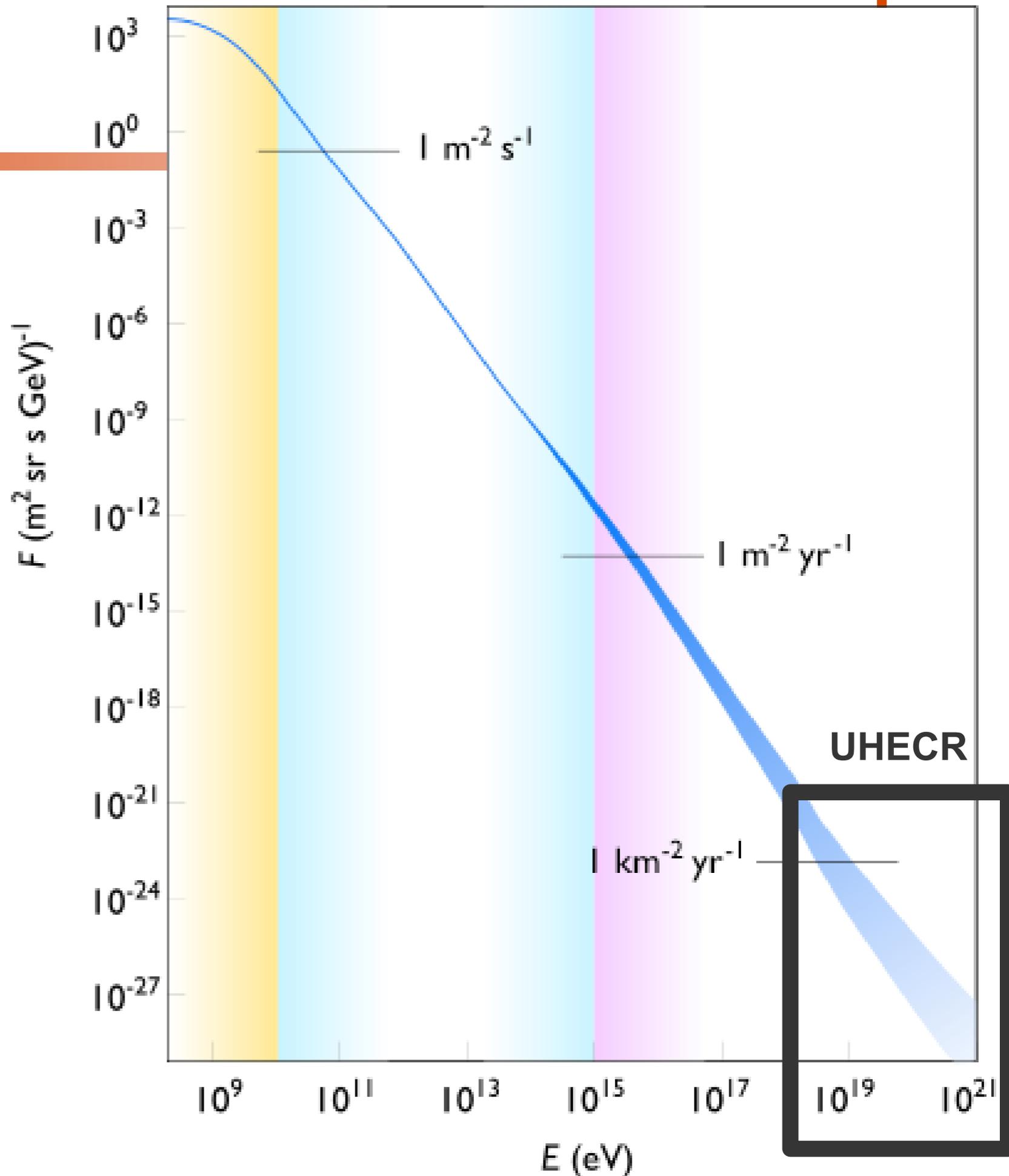


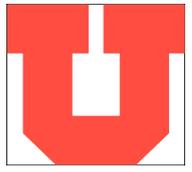


# Science

## *the spectrum*

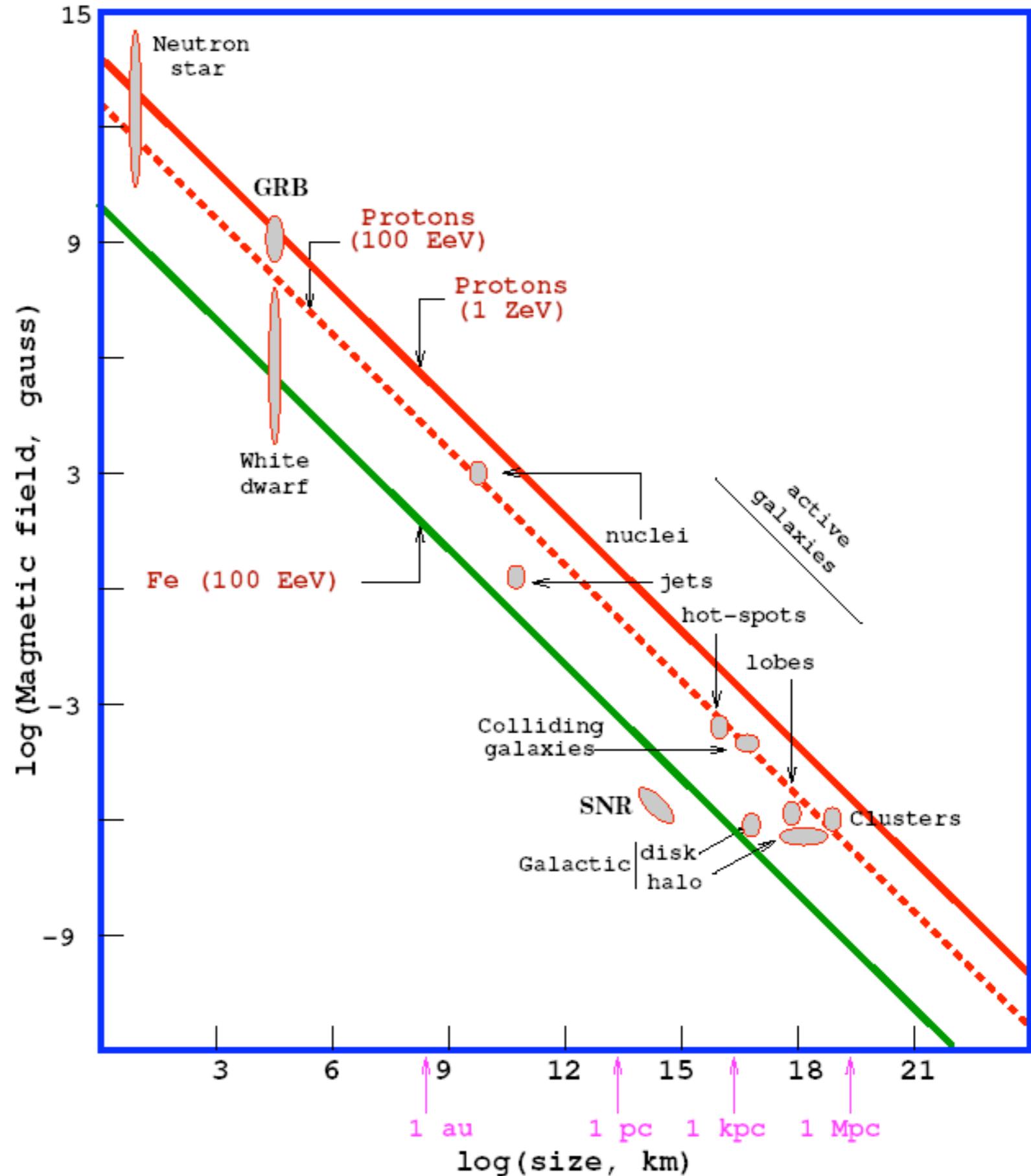
- Flux vs. Energy
- Flux per unit:
  - Area [ $m^2$ ]
  - Solid Angle [ $sr$ ]
  - Time [ $s$ ]
  - Energy [ $GeV$ ]

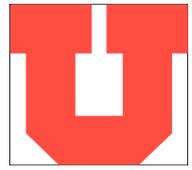




# Science

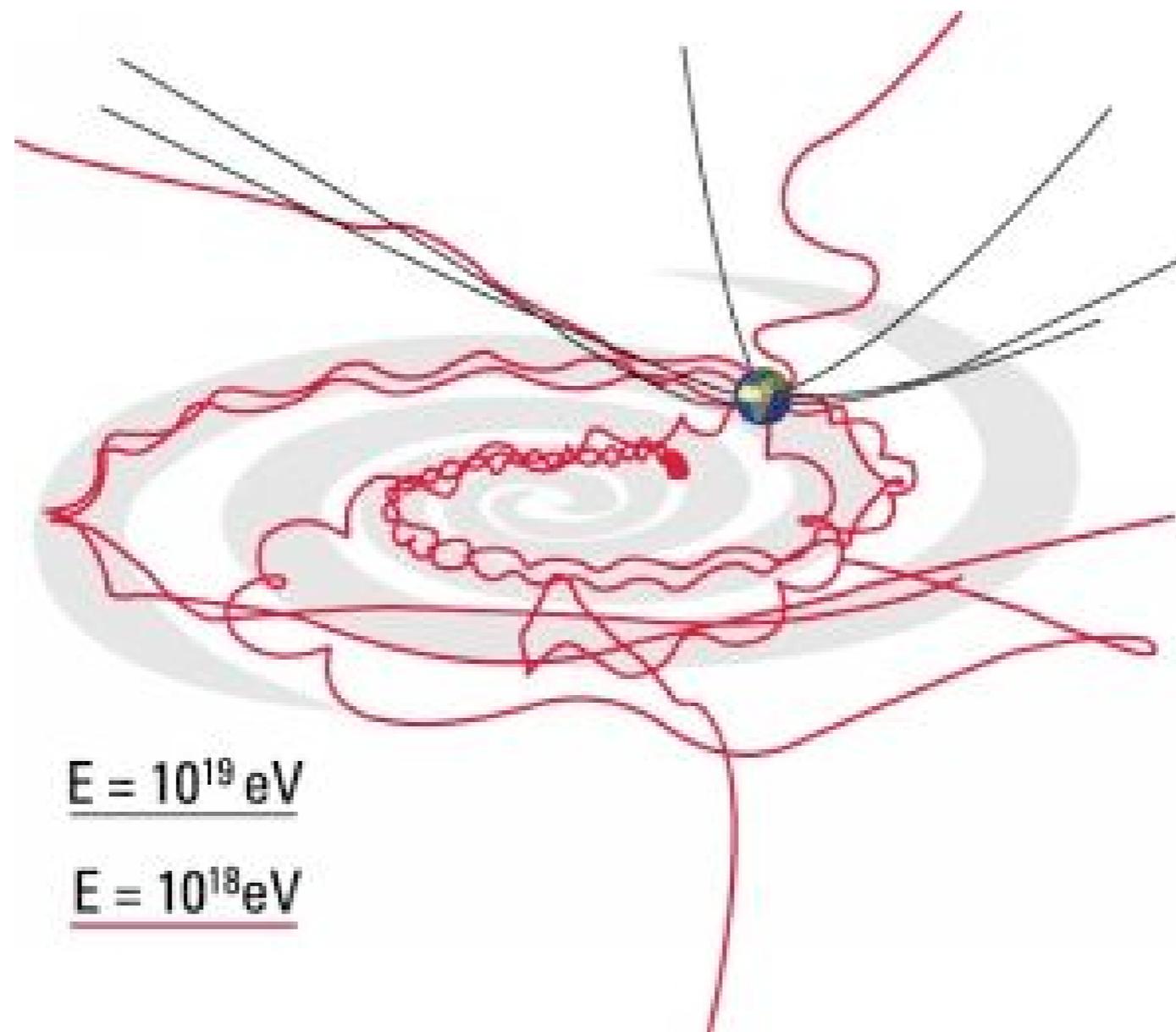
- acceleration mechanisms
  - accelerator
  - propagation
  - composition





# Science

- account for deflection!





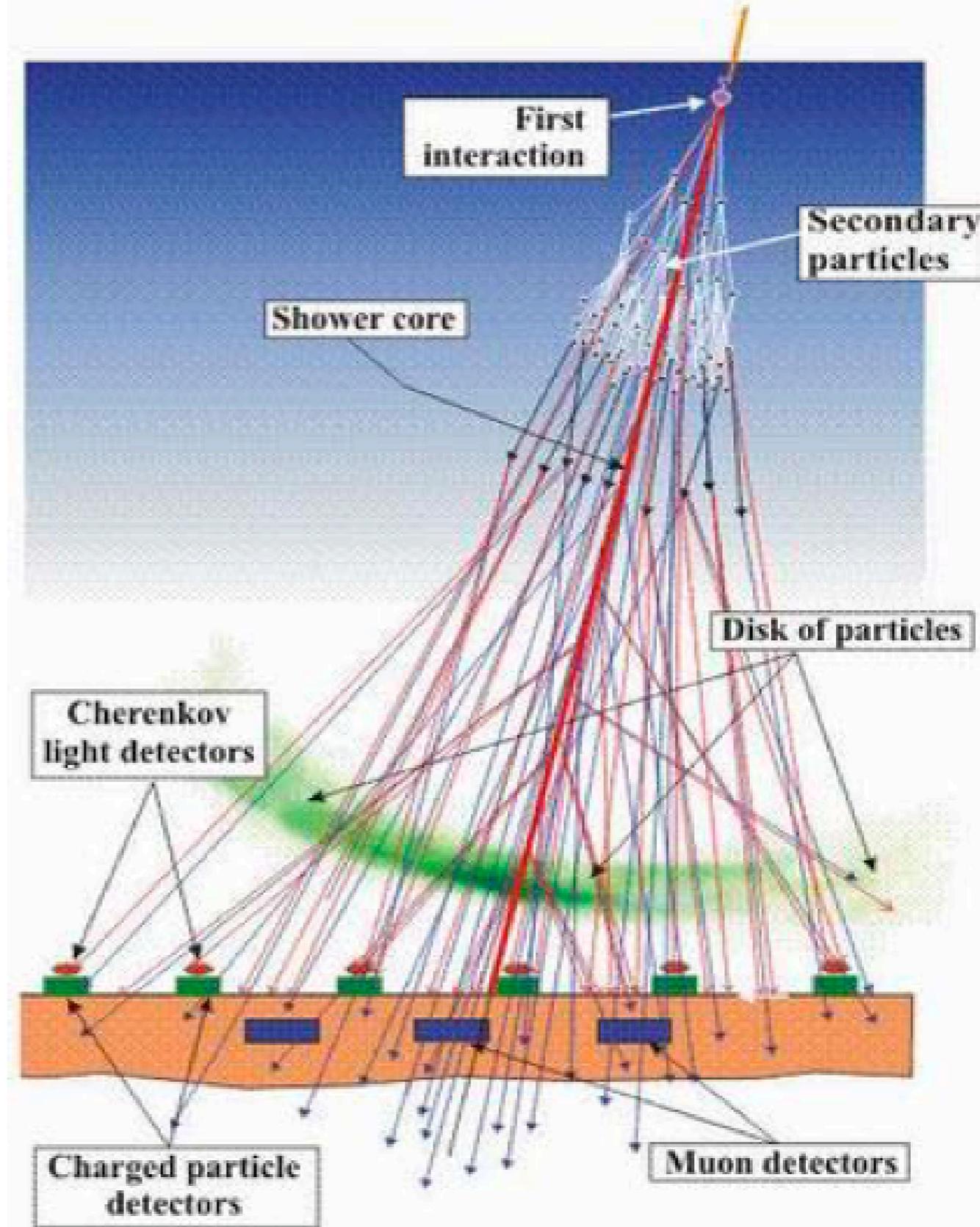
# Science Conclusion

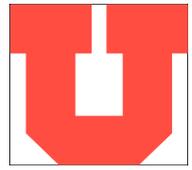
- We must address:
  - **Energy distribution**
    - GZK suppression?
    - Need for new physics?
  - **Directionality**
    - Known astrophysics?
    - New physics?
  - **Composition**
    - $p, \gamma, Fe, n, \nu, \dots$ ?



# Techniques

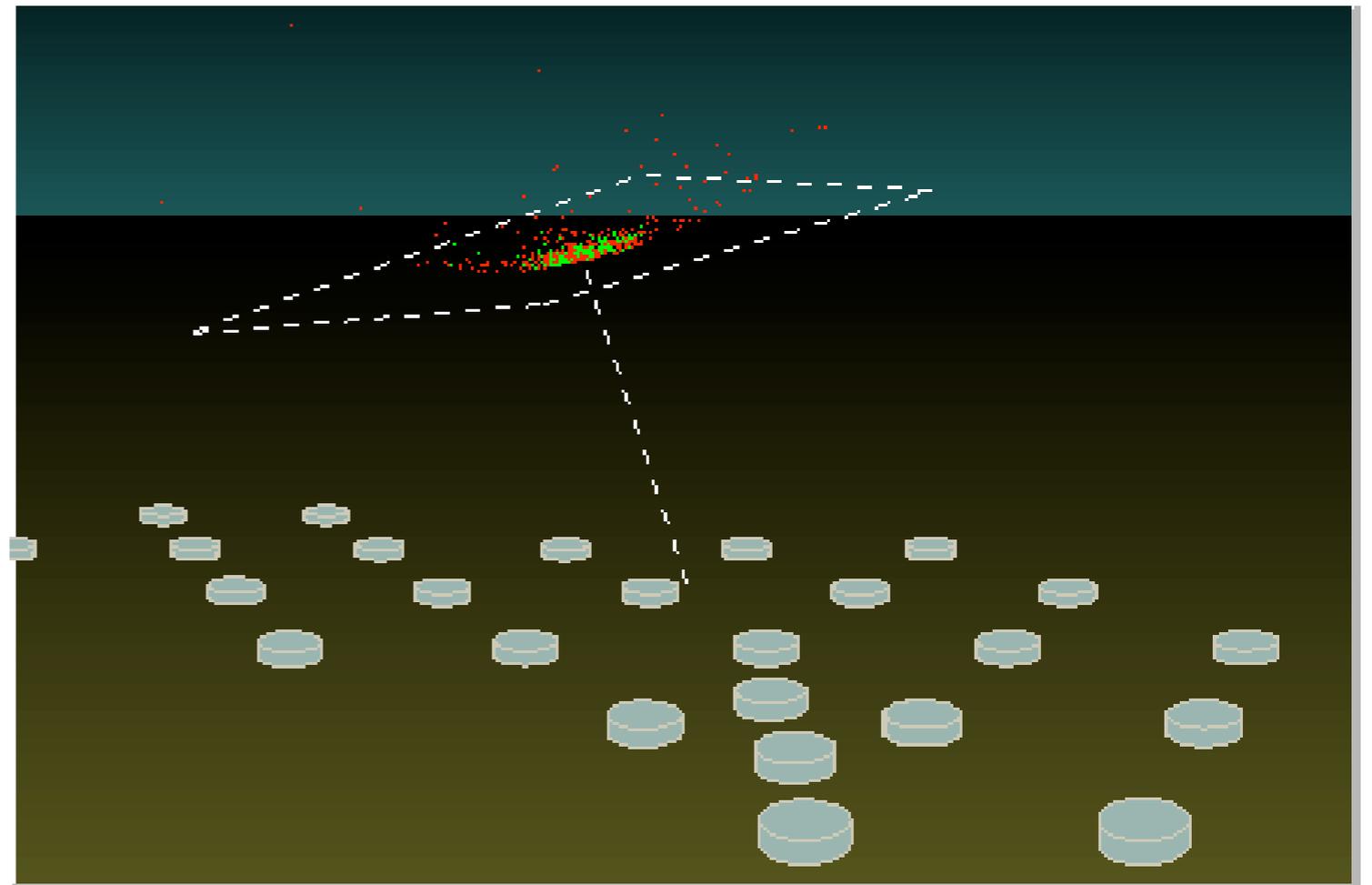
- @ UHE we can only measure the EAS (and *side effects*)

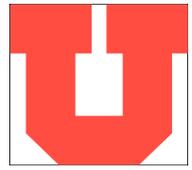




# Detection techniques

- particle counters on the ground

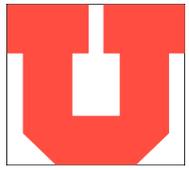




# Techniques

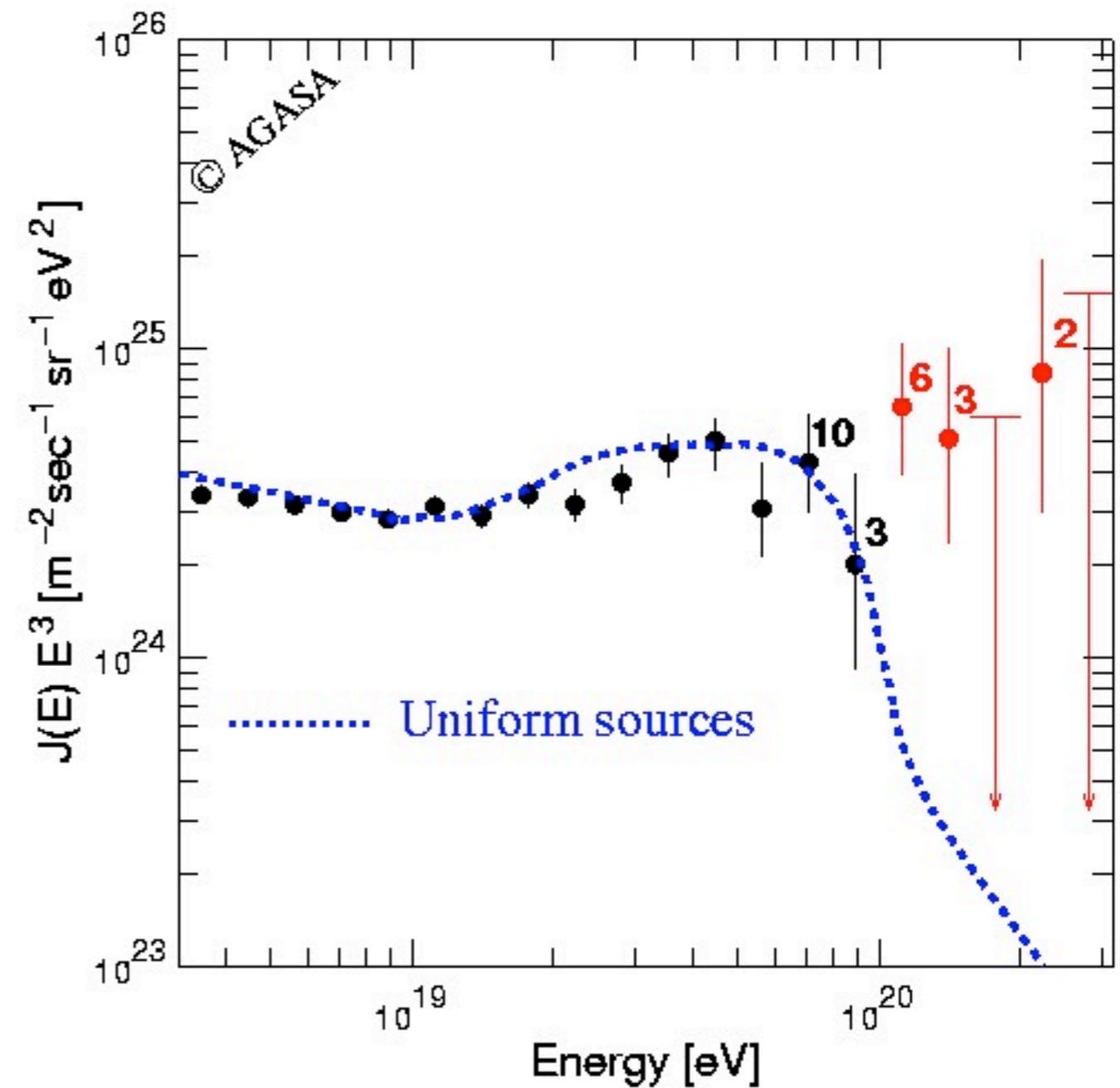
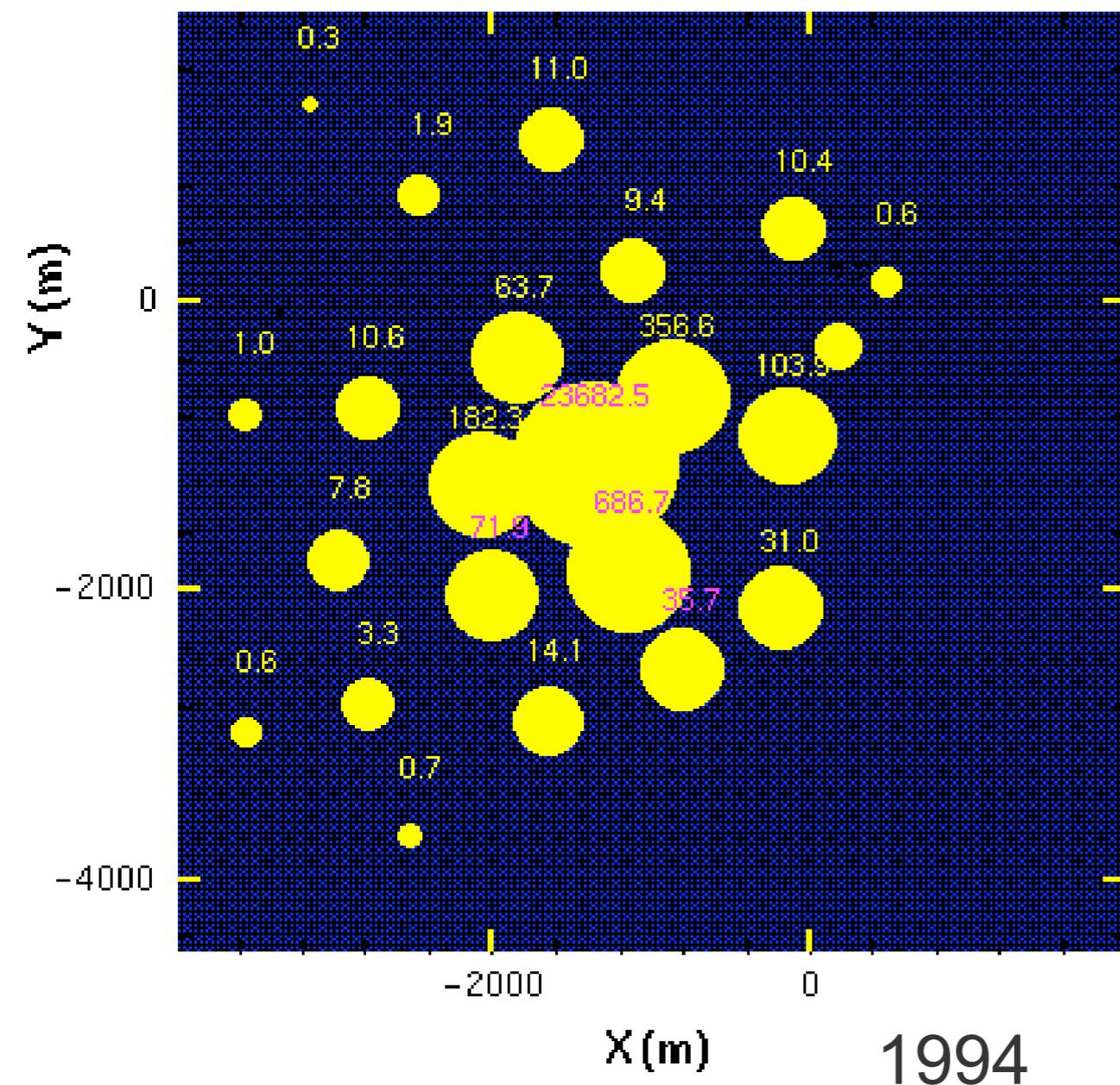
- AGASA
- 100 km<sup>2</sup> array
- plastic scintillators

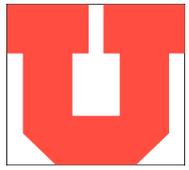




# Techniques

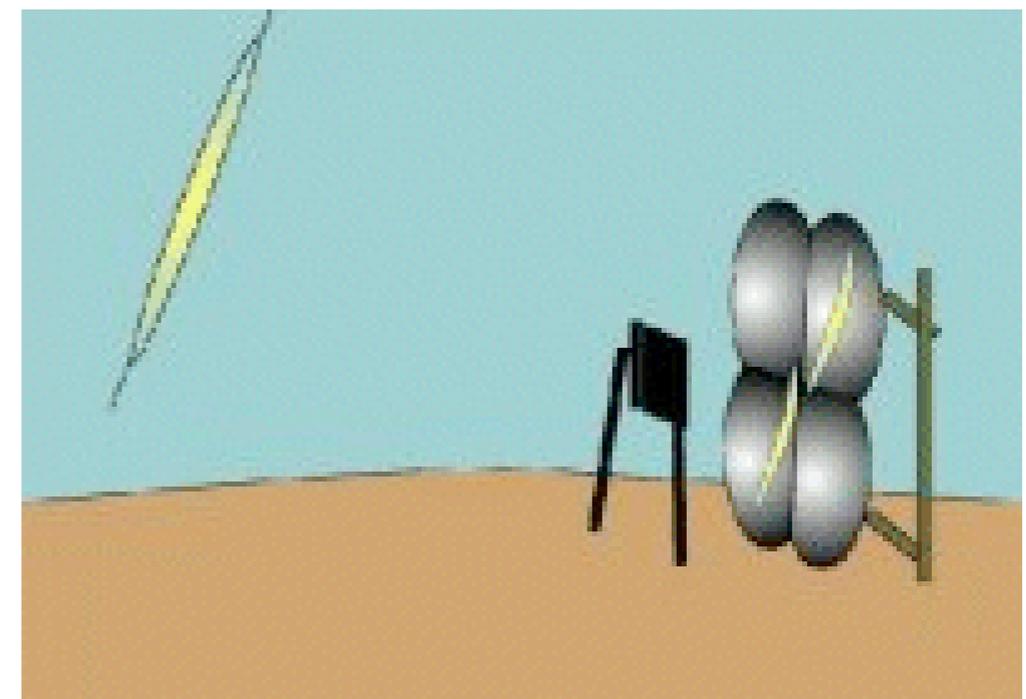
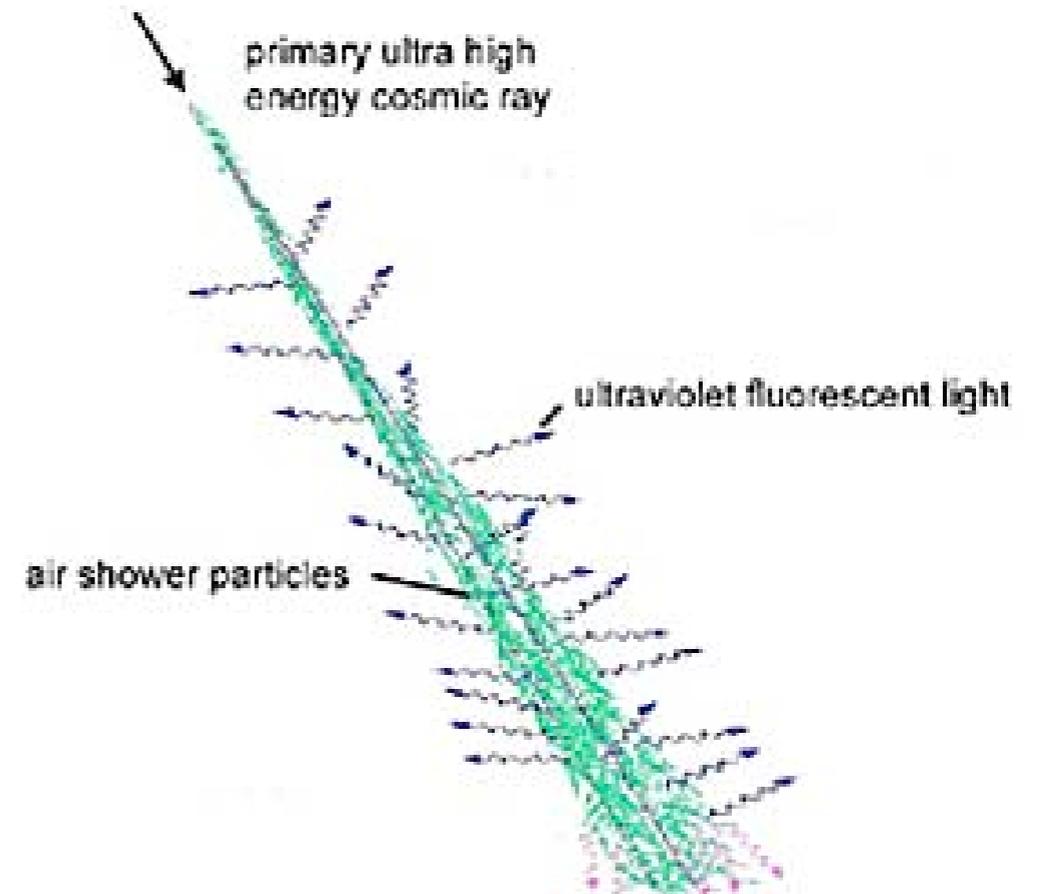
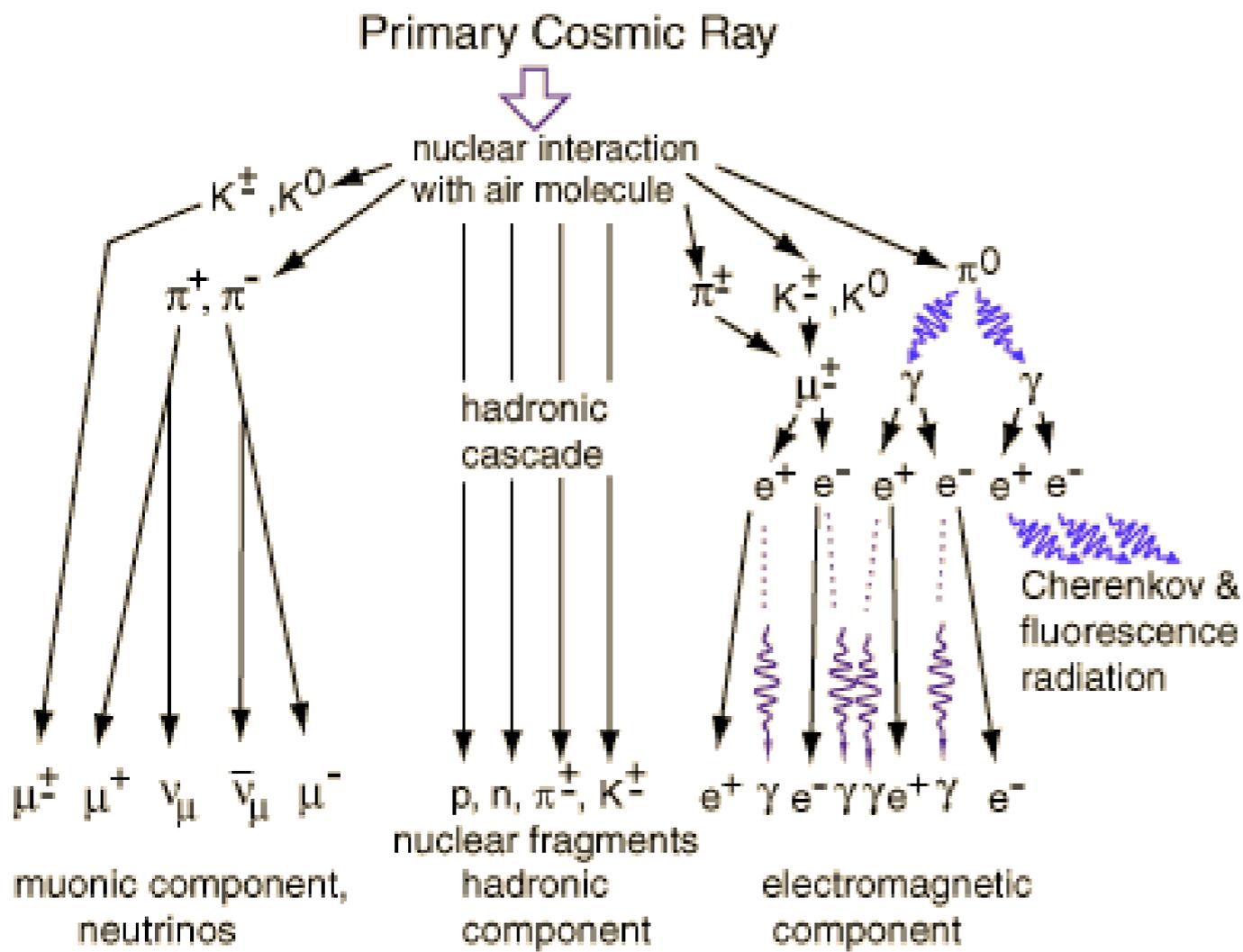
## AGASA results

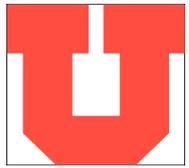




# Detection Techniques

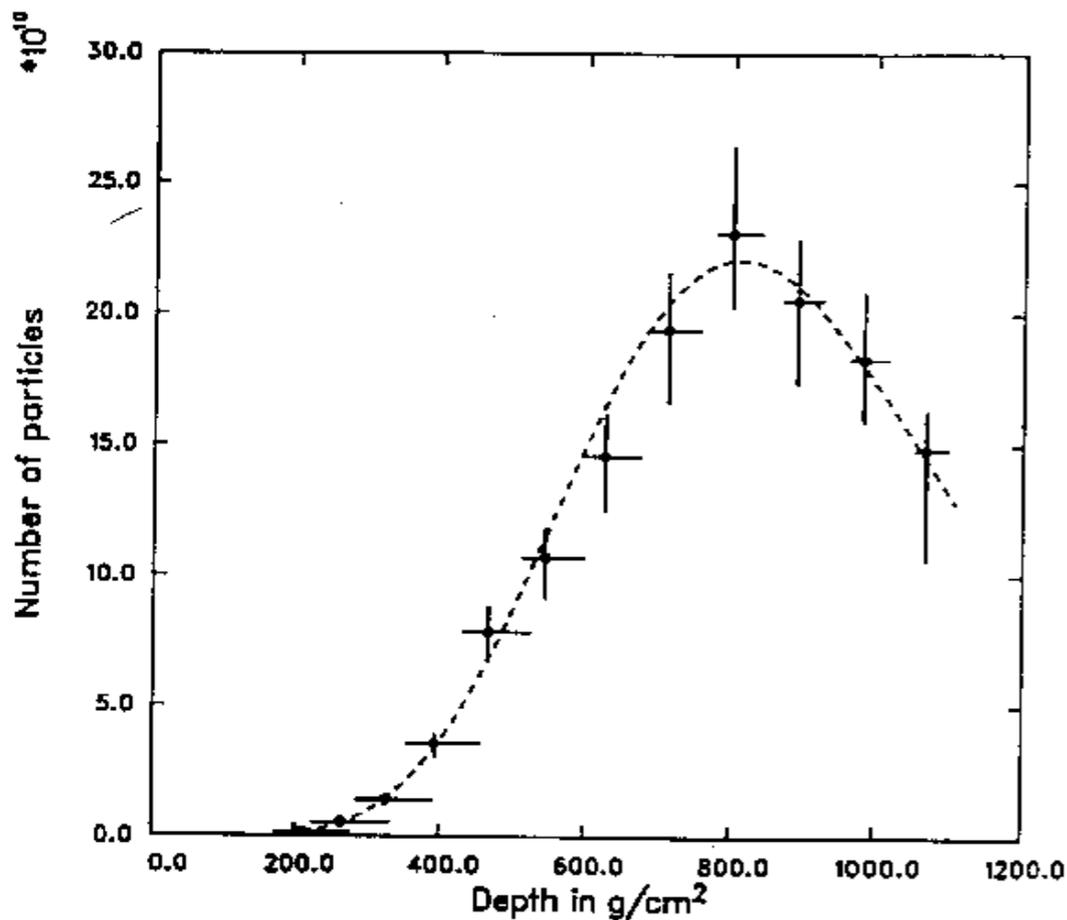
## Fluorescence emissions





# Techniques

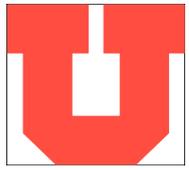
## the Fly's Eye



1991

The University of Utah





# Auger

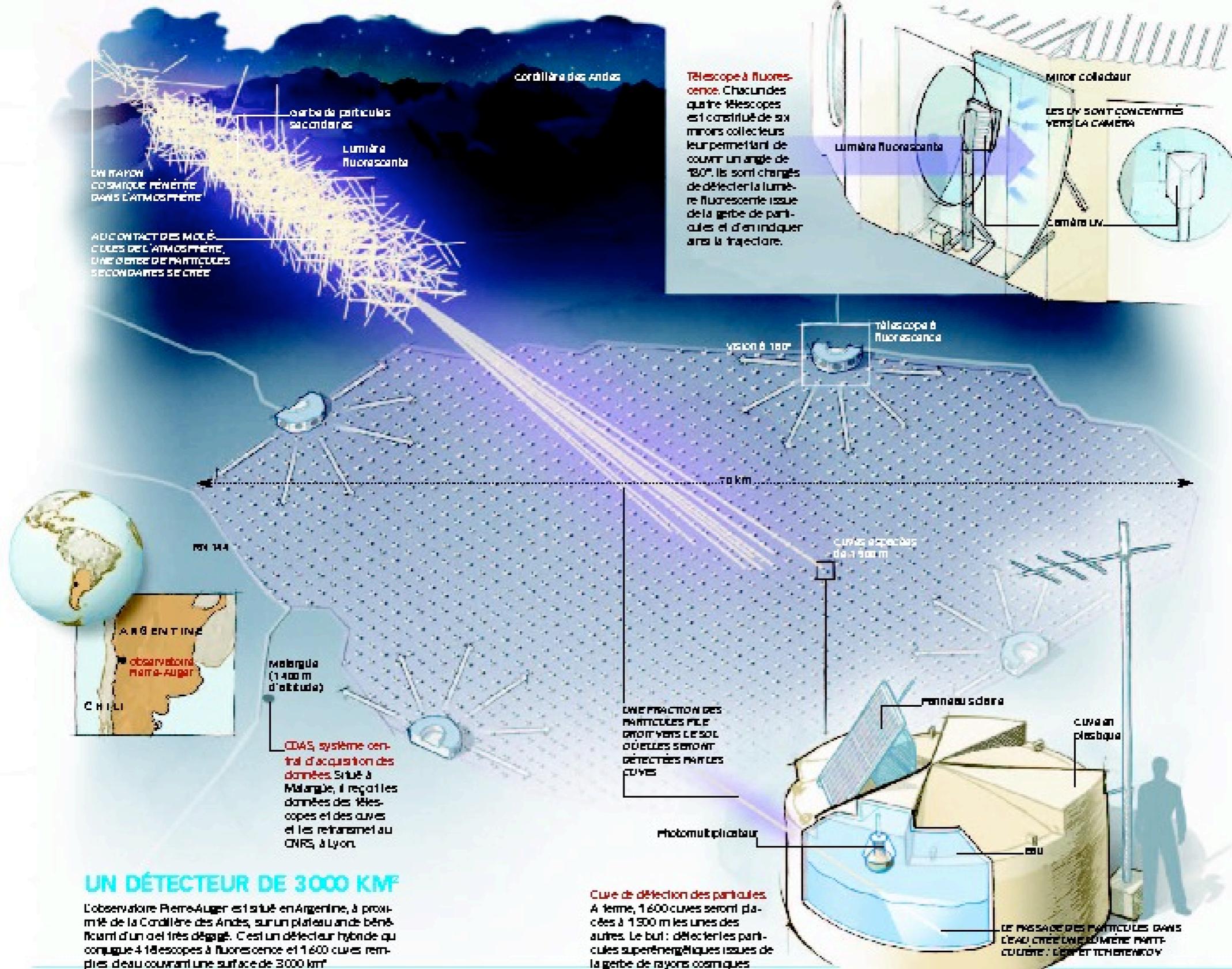


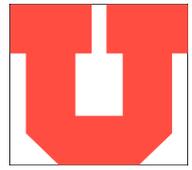
## ■ the Collaboration





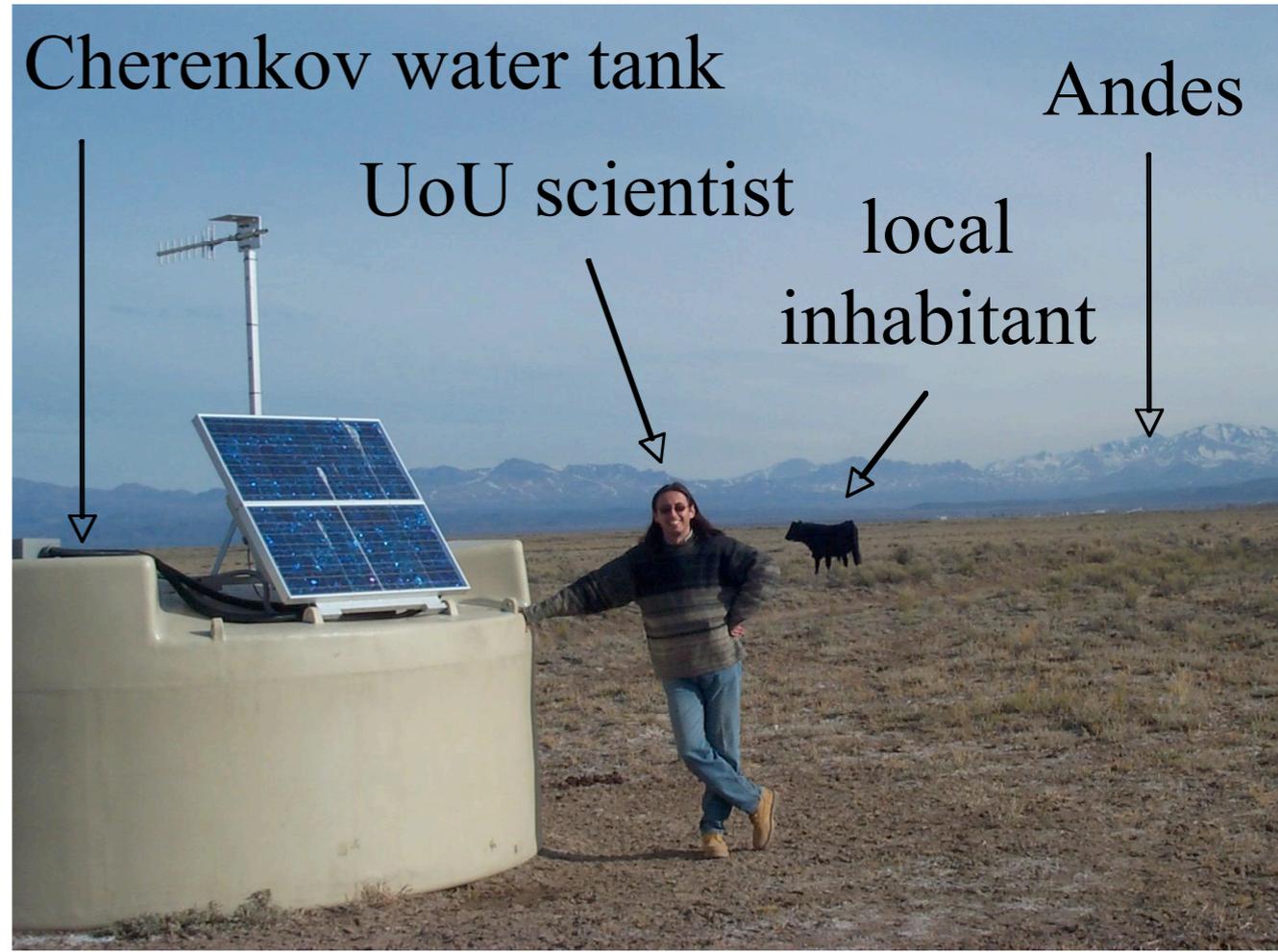
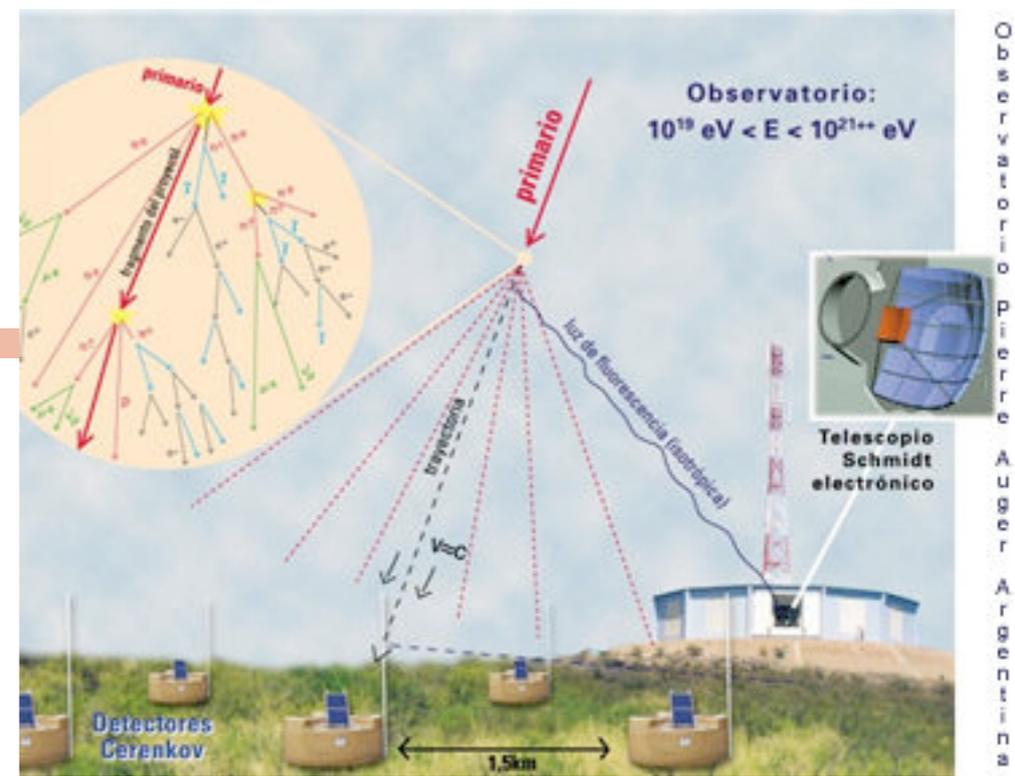
# the hybrid concept

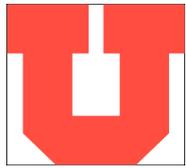




# Auger

- the hybrid detector

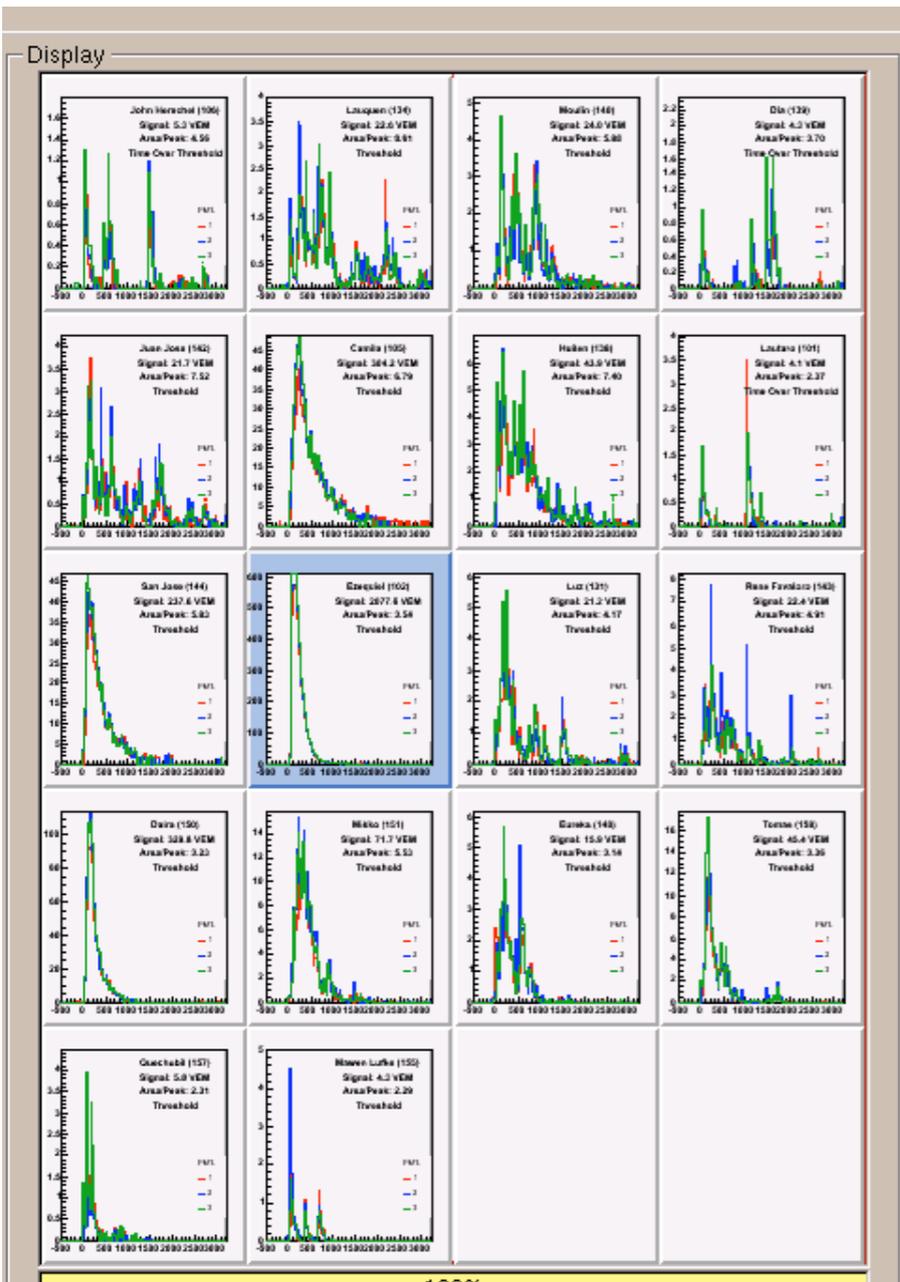
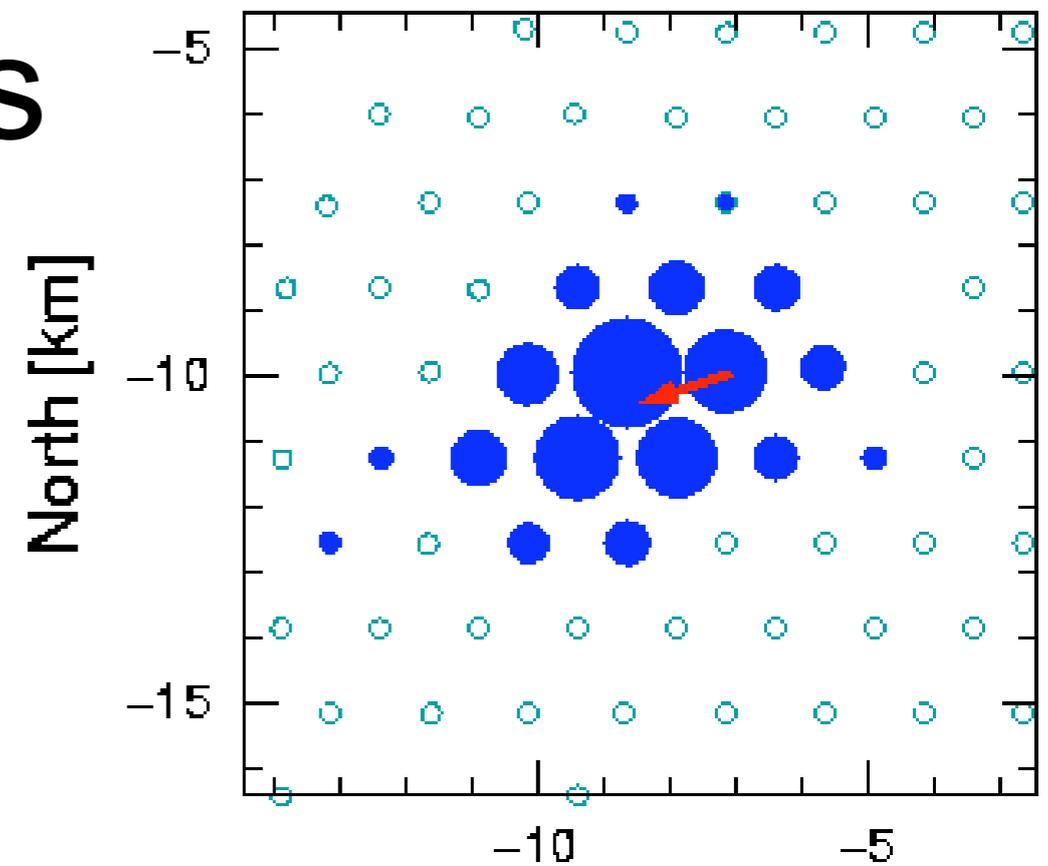




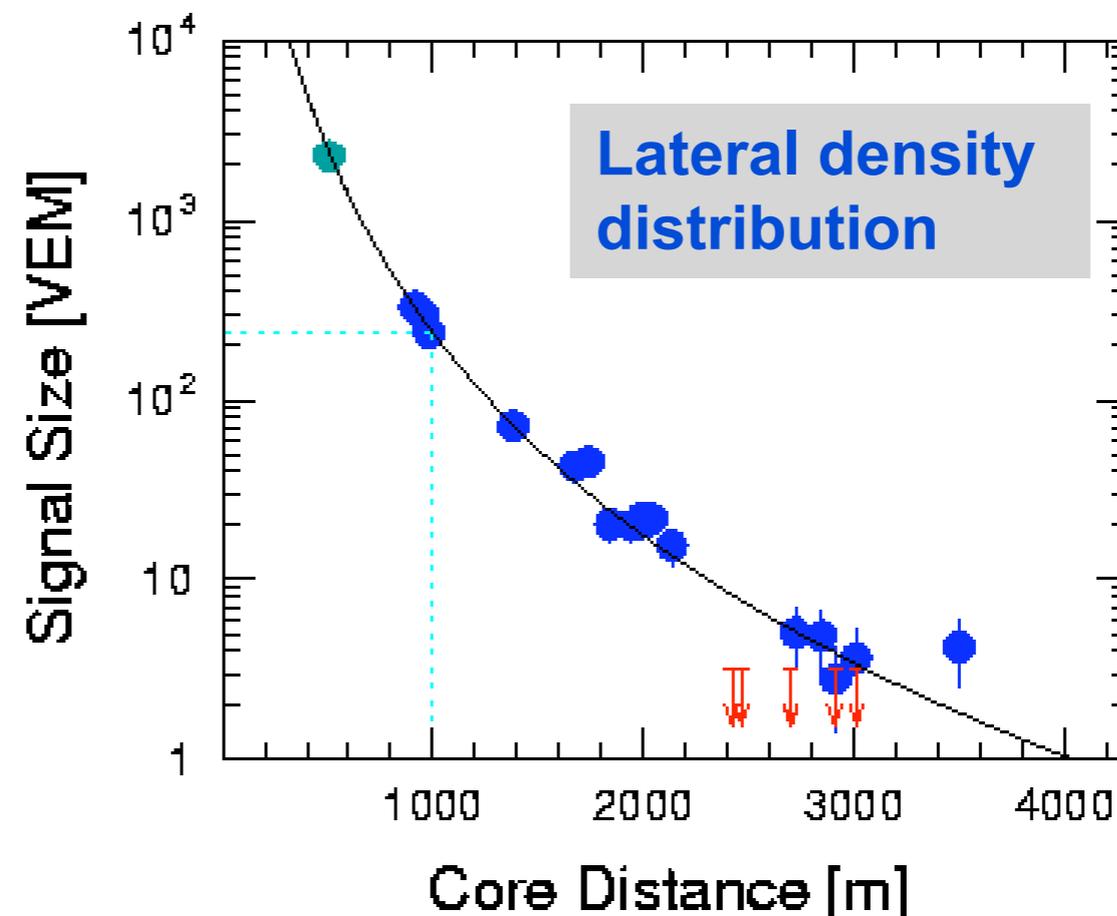
# detecting UHECRs

ID 762238

SD view



ID 762238





# Auger

- the hybrid detector



aperture box

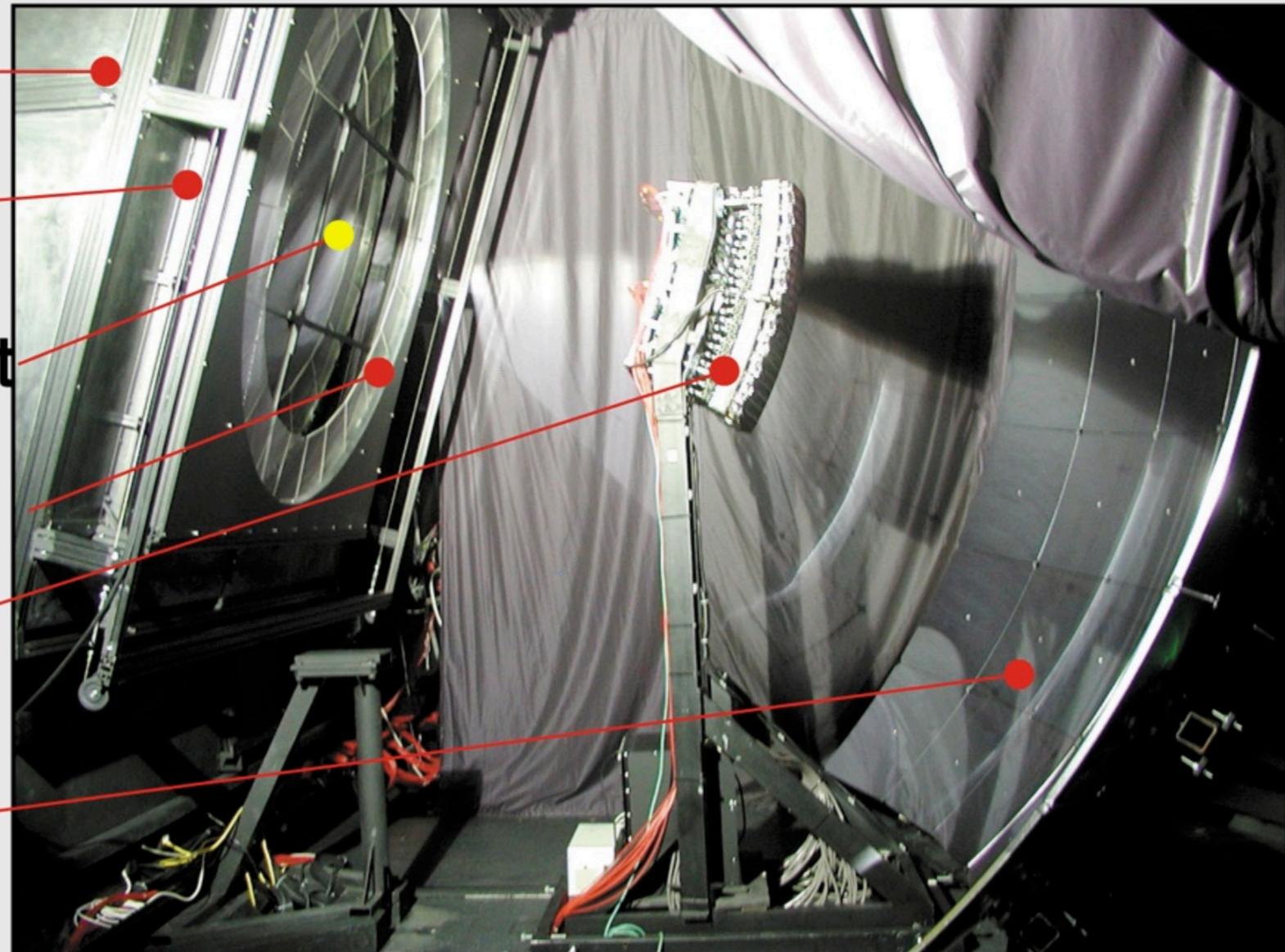
filter

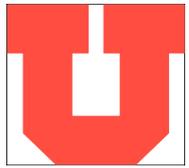
reference point

corrector ring

camera

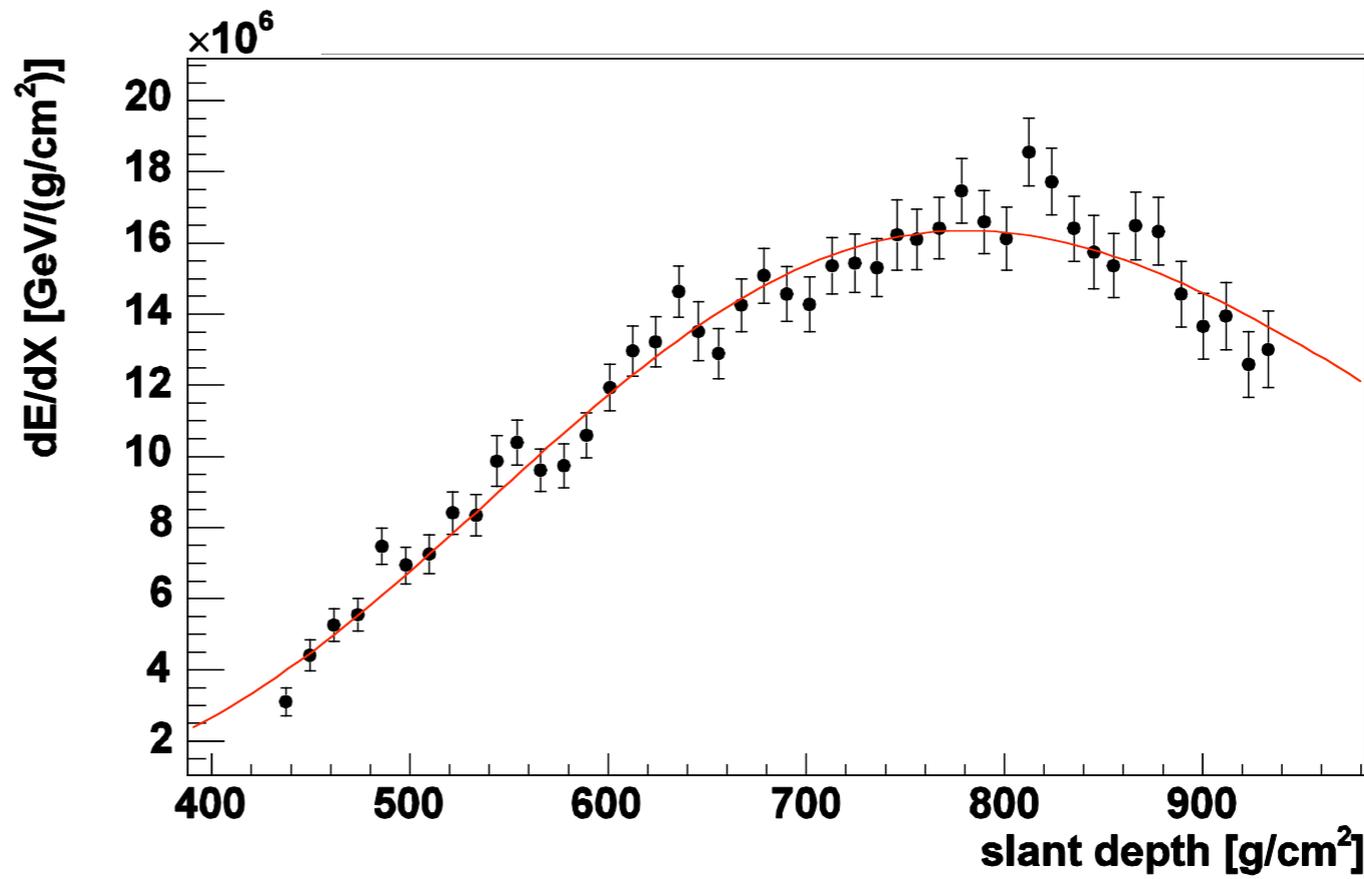
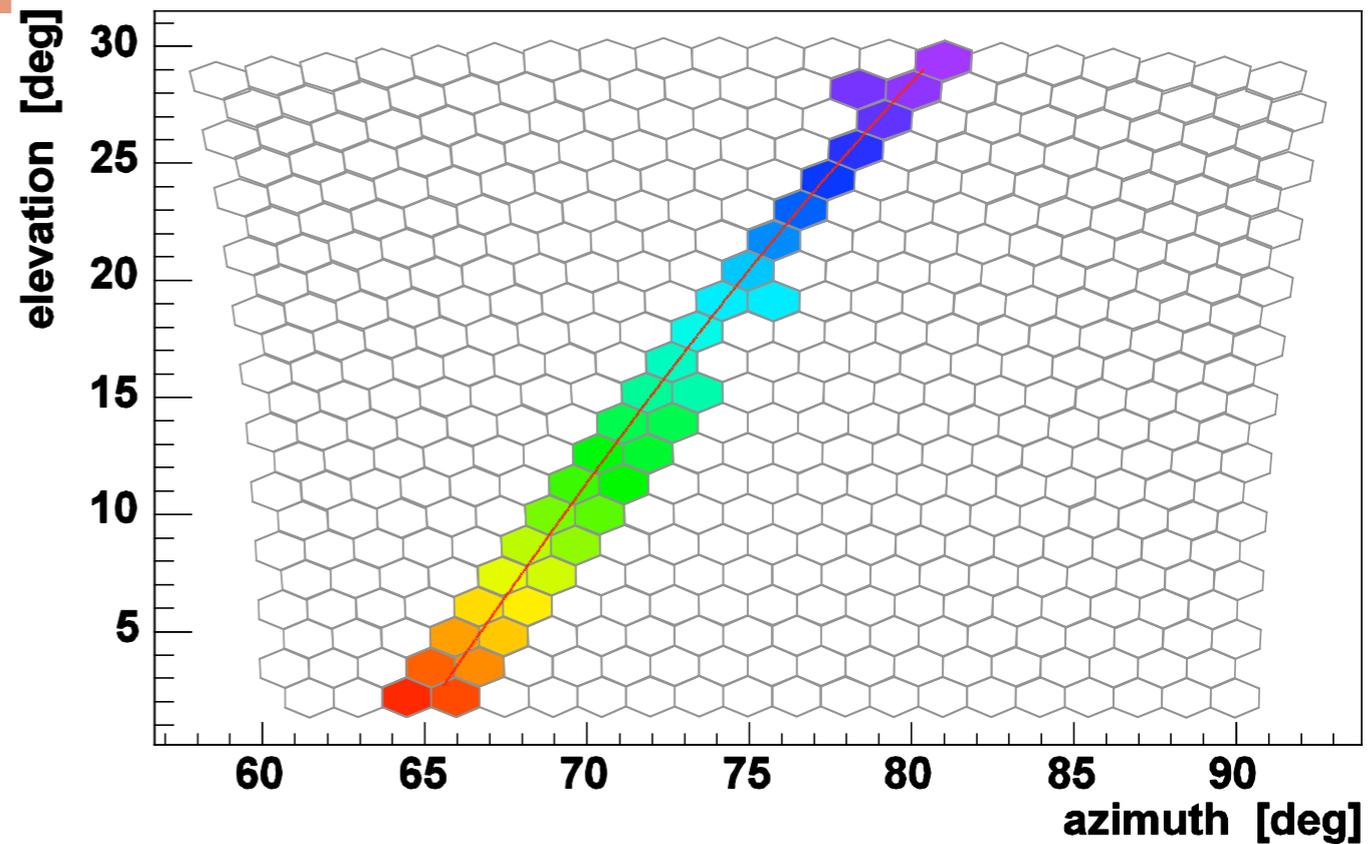
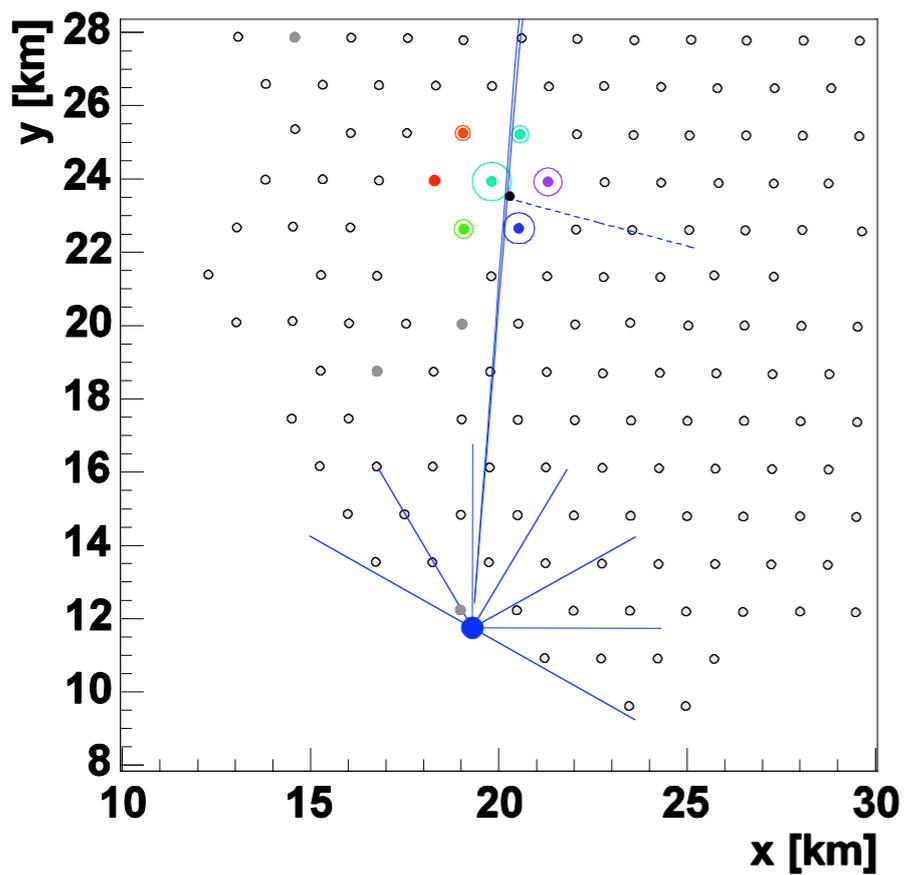
mirror system





# detecting UHECRs

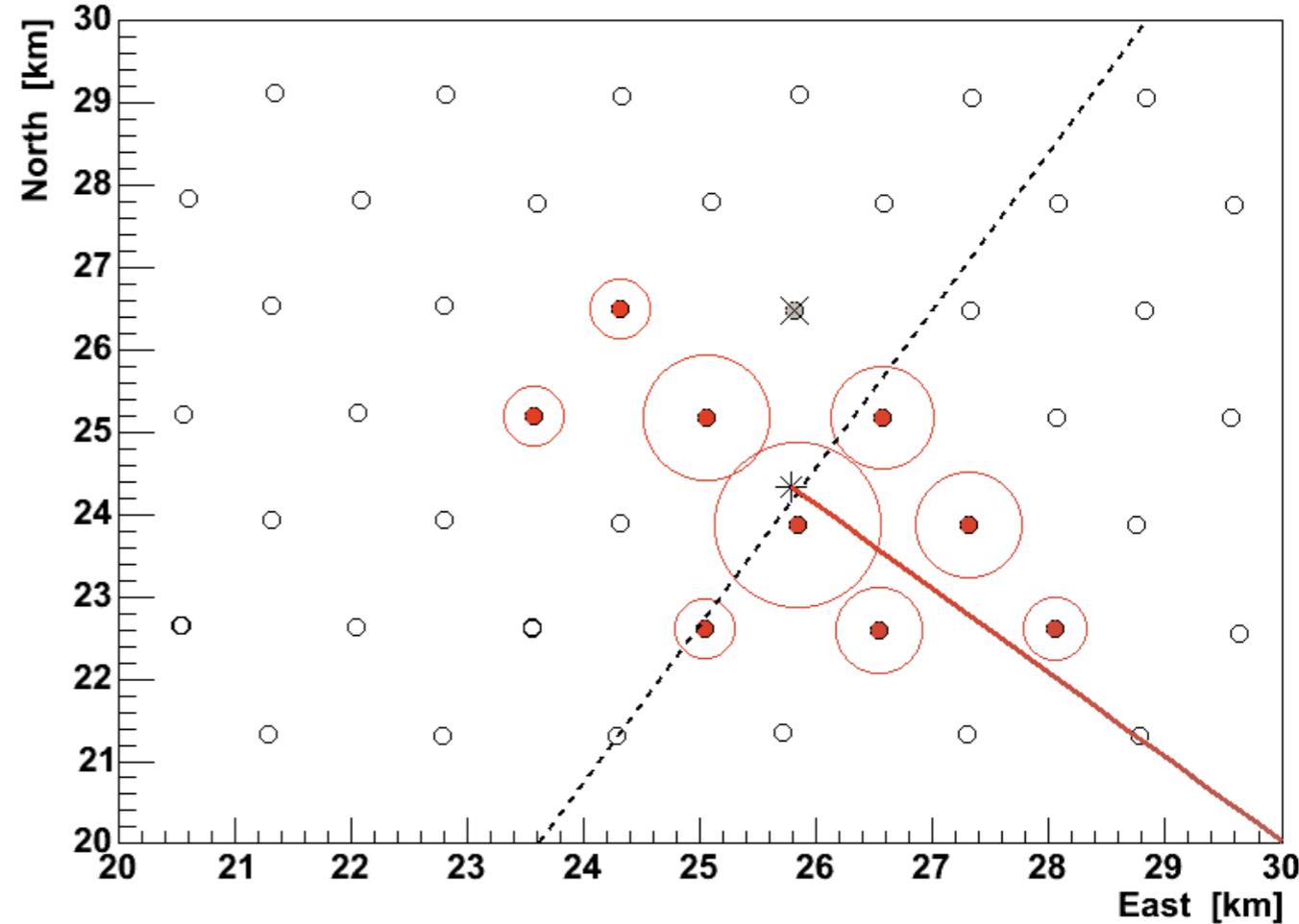
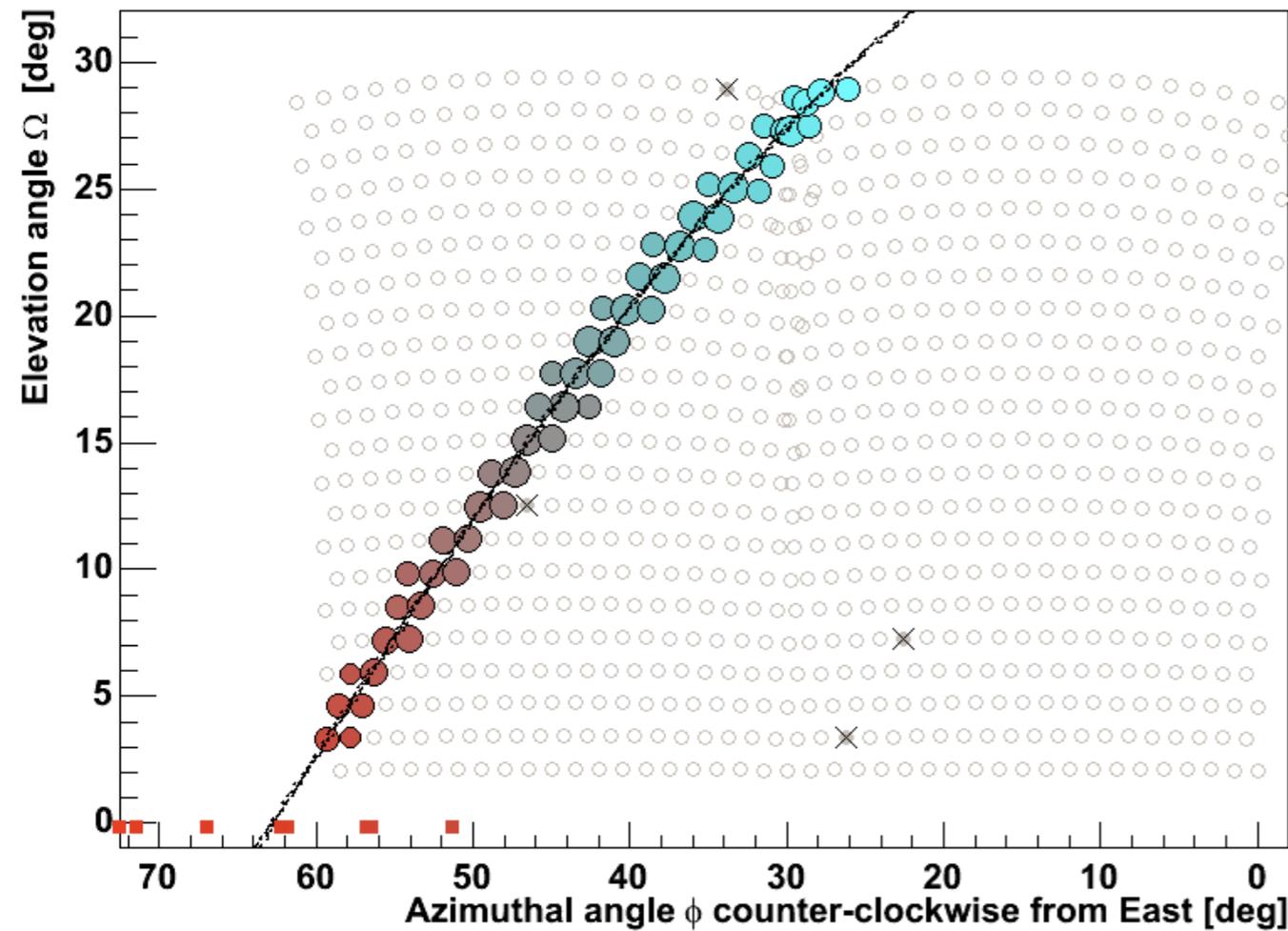
FD view

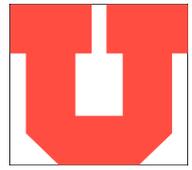




# detecting UHECRs

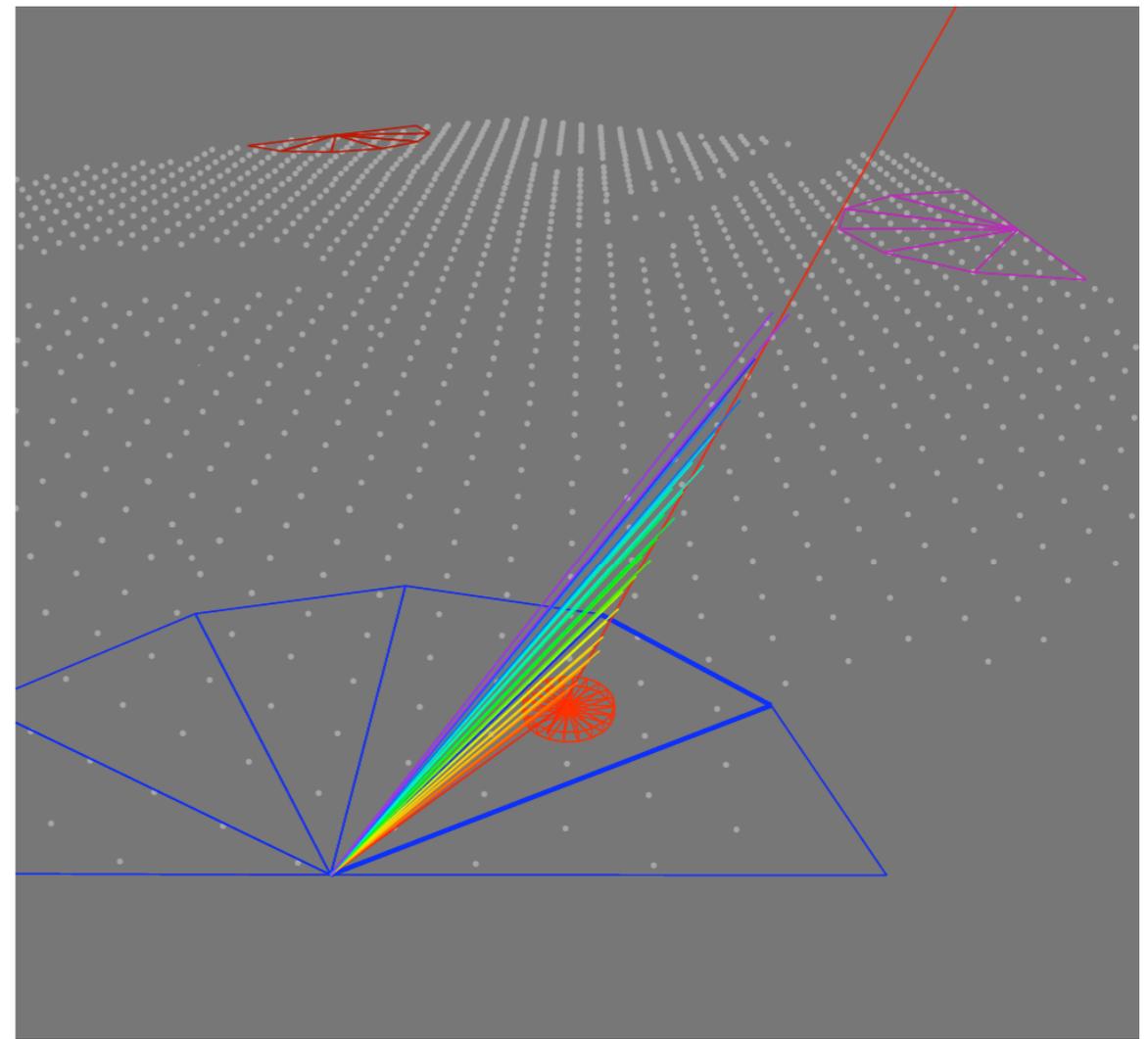
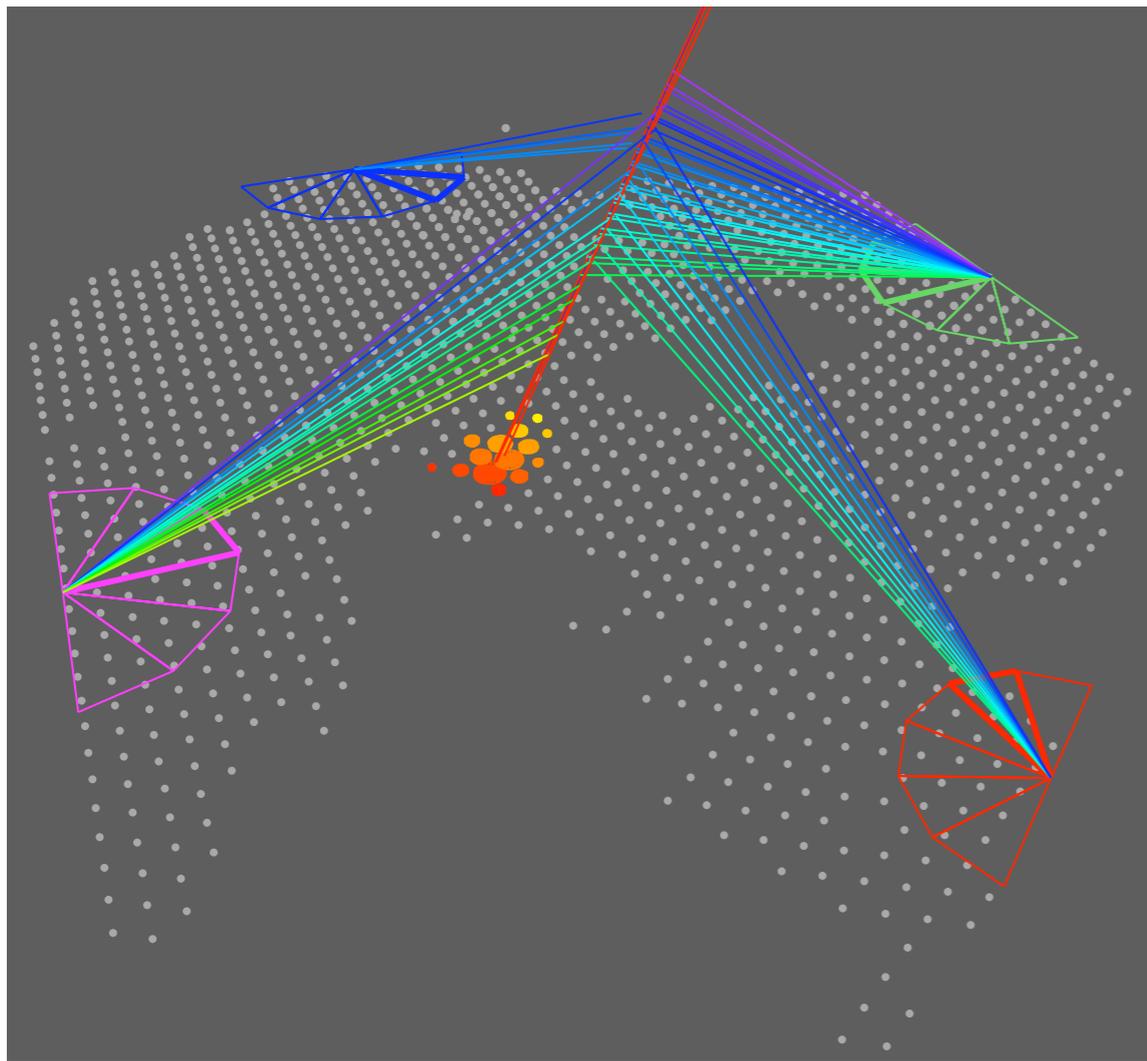
- *hybrid* reconst.: all avail **pixels** and **tanks**

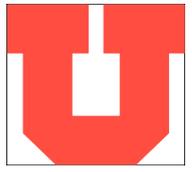




# hybrid Reconstruction

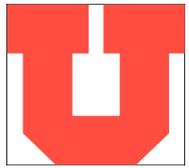
- reconstruct **golden** hybrids and **subthreshold**





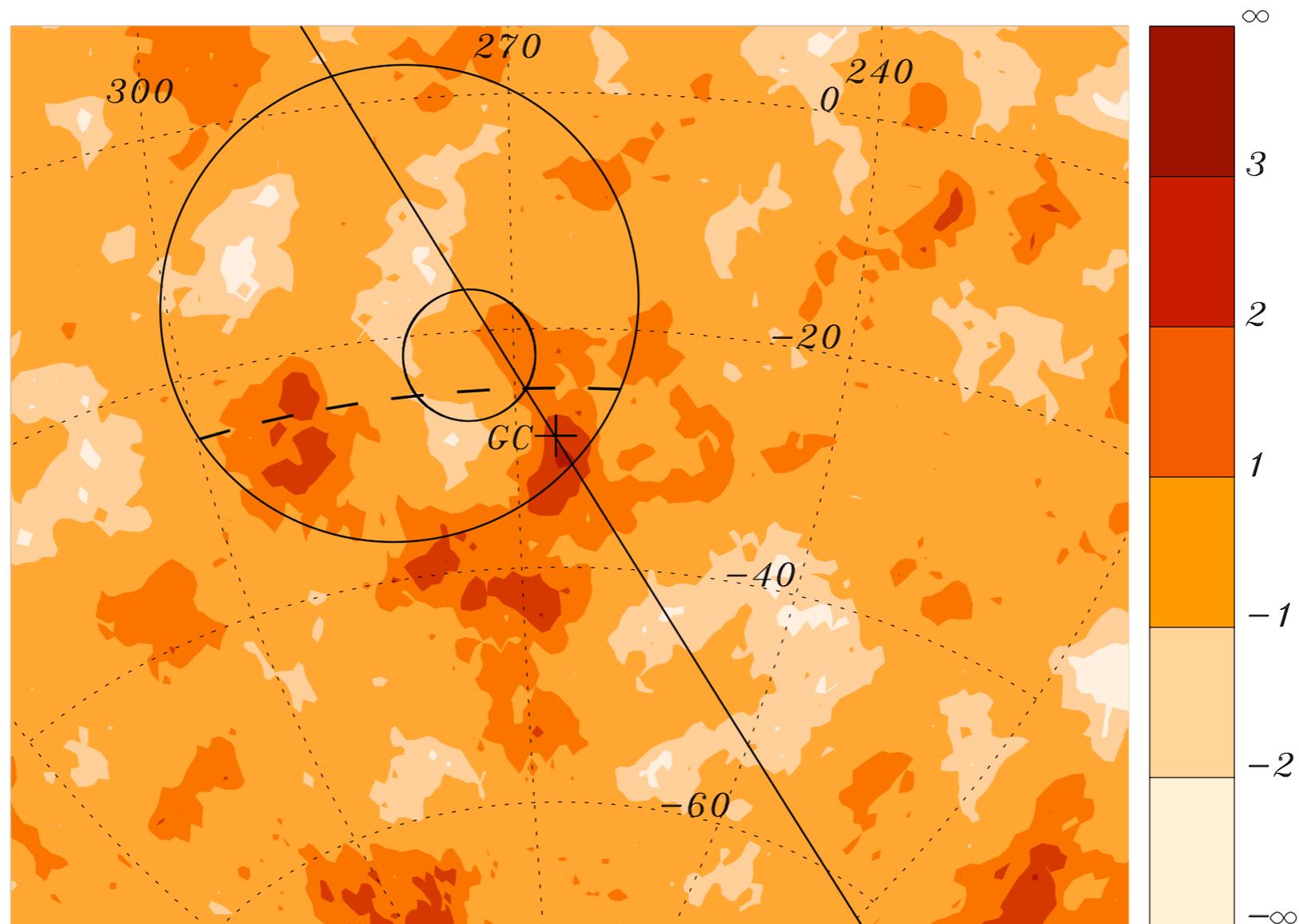
# Auger status





# Auger Results

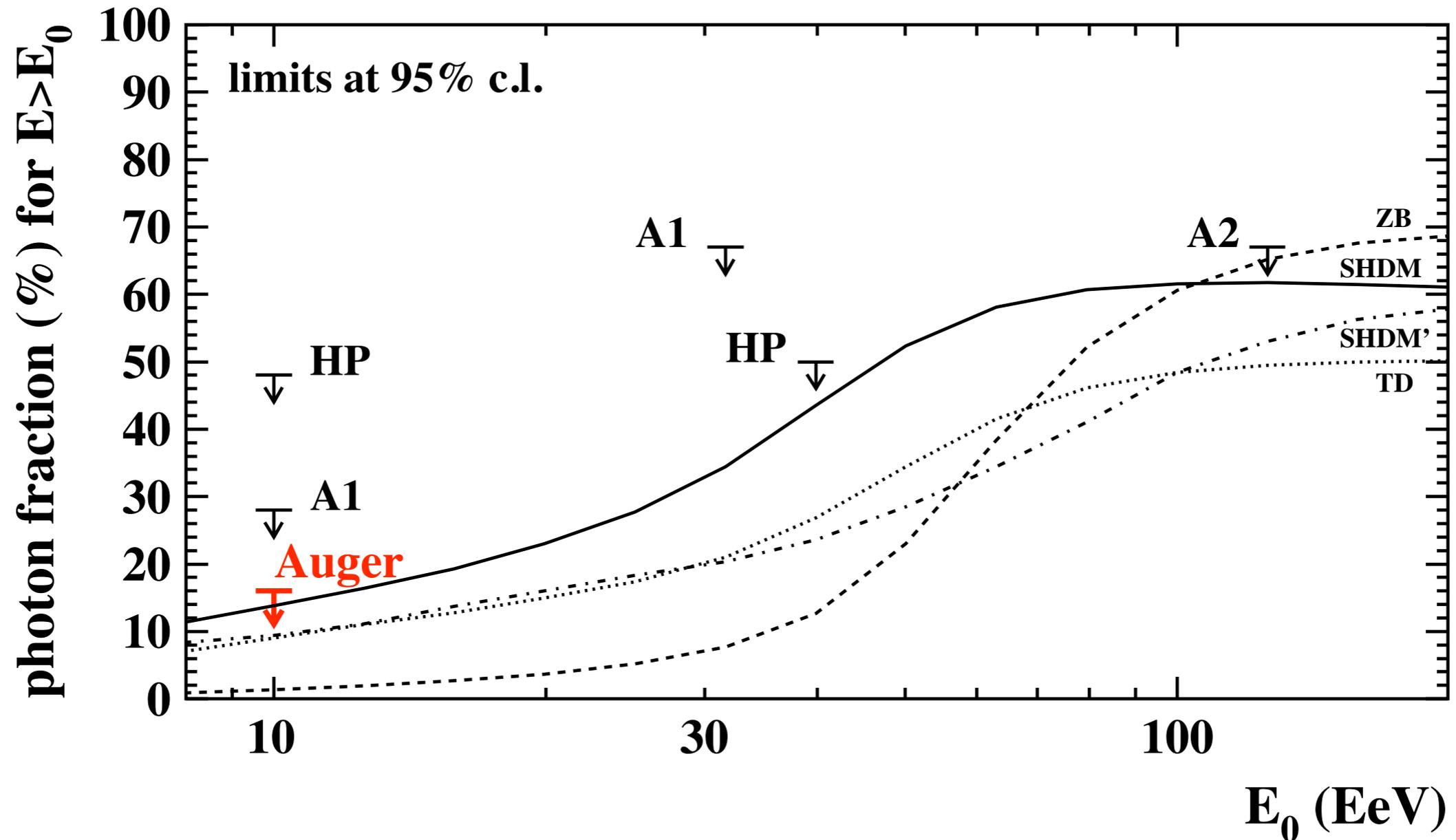
- Anisotropy around the GC at EeV energies

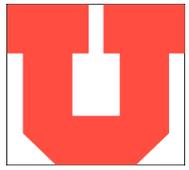




# Auger Results

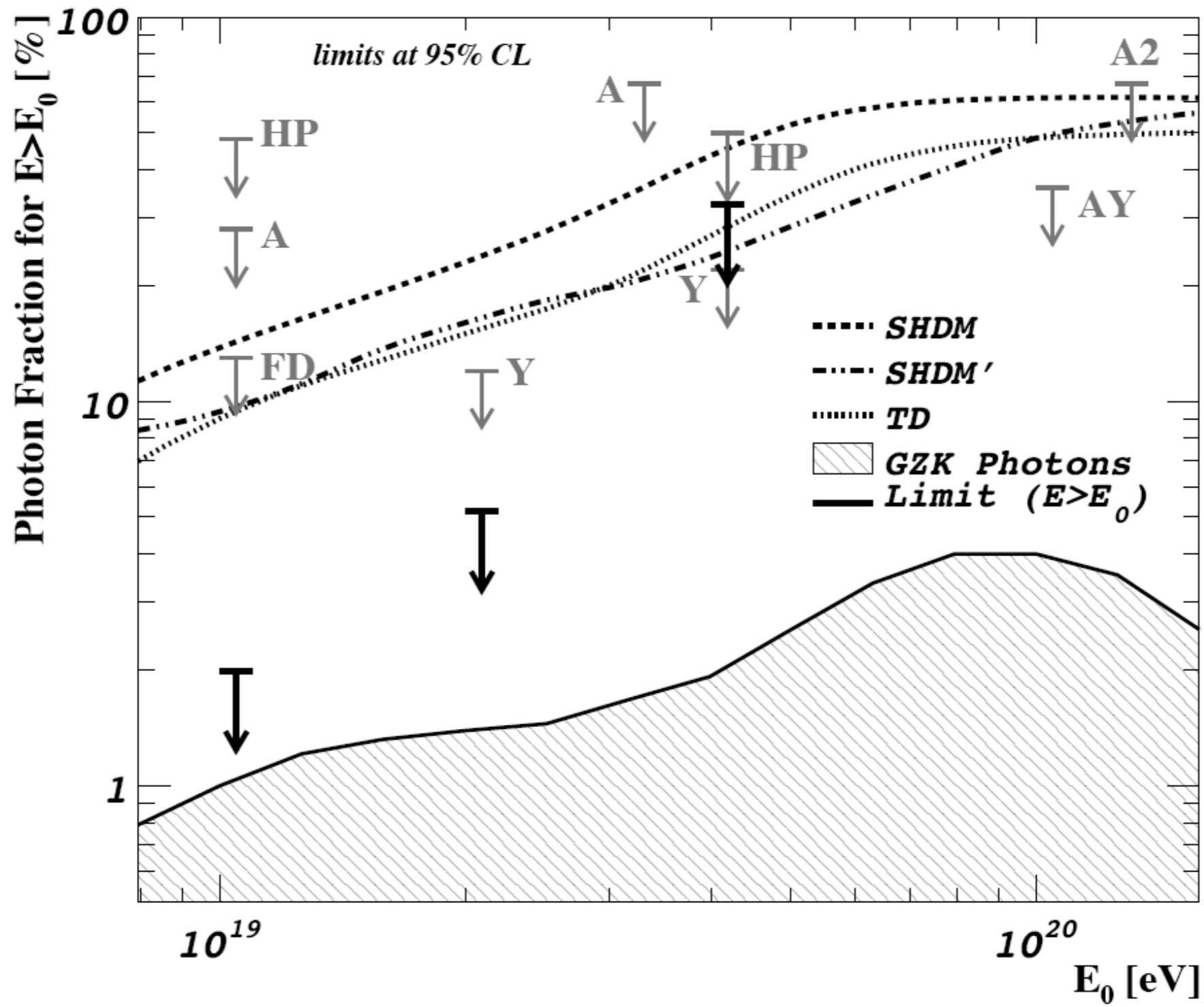
- Upper limit on *photon fraction* from **FD**

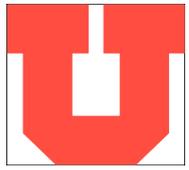




# Auger Results

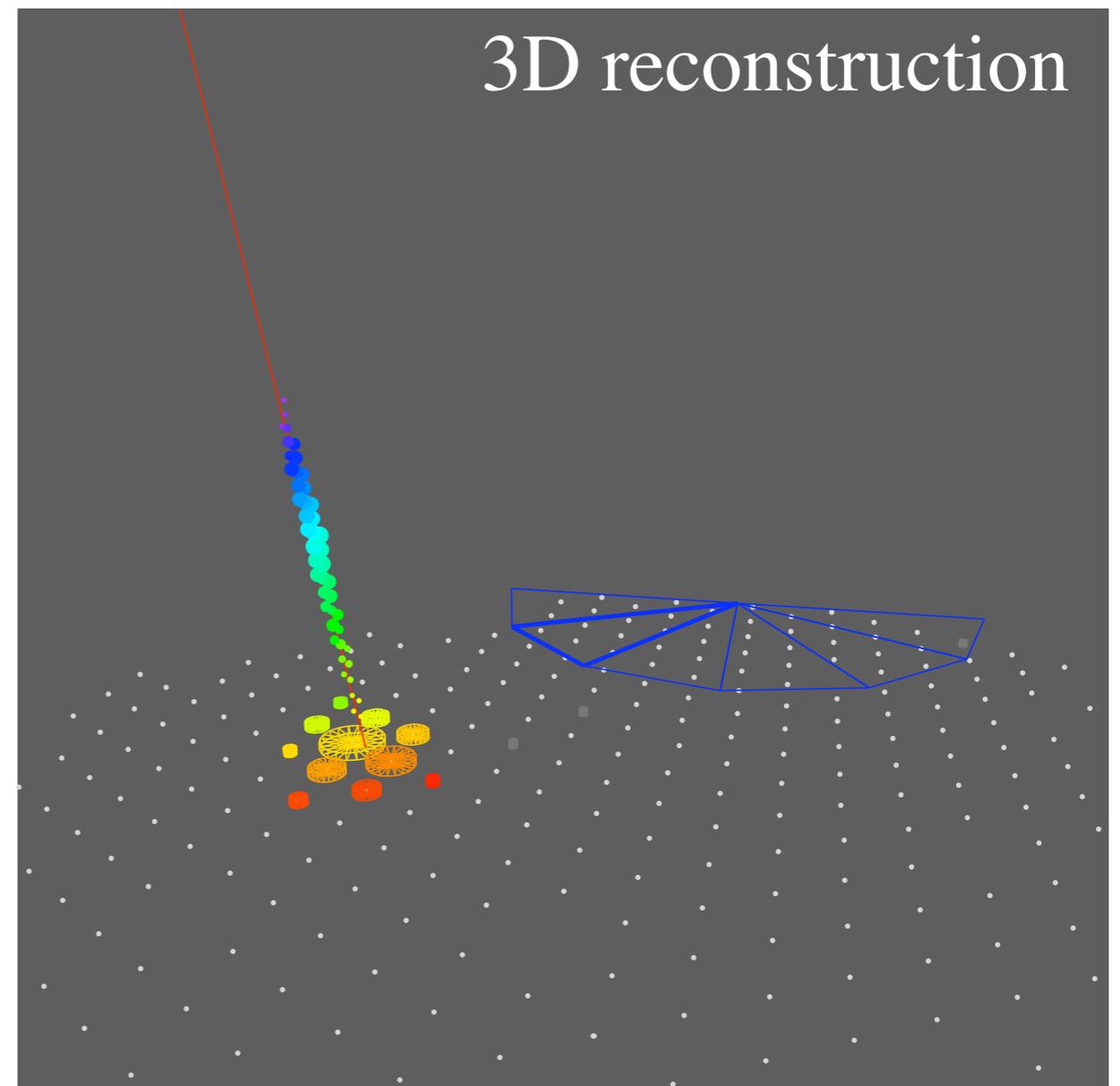
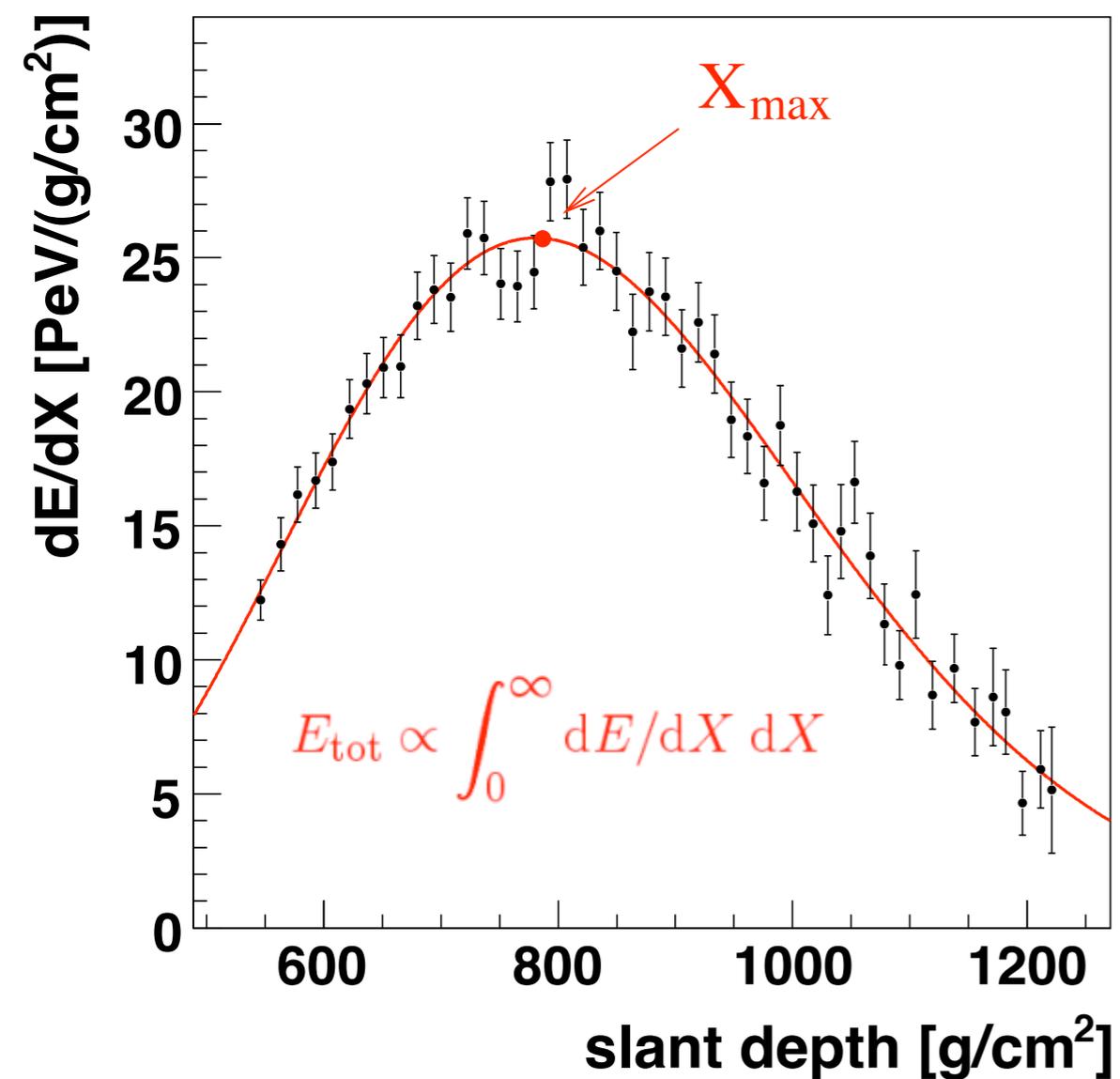
- Upper limit on *photon fraction* from SD

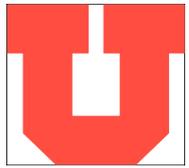




# Auger Analysis

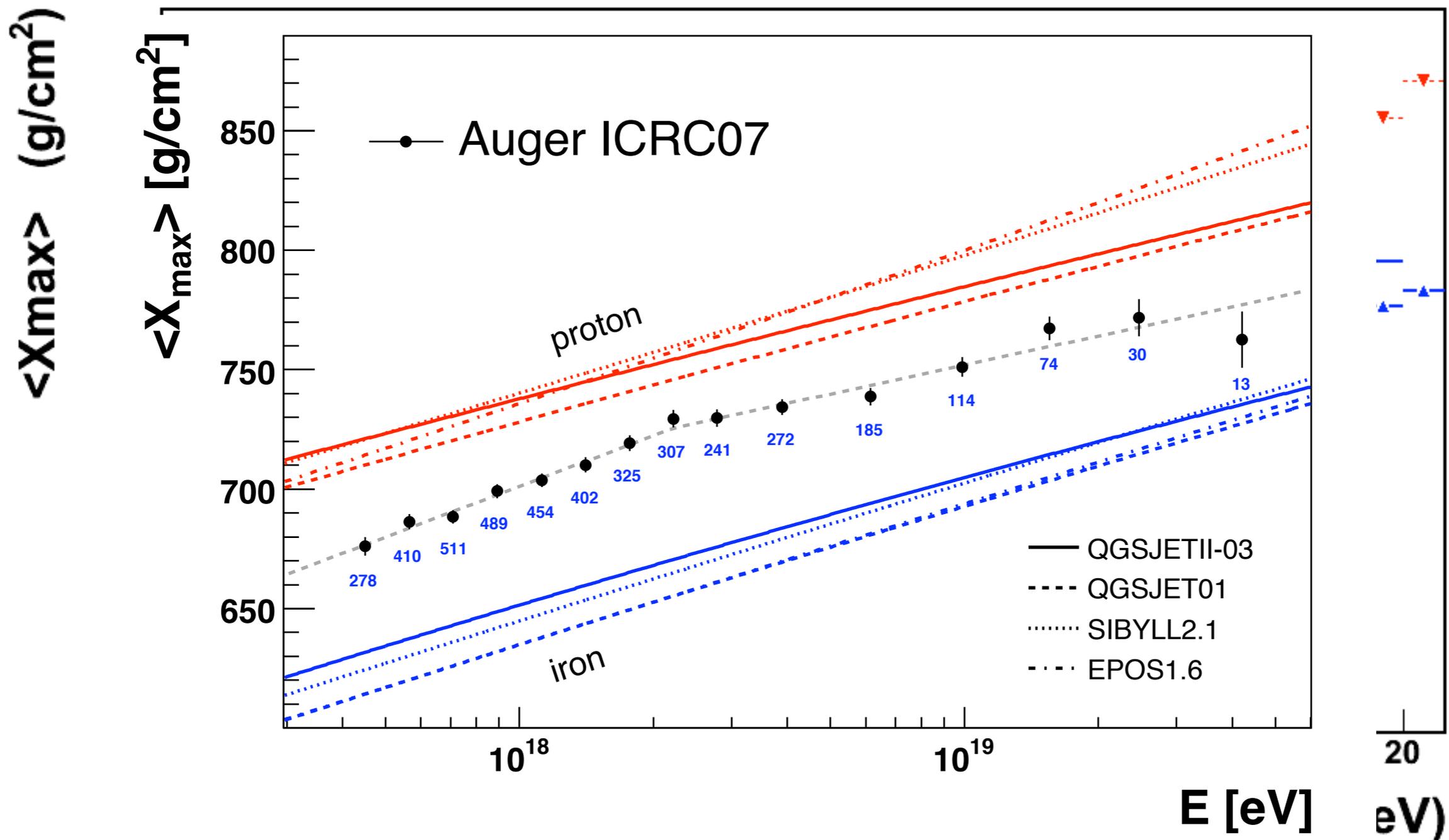
- longitudinal profile reconstruction





# Auger Analysis

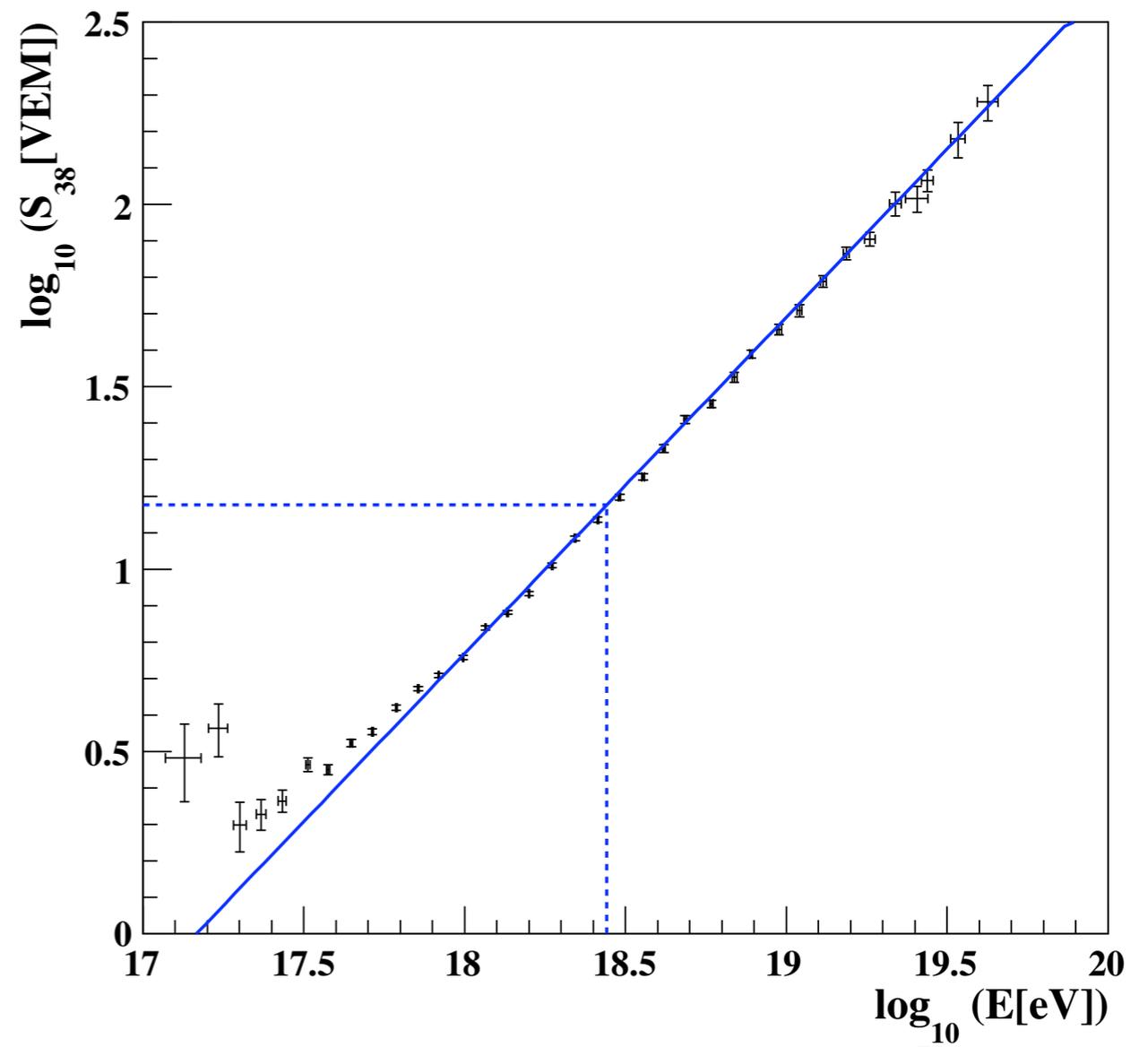
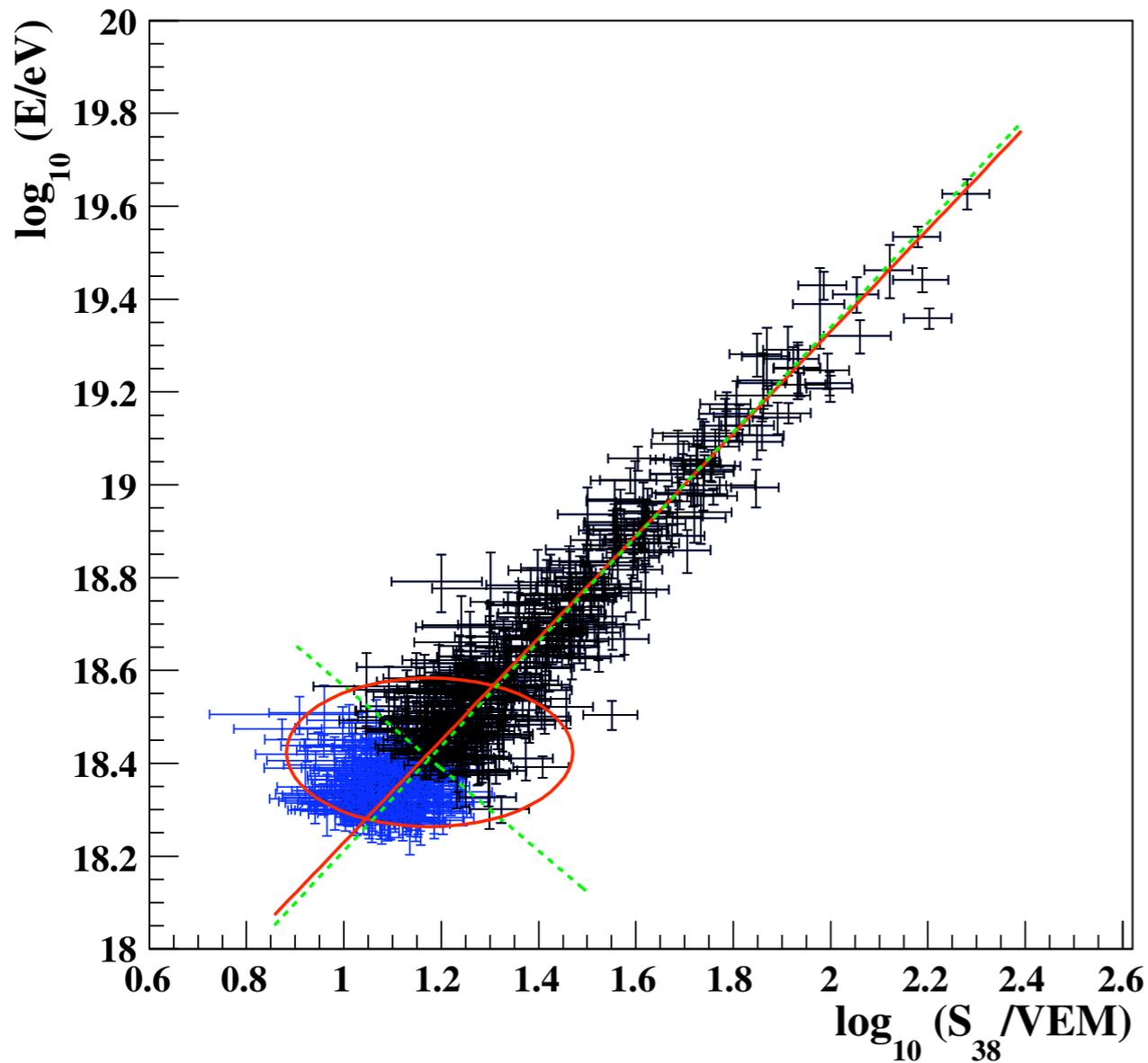
## ■ Elongation Rate

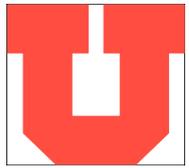




# Auger Analysis

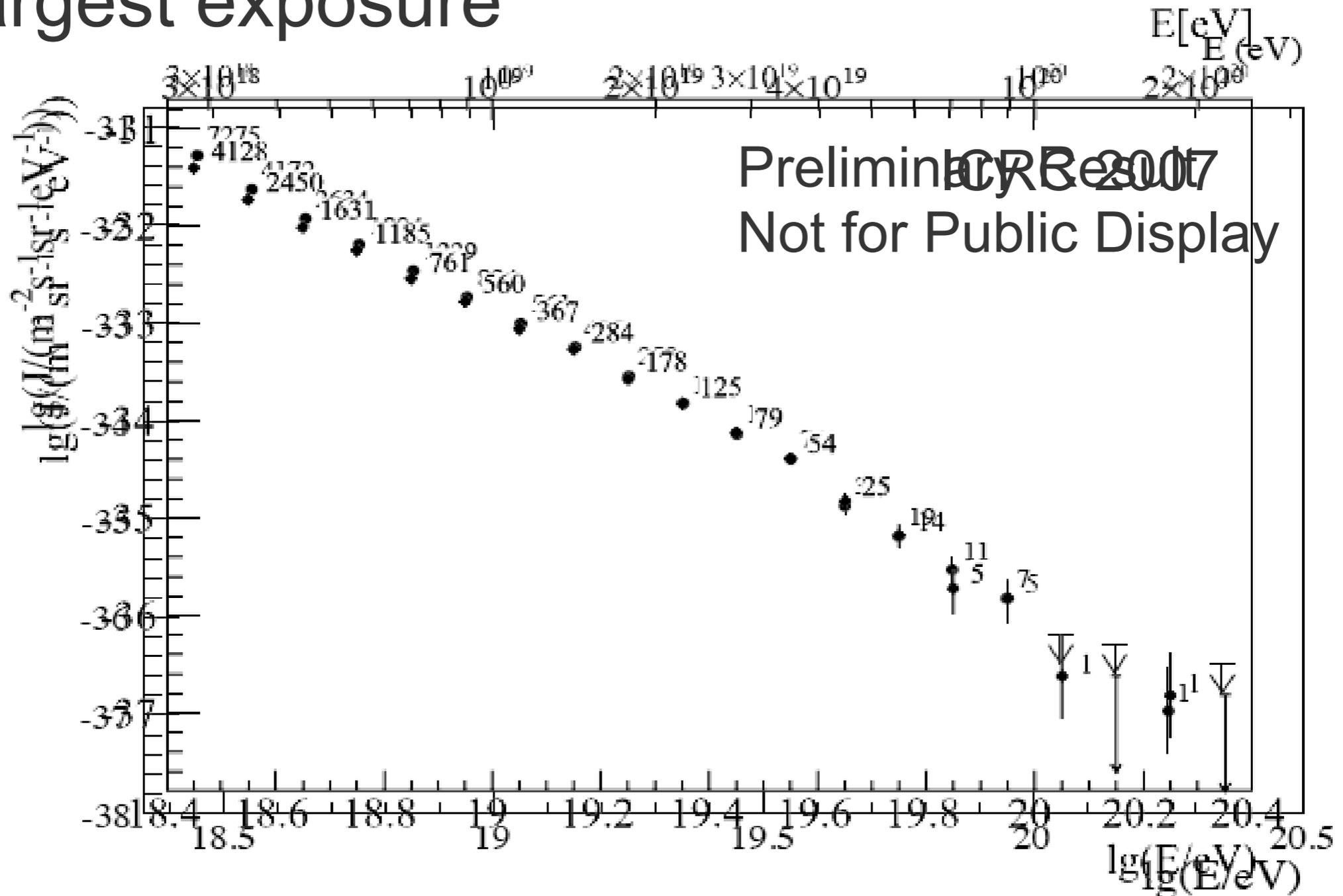
## energy calibration

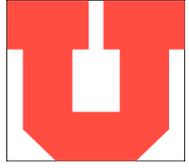




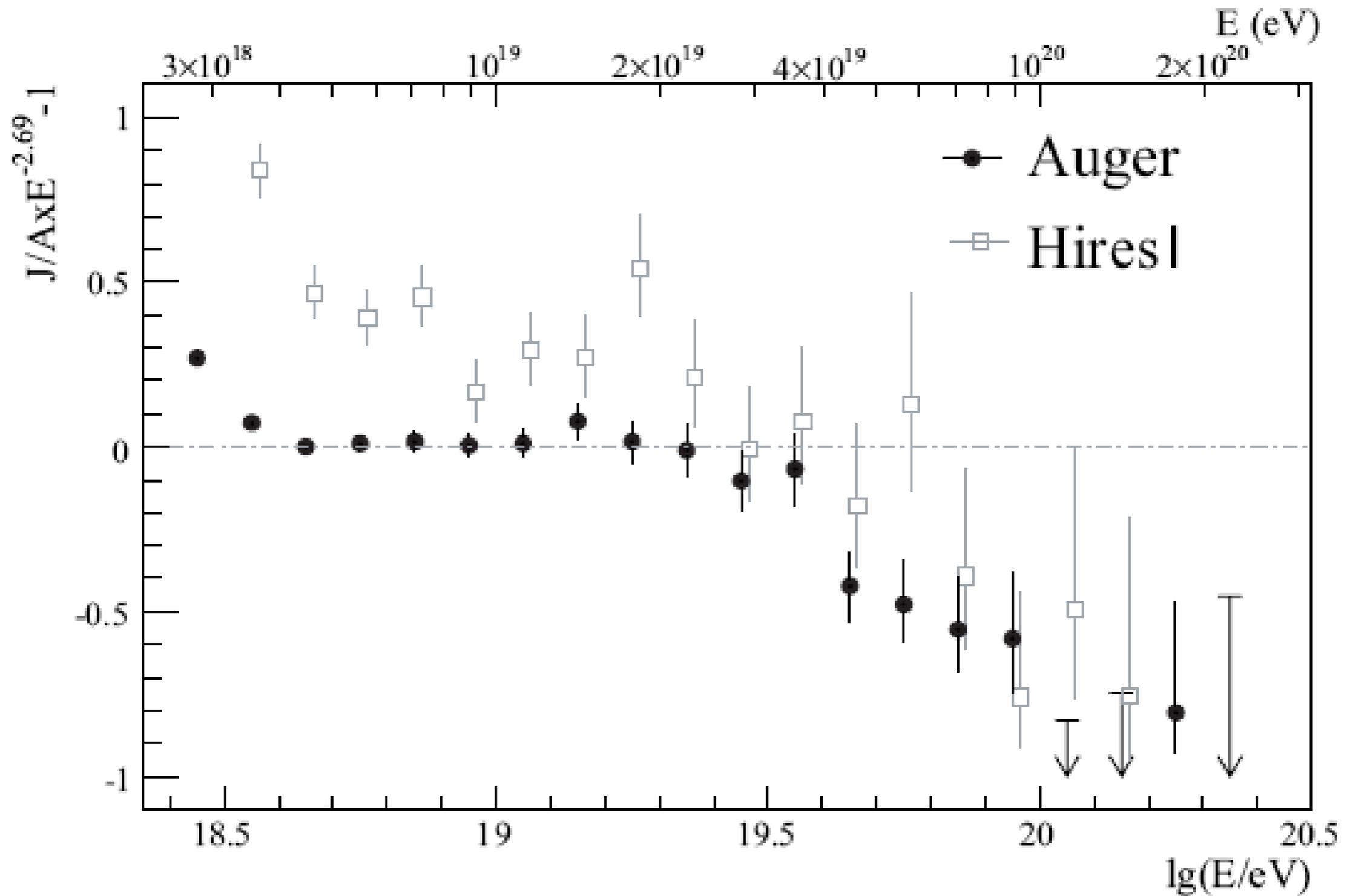
# Auger Results

- largest exposure





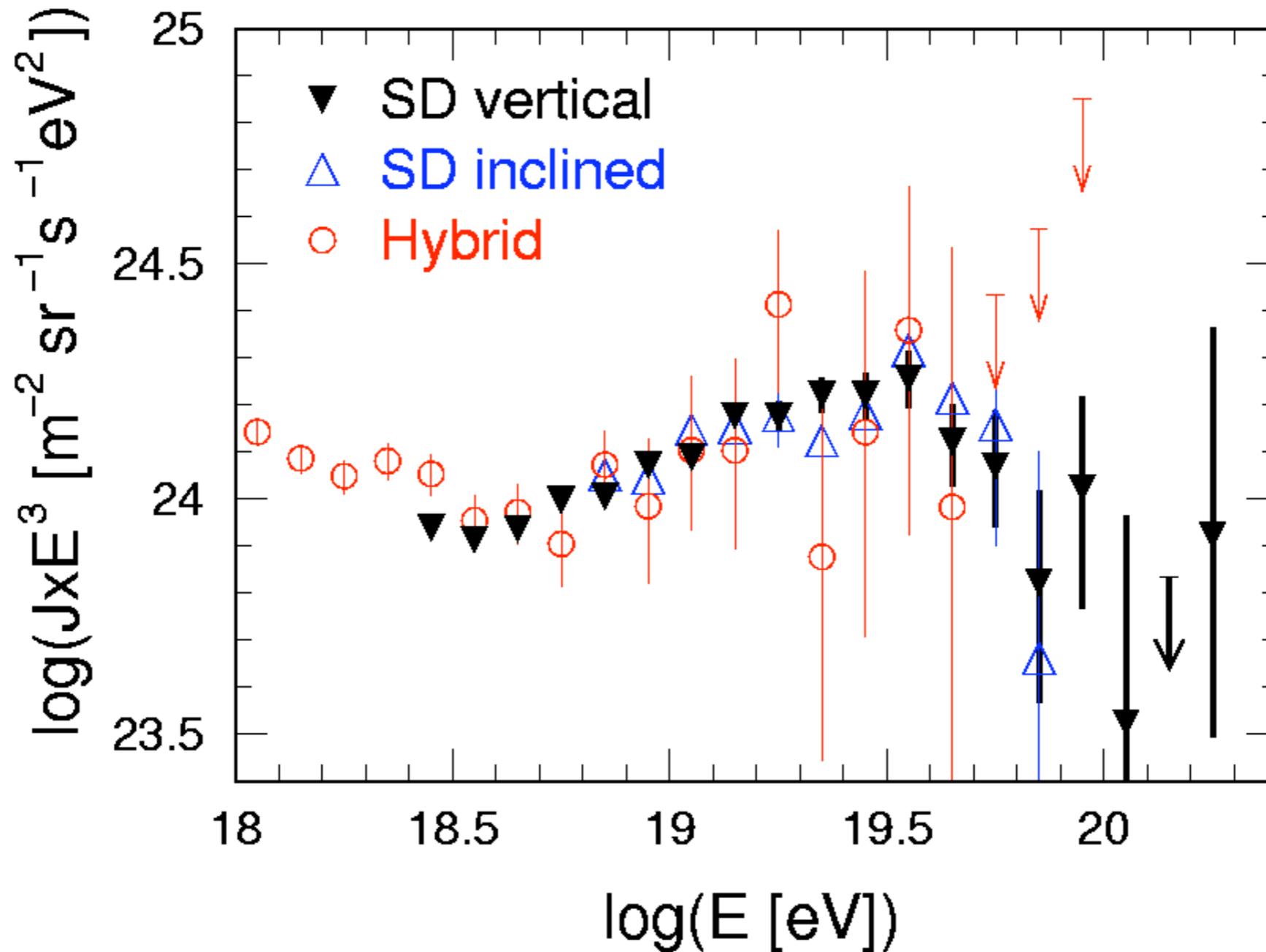
# Auger Analysis

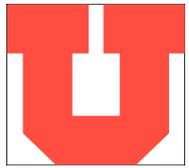




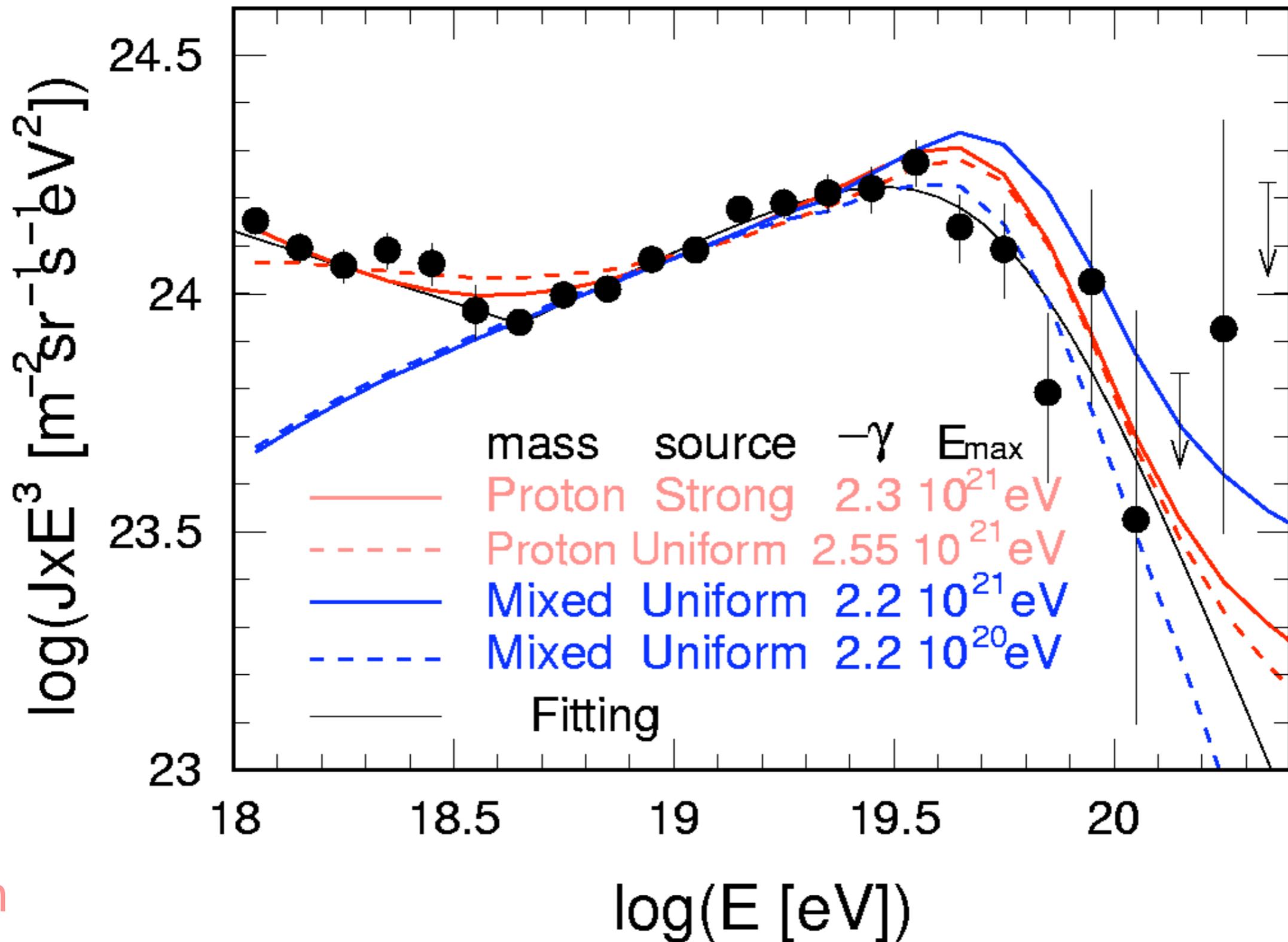
# Auger Analysis

- hybrid extension



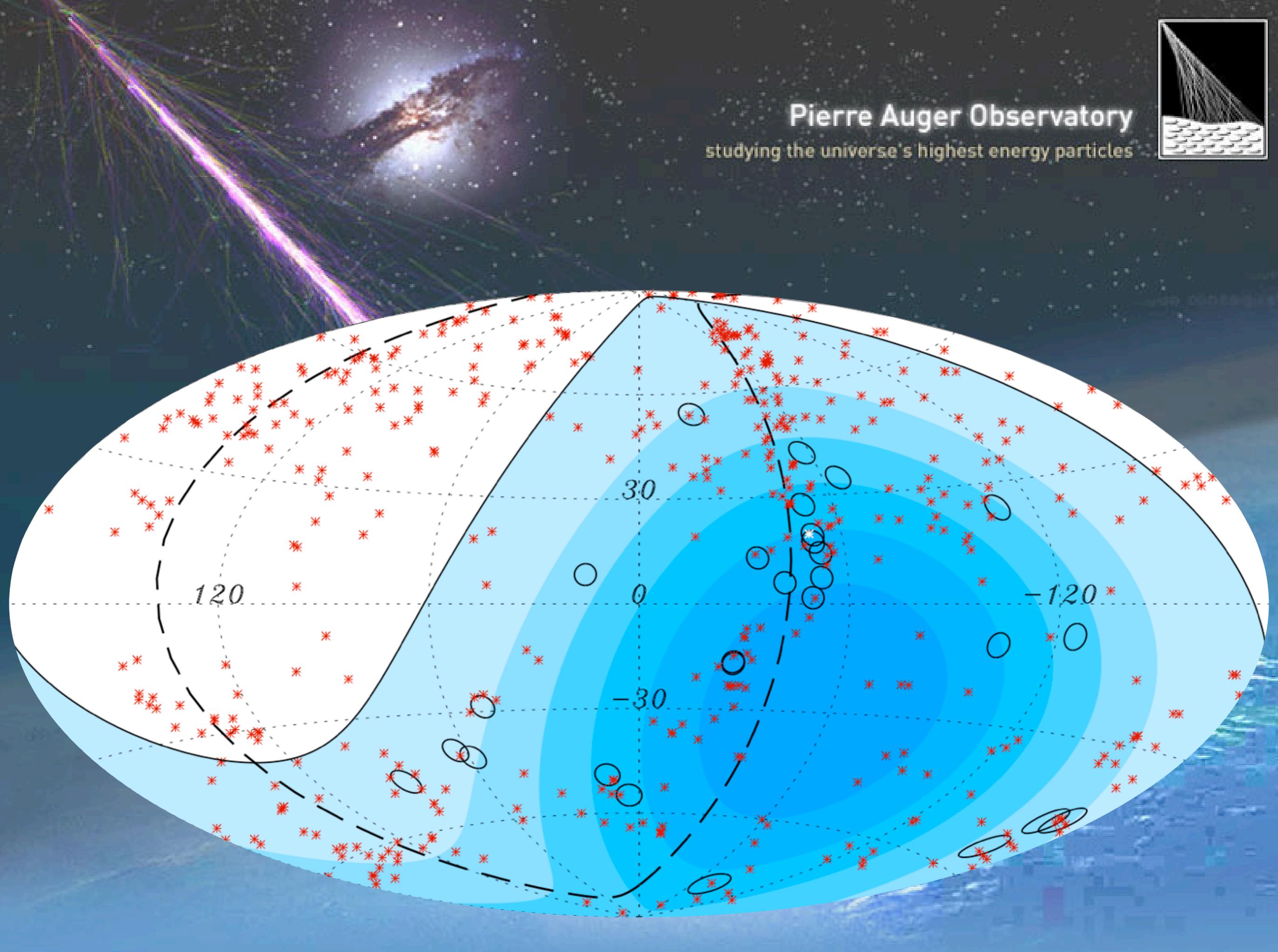
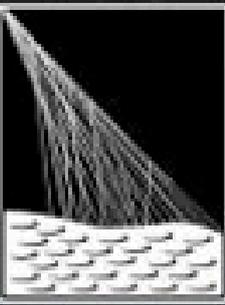


# astroph implications



# Pierre Auger Observatory

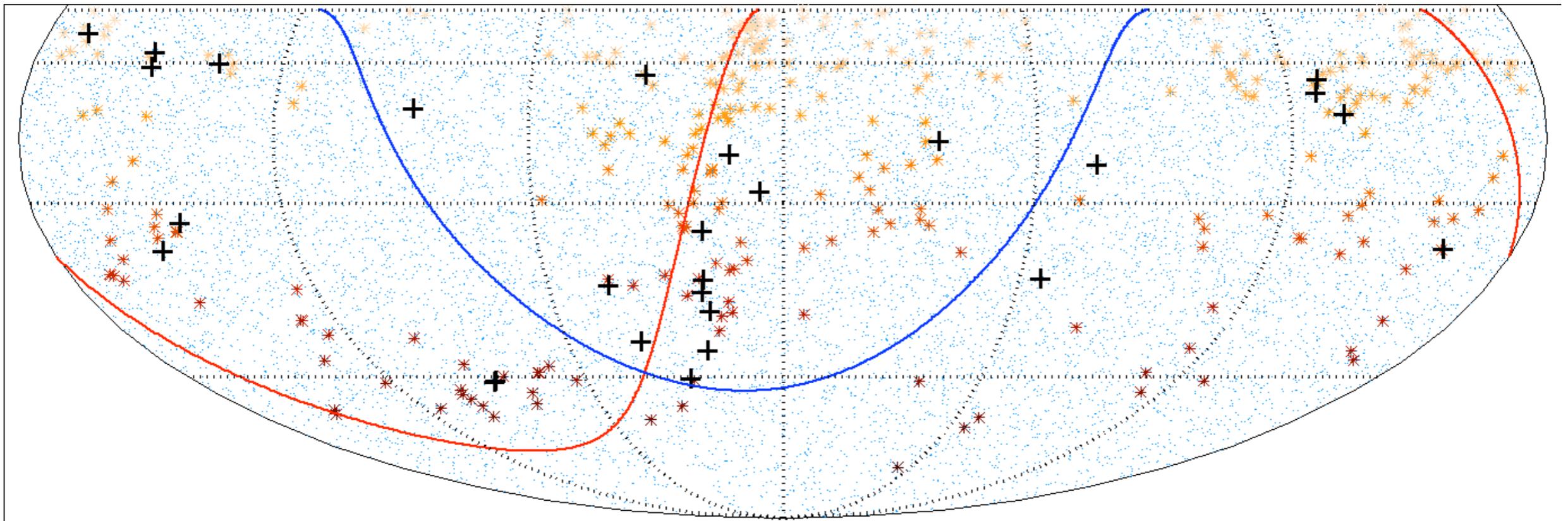
studying the universe's highest energy particles





# Auger Results

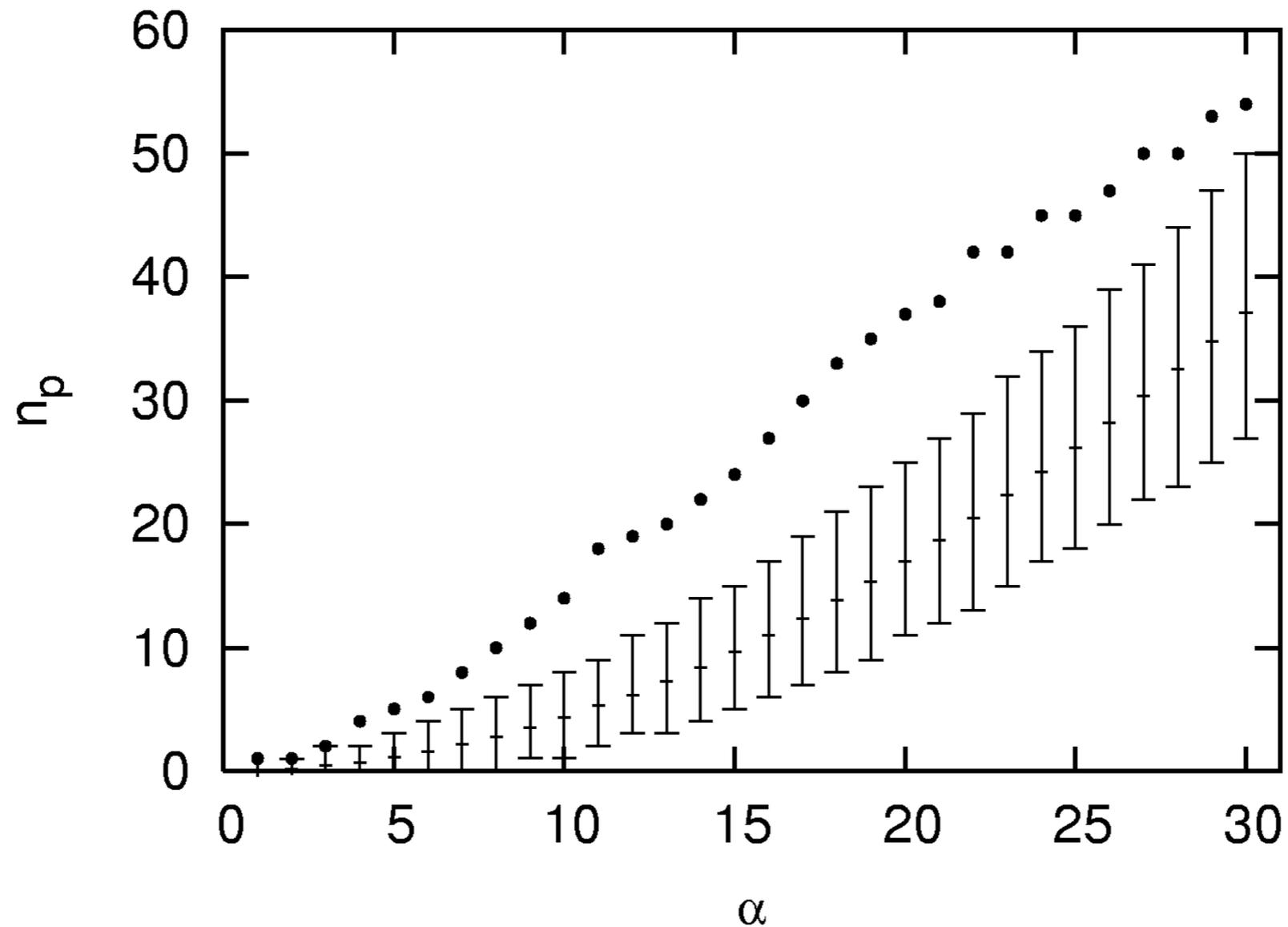
- an iso-exposure Mollweide map

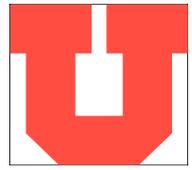




# Auger Analysis

- auto-correlation

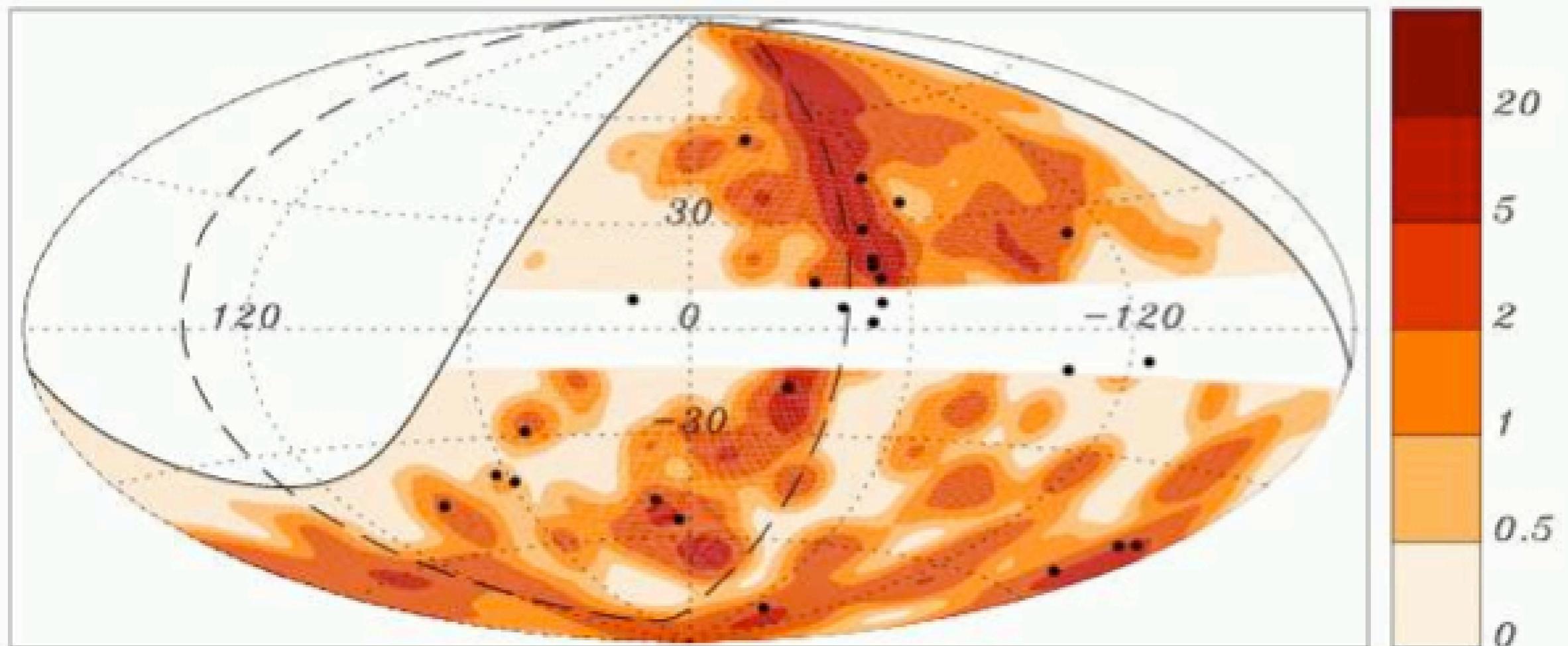




# Source Studies

- 100 Mpc horizon maps

*VC 4deg reference map*





# “AGN” conclusions

- Can we say anything about the sources?
  - They are **not Galactic**
  - Likely **astrophysical**
  - AGNs are interesting **plausible** sites
- More data are needed to identify and characterize the sources



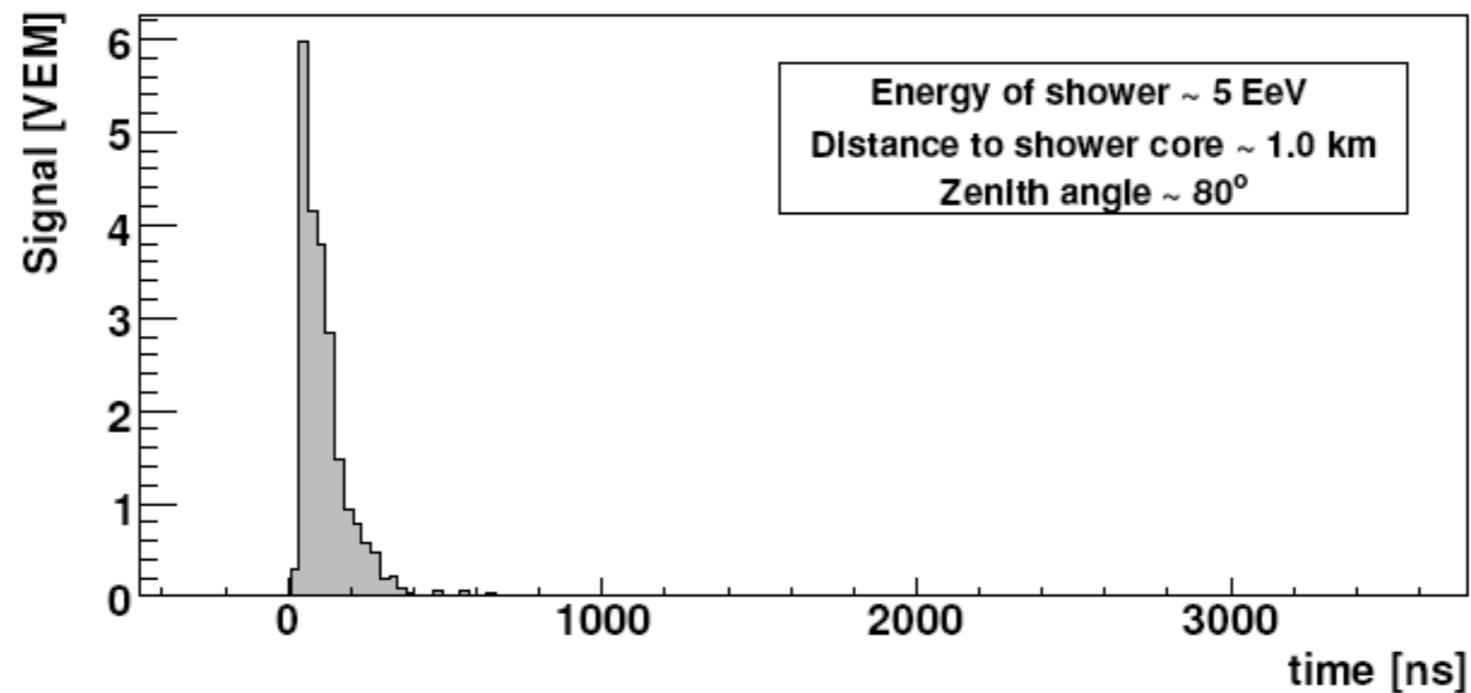
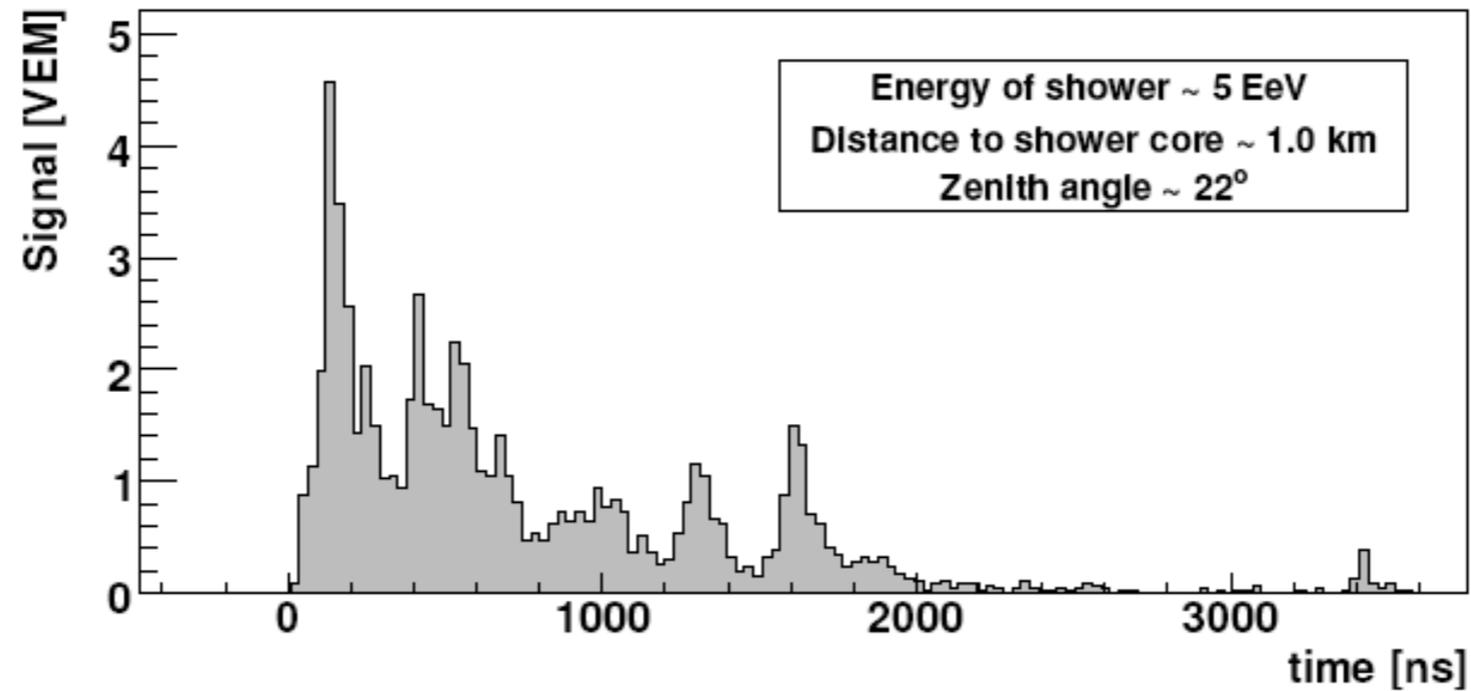
# “AGN” conclusions

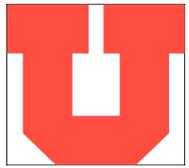
- Have we found the sources of EHECRs?
  - The results are certainly **interesting** if not (yet) *statistically compelling*
  - If/when our correlations are statistically compelling, we will have (arguably) the first experimental feedback on **magnetic deflections** of extra-galactic CRs
  - We will continue our analysis on the ever-**increasing** Auger data set



# Auger Analysis

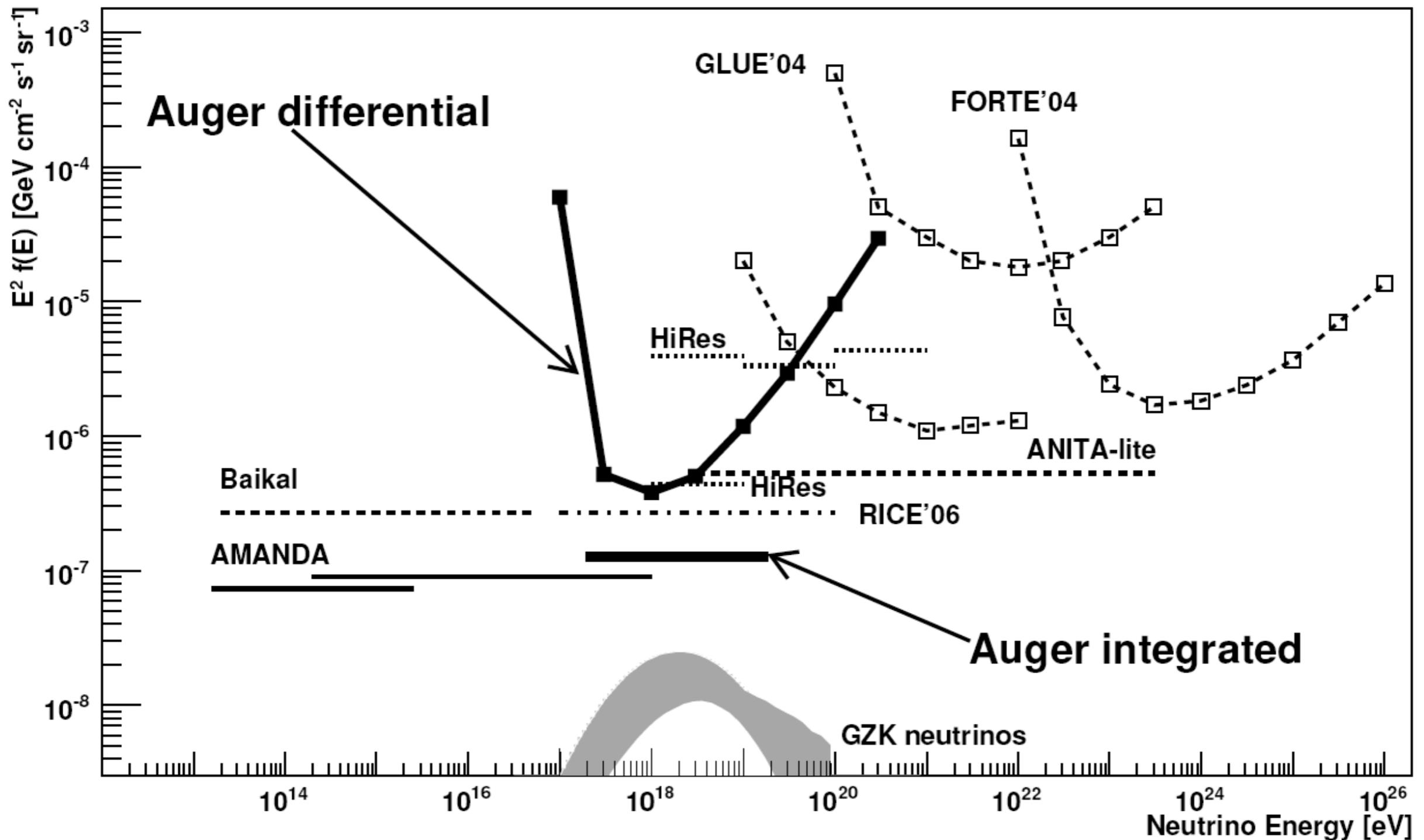
- vertical vs. horizontal showers

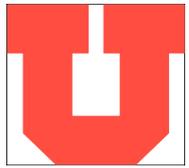




# Auger Analysis

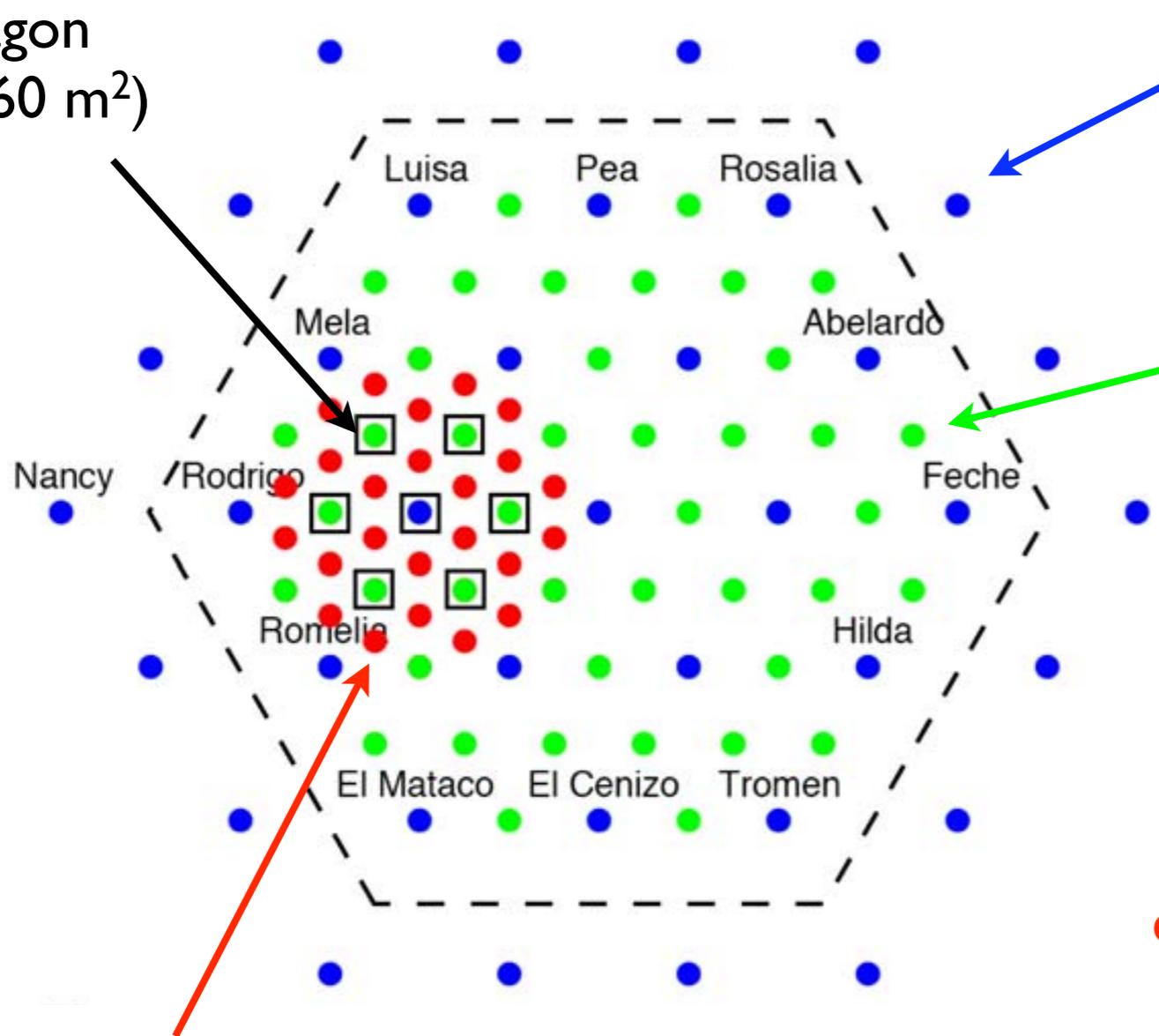
## neutrino limits





# Auger future - AMIGA

Hexagon  
(7 x 60 m<sup>2</sup>)



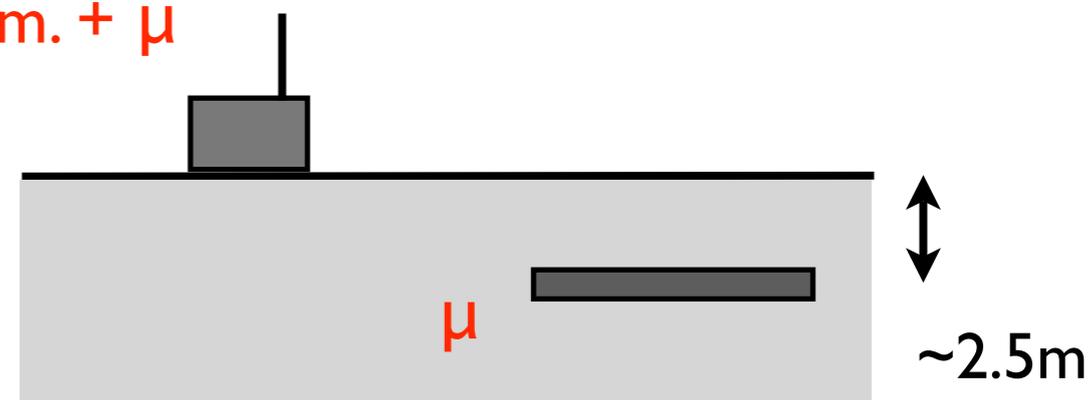
Existing tank array 1500m

Infill array 750m

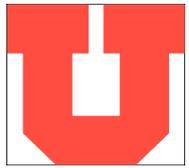
Muon detectors:  
54 (30m<sup>2</sup>) + 7 (60m<sup>2</sup>)  
Cherenkov tanks: 61  
Area ~ 23 km<sup>2</sup>

Infill array 433m  
Area ~ 5.9 km<sup>2</sup>

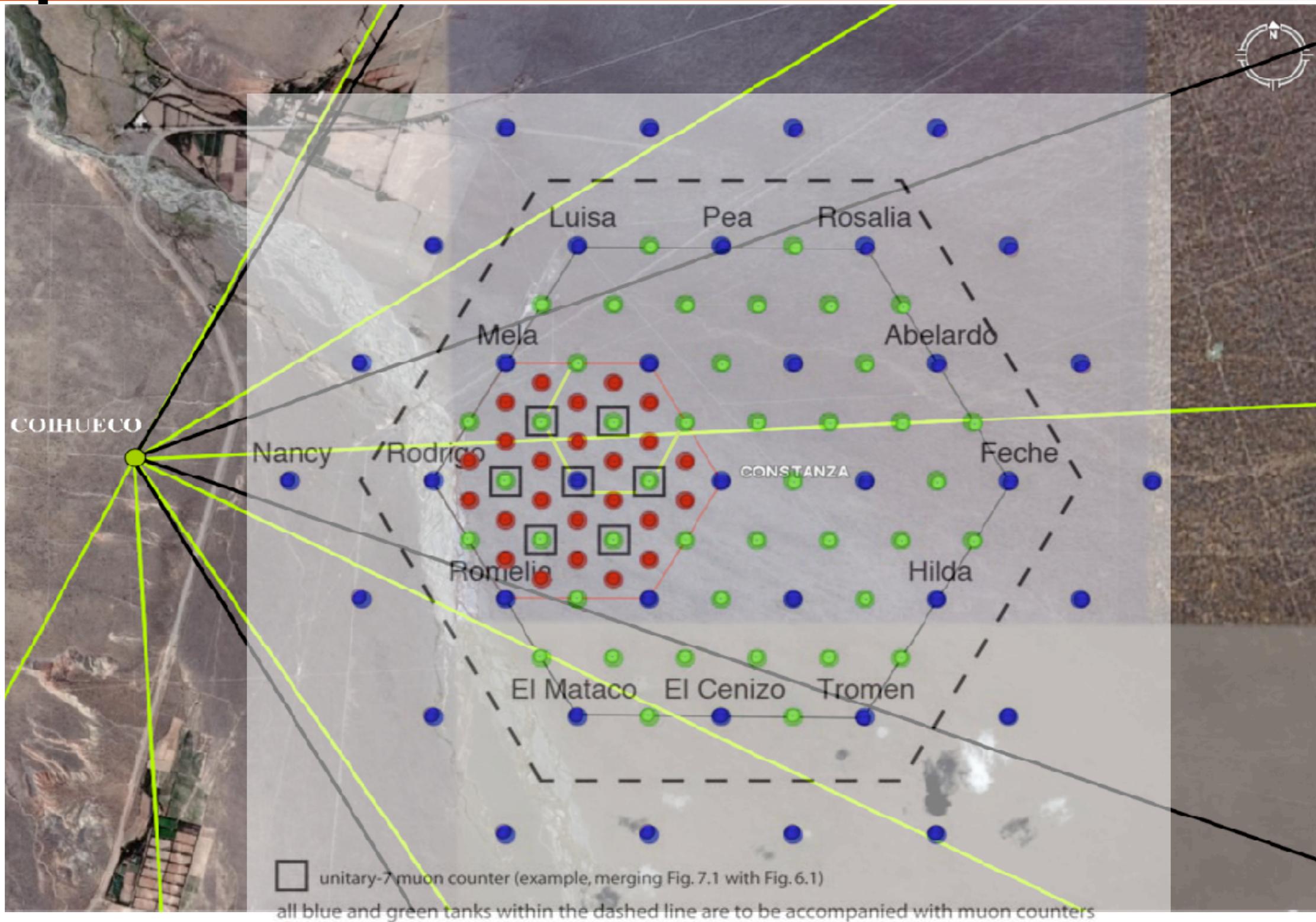
em. +  $\mu$



Detector pairs



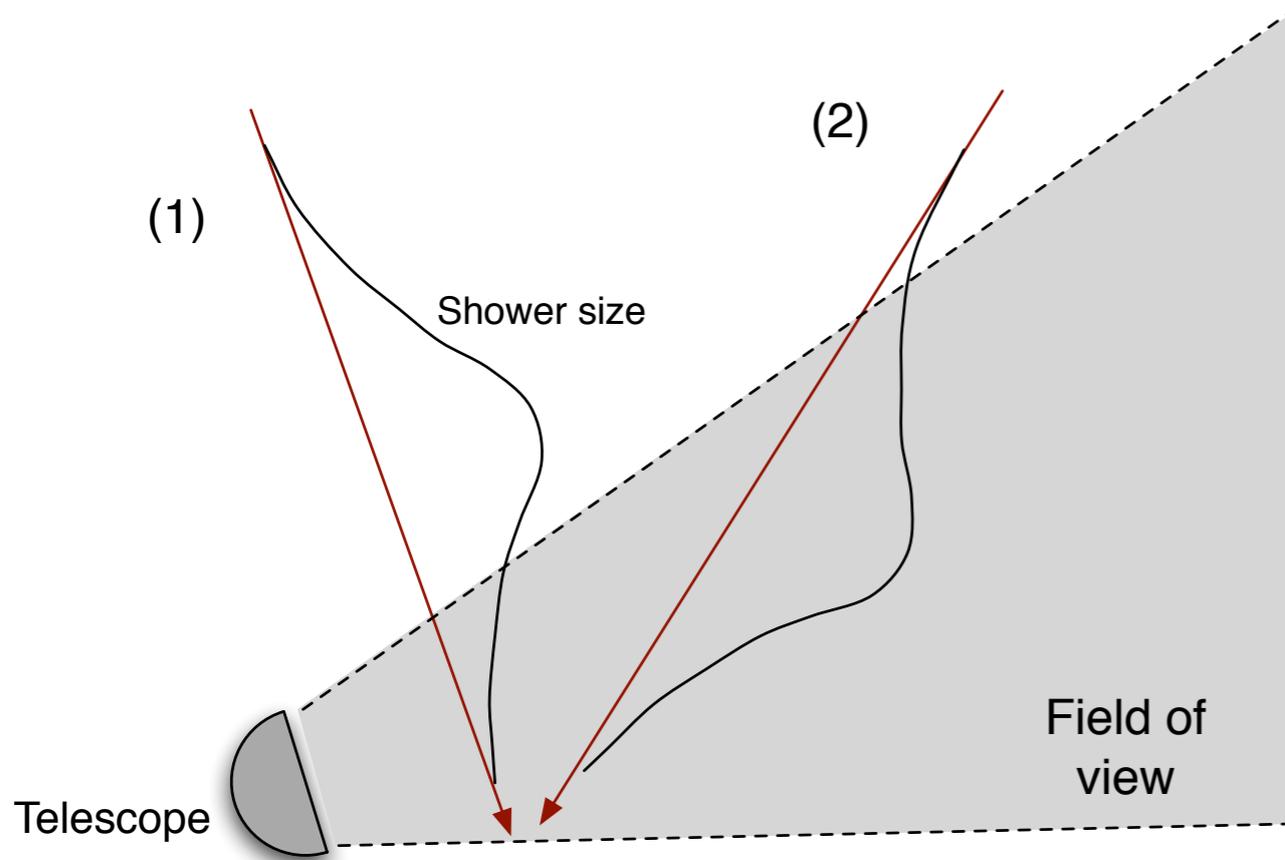
# Auger future



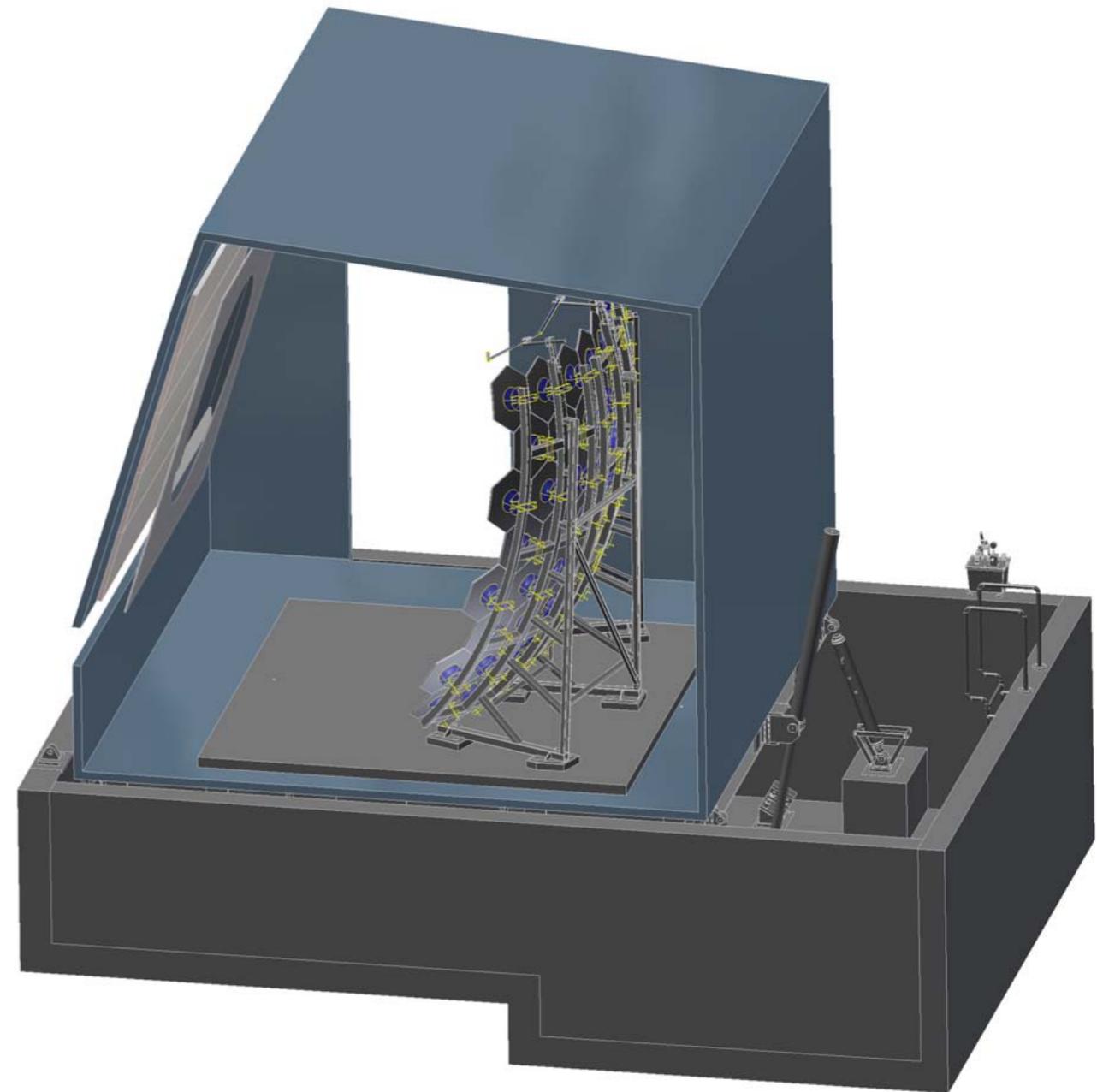


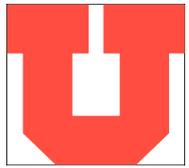
# Auger future

## High Elevation Auger Telescopes



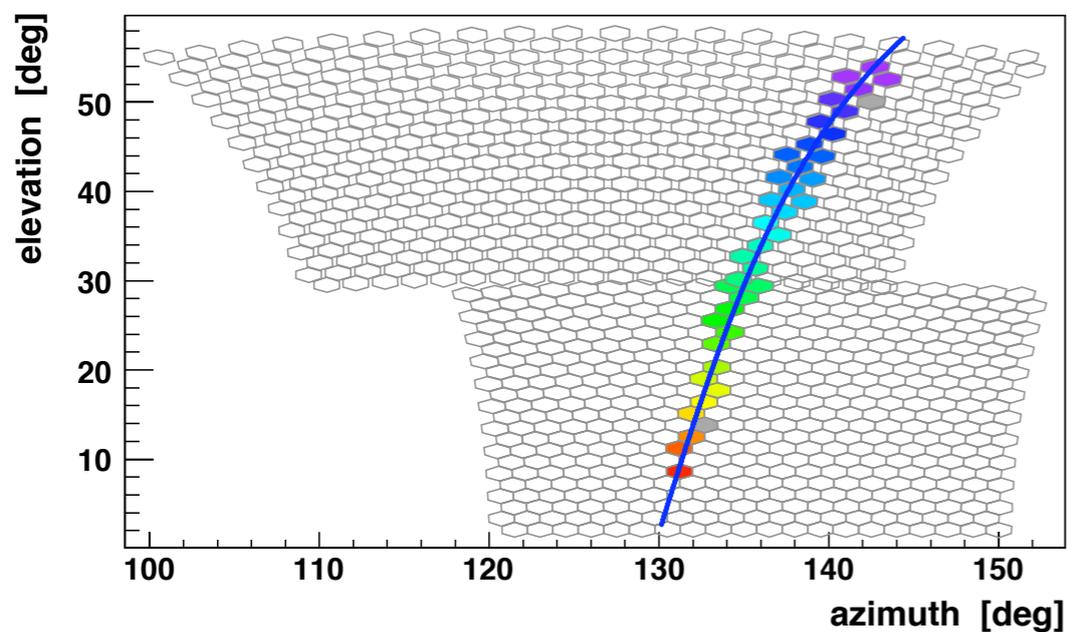
Auger fluorescence telescopes:  
1 - 30° FoV (elevation angle)



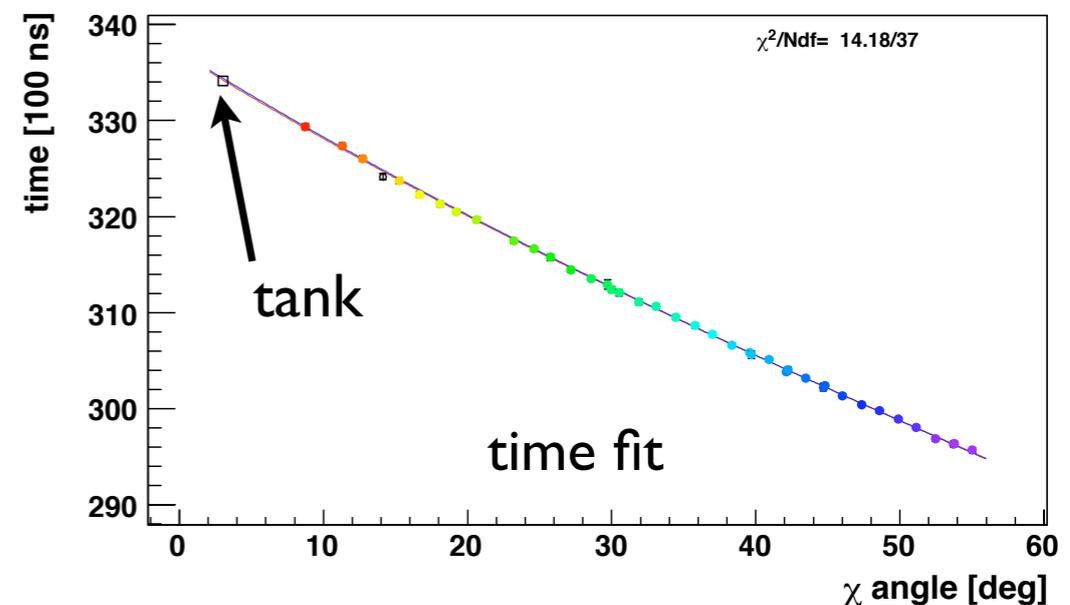
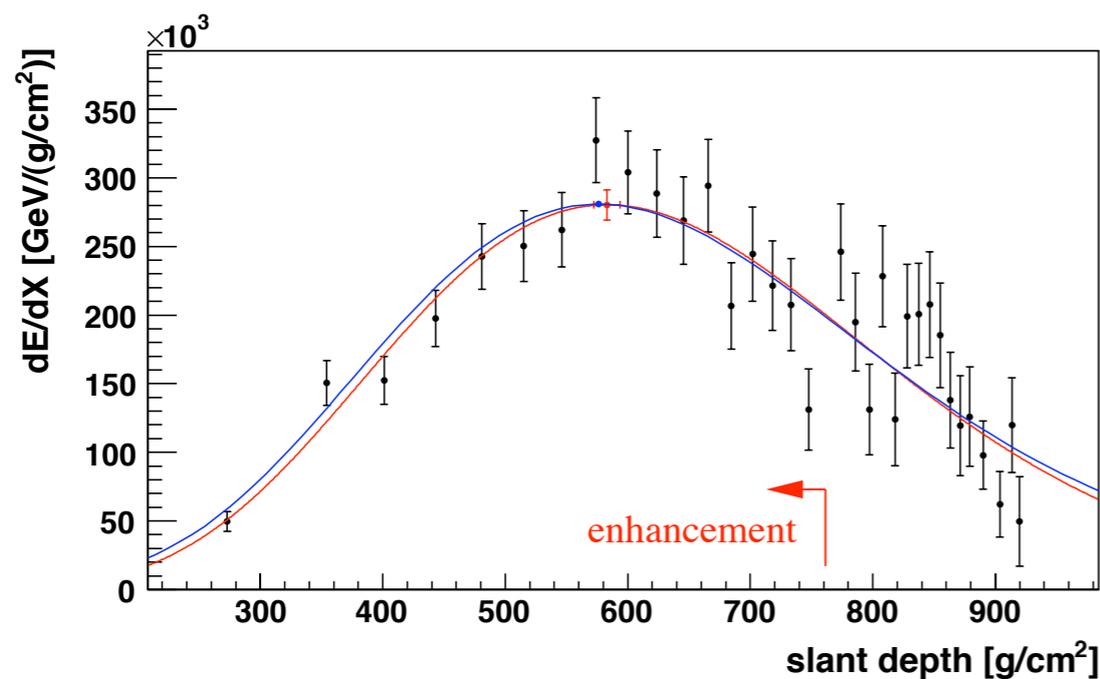


# Auger future

## ■ simulated nearby event



Simulated shower with core distance  
 $R_p = 1.2 \text{ km}$ ,  $E = 10^{17.25} \text{ eV}$

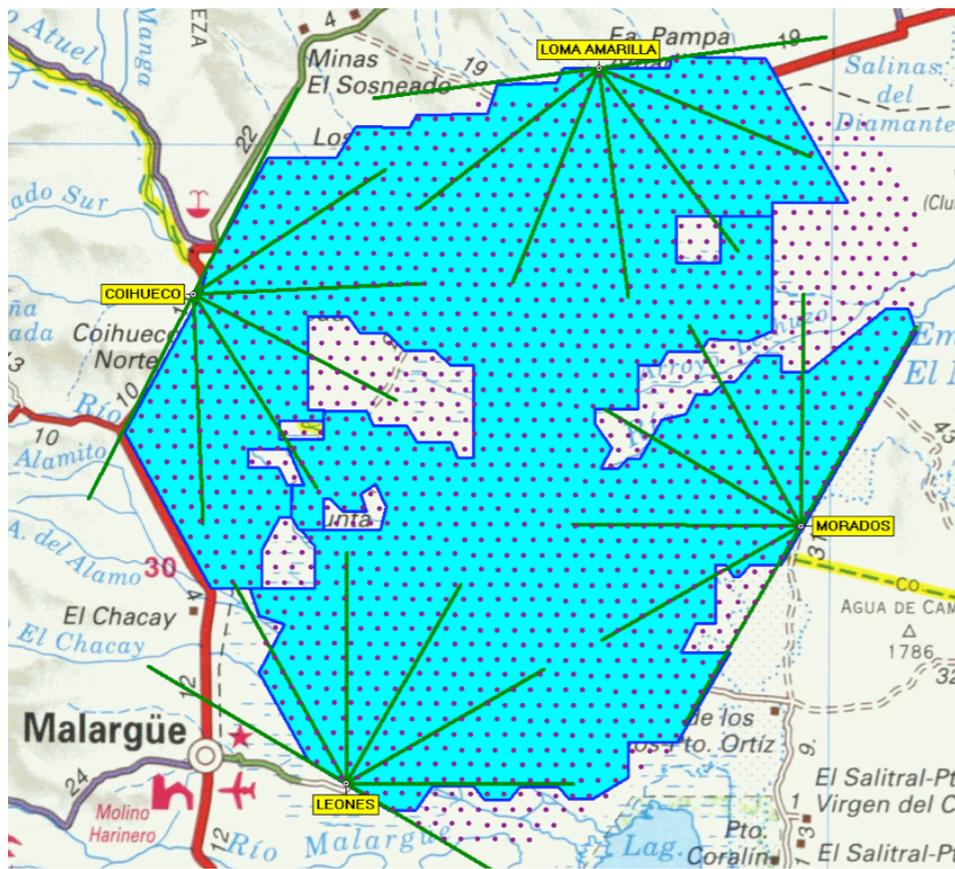


- simulated profile
- reconstructed profile



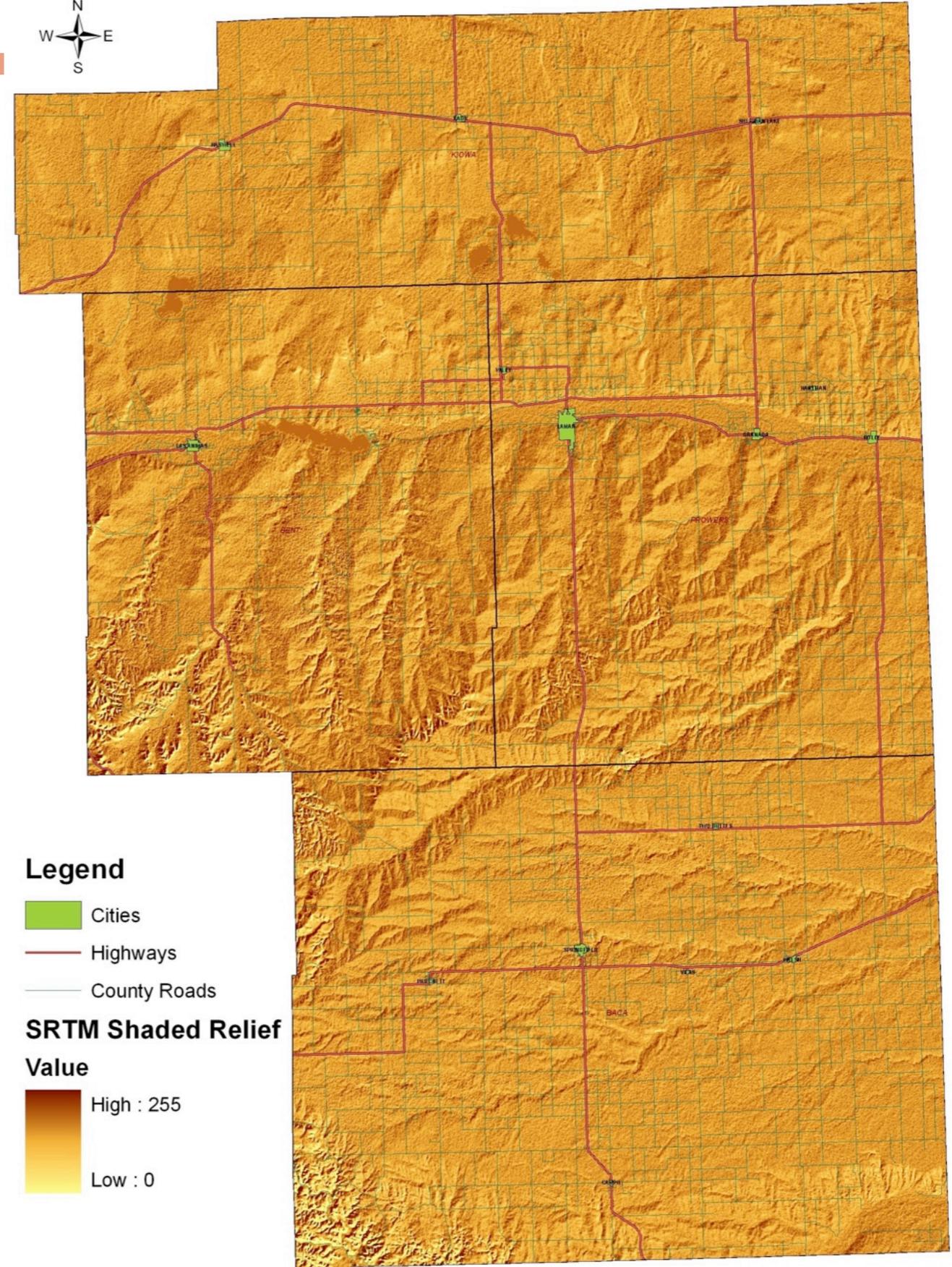
# Auger future

- Auger North (proposal in 2008)



Southern site

## SOUTHEAST COLORADO TOPO MAP Proposed Northern site





# Conclusions

- Summary

- largest exposure

- southern sky

- interesting results

Thank You!

- Prospects

- novel measurements

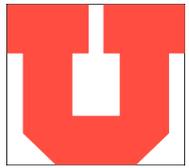
- enhance the Southern Observatory

- map sources in the North

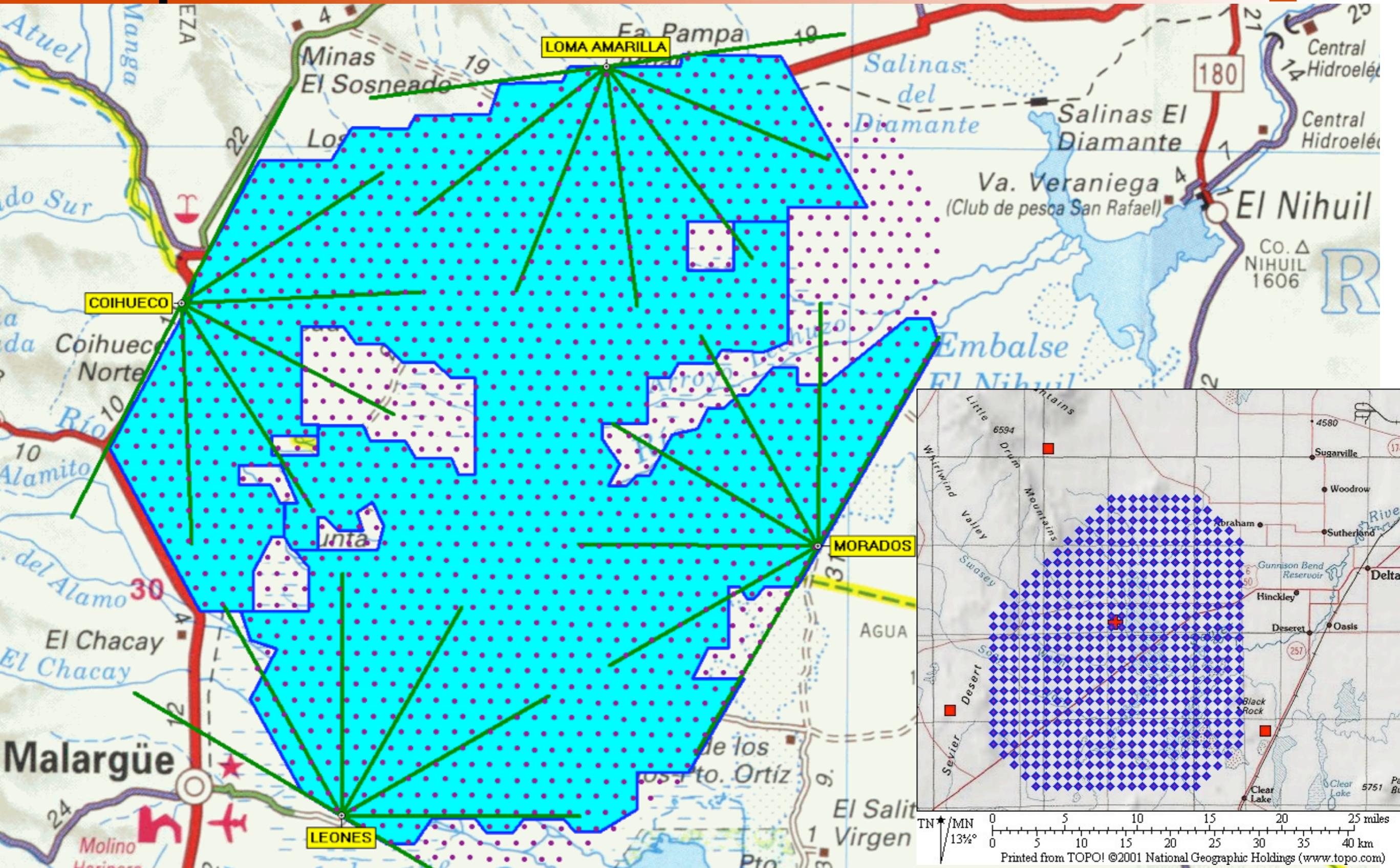


# Back up slides

Help is on the way!



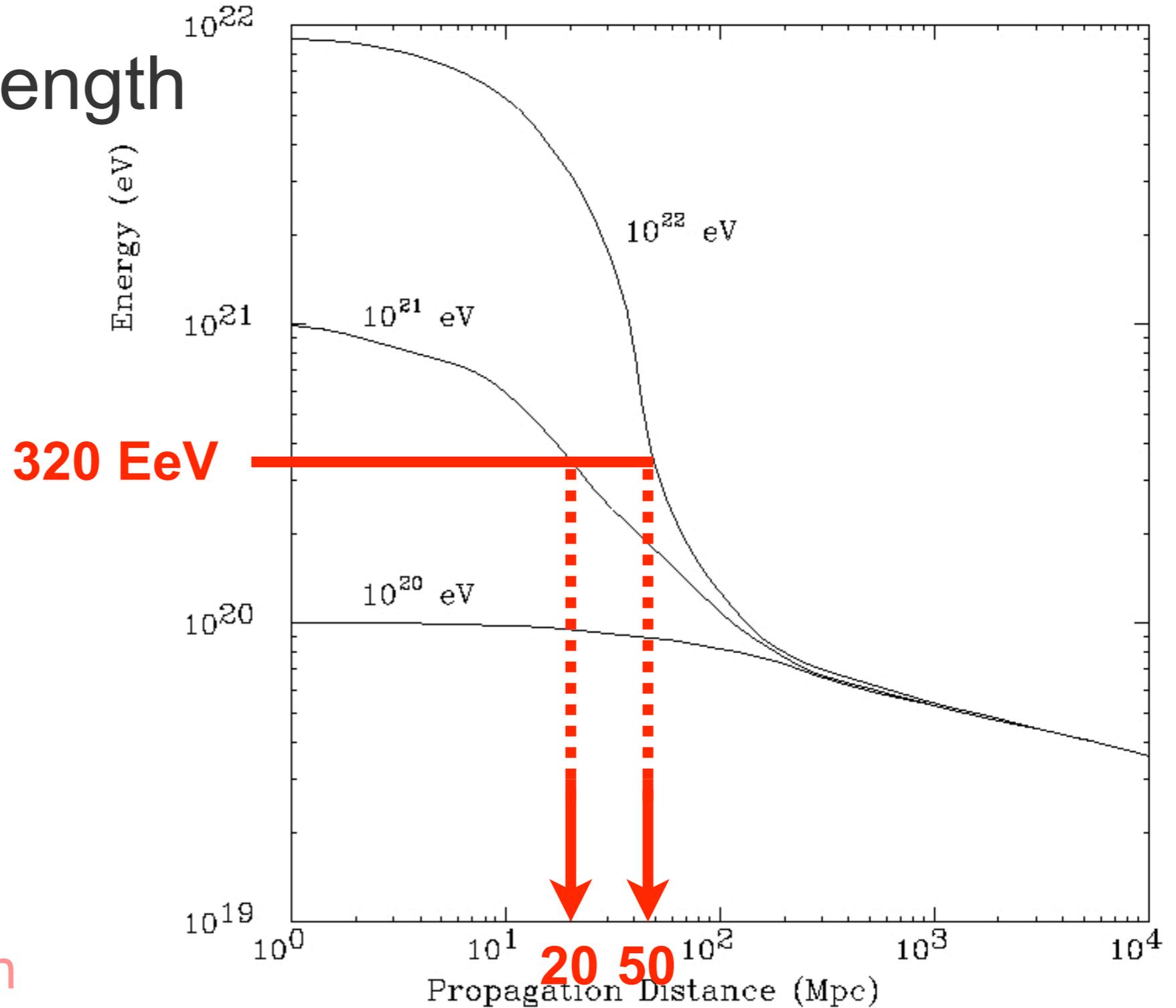
# Does size matter?

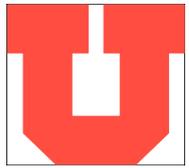




# more on GZK

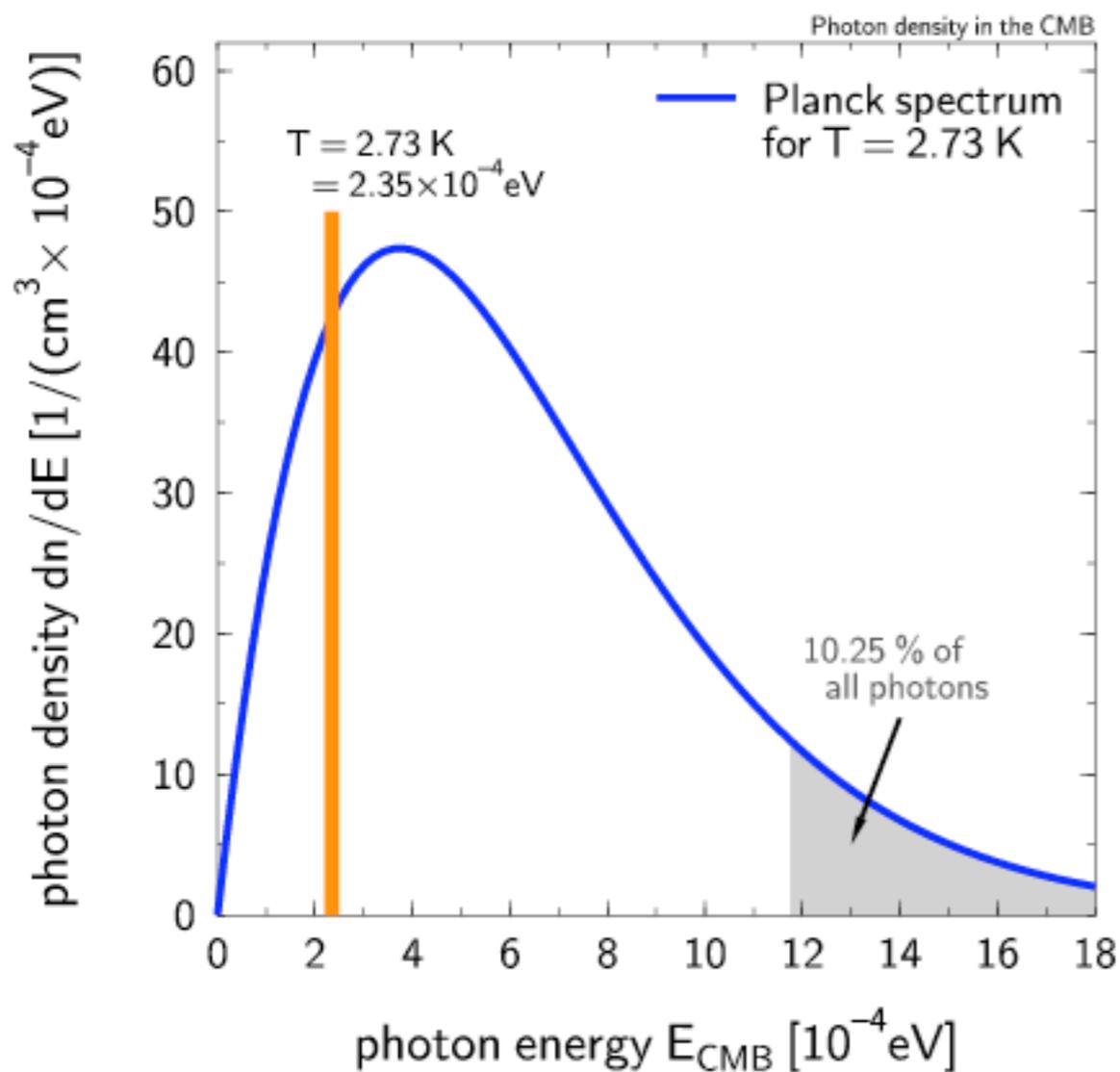
- Attenuation length



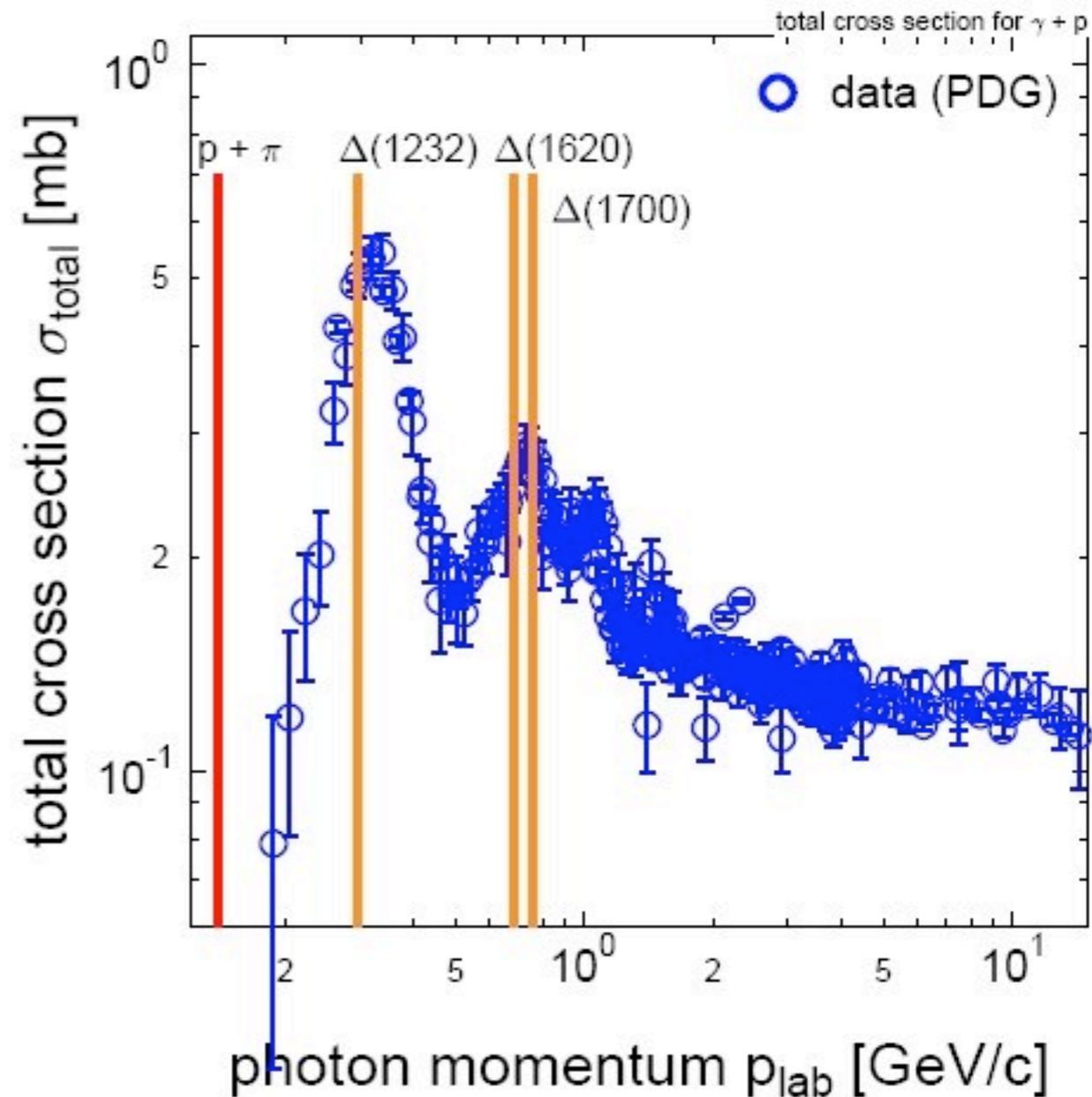


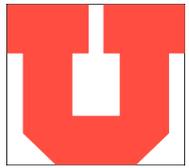
# more on GZK

## ■ photopion production



total cross section for  $\gamma + p$  collisions:





# more on ER

## ■ $X_{\max}$ and primary mass

primary protons:

$$\langle X_{\max} \rangle = D_{10} \lg(E) + \text{const}$$

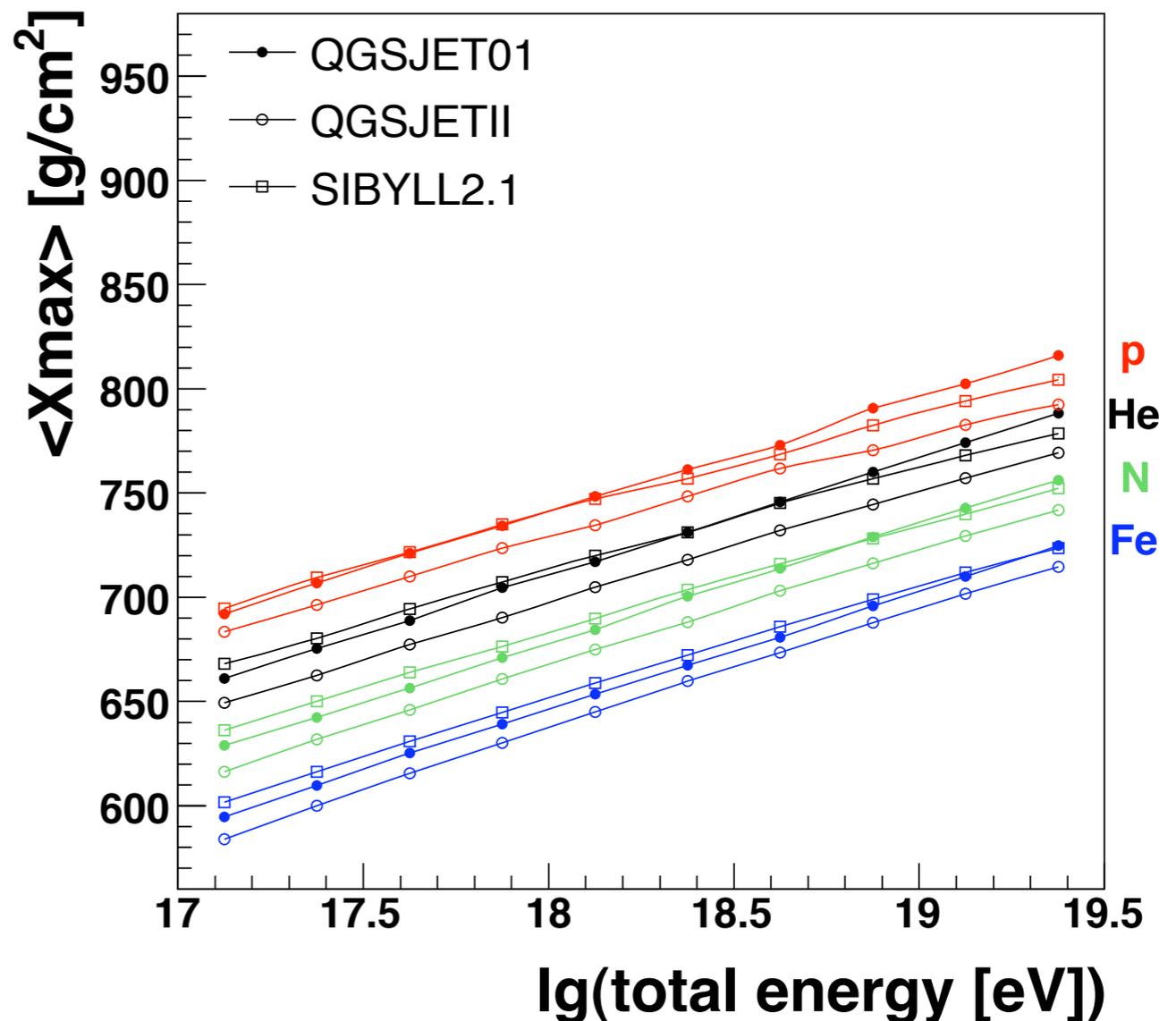
superposition model:

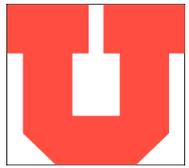
$$\langle X_{\max} \rangle = D_{10} \lg(E/A) + \text{const}$$

elongation rate theorem:

$$D_p \leq X_0 \log(10)$$

The





# more on photon fraction

- photon's elongation rate  
primary protons:

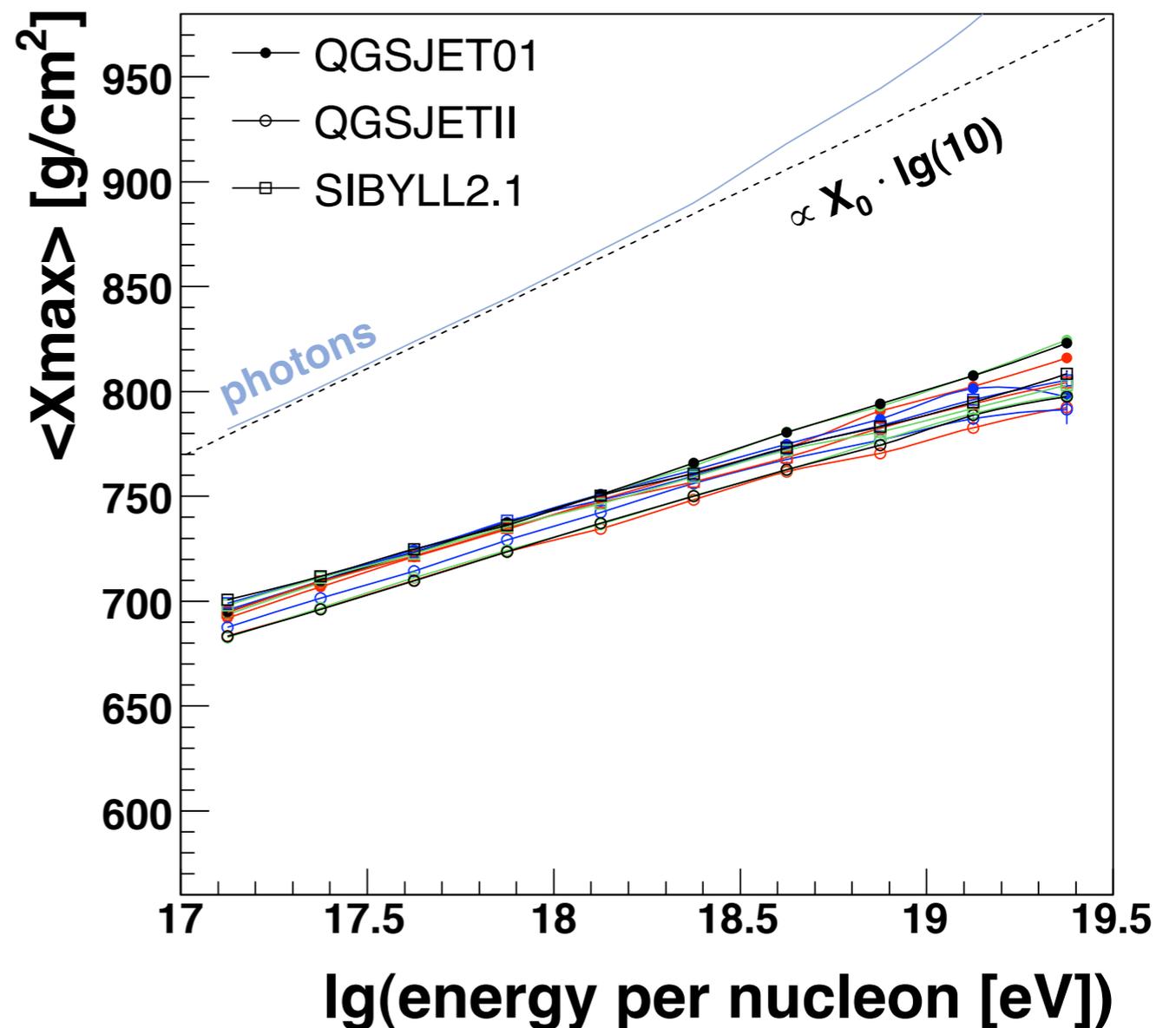
$$\langle X_{\max} \rangle = D_{10} \lg(E) + \text{const}$$

superposition model:

$$\langle X_{\max} \rangle = D_{10} \lg(E/A) + \text{const}$$

elongation rate theorem:

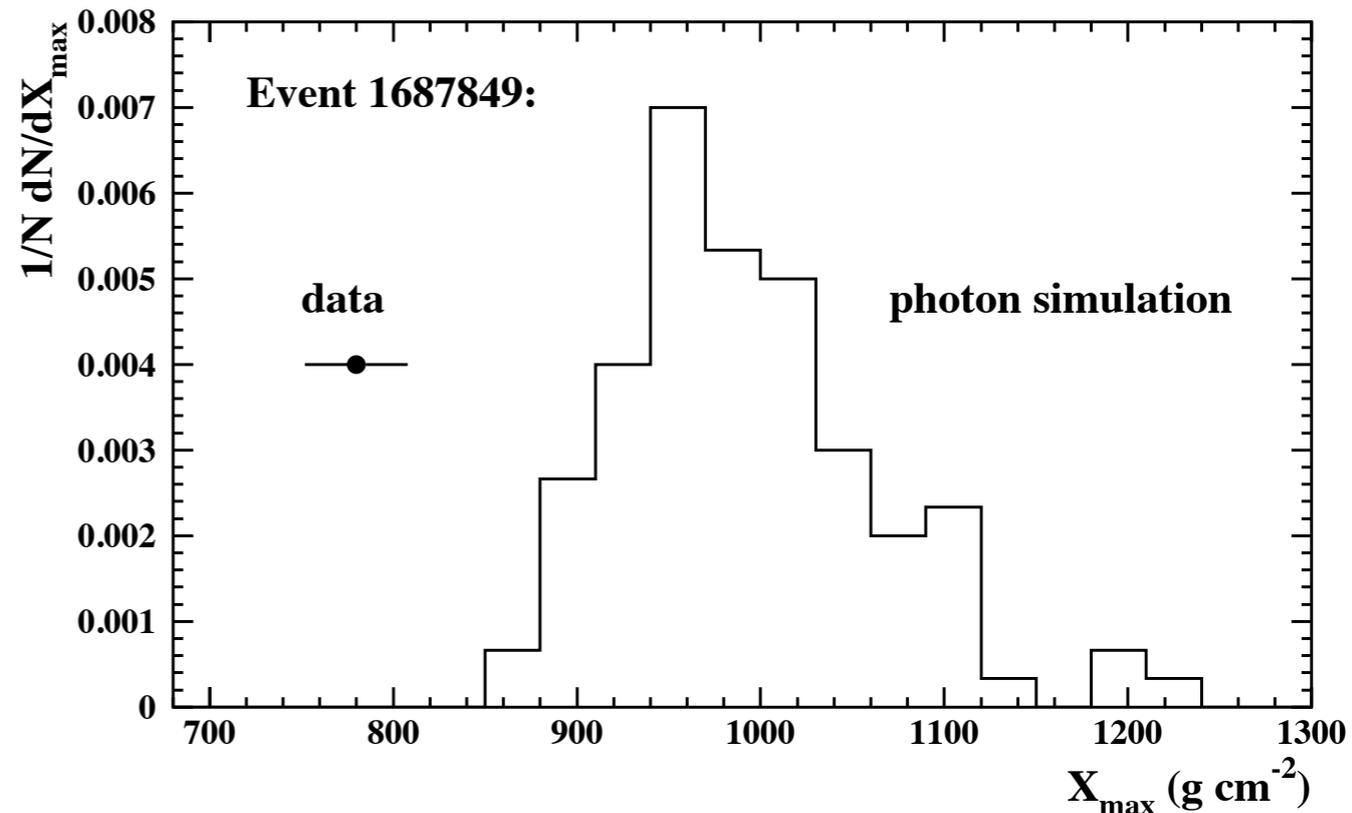
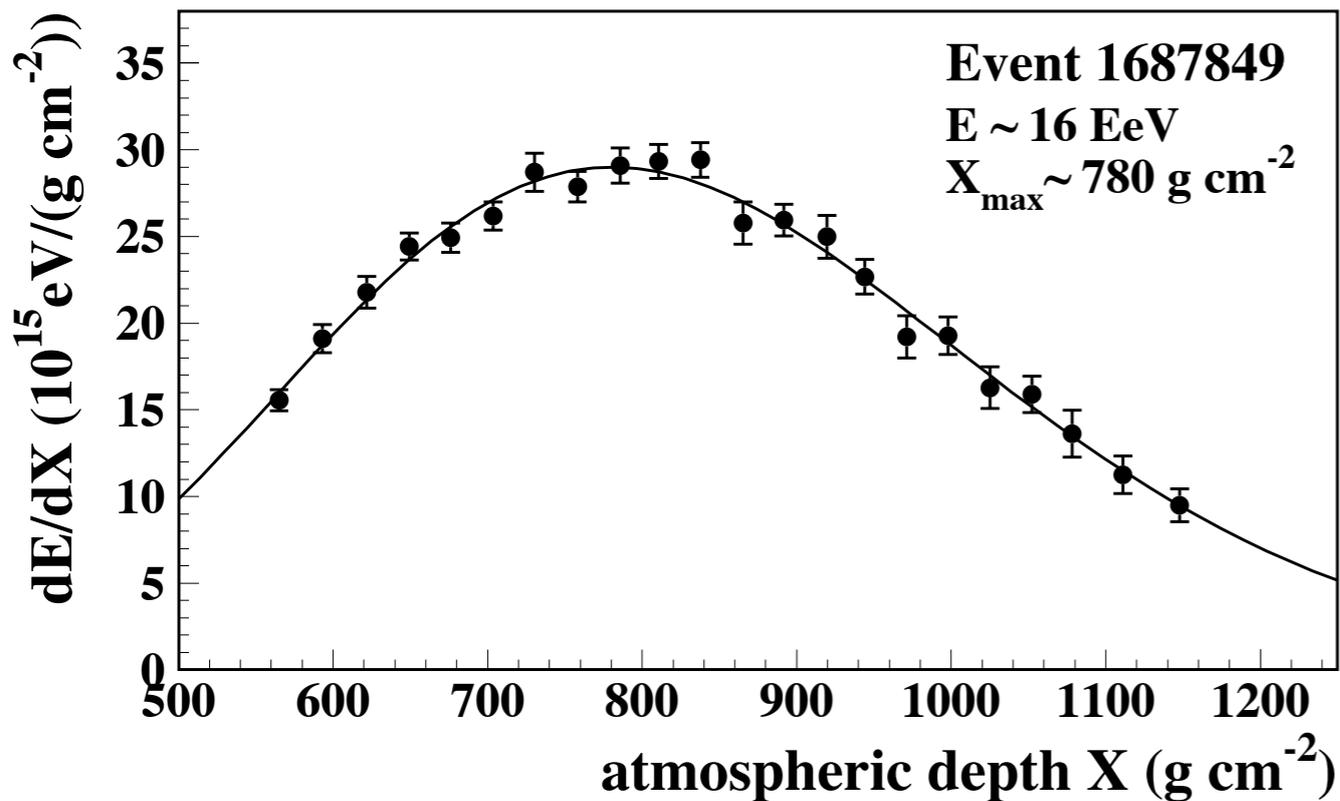
$$D_p \leq X_0 \log(10)$$

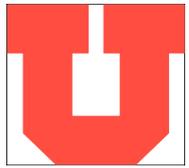




# more on photon fraction

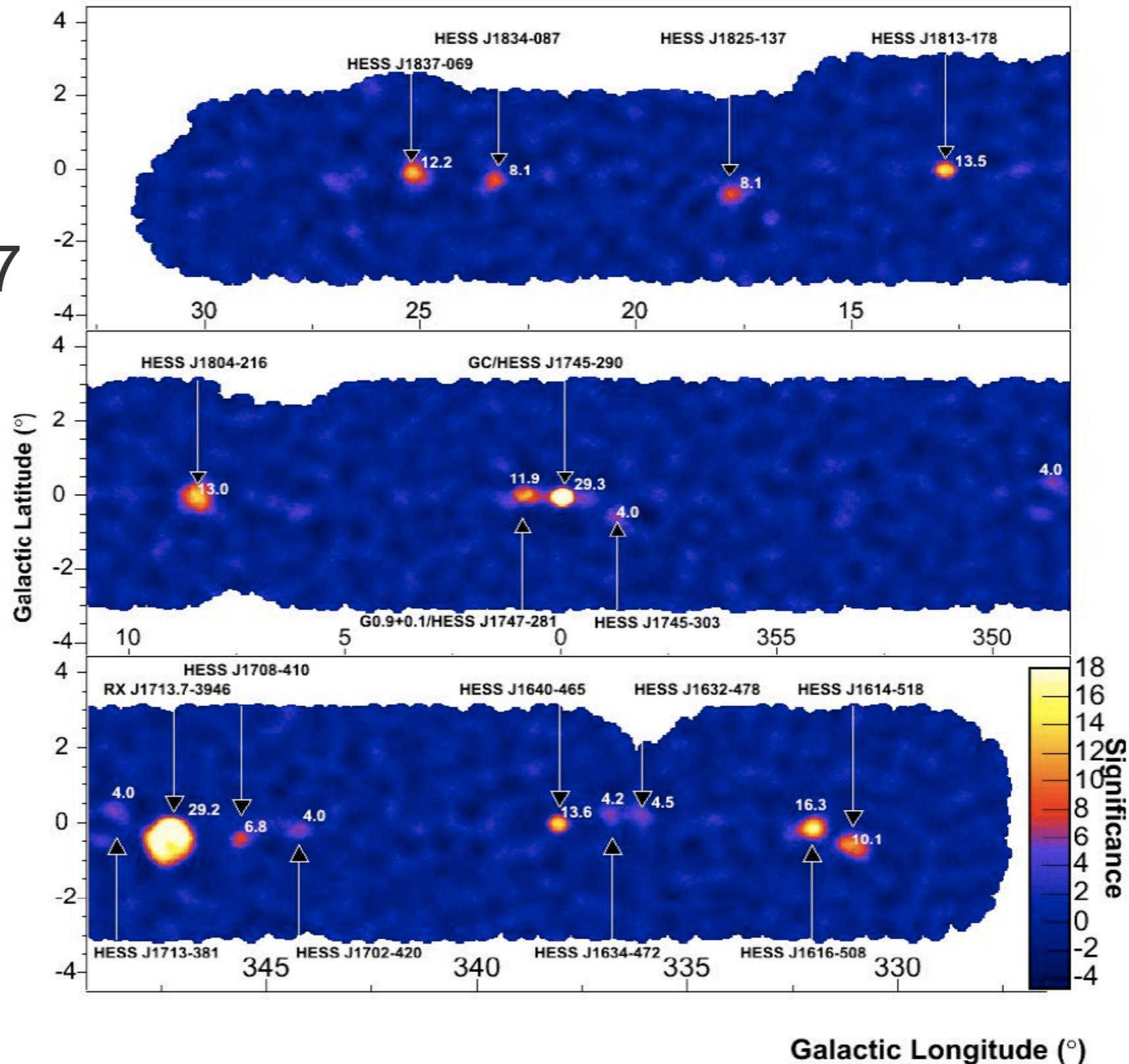
- our event selection

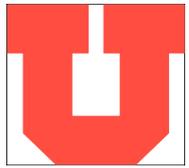




# more on galactic sources

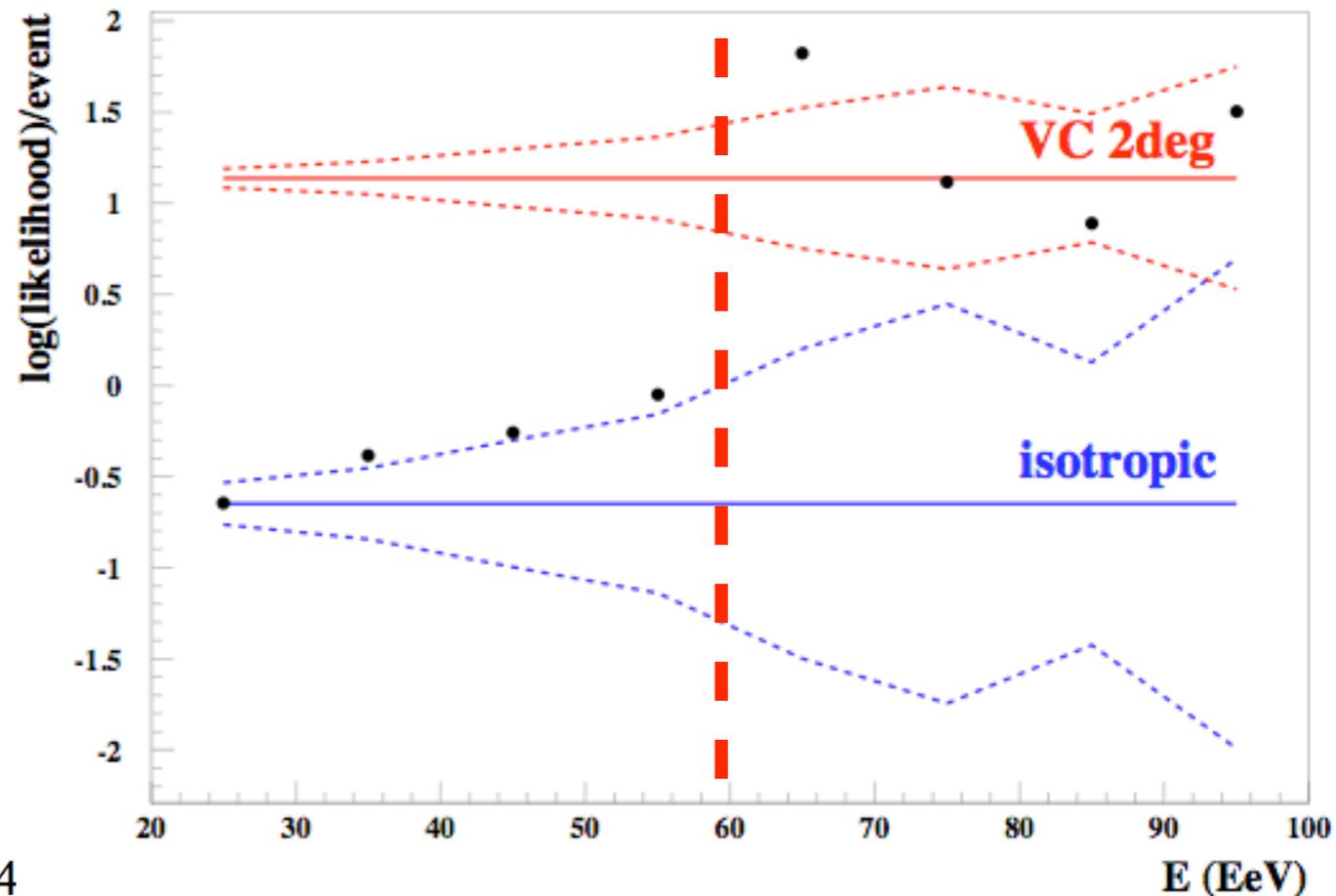
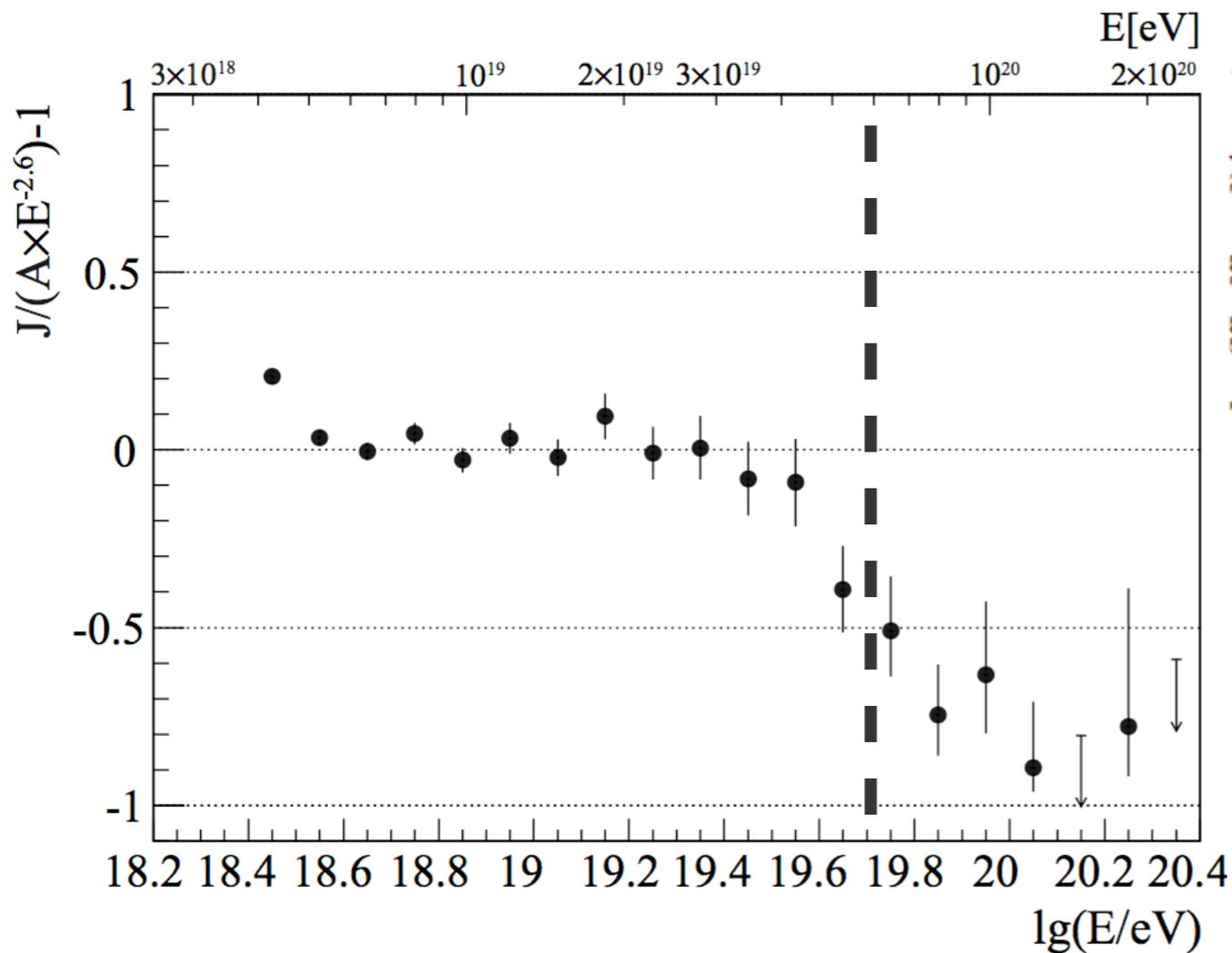
- HESS sources  
astro-ph/0510397
- Many have hard spectrum...
- are there (n or  $\gamma$ ) correlations in Auger data?

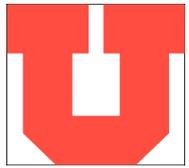




# more on AGNs

- Properties: max @ E/flux reduced by 50%

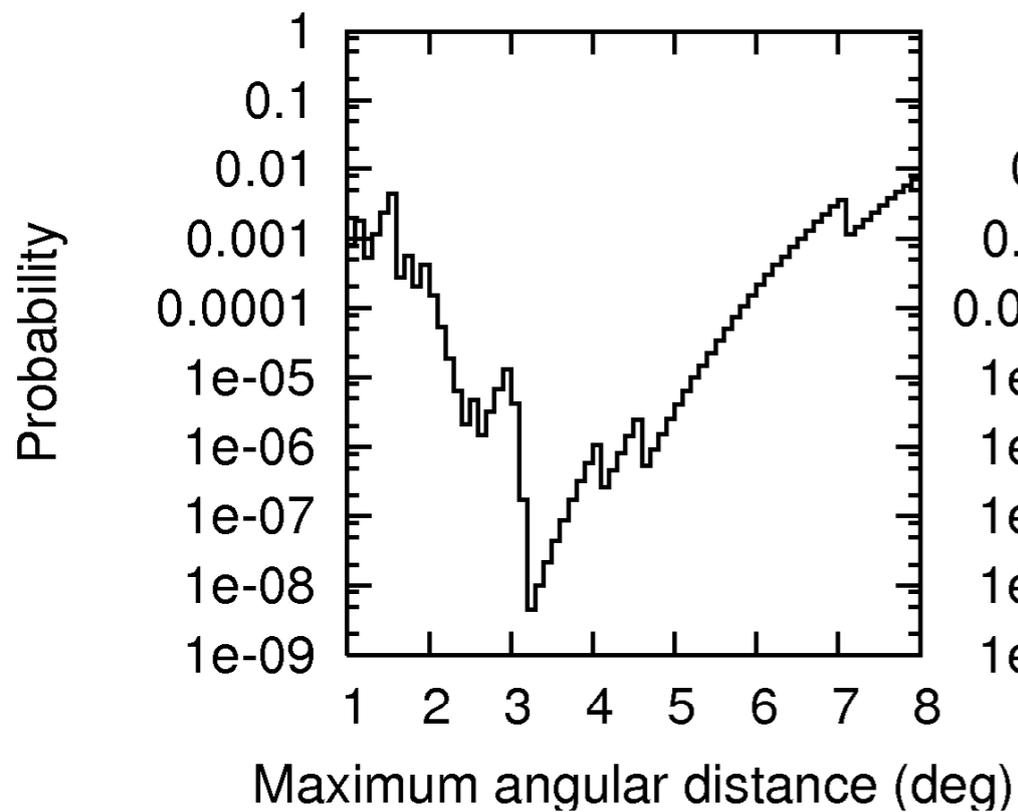




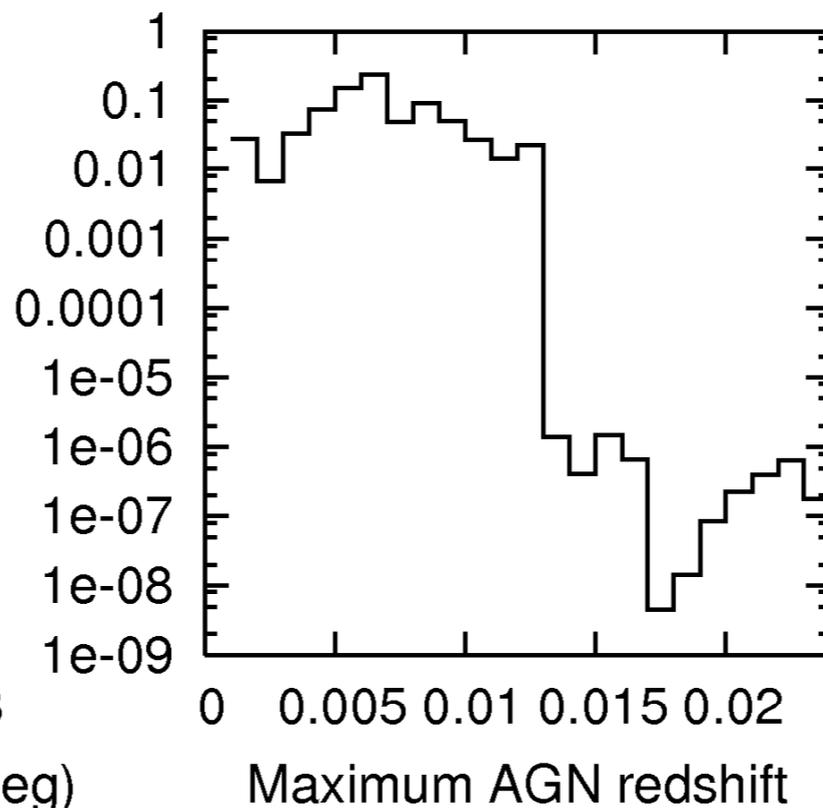
# more on AGNs

- full set scan

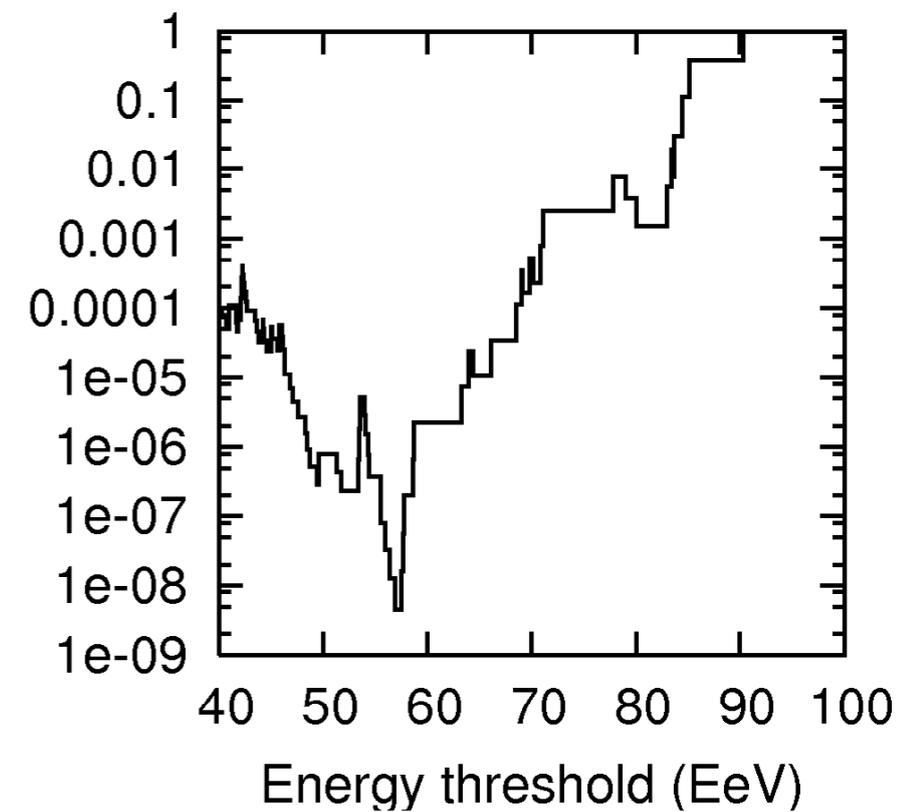
Angular Scan

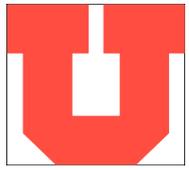


Redshift Scan



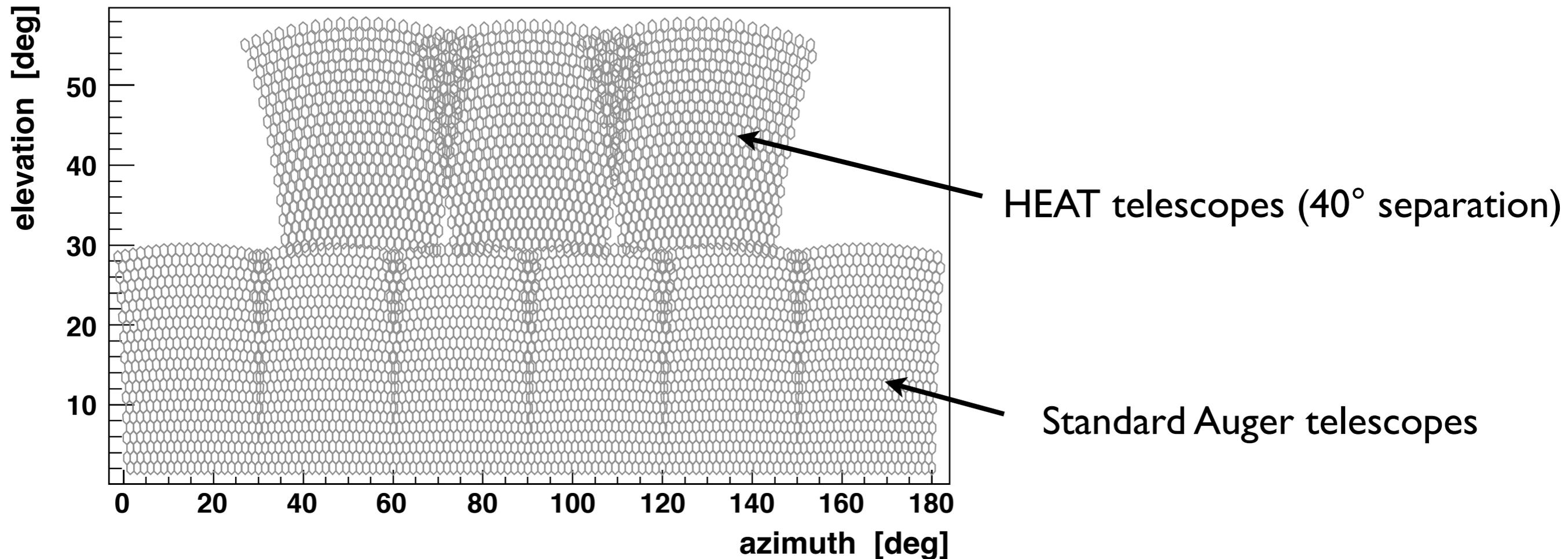
Energy Scan

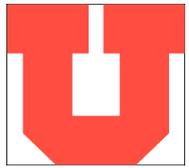




# more on HEAT

- combined field of view





# more on the enhancements

