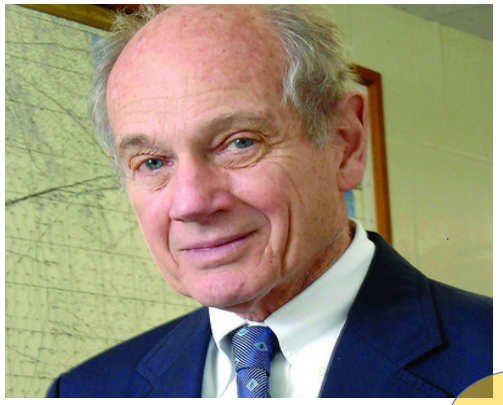
PIERRE AUGER OBSERVATORY

Presenter: Vitor de Souza
vitor@ifsc.usp.br

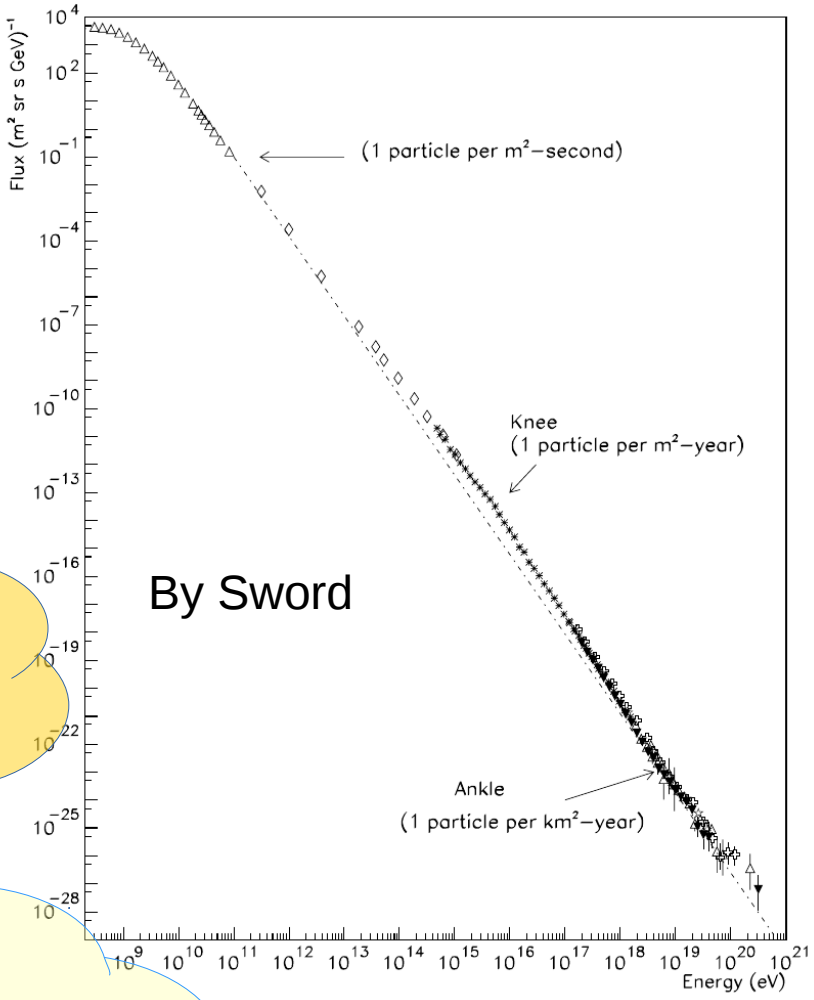
UNIVERSIDADE DE SÃO PAULO

FAPESP

1991: The idea was born



Let a thousand flowers blossom.



By Sword

Thousand and five hundred water Cherenkov detectors in the desert.


Santiago
Mendoza
Córdoba
Córdoba
Mendoza
San Luis
Argentina
Neuquén
La Pampa
Image © 2007 TerraMetrics
© 2007 Europa Technologies
Image NASA
©2007 Google™

Highlights from Auger

NOT mentioned in this talk

- Target search for neutron sources
- Target search for gamma-ray sources
- Upper limits on neutrino flux
- Neutrino coincidence with gravitational waves
- Hadronic interaction tests
- Radio signal from air-showers
- Atmospheric science
- Upper limits on monopoles

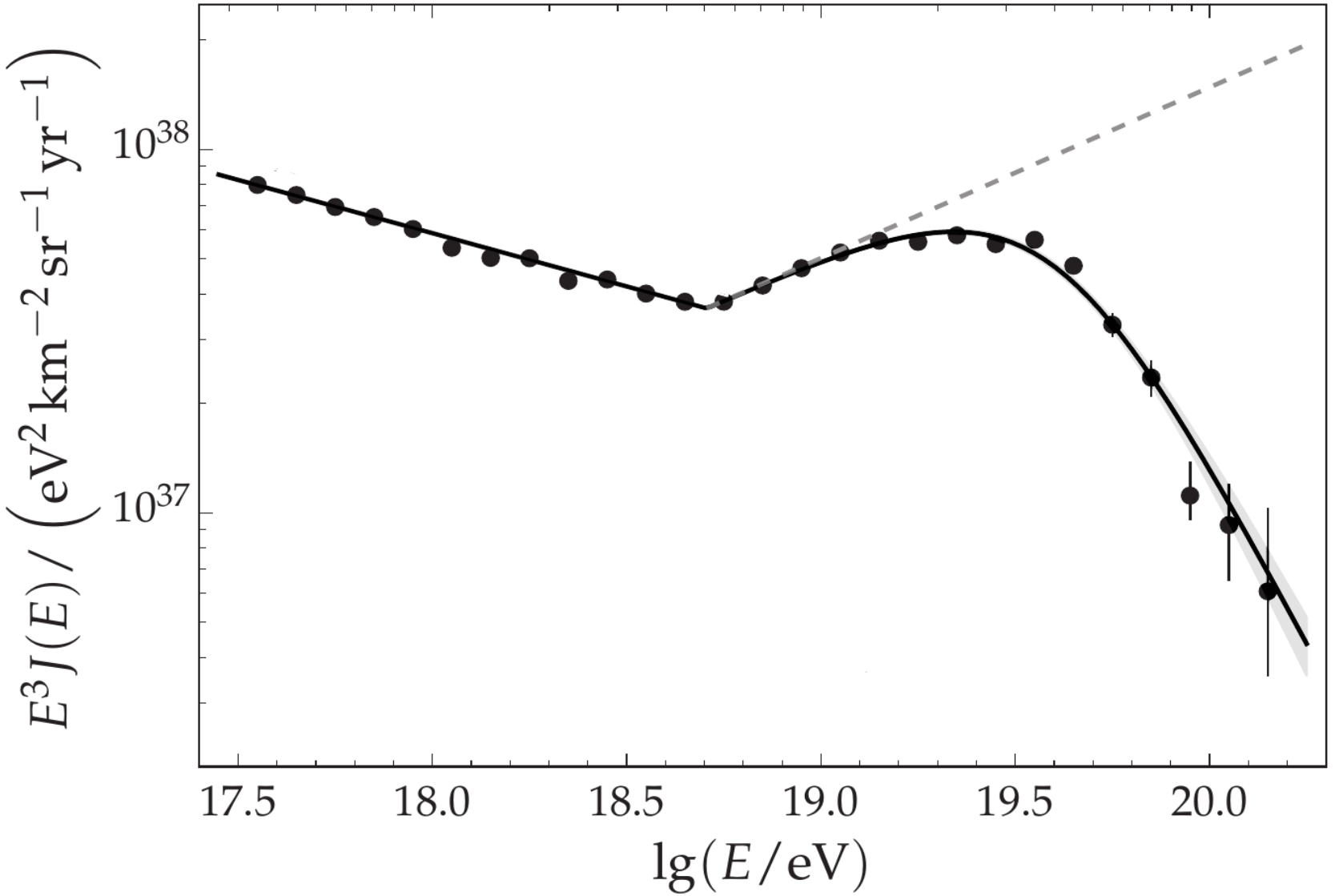
https://www.auger.org/index.php/science/journal-articles

Highlights from Auger
mentioned in this talk

1. Flux supression
2. Exotic scenarios ruled out
3. Proton-air cross section @ $\sqrt{s} = 57\,TeV$
4. Air showers with muons excess
5. **Challenging level of isotropy with a dipole**
6. **Unexpected mass composition**

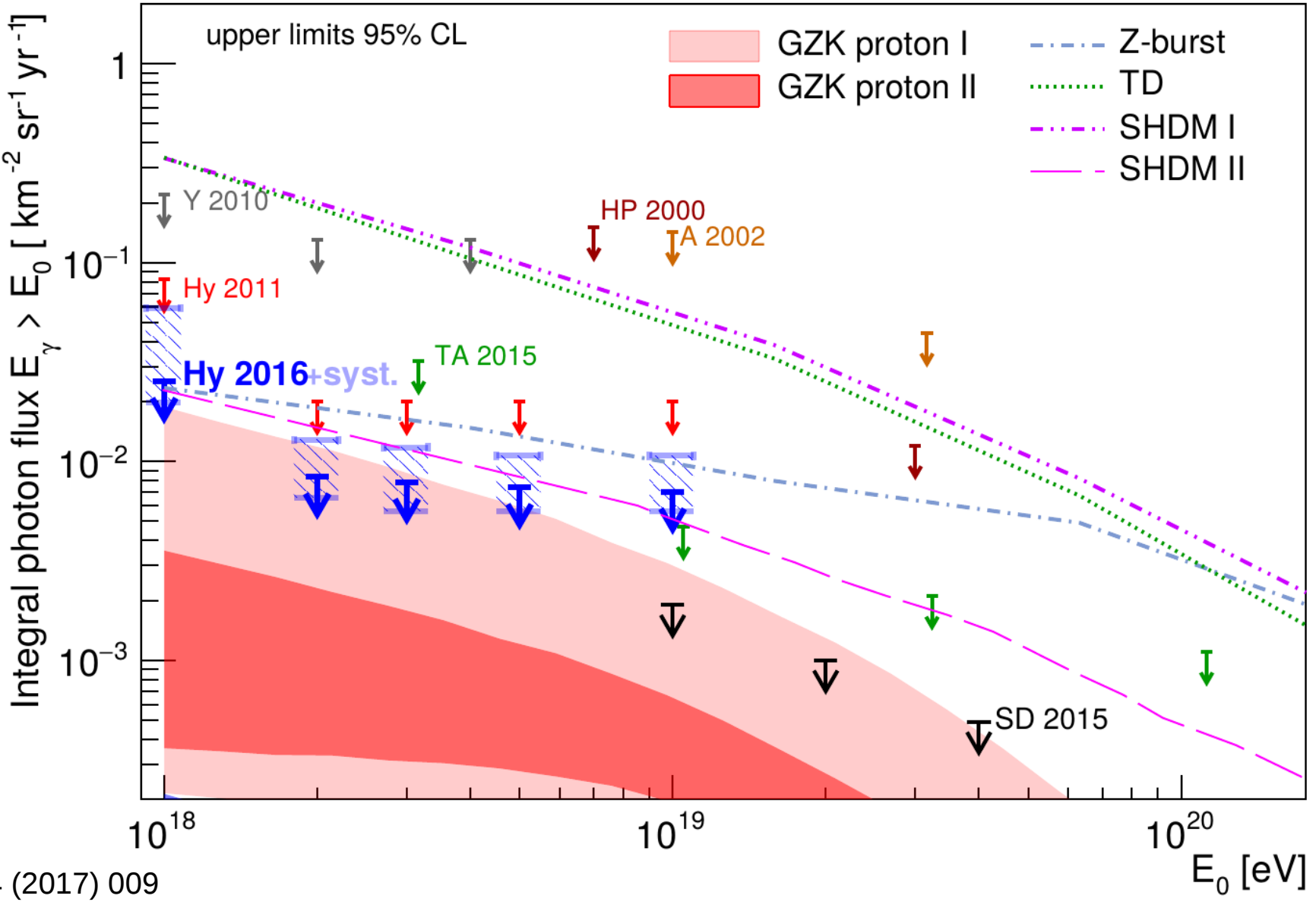
Highlights from Auger

1/6 Flux supression



Highlights from Auger

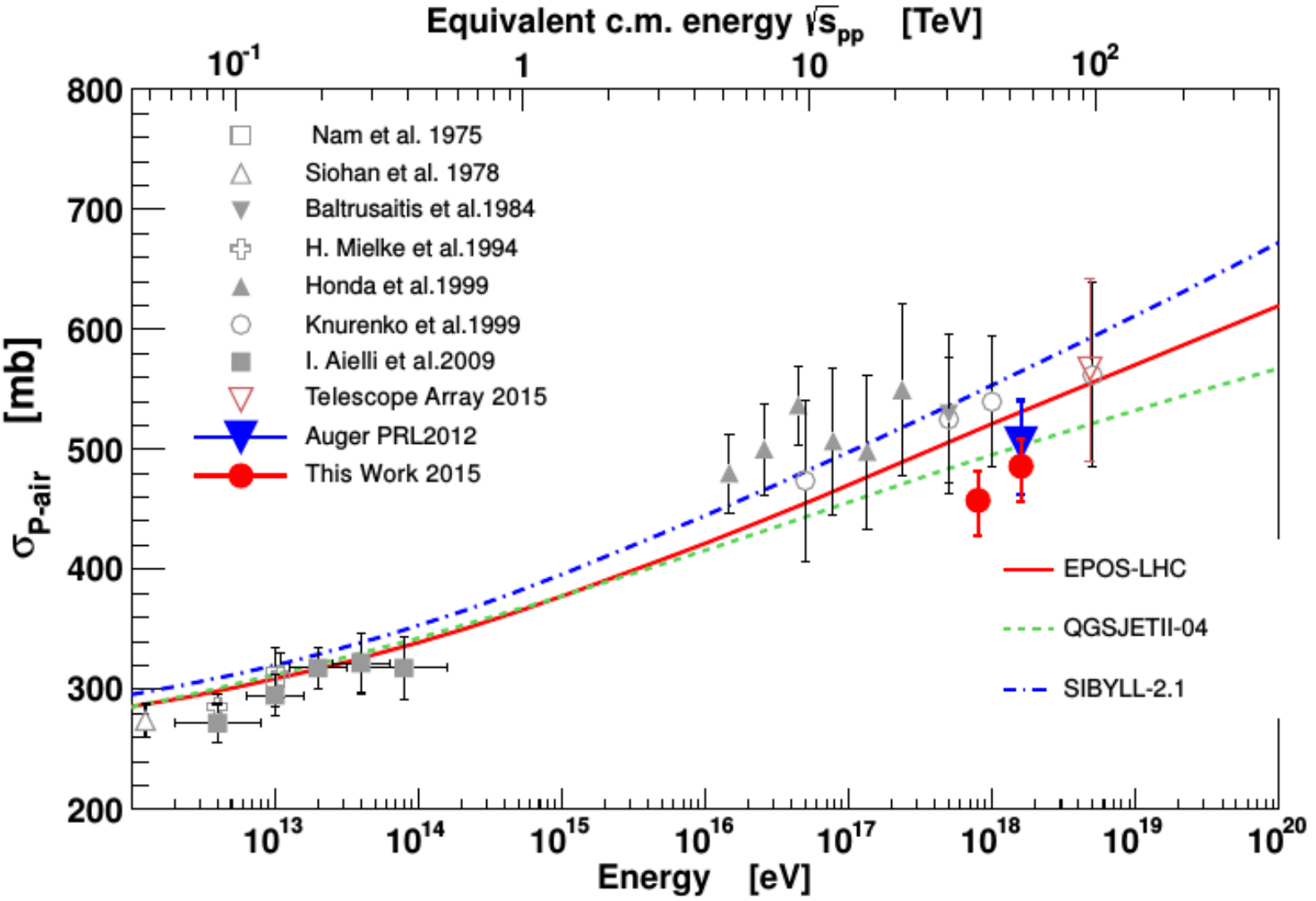
2/6 Exotic scenarios ruled out



JCAP 04 (2017) 009

Highlights from Auger

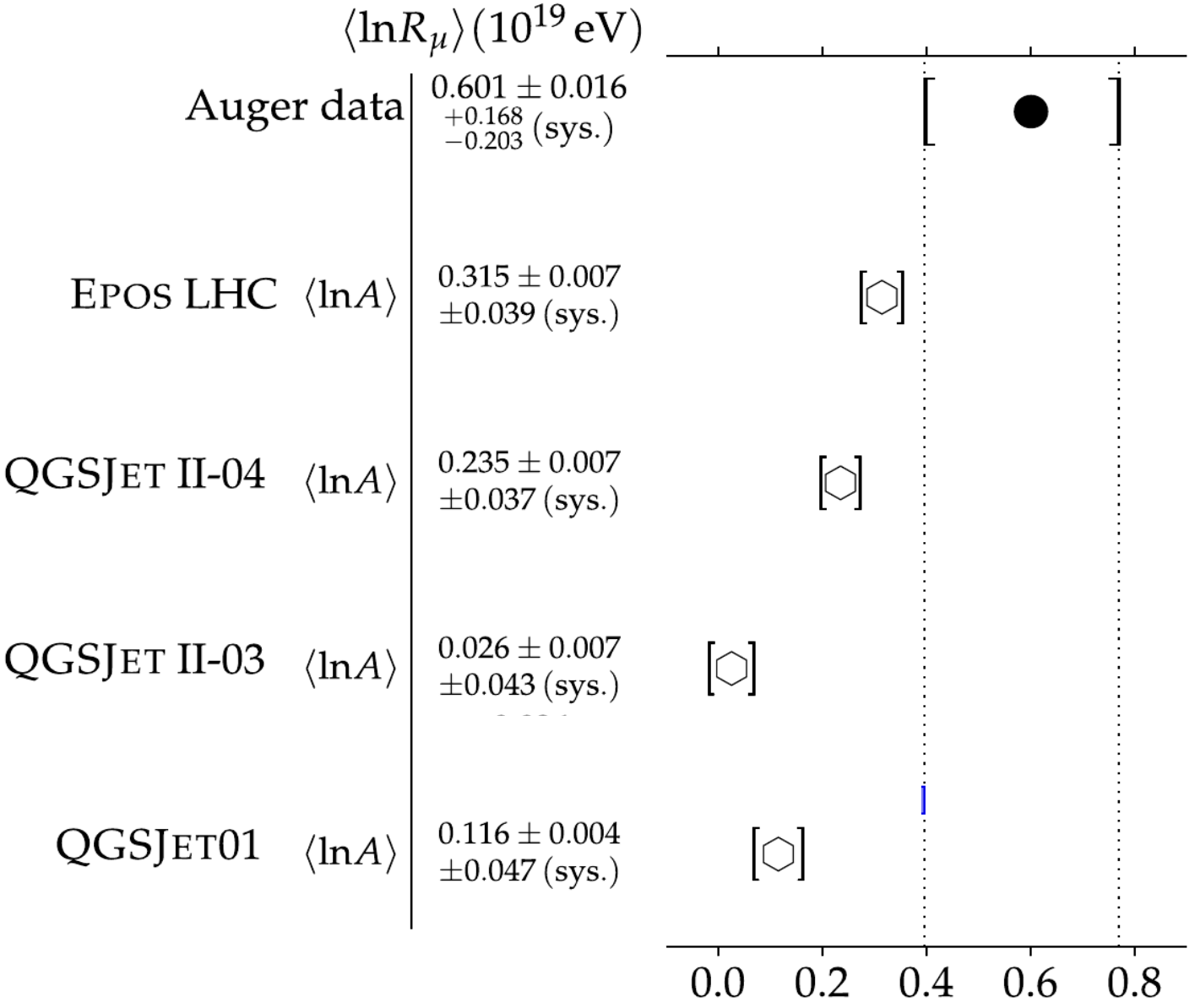
3/6 Proton-air cross section @ $\sqrt{s} = 57\,TeV$



Phys. Rev. Lett. 109, 062002 (2012)

Highlights from Auger

4/6 Air showers with muon excess



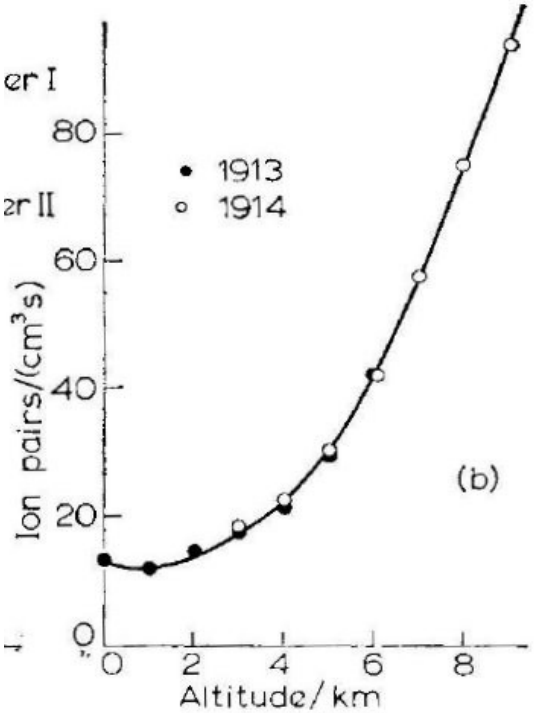
Physical Review D 91, 032003 (2015)

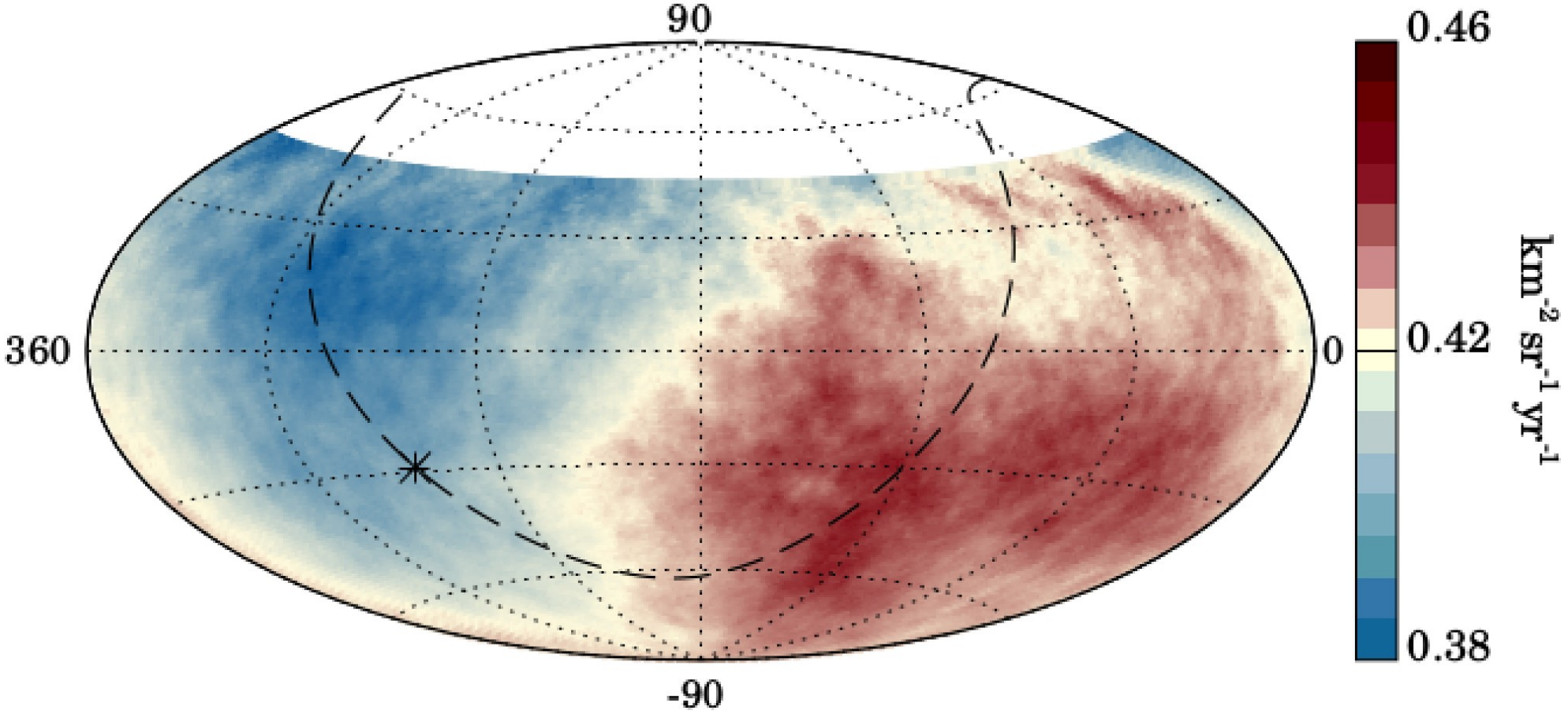
Highlights from Auger

5/6 Challenging level of isotropy with a dipole

Where do they come from ?

"decreases at nearly 300 m [altitude to] not even to half of its ground value".



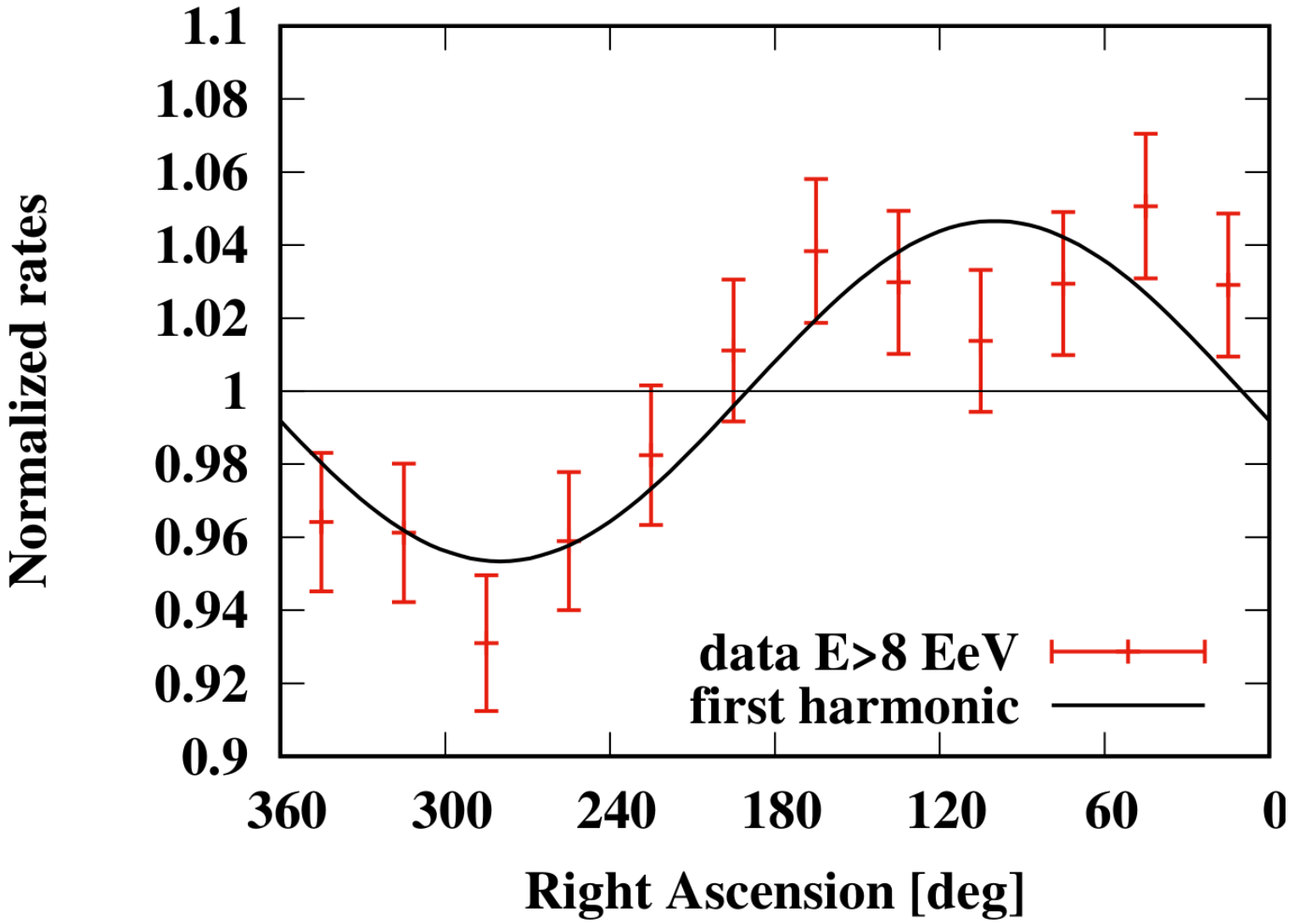


Equatorial coordinates - Hammer projection - E > 8 EeV

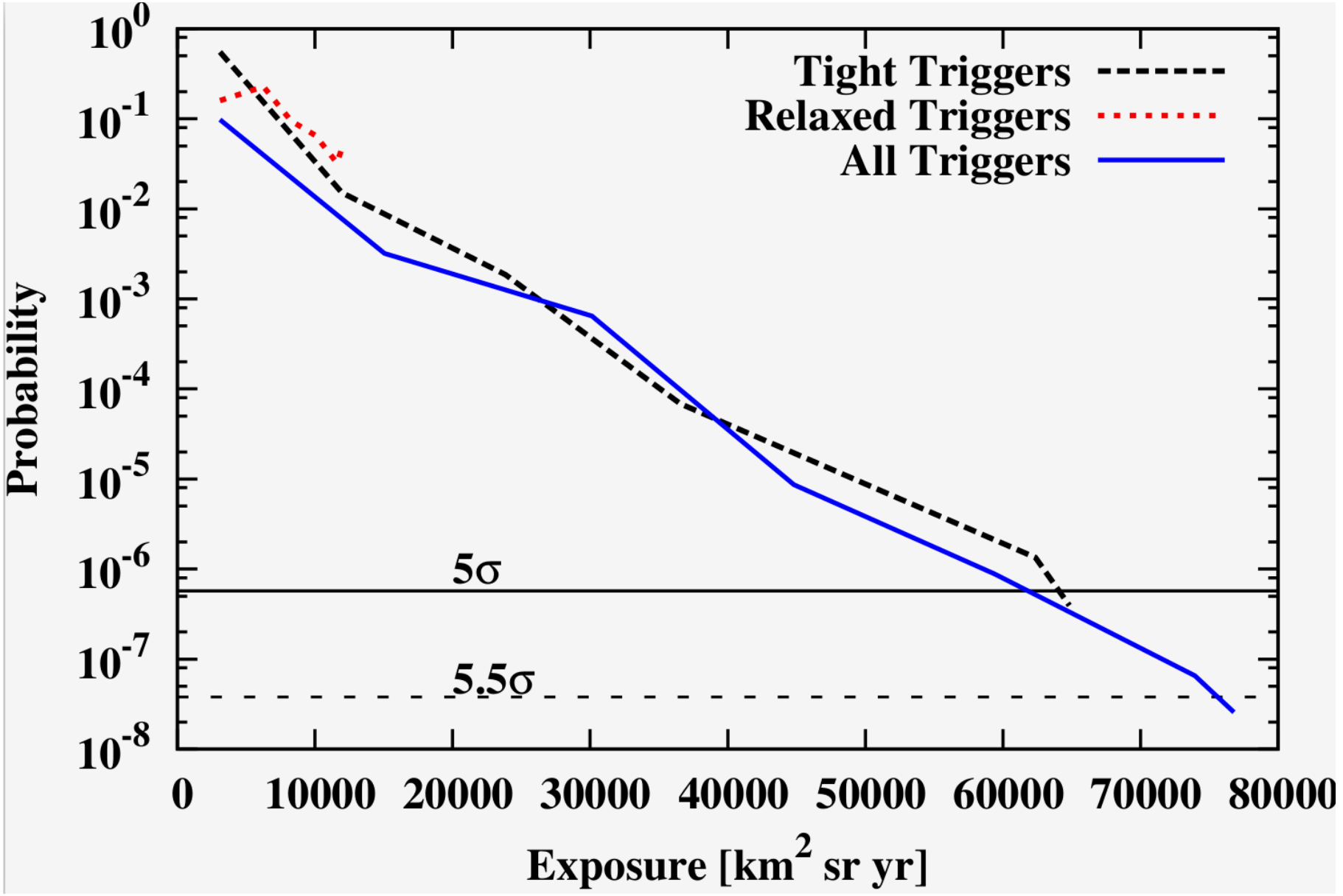
* Galactic center

\- - - Galactic plane

Science 357 (2017) 1266-1270



Science 357 (2017) 1266-1270



Science 357 (2017) 1266-1270

Arrival Direction Highlights from Auger

Centaurus A: 3σ excess

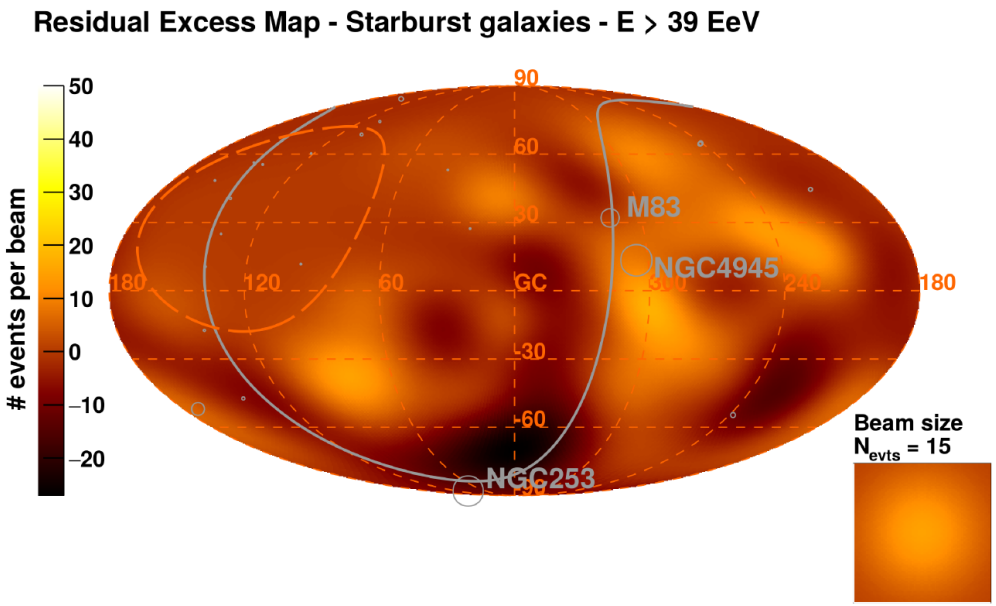
- E > 60 EeV — 15º window

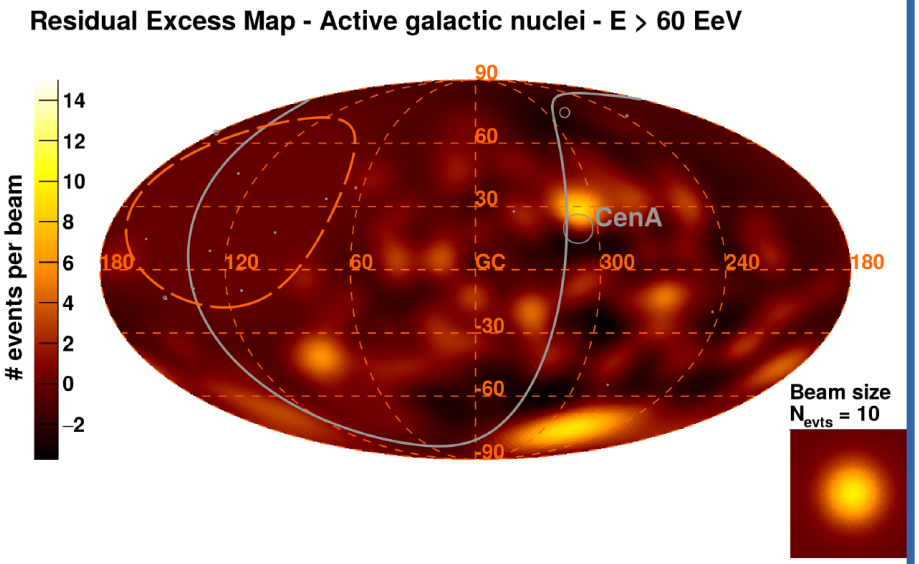
AGN: 2.7σ excess

- E > 63 EeV — 16º window

Starburst galaxies: 4σ excess

- E > 39 EeV — 7º window





Extragalatic origin favored:

- E > 8 EeV
- Anisotropy at 5.2σ level
- Dipole fits the data
  - Amplitude: 6.5
  - Direction: $\alpha = 100^{\circ}$ and $\delta = -24^{\circ}$

Highlights from Auger

6/6 Unexpected mass composition

What are they ?

The New York Times

VOL. LXXXII....No. 27,370. December 31, 1932

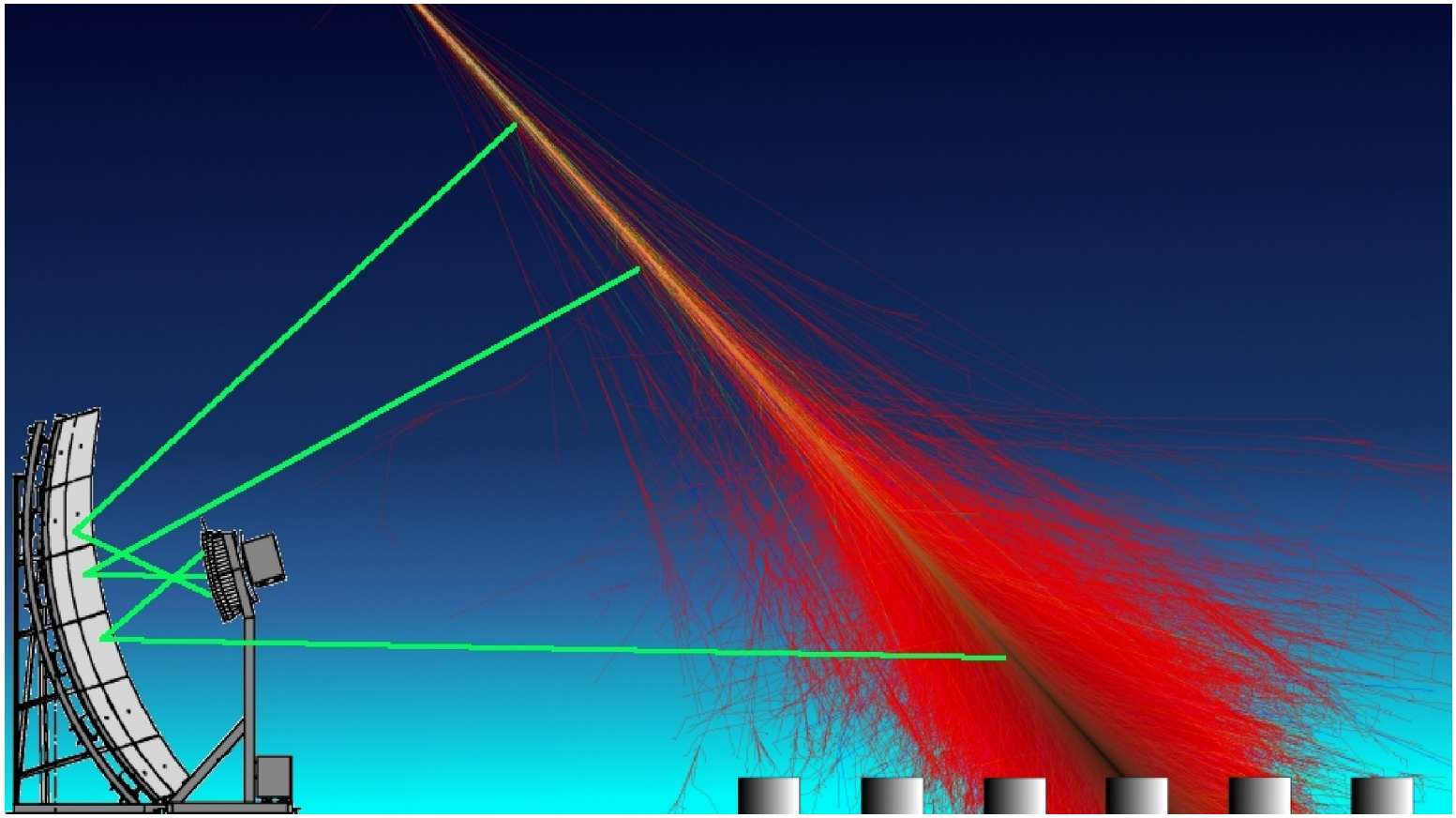
MILLIKAN RETORTS HOTLY TO COMPTON IN COSMIC RAY CLASH

Debate of Rival Theorists Brings Drama to Session of Nation's Scientists.

THEIR DATA AT VARIANCE

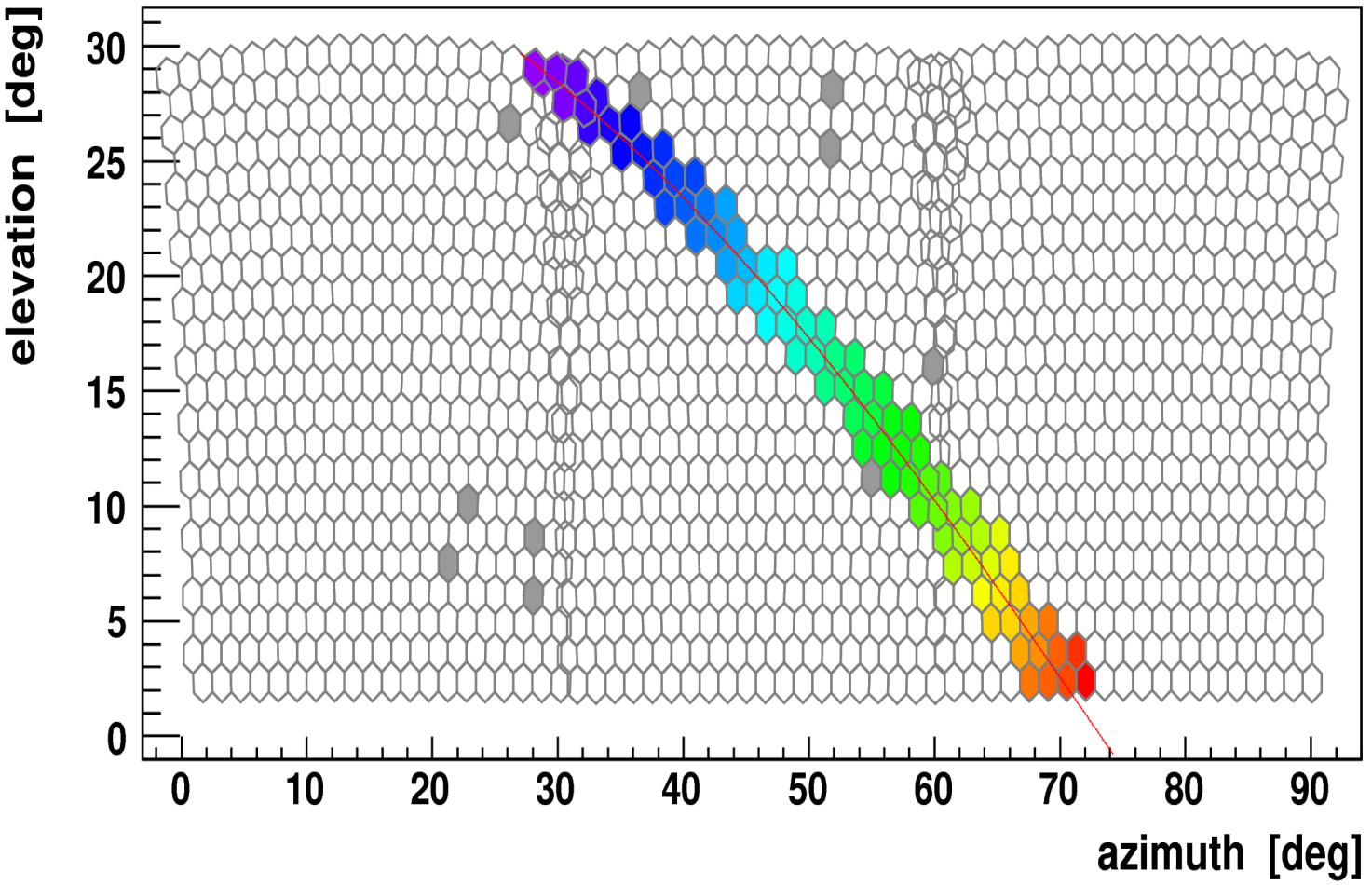
New Findings of His Ex-Pupil Lead to Thrust by Millikan at 'Less Cautious' Work.

Telescope view



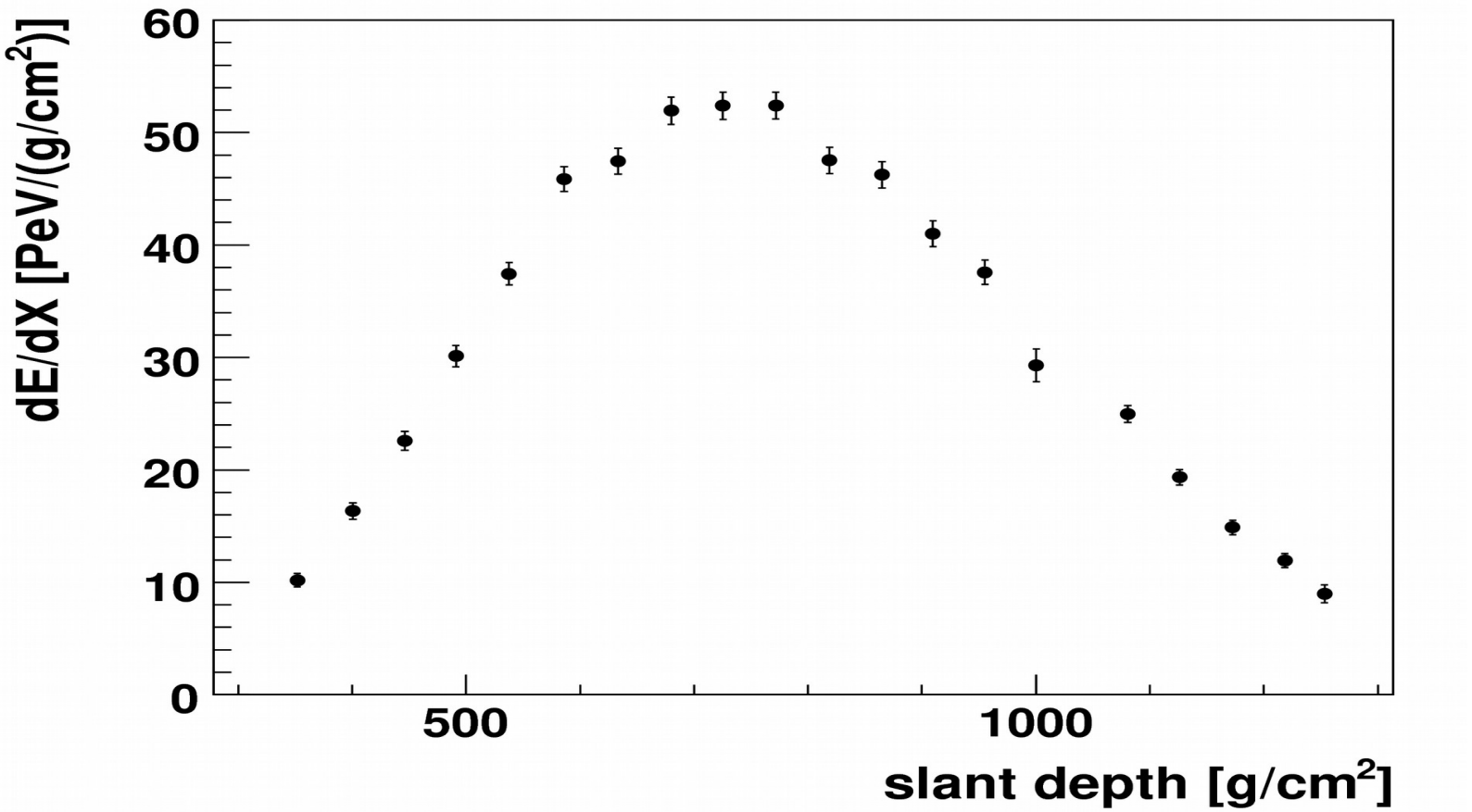
Telescopes measure the intensity and arrival time of the fluorescence light

Camera view



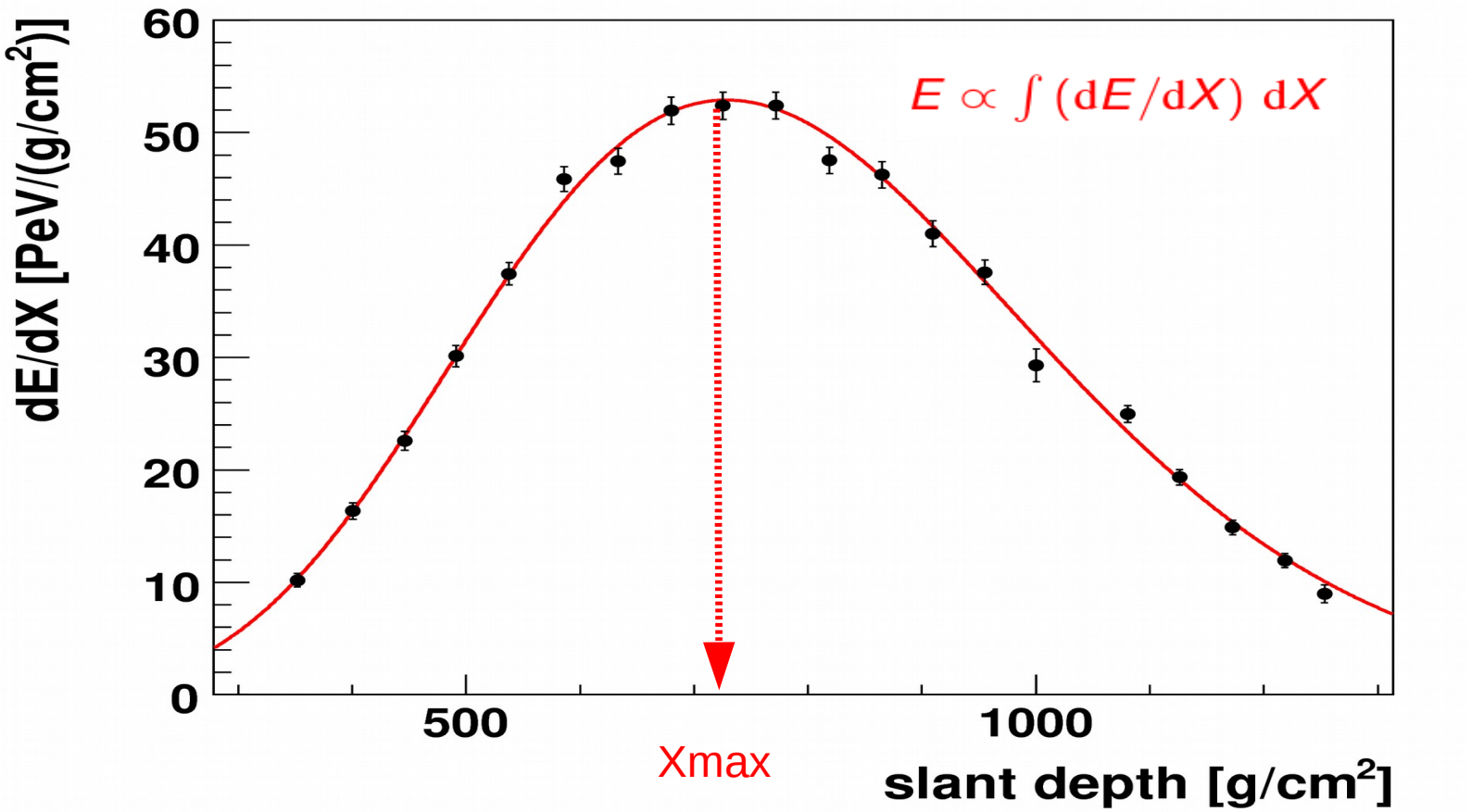
Telescopes measure the intensity and arrival time of the fluorescence light

Longitudinal Profile

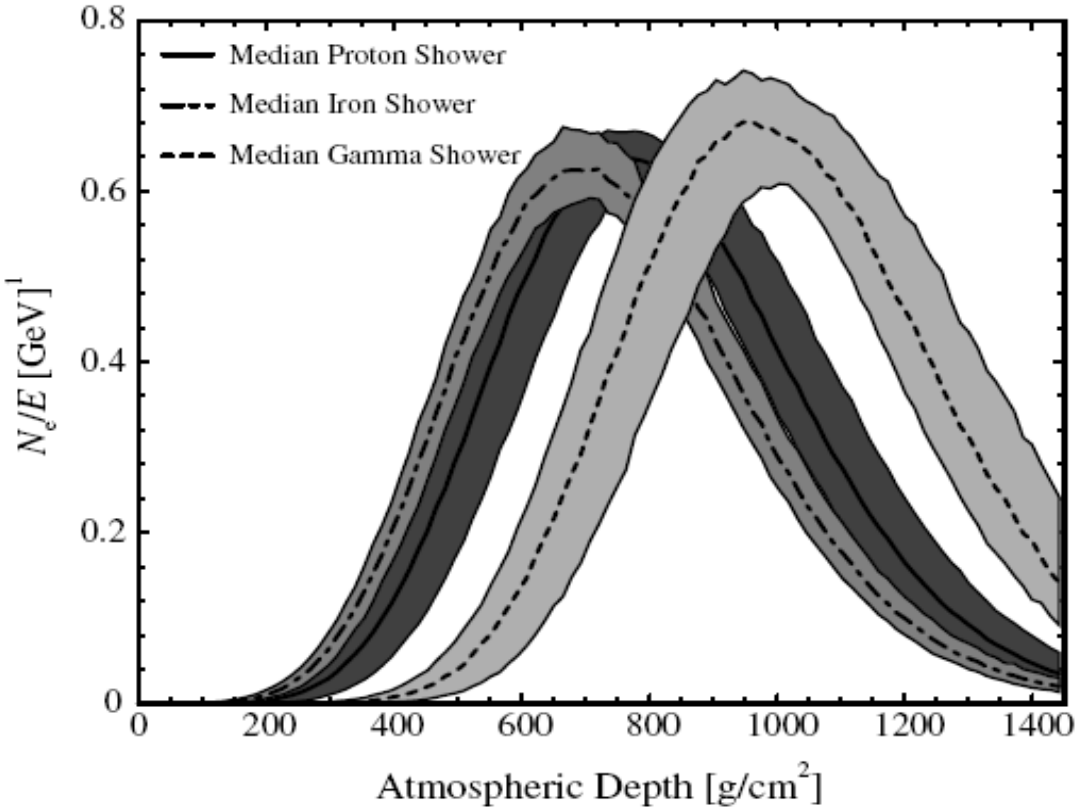


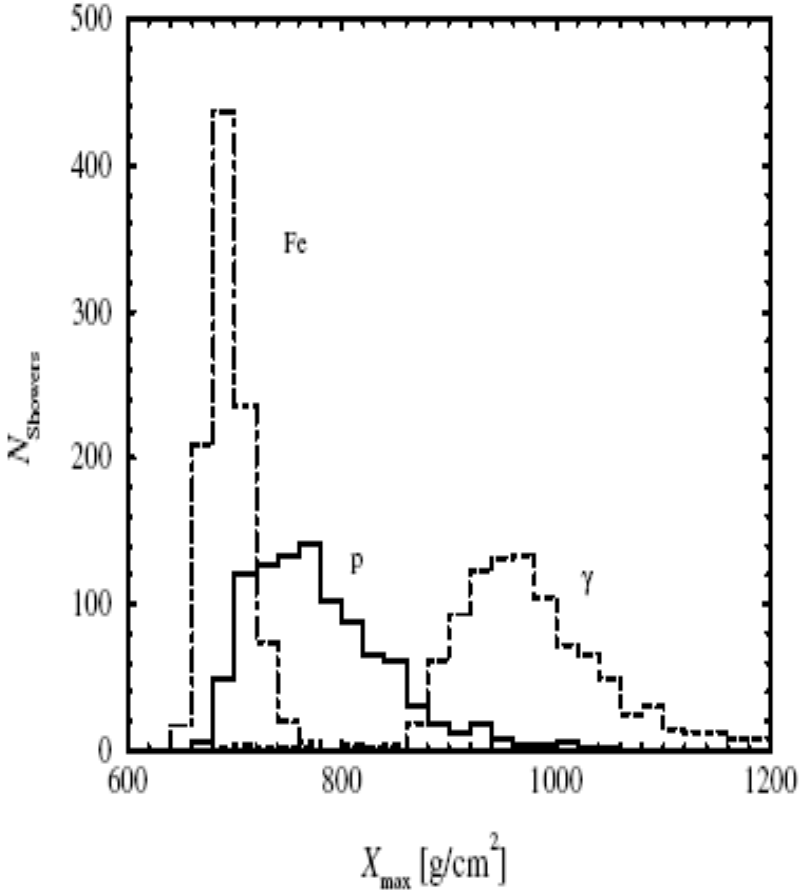
The intensity as a function of elevation can be transformed into the energy deposited in the atmosphere as a function of depth

Fitting the Longitudinal Profile



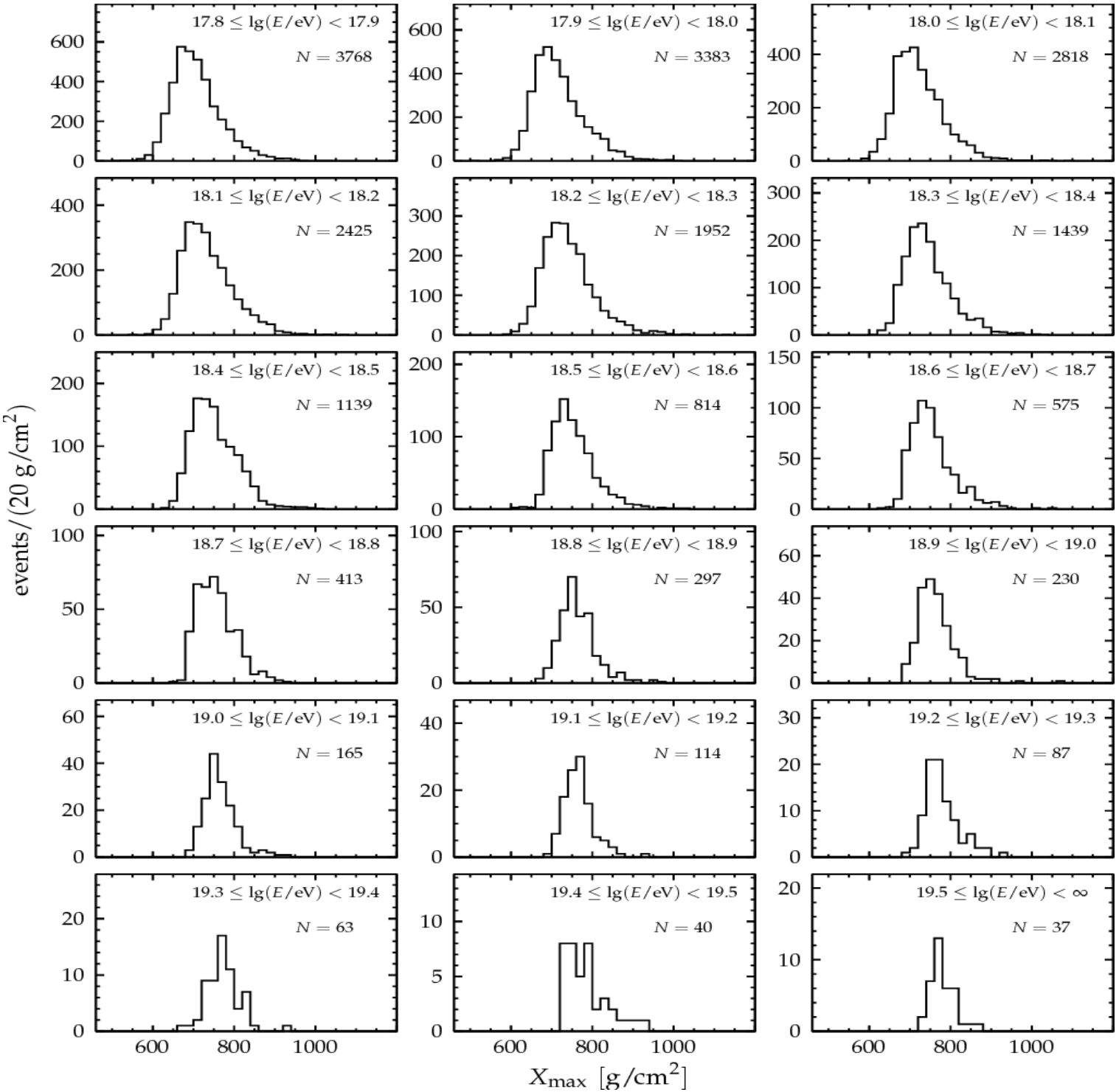
The total calorimetric energy of the shower is proportional to the integral of the energy deposited

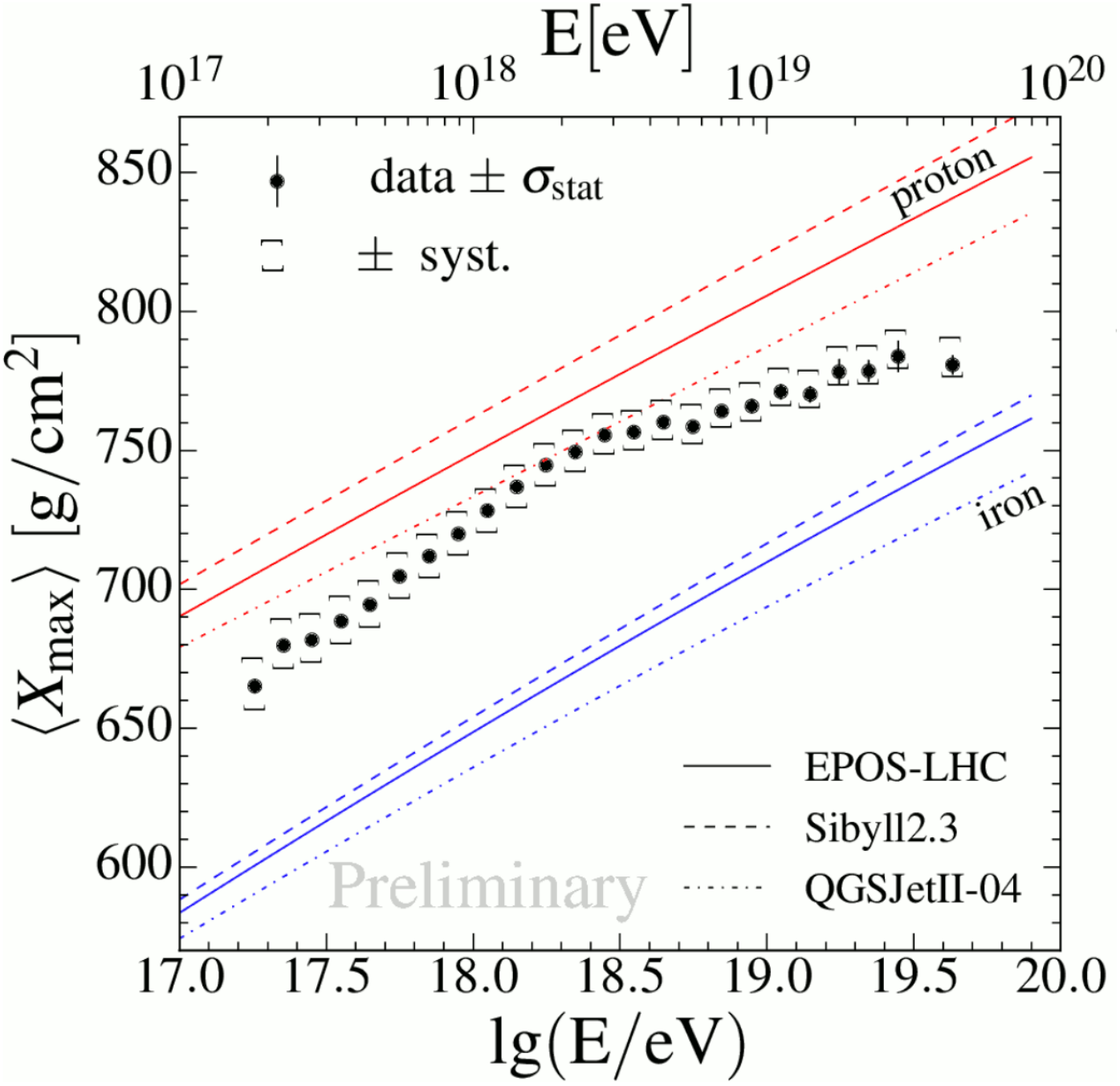




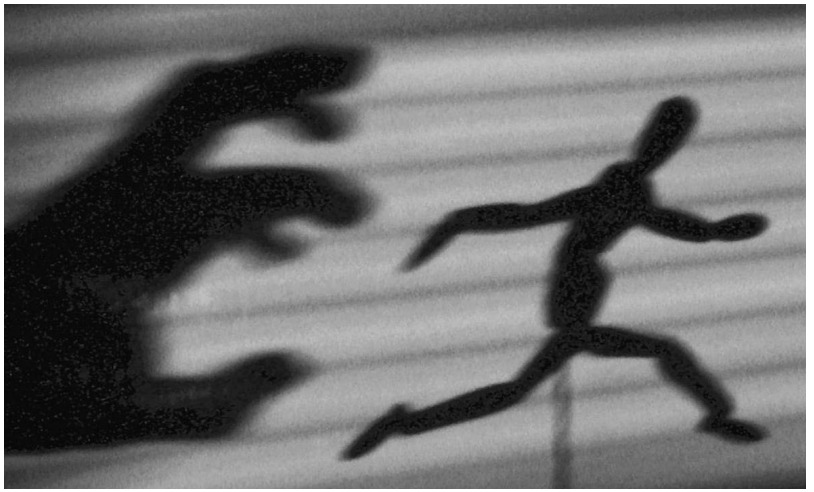
Mean Xmax correlates with mass of the primary particle

V. de Souza et al. Astroparticle Physics 23 (2005) 463


17.8 ≤ lg(E/eV) < 17.9
N = 3768
17.9 ≤ lg(E/eV) < 18.0
N = 3383
18.0 ≤ lg(E/eV) < 18.1
N = 2818
18.1 ≤ lg(E/eV) < 18.2
N = 2425
18.2 ≤ lg(E/eV) < 18.3
N = 1952
18.3 ≤ lg(E/eV) < 18.4
N = 1439
18.4 ≤ lg(E/eV) < 18.5
N = 1139
18.5 ≤ lg(E/eV) < 18.6
N = 814
18.6 ≤ lg(E/eV) < 18.7
N = 575
18.7 ≤ lg(E/eV) < 18.8
N = 413
18.8 ≤ lg(E/eV) < 18.9
N = 297
18.9 ≤ lg(E/eV) < 19.0
N = 230
19.0 ≤ lg(E/eV) < 19.1
N = 165
19.1 ≤ lg(E/eV) < 19.2
N = 114
19.2 ≤ lg(E/eV) < 19.3
N = 87
19.3 ≤ lg(E/eV) < 19.4
N = 63
19.4 ≤ lg(E/eV) < 19.5
N = 40
19.5 ≤ lg(E/eV) < ∞
N = 37
events/(20 g/cm²)
X_max [g/cm²]



Clear break @ lg(E/ev) = 18.27



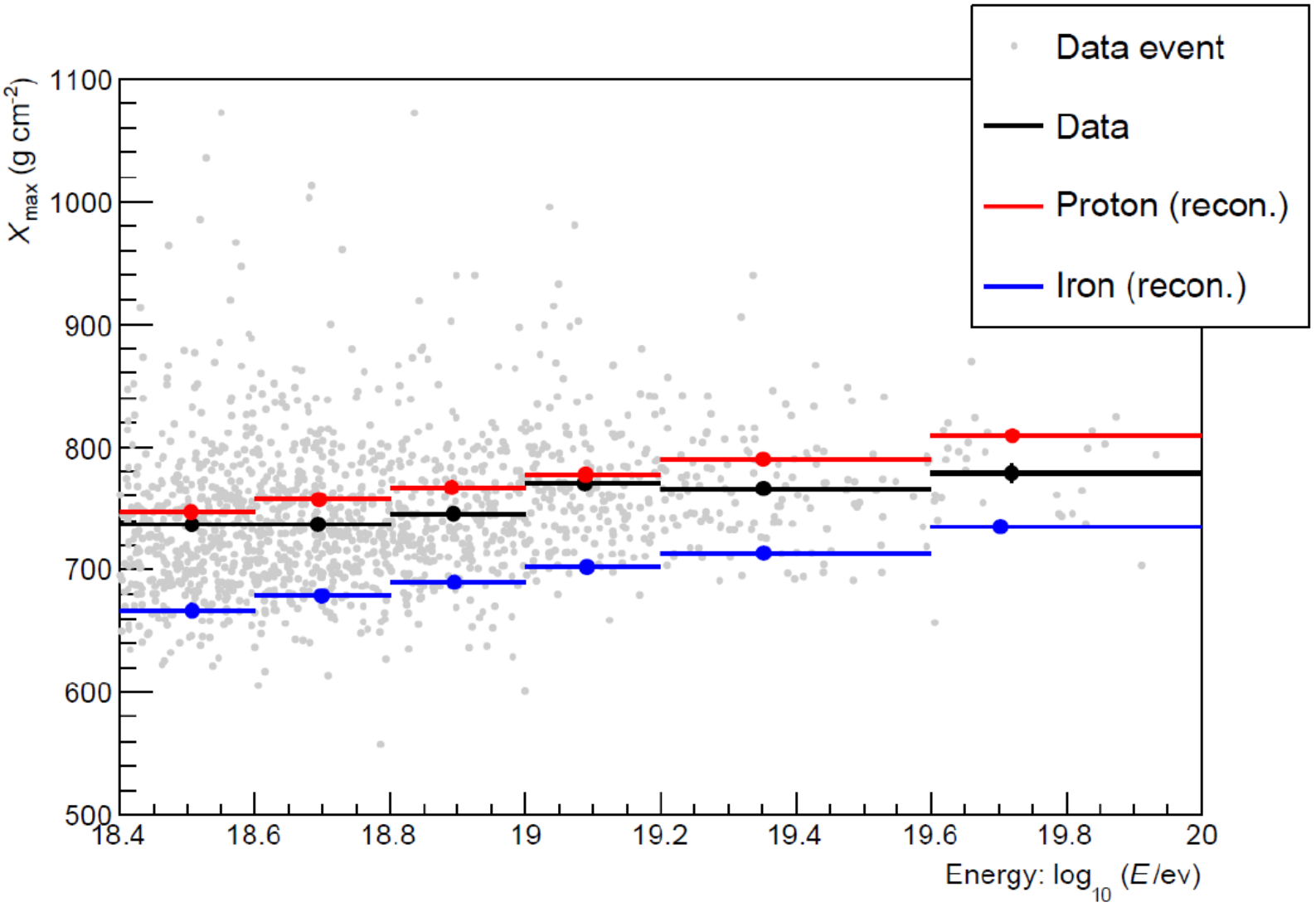
What about Telescope Array data ?

Don’t they measure only protons ?

PIERRE AUGER OBSERVATORY

TELESCOPE ARRAY PROJECT

Different detectors and analysis.



Don’t jump into conclusions

TA Collaboration, ICRC2017

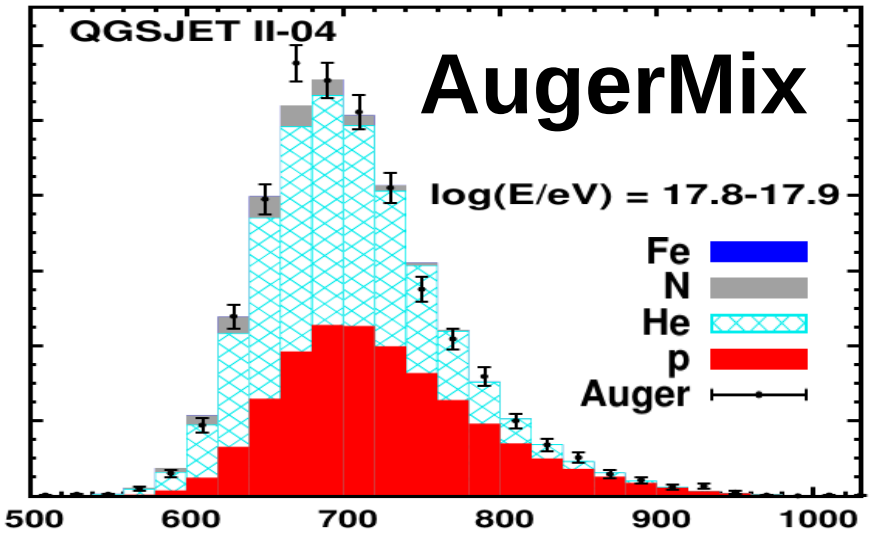
ICRC 2015 and 2017
UHECR 2014 and 2018

J. Bellido, J. Belz, S. Blaess, V. de Souza,
W. Hanlon, D. Ikeda, P. Sokolsky,
Y. Tsunesada, M. Unger, A. Yushkov,
for the Pierre Auger and TA Collaborations

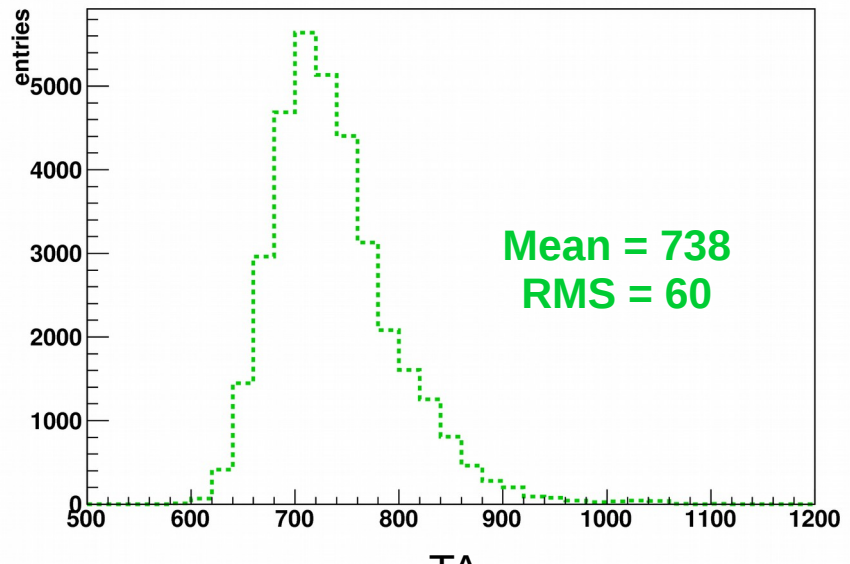
PIERRE AUGER OBSERVATORY

Presenter: Vitor de Souza
University of São Paulo

TELESCOPE ARRAY PROJECT



$Xmax^{Auger}$



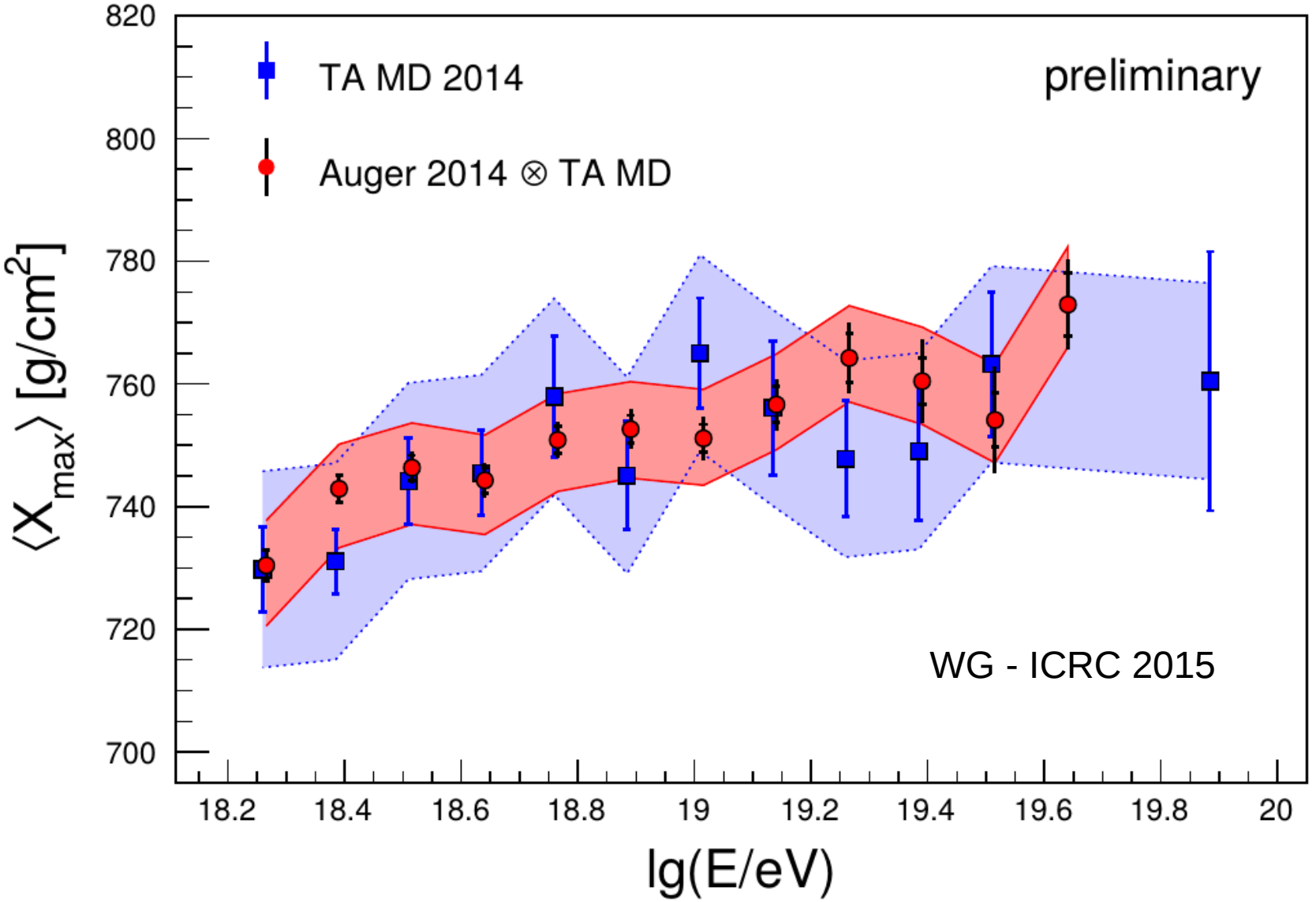
$Xmax^{TA}$(**AugerMix**)

SAME RESULTS WITH EPOS-LHC

TA Detector Simulation

TA Analysis

Mean Xmax Comparison

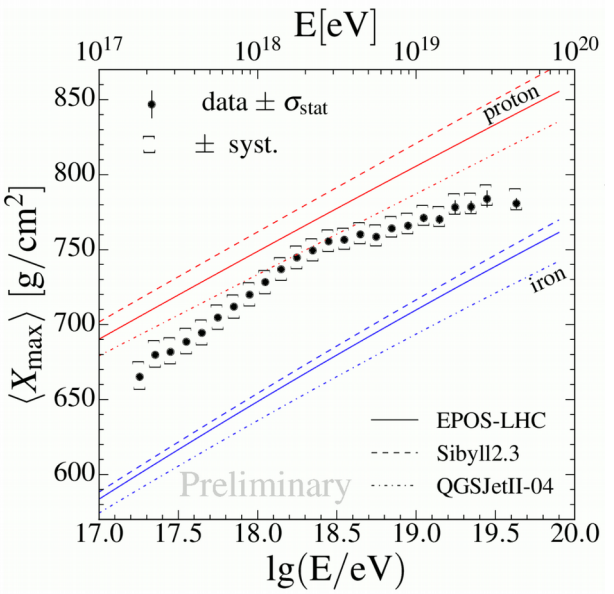


average difference: $\langle \Delta \rangle = (2.9 \pm 2.7\ (\text{stat.}) \pm 18\ (\text{syst.}))\ \text{g/cm}^2$

6/6 Composition Highlights

AUGER

- clear break @ E = $10^{18.27}$ eV
- showers are getting heavier with E > $10^{18.27}$ eV

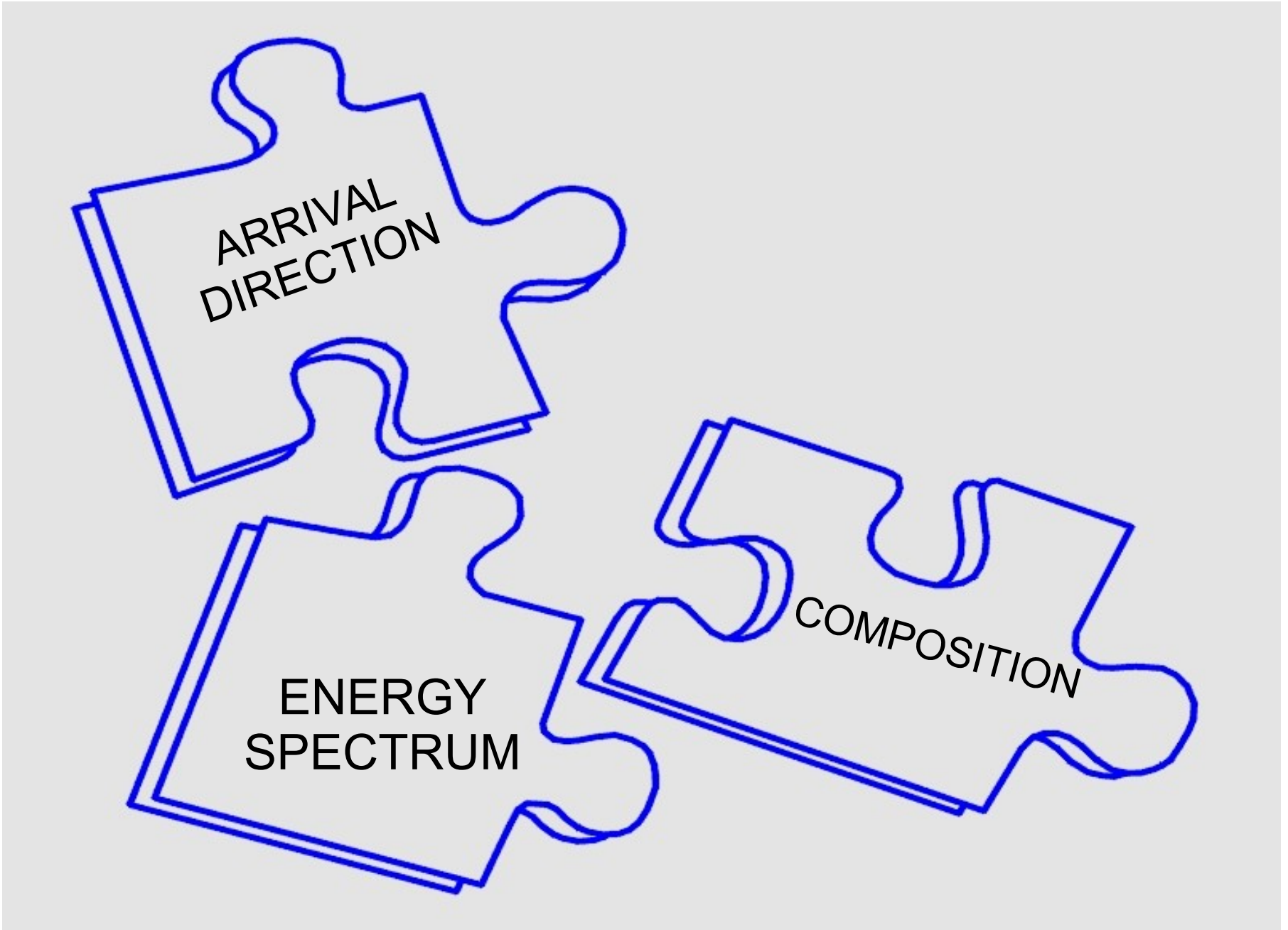


TA composition

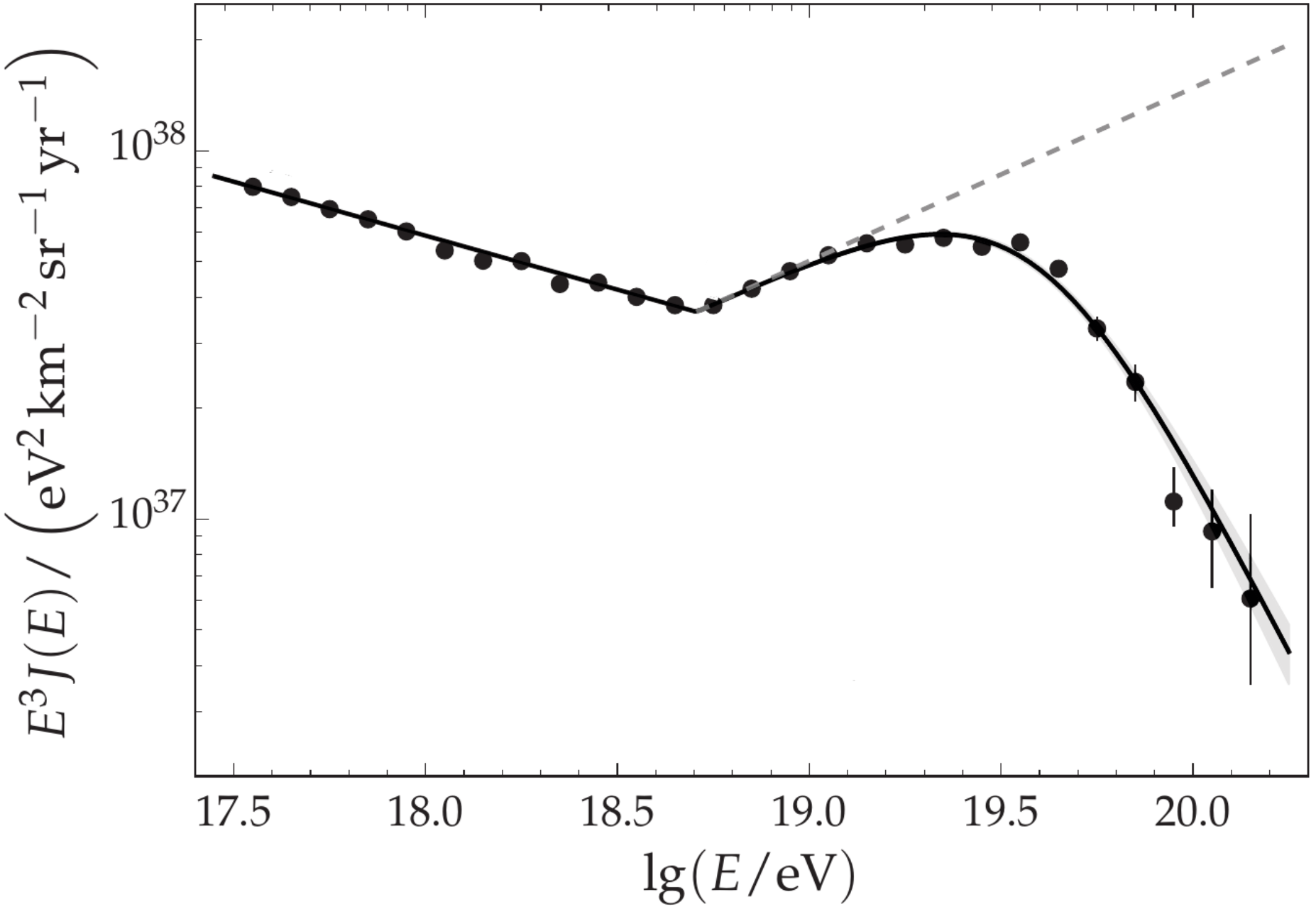
is compatible

to Auger

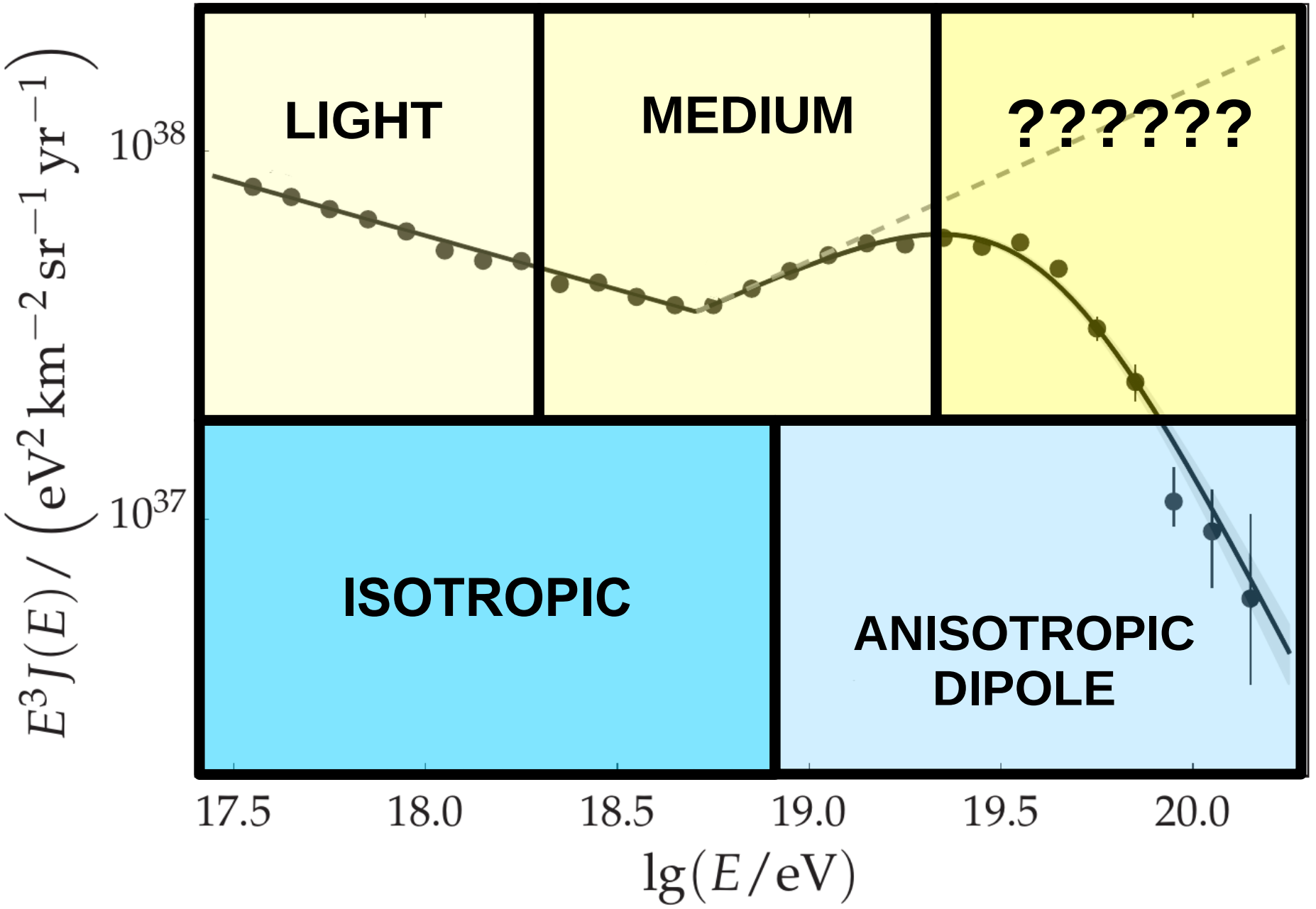
Ultra-high energy cosmic-ray

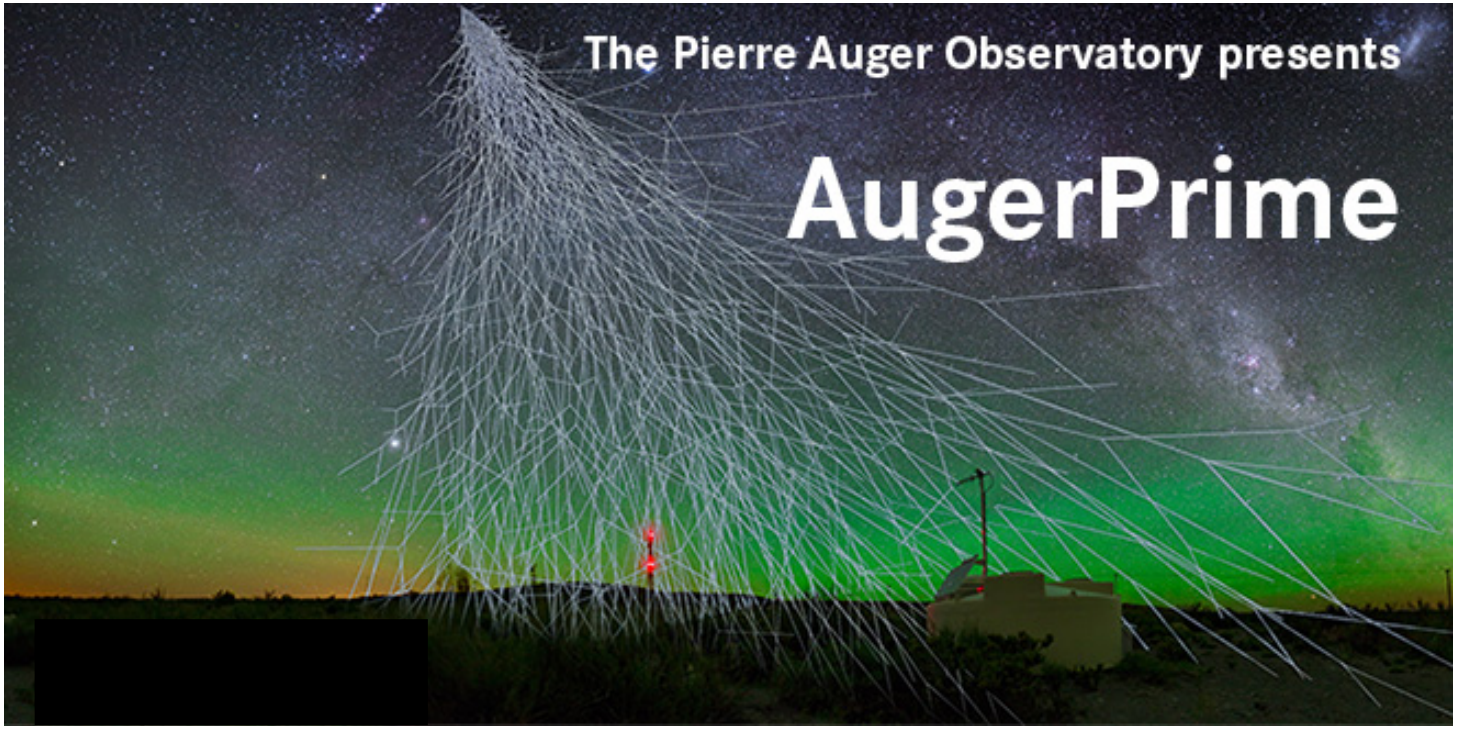


Auger Observatory Puzzle



Auger Observatory Puzzle

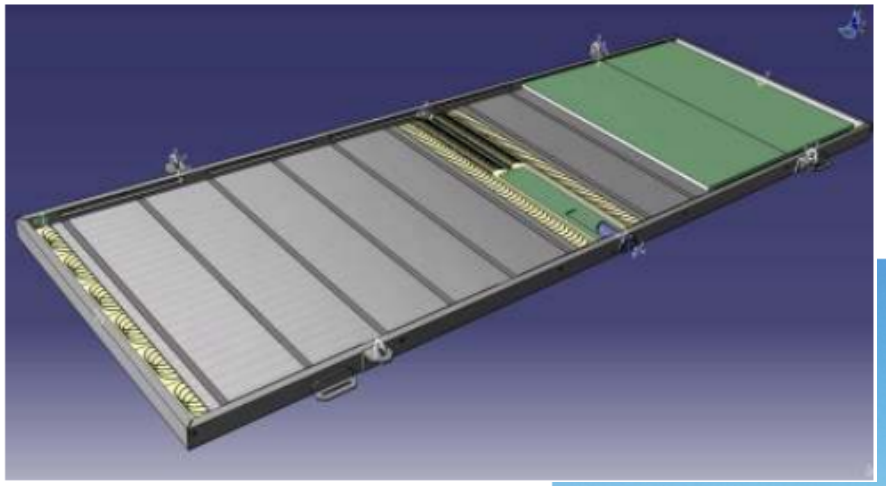


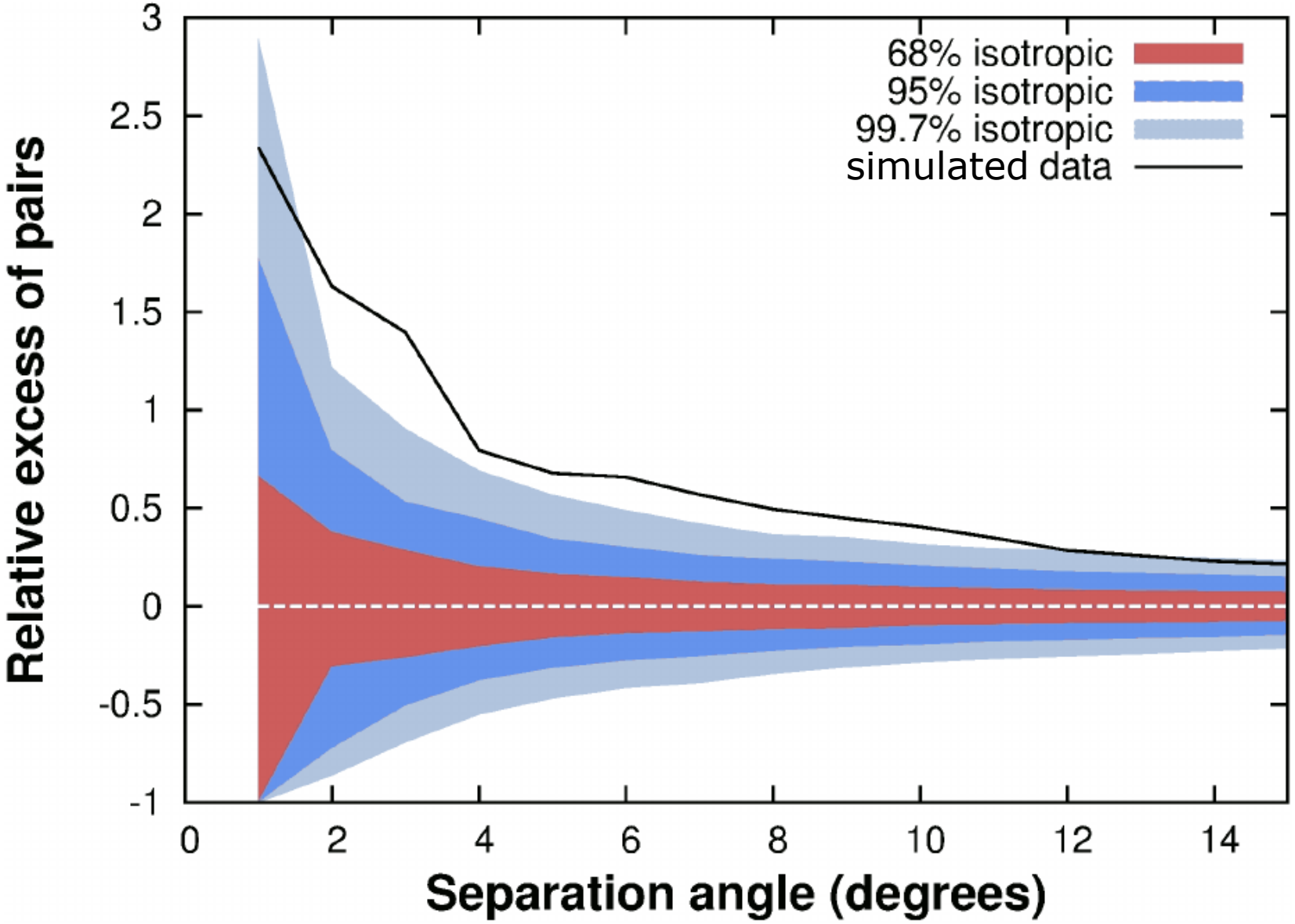


New muon detectors:

- select 10% of pure proton showers
- composition $\log_{10}(E/eV) > 19.5$
- muon excess: particle physics

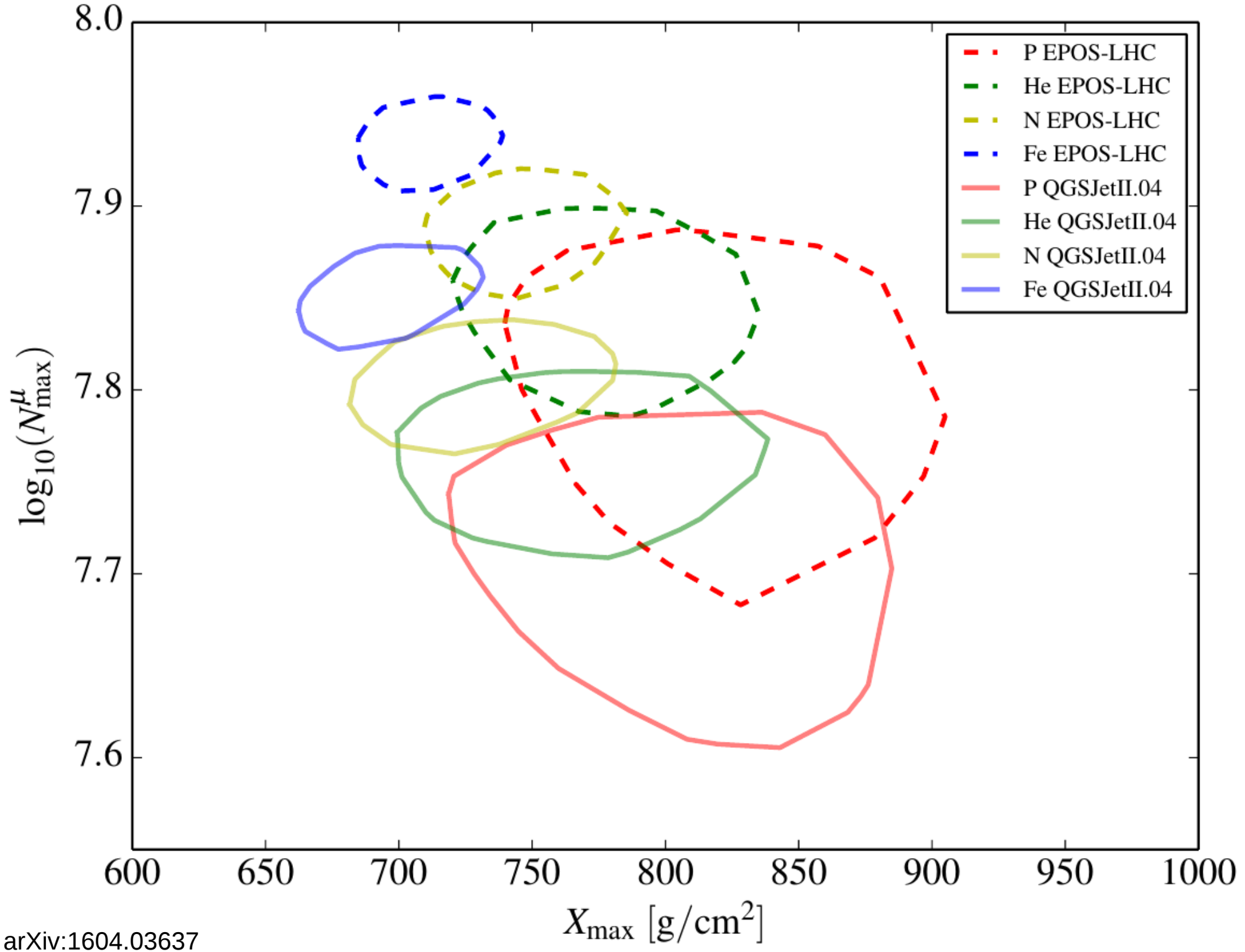
Prototypes Working

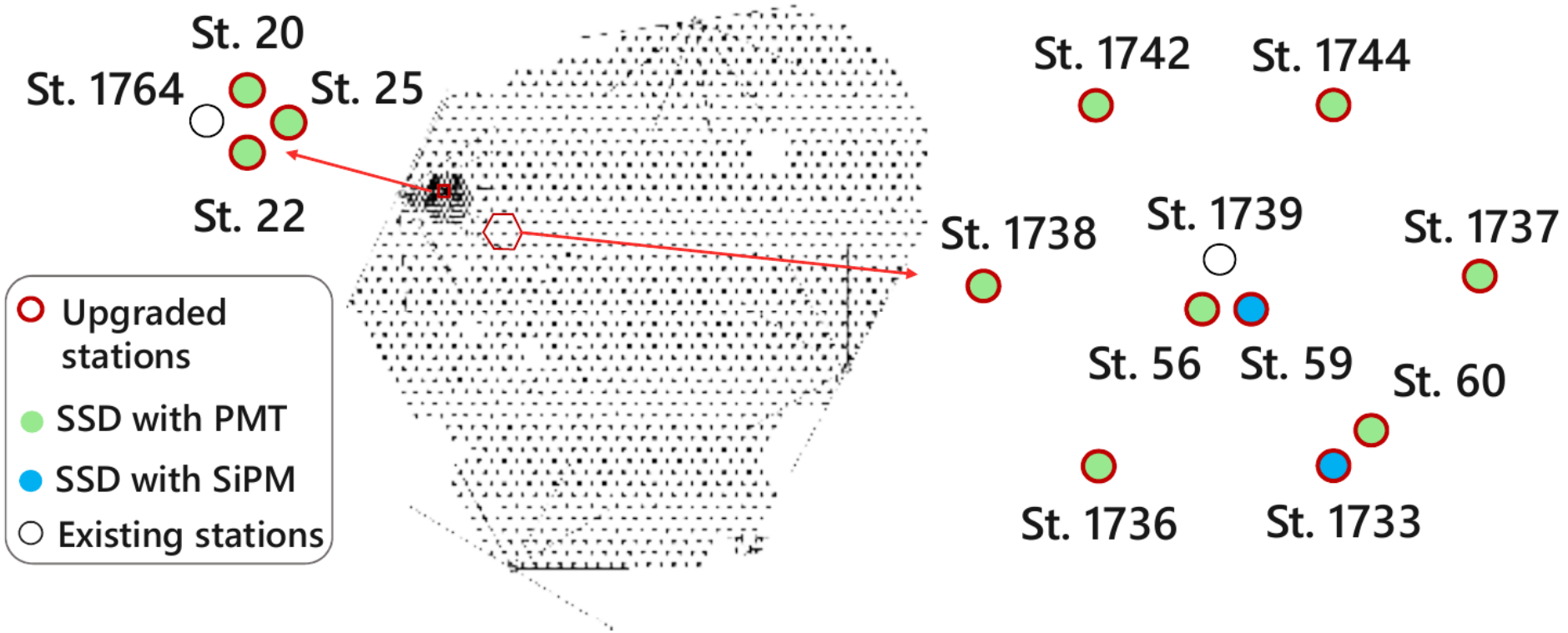


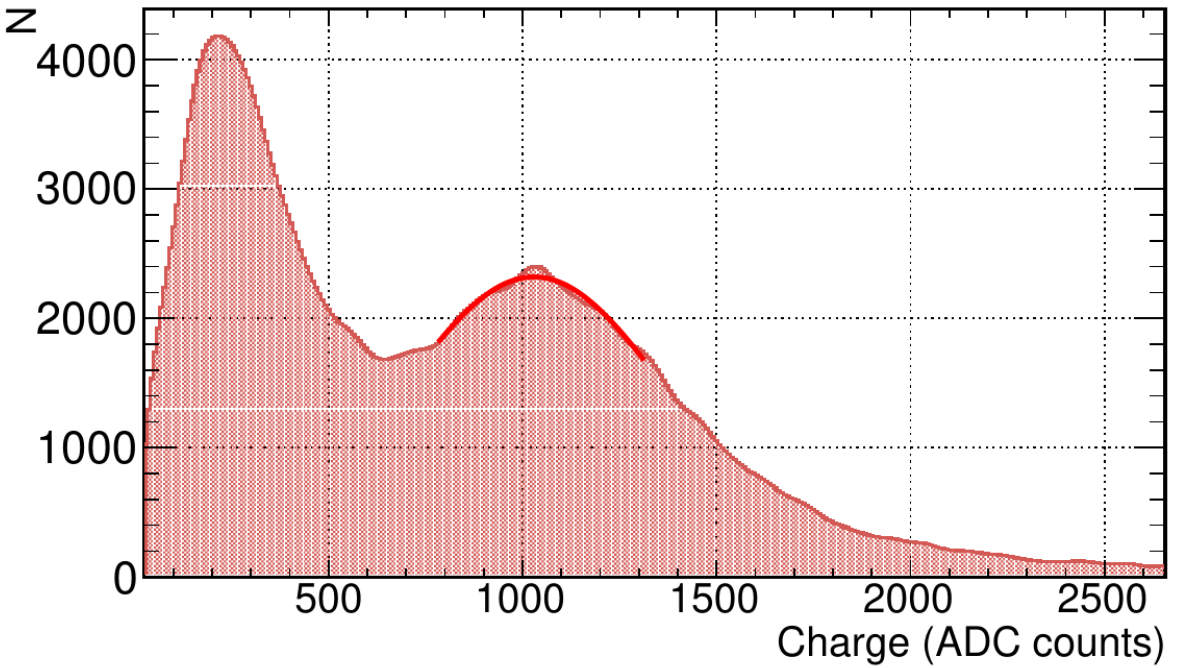


10% Proton Sample

arXiv:1604.03637




St. 20
St. 1764
St. 25
St. 22
Upgraded stations
SSD with PMT
SSD with SiPM
Existing stations
St. 1742
St. 1744
St. 1738
St. 1739
St. 1737
St. 56
St. 59
St. 60
St. 1736
St. 1733


N
4000
3000
2000
1000
0
500
1000
1500
2000
2500
Charge (ADC counts)

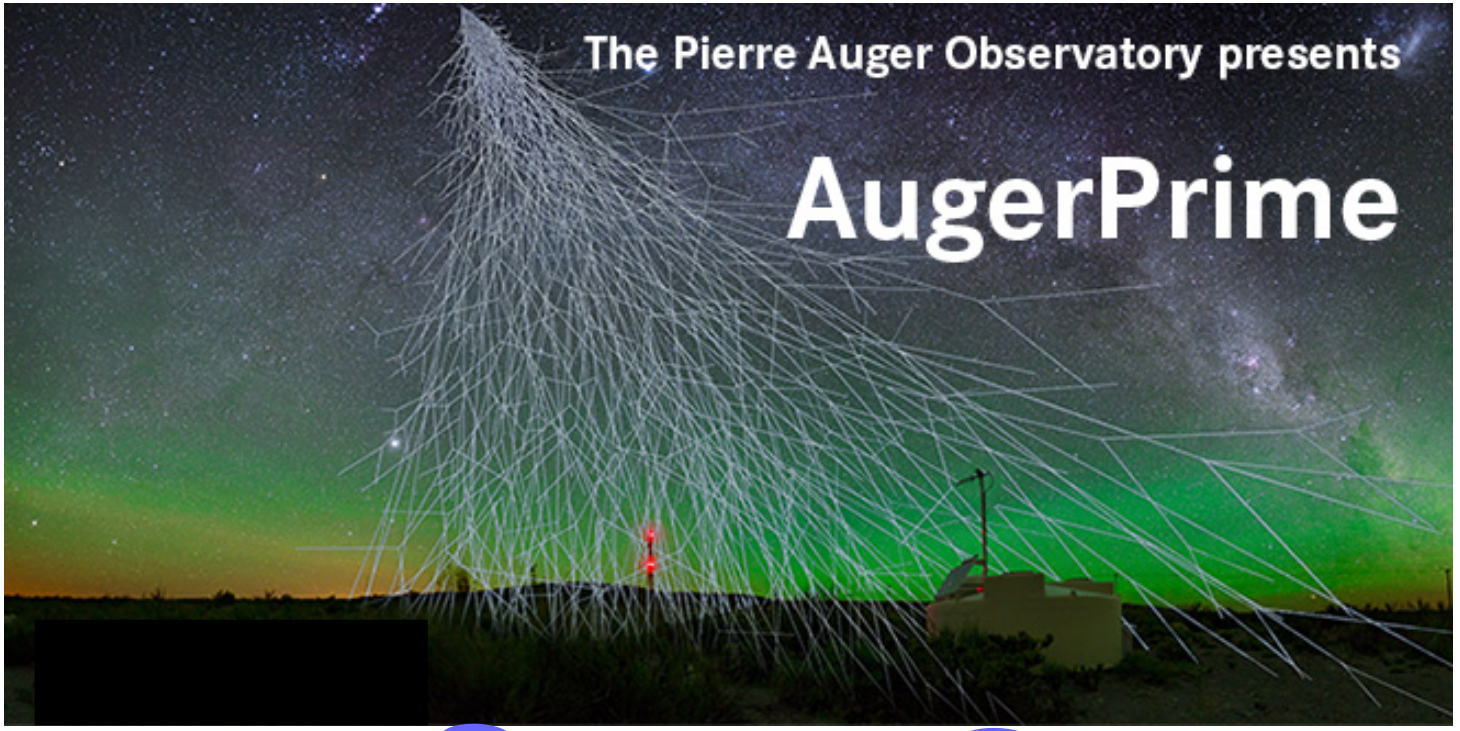
New open questions

Can we identify the sources ?

Can we explain why so many muons ?

What is the cause of the flux supression and of the abrupt change in the slope of the spectrum ?

With one way to answer:



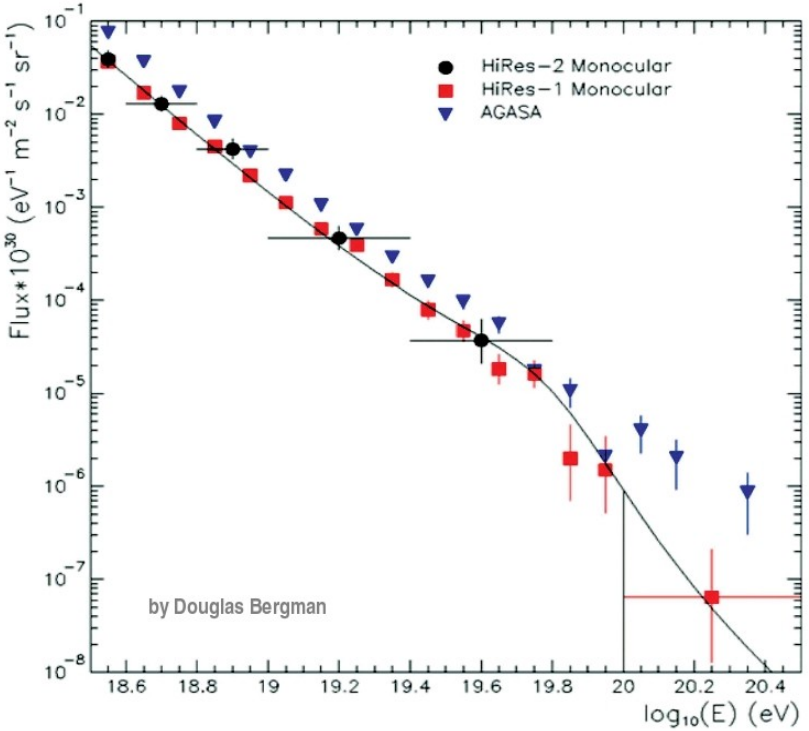
COMPOSITION
$E > 10^{19.5}$ eV

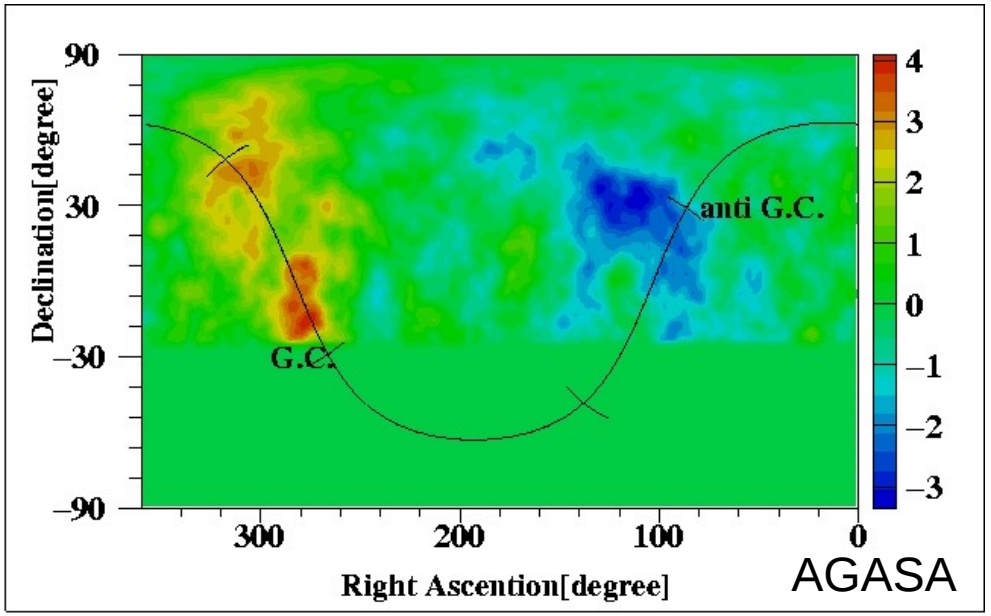
PURE PROTON SELECTION

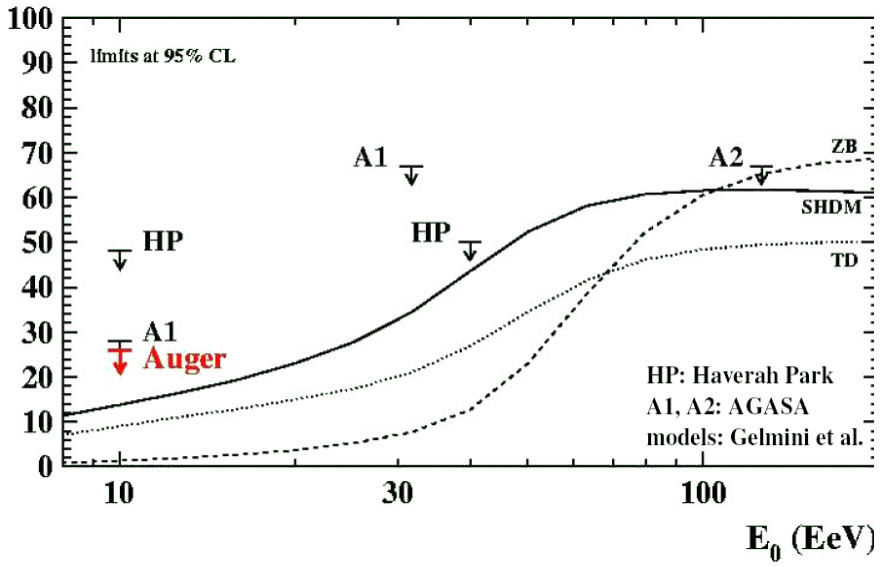

thank
you!

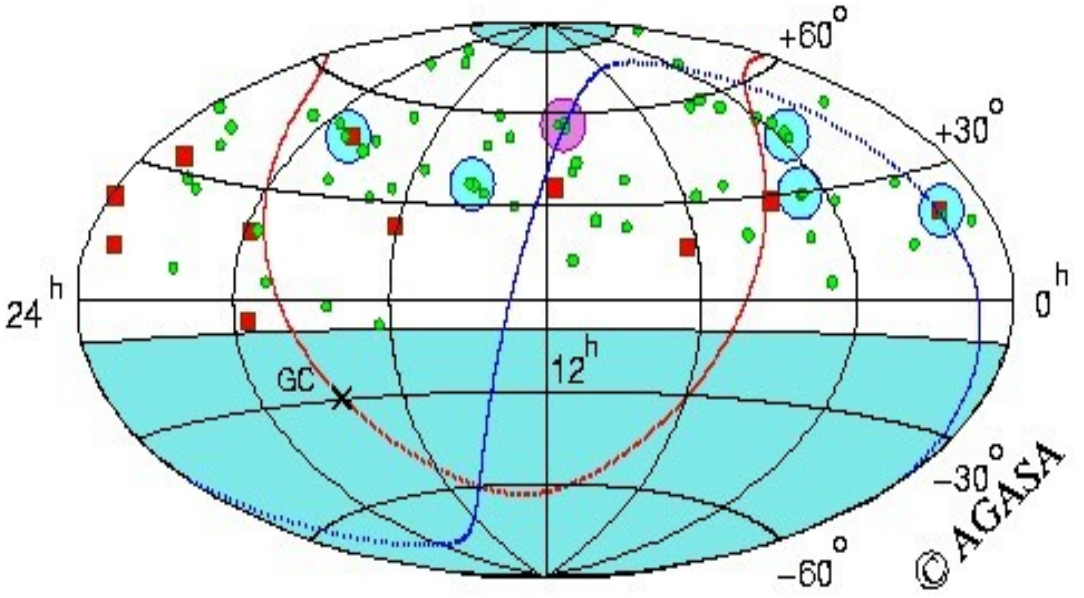
extras

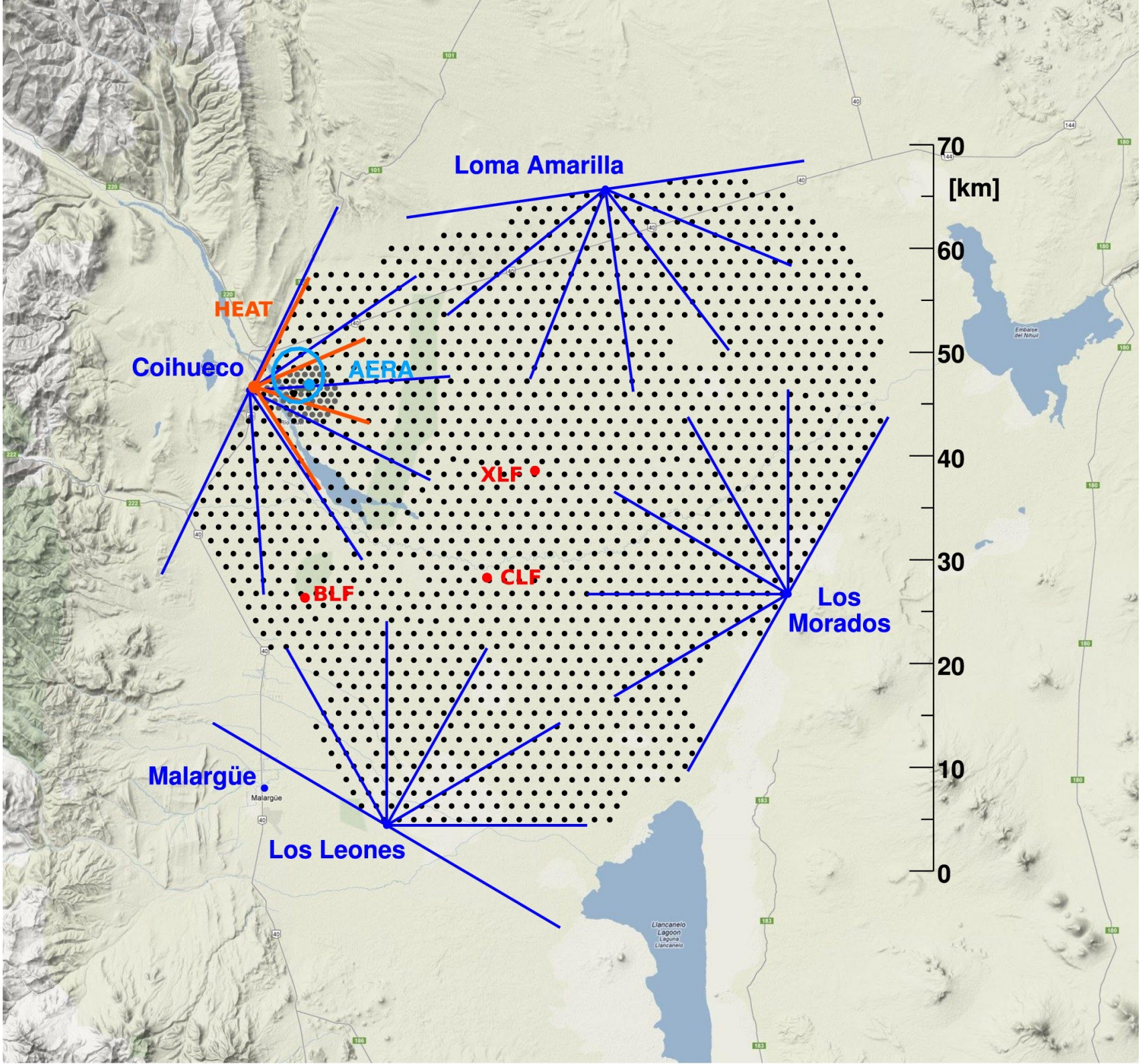
Before Auger Data










Loma Amarilla
HEAT
Coihueco
AERA
XLF
CLF
BLF
Los
Morados
Malargüe
Malargüe
Los Leones
70
[km]
60
50
40
30
20
10
0
Embalse
del Nihuil
Llancanelo
Lagoon
Laguna
Llancanelo

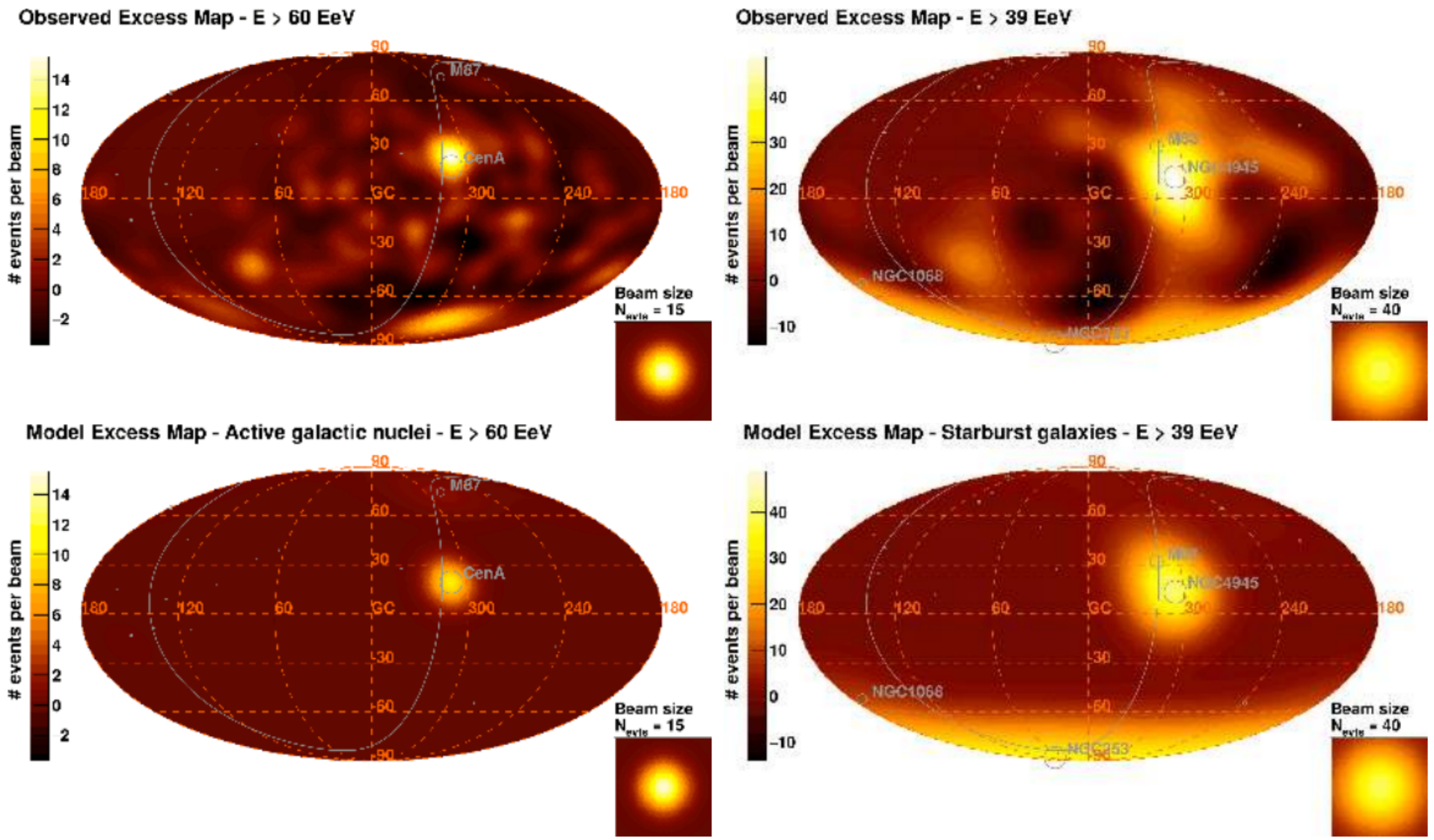
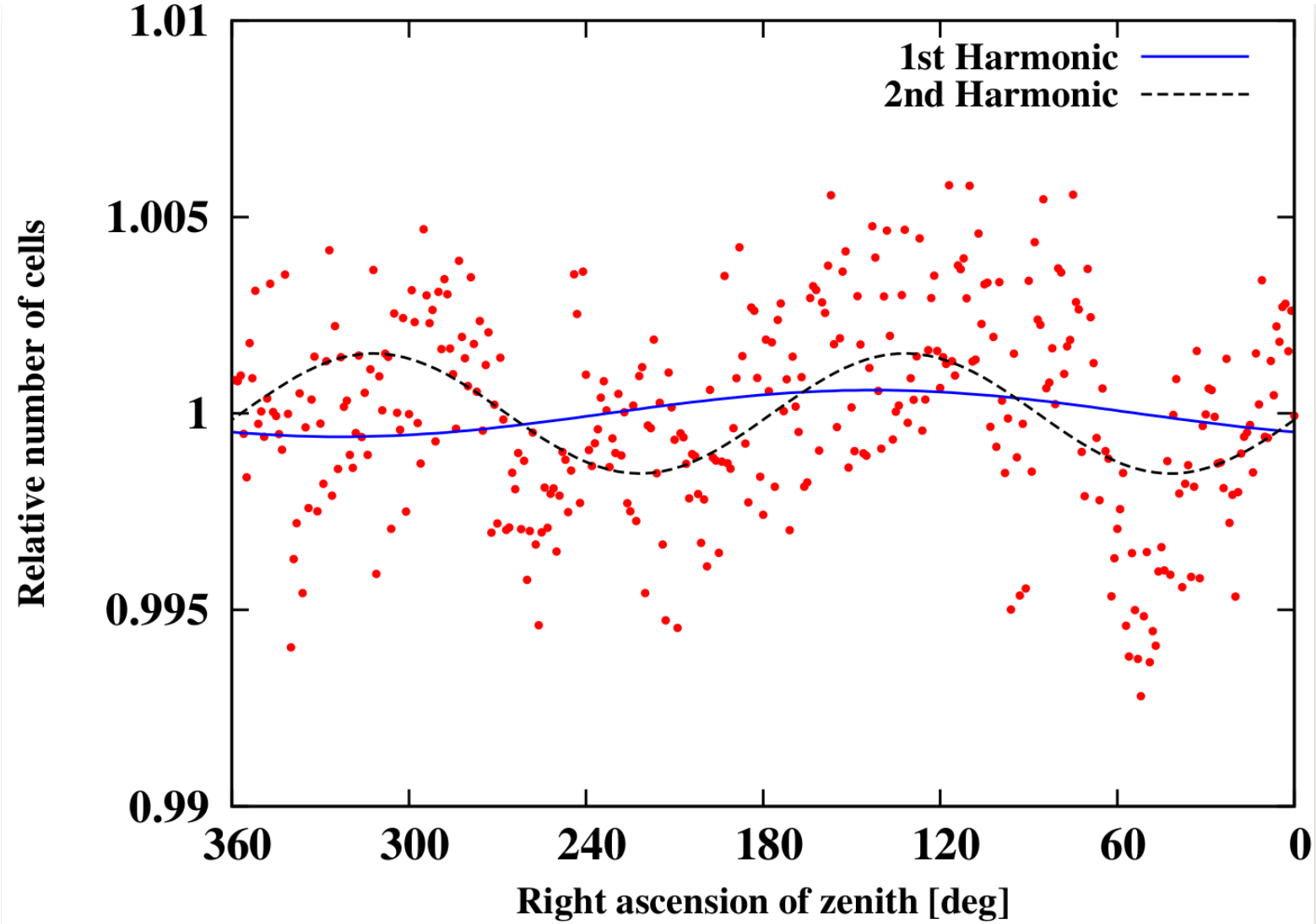
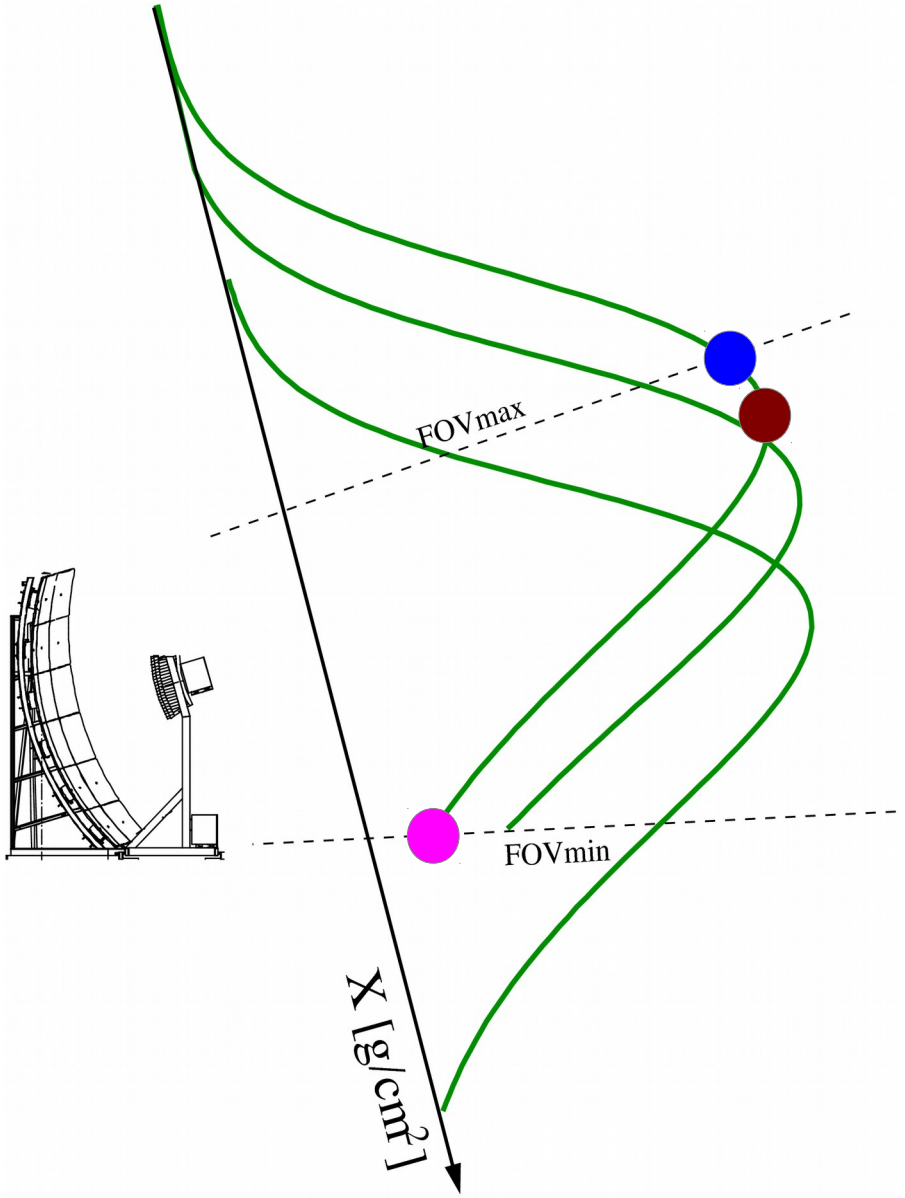


Figure 4: Observed (top) and model (bottom) excess maps obtained with the best-fit parameters for the gamma-ray AGNs (left) and for the starburst galaxies (right) in galactic coordinates.



Science 357 (2017) 1266-1270

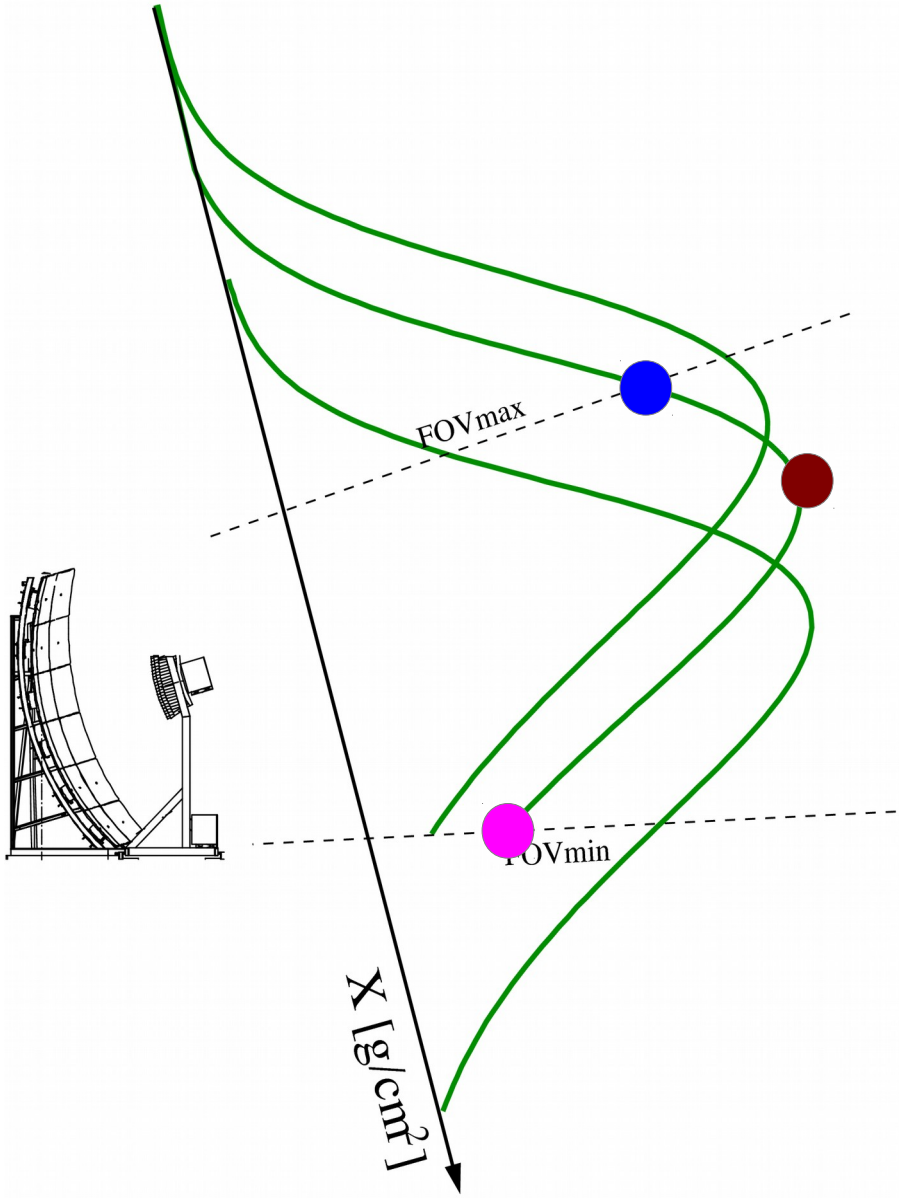
study how <Xmax> changes with FOV



From the data

Xmax	Xup	Xlow	Energy
780	750	970	1×10^{18}

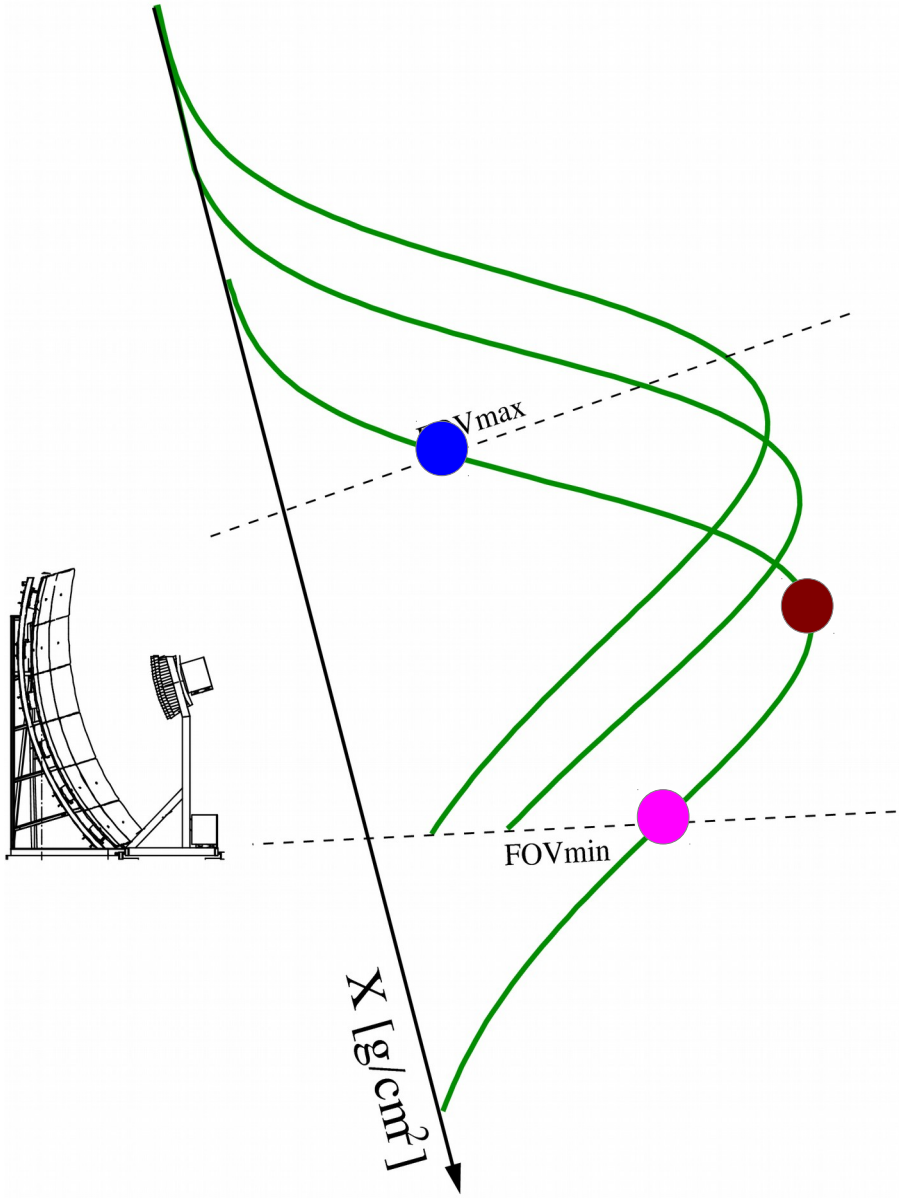
study how <Xmax> changes with FOV



From the data

Xmax	Xup	Xlow	Energy
780	750	970	7.0×10^{18}
760	740	990	1.2×10^{19}

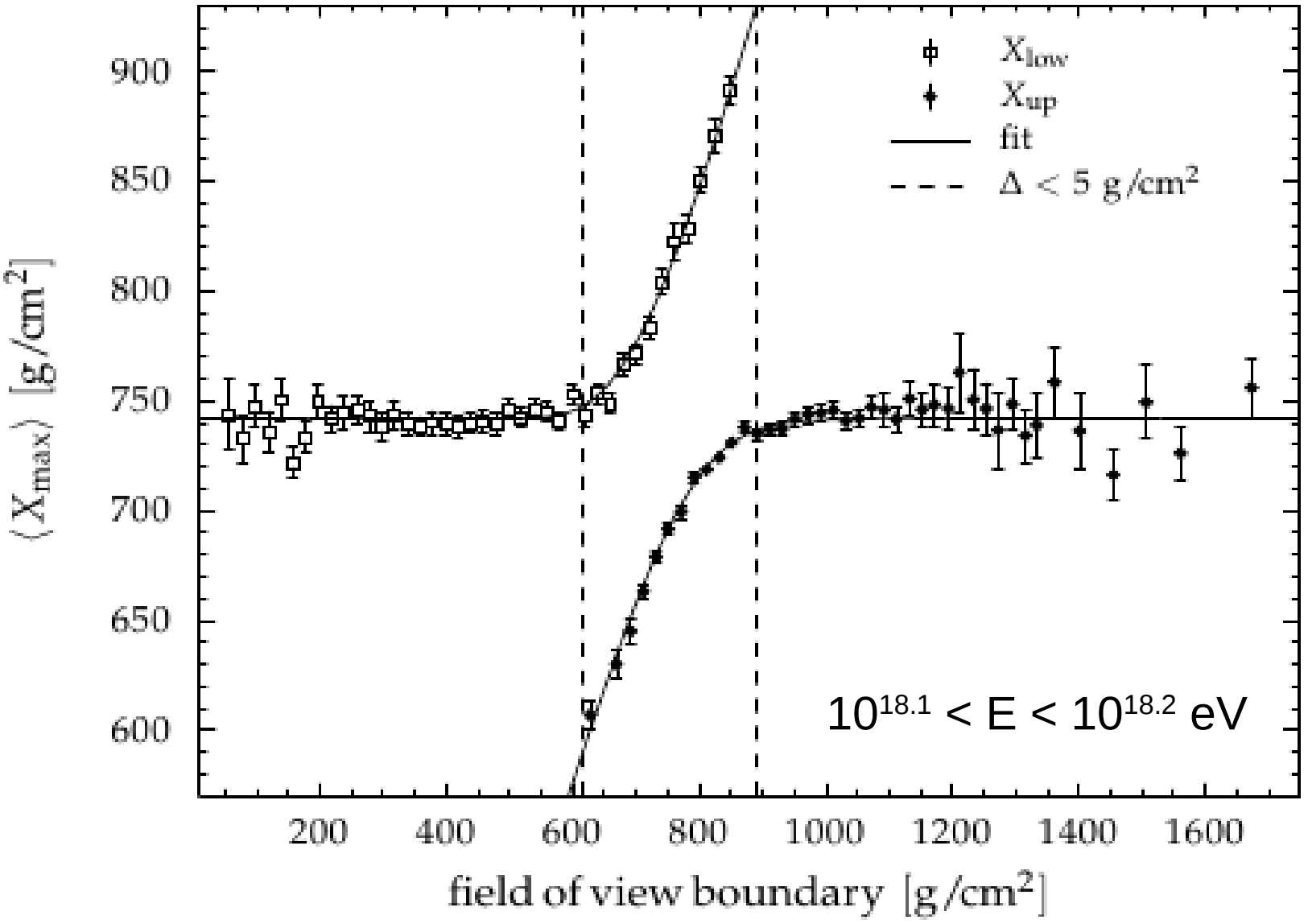
study how <Xmax> changes with FOV



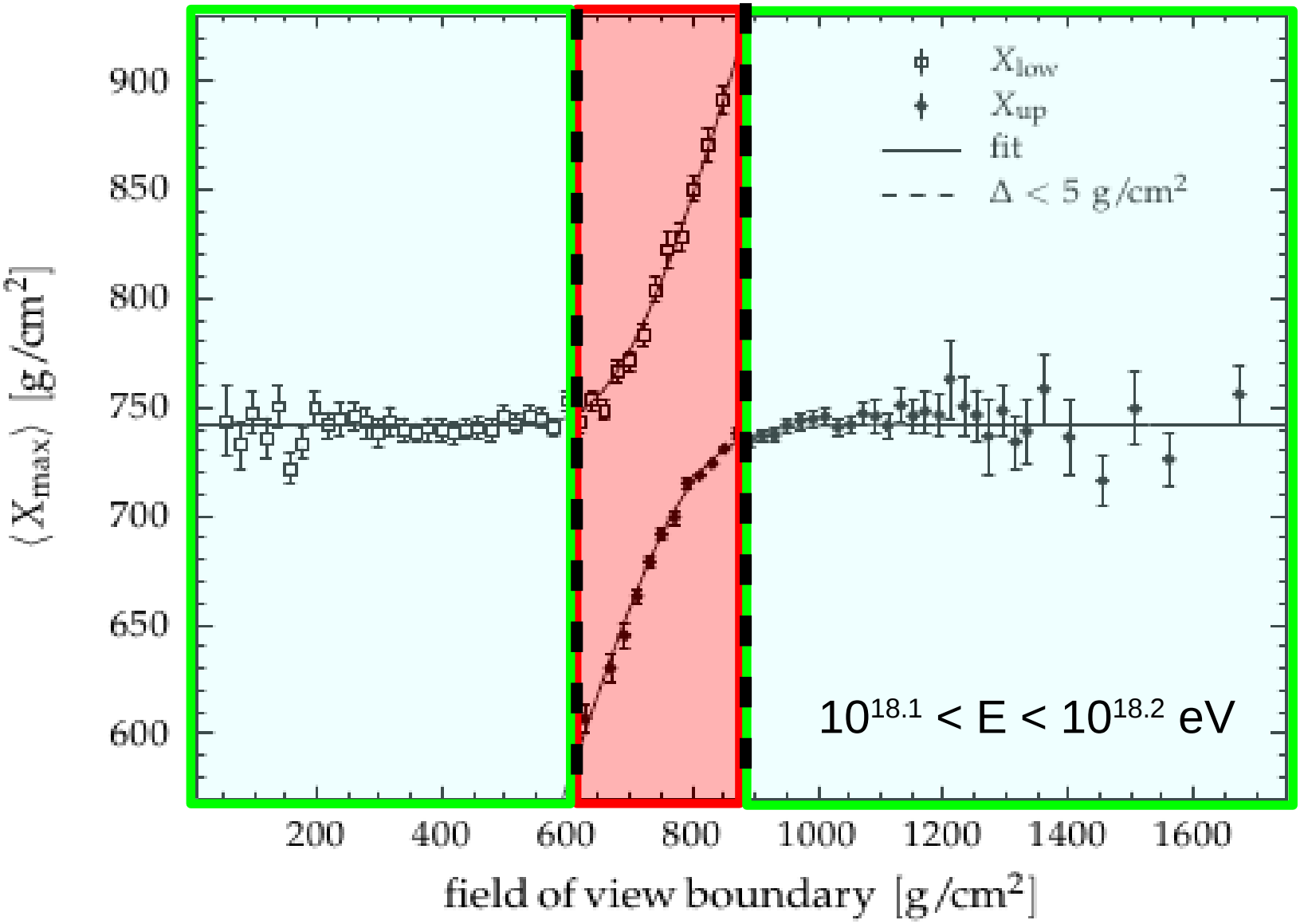
From the data

Xmax	Xup	Xlow	Energy
780	750	970	7.0×10^{18}
760	740	990	1.2×10^{19}

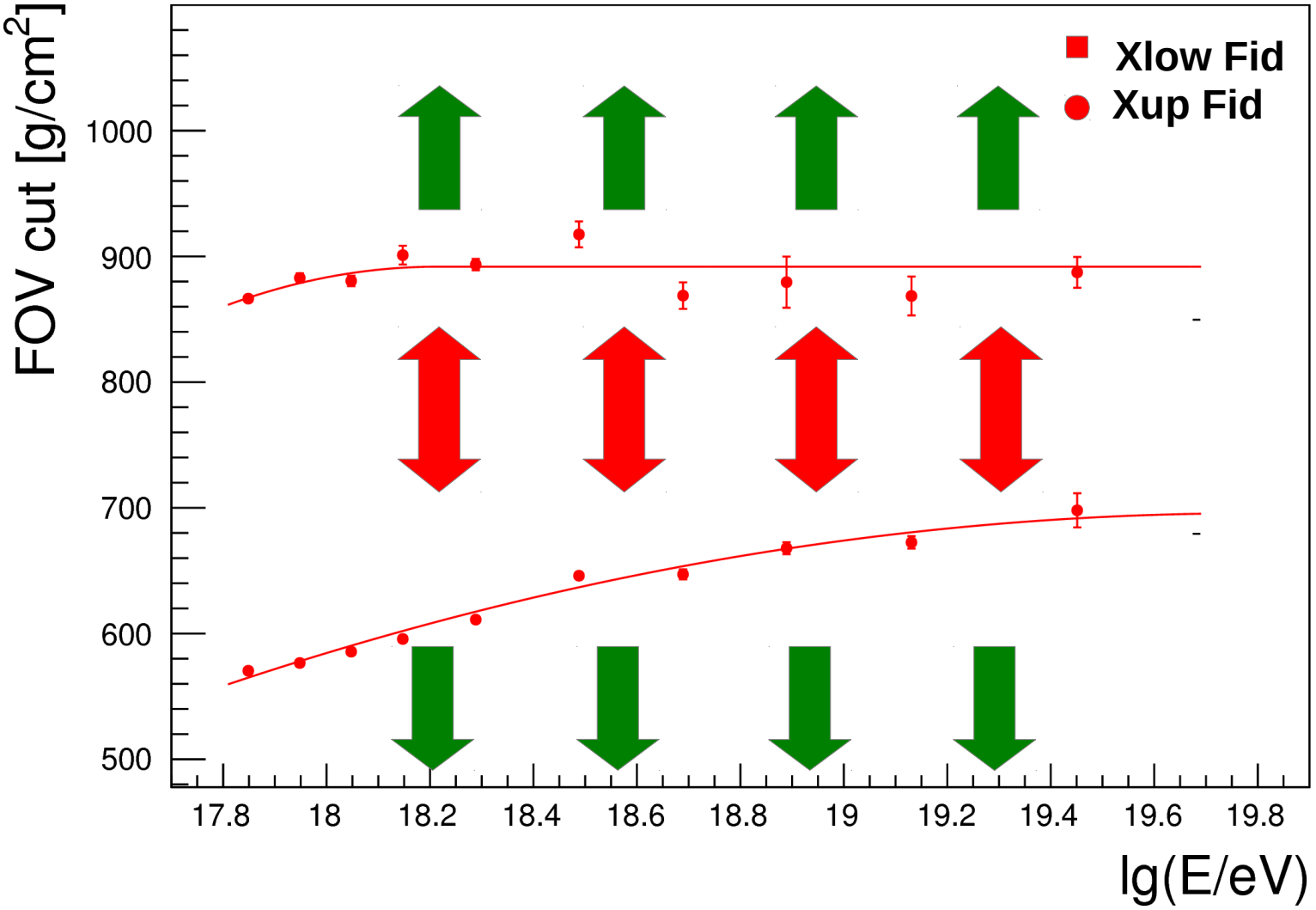
valid geometries ?



valid geometries ?



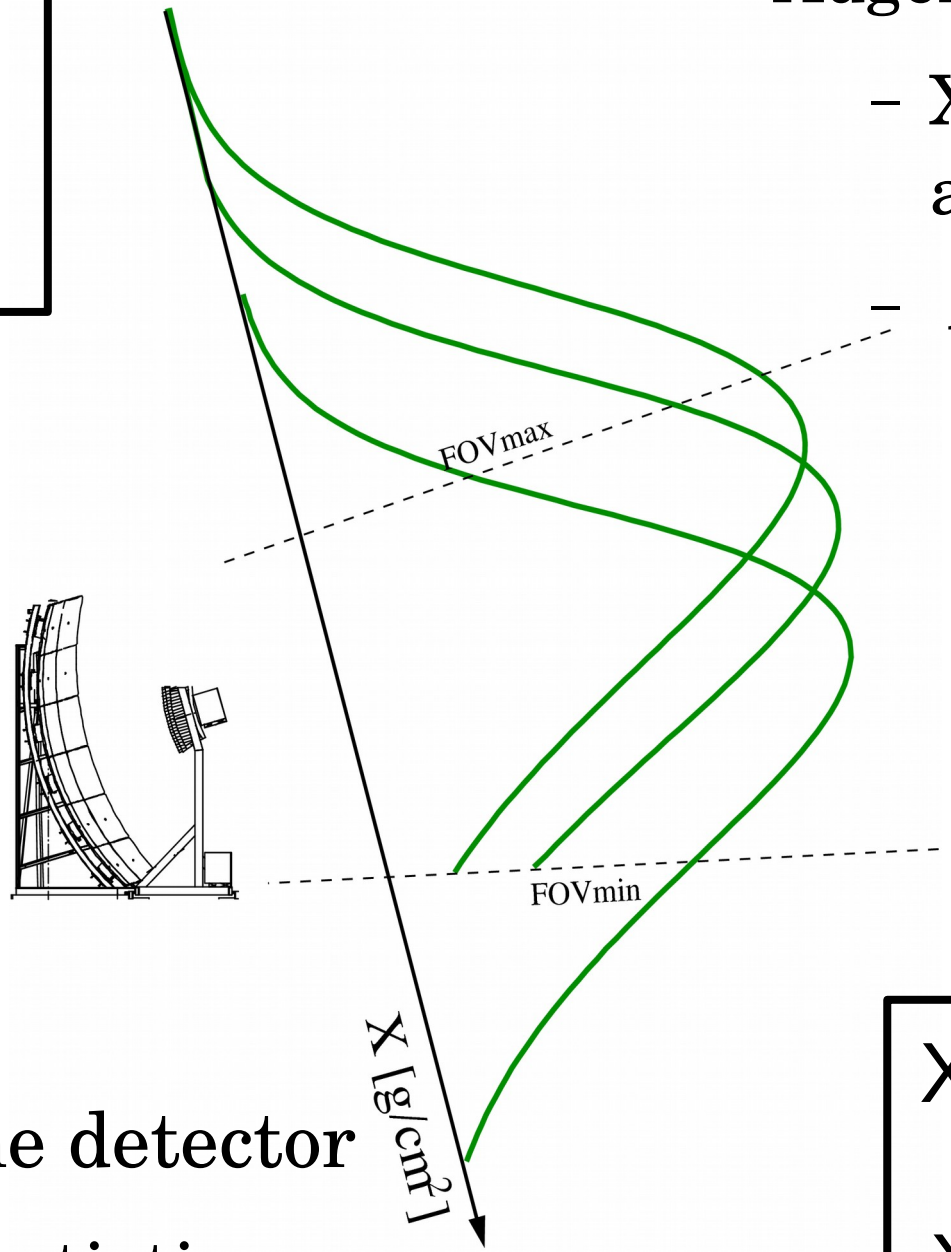
this is the valid geometry that assures unbiased Xmax distributions



Auger bias
≠
TA bias

Auger

- Xmax at the atmosphere
- Approx. unbiased

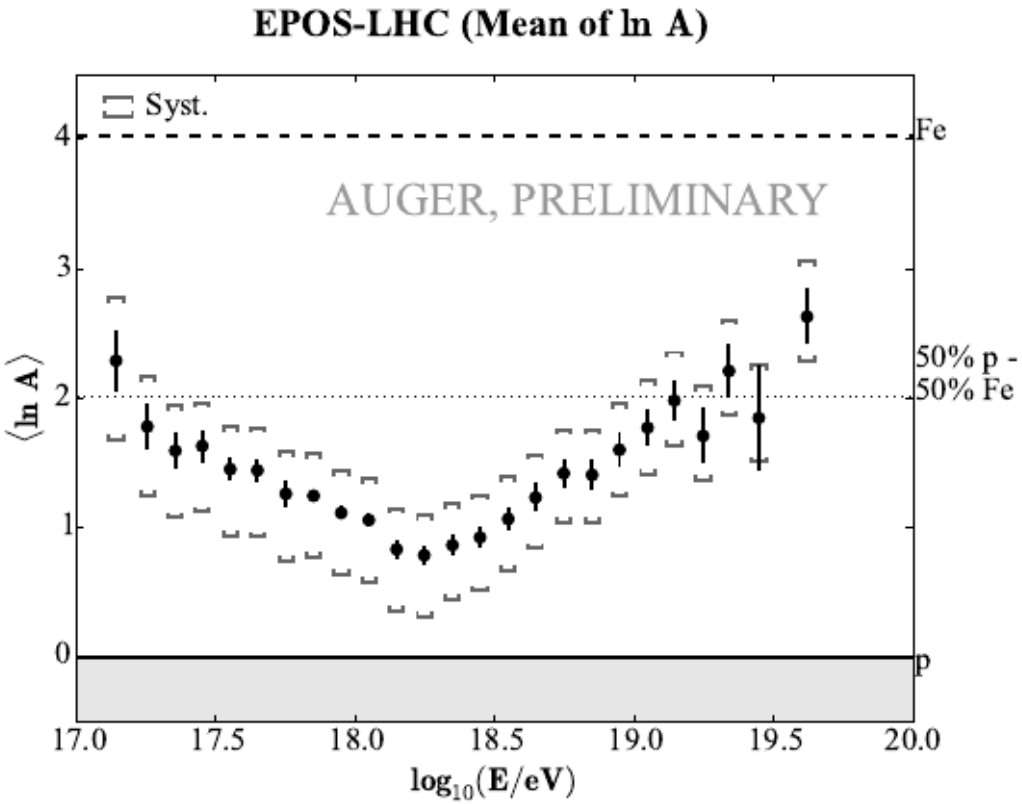


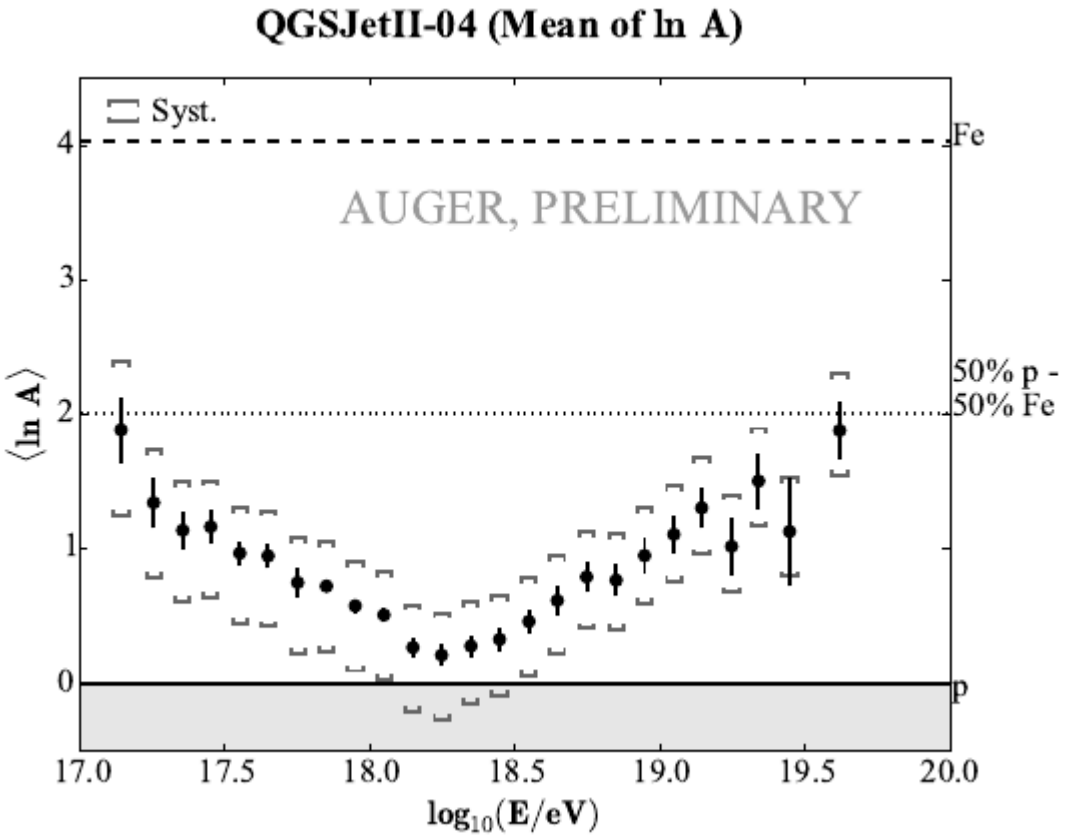
TA

- Xmax in the detector
- Enhance statistics

Xmax ATM
≠
Xmax DET

Mean ln A



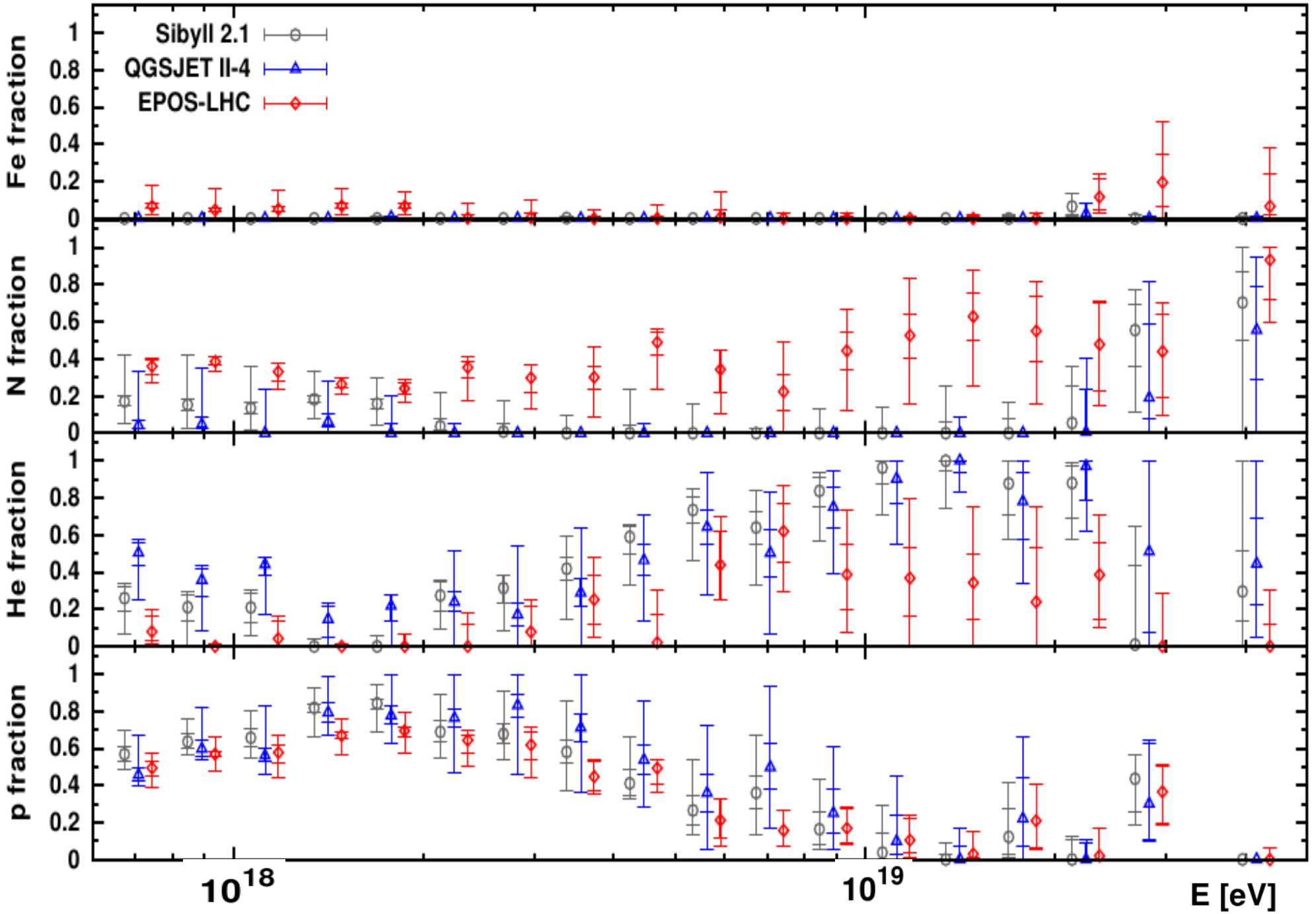


Clear trend:

$10^{17} < E < 10^{18.27}$ eV: getting ligther

$E > 10^{18.27}$ eV: getting heavier

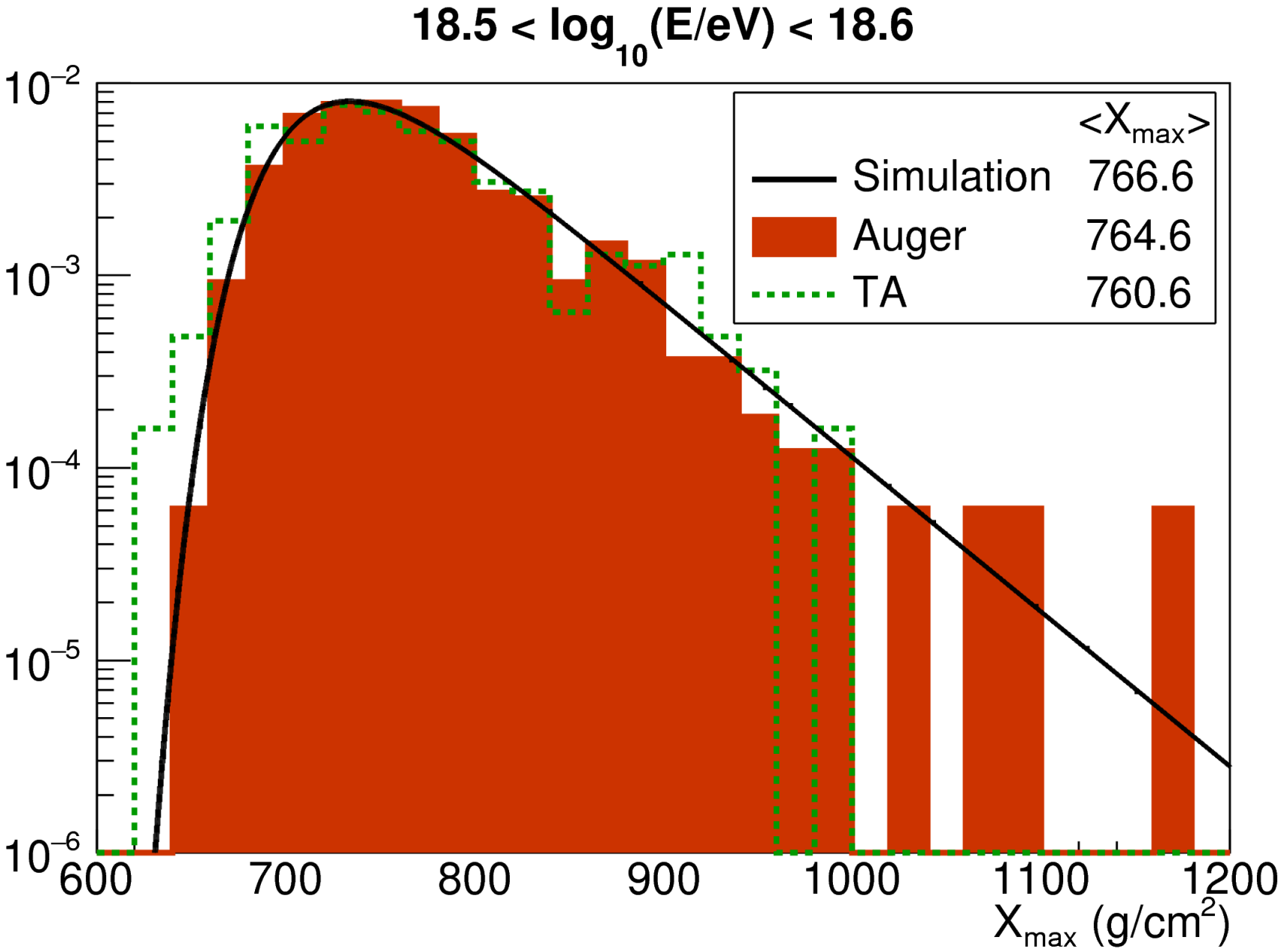
proton + helium + nitrogen + iron



Target: analyze the set of selected events in order to guarantee:

- minimum bias
- maximum statistical significance
- control over systematic uncertainties
- verification / cross-checks

Auger bias ≠ TA bias

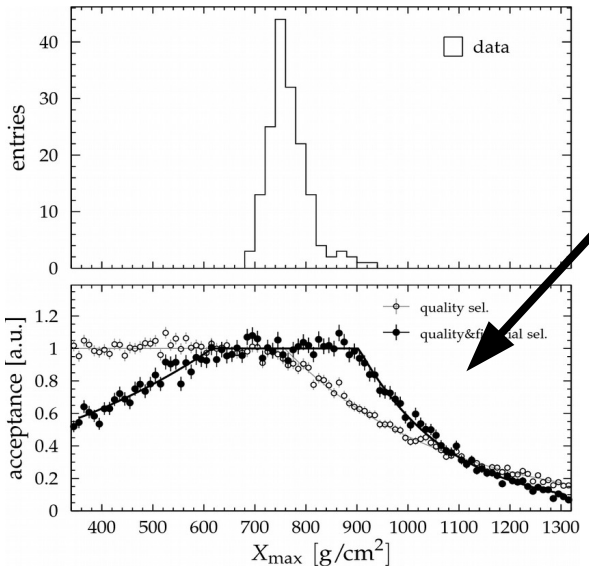


Pierre Auger Observatory Timeline

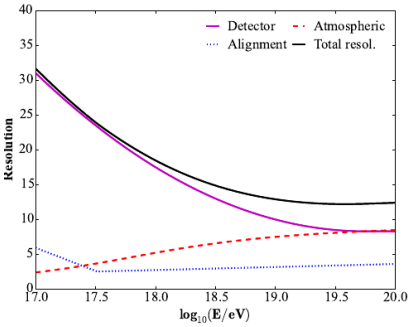
- 1991: The idea is born
- 1995-96: First meetings: Design started
- 1999: Signing of the international agreement
- 2000: Construction started
- 2001: First event
- 2008: Constrution ended
- 2008: First round of important results
- 2011: Second round of important results
- 2014: Need of an upgrade recognized: composition
- 2017: AugerPrime started

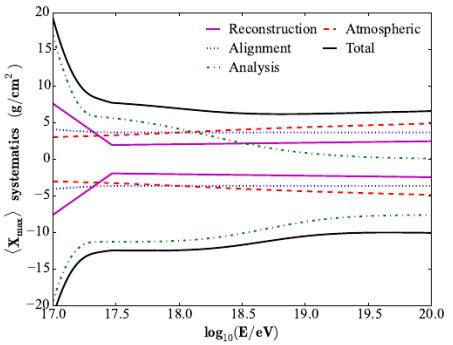
cut	$E > 10^{18}$ eV events	ε [%]
pre-selection:		
air-shower candidates	2573713	-
hardware status	1920584	74.6
aerosols	1569645	81.7
hybrid geometry	564324	35.9
profile reconstruction	539960	95.6
clouds	432312	80.1
$E > 10^{17.8}$ eV	111194	25.7
quality and fiducial selection:		
P(hybrid)	105749	95.1
$X_{\max}$ observed	73361	69.4
quality cuts	58305	79.5
fiducial field of view	21125	36.2
profile cuts	19947	94.4

complete data analysis



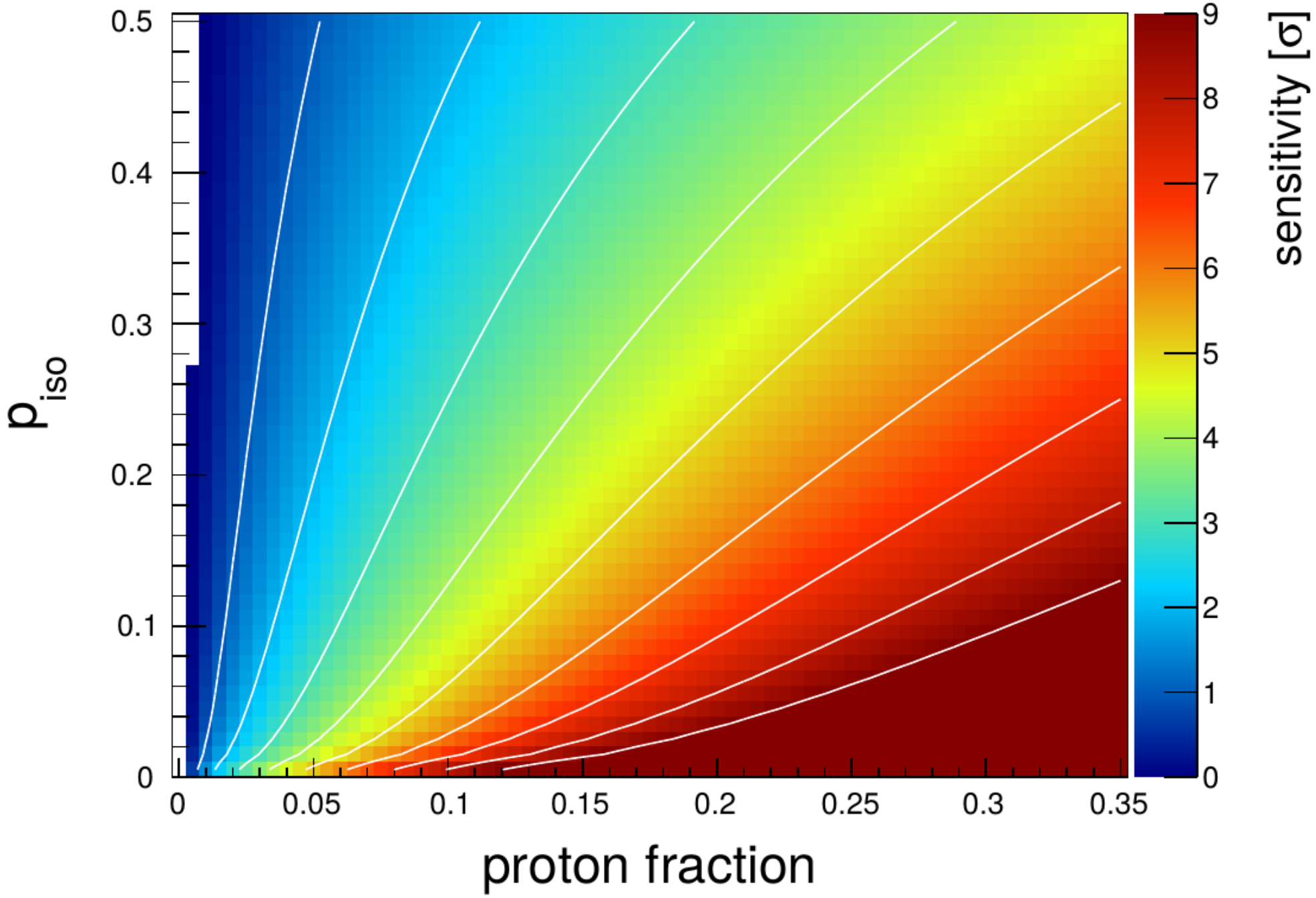
- acceptance
- resolution
- systematics



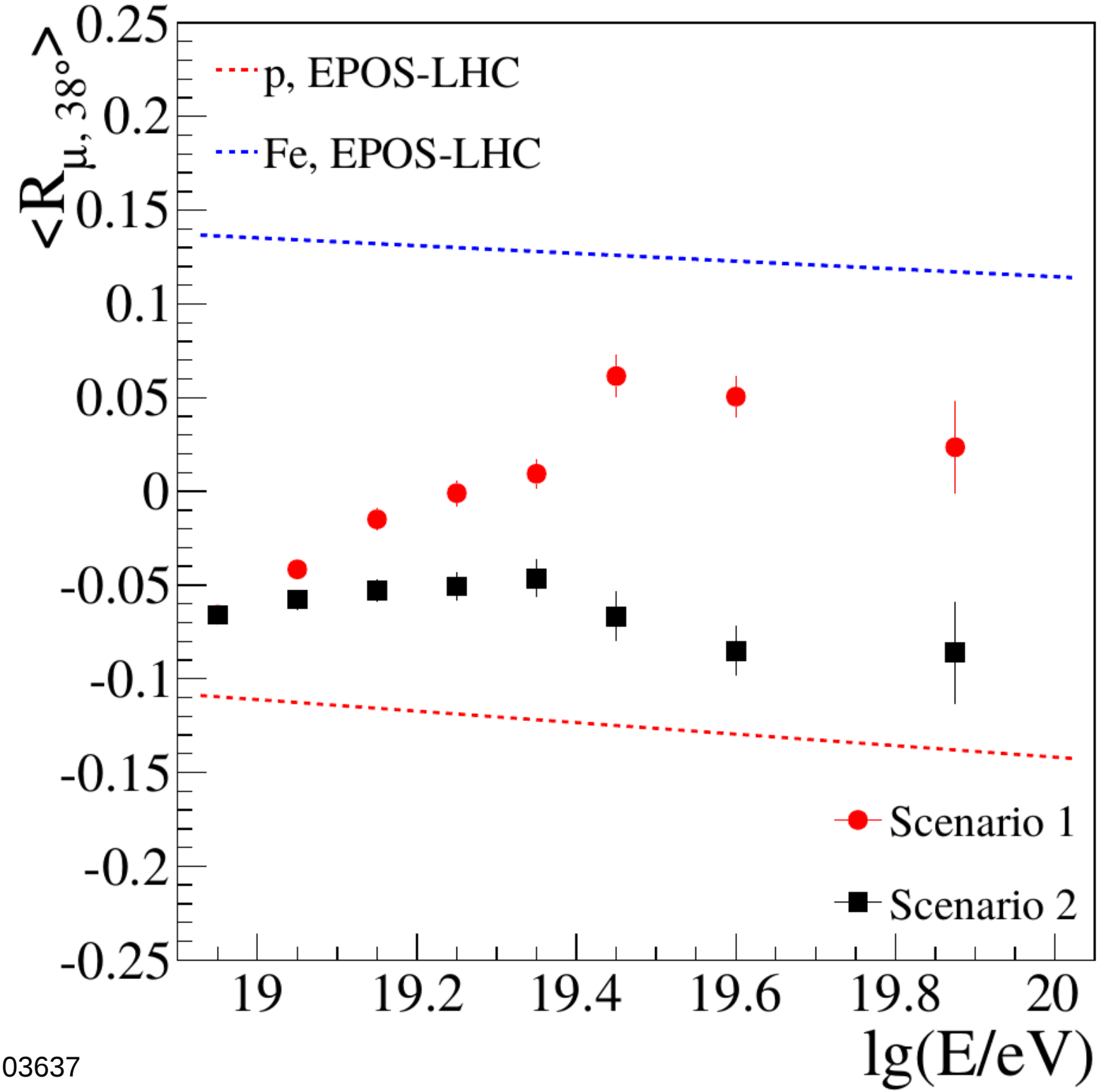


everything published

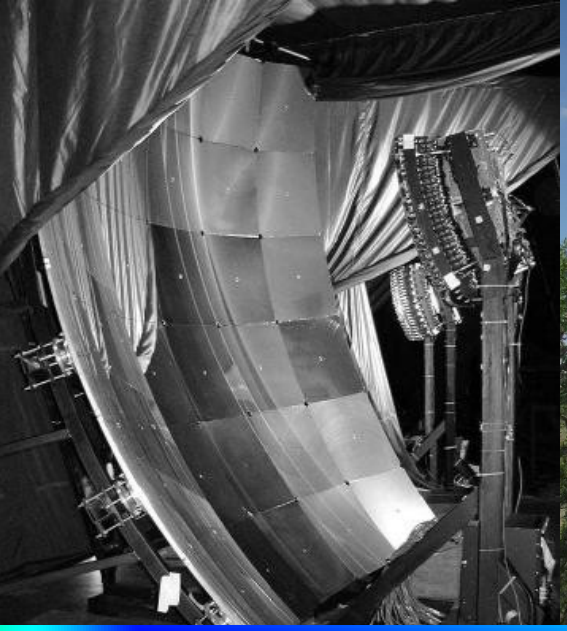
everybody can use Auger data
for comparison
to models and other measurements

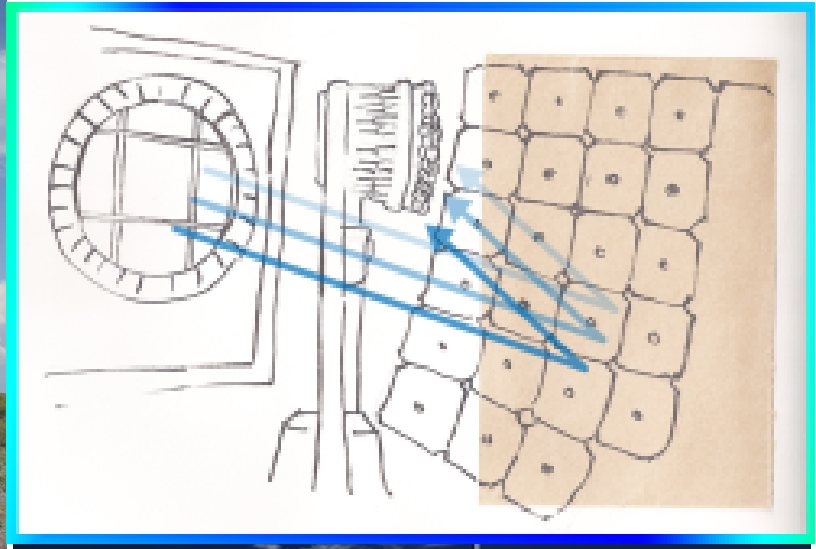


arXiv:1604.03637

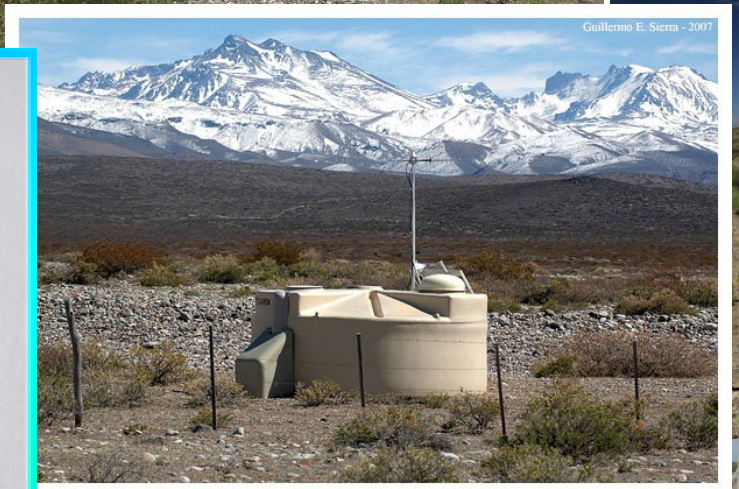


arXiv:1604.03637






Surface Detector
One station


Guillermo E. Sierra - 2007

Highlights from Auger

1/6 Flux supression