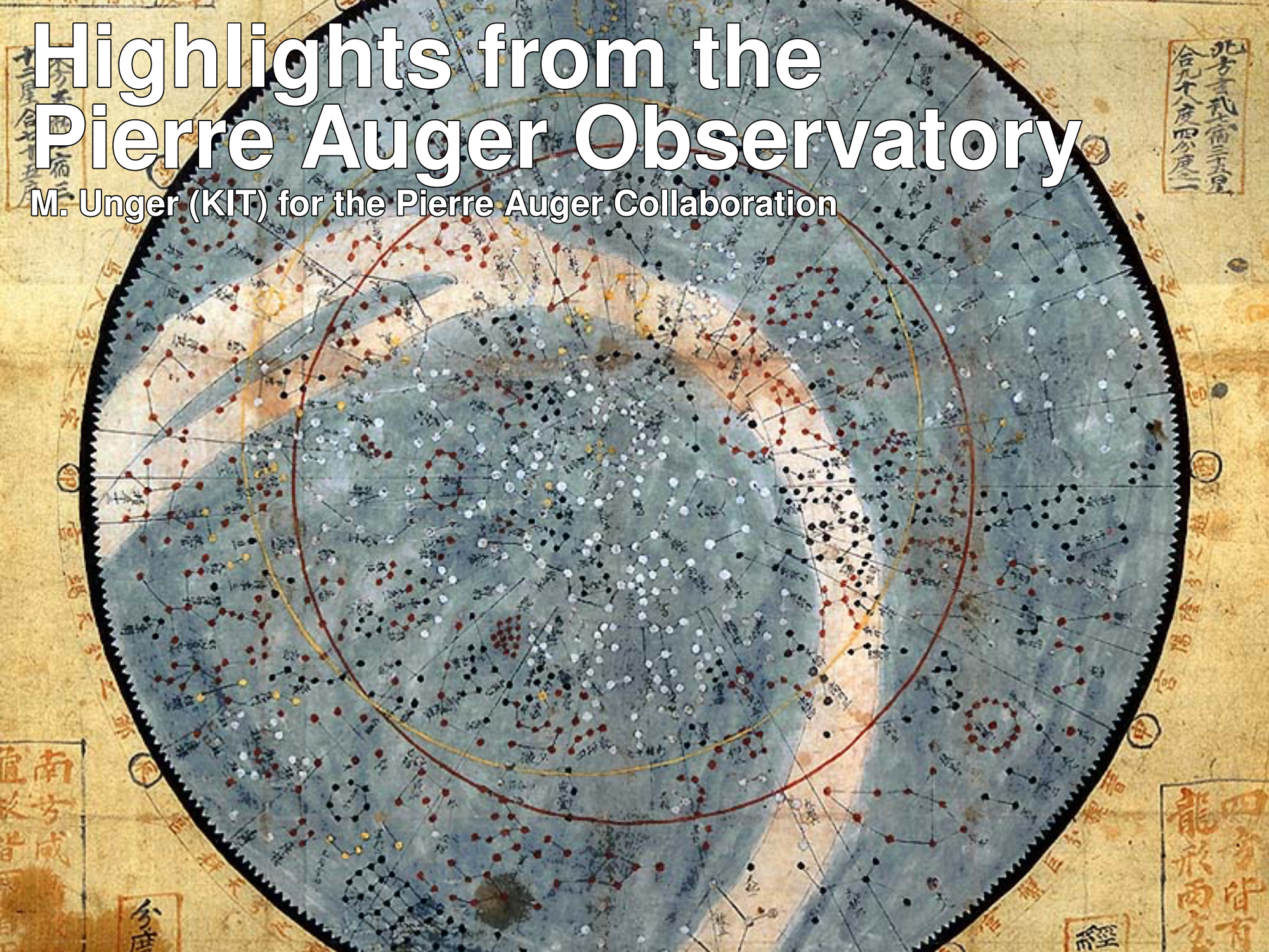
Highlights from the Pierre Auger Observatory

M. Unger (KIT) for the Pierre Auger Collaboration



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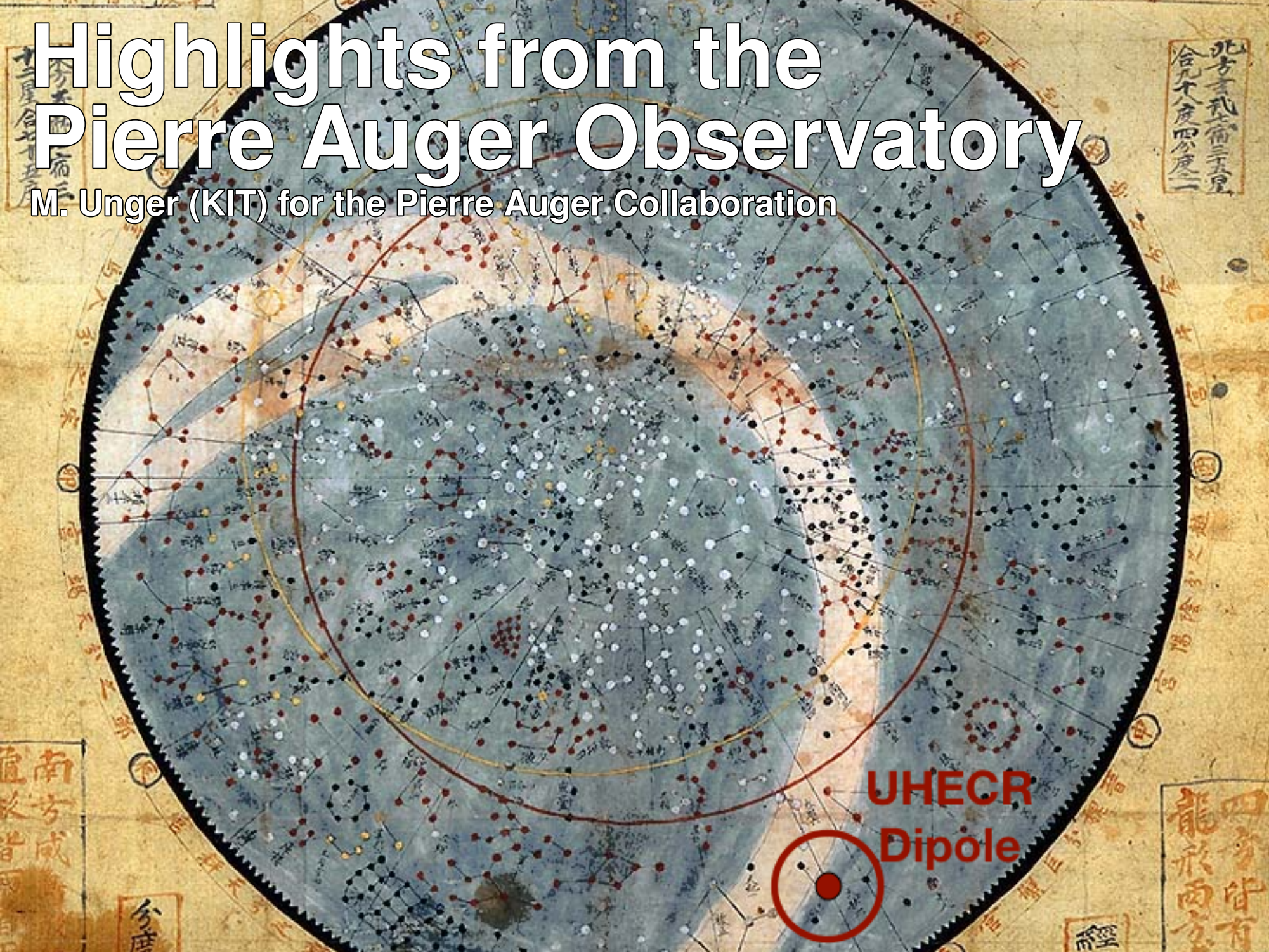
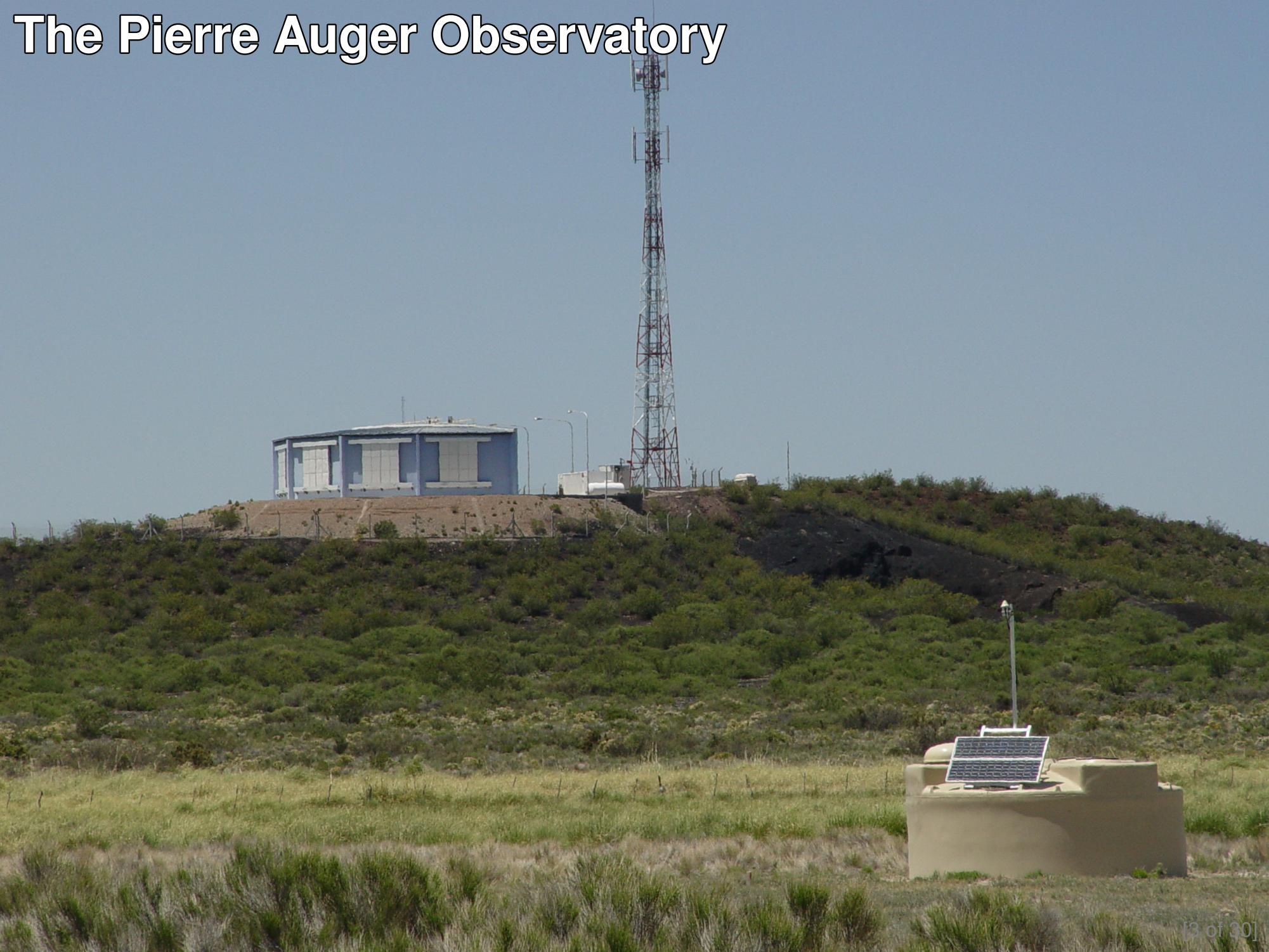
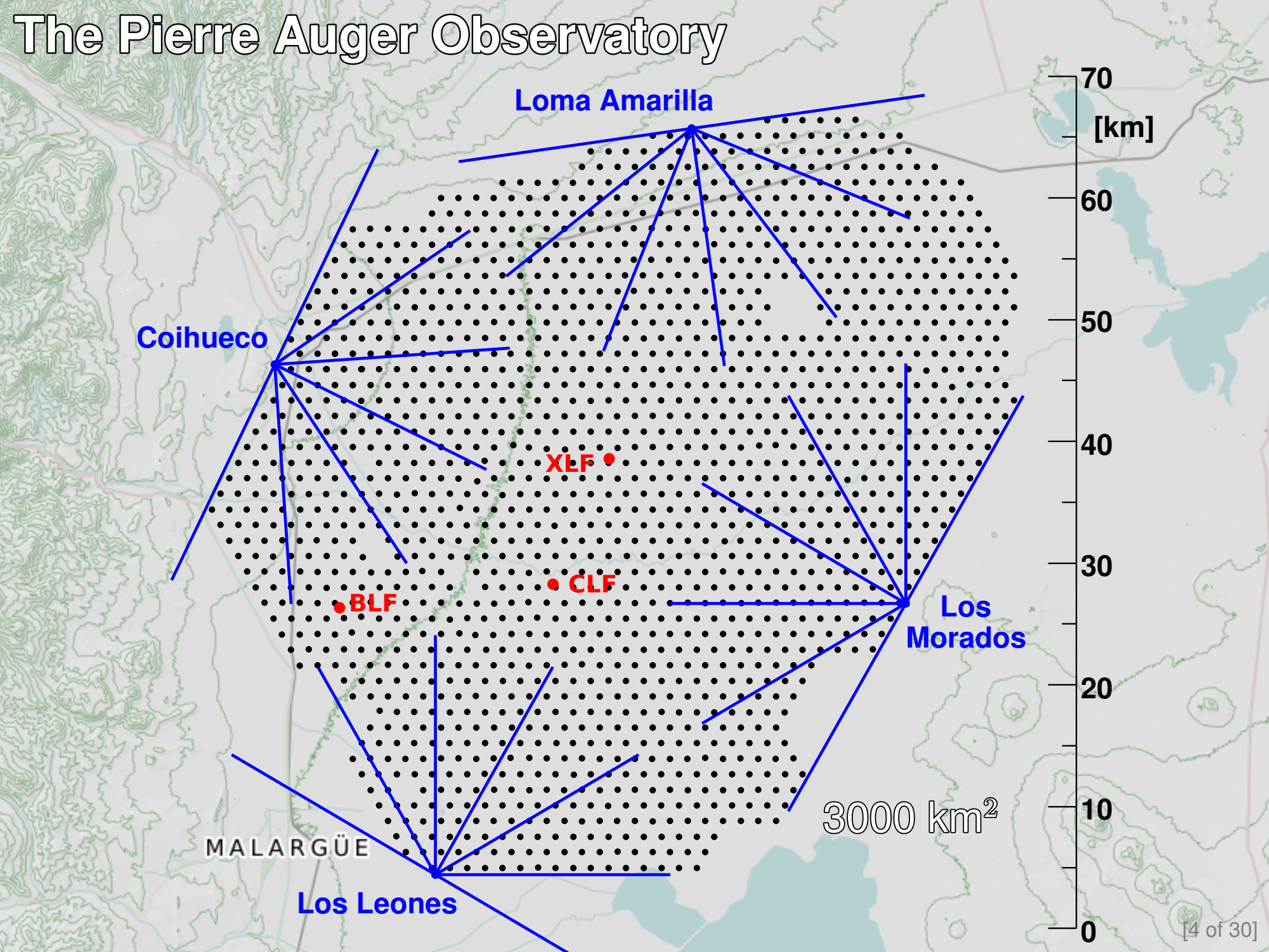


The Pierre Auger Observatory




The Pierre Auger Observatory
Loma Amarilla
Coihueco
XLF
CLF
BLF
Los Morados
MALARGÜE
Los Leones
3000 km²
70
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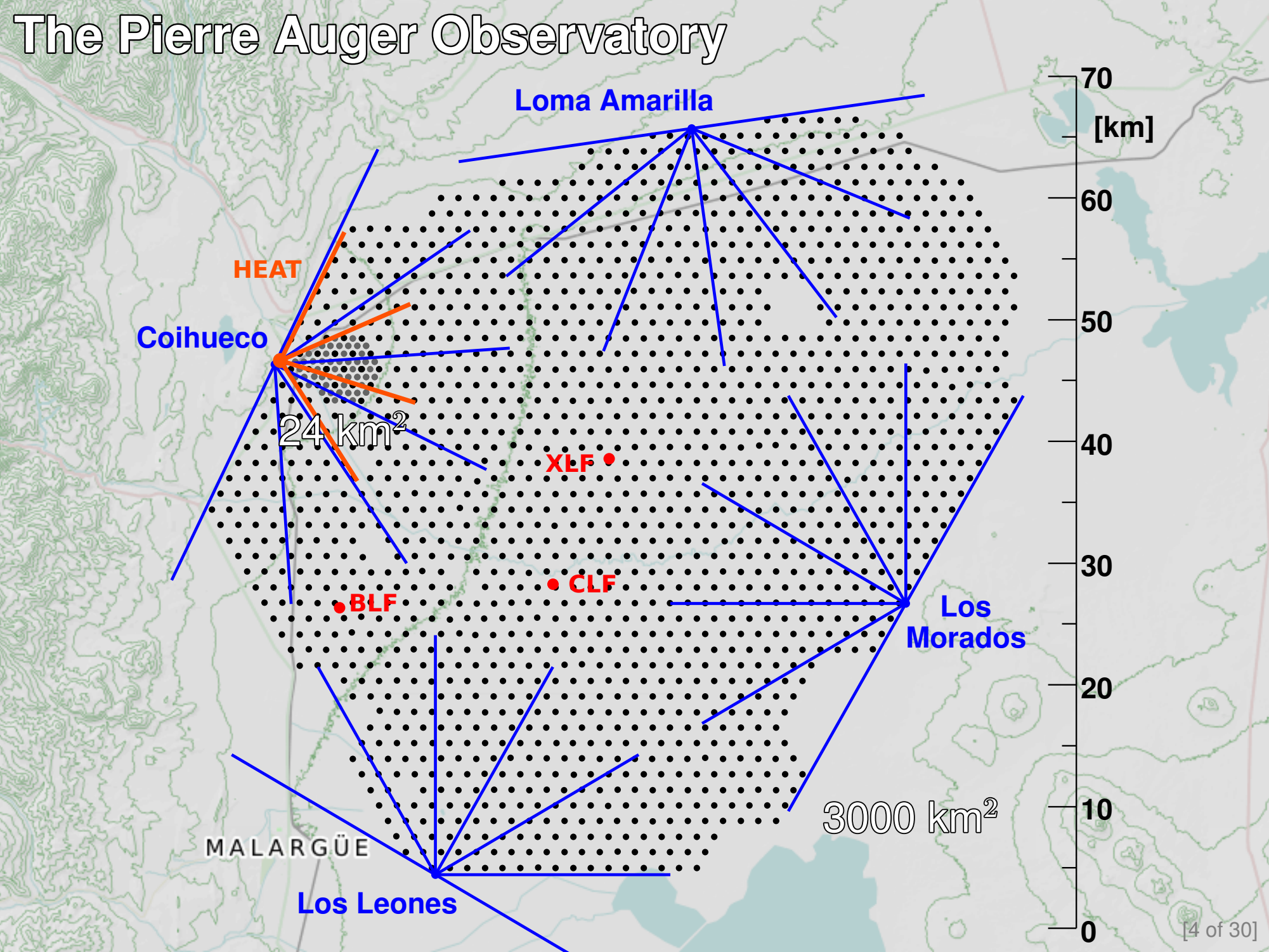
The Pierre Auger Observatory
Loma Amarilla
HEAT
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24 km²
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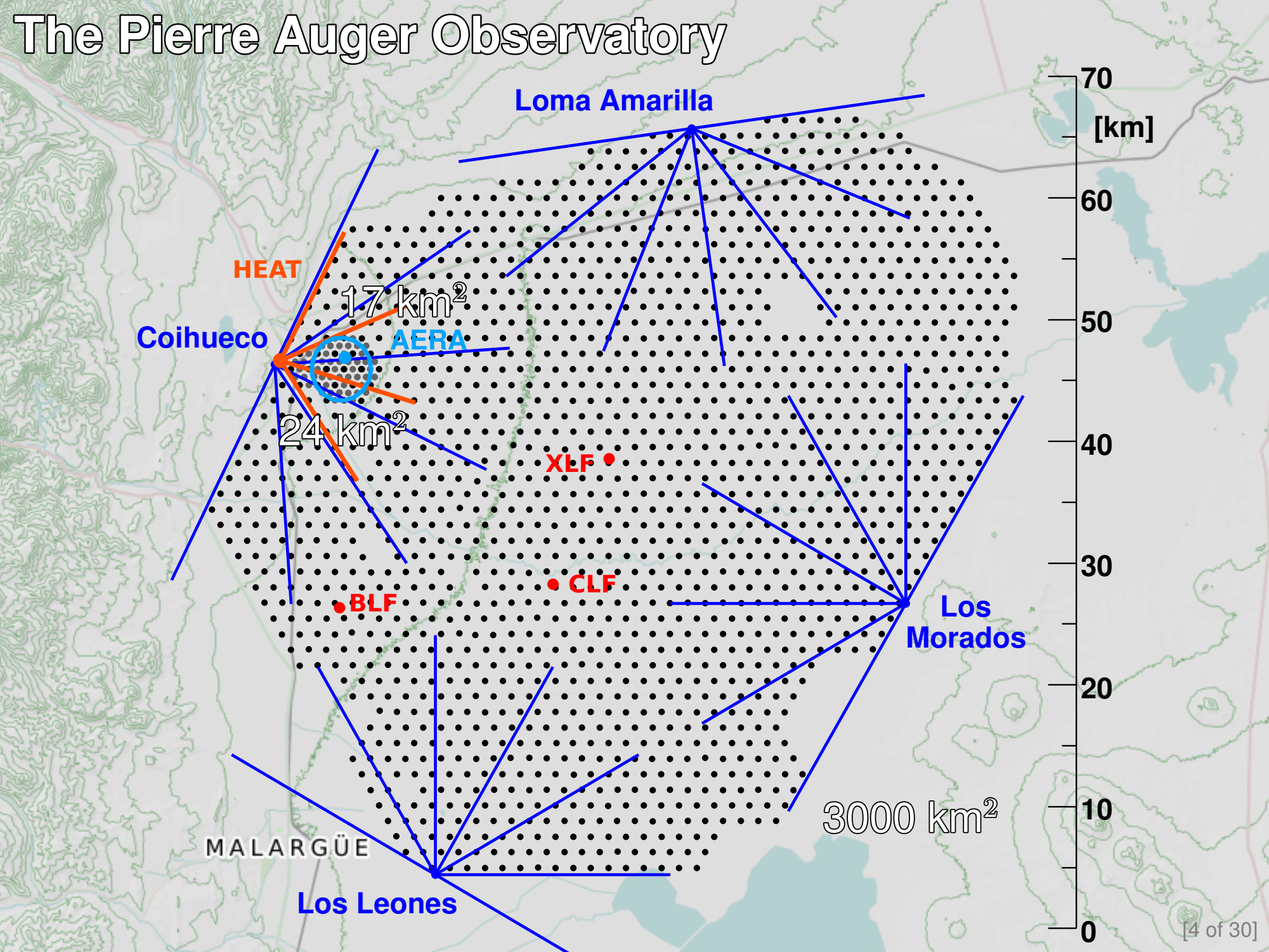
The Pierre Auger Observatory
Loma Amarilla
HEAT
17 km²
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AERA
24 km²
XLF
CLF
BLF
Los Morados
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MALARGÜE
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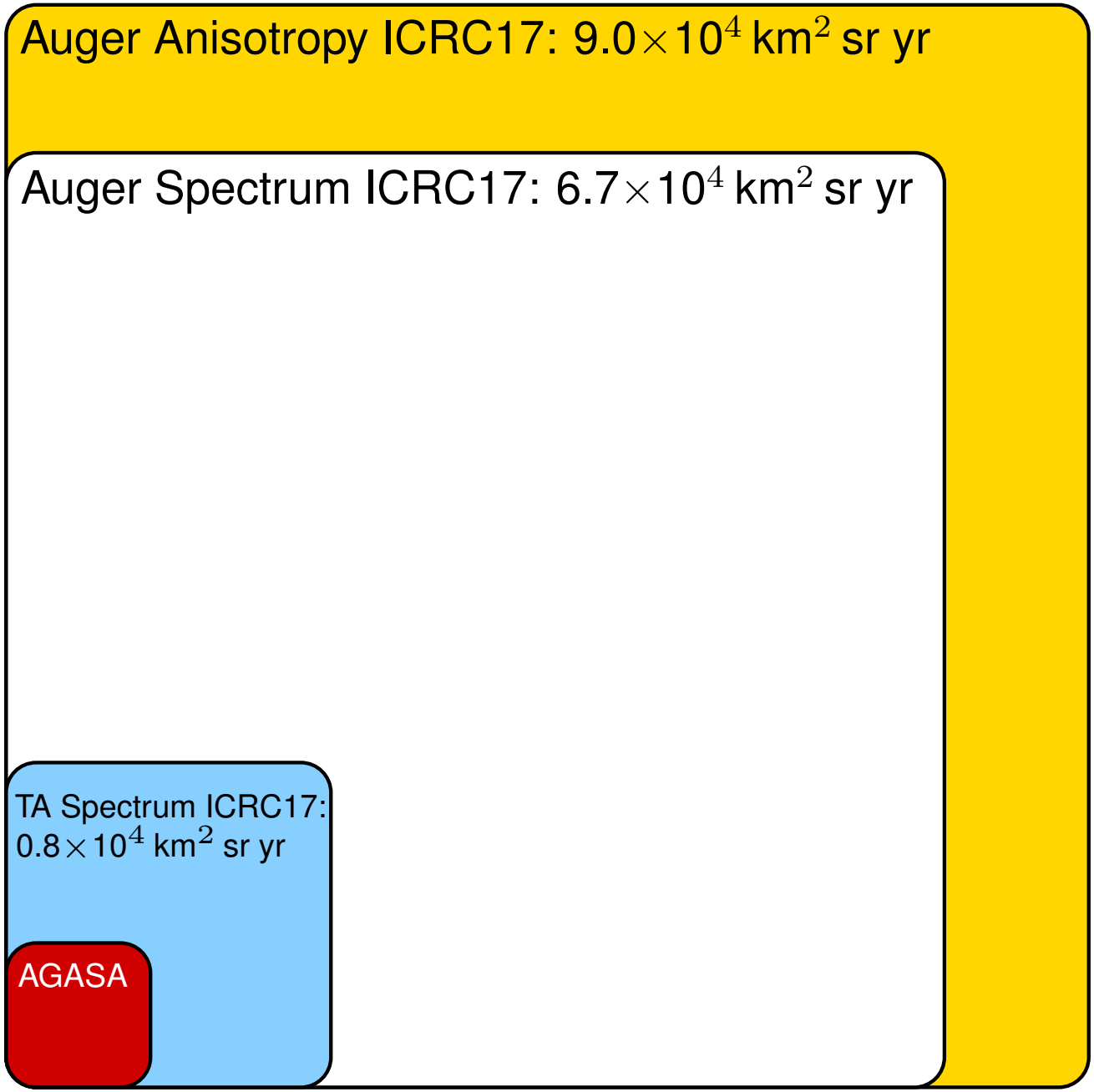
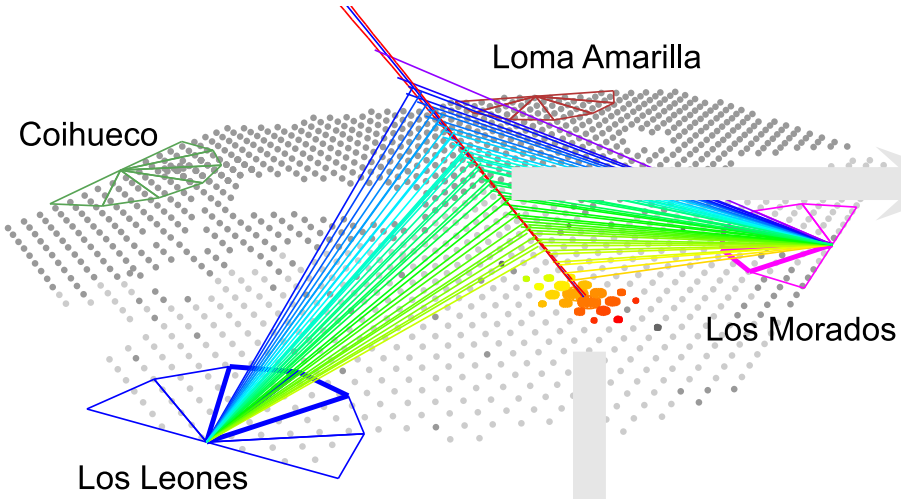
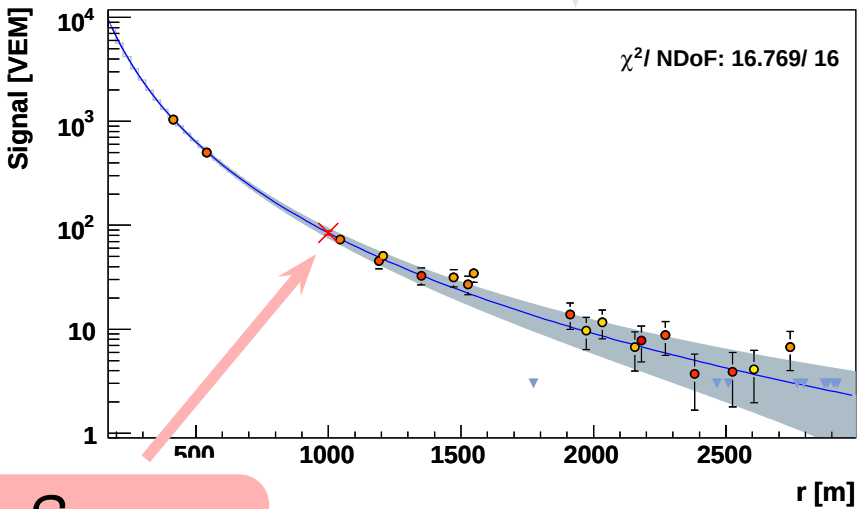
UHE Exposure



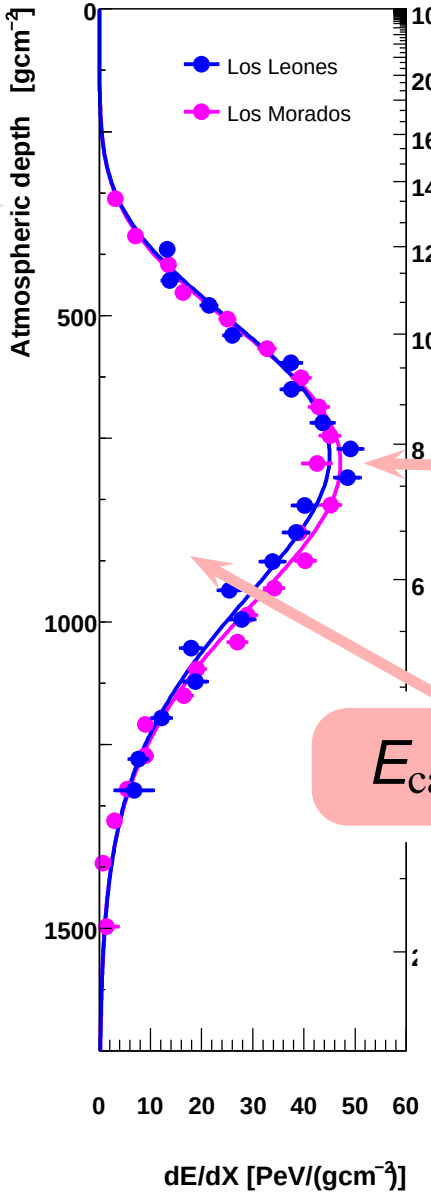
Hybrid Detection of Air Showers





S_{1000}

$E_{\text{surface}} = f(S_{1000}, \theta)$



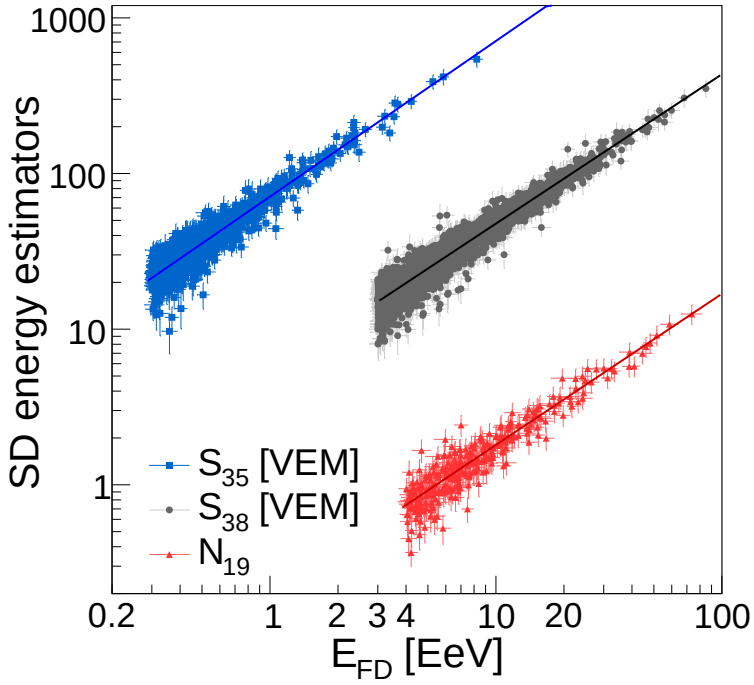
$\sigma_{X_{\max}} \leq 20\,\text{g/cm}^2$
$\Delta_{\text{sys}} \leq 10\,\text{g/cm}^2$

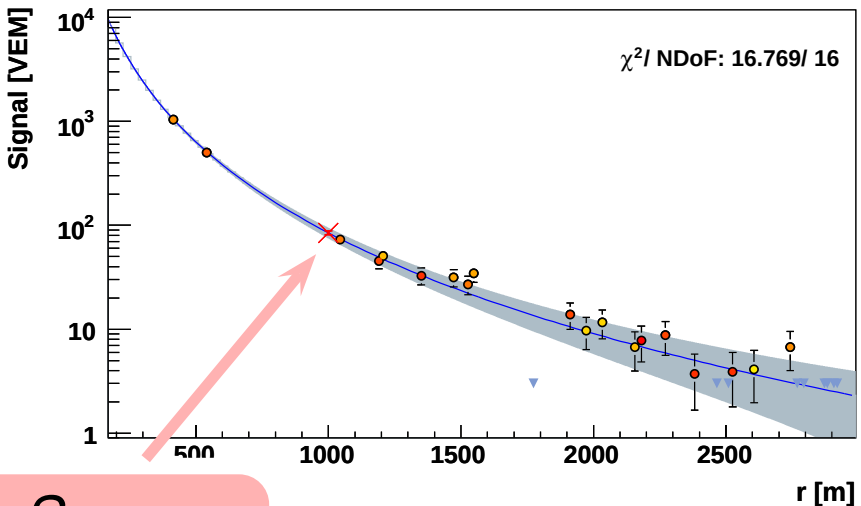
$X_{\max}$

$E_{\text{cal}} = \int \frac{dE}{dX}\, dX$

$\sigma_E/E \sim 8\,\%$
$\Delta_{\text{sys}} \approx 15\,\%$

Energy Calibration





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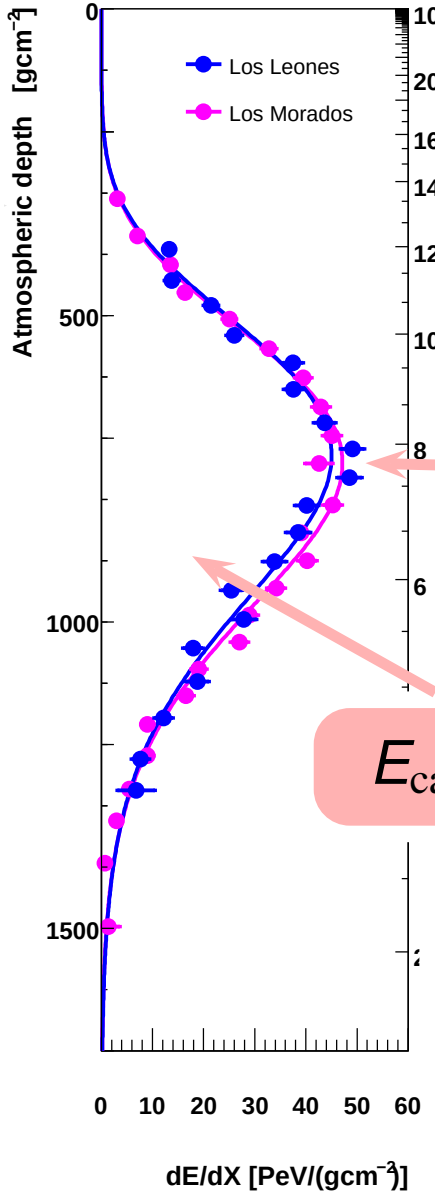

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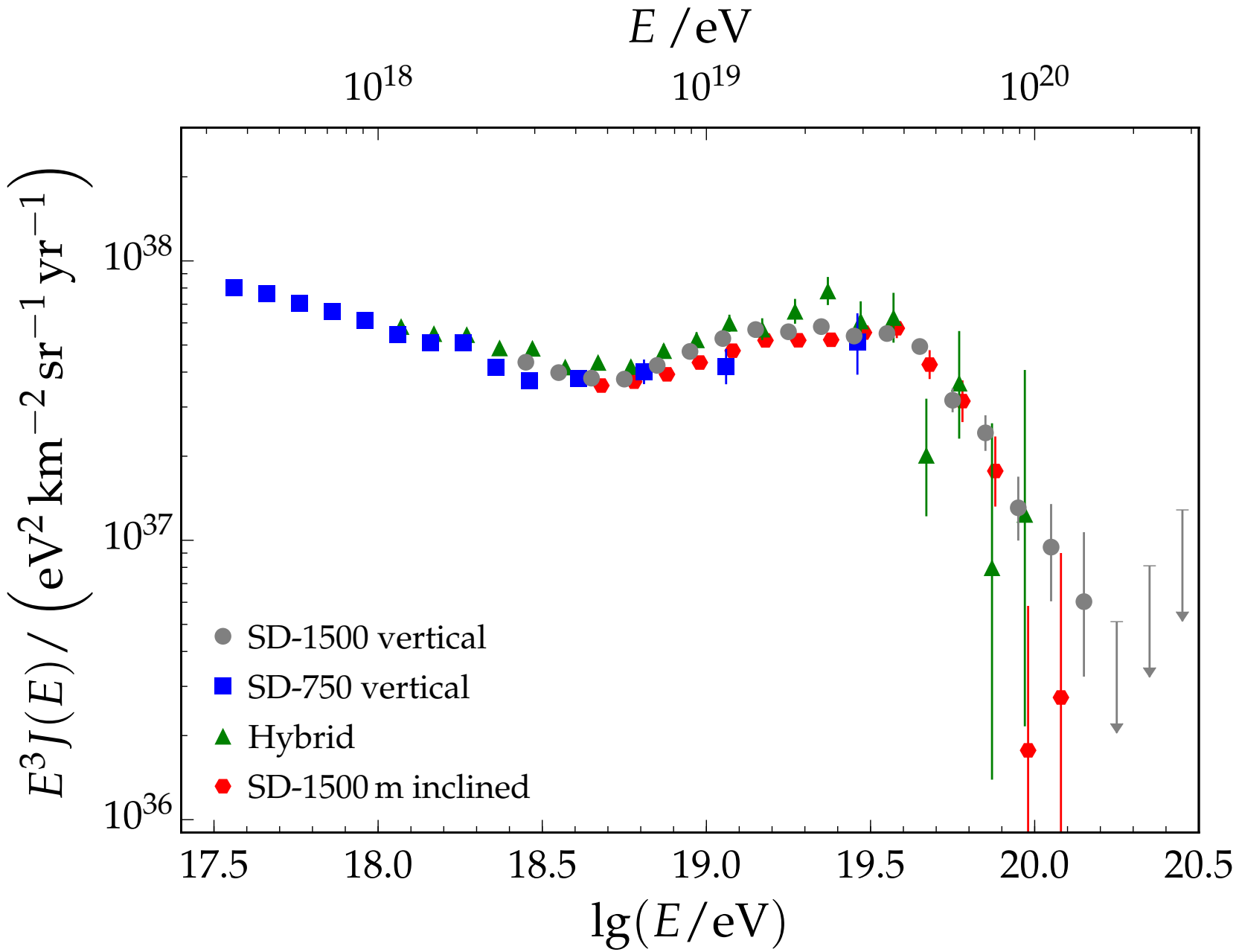
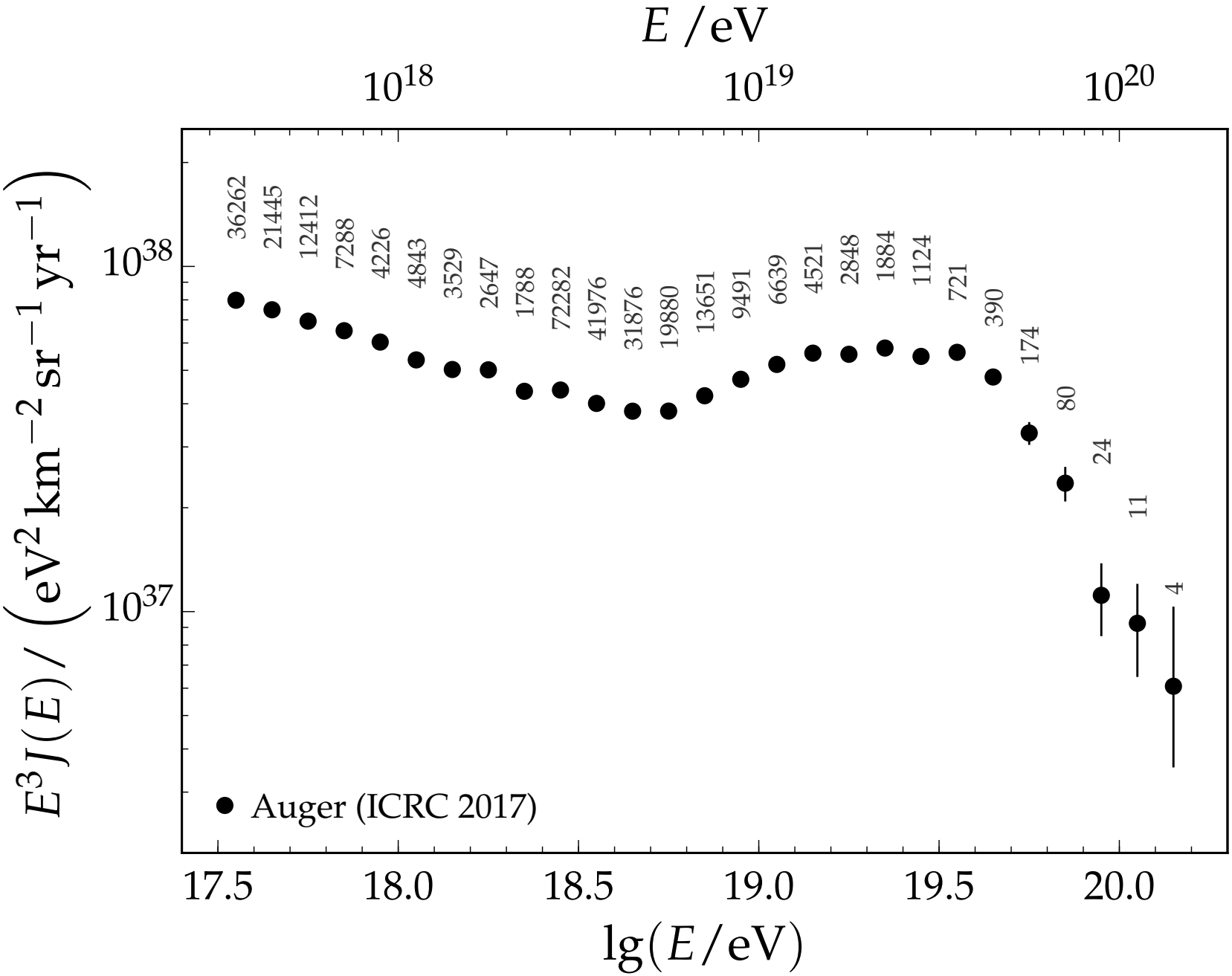
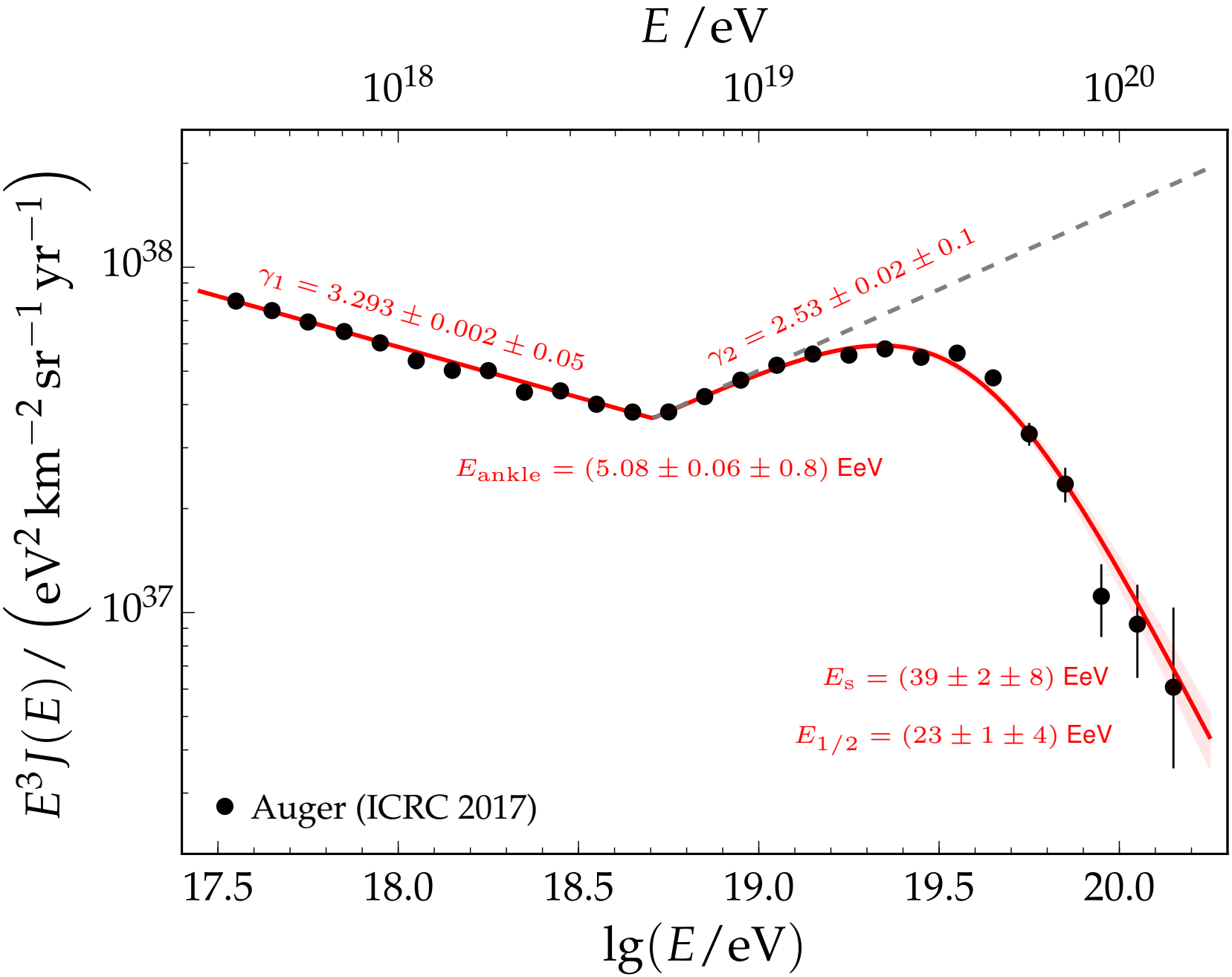
Energy Spectrum



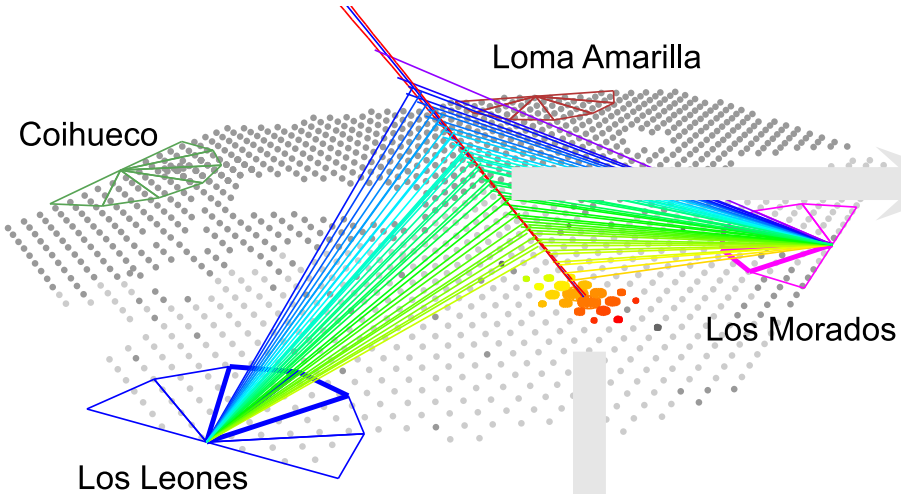
Combined Energy Spectrum

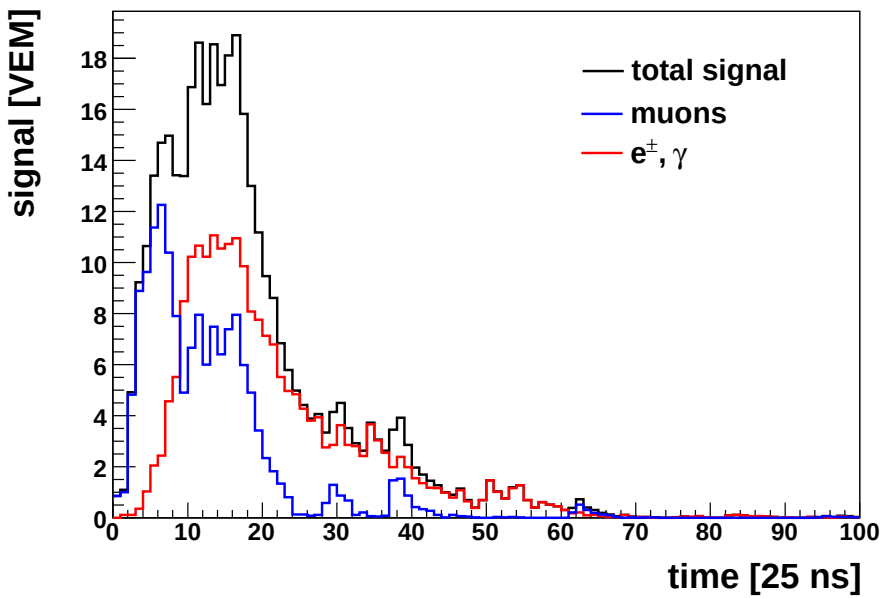


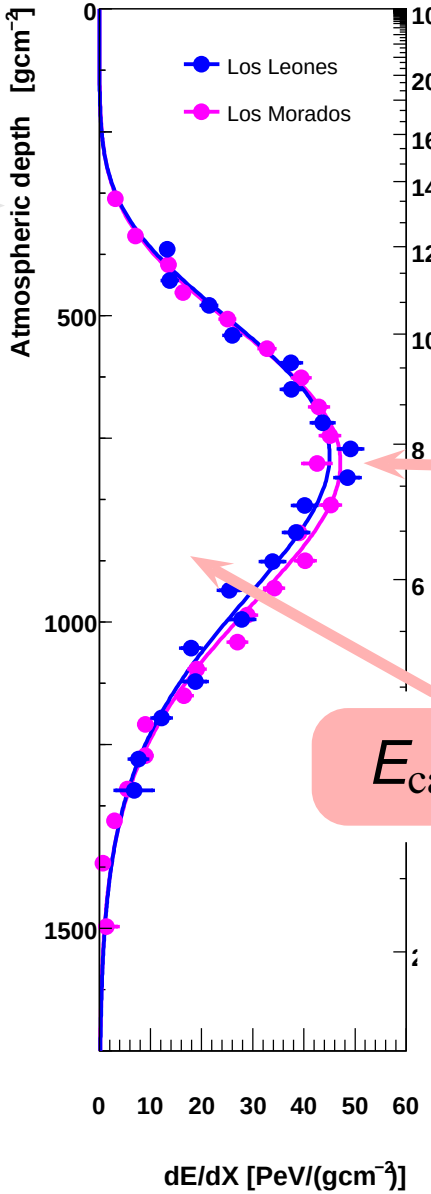
Combined Energy Spectrum



Mass Composition







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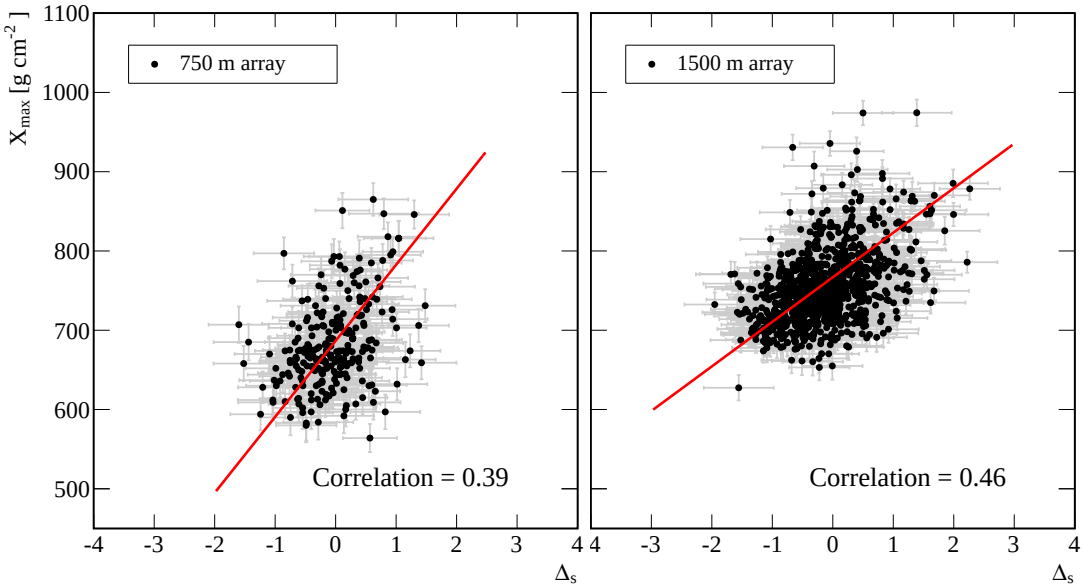

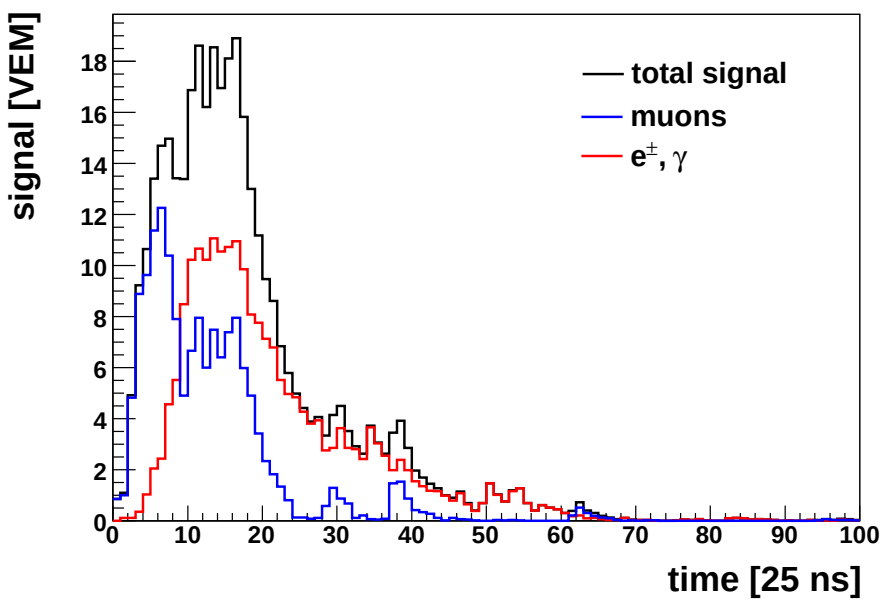

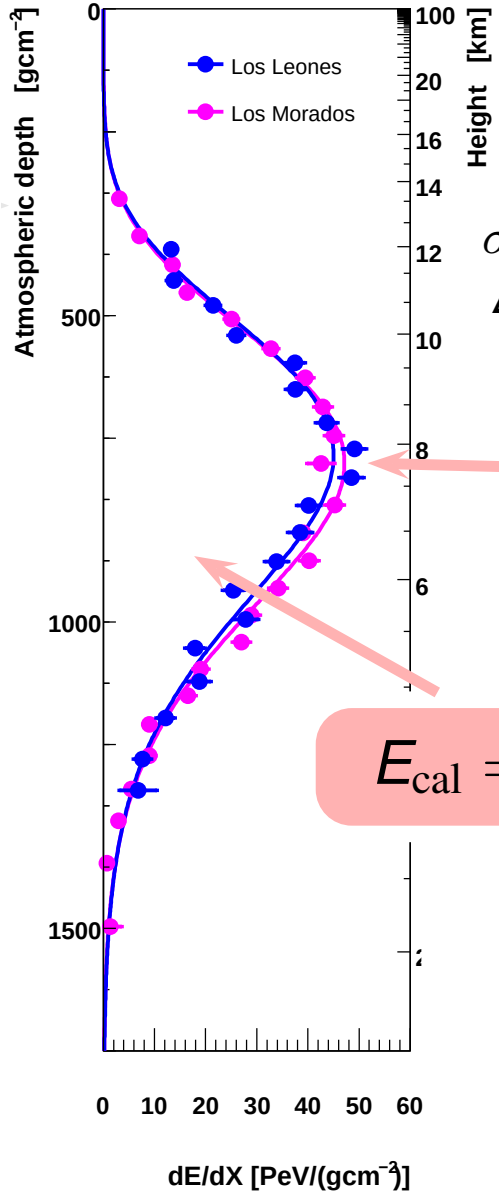

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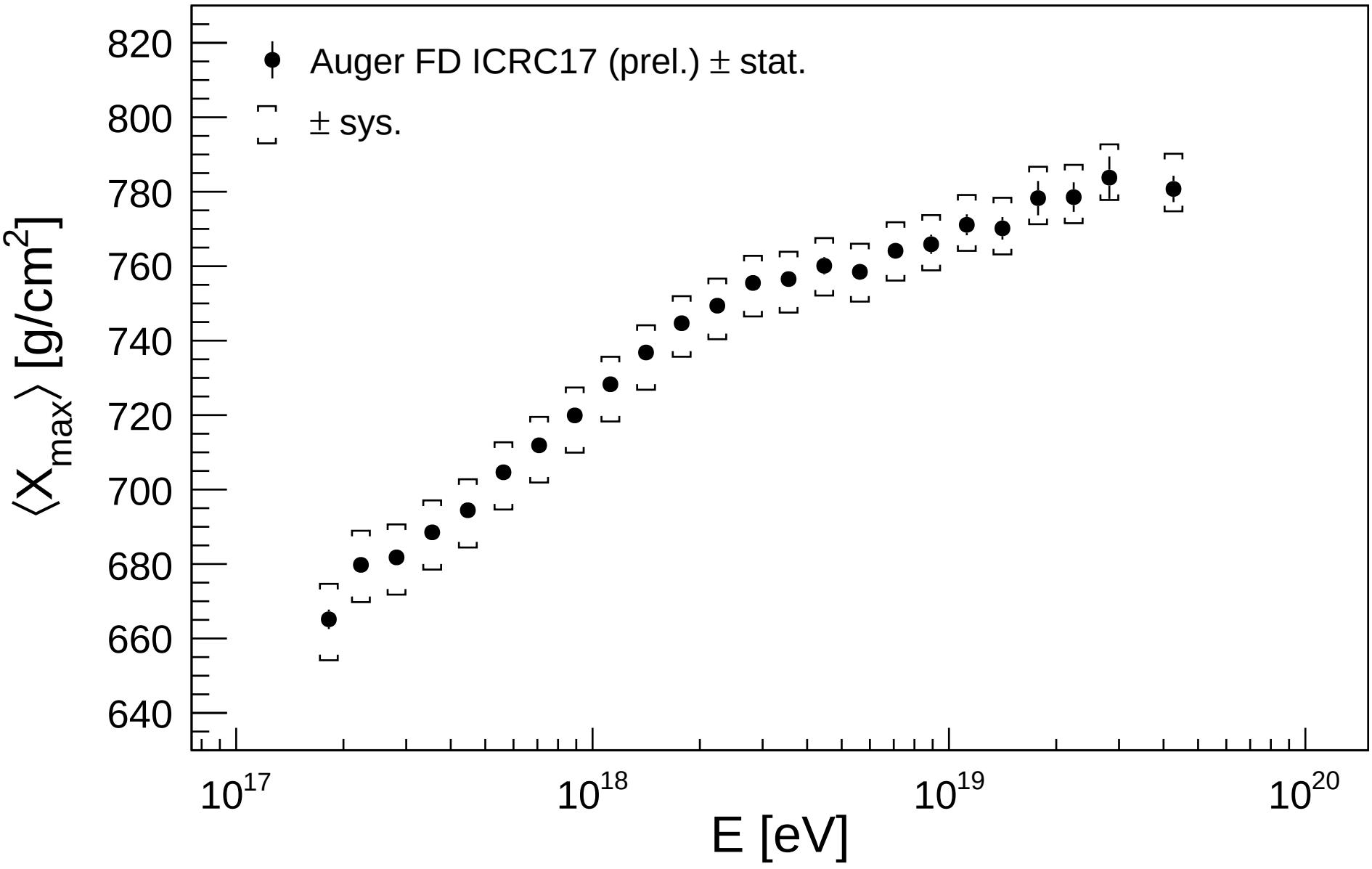
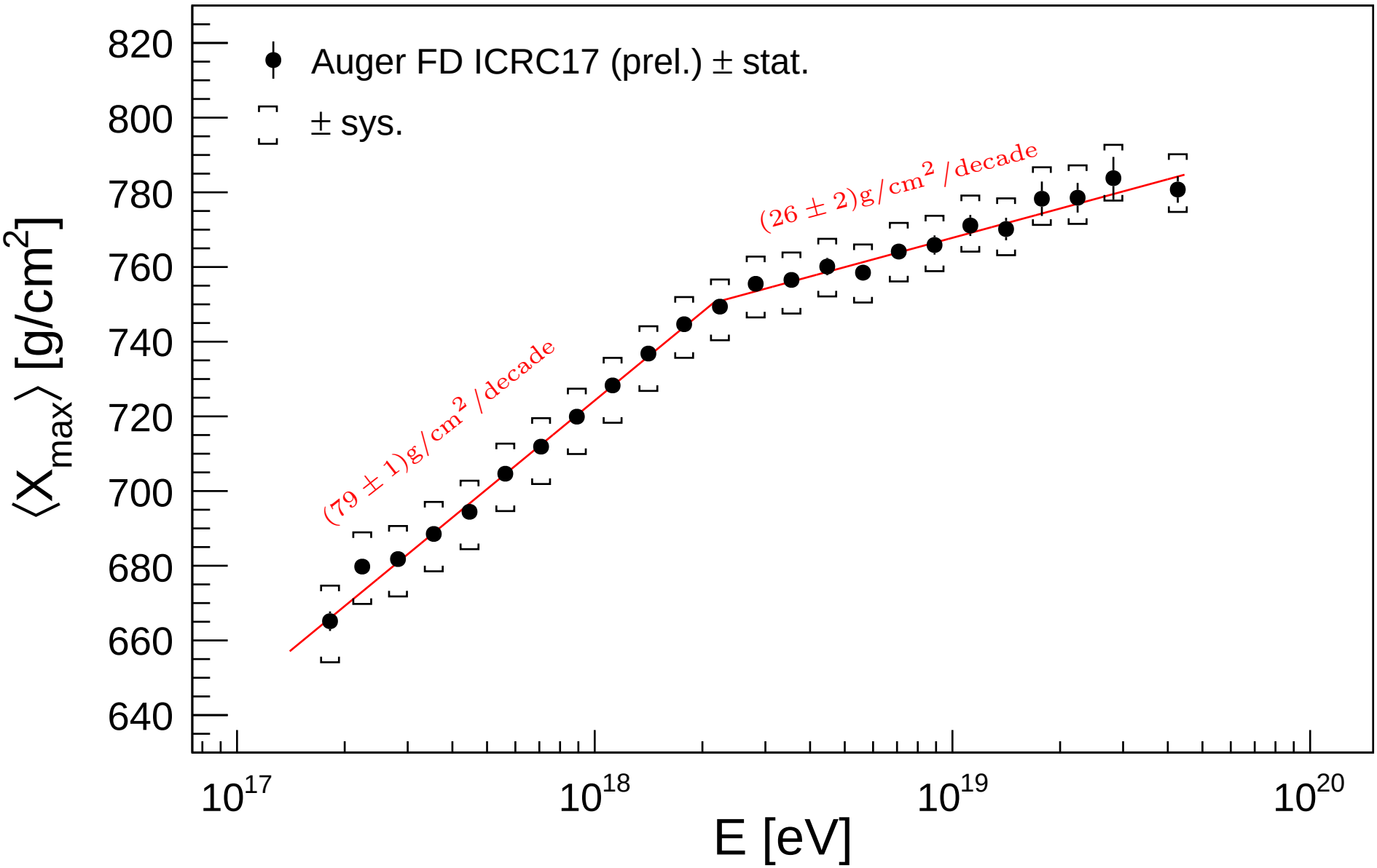
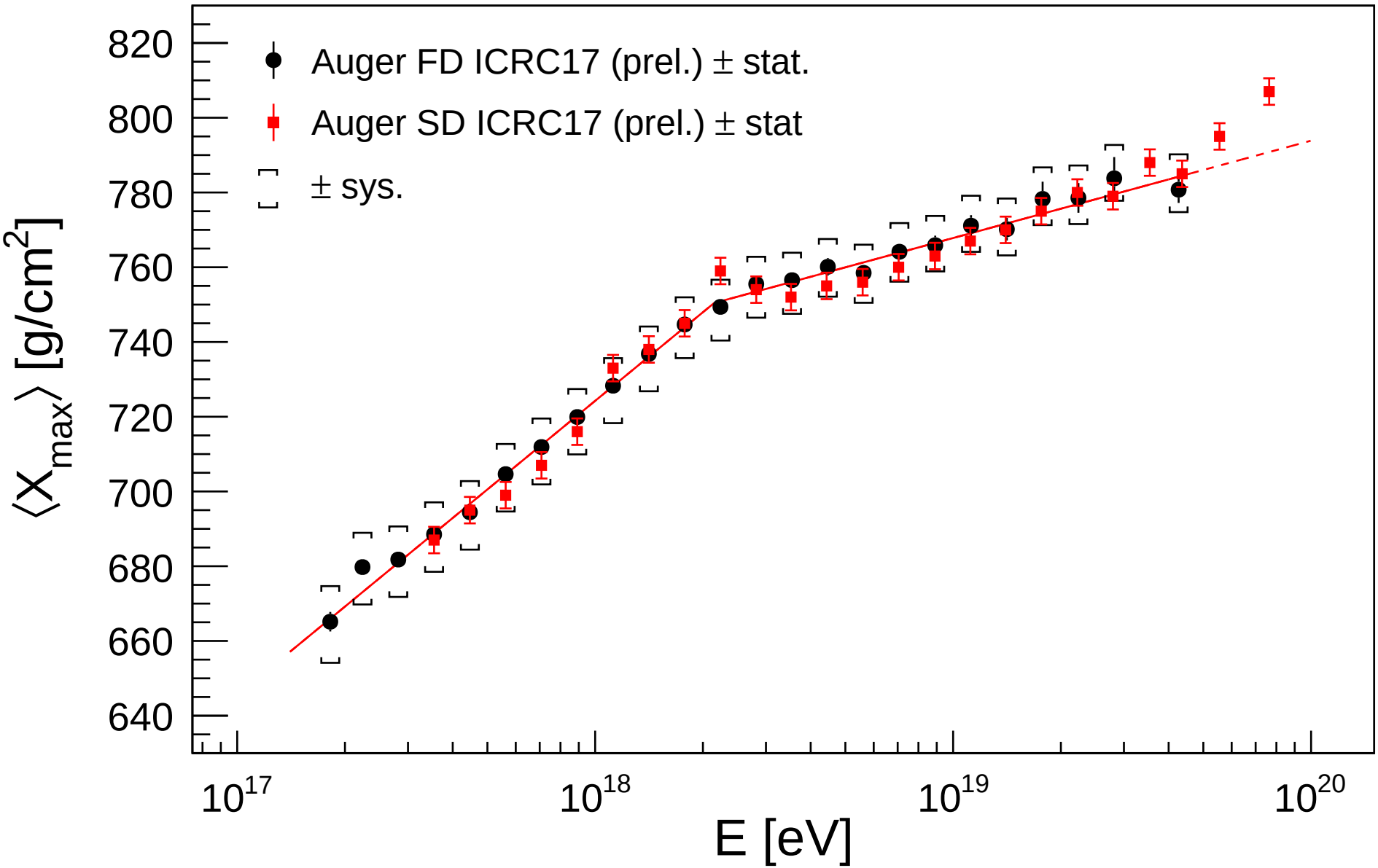
Average X_{max} Fluorescence Detector



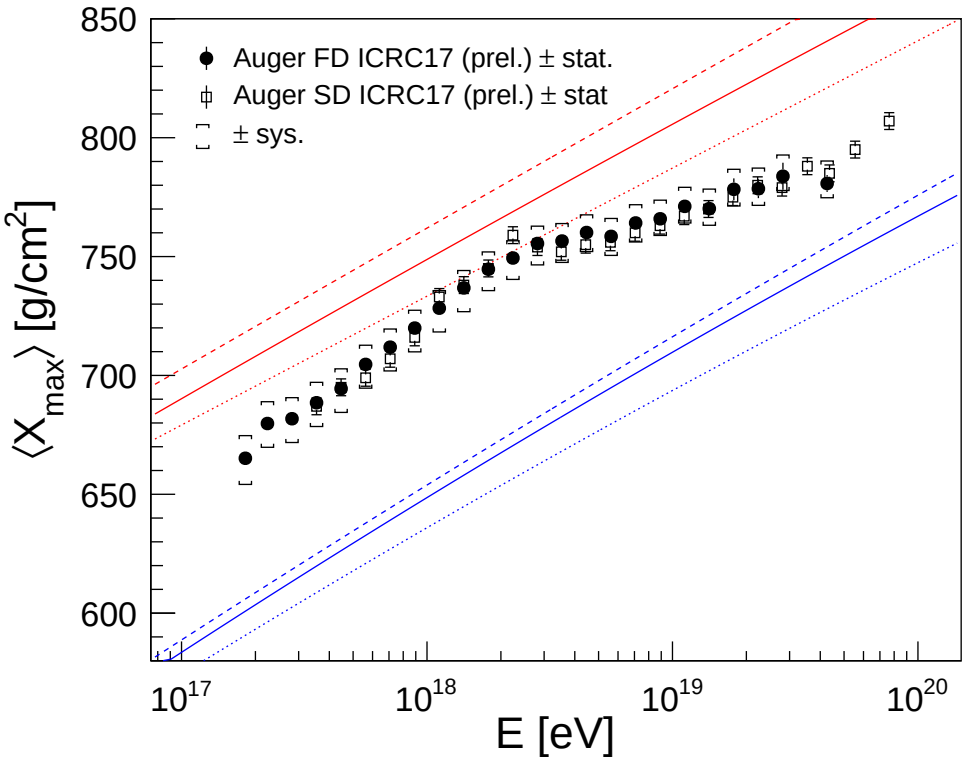
Average X_{max} Fluorescence Detector

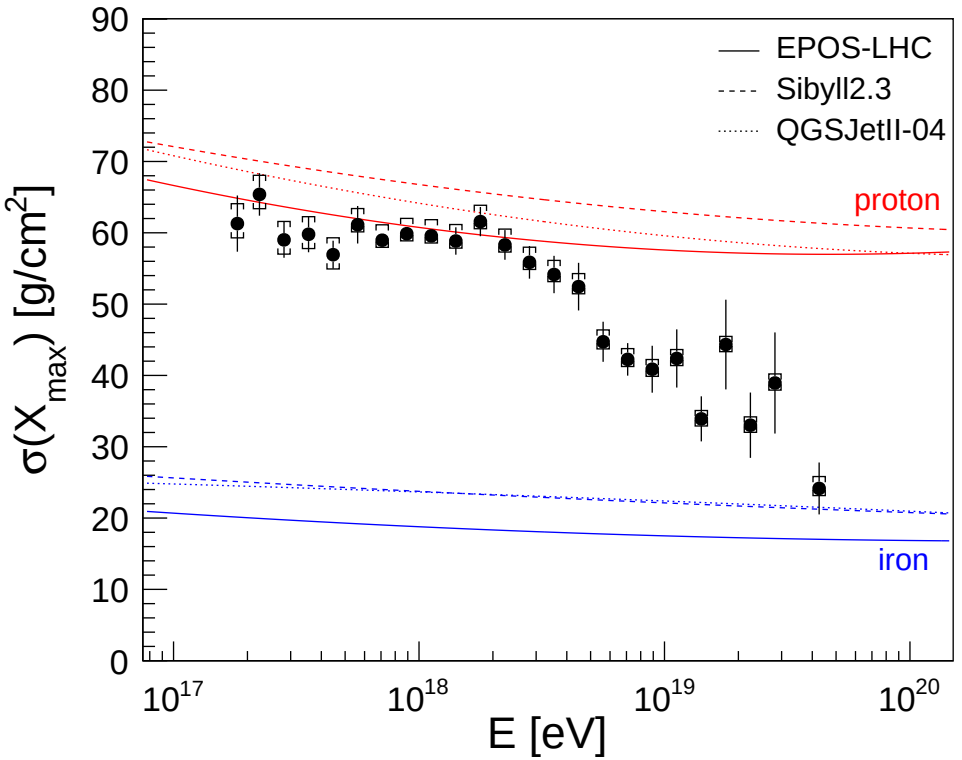


Average X_{max} Fluorescence and Surface Detector



Average X_{max} and X_{max}-fluctuations





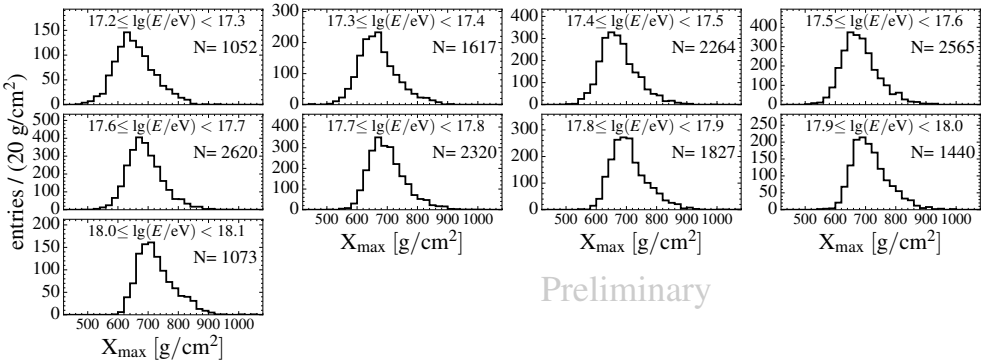
lines: air shower simulations using post-LHC hadronic interaction models

(p-He-N-Fe)-fit of X_{max} Distributions

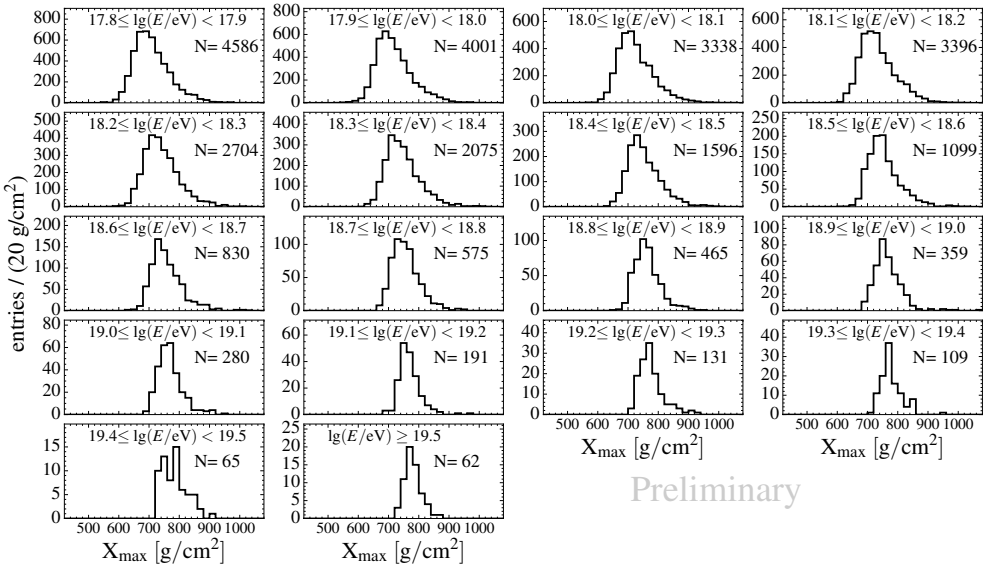
FD data:

(compatible with TA distributions, see WG report, V. de Souza et al., CRI167, Tuesday, 14:45)

$\lg(E/\mathrm{eV}) = 17.2 \ldots 18.1$

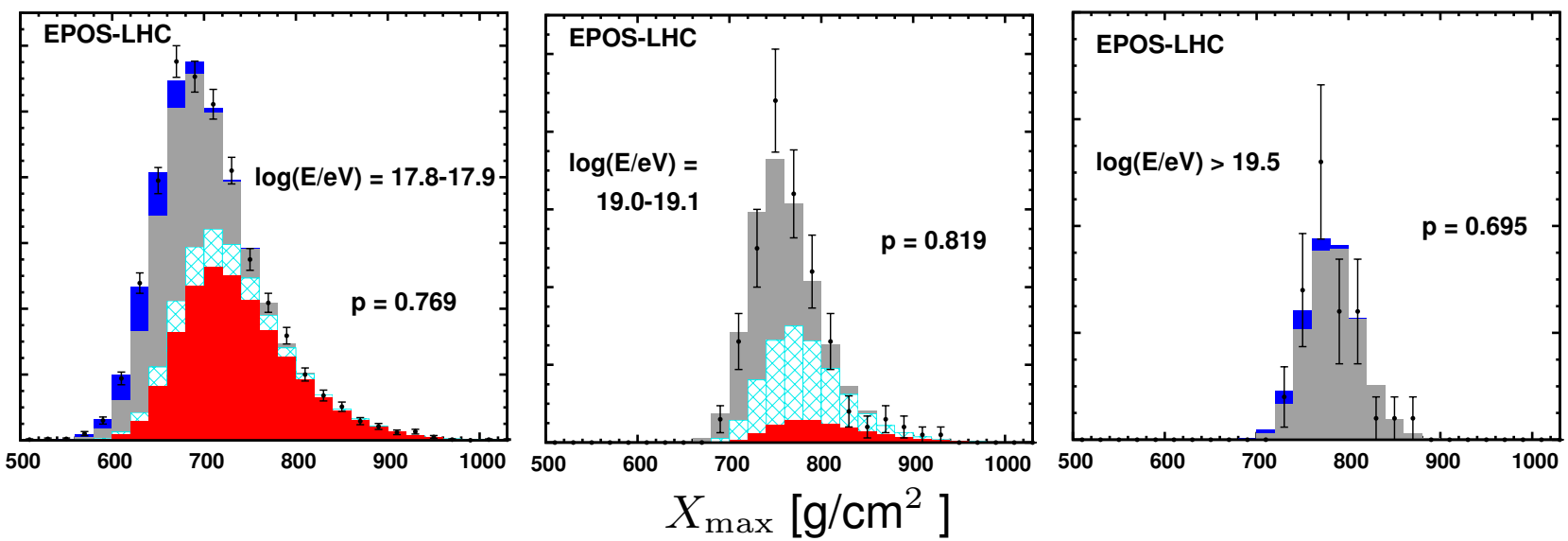


$\lg(E/\mathrm{eV}) = 17.8 \ldots > 19.5$

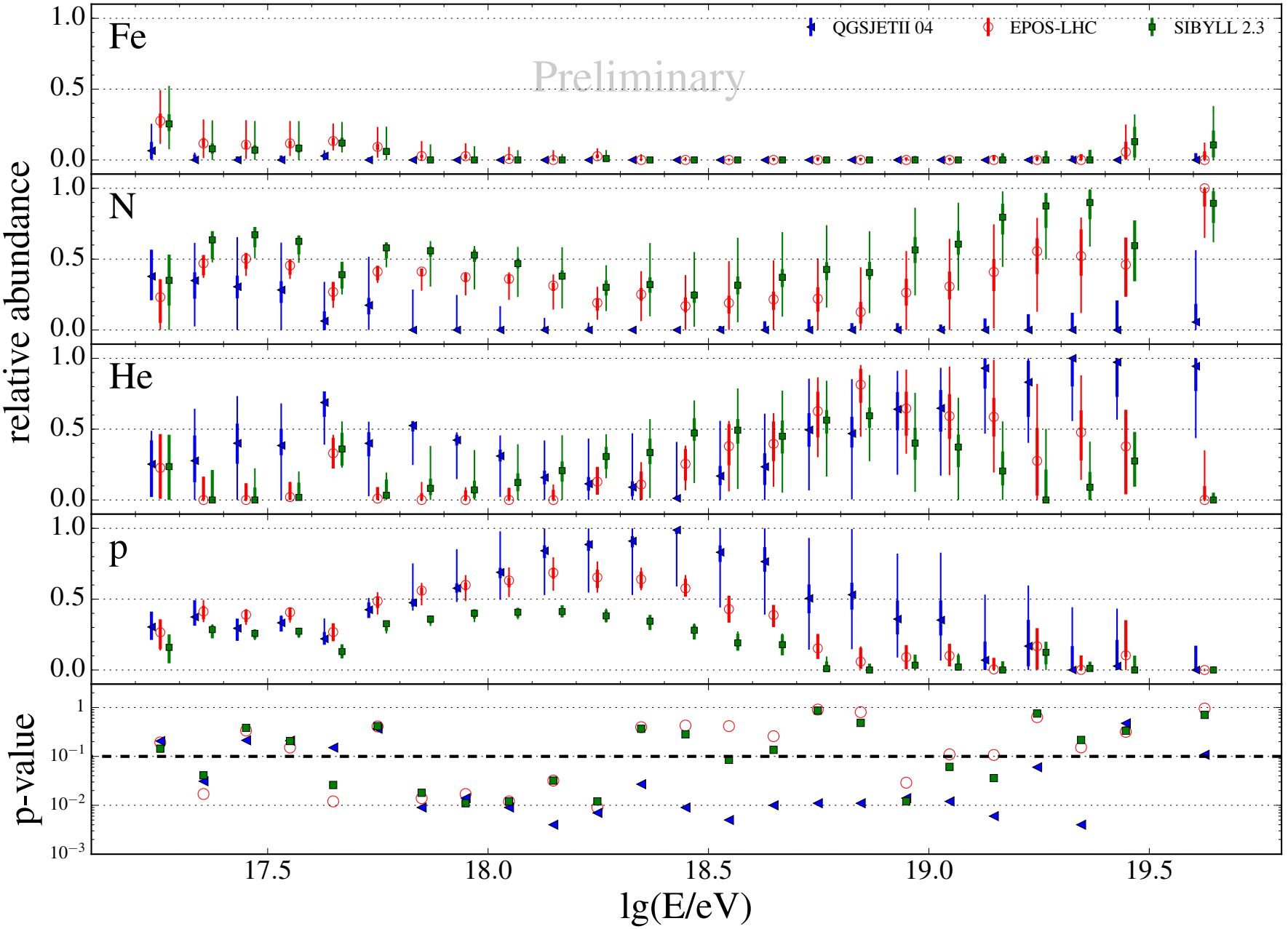


Examples of 4-component fit:

p He N Fe

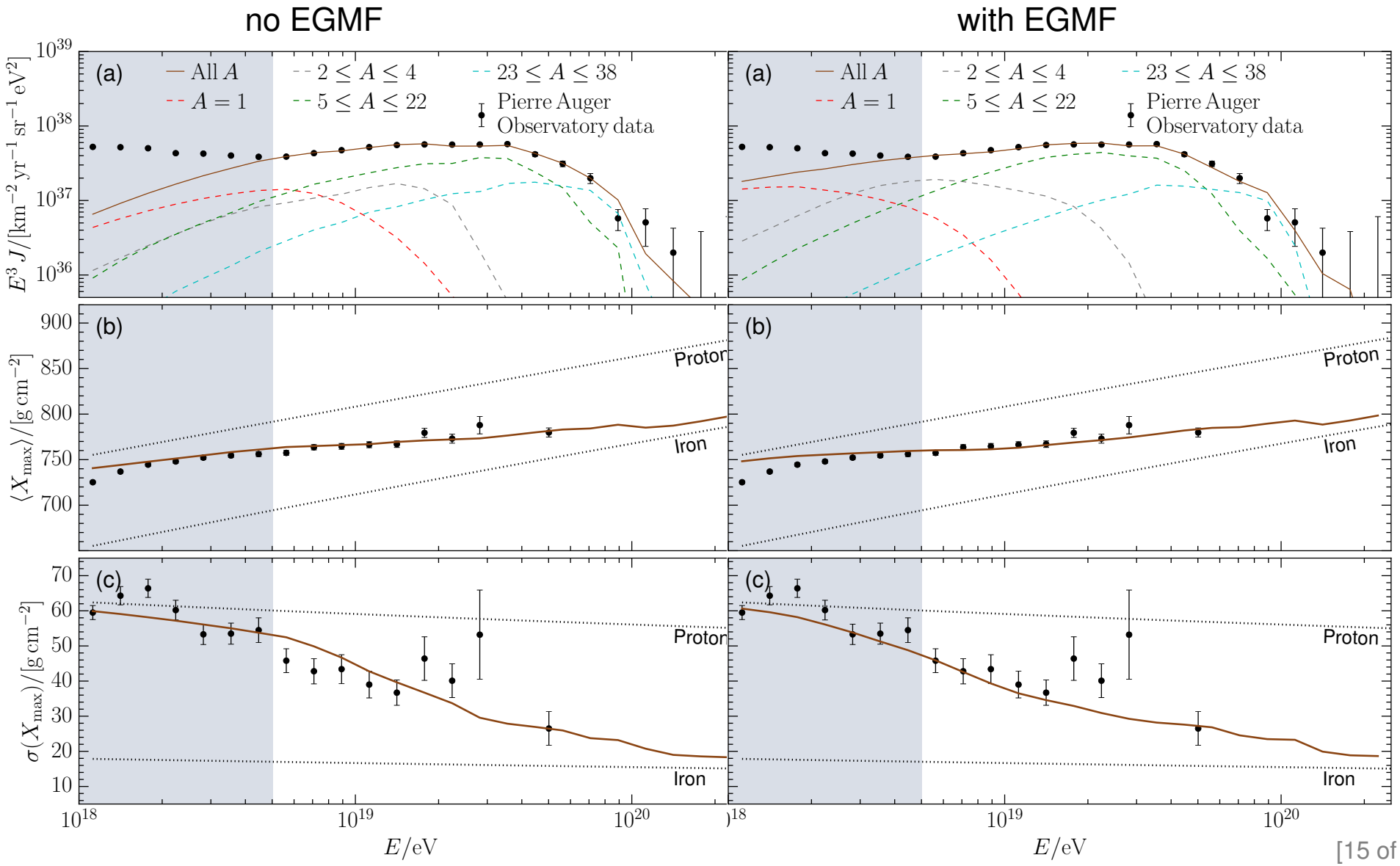


Composition Fractions



Combined Fit of Spectrum and X_{max} Distributions

rigidity-dependent cutoff at source: $E_{max} = R_{cut}\, Z$, power law injection $E^{-\gamma}$, propagation with CRPropa3, Gilmore12 EBL, Dolag12 LSS



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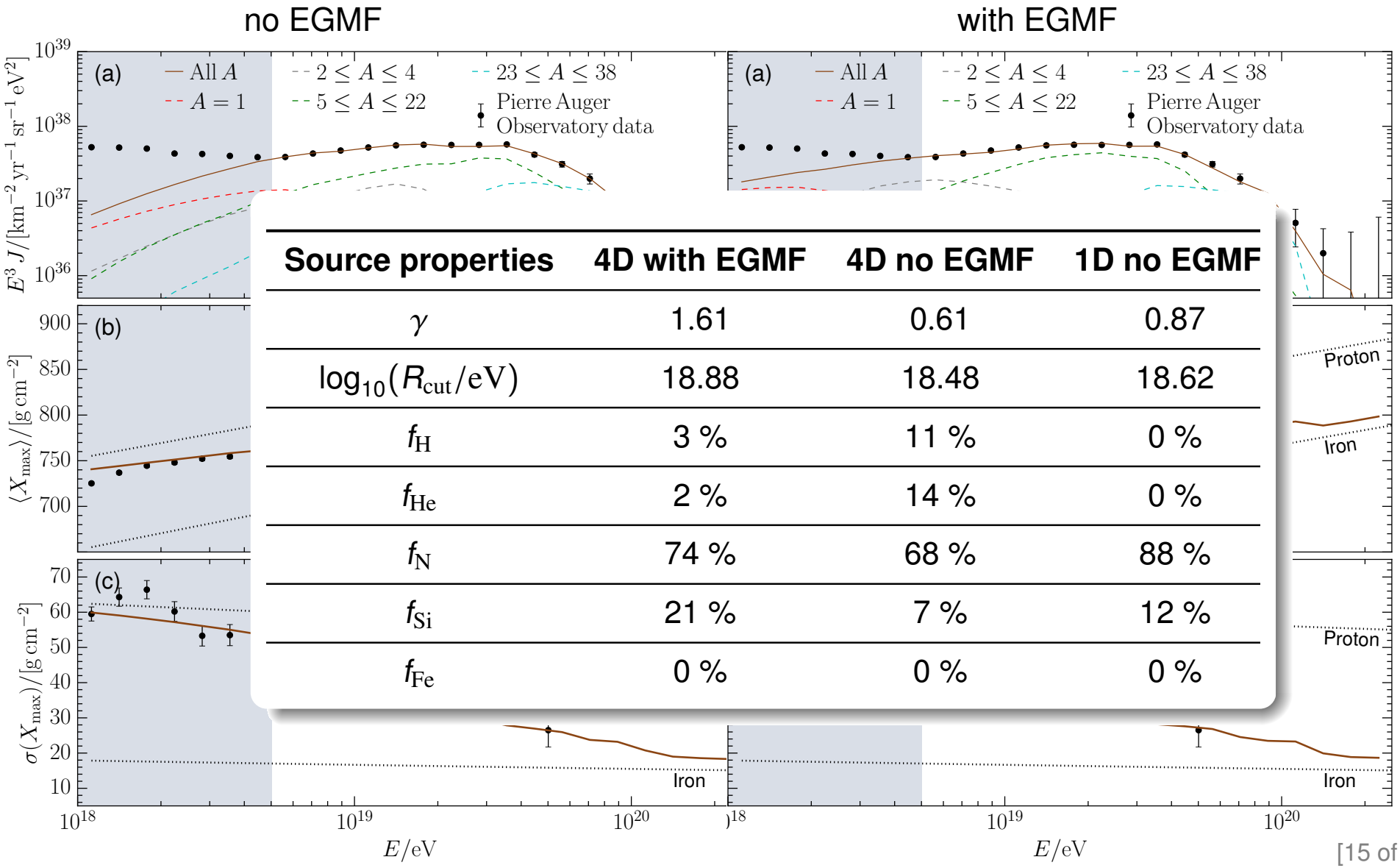
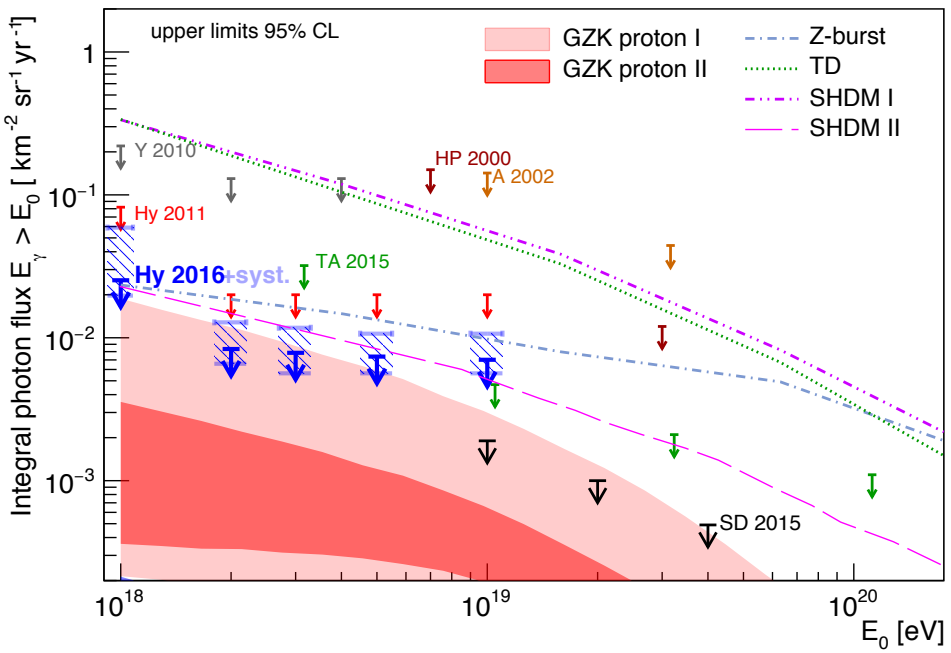


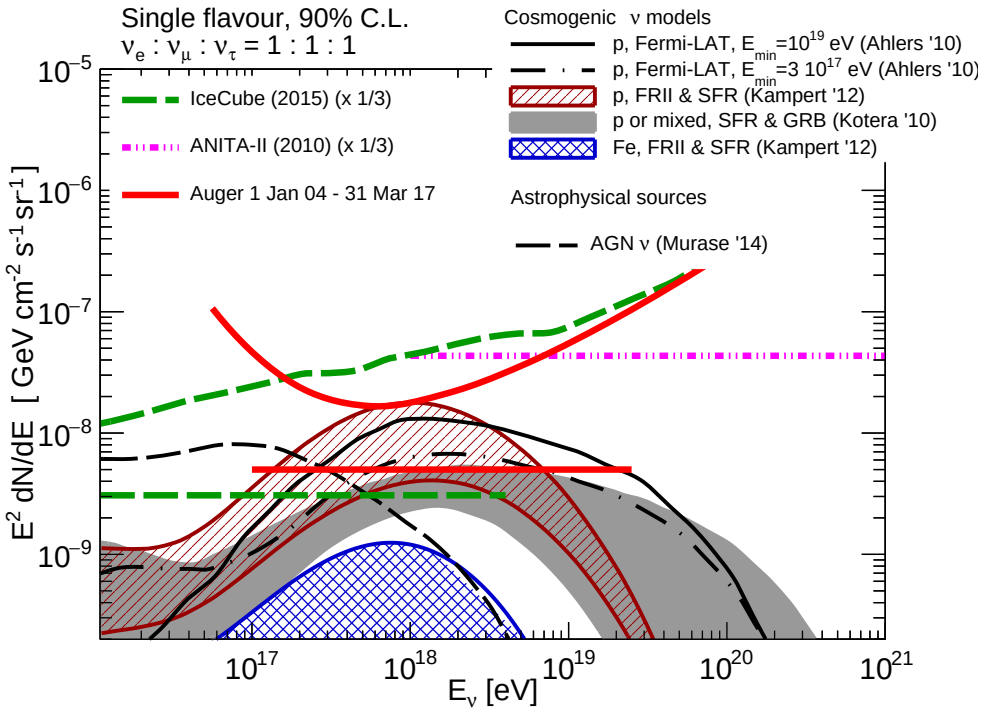
Source properties	4D with EGMF	4D no EGMF	1D no EGMF
γ	1.61	0.61	0.87
$\log_{10}(R_{cut}/\mathrm{eV})$	18.88	18.48	18.62
f_H	3 %	11 %	0 %
f_{He}	2 %	14 %	0 %
f_N	74 %	68 %	88 %
f_{Si}	21 %	7 %	12 %
f_{Fe}	0 %	0 %	0 %

Searches for Cosmogenic Photons and Neutrinos

$$p + \gamma_{CMB} \rightarrow p + \pi^0 \searrow \gamma\gamma$$

$$p + \gamma_{CMB} \rightarrow n + \pi^+ \searrow e^+ + 3\nu$$

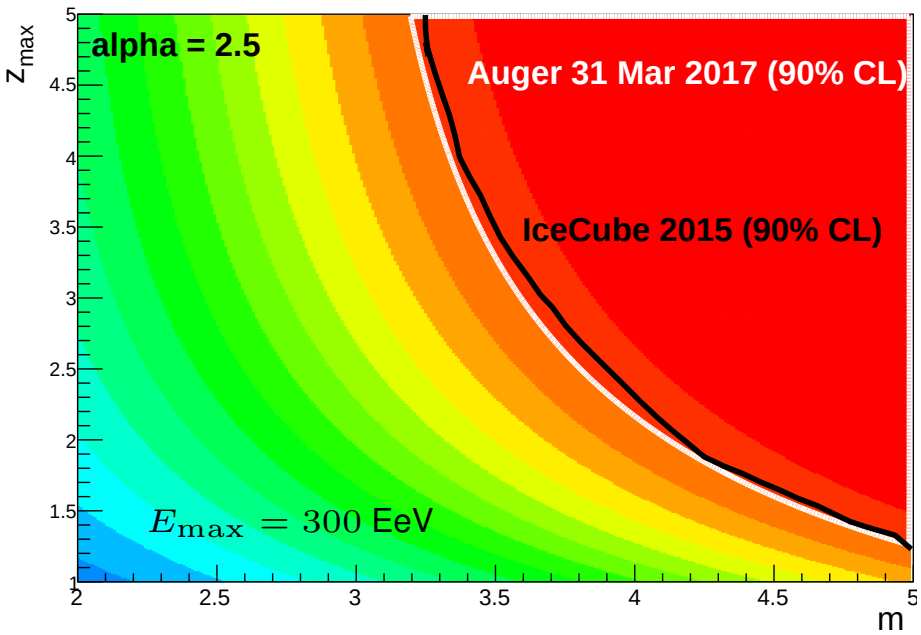




Constraints on Source Evolution from ν Limits

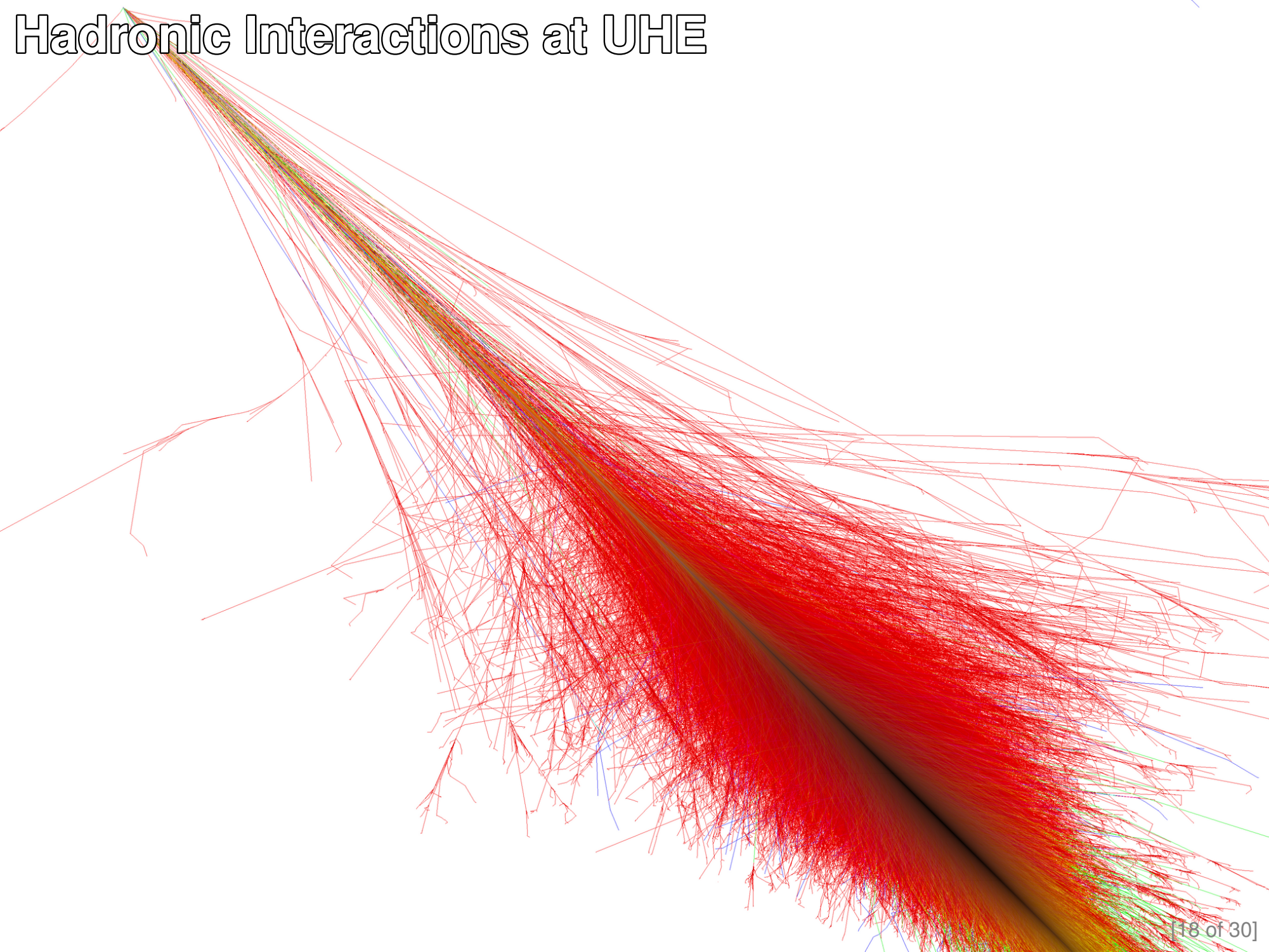
Diffuse flux neutrino model	Expected events (1 Jan 04 - 31 Mar 17)
Cosmogenic - proton - strong source evolution	
Cosmogenic - proton, FRII evol. (Kampert 2012)	~ 5.2
Cosmogenic - proton, FRII evol. (Kotera 2010)	~ 9.2
Cosmogenic - proton - moderate source evolution	
Cosmogenic - proton, SFR evol (Aloisio 2015)	~ 2.0
Cosmogenic - proton, SFR evol, $E_{max} = 10^{21}$ eV (Kotera 2010)	~ 1.8
Cosmogenic - proton, SFR evol. (Kampert 2012)	~ 1.2
Cosmogenic - proton, GRB evol. (Kotera 2010)	~ 1.5
Cosmogenic - proton - normalized to Fermi-LAT GeV γ-rays	
Cosmogenic - proton, Fermi-LAT, $E_{min} = 10^{19}$ eV (Ahlers 2010)	~ 4.0
Cosmogenic - proton, Fermi-LAT, $E_{min} = 10^{17.5}$ eV (Ahlers 2010)	~ 2.1
Cosmogenic - mixed and iron	
Cosmogenic - mixed (Galactic) UHECR composition (Kotera 2010)	~ 0.7
Cosmogenic - iron, FRII (Kampert 2012)	~ 0.35
Astrophysical sources	
Astrophysical - radio-loud AGN (Murase 2014)	~ 2.6
Astrophysical - Pulsars - SFR evol. (Fang 2014)	~ 1.3

$$n(z) \propto (1+z)^m, \; z < z_{\max}$$



EXCLUDED (> 90% CL), **DISFAVORED** (85% < CL < 90%), **ALLOWED**

Hadronic Interactions at UHE



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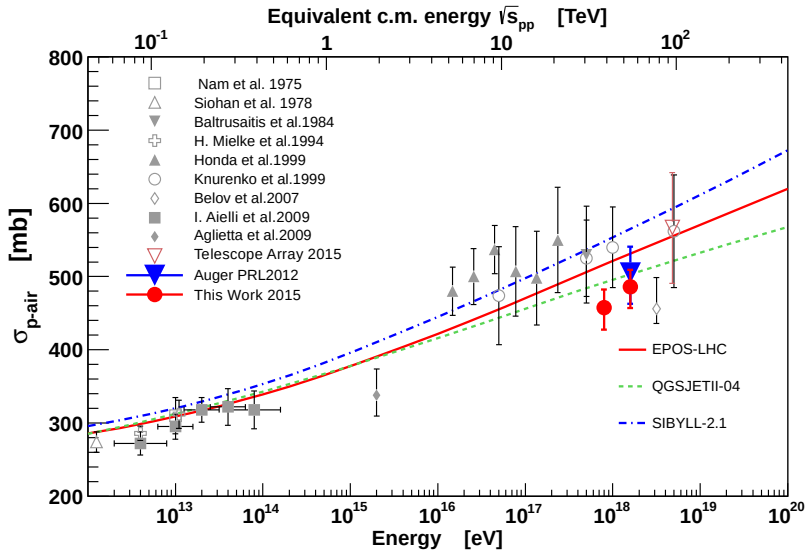
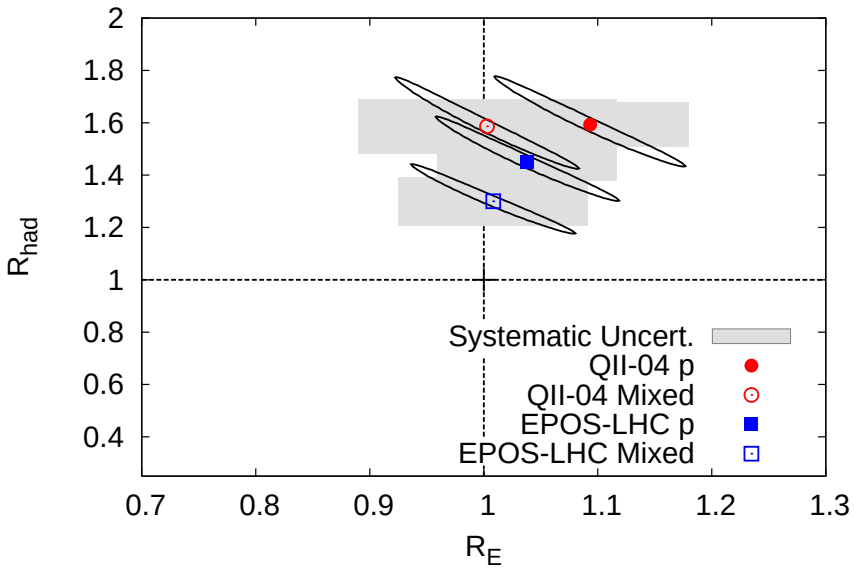
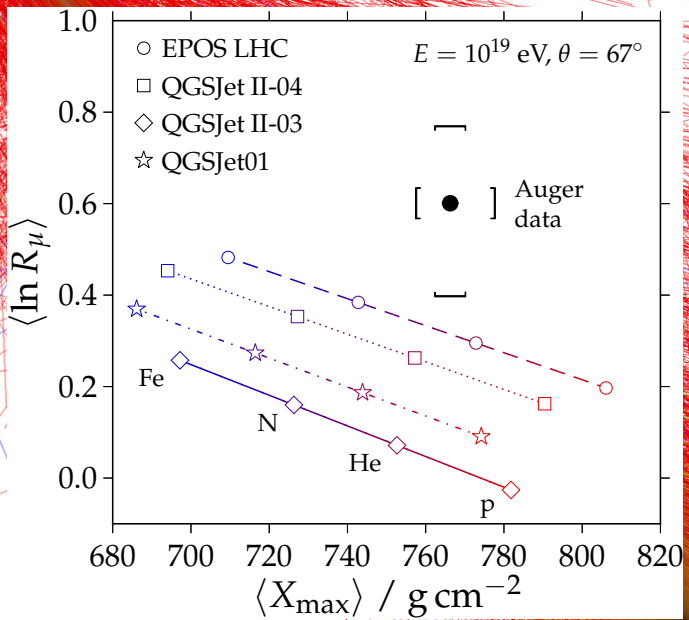
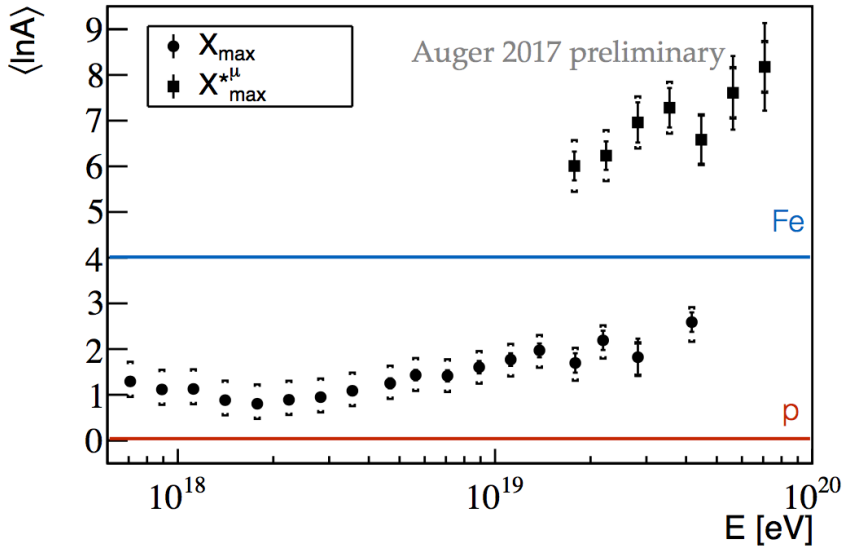
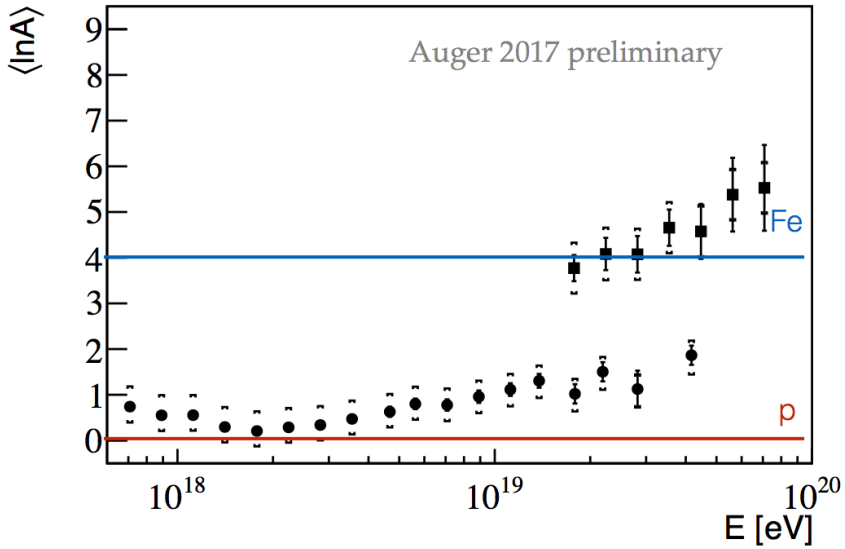


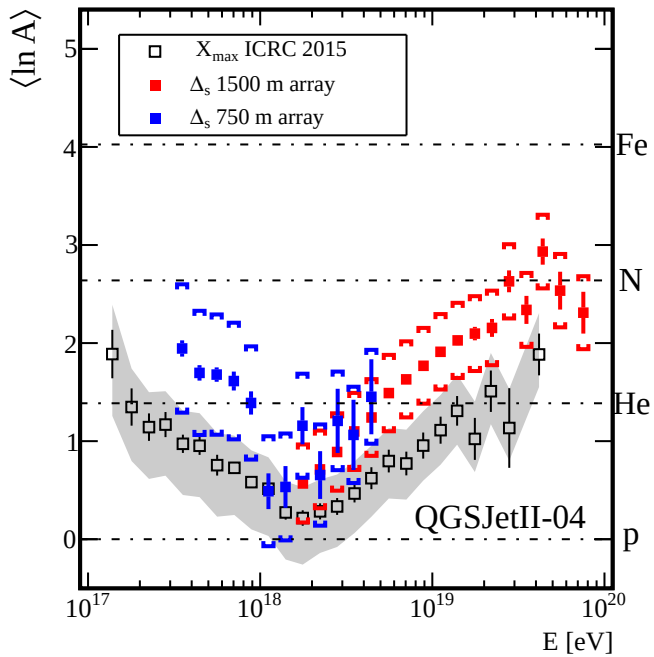


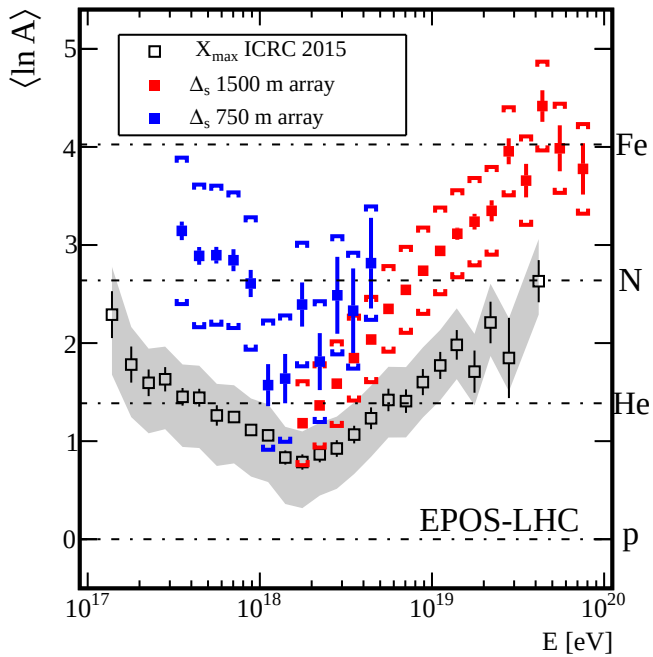


Hadronic Interactions at UHE: ⟨ln A⟩ compatibility









Search for Intermediate-scale UHECR Anisotropies

Active Galactic Nuclei

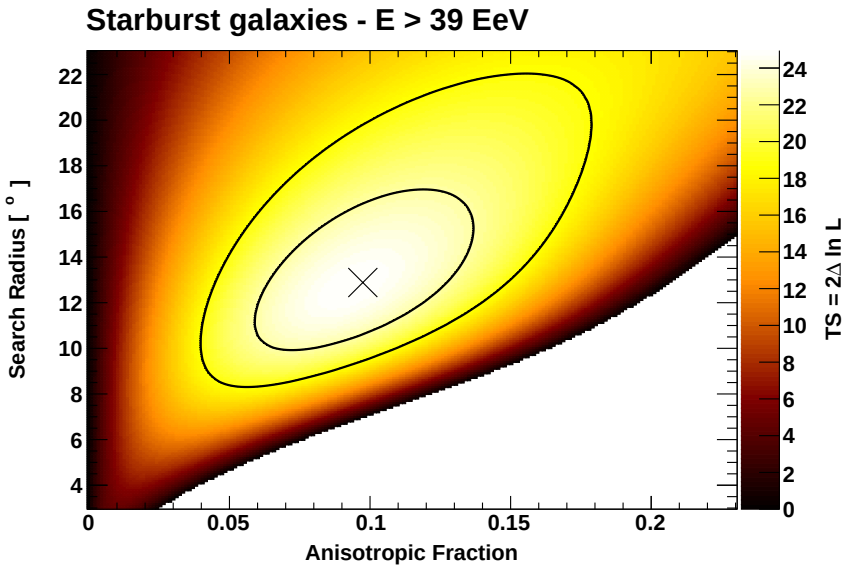
- 2FHL AGNs
- flux proxy: $\Phi(> 50\,\mathrm{GeV})$
- 17 objects within 250 Mpc

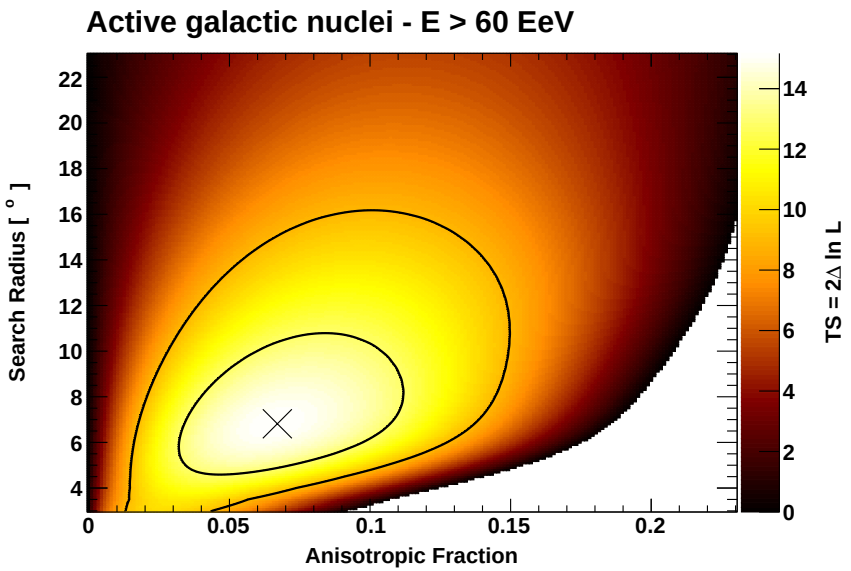
Star-forming of Starburst Galaxies

- Fermi-LAT search list (Ackermann+2016)
- $\Phi(> 1.54, \mathrm{GHz}) > 0.3$ Jy
- flux proxy: $\Phi(> 1.54, \mathrm{GHz})$
- 23 objects within 250 Mpc

Likelihood ratio analysis

- smearing angle ψ
- H_0: isotropy
- H_1: $(1-f)\times$ isotropy + $f\times$ fluxMap(ψ)
- $\mathrm{TS} = 2\log(H_1/H_0)$





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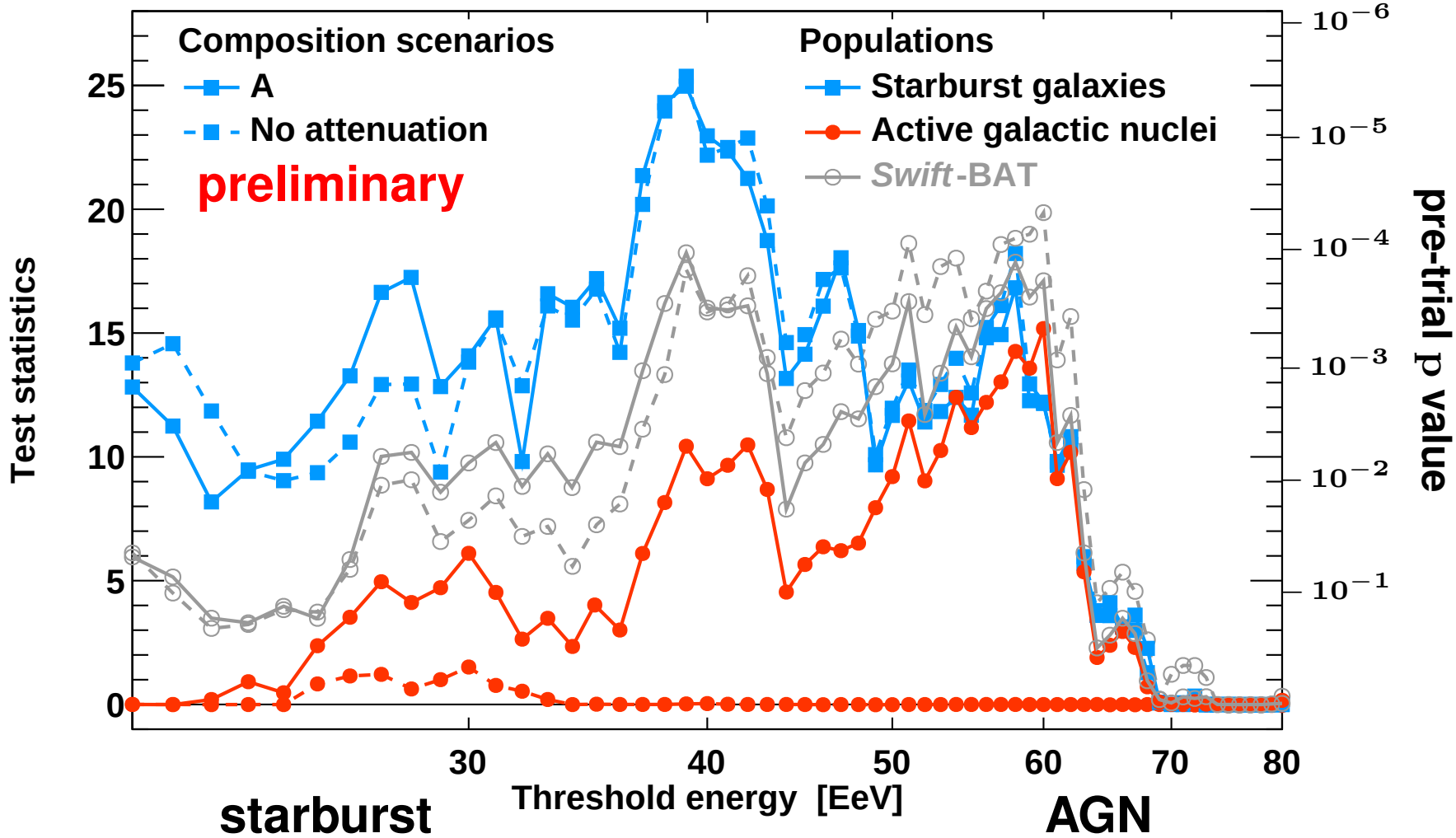


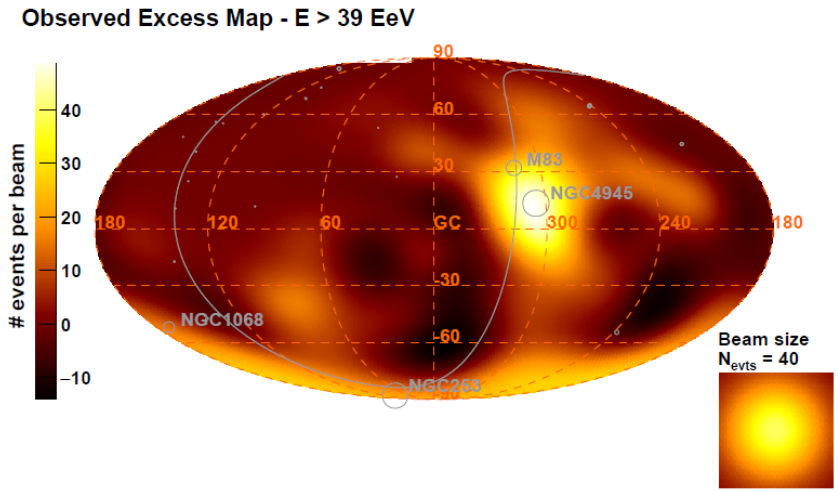
$f = 10\%,\ \psi = 13^\circ$
pre-trial* p-value: 4×10^{-6}
post-trial** p-value: 4×10^{-5}
post-trial** significance: $3.9\,\sigma$

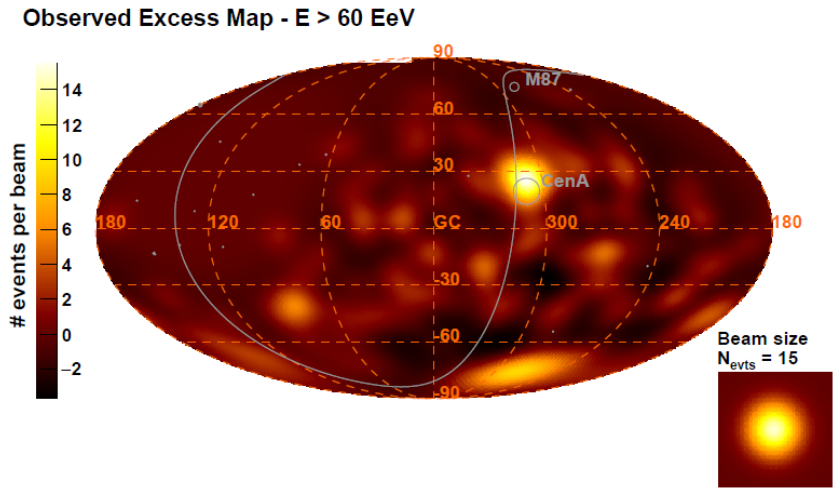
$f = 7\%,\ \psi = 7^\circ$
pre-trial* p-value: 5×10^{-4}
post-trial** p-value: 3×10^{-3}
post-trial** significance: $2.7\,\sigma$

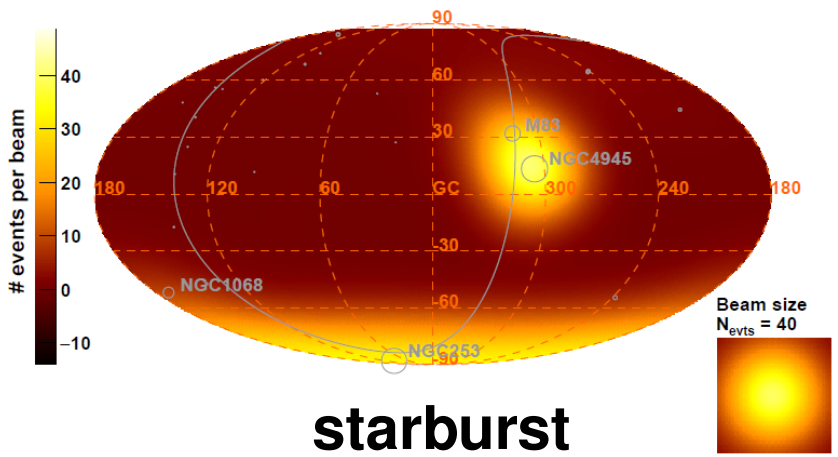
* incl. f and ψ fit ** penalization for energy scan only. $N_{\rm cat} = 3$, previous searches and hidden trials not accounted for.

Search for Intermediate-scale UHECR Anisotropies

preliminary







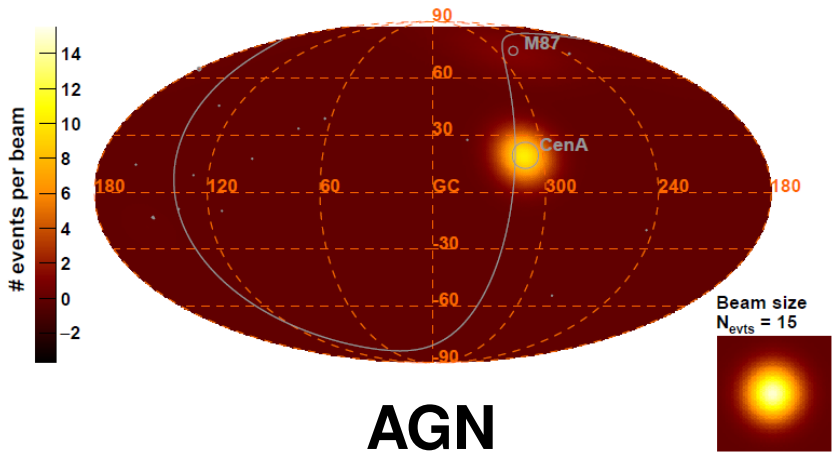
starburst

$f = 10\%,\ \psi = 13^\circ$

pre-trial* p-value: 4×10^{-6}

post-trial** p-value: 4×10^{-5}

post-trial** significance: $3.9\,\sigma$



AGN

$f = 7\%,\ \psi = 7^\circ$

pre-trial* p-value: 5×10^{-4}

post-trial** p-value: 3×10^{-3}

post-trial** significance: $2.7\,\sigma$

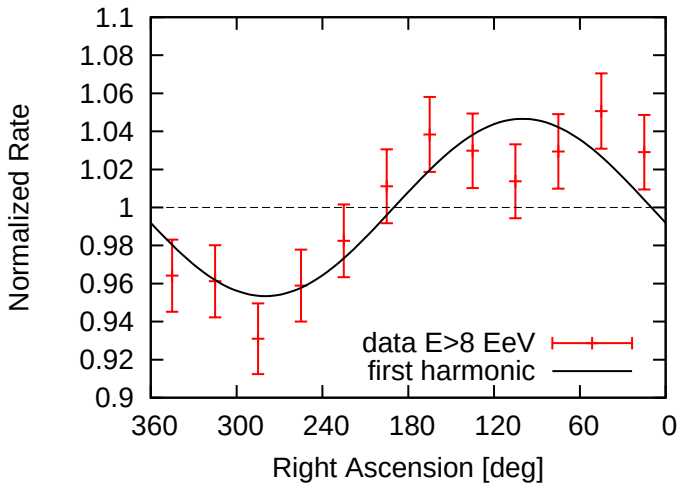
* incl. f and ψ fit ** penalization for energy scan only. $N_{\rm cat} = 3$, previous searches and hidden trials not accounted for.

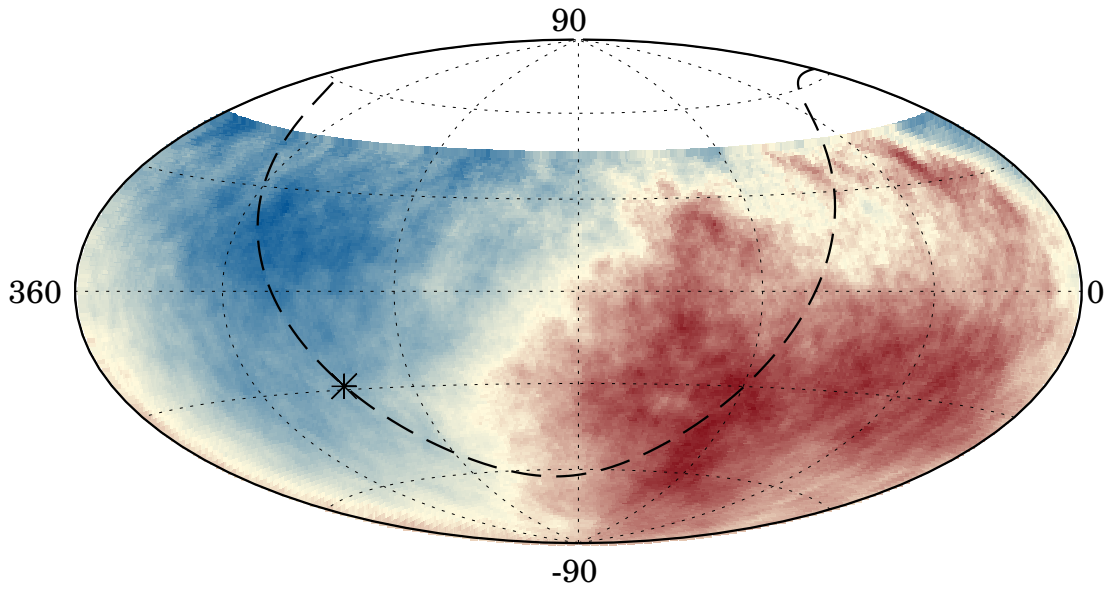
Observation of Dipolar anisotropy above 8 EeV

Harmonic analysis in right ascension α

E [EeV]	events	amplitude r	phase [deg.]	$P(\geq r)$
4-8	81701	$0.005^{+0.006}_{-0.002}$	80 ± 60	0.60
> 8	32187	$0.047^{+0.008}_{-0.007}$	100 ± 10	2.6×10^{-8}

significant modulation at 5.2σ (5.6σ before penalization for energy bins explored)

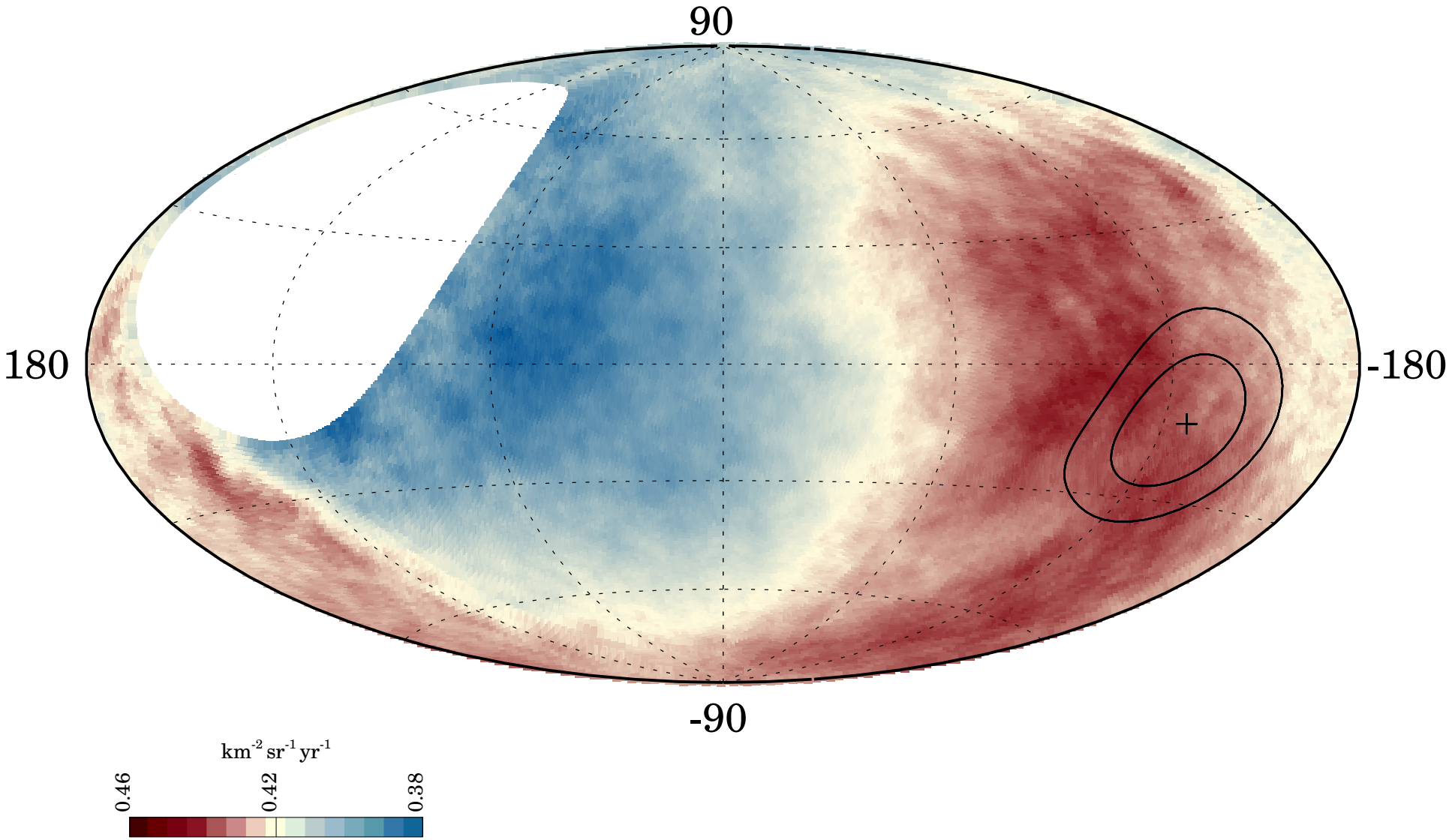




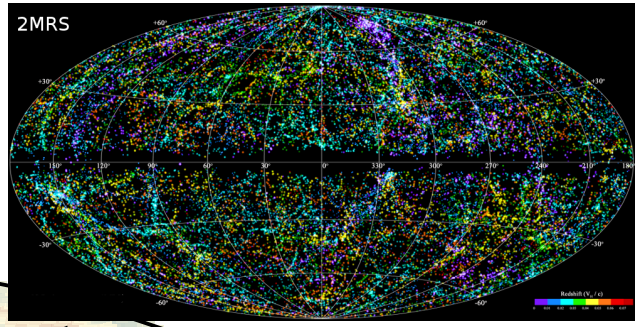
3-d dipole above 8 EeV:

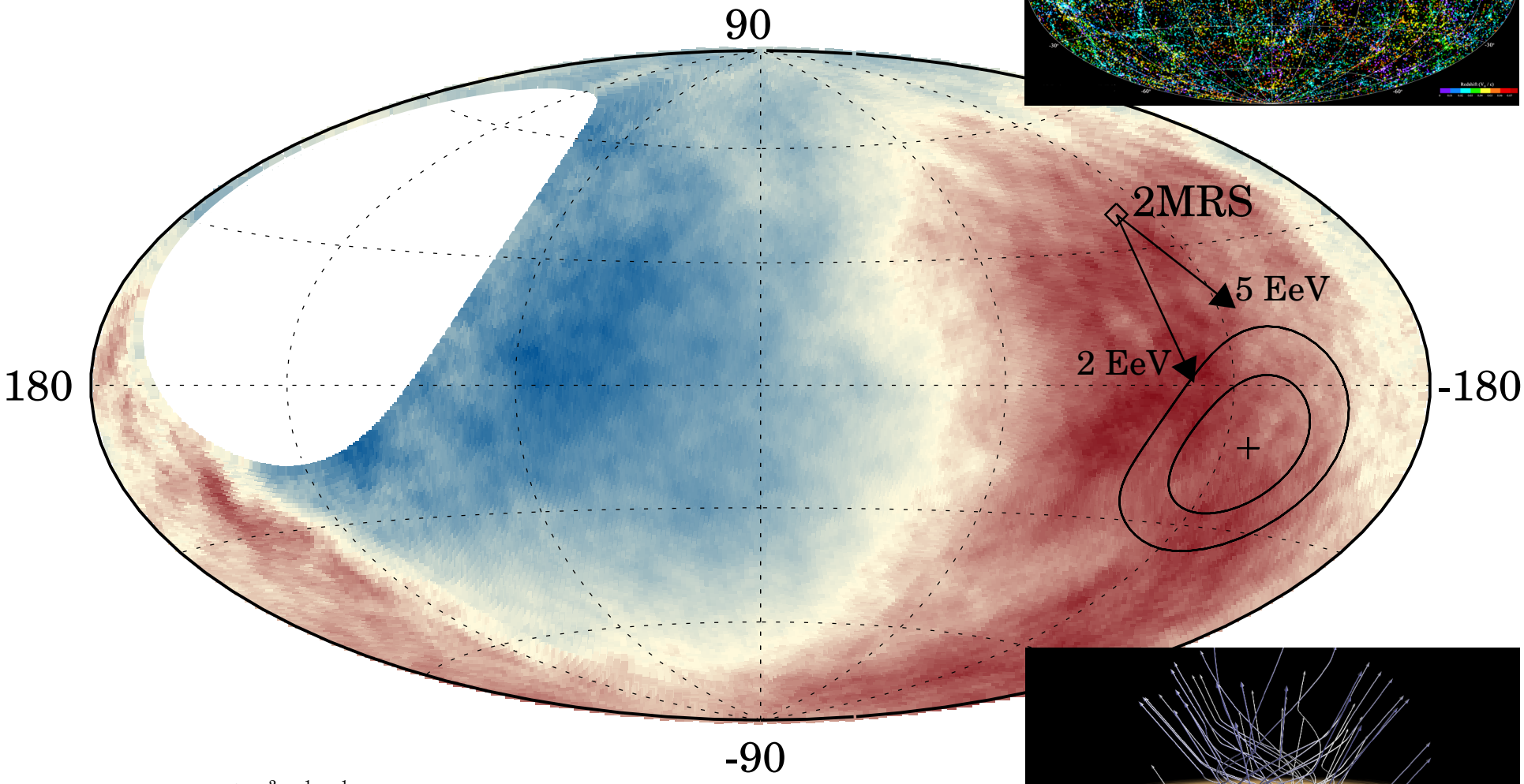
$(6.5^{+1.3}_{-0.9})\%$ at $(\alpha, \delta) = (100°, -24°)$

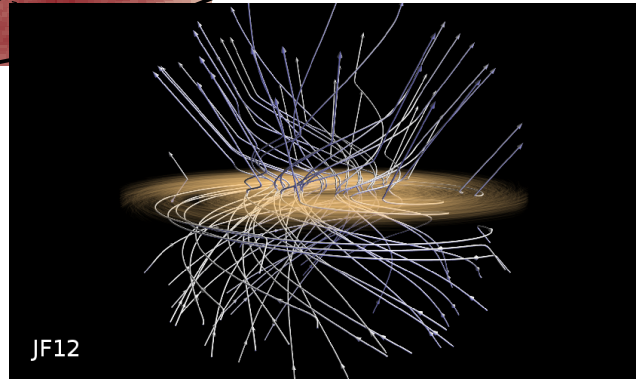
Dipole in Galactic Coordinates



Dipole in Galactic Coordinates







Summary of Results

spectrum, composition, secondaries:

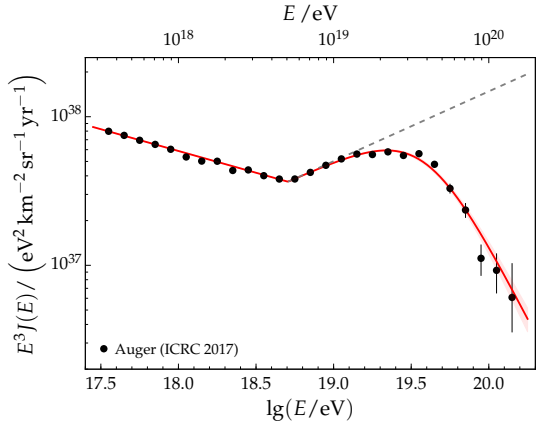
- high-exposure study of UHE flux
  $\rightarrow$ strong flux suppression
- FD/SD composition studies
  $\rightarrow$ light composition at ankle
  $\rightarrow$ mixed composition at UHE
  $\rightarrow$ Galactic Fe around $10^{17.2}$ eV?
- constraints on p-dominated sources via ν/γ
- compatible with rigidity-dependent $E_{\max}$

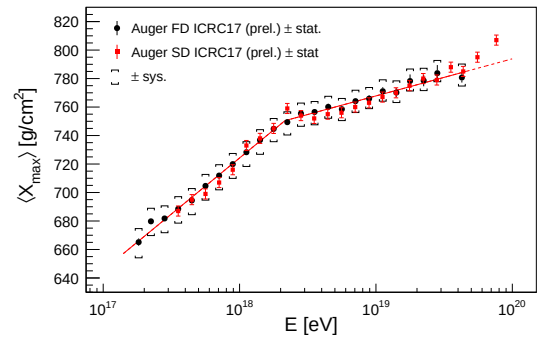
hadronic interactions:

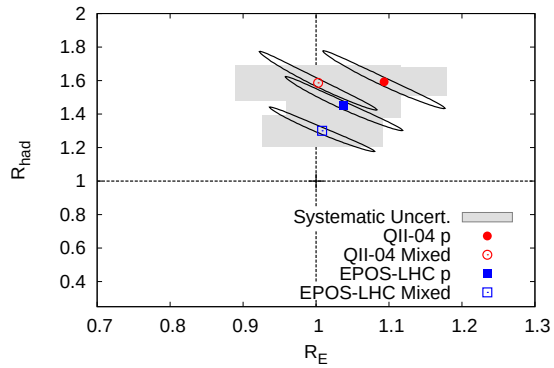
- standard UHE cross section
- muon deficit in models

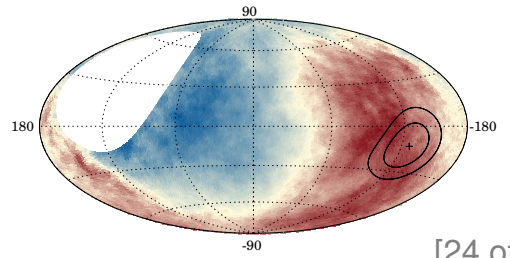
arrival directions:

- indication for intermediate-scale anisotropy
- observation of dipolar anisotropy









Questions for the next ICRCs

- Origin of the flux suppression?
- Proton fraction at UHE?
- Rigidity-dependence of anisotropies?
- Hadronic physics above $\sqrt{s} = 140$ TeV?

need large-exposure detector with composition sensitivity!

The Pierre Auger Observatory Upgrade

"AugerPrime"

Preliminary Design Report

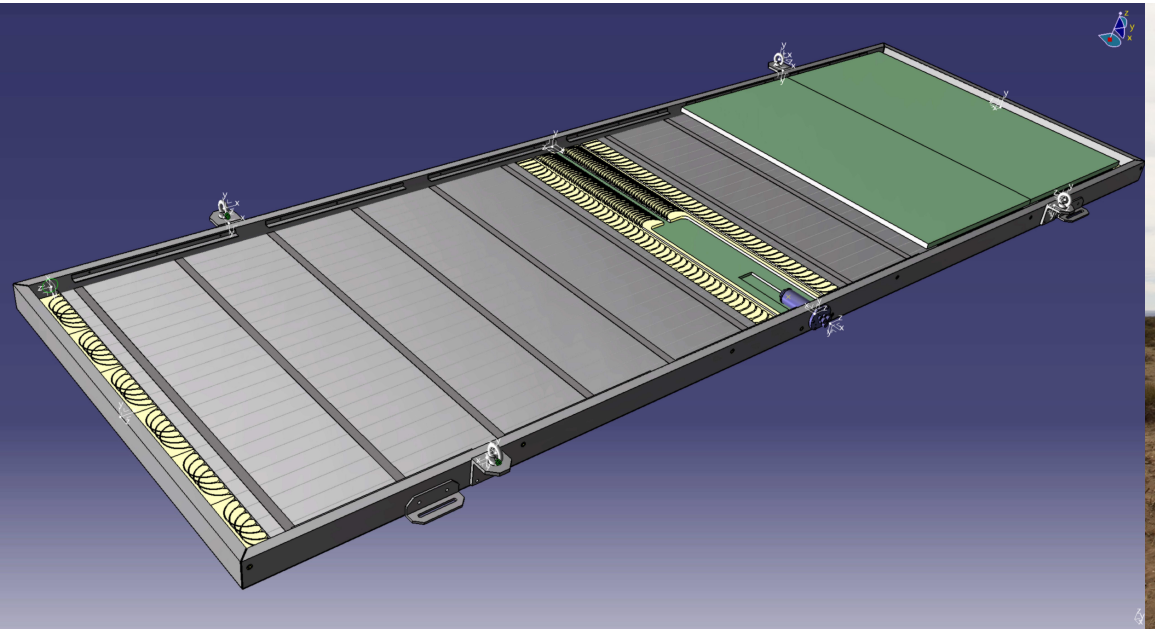
The Pierre Auger Collaboration
April, 2015

PIERRE AUGER OBSERVATORY

Observatorio Pierre Auger,
Av. San Martín Norte 304,
5613 Malargüe, Argentina

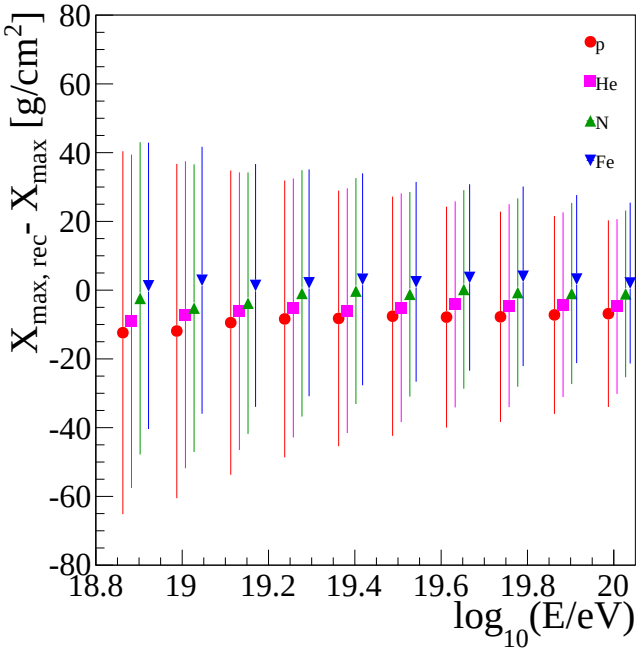
Detector Upgrades for AugerPrime

- 3.8 m^2 scintillators (SSD) on each 1500-m array station
- upgrade of station electronics
- additional small PMT to increase dynamic range
- buried muon counters in 750-m array (AMIGA)
- increased FD uptime

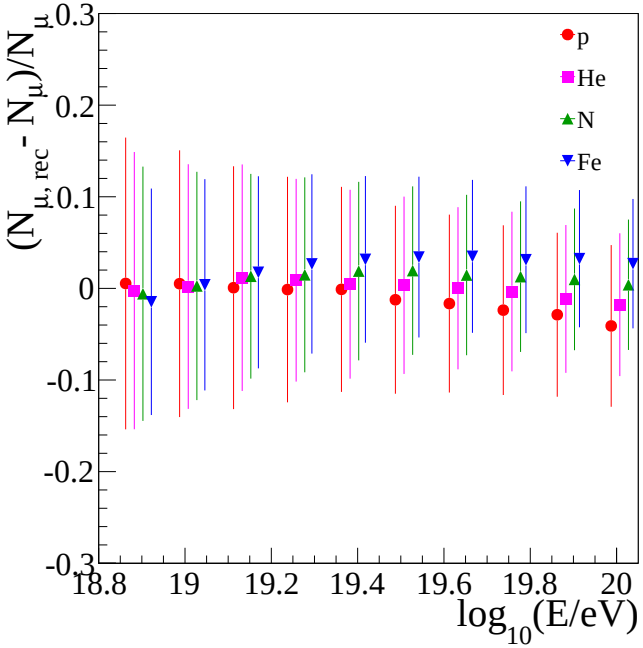


Expected Performance of AugerPrime

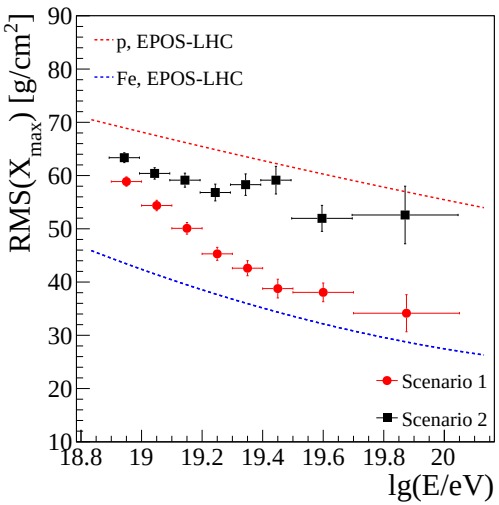
$X_{\max}$ determination:

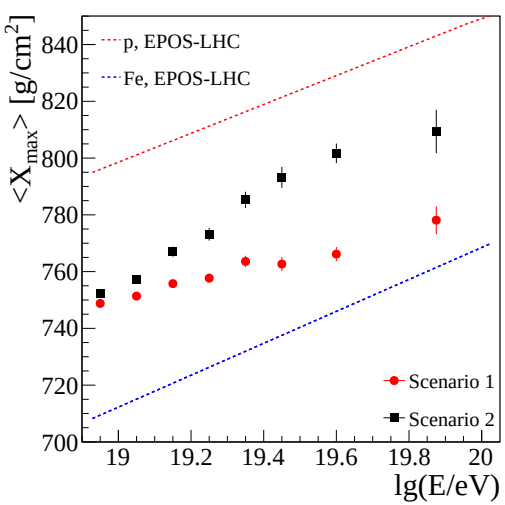


muon determination:

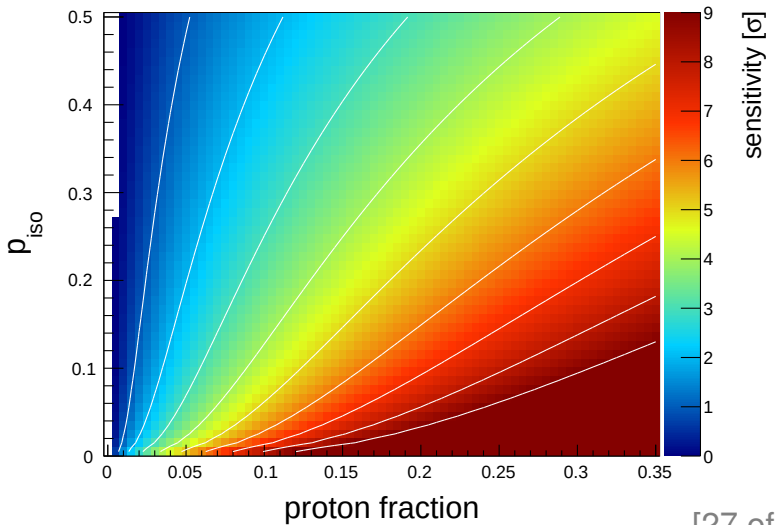


high- vs. low-R_{cut} scenario:

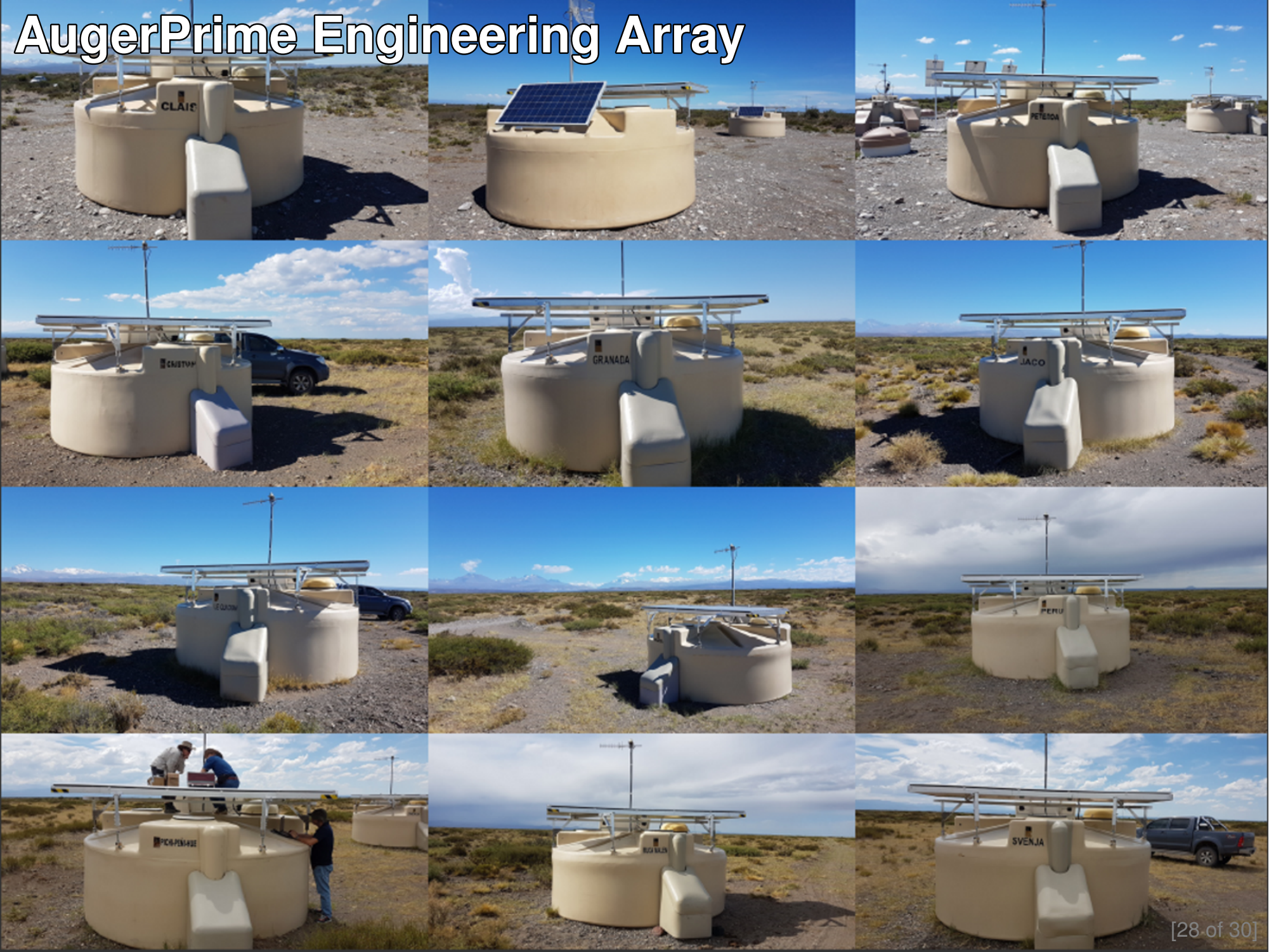




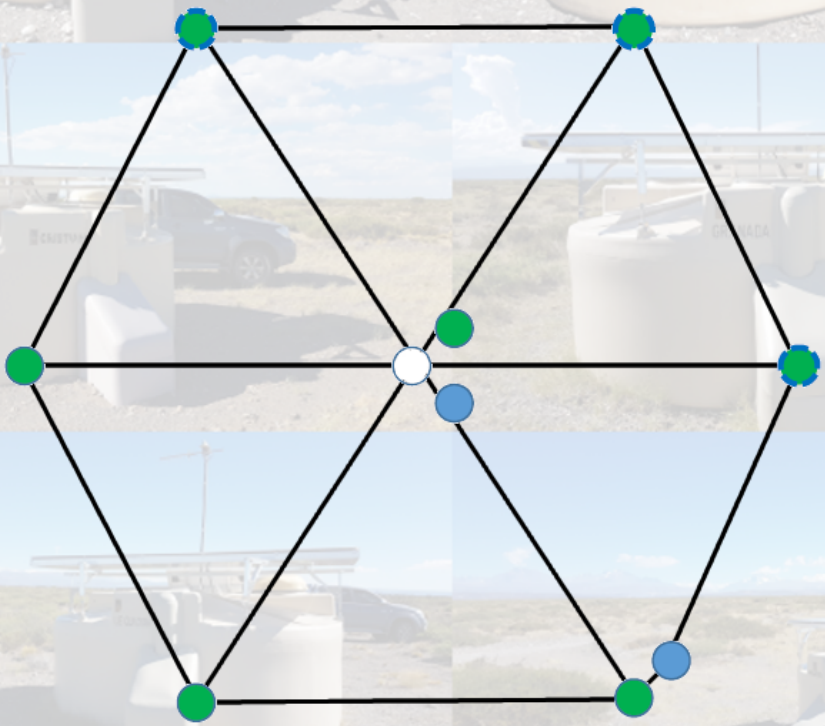
low-Z particle astronomy:



AugerPrime Engineering Array



AugerPrime Engineering Array

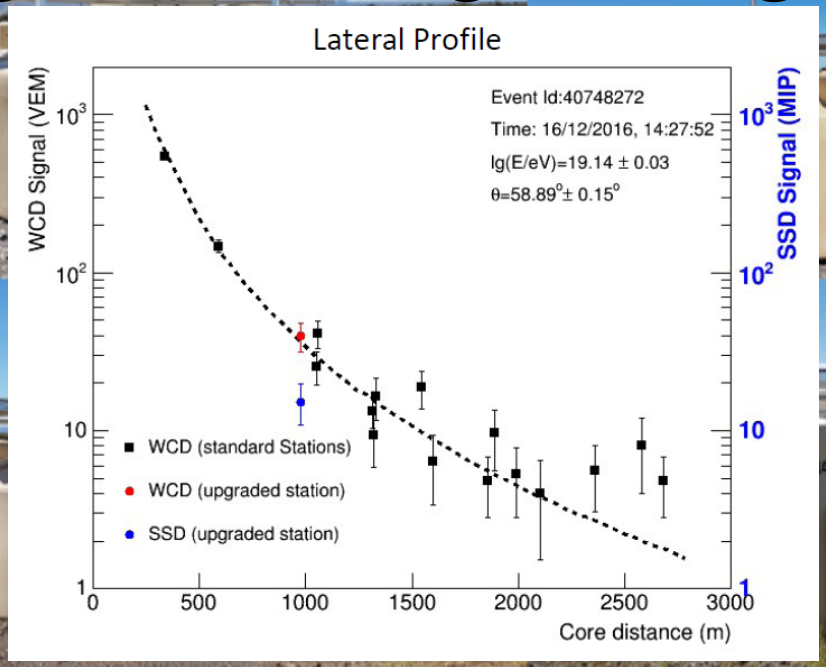


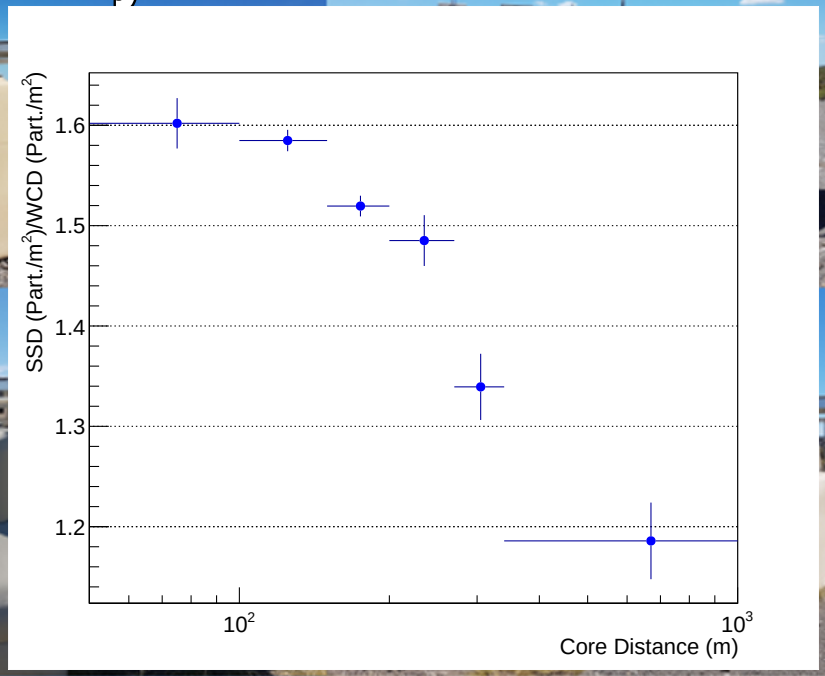
1500 m hexagon

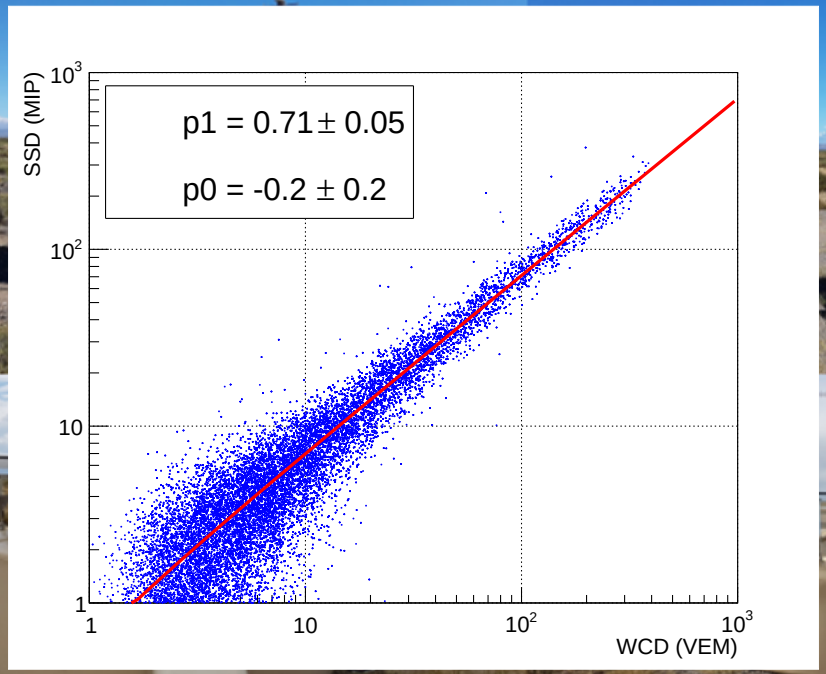
- SSD w PMT-ISEG base
- SSD w PMT-passive base
- SSD w SiPM
- WCD w/o SSD

quadruplet in
750 m array

AugerPrime Engineering Array







- design finalized and tested
- 180 SSDs to be shipped 2017
- finish construction by 2019
- data taking until 2025

Dipolar anisotropy of cosmic rays above 8 EeV	Oscar Taborda
Arrival directions of the highest-energy cosmic rays	Ugo Giaccari
Improvements to aerosol attenuation measurements	Max Malacari
The FRAM telescope	Jiri Blazek
Energy scale for high-energy cosmic rays using MHz radio measurements	Raphael Krause
Peculiar lightning-related events observed by the surface detector	Roberta Colallilo
Measurements of the depth of maximum muon production and of its fluctuations	Manuela Mallamaci
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An improved reconstruction method for the AMIGA detectors	Juan Manuel Figueira
Recent Results from the Auger Engineering Radio Array	Ewa Holt
AugerPrime implementation in the Offline framework	David Schmidt
Studies of the microwave emission of extensive air showers	Romain Gaior
Auger at Telescope array	Sean Quinn
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New electronics for the surface detectors	Tiina Suomijärvi
The dynamic range of the AugerPrime Surface Detector	Antonella Castellina
Scintillator detectors of AugerPrime	Radomir Smida
First results from the AugerPrime Engineering Array	Zizhao Zong
Report of the TA-Auger Working Group on Energy Spectrum	Dmitri Ivanov
Report of the TA-Auger Working Group on Composition	Vitor de Souza
Report of the IC-TA-Auger Working Group on Arrival Directions	Imen Al Samarai