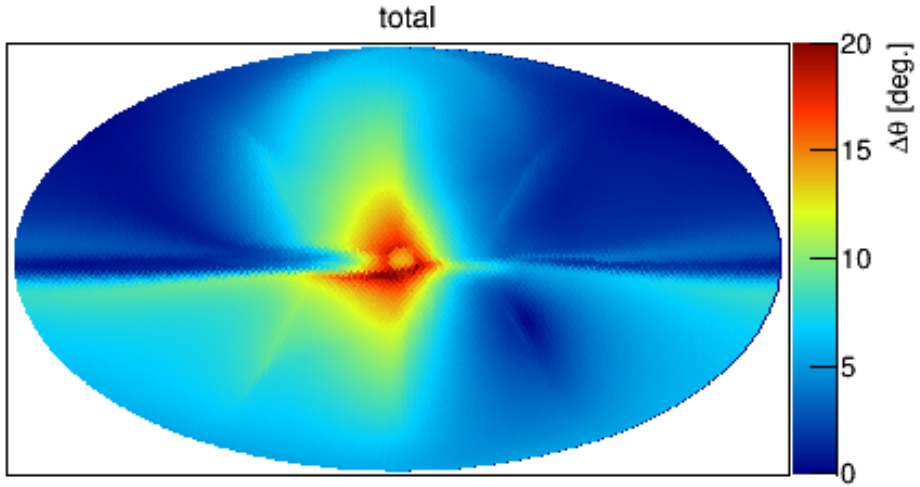
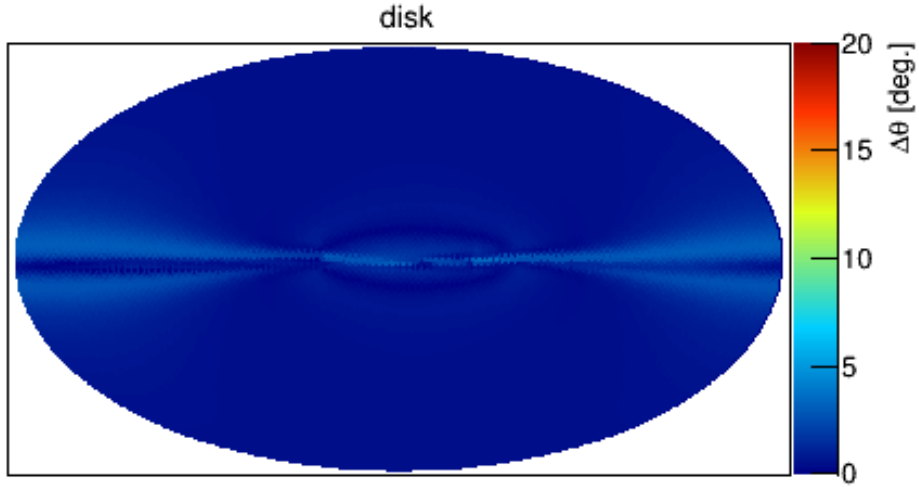
Air Showers and Magnetic Field Deflections

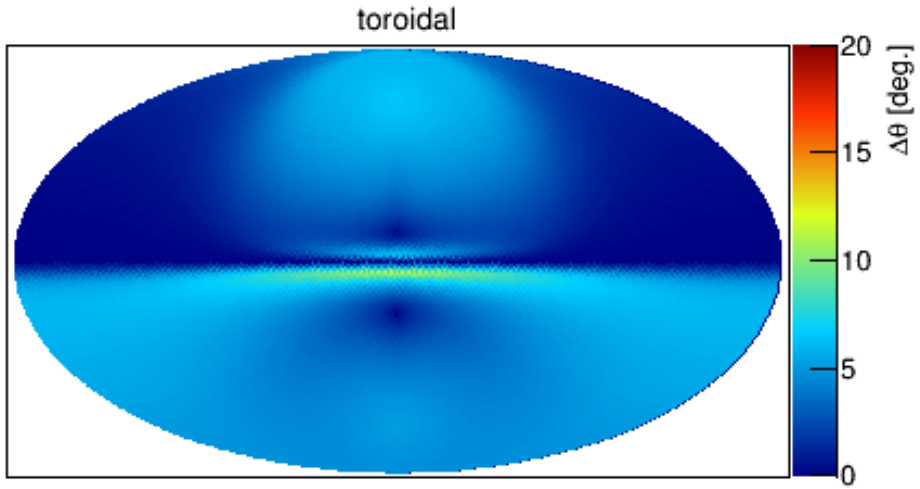
Michael Unger
KIT&NYU

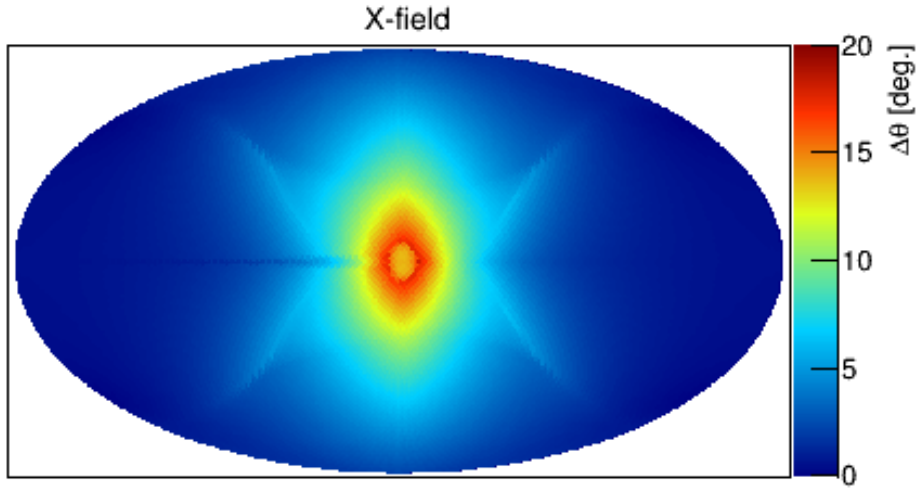
1/Deflection $\propto$ Rigidity = Energy / Charge

Deflection in Regular JF12: Proton, 60 EeV



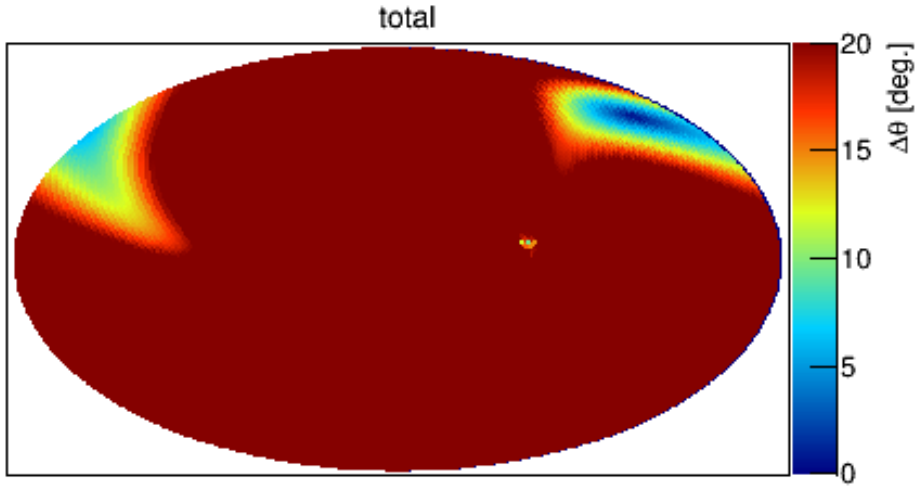


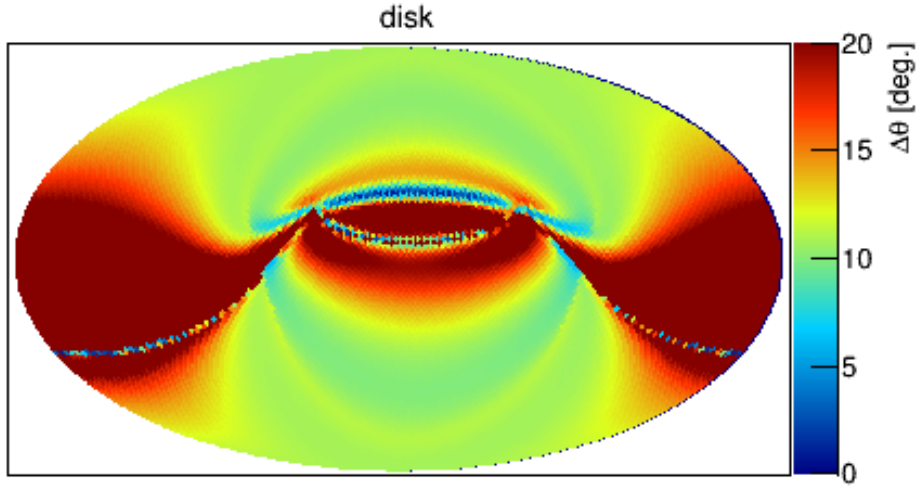


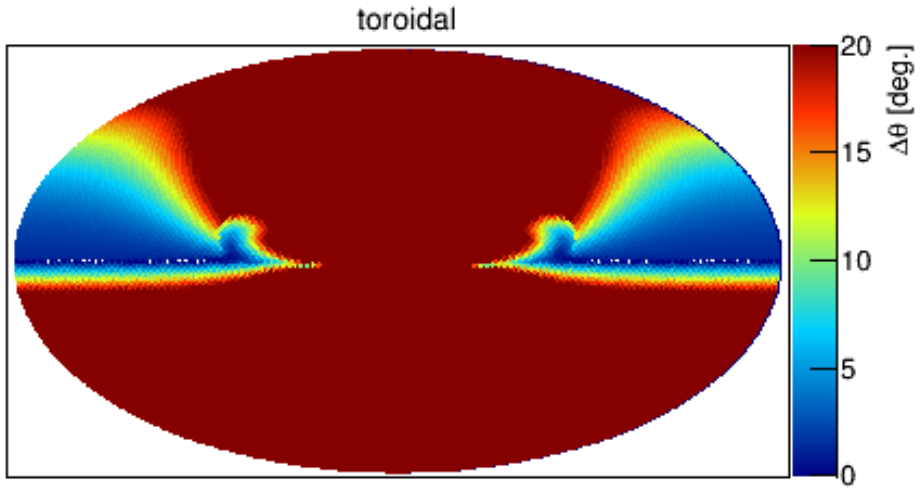


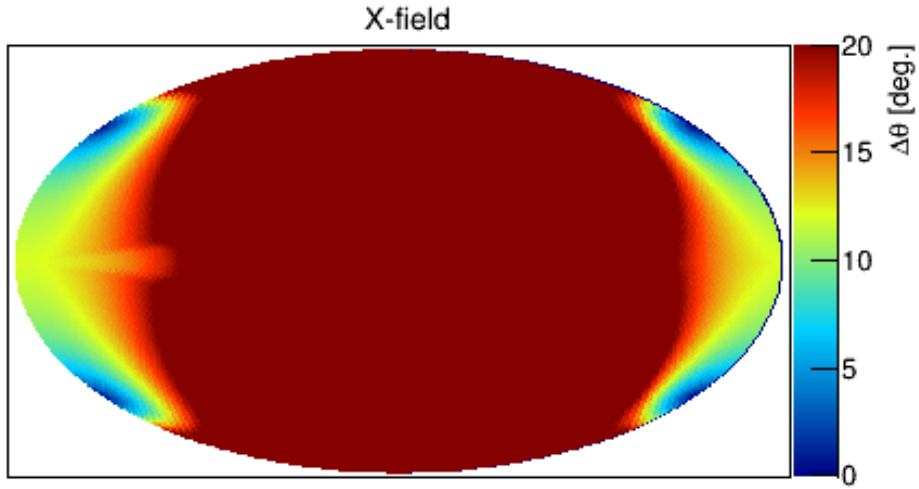
color scale truncated at 20 deg.

Deflection in Regular JF12: Iron, 60 EeV



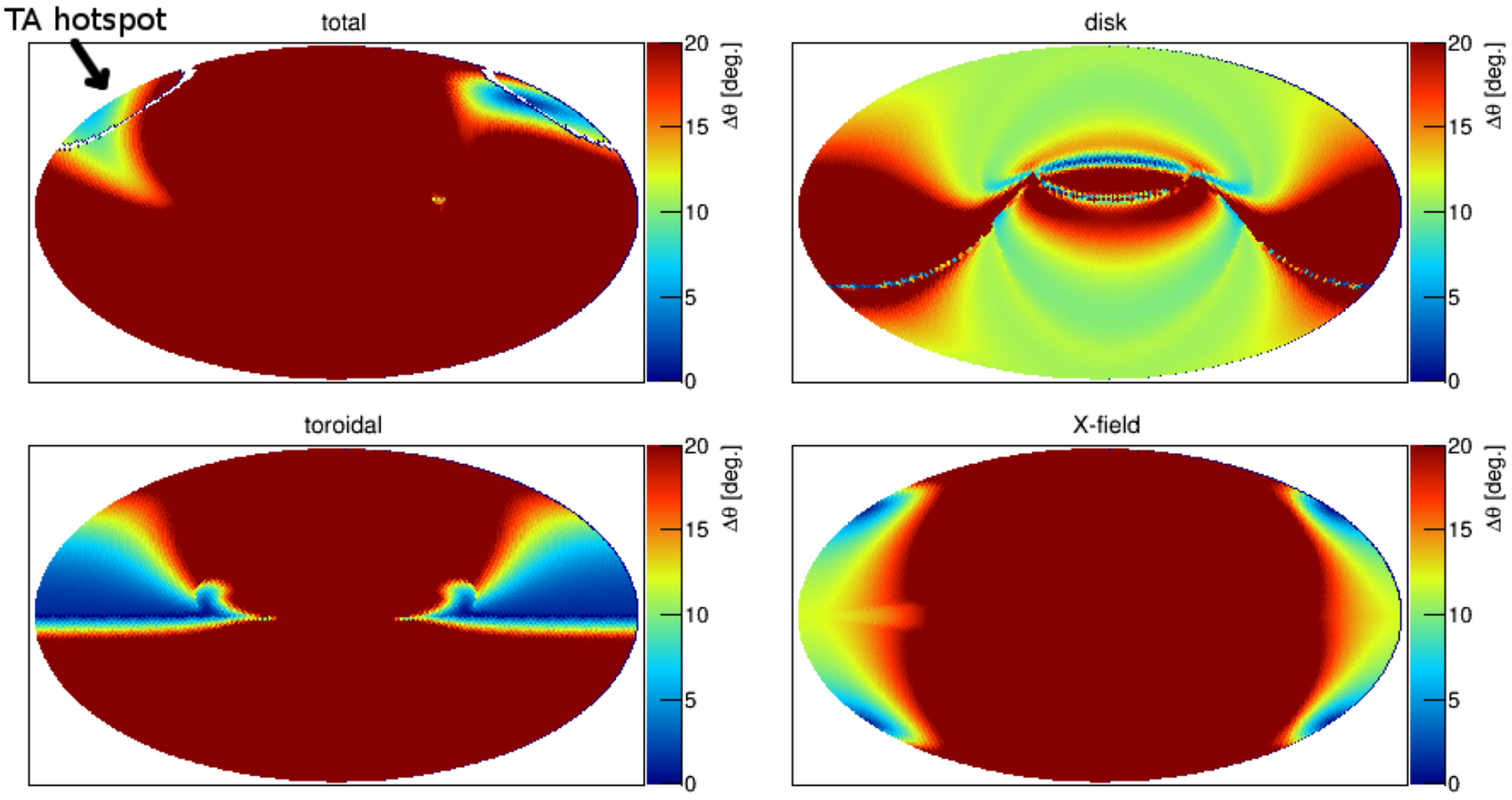






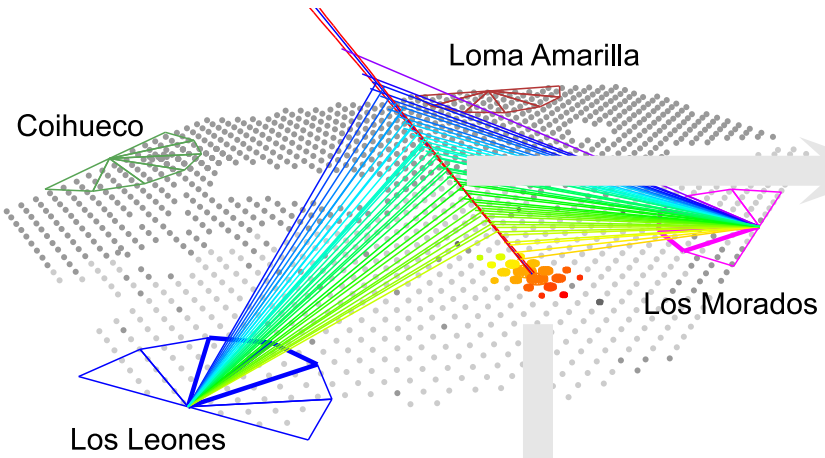
color scale truncated at 20 deg.

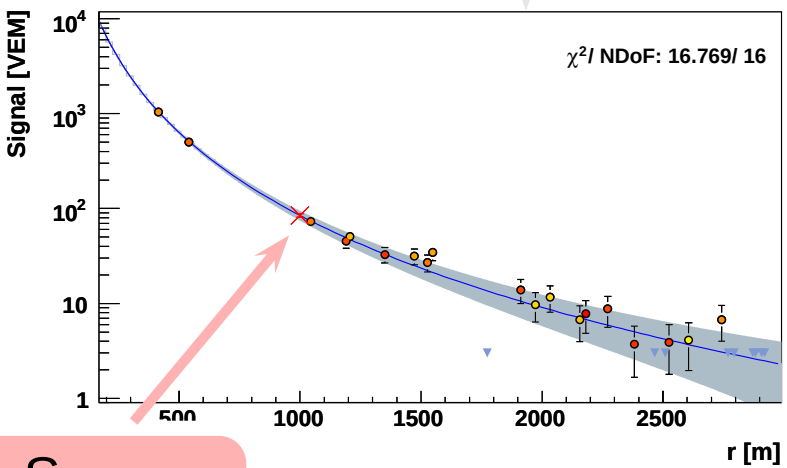
Deflection in Regular JF12: Iron, 60 EeV



color scale truncated at 20 deg.

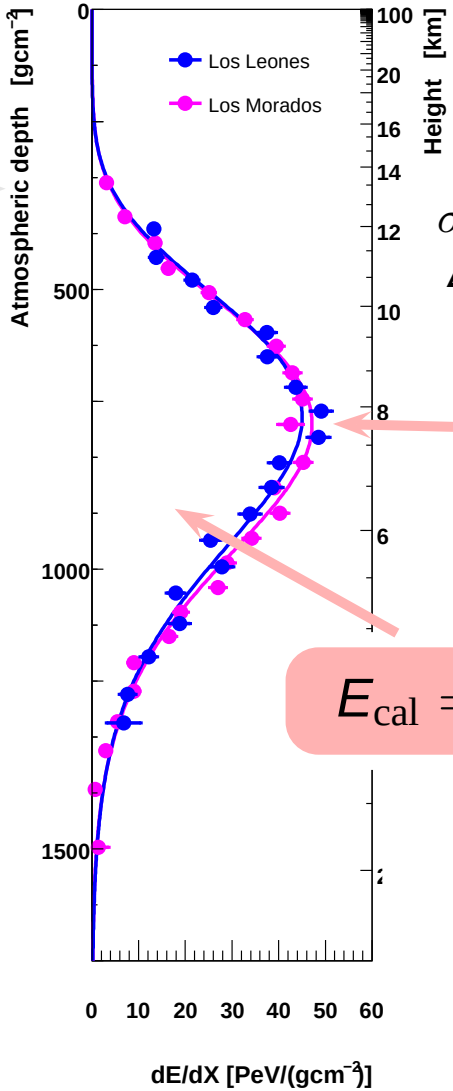
Energy and Mass with the Pierre Auger Observatory





S_{1000}

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



$\sigma_{X_{\max}} < 20\,\text{g/cm}^2$
$\Delta_{\text{sys}} \approx 15\,\text{g/cm}^2$

$X_{\max}$

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

$\sigma_E/E \sim 8\,\%$
$\Delta_{\text{sys}} \approx 22\,\%$

Energy Scale Uncertainty

Absolute fluorescence yield	3.4%
Fluores. spectrum and quenching param.	1.1%
Sub total (Fluorescence Yield)	**3.6%**
Aerosol optical depth	3% ÷ 6%
Aerosol phase function	1%
Wavelength dependence of aerosol scattering	0.5%
Atmospheric density profile	1%
Sub total (Atmosphere)	**3.4% ÷ 6.2%**
Absolute FD calibration	9%
Nightly relative calibration	2%
Optical efficiency	3.5%
Sub total (FD calibration)	**9.9%**
Folding with point spread function	5%
Multiple scattering model	1%
Simulation bias	2%
Constraints in the Gaisser-Hillas fit	3.5% ÷ 1%
Sub total (FD profile rec.)	**6.5% ÷ 5.6%**
Invisible energy	**3% ÷ 1.5%**
Statistical error of the SD calib. fit	**0.7% ÷ 1.8%**
Stability of the energy scale	**5%**
TOTAL	**14%**

FD CORRELATED UNCERTAINTIES

largest contribution from FD calibration

TOTAL UNCERTAINTY 14% ≈ energy independent

1500 m array $\theta < 60^0$

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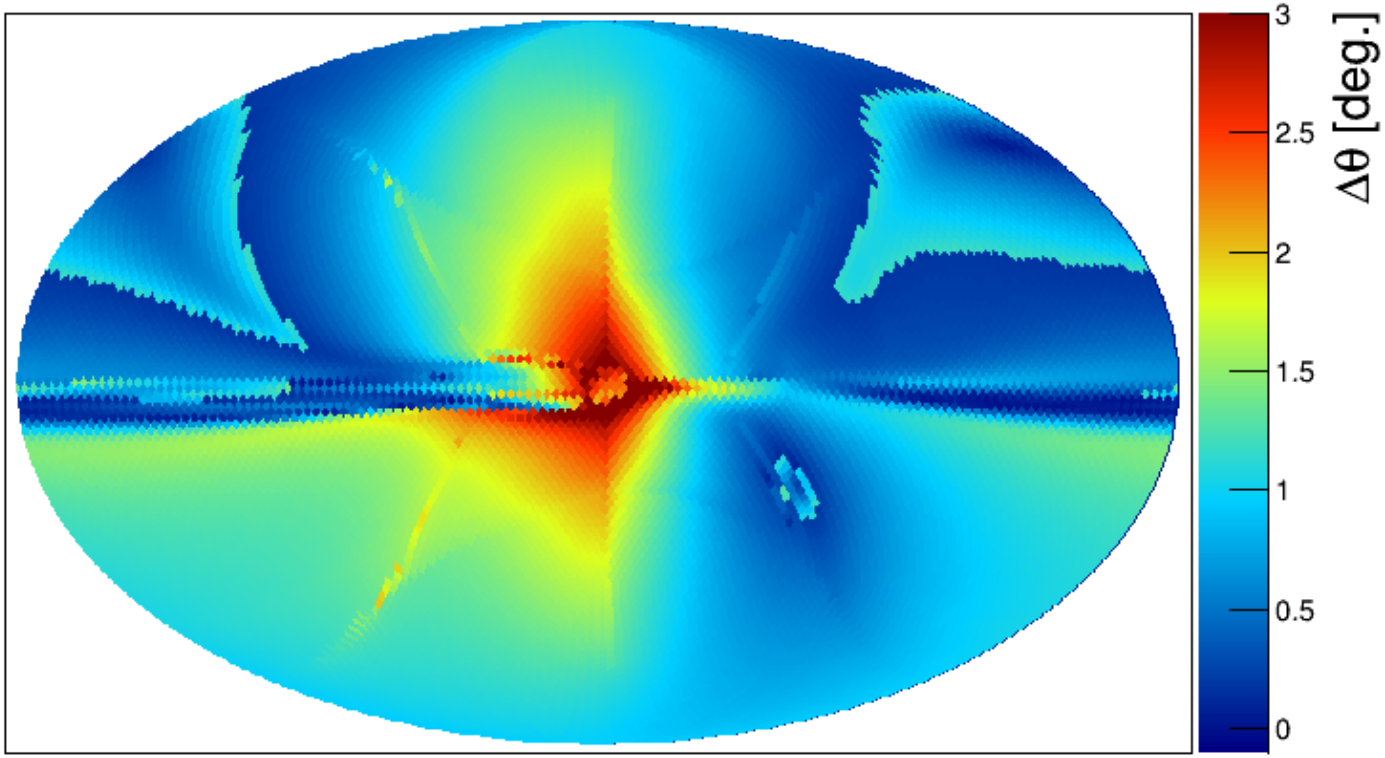
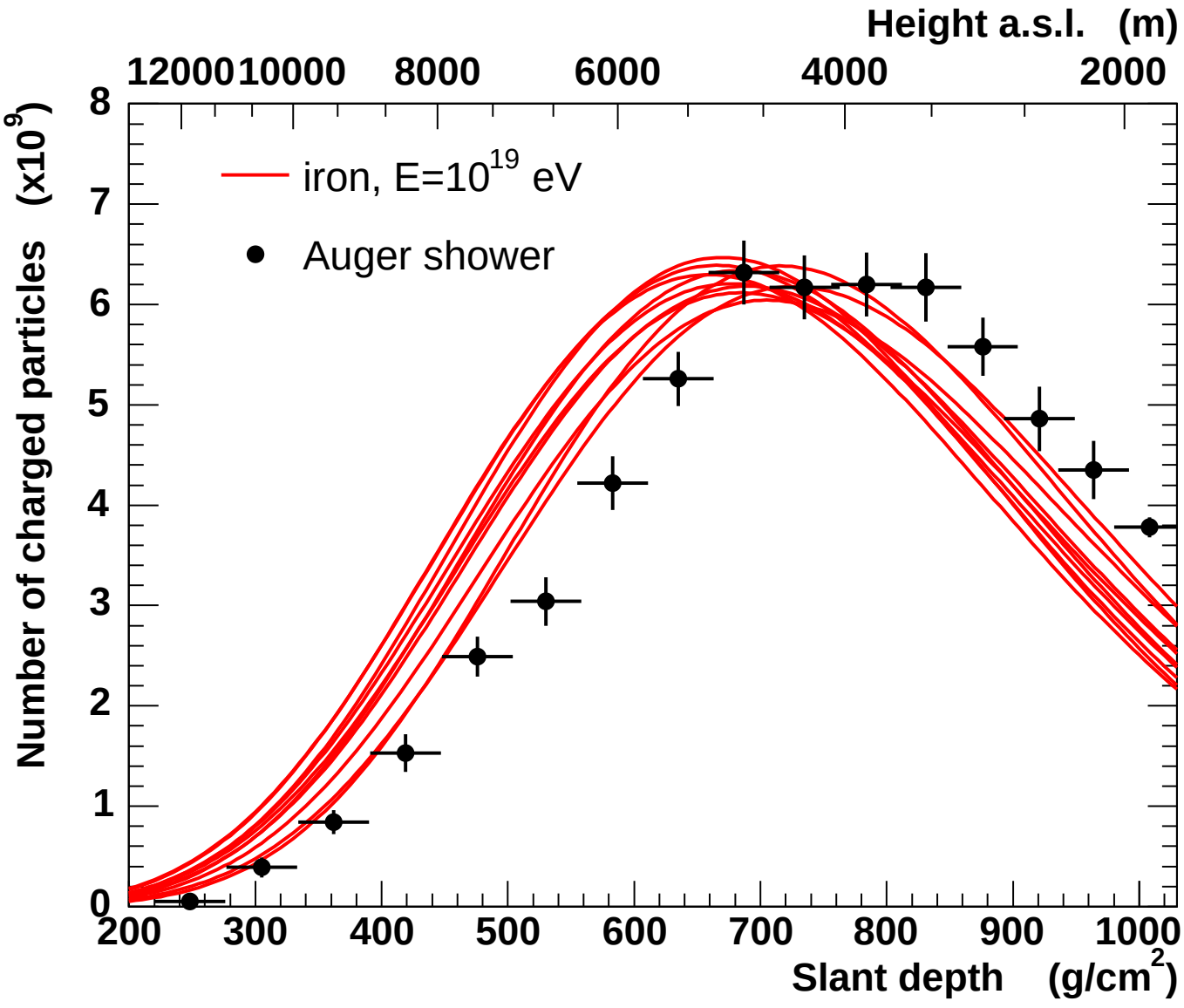
V. Verzi for the Pierre Auger Collaboration, Proc. 33nd ICRC (2013), arXiv:1307.5059

Energy Scale Uncertainty $\leftrightarrow$ Deflection Uncertainty

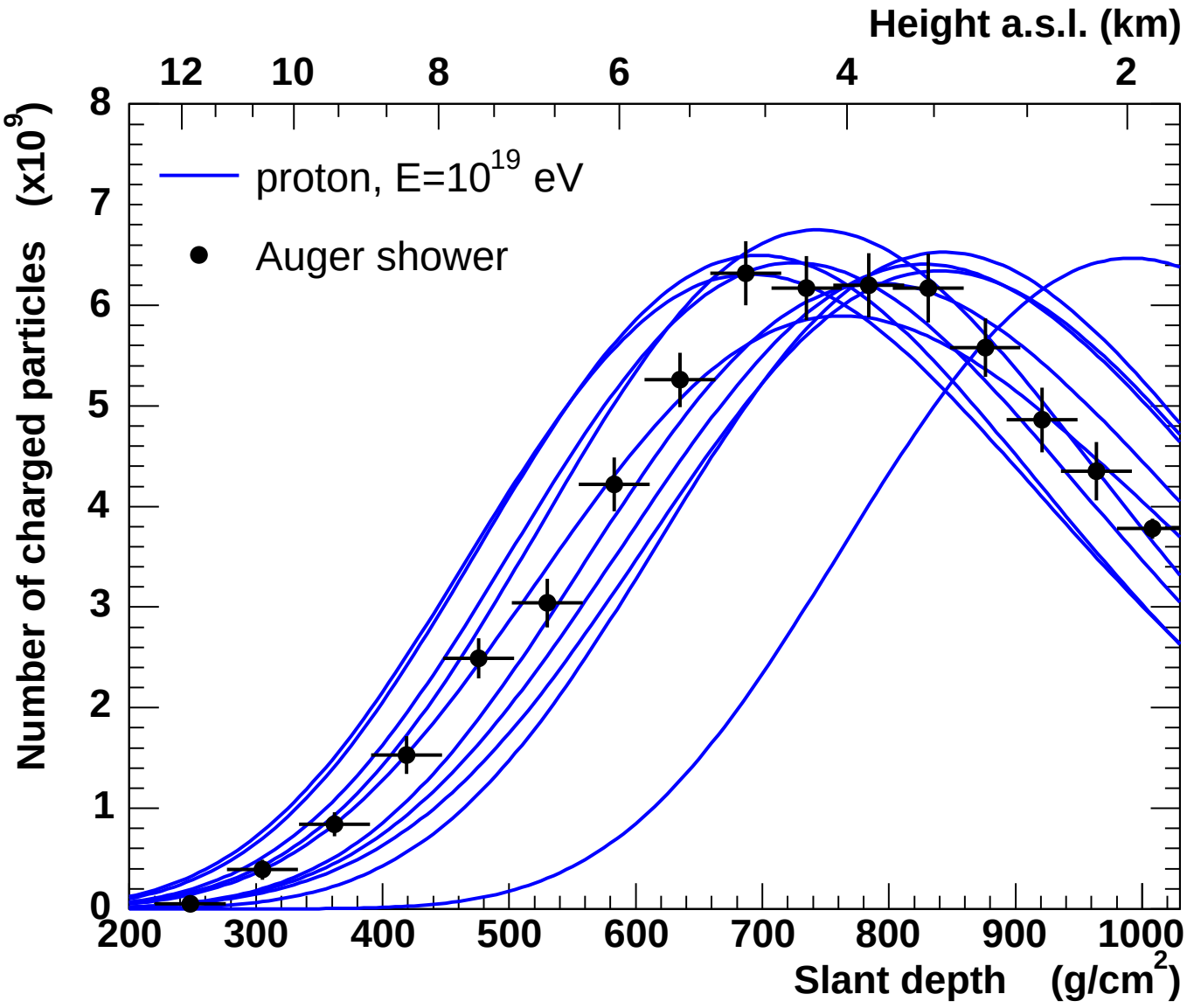


$\Delta E/E = 14\%$, regular JF12 at $R = 60$ EeV

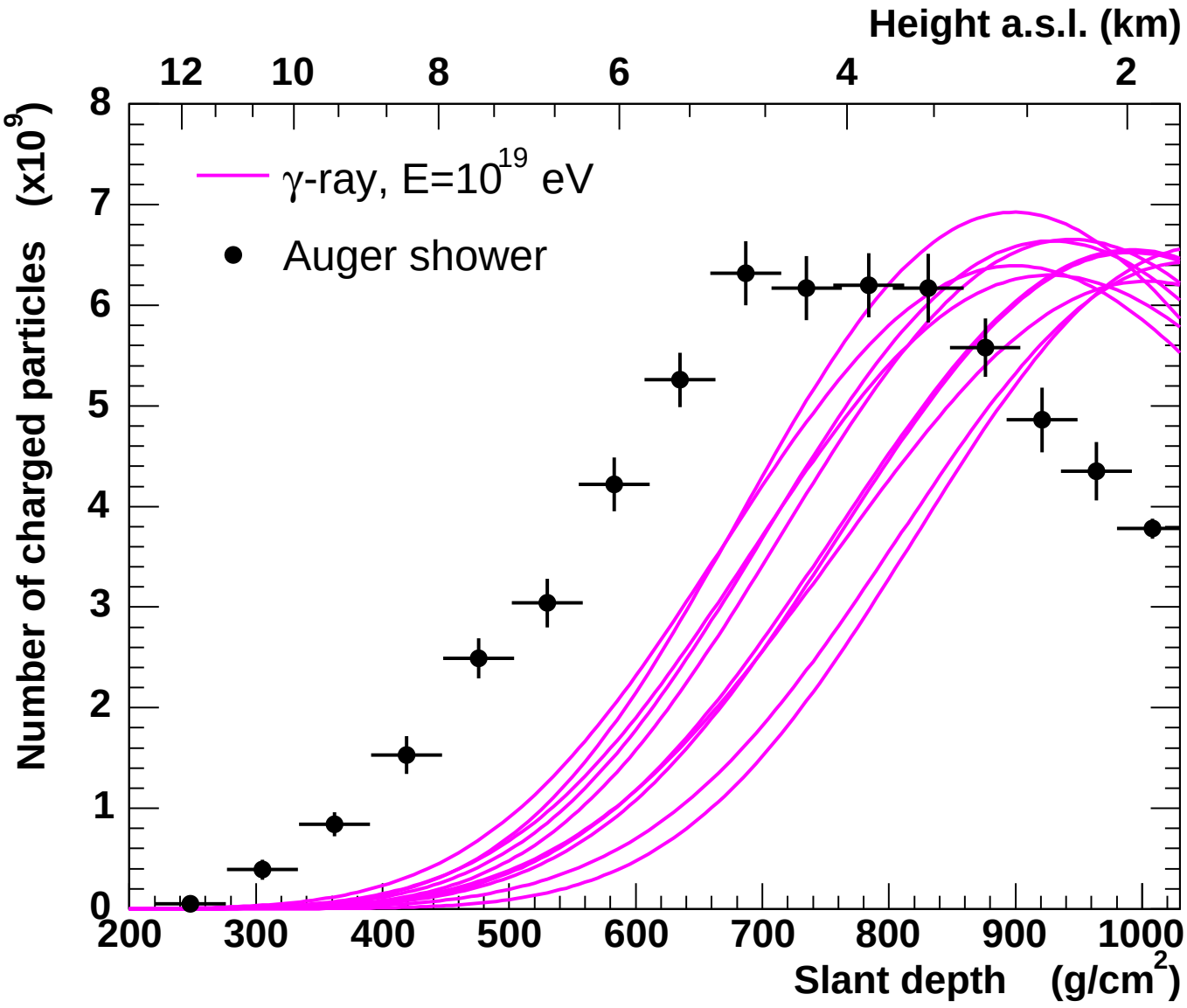
Primary Mass and Longitudinal Shower Profiles



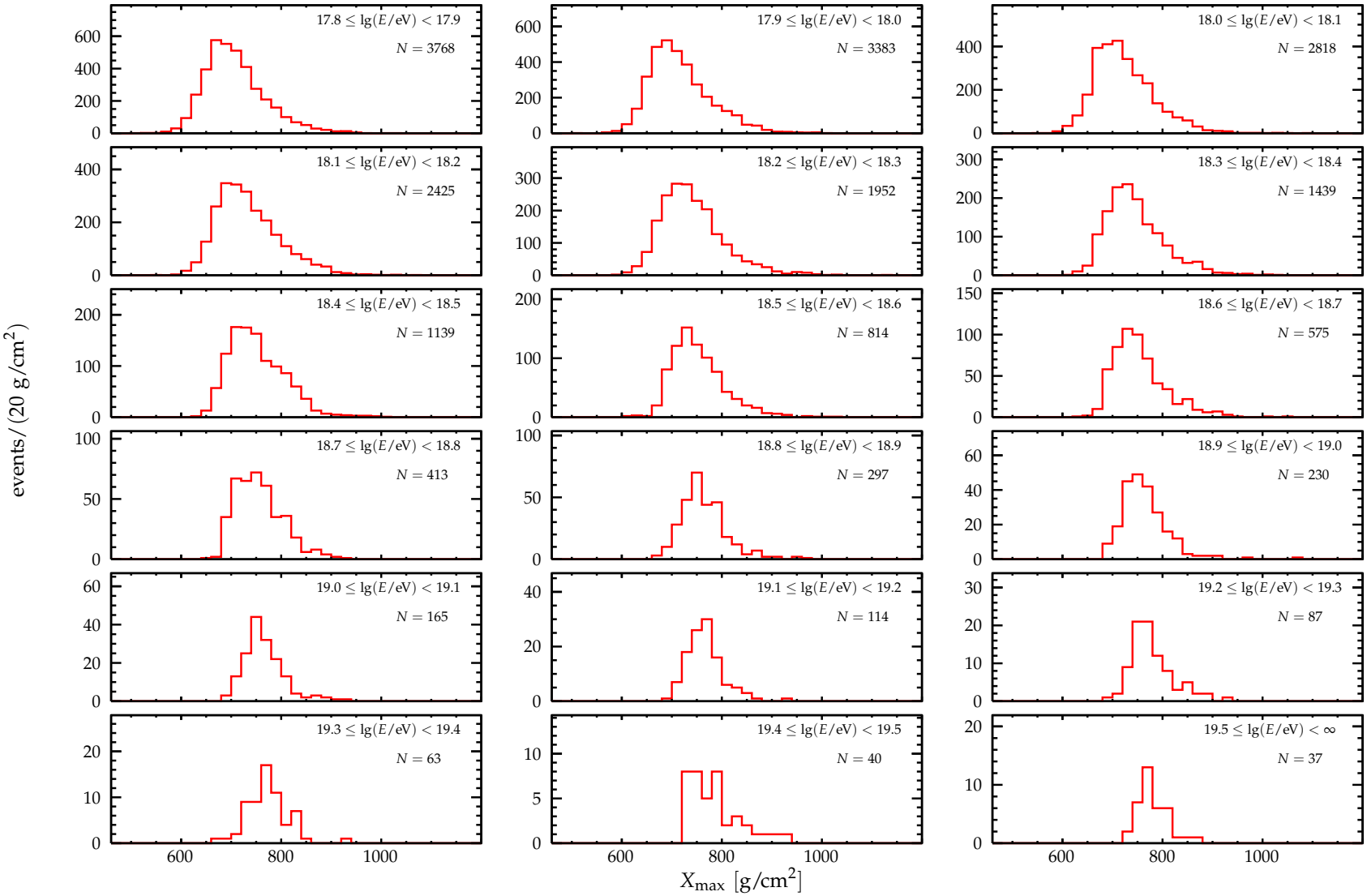
Primary Mass and Longitudinal Shower Profiles



Primary Mass and Longitudinal Shower Profiles

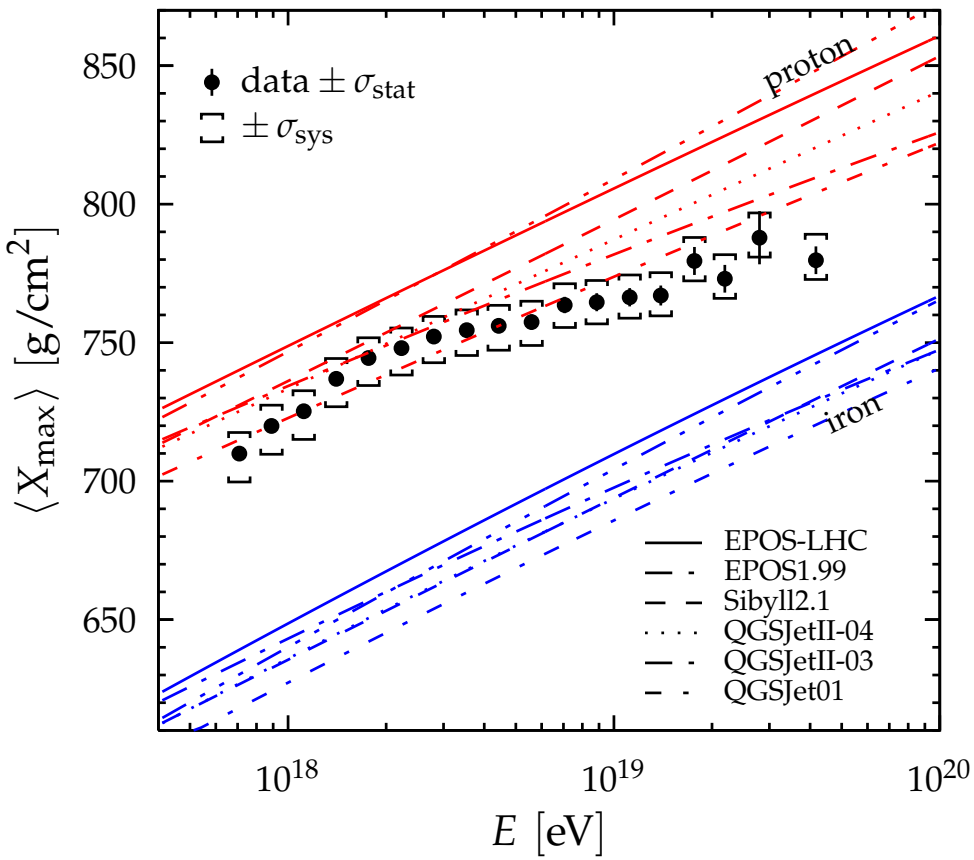


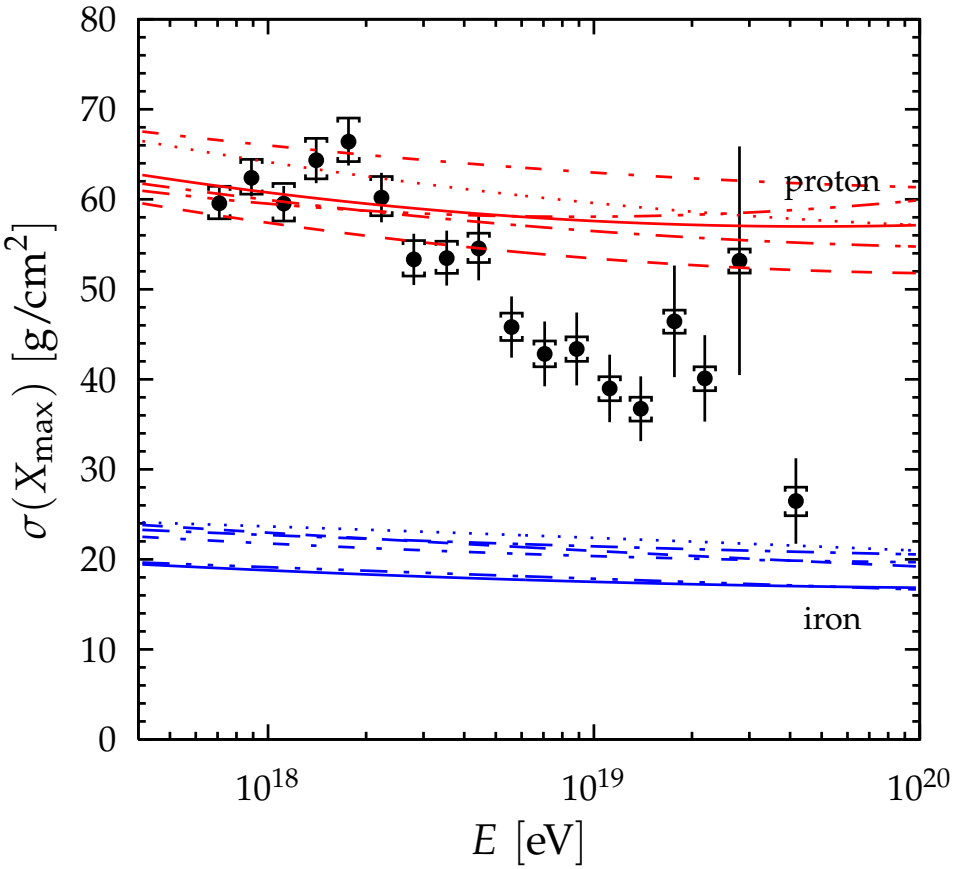
X_{max} Distributions



The Pierre Auger Collaboration, accepted in PRD, arXiv:1409.4809

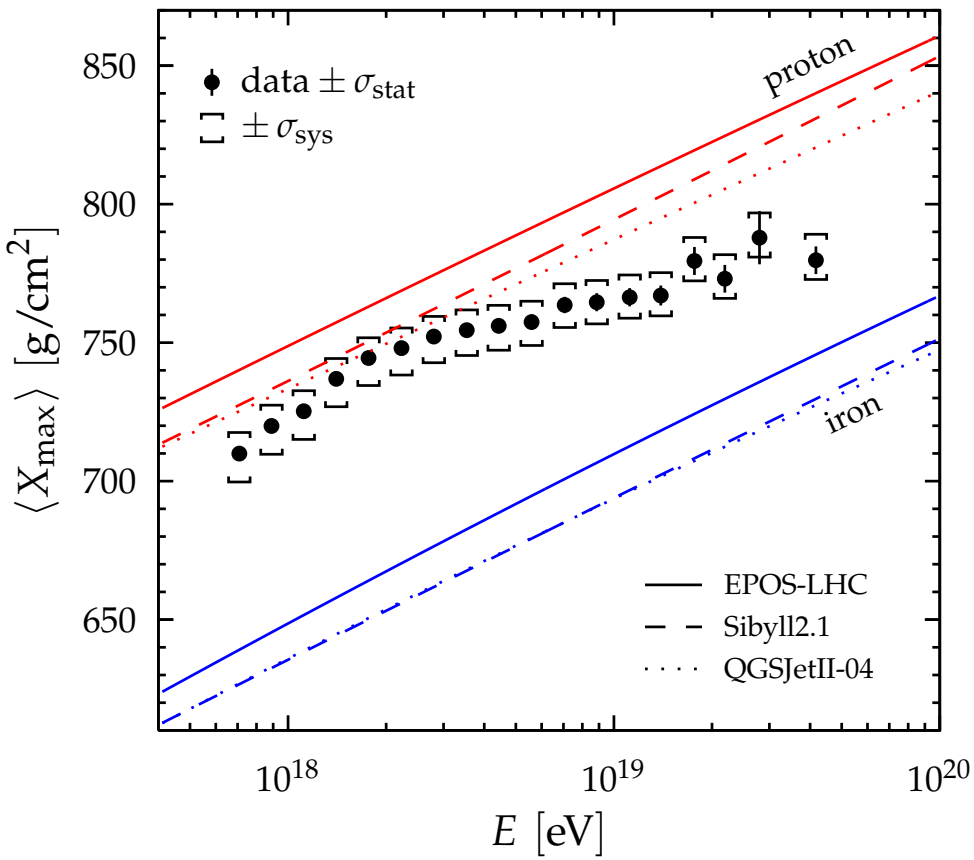
Moments of $X_{\max}$ Distributions – All Models

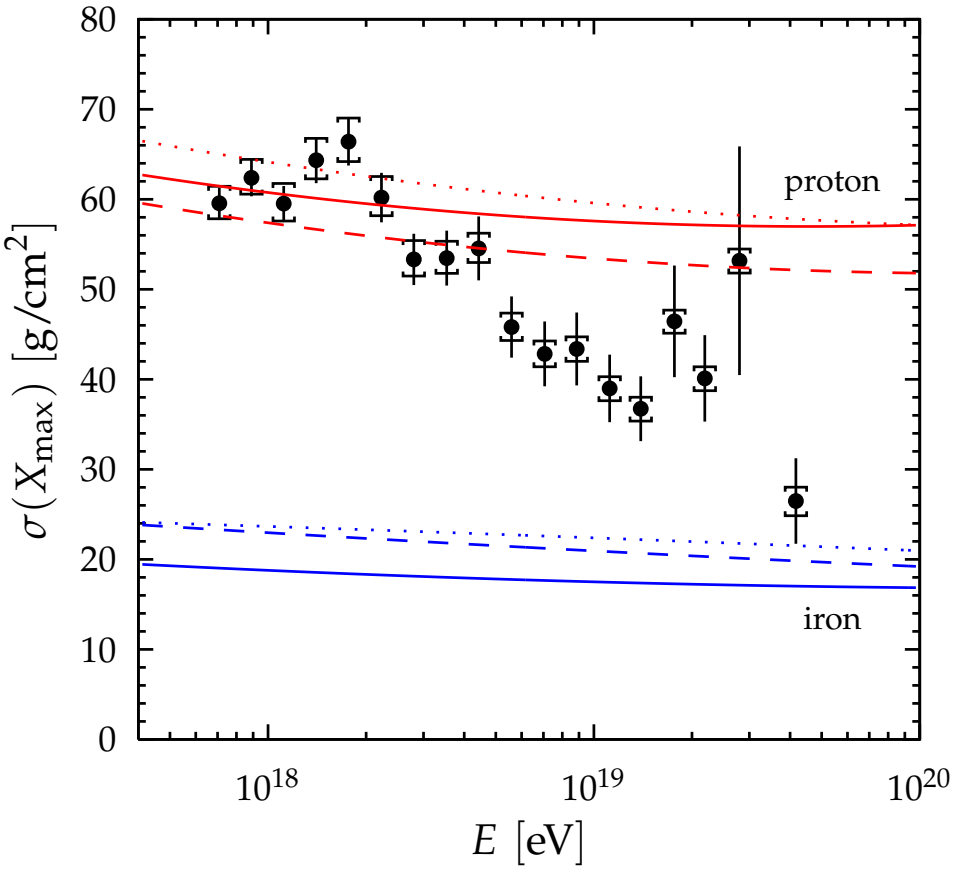




The Pierre Auger Collaboration, accepted in PRD, arXiv:1409.4809

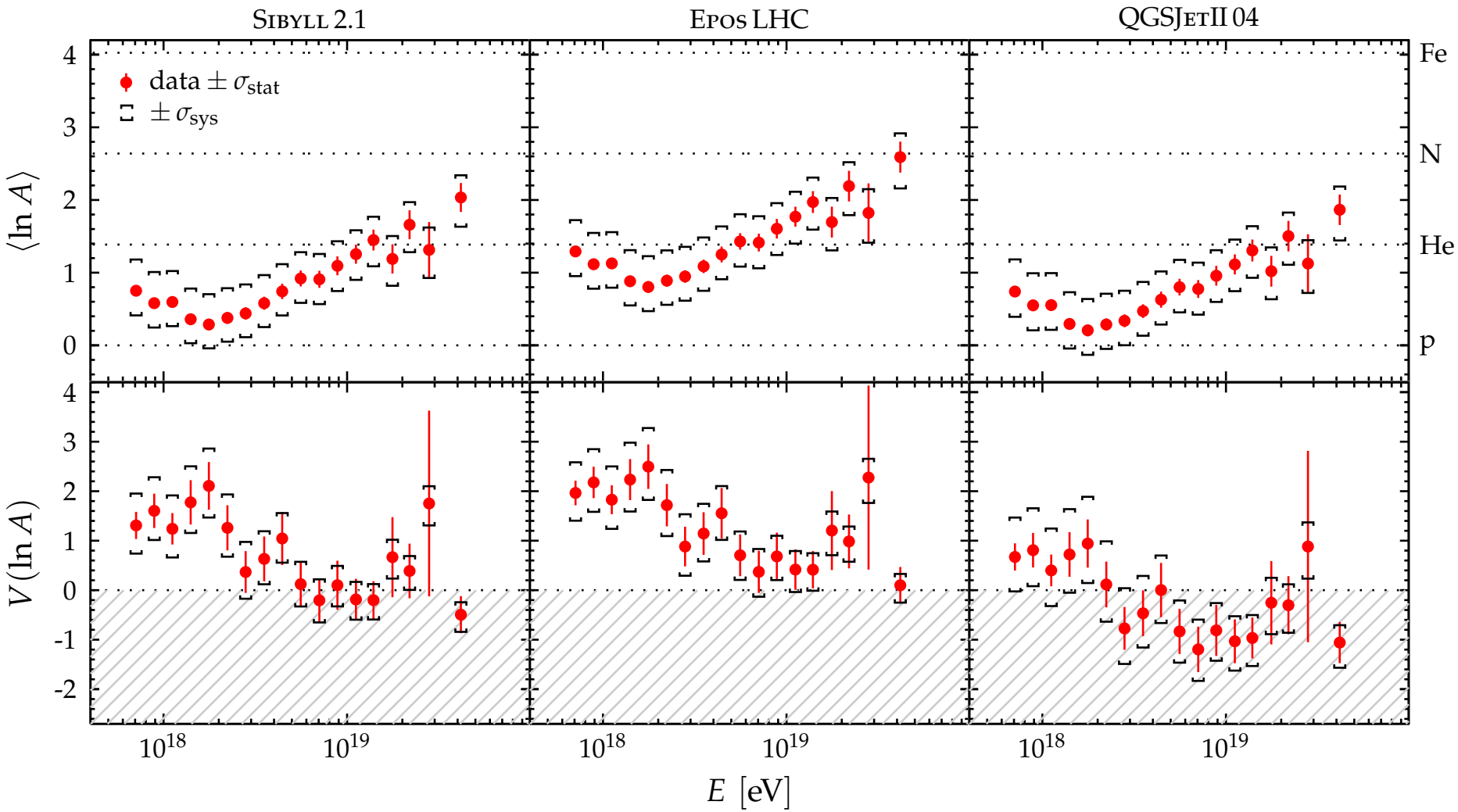
Moments of $X_{\max}$ Distributions – 'post-LHC' (7 TeV)





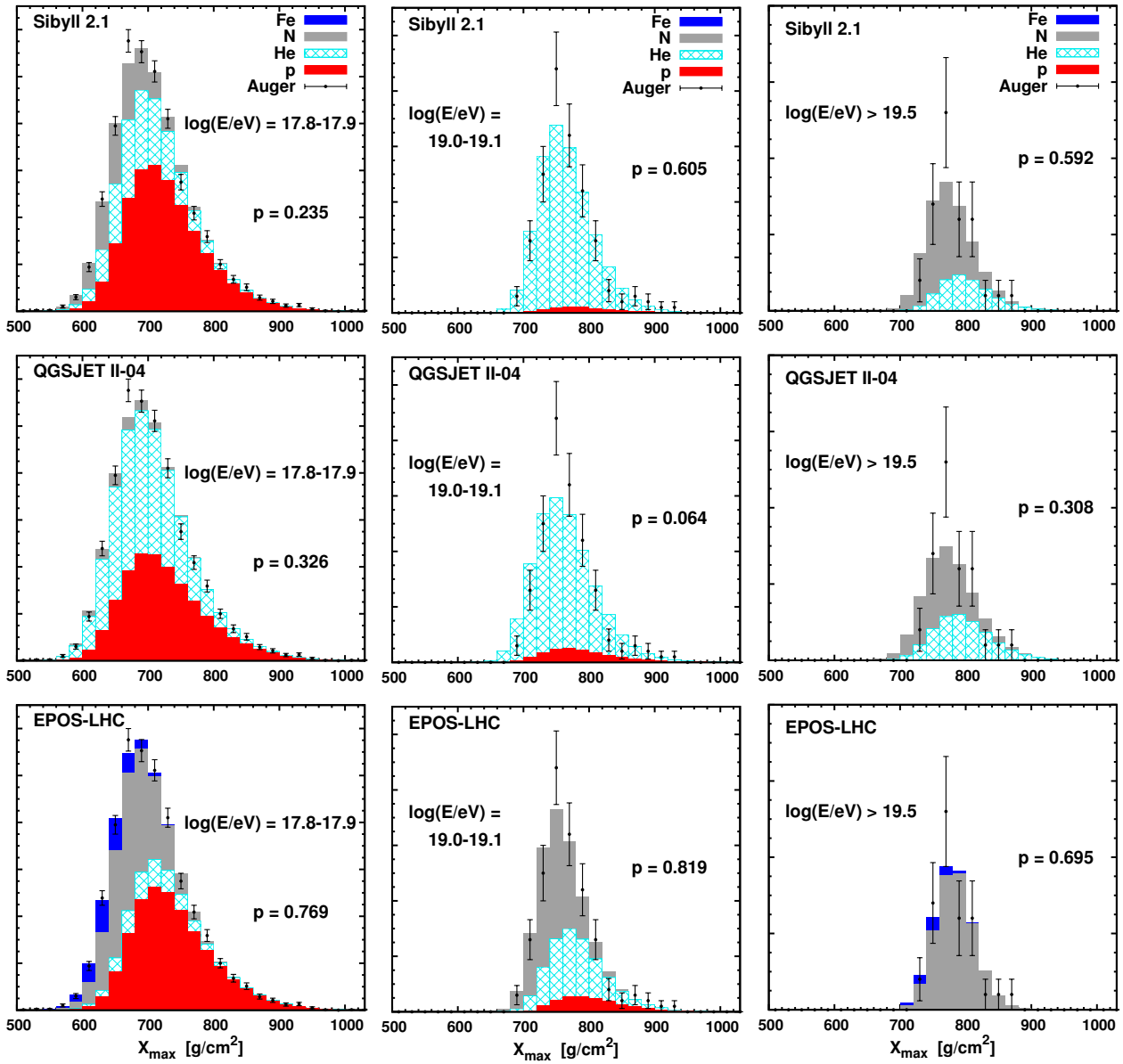
The Pierre Auger Collaboration, accepted in PRD, arXiv:1409.4809

Moments of ln(A) Distributions



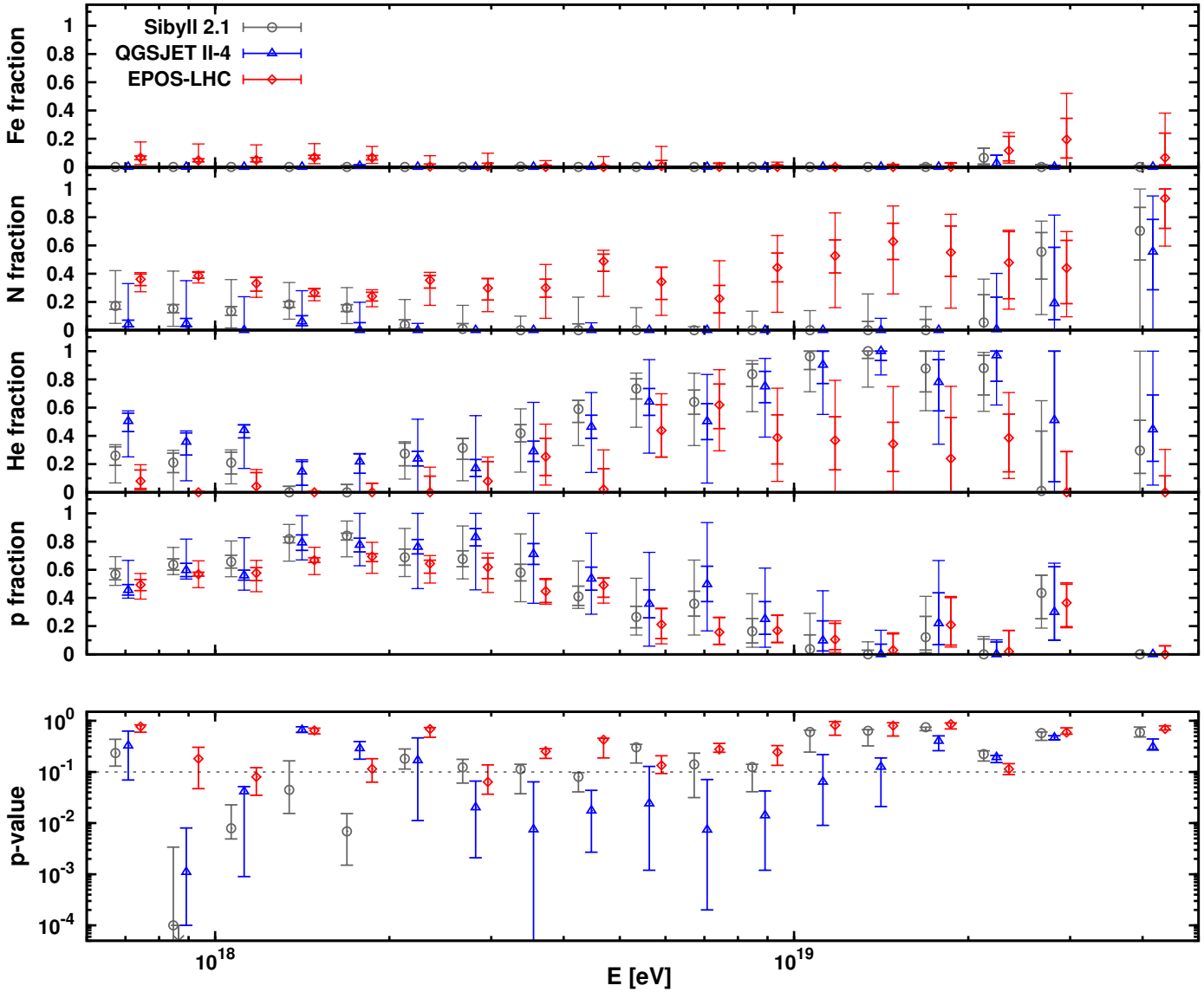
The Pierre Auger Collaboration, accepted in PRD, arXiv:1409.4809

Fit of X_{max} Distributions



The Pierre Auger Collaboration, accepted in PRD, arXiv:1409.5083

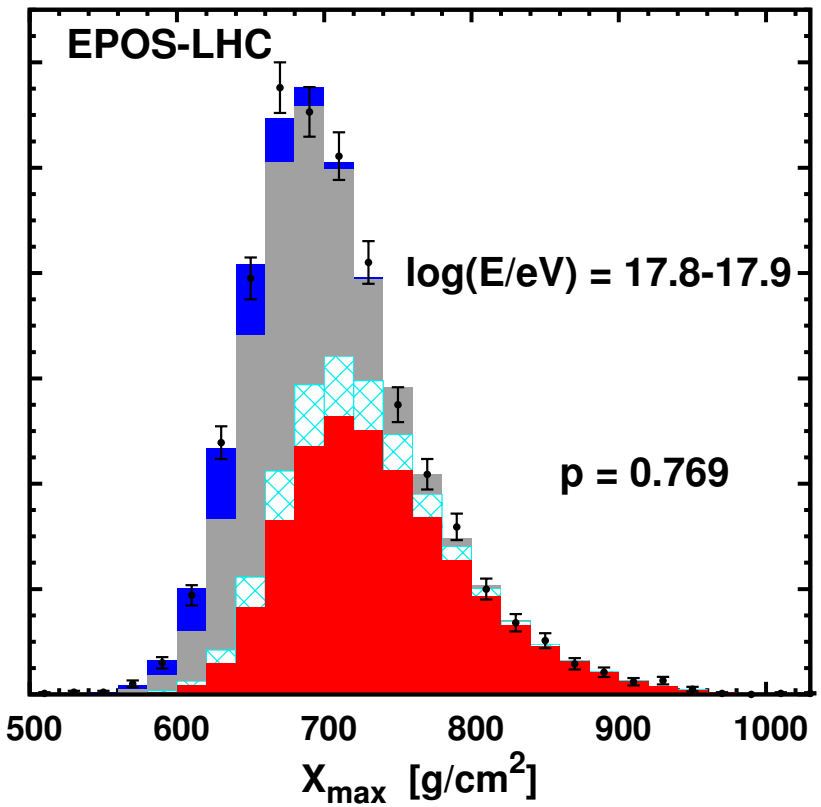
Fit of X_{max} Distributions

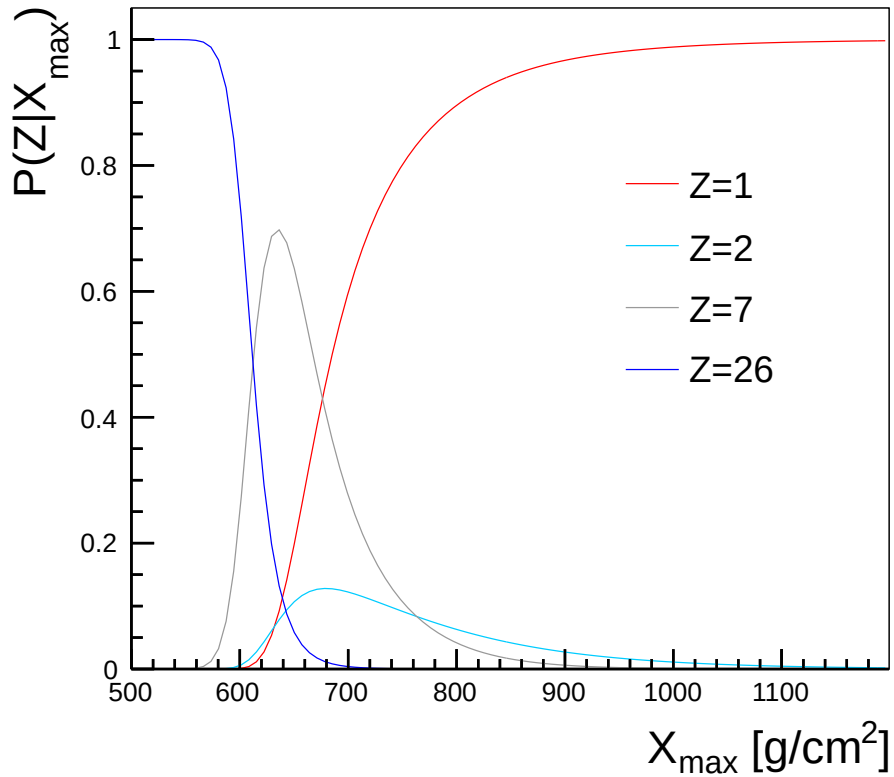


The Pierre Auger Collaboration, accepted in PRD, arXiv:1409.5083

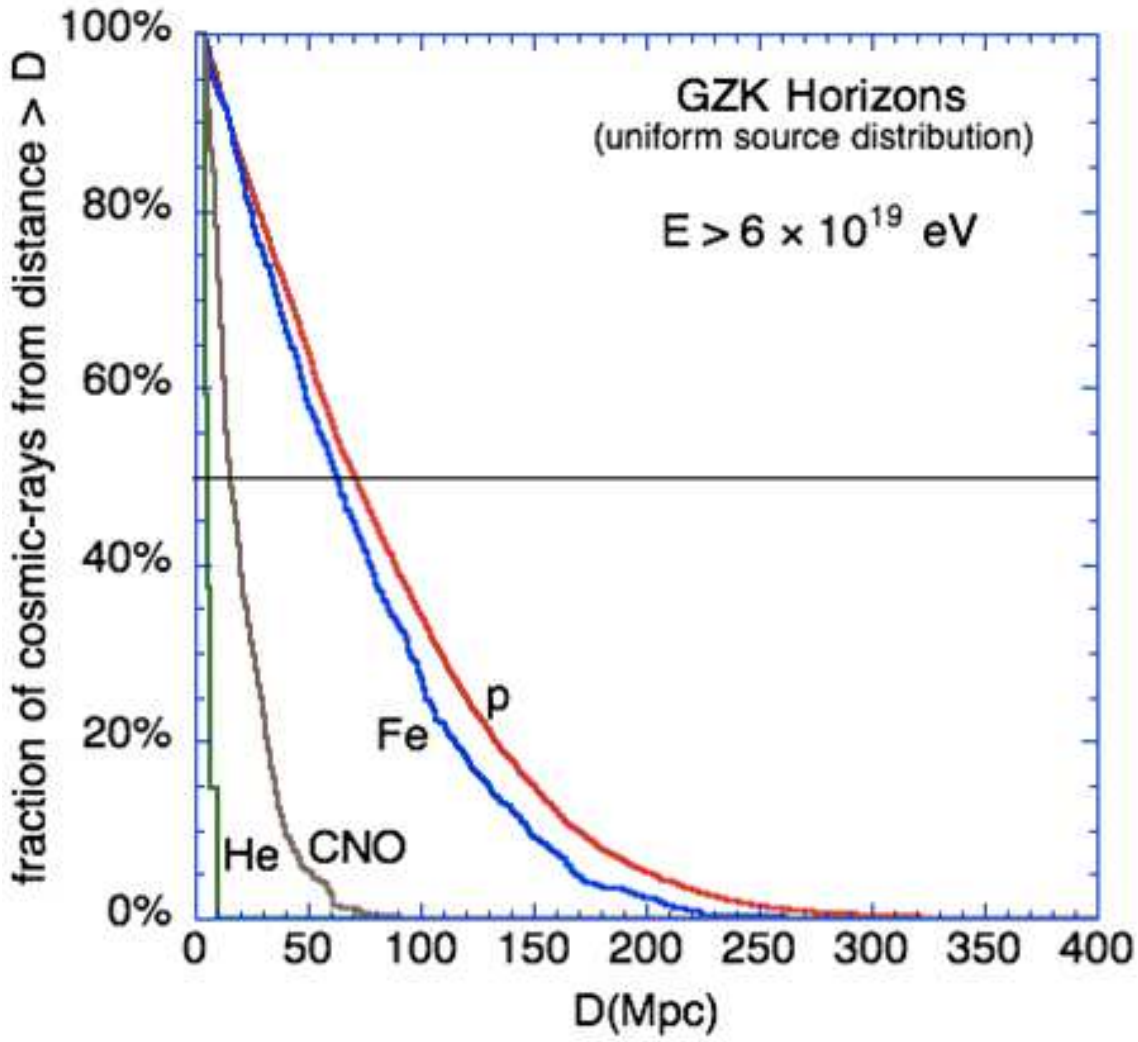
Event-by-Event Charge Estimate?

$$P(Z|X_{\max}) = \frac{P(X_{\max}|Z)\,P(Z)}{P(X_{\max})}$$



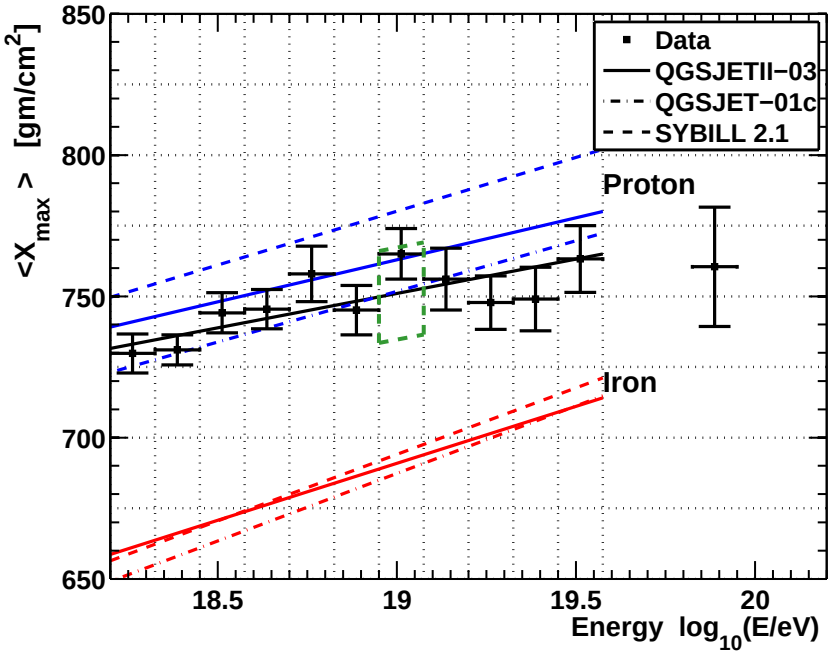


Additional Prior at UHE: Propagation

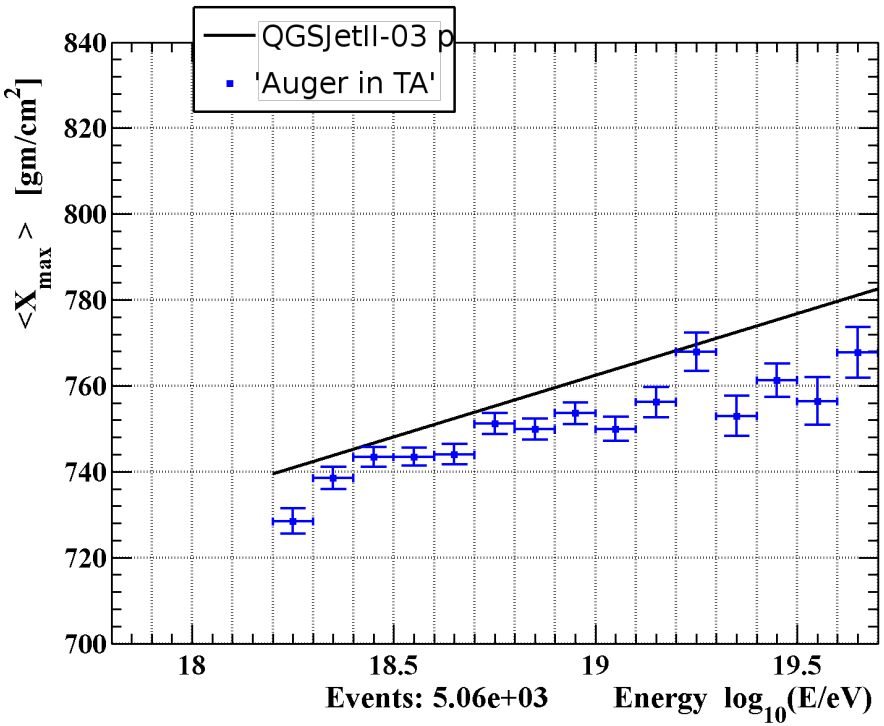


(Allard et al. JCAP 0810:033,2008)

Moments of X_{max} Distributions – Comparison to TA



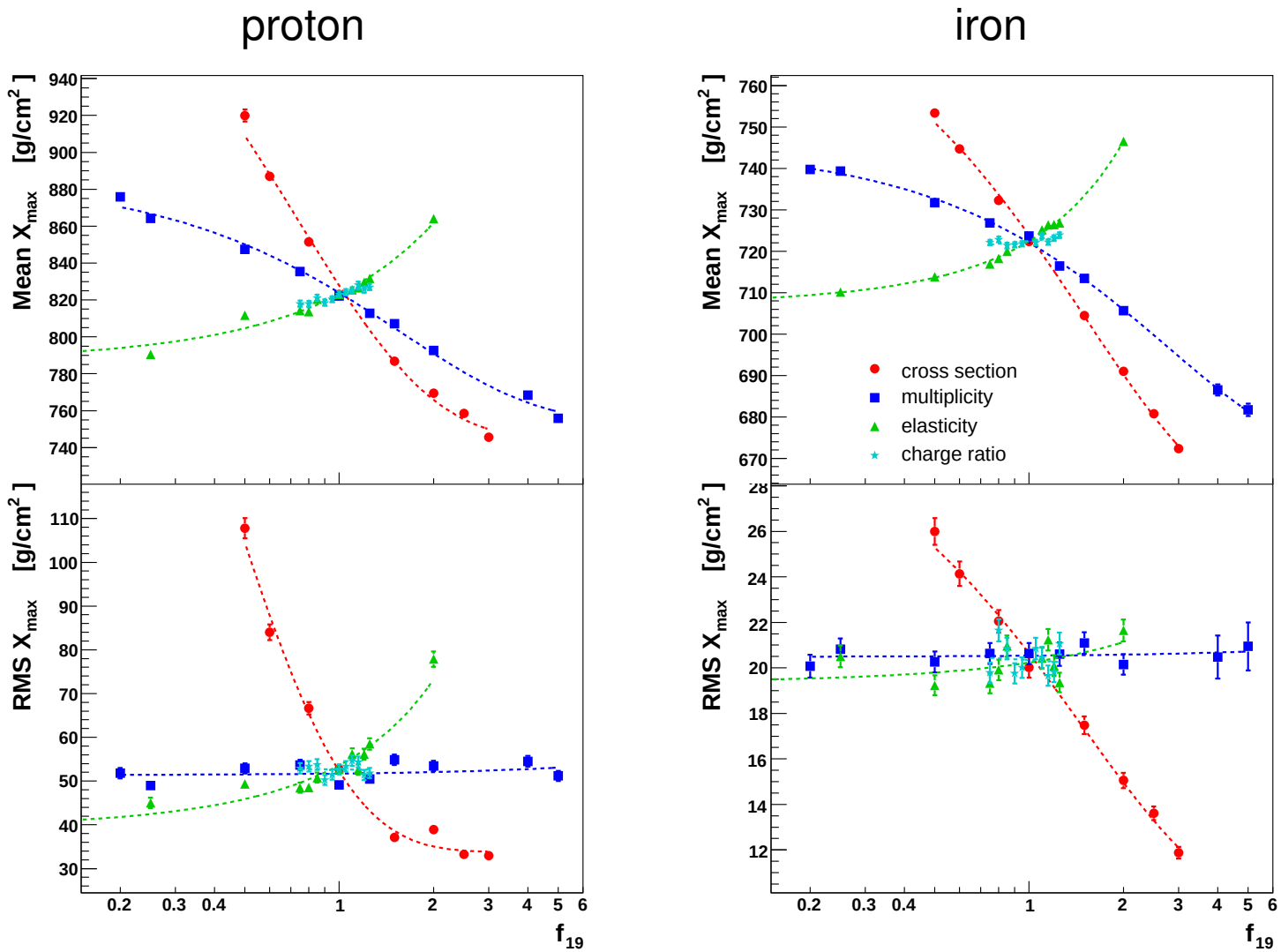
TA Collaboration, arXiv:1408.1726v3



P. Sokolsky, UHECR14

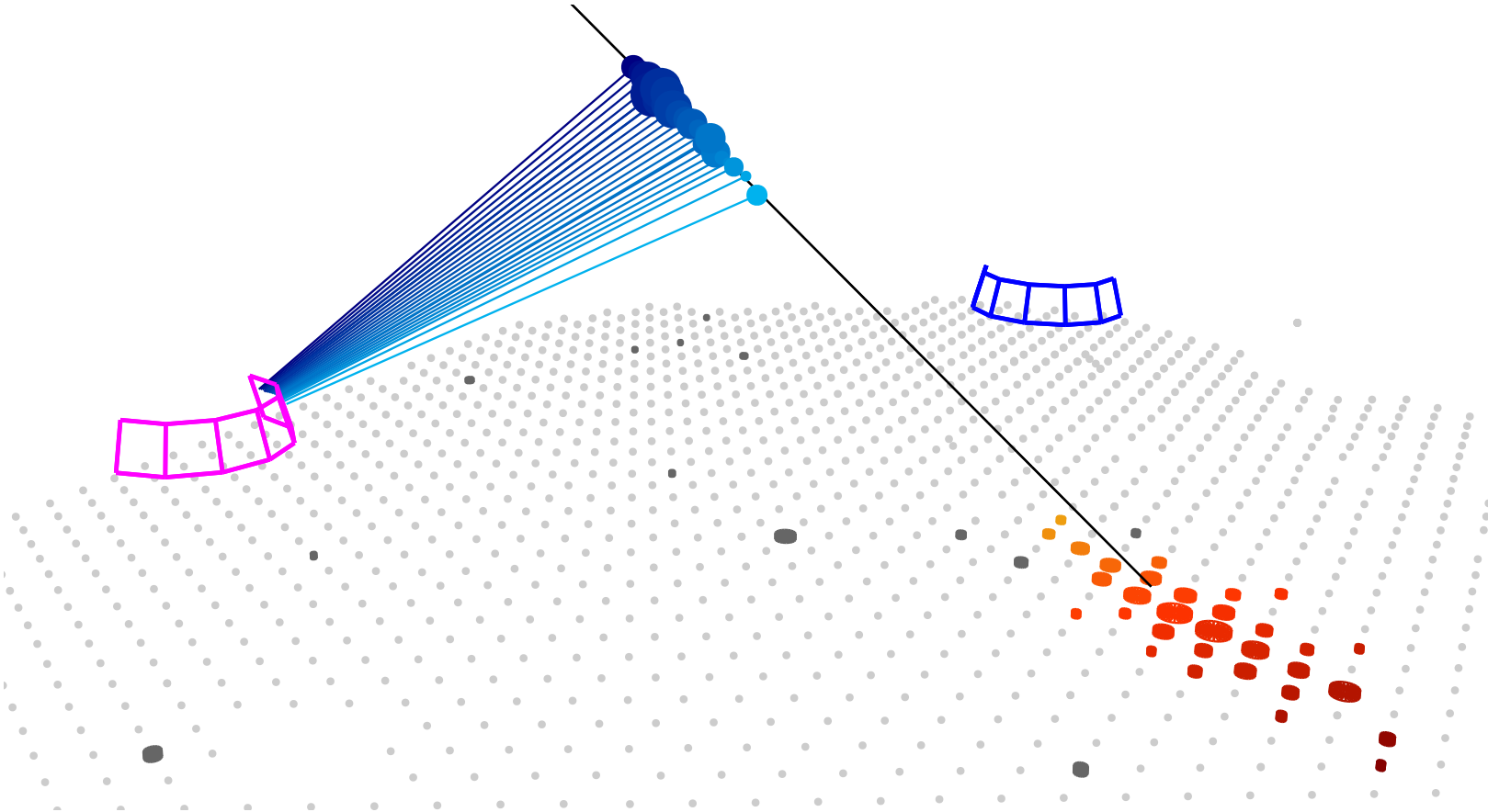
Caveat: Hadronic Interactions at UHE

$E_p = 60\ EeV \leftrightarrow \sqrt{s} = 340$ TeV!!



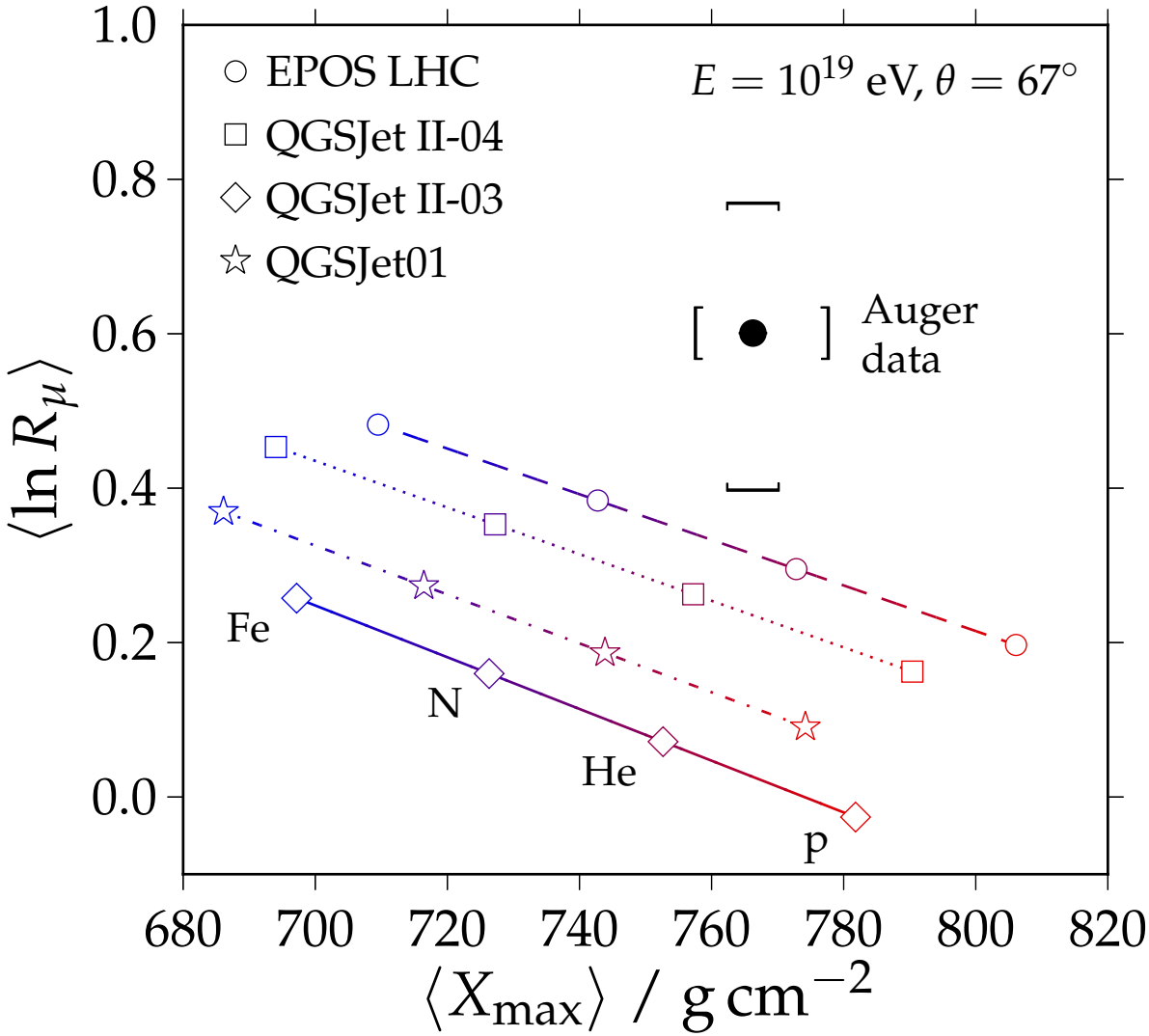
R. Ulrich, R. Engel, MU, Phys. Rev. D83 (2011) 054026

Muon studies with inclined hybrid events (62°-80°)



event 201114505353, $\theta = 75.6^{\circ}$, $E = 15.5$ EeV

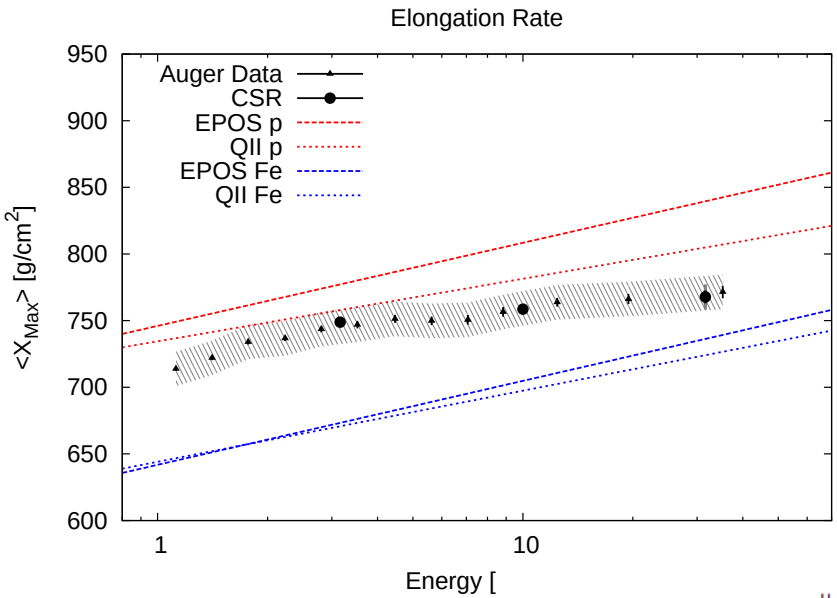
Muon scale vs. $X_{\max}$ (FD)

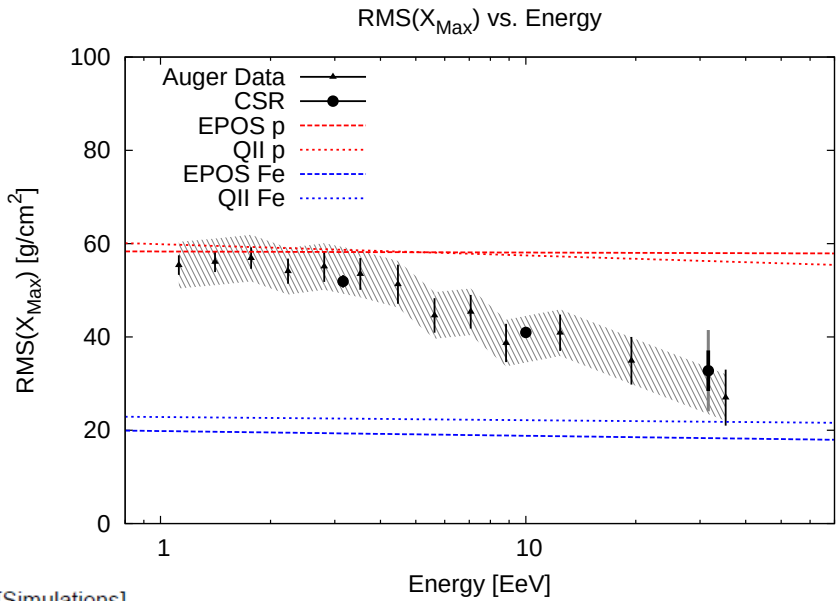


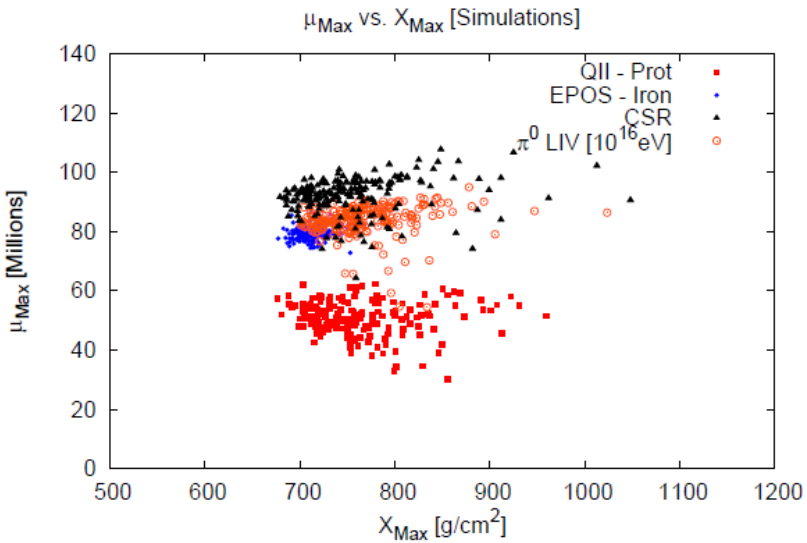
The Pierre Auger Collaboration, accepted in PRD, 2014

100% *p* + New Physics?

'Chiral Symmetry Restauration' model (suppression of π-production)

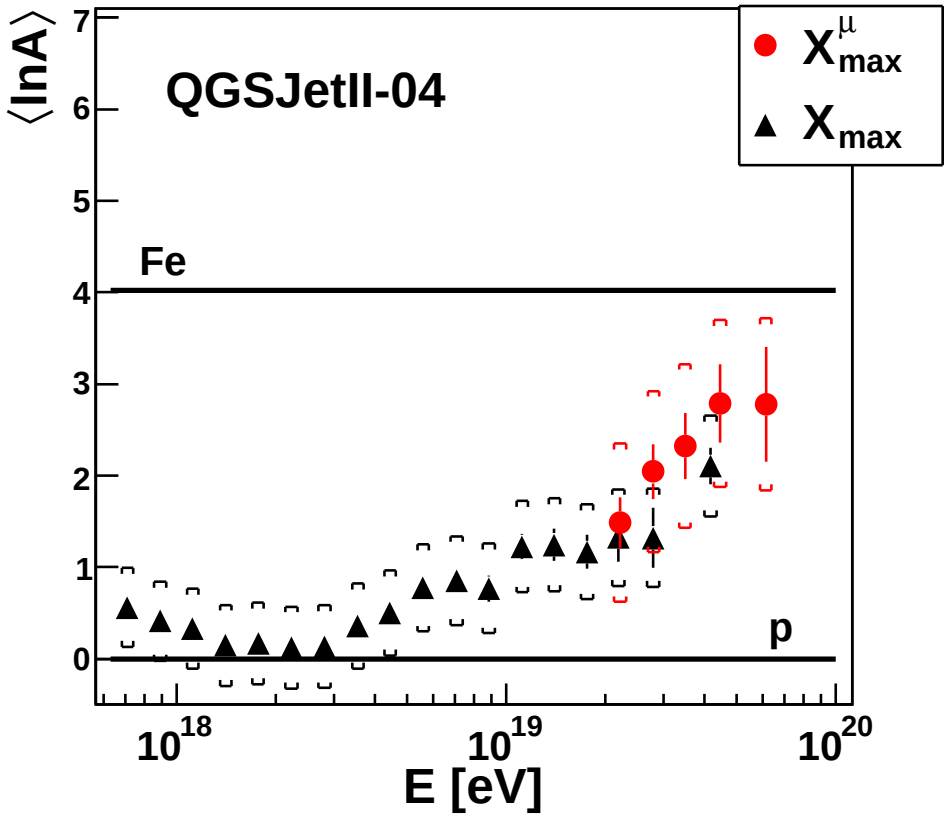


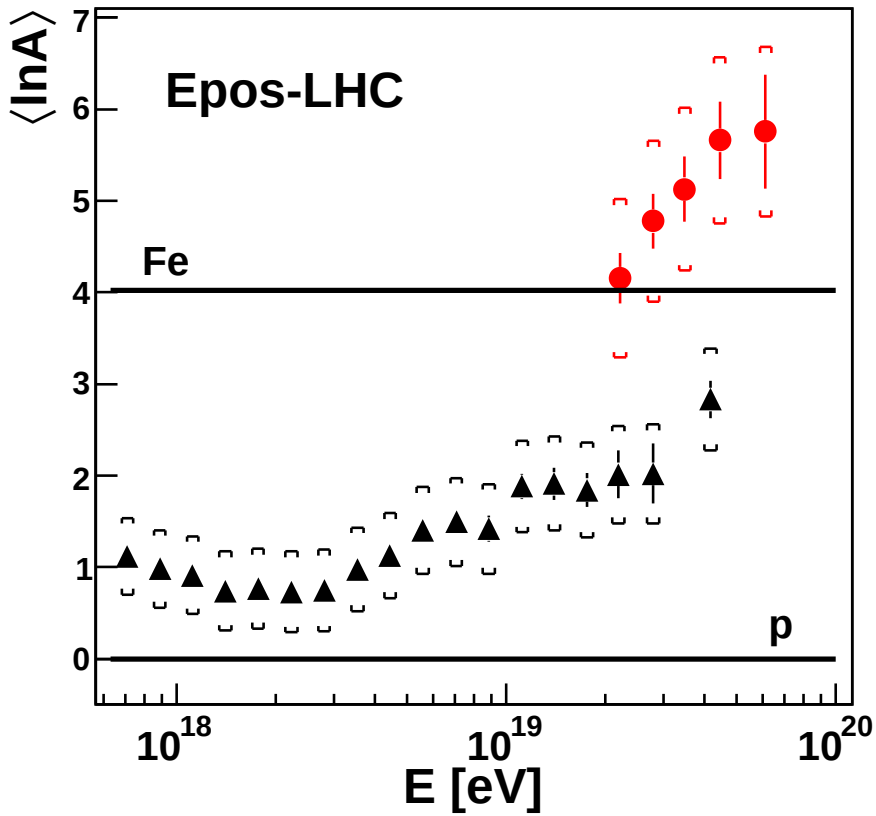




G.Farrar&J.Allen, UHECR12, arXiv:1307.2322

Comparison of ln$A$ from $X_{\max}^{\mu}$ and $X_{\max}$





The Pierre Auger Collaboration, JCAP 1302 (2013) 026

The Pierre Auger Collaboration, Phys. Rev. D90 (2014) 012012

Auger Beyond 2015

- origin of flux suppression?
- proton fraction at UHE?
- hadronic physics above $\sqrt{s} = 70$ TeV

The Next 10 Years in UHECR

Auger:

- $\sim$ 200 events above 55 EeV with upgraded SD
  $\rightarrow$ event-by-event charge estimate
- enlarged FD duty cycle
- 'high precision array' $\mathcal{O}(100\ \mathrm{km}^2)$?

TA:

- TA$\times$4?

Hadronic Interactions:

- LHC at 14 TeV ($E_p = 10^{17}$ eV)
- p+O runs at LHC?
- NA61/SHINE π+C data
- constraints from CR data
- ...

Jem-EUSO?