Latest results from Auger

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Outline

- The Auger Observatory
- The hybrid mode of operation
- The role of p-air cross section in EAS
- Systematics on the cross section
- Summary

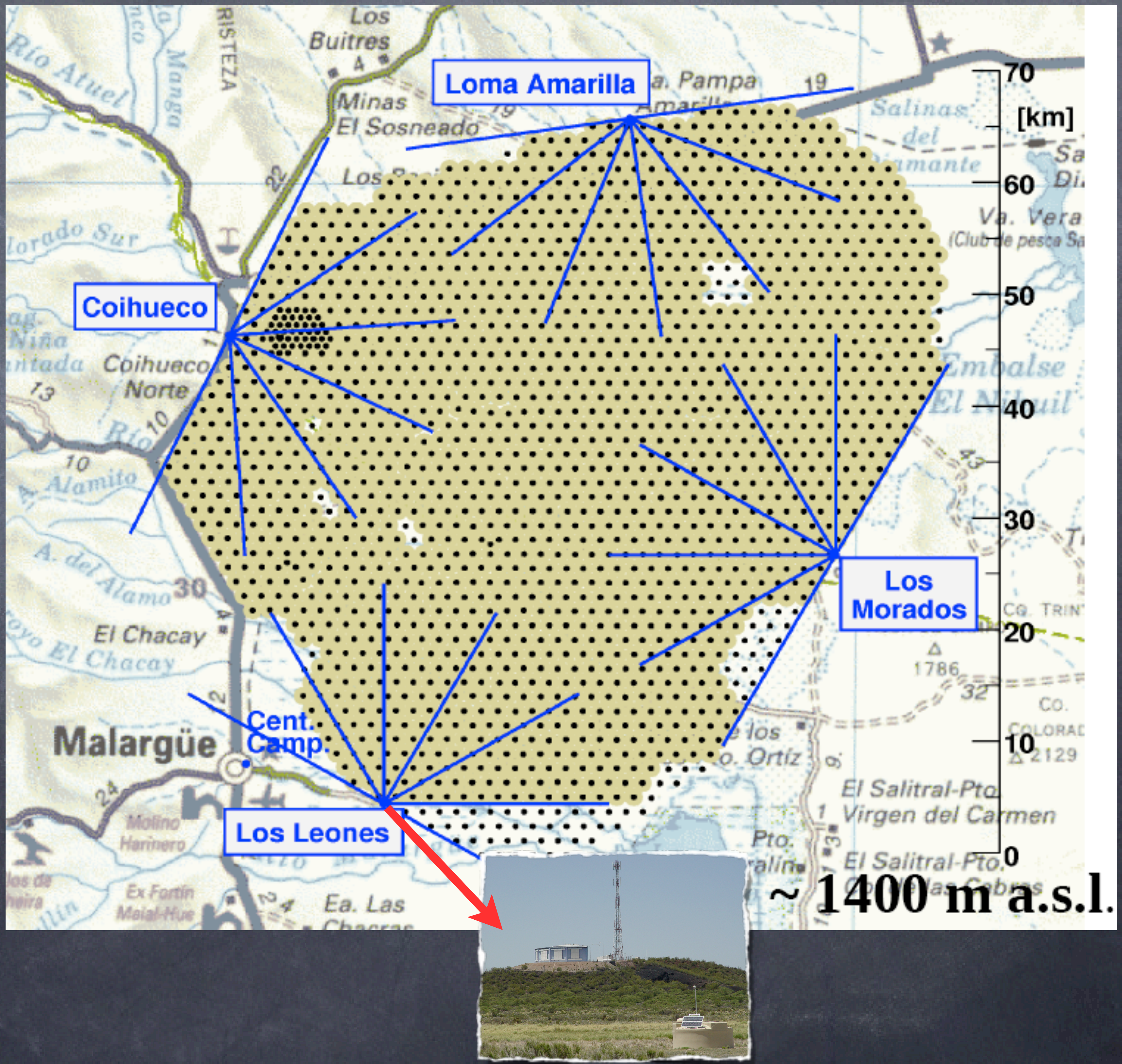
The Auger Observatory

1660 water Cherenkov detectors

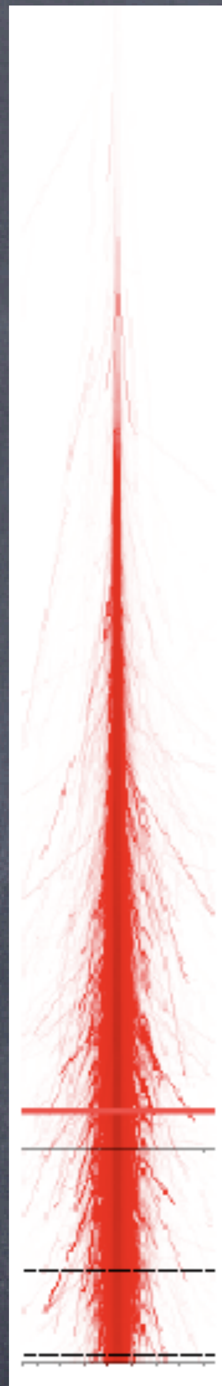
1.5 km regular triangular grid covering 3000 km^2

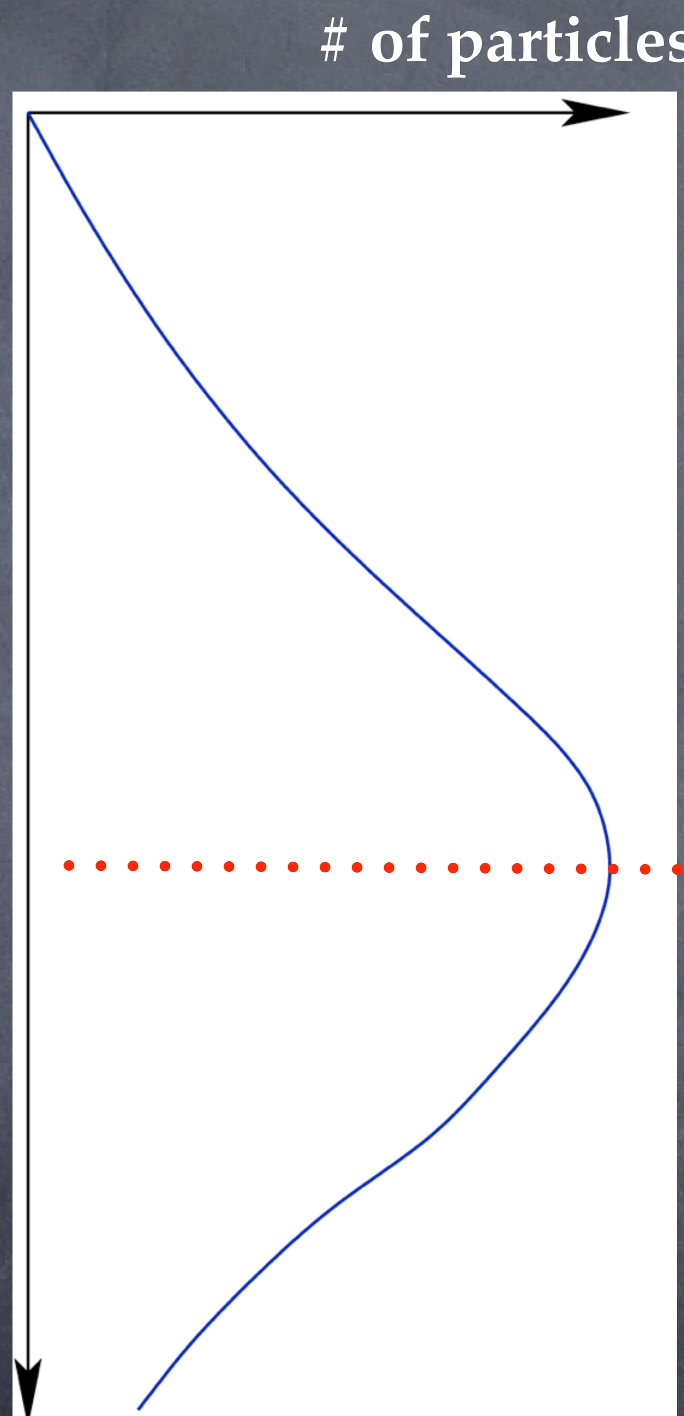
0.75 km infill-grid

27 fluorescence telescopes



The Extensive Air Shower





bremsstrahlung + pair production

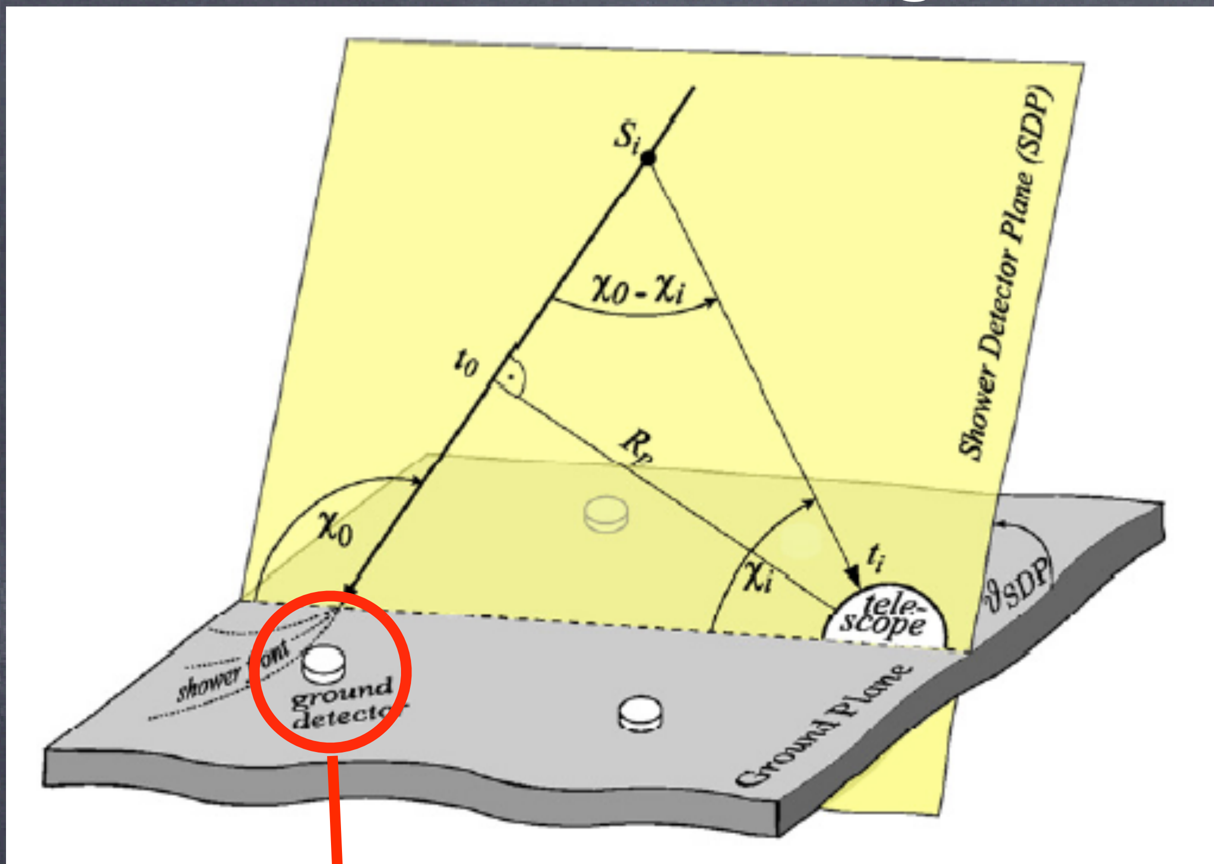
cascade particles reach the critical energy in air (~ 84 MeV)

ionization losses

$$X = \int \rho dx \quad (\mathrm{g/cm^2})$$

$$\left(\frac{dE}{dx}\right)_{brems} = \left(\frac{dE}{dx}\right)_{ioni}$$

Hybrid geometry reconstruction



time of pixel in FD camera pixel:

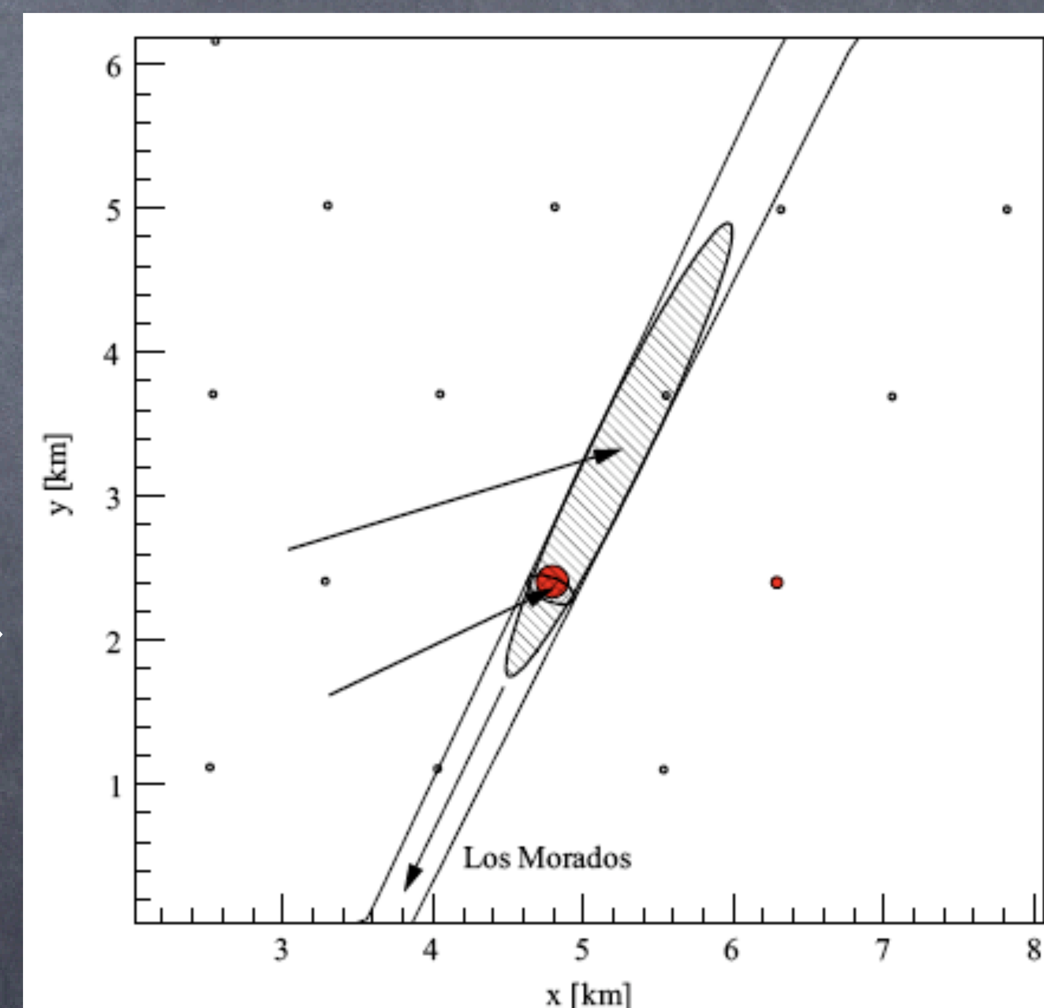
$$t_i = t_0 + \frac{R_p}{c}\tan\left(\frac{\chi_0 - \chi_i}{2}\right)$$

+ a single tank on ground:

$$t_{\rm tank} = T_0 - \frac{u x_{\rm tank} + v y_{\rm tank}}{c}$$

$$= \sin\theta\cos\phi$$

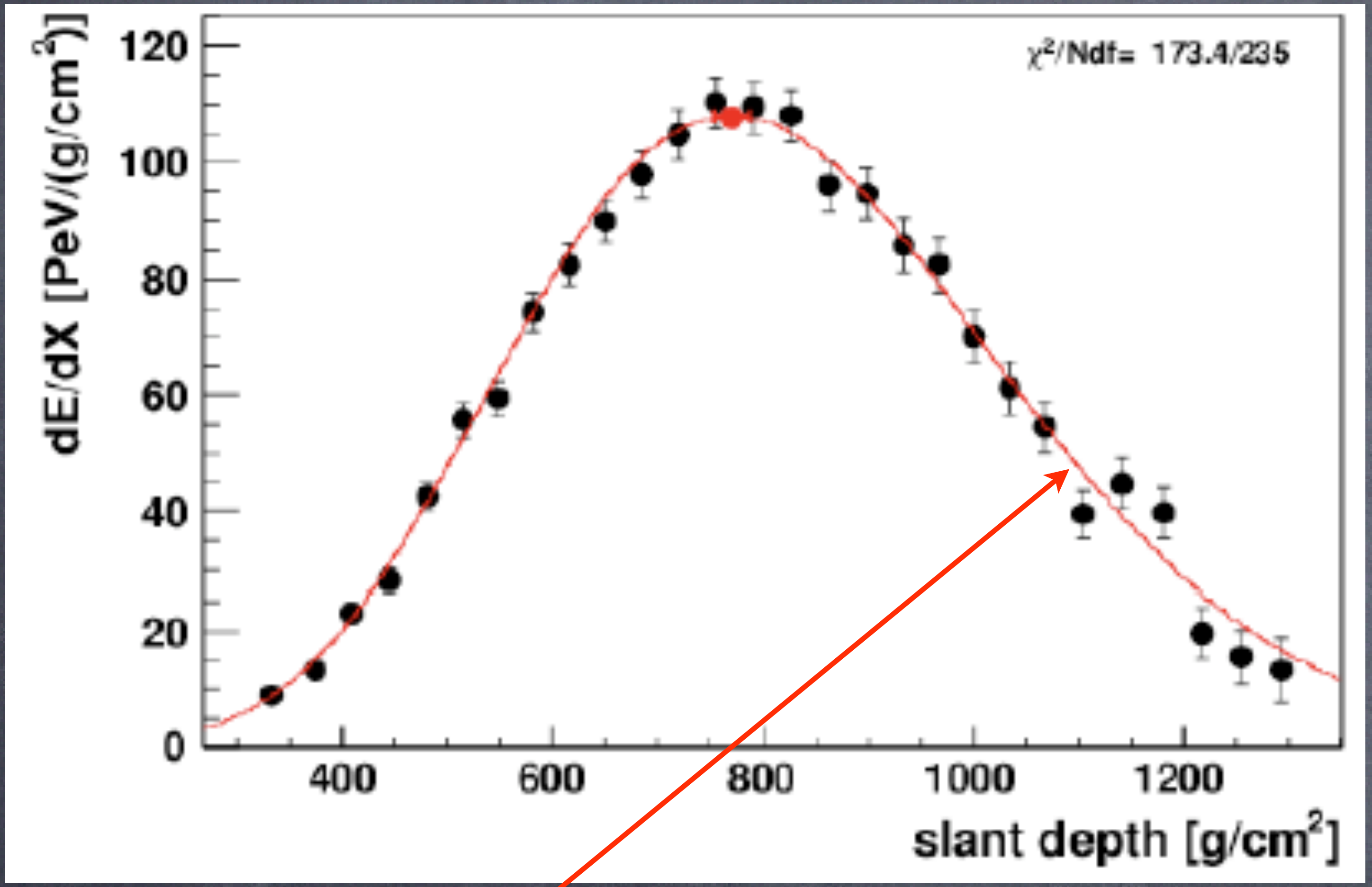
$$v = \sin\theta\sin\phi$$



angular resolution below 1°

Longitudinal profile in hybrid mode

Precise geometrical reconstruction provides a reliable shower profile!



Energy

$E = (7.1 \pm 0.2)\ 10^{19}$ eV

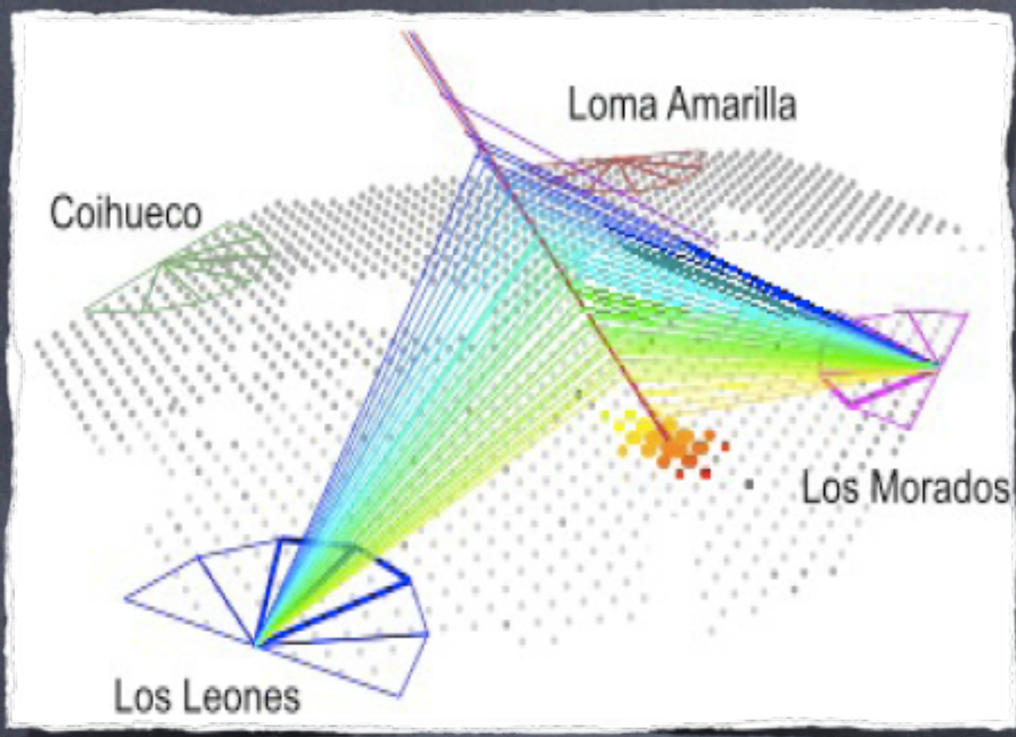
Depth of the maximum

$X_{max} = (752 \pm 7)$ g/cm^2

Gaisser-Hillas profile:

$$N_e(X) = N_{e_{\max}} \left(\frac{X - X_0}{X_{\max} - X_0} \right)^{\frac{X_{\max} - X_0}{\lambda}} e^{\frac{X_{\max} - X_0}{\lambda}}$$

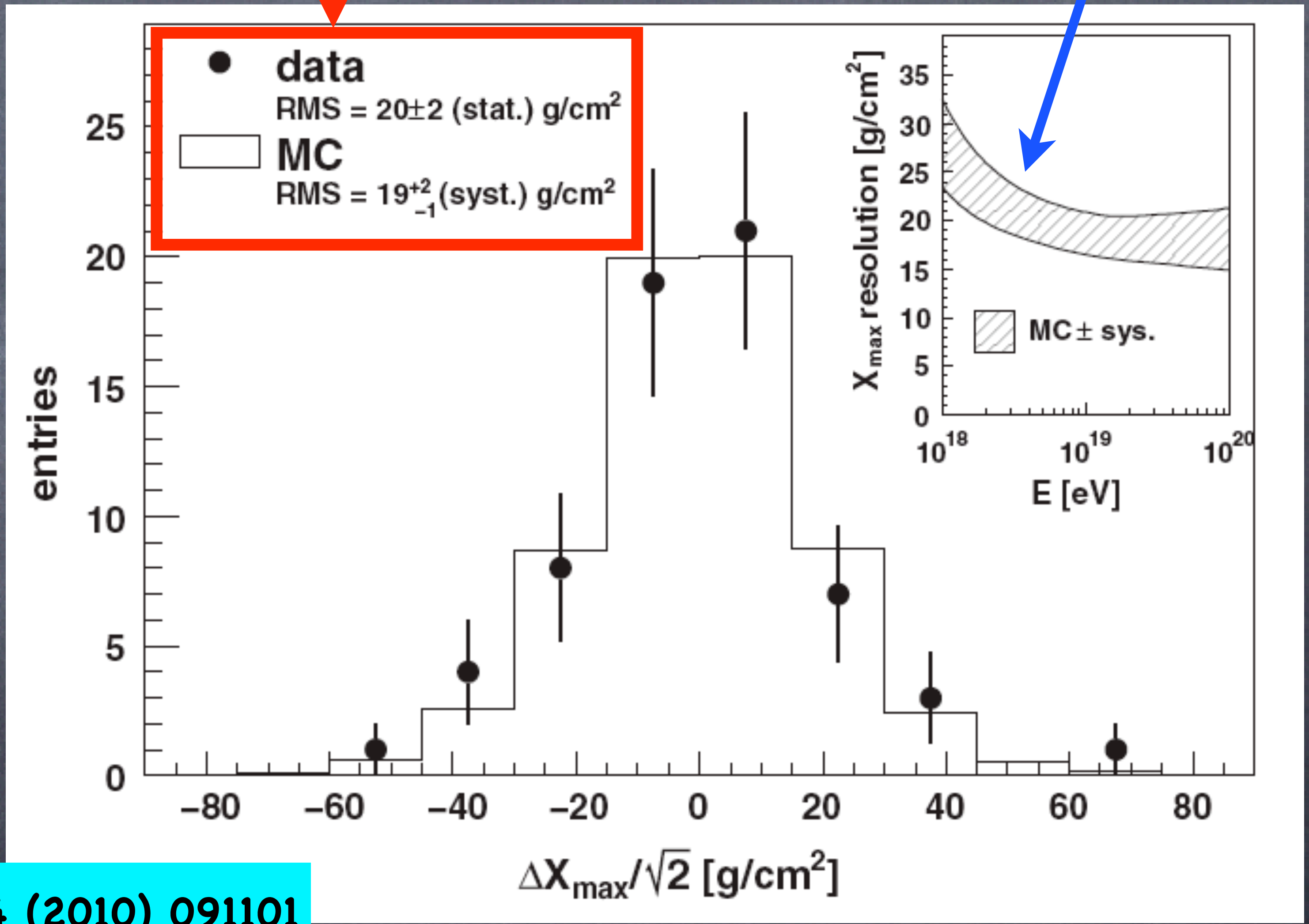
X_{max} resolution



Resolution of ~20 g/cm² obtained with stereo events...

...and verified with Monte Carlo

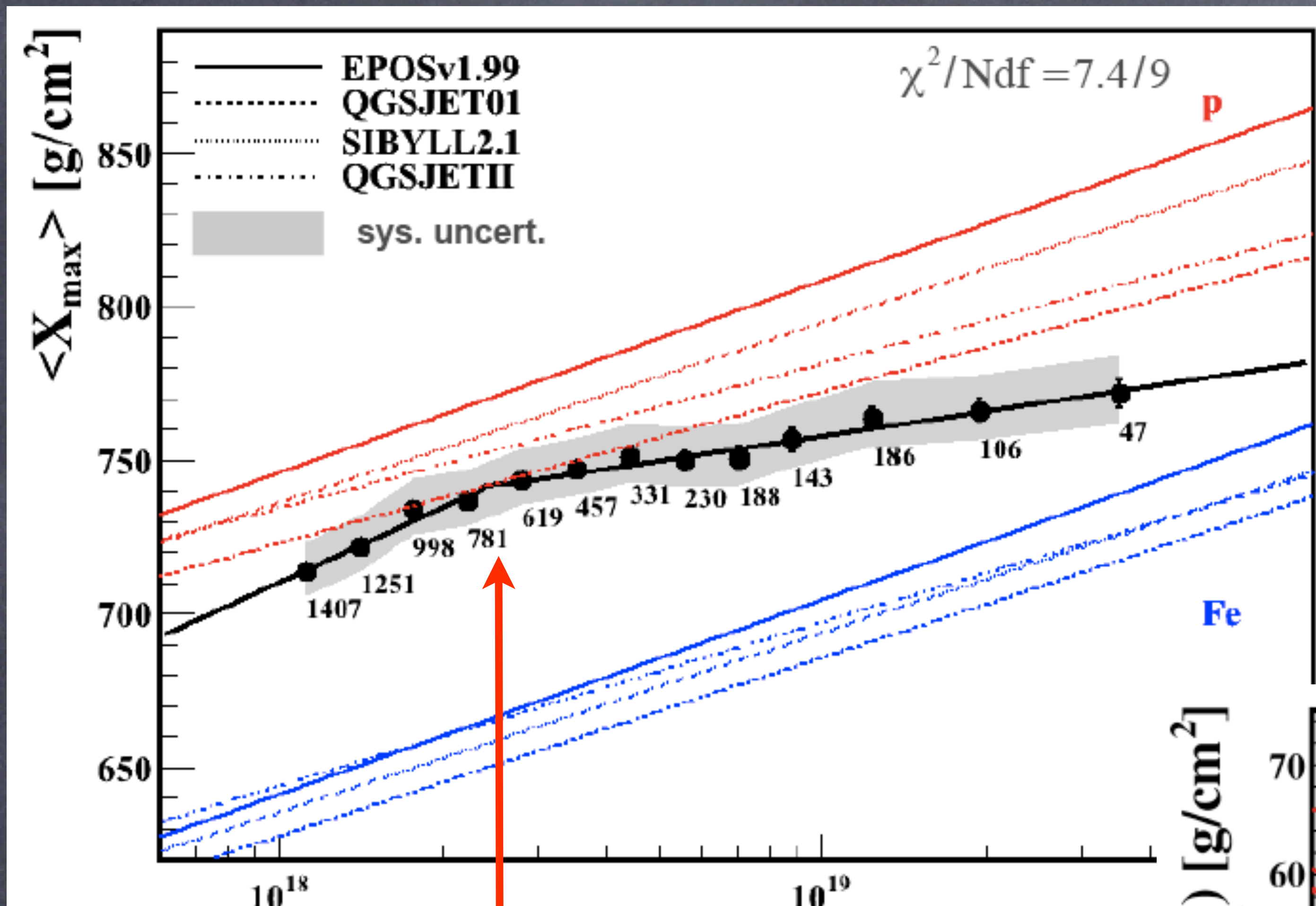
evolution with energy



PRL 104 (2010) 091101

systematics include: detector + density profiles + aerosols

X_{max} and its fluctuations



Low Energy

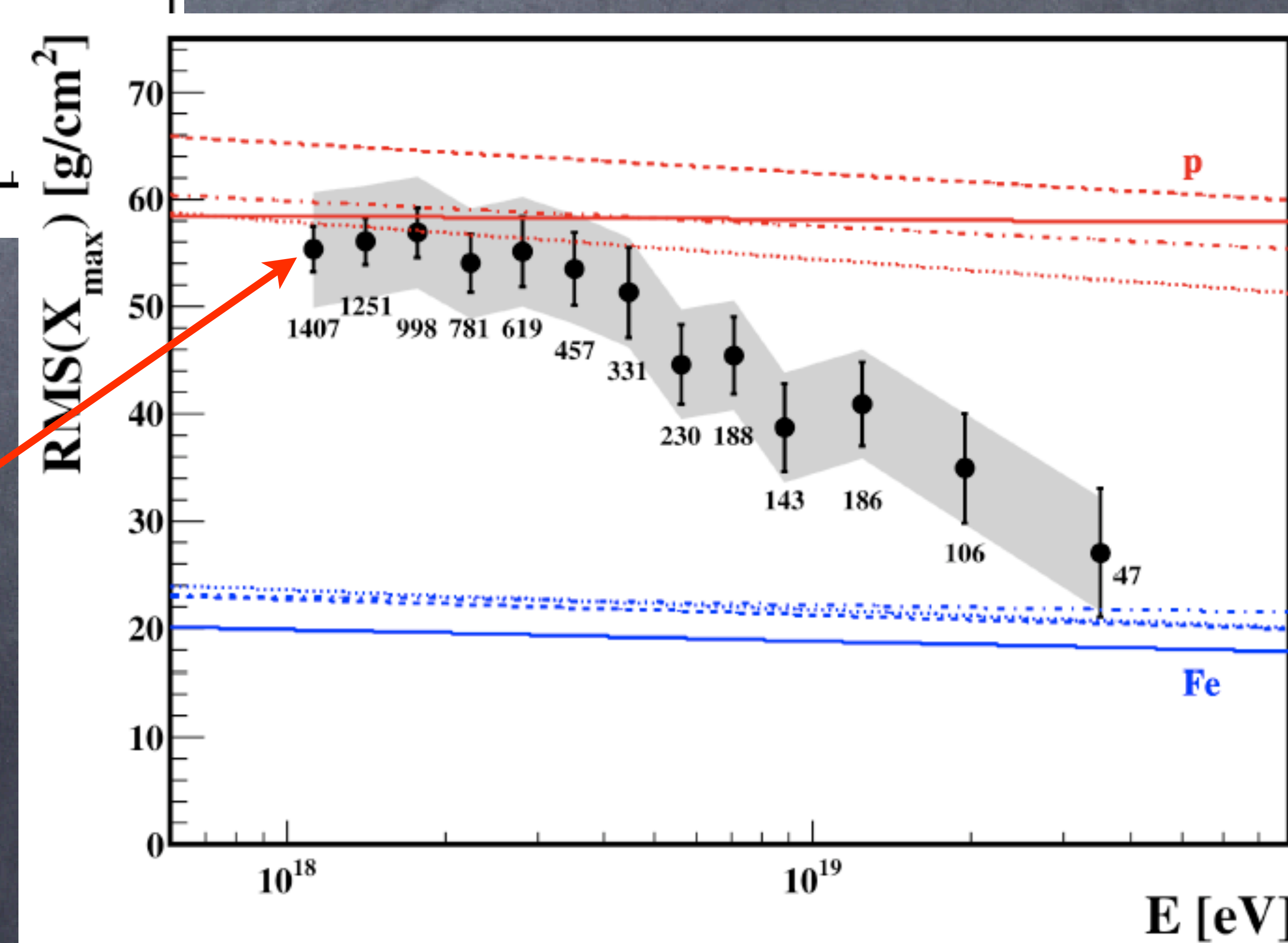
$D_{10} = 82^{+48}_{-8}$ g/cm²/decade

High Energy

$D_{10} = 27^{+3}_{-8}$ g/cm²/decade

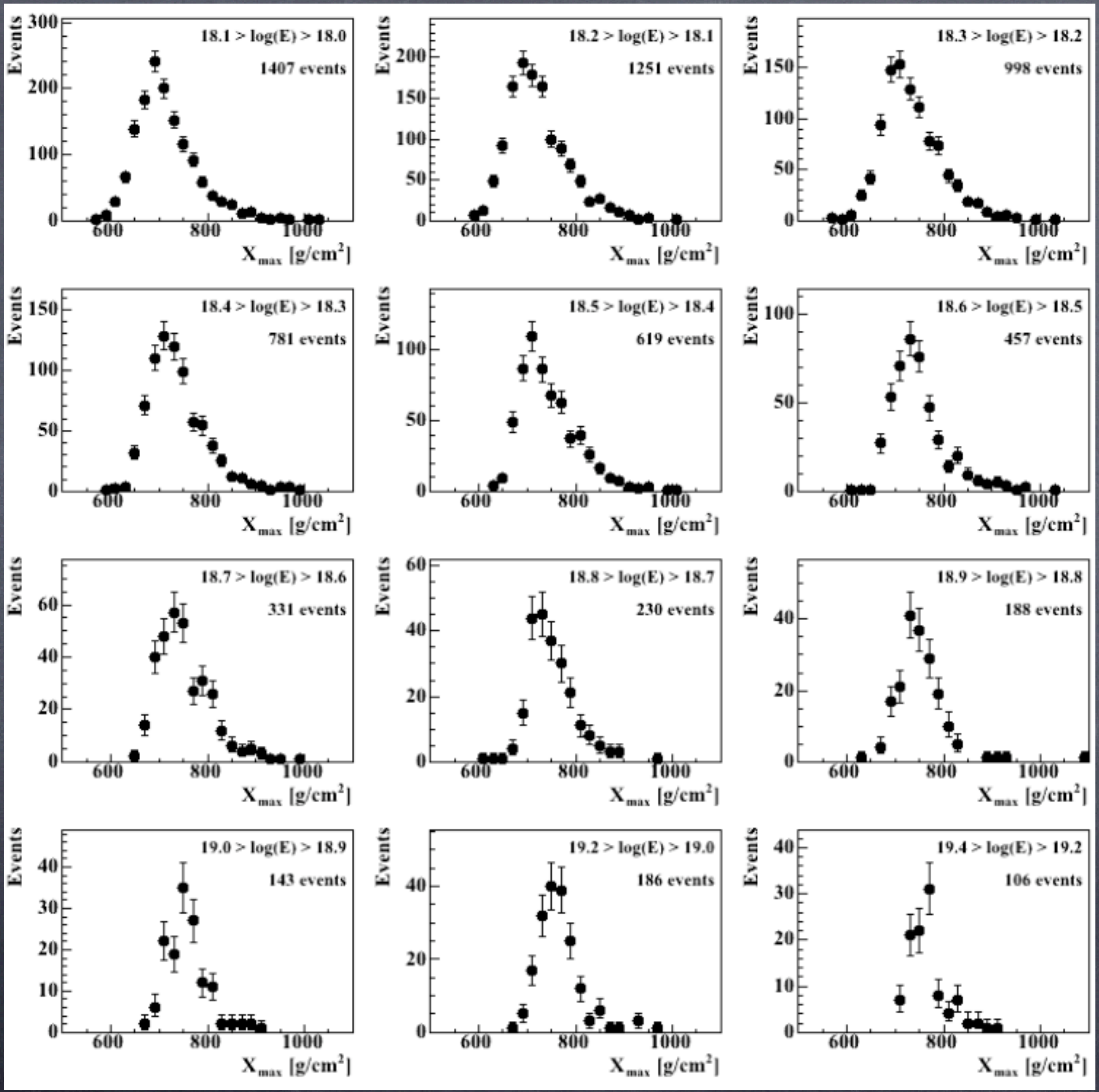
Energy break

$\log(E_{break}/\mathrm{eV}) = 18.38^{+0.07}_{-0.17}$



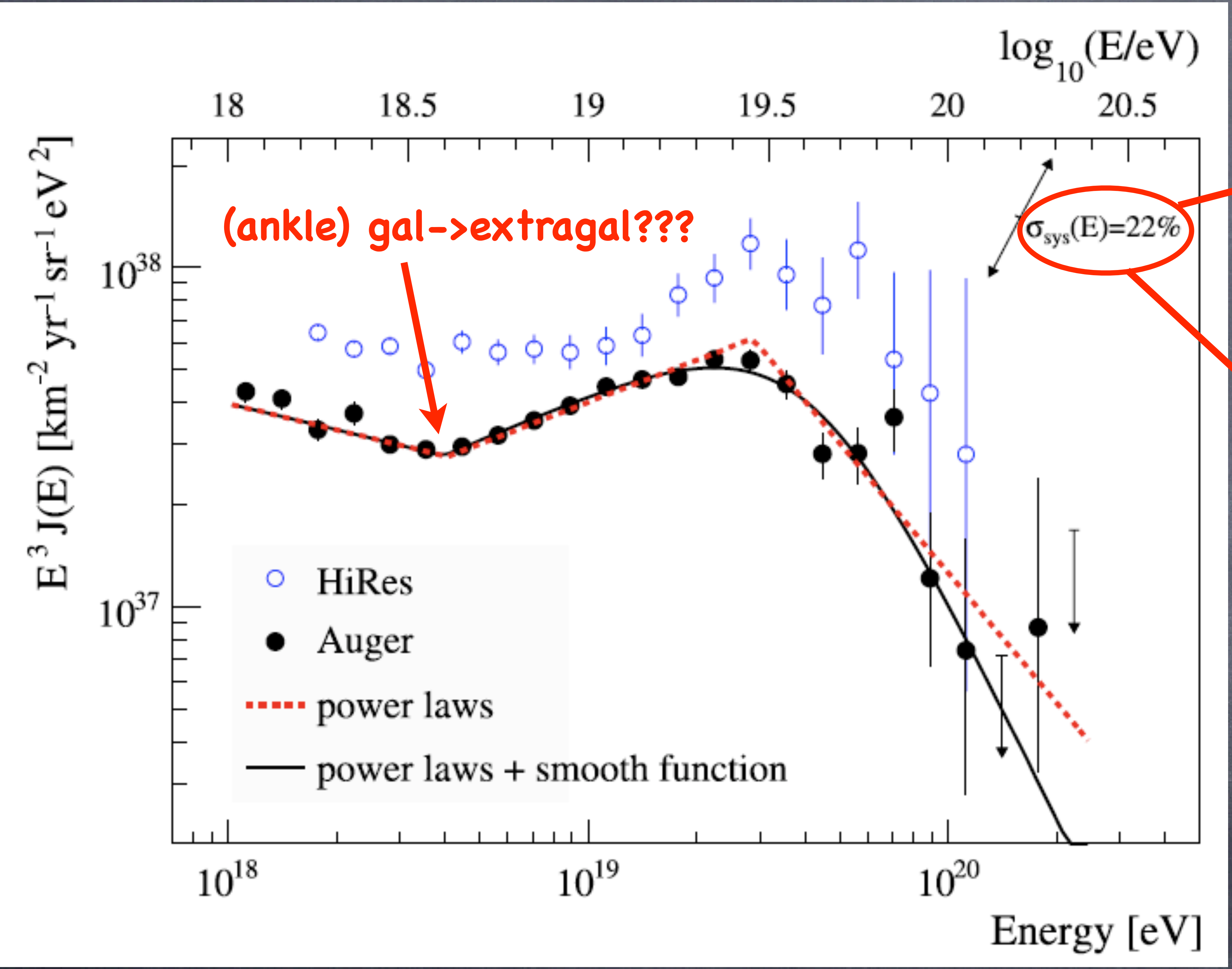
detector resolution subtracted

arXiv:1107.4804



arXiv:1107.4804

The spectrum



dominated by fluorescence yield uncertainty

leads to **energy dependent** bin to bin migration

$$J(E) \propto E^{-\alpha} \Longrightarrow \Delta J \propto -\alpha E^{-(\alpha+1)} \Delta E$$

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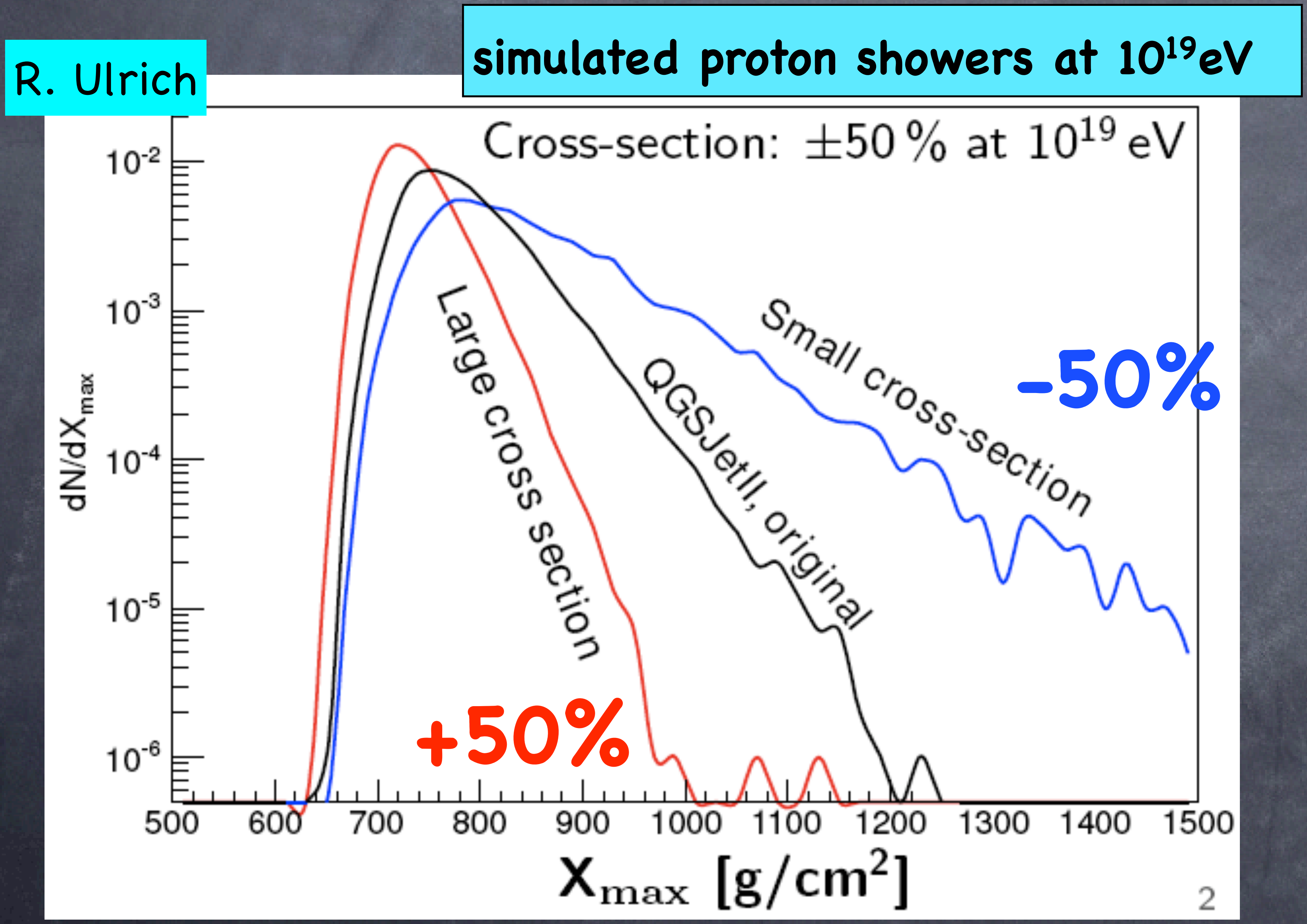
The role of the p-air cross section

Tail of X_{max} distribution is sensitive to inelastic proton-air cross section



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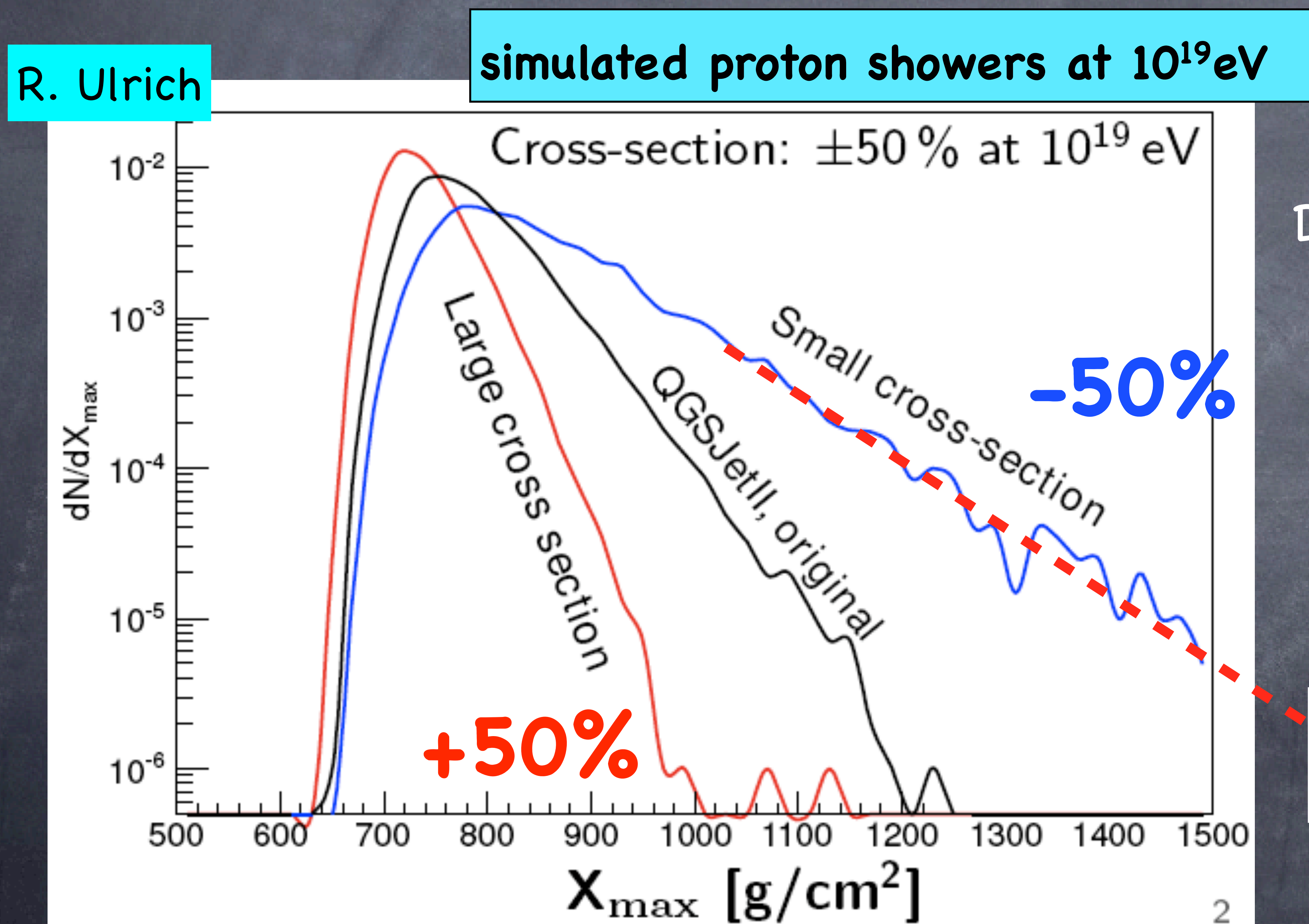


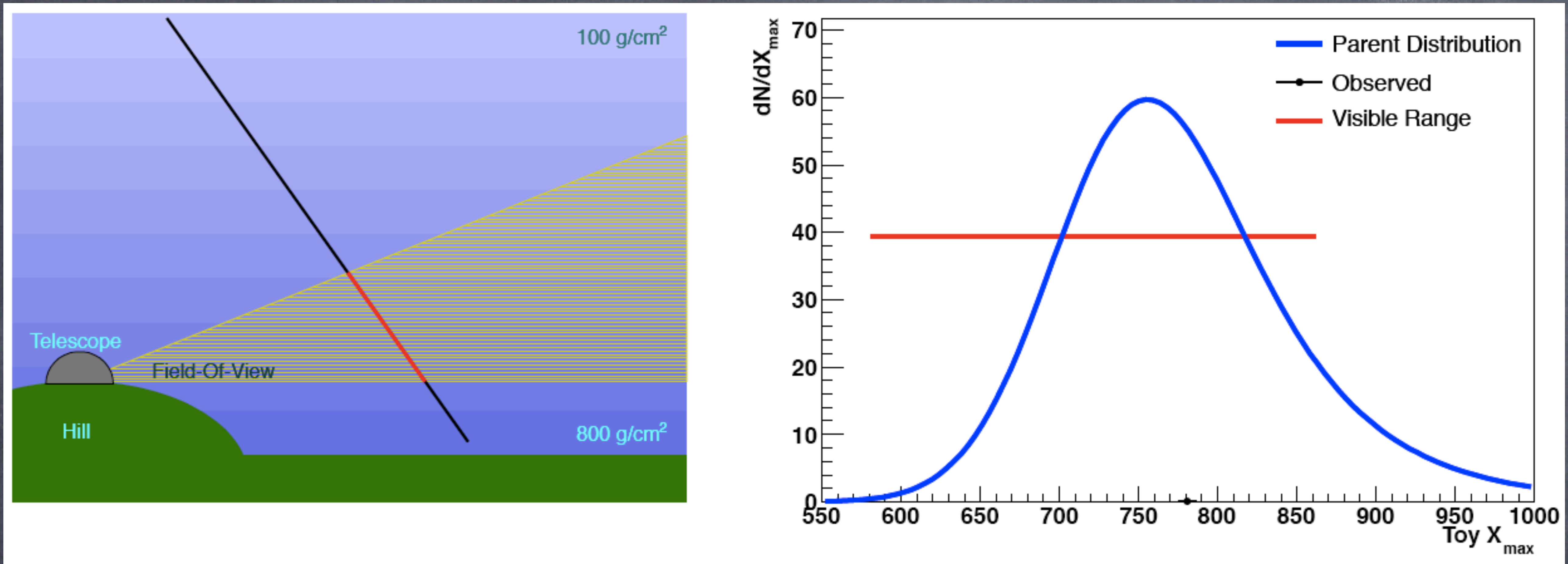
Determine cross section values consistent with exponential tail observed in data

$$\frac{dN}{dX} \propto e^{-X/\Lambda}$$

Difficulties of such a measurement

- Need pure proton beam, but...
- ...chemical composition at these energies is unknown
- Limited field of view can bias measurement

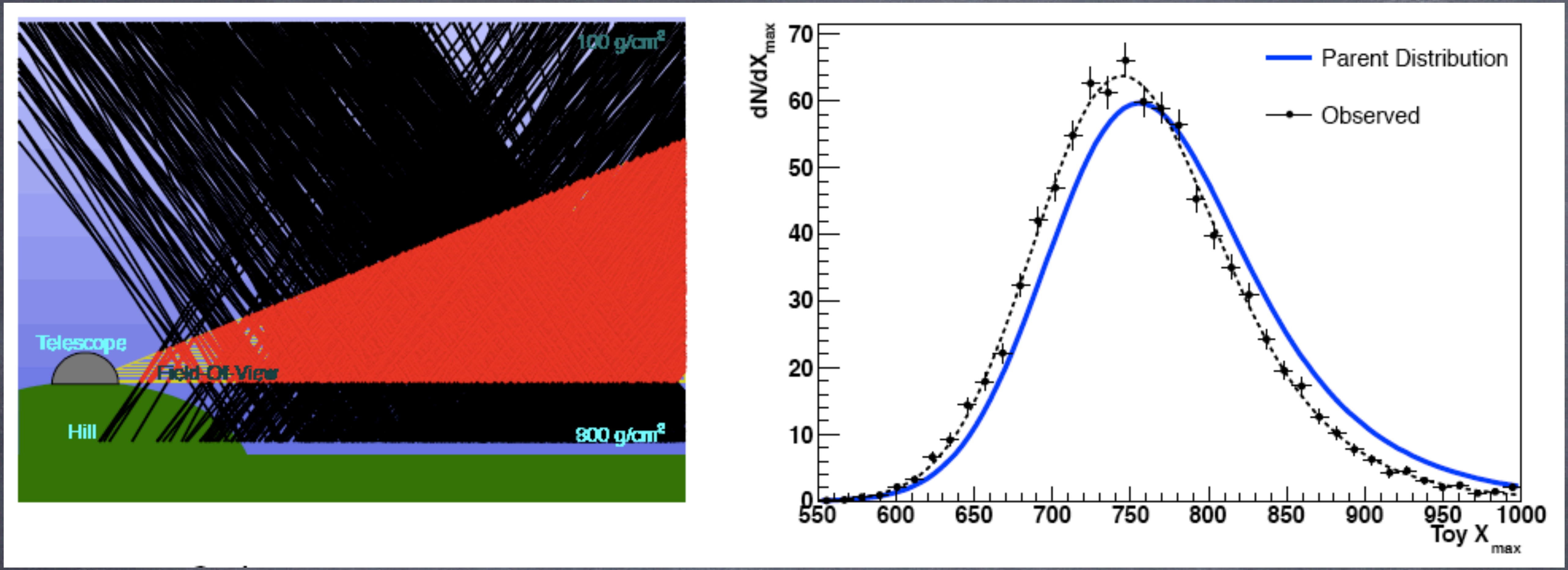
Field Of View (FOV) bias



Simple toy Monte Carlo done by **R. Ulrich**

For a given geometry (direction and distance to telescope), only part of the profile is observed

Field Of View (FOV) bias

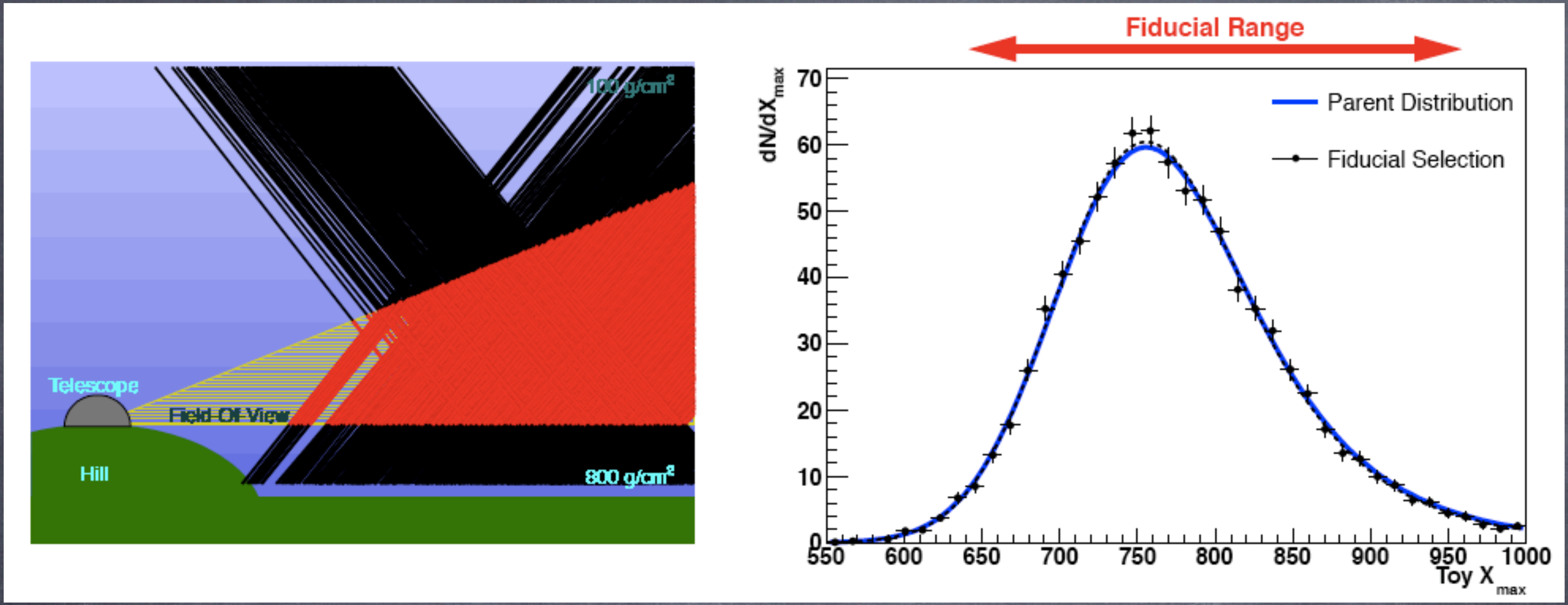


Since tails of X_{max} distribs are not completely sampled

Clear selection bias!

R. Ulrich

Field Of View (FOV) bias



But can be corrected with fiducial geometry selection!

Only geometries for which a broad range of the X_{max} distribution is observed are selected.

R. Ulrich

Careful (=tough) analysis

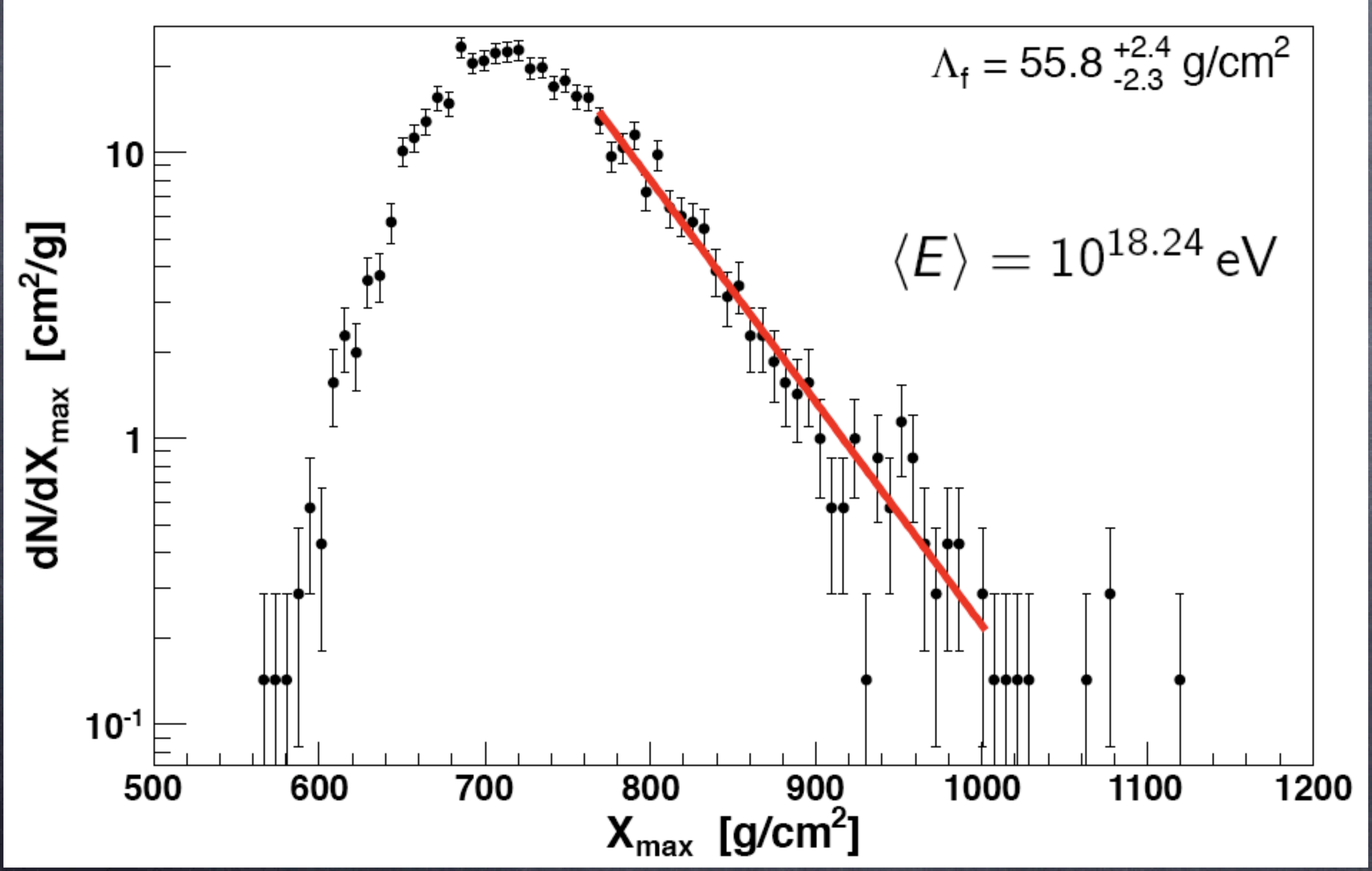
- pre-selection (camera calibration, good pixels, good atmospheric condition, hybrid geometry)
- fiducial cuts (zenith angle, tank distance, FOV)
- quality cuts (Xmax in FOV, good χ^2, etc)

X_{max} distribution and its tail

$$\frac{dN}{dX} \propto e^{-X \quad /\Lambda}$$

$$\Lambda_\eta = [55.8 \ \pm 2.3(\text{stat}) \ \pm 1.6(\text{sys})] \ \text{g/cm}^2$$

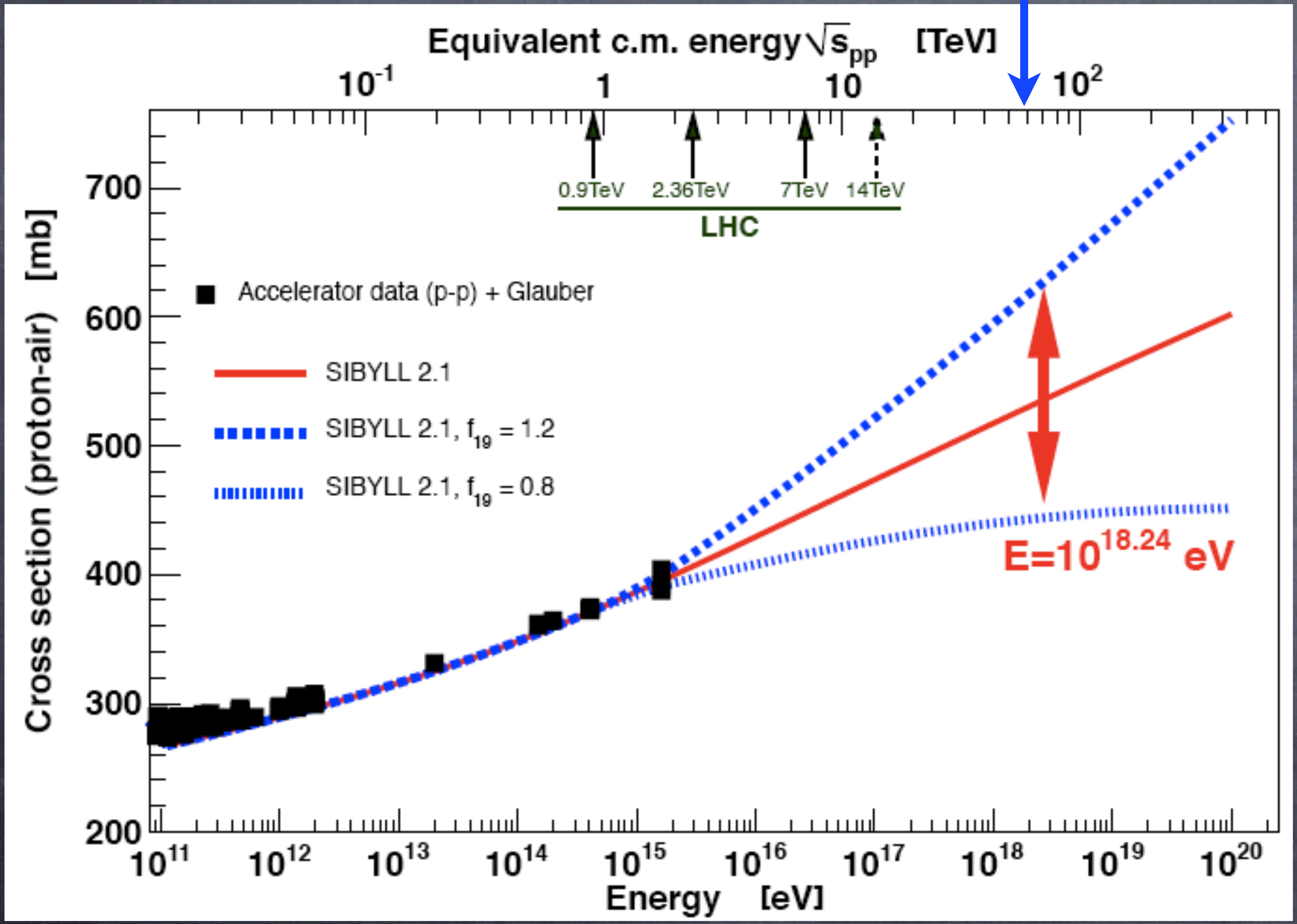
10^{18}eV-$10^{18.5}$ eV ⟶ Region where X_{max} seems to indicate proton dominance



arXiv:1107.4804

From Λ_η to $\sigma_{\text{p-air}}$

$$E_{\text{CM}} = \sqrt{s} = \sqrt{2m_N^2 + 2m_N E_{\text{CR}}/A} \simeq 57\ \text{TeV}$$



$$f(E,\ f_{19}) = 1 + (f_{19} - 1)\ F(E)$$

$$F(E) = \frac{\lg\left(E/10^{15}\,\text{eV}\right)}{\lg\left(10^{19}\,\text{eV}/10^{15}\,\text{eV}\right)}$$

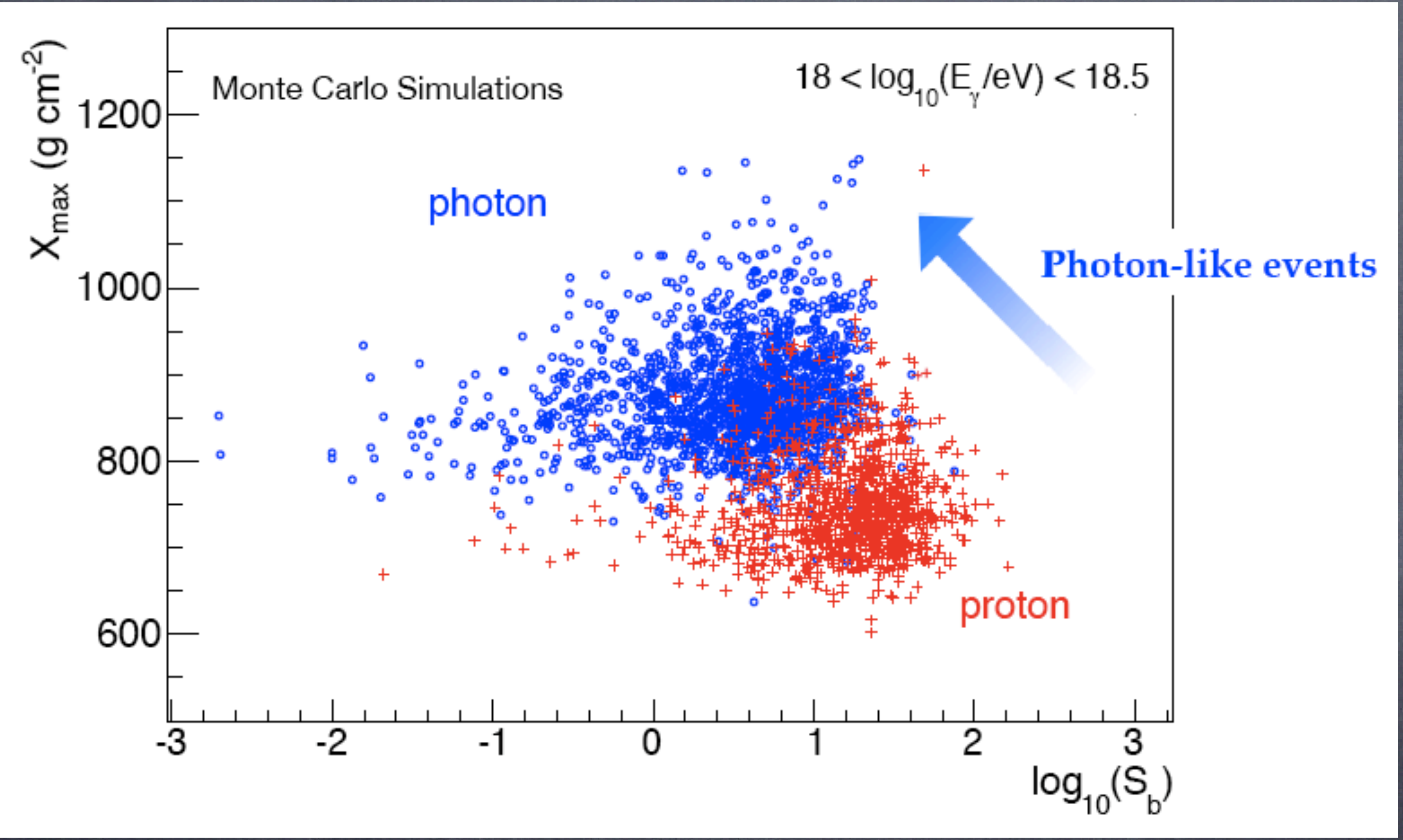
arXiv:1107.4804

Systematics to $\sigma_{p\text{-}air}$

Photon contamination

arXiv:1107.4805

Photon induced showers are very penetrating (LPM effect)



Can be identified combining SD and FD observables

$$S_b = \sum_i S_i \left(\frac{R_i}{1000} \right)^4$$

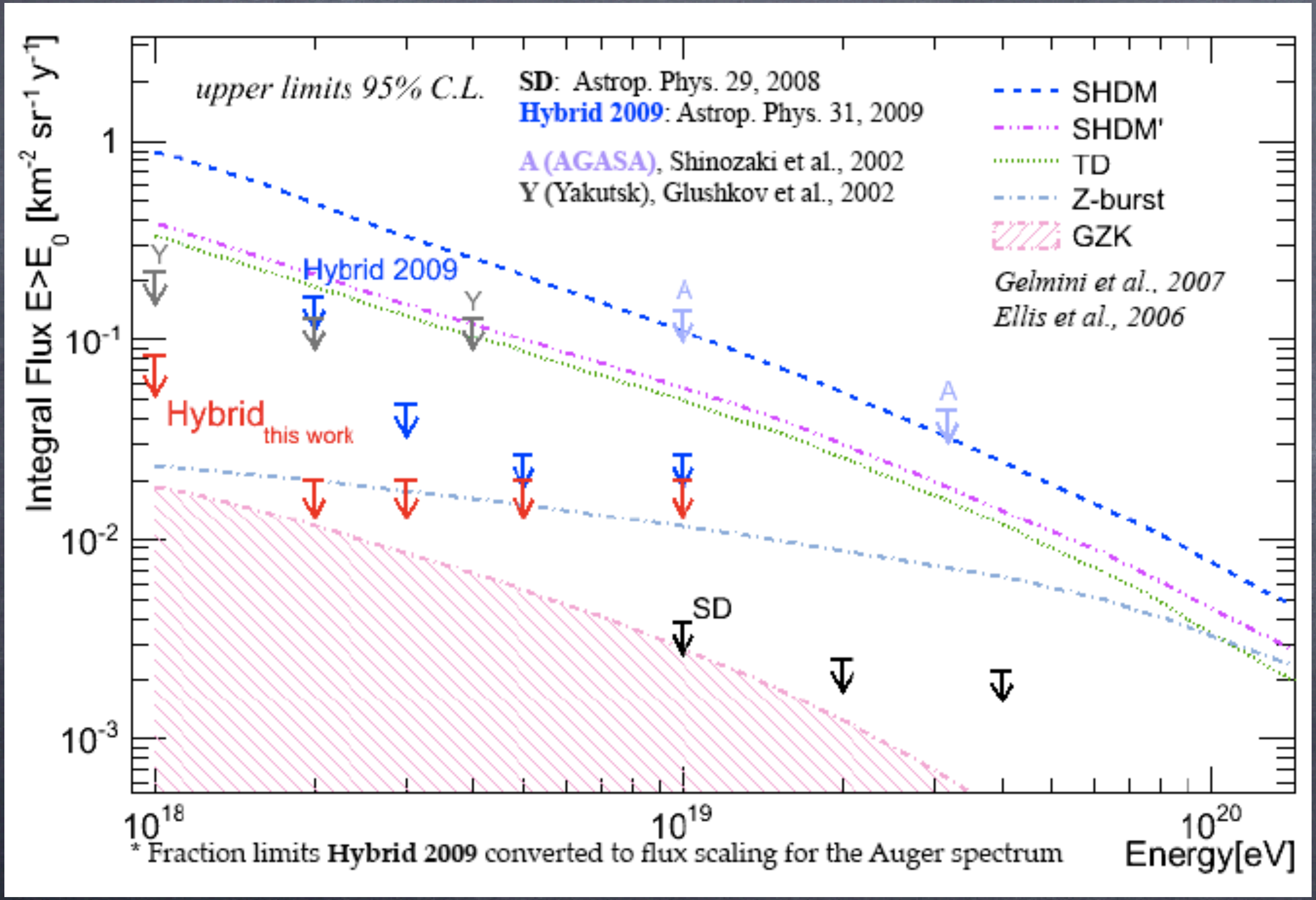
Photon contamination

arXiv:1107.4805

Fortunately their contribution at UHECRs energies is very small

Φ_γ/Φ_{tot}<0.5%

$\Delta\sigma$<+10 mb

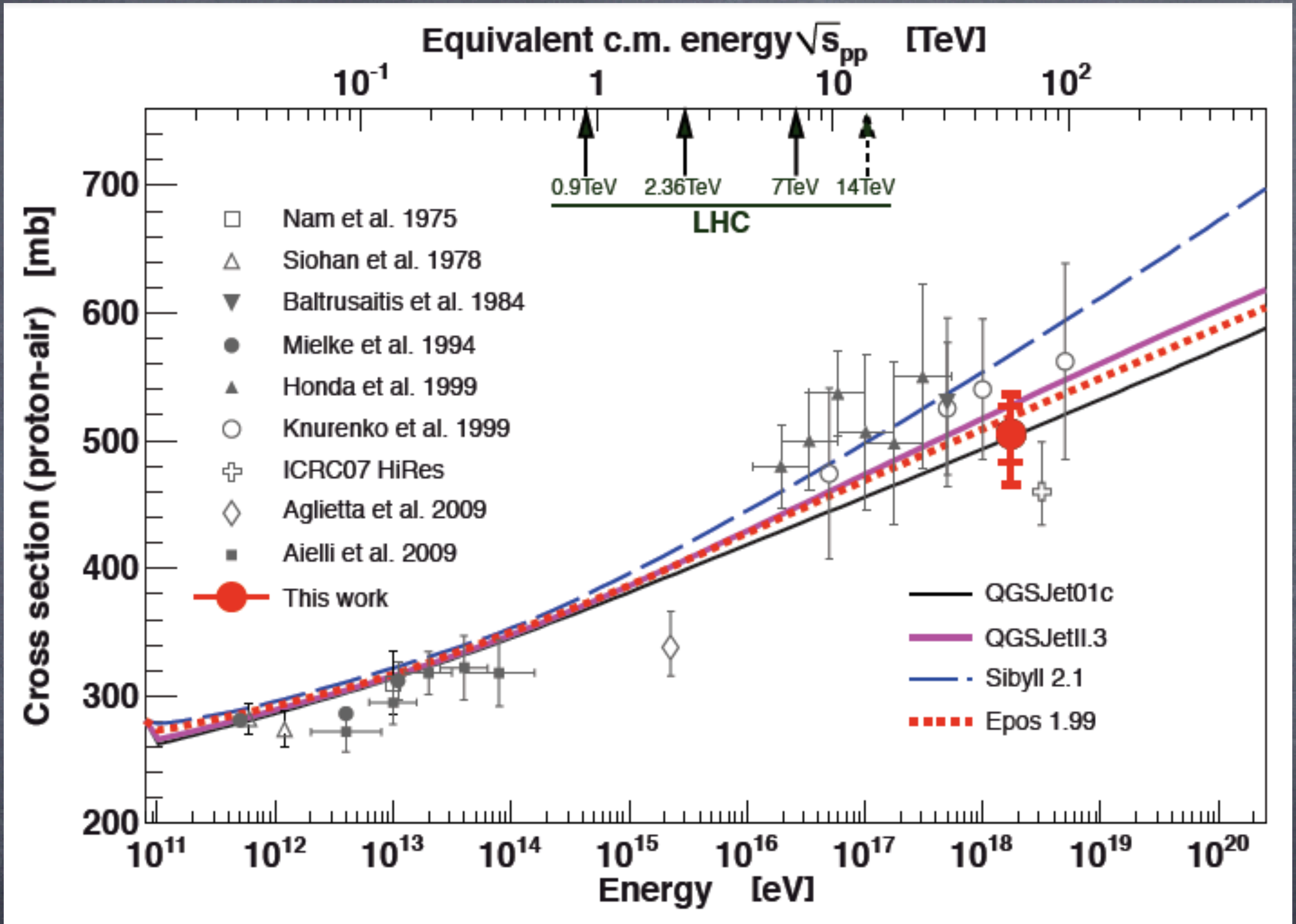


Summary of systematics

Description	Impact on $\sigma_{\text{p-air}}$
Λ_η systematics	± 15 mb
Hadronic interaction models	$^{+19}_{-8}$ mb
Energy scale	± 7 mb
Conversion of Λ_η to $\sigma_{p\text{-air}}^{\text{prod}}$	± 7 mb
Photons, $<0.5\,\%$	$< +10$ mb
Helium, $10\,\%$	-12 mb
Helium, $25\,\%$	-30 mb
Helium, $50\,\%$	-80 mb
Total ($25\,\%$ helium)	-36 mb, $+28$ mb

Our X_{max} resolution (20 g/cm^2) implies that He is the most important contamination

$\sigma_{\text{p-air}}$ compilation



$$\sigma^{\text{prod}}_{p\text{-air}} = \left[505 \pm 22(\text{stat}) \,{}^{+28}_{-36}(\text{sys})\right] \text{ mb}$$

arXiv:1107.4804

What are we really sensitive to?

no sensitivity (no cascade initiated)

$$\sigma_{\rm tot} = \sigma_{\rm ela} + \sigma_{\rm quasi-ela} + \sigma_{\rm prod}$$

strong sensitivity

weak sensitivity: when beam is diffractive dissociated

Summary

- Determined $\sigma_{\text{p-air}}$ cross section consistent with X_{max} distribution at sqrt(s)=57 TeV
- Fiducial cuts to eliminate selection bias
- composition bias studied carefully and dominated by He
- Impact of different interaction models included
- conversion to σ_{pp} is model dependent

$$\sigma_{p\text{-air}}^{\text{prod}} = \left[505\ \pm 22(\text{stat})\ {}^{+28}_{-36}(\text{sys})\right]\ \text{mb}$$

Thank you for the attention!