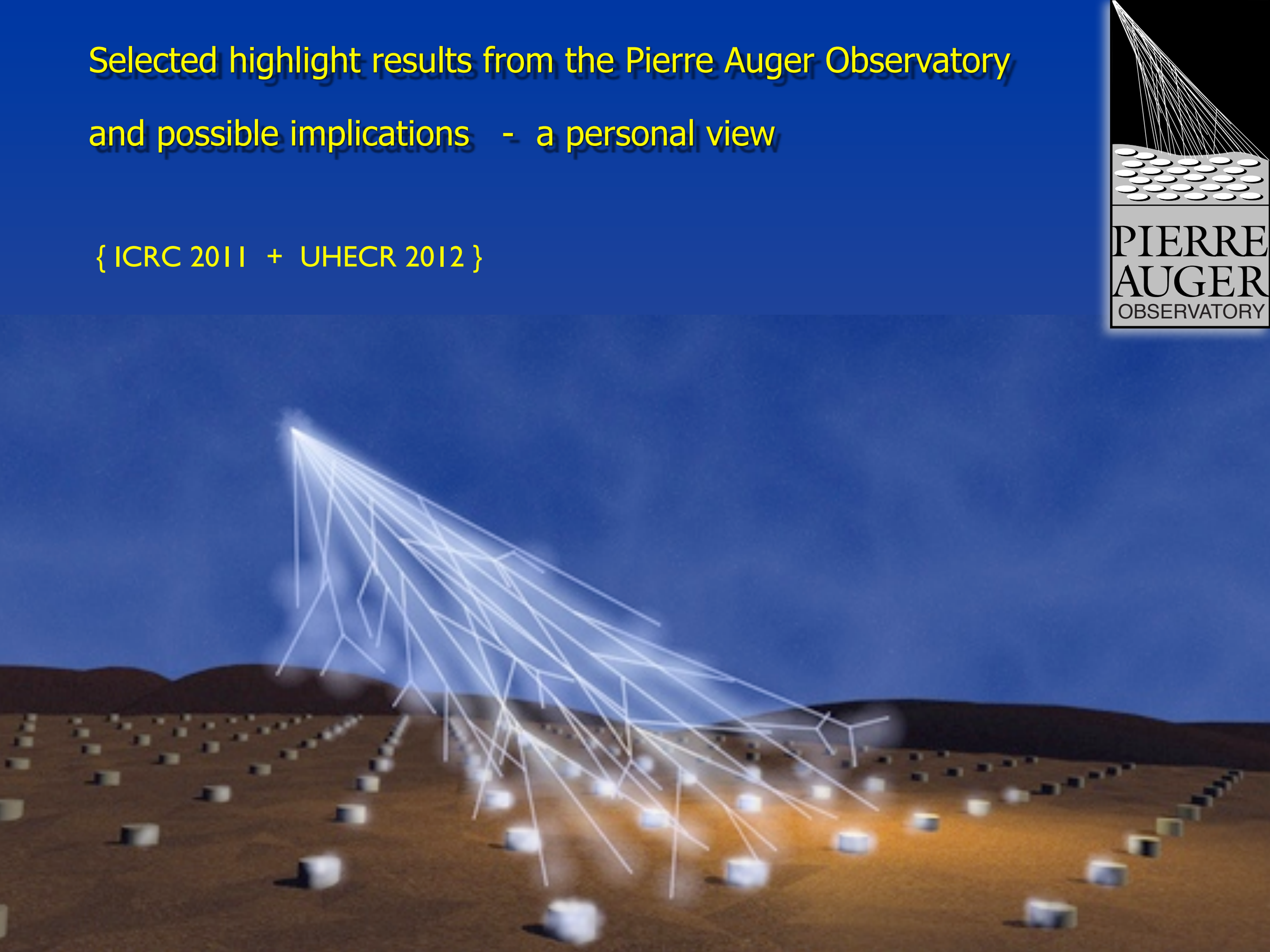
Selected highlight results from the Pierre Auger Observatory and possible implications - a personal view

{ ICRC 2011 + UHECR 2012 }



Energy Spectrum and Energy Scales

*

Elongation Rate and Mass Composition

*

Anisotropy, Correlations, and Multiplets

*

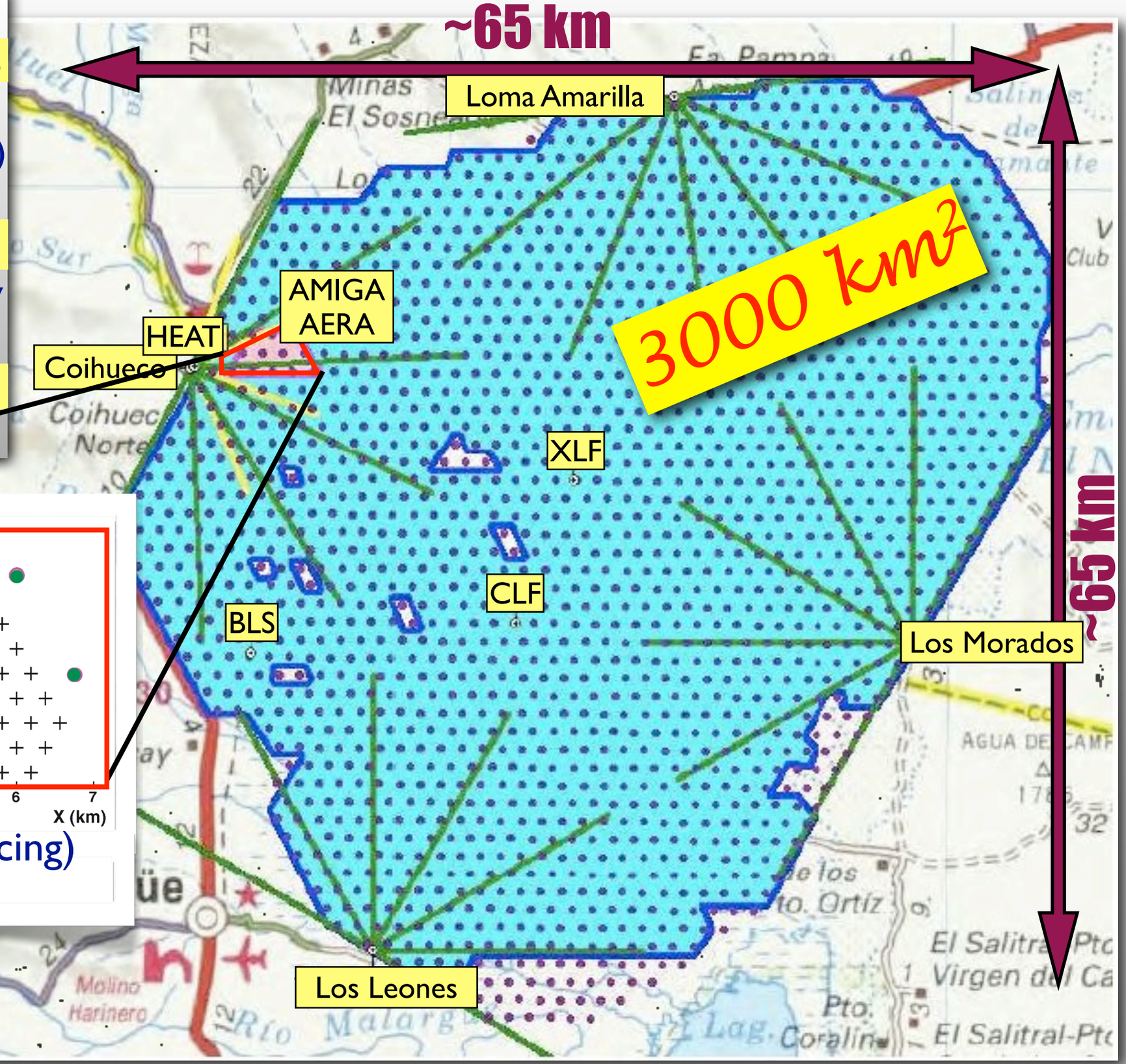
Muons and Model Predictions

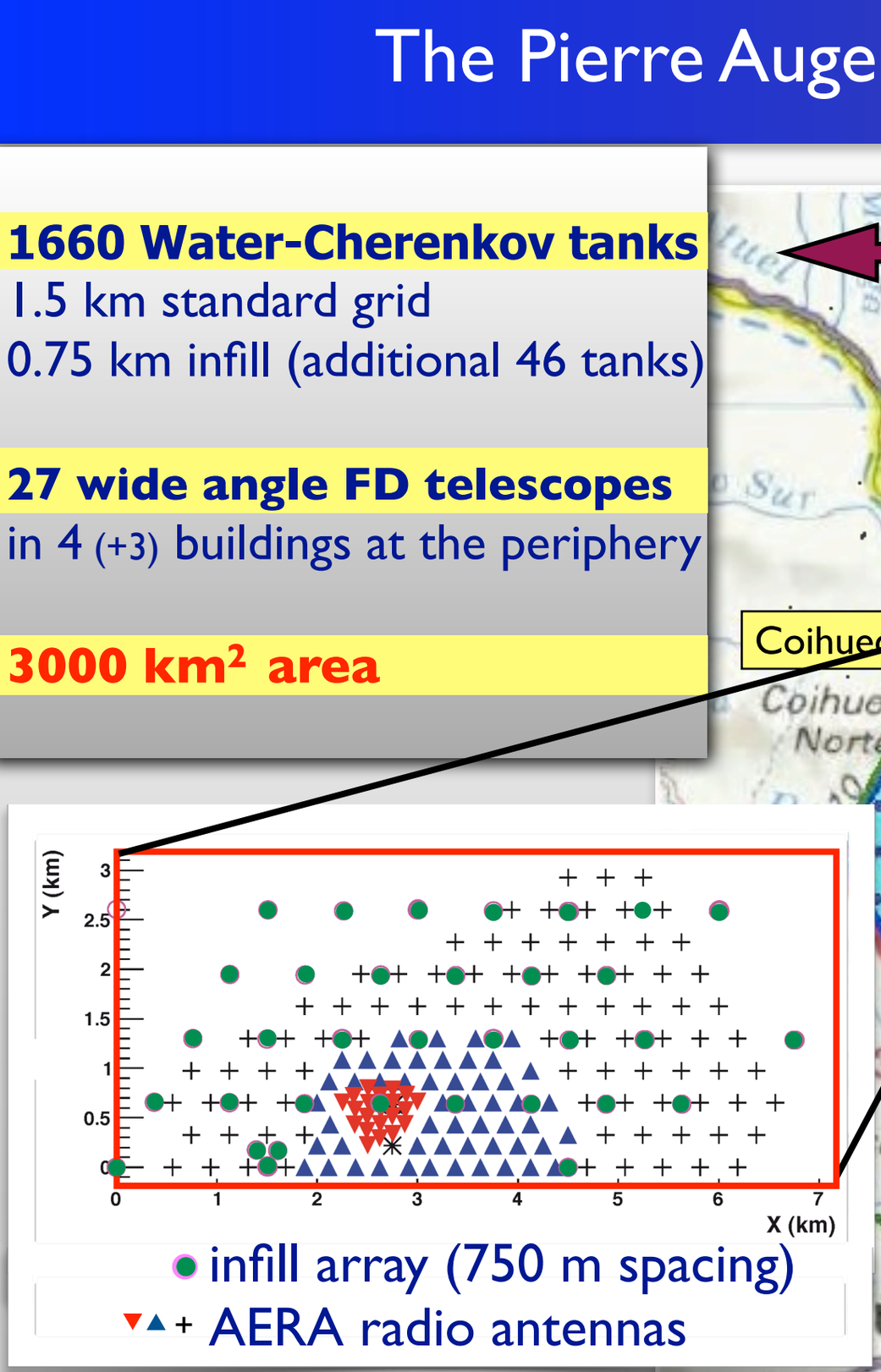
The Pierre Auger Observatory in Argentina

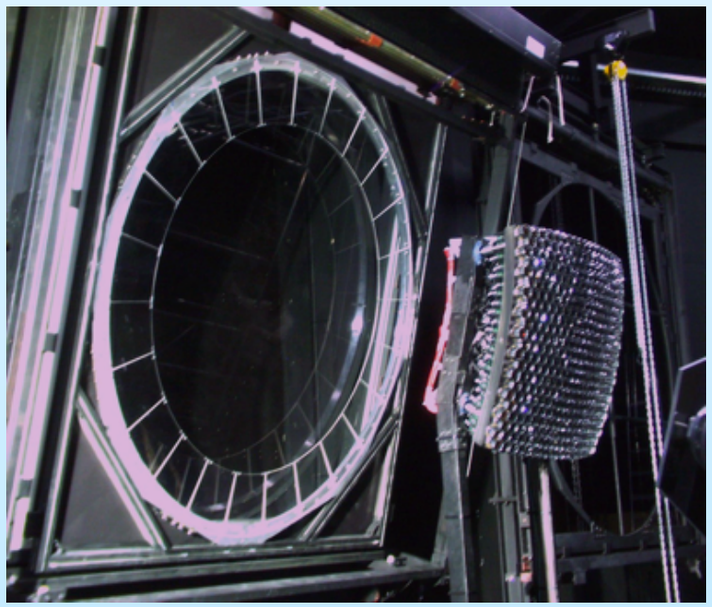
1660 Water-Cherenkov tanks
1.5 km standard grid
0.75 km infill (additional 46 tanks)

27 wide angle FD telescopes
in 4 (+3) buildings at the periphery

3000 km² area



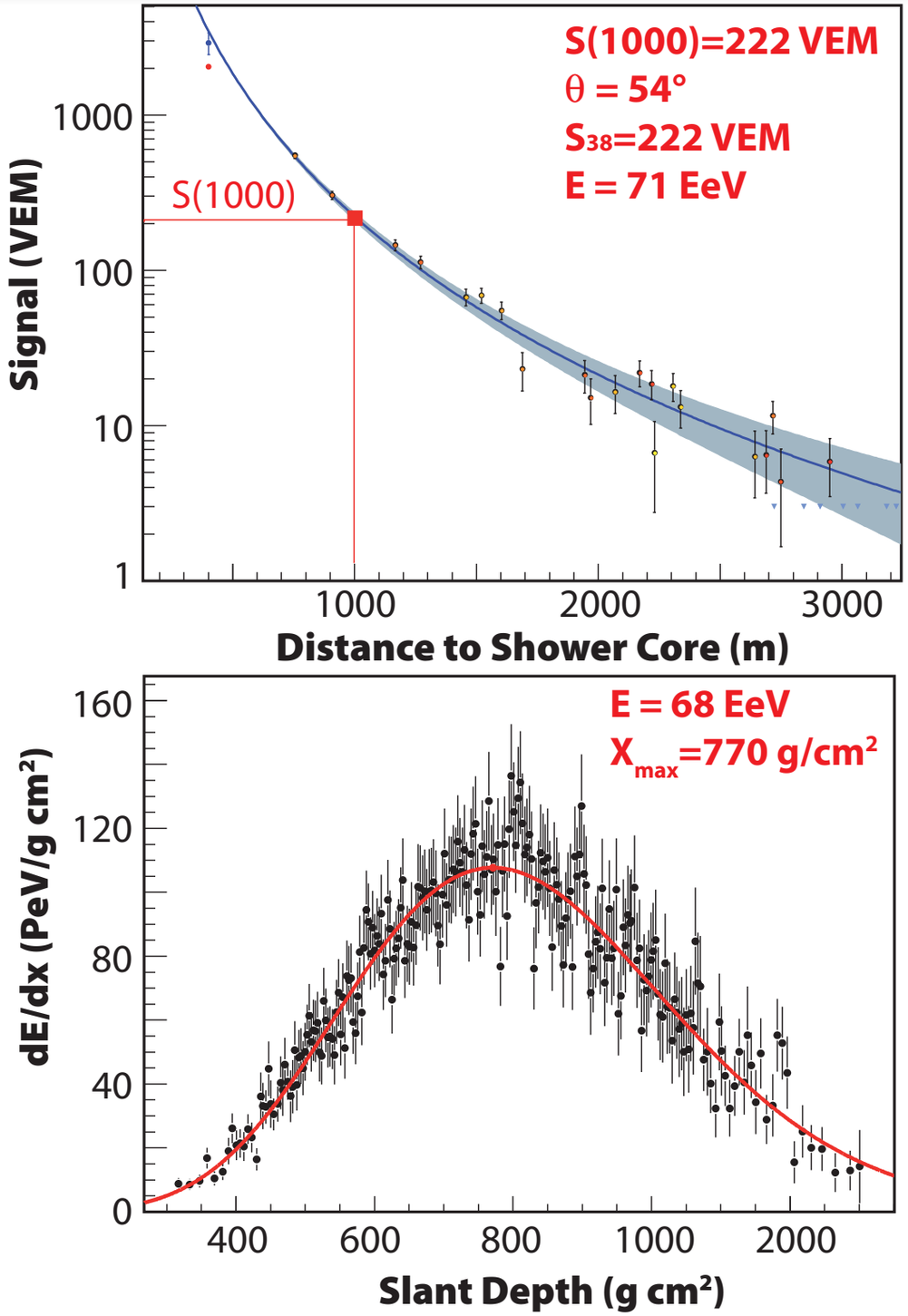


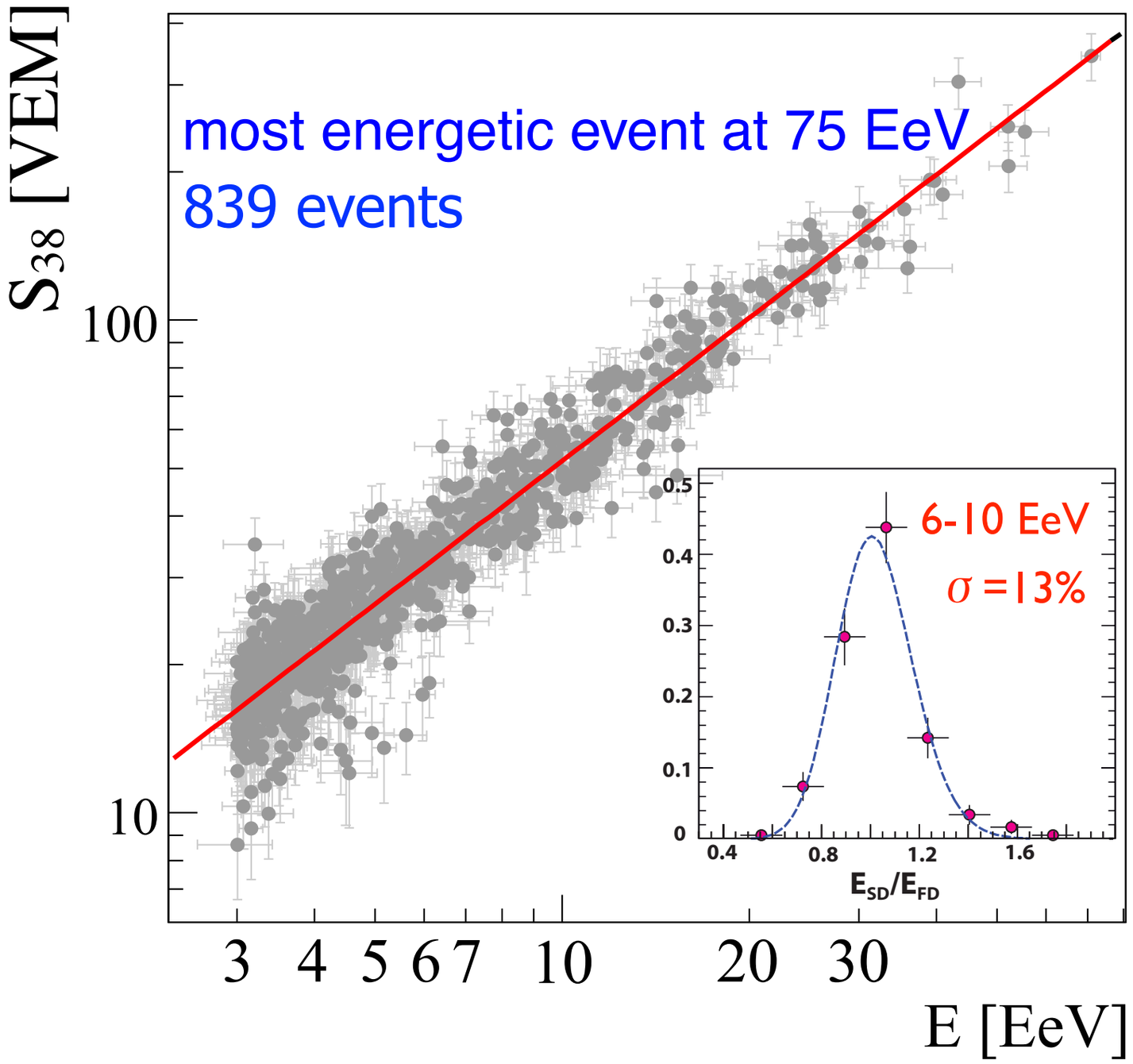


27 FD Telescopes

HEAT

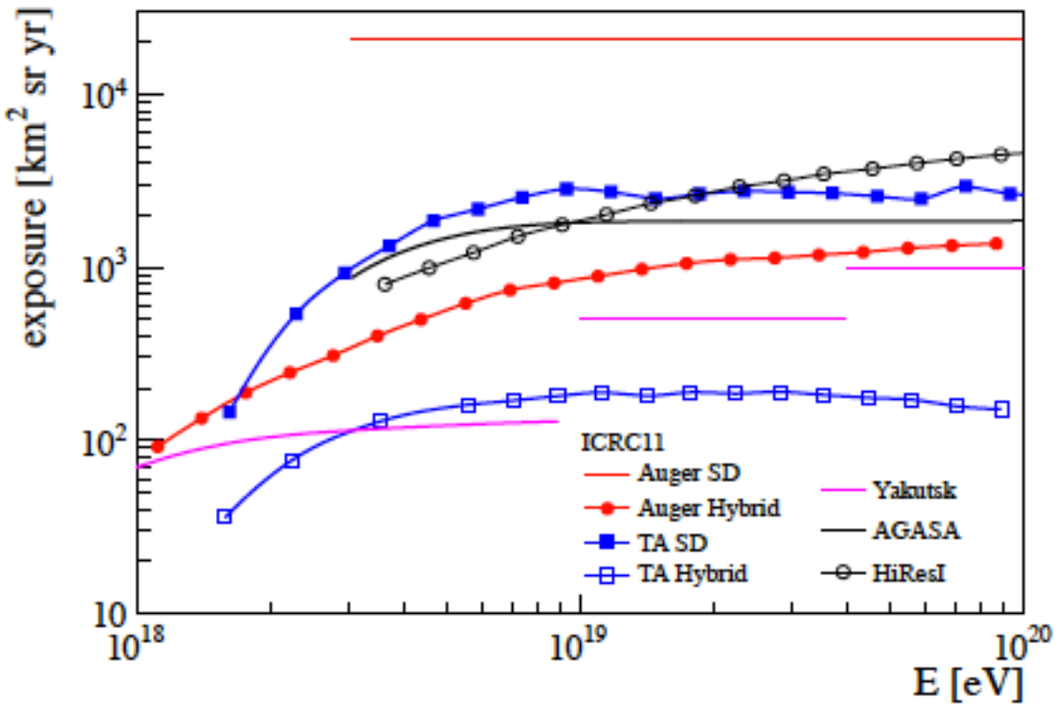
SD Energy Calibration by FD

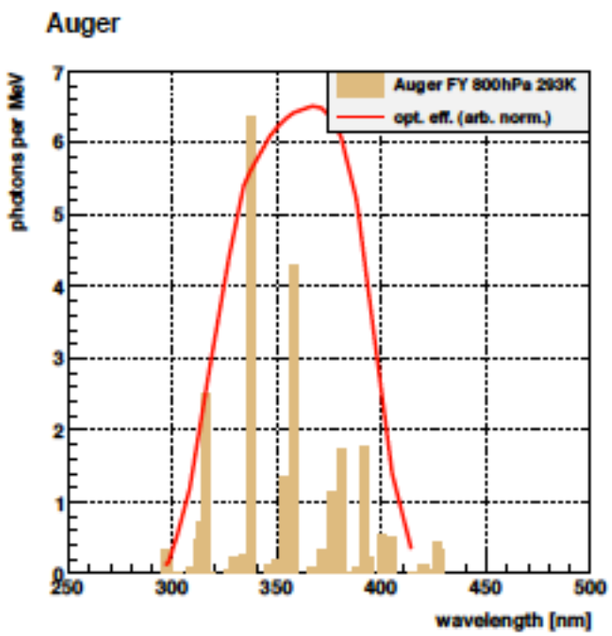


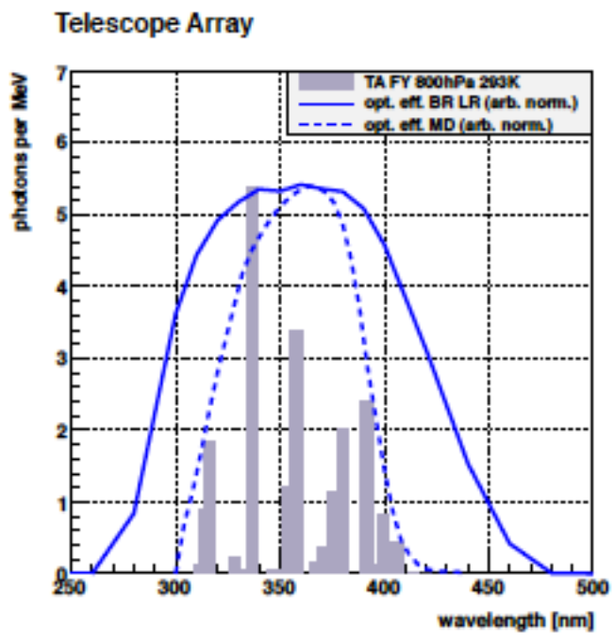


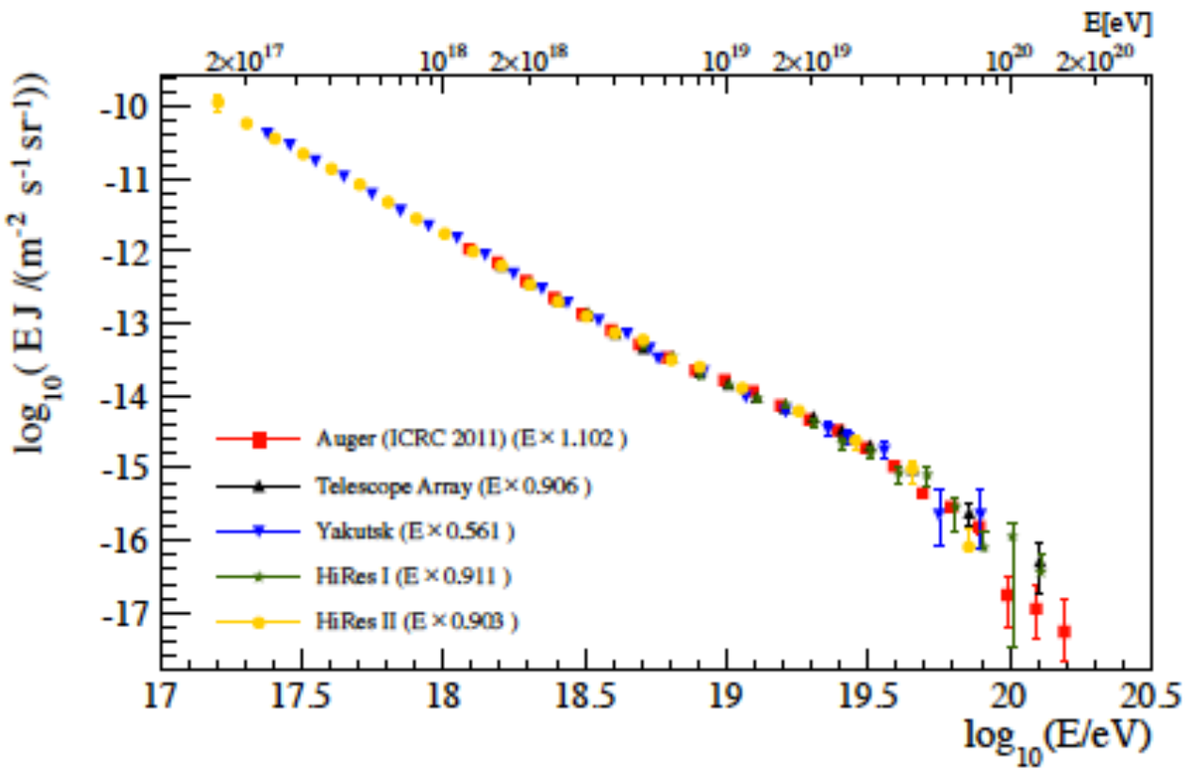
Systematic uncertainty 7% (15%) at 10 EeV (100 EeV)
total uncertainty of E-scale : 22% (dominated by Fl.-yield : 14%)

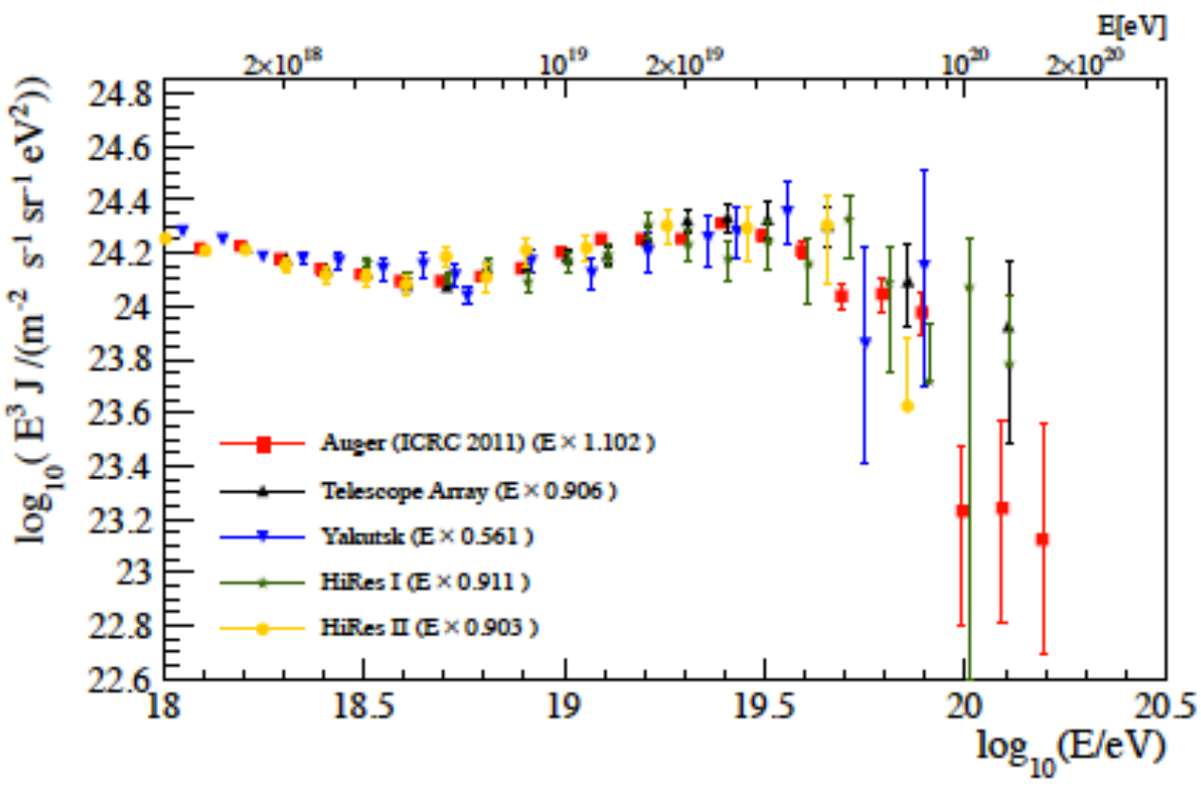
2011 exposures, AFYs used, and combined energy spectra



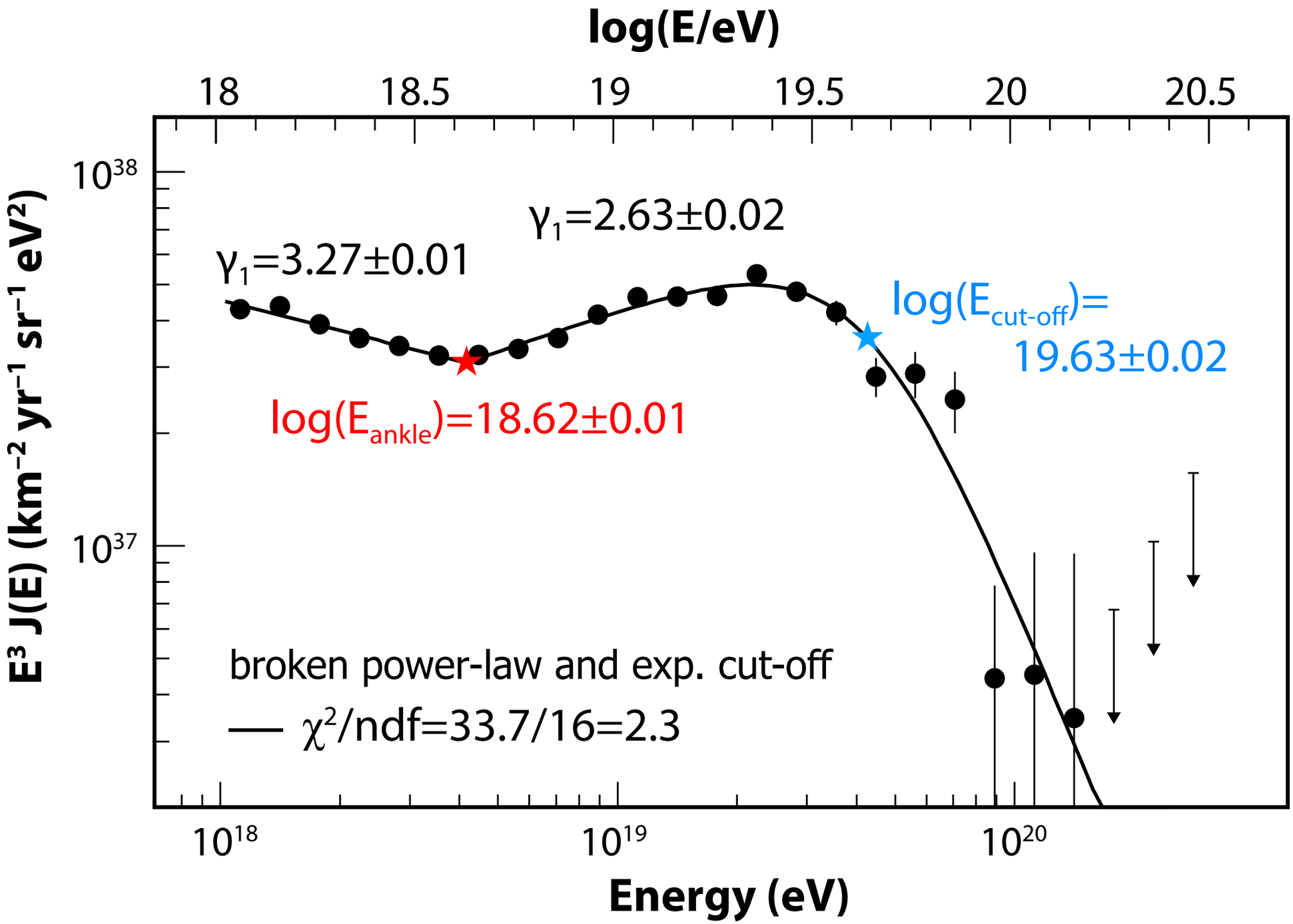








Auger SD + Hybrid combined spectrum



! Steep spectrum above 40 EeV requires excellent energy resolution !

Energy Spectra and Energy Scales

distinct ankle at 4 EeV

steep cut off at 40 EeV (GZK ?)

energy resolution ?

PAO and TA energy scales differ by 20%

Determination of a common Air Fluorescence Yield

HiRes, Auger, and TA use different AFY values for their data analysis - systematic error on energy scales dominated by AFY

>

since 2002 - 2011 eight international workshops on Air Fluorescence and several new precise experiments on AFY !

>

international working group (Auger, HiRes, TA, ..) with goal :
common description of AFY(de/dx, p, T, humidity, ...)

>

energy scales could change up to 10% , scale errors would shrink

A flying UV - flasher for the calibration of fluorescence telescopes

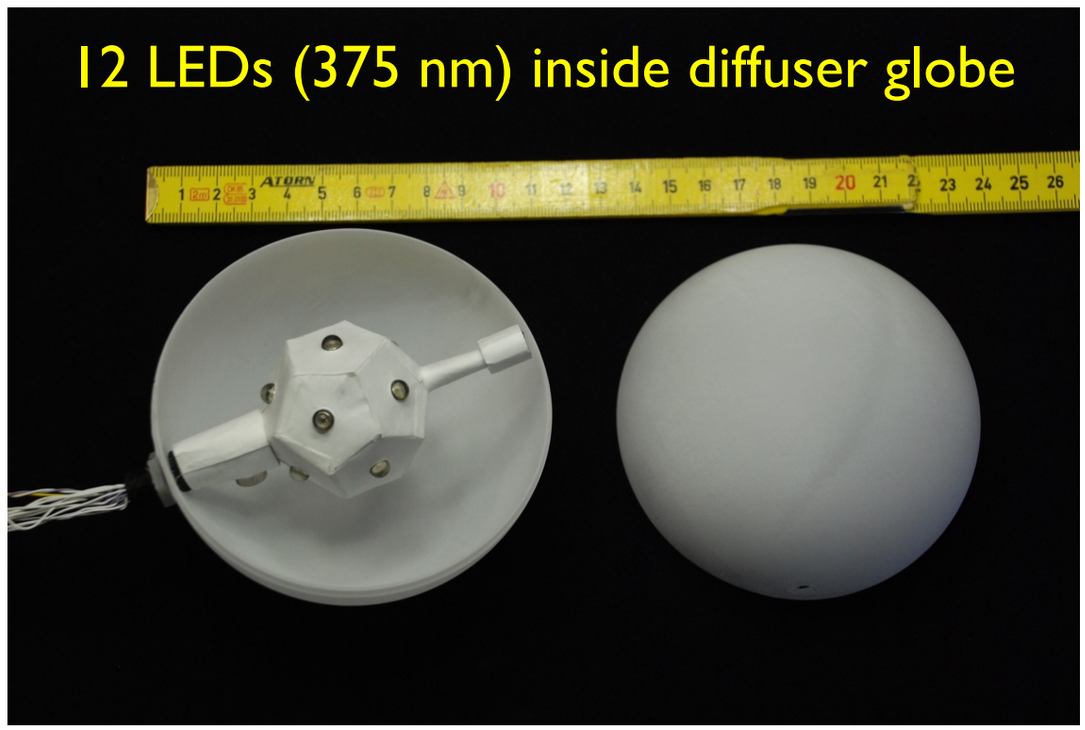
distance to telescopes 1 - 3 km

position accuracy < 3 m

absolute photon flux < 3%

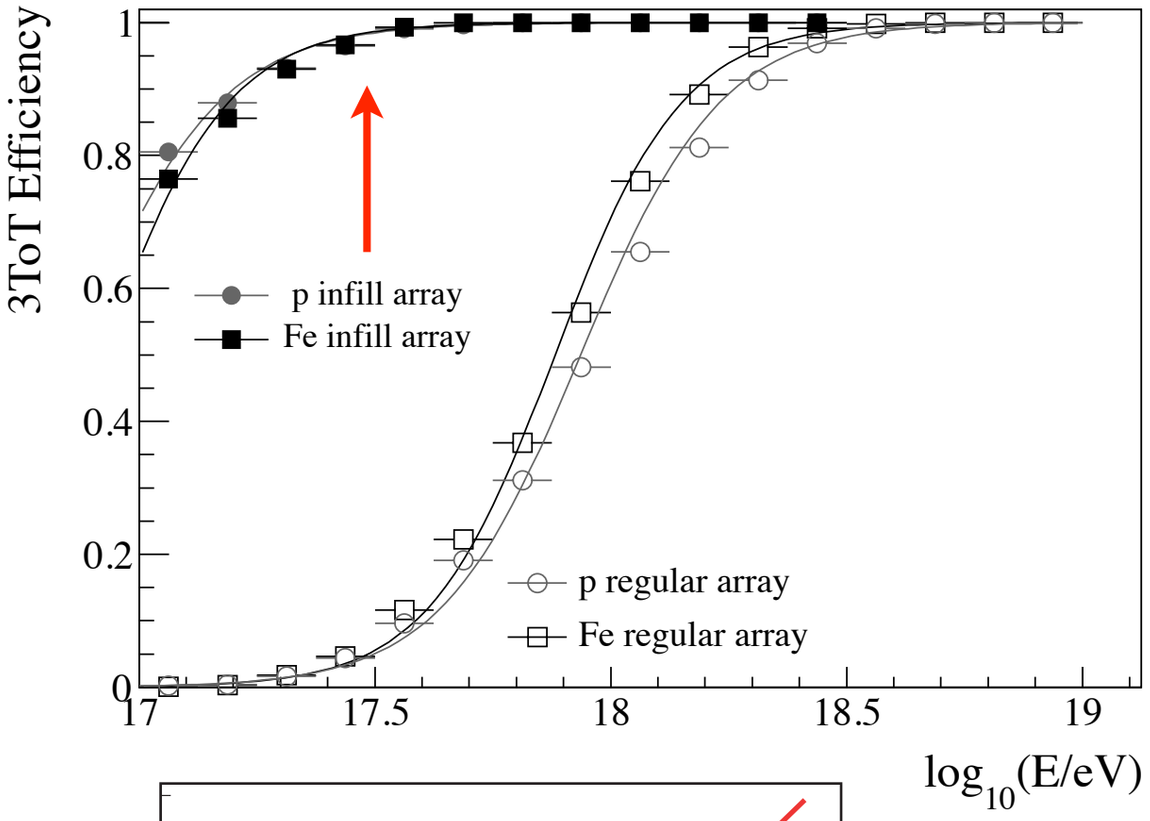
flux stability < 1%

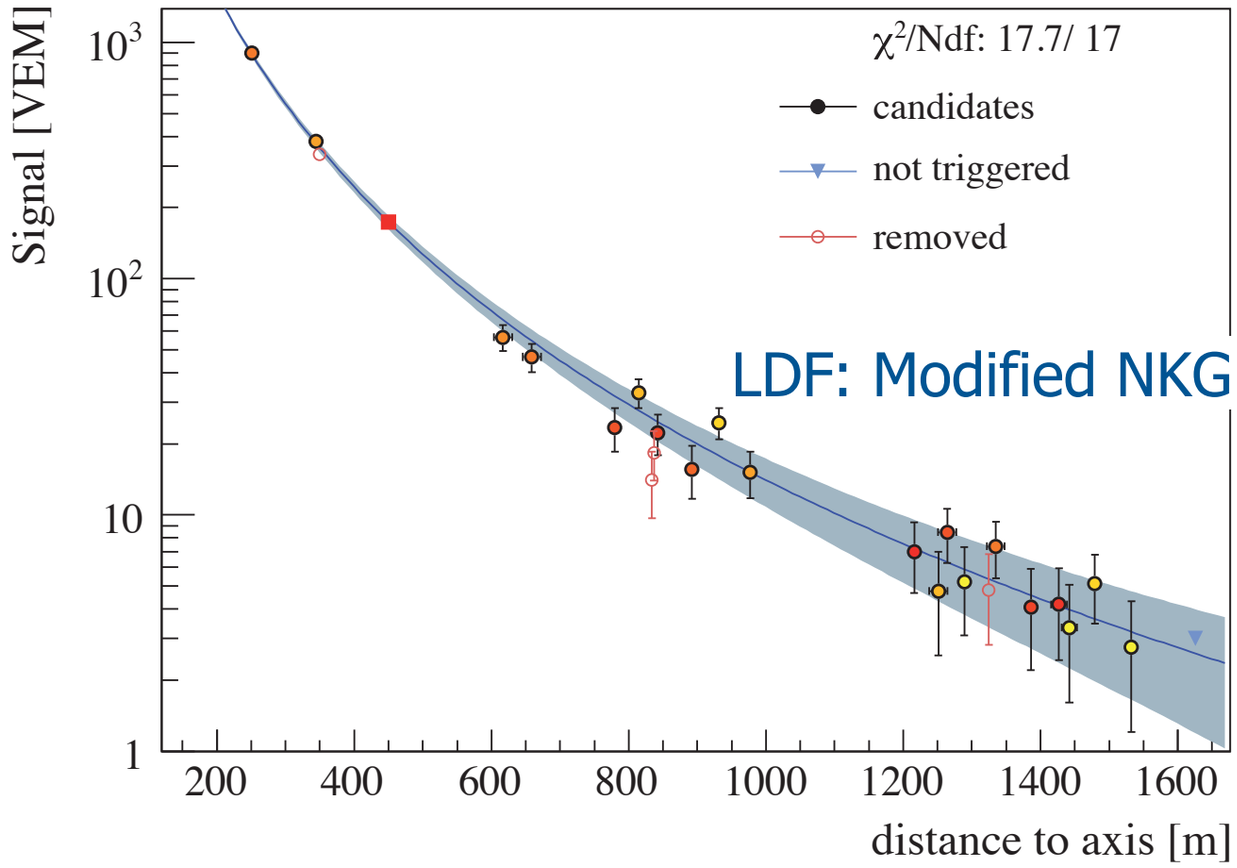
will fly soon at TA and at PAO

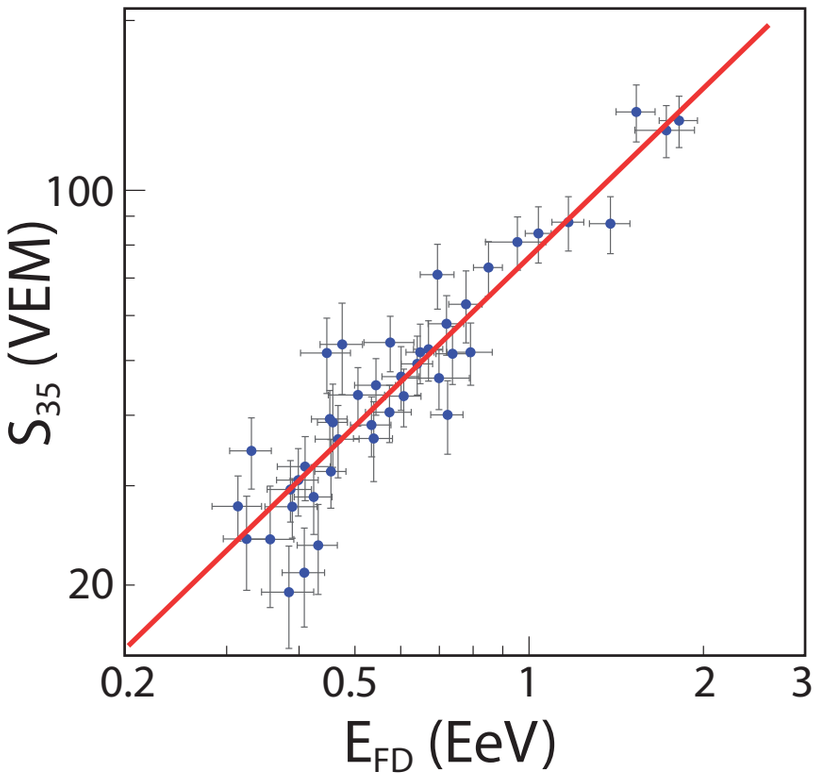


Towards lower energies with an infill array

48 additional tanks at 750m grid : fully efficient at $3 \cdot 10^{17}$ eV and $\theta < 55°$



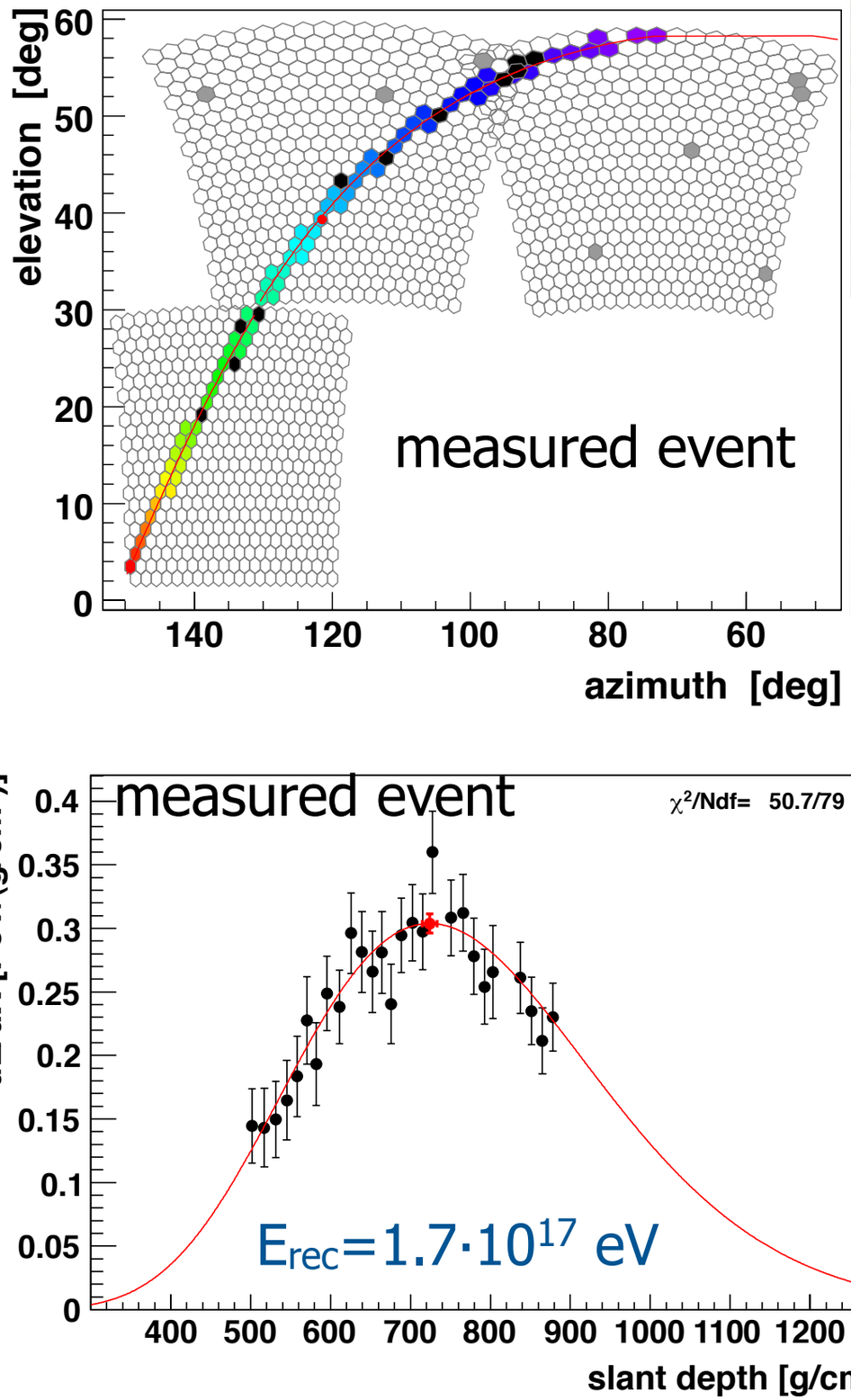




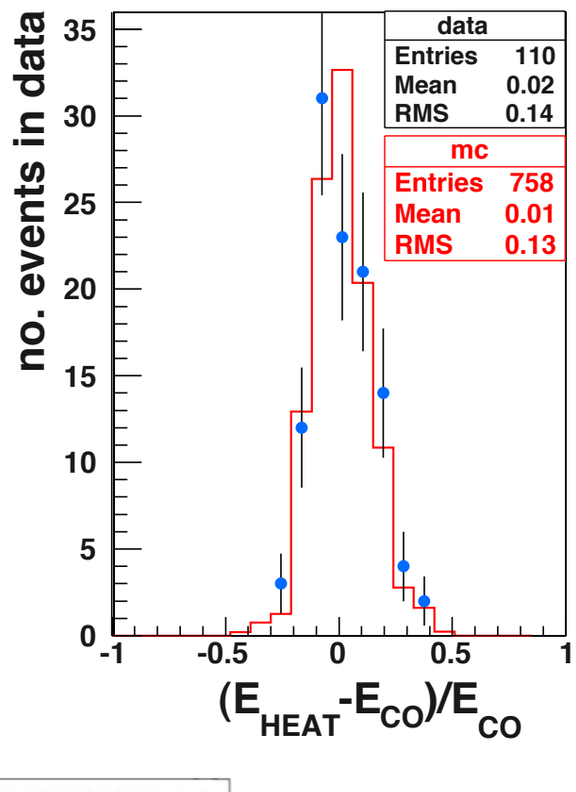
Energy calibration again with FD

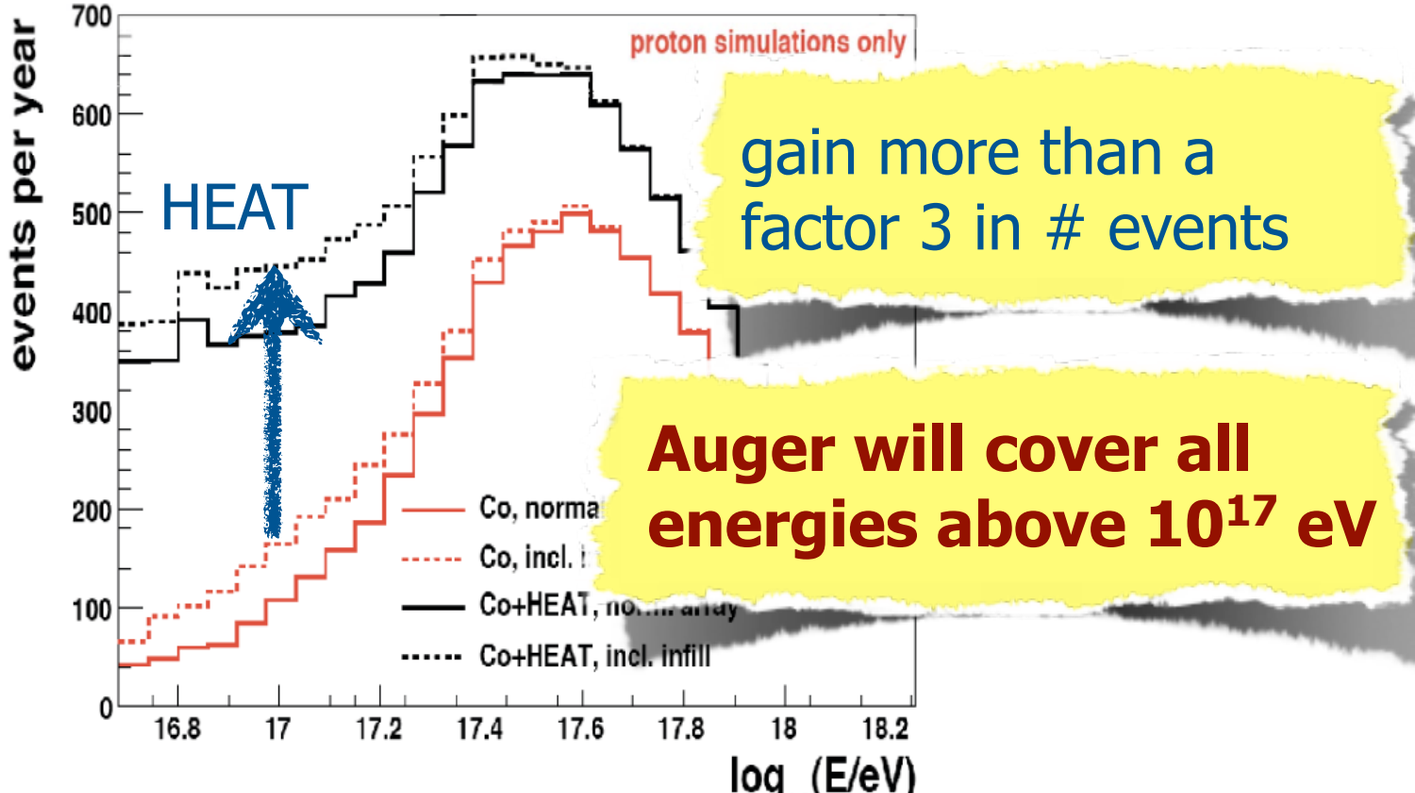
- event selection to assure unbiased energy calibration
- quality cuts and fiducial field of view cuts
- 44 events with 0.3 EeV < E_{FD} < 2 EeV

Even further down in energy by looking higher up : HEAT



cross-calibration





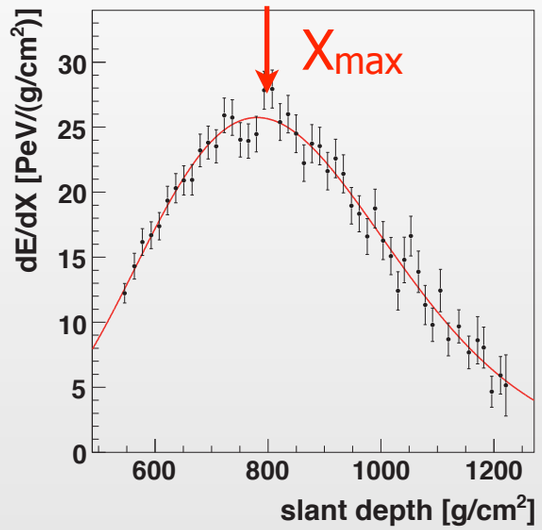
gain more than a factor 3 in # events

Auger will cover all energies above 10^{17} eV

Measurements of longitudinal shower development

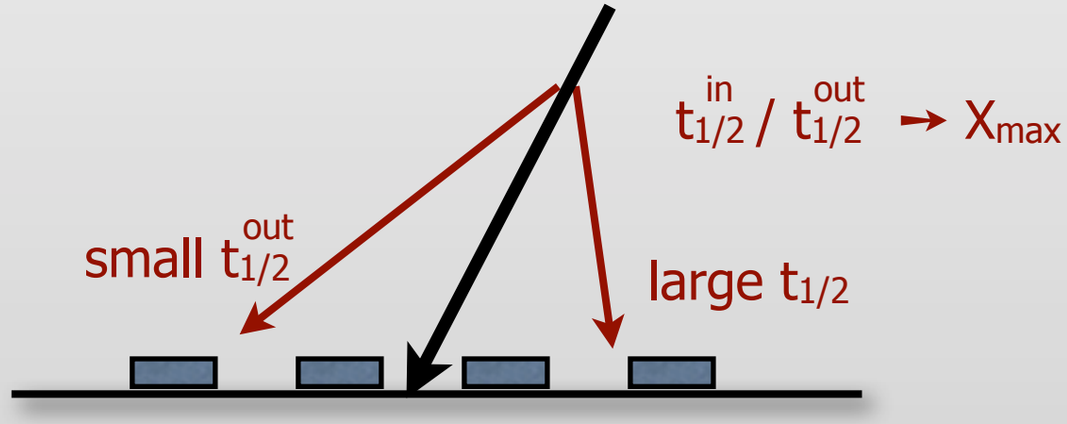
Fluorescence Detector:

- $\langle X_{max} \rangle$
- RMS(X_{max})
- full X_{max}-distributions

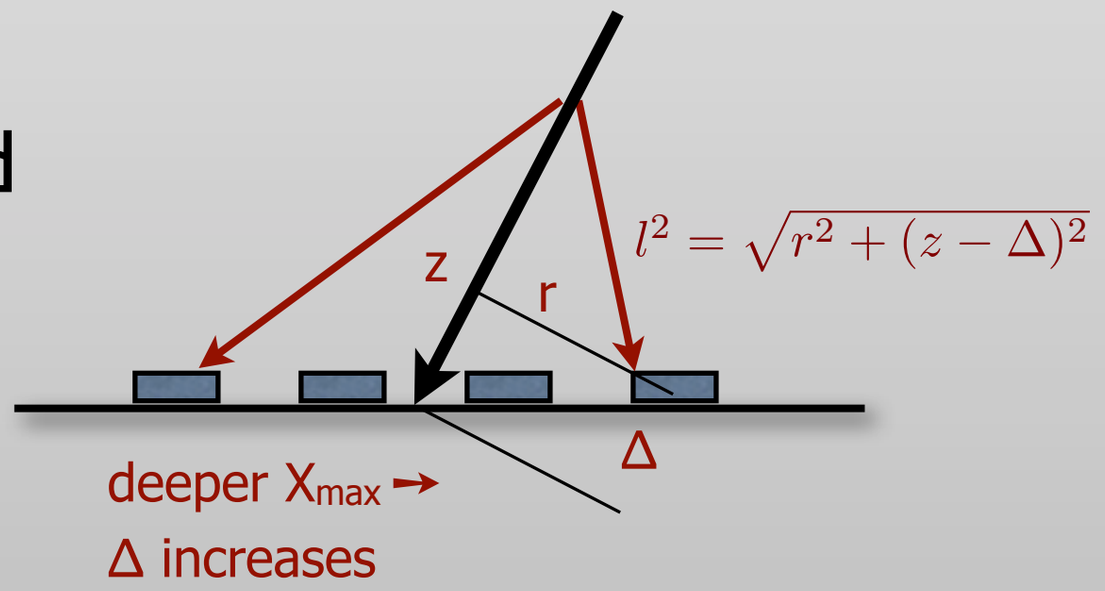


Surface Detector:

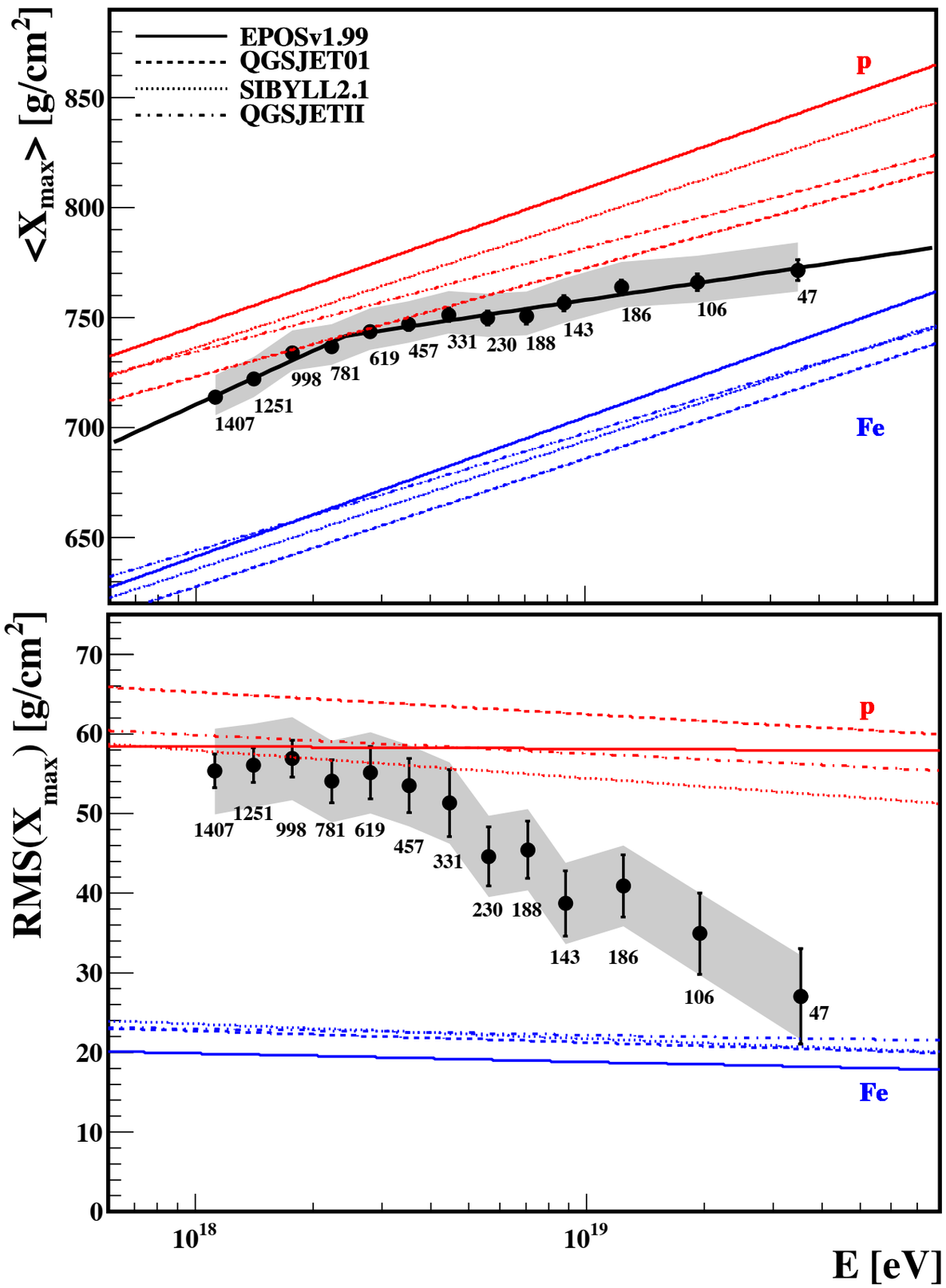
- azimuthal asymmetry of the signal risetime: Θ_{max}



- time difference between μ and shower plane → $\langle X^{\mu}_{max} \rangle$



Update on X_{max} and RMS(X_{max})



Statistics:

- 6744 high quality events

Resolution:

- X_{max} resolution ≈ 20 g/cm^2
  verified by multi-eye events

Systematics:

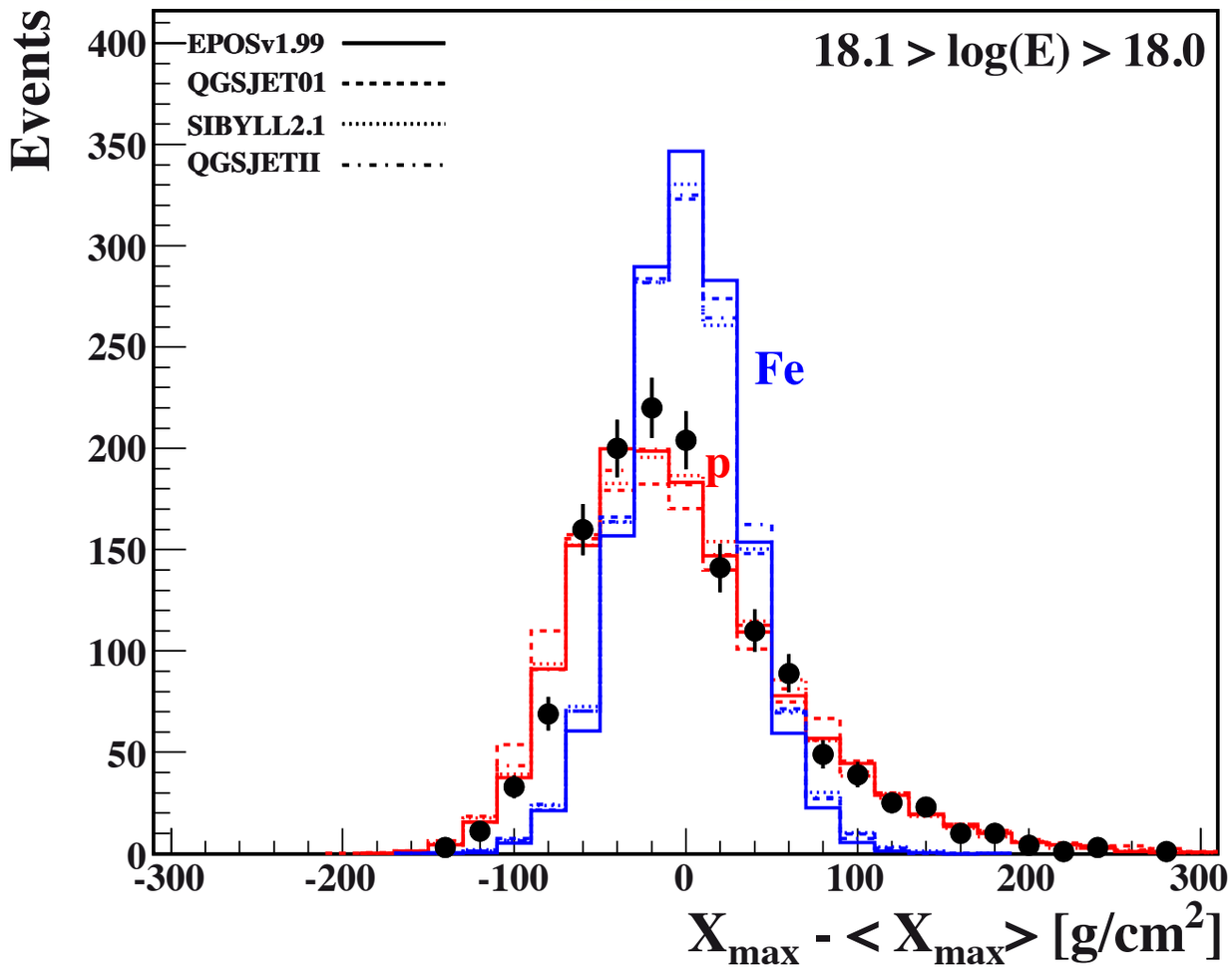
- X_{max}: 10-13 g/cm^2
- RMS(X_{max}): 5 g/cm^2

p-dominated at 10^{18} eV

heavy component >10^{19} eV

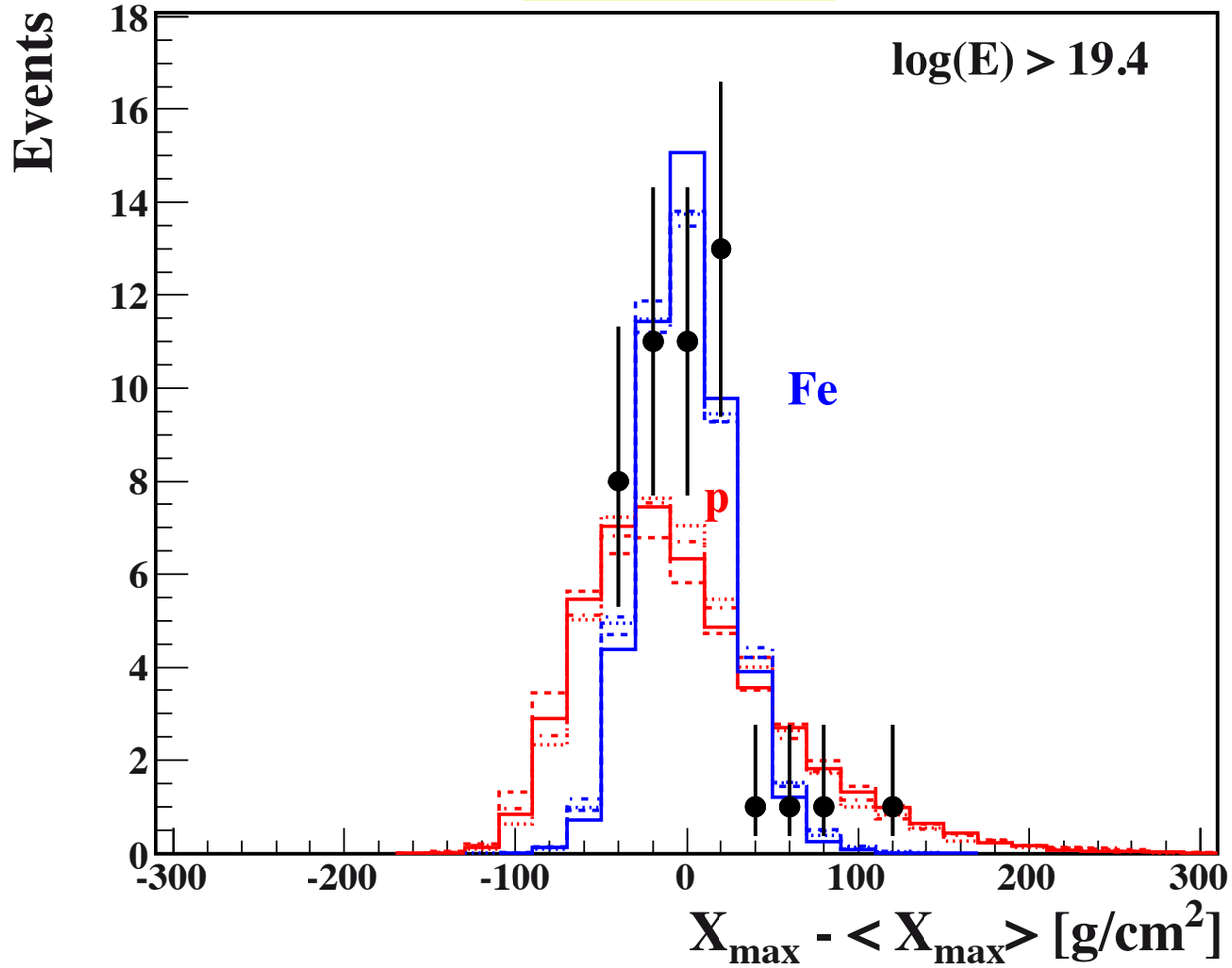
X_{max} Data vs Model Distributions

10^{18} eV



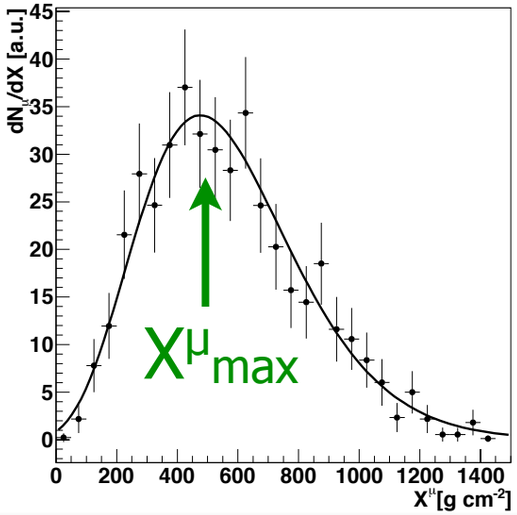
- wide distribution
- well described with a substantial fraction of protons

> $10^{19.4}$ eV

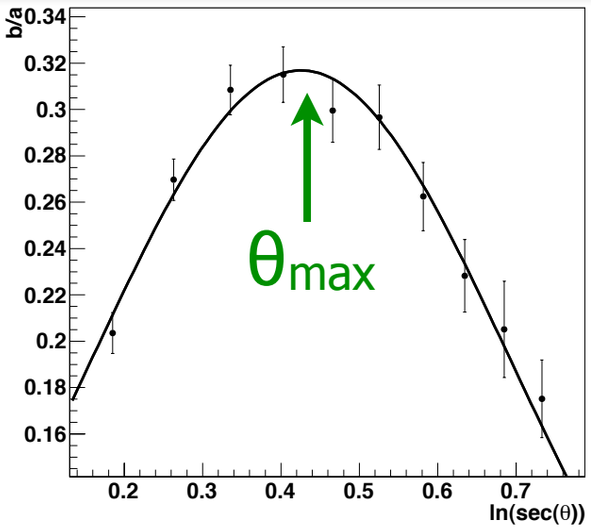


- narrow distribution
- compatible with a significant fraction of heavy nuclei

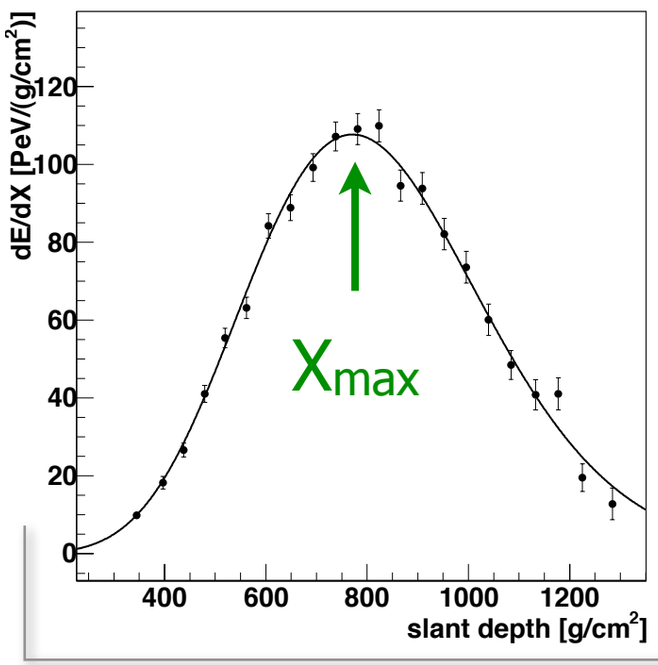
Comparison of Methods



Muon Production Depth from timing differences



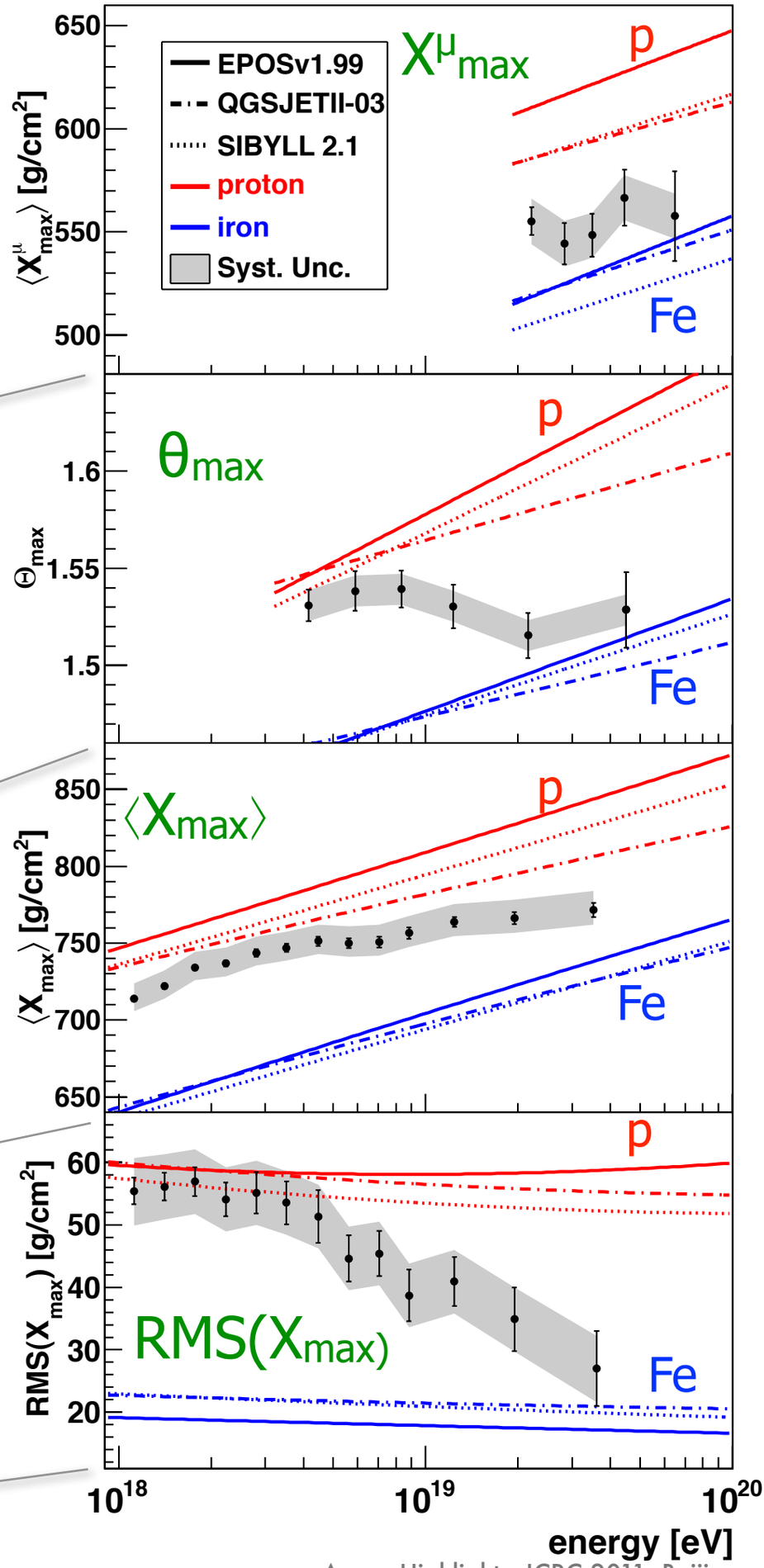
Shower Depth from asymmetry of rise times



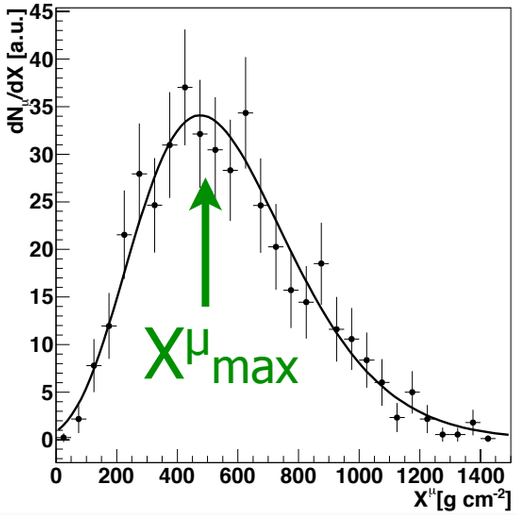
X_{max} observation by FD

➙ $\langle X_{max} \rangle$

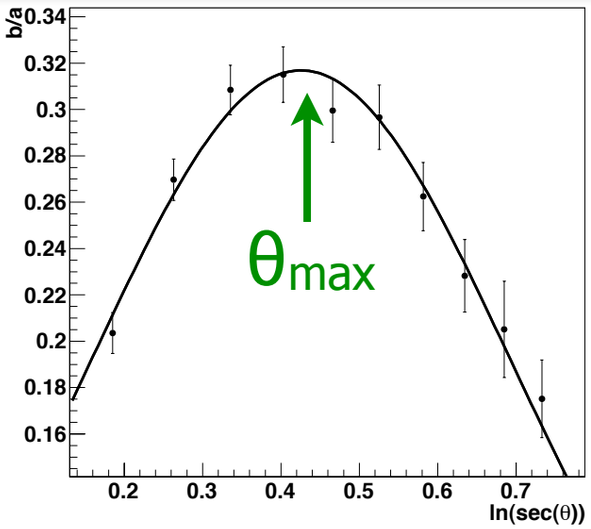
➙ **and RMS(X_{max})**



Comparison of Methods



Muon Production Depth from timing differences



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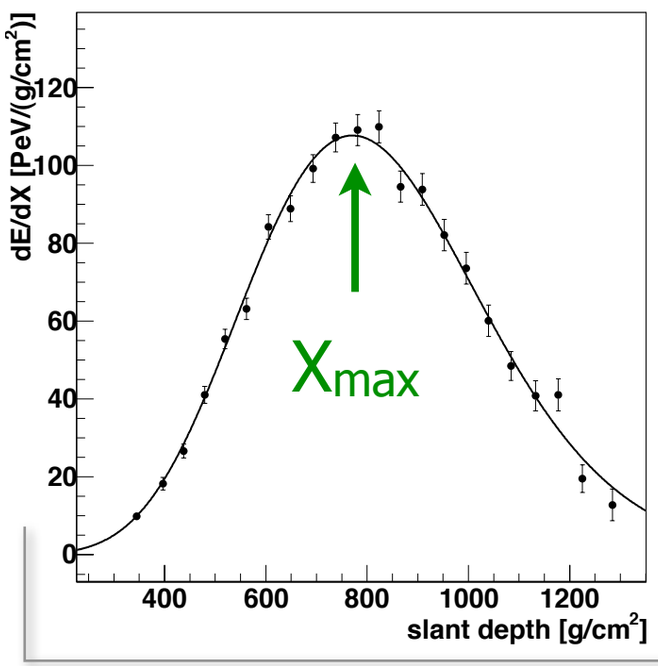
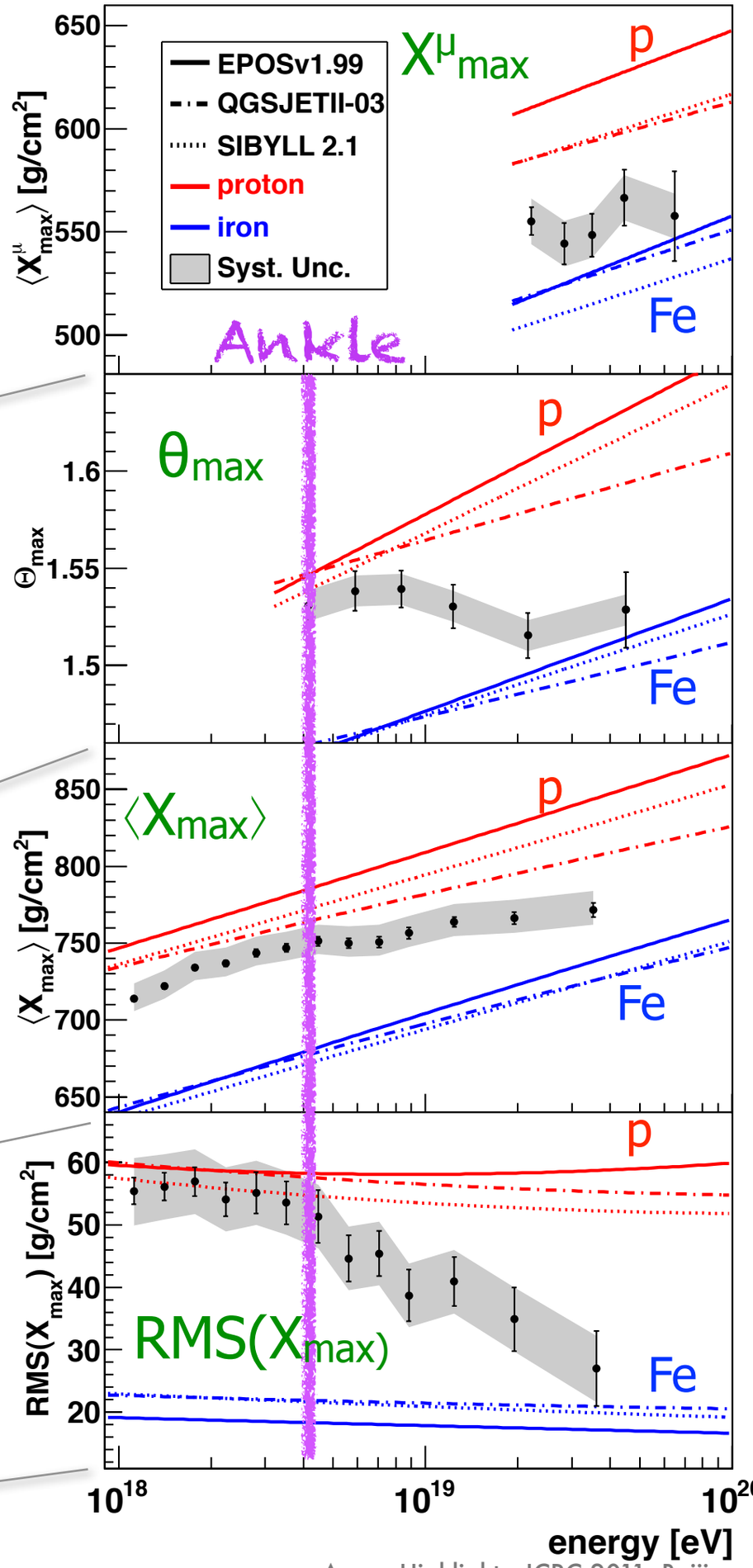


X_{max} observation by FD

➙ $\langle X_{max} \rangle$

➙ **and RMS(X_{max})**



Mass composition and elongation rate

Several „mass indicators“ in FD and SD data.

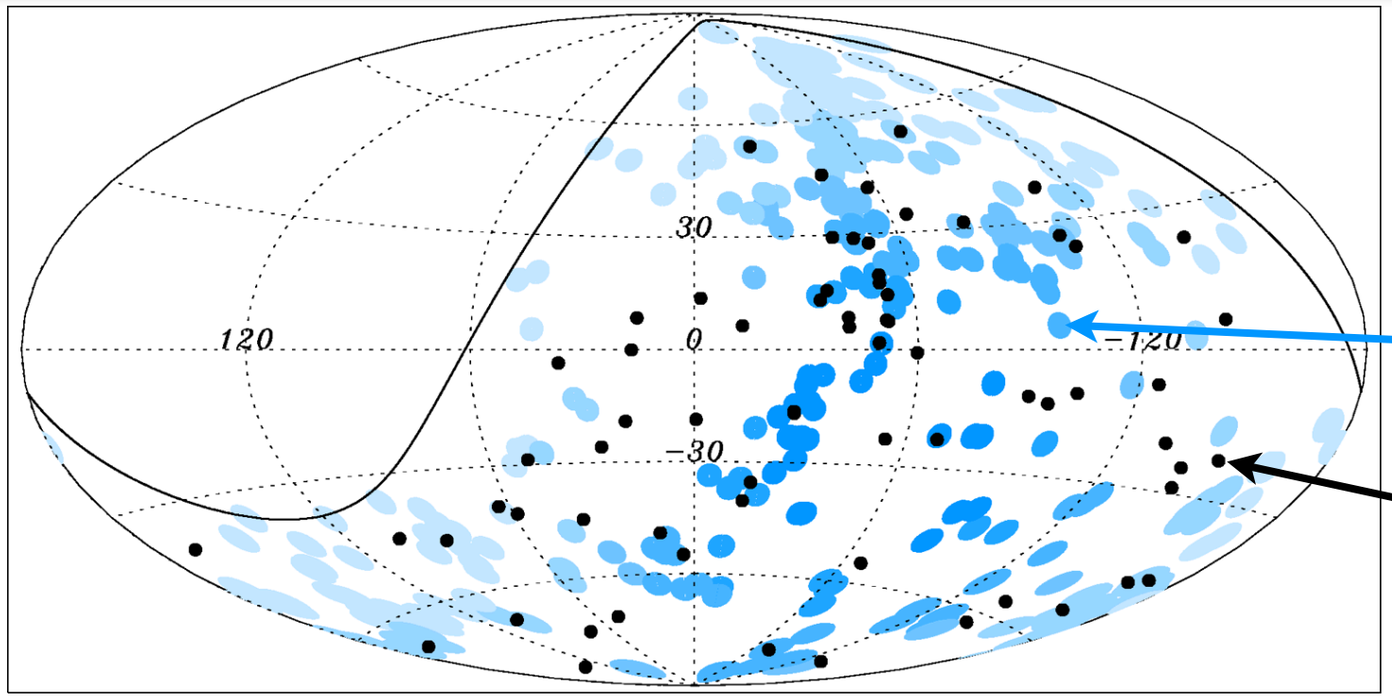
All parameters suggest a change
to heavier masses above the ankle !

High statistical quality of „mass data“ up to 40 EeV

Anisotropy starts above 40 EeV !

More FD observation time needed !!!
Take HE data every night ?

Update of correlation with VCV - AGN



AGN position
(3.1° circle)

event position

E > 56 EeV

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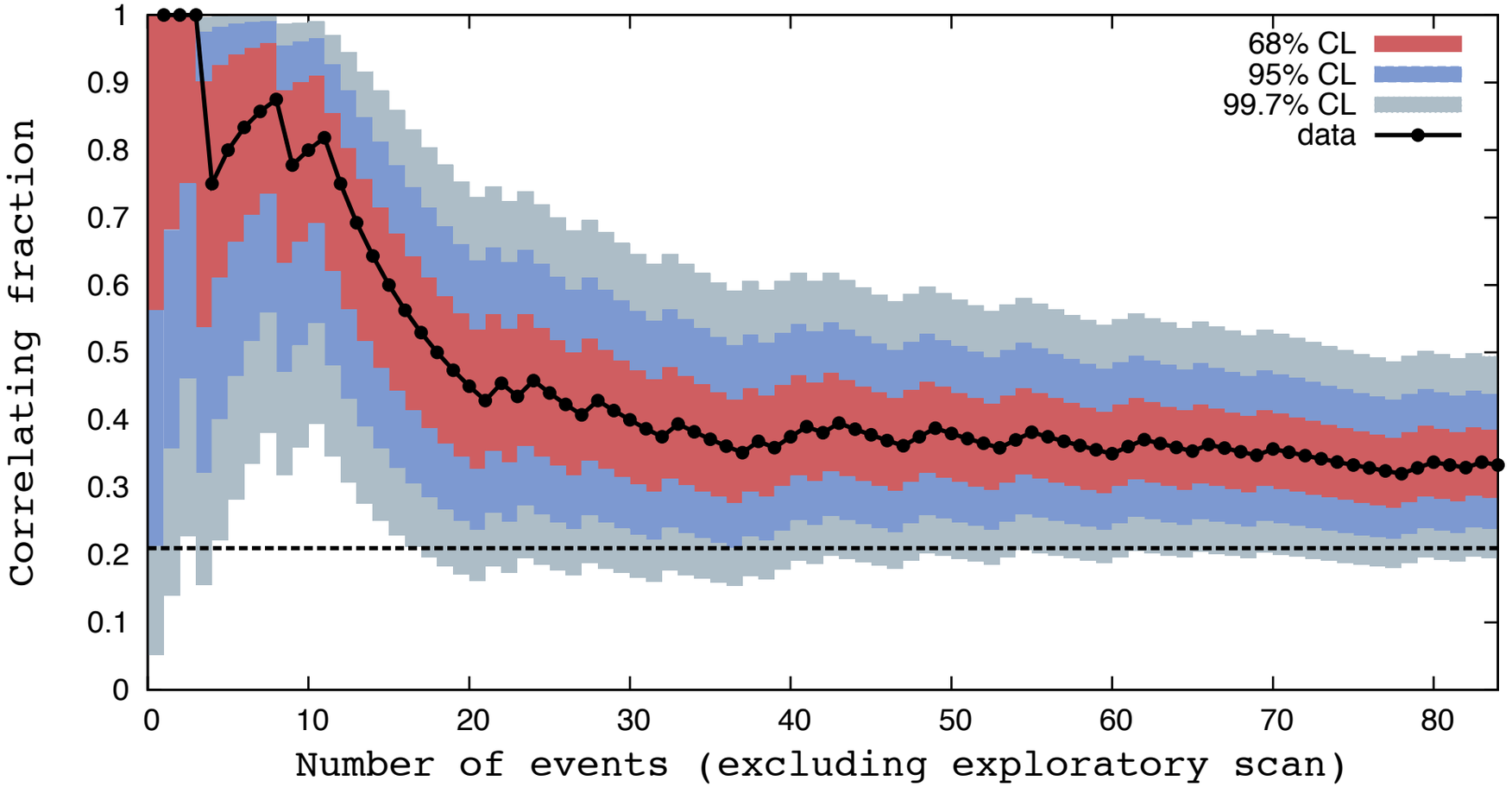


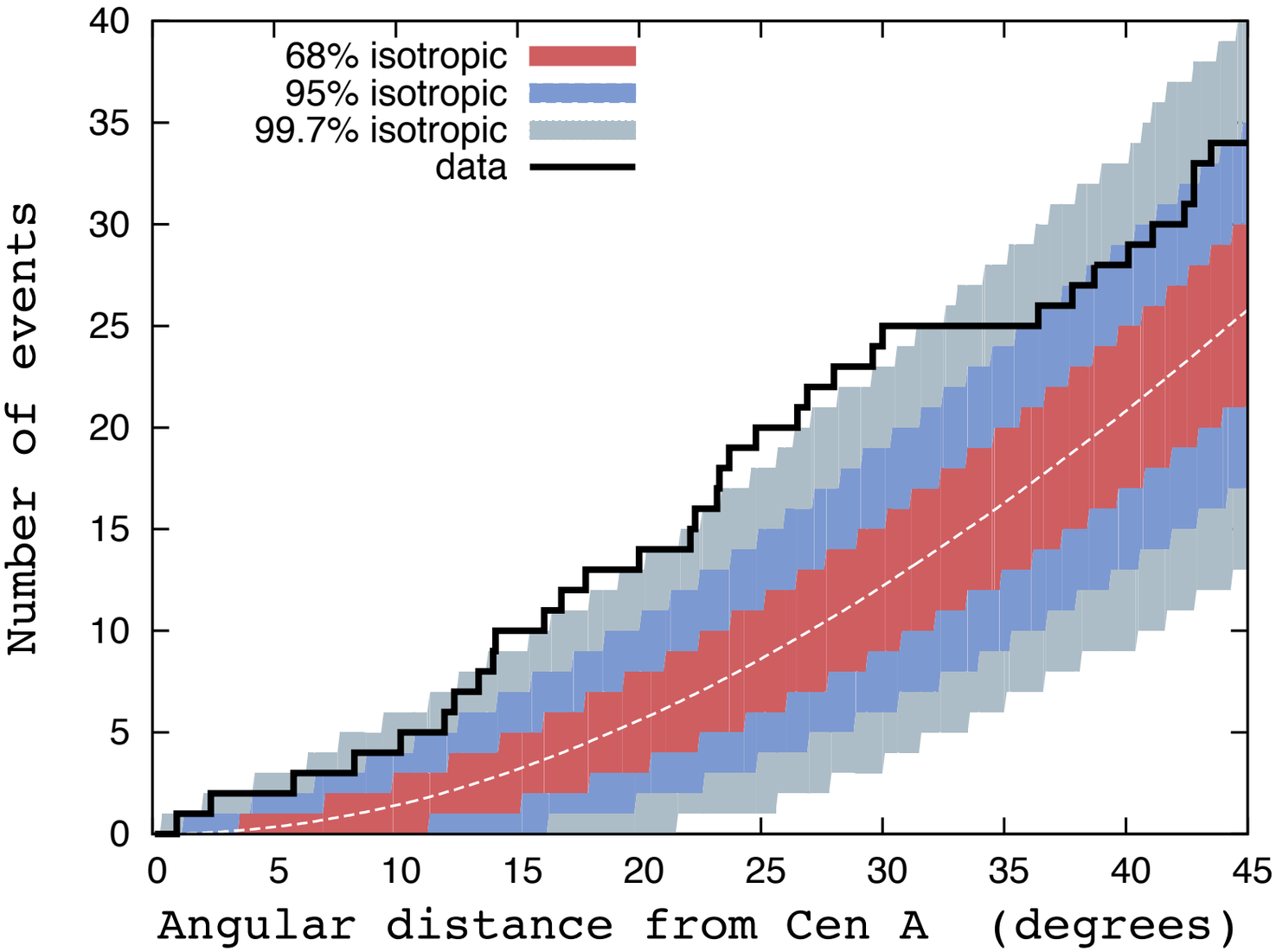
Update including June 2011

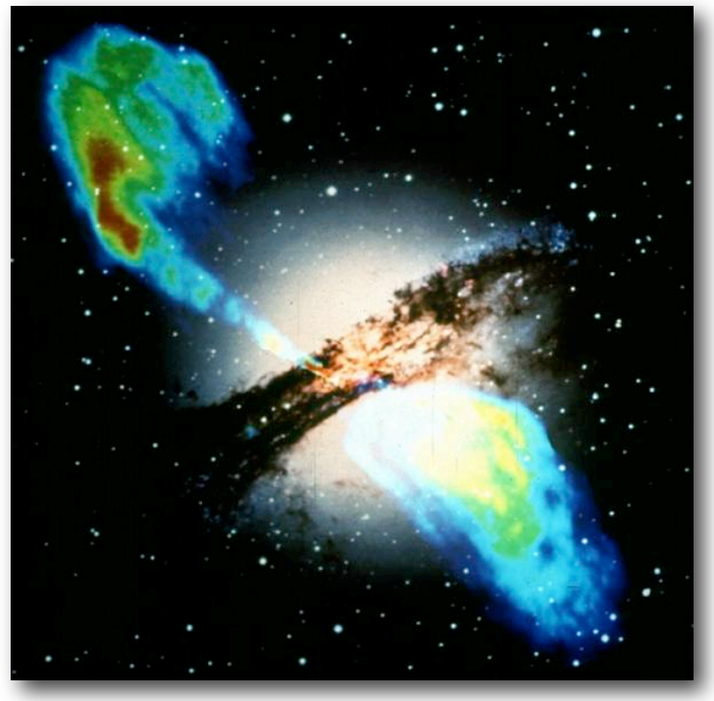
33±5%

Total: 28/84

P=0.006

Update on Cen A





Update including June 2011

KS test yields 4% isotropic probability
Largest departure now at 24°: 19 observed / 7.6 expected

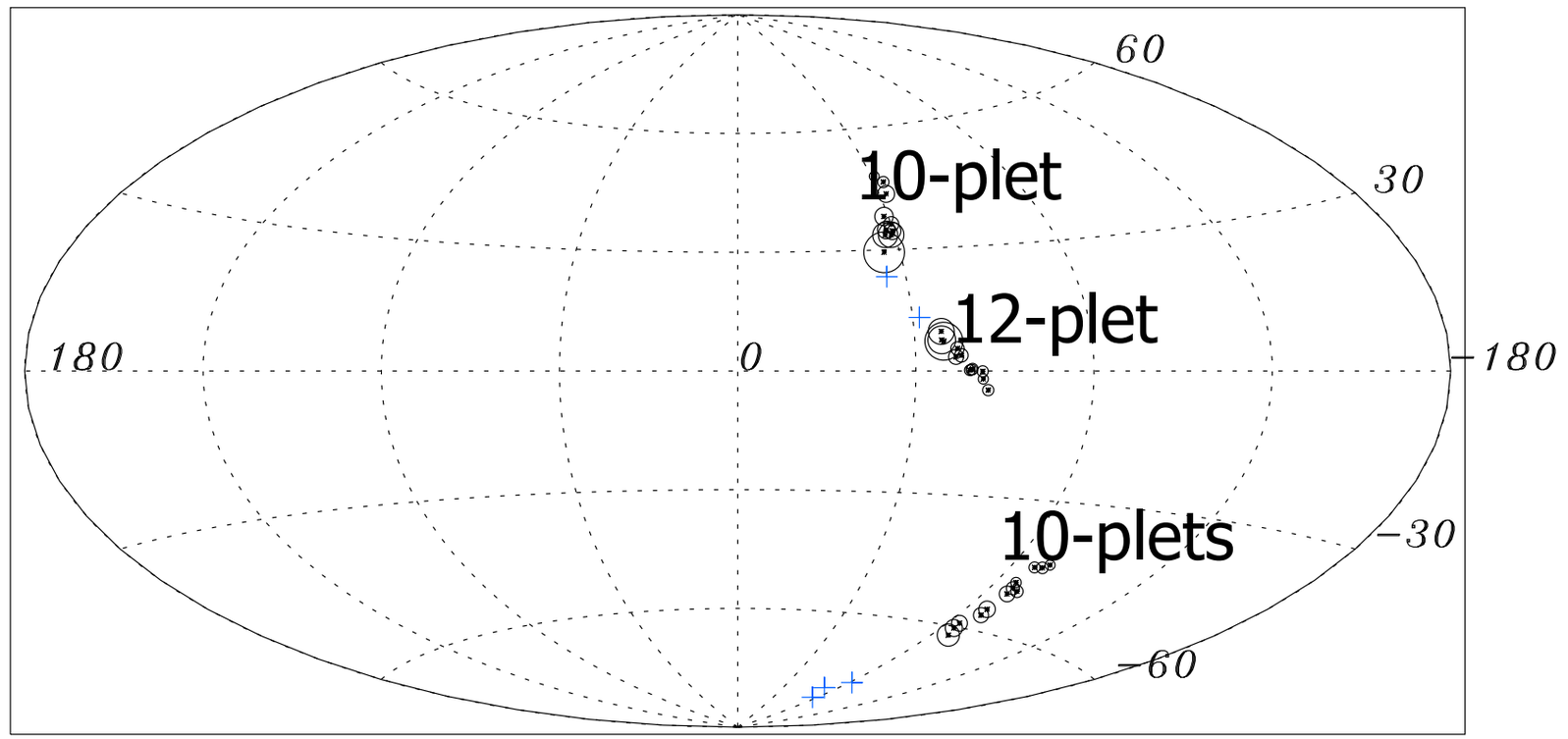
Multiplets and local neutron sources

Multiplet-Search E > 20 EeV

chance probability : 6%

➞ source density ≲ 10^{-4} Mpc^{-3}

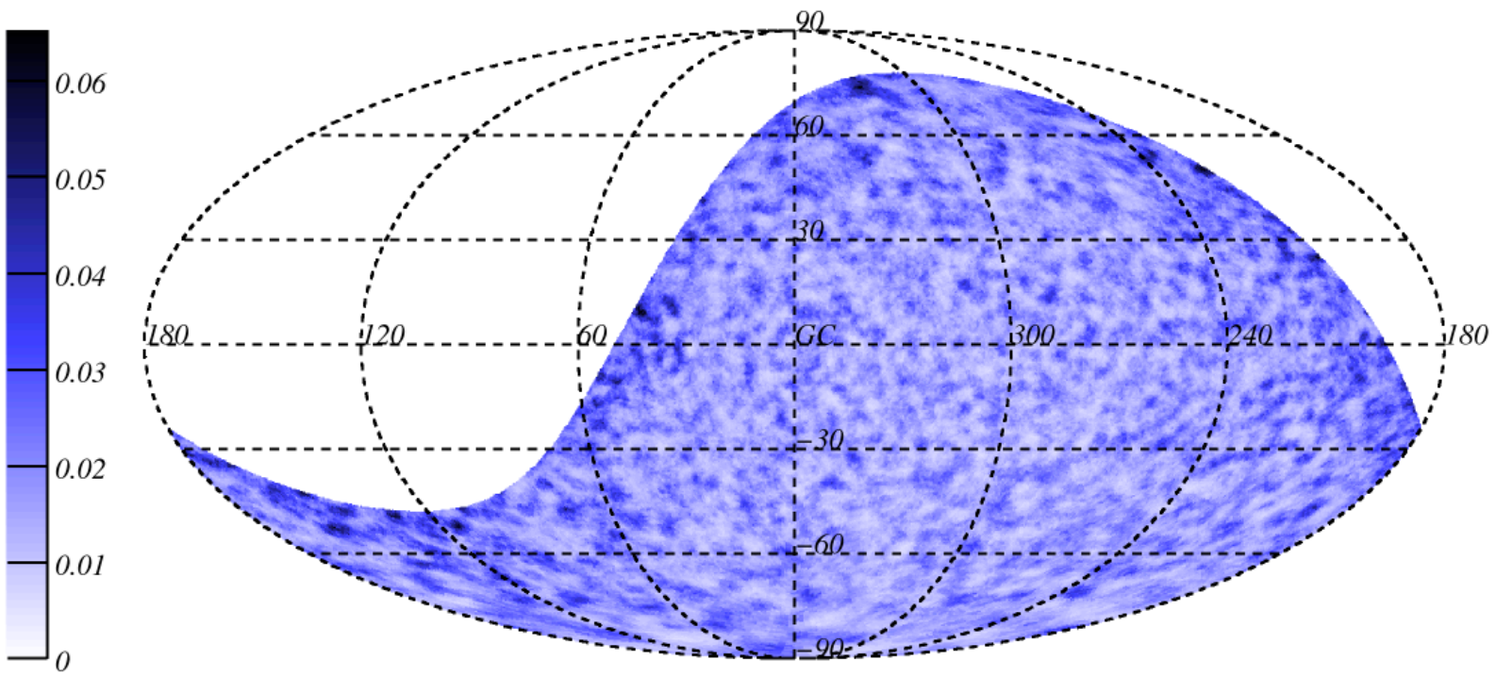
? the most promising signal ?



Neutron Point Source Search

E >1 EeV; no excess near GC

search for
HESS / Fermi-LAT sources
- also no excess



upper limit of neutron flux in $km^{-2}\,yr^{-1}$ (95% CL)

Anisotropy - Correlations - Multiplets

Weak correlation with AGNs

„Crowded area“ around CenA

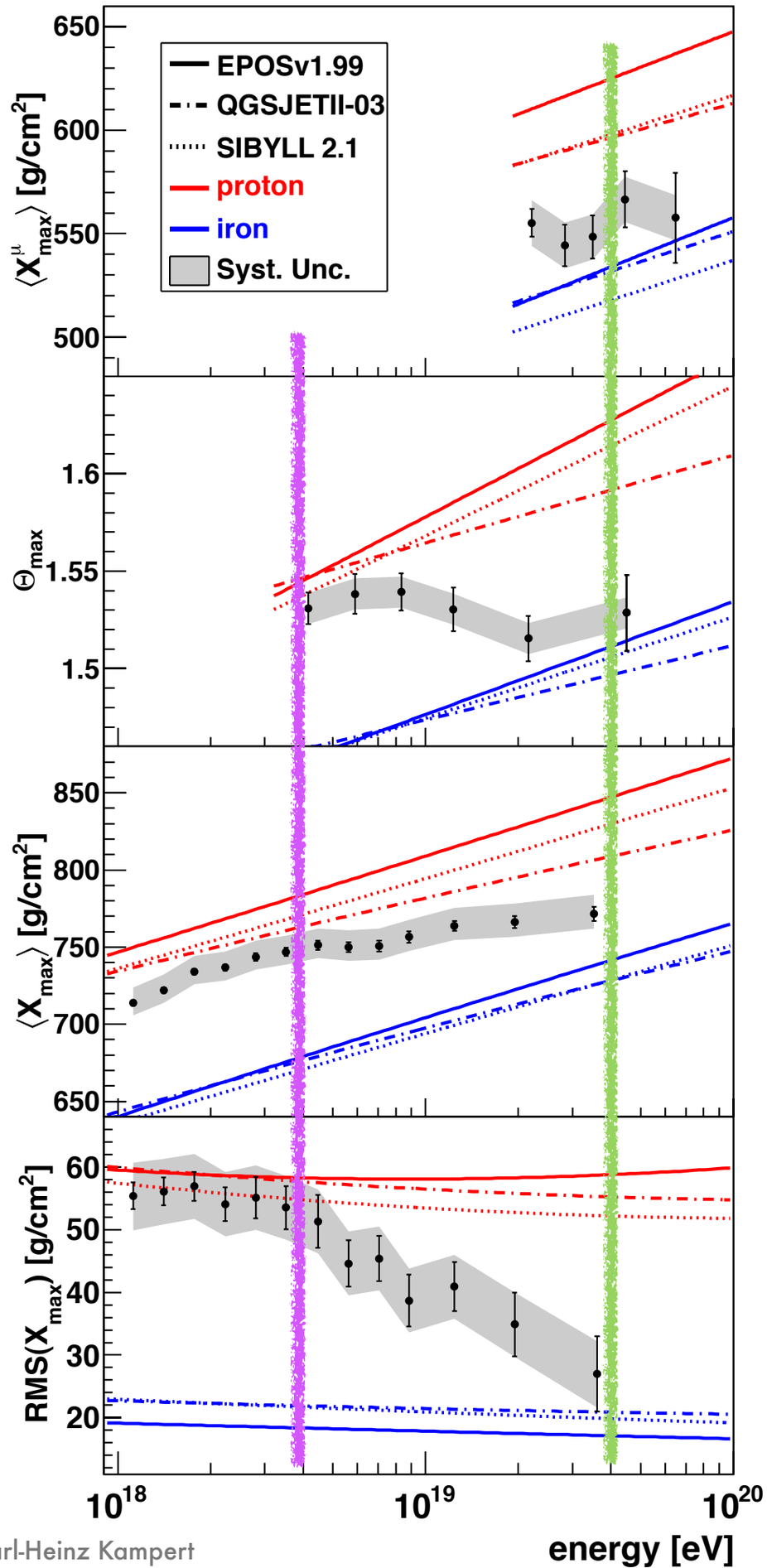
No neutron excess from Galactic Center

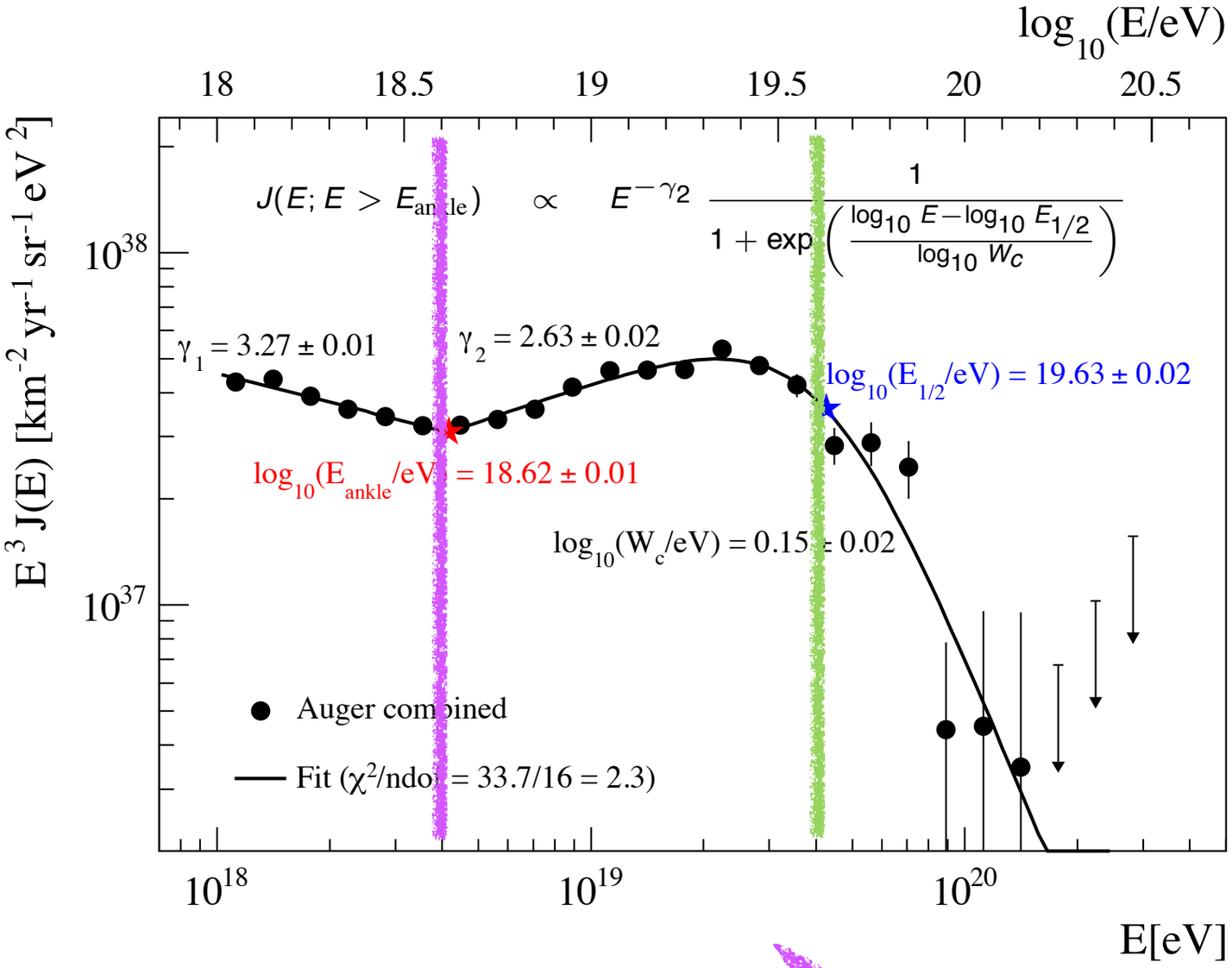
Some very interesting multiplets

...but nothing significant yet !

Heavy primaries ? or „Spill over“ due to energy resolution ?

Spectrum, Composition, and Anisotropy



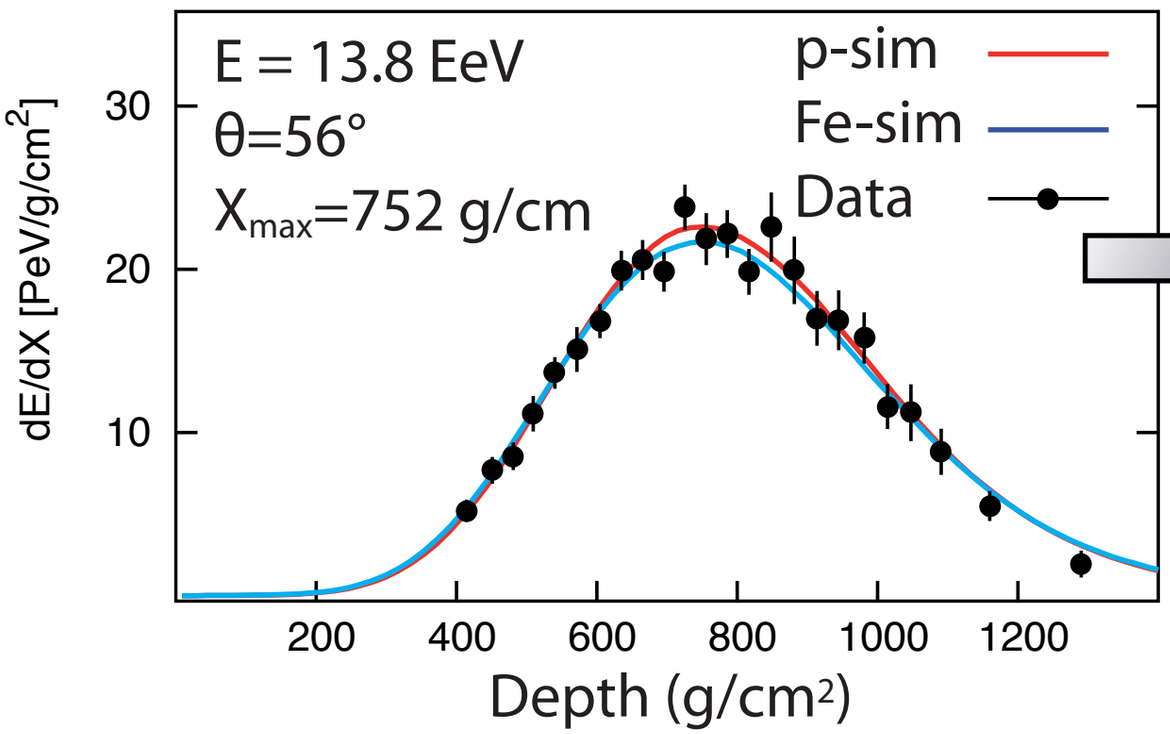


light → heavy

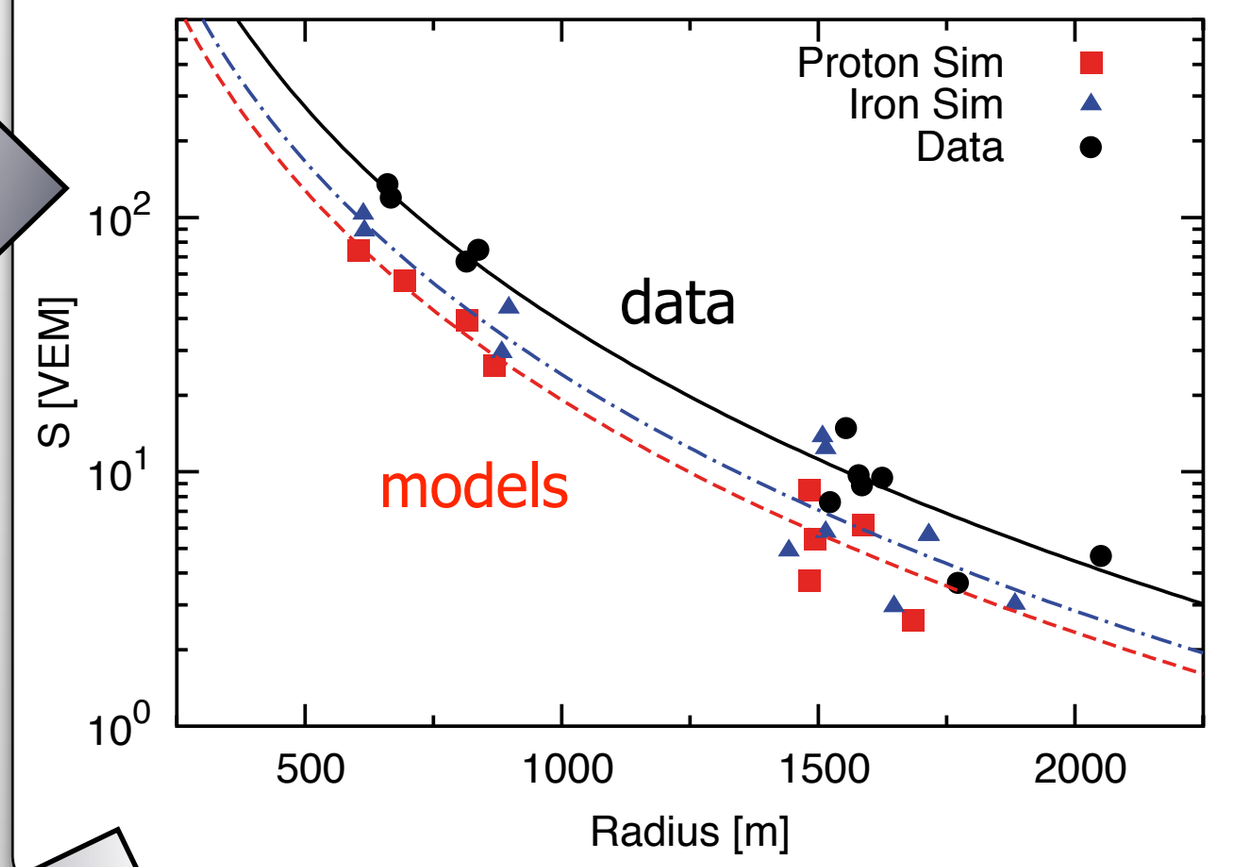
anisotropy

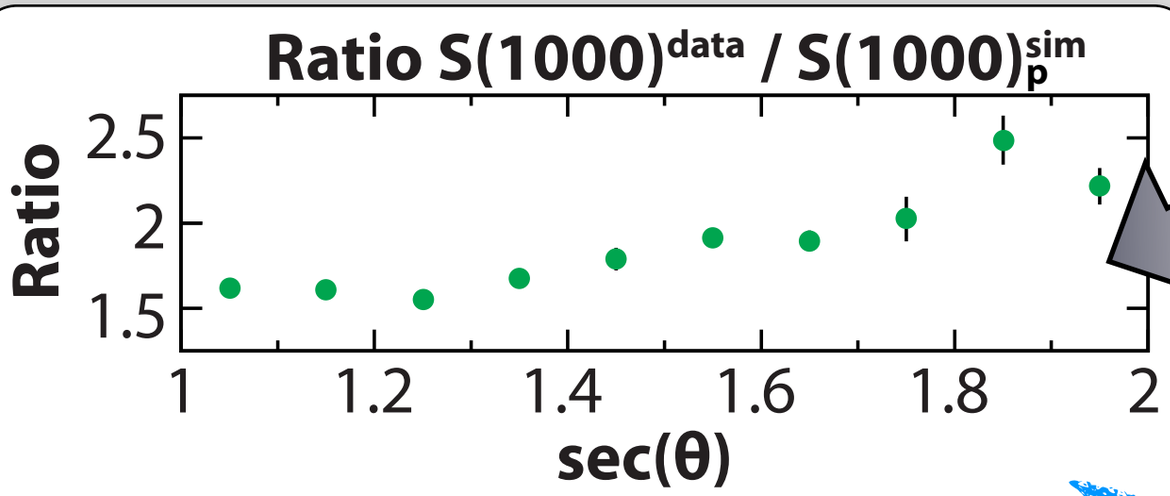
Models underestimate measured ground signals

Measured event with matching
p- and Fe- simulations



Same measured event
with predicted signals for p and Fe





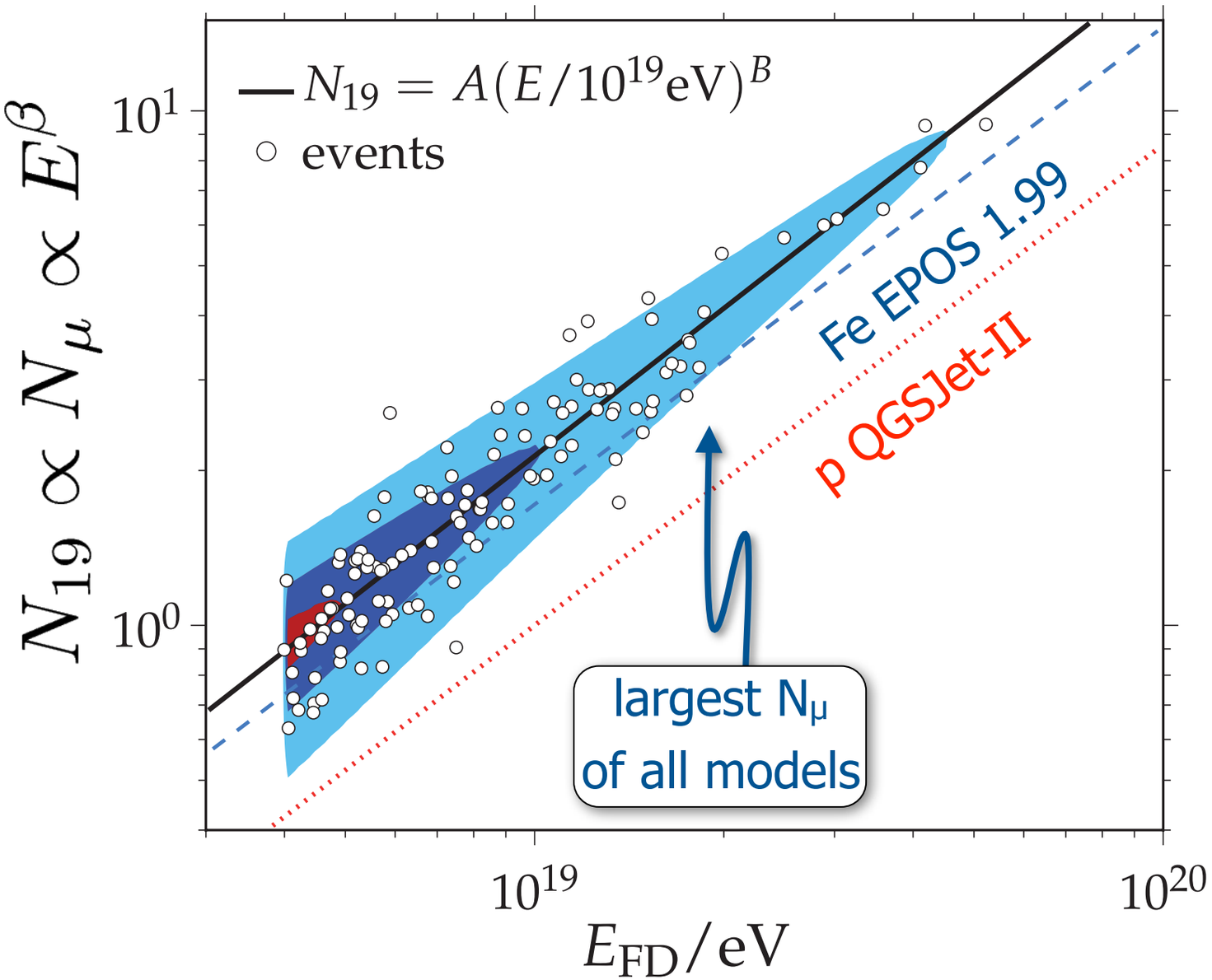
fraction of μ in SD increases

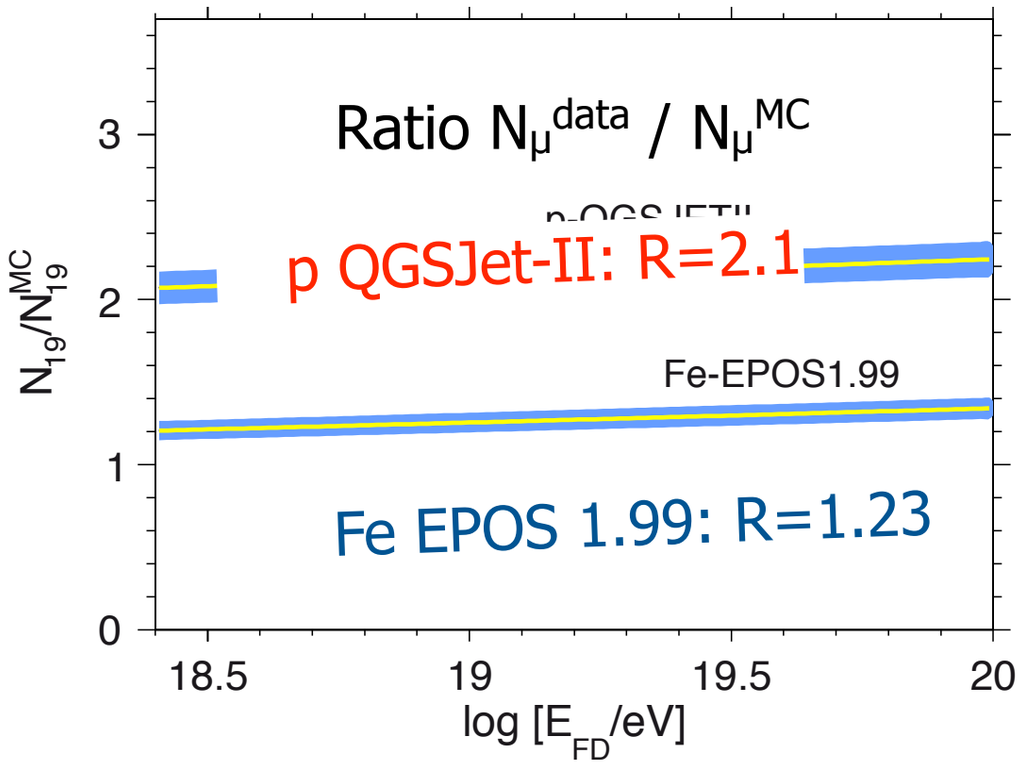
Models underestimate
ground signals by ~ 1.5 - 2

(for TA : 30% different energy scales)

Inclined Showers : models underestimate μ-number

- Inclined showers (62°- 80°) dominated by HE muons
- show broken circular symmetry; accounted for by μ-map
- small EM contribution subtracted from signals → N_μ





Models underestimate μ-number by

~ 25% (if data were pure Fe)

~ 100% (if data were pure p)

difficult to account for by models !

Conclusions and Outlook

The Pierre Auger Observatory is very successful,
but there remains a lot to do, e.g. :

energy spectrum and composition from 0.1 EeV to 100 EeV (HEAT)

explore SD mass sensitivity event-by-event above 40 EeV (SD) -- correlations ?

enlarge FD duty cycle for the highest energies -- take EHE data every night ?

improve muon counting (AMIGA / black top tanks) + interaction models

and

develope new detection schemes for EHECRs (MHz, GHz, ...)

*

*

... and probably much more as we will learn more !