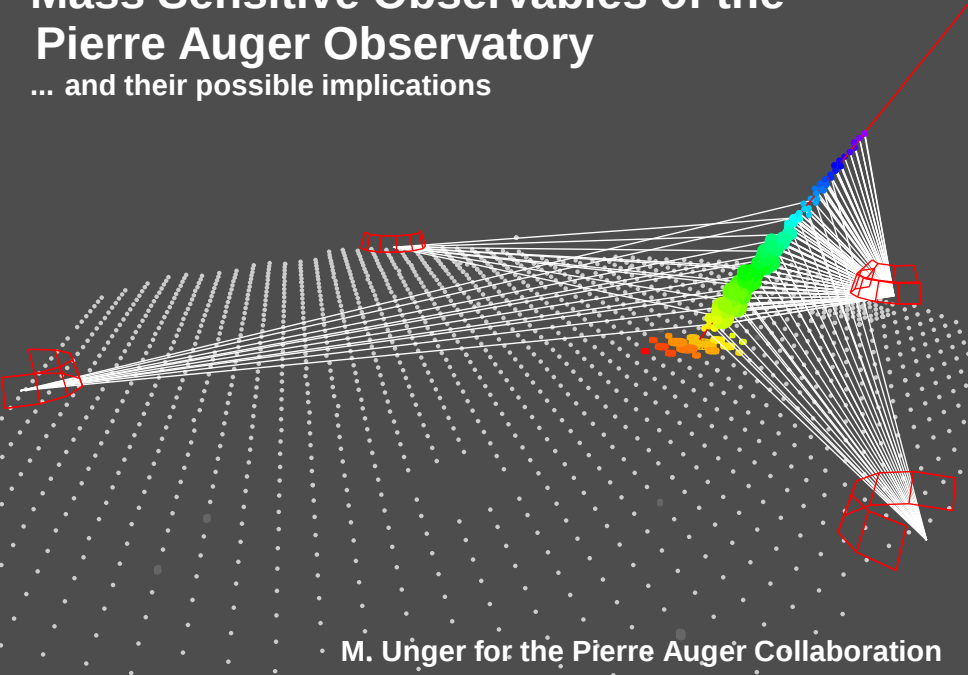


Mass Sensitive Observables of the Pierre Auger Observatory

... and their possible implications

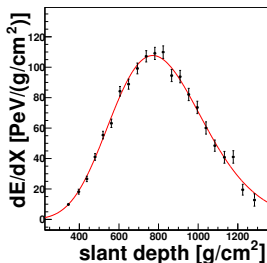


M. Unger for the Pierre Auger Collaboration

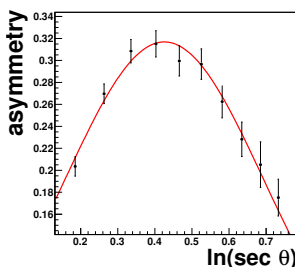
Overview

currently used in Auger:

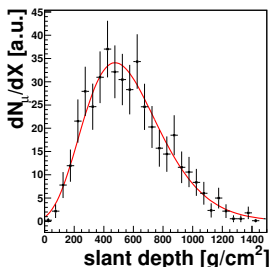
FD: $X_{\max}$



SD: rise-time asym.



SD: μ -prod. depth



→ three observables that are robust wrt. muon number
(see A. Yushkov, this afternoon, for N_{μ} in Auger)

under study:

- ▶ FD: shape of profile
- ▶ SD: shower front curvature, magnitude of rise-time, muons from shower universality, ...

$X_{\max}$ Analysis

Goal: determine properties of $X_{\max}$ distribution in the atmosphere (not in detector)

▶ data base cuts

- ▶ clear atmosphere
- ▶ good calibration
- ▶ no clouds

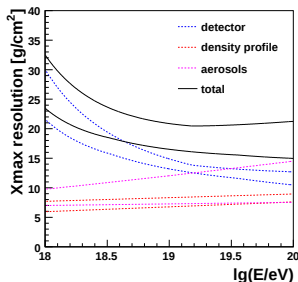
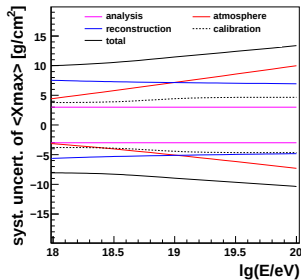
▶ quality cuts

- ▶ $X_{\max}$ observed
- ▶ $\sigma(X_{\max}) \leq 40 \text{ g/cm}$
- ▶ minimum viewing angle

▶ fiducial cuts

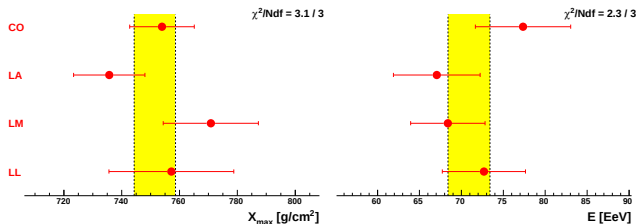
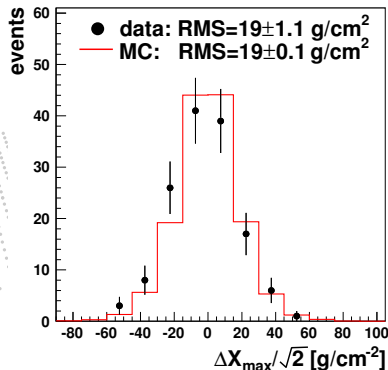
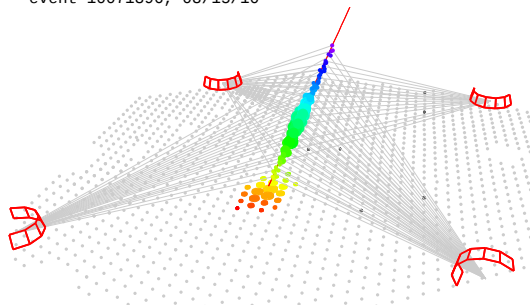
- ▶ distance to hybrid station
→ hybrid trigger 100%
- ▶ large field of view
→ unbiased sampling of $X_{\max}$ distr.

(see poster by V. De Souza)

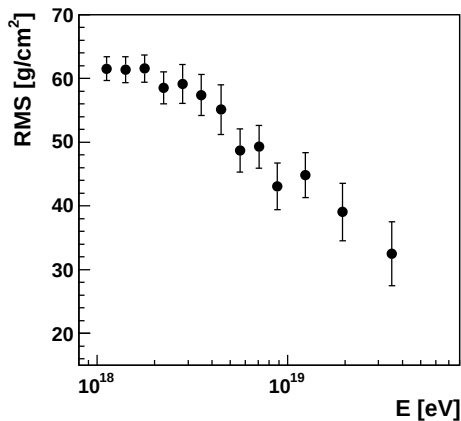
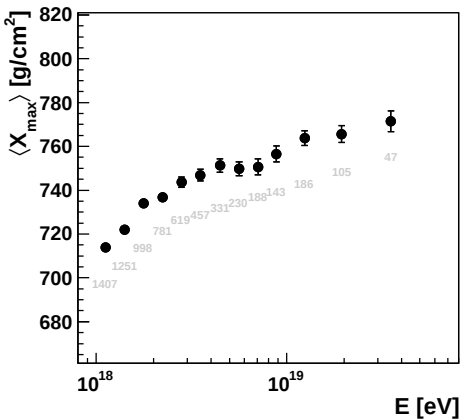


Cross-checks with 'multi-eye' Events

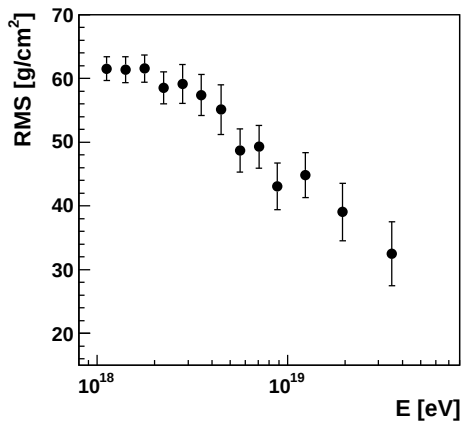
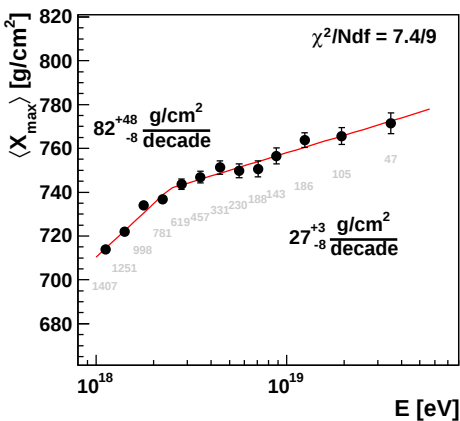
event 10071896, 08/15/10



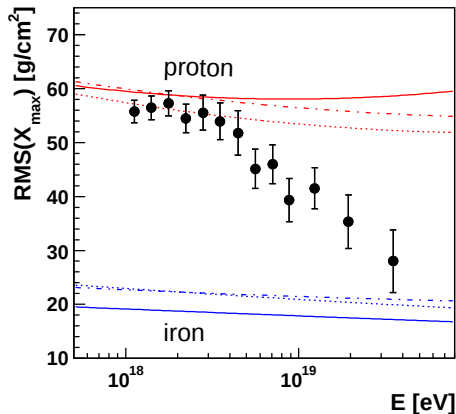
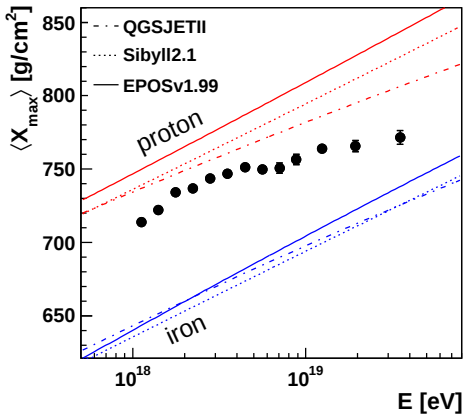
$\langle X_{\max} \rangle$ and RMS



$\langle X_{\max} \rangle$ and RMS

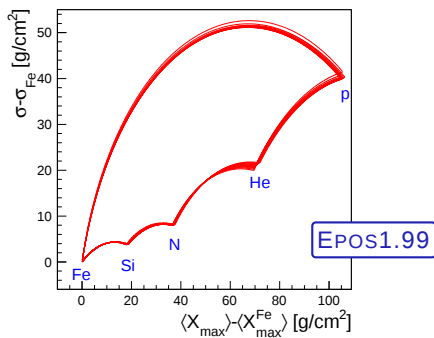
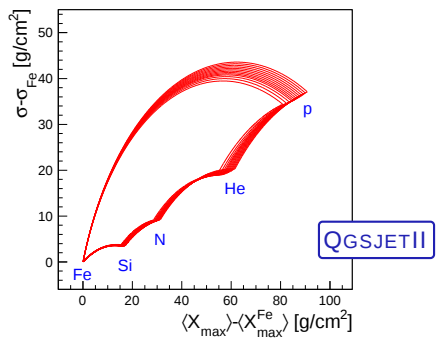
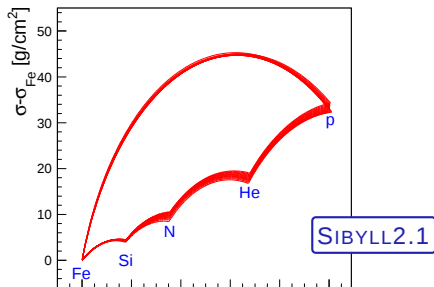
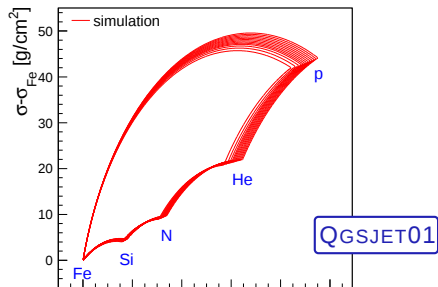


$\langle X_{\max} \rangle$ and RMS



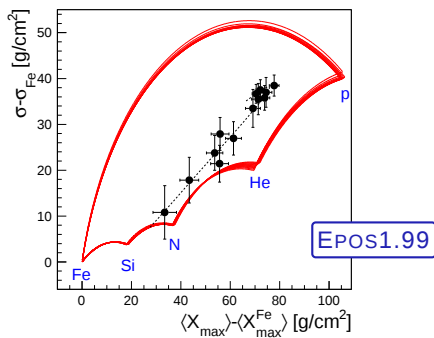
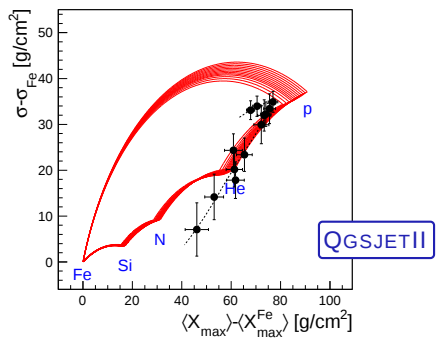
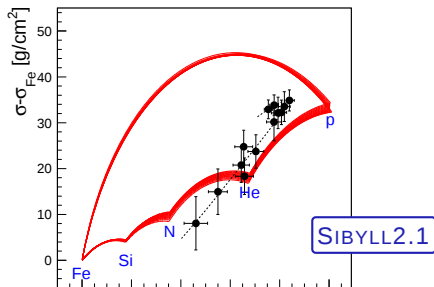
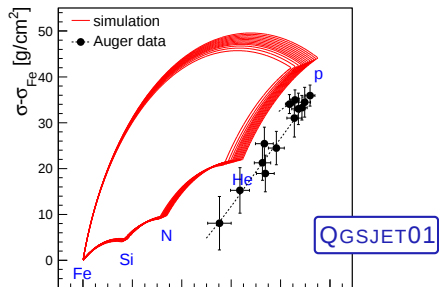
$\langle X_{\max} \rangle$ vs. RMS

arXiv:1201.0018



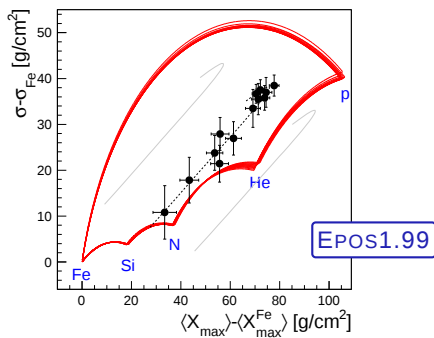
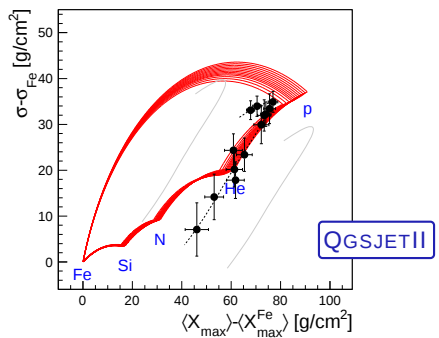
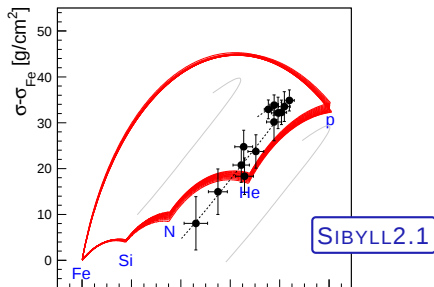
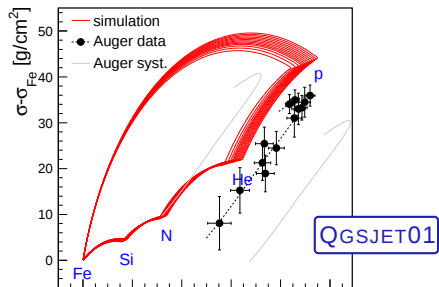
$\langle X_{\max} \rangle$ vs. RMS

arXiv:1201.0018



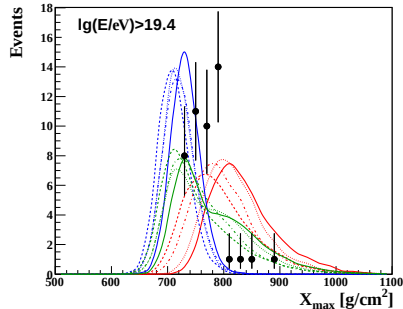
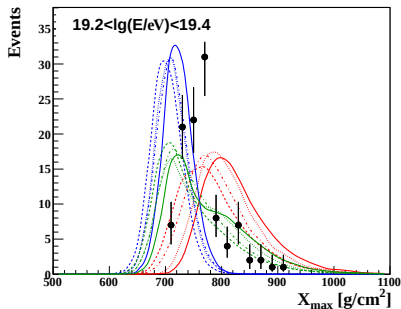
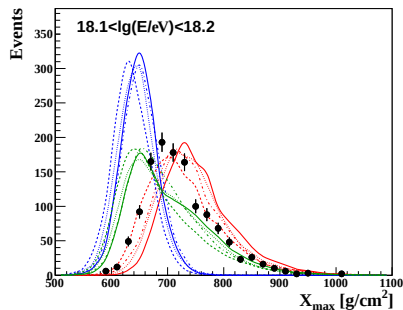
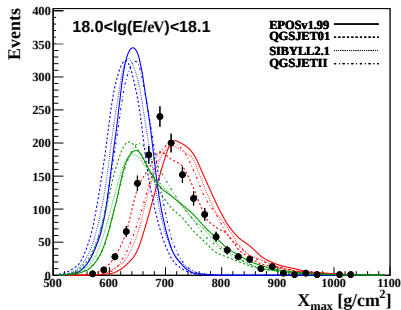
$\langle X_{\max} \rangle$ vs. RMS

arXiv:1201.0018



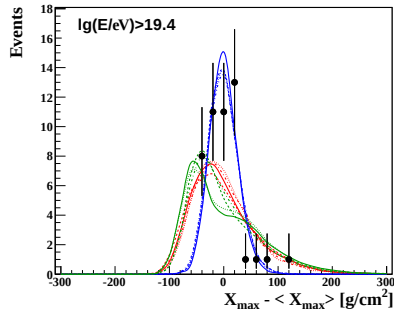
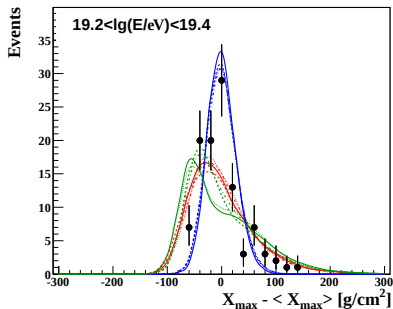
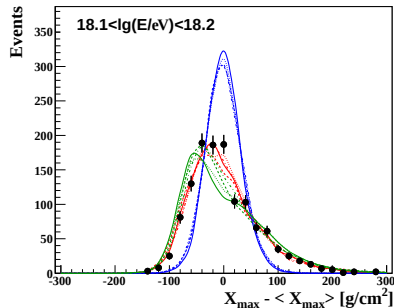
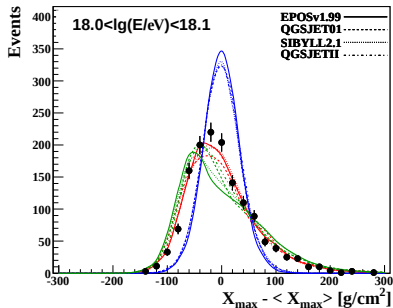
$X_{\max}$ Distributions

p, Fe, 50:50

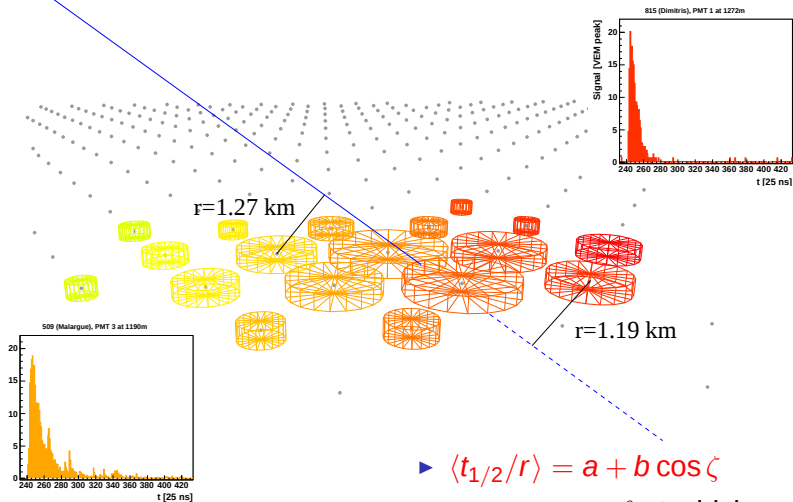


$X_{\max}$ Distributions

p, Fe, 50:50

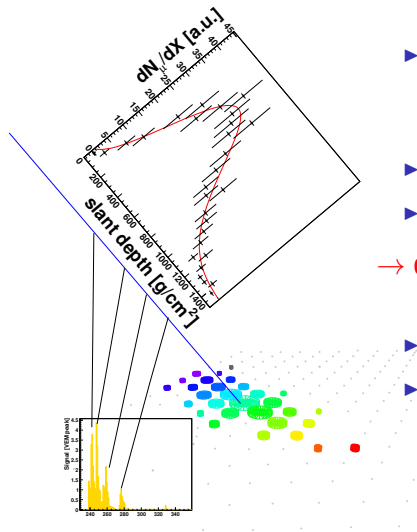


Rise Time Asymmetry



- ▶ $\langle t_{1/2}/r \rangle = a + b \cos \zeta$
- ▶ measure $\sec \theta$ at which asymmetry b/a is maximal

Muon Production Depth



- ▶ muon-rich stations:
 - ▶ events with zenith angle 55-65 deg.
 - ▶ stations with core distance >1.8 km
- ▶ projection of signal time traces to axis
- ▶ sum up stations

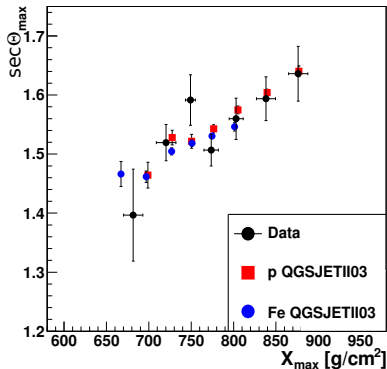
→ distribution of muon production heights

- ▶ distance to slant depth conversion
- ▶ fit with Gaisser-Hillas

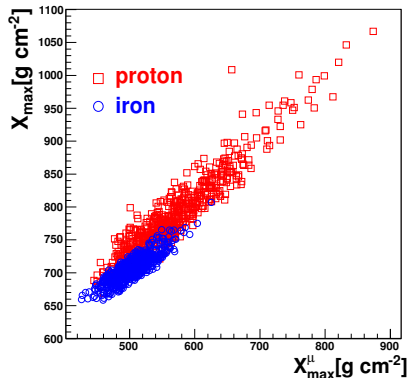
→ maximum at $X_{\max}^{\mu}$

SD observables vs. $X_{\max}$

rise time asymmetry

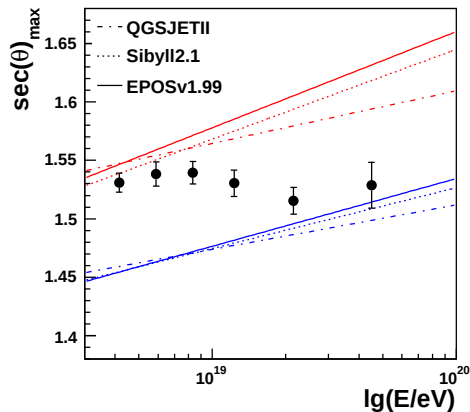


muon production depth

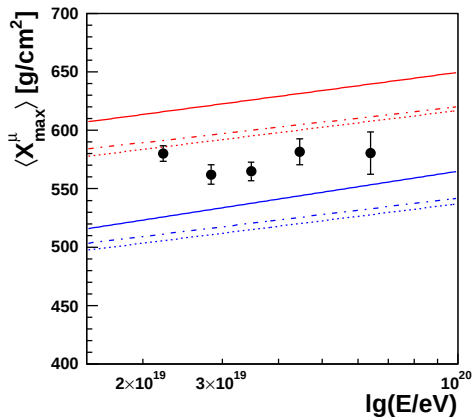


→ estimators of the longitudinal air shower development

$\sec(\theta)_{\max}$ and $X_{\max}^{\mu}$ vs. energy

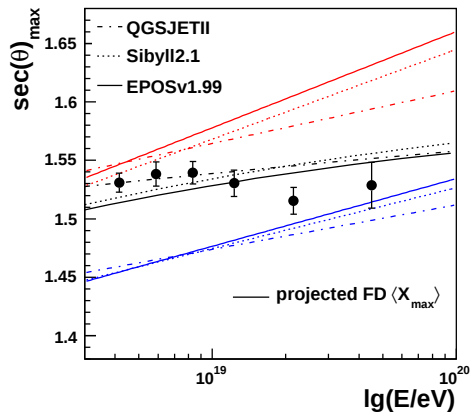


$\sigma(\text{syst.}) \approx 0.01$

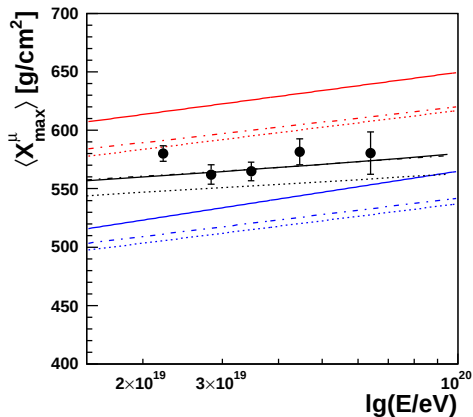


$\sigma(\text{syst.}) \approx 15 \text{ g/cm}^2$

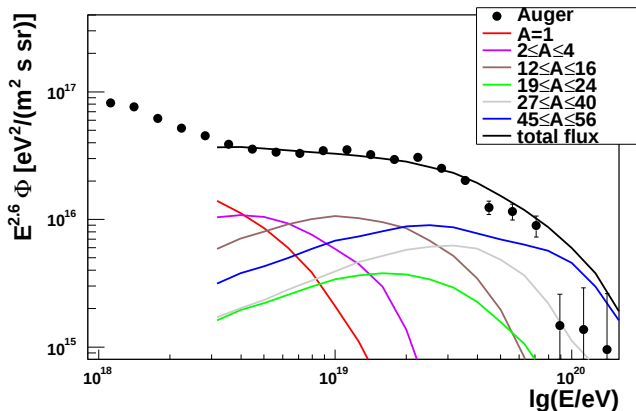
$\sec(\theta)_{\max}$ and $X_{\max}^{\mu}$ vs. energy



$\sigma(\text{syst.}) \approx 0.01$



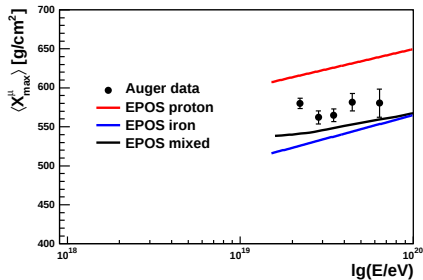
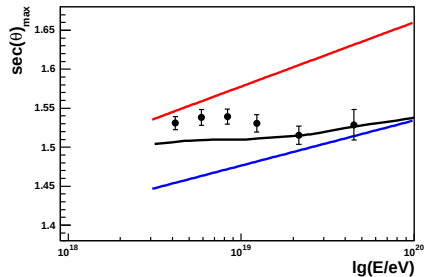
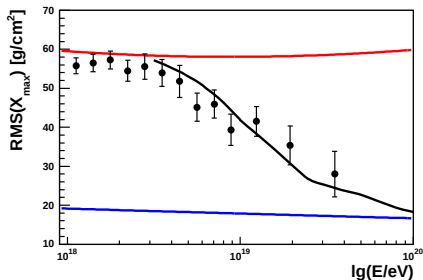
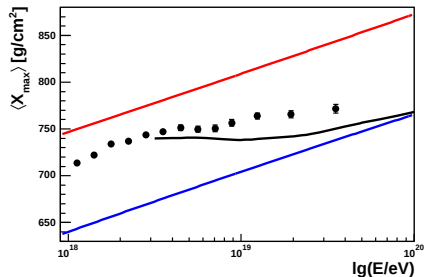
$\sigma(\text{syst.}) \approx 15 \text{ g/cm}^2$



- ▶ Peters cycle: $E_{\max} = Z \cdot (4 \cdot 10^{18}) \text{ eV}$
- ▶ composition mix as low energy galactic
- ▶ hard spectral index at the sources ($\beta = 1.6$)

(see also V. Berezhinsky yesterday and A. Taylor tomorrow afternoon)

Astrophysics?

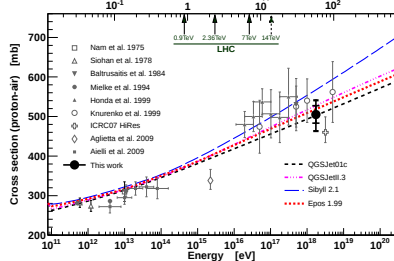
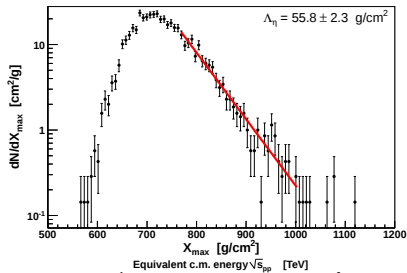


not a fit! Two-parameter model adjusted to Auger flux, not composition data

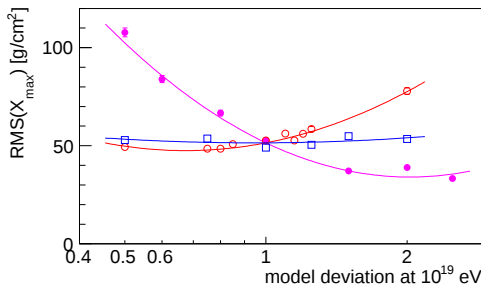
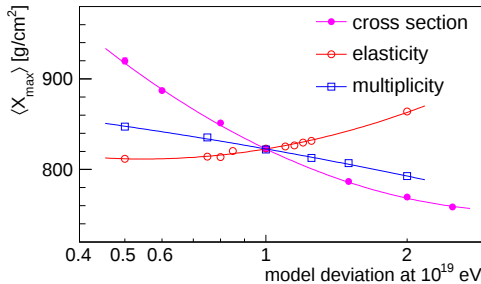
Hadronic Interactions?

PRD83 (2011), 054026

10^{18} to $10^{18.5}$ eV



above $10^{19.4}$ eV

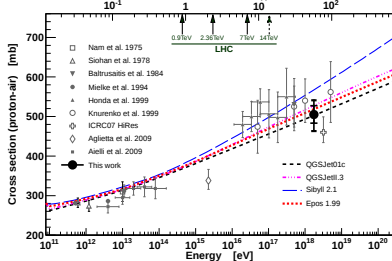
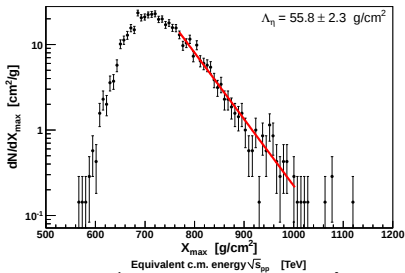


(see R. Ulrich this afternoon)

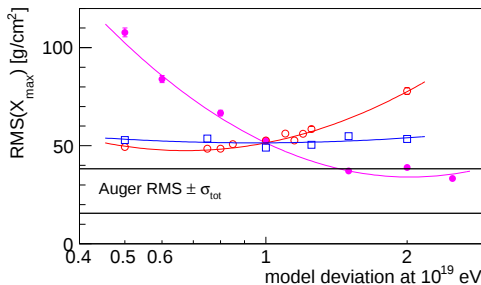
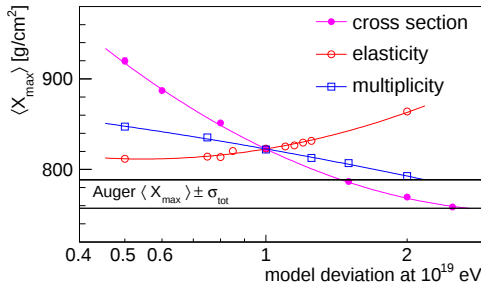
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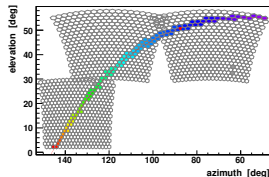


(see R. Ulrich this afternoon)

Outlook: Composition from 0.1 to 1 EeV



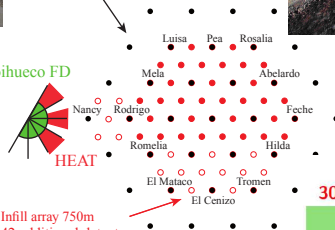
Existing tank array 1500m



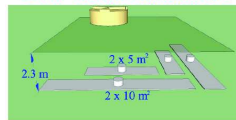
Coihueco FD

HEAT

Infill array 750m
42 additional detectors
Area ~ 23.5 km



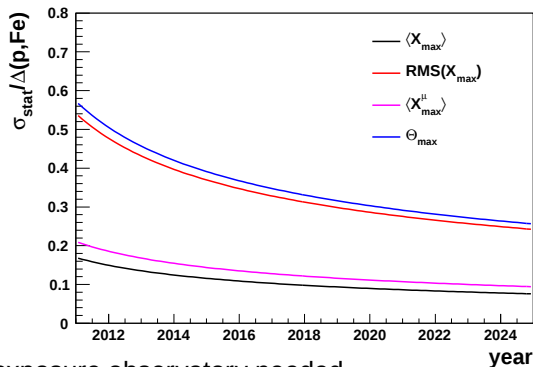
SD station +
30 m² buried scintillators



- ▶ HEAT: stable data taking since 1.5 years
- ▶ Muon Counters: start physics data taking with 6 stations this month

Outlook: Composition above the Flux Suppression

extrapolation of stat. uncertainty above 57 EeV



- ▶ large exposure observatory needed
- ▶ and/or significant improvement of observables
 - ▶ better modeling of μ and em component in trace?
 - ▶ multicomponent analysis?
 - ▶ additional information from radio/GHz?
 - ▶ scintillators, RPCs, ... ?