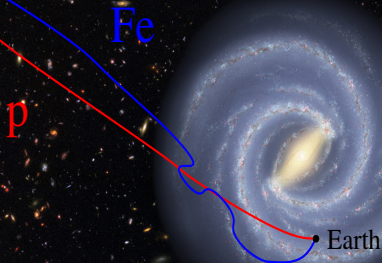


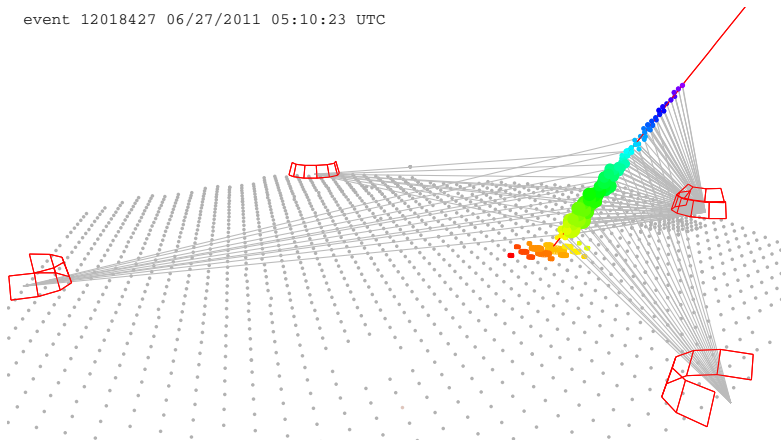
Cosmic Ray Composition and Charged Particle Astronomy

Michael Unger (KIT)



Mass Composition From Air Showers

event 12018427 06/27/2011 05:10:23 UTC



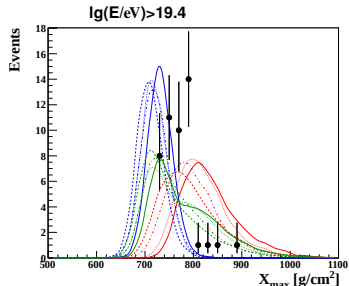
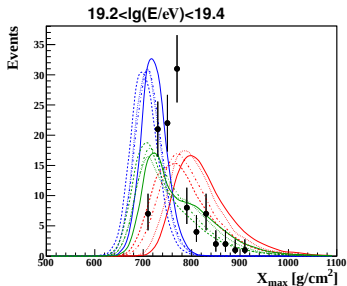
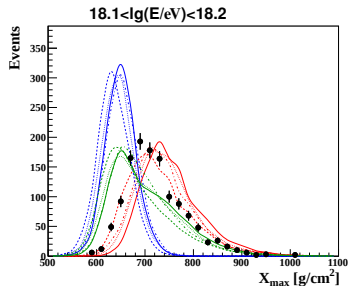
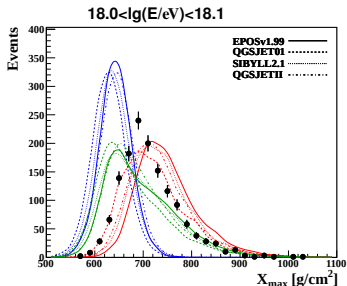
Auger hybrid event

sensitivity to primary mass A :

- longitudinal development: $X_{\max} \propto \ln A$
- ground level muons: $N_{\mu} \propto A^{1-\beta}$

$X_{\max}$ Results from Auger

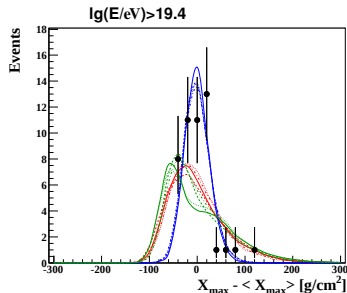
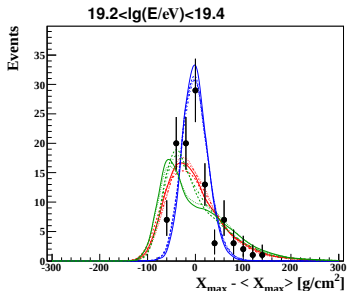
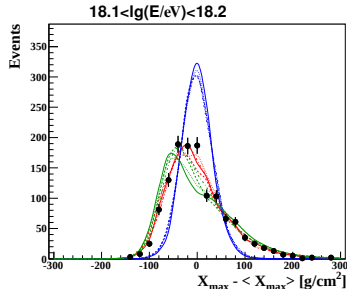
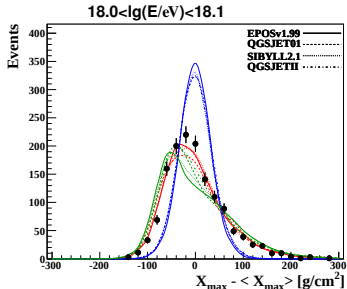
PAO at ICRC11



p, Fe, 50:50

$X_{\max}$ Results from Auger

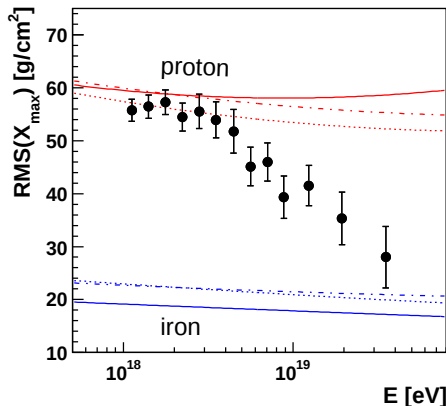
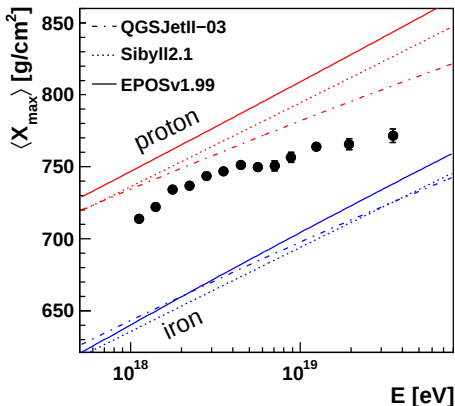
PAO at ICRC11



p, Fe, 50:50

$X_{\max}$ Results from Auger

PAO, PRL **104** (2010) 091101 and ICRC11

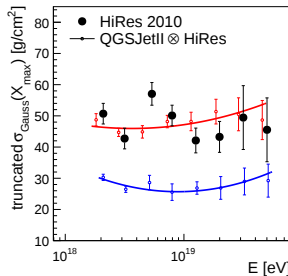
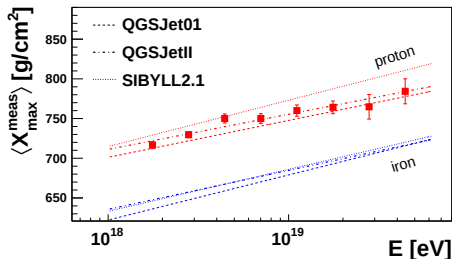


change of slope of $\langle X_{\max} \rangle$ vs E and decreasing fluctuations

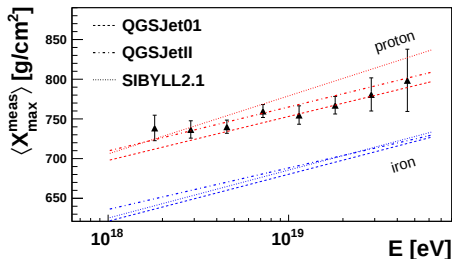
... and similar results on average longitudinal development from surface detector data of Auger

$X_{\max}$ Results from Northern Hemisphere

HiRes:



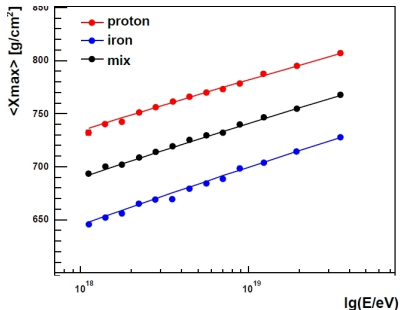
Telescope Array (prel.):



compatible with proton composition within uncertainties

Note: Different $X_{\max}$ Measurement Strategies

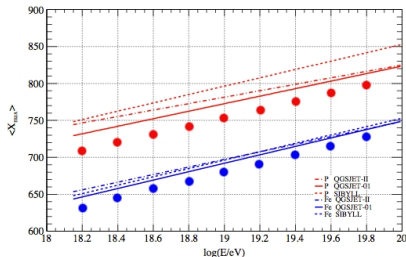
Auger



- correct rec. bias ($\sim 5 \text{ g/cm}^2$)
- apply fiducial volume cuts
- compare unbiased data to simulations at generator level

J. Bellido [Auger Coll.], ICRC09

TA/HiRes

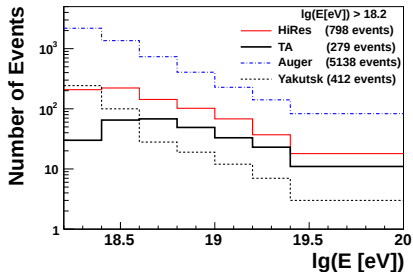


- apply same cuts in data/MC
- compare biased data to biased MC

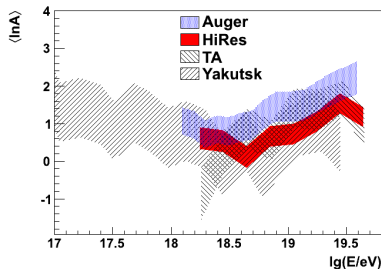
A. Tameda [TA Coll.] ICRC11

Mass Composition Working Group Auger/HiRes/TA/Yakutsk

statistics (energy scales adjusted):



logarithmic mass (Sibyll2.1):

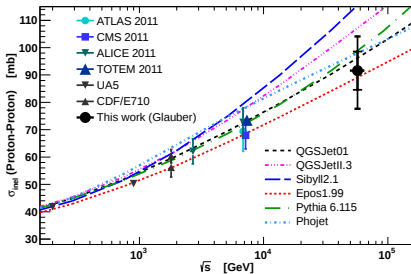


From the UHECR12 working group report:

“We need more statistics in the Northern Hemisphere (about 3 times the current statistics) in order to provide a conclusive statement to whether or not the composition is changing with energy in this Hemisphere. The current data, while completely consistent with a constant light composition, cannot definitively exclude a changing composition as suggested by Auger.”

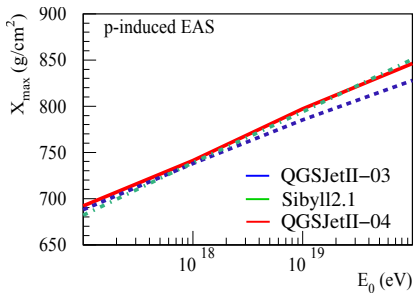
Hadronic Interactions?

Cross section:



PAO, PRL **109** (2012) 062002

LHC-tune of QGSJetII:



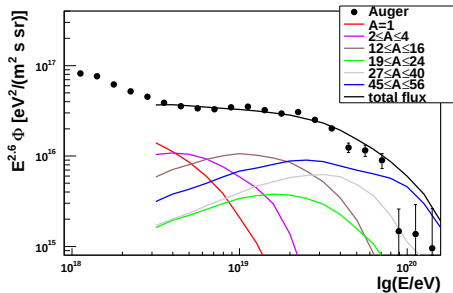
S. Ostapchenko, ICRC11

→ no sign of dramatic changes in hadronic interactions

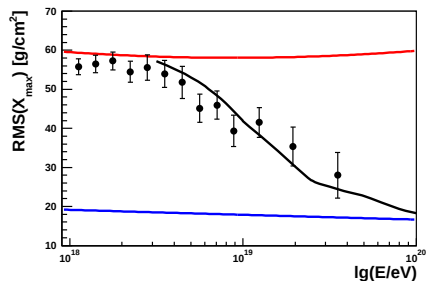
A Possible Astrophysical Scenario

e.g. D. Allard, arXiv:1111.3290

flux

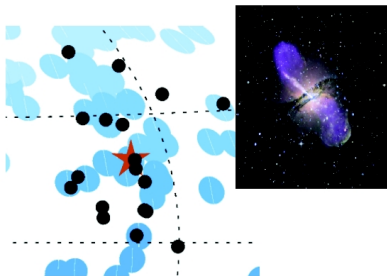


X_{max} fluctuations

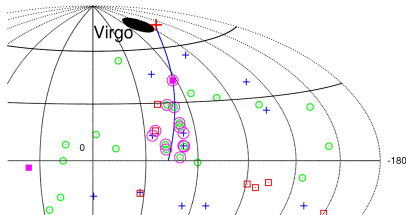


- Peters cycle: $E_{\text{max}} = Z \cdot (4 \cdot 10^{18}) \text{ eV}$
- composition mix as low energy galactic
- hard spectral index at the sources ($\beta = 1.6$)!

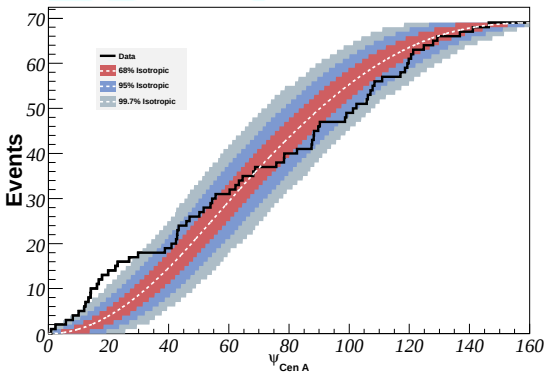
Nuclei from CenA?



... or Virgo?



Giacinti&Semikoz at ICRC11



Auger, APP **34** 2010,
a posteriori:

13/62 within 18° , expect 3.2
($E > 57$ EeV)

Nuclei from CenA?

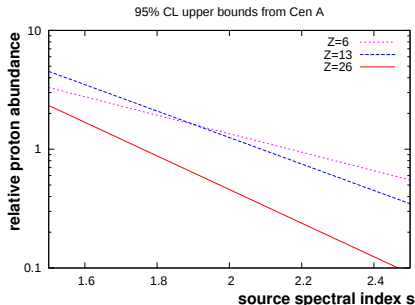
Lemoine & Waxman:

- nuclei of charge Z and energy E follow the same path in magnetic field as protons of energy E/Z
- anisotropies due to heavy primaries at $E > E_{\text{thr}}$ must be also present at $E > E_{\text{thr}}/Z$ if protons are accelerated in the source

Auger data:

JCAP 0911 (2009) 009

- no low energy anisotropy observed $\rightarrow$ limits on source composition and spectral index

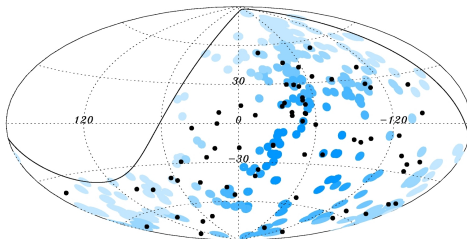


JCAP 1106 (2011) 022

Correlation with Nearby Extragalactic Matter

VCV catalogue, $E > 57$ EeV, $z < 0.018$, distance < 3.1 deg.

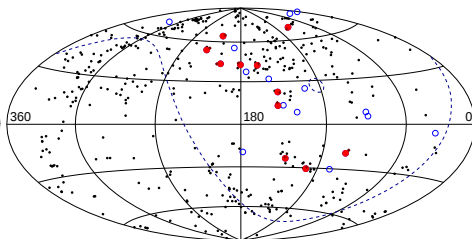
Auger



ICRC11 and APP **34** (2010) 314

28 out of 84, $P_{\text{chance}} = 1\%$

Telescope Array



Astrophys.J. **757** (2012) 26

11 out of 25, $P_{\text{chance}} = 2\%$

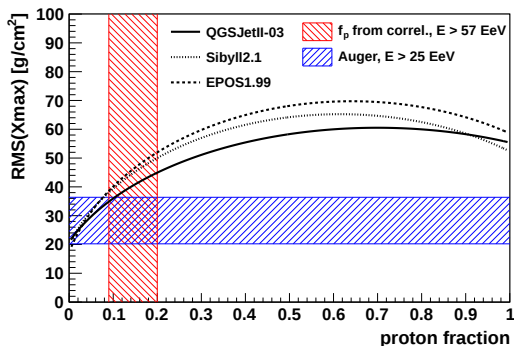
combined chance probability $\sim 10^{-3}$

Correlation with Nearby Extragalactic Matter

simplistic interpretation of correlation and composition:

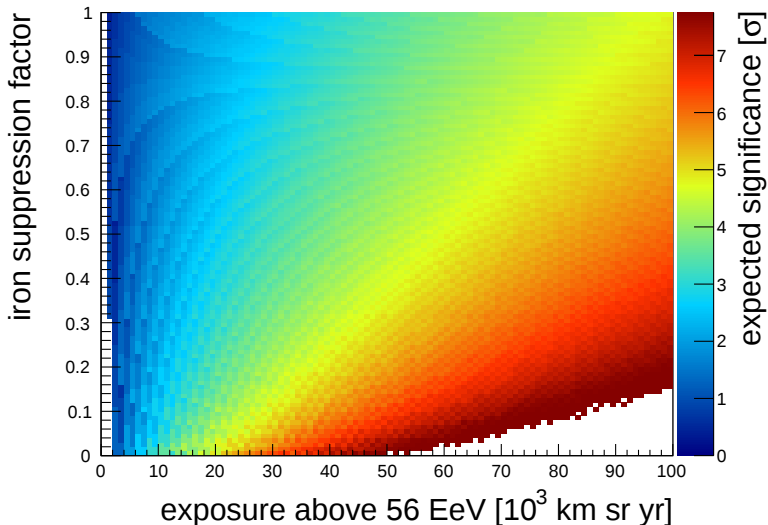
- fraction f_p of correlating protons
- $1 - f_p$ isotropized iron
- no intermediate nuclei (too small mean free path)
- Auger: $f_p = 12^{+7}_{-6} \%$, TA: $f_p = 20^{+15}_{-12} \%$

$$\rightarrow \langle f_p \rangle = 14^{+6}_{-5} \% (E > 57 \text{ EeV})$$



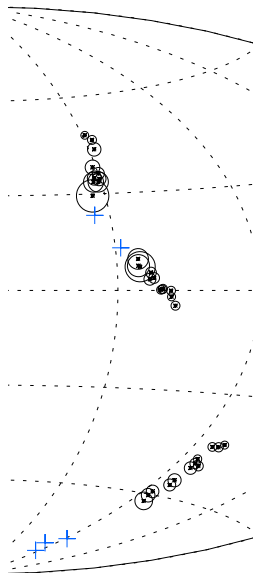
'Composition-enhanced' Astronomy?

expected significance of a 14% anisotropic light component:



Summary

- air shower data from Auger
→ nuclei at UHE?
- interpretation unchanged by new hadronic interaction data from LHC
- TA/HiRes compatible with proton, but cannot (yet) exclude Auger X_{max} in Northern hemisphere
- consistent picture assuming small fraction of light nuclei at UHE?
- composition sensitivity can enhance capabilities for astronomy of future UHE observatories
- ... and vice versa: galactic magnetic field can be used for mass spectroscopy



Auger multiplets at ICRC11