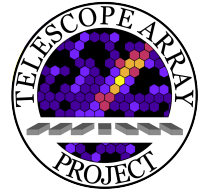


Report of the Working Group on the Composition of Ultra-High Energy Cosmic Rays

R. Abbasi, J. Bellido, J. Belz, V. de Souza, W. Hanlon, D. Ikeda, J.P. Lundquist, P. Sokolsky, T. Stroman, Y. Tameda, Y. Tsunesada, M. Unger and A. Yushkov

for the Pierre Auger and Telescope Array Collaborations

UHECR Working Groups

- Spectrum (TA+Auger)
- Anisotropy (TA+Auger), → ICRC #607, Astrophys.J. 794 (2014) 2, 172
- Composition (TA+Auger) → this presentation
- Hadronic Interactions (IC+TA+Auger)
- Multi-Messenger (IC+Auger+TA)
- Anisotropy (IC+Auger+TA) → ICRC #346

UHECR Symposium 2012, CERN

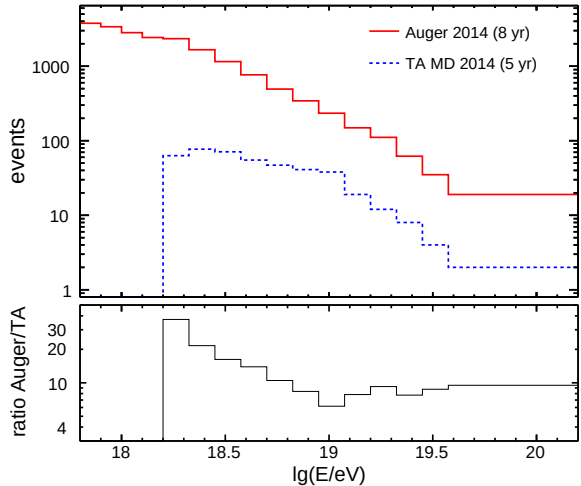
Data Samples

Auger:

- 8 years
- hybrid (at least one surface detector station)
- 24 telescopes
- 19,759 events above $10^{17.8}$ eV, 7365 events above $10^{18.2}$ eV
- PRD **90** (2014) 12, 122005

TA:

- 5 years
- hybrid (at least three surface detector station)
- Middle Drum telescopes (MD)
- 438 events above $10^{18.2}$ eV
- APP **64** (2014) 49



Composition from Shower Maximum ($X_{\max}$)

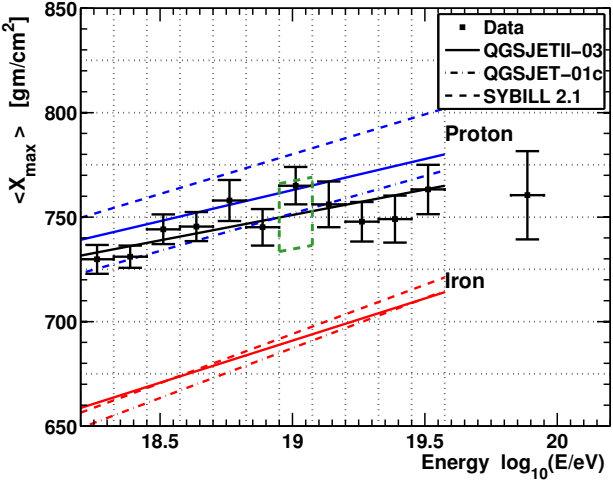
Telescope Array Collaboration, APP **64** (2014) 49:

"[...] good agreement is evident between data and a light, largely protonic, composition when comparing the measurements to predictions obtained with the QGSJetII-03 and QGSJet-01c models."

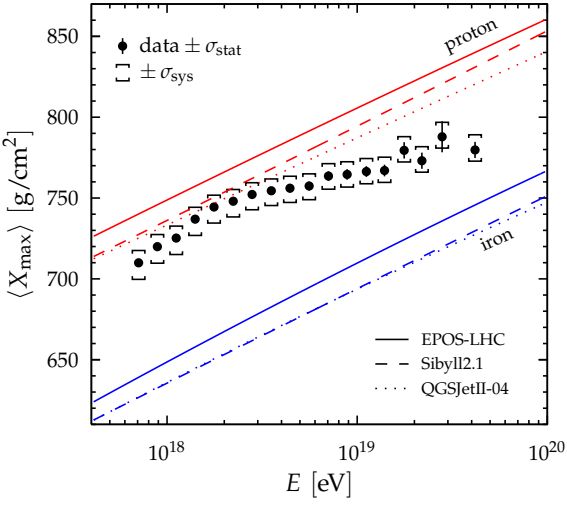
Pierre Auger Collaboration, PRD **90** (2014) 12, 122005:

"[...] simulations have been performed using the three contemporary hadronic interaction models (QGSJETII-04, EPOS-LHC, SIBYLL2.1). [...] there is an evolution of the average composition of cosmic rays towards lighter nuclei up to energies of $10^{18.27}$ eV. Above this energy, the trend reverses and the composition becomes heavier."

Average Shower Maximum, $\langle X_{\max} \rangle$

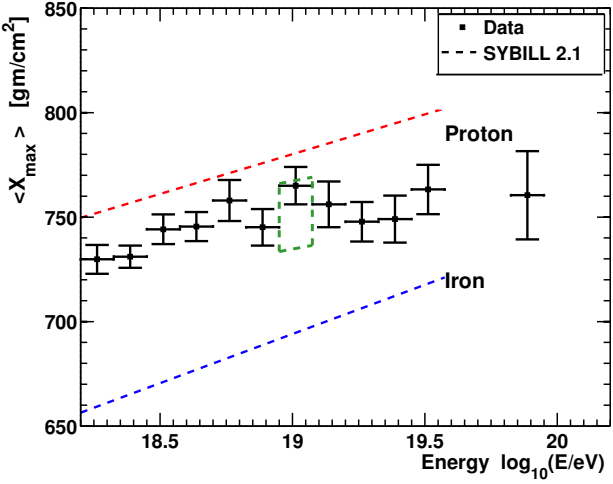


Telescope Array Collaboration, APP **64** (2014) 49

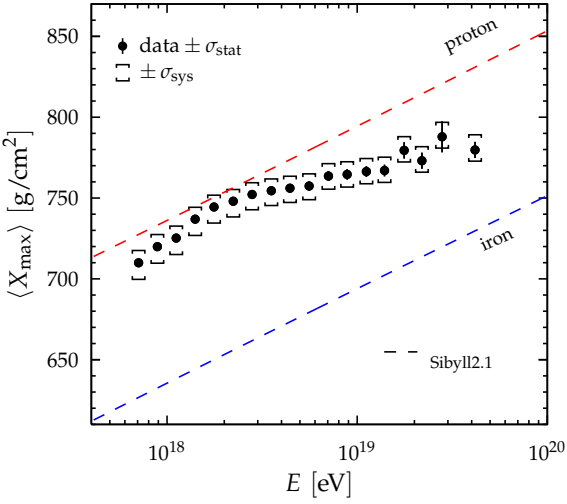


Pierre Auger Collaboration, PRD **90** (2014) 12, 122005

Average Shower Maximum, $\langle X_{\max} \rangle$



Telescope Array Collaboration, APP **64** (2014) 49



Pierre Auger Collaboration, PRD **90** (2014) 12, 122005

Different Analysis Strategies

Steven Saffi, University of Adelaide

Ben Stokes, University of Utah

Auger:

- minimize measurement bias
- result: "$\langle X_{\max} \rangle$ in atmosphere"
- compare to: simulations at generator level

TA:

- maximize statistics
- result: "$\langle X_{\max} \rangle$ in detector"
- compare to: simulations including detector effects

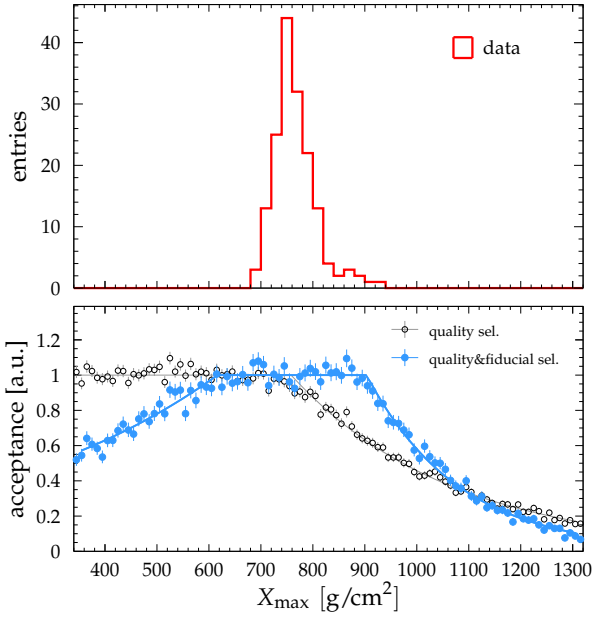
Different Analysis Strategies

Auger $X_{\max}$ results:

- $\sim$ no acceptance bias

TA $X_{\max}$ results:

- includes acceptance bias

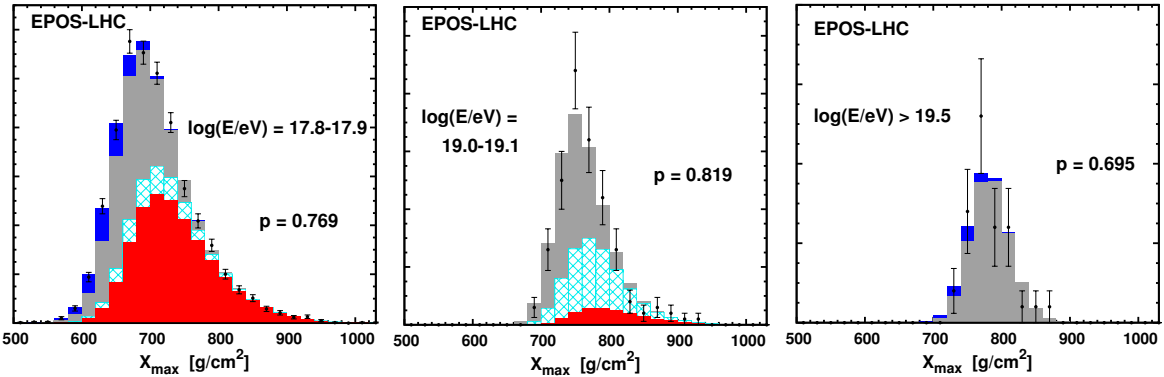


example: Auger $X_{\max}$ acceptance, $19.0 < \lg(E/\mathrm{eV}) < 19.1$

How to Compare $\langle X_{\max} \rangle$ of the $X_{\max}$ Distributions from TA and Auger

Step 1: Construct a model of the $X_{\max}$ distribution that describes the Auger data

proton, helium, nitrogen, iron

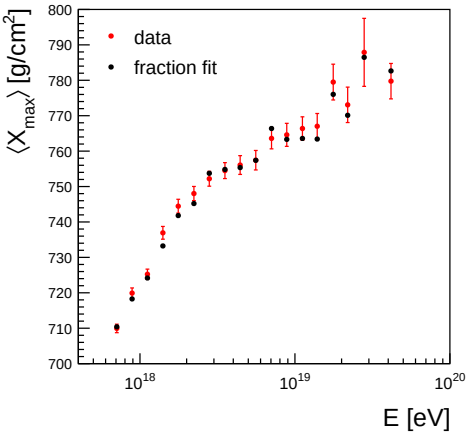


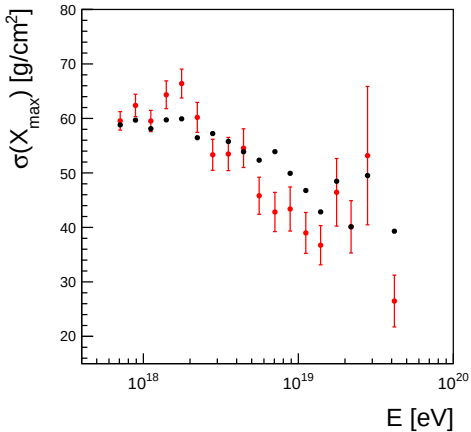
Pierre Auger Collaboration, PRD **90** (2014) 12, 122006

How to Compare $\langle X_{\max} \rangle$ of the $X_{\max}$ Distributions from TA and Auger

Step 1: Construct a model of the $X_{\max}$ distribution that describes the Auger data

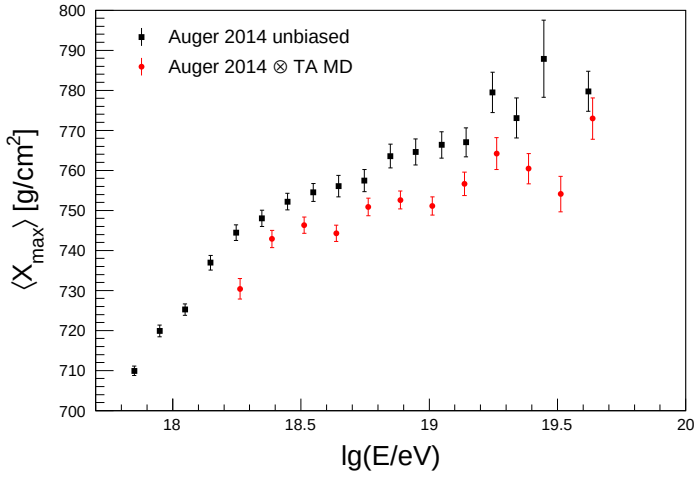
here: use QGSJETII-03 for fitting composition fractions $\rightarrow$ reasonable agreement with data



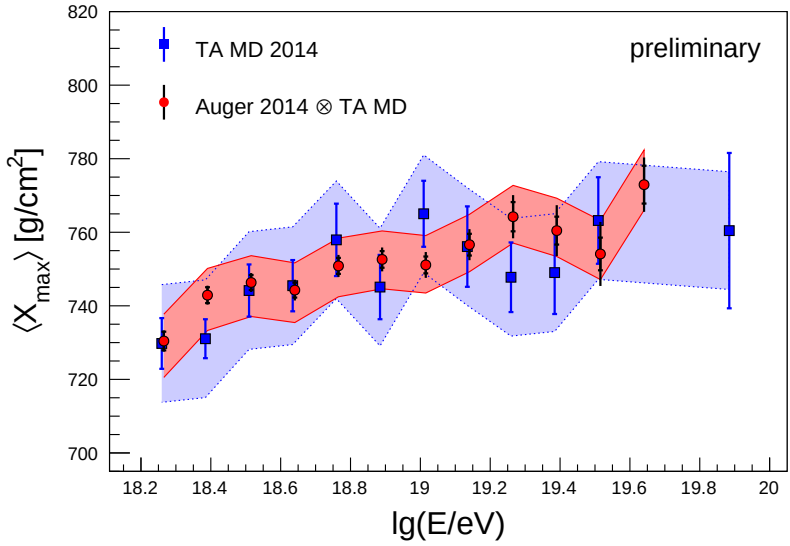


How to Compare $\langle X_{\max} \rangle$ of the Auger and TA Data

Step 2: Pass this "Auger-like" $X_{\max}$ distribution through TA detector simulation, reconstruction and analysis



Result



average difference: $\langle \Delta \rangle = (2.9 \pm 2.7\ (\text{stat.}) \pm 18\ (\text{syst.}))\ \text{g/cm}^2$

Summary and Outlook

Comparison:

- account for acceptance bias included in TA result
- average X_{max} agrees within uncertainties,
  $\langle \Delta \rangle = (2.9 \pm 2.7\ (\mathrm{stat.}) \pm 18\ (\mathrm{syst.}))\ \mathrm{g/cm^2}$

Next Steps:

- improve model of X_{max} distribution by using EPOS-LHC (describes Auger data better than QGSJetII-03)
- compare full distributions
- repeat analysis for new TA analyses with higher statistics
  (see John's talk later this session)

...

Mean and Standard Deviation of $X_{\max}$ Distribution