

Relation of Interaction Characteristics at Ultra-High Energies to Extensive Air Shower Observables

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Measurement of the primary cosmic ray mass composition

⇒ What are the systematic uncertainties in air shower modeling?

Results

- Interaction model differences are not a perfect tracer of air shower modeling systematics
- Currently, uncertain interaction characteristics have comparable magnitude than mass composition differences
- LHC has the potential to drastically improve cosmic ray data interpretation

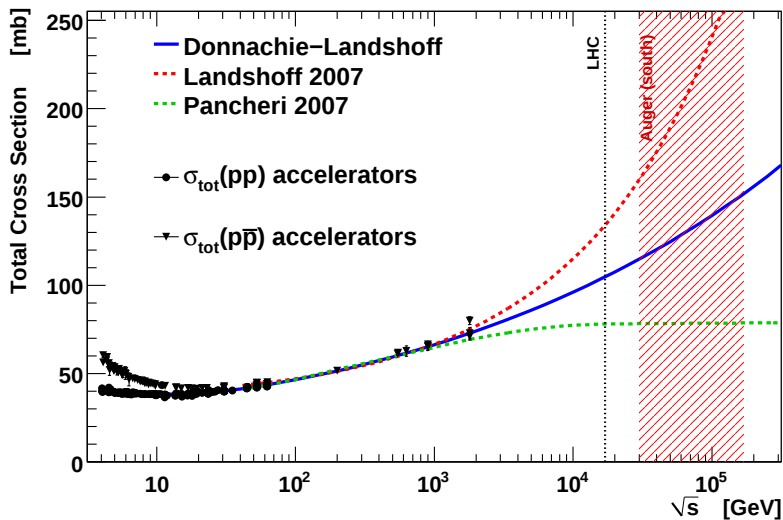
Measurement of the primary cosmic ray mass composition

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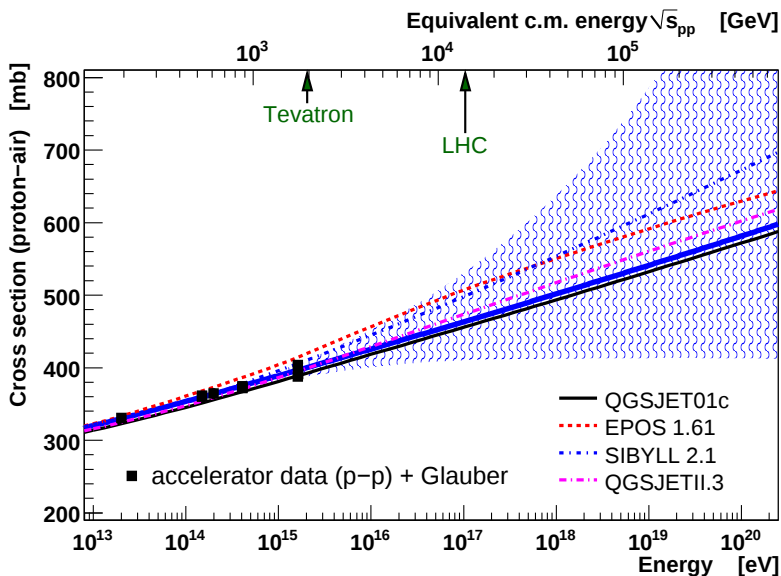
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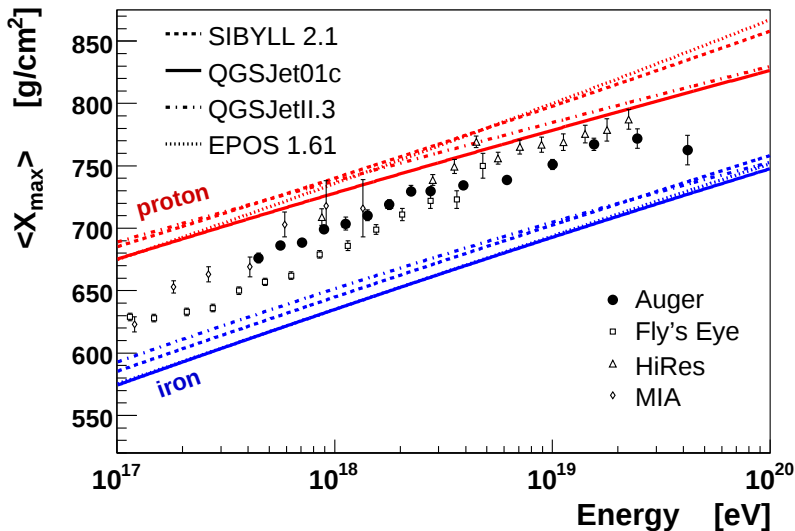
Model Extrapolations



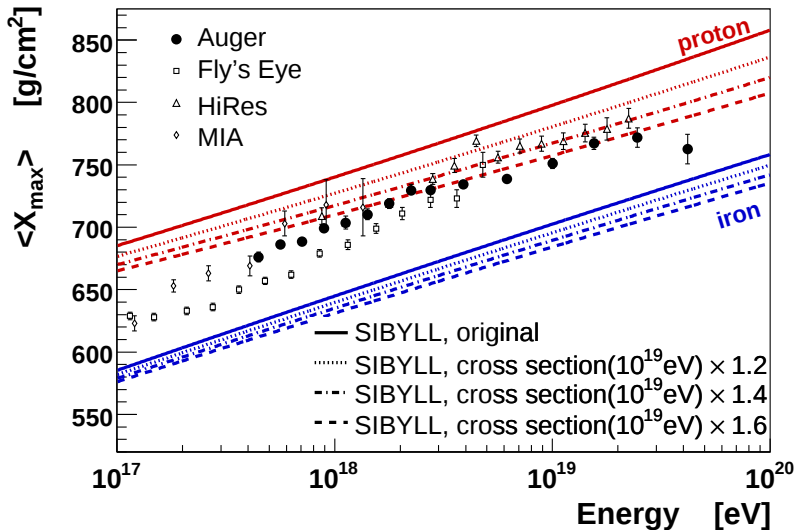
Relevance to Air Showers: Proton-Air Cross Section



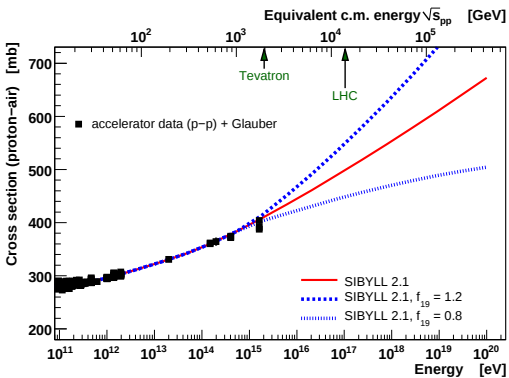
Interpretation of Air Shower Data



Interpretation of Air Shower Data



Method, Definition of f_{19}



f_{19} is the value of a multiplicative factor

$$f(E, f_{19}) = 1 + (f_{19} - 1) \begin{cases} 0 & E \leq 1 \text{ PeV} \\ \frac{\log_{10}(E/1 \text{ PeV})}{\log_{10}(10 \text{ EeV}/1 \text{ PeV})} & E > 1 \text{ PeV} \end{cases},$$

at 10¹⁹ eV

Extension to Particle Production Characteristics

Modification of:

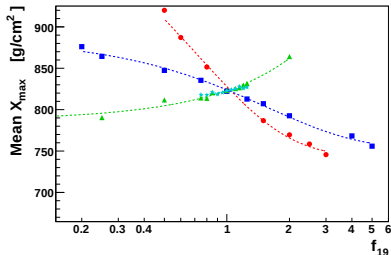
- Multiplicity: n_{mult}
- Elasticity: $k_{\text{ela}} = E_{\text{leading}}/E_{\text{max}}$
- Pion-Charge Ratio: $c = n_{\pi^0}/(n_{\pi^0} + n_{\pi^+} + n_{\pi^-})$

Modify hadronic event generators during the shower simulation process:

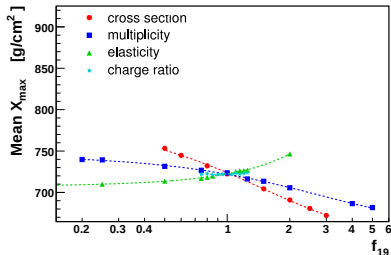
- CONEX Air Shower Simulation Program
- SIBYLL interaction model (semi-superposition model)
- Proton and iron induced showers at $10^{19.5}$ eV

Results for $\langle X_{\max} \rangle$

Proton



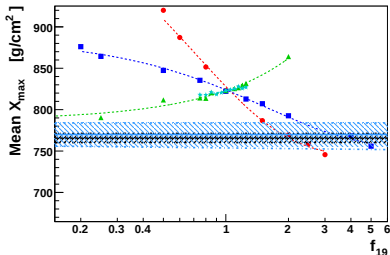
Iron



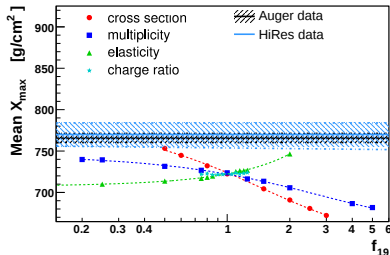
- $\langle X_{\max} \rangle$ can be shifted significantly
- Auger and HiRes data are suggesting
 - Large cross section for a proton dominated composition
 - Small cross section for a iron dominated composition
 - or: intermediate mass, mixed composition

Results for $\langle X_{\max} \rangle$

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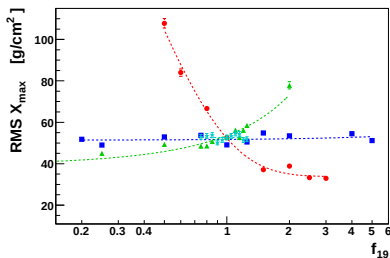
Iron



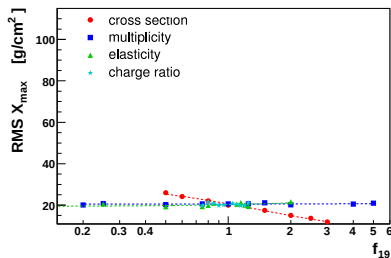
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Results for $\text{RMS}(X_{\text{max}})$

Proton



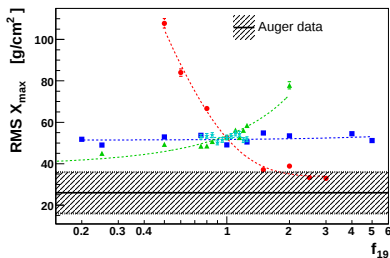
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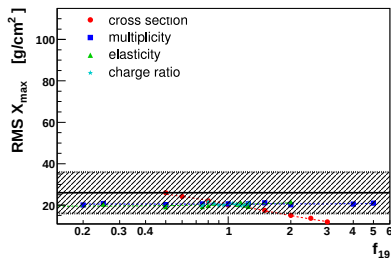
- $\text{RMS}(X_{\text{max}})$ mostly impacted by cross section, and elasticity
- Iron induced showers very robust
- Auger data only marginally compatible with protons in a high cross section scenario

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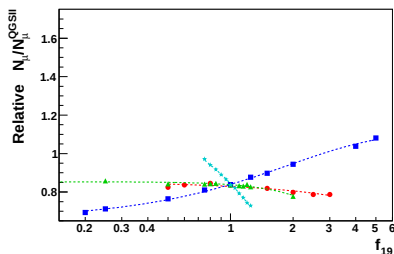
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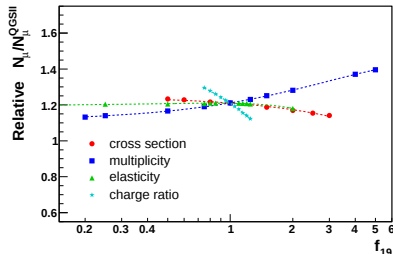
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Results for Muon Numbers

Proton



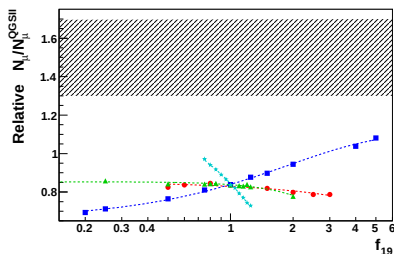
Iron



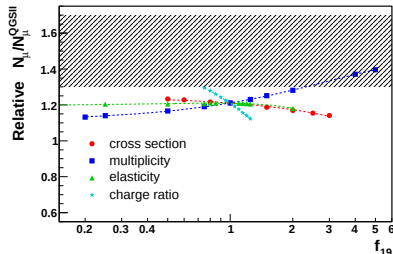
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- Auger muon data incompatible with proton scenario
- Even for iron primaries: multiplicity must be high and pion-charge-ratio small

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Proton



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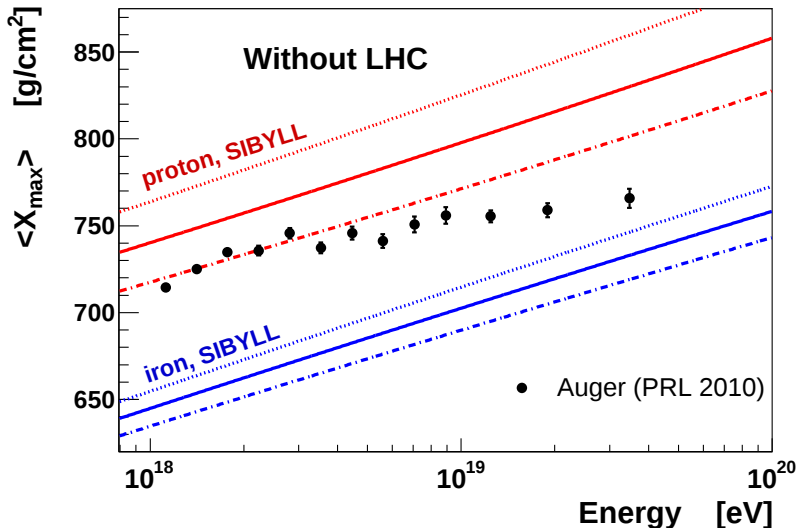
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Caution: Definition of Muon number is not identical, e.g.:
Auger measures at 1000 m, Simulations give total muon number

Potential Impact of LHC on Interpretation of EAS Data

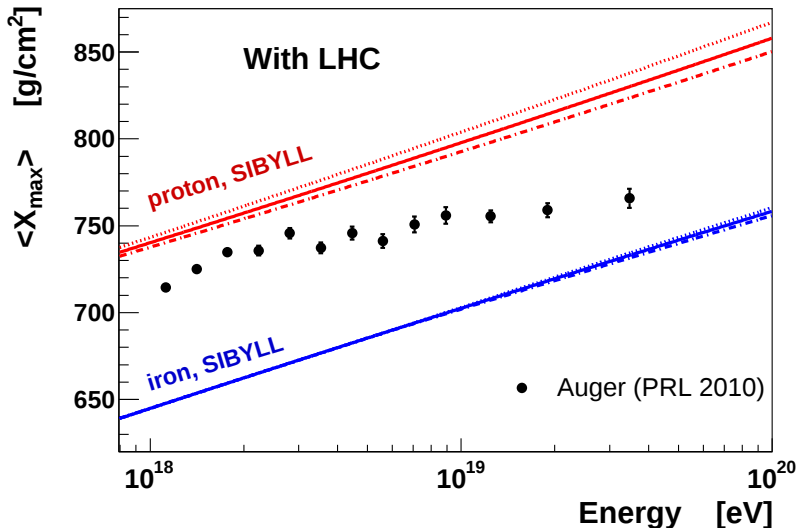
At the example of a precise measurement of the elasticity

Impact of Elasticity / Leading Particles



- Precise measurement of elasticity at 300 GeV
- Extrapolation uncertainty grows by 10 % per decade in energy

Impact of Elasticity / Leading Particles

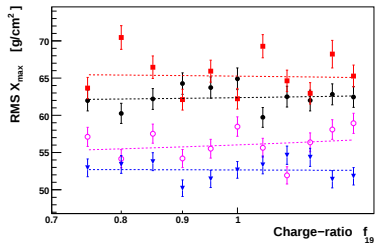
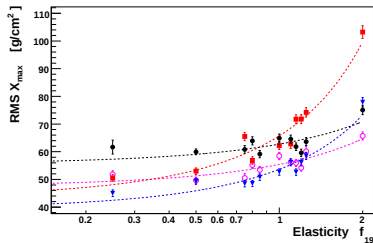
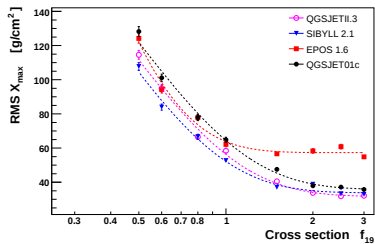
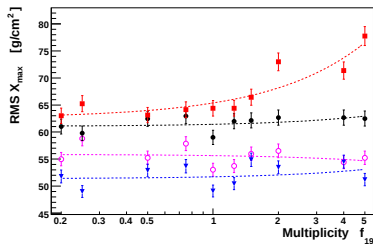


- Precise measurement of elasticity at 14 TeV
- Extrapolation uncertainty grows by 10 % per decade in energy

- High energy models are not sampling the full range of existing uncertainties
- Models need tuning to data as close to the phase space relevant in air showers as possible
- Interaction characteristics has impact on air shower observables on the same order of magnitude as as primary mass composition
 - ⇒ Almost impossible to “measure” mass composition from air shower observables in the moment
- LHC has the potential to bring significant improvements in analysing air shower data

Additional Slides

Model Dependence – $\text{RMS}(X_{\text{max}})$



Model Dependence – Muon Numbers

