Air showers, hadronic models, and muon production

S. J. Sciutto

Departamento de Física and IFLP/CONICET
Universidad Nacional de La Plata
La Plata, Argentina

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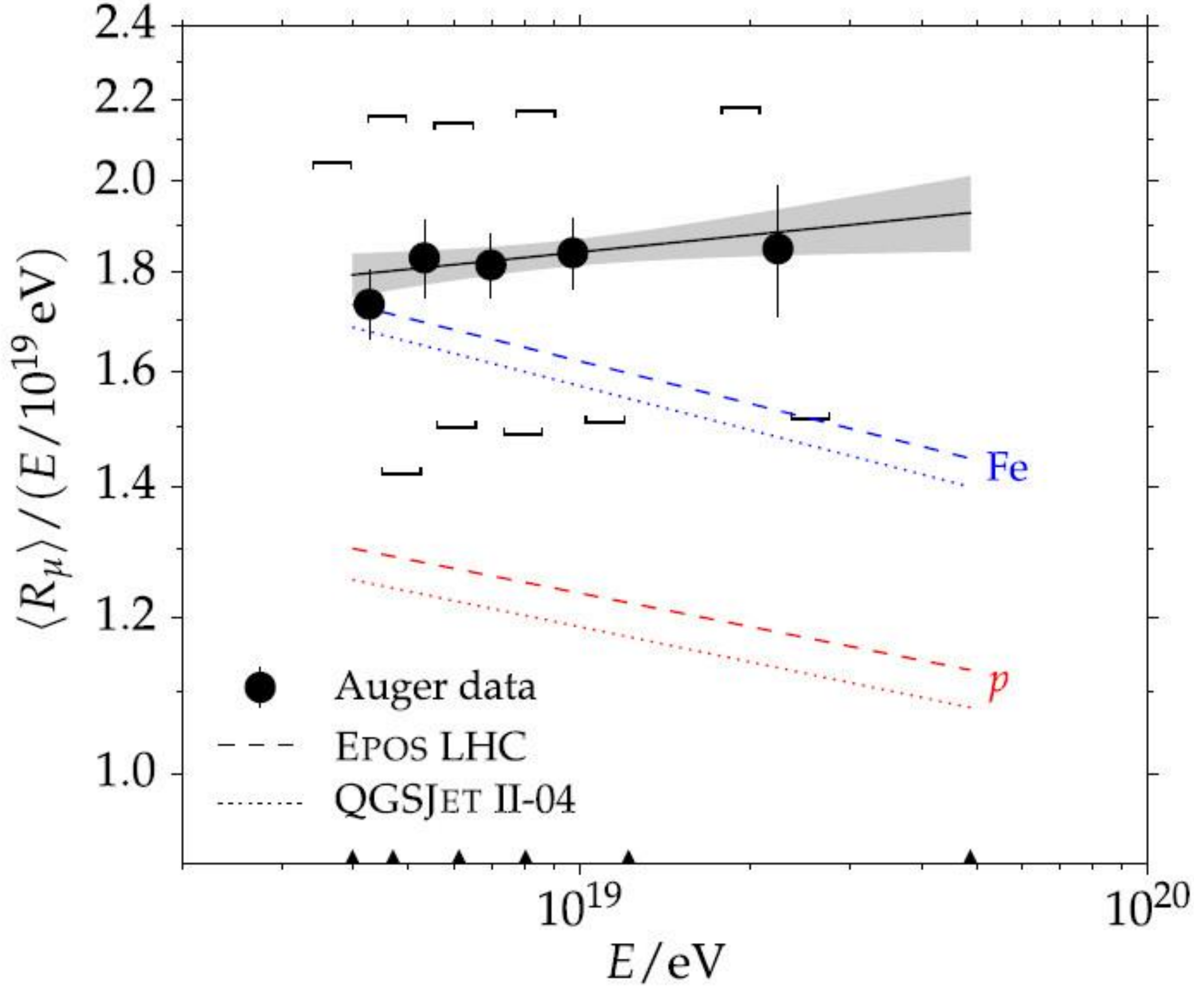
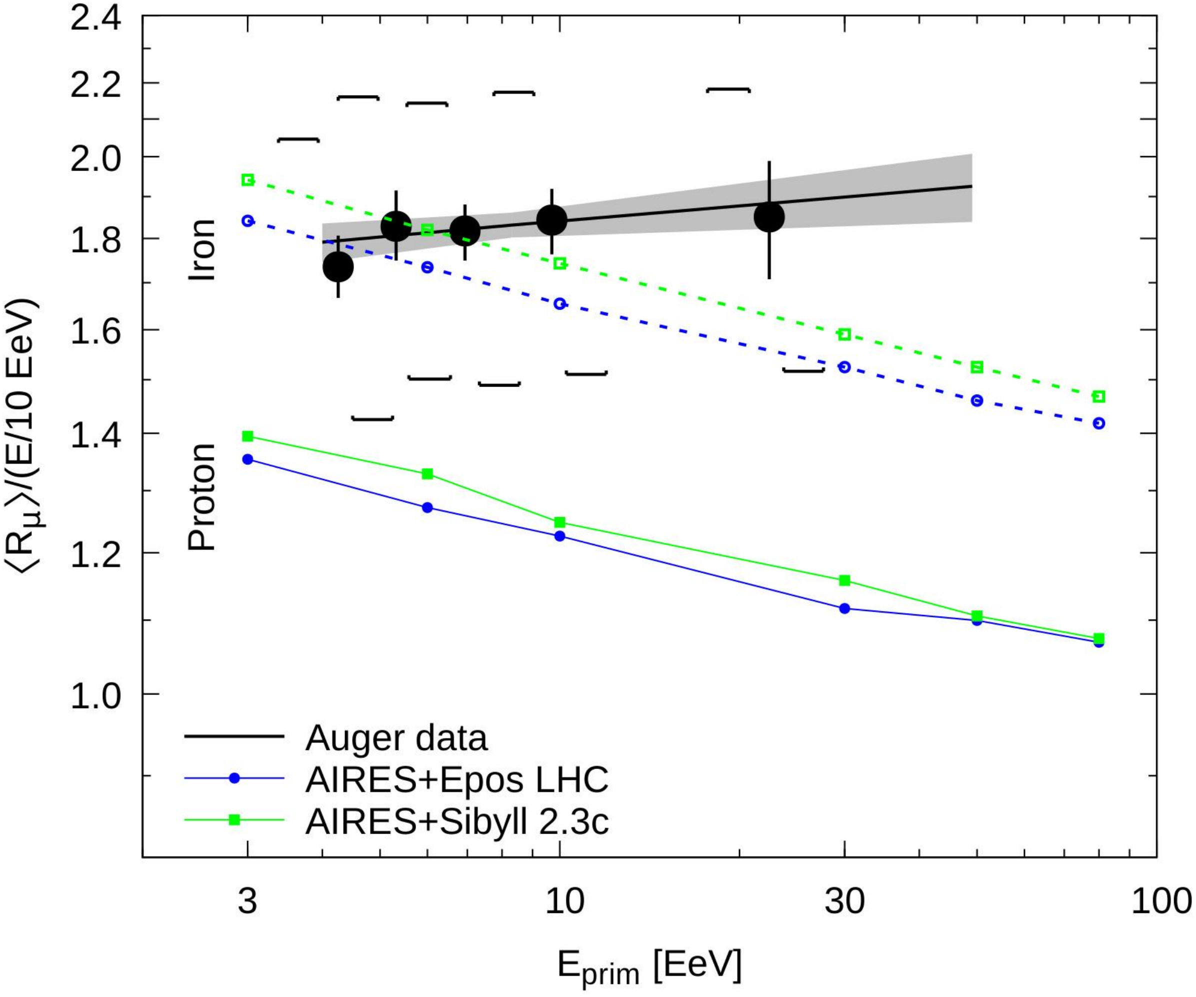


AUGER muons in highly inclined events.

Auger Collab., *Phys. Rev. D*, **91**, 032003 (2015).



Muons in inclined showers

New analysis with AIRES 18.09.00

R_μ evaluated from ground muons with E > 300 MeV produced in showers inclined 67 deg.

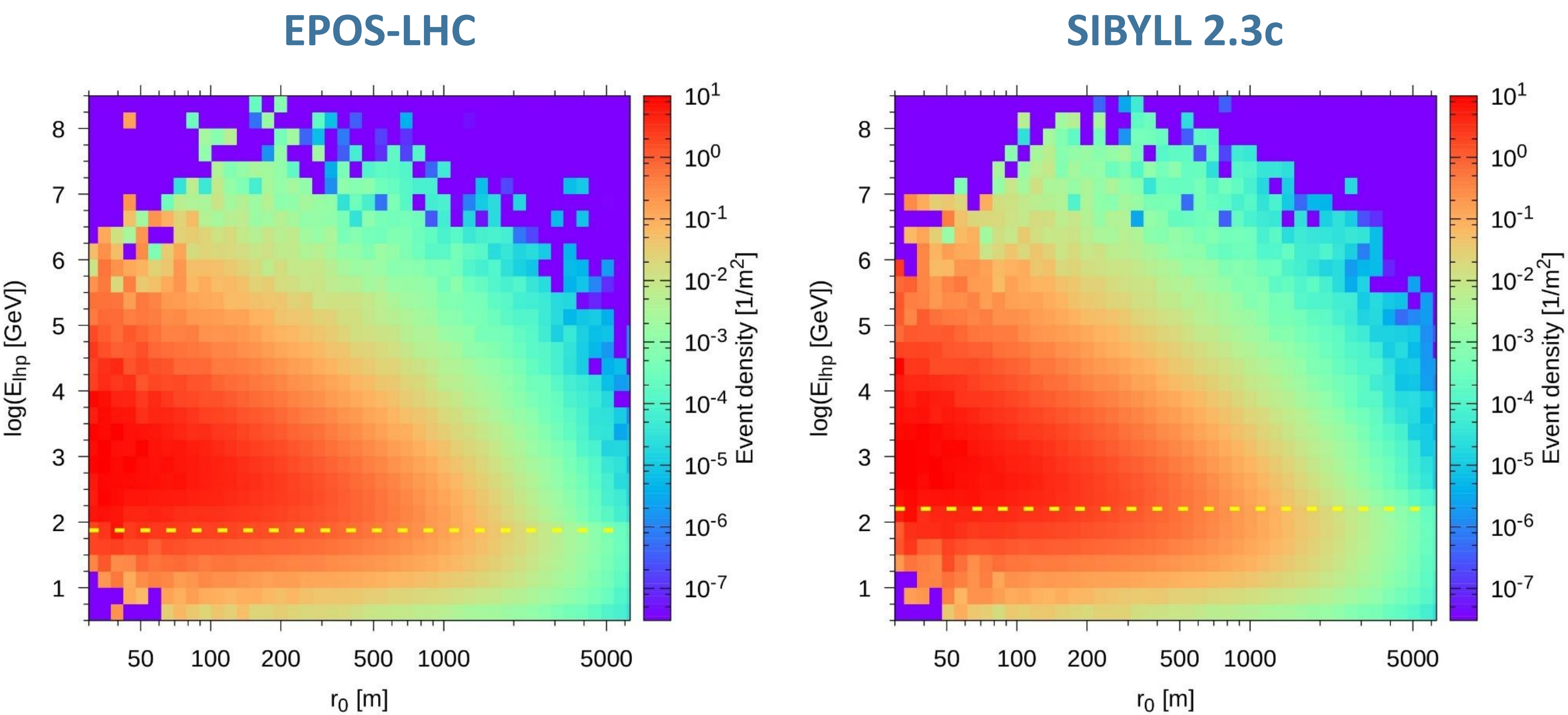
AIRES 18.09.00.

- Pre and post-LHC versions of the hadronic models EPOS, QGSJET, and SIBYLL.
- Propagation of an extended set of particles.
- Detailed decay of unstable particles.
- Extended set of particle data available for analysis:
  - ***Parent particle info*** *(identity, energy, altitude).*
  - ***Last hadronic event info*** *(proj. identity and energy, altitude).*
- Numerous technical improvements.

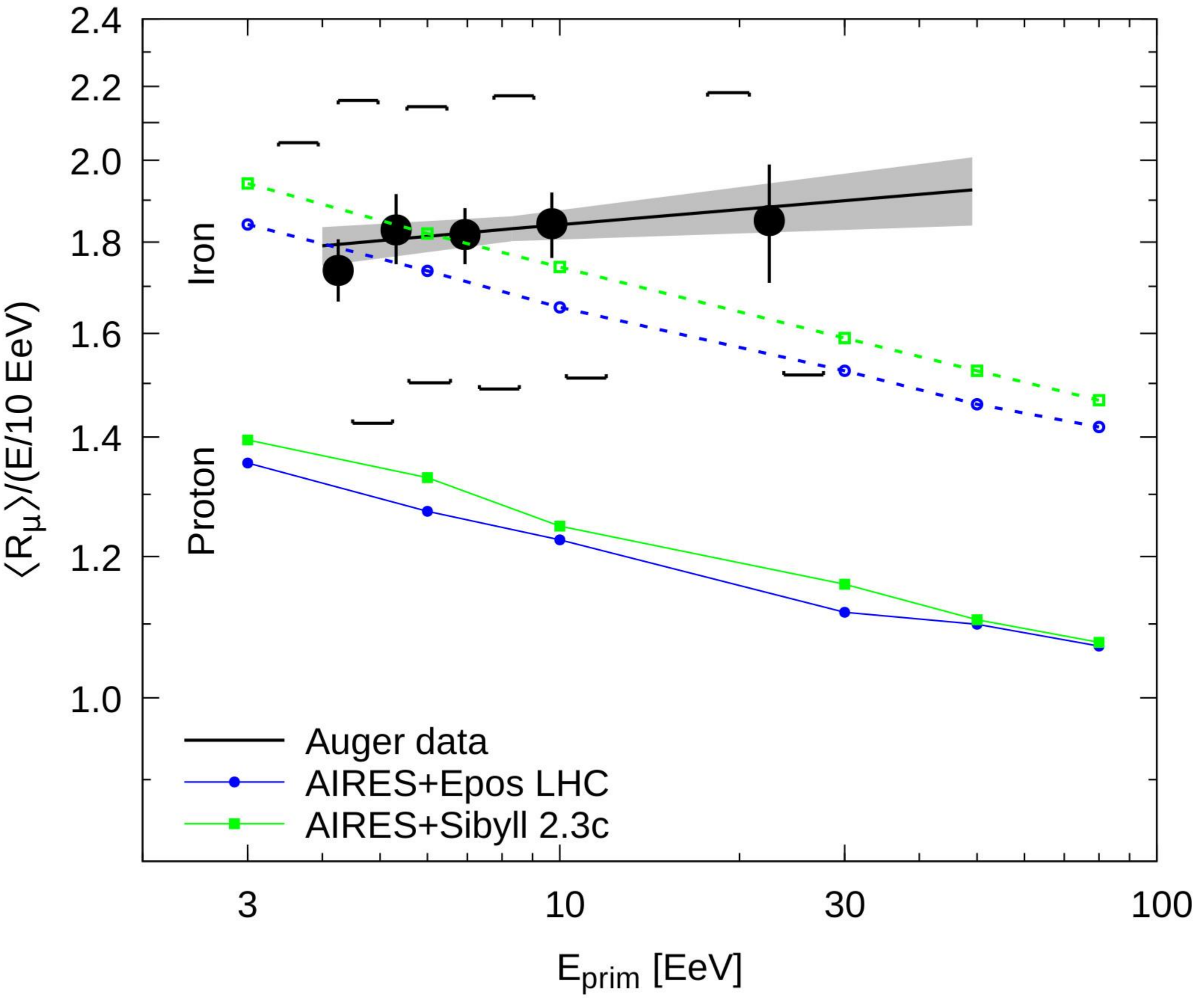
- **Visit *aires.fisica.unlp.edu.ar***

Ground muon analysis with AIRES.

Muon lateral vs last hadronic projectile energy distrib.



10 EeV proton showers inclined 67 deg.
Ground muons with E > 300 MeV

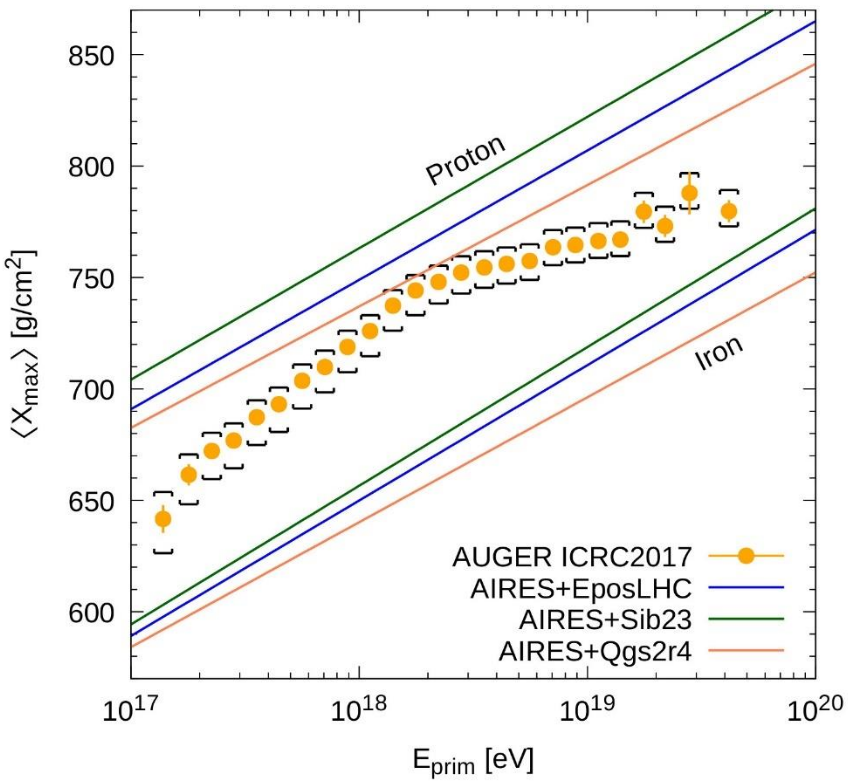


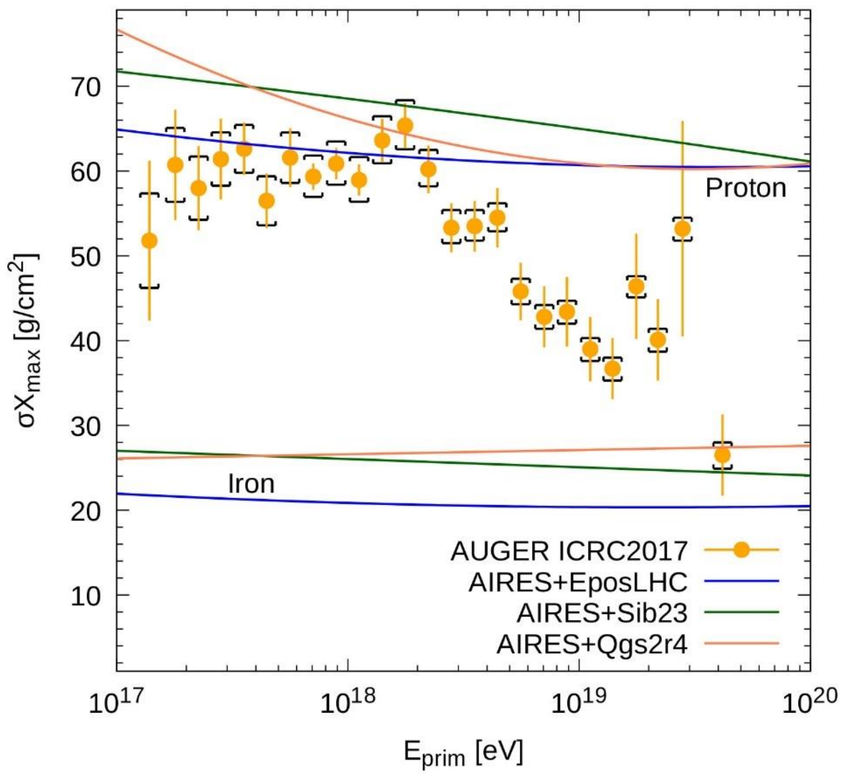
Muons in inclined showers

New analysis with AIRES 18.09.00 (II).

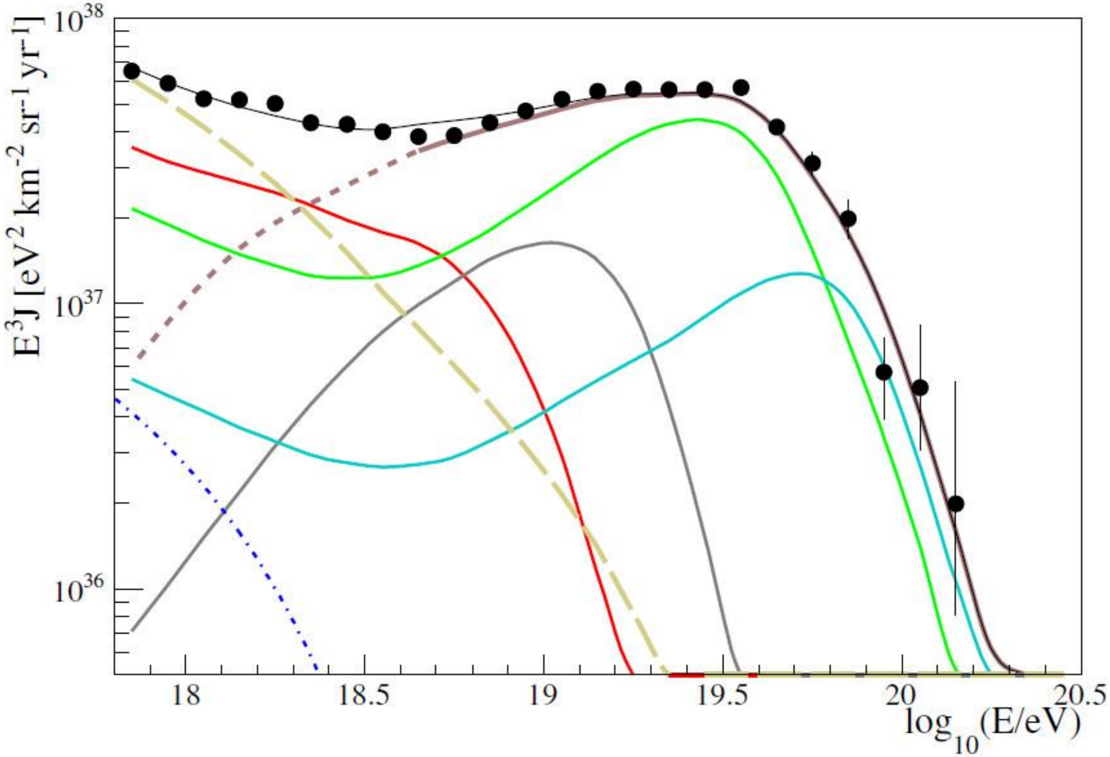
R_μ evaluated from ground muons with E > 300 MeV produced in showers inclined 67 deg.

Longitudinal analysis with AIRES.
X_{max} versus primary energy





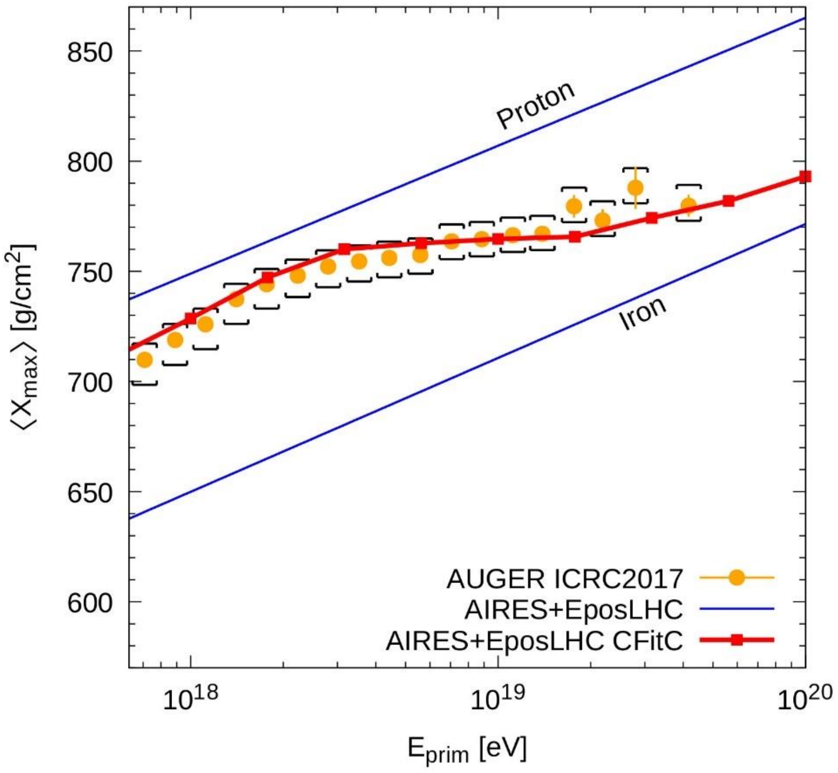
AUGER spectrum and X_{max} combined fit

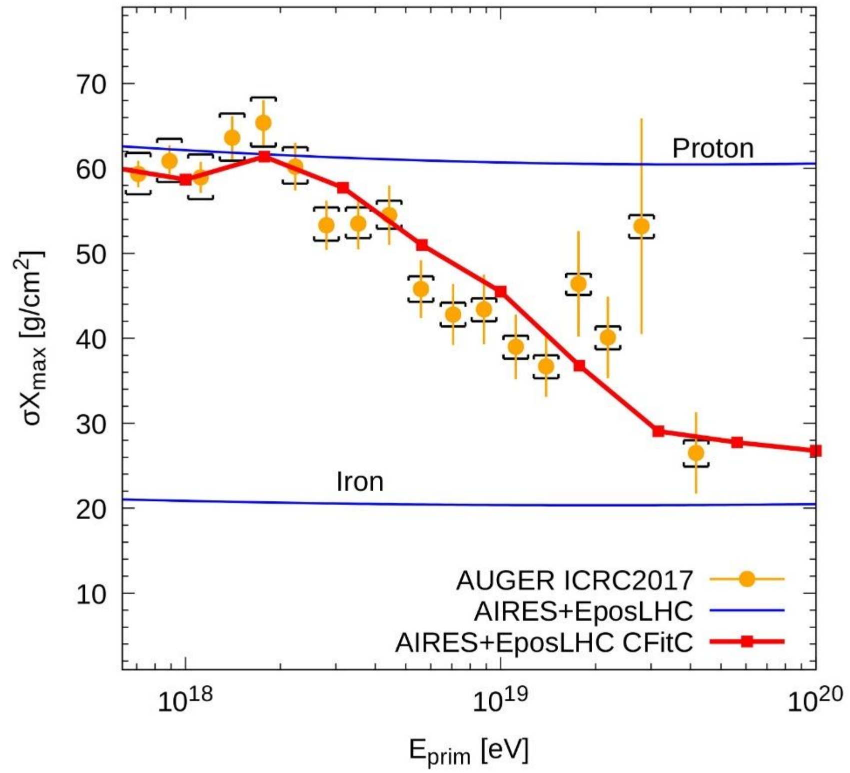


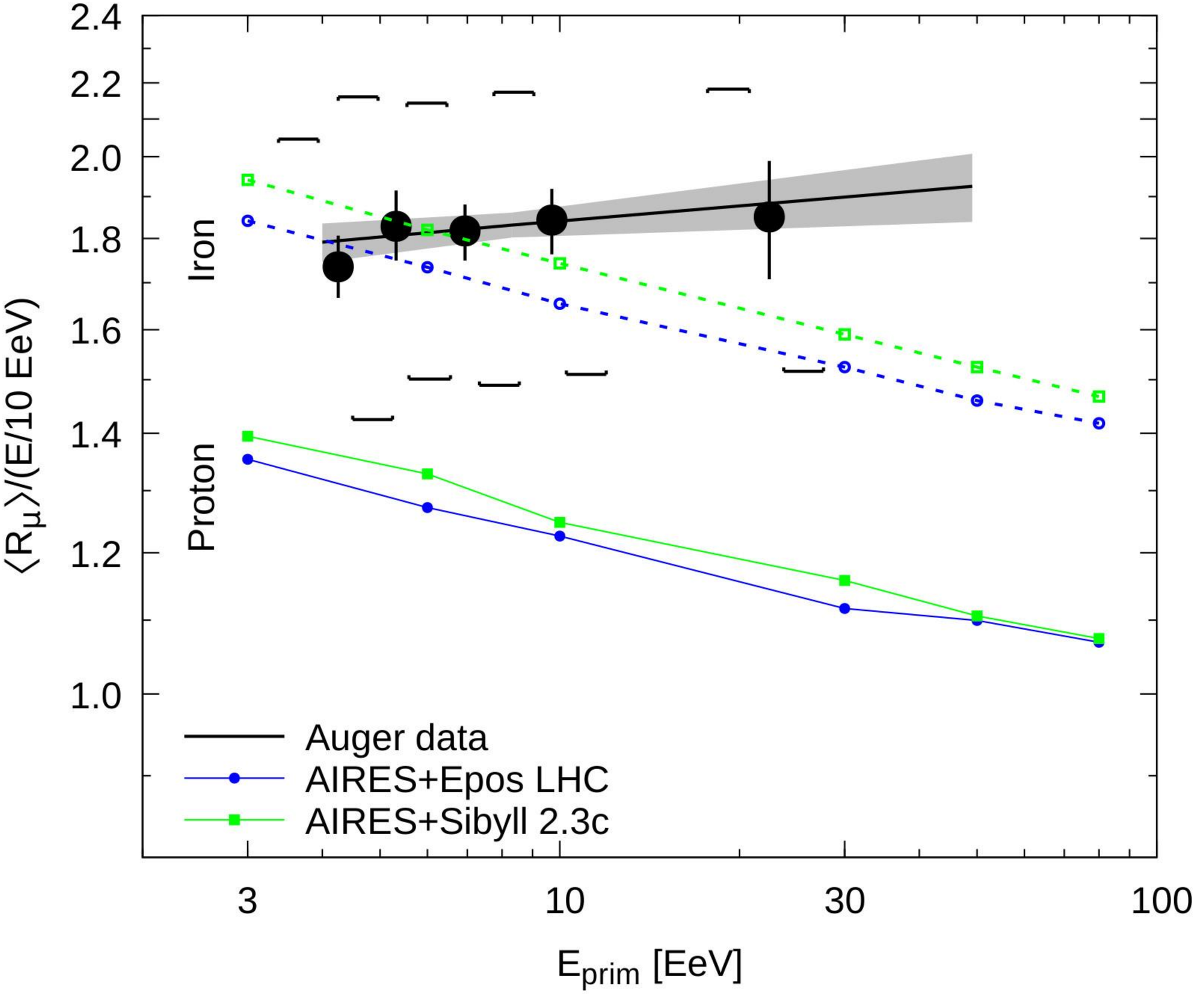
H^1 (red) , He^4 (grey), N^{14} (green), Si^{28} (cyan), Fe^{56} (blue)

Auger Collab., *JCAP,* **04**, 038 (2017).

X_{max} and combined fit composition.
New analysis with AIRES 18.09.00



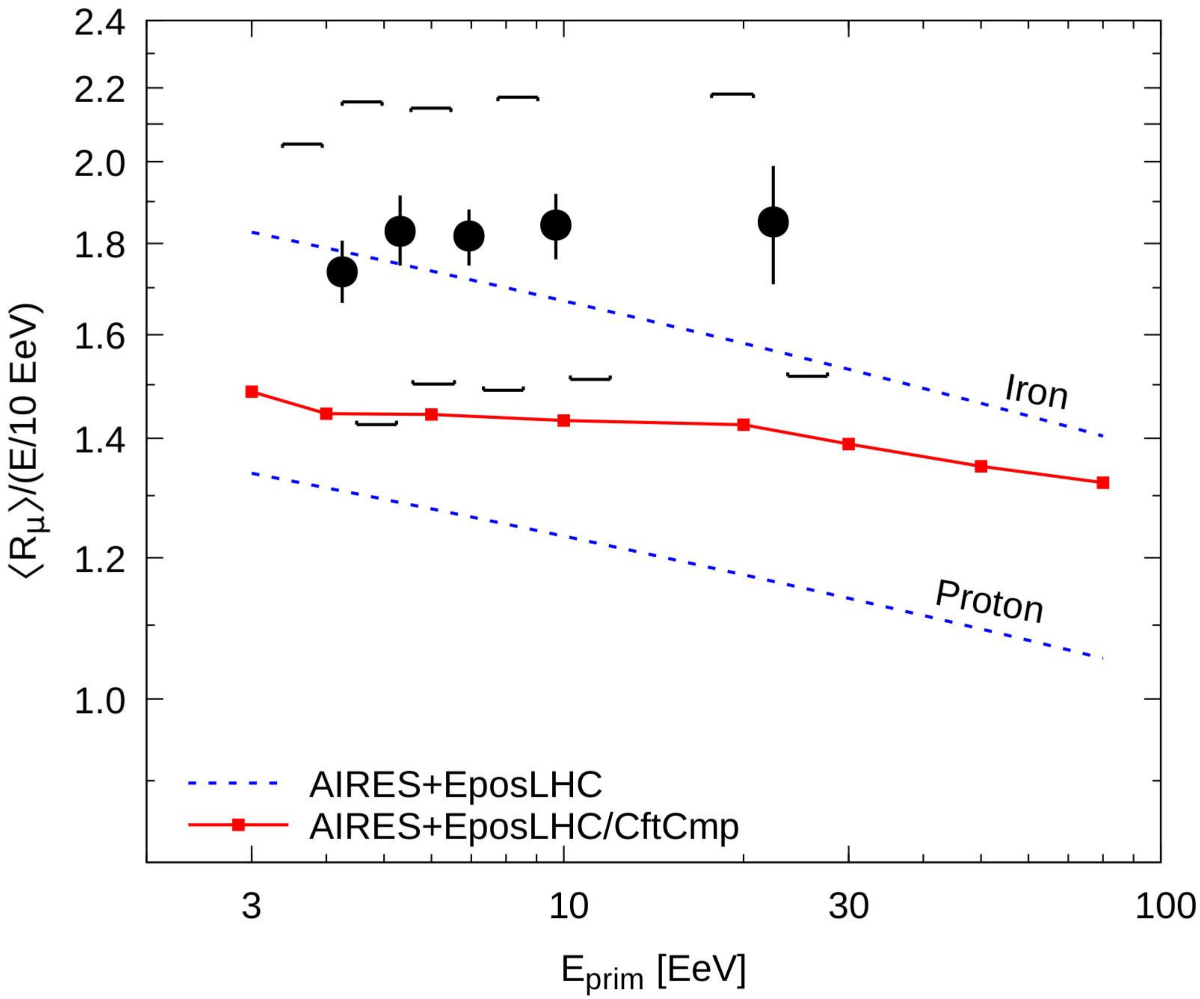




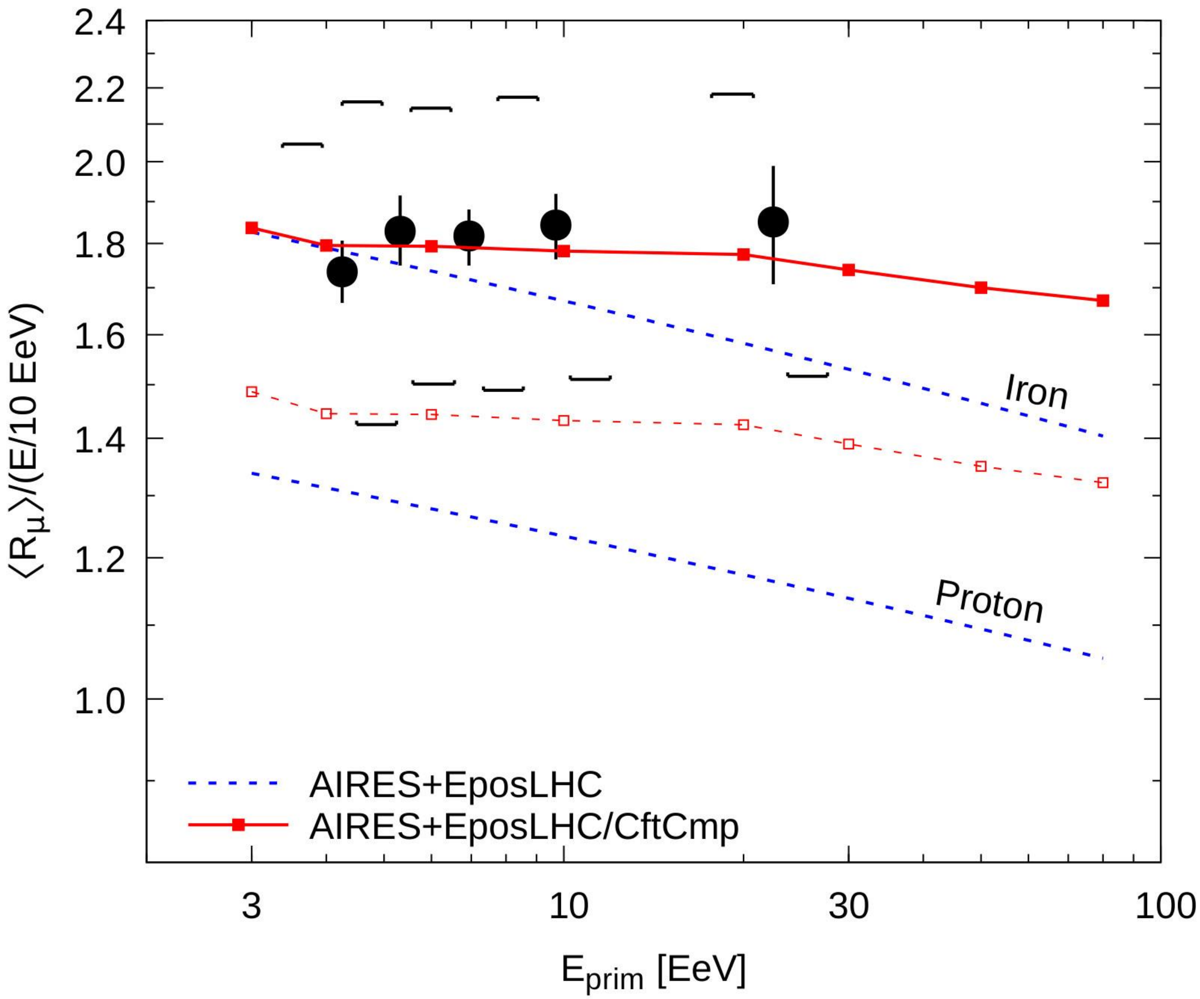
Muons in inclined showers

New analysis with AIRES 18.09.00 (III).

R_μ evaluated from ground muons with E > 300 MeV produced in showers inclined 67 deg.

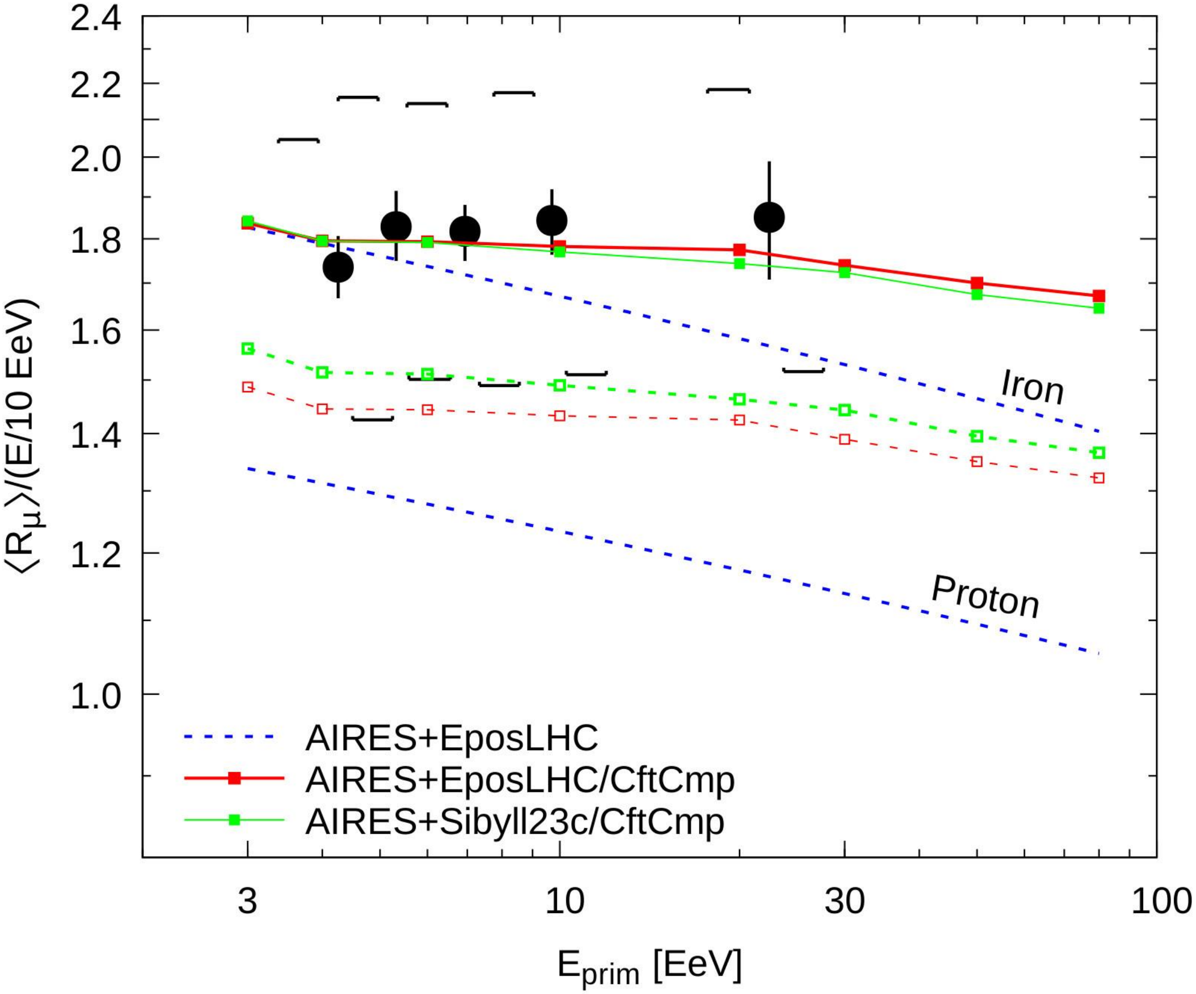


Combined fit composition and ground muons



Combined fit composition and ground muons *(Again!)*

Solid curve shifted by a constant offset to match data points.

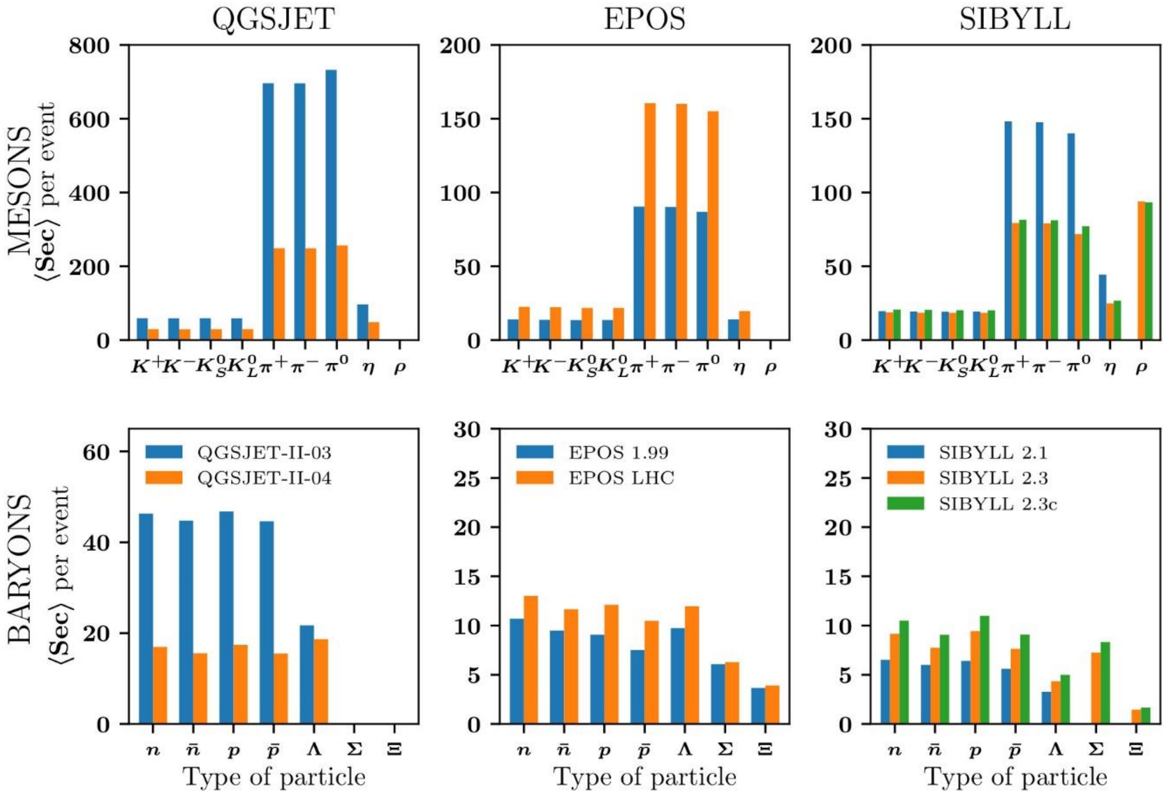


Combined fit composition and ground muons

(Again, including SIBYLL)

Solid curves shifted by constant offsets to match data points.

Analysis of model differences.
Kinds of secondaries



Secondary particles generated in100 EeV proton-N^{14} collisions

L. Calcagni, C. A. García Canal, SJS, T. Tarutina, *Phys. Rev. D,* **98**, 083003 (2018).

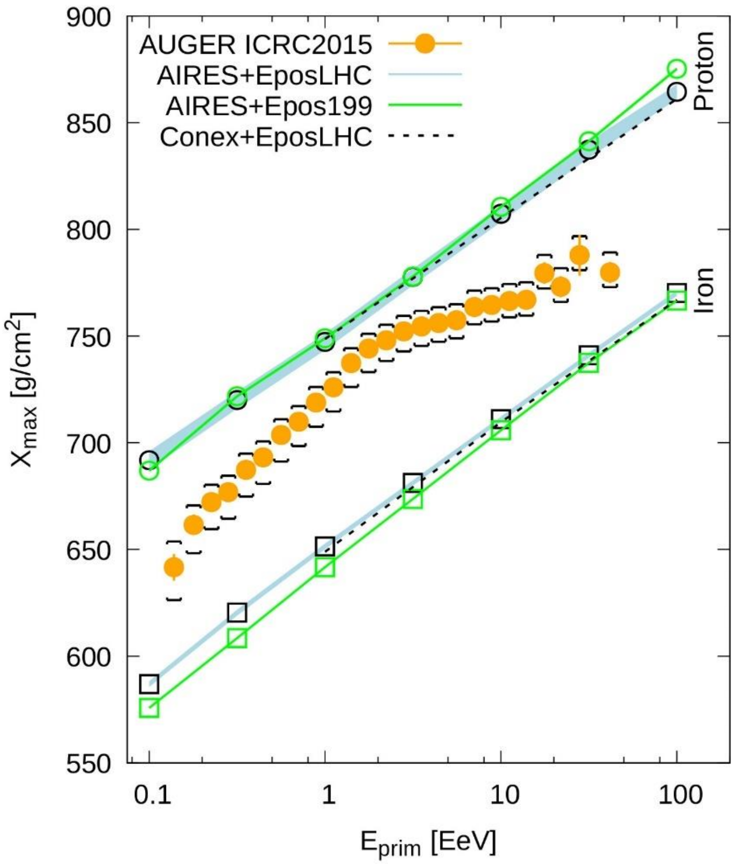
Some remarks

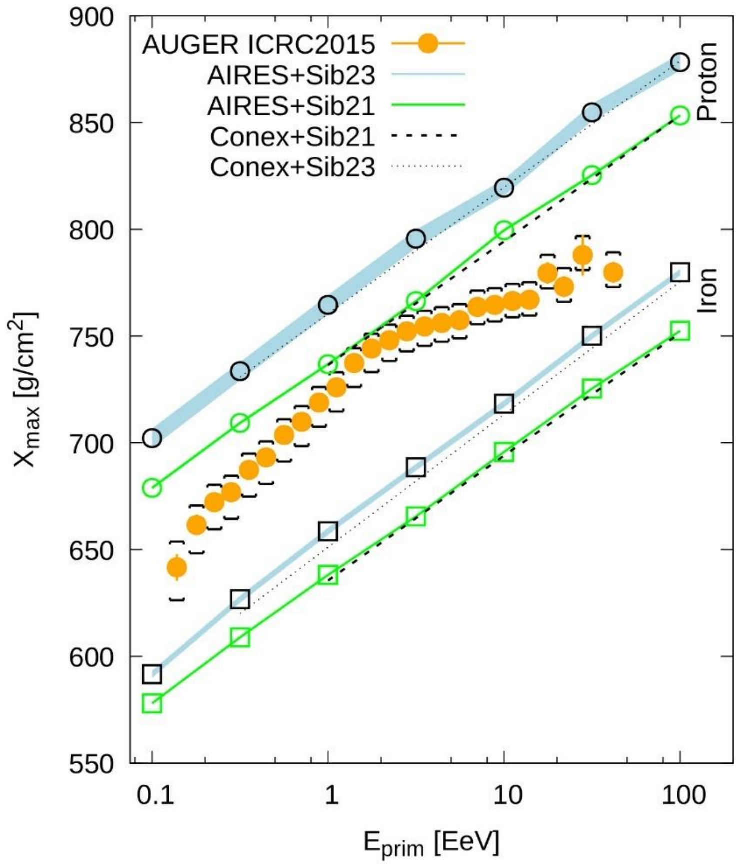
- Energy dependence of muon number measured in inclined showers shows reasonable consistency with mixed primary composition.
- Persisting deficit in the simulated muon numbers, for all the hadronic models.
- **Work in progress:** Extend and refine our analysis of the secondaries produced.

Thank you!

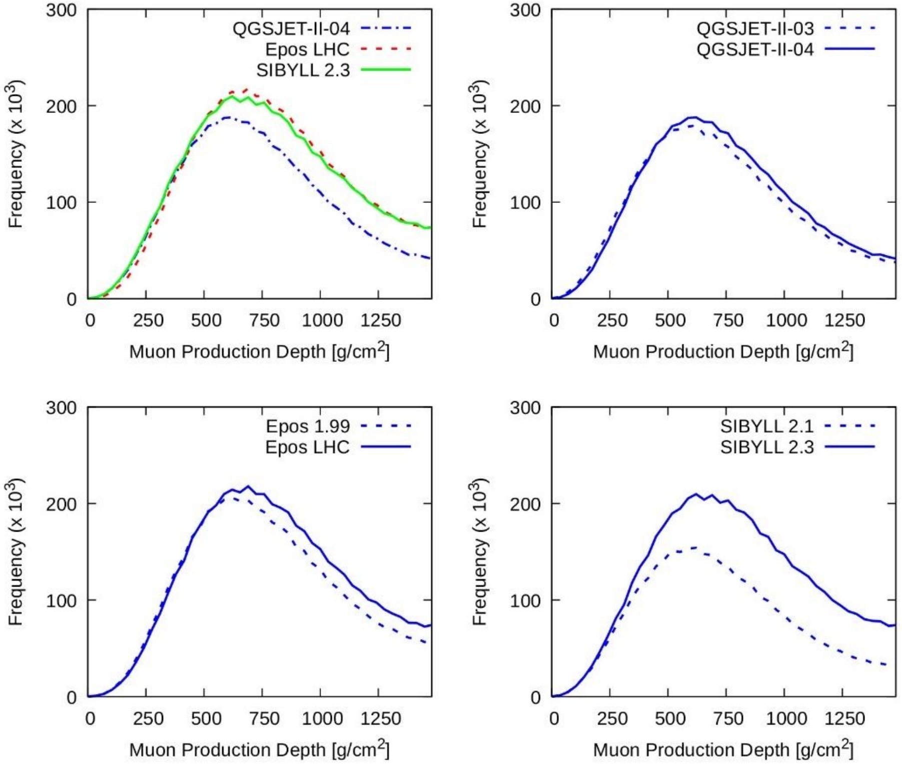
Backup Slides.

Longitudinal development (X_{max})
New analysis with AIRES 18.09.00





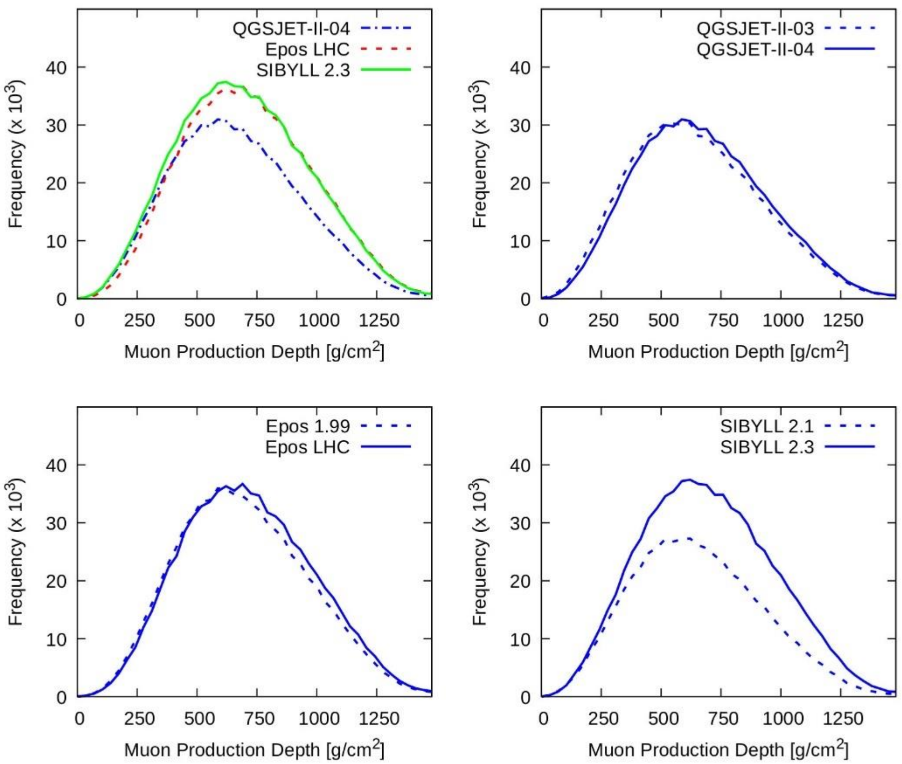
Analysis of model differences.
Muon Production Depth



32 EeV proton showers inclined 55 deg.
Ground muons with $E > 300$ MeV, distant more than 200 m from the shower axis

See, L. Calcagni, C. A. García Canal, SJS, T. Tarutina, *Phys. Rev. D,* **98***,* 083003 (2018).

Analysis of model differences.
Muon Production Depth



32 EeV proton showers
inclined 55 deg.
Ground muons with
$E > 300$ MeV,
distant more than 1200 m
from the shower axis

See, L. Calcagni, C. A. García Canal, SJS, T. Tarutina, *Phys. Rev. D,* **98***,* 083003 (2018).