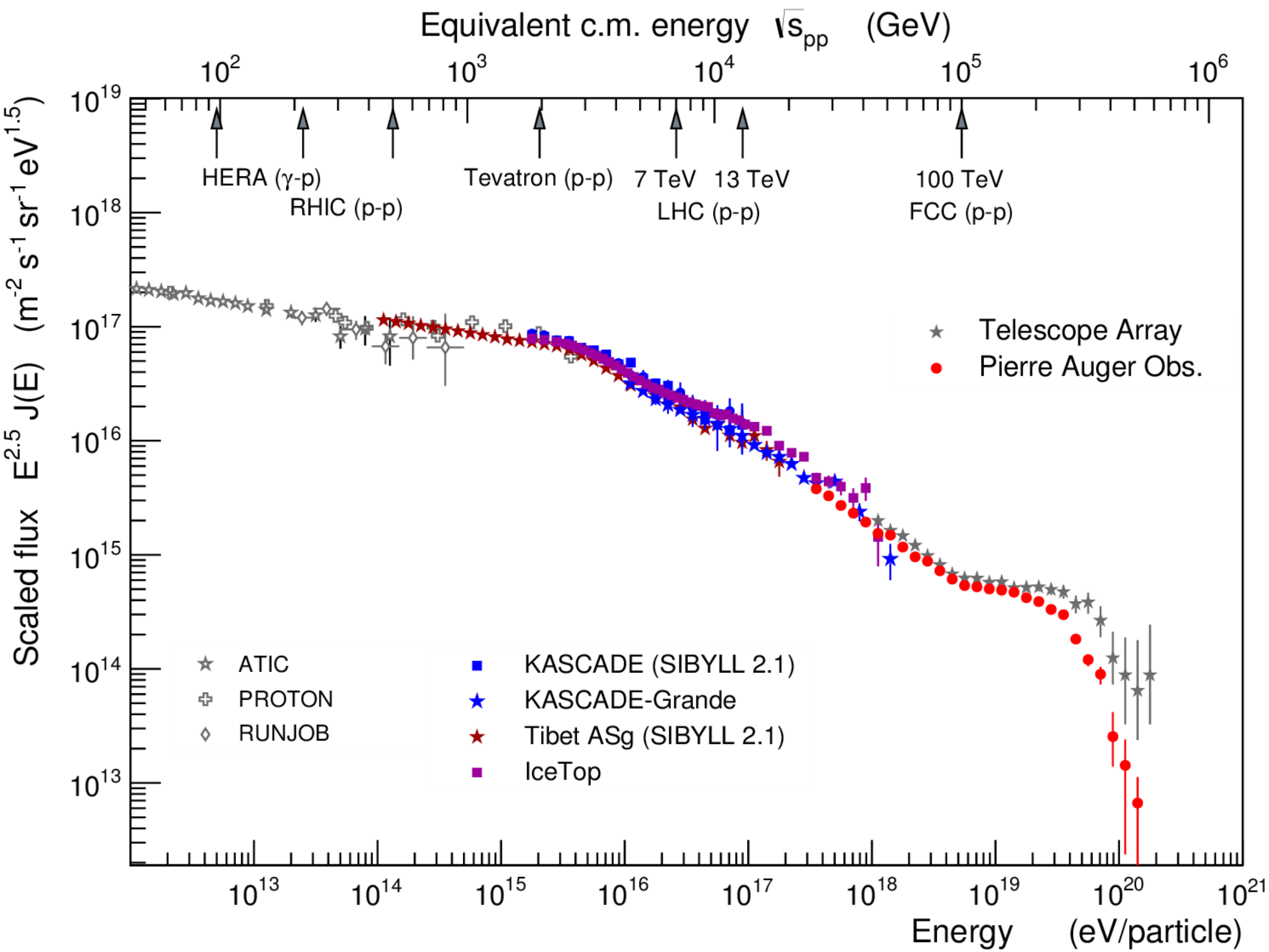
Modeling interactions 20km high

(and other works of the Auger group)

F. Riehn – LIP Jornadas 2018

PIERRE AUGER OBSERVATORY

Ultra-high energy cosmic rays

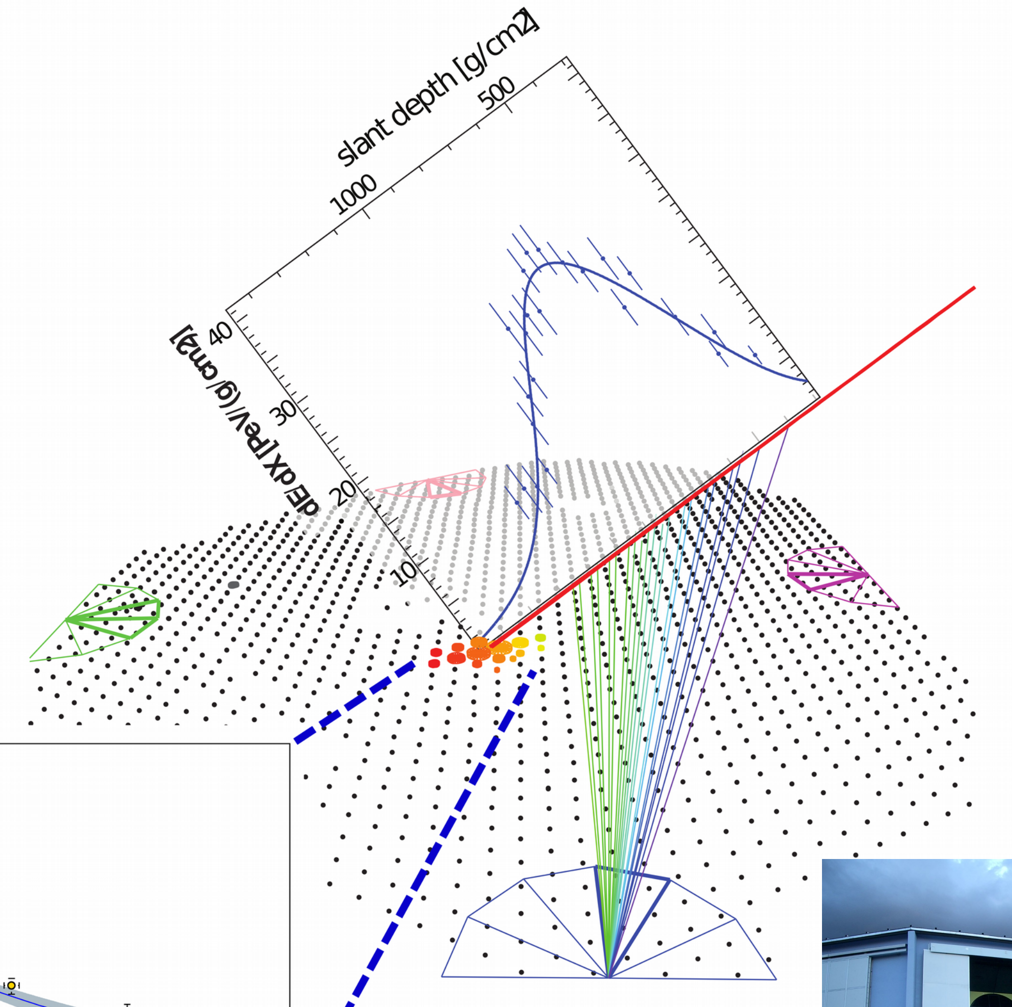


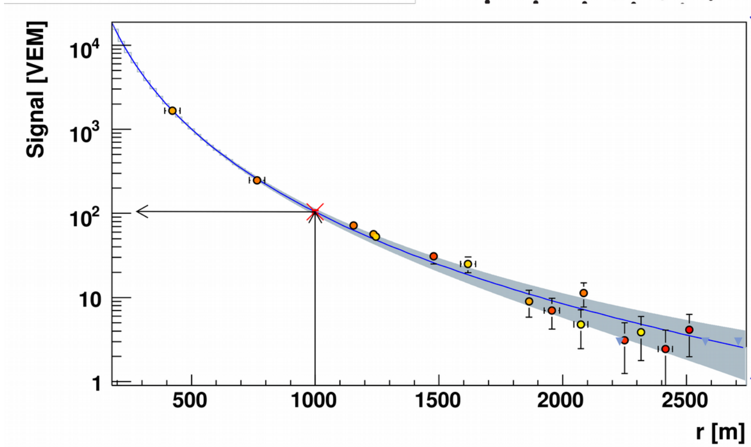
Natural beam
With ultra-high
energy

How do we
measure
UHECR?

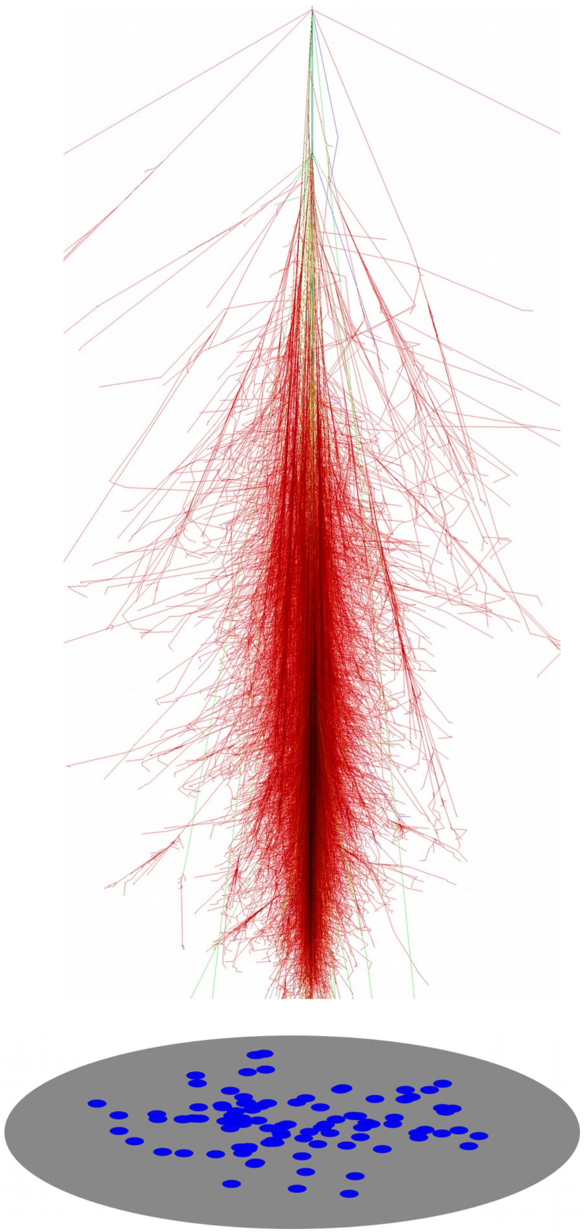
Experiment

Hybrid detector





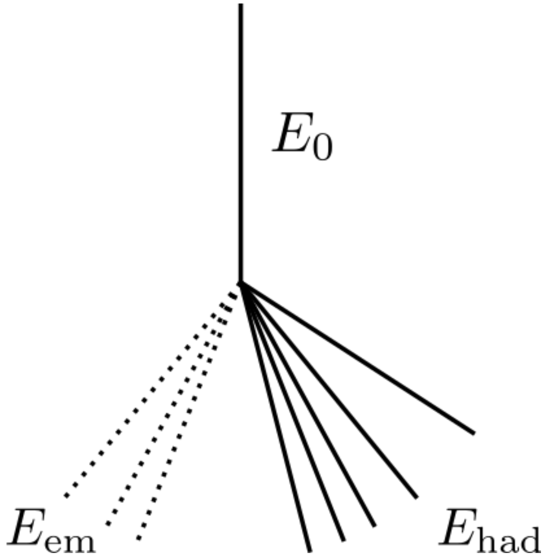
Air showers



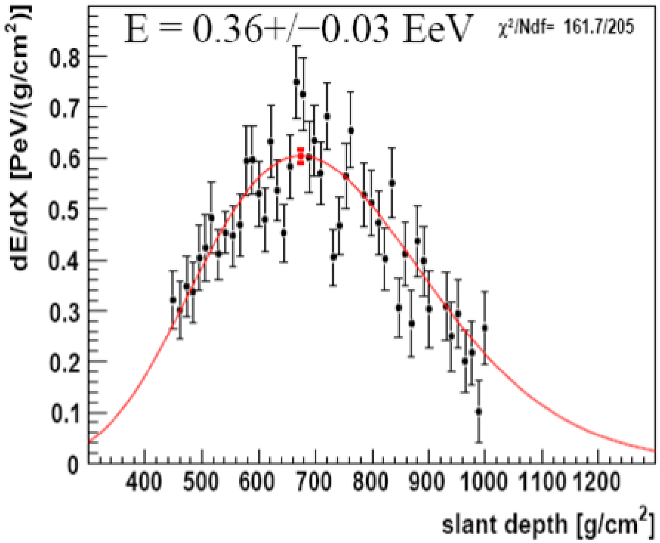
$$\pi^{\pm} \rightarrow \mu + \nu$$

$$\pi^{0} \rightarrow \gamma\gamma$$

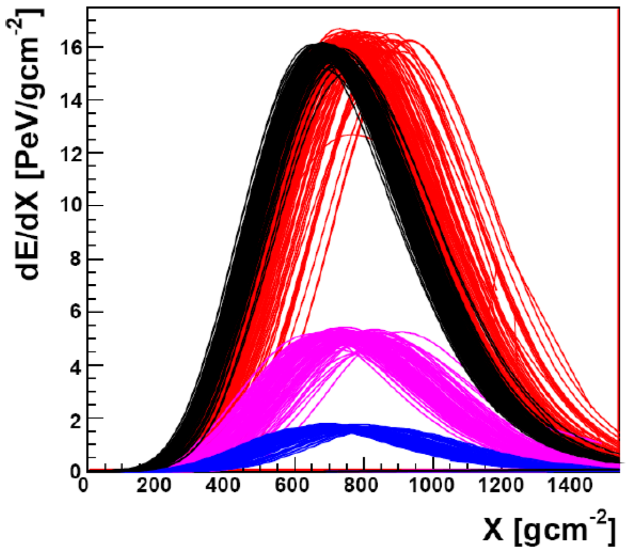
Two components

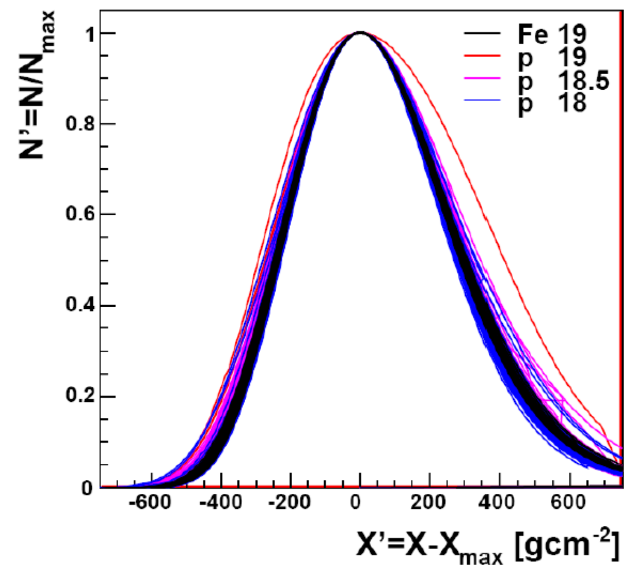


EM profiles



Primary particle!





Universal shape !
L,R parameters capture difference

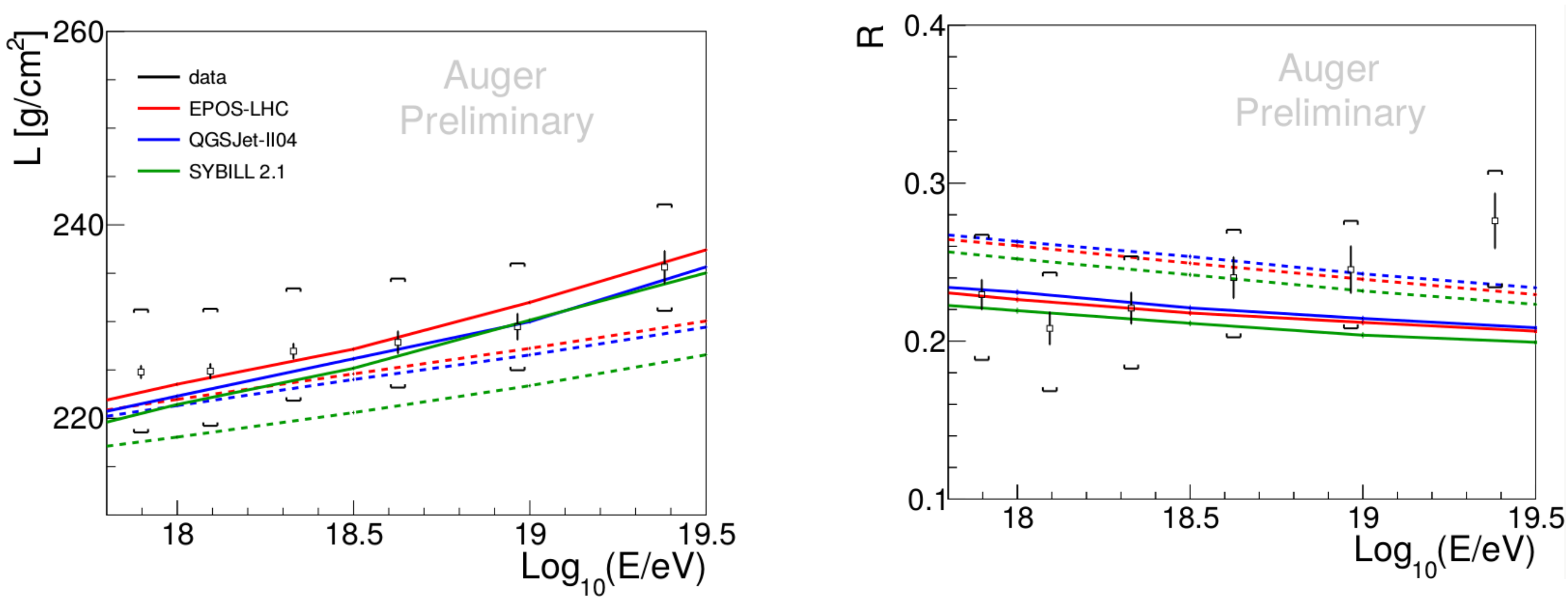
$$N' = \exp\Big(-\frac{1}{2}\Big(\frac{X'}{L}\Big)^2\Big) \prod_{n=3}^{\infty} \exp\Big(-\frac{R^{n-2}}{n}\Big(-\frac{X'}{L}\Big)^n\Big)$$

Gaussian(L) × Distortion(R)

Low resolution ==> average profile

PhD thesis F. Diogo

Average shape parameters



Publication imminent

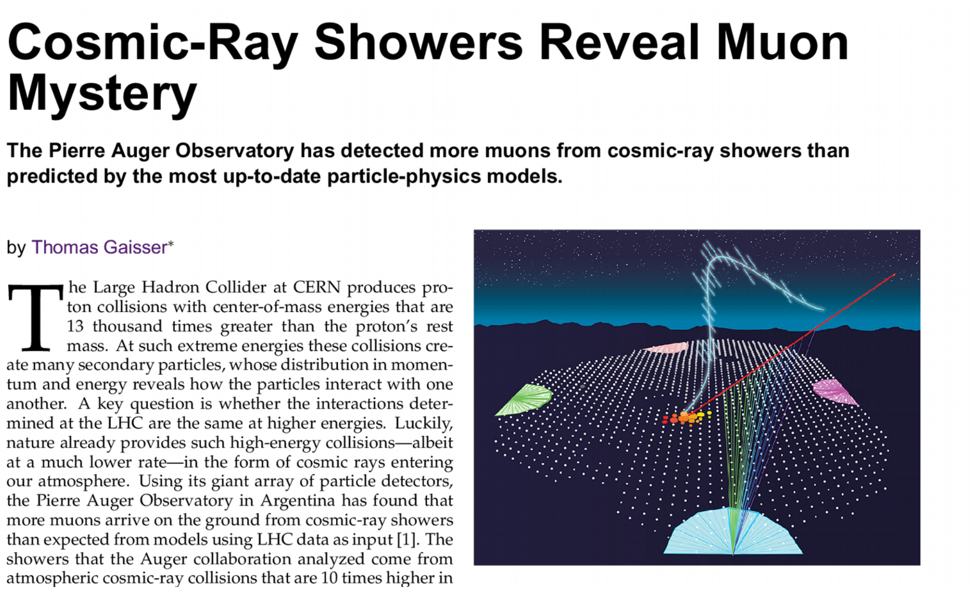
S. Andringa and F. Diogo

II – muon measurements

("we have no idea", G. Cham)

Published in PRL as DOI:10.1103/PhysRevLett.117.192001

Testing Hadronic Interactions at Ultrahigh Energies with Air Showers Measured by the Pierre Auger Observatory

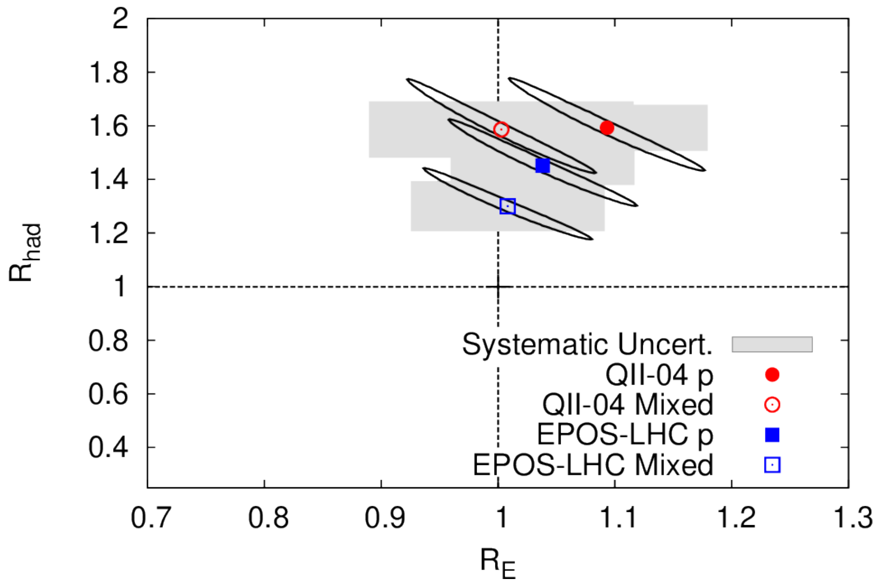


Cosmic-Ray Showers Reveal Muon Mystery

The Pierre Auger Observatory has detected more muons from cosmic-ray showers than predicted by the most up-to-date particle-physics models.

by Thomas Gaisser*

The Large Hadron Collider at CERN produces proton collisions with center-of-mass energies that are 13 thousand times greater than the proton's rest mass. At such extreme energies these collisions create many secondary particles, whose distribution in momentum and energy reveals how the particles interact with one another. A key question is whether the interactions determined at the LHC are the same at higher energies. Luckily, nature already provides such high-energy collisions—albeit at a much lower rate—in the form of cosmic rays entering our atmosphere. Using its giant array of particle detectors, the Pierre Auger Observatory in Argentina has found that more muons arrive on the ground from cosmic-ray showers than expected from models using LHC data as input [1]. The showers that the Auger collaboration analyzed come from atmospheric cosmic-ray collisions that are 10 times higher in



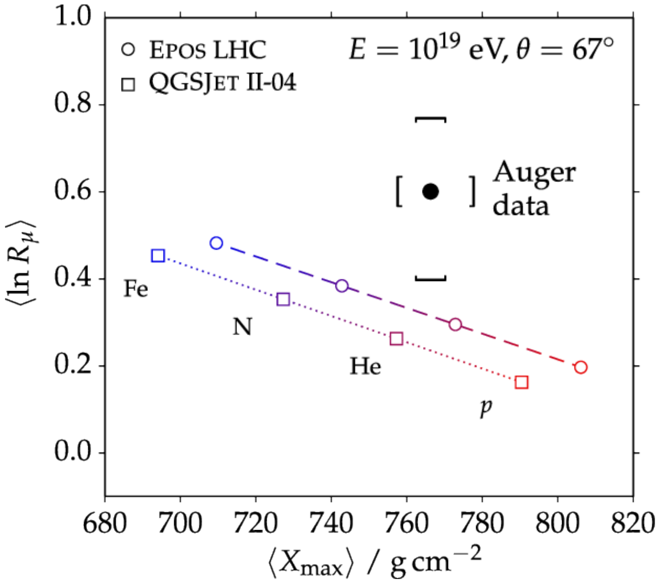
LIP contribution (L. Cazon)
* consistency tests
* check of detector systematics with RPCs
→ see Ricardo Luz' talk

Muons in air showers at the Pierre Auger Observatory: Fluctuations of the muon number in highly inclined events

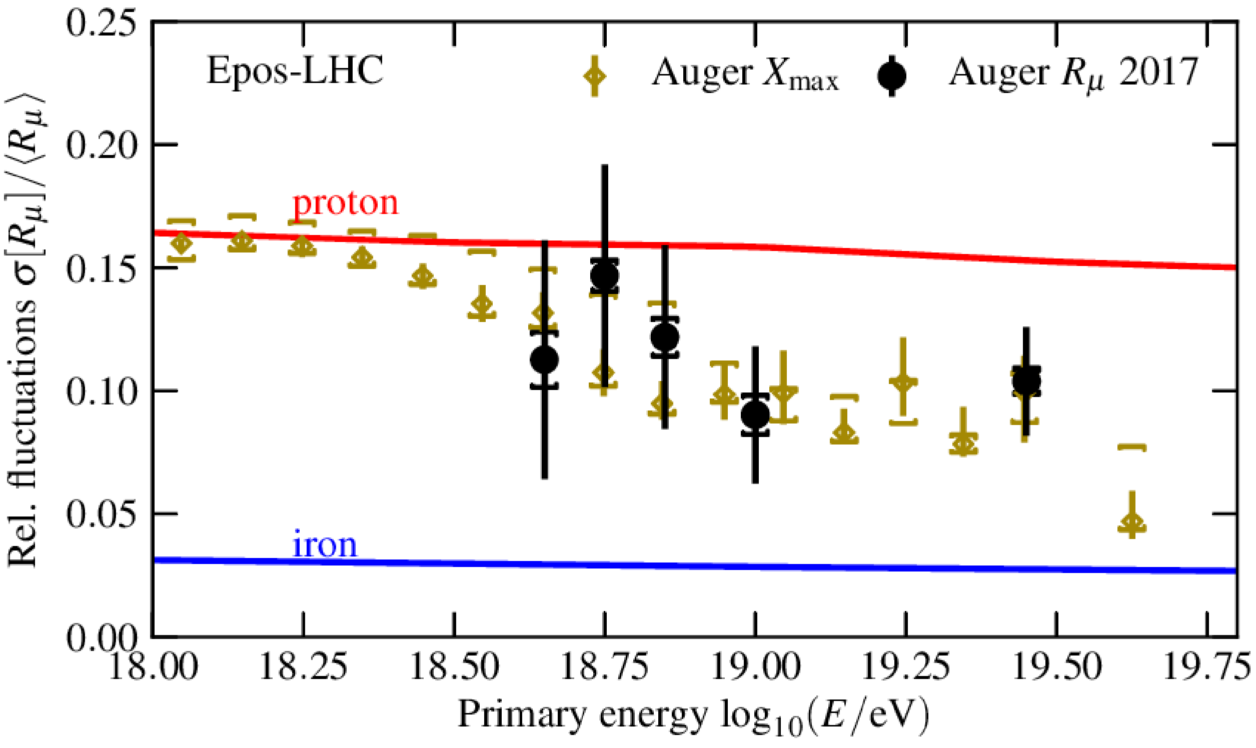
We present the first measurement of the fluctuations in the number of muons in highly inclined

L. Cazon, R. Conceição, F. Riehn

Average



Fluctuations

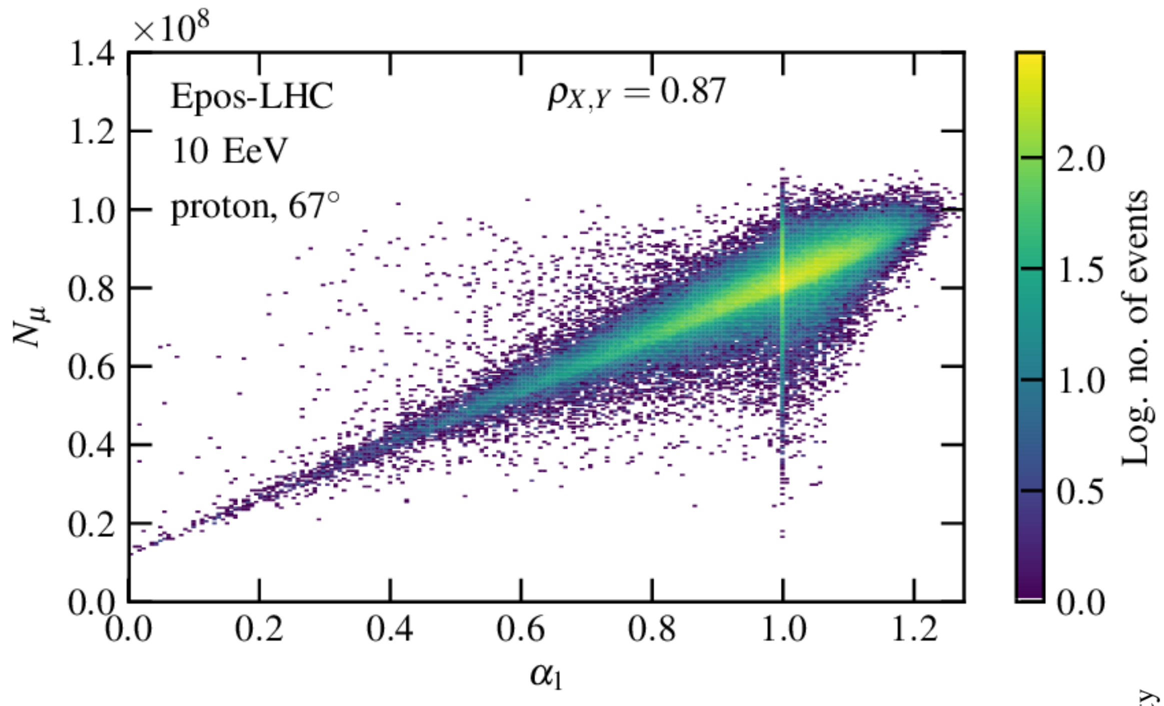


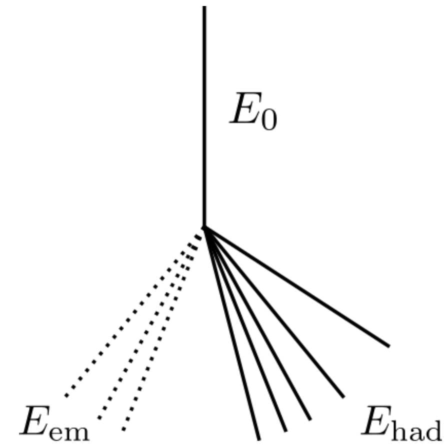
Models and data agree !
Observables compatible

???

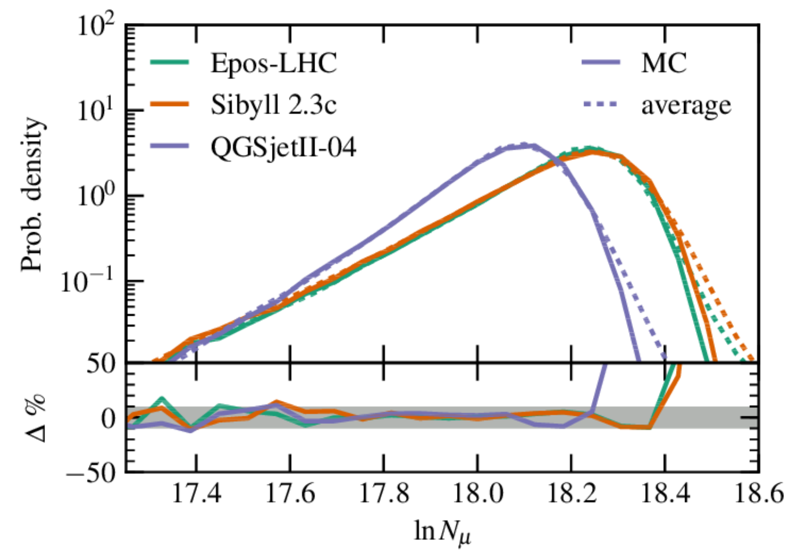
Probing the properties of the first interaction of Ultra-High-Energy Cosmic Rays through the muon content of Extensive Air Showers

Lorenzo Cazon, Ruben Conceição, and Felix Riehn*



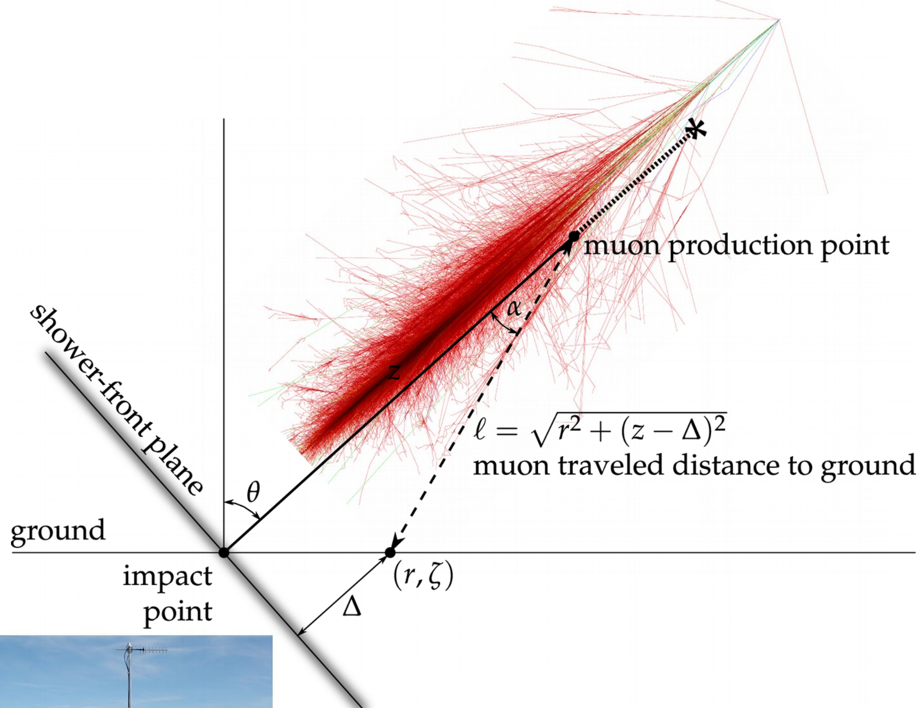


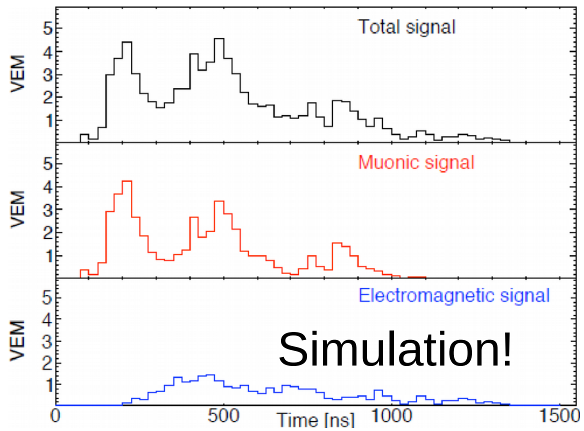
Explain shape of full distribution !!



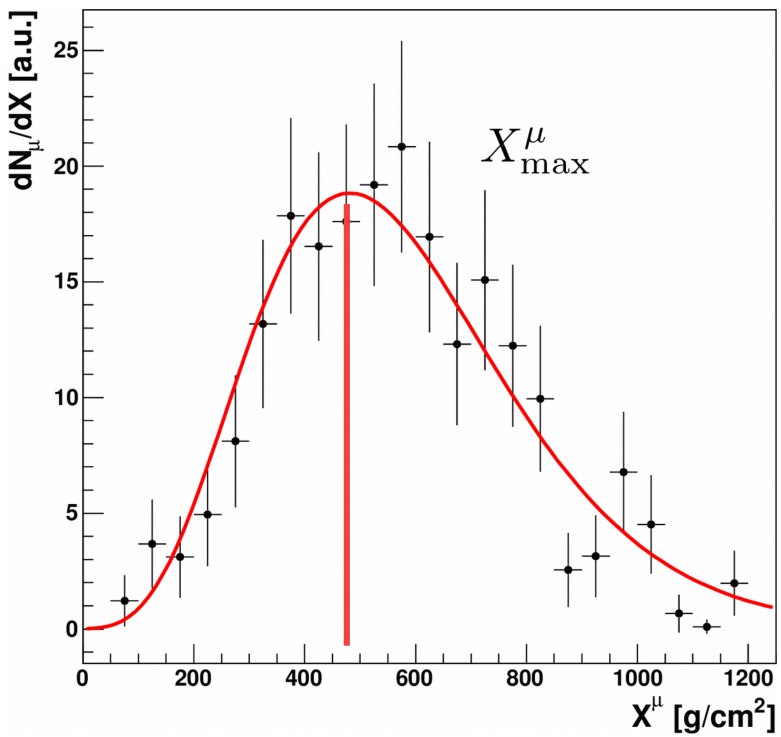
Submitting to PRL

Muon production depth





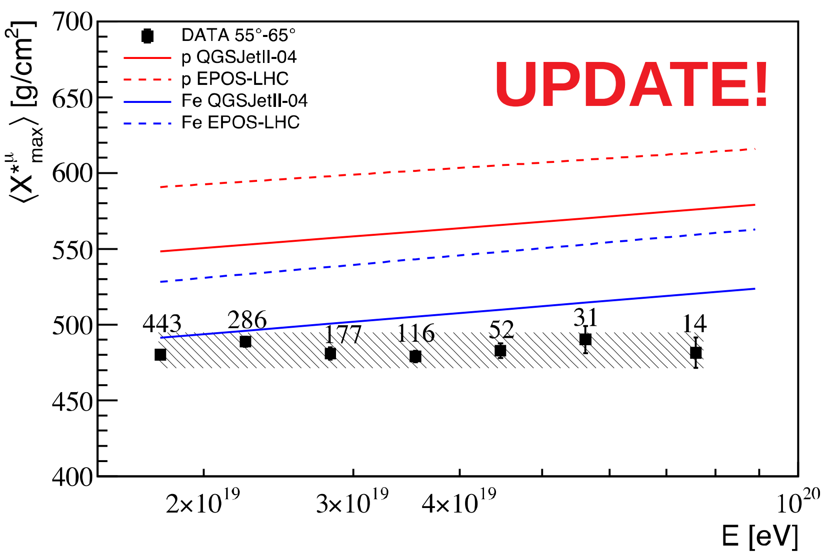
Height → timing in tank signal

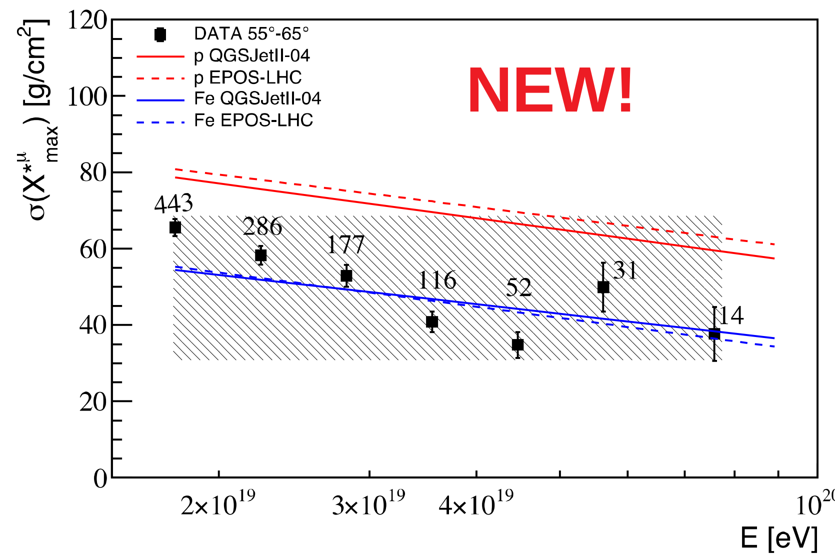


Tests of hadronic interactions in air showers using measurements of the depth of maximal muon production from the Pierre Auger Observatory

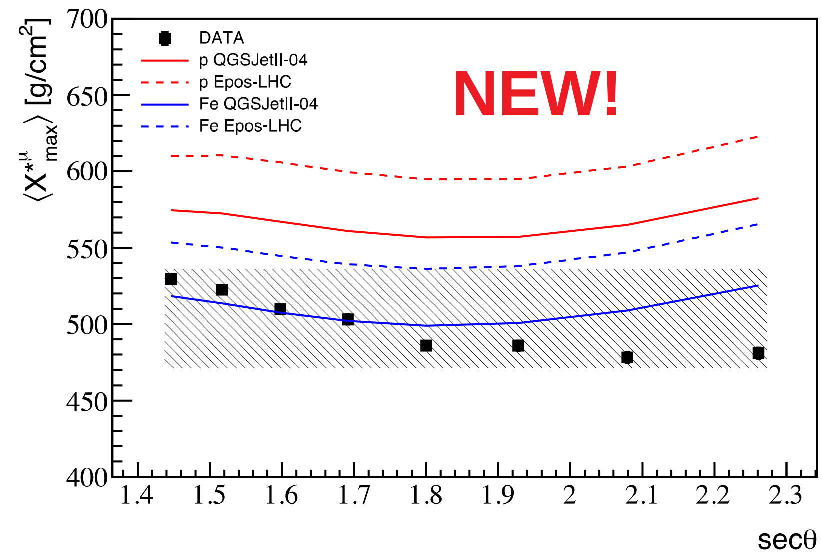
The Pierre Auger Collaboration*

Coordinated by L. Cazon





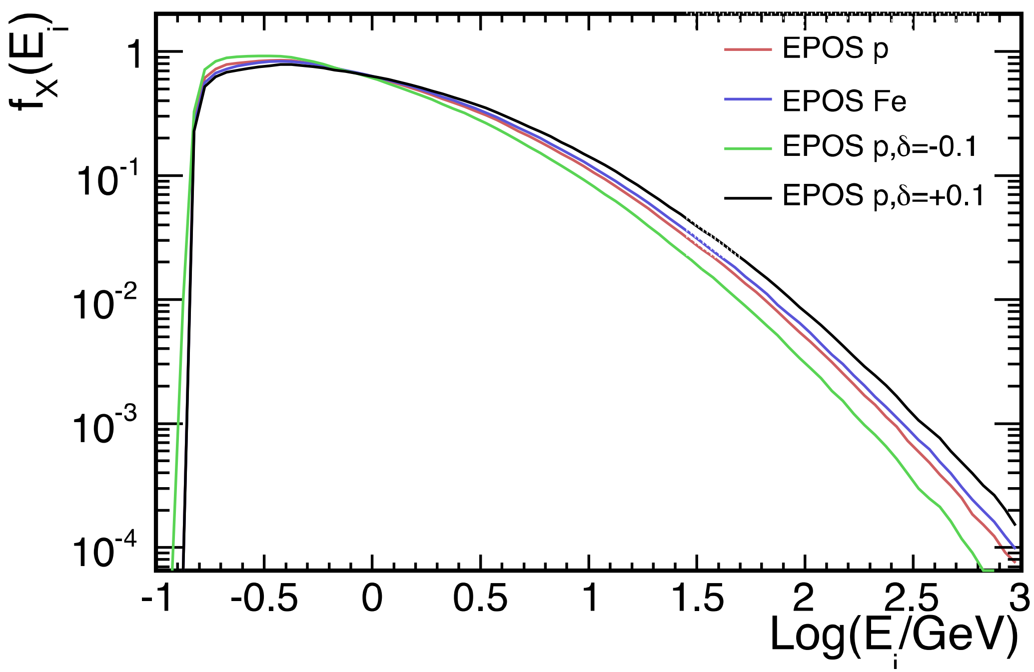
Models under stress!



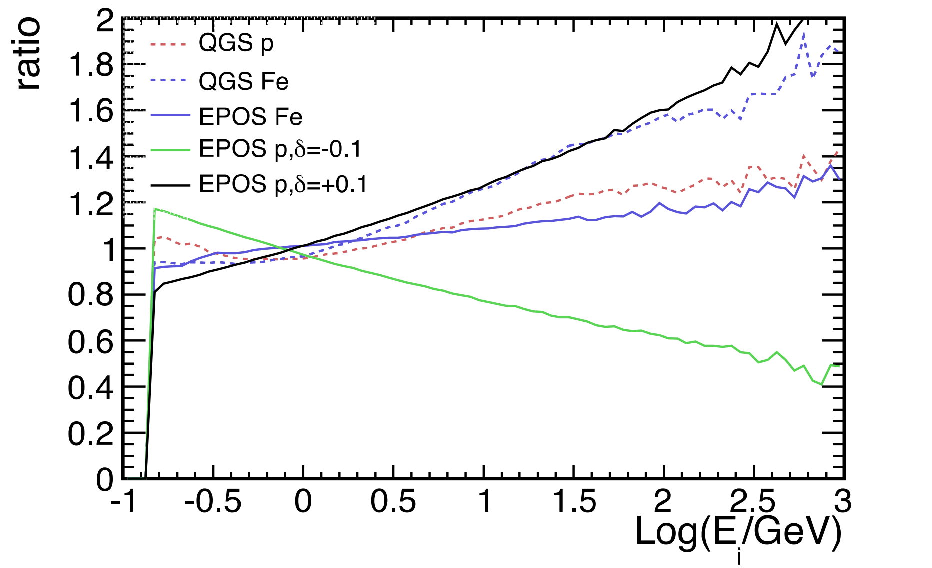
Angular distribution already understood!

Sensitivity of EAS measurements to the energy spectrum of muons

J. Espadanal[a,*], L. Cazon[a], R. Conceição[a,b]



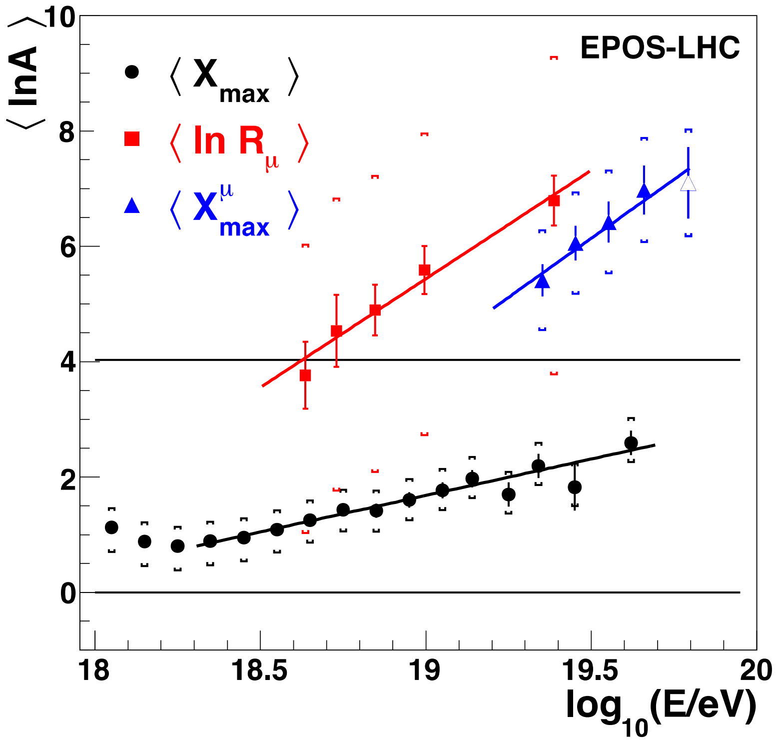
Modified muon production

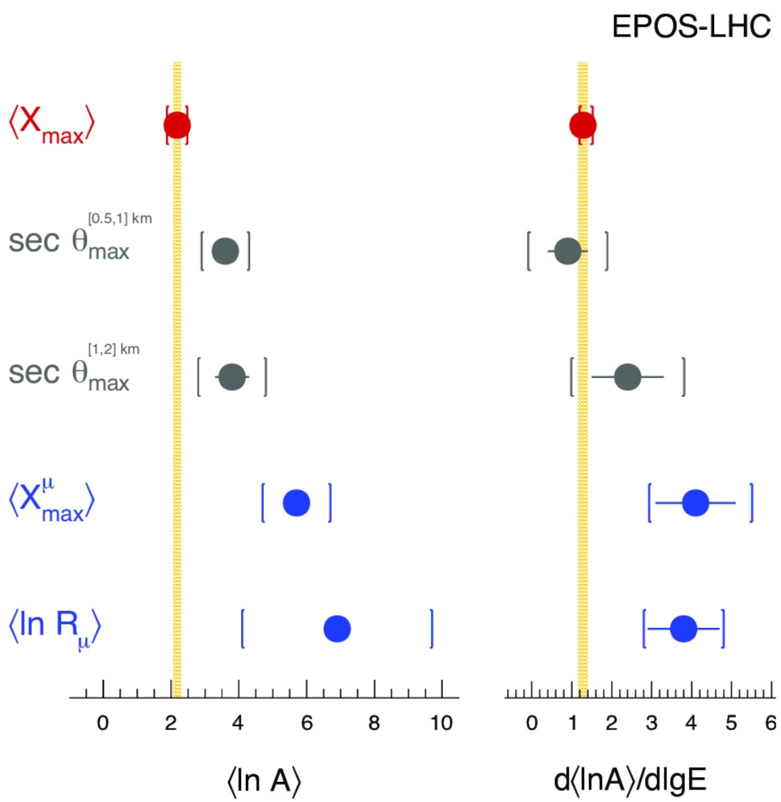


MPD zenith angle evolution indicates that muon E-spectrum is different from High Energy Hadronic Models.

$D_{10}\langle \ln A \rangle$ from hadronic-type and EM-type cascade observables

L. Cazon[a], F. Diogo[a], R. Conceição[a],
S. Andringa[a], J. Espadanal[a], M. Pimenta[a,b]

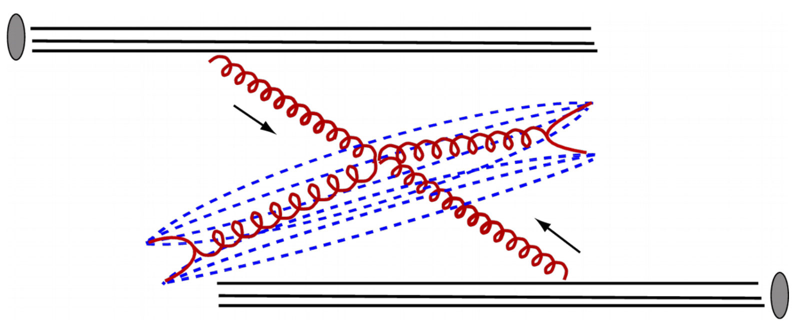




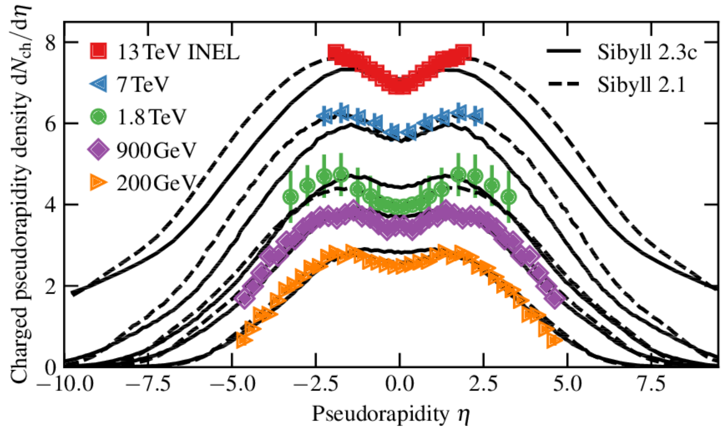
Compatibility of all hadronic observables.

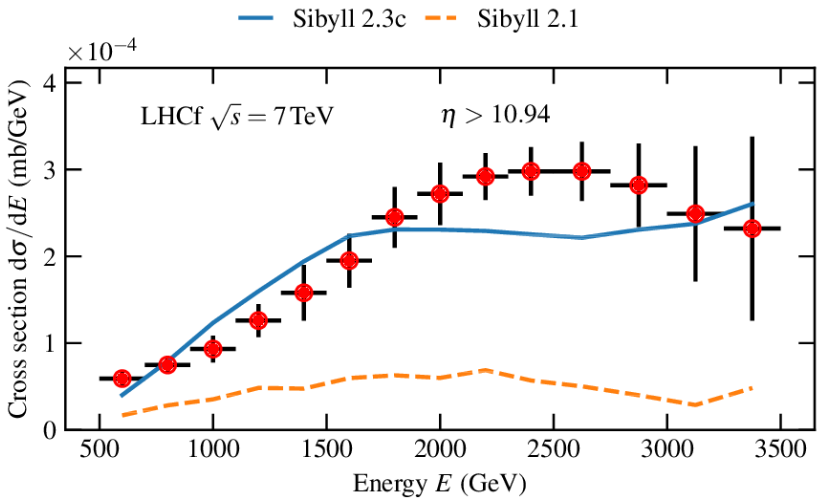
Waiting for update, to be proposed as publication of Auger.

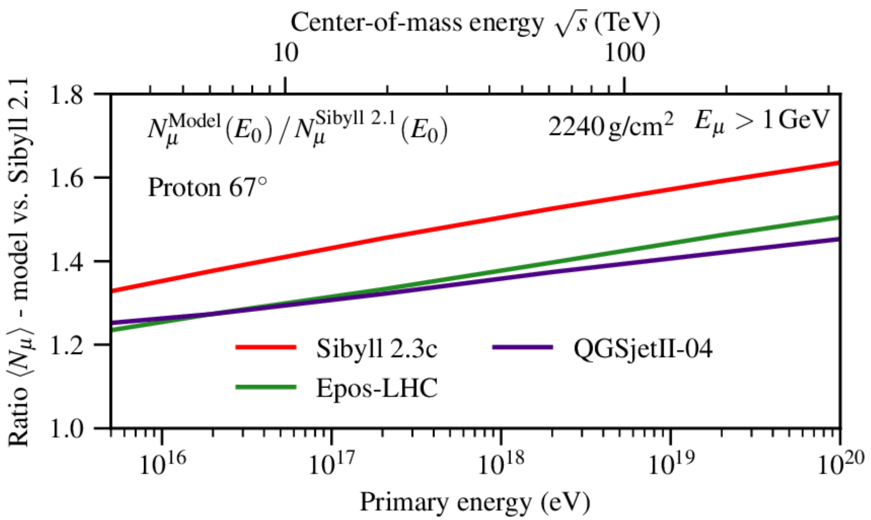
Microscopic origin of the muon mystery?



LHC tuning







R. Concecao, S. Silva

Impact summary

Observable	Fixed energy	Umbrella	Energy evolution
X_{max}	1	1	1
X^{μ}_{max}	1	1	1
L	-	1	2
R	-	3	3
N_{μ}	2	3	4
X_{max} - X^{μ}_{max}	2	4	4

Poor discr.	1	2	3	4	Good discr.

Good variables to distinguish scenarios are N_{μ}, $X_{\max} - X^{\mu}_{\max}$ and R.

- SIBYLL (F.Riehn). 1’
- MPD (L.Cazon). 2’
- Mu E-spectrum (J. Espadanal, L. Cazon, R. Conceição) 1’
- Sigma(Rmu)/Rmu (F.Riehn, L.Cazon, R. Conceição) 1’
- Alpha (F.Riehn, L.Cazon, R. Conceição,). 2’
- R-L (F. Diogo, S. Andringa,). 2’
- p-Air (Steven, R. Conceição). 1’
- dlnA/dlogE (L. Cazon, F. Diogo, R. Conceição, S. Andringa, J. Espa M. Pimenta). 1’