Measuring the pion production cross section in proton-air interactions

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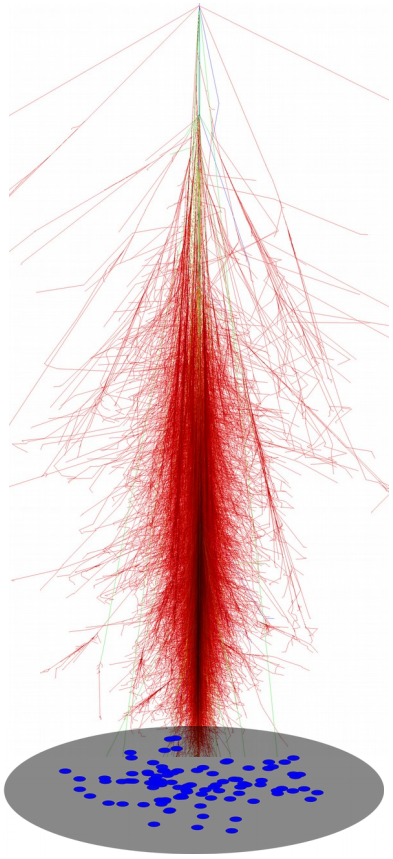
Take home message

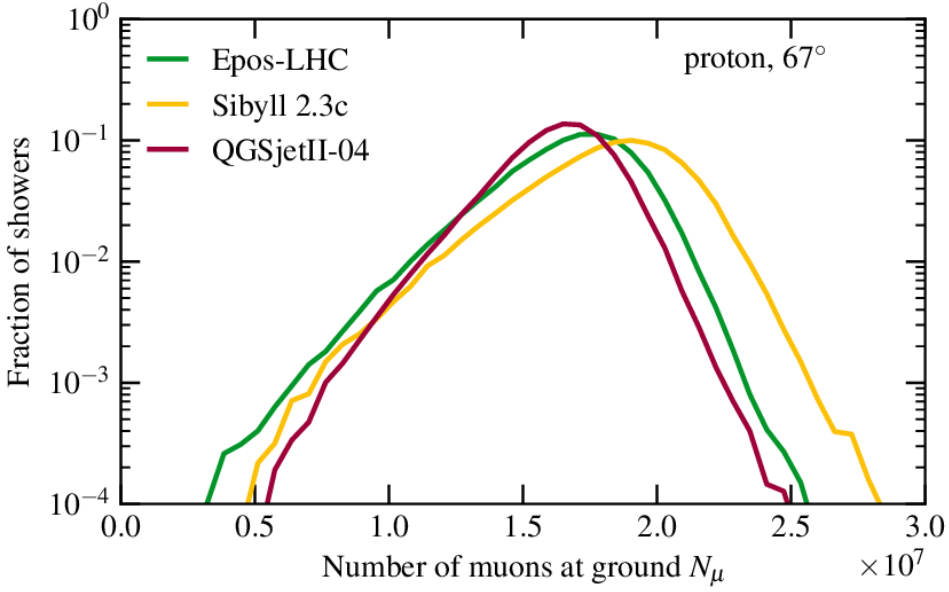
"The **distribution** of the number of muons contains information on the particle physics of the **first** interaction of cosmic rays"

==> very much worth measuring

Distribution of the number of muons



At ground !



shower-to-shower

Average muon content

* mostly $\langle N_\mu \rangle$ measured in UHECR

Example:

$\langle N_\mu \rangle$ in inclined showers at the Pierre Auger Observatory

Physics

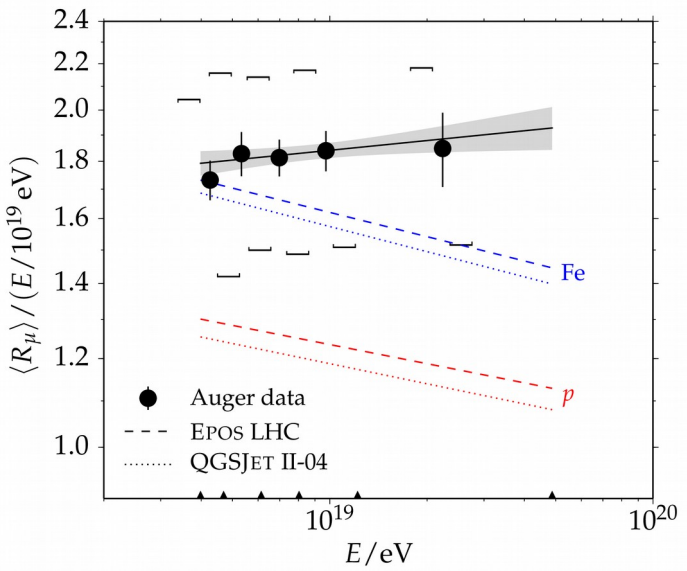
VIEWPOINT

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*

(https://physics.aps.org/articles/v9/125)



(Phys.Rev. D91 (2015) no.3, 032003)

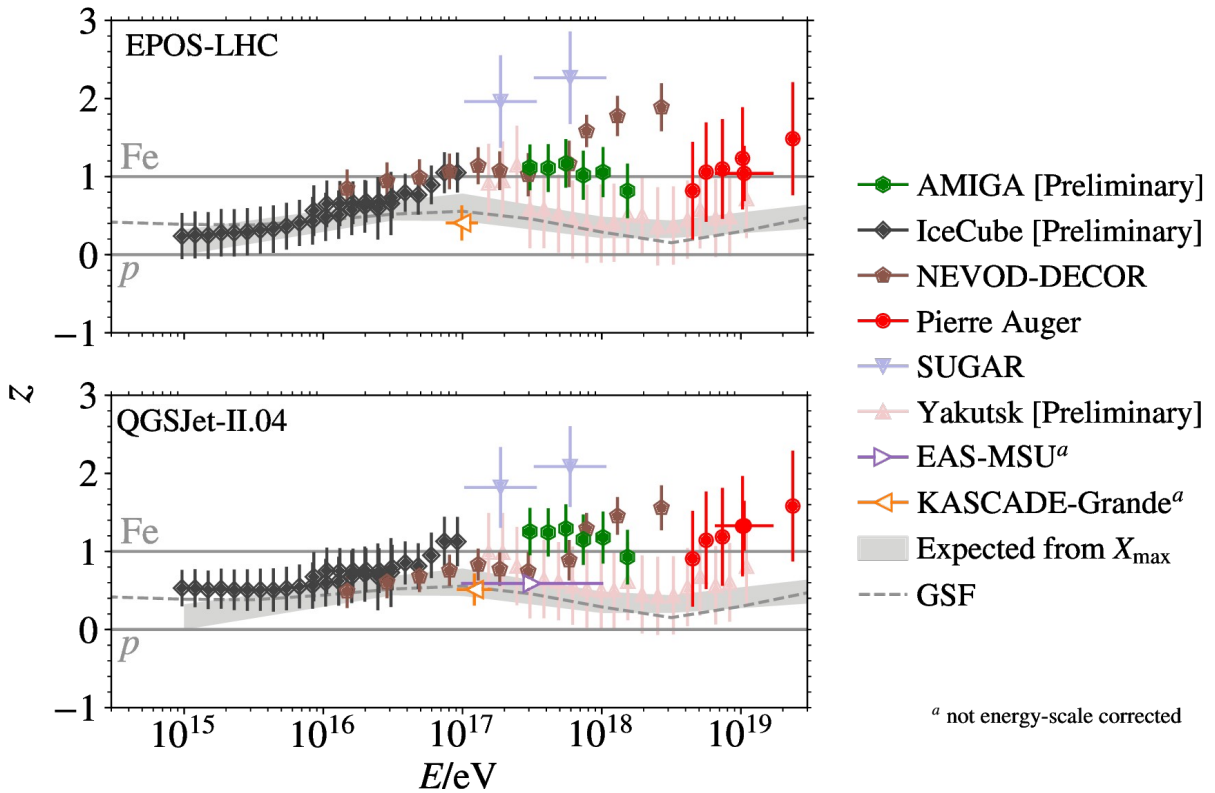
Muon mystery

Many measurements with different techniques in broad energy range

Unified muon scale

$$z = \frac{\ln N_\mu - \ln N_\mu^{\mathrm{ref},p}}{\ln N_\mu^{\mathrm{ref},Fe} - \ln N_\mu^{\mathrm{ref},p}}$$

Astrophysical sane region $z \in [0, 1]$



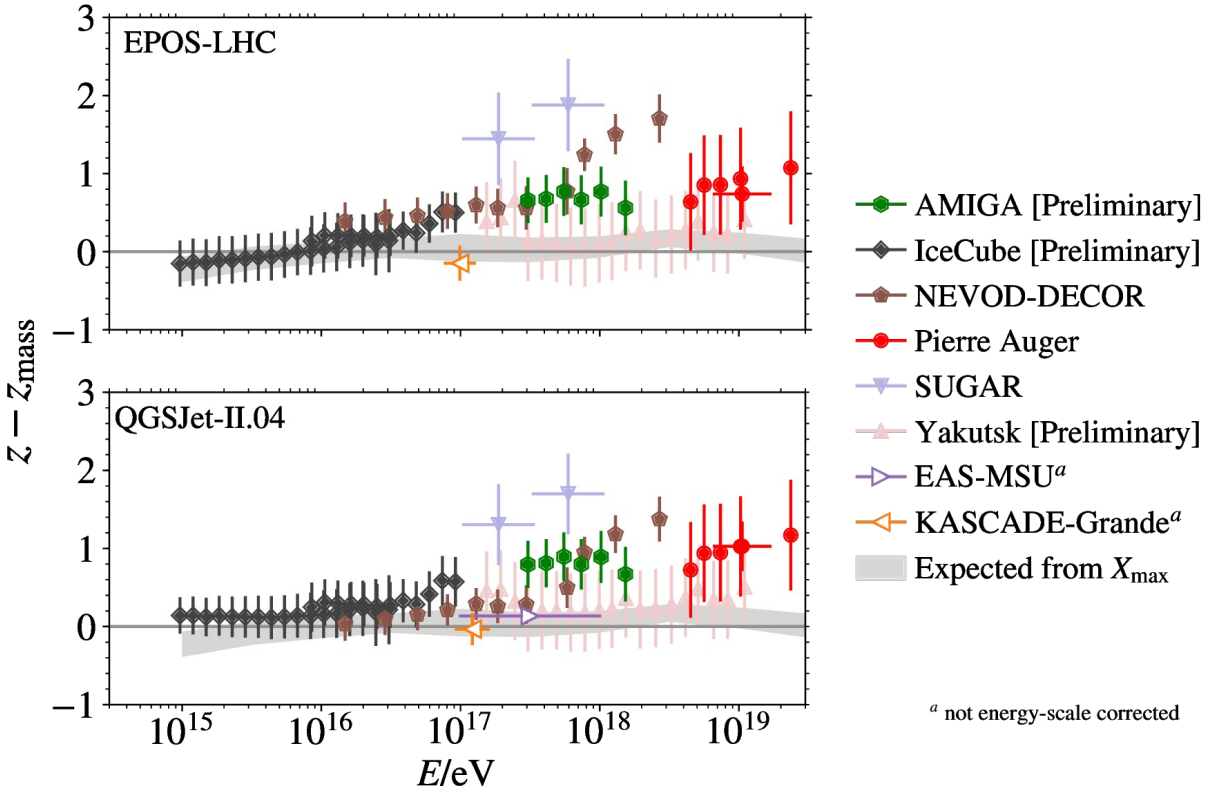
(energy scale correction applied, details see UHECR proceedings, arxiv:1902.08124)

Muon mystery

Many measurements with different techniques in broad energy range

Unified muon scale removing composition

$$z \rightarrow z - z_{\mathrm{mass}}$$



Origin of muon mystery

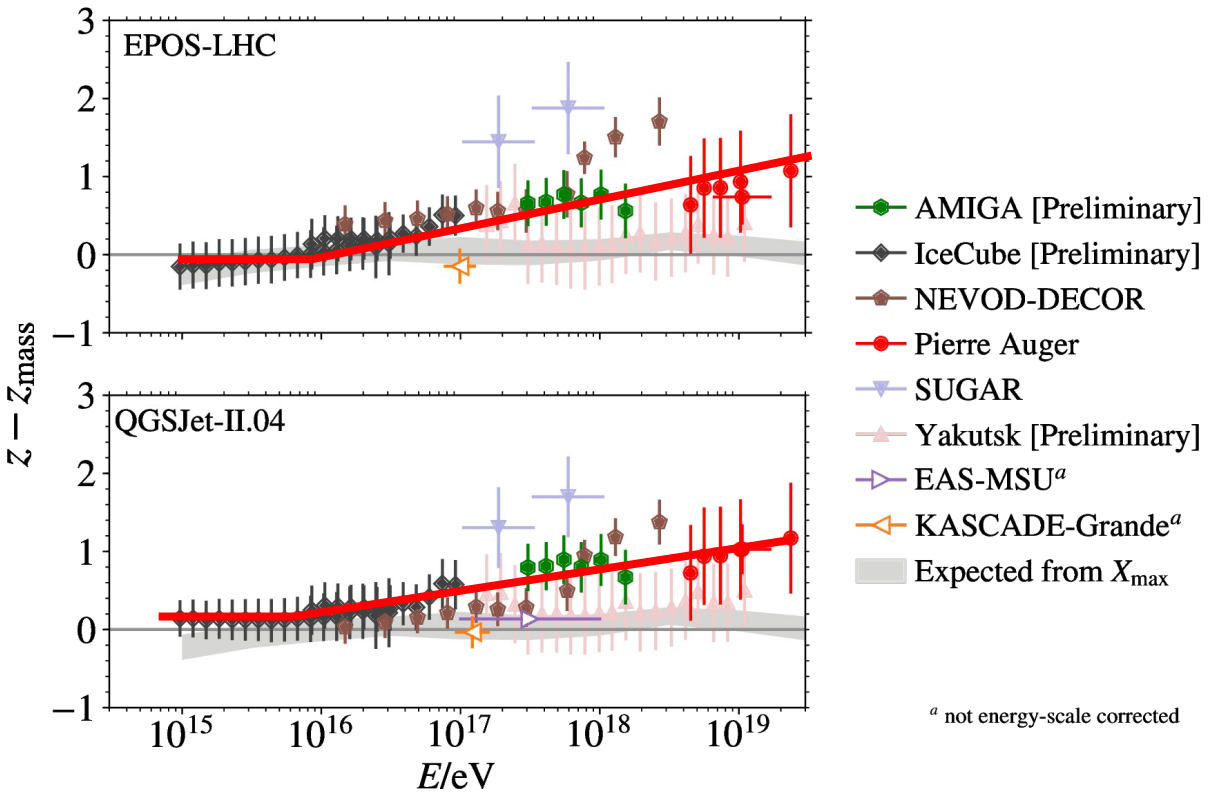
Many measurements with different techniques in broad energy range

Problem starts at ~10**16 ?
Increases with energy?

$\langle N_\mu \rangle$ with GrandProto300:

* fill the gap at 10**17

* radio for energy measurement !



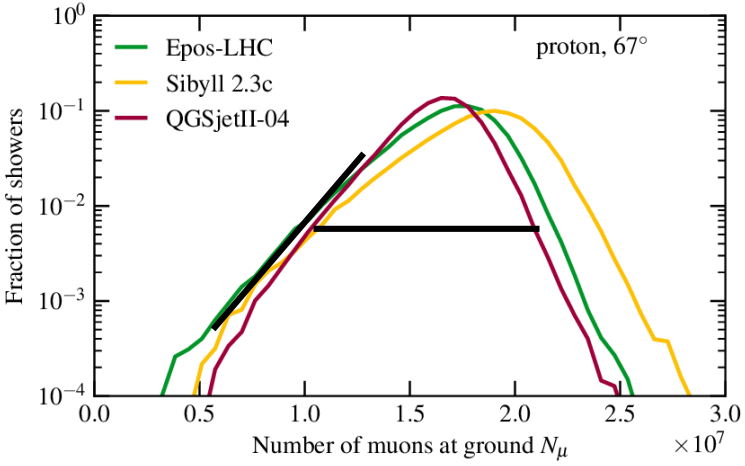
GP300

So much for the boring scenario ...

much more interesting: higher moments!

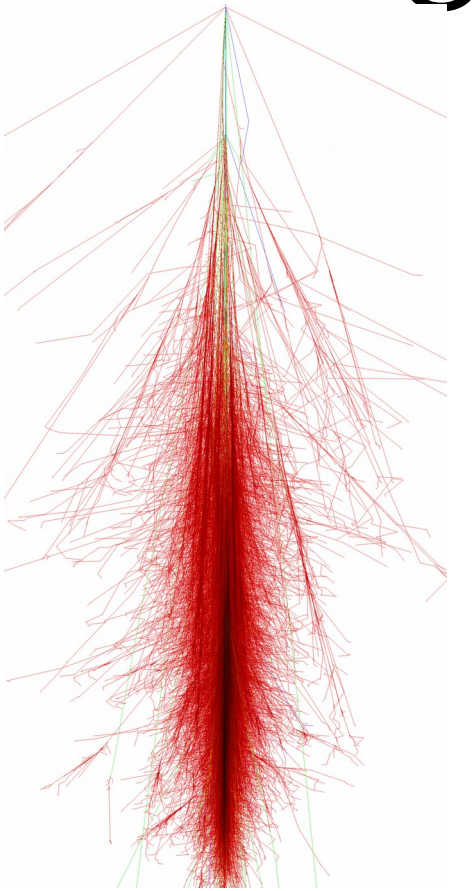
1. fluctuations of the number of muons, $\sigma(N_\mu)/\langle N_\mu \rangle$

2. tail of the distribution, Λ_μ



Why?

Origin of muons in EAS



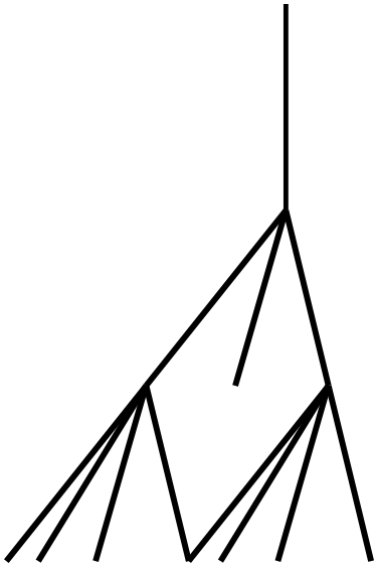
Multiplication of hadrons through interactions

⬇

Meson decays

⬇

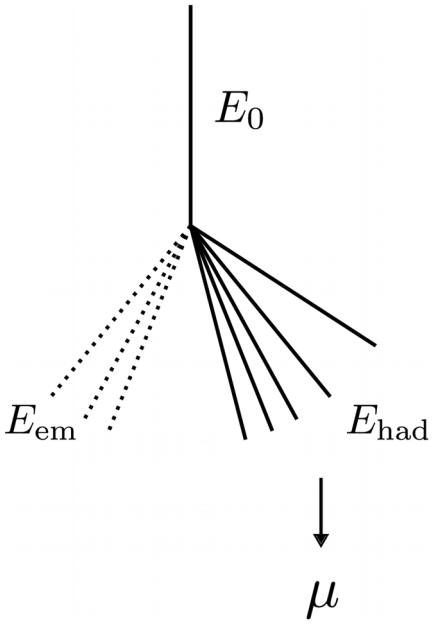
Muons



$$\langle N_\mu \rangle \sim E^\beta$$

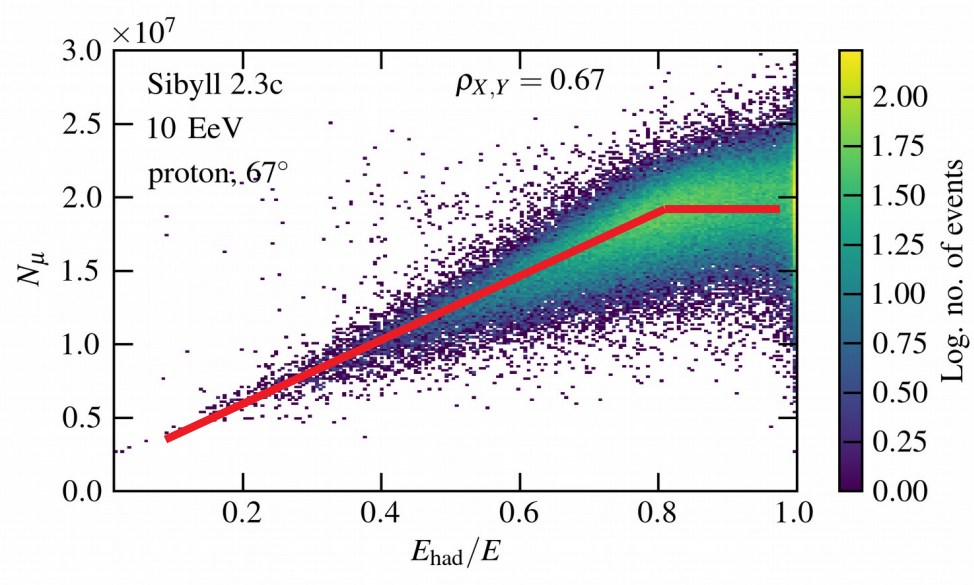
(Astro. Part.Ph 22, 387, 2005)

Origin of fluctuations: first interaction!



$$N_\mu \sim E_{\rm had}$$

(L. Cazon, R. Conceição, FR: PLB 784 (2018) 68-76)



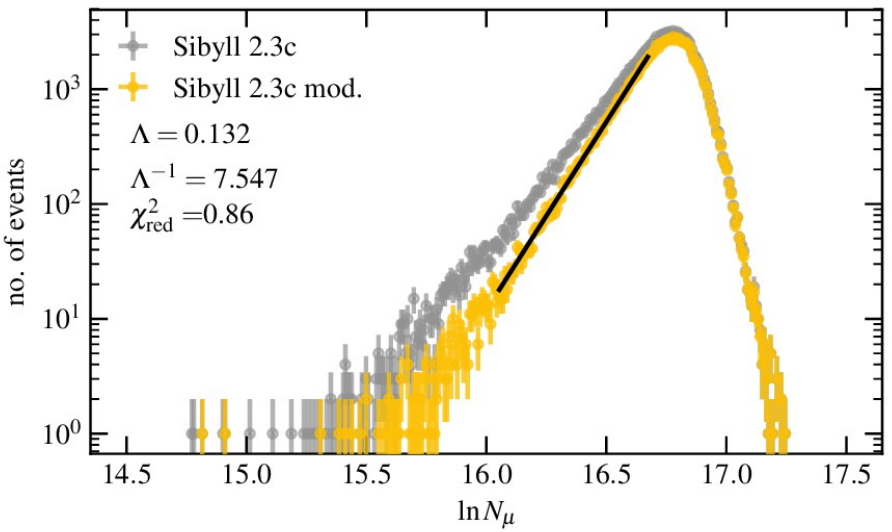
$$\sigma(E_{\rm had}) \to 50\%\,\sigma(N_\mu)$$

$$\sigma(E_{\rm had}, m_{\rm had}) \to 70\%\,\sigma(N_\mu)$$

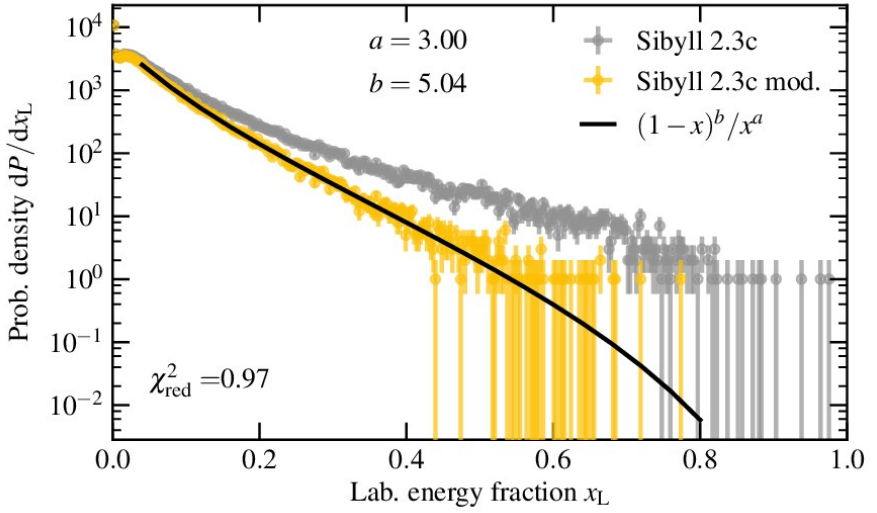
3rd moment?

Tail of the Nmu distribution

Distribution of number of muons



Inclusive neutral pion prod. spectrum



(details see: UHECR proceedings, 1812.09121)

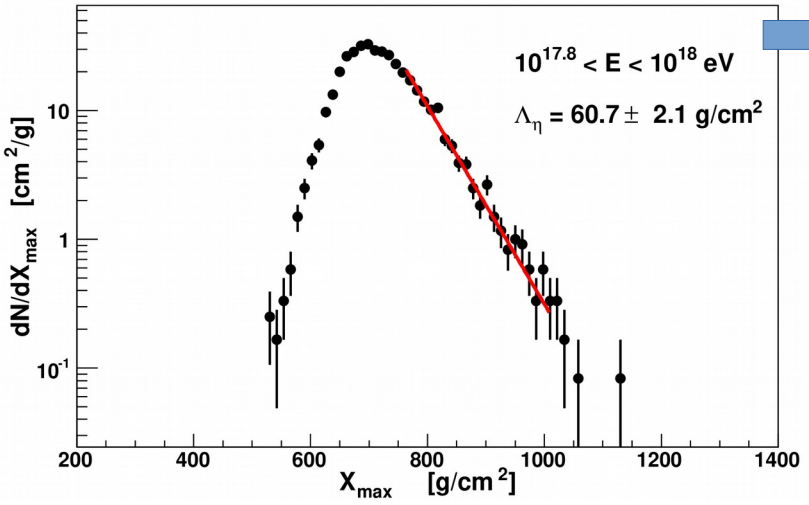
$$N_\mu \sim E_{\mathrm{had}} = E_0 - E_{\mathrm{EM}}$$

$$E_{\mathrm{EM}} \sim E_{\pi^0} \sim E_{\pi^0}^{\mathrm{lead.}}$$

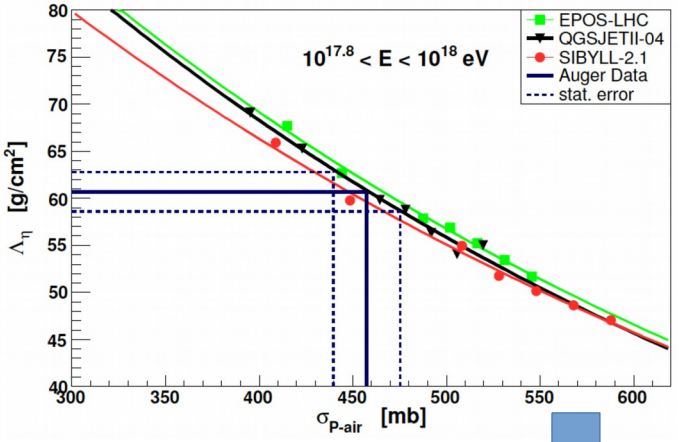
Remember cross section measurement with UHECR !

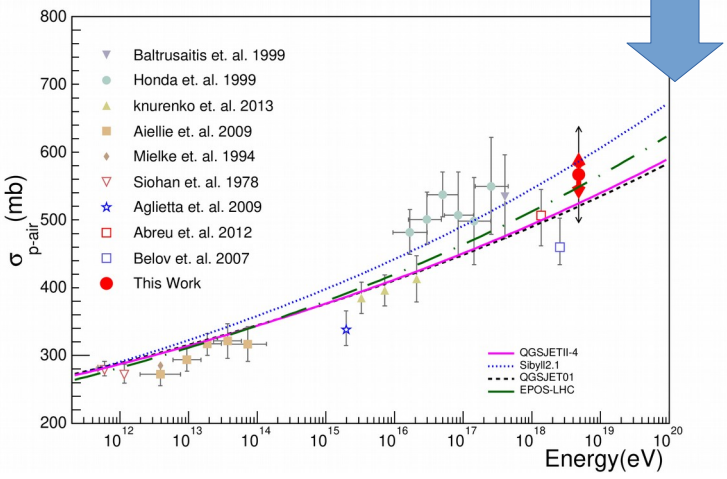
Example: cross section measure.

$$X_{\max} = X_{\text{first}} + \Delta X$$

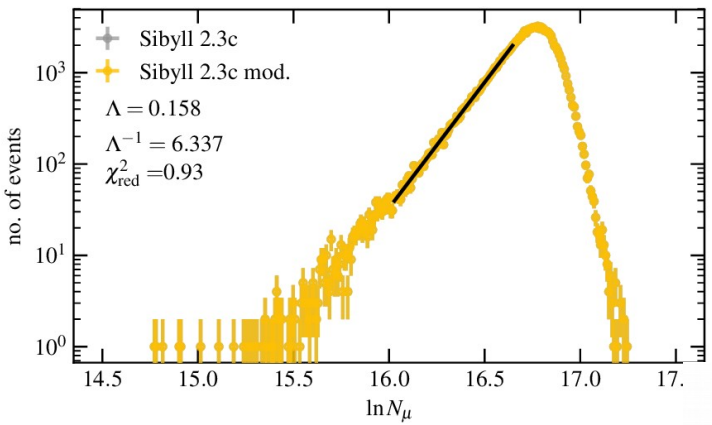


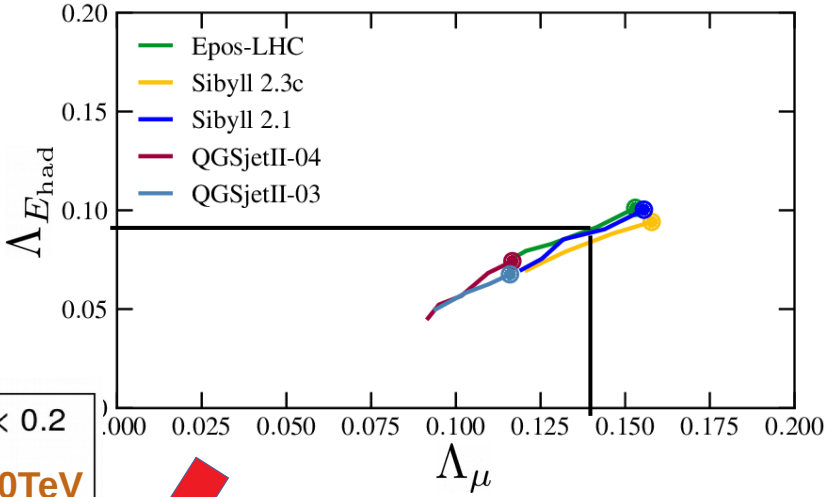
(Pierre Auger Observatory, PRL 109 (2012) 062002)

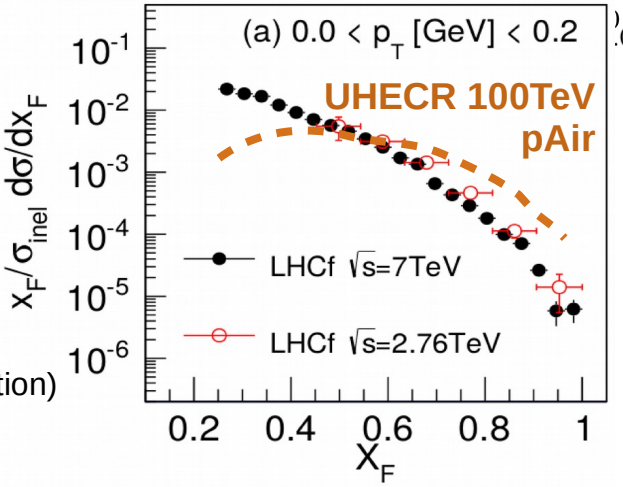




Measurement of pion spectrum



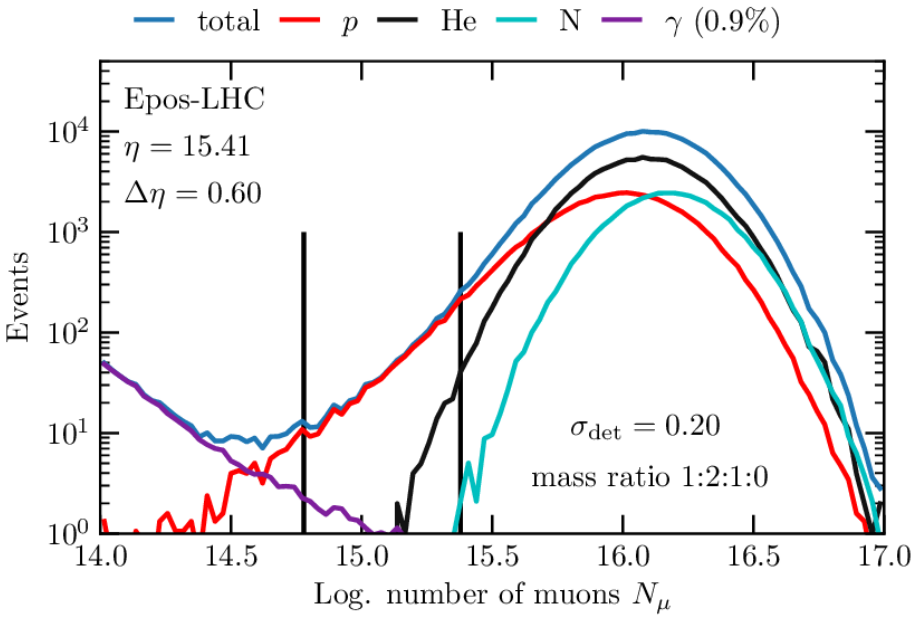


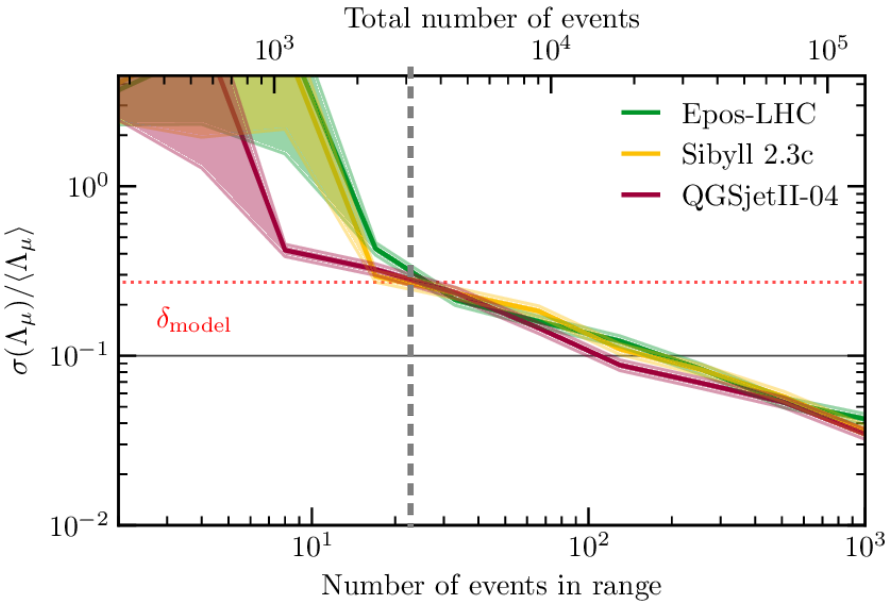


(illustration)

(LHCf PRD 94 032007 (2016))

A scenario





Helium contamination

Summary

* $\langle N_\mu \rangle$ with GrandProto300 can establish energy dependence of muon problem

* Fluctuations of N_μ dominated by first interaction
→ sensitive to modifications of high energy interactions
limits on LIV, etc
→ test exotic scenarios for muon problem
→ measure !

* Shape of N_μ distribution sensitive to shape of
inclusive production cross section of neutral pions
→ Possibility of measurement of a concrete observable of multiparticle production with UHECR.
→ LHC ~ GrandProto300 energy range !