

# A measurement of the pion production cross section in proton-air interactions ?

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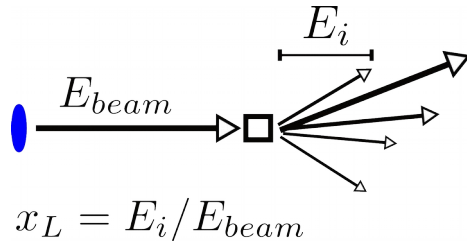
LIP-Lisbon

2<sup>nd</sup> LIP-IGFAE-workshop

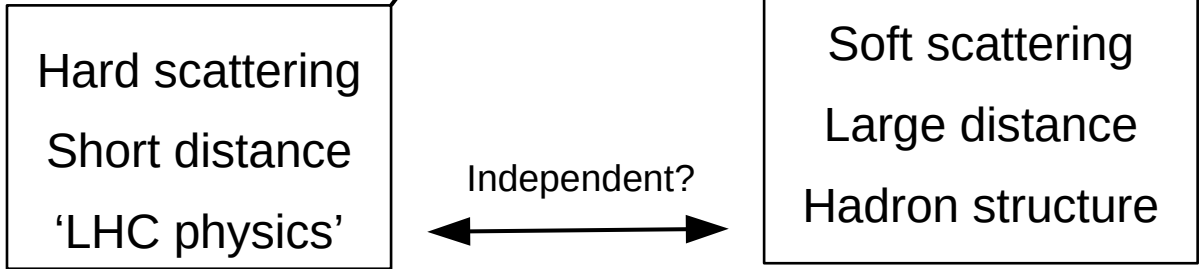
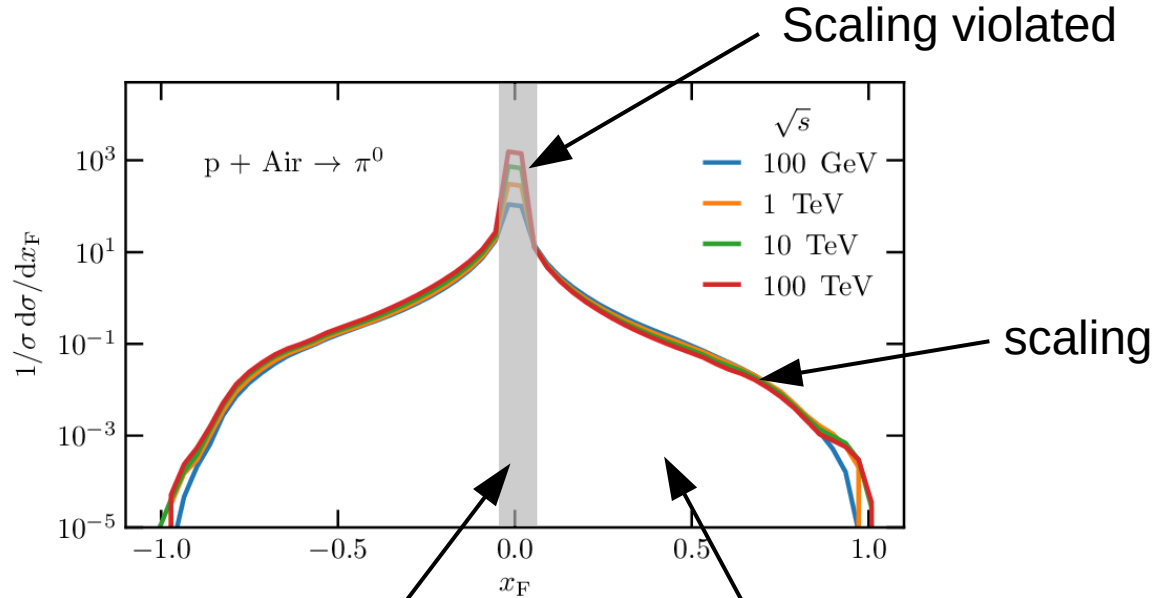
26. 04. 2019

# Production cross section

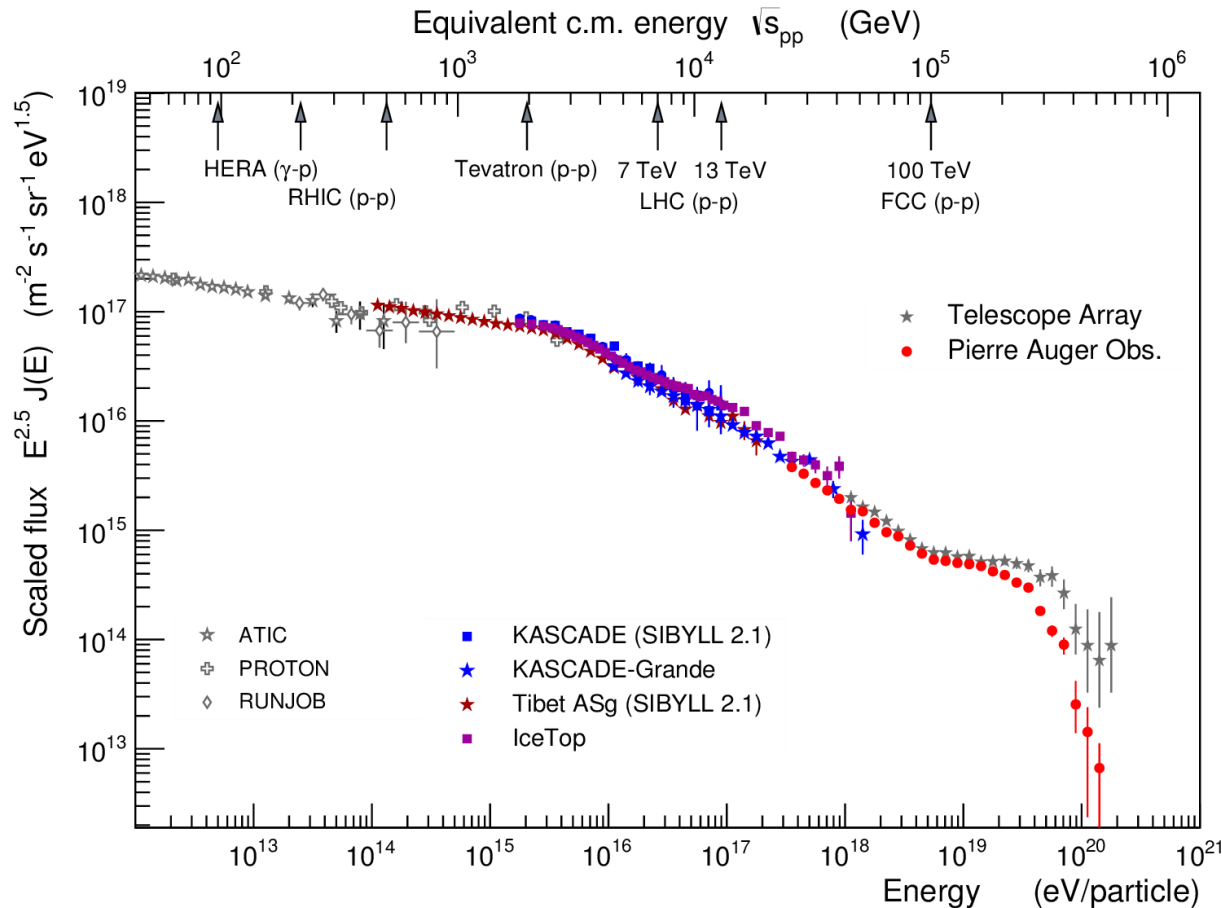
$$A + B \rightarrow C + X$$



$$\frac{d^3\sigma_{A+B \rightarrow C}}{dx_L d^2\vec{p}_T}$$



# Ultra-high energy cosmic rays



Natural UHE beam

Accelerator:

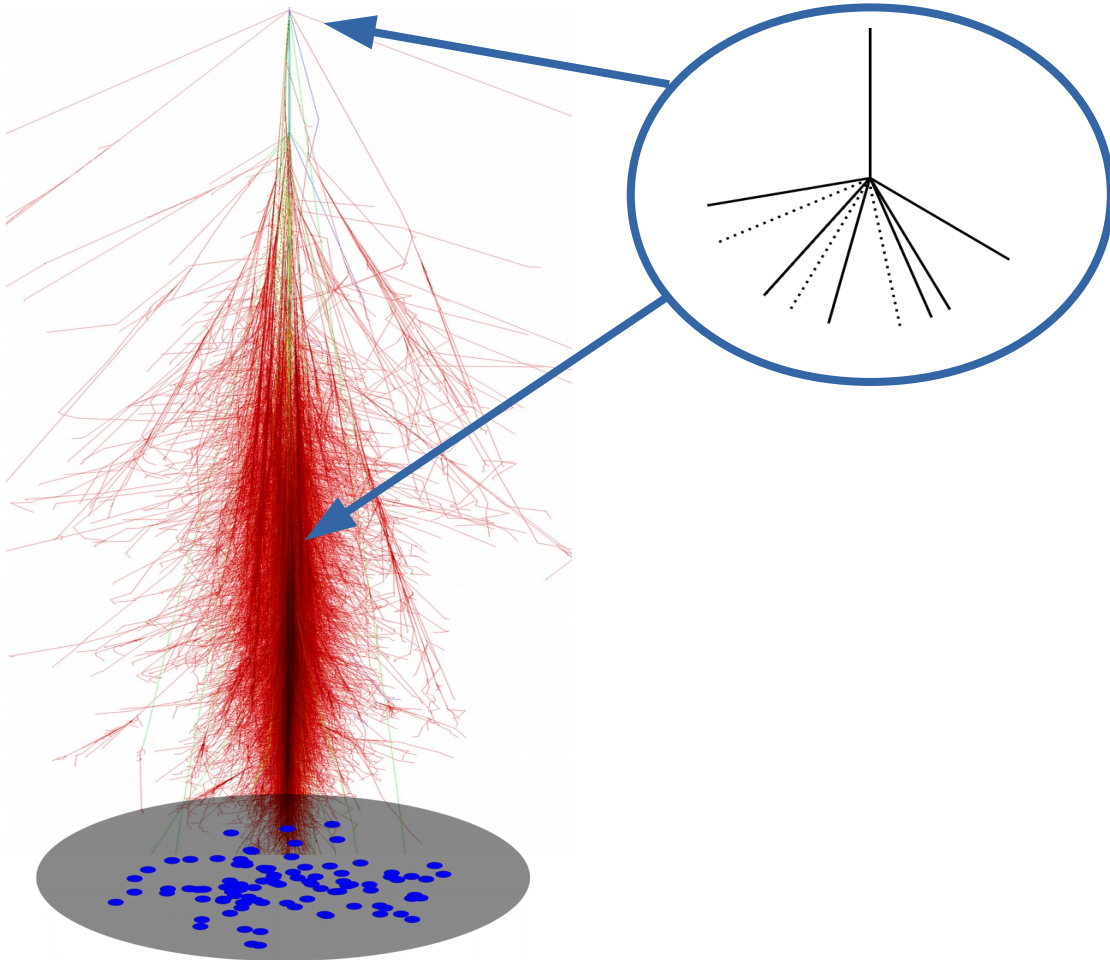
unknown, don't care

Particle type:

unknown, mixed

some protons!

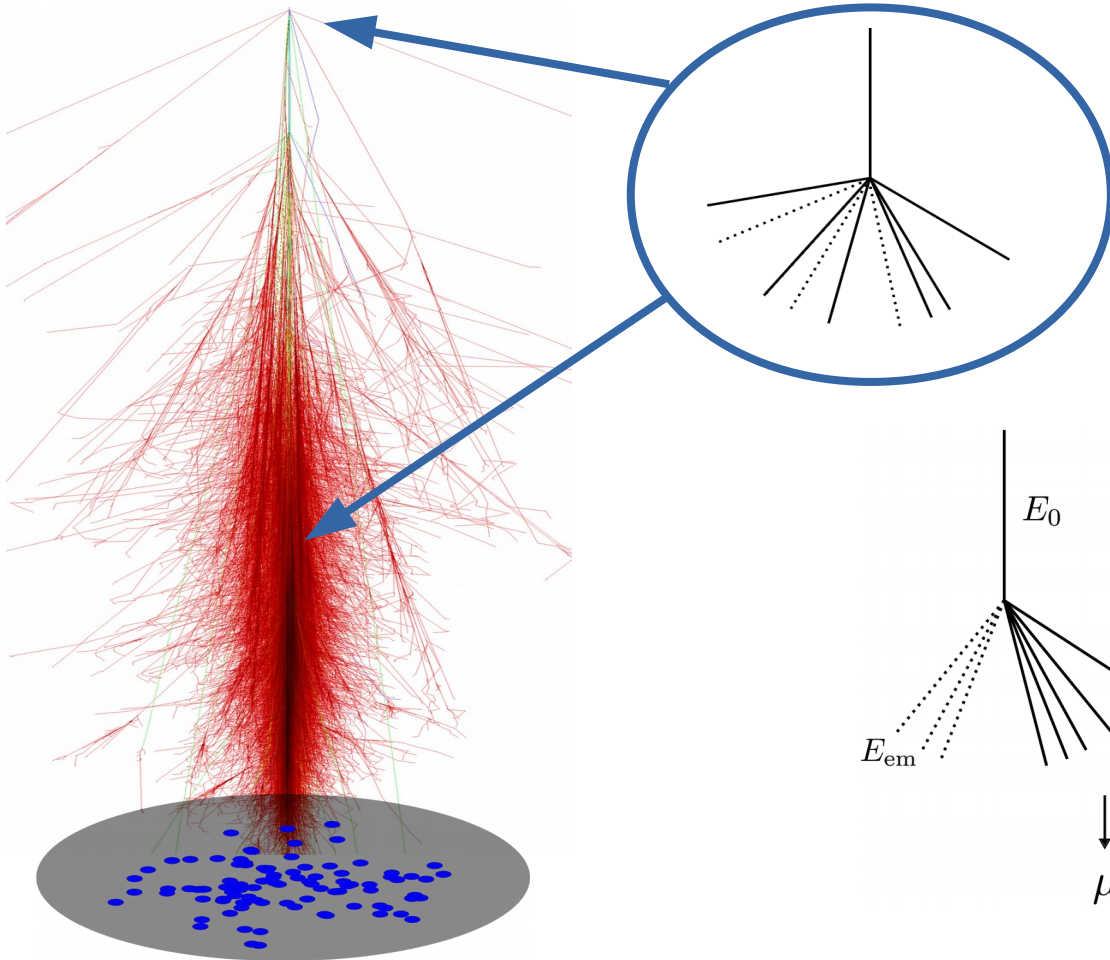
# Problem: extensive air showers



many interactions !  
many particles

Do not measure products of  
first interaction

# Basic shower development



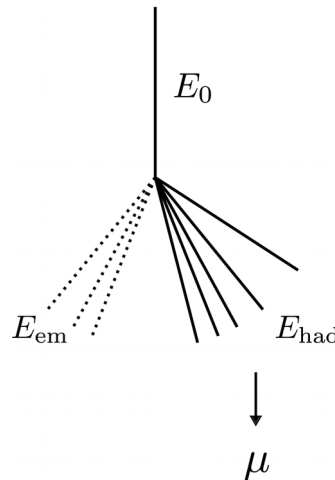
Two showers:

\* Electromagnetic  $\pi^0 \rightarrow \gamma\gamma$

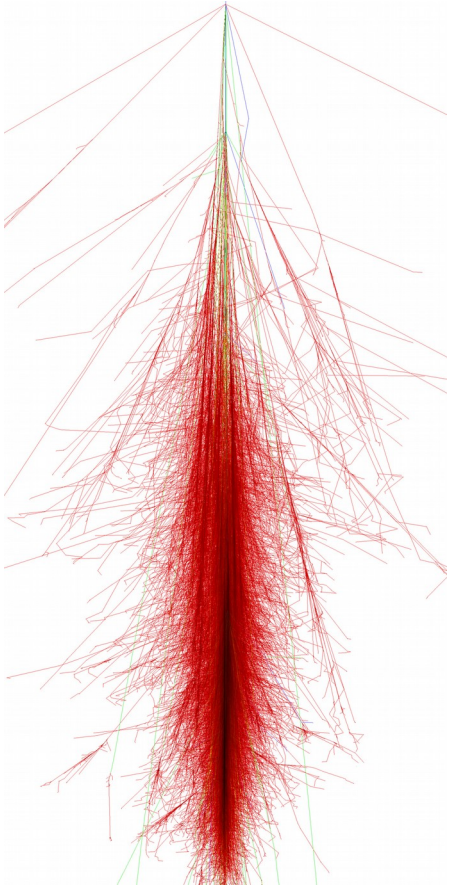
\* hadronic

Hadronic  $\rightarrow$  muons

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



# Origin of muons in EAS



Multiplication of hadrons  
through interactions



Meson decays



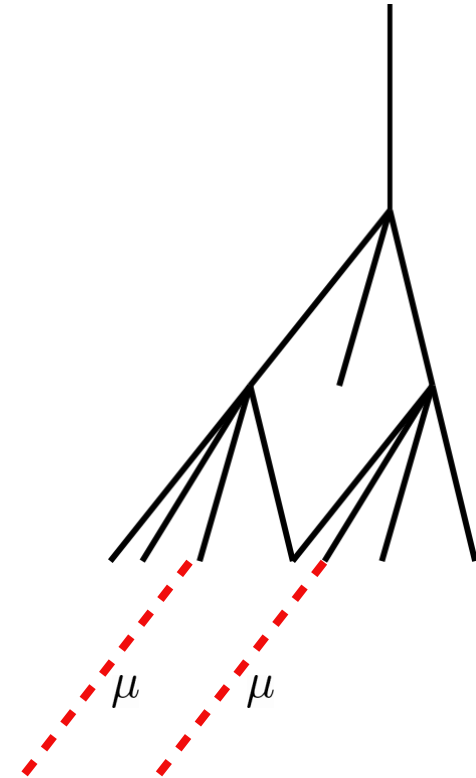
Muons

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

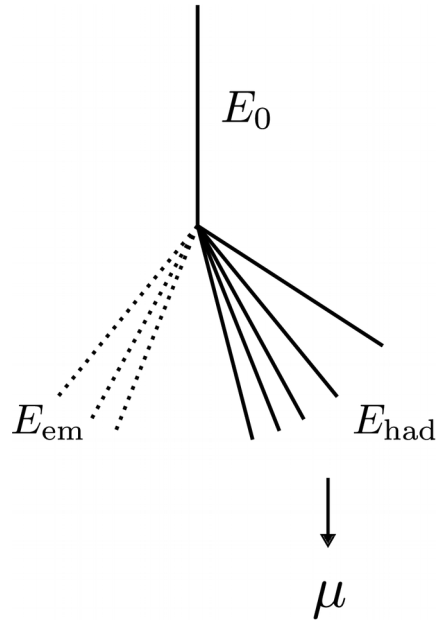
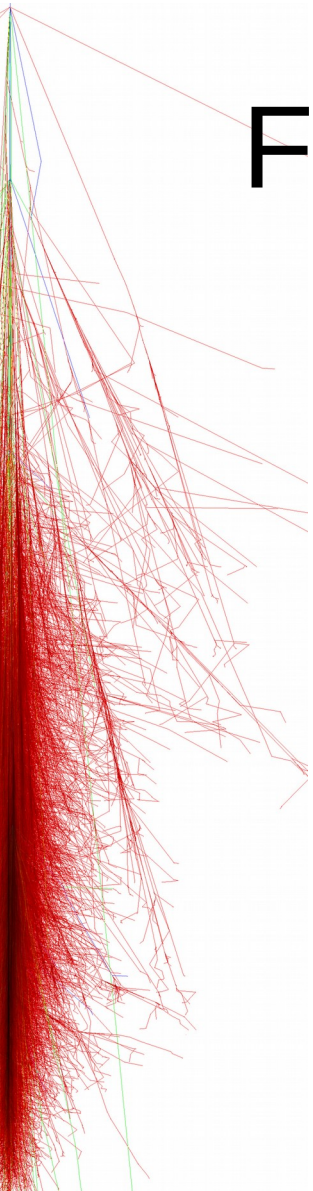
(Astro. Part.Ph 22, 387, 2005)

All along the  
shower :(

But causally  
connected to first !

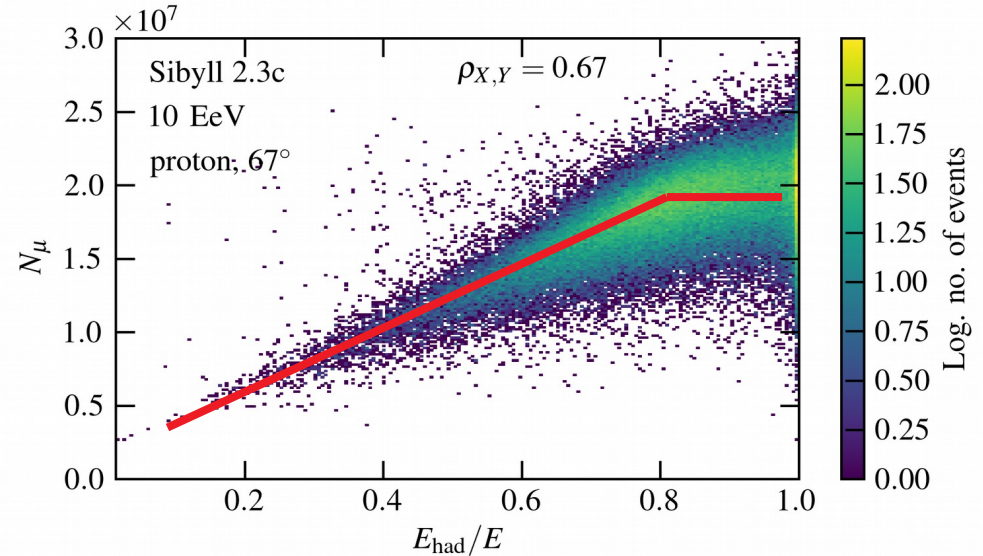


# Fluctuations == first interaction!



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

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



$$\sigma(E_{\text{had}}) \rightarrow 50\% \sigma(N_{\mu})$$

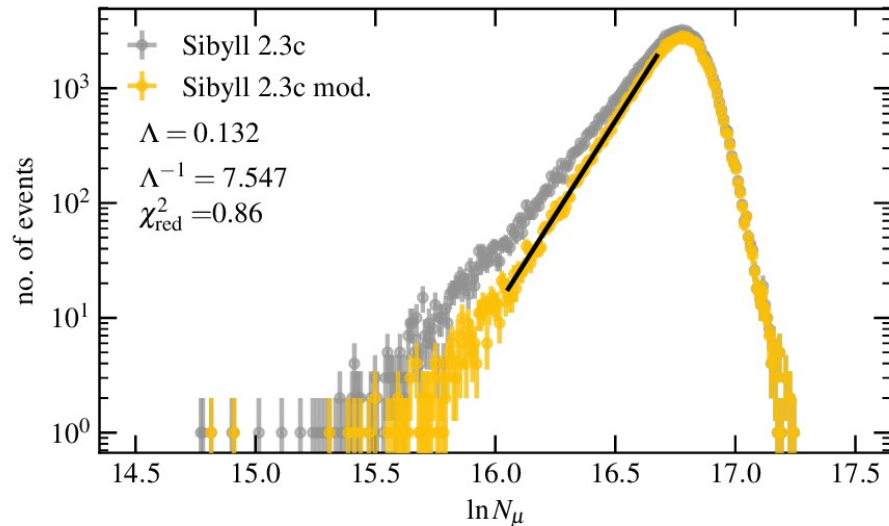
$$\sigma(E_{\text{had}}, m_{\text{had}}) \rightarrow 70\% \sigma(N_{\mu})$$

More!

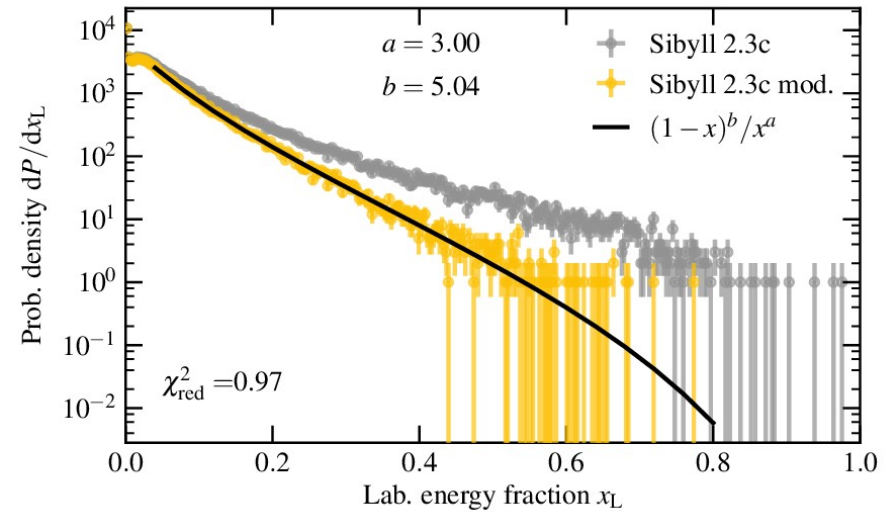


# Extreme fluctuations

Distribution of number of muons



Inclusive neutral pion prod. spectrum



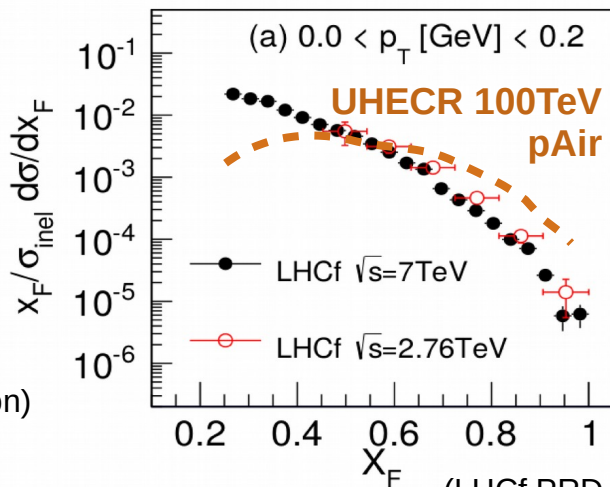
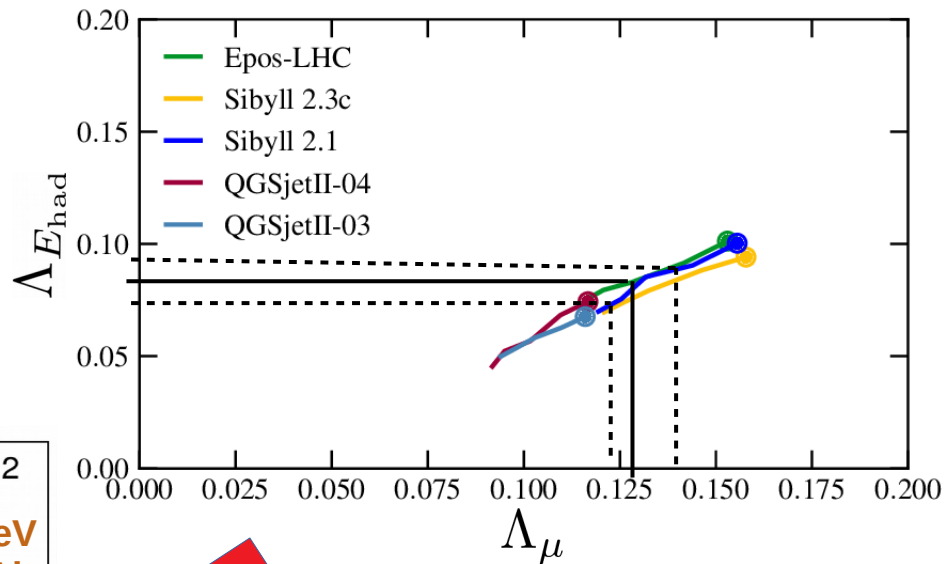
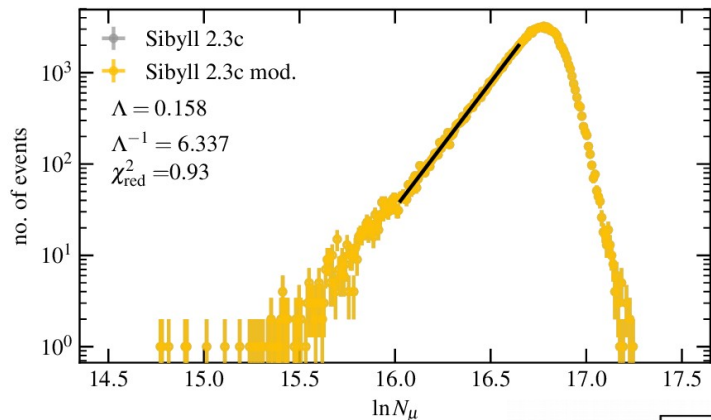
(details see: UHECR  
proceedings, 1812.09121)

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

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



# Measurement of pion spectrum

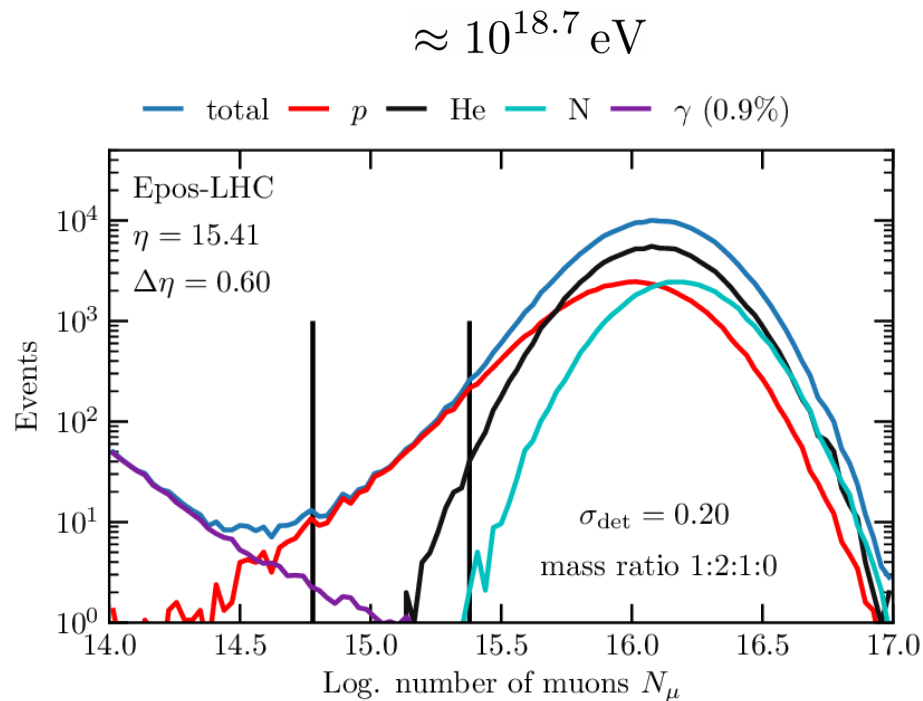


(illustration)

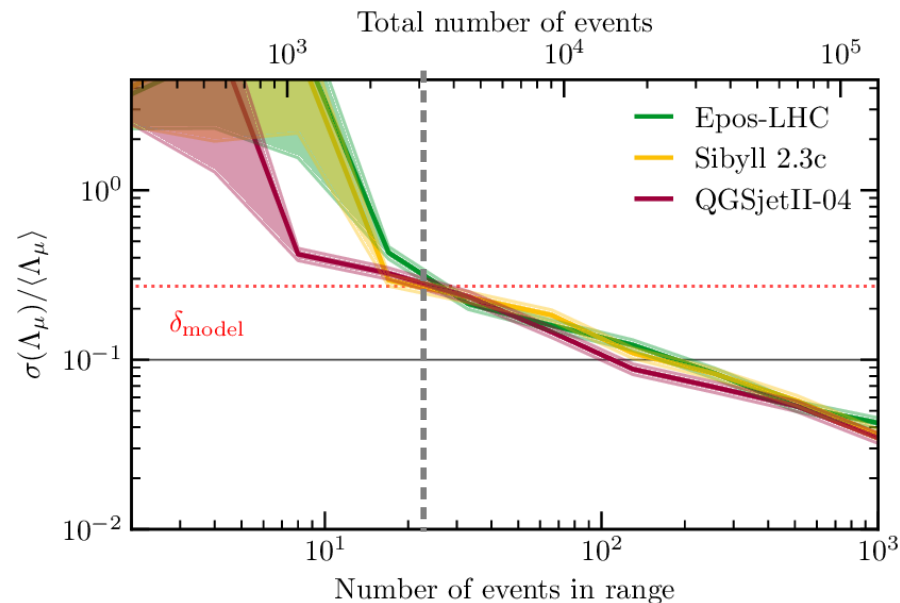
(LHCf PRD 94 032007 (2016))

Work in progress

# A scenario

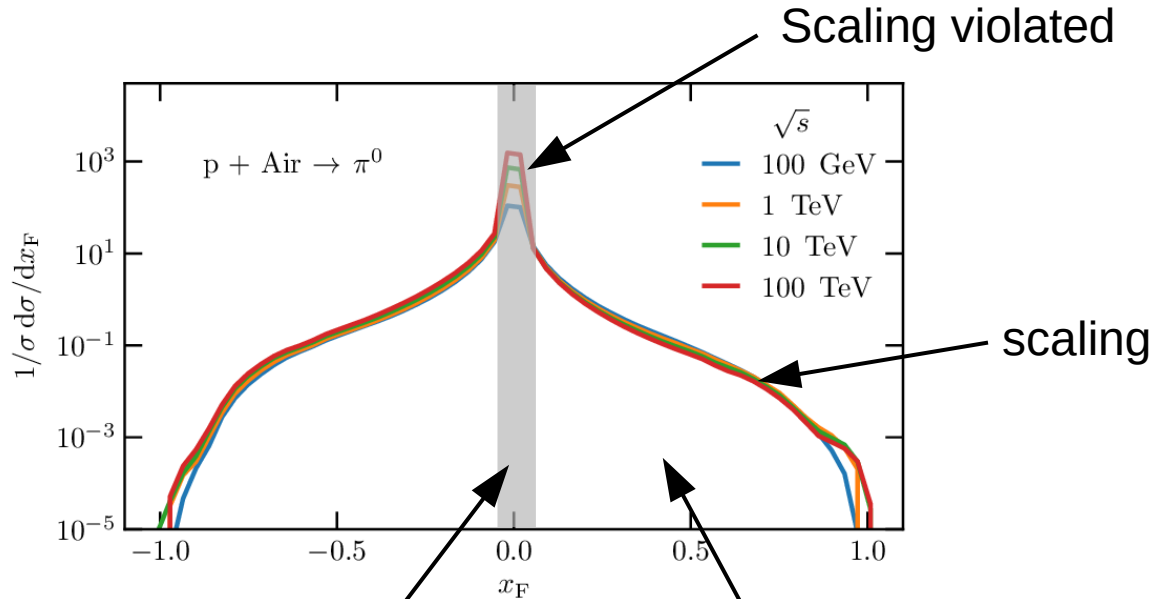


Helium  
contamination



$\sim 3000$  events needed

# Possibilities



Hard scattering  
Short distance  
'LHC physics'

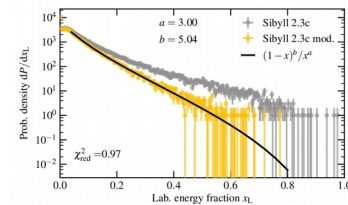
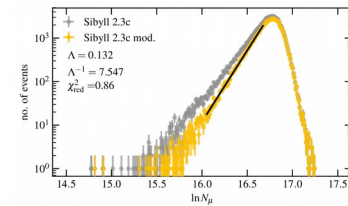
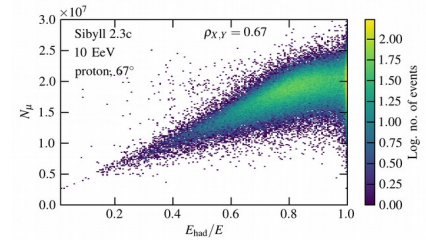
Soft scattering  
Large distance  
Hadron structure

- \* scaling violated in forward?
  - probe soft QCD models
  - factorization breakdown

- \*  $\pi^0$  still decay into  $\gamma\gamma$  at EeV ??
  - LIV limits
  - Chiral symmetry rest.

# Summary

- \* shower-to-shower fluctuations of muons  
give access to first interaction
- \* tail of muon distribution sensitive to  
neutral pion production cross section at large  $x$
- \* probe hadron interactions at UHE  
(for real this time)





# Example: cross section measure.

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

