Probing the pion spectrum at high-x with ultra-high energy cosmic rays

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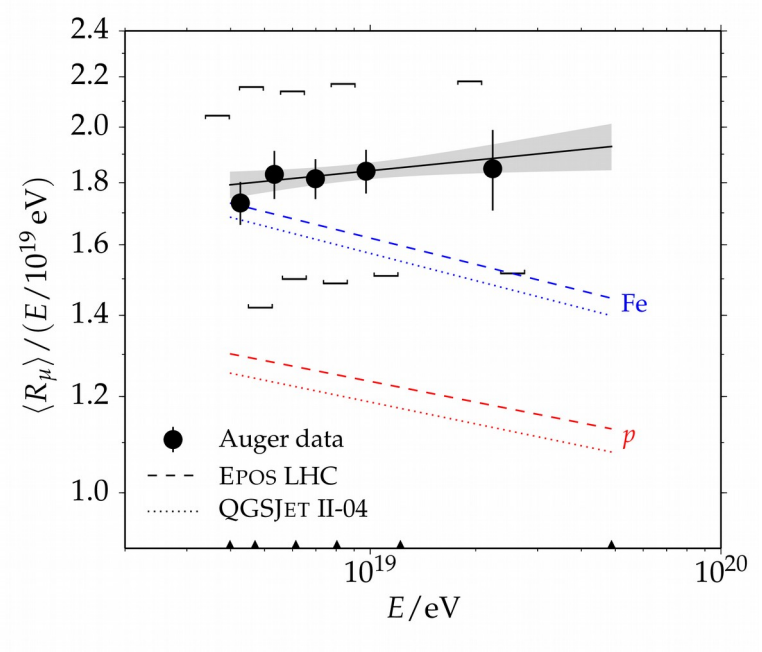
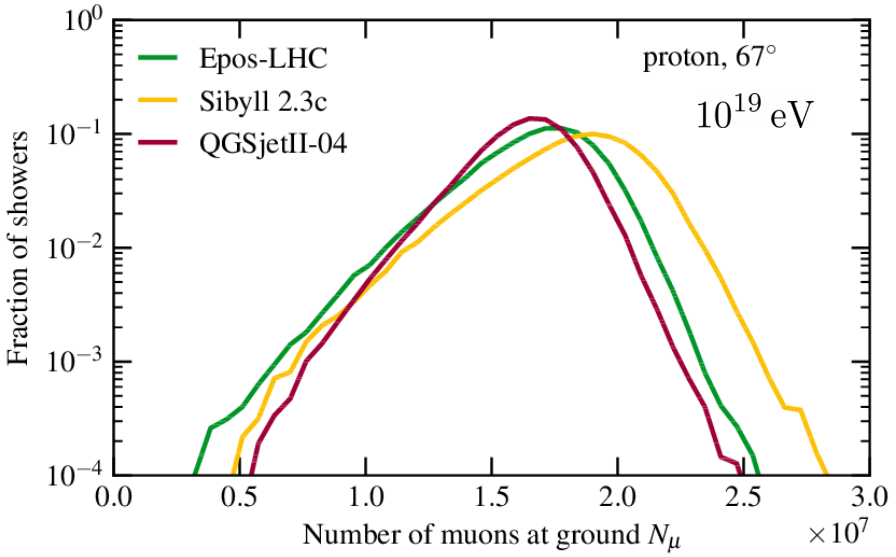
Motivation

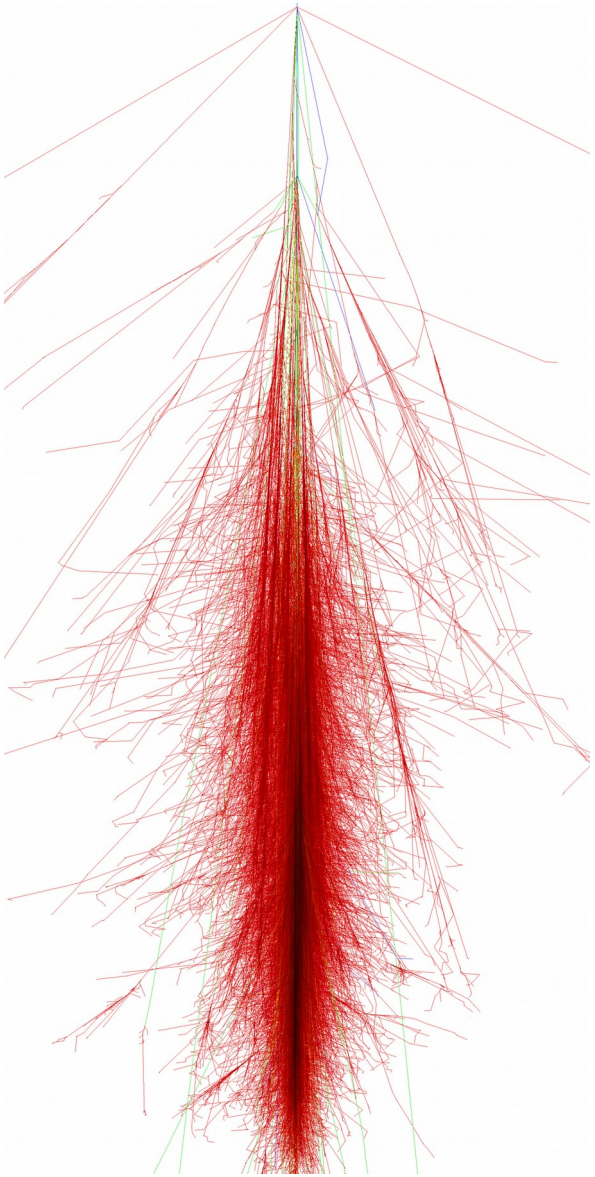
Average → muon problem
(see talk HadronicInteractionsWG)



Physics in muon distribution ?



Muons in EAS



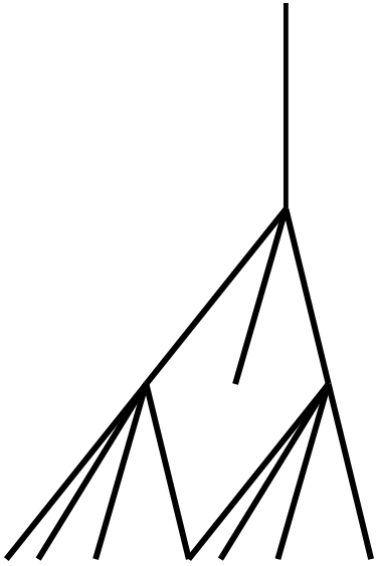
Cascade of
hadron interactions

⬇

Meson decays

⬇

Muons



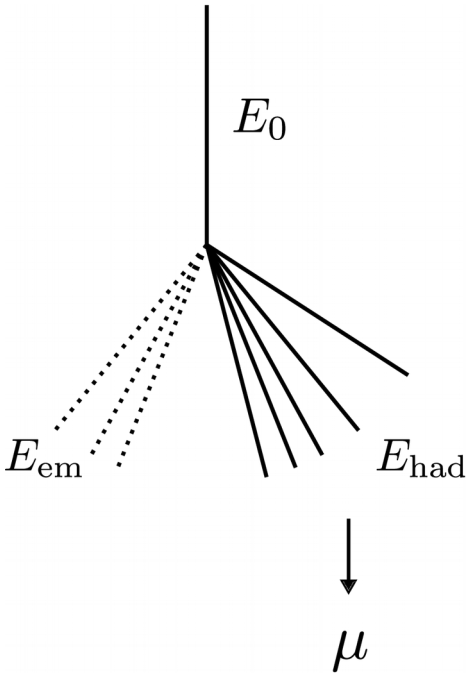
$$\langle N_\mu \rangle \sim E^\beta$$

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

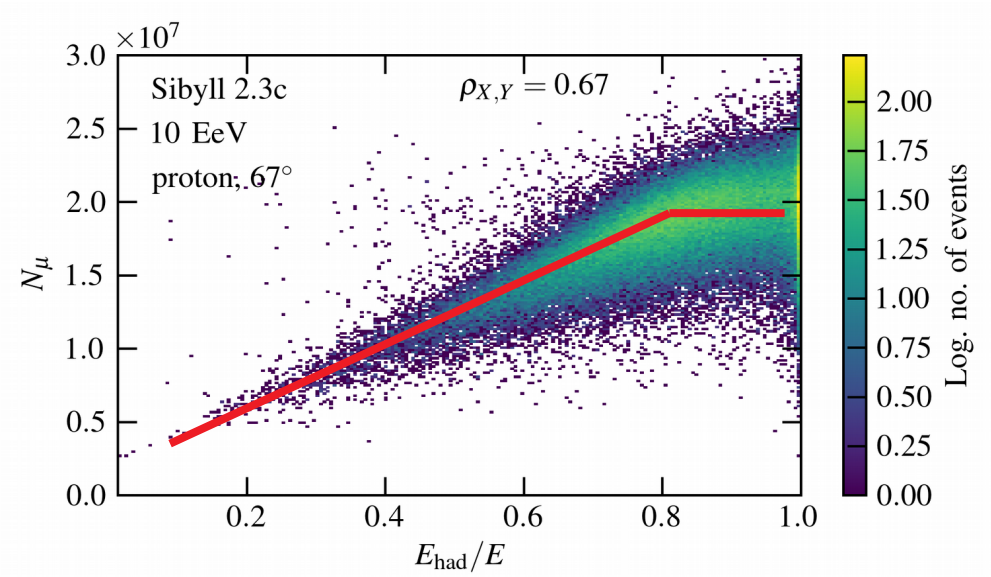
Corsika simulation

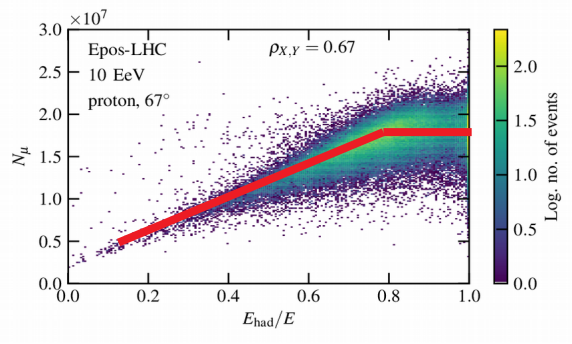
Fluctuations of the muon content I

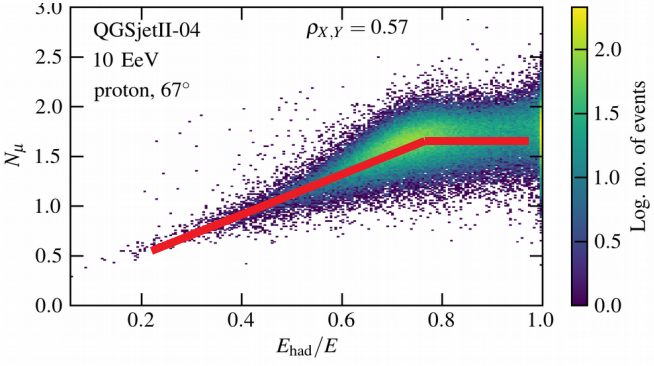
(L. Cazon, R. Conceição, FR: PLB 784 (2018) 68-76)



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

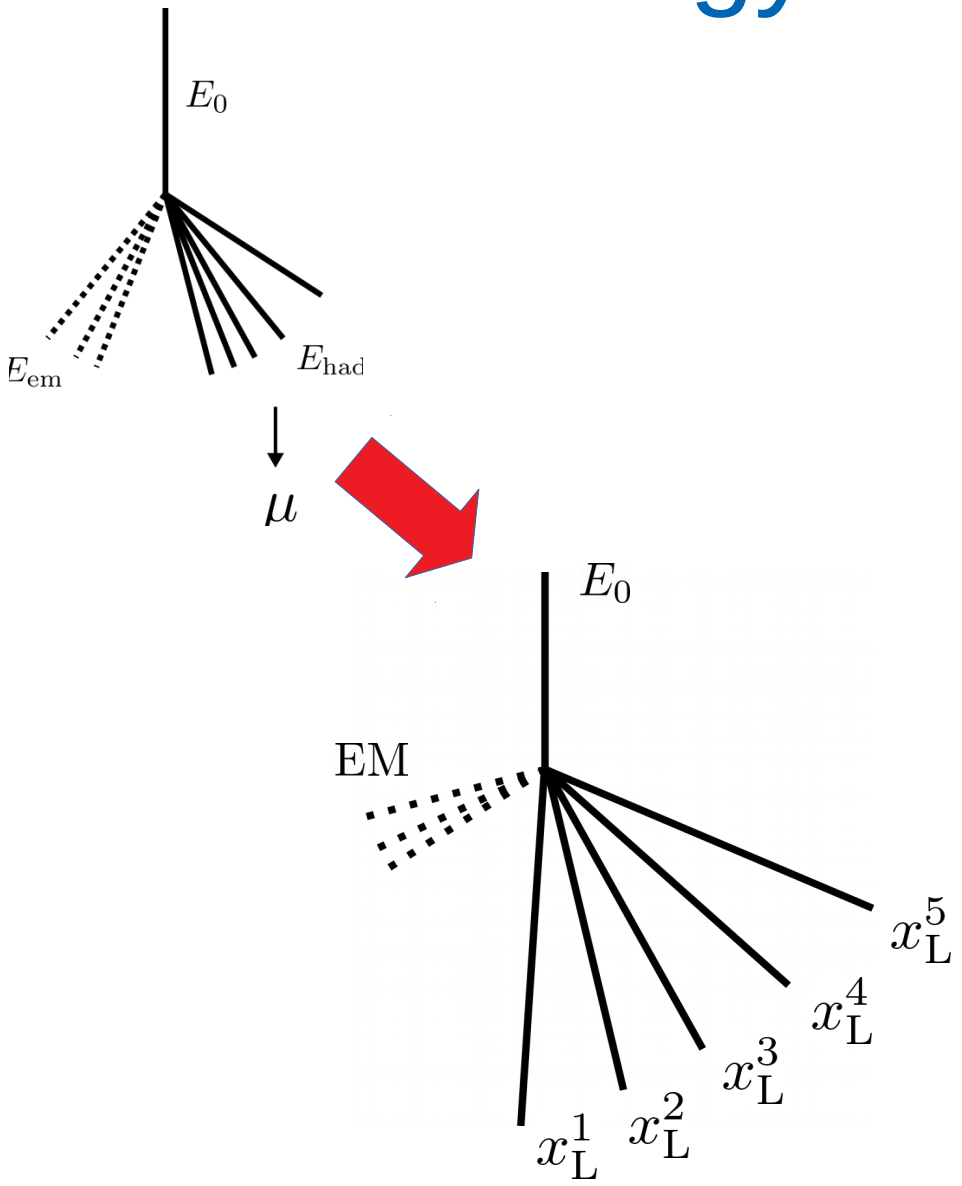






(Figsize ~ 1 / runtime)

Energy and multiplicity



$$x_{\rm L}^i = E_i/E_0 \qquad E_{\rm had} = E_0 \sum_i x_{\rm L}^i$$

$$\langle N_\mu \rangle = a\, E_0^\beta$$

HM, MC, measurement, CE

$$N_\mu = \sum_i N_\mu^i \approx \sum_i \langle N_\mu(E_i) \rangle = a \sum_i (x_{\rm L}^i)^\beta$$

$$\alpha = \sum_i^{m_{\rm had}} (x_{\rm L}^i)^\beta$$

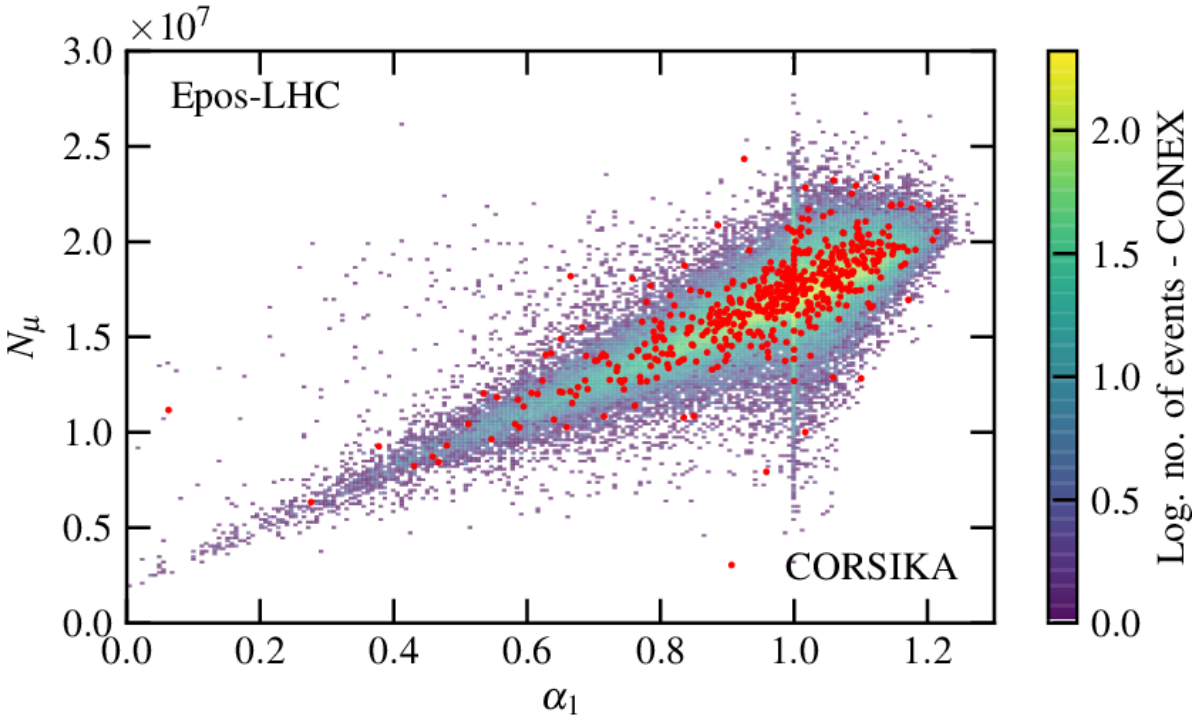
(cite muon bundles)

Fluctuations of the muon content II

Strong correlation
Independent of:

* int. model
* energy
* zenith angle

$$\sigma(\alpha) \rightarrow 70\%\,\sigma(N_\mu)$$

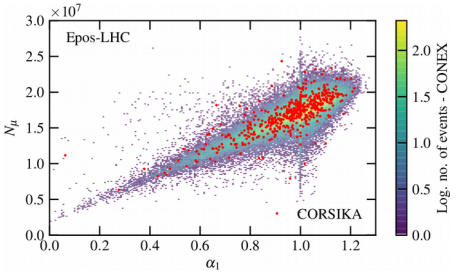


→ sensitive to first interaction !!!
→ constrain exotic solutions to muon problem

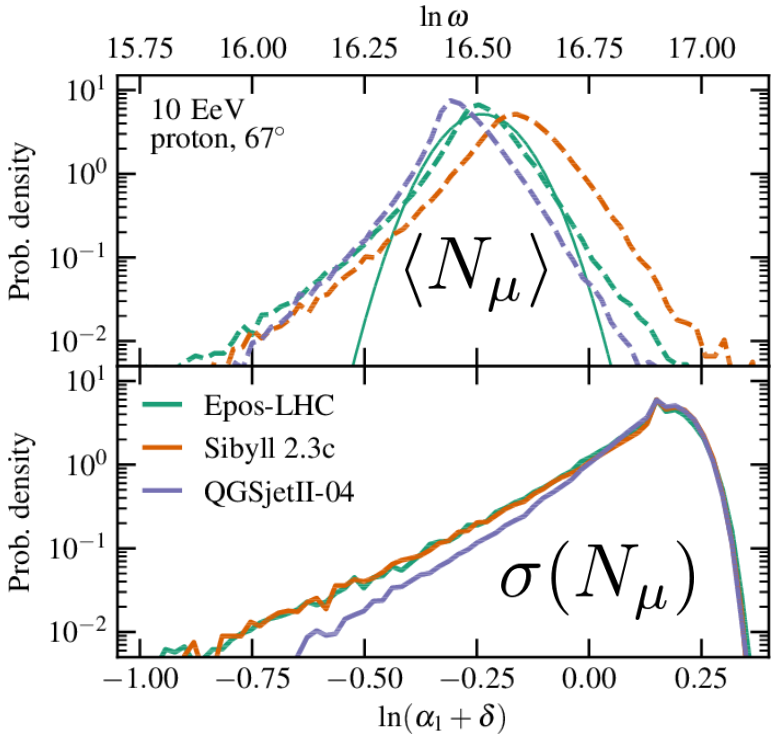
(LIV, CSR, SPM..)

(Astro. Phys. 31 220 2008, EPJ Web Conf. 53 07007 2013, 1209.6474, EPJ C53 585 2008)

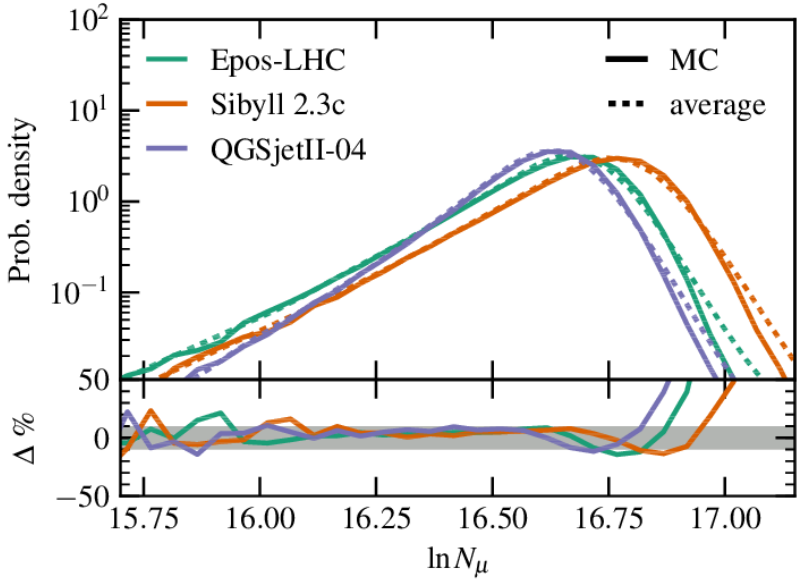
First interaction & shower



$$N_\mu = \alpha \cdot \omega$$

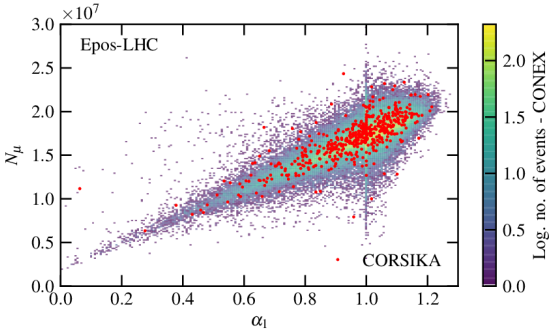


convolve



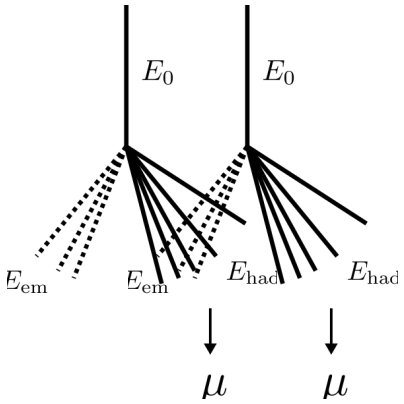
Different primaries

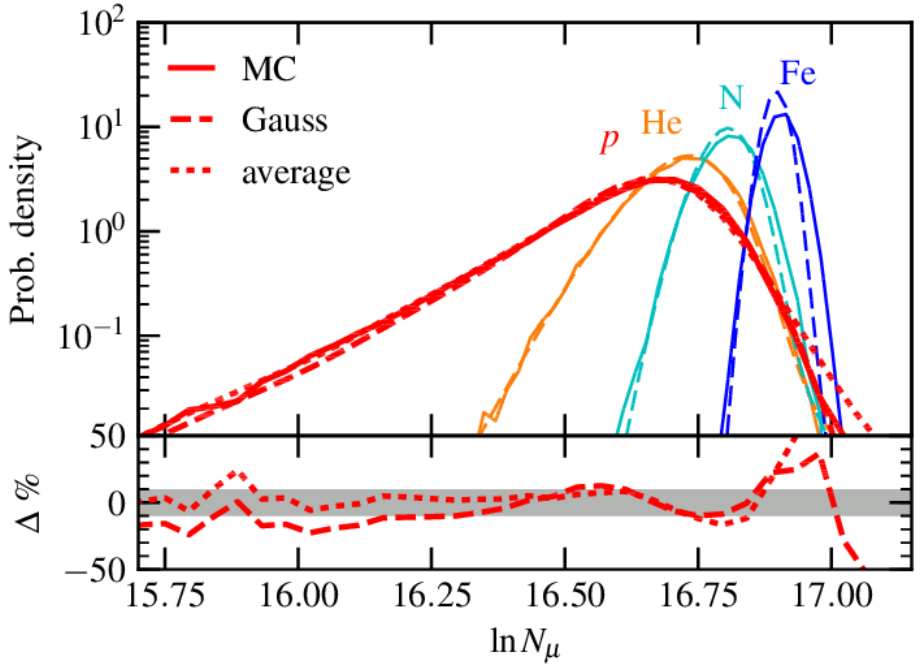
* Energy fluctuations p-Air



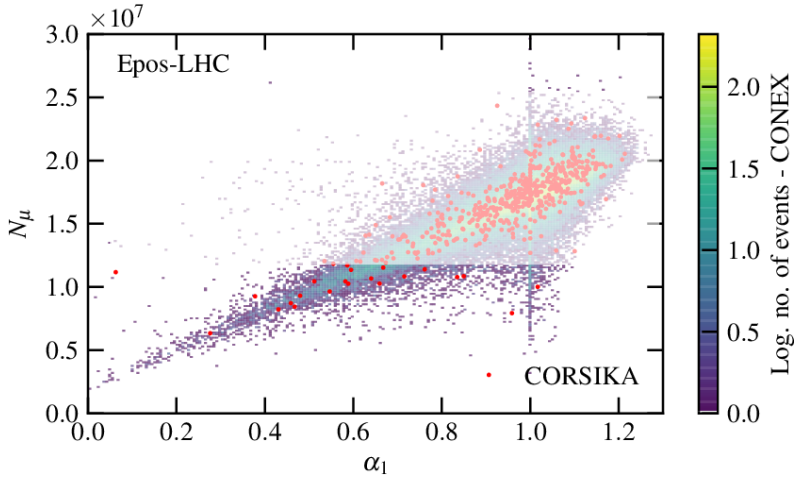
* Superposition model

$$N_\mu(E, A) = A \cdot N_\mu(E/A)$$

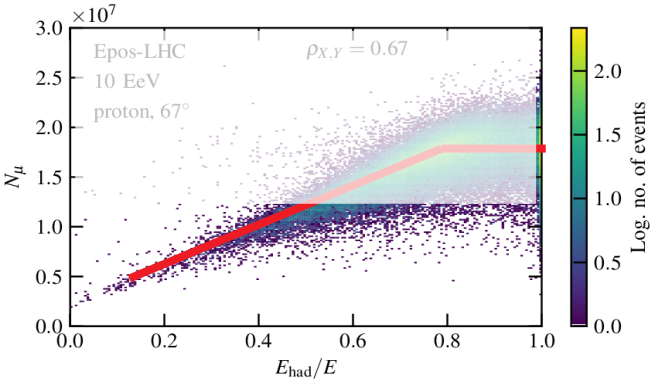




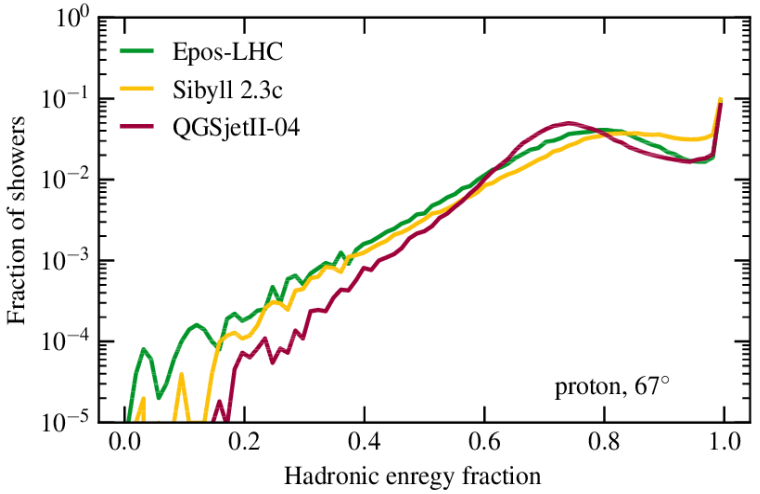
Access hadronic interactions ?

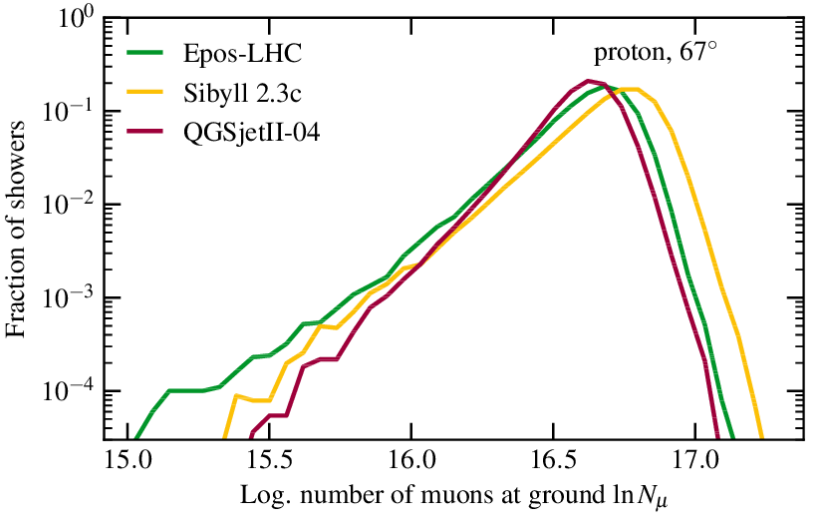


Tail dominated by first interaction



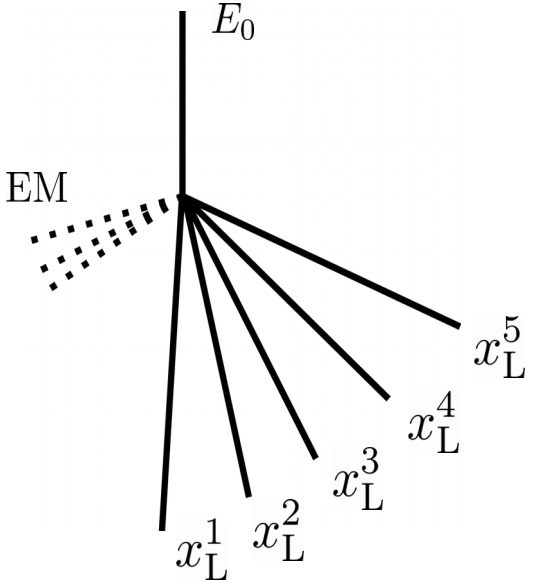
Had. Energy sufficient





What can we learn about hadronic interactions ?

What determines had. Energy? (tail)

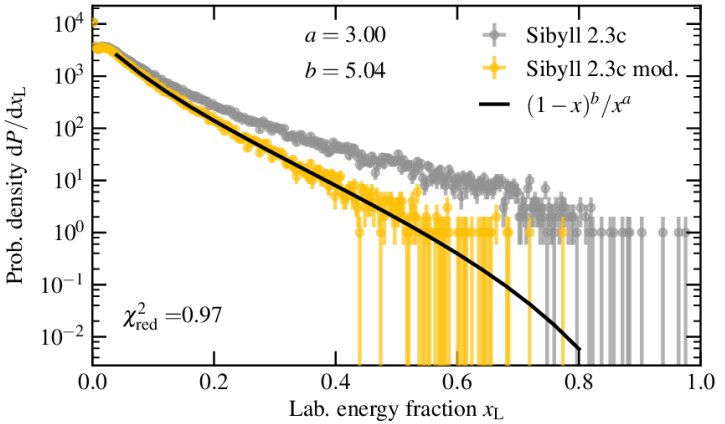


$$E_{\rm had}/E_0 = \sum_i x_{\rm L}^i = (1 - E_{\rm EM}/E_0)$$

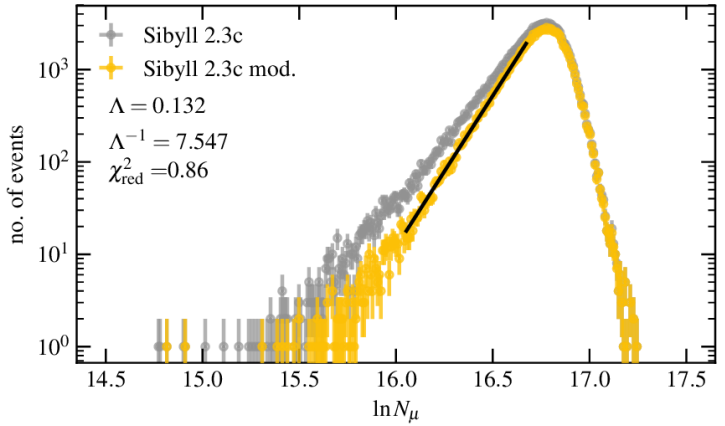
π^0

Inclusive production cross section

$$p + Air \rightarrow \pi^0 + X$$

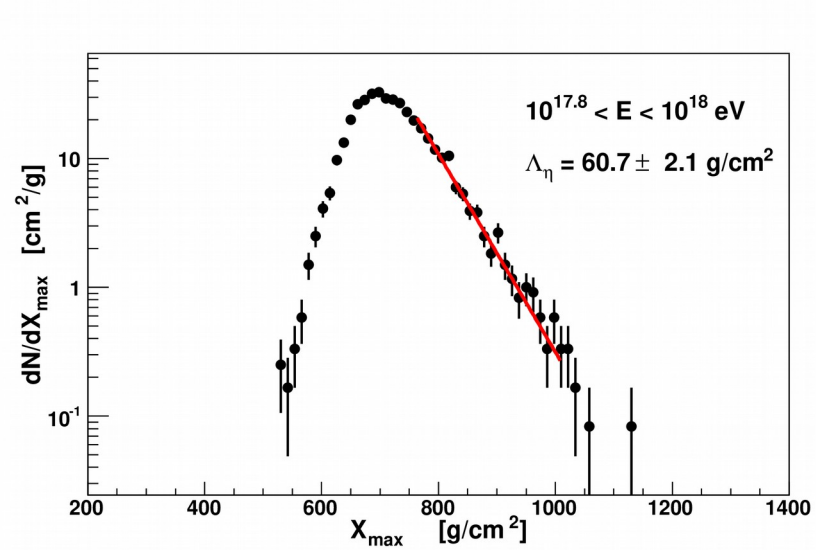


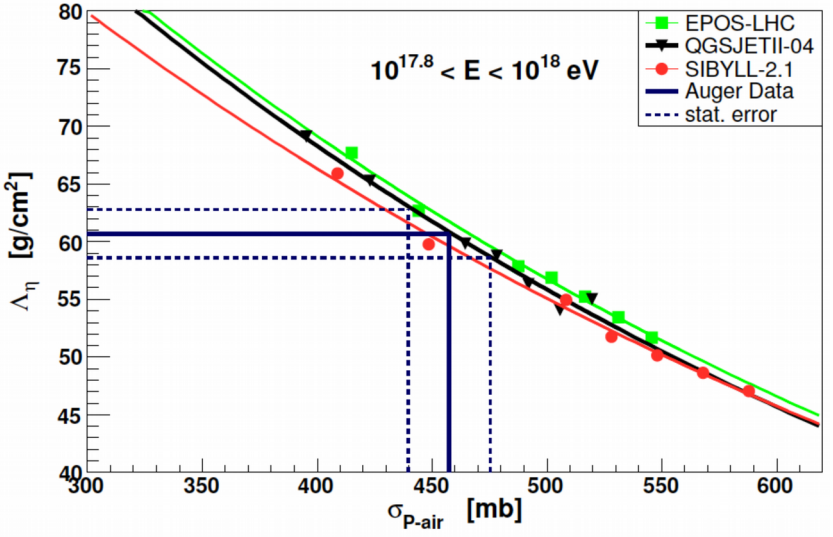
Modify!



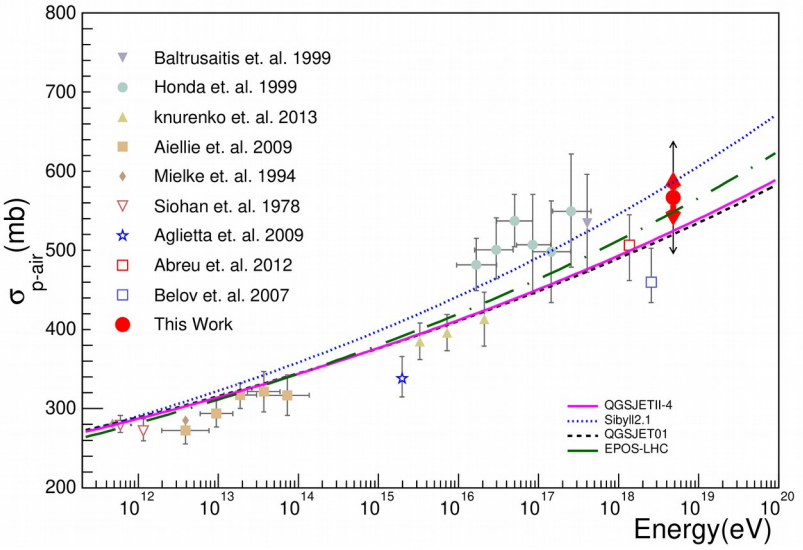
Slope of muon distribution == Shape of inclusive production cross section at high-x !

Example: cross section measurement



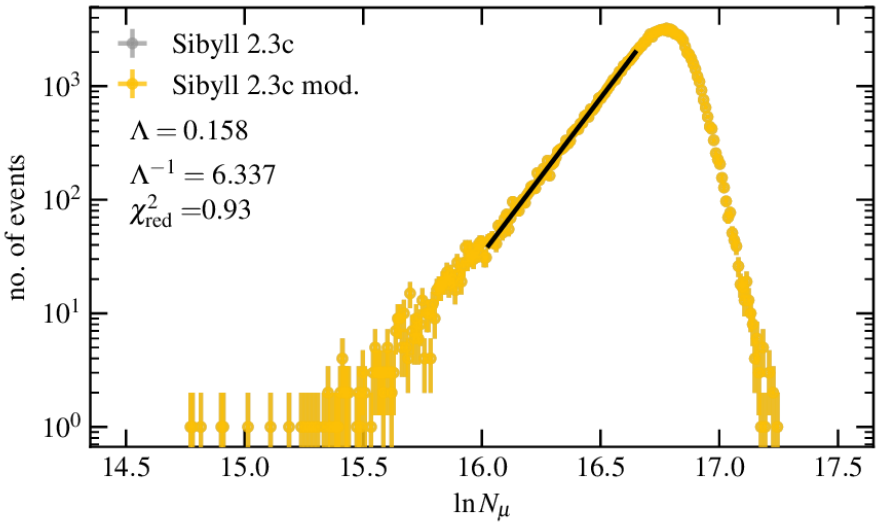


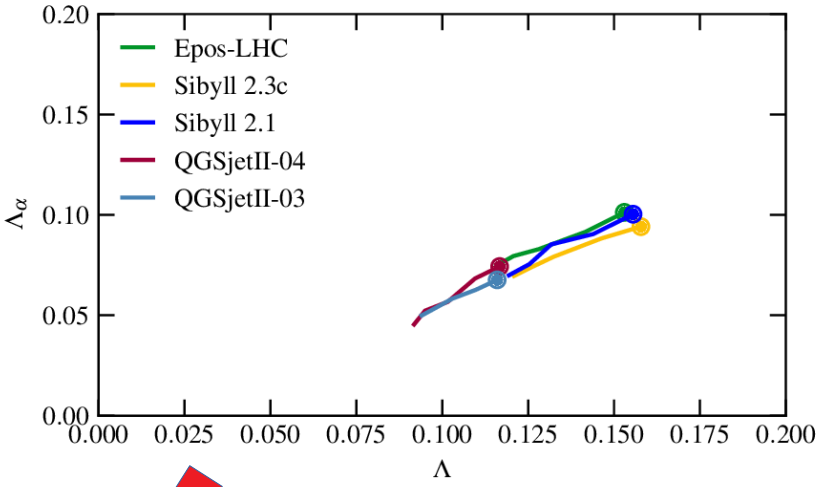
(cite Auger cross secti
RU analysis)



Same approach
for muons

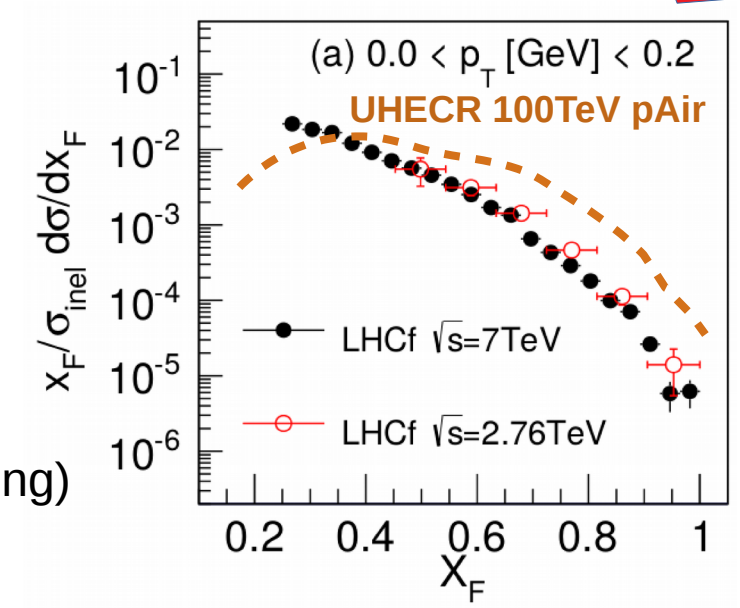
Measurement of pion spectrum



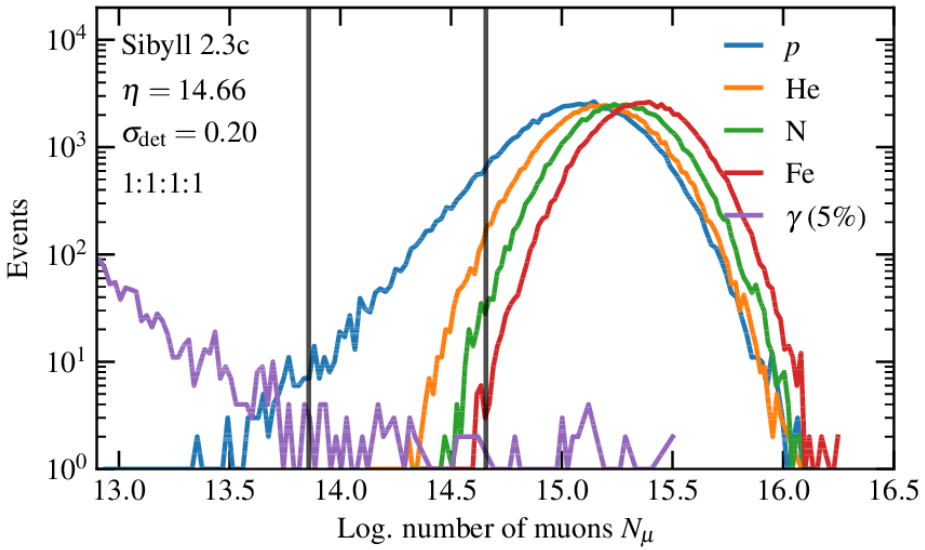


(LHCf PRD 94 032007 (2016))

(work ongoing)



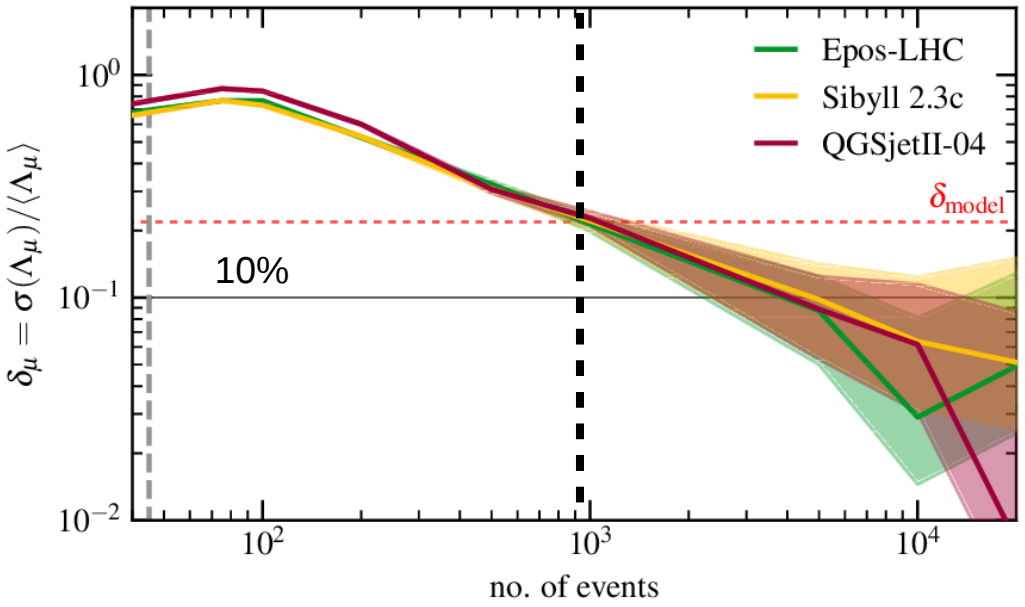
Scenario of a measurement



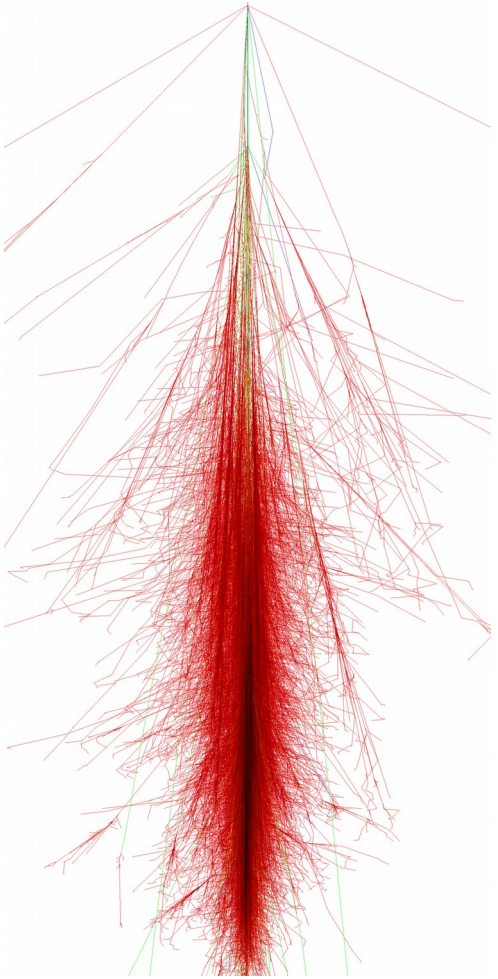
1:1 p-He ratio: ~1000 events

1:2 p-He ratio: ~5k events

Sensitive to model difference



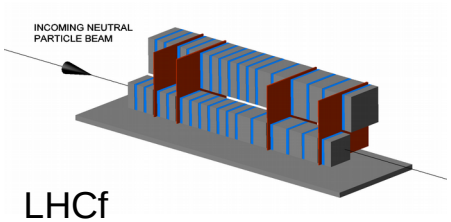
Summary



* Fluctuations of N_μ dominated by first interaction
  - → sensitive to modifications of high energy interactions
  - → test exotic scenarios for muon problem

* Shape of N_μ distribution sensitive to shape of inclusive production cross section of neutral pions at high-x

  - → Possibility of measurement of a concrete observable of multiparticle production with UHECR.
  - → test nature of hadronic interactions (models) at UHE
  - → complementary measurement to LHCf



LHCf