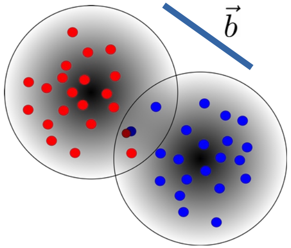
Sibyll 2.3d

Felix Riehn, R. Engel, A. Fedynitch, T.K. Gaisser and T. Stanev

CORSIKA 8 workshop
June 23rd 2020

Hadron-hadron interactions in SIBYLL



Hadron-hadron interaction == parton scattering * hadronization

$$P_n(\vec{b}) = \frac{\langle n(\vec{b})\rangle^n}{n!} \exp\left(-\langle n(\vec{b})\rangle\right) \qquad \langle n(\vec{b}, s)\rangle = A(\vec{b}, s)\,\sigma(s)$$

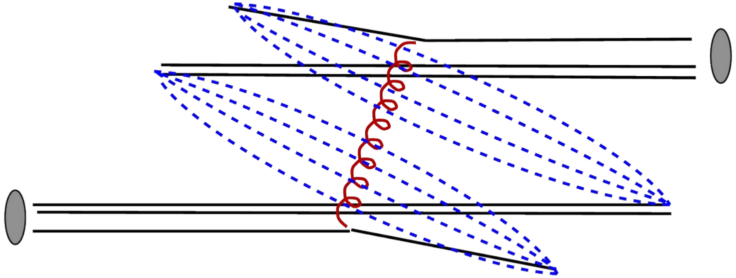
$$\sigma_{\rm QCD}(s, p_{\rm T}^{\rm min}) \qquad \sigma_{\rm soft}(s)$$

String fragmentation

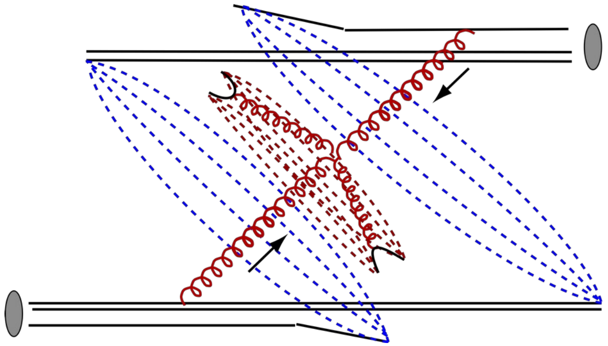
PRD 80, 094003 (2009)
PRD (2020), arXiv:1912.03300

All Sibyll 2.x

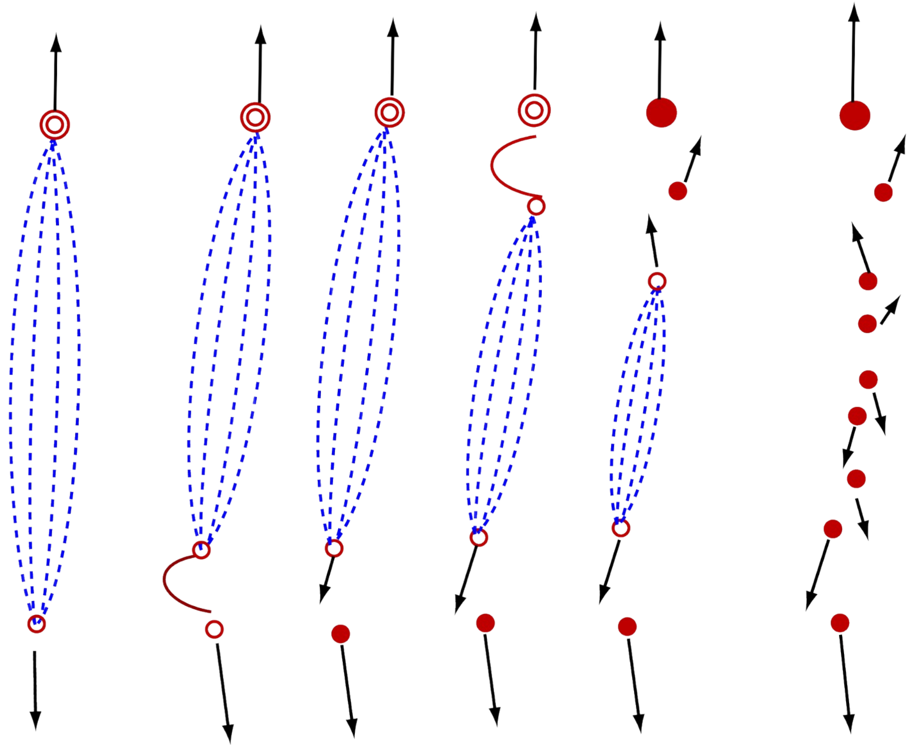
Low energy, soft single scattering



High energy, multiple scattering



Hadronization



String fragmentation

$$f(z) = \frac{(1-z)^{\alpha}}{z} e^{-bm_{\mathrm{T}}/z}$$

flavors: u,d,s

Timeline

SIBYLL 2.1 | SIBYLL 2.3 | SIBYLL 2.3c | SIBYLL 2.3d

~2000 | 2014 | 2017 | 2020

TeVatron

First LHC data

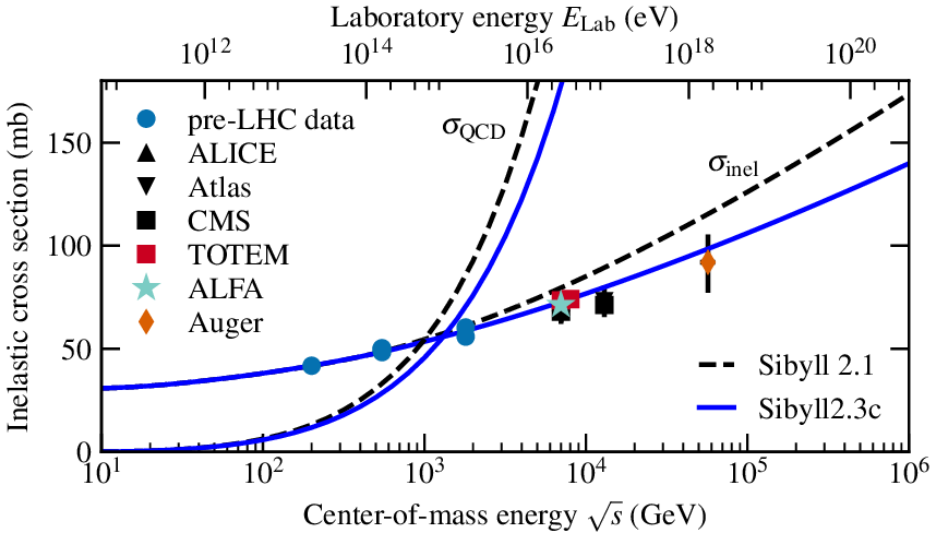
LHC Run II,III

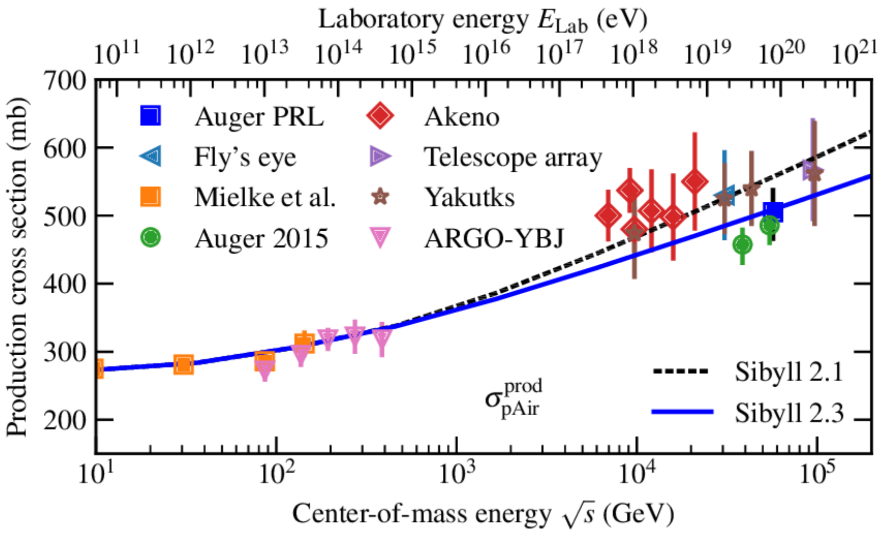
Muon deficit in EAS

Astrophysical neutrinos

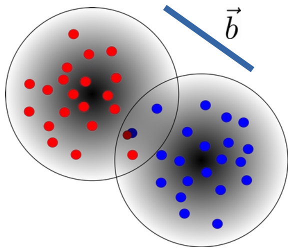
Sibyll 2.3: extend Sibyll 2.1 for ‘precision era’ (LHC, Auger, IceCube)

Sibyll 2.3: cross section in p-p





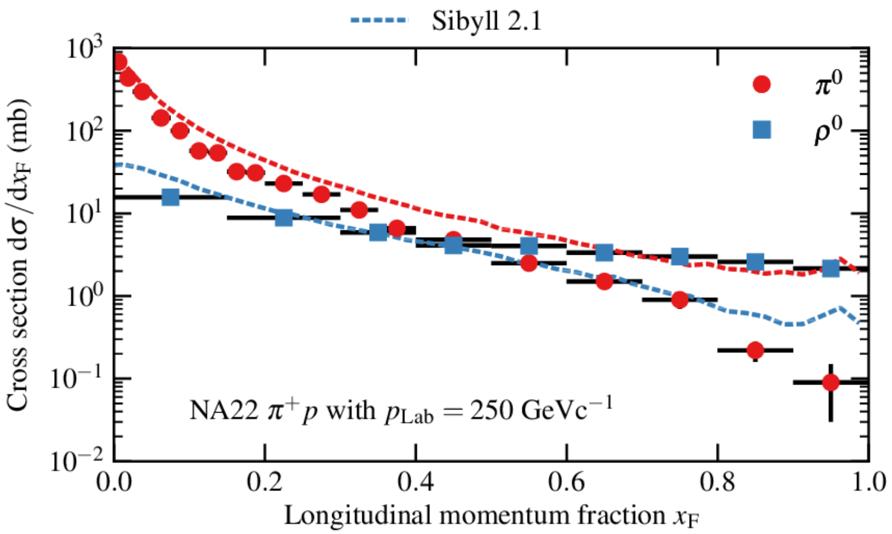
Sibyll 2.1 (TeVatron tuned)

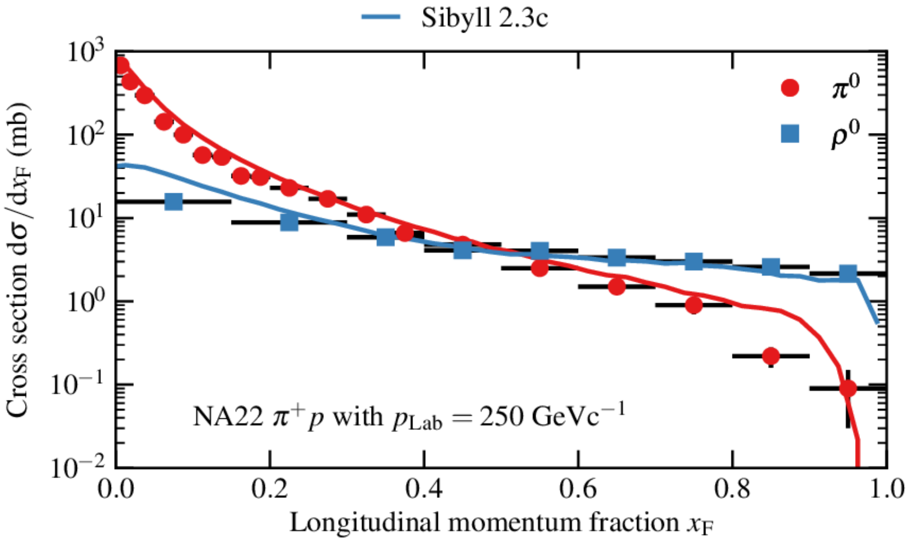


- narrow hadron profile
- increase soft-hard threshold

Sibyll 2.3: leading particles

$\pi^+ + p \;\rightarrow\; \text{leading} + X$ $\qquad$ $\text{leading} : \pi,\ \rho$ $\qquad$ NA22 (Z. Phys. C 35, 7 (1987), Z. Phys. C 46, 387–395 (1990))





$\pi\text{Air?}$

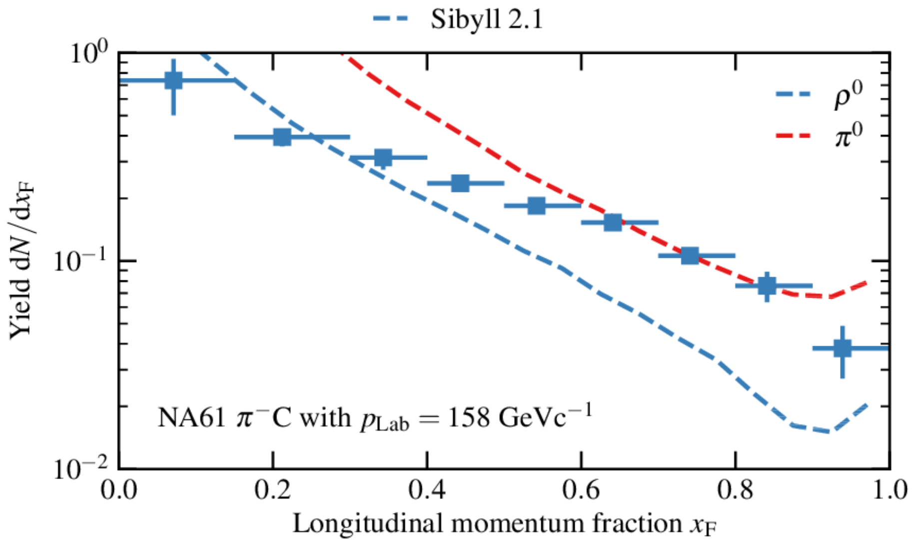
$$x_{\rm F} = \frac{p_z^\star}{p_z^{\star\max}}$$

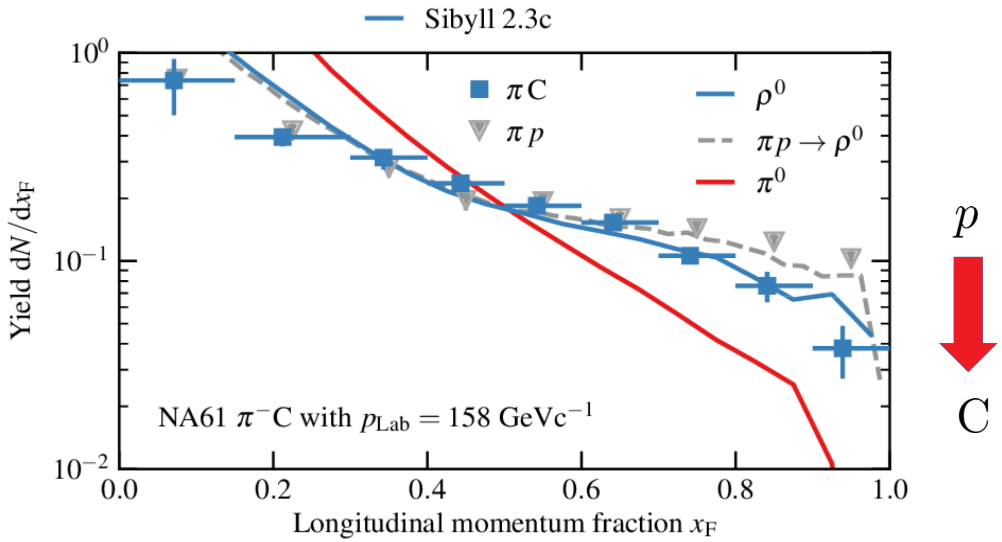
$$P_{\pi:\rho} = 1/3$$

Sibyll 2.3: leading particles

$\pi^+ + \mathrm{C} \;\rightarrow\; \text{leading} + X$ NA61   (Eur. Phys. J. C 77, 626 (2017))

Prediction!

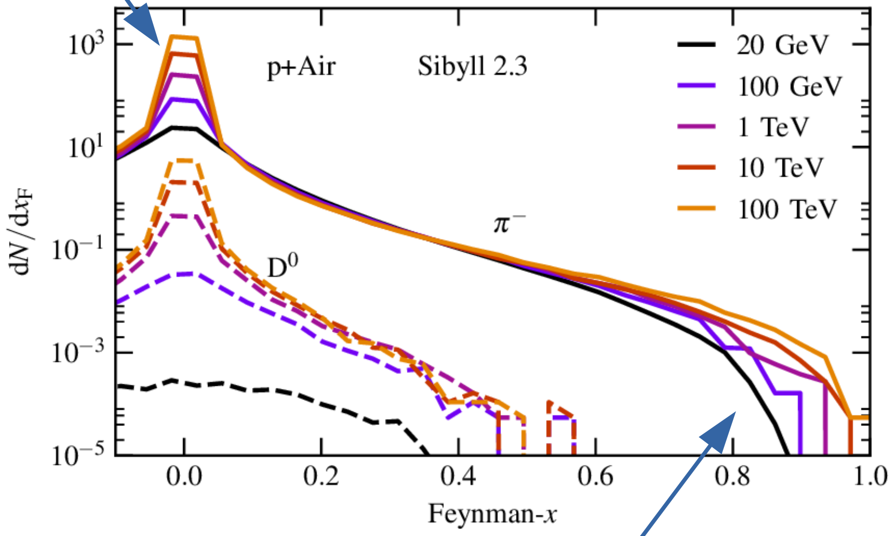




P → C transition reproduced

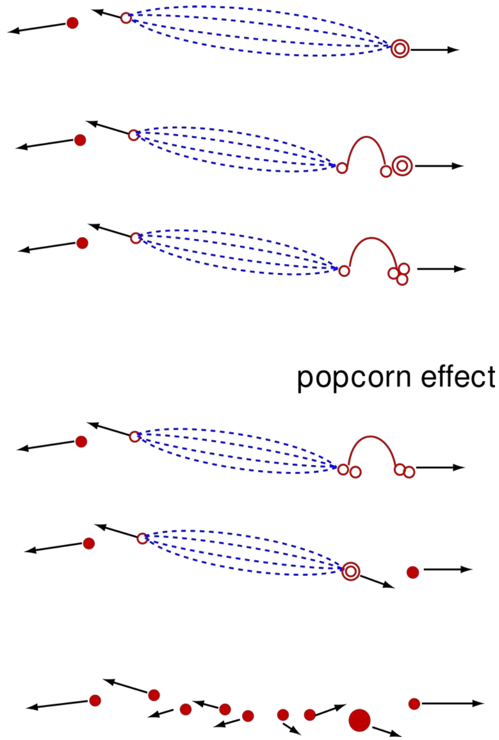
Sibyll 2.3c: very leading particles

Expected scaling violations due to jets



Scaling violations unexpected direction

Leading baryon



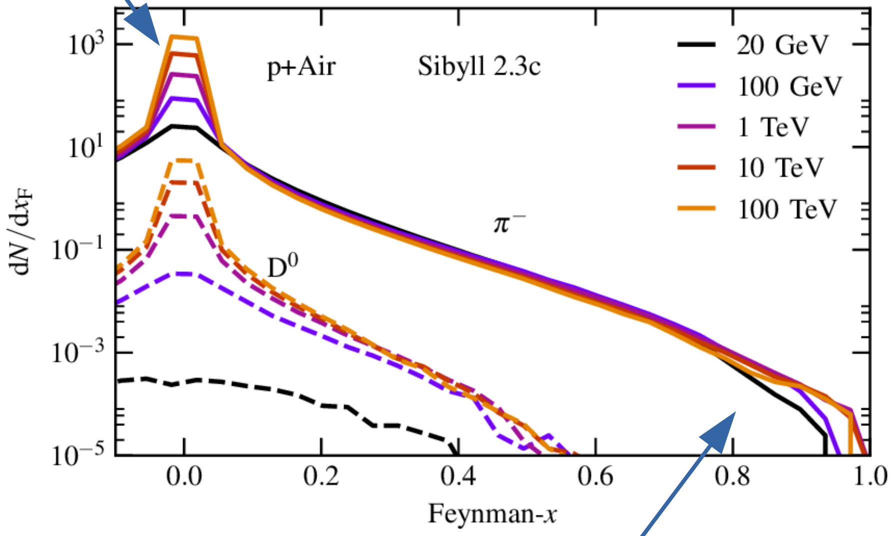
popcorn effect

Meson now leading !

See ICRC 2017 proceedings

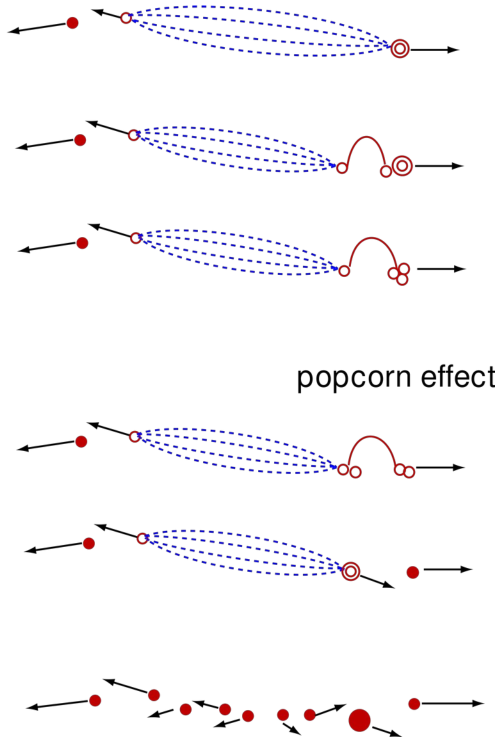
Sibyll 2.3c: very leading particles

Expected scaling violations due to jets



Expected scaling violations

Leading baryon



popcorn effect

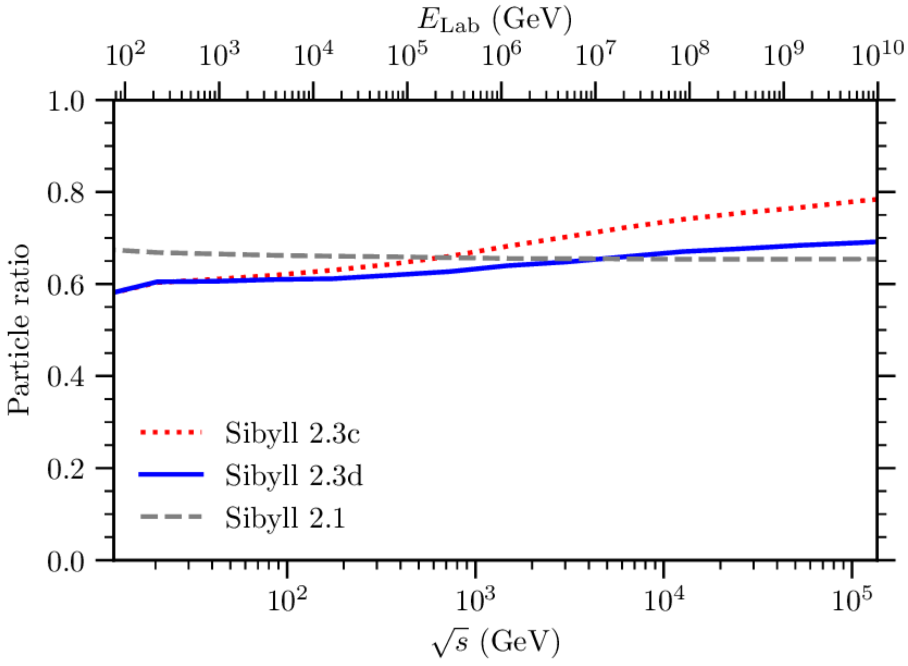
Meson now leading !

(PoS ICRC2017 (2018) 301, 1709.07227 [hep-ph])

Sibyll 2.3d: charged vs neutral pion ratio

$\pi^{\pm}/\pi^{0} - 1$

See M. Perlin talk tomorrow



Theory: isospin symmetry,
string fragmentation fixed parameters

➡ Ratio constant!

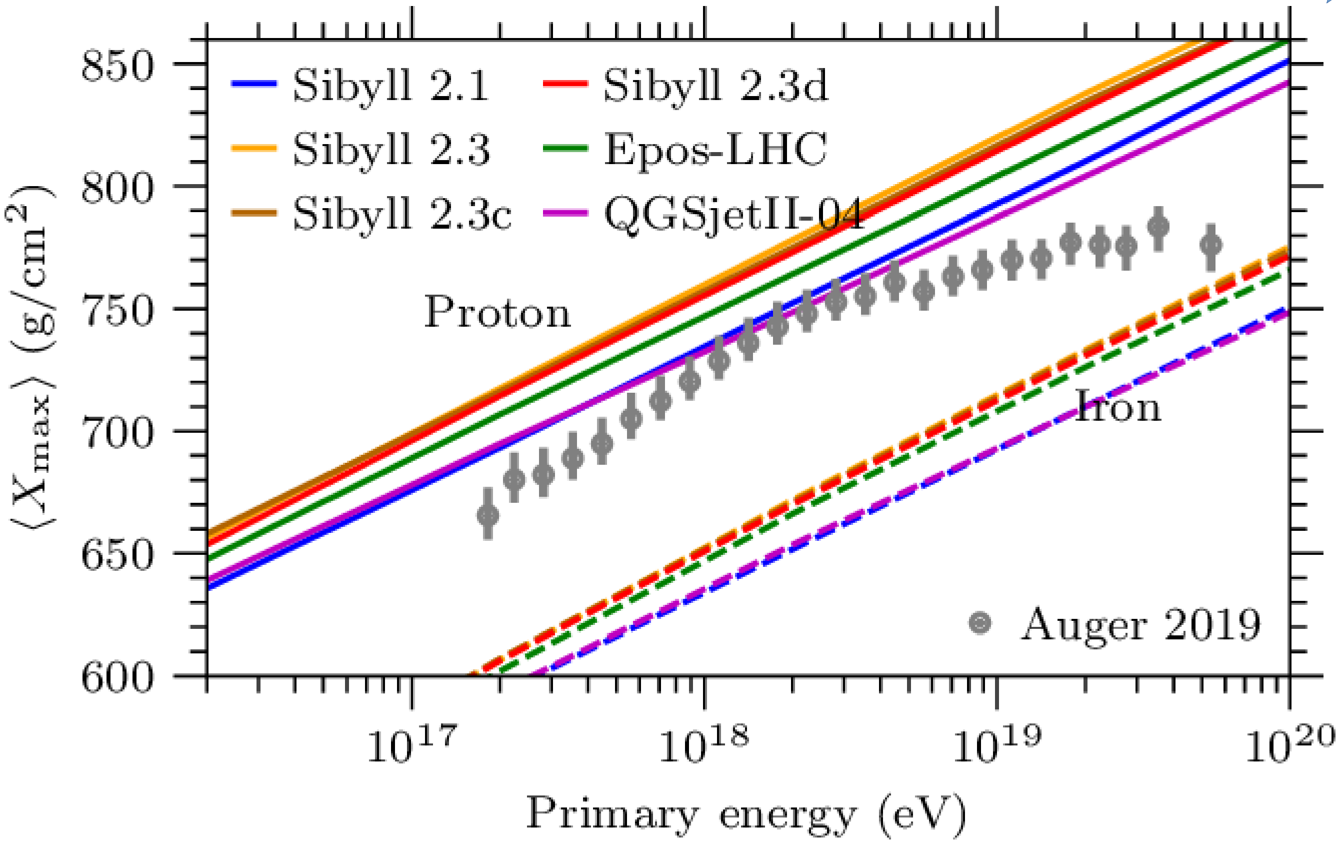
Sibyll 2.1:
universal hadronization

Sibyll 2.3c: (Sibyll 2.3)
varying hadr. (valence ↔ sea quarks/gluons)
valence applied to gluons! (unintended)

Sibyll 2.3d:
varying hadr. (valence ↔ sea quarks/gluons)

(appendix in PRD (2020))

Sibyll EAS predictions

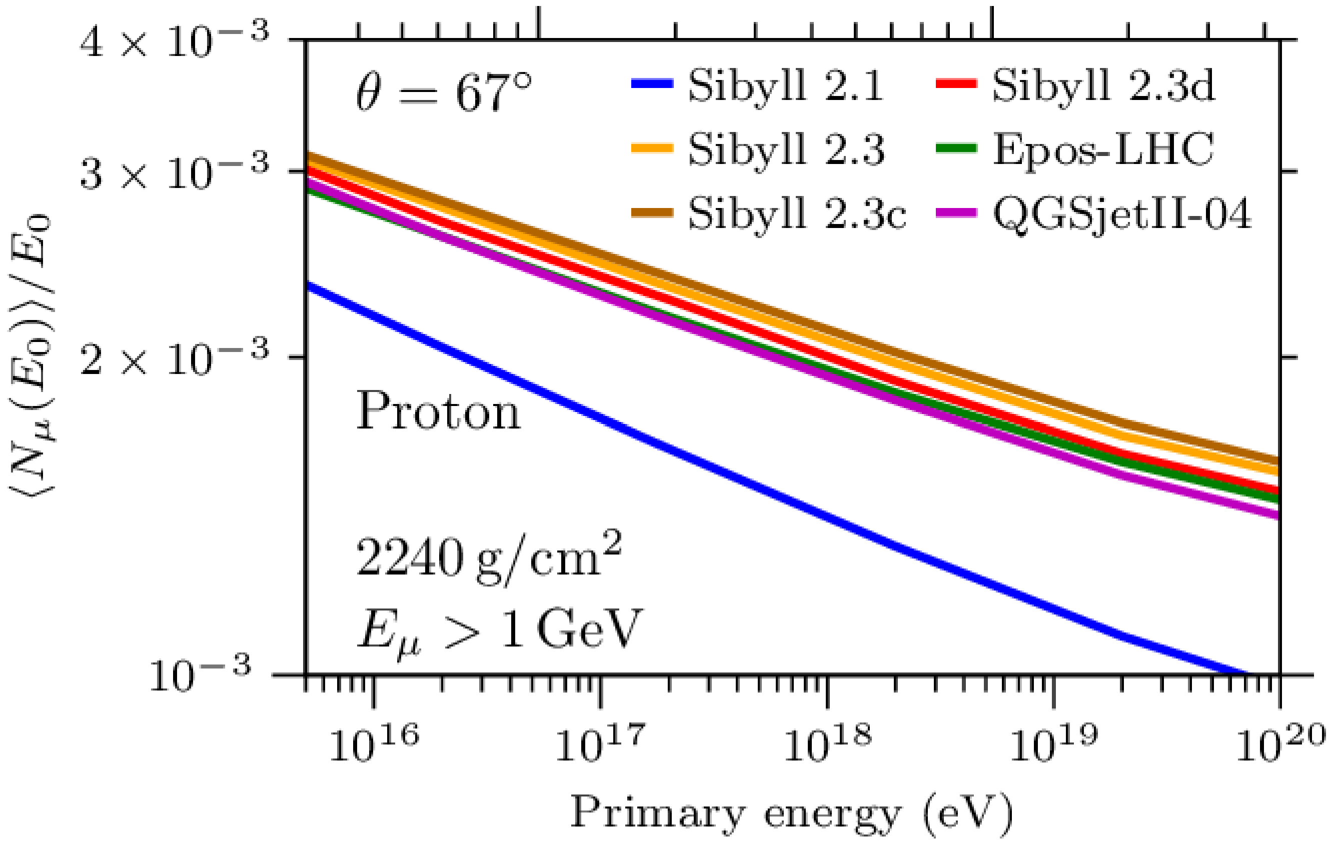


Cross section!

Particle production changes
2.3 → 2.3c → 2.3d

Hardly any effect!

Sibyll EAS prediction

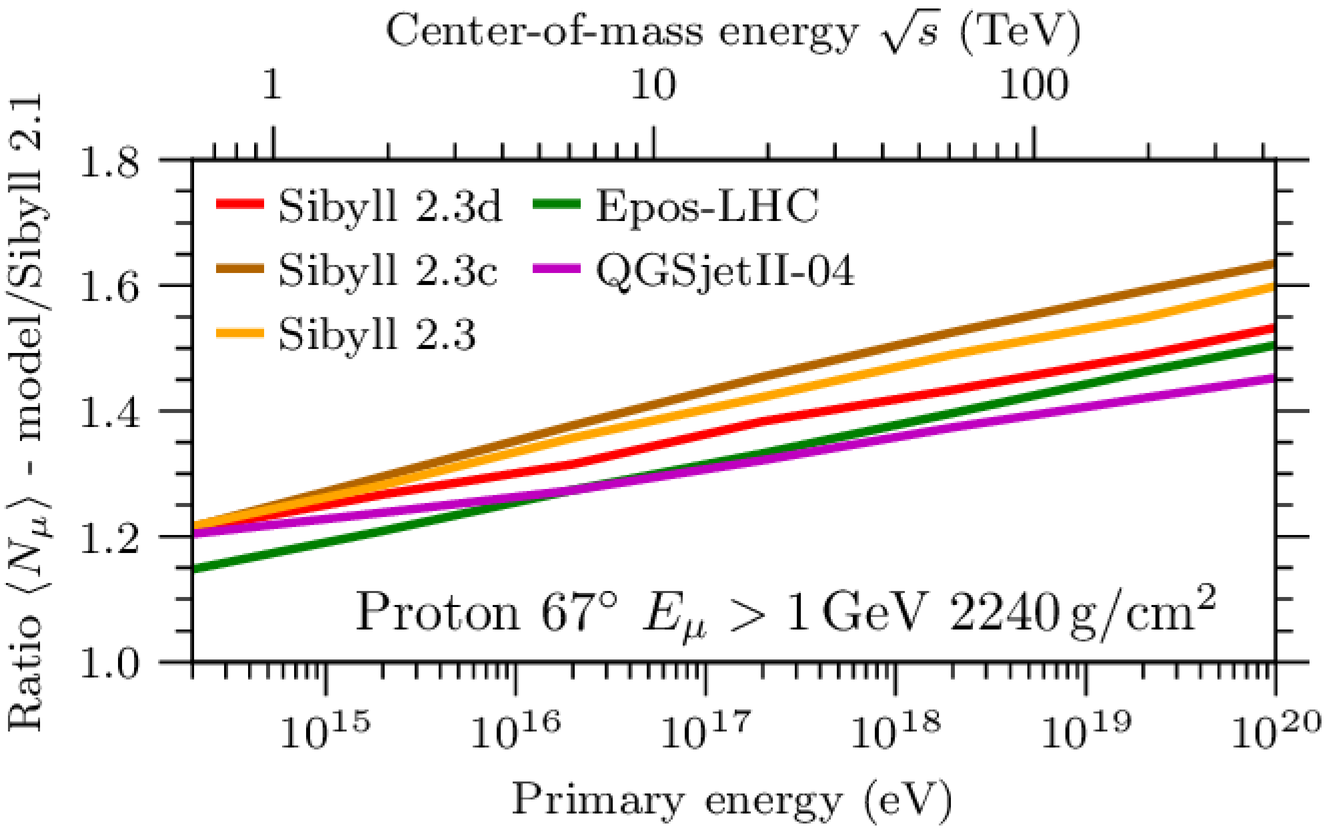


Major change
2.1 → 2.3

Small change
2.3 → 2.3c → 2.3d

$$\frac{\mathrm{d}\ln N_\mu}{\mathrm{d}\ln E} \propto \frac{\ln n_{\mathrm{ch}}}{\ln n_{\mathrm{tot}}}$$

Sibyll EAS predictions

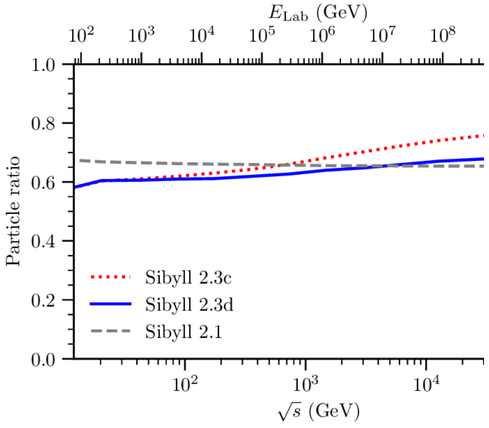


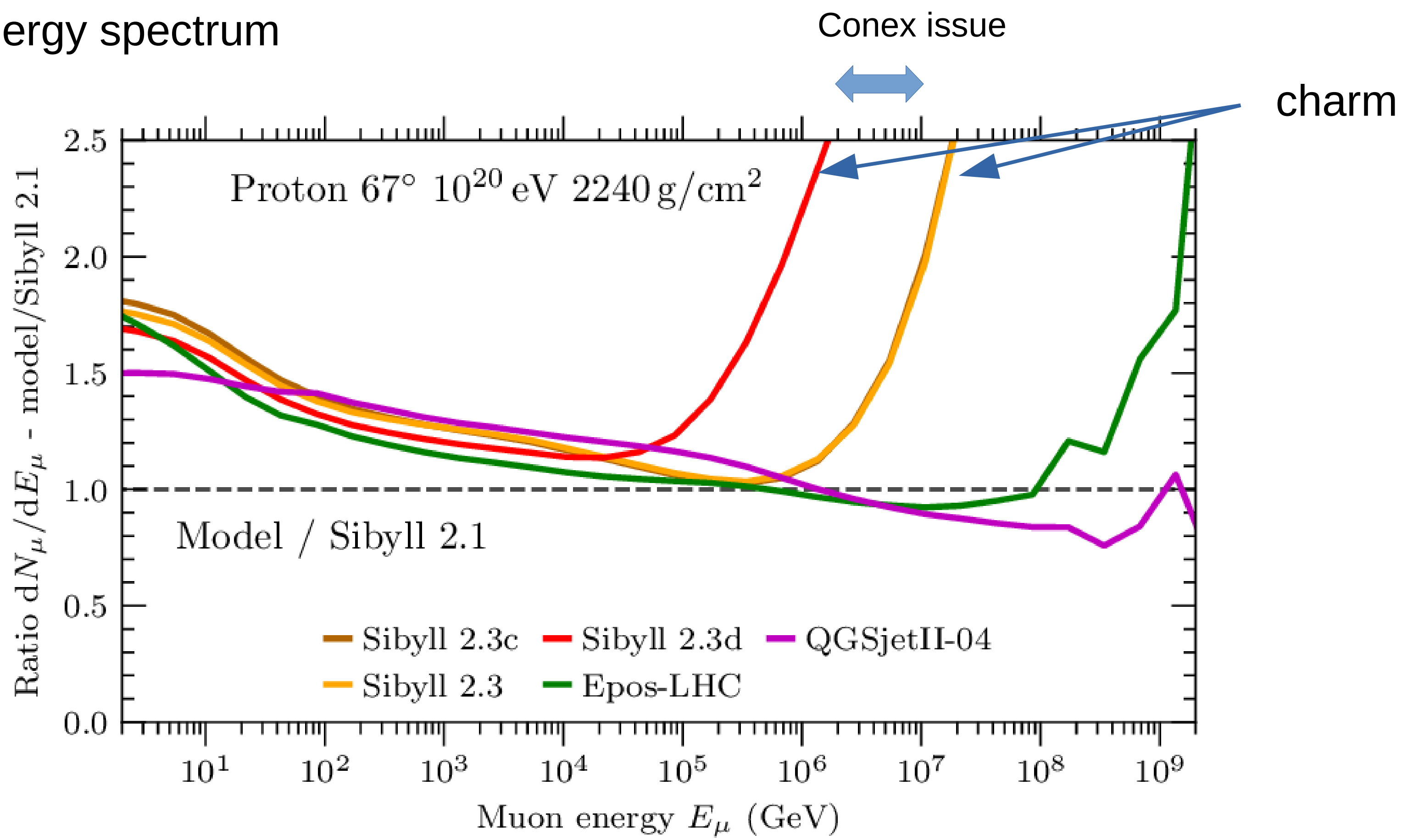
similar slope
→ similar $\pi^\pm/\pi^0$

$$\frac{\mathrm{d}\ln N_\mu}{\mathrm{d}\ln E} \propto \frac{\ln n_{\mathrm{ch}}}{\ln n_{\mathrm{tot}}}$$

Sibyll EAS predictions

muon energy spectrum





Timeline

SIBYLL 2.1 — ~2000

SIBYLL 2.3 — 2014

SIBYLL 2.3c — 2017

SIBYLL 2.3d — 2020

TeVatron

LHC Run I

LHC Run II,III

Muon deficit in EAS

Astrophysical neutrinos

Sibyll 2.3: extended baryon production, charm production, rho0 production, cross section...

(PRD (2020), arXiv:1912.03300, charm & incl. Flux: Phys.Rev.D 100 (2019) 10, 103018)

Sibyll 2.3c: ensure Feynman scaling of leading particles → mostly affects inclusive flux

(PoS ICRC2017 (2018) 301, 1709.07227)

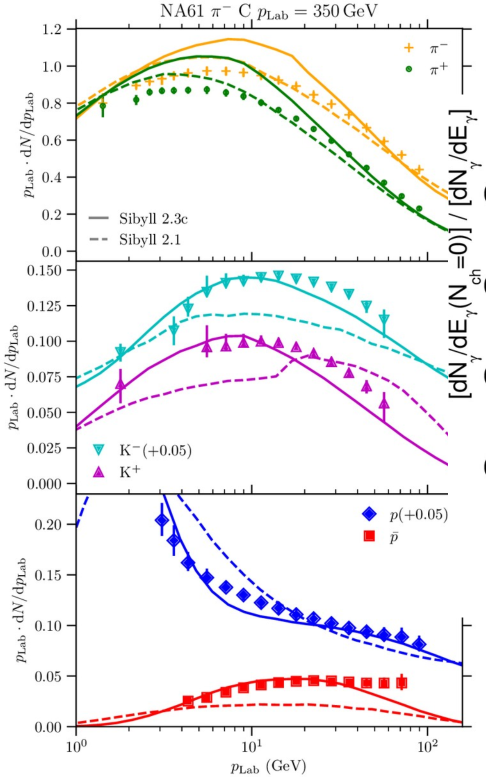
Sibyll 2.3d: ensure moderate rise of pion ratios → 5% change in muons for EAS

(PRD (2020), arXiv:1912.03300)

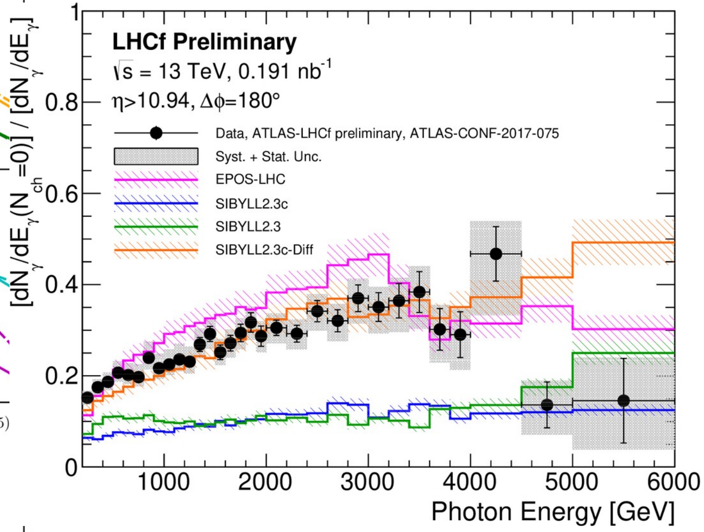
The future, cases for ..

Sibyll 2.3e

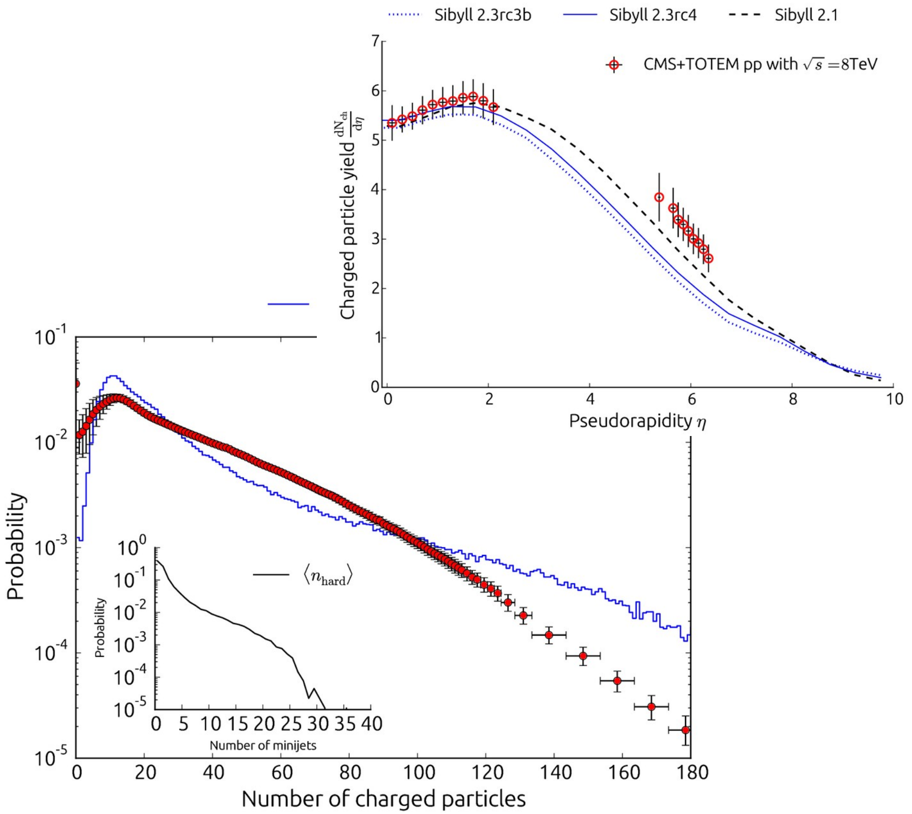
NA61, LHCf, CMS+Castor



ATLAS+LHCf



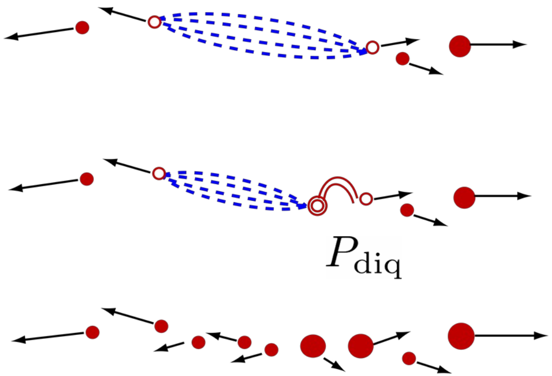
Sibyll 3 / Cibyll / Sibyll++ ?

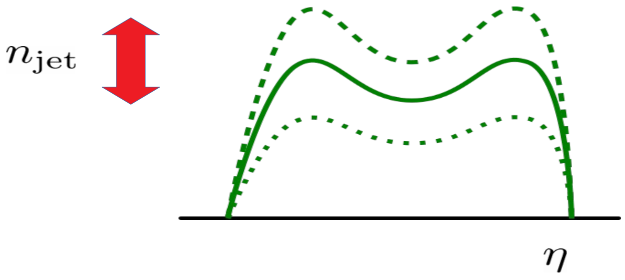


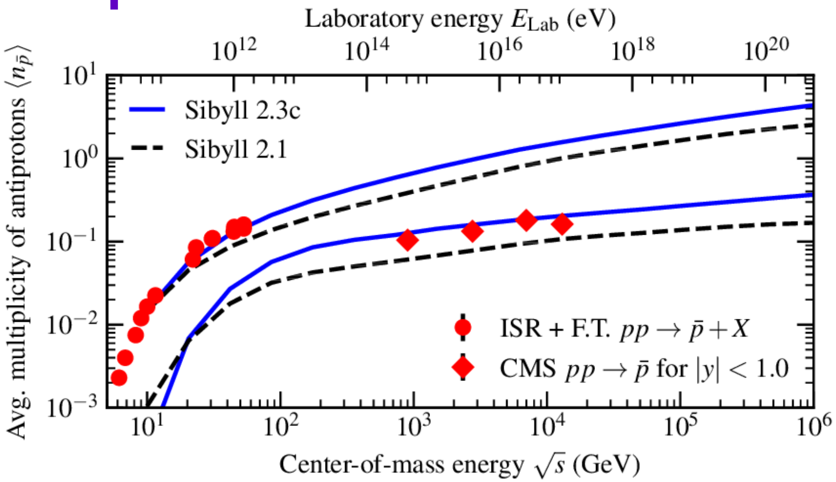
or Sibyll + DPMjet ?

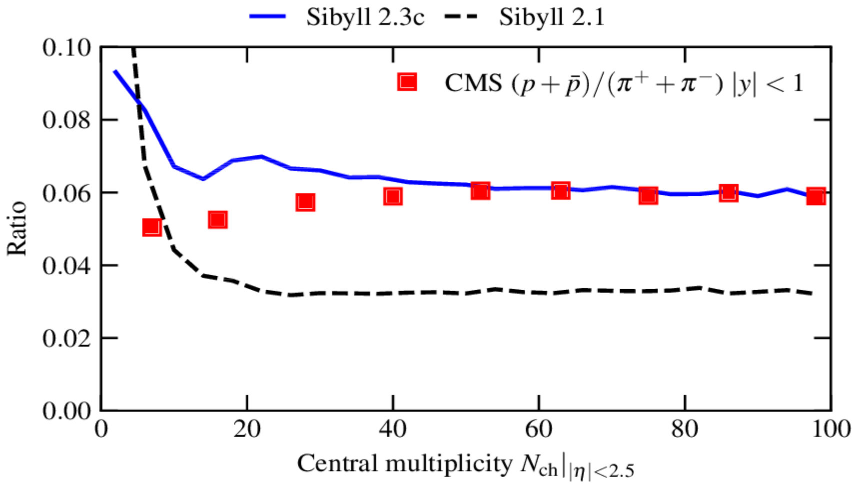
but no promises..

Sibyll 2.3: baryon production









Sibyll EAS prediction