Karlsruhe Institute of Technology

Performance and future Evolution of SIBYLL

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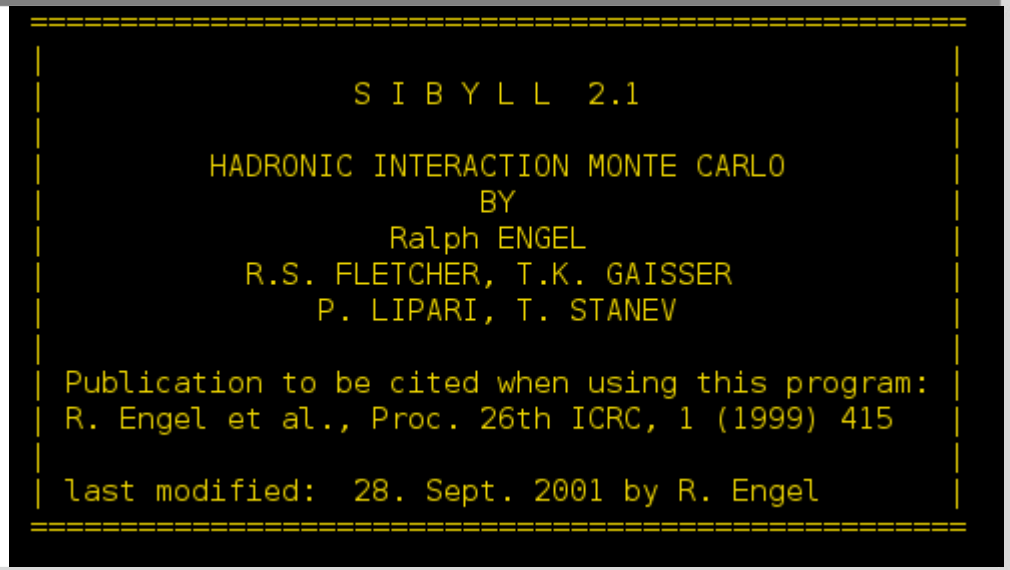
HAP composition workshop 2015

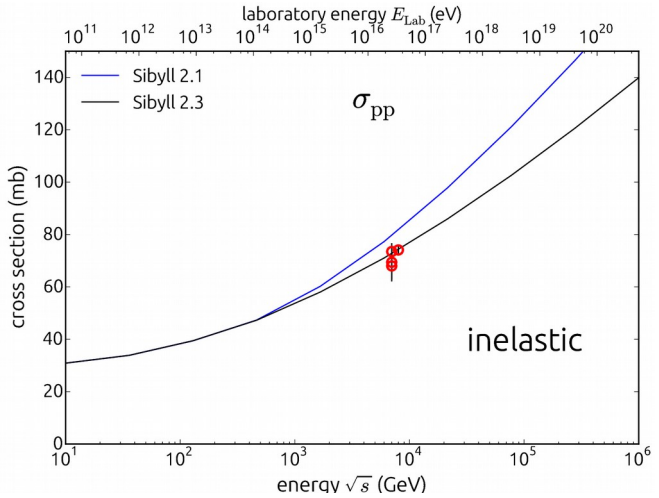
Institut für Kernphysik

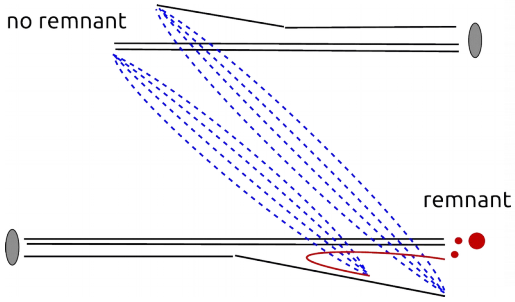


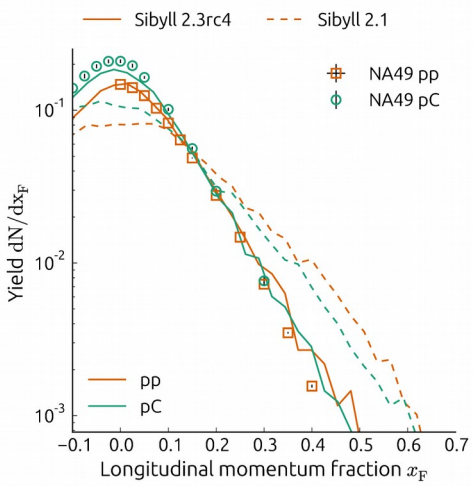
Sibyll 2.3 – Release notes

Updates, changes to Sibyll 2.1 (PRD 2009, last mod. 2001 !!):

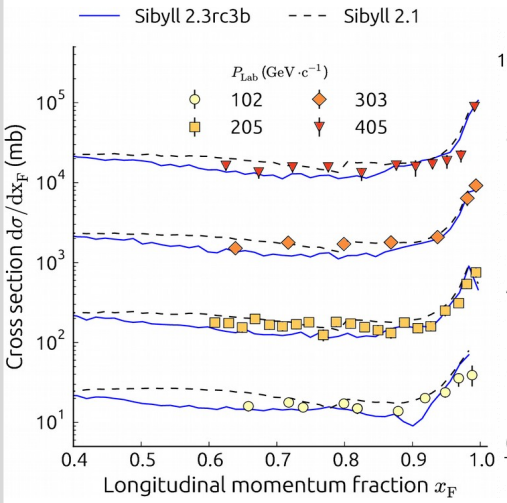
- pp cross section
- Increased baryon pair production
- Added charm production
- Leading vector mesons
- Updated PDFs
- Changed pT – distributions to mT
- Revised leading particle model 'remnant treatment'
- Inel. Screening in nuclear collisions
- Bugfixes (off-shell particles, energy conservation)

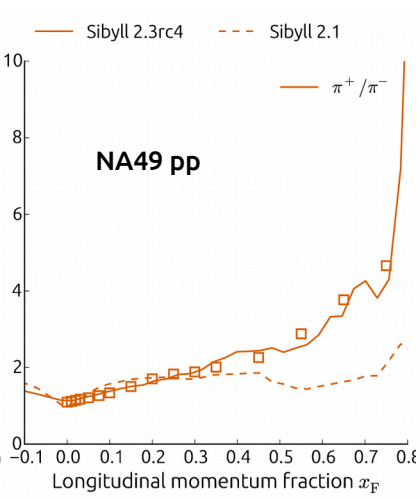


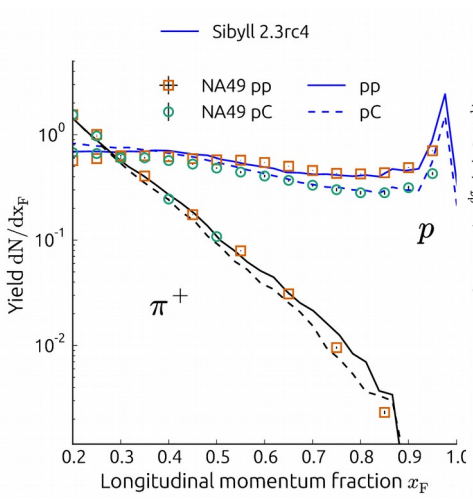


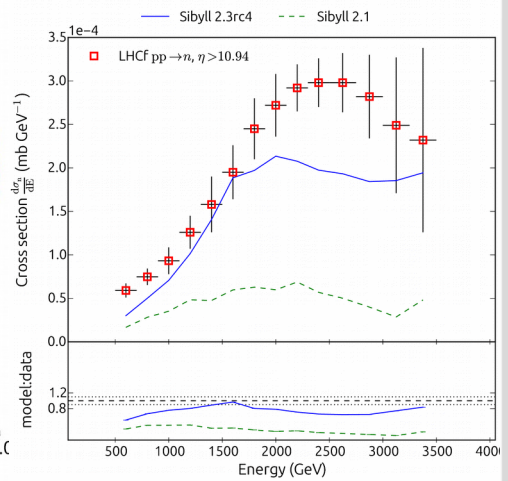


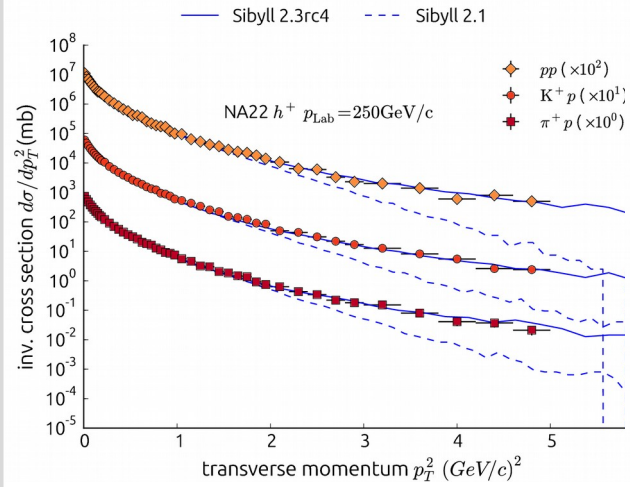
Sibyll 2.3 - Performance

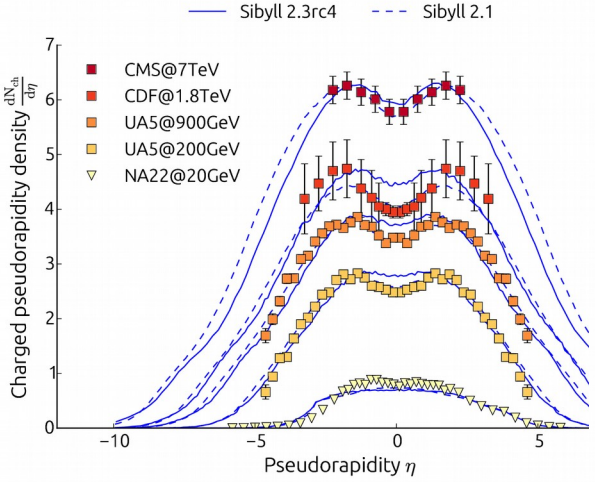


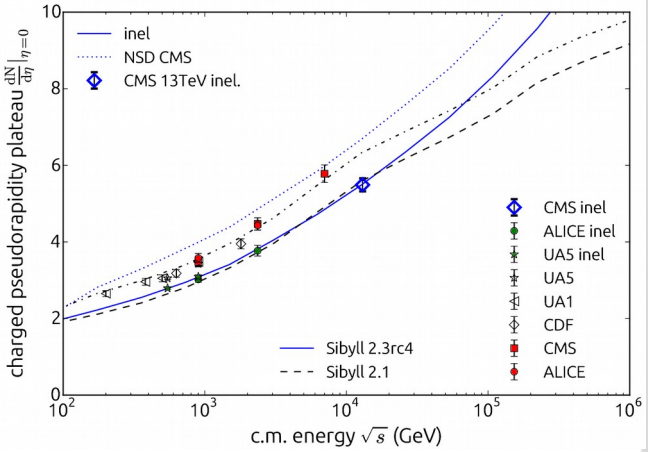












Muon number prediction

Muon production in extensive air showers

Baryons:

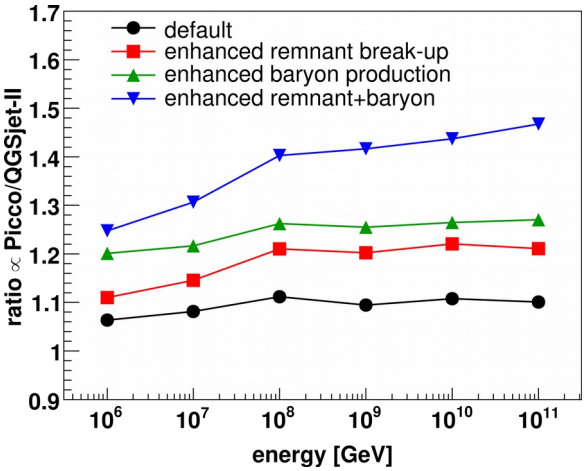
- More energy in hadrons
- Low energy muons

Neutral pions vs. rho:

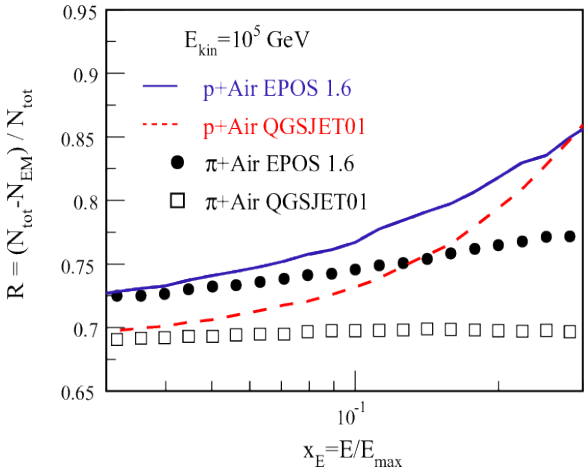
- Keep energy in hadrons
- Anti-correlation

Short-lived hadrons (charm):

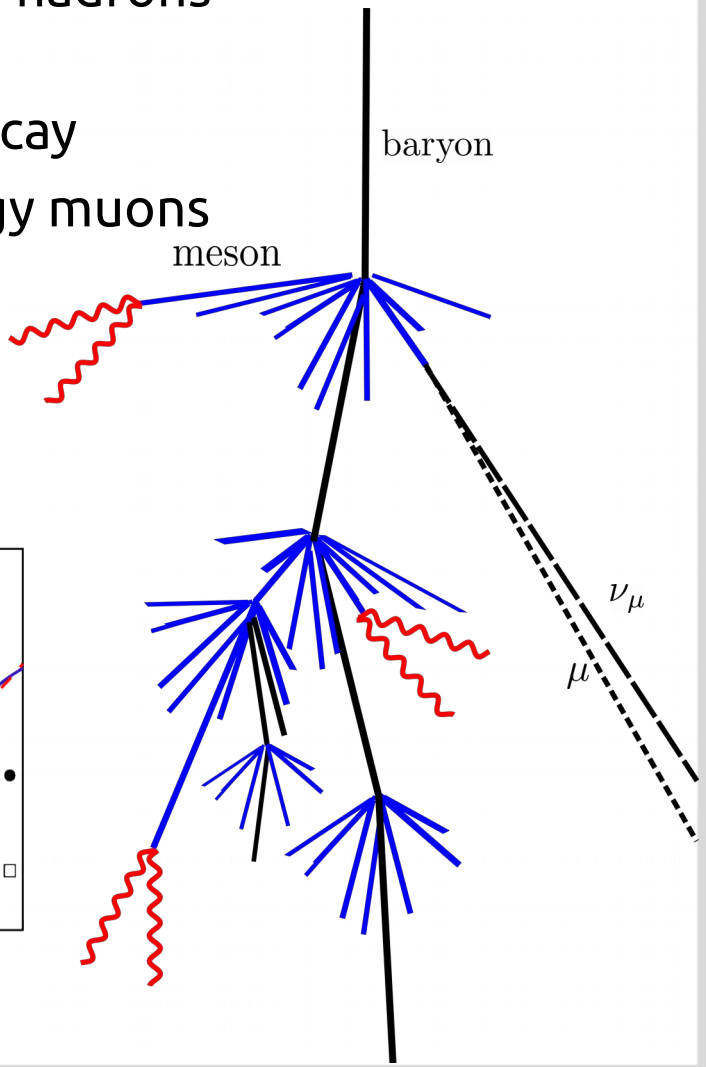
- Prompt decay
- High energy muons



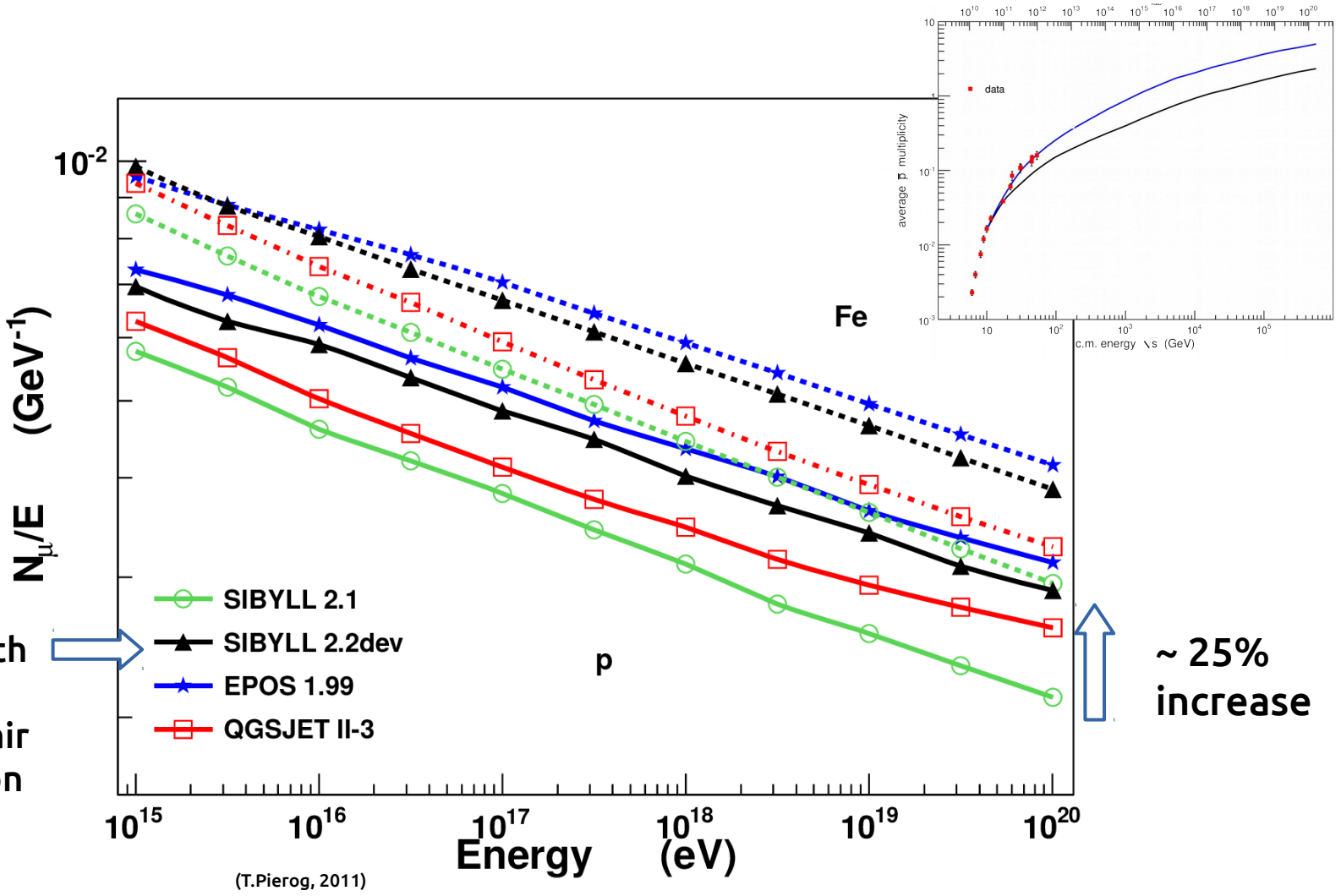
(Drescher, PRD 77 2008)



(Pierog, PRL 101 2008)



Muon number with increased baryon prod.



(T.Pierog, 2011)

Model with increased baryon pair production

~ 25% increase

Rho0 in air showers

- **In itself not very important**
  - Negligible contribution to prompt muons
- **New production mechanism!**
  - Data suggest few leading neutral pions in meson interactions

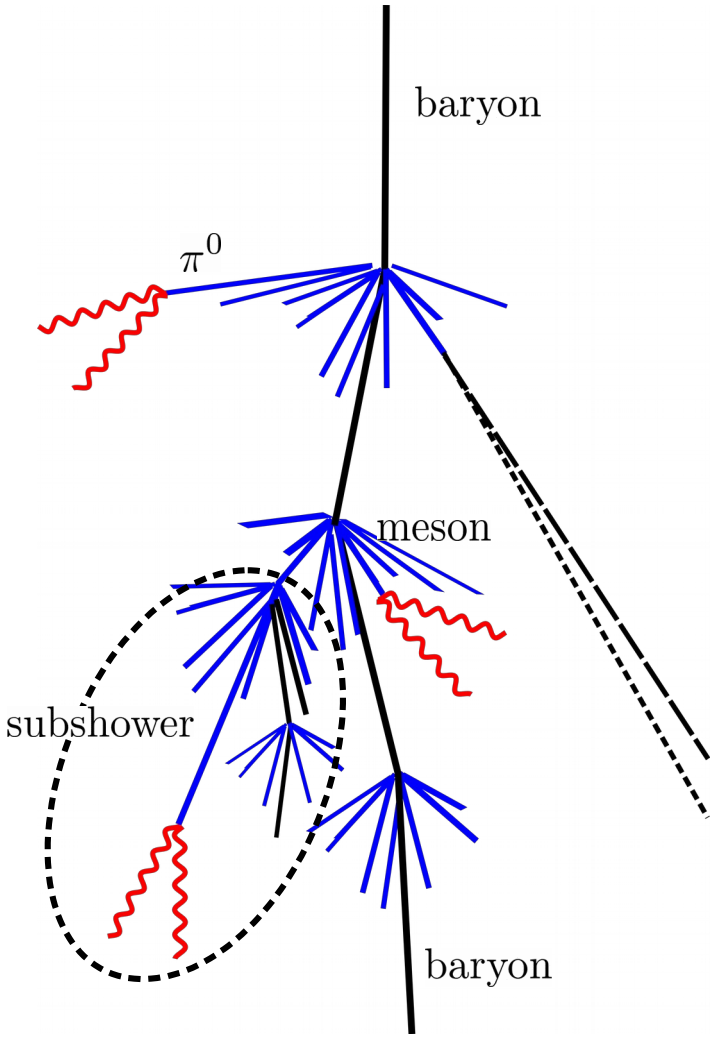
$$\pi^{\pm} + p \not\rightarrow \pi^{0}_{\mathrm{lead}} + X$$

Instead

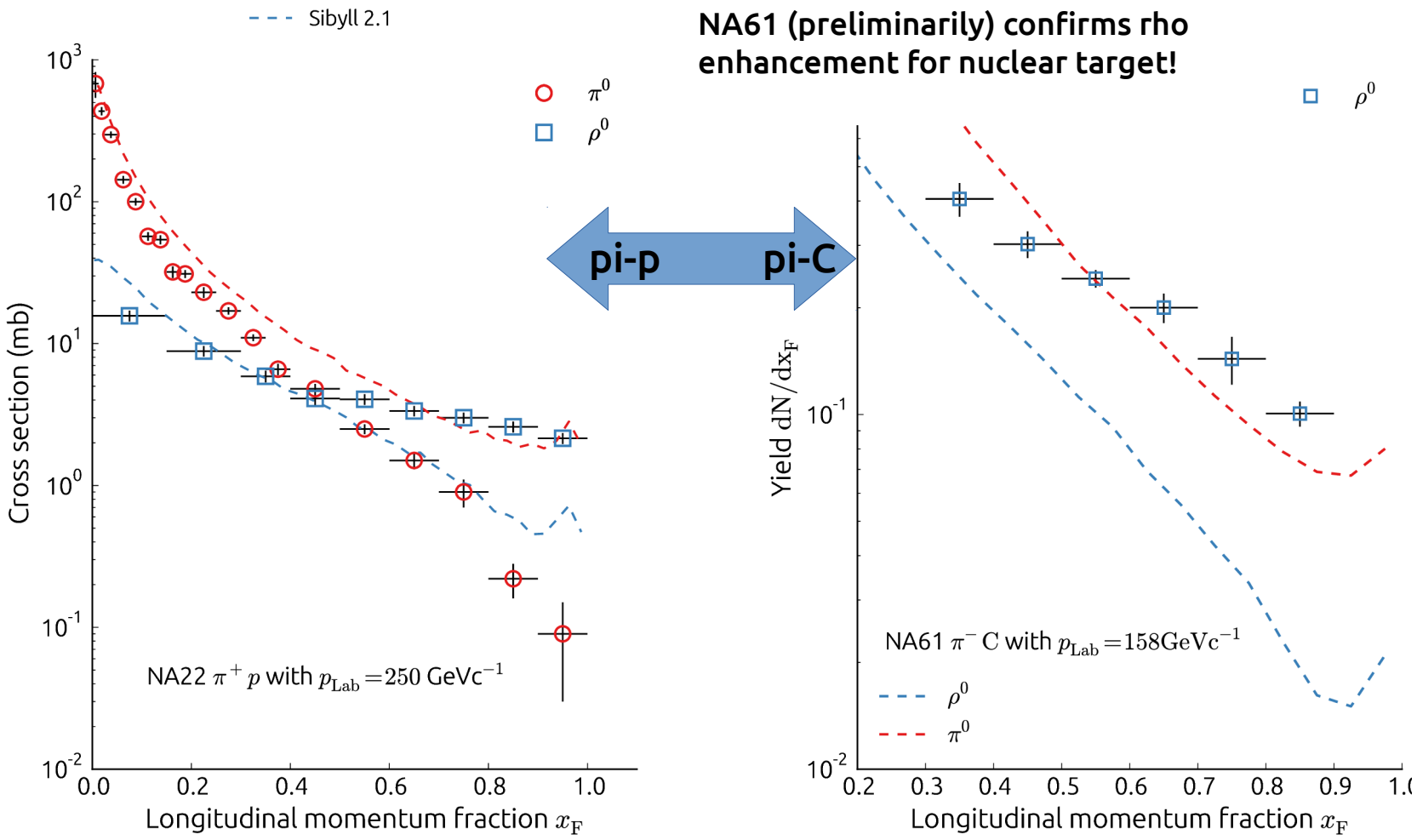
$$\pi^{\pm} + p \rightarrow \rho^{0}_{\mathrm{lead}} + X$$

- **More hadronic subshowers!**

→ more muons



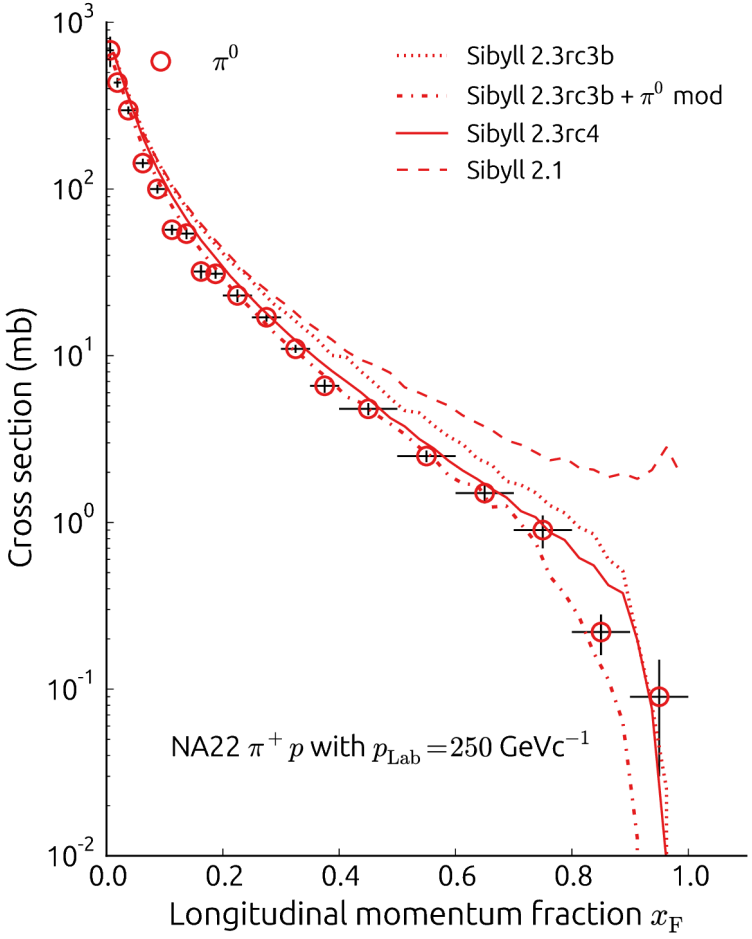
Pi0 vs. Rho0 in pi-p and pi-C

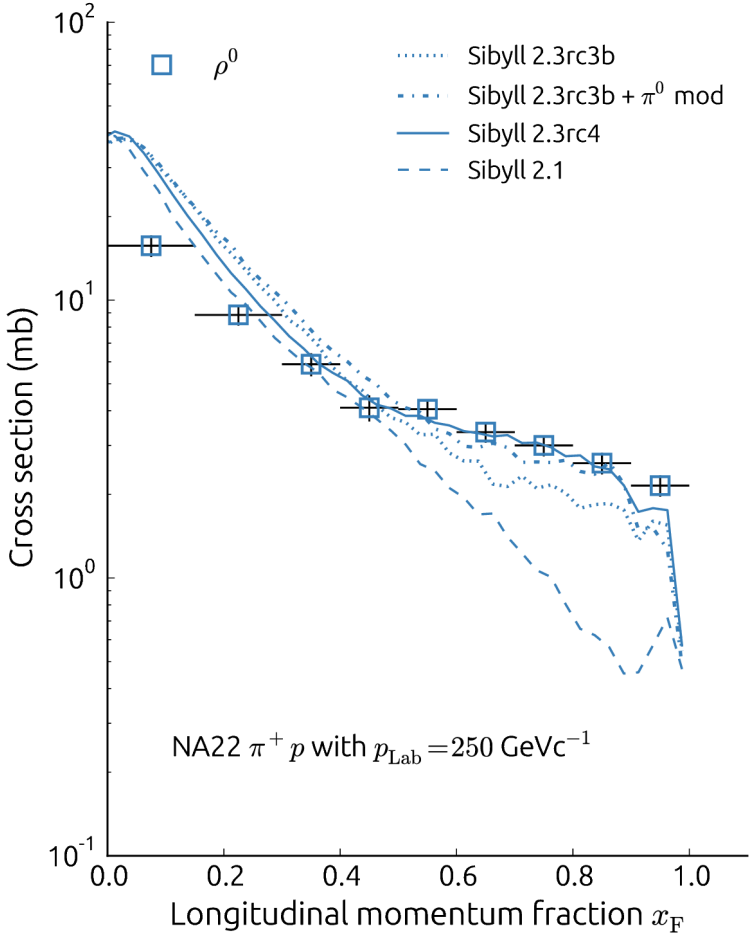


Presumably pi0 suppressed as in pi-p

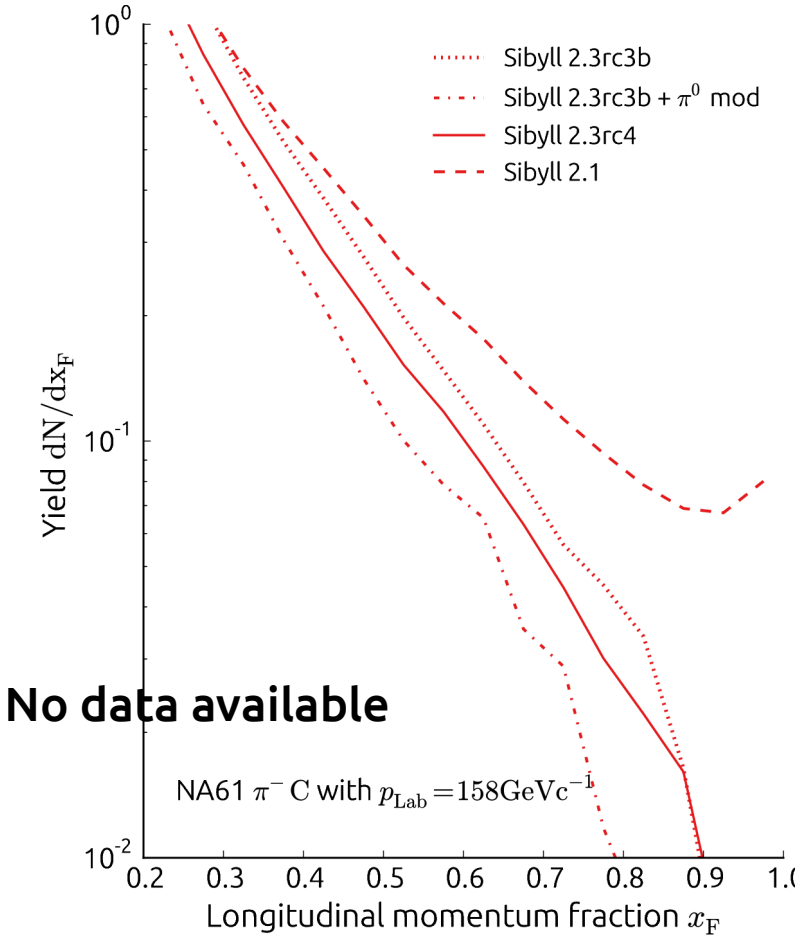
(NA61 data: Herve, ICRC 2015)

NA22 pi0 / rho0: four models

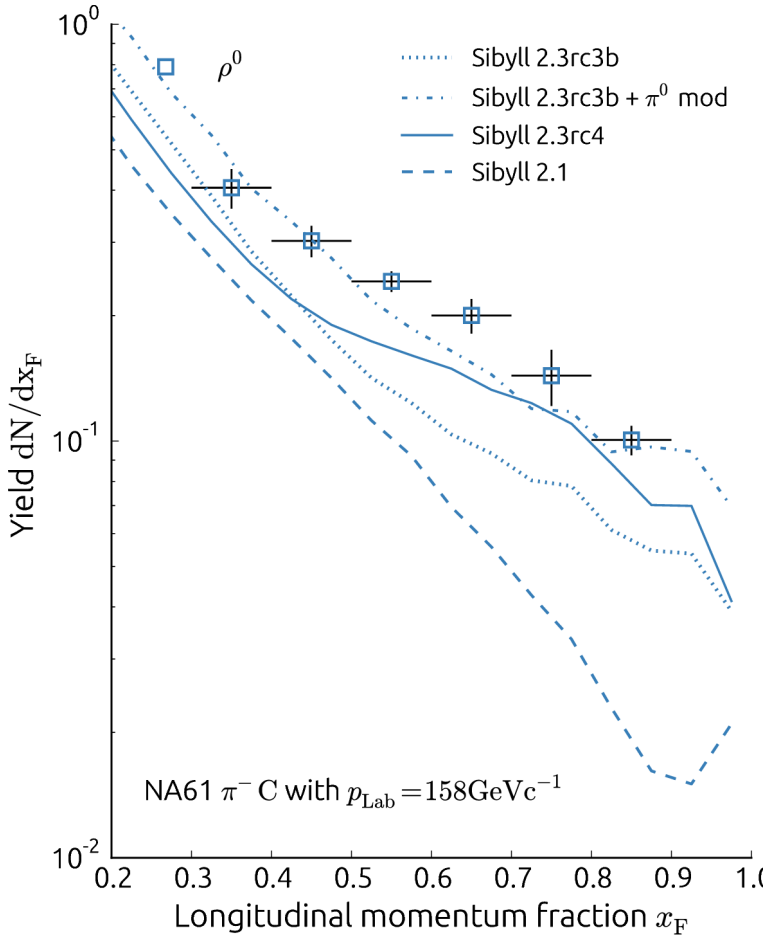




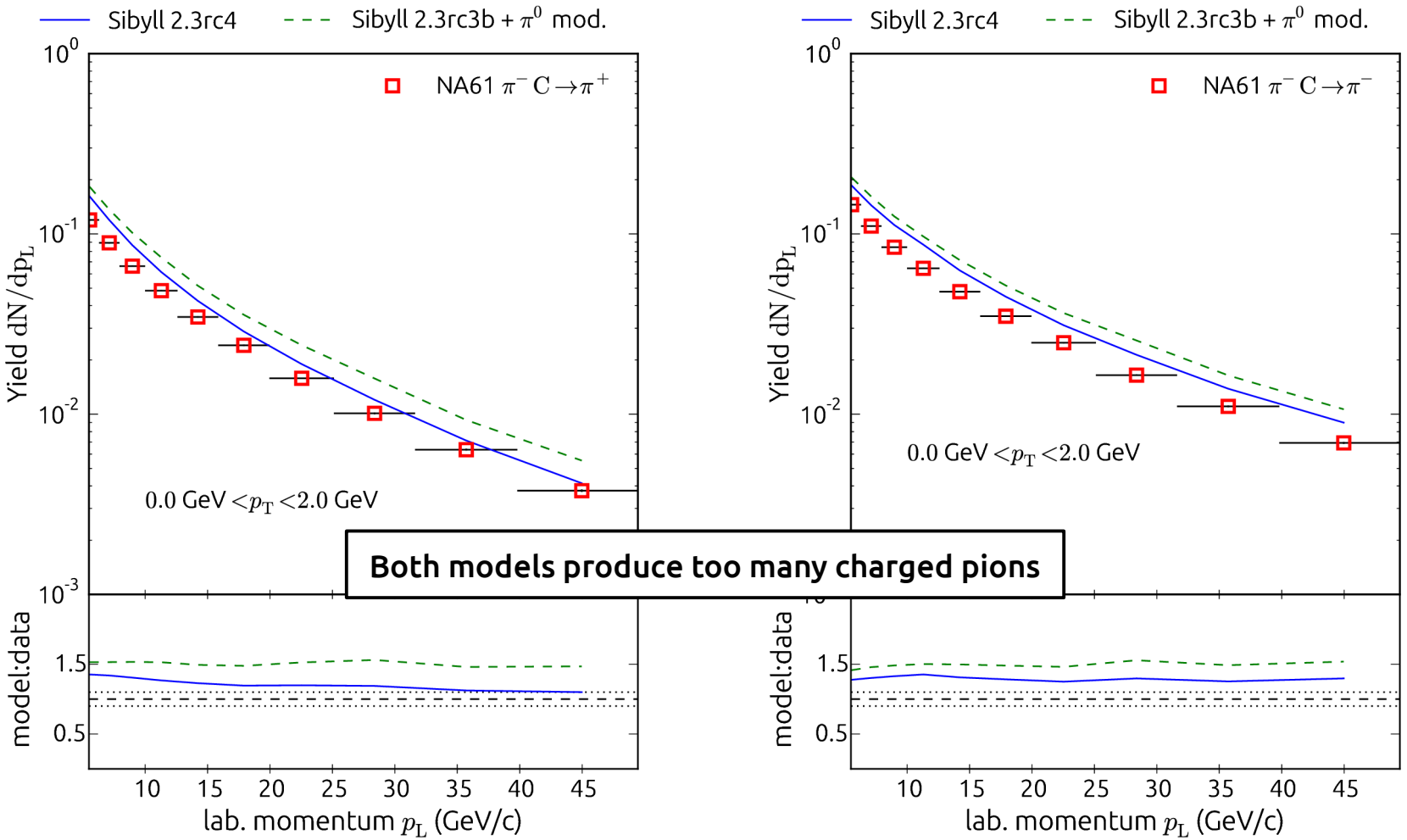
NA61 pi0 / rho0: four models



No data available



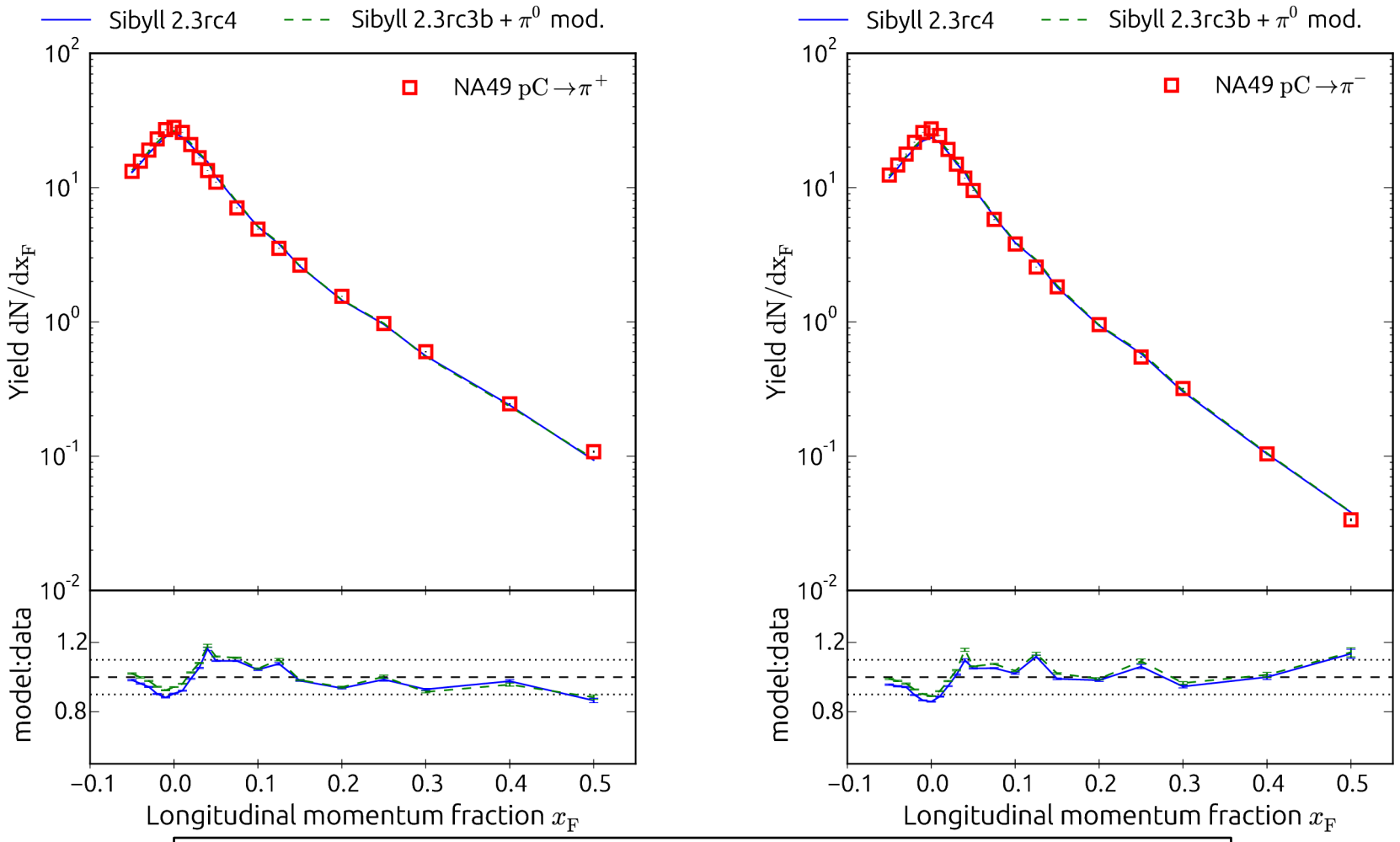
NA61: pion + carbon → charged pions



Both models produce too many charged pions

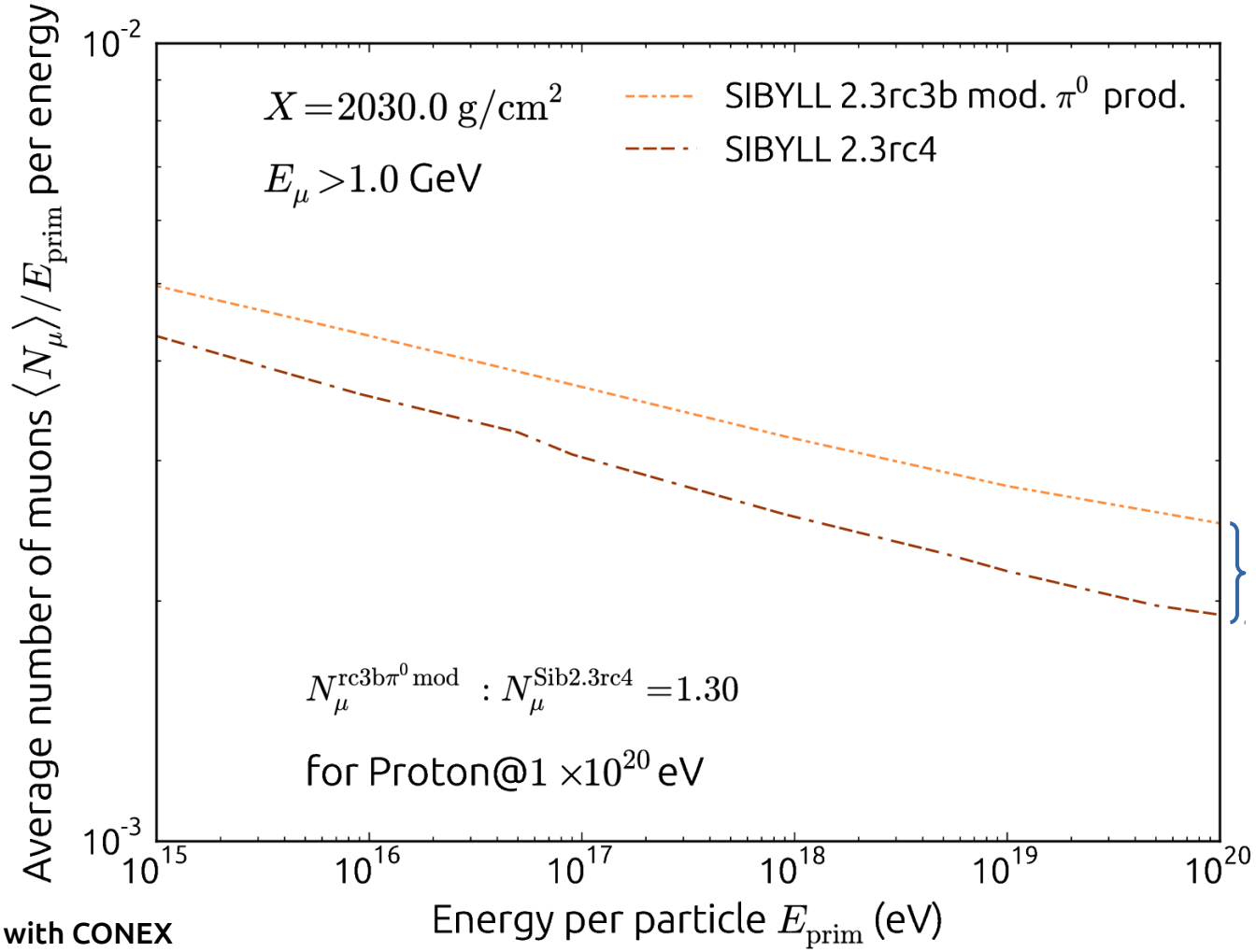
Not much data available for Meson projectiles
BUT central region expected to be ~universal (hadrons look alike on small scales)

NA49: proton + carbon → charged pions



Not much data available for Meson projectiles
BUT central region expected to be ~universal (hadrons look alike on small scales)

Sibyll evolution: Number of muons

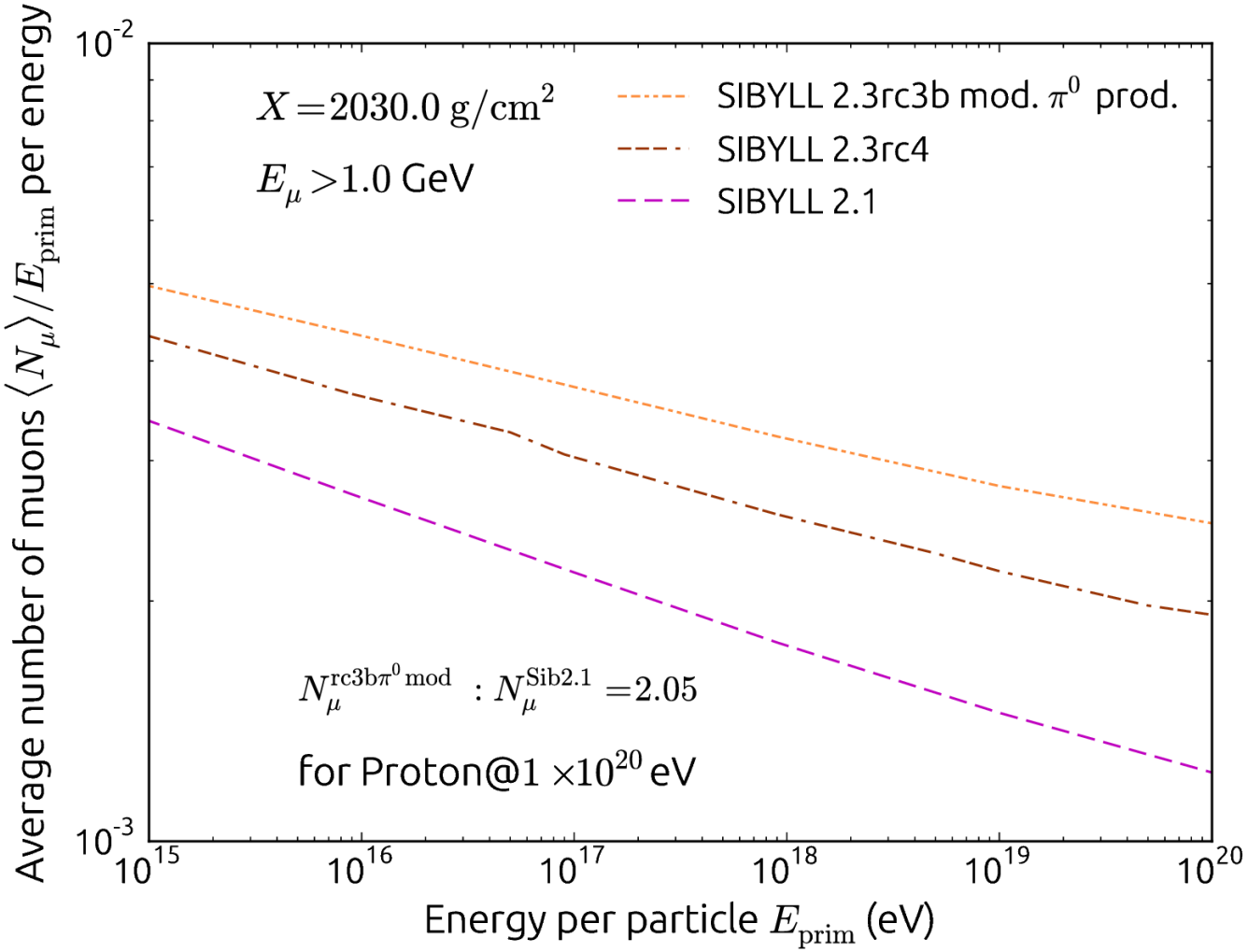


Range given by NA22 & NA61 rho0 data

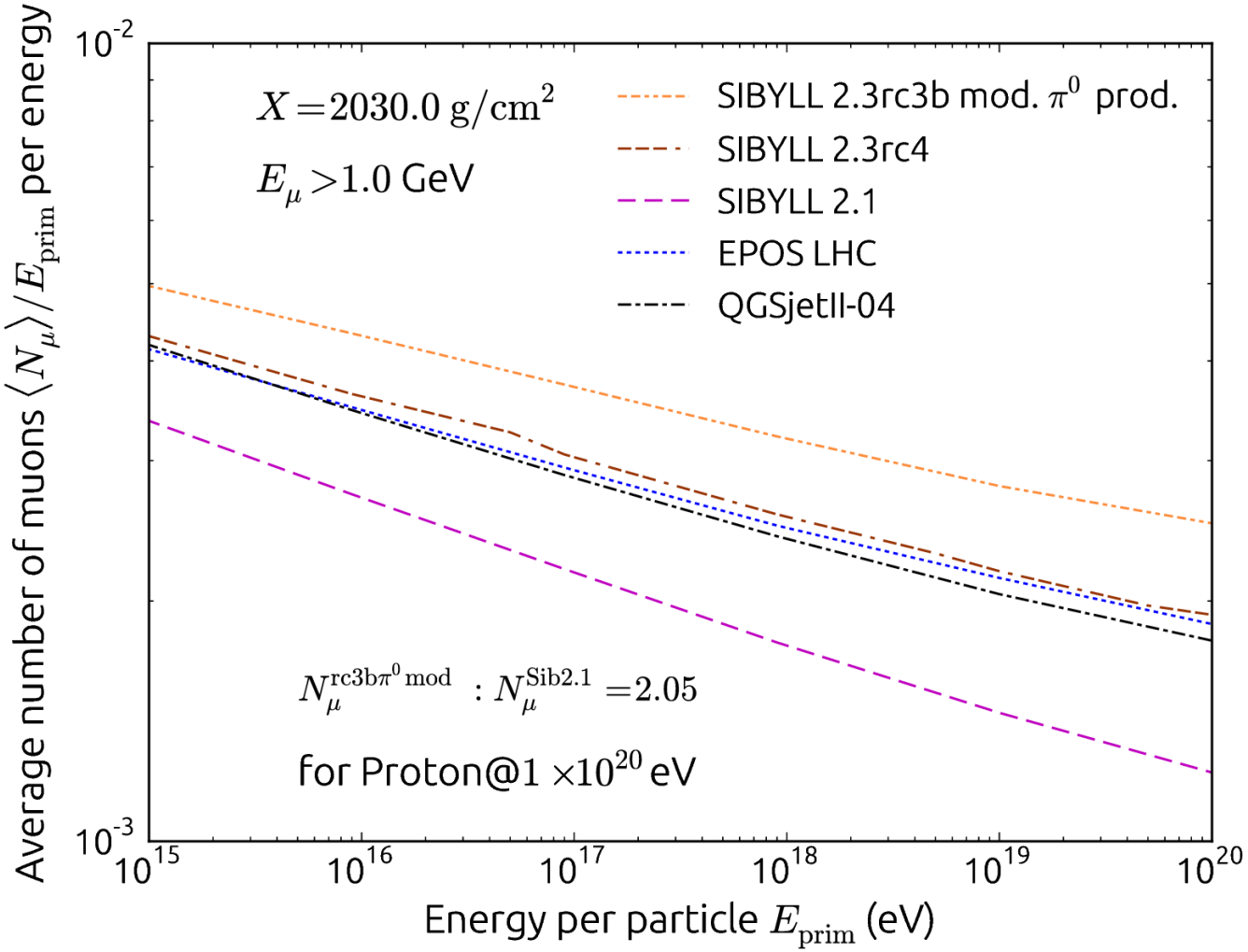
Pi-Nuc → Pi0 data very valuable to distinguish

Calculated with CONEX

Sibyll evolution: Number of muons

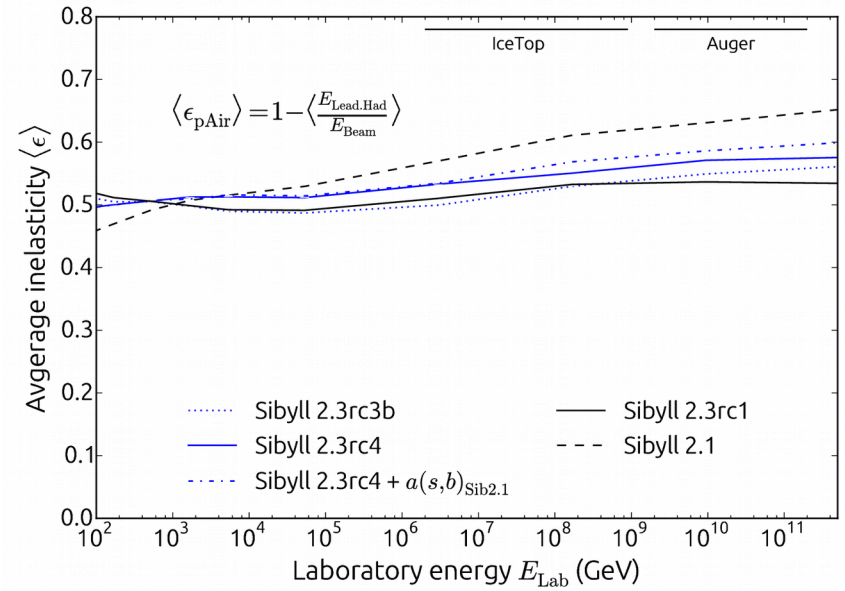


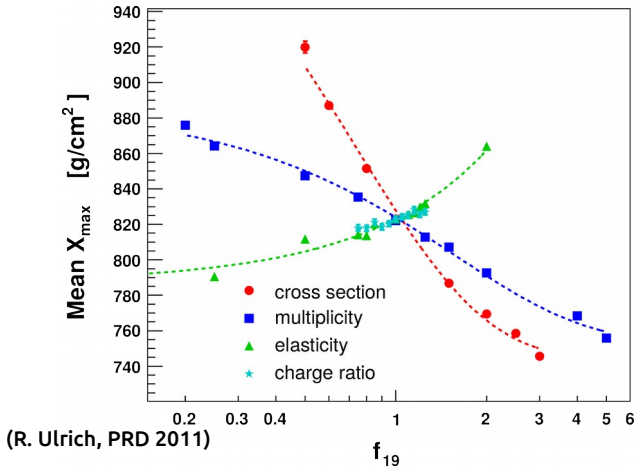
Sibyll evolution: Number of muons



Xmax prediction

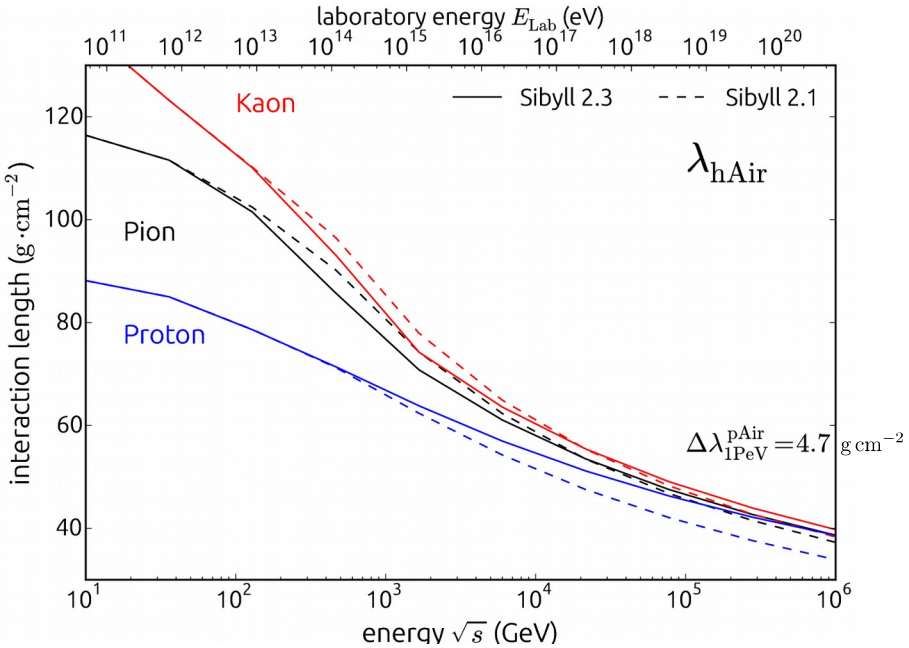
Influences on Xmax



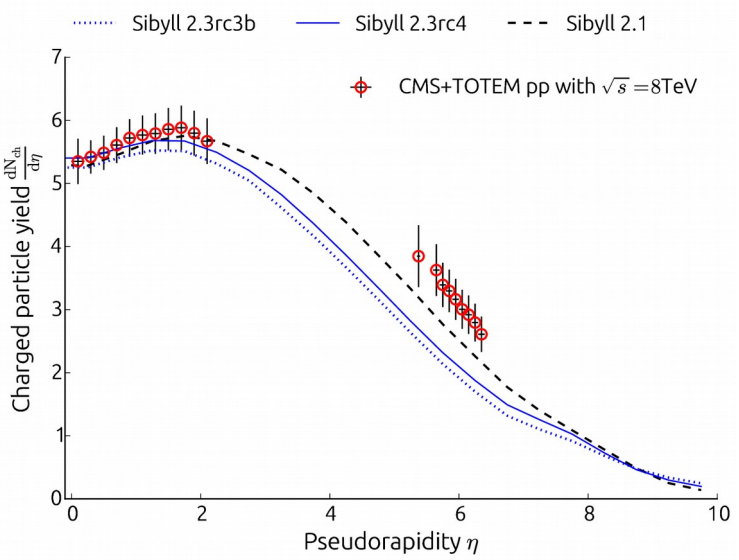


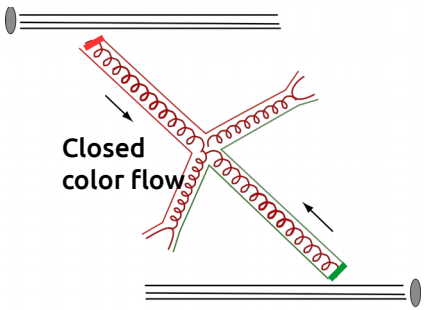
(R. Ulrich, PRD 2011)

- Cross section / interaction length
- Inelasticity
- Multiplicity



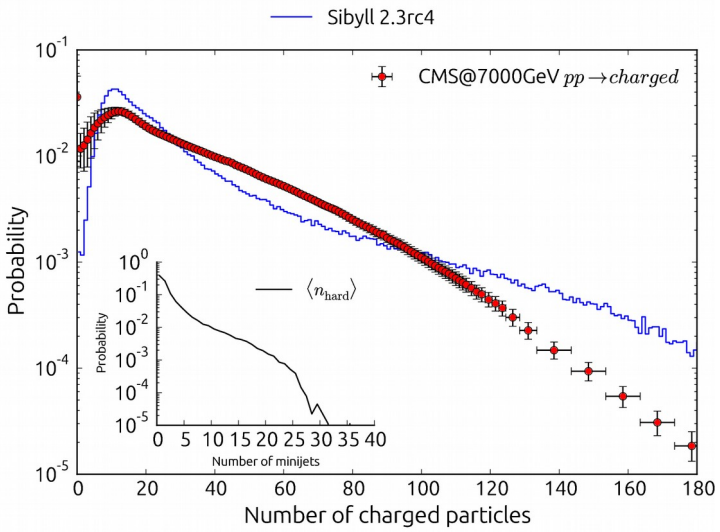
Open problem: minijets



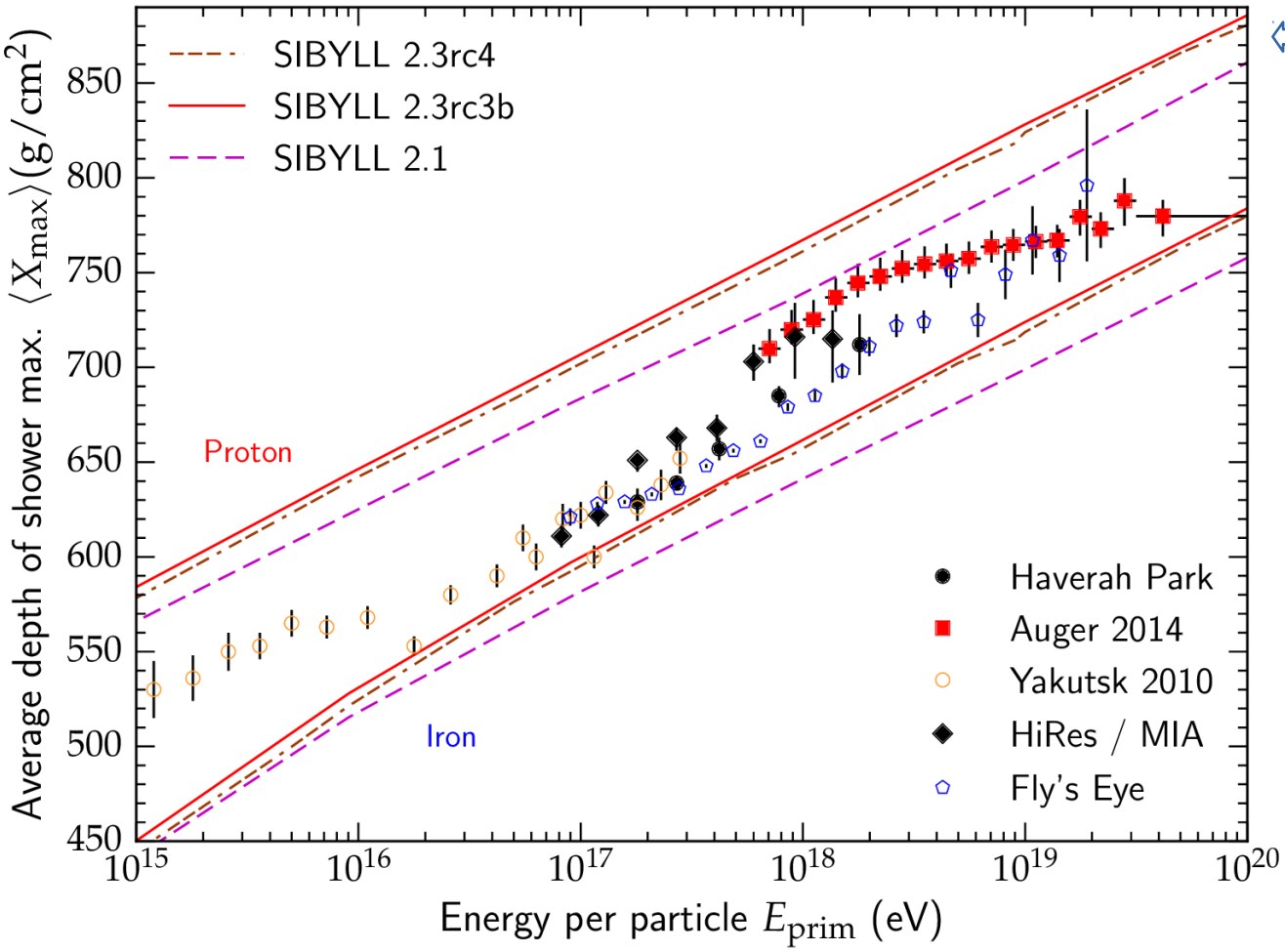


- Broad dN/deta in Sibyll 2.1 by accident
- Minijet color flow disconnected from rest of hadron
- Large tail in multiplicity distribution

  Number of minijets very high
  → saturation effects missing

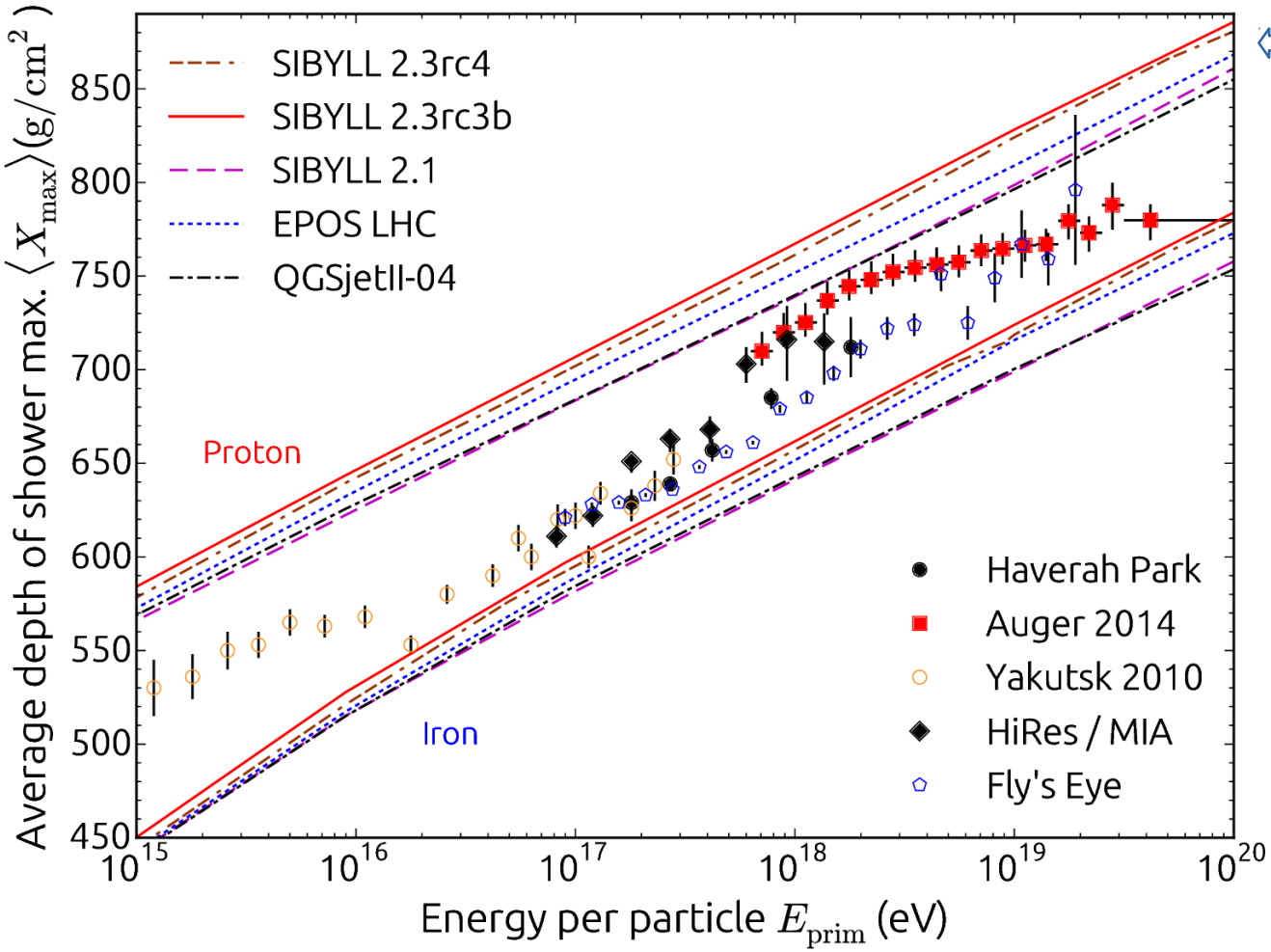


Xmax prediction, Sibyll



⇦ **All new predictions probably overestimate Xmax**

Xmax prediction, latest models

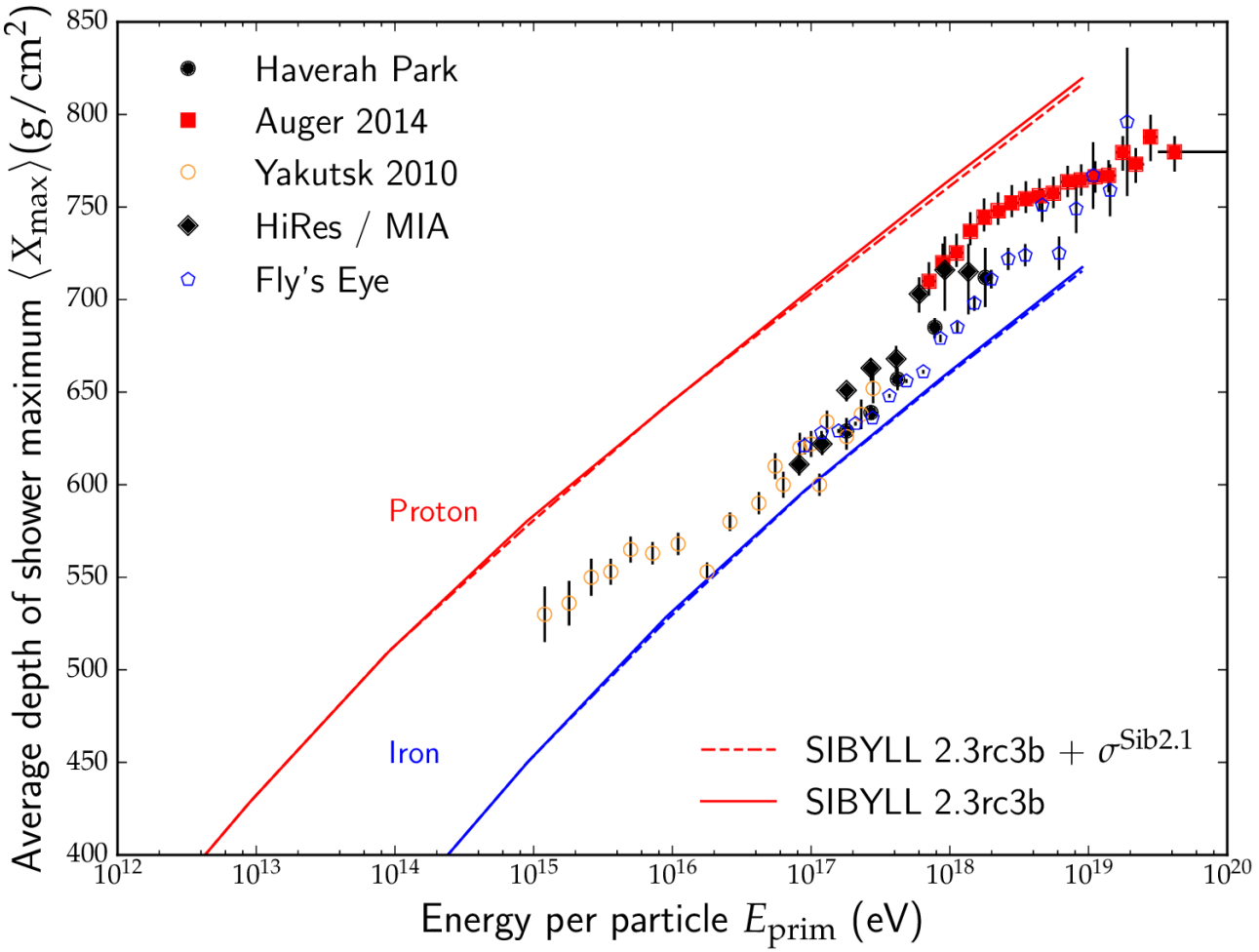


⇦ **All new predictions probably overestimate Xmax**

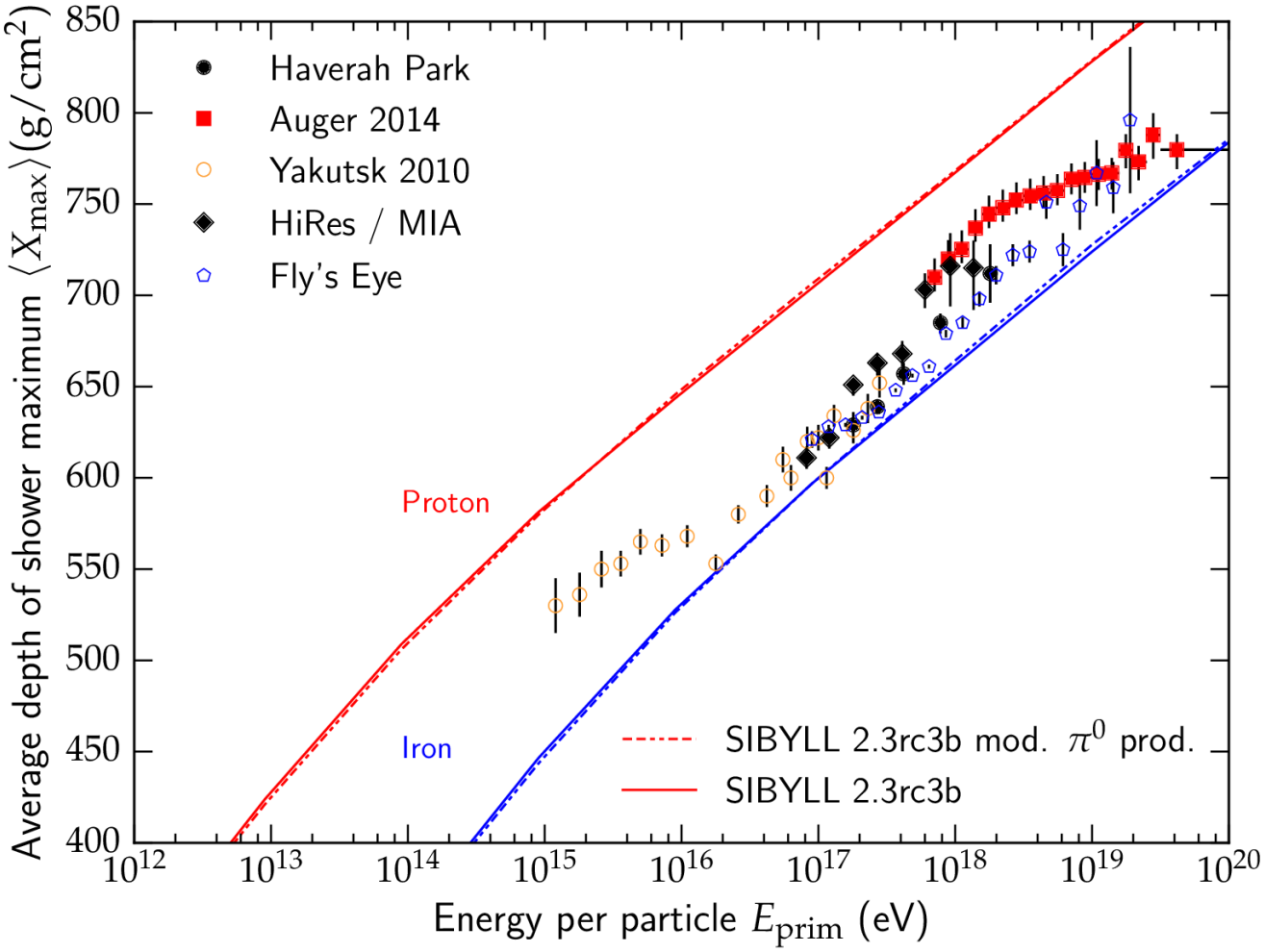
Conclusions

- **Model improved in many aspects**
  - Low & high energy particle production
  - Leading particles (LHCf neutrons & pions)
  - Charm production included
- **Open problems:**
  - Large tail in multiplicity distribution, incomplete saturation (?)
  - Narrow pseudorapidity distribution, disconnected minijets (?)
- **Predictions:**
  - Increased number of muons at ground (low and very high energy)
  - Much deeper Xmax, but inelasticity suggests Xmax probably lower
  - Consistency (Xmax, RMS(Xmax)) probably improved

Role of the p-p cross section

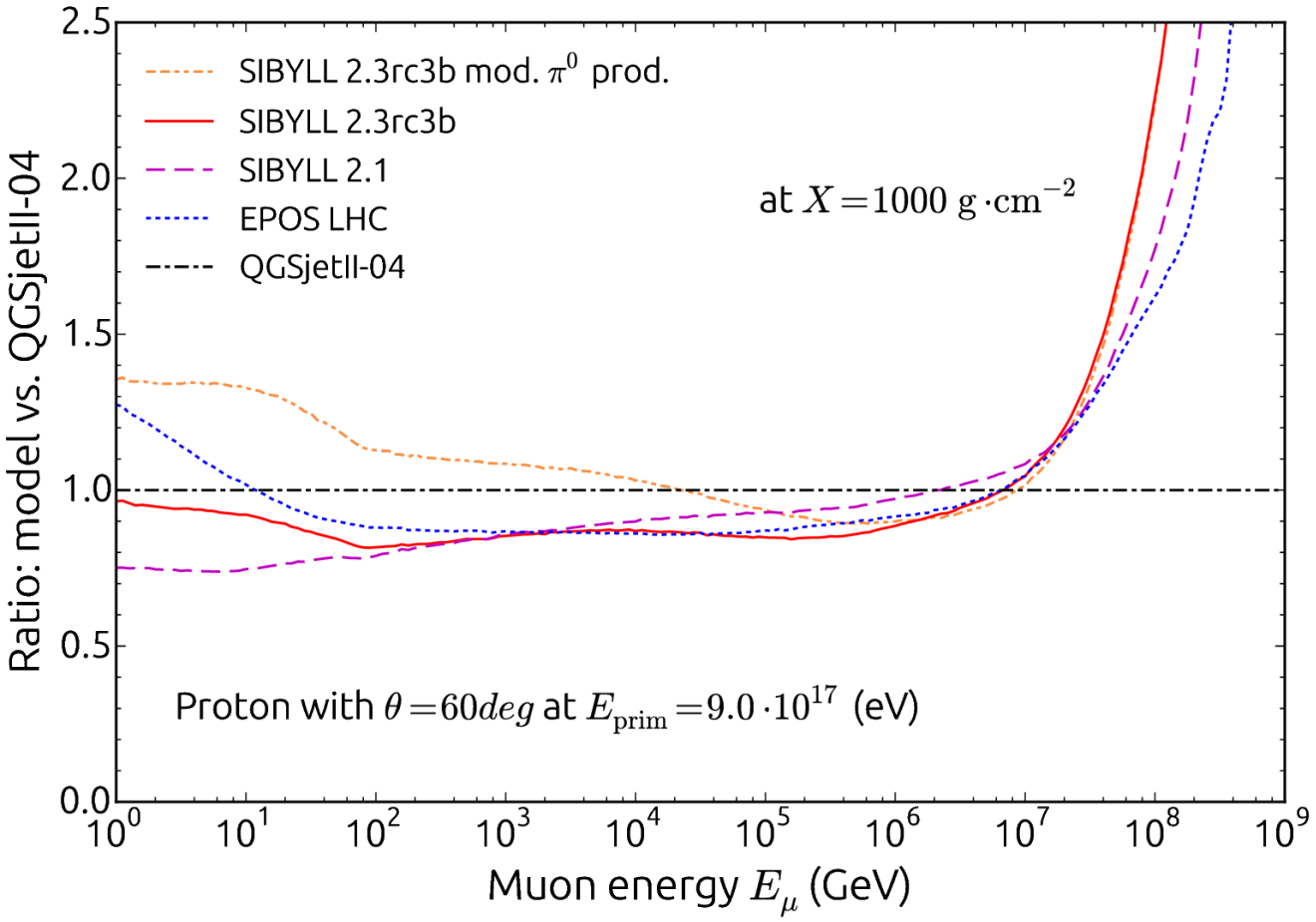


Role of neutral pion production: Xmax

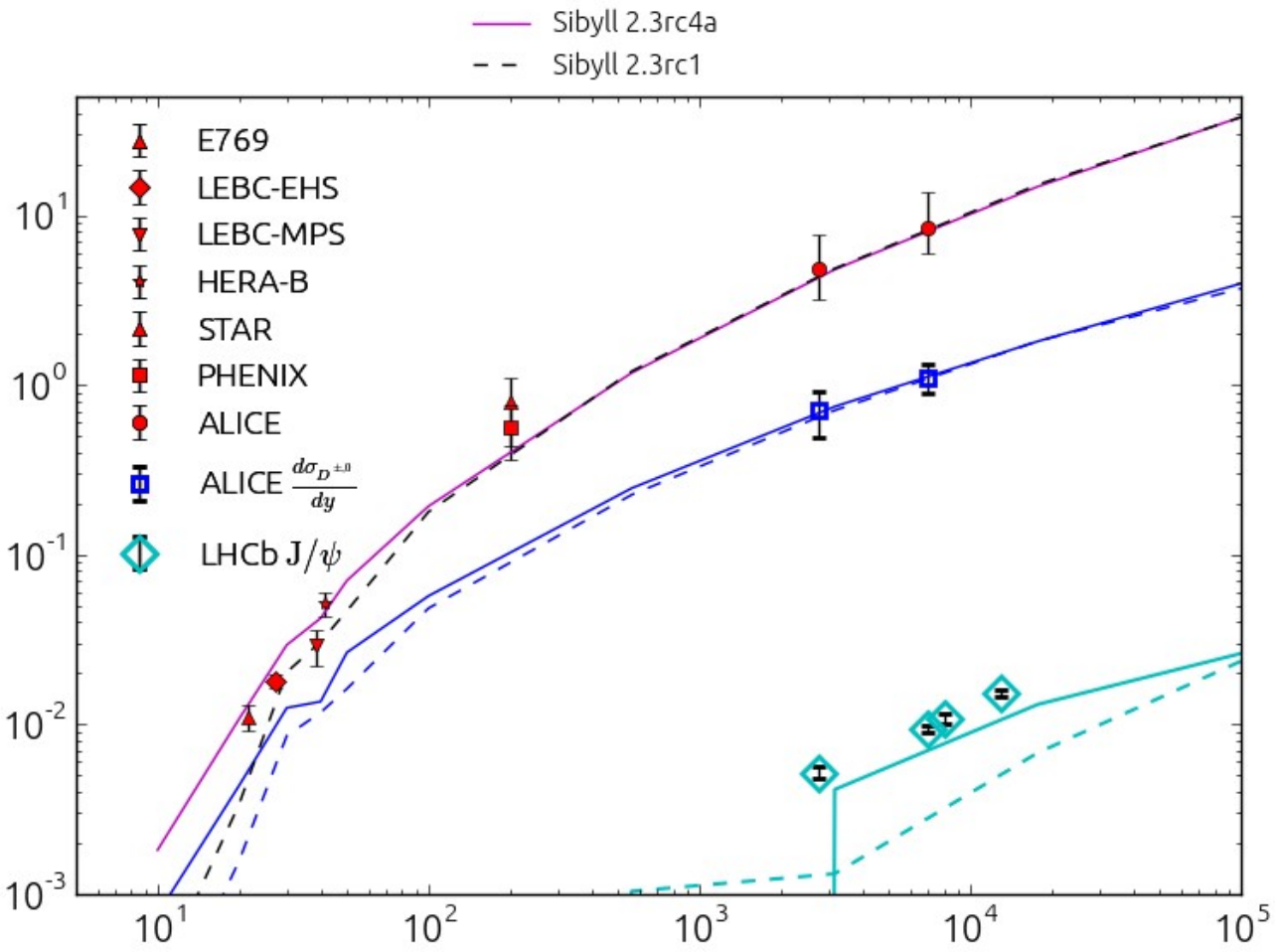


No influence on Xmax, probably because meson interactions are important in late stages when the bulk em cascade was formed

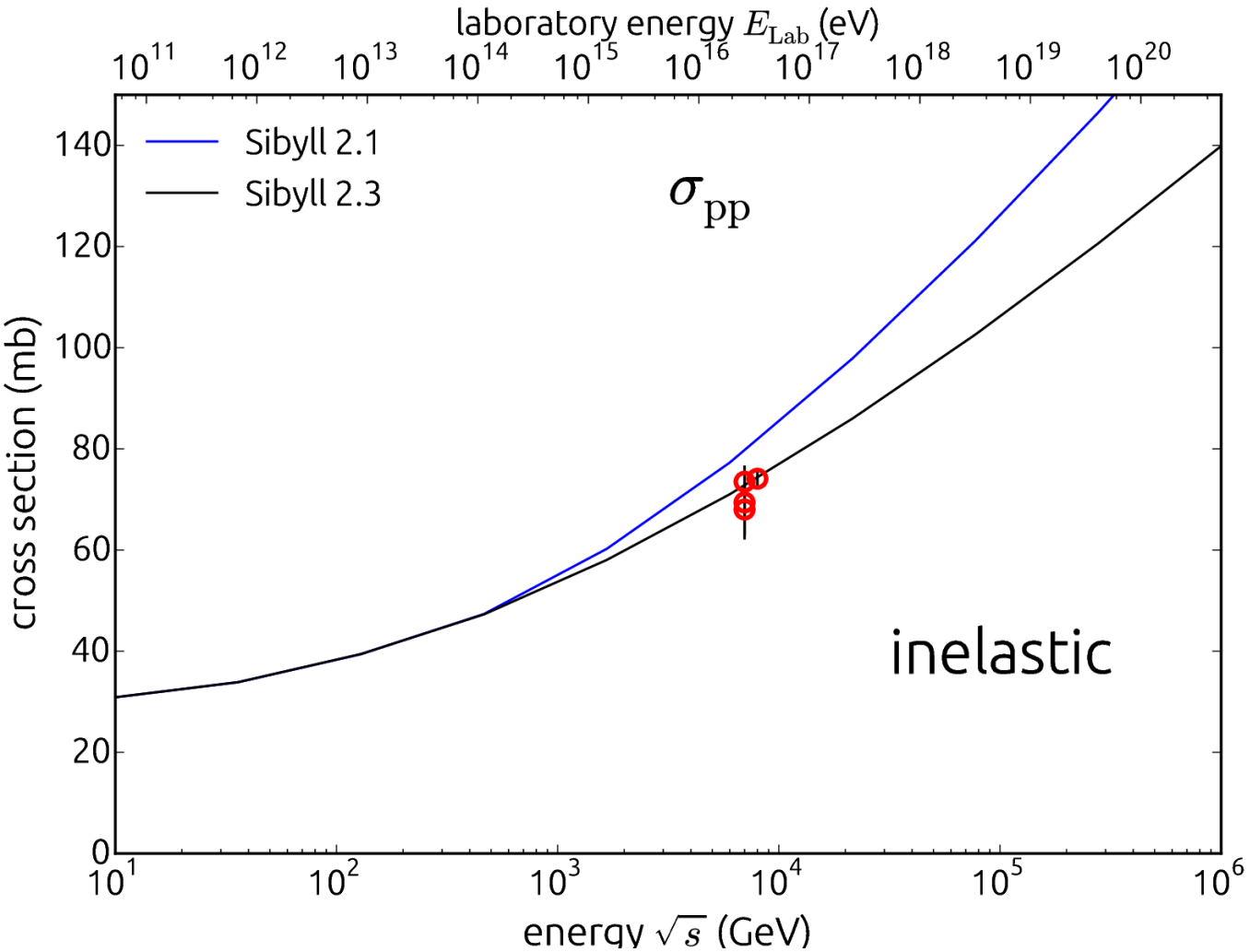
Sibyll evolution: muon energy spectrum



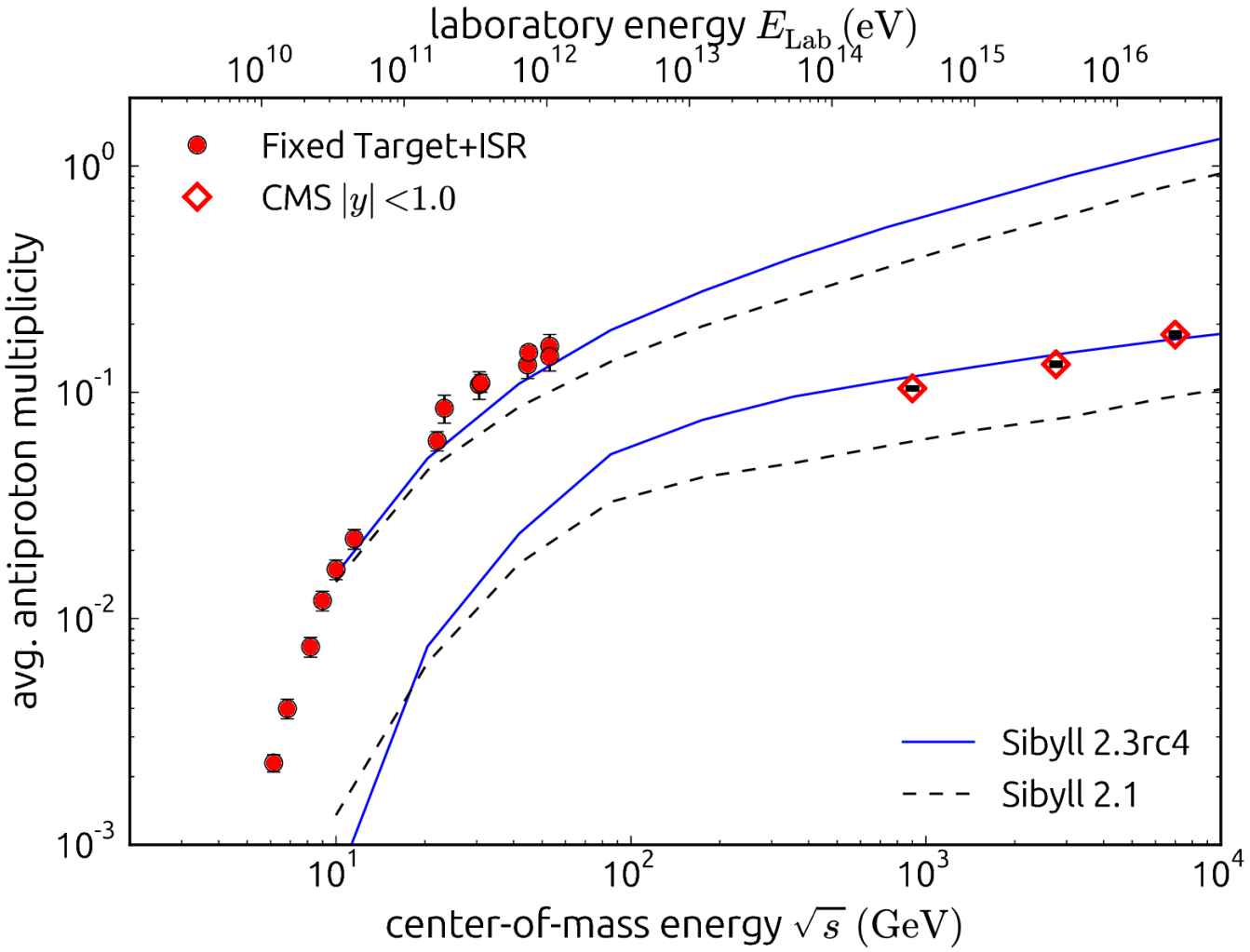
Sibyll evolution: charm production



Sibyll evolution: cross section



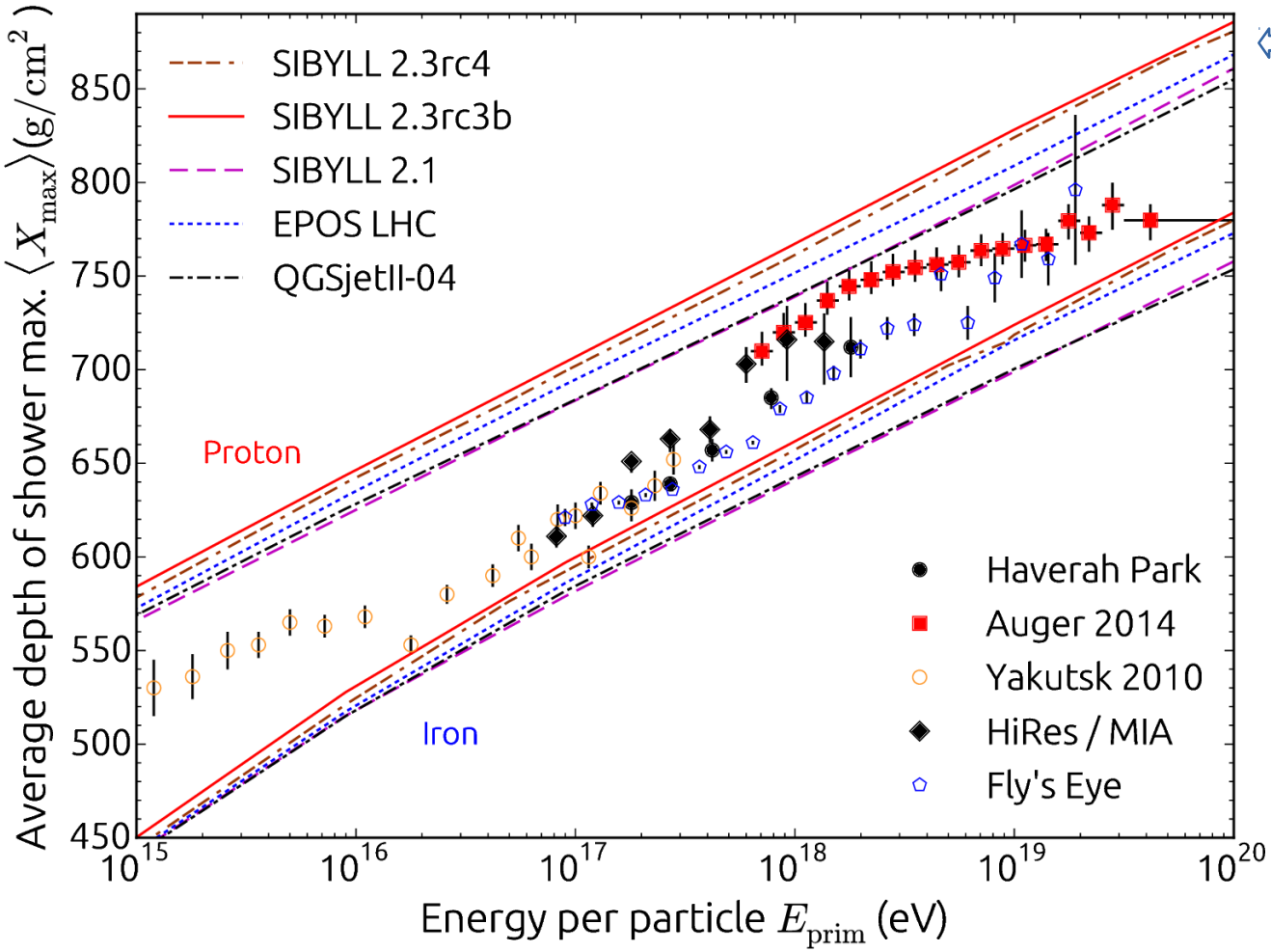
Sibyll evolution: baryon production



Sibyll evolution: remnant

Inclusive atmospheric flux predictions

RMS(Xmax) prediction



⇦ **All new predictions probably overestimate Xmax**