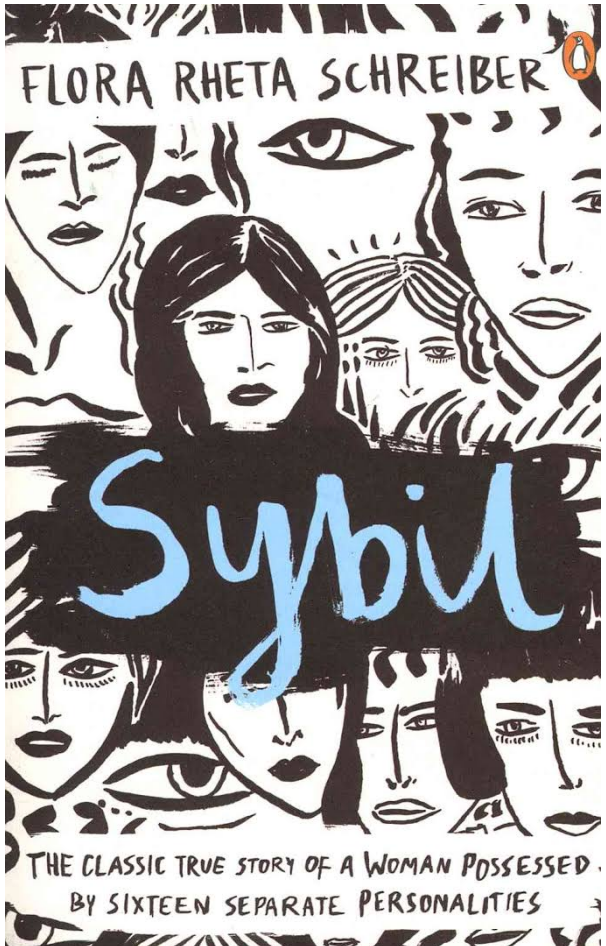
The hadronic interaction model Sibyll 2.3c



(4/5 goodreads)

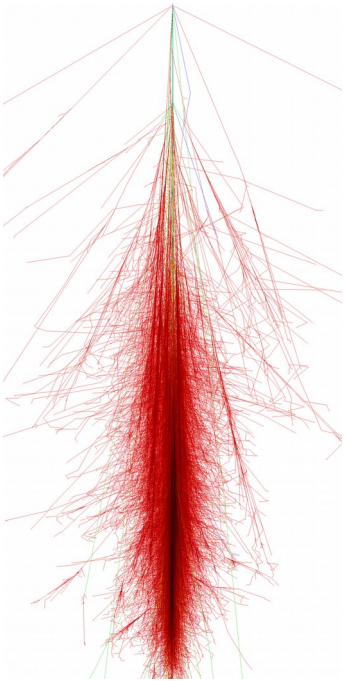
Felix Riehn, R. Engel, A. Fedynitch, T.K. Gaisser and T. Stanev

ISVHECRI 2018

May 24th 2018, Nagoya, Japan

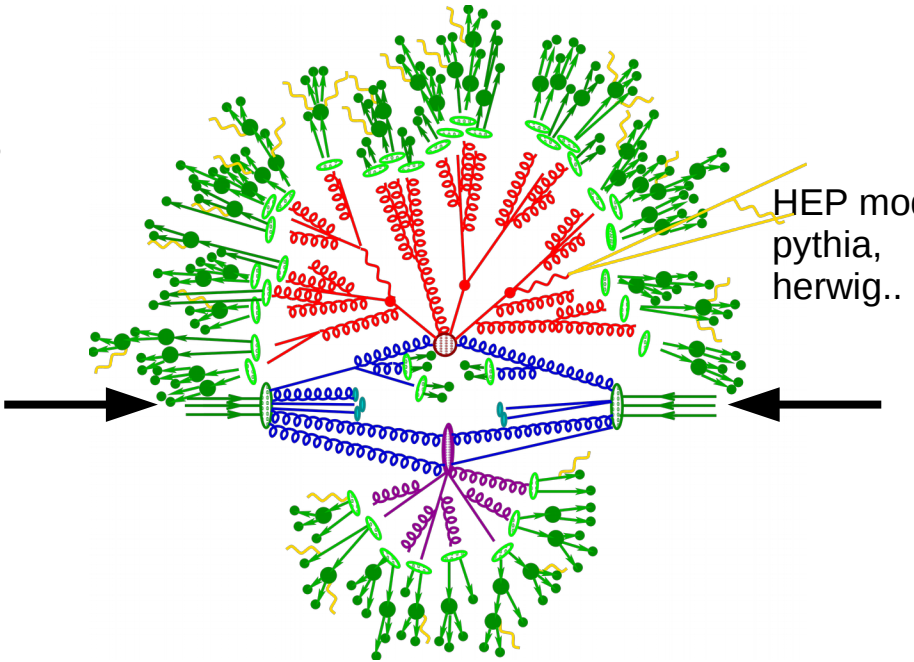
LIP

The Sibyll way



Hadronic interaction MC for
extensive air shower simulations

→ focus on leading order
→ describe average interaction
→ reliable extrapolation

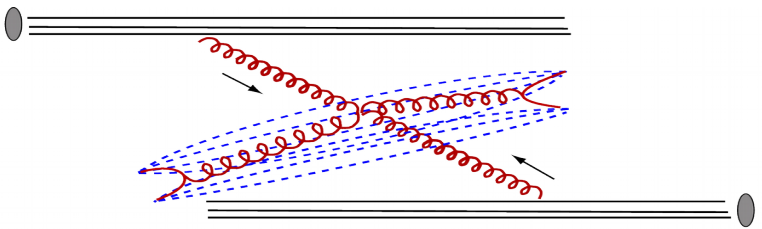


HEP models:
pythia,
herwig..

Complicated..

The Sibyll way

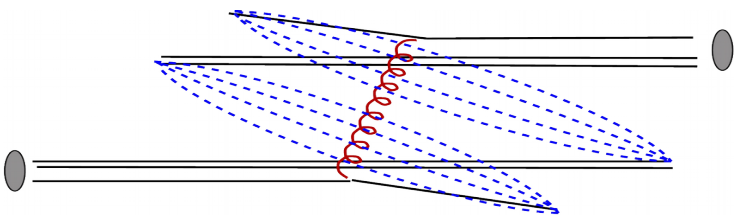
Hard & soft scattering



* parton picture
* LO QCD jets → minijets
* Multiparticle interactions

* diffraction dissociation
* leading particles, assoc. production

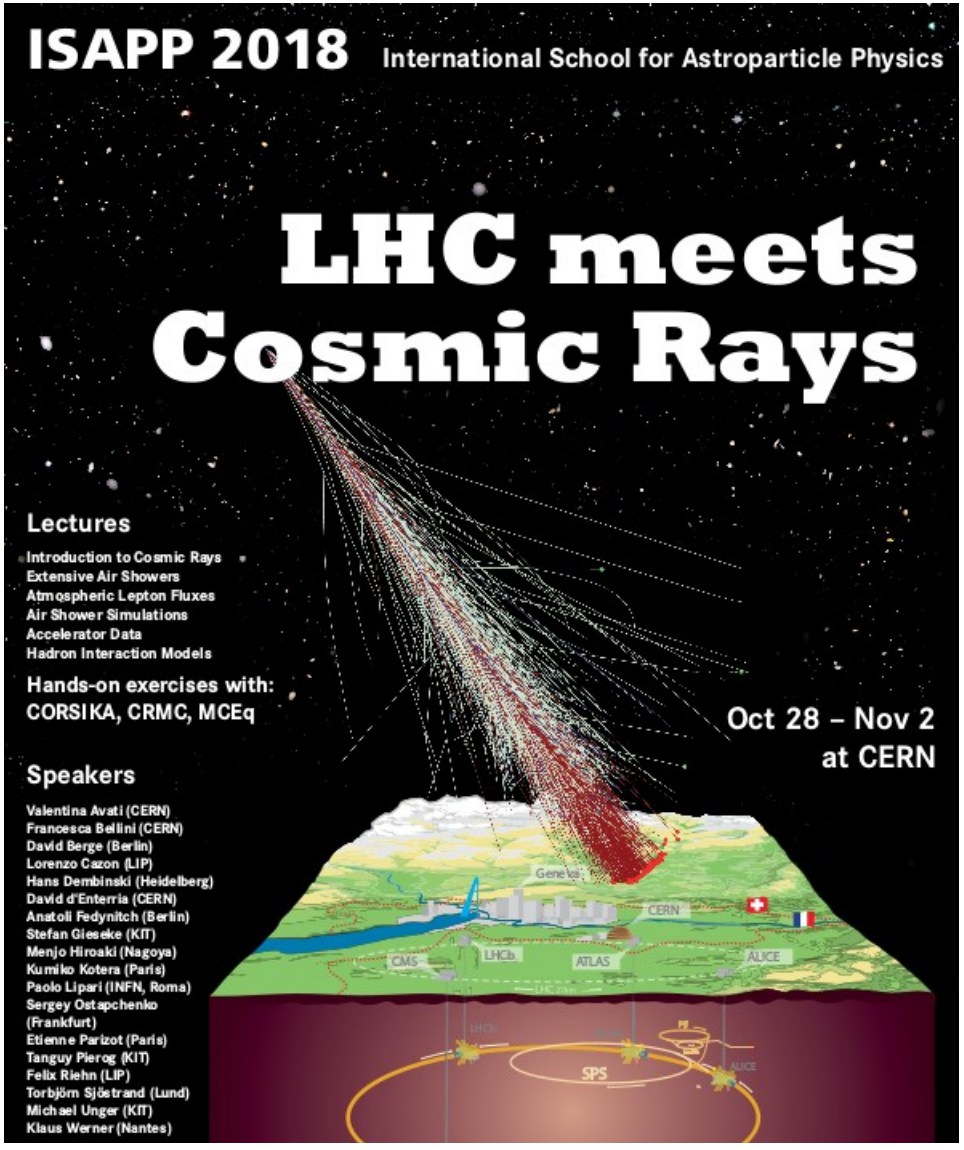
soft



For more: Sibyll 2.1 (PRD 80 094003 (2009)), Sibyll 2.3c arXiv:1806.xxxx

Or...

Send your students
and let them teach you



Whats new

* Cross section
* Remnant model
* Enhanced baryon production
* Inelastic screening in nuclear interactions
* Charm production
* ...

The hadronic interaction model SIBYLL 2.3c and extensive air showers

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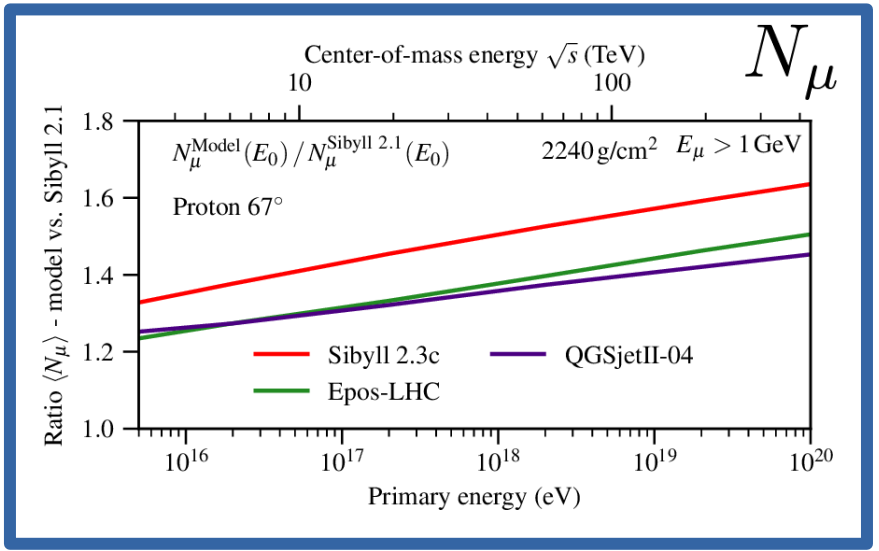
Thomas K. Gaisser and Todor Stanev
Bartol Research Institute, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA

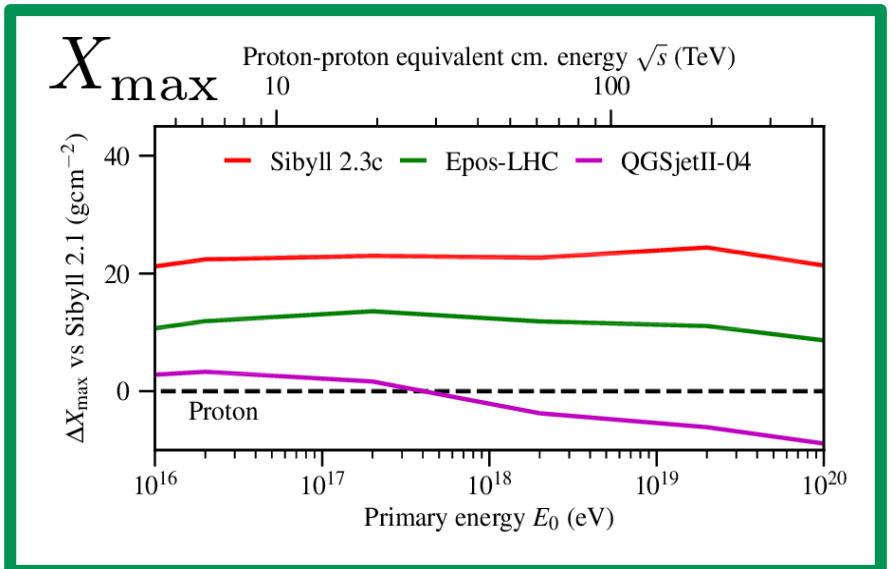
Meaning ..

Whats new

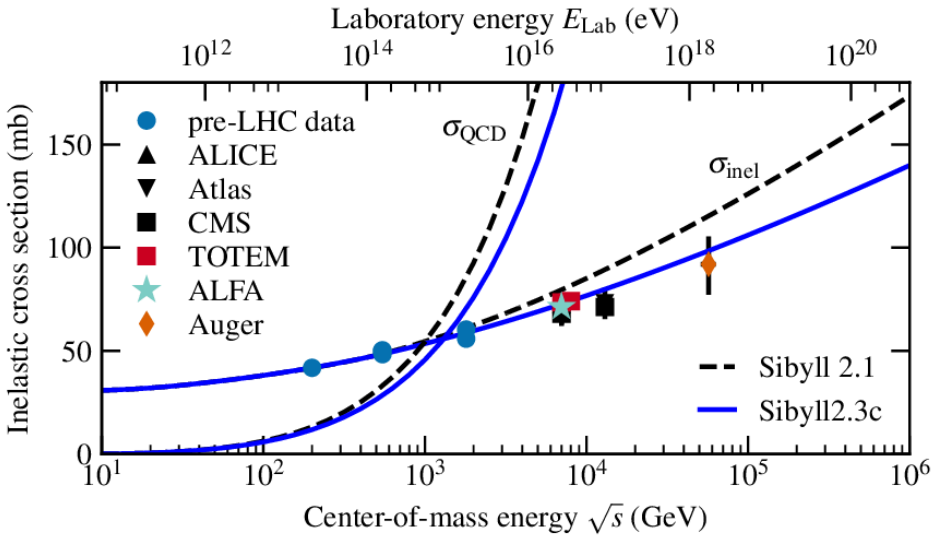
- Cross section
- Remnant model (rho0)
- Enhanced baryon production
- Inelastic screening in nuclear interactions
- Charm production
- ...

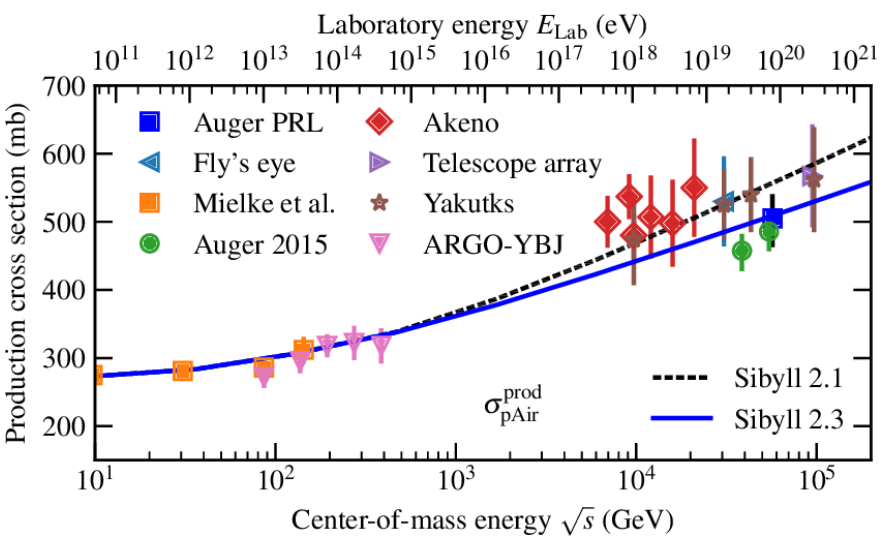
- Atmospheric fluxes (later)



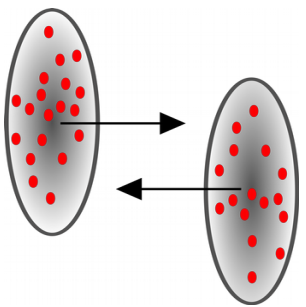


Cross section: p-p

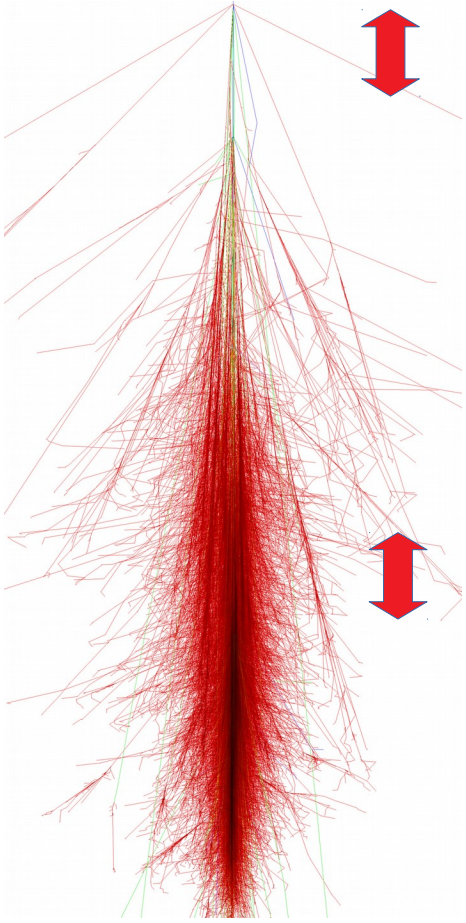




Sibyll 2.1 from 2001
(TeVatron)



- narrow hadron profile
- increase soft-hard threshold

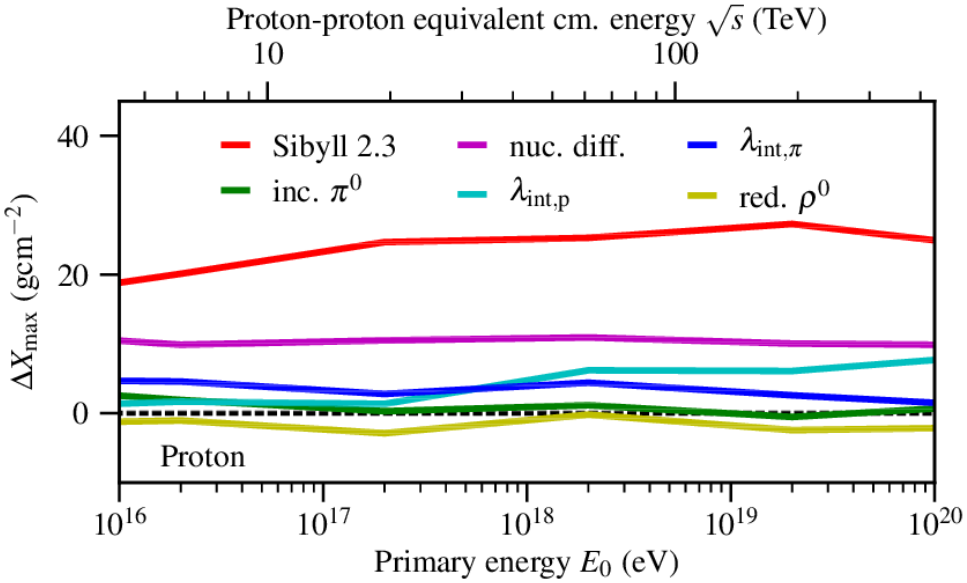


Xmax

* p-p cross section reduced

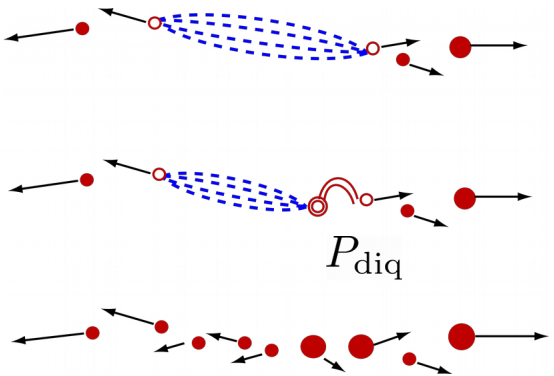
* p-air cross section reduced

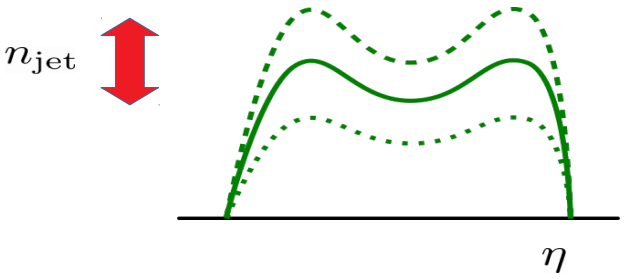
* p-air diffraction increased
  (coherent diffraction)

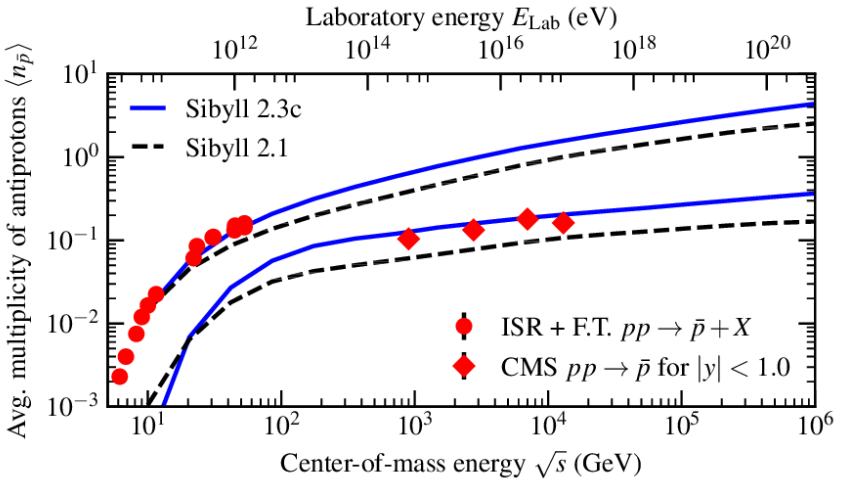


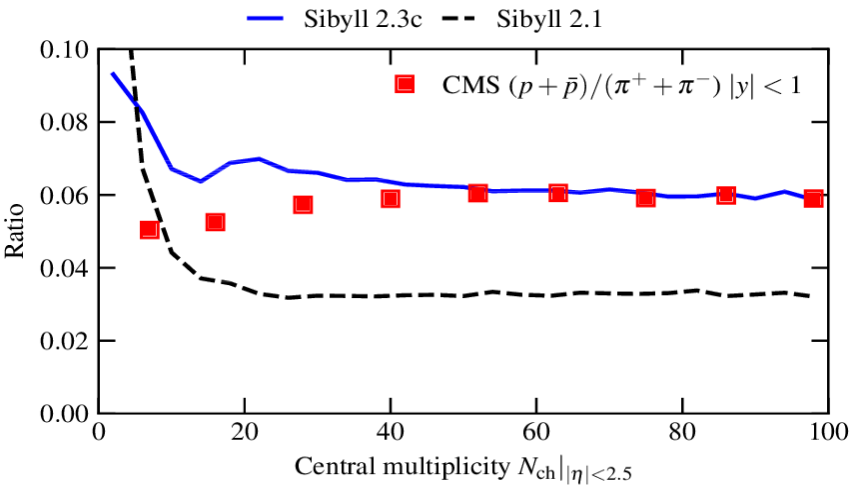
→ 20 g/cm**2 deeper proton shower

Baryon production



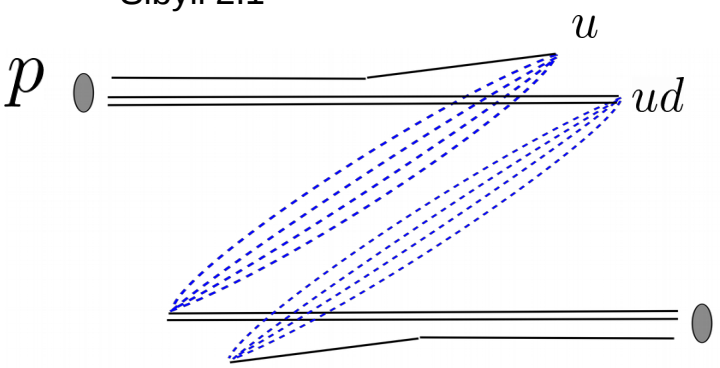






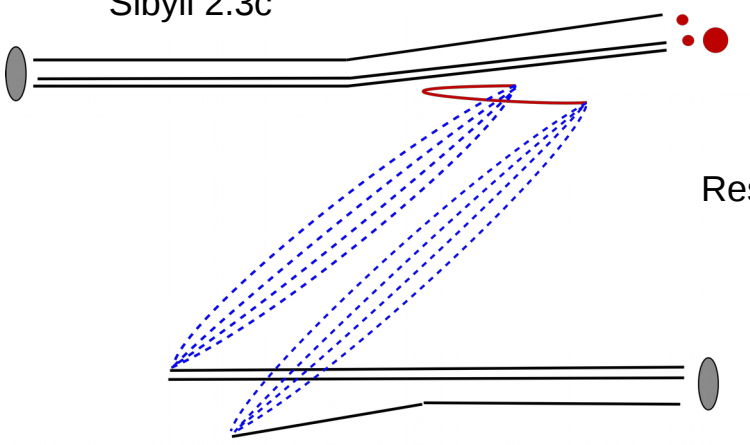
Remnants

Sibyll 2.1



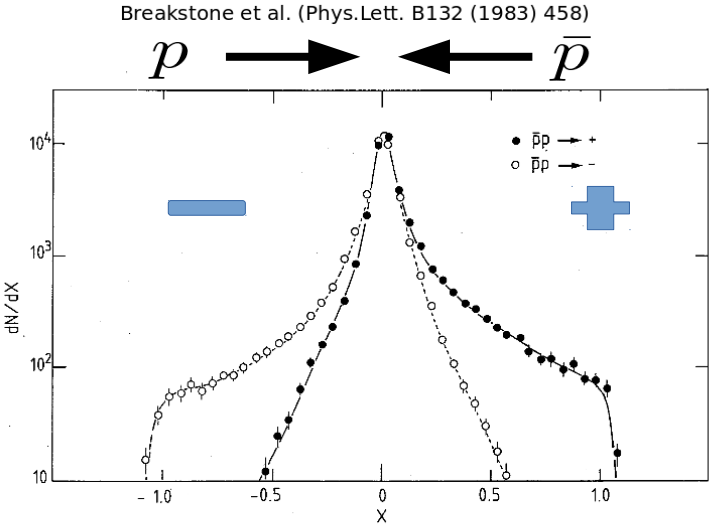
continuum

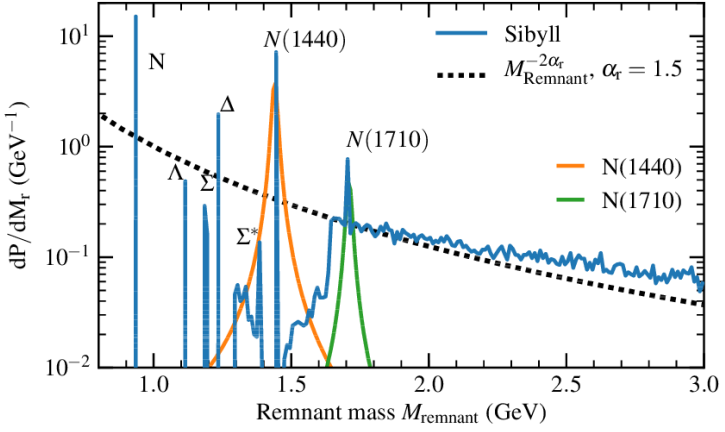
Sibyll 2.3c



Resonances
+ continuum

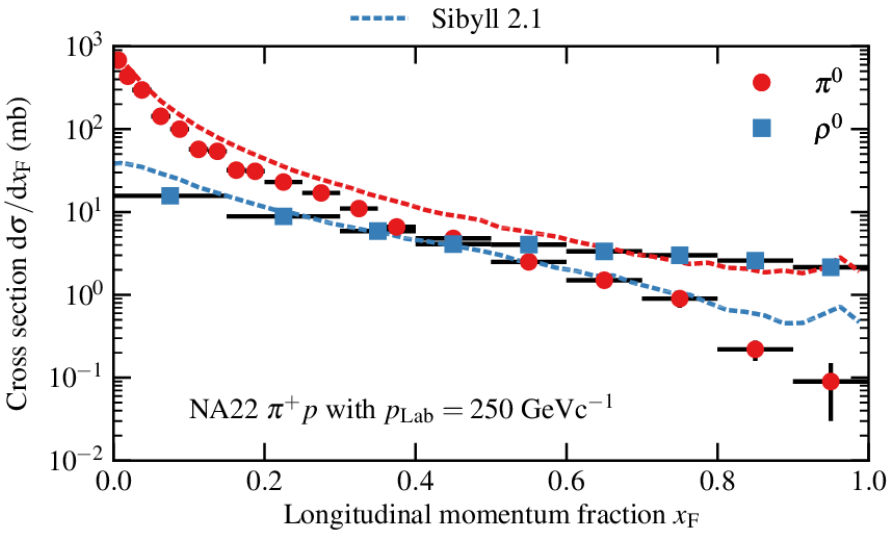
Breakstone et al. (Phys.Lett. B132 (1983) 458)

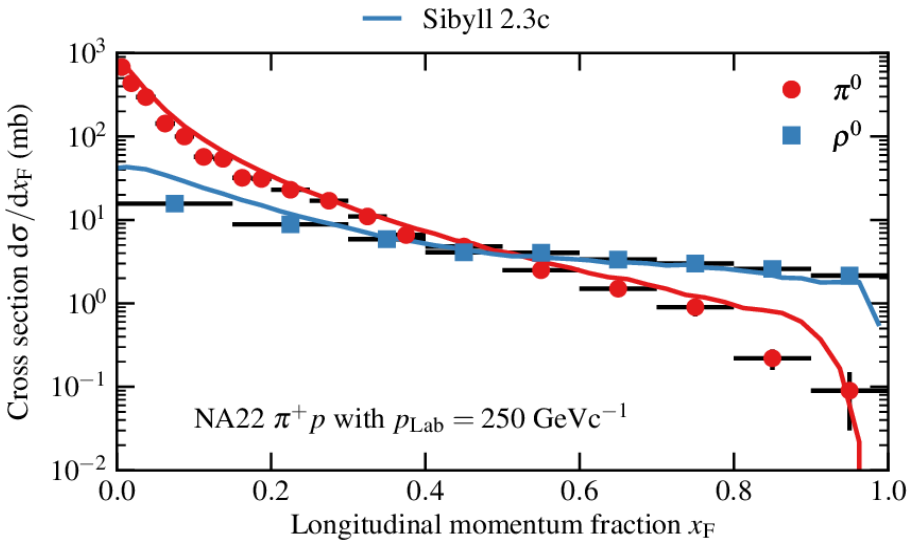




Leading particles

$\pi^+ + p \rightarrow \text{leading} + X$ $\quad$ leading : $\pi,\ \rho$



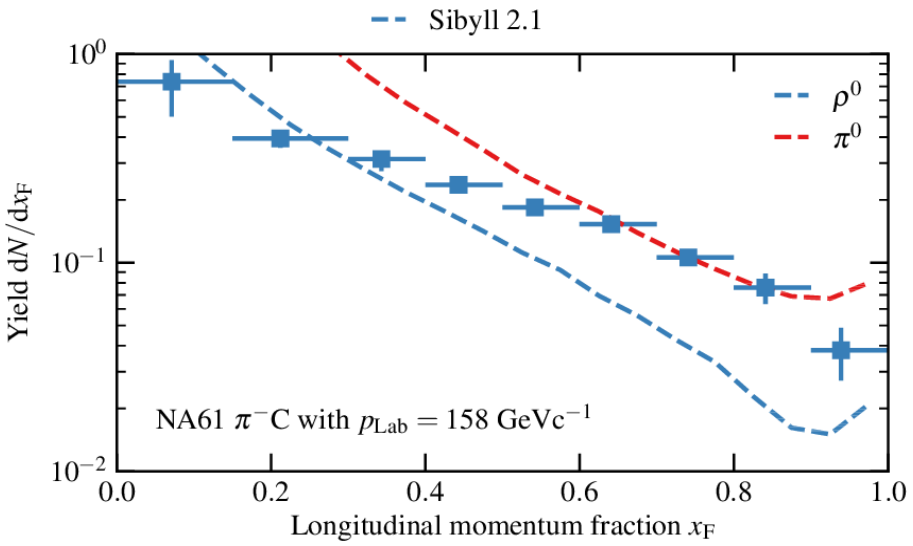


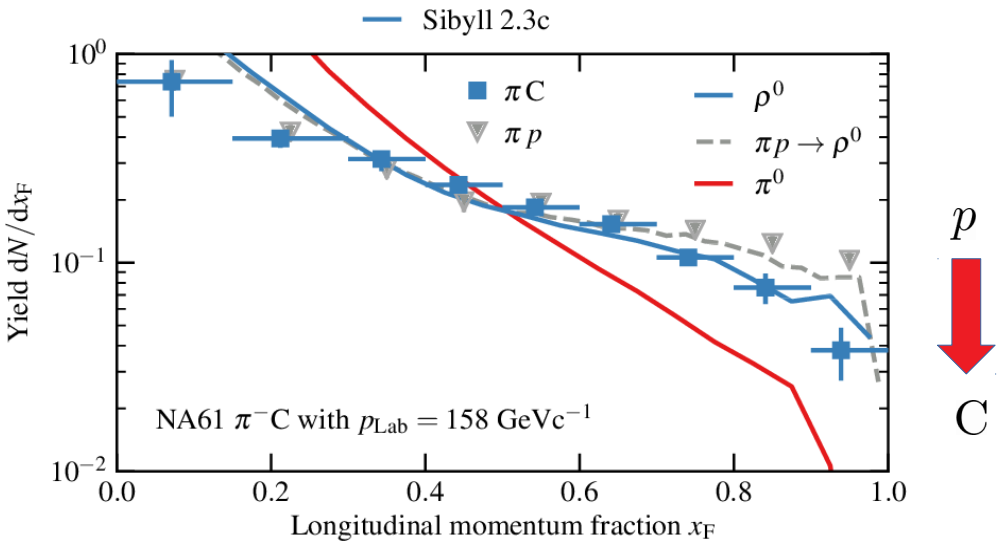
$P_{\pi:\rho} = 1/3$

πAir?

Leading particles

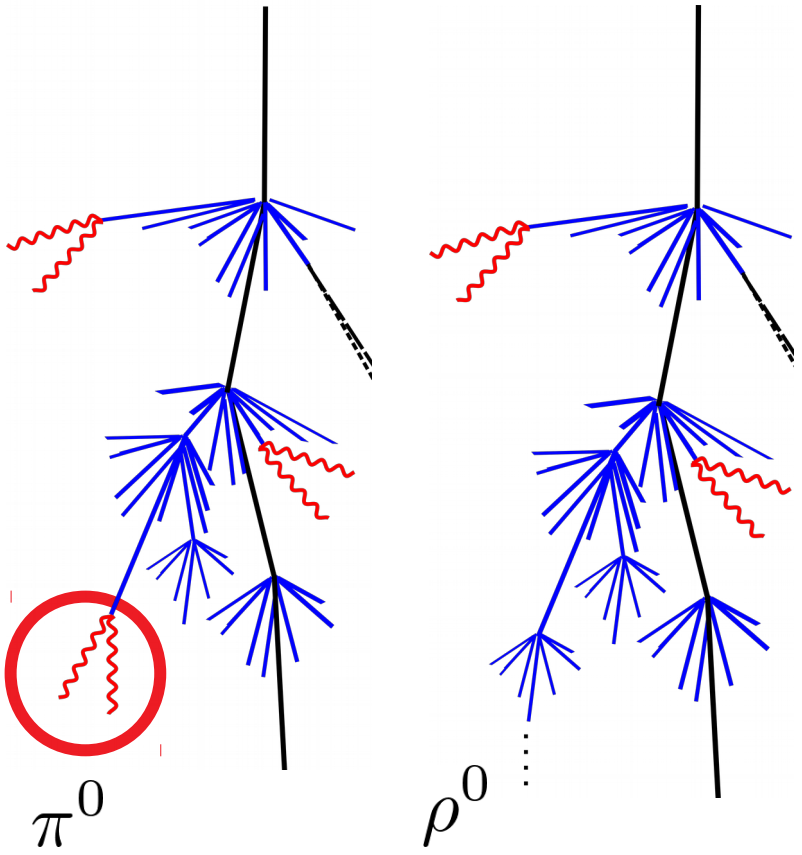
$$\pi^+ + \mathrm{C} \rightarrow \text{leading} + X$$

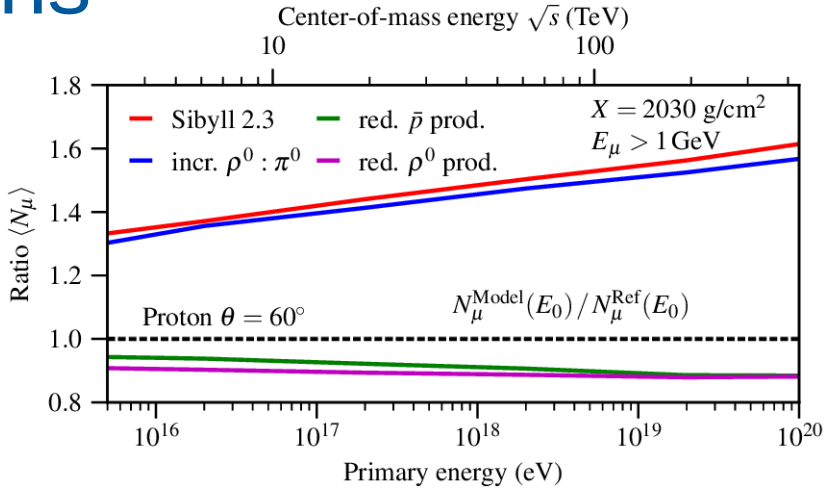


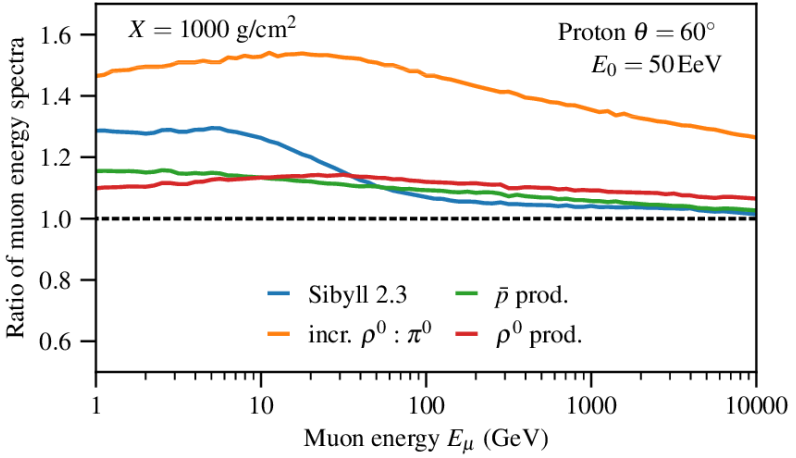


P → C transition reproduced

Muons

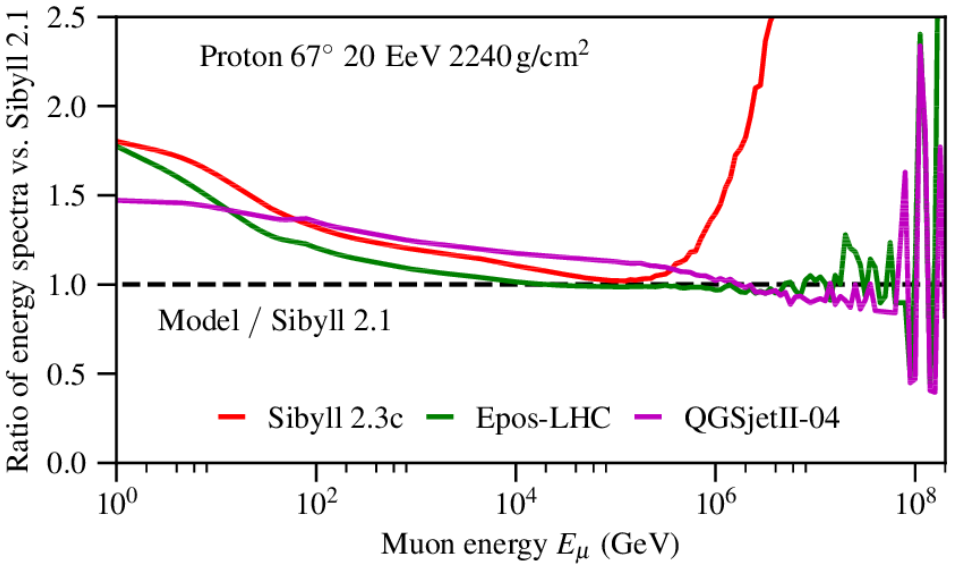

π^0
ρ^0


Center-of-mass energy $\sqrt{s}$ (TeV)
10
100
Sibyll 2.3
incr. $\rho^0 : \pi^0$
red. $\bar{p}$ prod.
red. ρ^0 prod.
$X = 2030$ g/cm^2
$E_\mu > 1$ GeV
Proton $\theta = 60°$
$N_\mu^{\mathrm{Model}}(E_0) / N_\mu^{\mathrm{Ref}}(E_0)$
Ratio $\langle N_\mu \rangle$
Primary energy (eV)

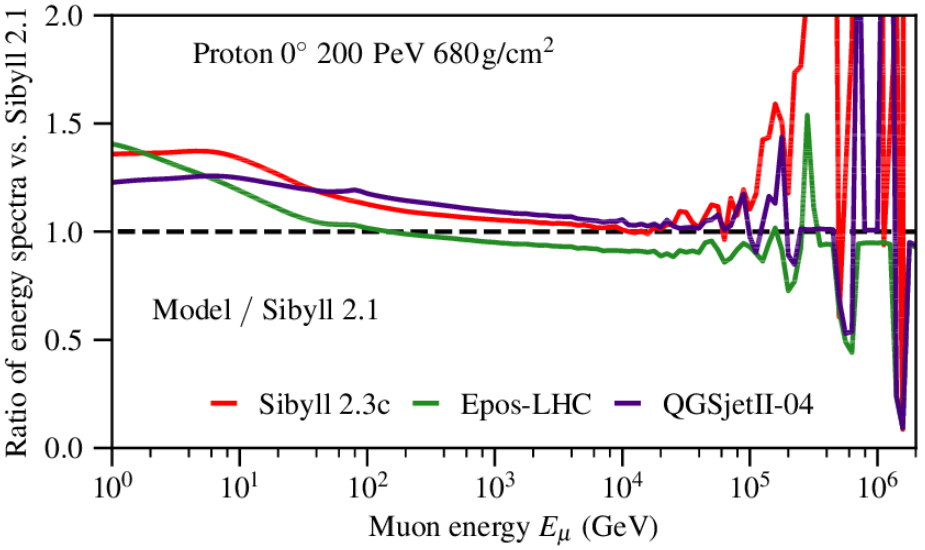

$X = 1000$ g/cm^2
Proton $\theta = 60°$
$E_0 = 50$ EeV
Sibyll 2.3
incr. $\rho^0 : \pi^0$
$\bar{p}$ prod.
ρ^0 prod.
Ratio of muon energy spectra
Muon energy E_μ (GeV)

Muon energy spectrum

Auger



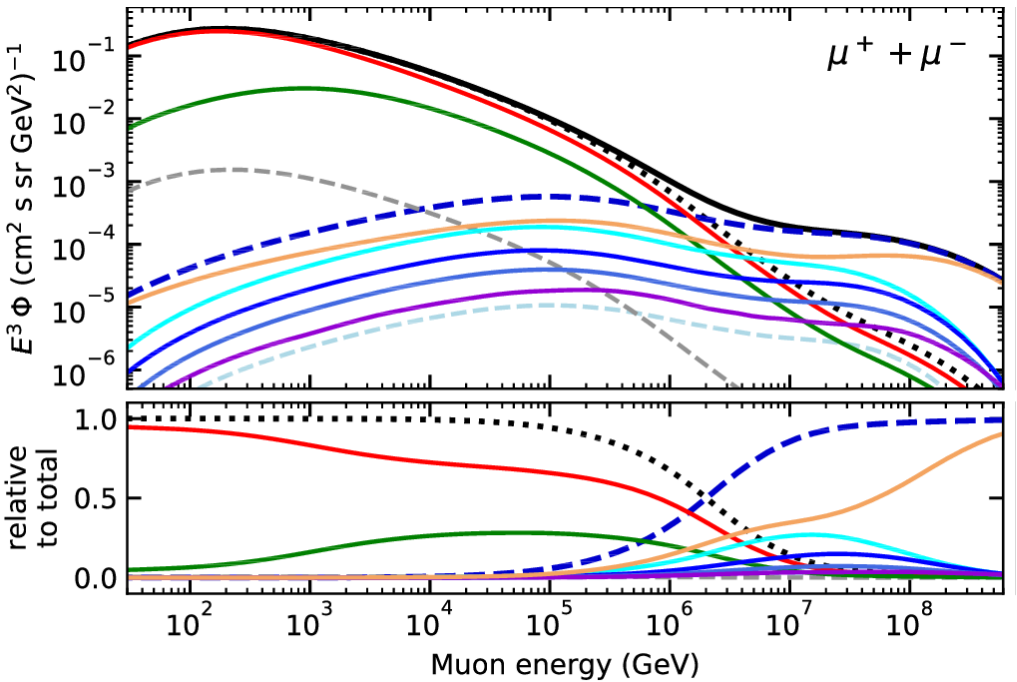
IceTop



Beyond EAS ..

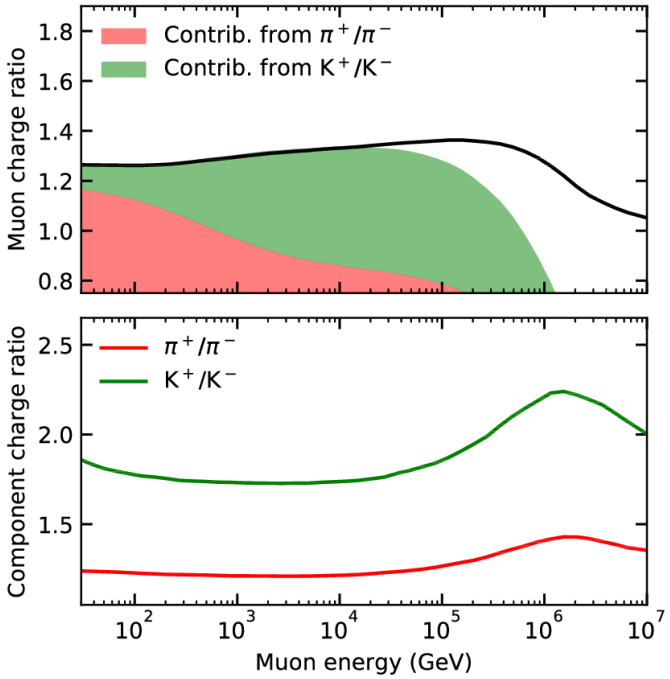
Inclusive flux of leptons in the atmosphere

A new challenge ..



(A. Fedynitch)

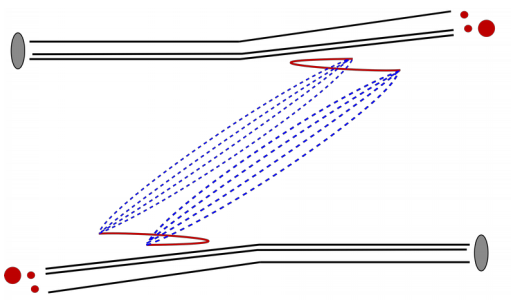
Charge ratio

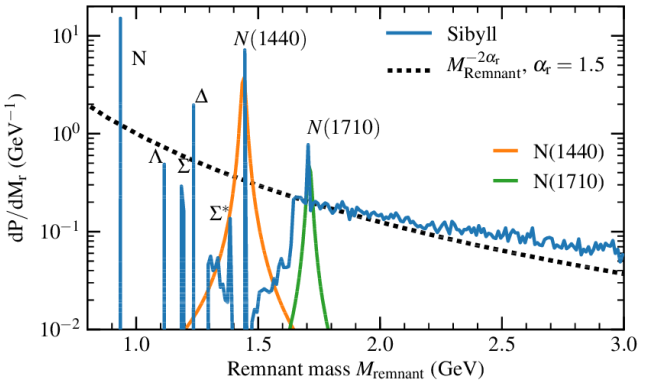


Sensitive to forward phase space

Remnant & forward charge ratios

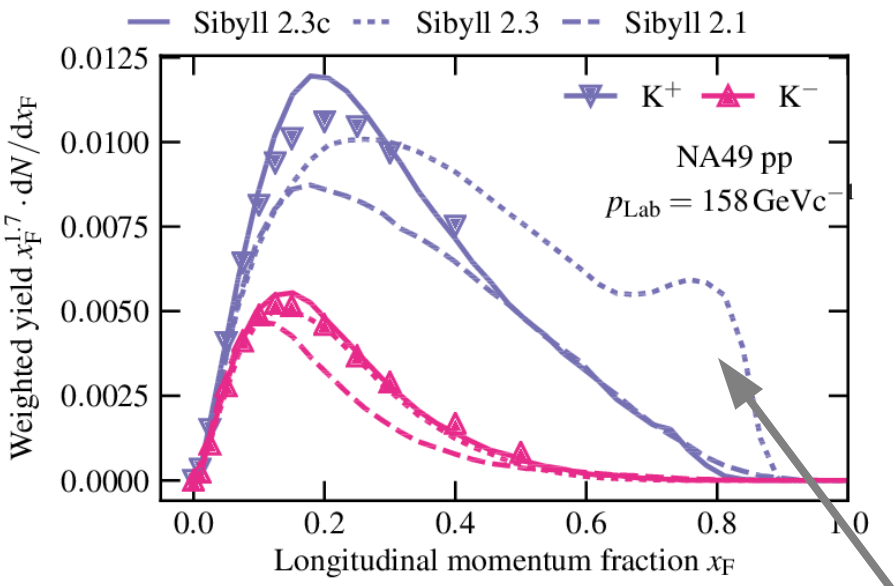
remnant

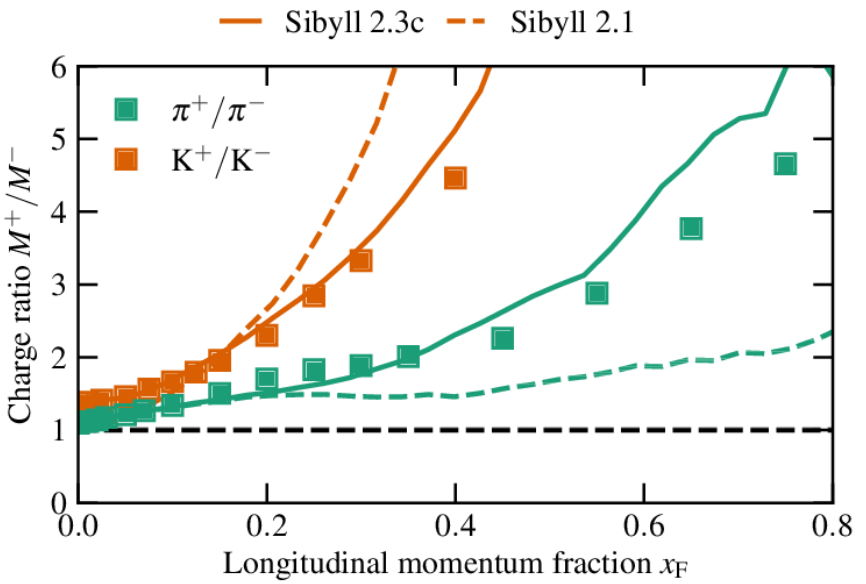




	Δ^{++}				
$\pi^+ p$	1	Δ^+	N^+		
$\pi^+ n$	1/3	2/3			
$\pi^0 p$	2/3	-1/3	Δ^0	N^0	
		$\pi^0 n$	2/3	1/3	
		$\pi^- p$	1/3	-2/3	Δ^-
				$\pi^- n$	1

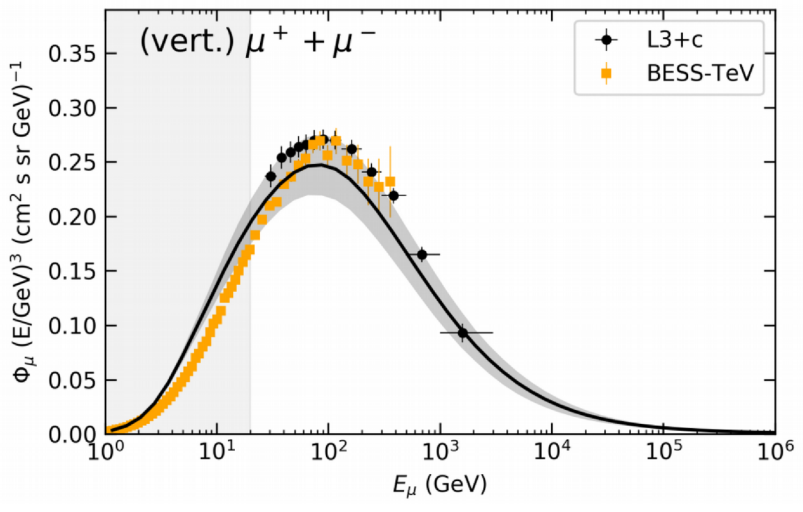
Leading mesons & charge ratios

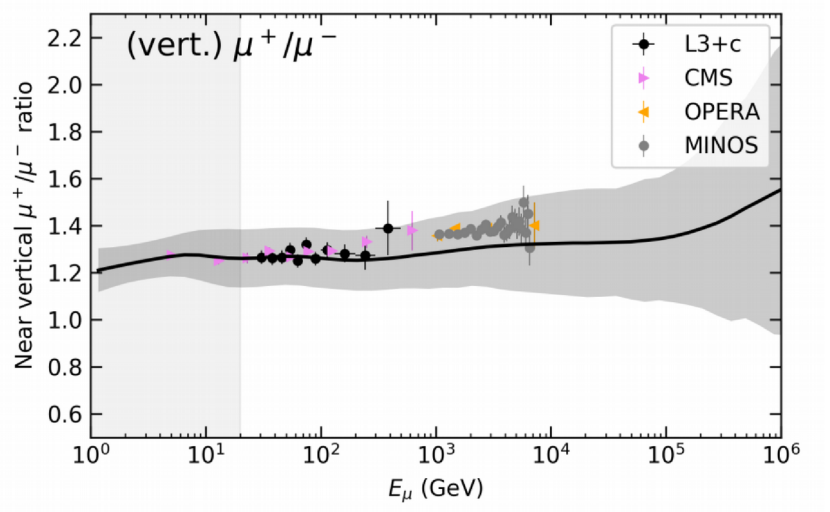




(see ICRC 2017 contribution arXiv: 1709:07227)

Muon flux & charge ratio





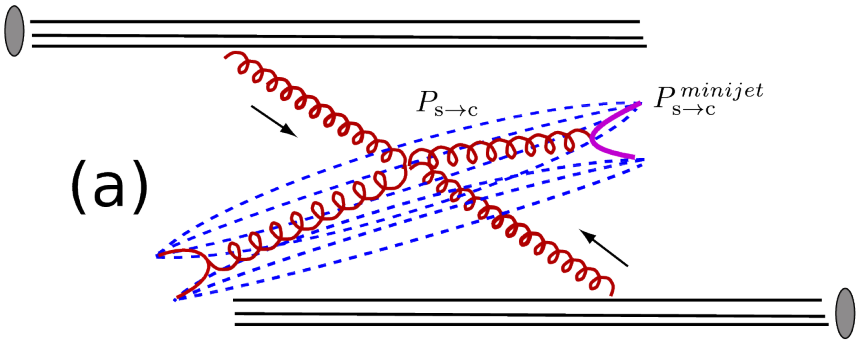
For more:

The hadronic interaction model SIBYLL 2.3C and inclusive lepton fluxes

Anatoli Fedynitch
DESY, Platanenallee 6, 15738 Zeuthen, Germany and
Karlsruher Institut für Technologie, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe, Germany

Felix Riehn
Laboratório de Instrumentação e Física Experimental de Partículas (LIP) - Lisbon,
Av. Prof. Gama Pinto 2, 1649-003 Lisbon, Portugal and

Charm production

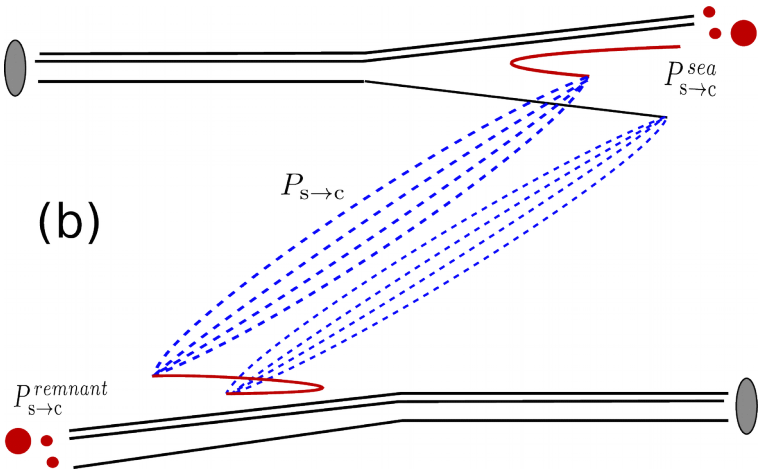


$$m_{\mathrm{c}} \approx 2\,\mathrm{GeV} \;\rightarrow\; \mathrm{pQCD} \;\rightarrow\; \mathrm{minijets}$$

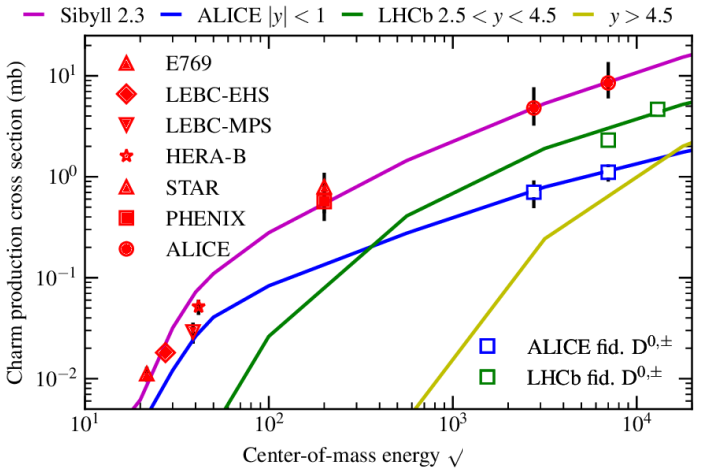
Evidence for leading, soft charm

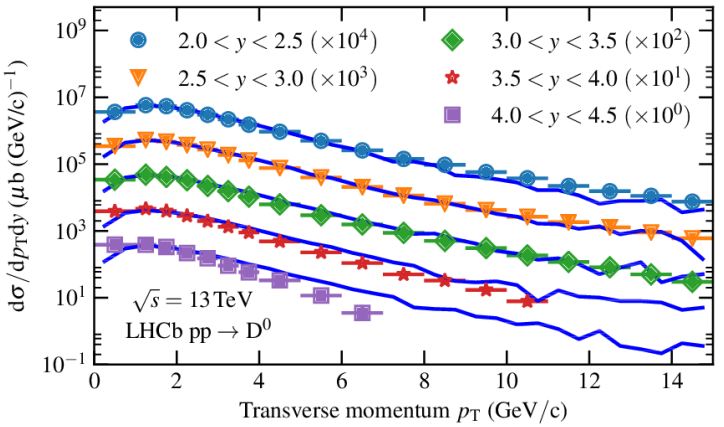
Mechanism:
Replace strange → charm

$$P_{\mathrm{s}\to\mathrm{c}}$$

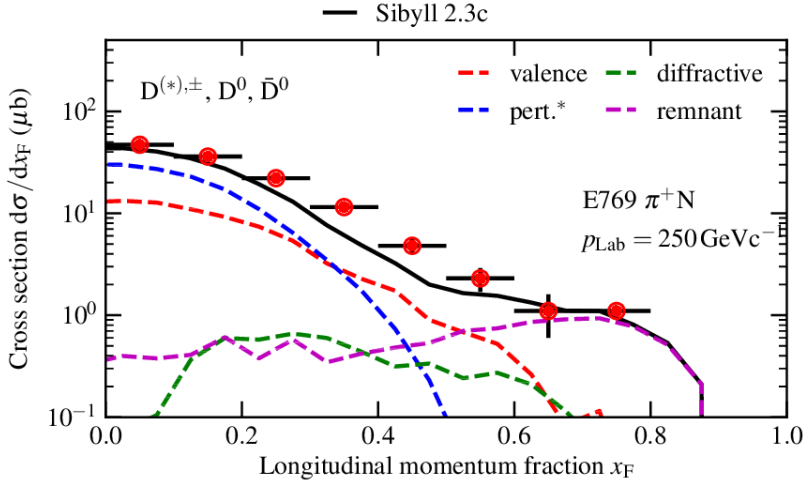


Charm tuning



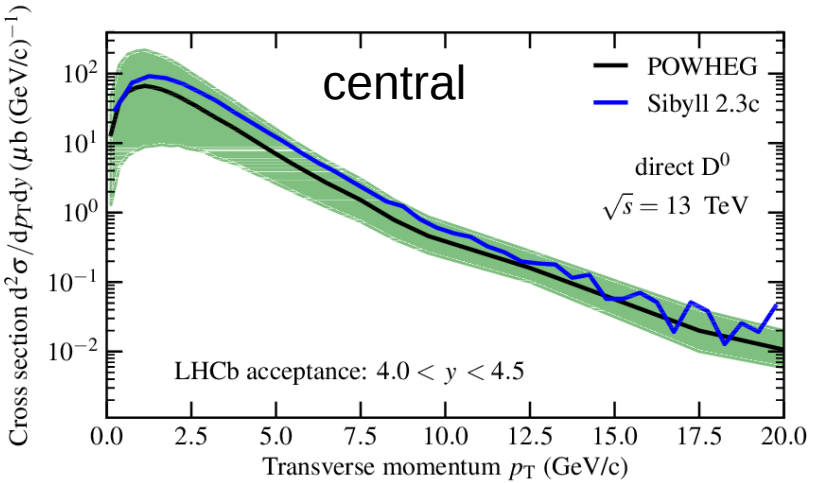


parameter	value
perturbative	
$P_{s\to c}^{minijet}$	0.08
non-perturbative	
$P_{s\to c}^{soft}$	0.004
$P_{s\to c}^{sea}$	0.002
$P_{s\to c}^{remnant}$	0.0
$P_{s\to c}^{string}$	0.004

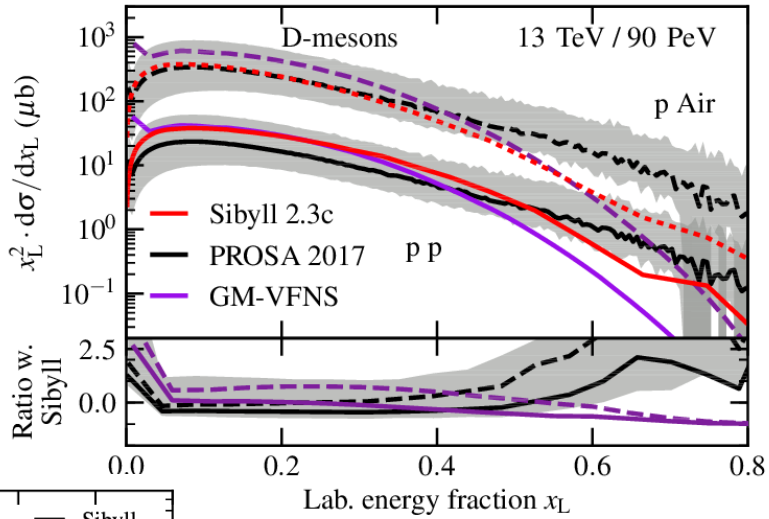


Fixed target
Fix shape!

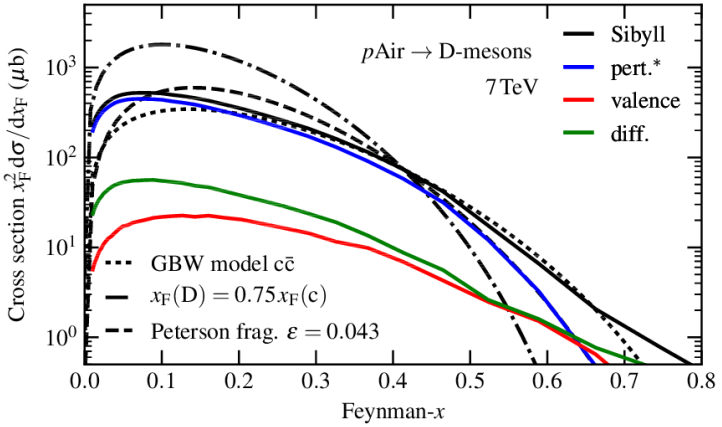
Sibyll vs. other models



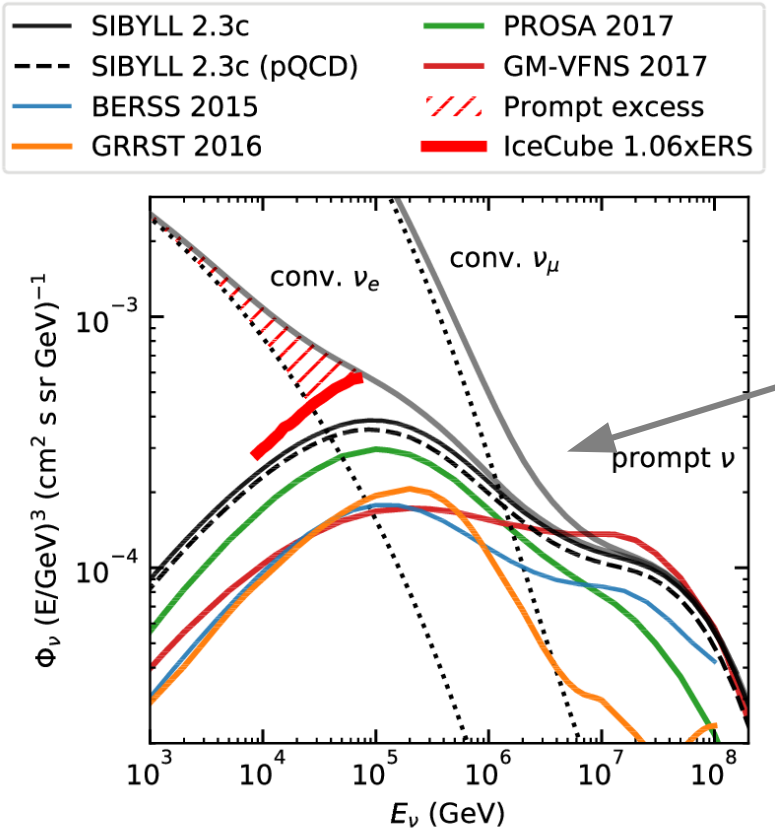
NLO QCD



(with M.V. Garzelli)



Atmospheric lepton fluxes



Complete inclusive prediction conventional & prompt

(MCEq)

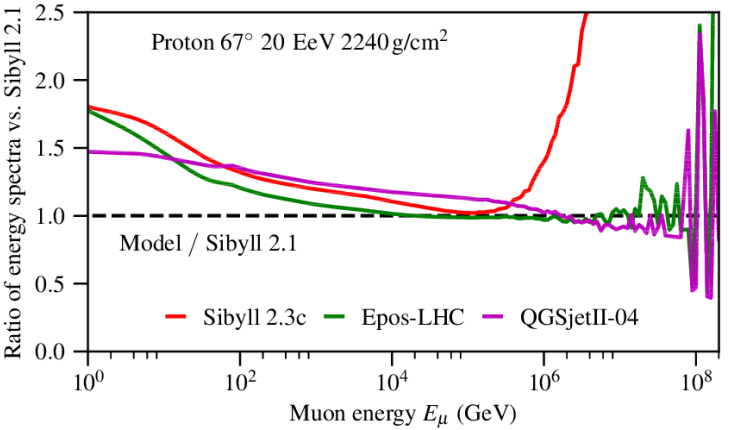
Summary

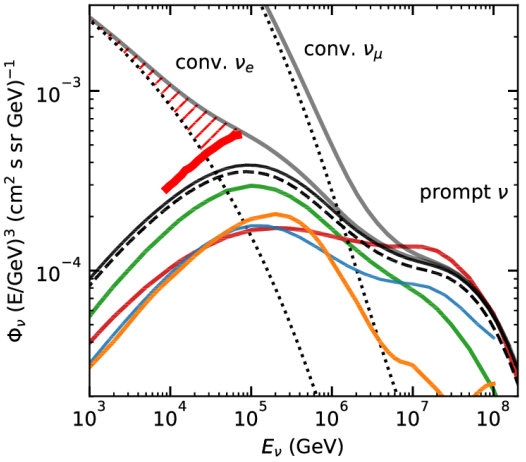
* new Sibyll 2.3c including:
  - remnant model
  - charm production
  - pp cross section
  - coherent nuclear diffraction

* improved description of accelerator measurements
  → shortcomings not mentioned

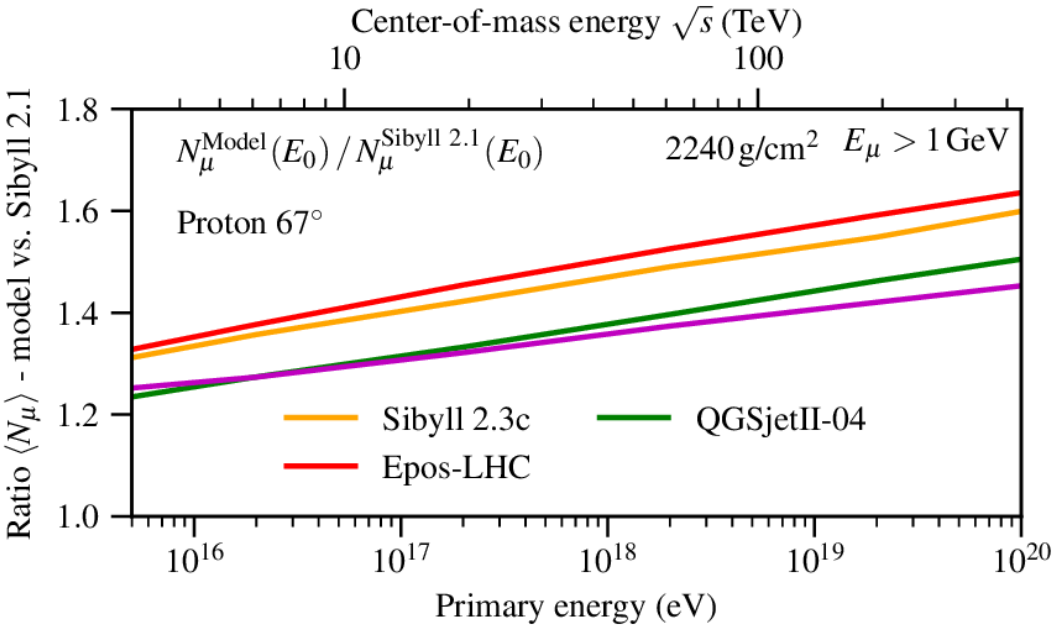
* predictions for EAS:
  - ~20g/cm2 deeper Xmax
  - ~1.6 more muons (all ground, E>1GeV)

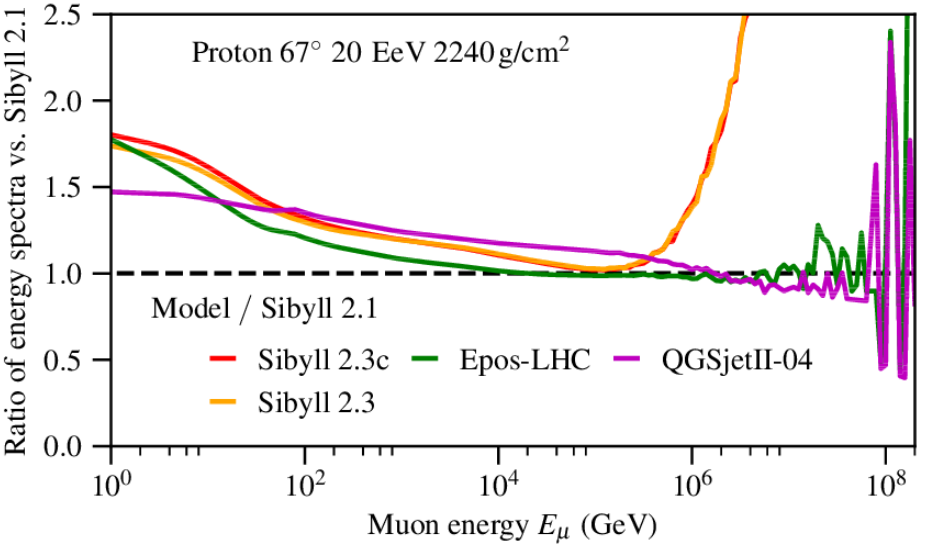
* atmospheric fluxes:
  - muon charge ratio compatible with measurements
  - prompt component



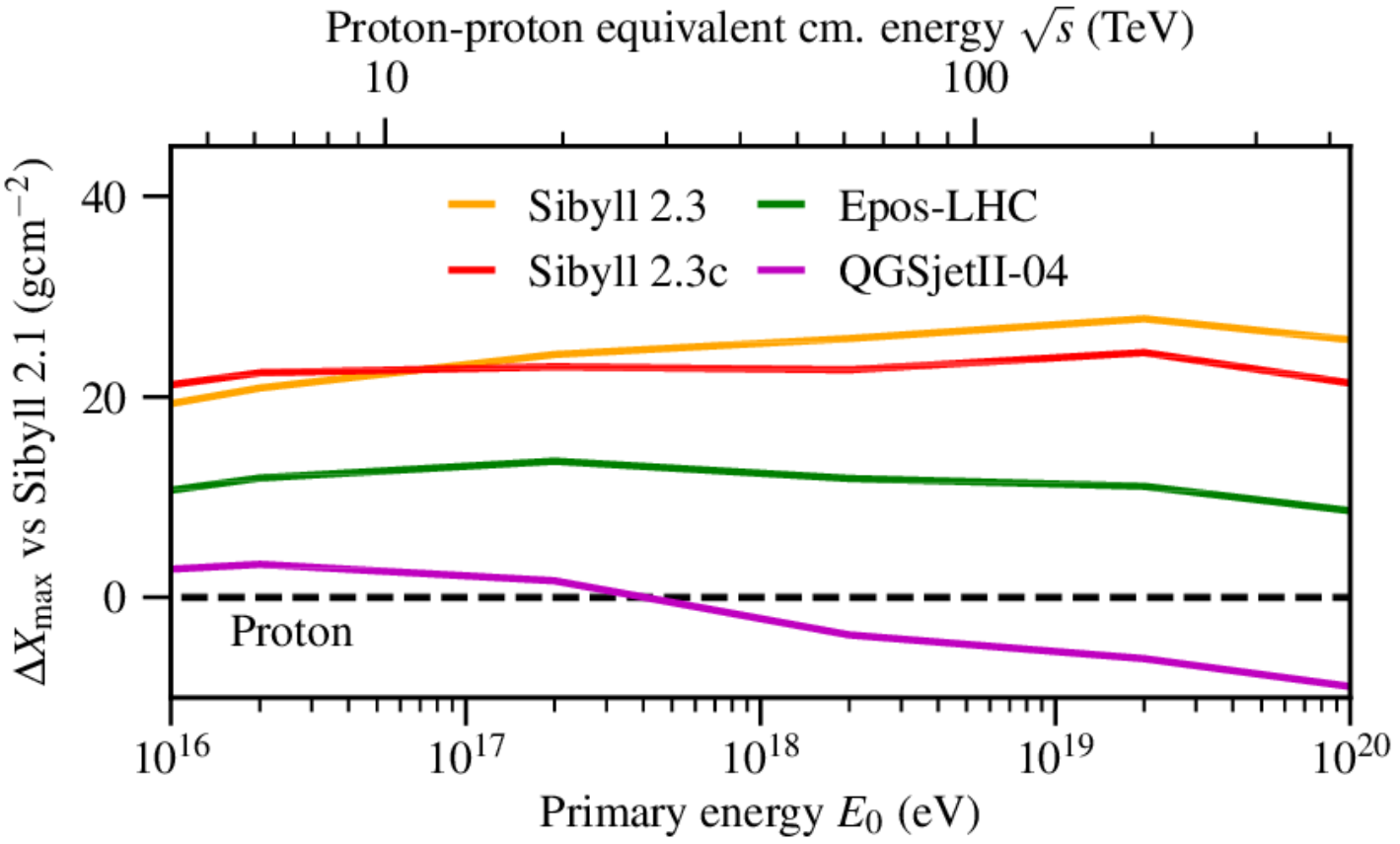


Sibyll 2.3 vs 2.3c: muons

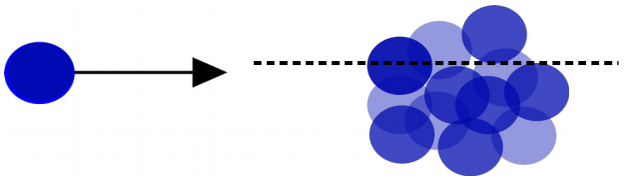


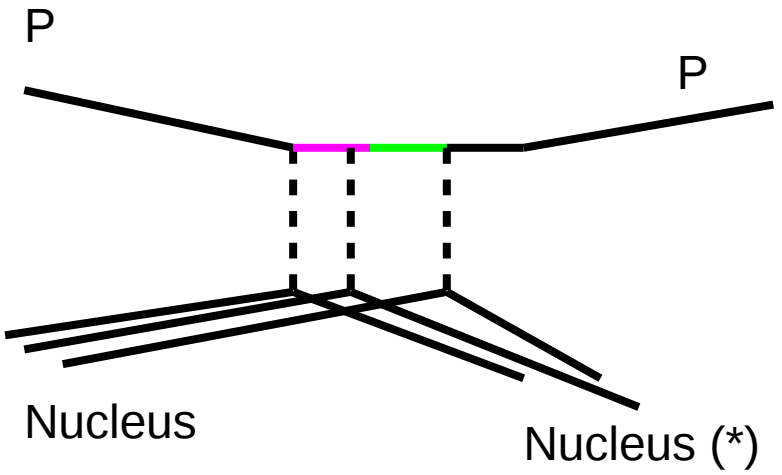


Sibyll 2.3 vs 2.3c: xmax



Inelastic screening: p-A





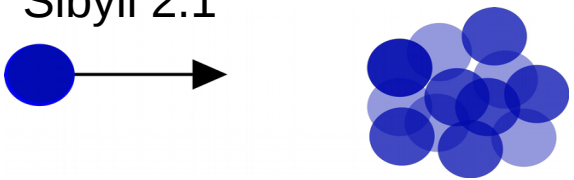
$$\sigma_{\mathrm{ela}} = \left| \langle p | \sum_i |i\rangle\langle i| \, |p\rangle \right|^2$$

$$\sigma_{\mathrm{prod}} = \sigma_{\mathrm{tot}} - \sigma_{\mathrm{ela}} - \sigma_{\mathrm{q.ela}}$$

→ reduced production cross section

Coherent & incoherent diffraction

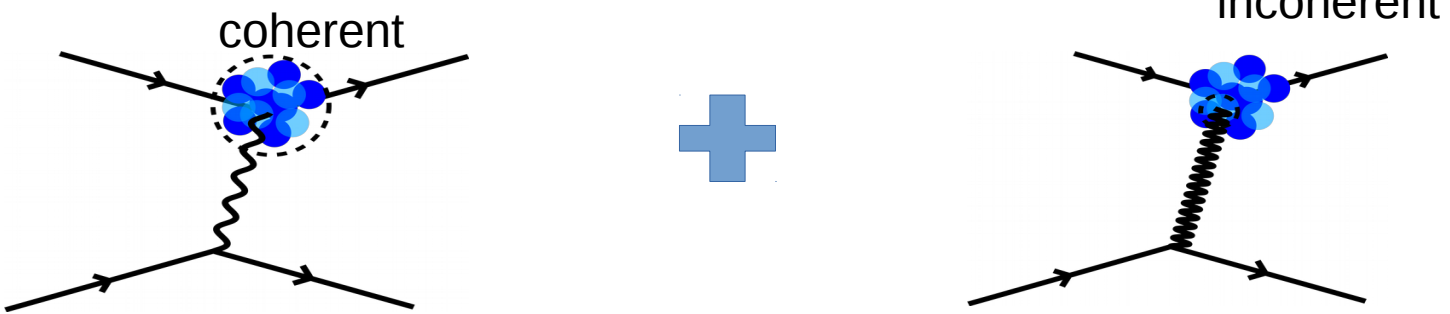
Sibyll 2.1



N_w Independent interactions

$$\sigma_{\mathrm{diff}}^{pA} = (\sigma_{\mathrm{diff}}^{pp})^{N_w}$$

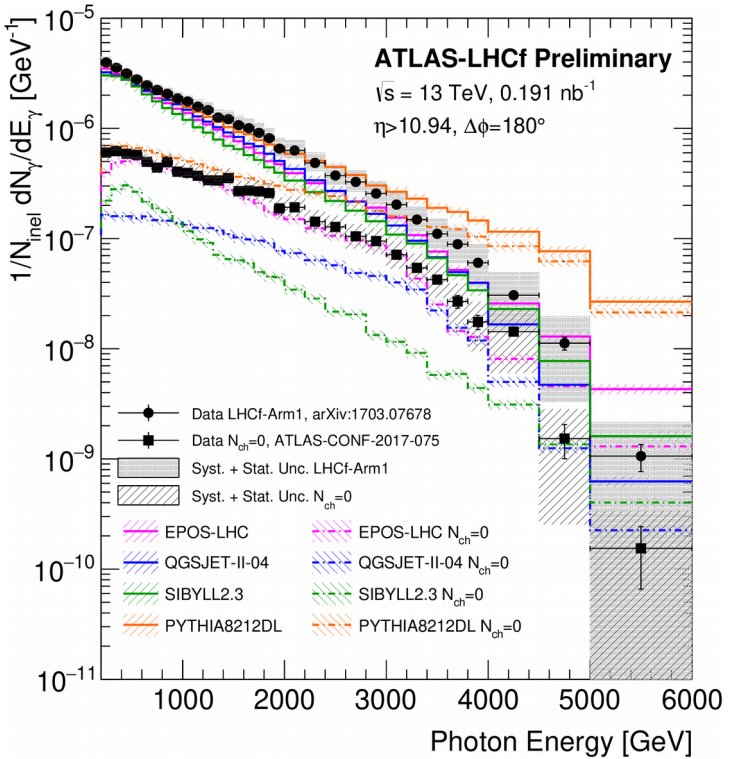
Sibyll 2.3c



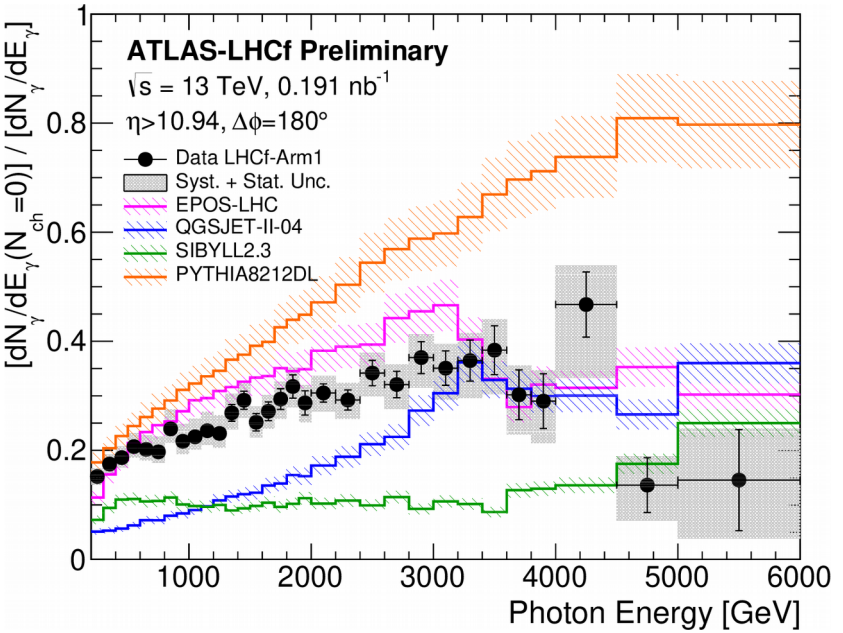
Beyond Sibyll 2.3c ..

future challenges
(problems)

LHCf: Forward photons

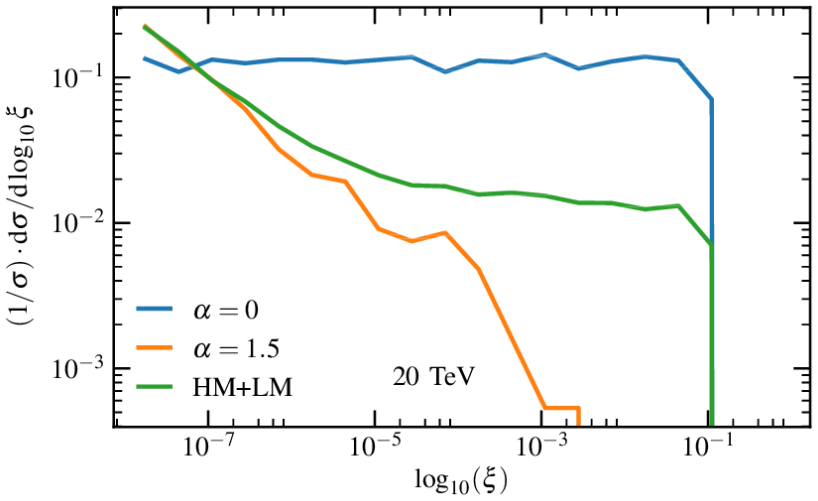


LHCf + ATLAS veto



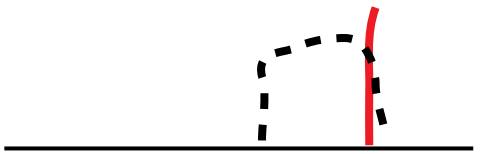
(see also poster by Quidong Zhou)

Diffractive mass

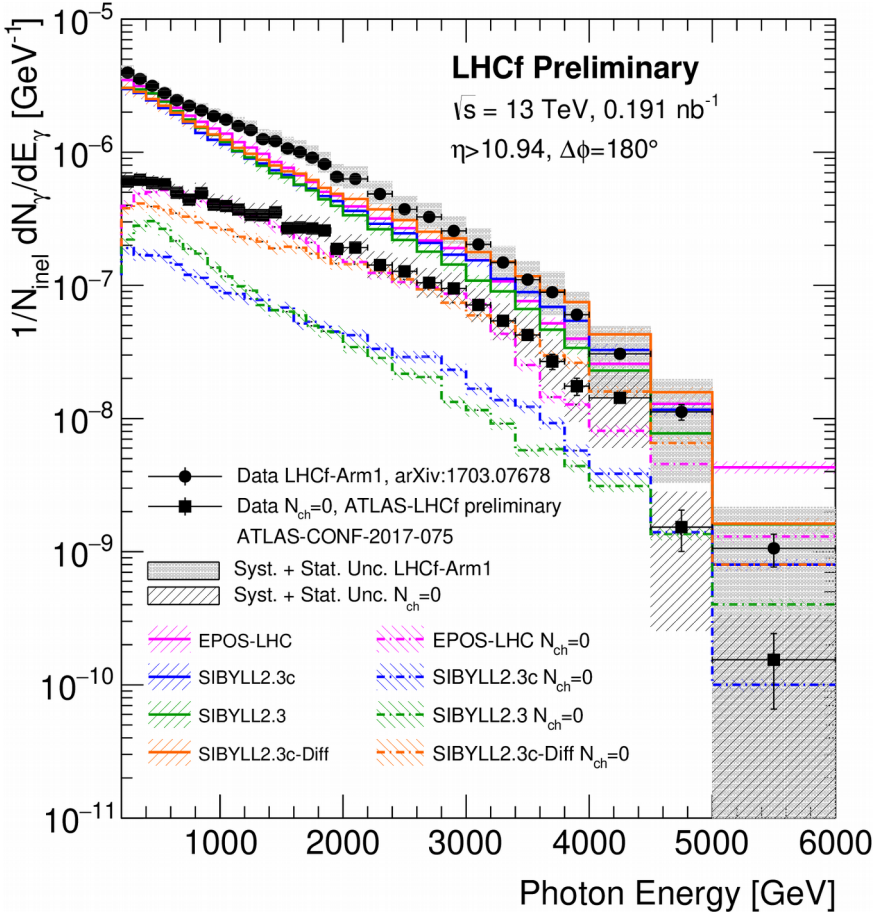


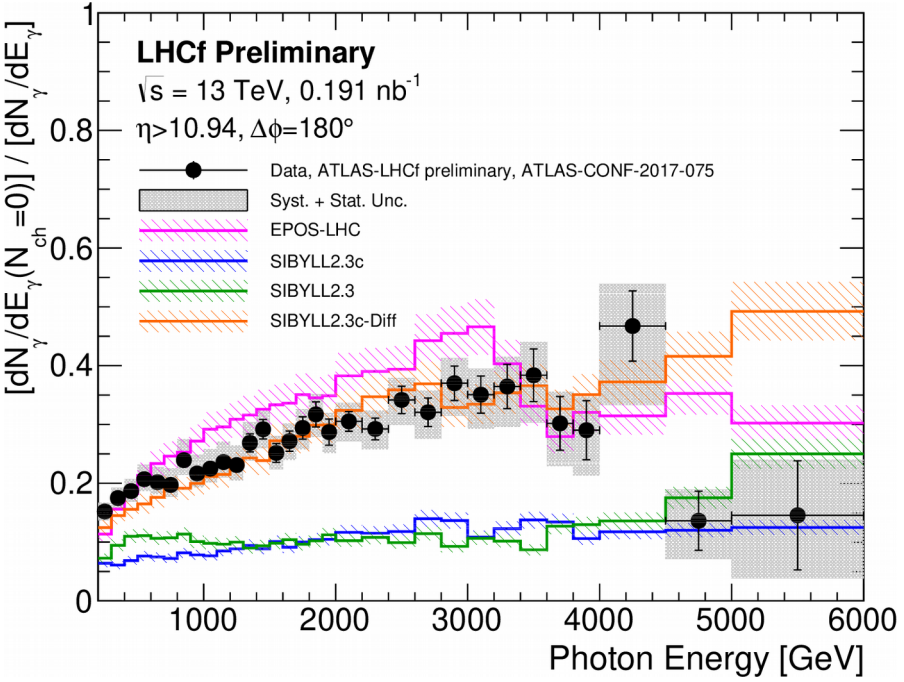
Lower mass → more forward

$$\Delta\eta \sim M_X^2$$

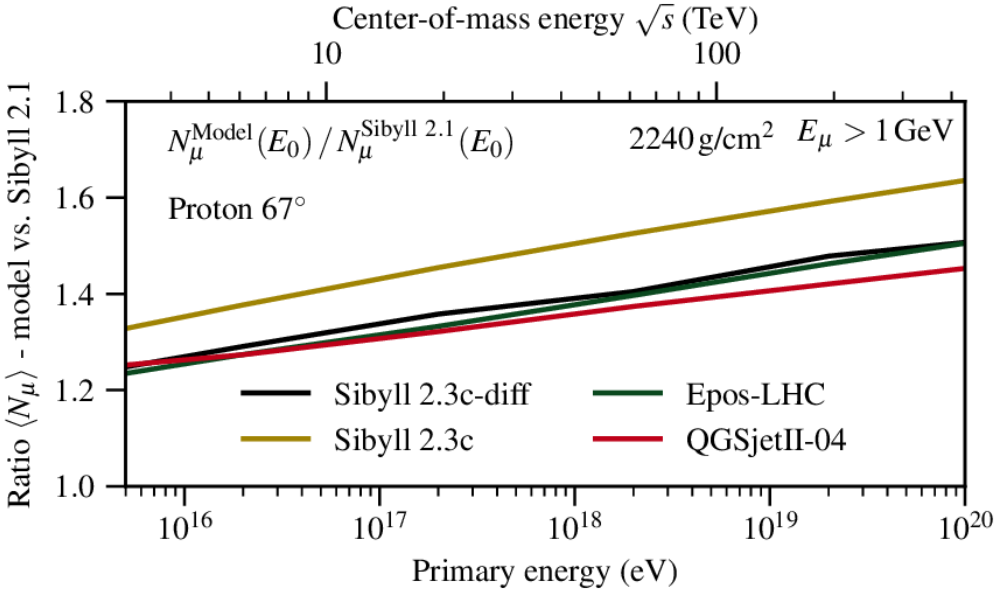


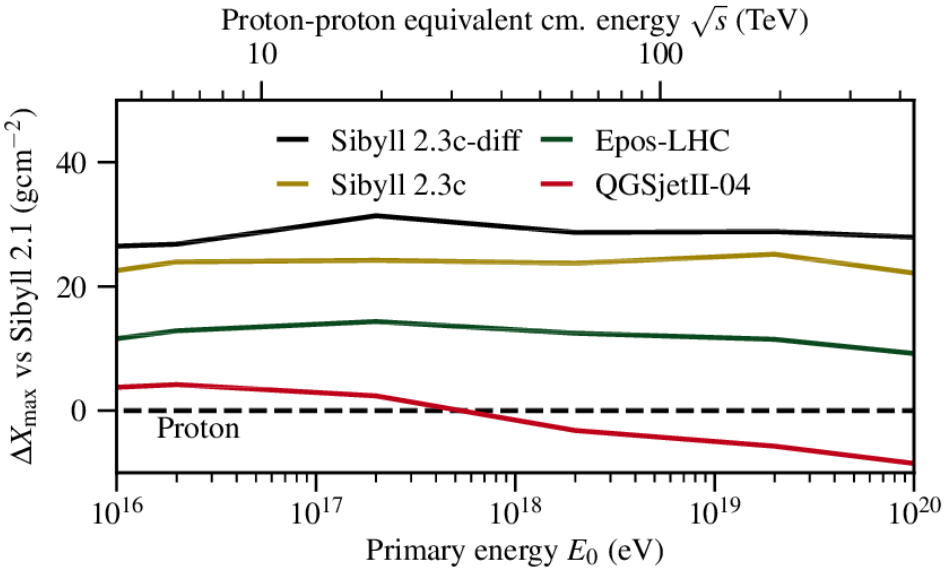
LHCf: forward photons





Effect on EAS





Limits of the simplified minijet model