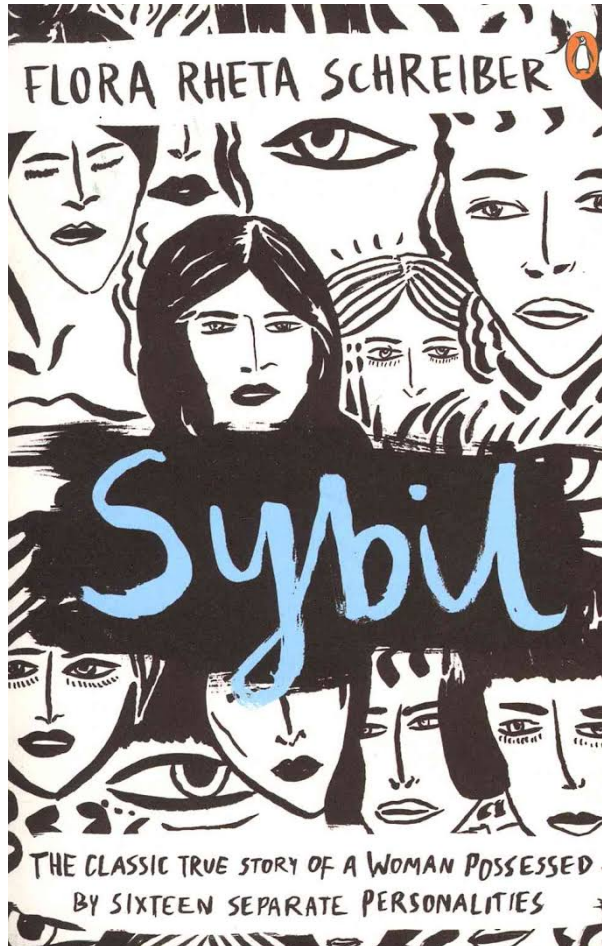


The hadronic interaction model Sibyll 2.3c



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

ISVHECRI 2018

May 24th 2018, Nagoya, Japan

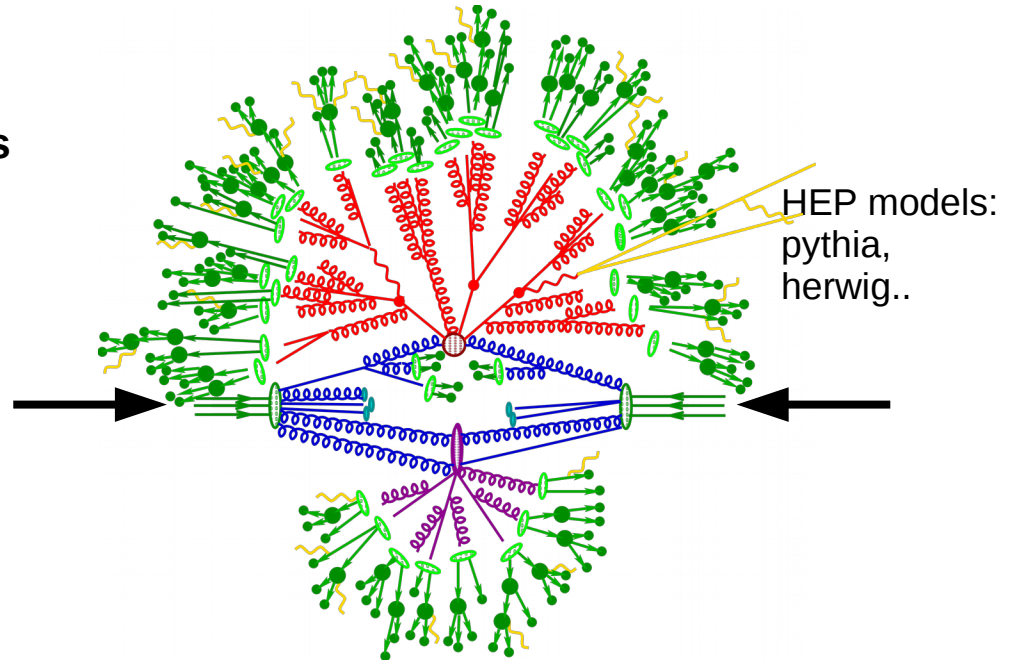
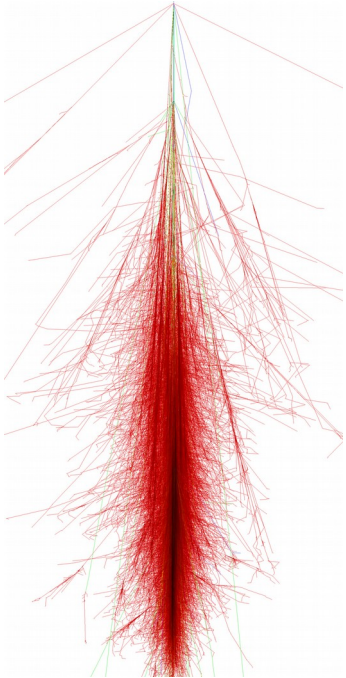
(4/5 goodreads)



The Sibyll way

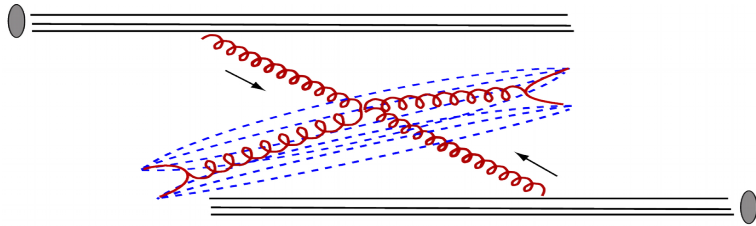
Hadronic interaction MC for
extensive air shower simulations

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



The Sibyll way

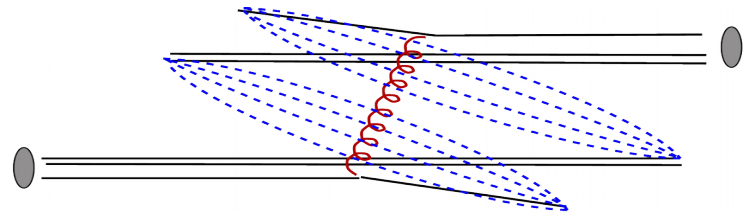
Hard & soft scattering



- * parton picture
- * LO QCD jets \rightarrow minijets
- * Multiparticle interactions

- * diffraction dissociation
- * leading particles, assoc. production

soft



Send your students
and let them teach you

ISAPP 2018 International School for Astroparticle Physics

LHC meets Cosmic Rays

Lectures

- Introduction to Cosmic Rays
- Extensive Air Showers
- Atmospheric Lepton Fluxes
- Air Shower Simulations
- Accelerator Data
- Hadron Interaction Models

Hands-on exercises with:
CORSIKA, CRMC, MCEq

Speakers

- Valentina Avati (CERN)
- Francesca Bellini (CERN)
- David Berge (Berlin)
- Lorenzo Cazon (LIP)
- Hans Dembinski (Heidelberg)
- David d'Enterria (CERN)
- Anatoli Fedynitch (Berlin)
- Stefan Gieseke (KIT)
- Menjo Hiroaki (Nagoya)
- Kumiko Kotera (Paris)
- Paolo Lipari (INFN, Roma)
- Sergey Ostapchenko (Frankfurt)
- Etienne Parizot (Paris)
- Tanguy Pierog (KIT)
- Felix Riehn (LIP)
- Torbjörn Sjöstrand (Lund)
- Michael Unger (KIT)
- Klaus Werner (Nantes)

Oct 28 – Nov 2
at CERN

The poster features a central illustration of a cosmic ray shower hitting the Earth's surface. The shower is depicted as a dense, multi-colored cone of particles (red, orange, yellow, green, blue) descending from a starry black sky. Below the shower, a 3D map of the CERN complex is shown, with labels for various experiments: CMS, LHCb, ATLAS, ALICE, and the Super Proton Synchrotron (SPS). The SPS is shown as a circular accelerator with a proton beam path. The ALICE experiment is shown as a detector with a central detector and two side detectors. The ATLAS and LHCb experiments are shown as large detectors. The CMS experiment is shown as a large detector. The map also shows the location of CERN in Geneva, Switzerland, with a Swiss flag and a French flag. The background of the entire poster is a dark, starry space.

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

Felix Riehn*

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Av. Prof. Gama Pinto 2, 1649-003 Lisbon, Portugal

Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA and

Karlsruher Institut für Technologie, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe, Germany

Ralph Engel†

Karlsruher Institut für Technologie, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe, Germany

Anatoli Fedynitch

DESY, Platanenallee 6, 15738 Zeuthen, Germany and

Karlsruher Institut für Technologie, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe, Germany

Thomas K. Gaisser and Todor Stanev

Bartol Research Institute, Department of Physics and Astronomy,

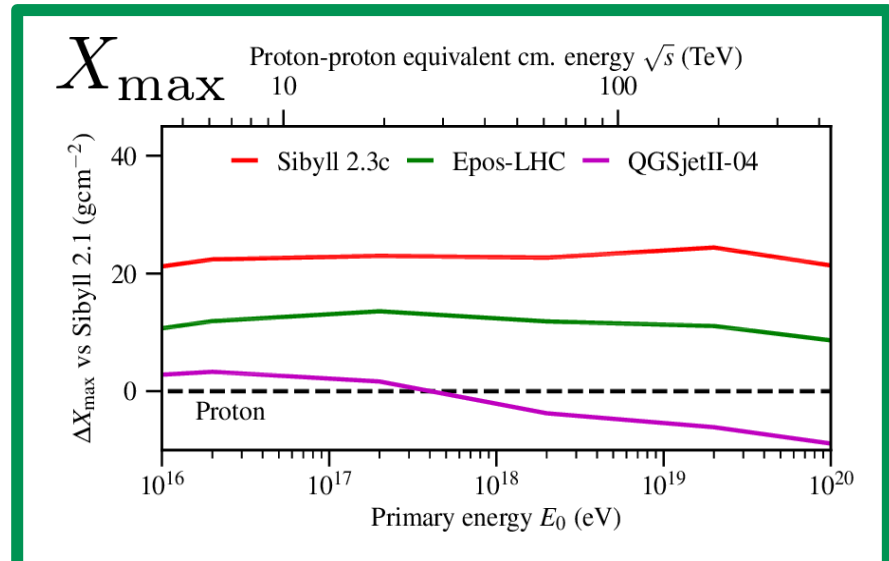
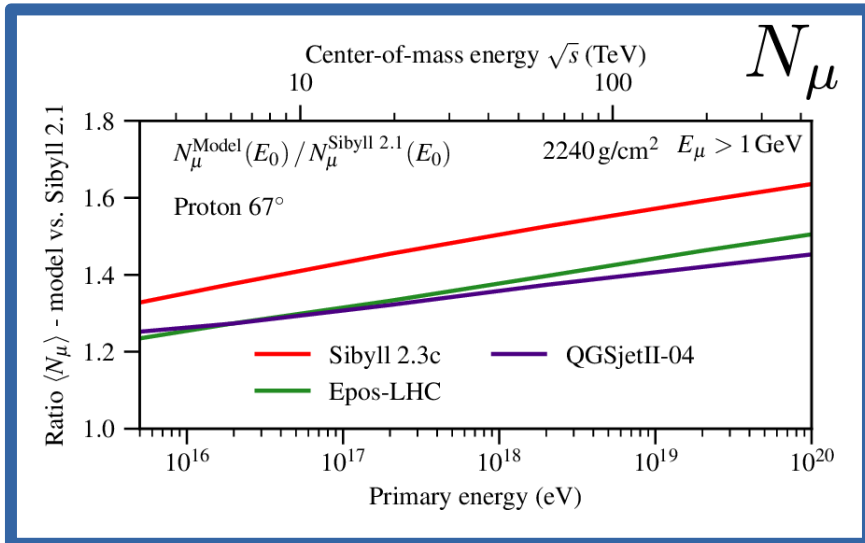
University of Delaware, Newark, DE 19716, USA

Meaning ..

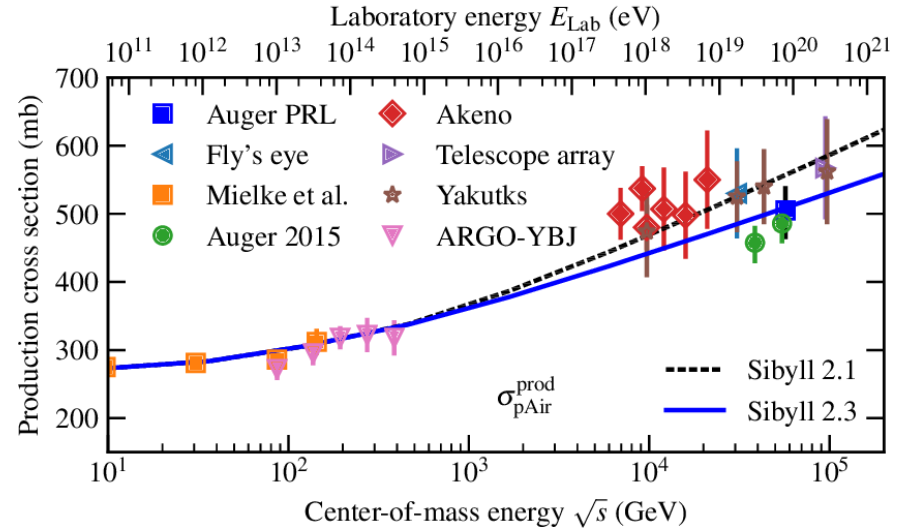
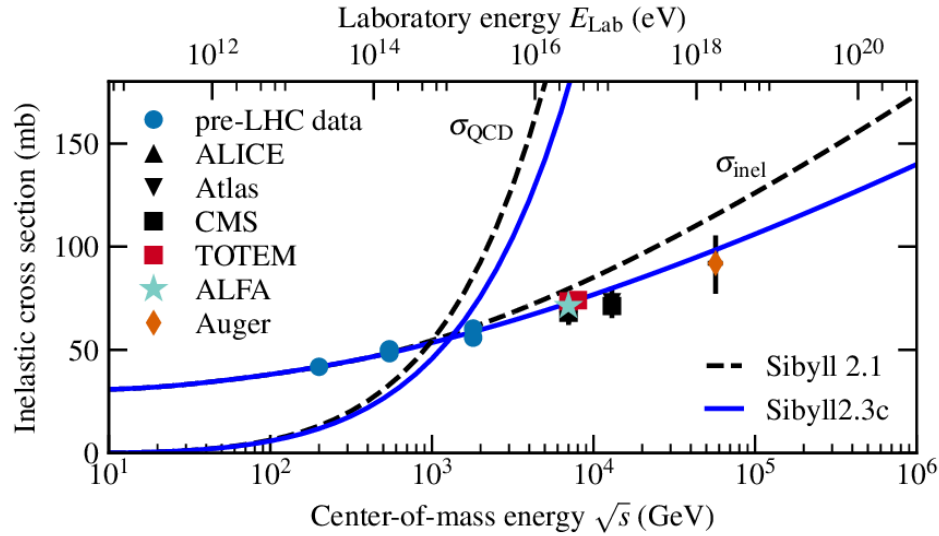
Whats new

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

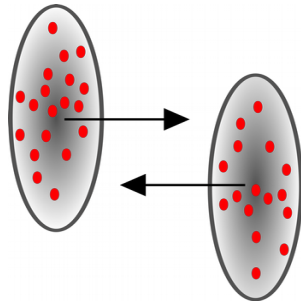
● Atmospheric fluxes (later)



Cross section: p-p

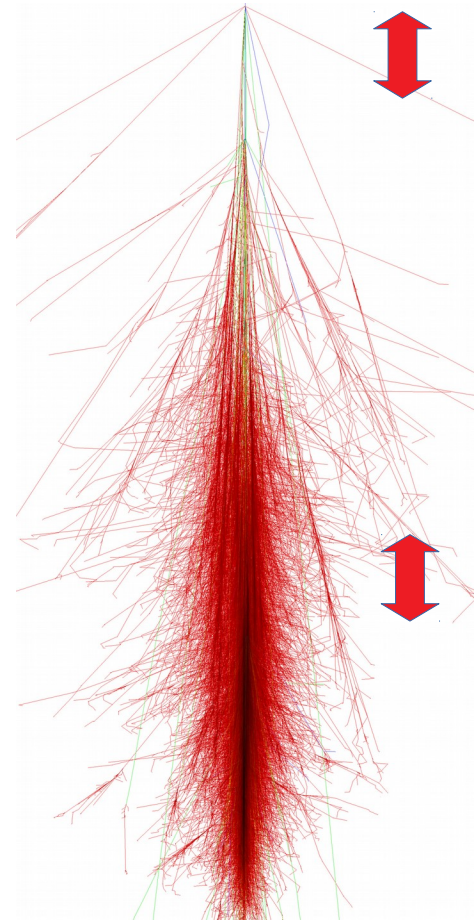


Sibyll 2.1 from 2001
(TeVatron)

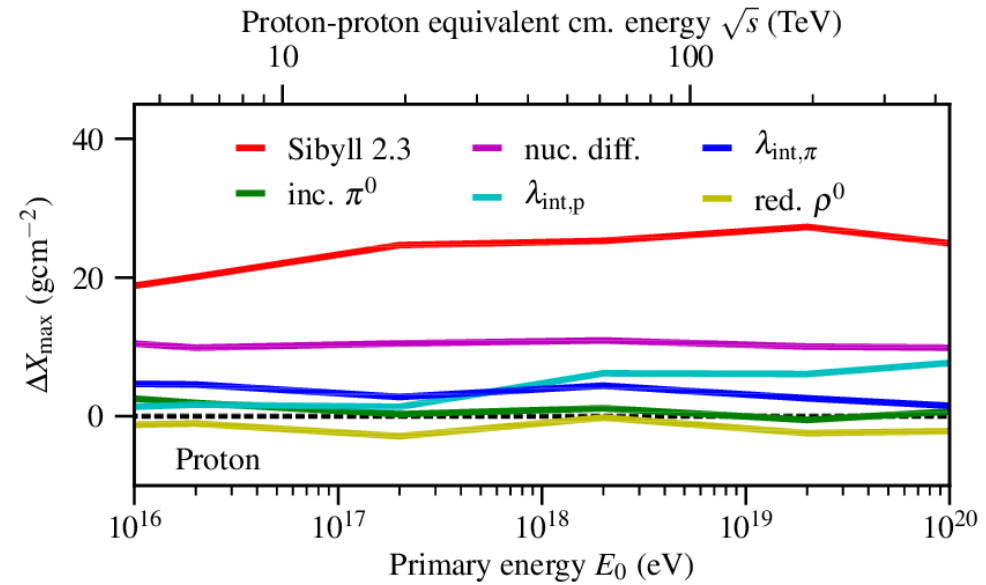


- narrow hadron profile
- increase soft-hard threshold

Xmax

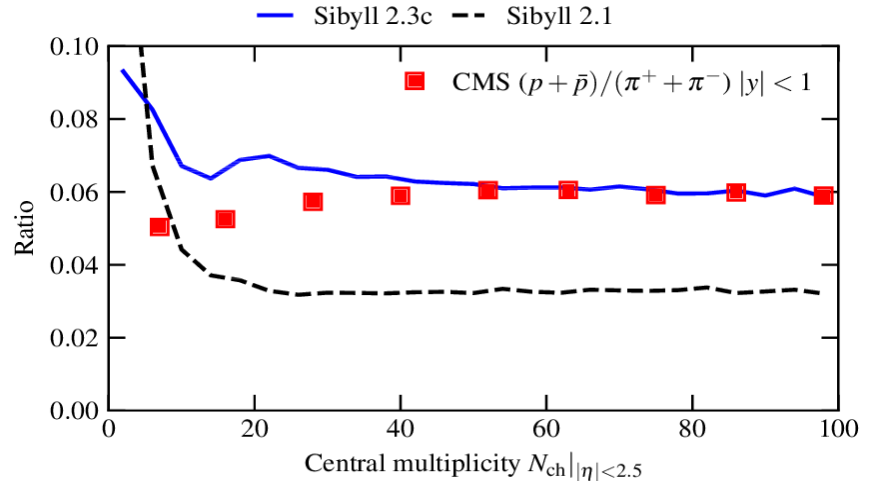
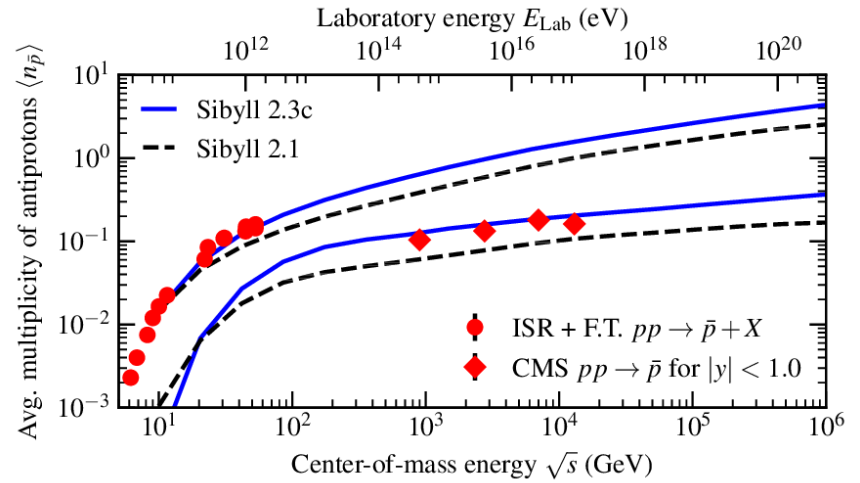
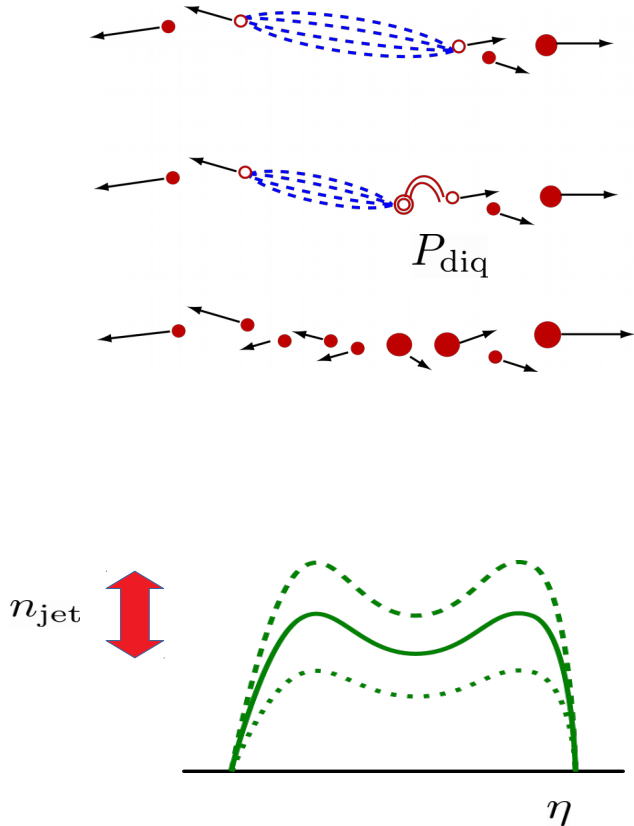


- * p-p cross section reduced
- * p-air cross section reduced
- * p-air diffraction increased (coherent diffraction)

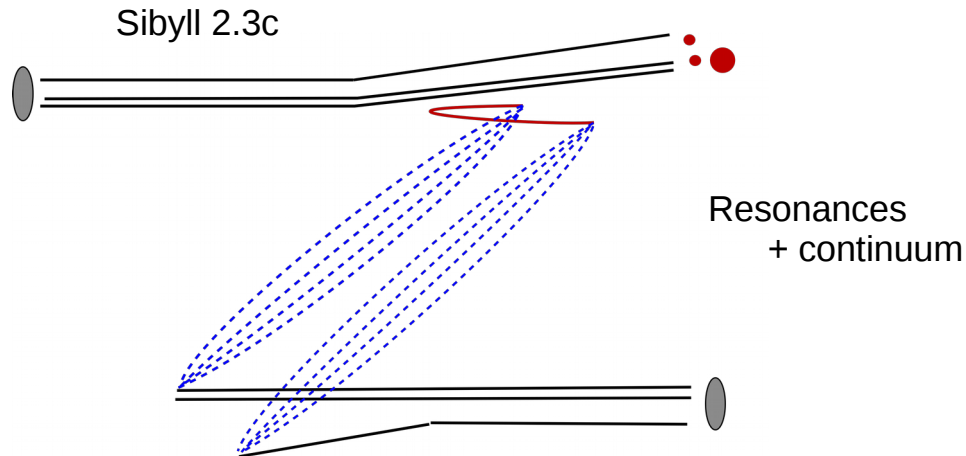
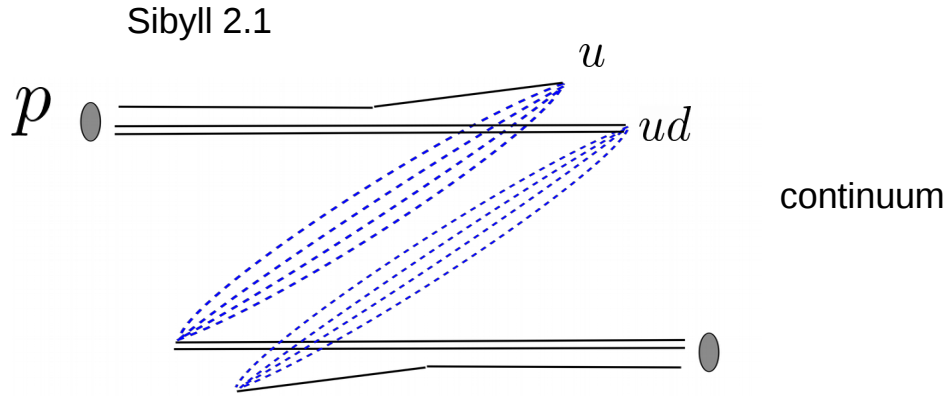


→ 20 g/cm^{**2} deeper proton shower

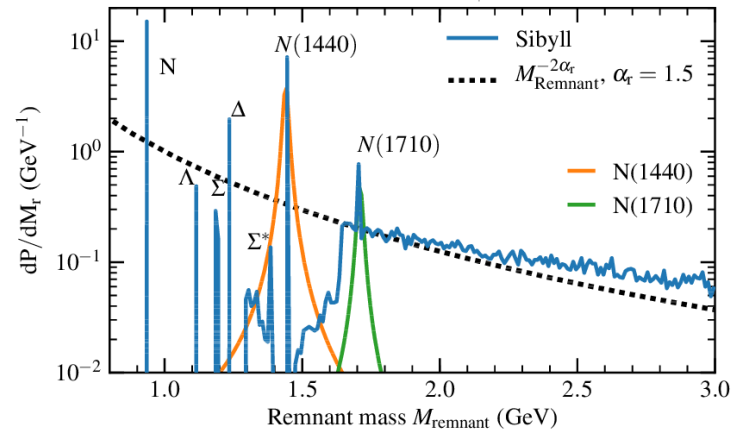
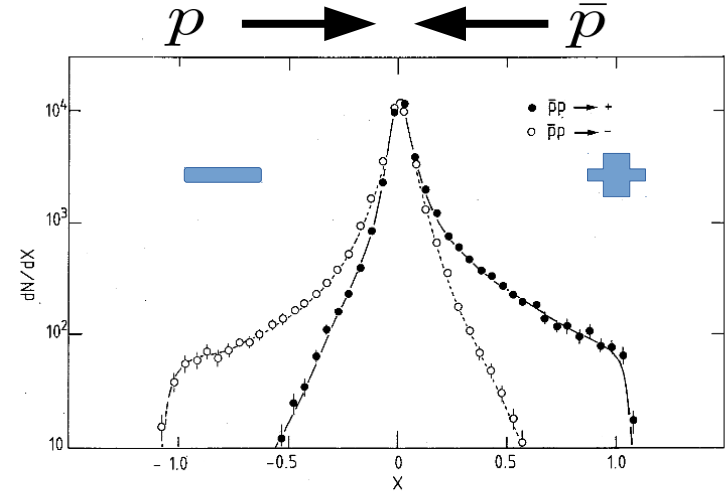
Baryon production



Remnants



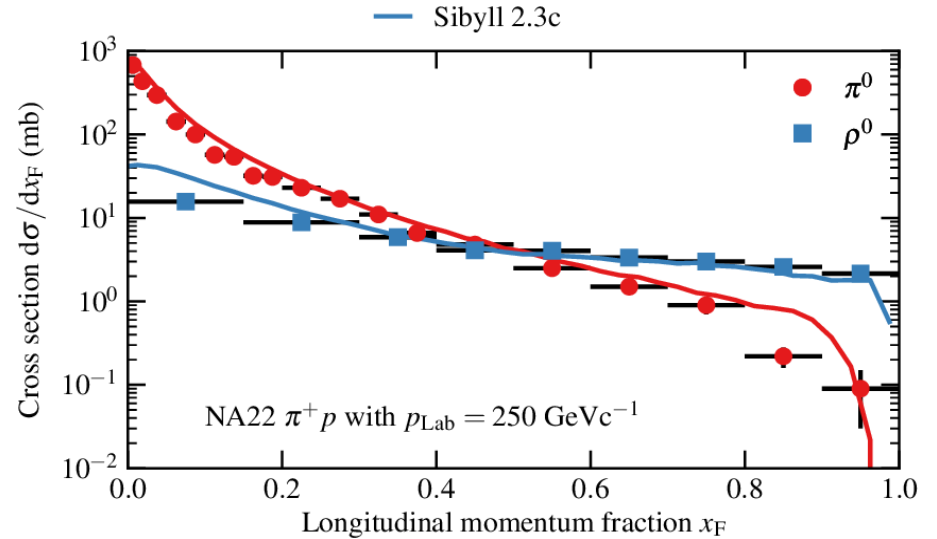
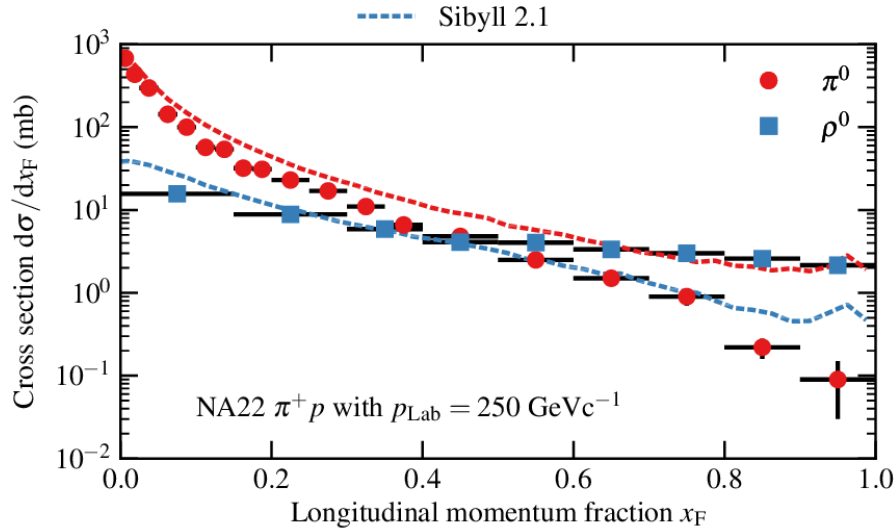
Breakstone et al. (Phys.Lett. B132 (1983) 458)



Leading particles



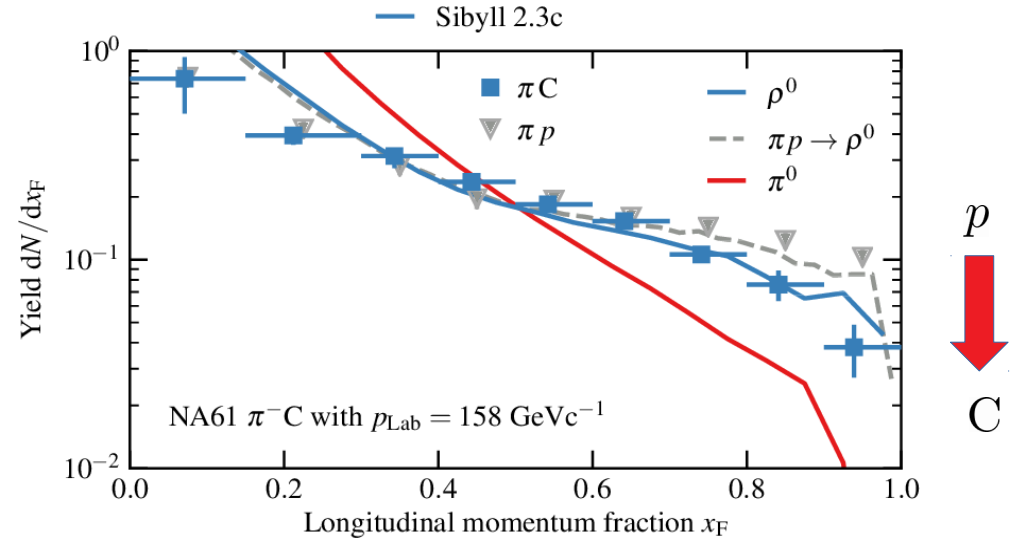
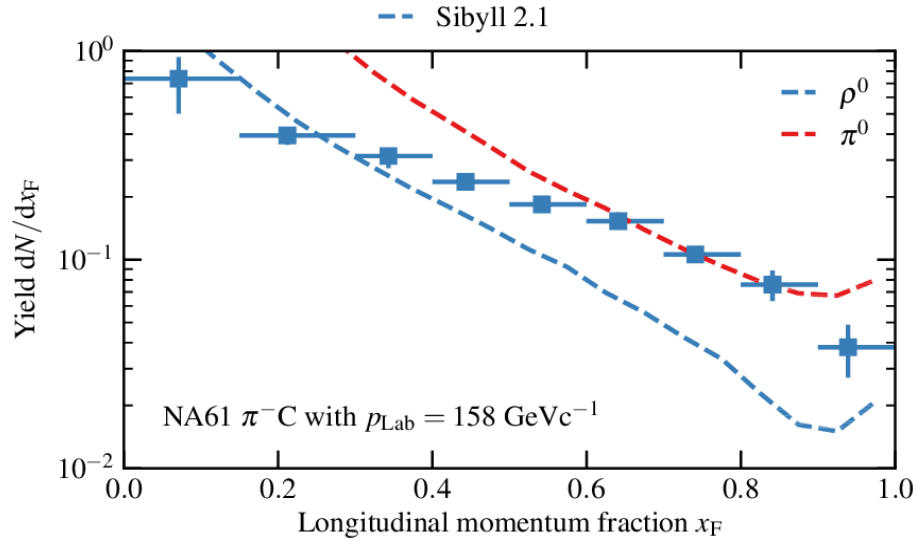
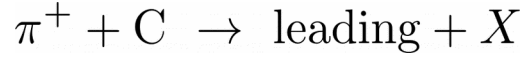
leading : π, ρ



π Air?

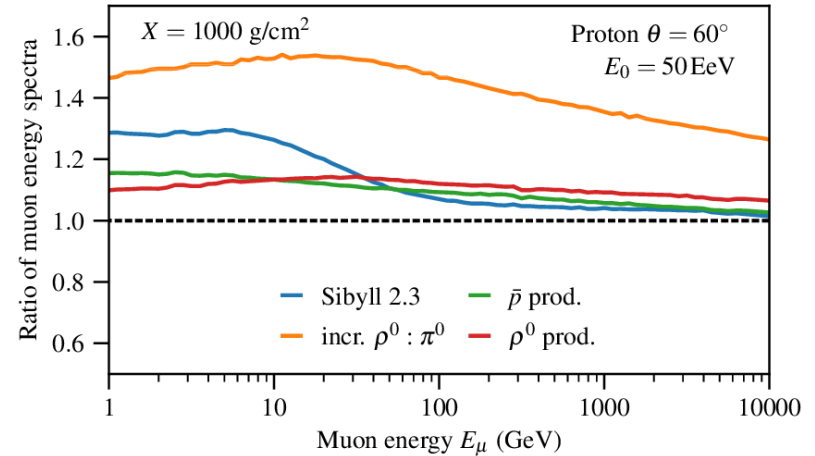
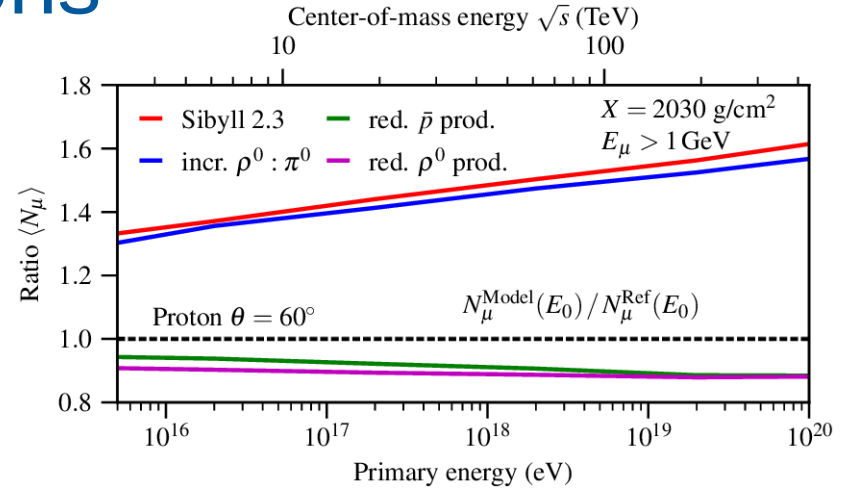
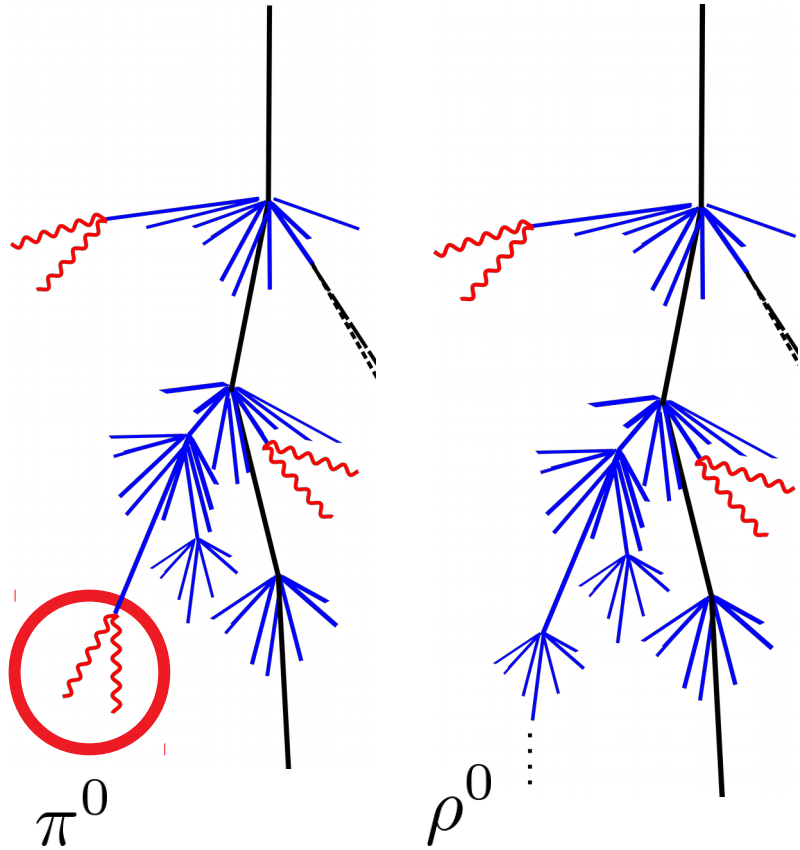
$$P_{\pi:\rho} = 1/3$$

Leading particles



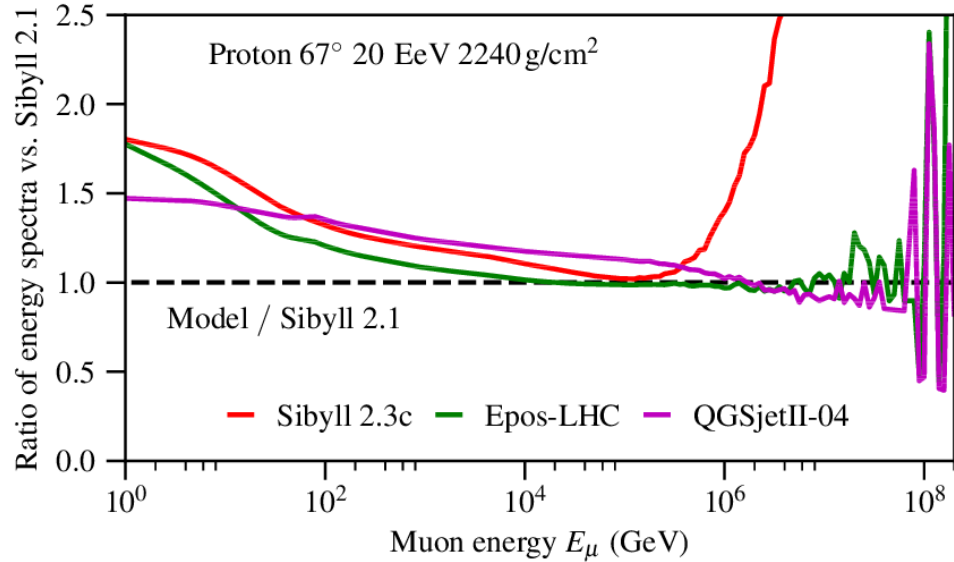
P \rightarrow C transition reproduced

Muons

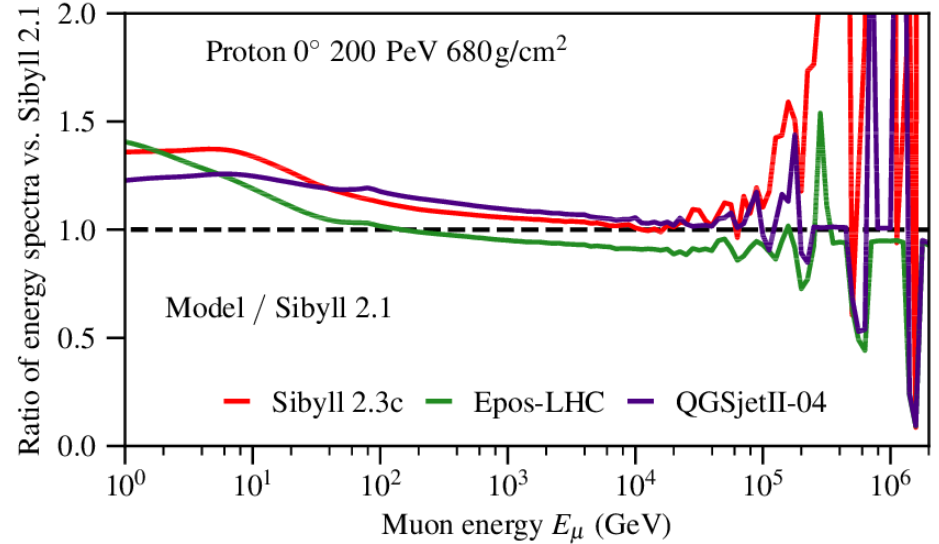


Muon energy spectrum

Auger



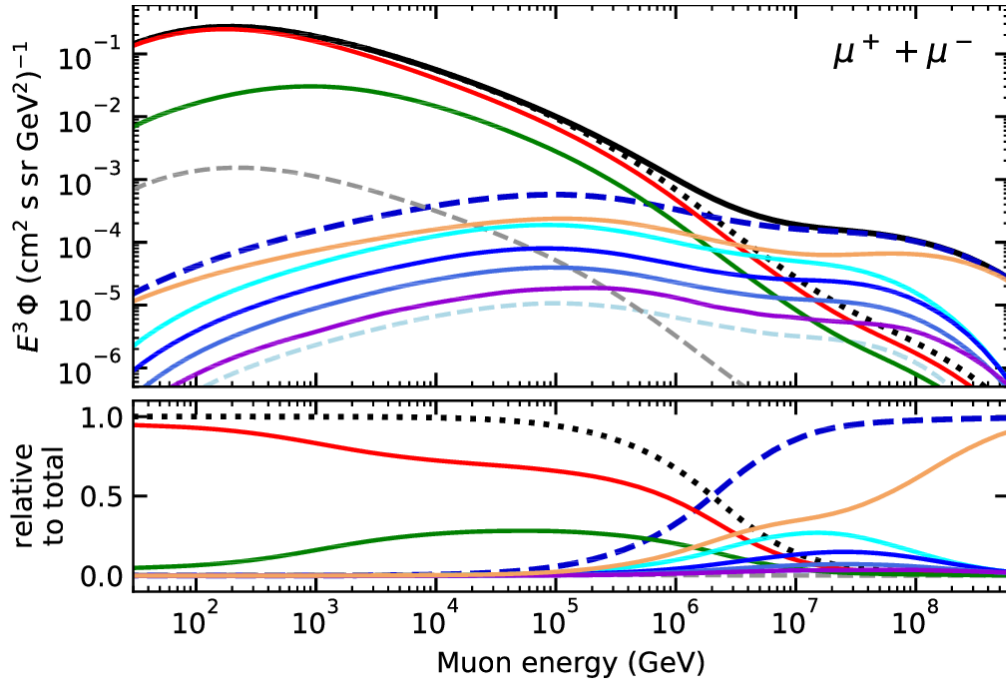
IceTop



Beyond EAS ..

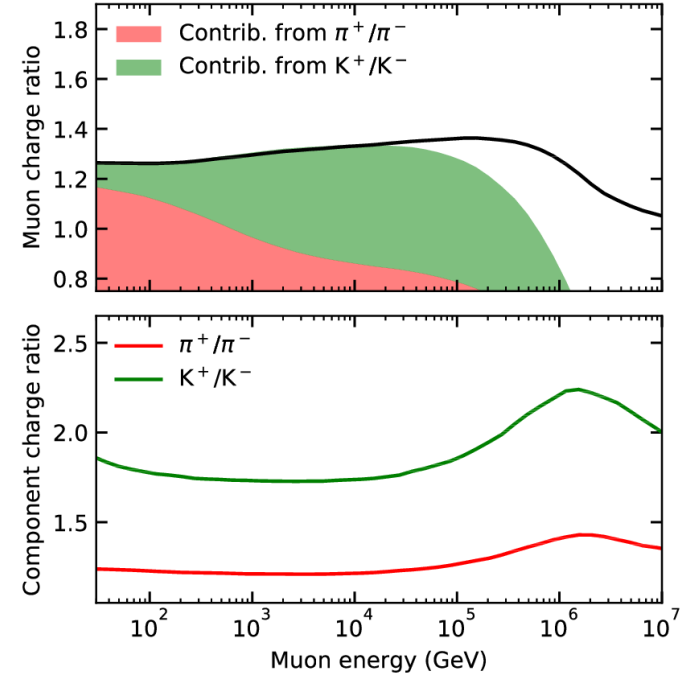
Inclusive flux of leptons in the atmosphere

A new challenge ..



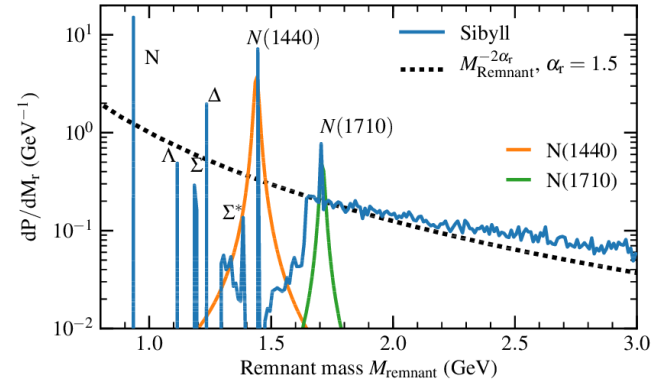
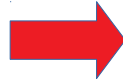
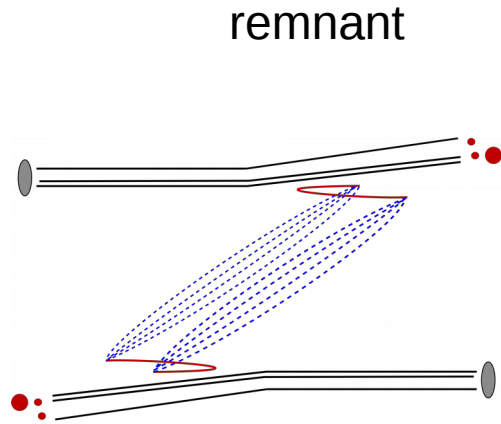
(A. Fedynitch)

Charge ratio



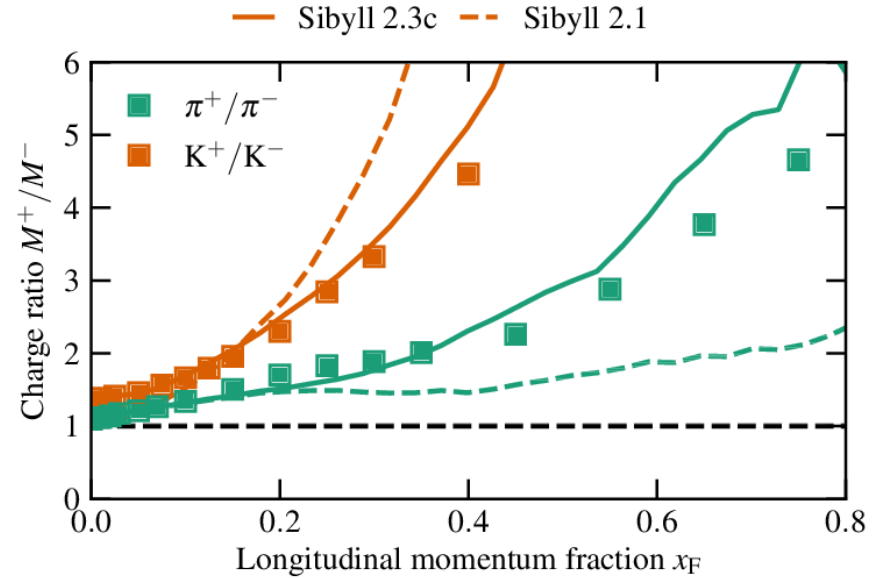
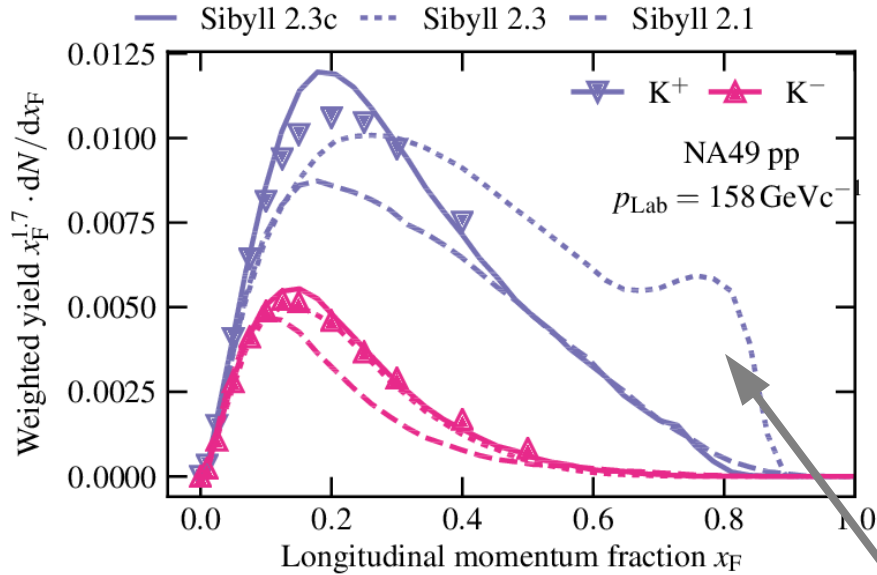
Sensitive to forward phase space

Remnant & forward charge ratios



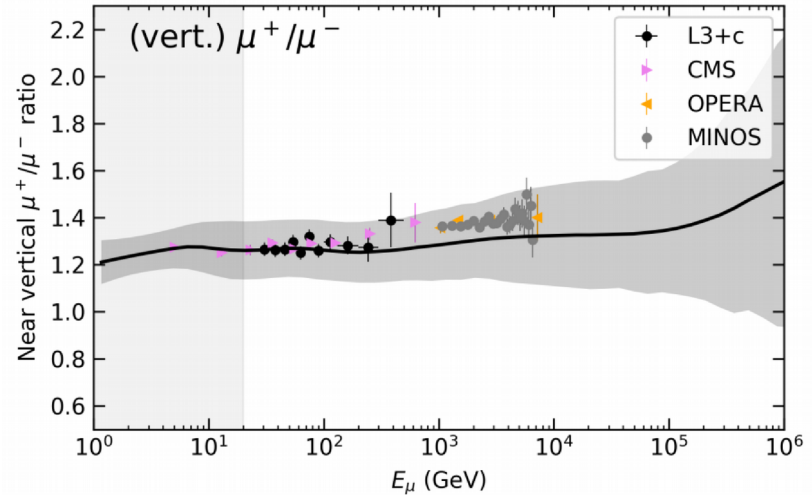
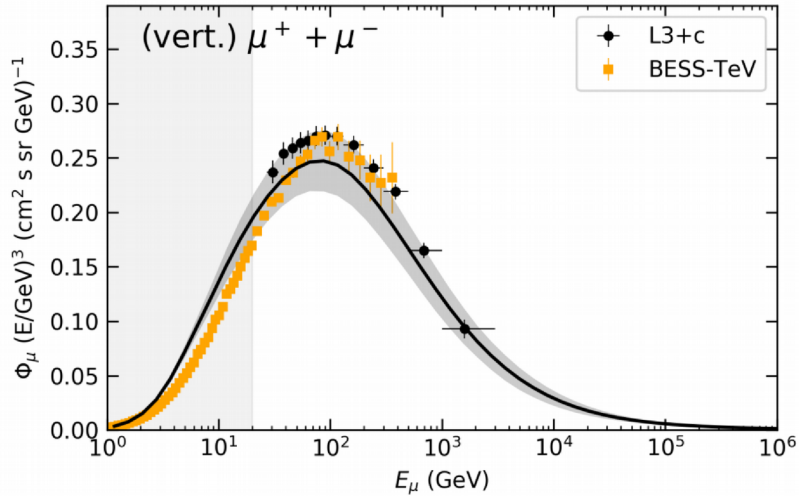
	Δ^{++}				
$\pi^+ p$	1	Δ^+	N^+		
$\pi^+ n$	1/3	2/3			
$\pi^0 p$	2/3	-1/3	Δ^0	N^0	
		$\pi^0 n$	2/3	1/3	
		$\pi^- p$	1/3	-2/3	Δ^-
			$\pi^- n$	1	

Leading mesons & charge ratios



(see ICRC 2017 contribution arXiv: 1709:07227)

Muon flux & charge ratio



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

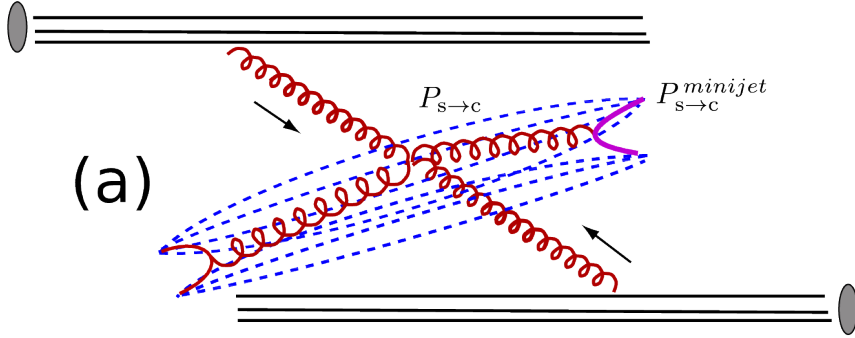
Laboratório de Instrumentação e Física Experimental de Partículas (LIP) - Lisbon,

Av. Prof. Gama Pinto 2, 1649-003 Lisbon, Portugal and

Centro de Física Nuclear da Universidade de Lisboa, Av. Prof. Gama Pinto 2, 1649-003 Lisbon, Portugal

For more:

Charm production

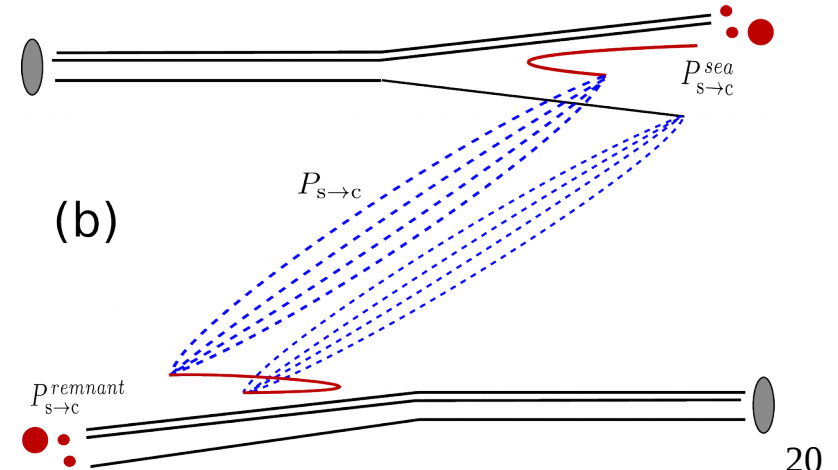


$$m_c \approx 2 \text{ GeV} \rightarrow \text{pQCD} \rightarrow \text{minijets}$$

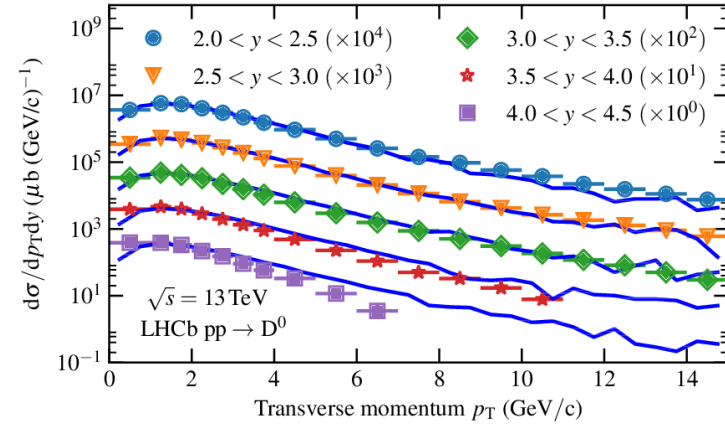
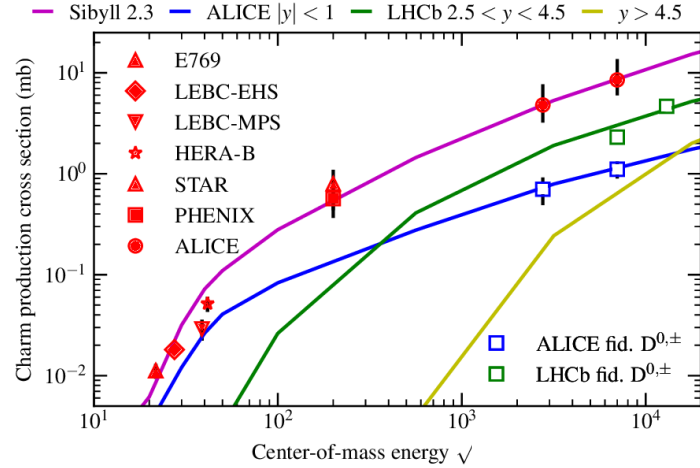
Evidence for leading,
soft charm

Mechanism:
Replace strange \rightarrow charm

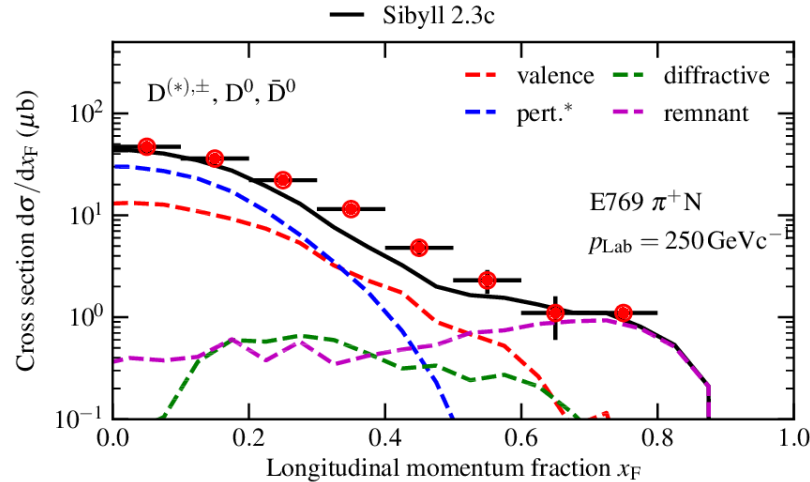
$$P_{s \rightarrow c}$$



Charm tuning

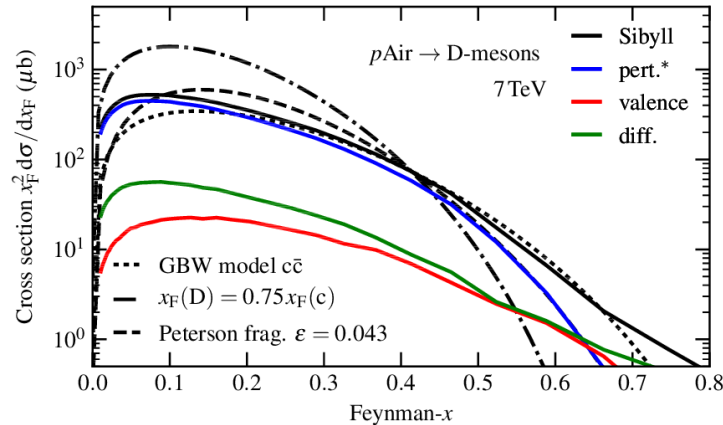
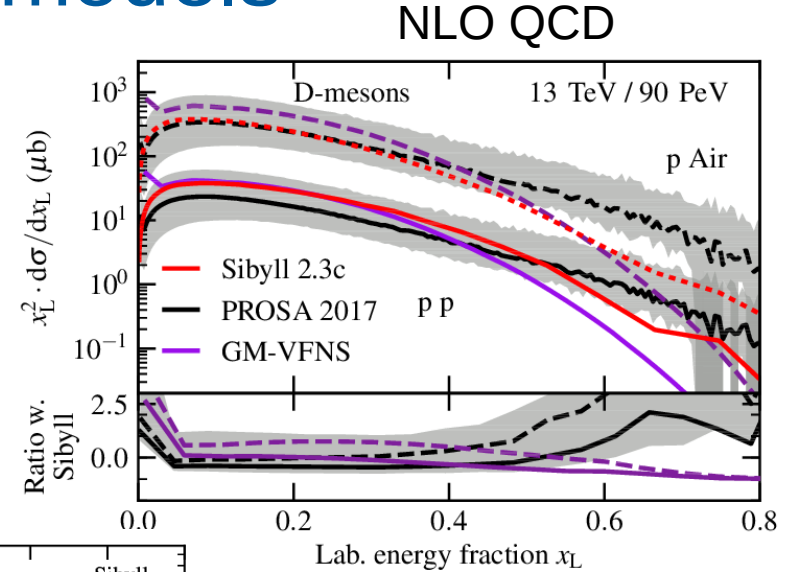
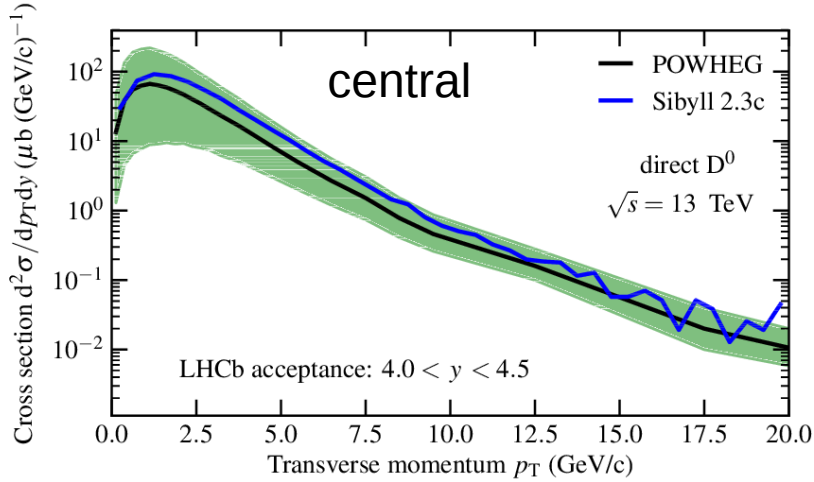


parameter	value
perturbative	
$P_{s \rightarrow c}^{\text{minijet}}$	0.08
non-perturbative	
$P_{s \rightarrow c}^{\text{soft}}$	0.004
$P_{s \rightarrow c}^{\text{sea}}$	0.002
$P_{s \rightarrow c}^{\text{remnant}}$	0.0
$P_{s \rightarrow c}^{\text{string}}$	0.004



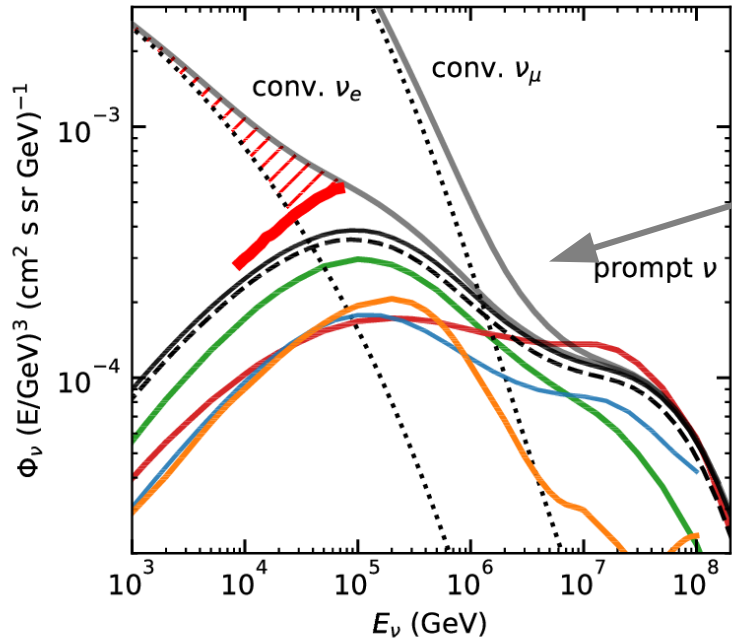
Fixed target
Fix shape!

Sibyll vs. other models



(with M.V. Garzelli)

Atmospheric lepton fluxes



(MCEq)

Complete inclusive prediction
conventional & prompt

Summary

* new Sibyll 2.3c including:

- remnant model
- charm production
- pp cross section
- coherent nuclear diffraction

* improved description of accelerator measurements

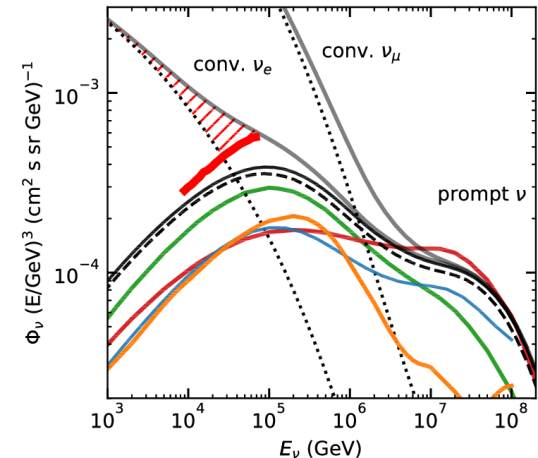
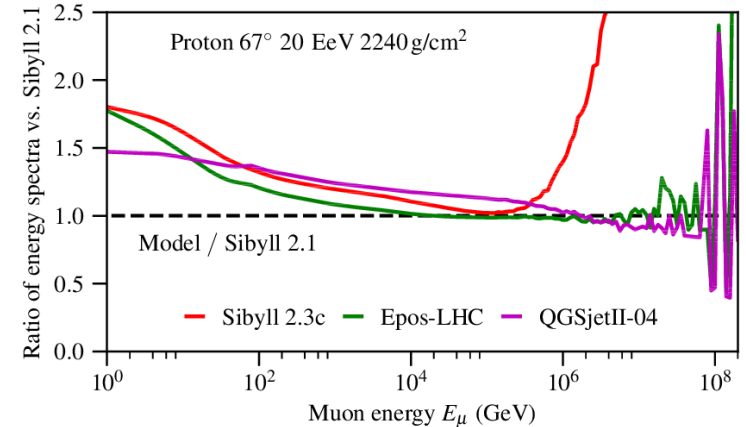
→ shortcomings not mentioned

* predictions for EAS:

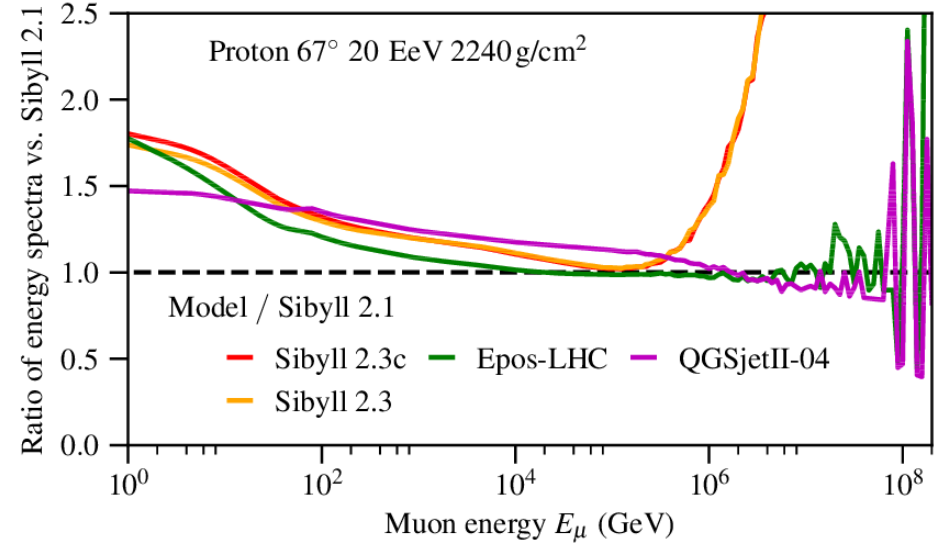
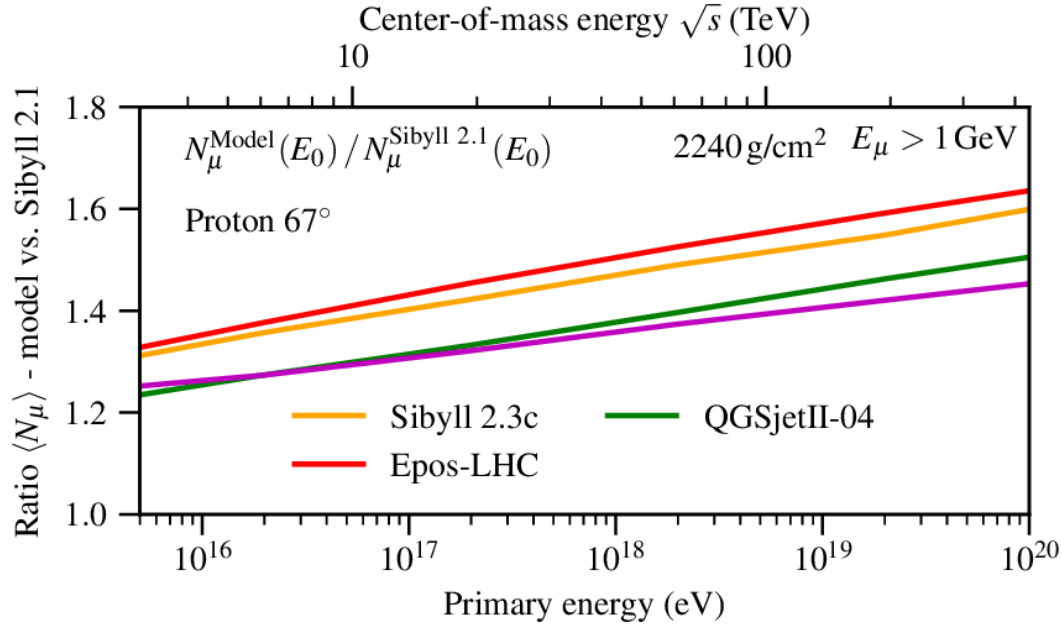
- ~20g/cm² deeper X_{max}
- ~1.6 more muons (all ground, E>1GeV)

* atmospheric fluxes:

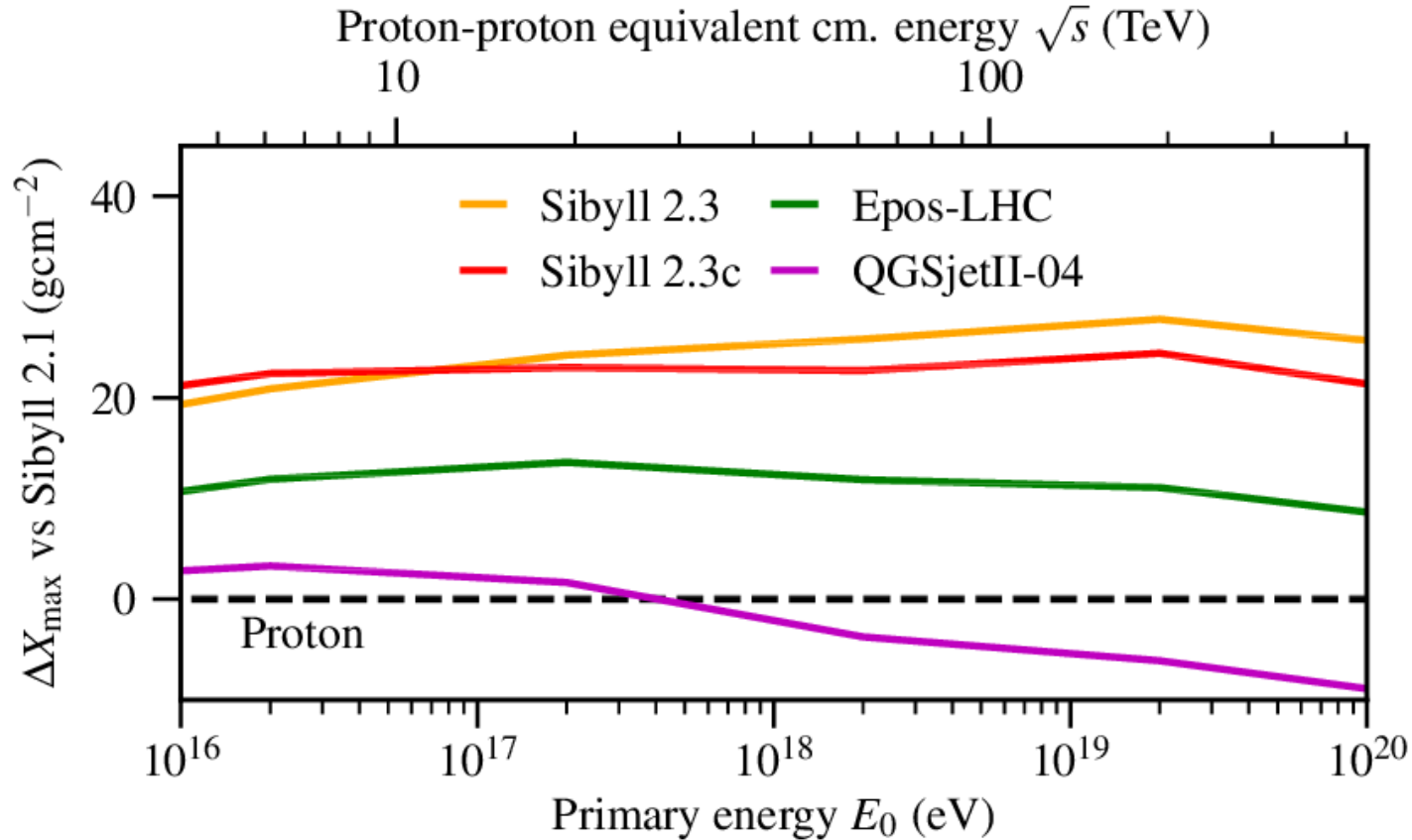
- muon charge ratio compatible with measurements
- prompt component



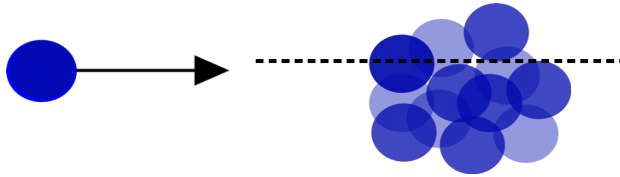
Sibyll 2.3 vs 2.3c: muons



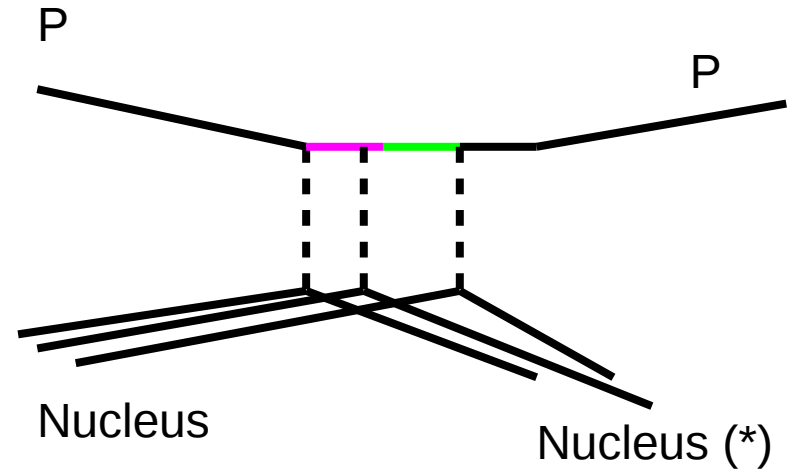
Sibyll 2.3 vs 2.3c: xmax



Inelastic screening: p-A



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

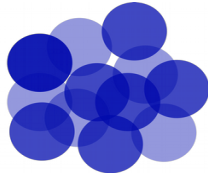
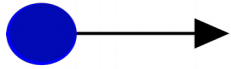


$$\sigma_{\text{prod}} = \sigma_{\text{tot}} - \sigma_{\text{ela}} - \sigma_{\text{q.ela}}$$

→ reduced production cross section

Coherent & incoherent diffraction

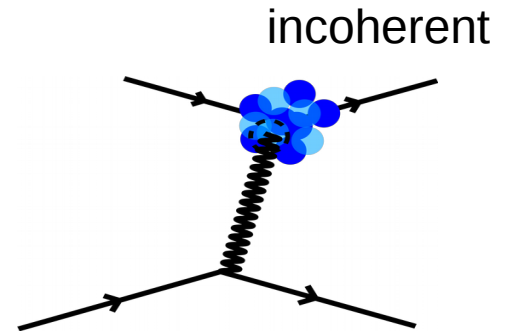
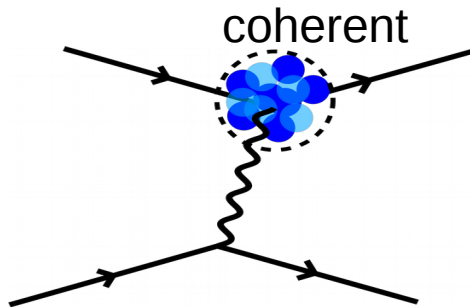
Sibyll 2.1



N_w Independent interactions

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

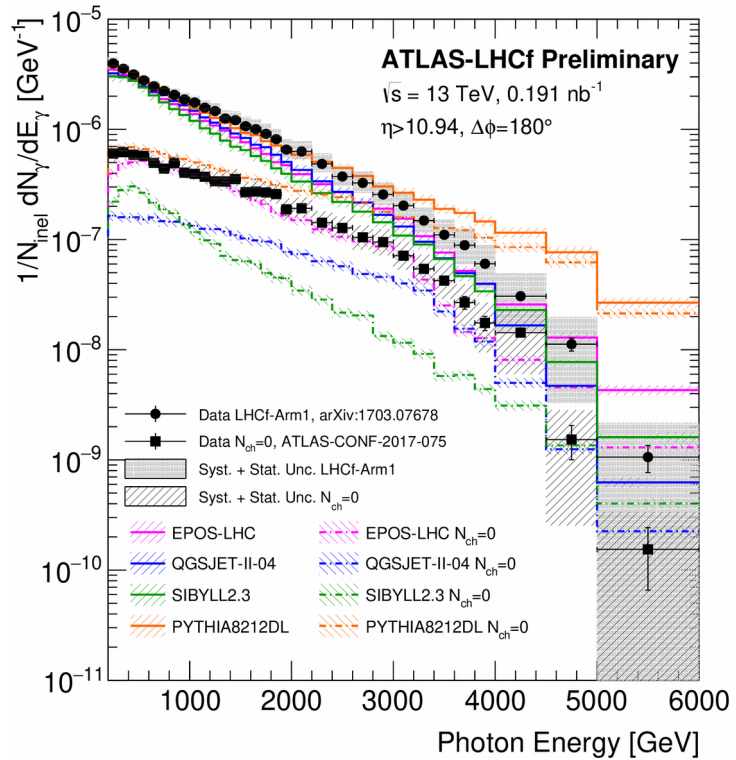
Sibyll 2.3c



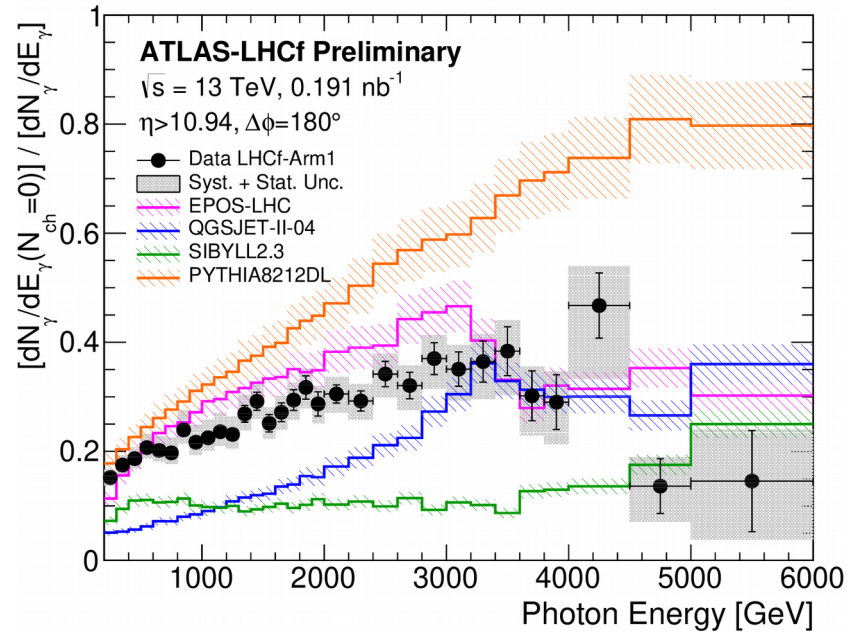
Beyond Sibyll 2.3c ..

future challenges
(problems)

LHCf: Forward photons

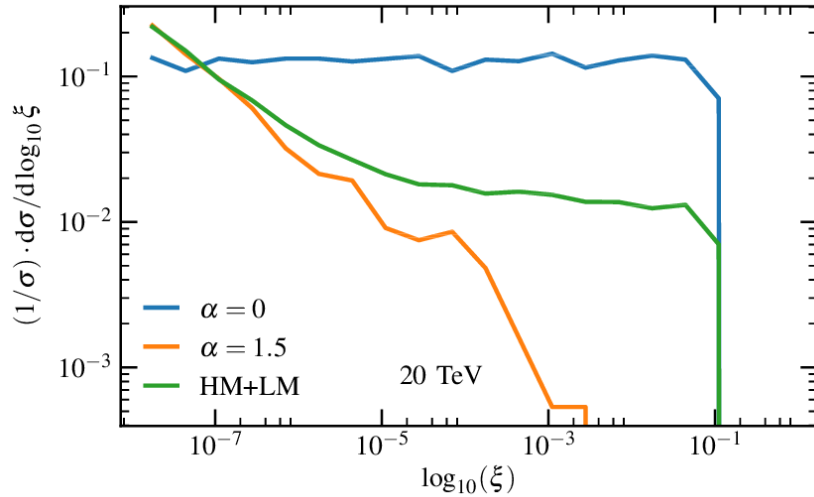


LHCf + ATLAS veto



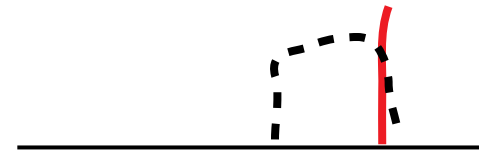
(see also poster by Quidong Zhou)

Diffractive mass

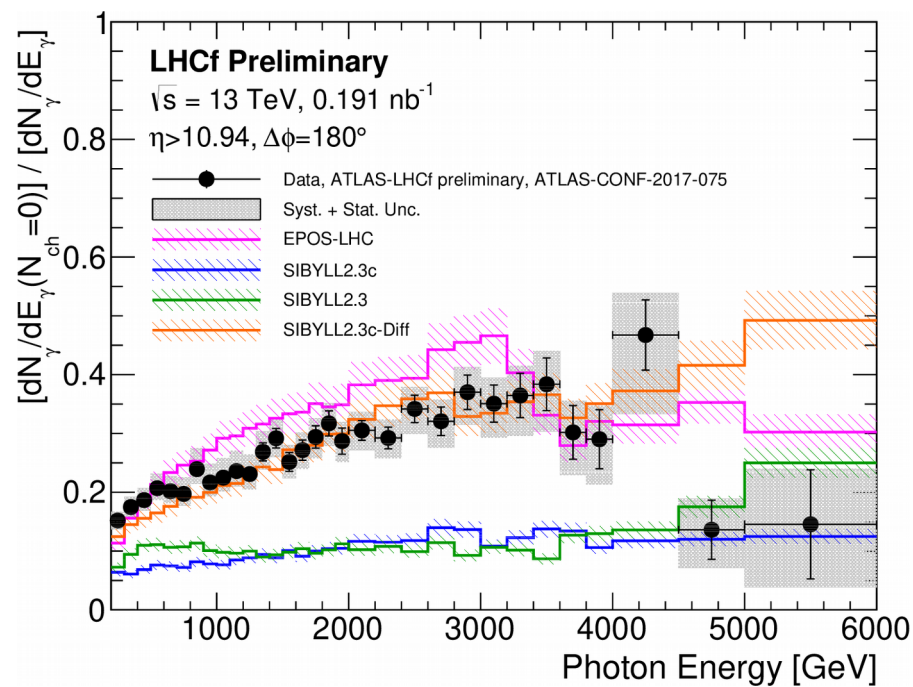
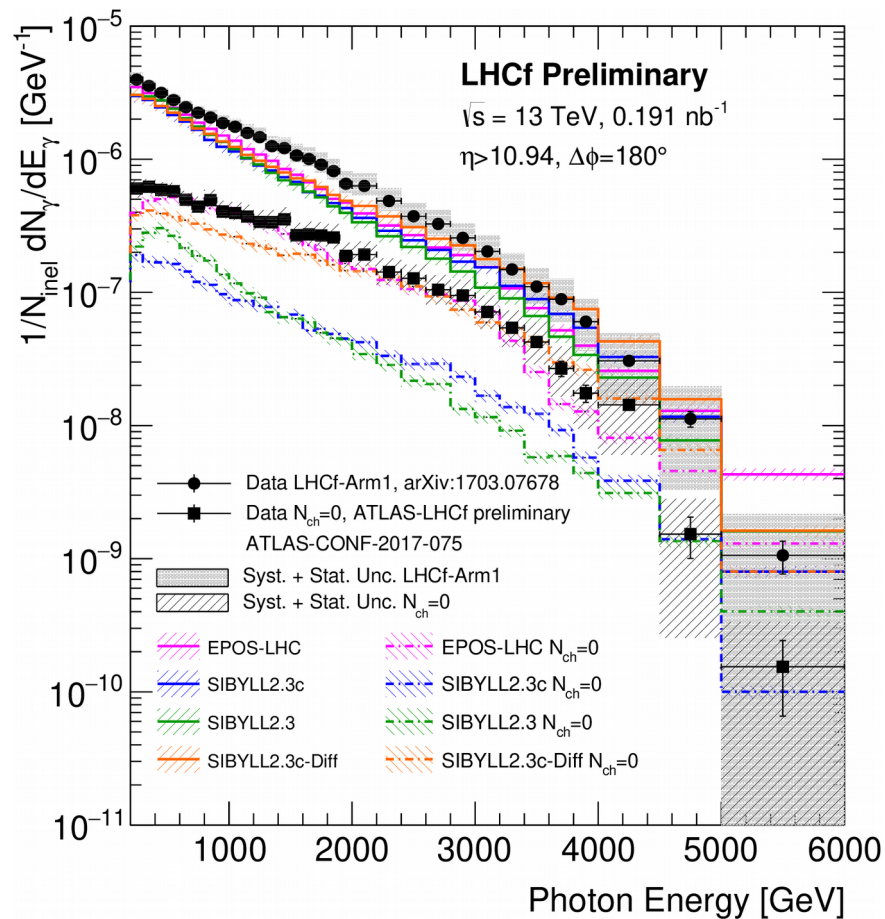


Lower mass \rightarrow more forward

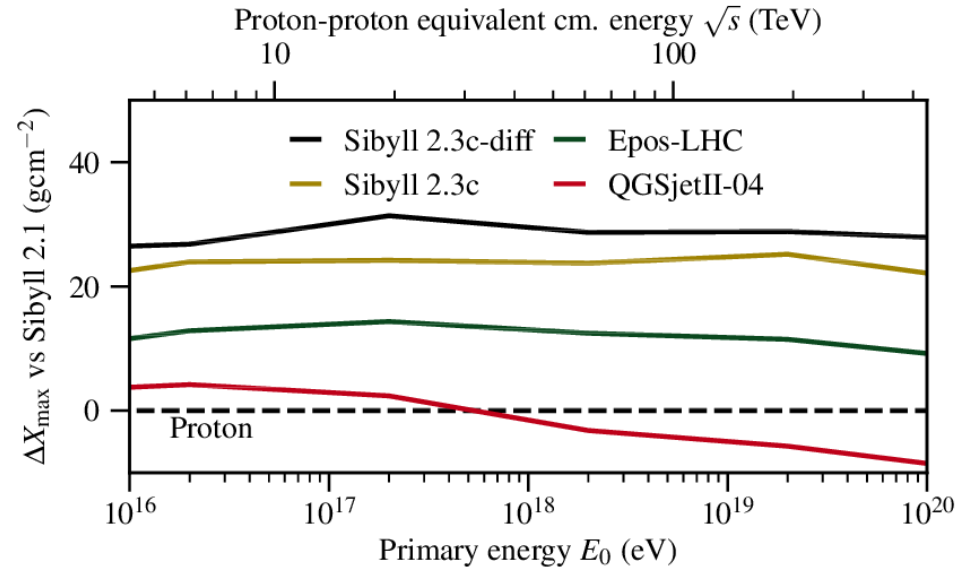
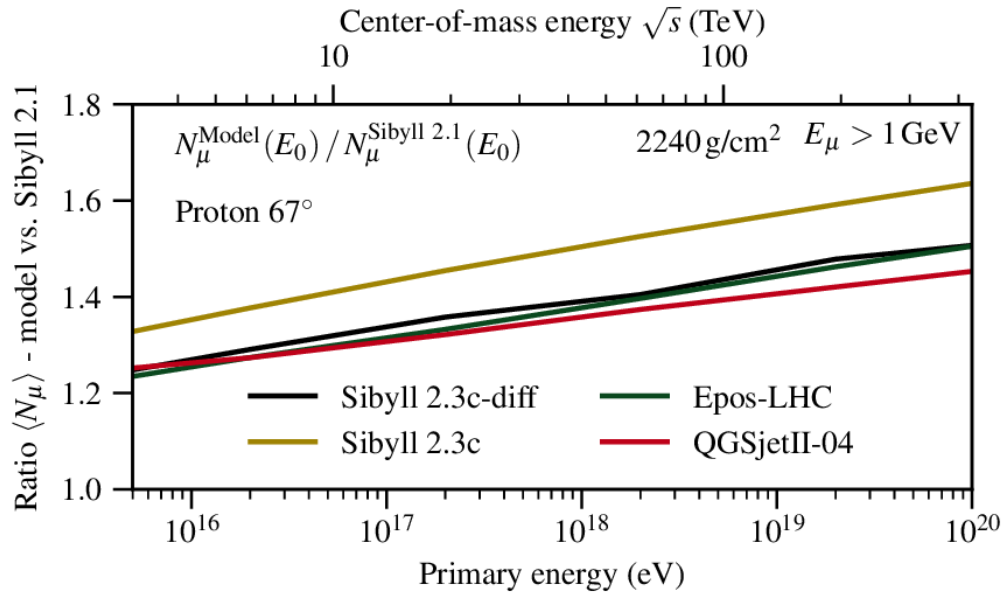
$$\Delta\eta \sim M_X^2$$



LHCf: forward photons



Effect on EAS



Limits of the simplified minijet model

