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Charm production in Sibyll

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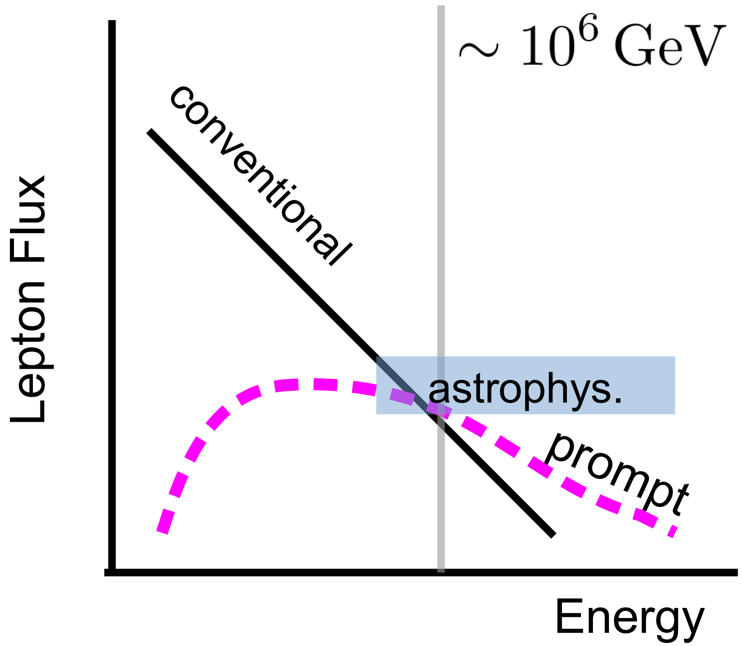
Motivation

- Charmed particles short lived compared to pions/kaons
  - very unlikely to interact after production → No energy loss
  - Form so-called „prompt“ component in muon and neutrino flux
- Similar to signal expected from astrophysical neutrinos!
  - Need to determine contribution to neutrino flux at high energy
- Charm quark mass scale in transition region between hard and soft processes
  → behaviour of model reasonable?

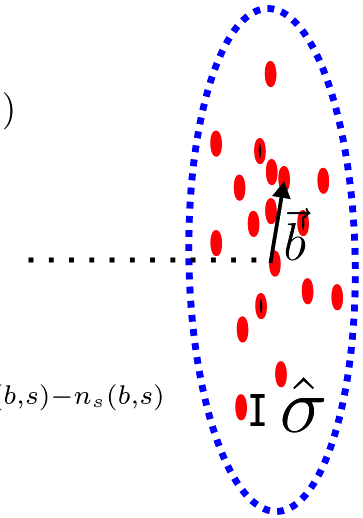


The hadronic event generator Sibyll

Includes:

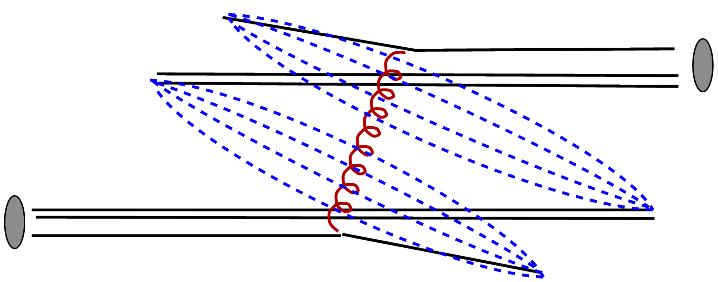
- Multiple parton interactions
- Soft and hard scattering
- Diffraction dissociation
- Lund fragmentation

$$n_i(b,s) = A(b)\sigma_i(s)$$

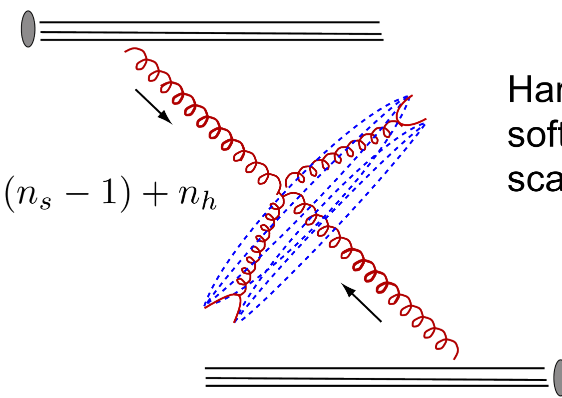


$$P_{N_s,N_h}(s) = \int d^2b \frac{n_s(b,s)^{N_s}}{N_s!} \times \frac{n_h(b,s)^{N_h}}{N_h!} e^{-n_h(b,s)-n_s(b,s)}$$

$$\sigma_{QCD}(s,p_T^{min}) = \int_{p_T^{min}}^{\mathrm{inf}} dp_T \int dx_1 \int dx_2 \sum_{i,j,k,l} f_i(x_1,Q^2) f_j(x_2,Q^2) \frac{d\hat{\sigma}^{i,j\to k,l}}{dp_T}(\hat{s},\hat{t})$$



Special case of soft interaction: valence scattering



Hard and soft scattering

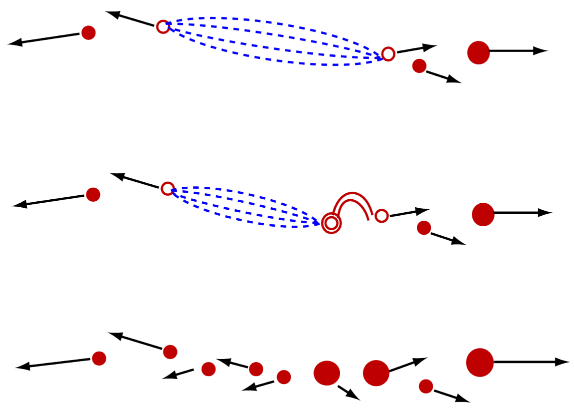
How to include charm quarks?

- Large contribution from QCD processes (many NLO calculations available)
  → add charm to hard scattering
- Non-perturbative component seen in data (leading charmed particles, asymmetries)
  → add charm to valence scattering
- effective partons only
  → no need to add charm diagrams

→ Add charm quarks in fragmentation step

Charm rate relative to strange:

$$P_{c/s} = P_0 e^{-\frac{m^c_{eff}}{\hat{s}}}$$

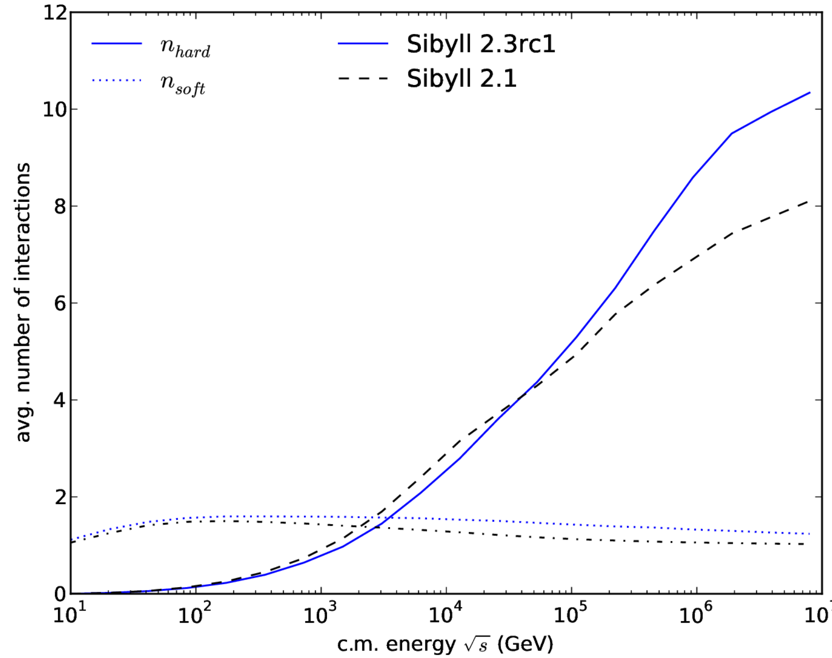


Peterson fragmentation:

$$D(x) = \frac{A}{x(1 - 1/x - \epsilon/(1-x))}$$

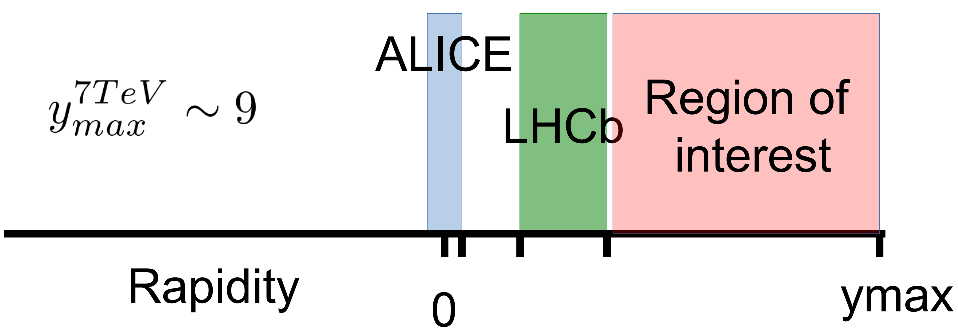
How to adjust the parameters?

- Low energy: fixed target data
  - Full phase space coverage
  - Mostly non-perturbative
- High energy: collider data
  - Mostly perturbative
  - Limited coverage



$$y = \frac{1}{2} ln \left(\frac{E + p_z}{E - p_z} \right) \leq ln \left(\frac{\sqrt{s}}{m_p} \right)$$

$$y_{max}^{7TeV} \sim 9$$



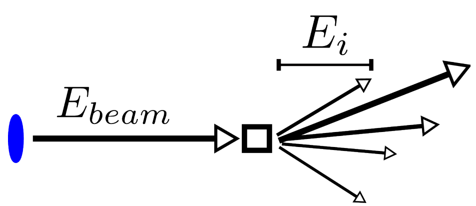
ALICE: |y| < 0.5
LHCb: 2.5 < |y| < 4.5

Interlude: Spectrum weighted moments

Spectral index of cosmic rays

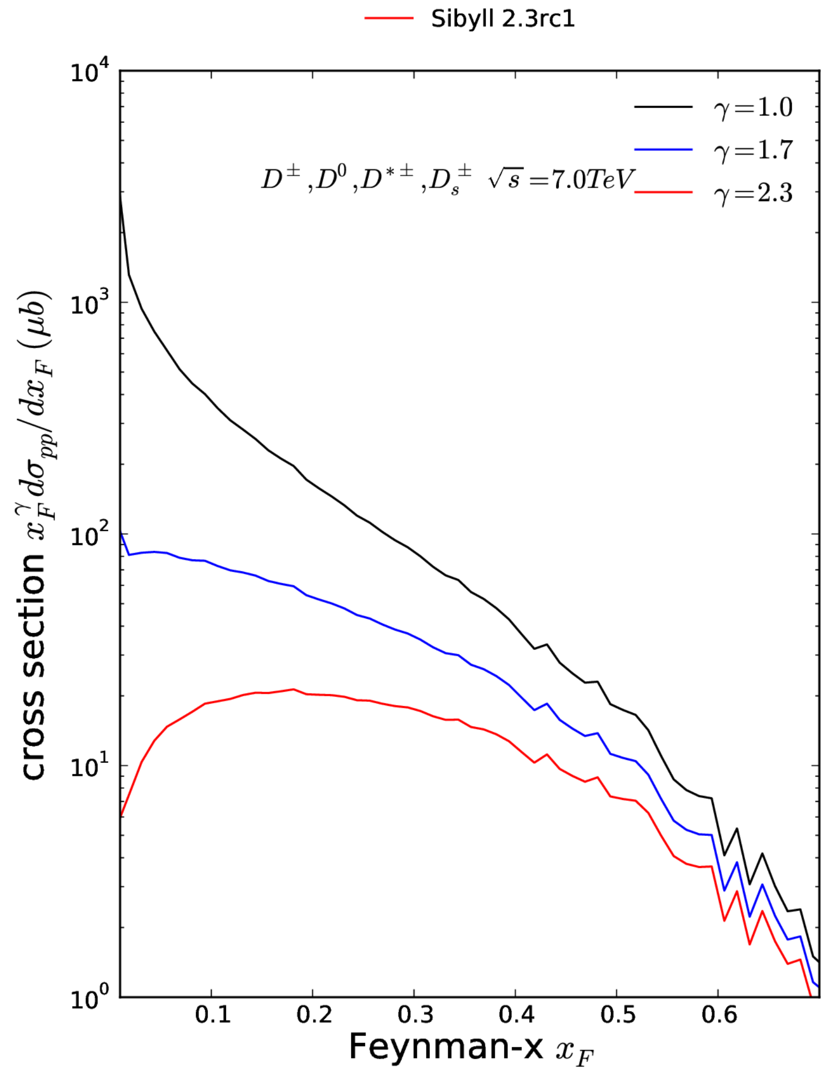
$$Z \sim \int x_L^{(\gamma-1)} \frac{dn}{x_L} dx_L$$

- represent hadronic interactions in cascade equations



$$x_L = E_i / E_{beam}$$

$$x_F = p_z^{cms} / p_{max}^{cms} \qquad x_L \approx x_F \;,\; p_T << p_z$$



LHCb phasespace, how limiting is limited?

- 7TeV c.m energy well beyond the knee

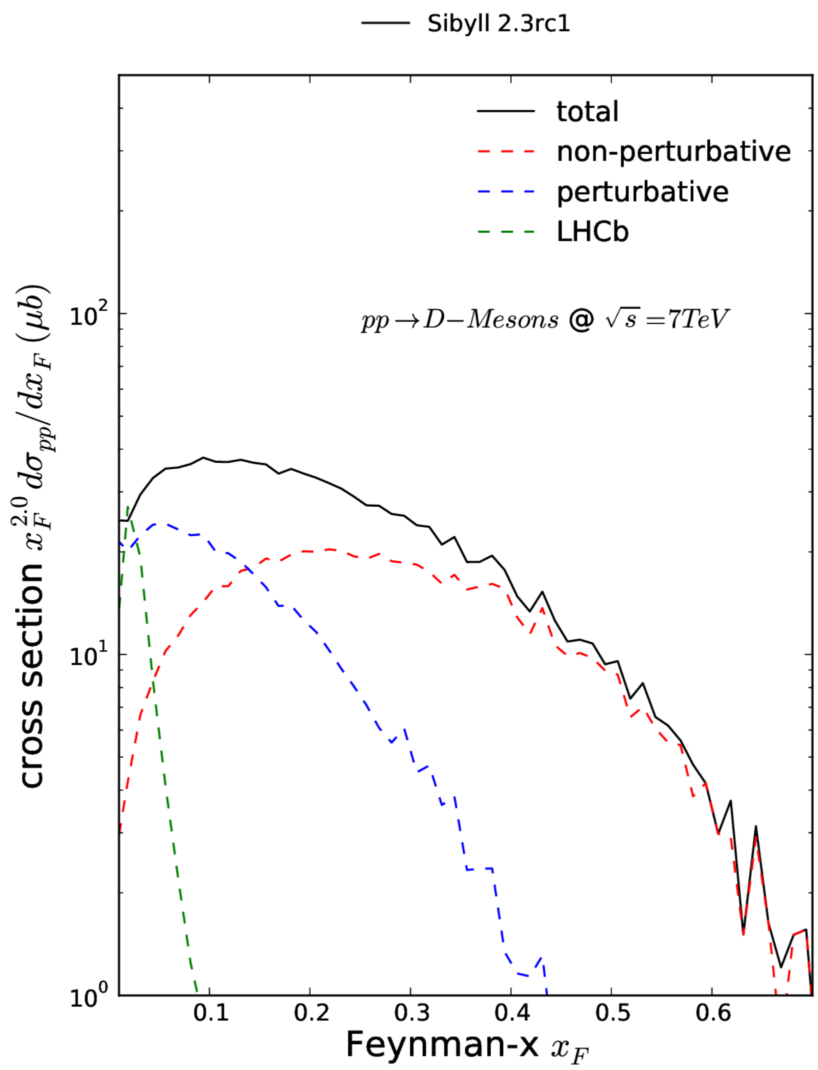
$$\sqrt{s} = 7TeV \rightarrow E_{lab} = 26PeV$$

$$\gamma_{CR} \approx 3$$

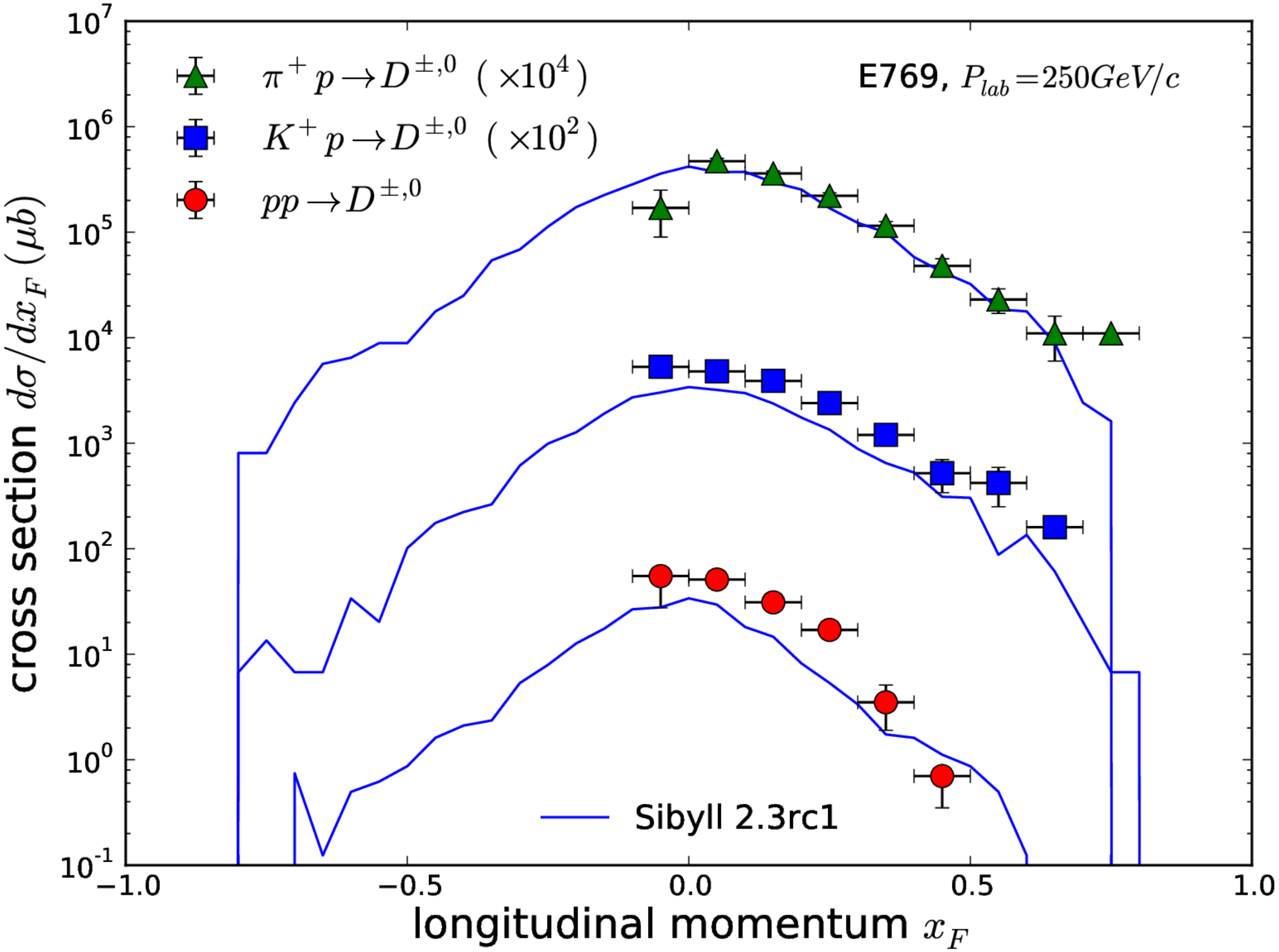
- How much does LHCb phasespace contribute to integrated spectrum?

	%
LHCb	7
perturbative	37
Non-perturbative	59

→ LHC data **not** restrictive



Low energy: E769 xF spectrum



$\sqrt{s} = 22GeV$

Close to low-energy threshold of the model

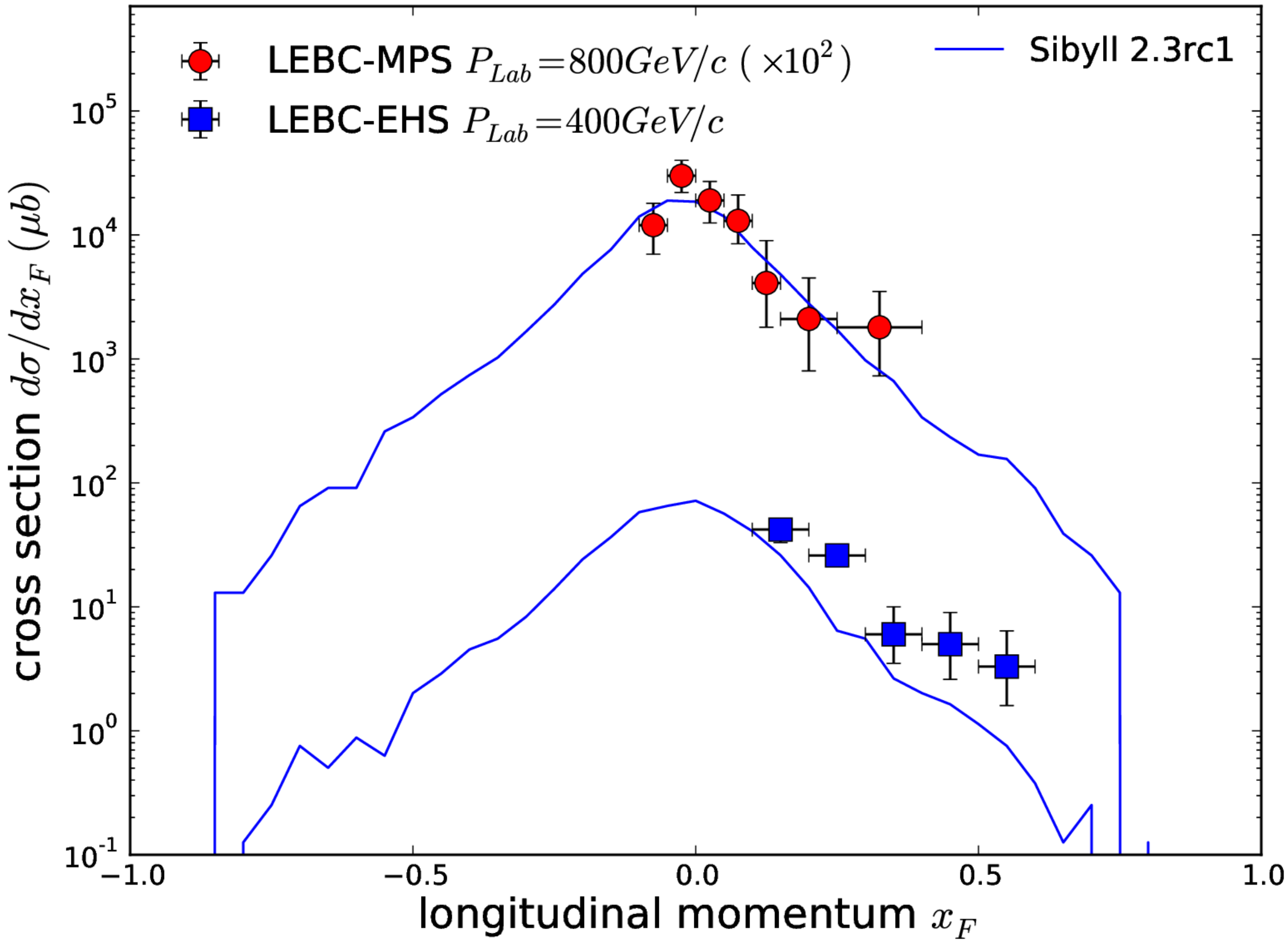
very limited by kinematics

LEBC-EHS/MPS – xF spectra at 400 / 800GeV/c

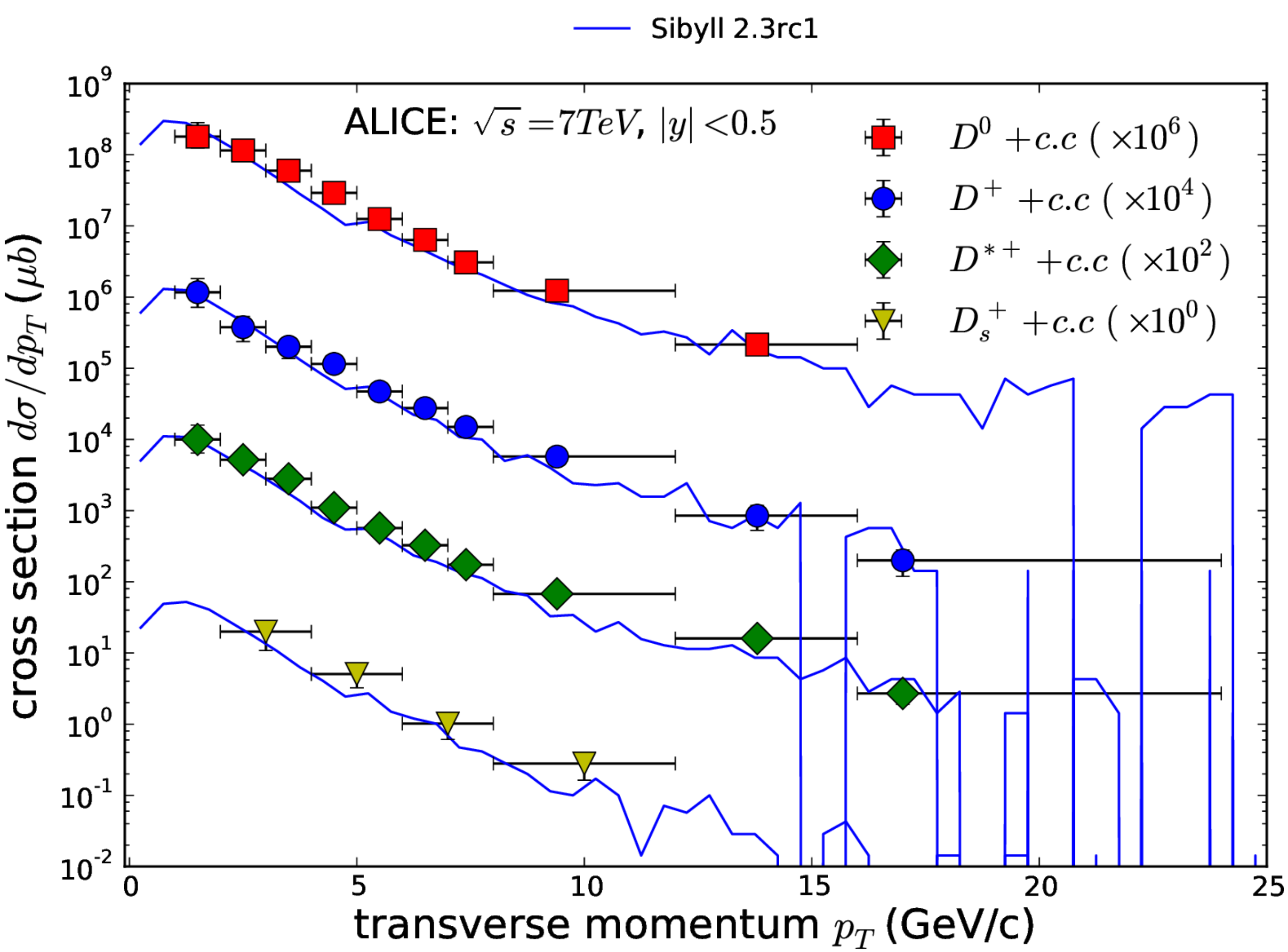
$\sqrt{s} = 27/39GeV$

Energy low but full phasespace coverage possible!

$y_{max}^{39GeV} = 3.7$

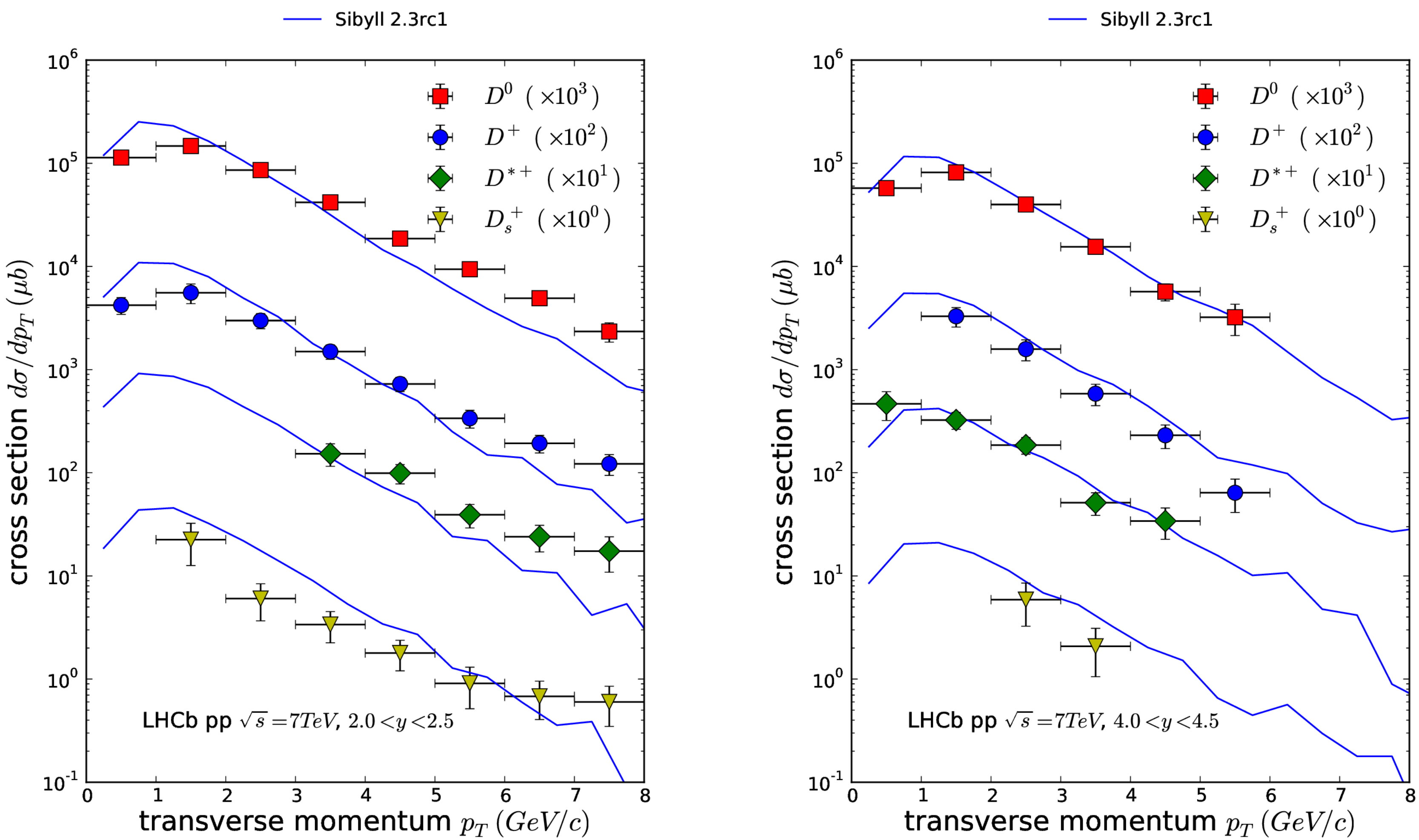


High energy: ALICE – central D-mesons

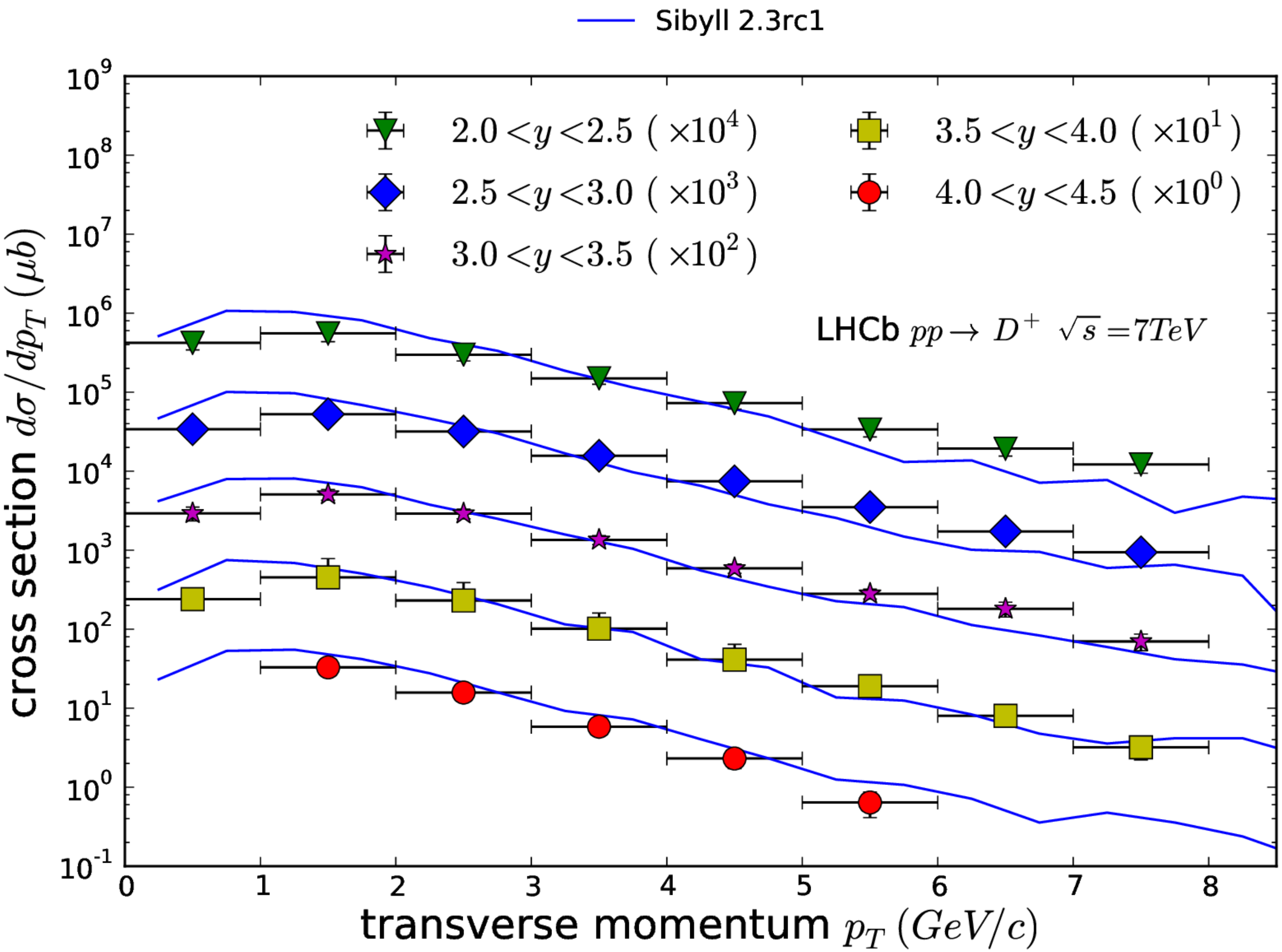


Central production almost entirely due to perturbative process

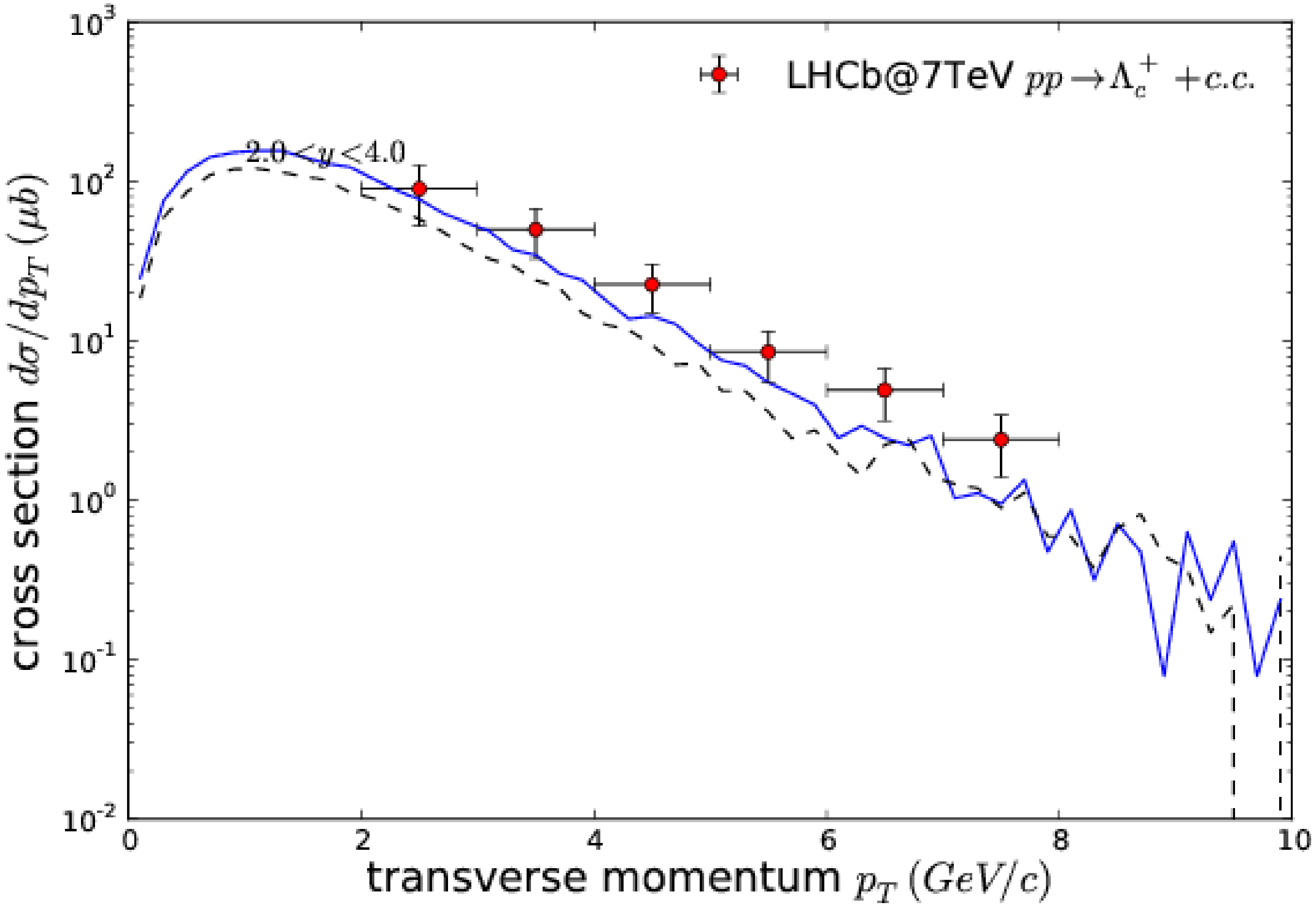
LHCb all D-meson spectra
most central and forward rapidity region



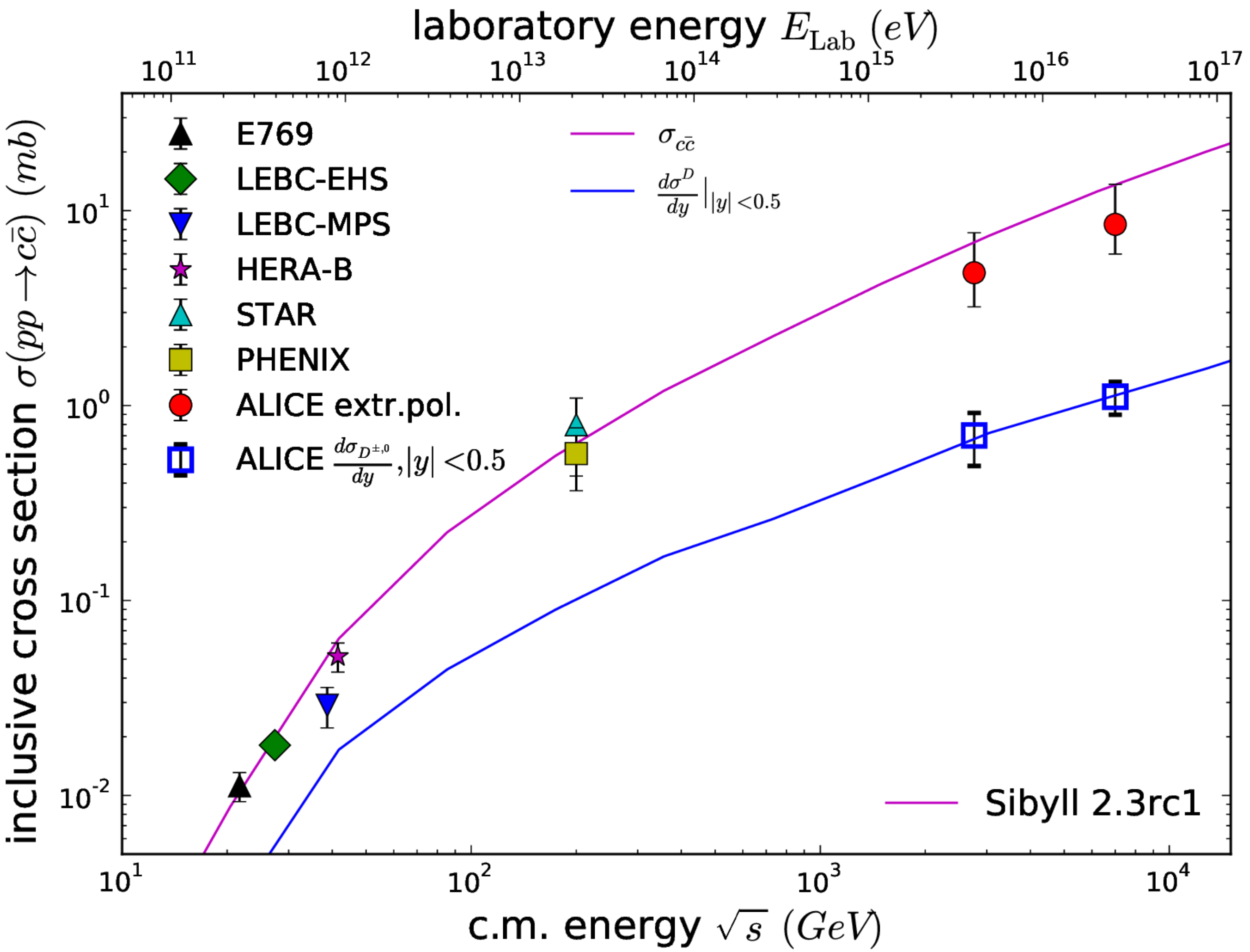
LHCb charged D-meson spectrum



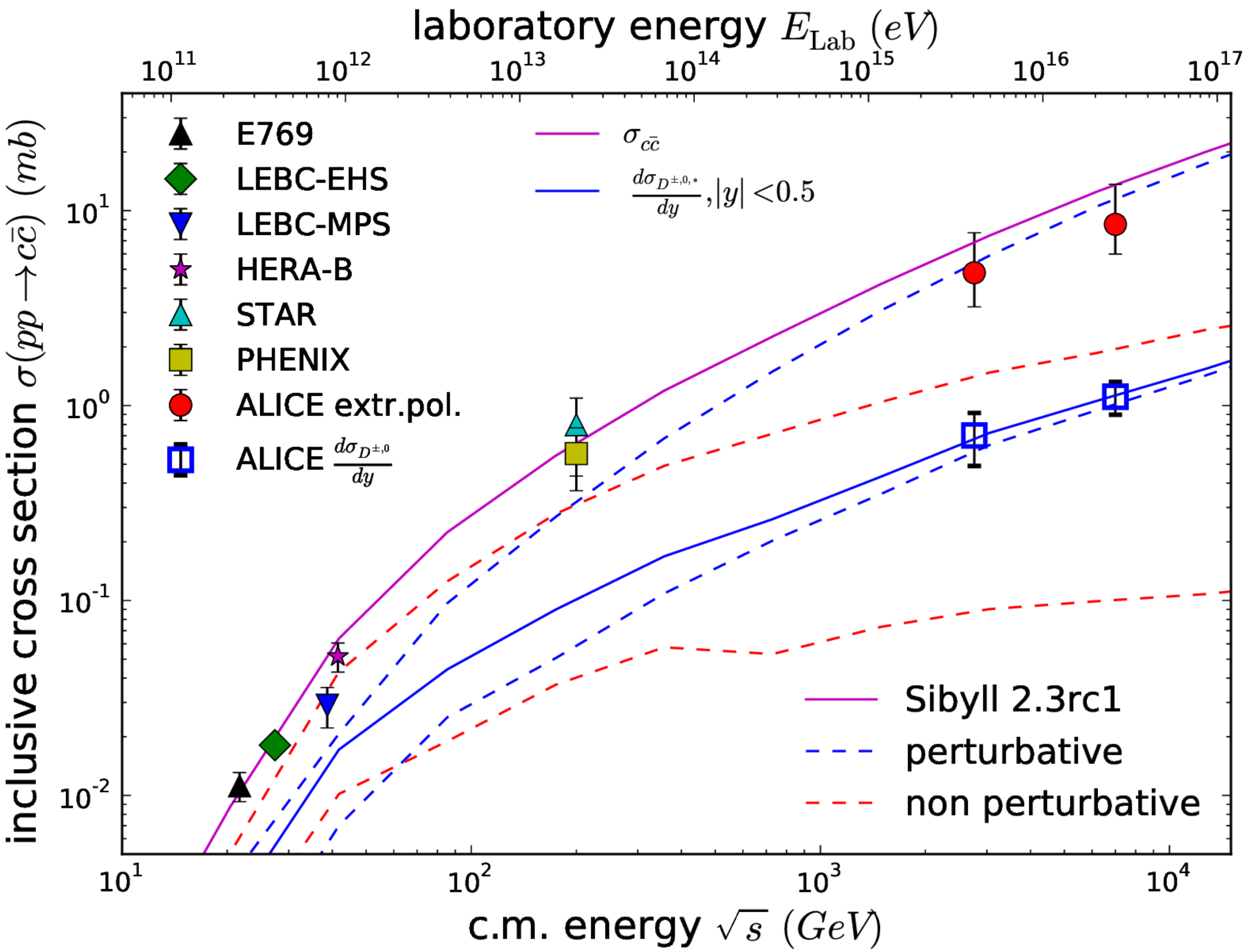
LHCb charmed Lambda spectrum



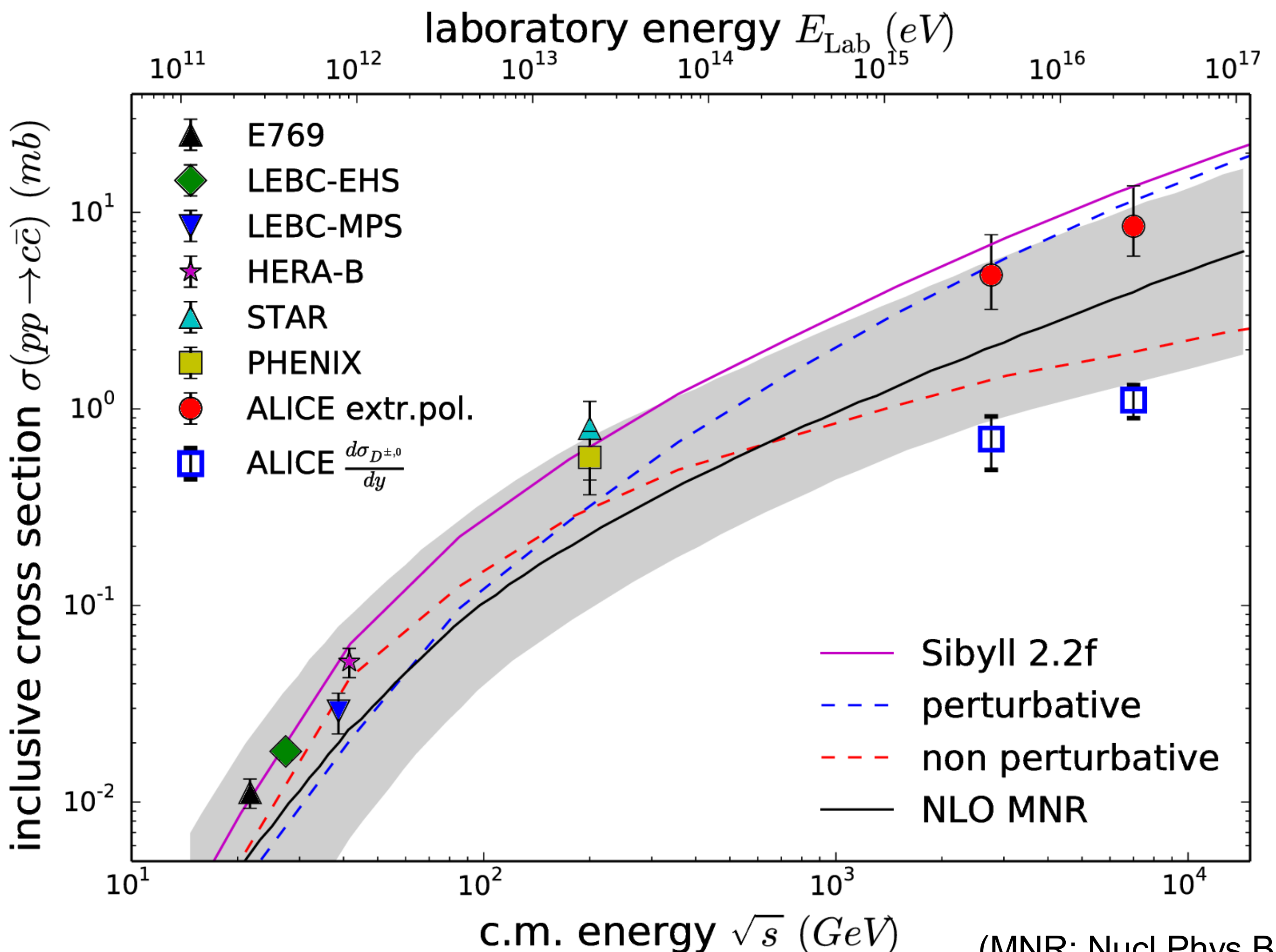
Inclusive charm production



Inclusive charm production, by process



Inclusive charm production, compared to NLO QCD



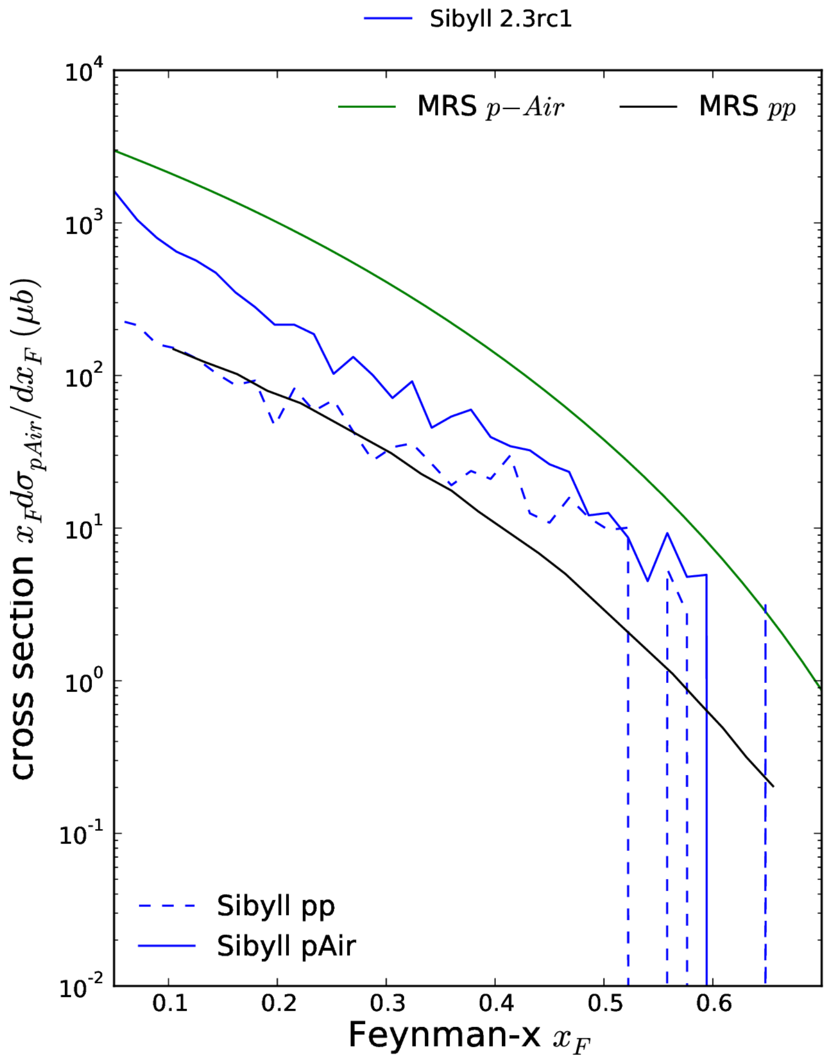
(MNR: Nucl.Phys.B373(1992) 295)

Charmed Sibyll compared to the MRS model

- perturbative QCD
- Extrapolating to low x
- Inlcuding saturation effects

(Martin, Ryskin, Staśto: MRS
Acta Phys.Polon. B34 (2003) 3273-3304)

- Overall charm scale very different
- Component due to perturbative QCD in Sibyll similar



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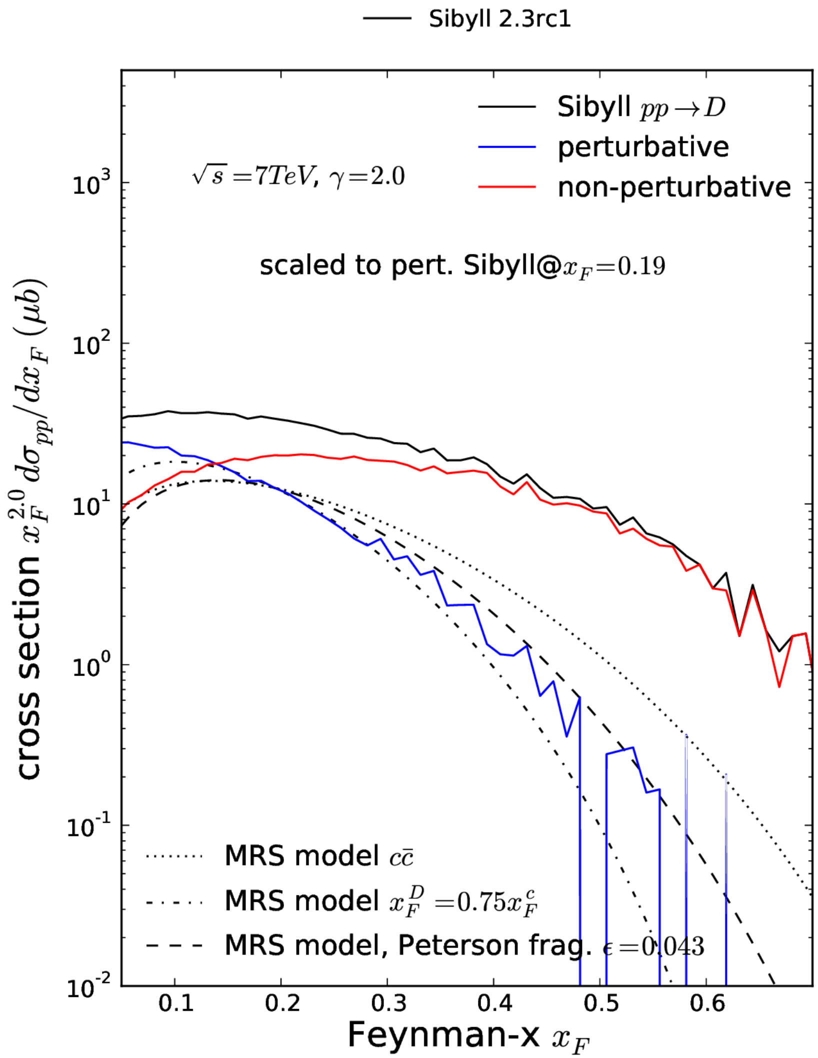

Summary

- Charm production included in Sibyll event generator
  - Charm model phenomenologic
  - Perturbative component similar to NLO QCD predictions
  - Essential non-perturbative component that dominates forward production

- Phasespace covered by LHC experiments is **not** sufficient to determine the prompt atmospheric component due to charm

Todo:

- Detailed look at charm in nuclear interactions
- Charmed interactions (?)

SELEX charmed hyperon asymmetry