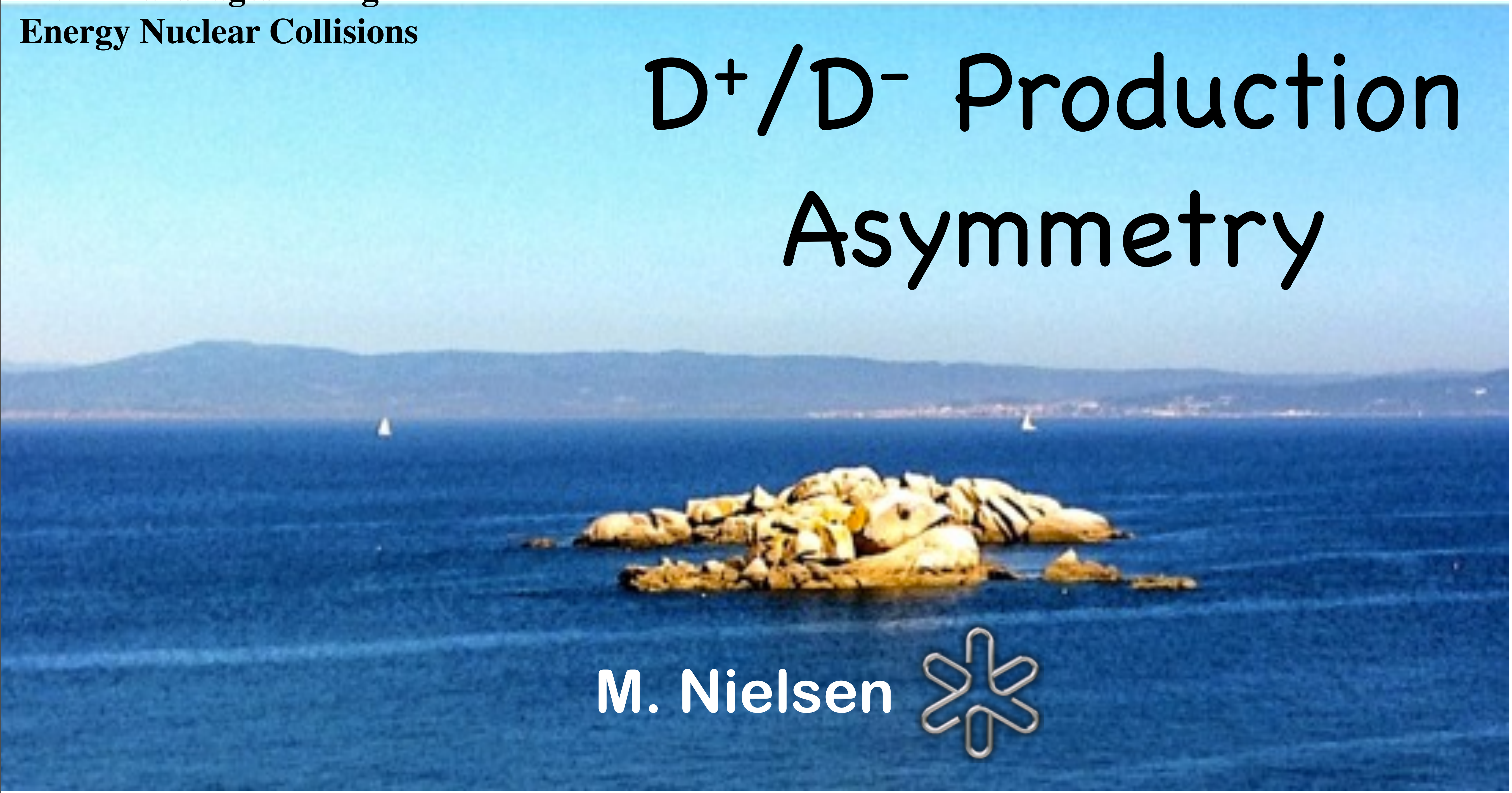
IS2013

International Conference on the Initial Stages in High-Energy Nuclear Collisions

D^+/D^- Production Asymmetry

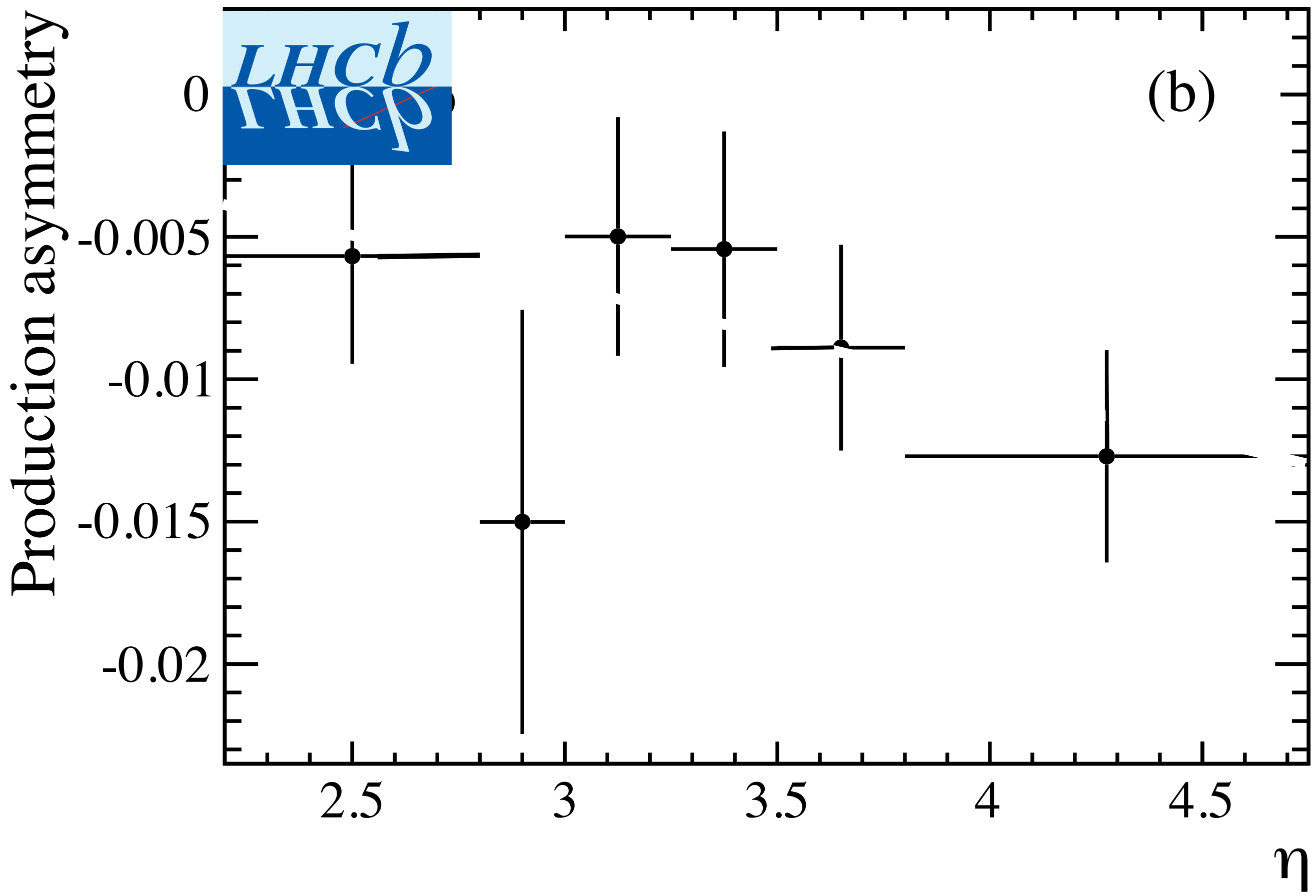


M. Nielsen

Universidade de São Paulo

Cazaroto, Goncalves, Navarra, MN, arXiv:1302.0035

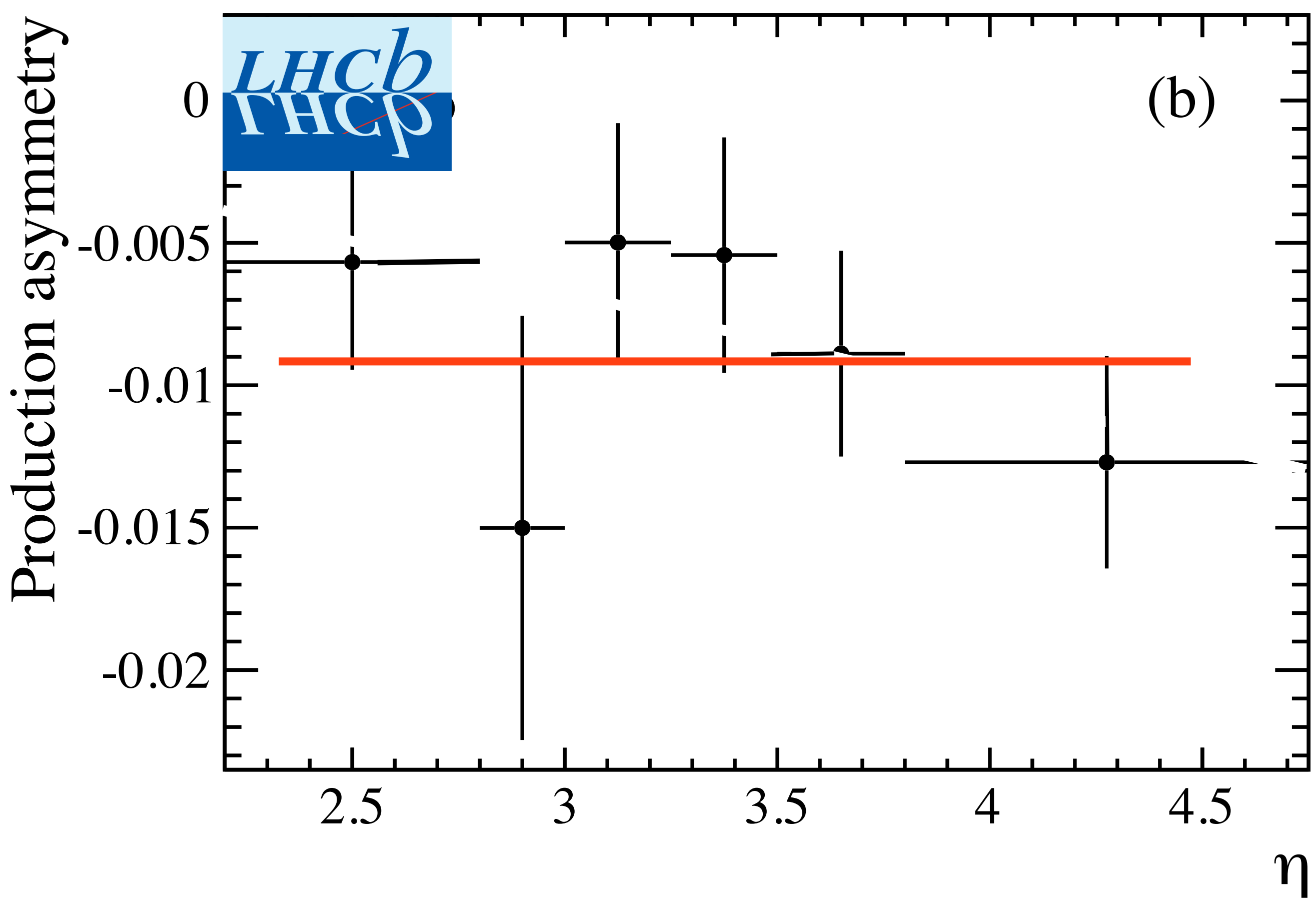
arXiv:1210.4112



$$A = \frac{N_{D^-} - N_{D^+}}{N_{D^-} + N_{D^+}}$$

7 TeV, pp collisions

arXiv:1210.4112



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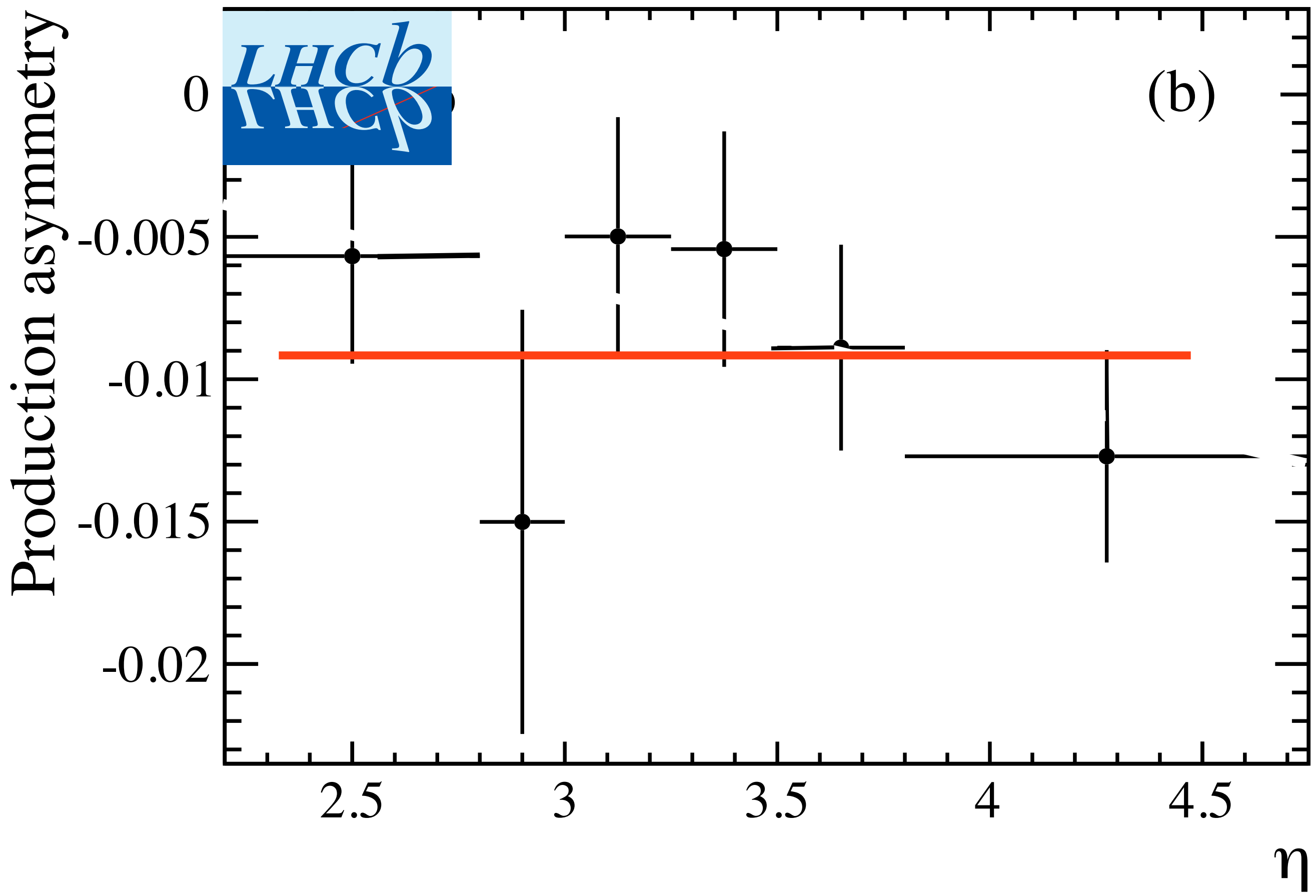

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$$x_F = \frac{2\, m_T\, cosh(y)}{\sqrt{s}}$$

$$\simeq \frac{2\, m_T\, cosh(\eta)}{\sqrt{s}} \simeq \frac{2\, m_T\, e^{\eta}}{\sqrt{s}}$$

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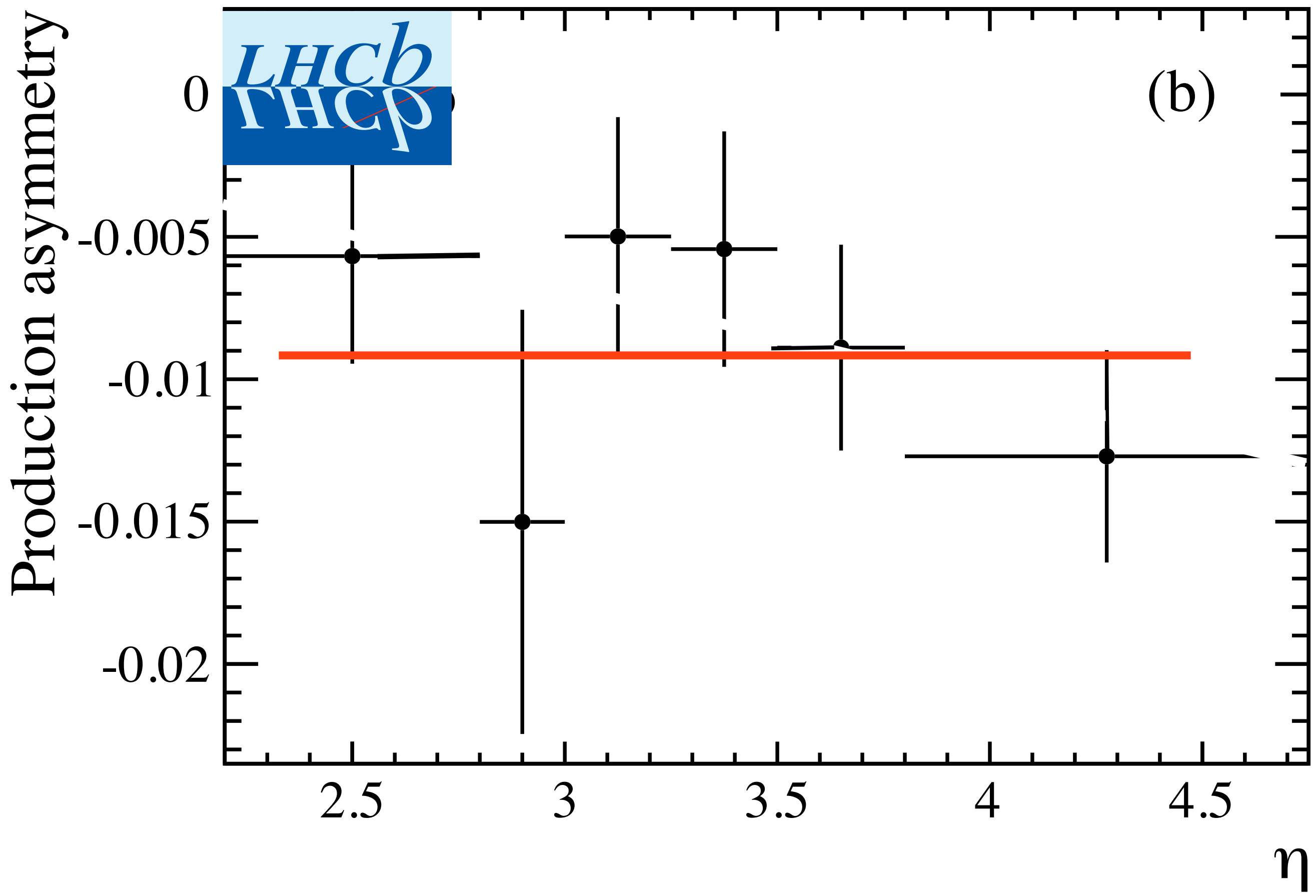

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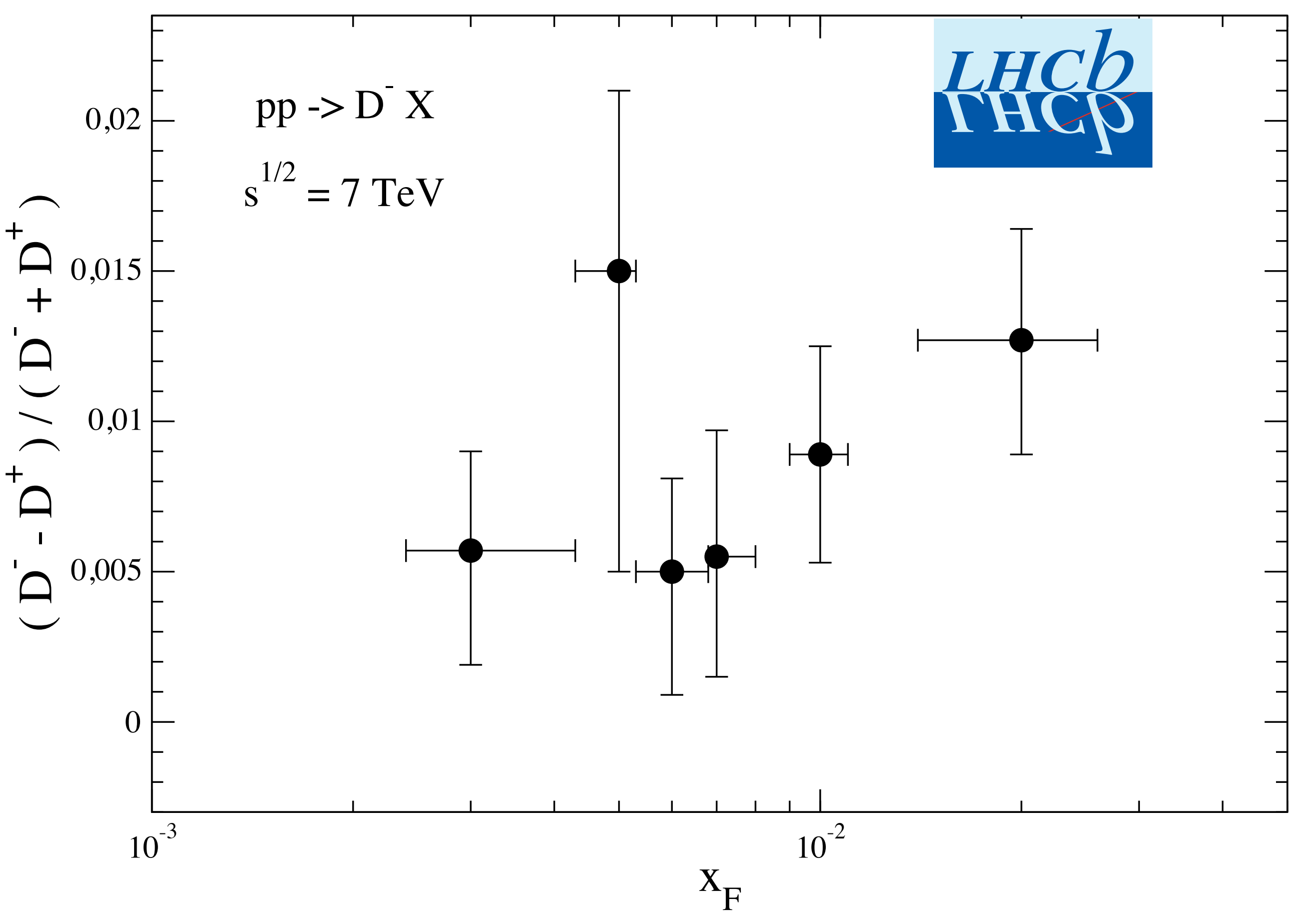

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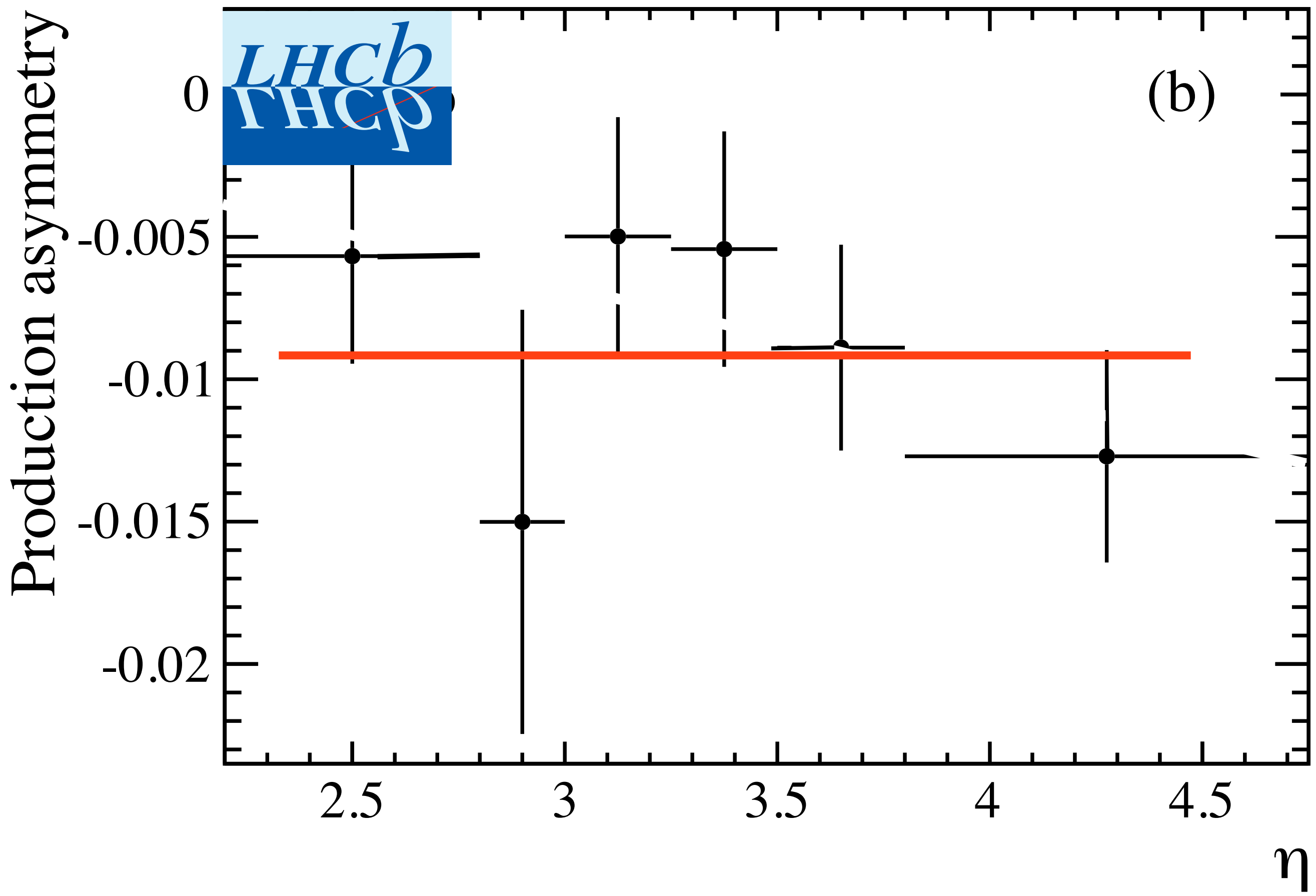

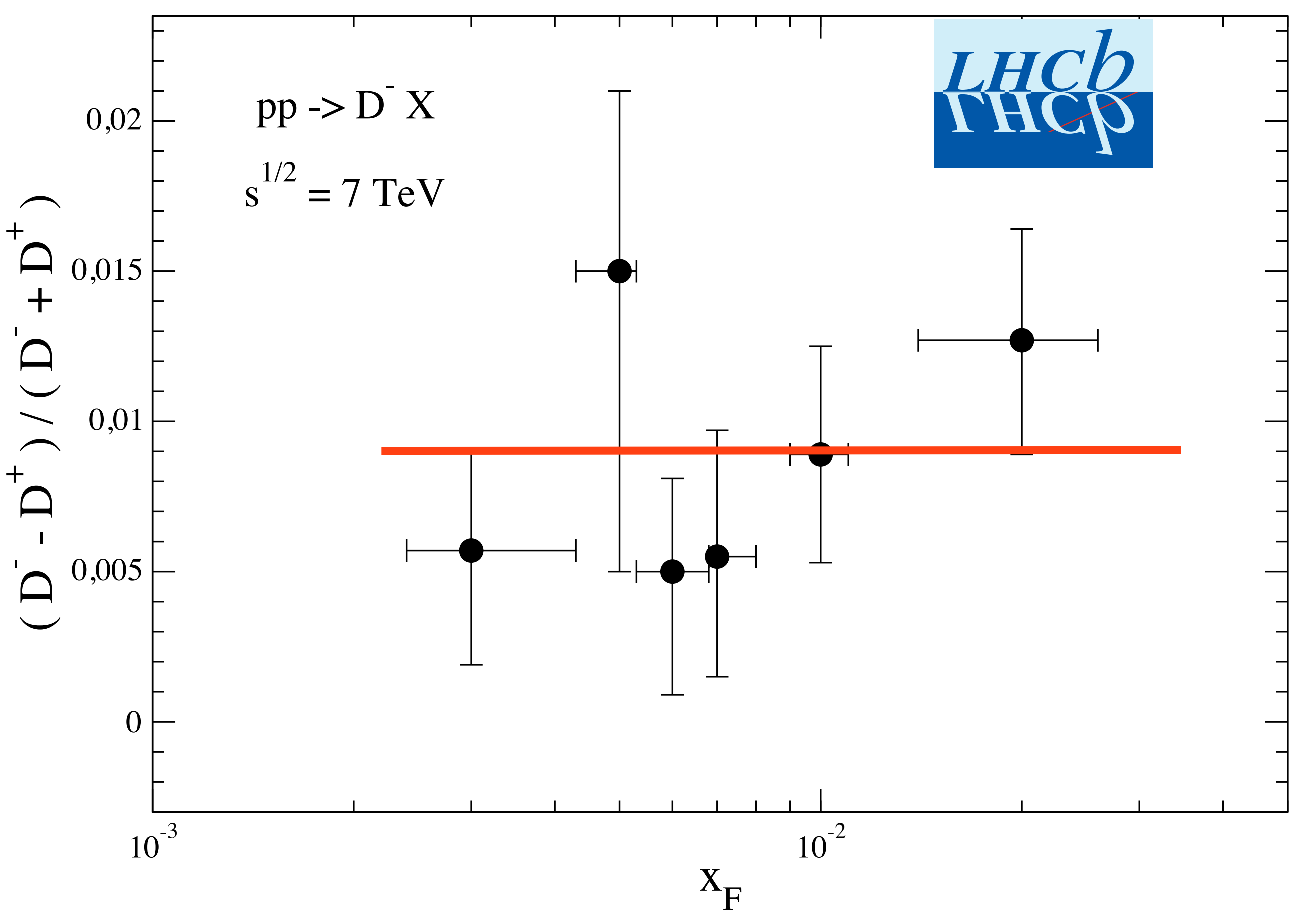

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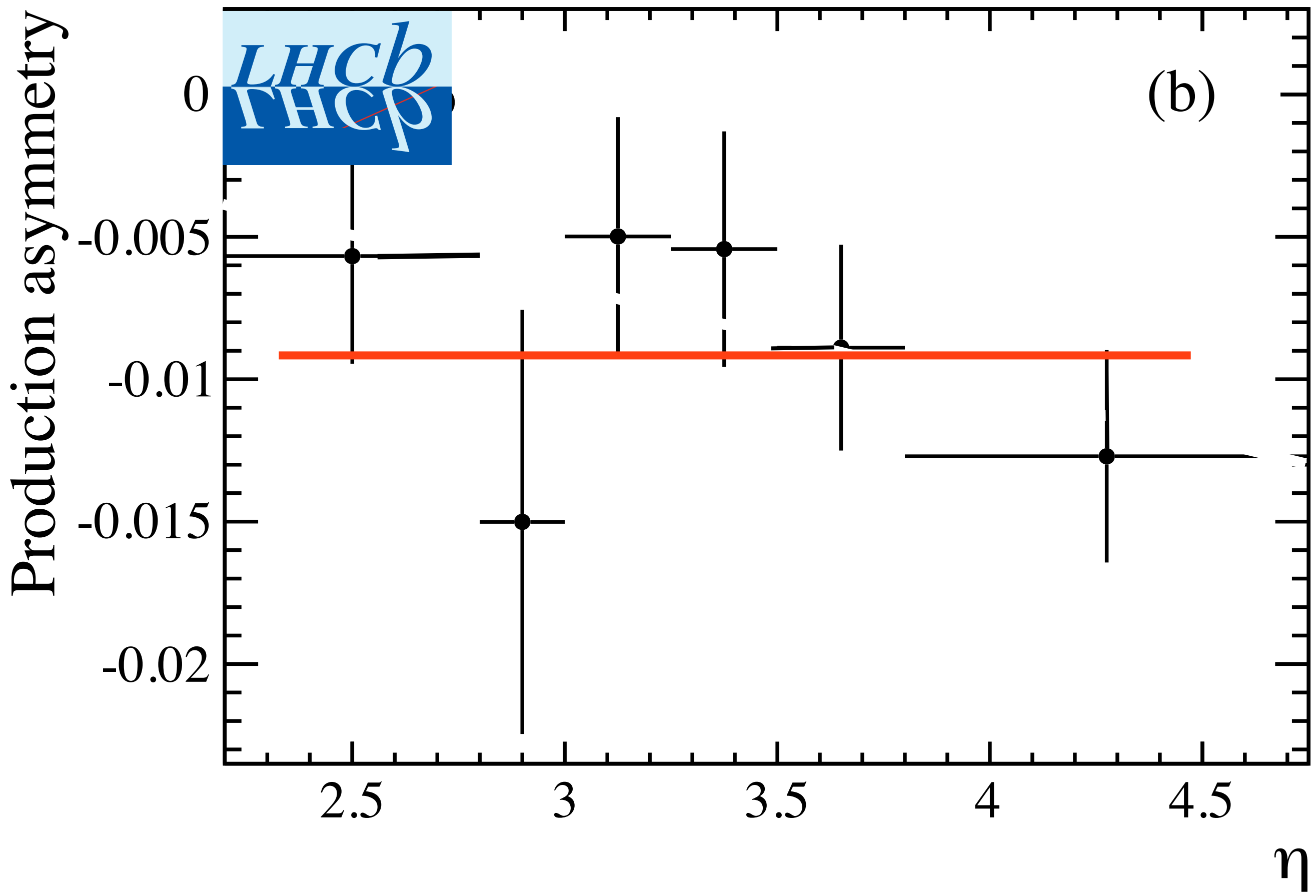

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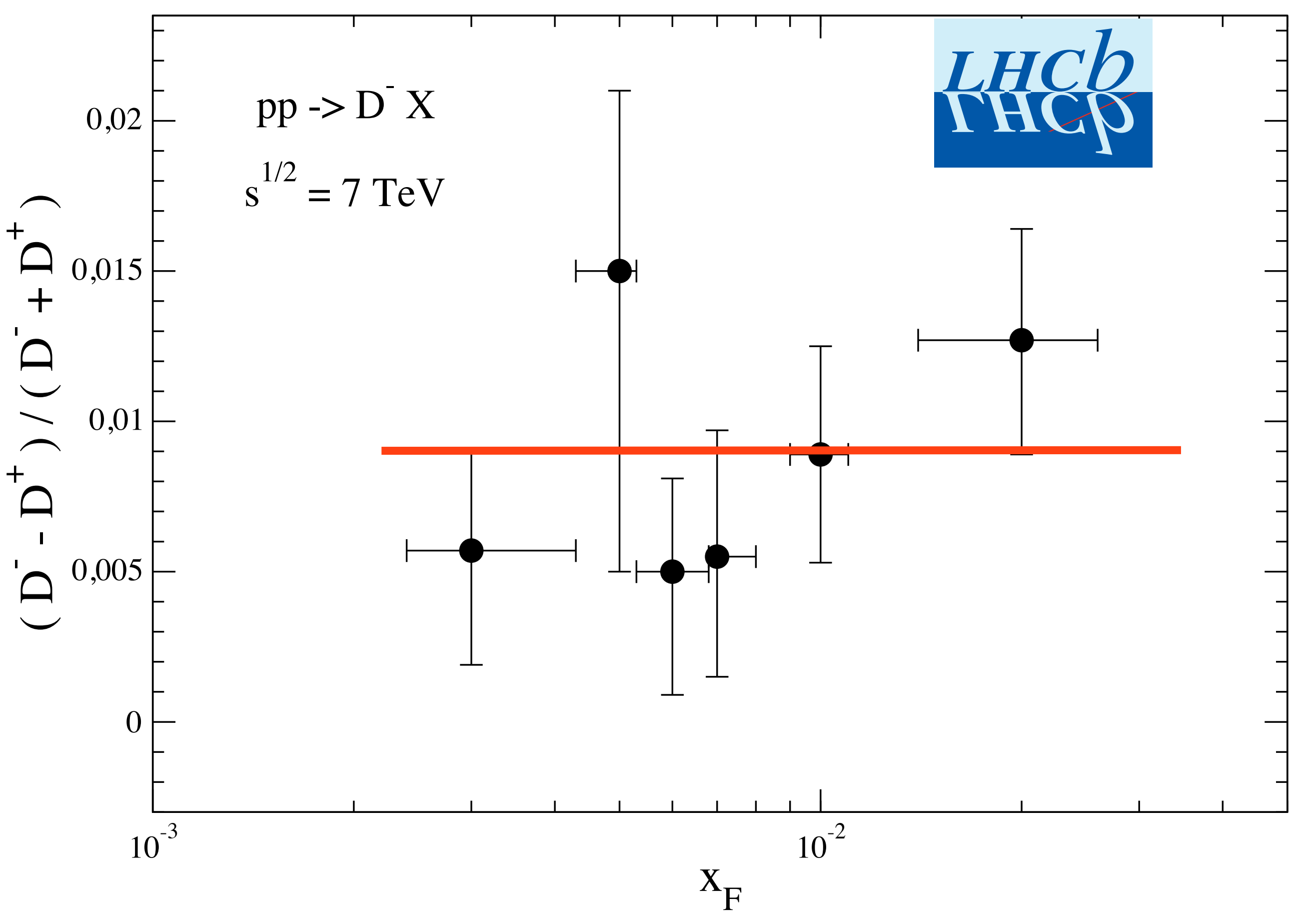
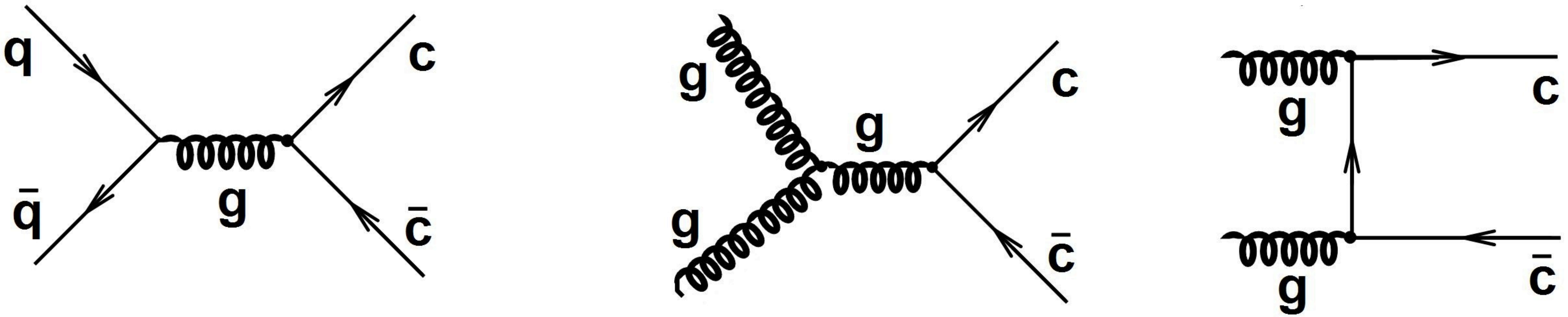


What is the origin of the asymmetry?

Standard charm production in perturbative QCD



same number of c and $\bar{c}$ is produced

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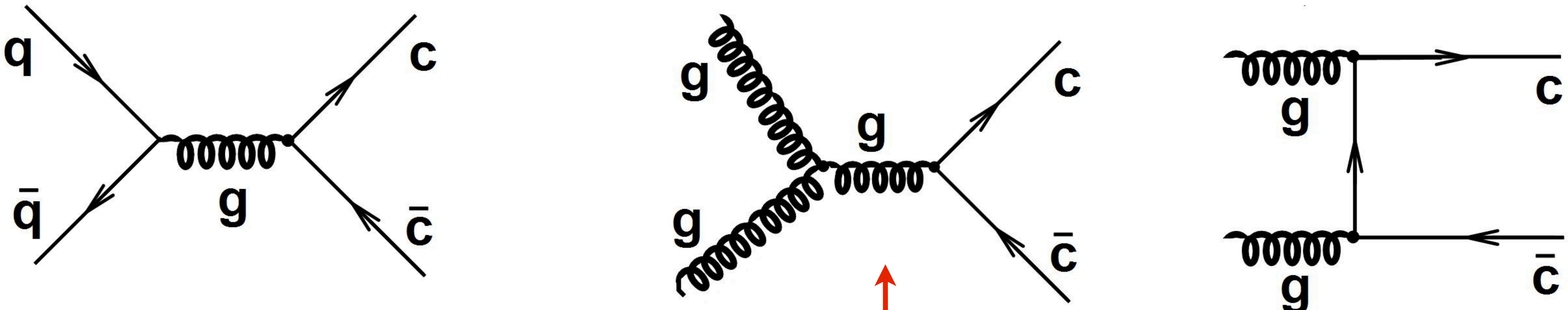


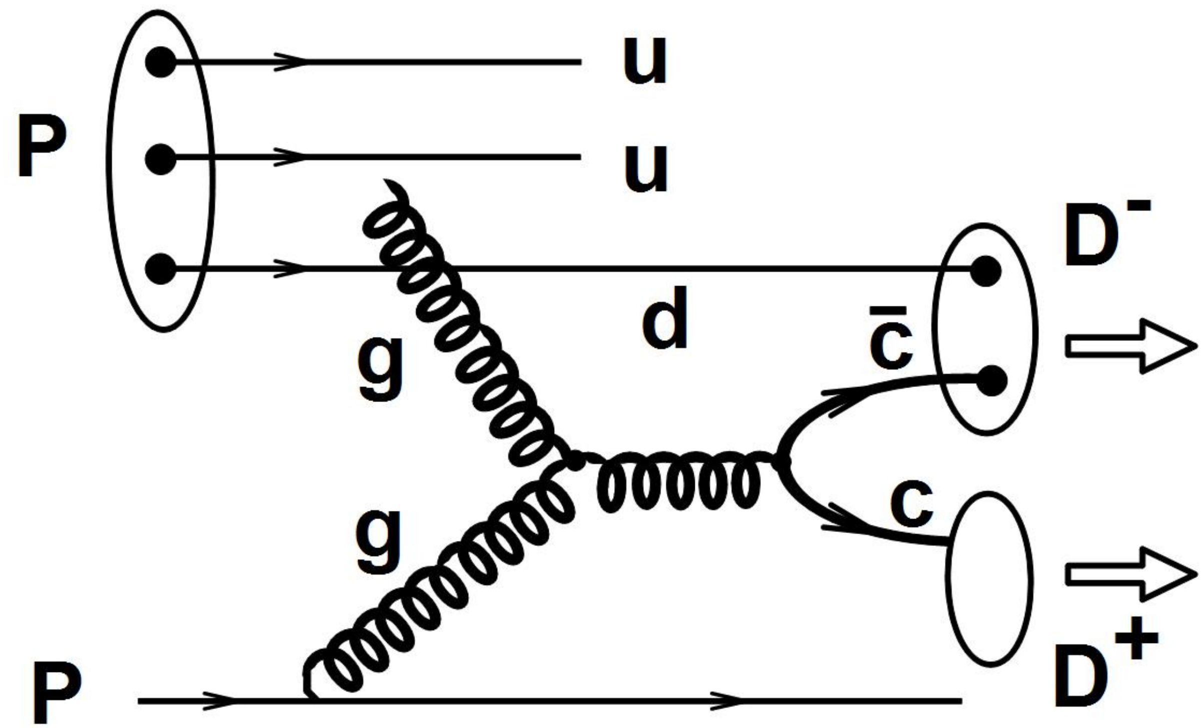
same number of c and $\bar{c}$ is produced

more important at
high energy

recombination with a projectile valence quark

Vogt, Brodsky,
NPB (1995) ; NPB(1996)

Rapp, Shuryak, PRD (2003)



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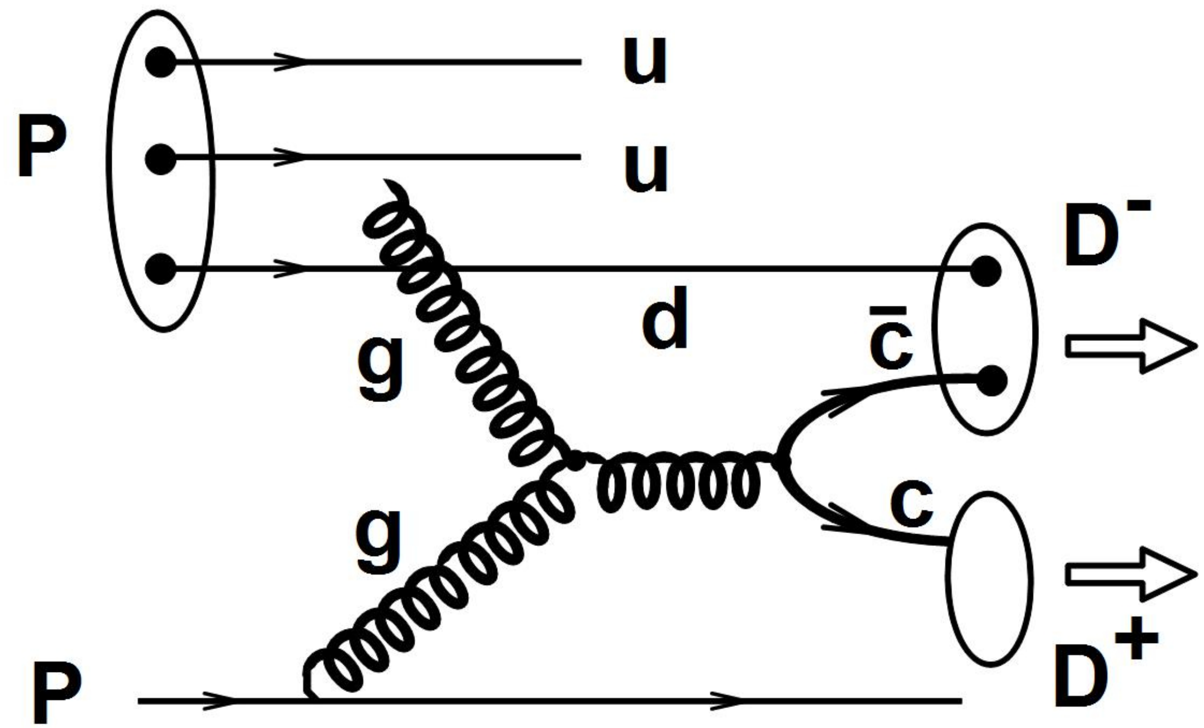

$\overline{c}$ is "dragged" by the "fast" d quark and D^- is "faster"

D^- = "leading meson" D^+ = "nonleading meson"

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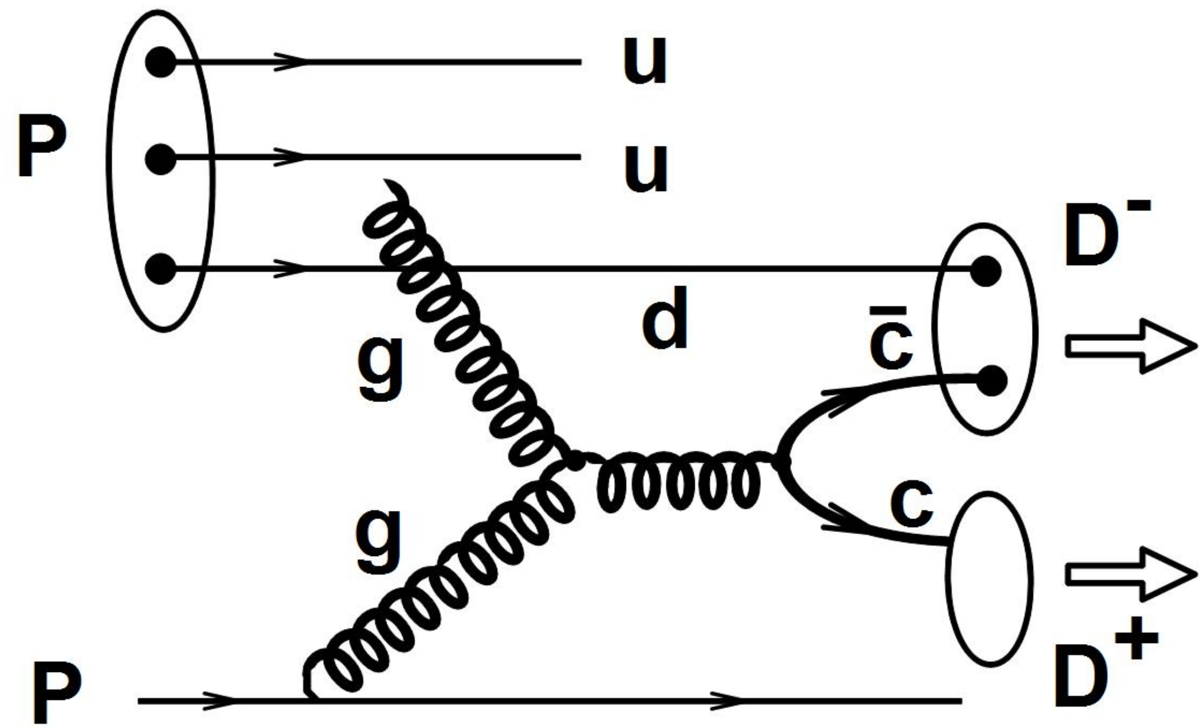
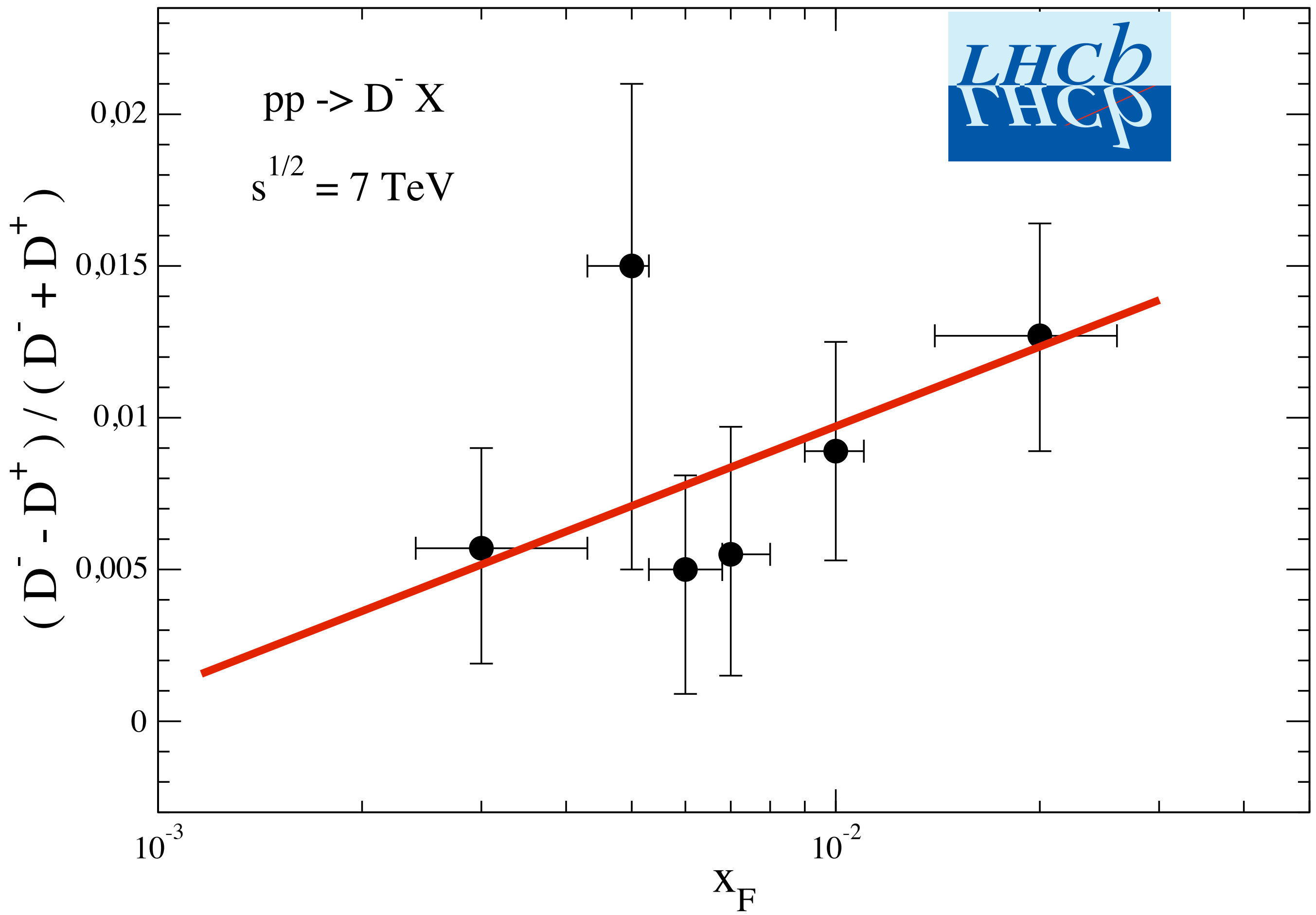


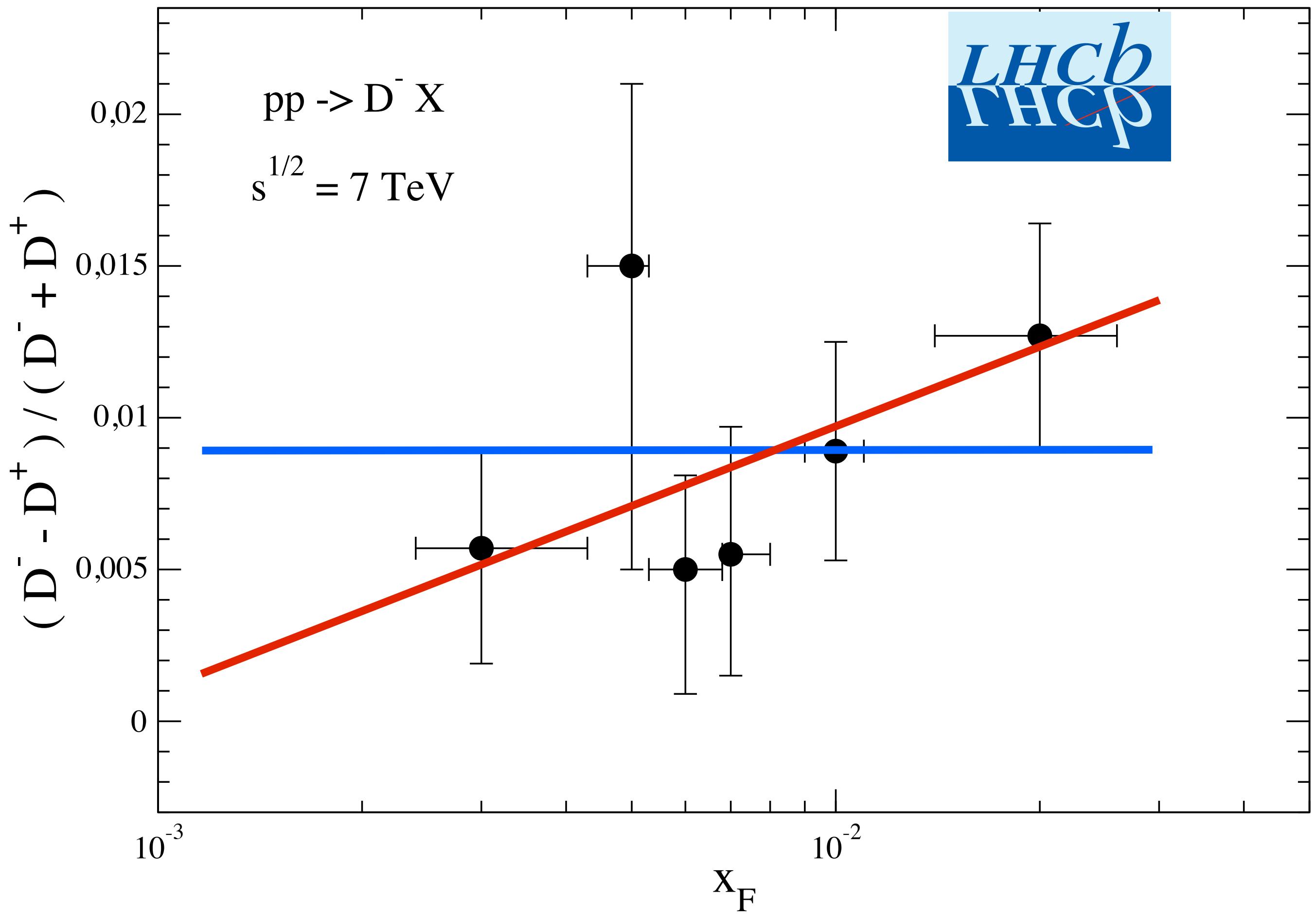
$\bar{c}$ is "dragged" by the "fast" d quark and D^- is "faster"

D^- = "leading meson" D^+ = "nonleading meson"

pQCD + recombination: equal number of D$^+$ and D$^-$ at low x_F and higher number of D$^-$ at high x_F



Is the LHCb data compatible with the pQCD + recombination approach?



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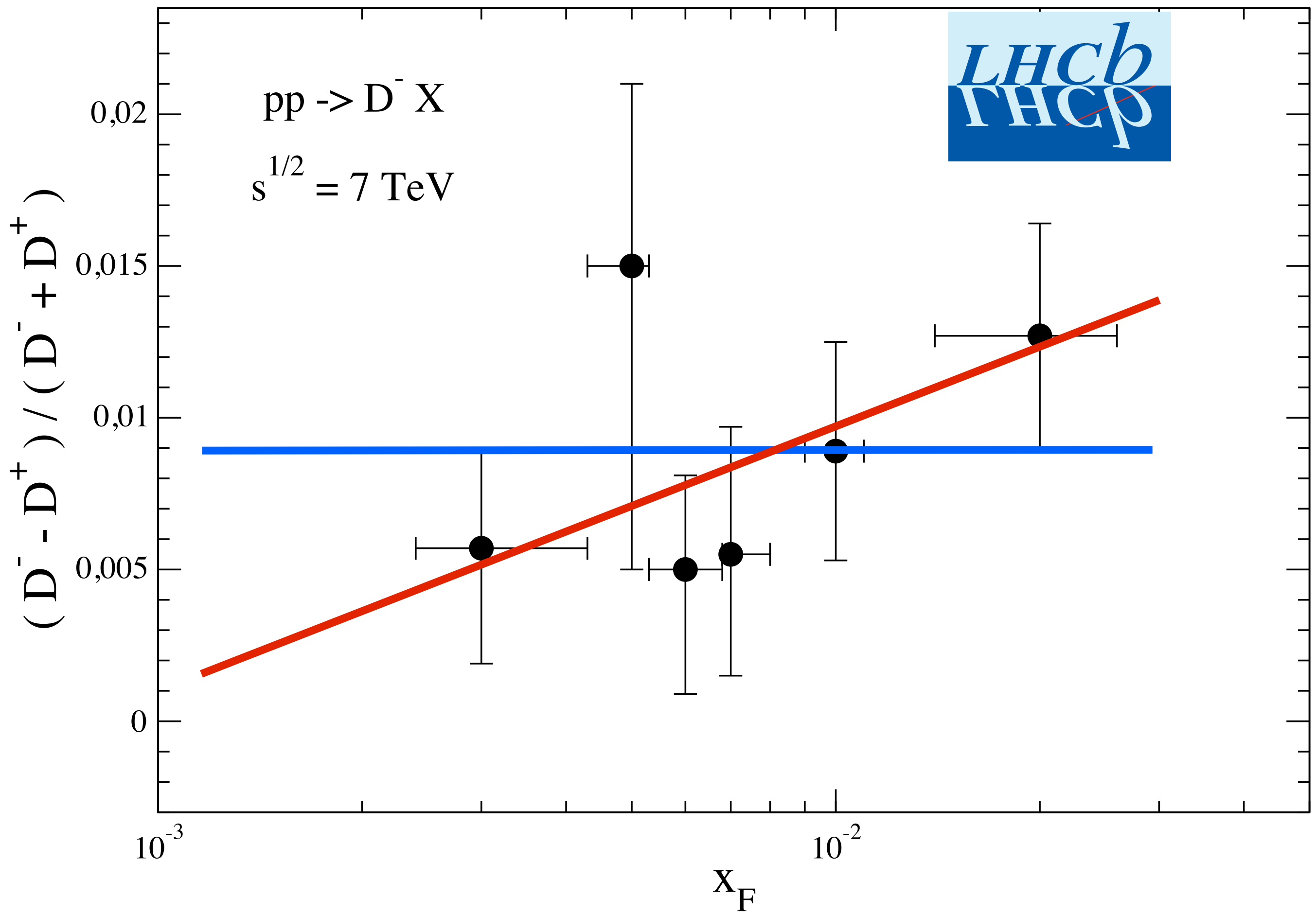
Is there a residual asymmetry at low x_F?



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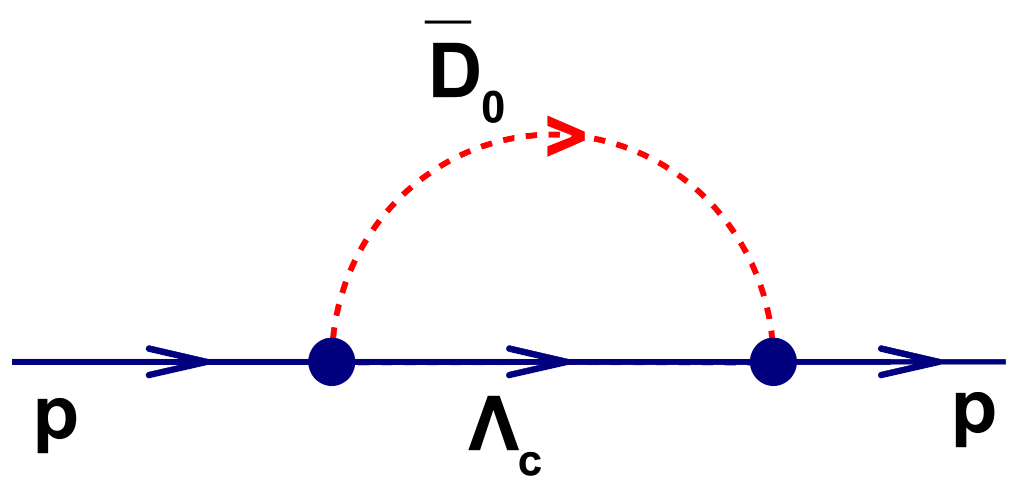
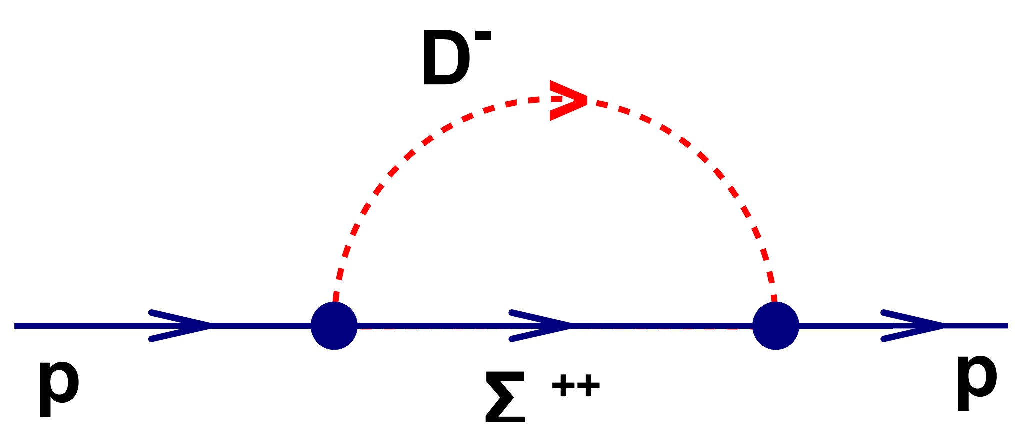
Charm production from the Meson Cloud Model (MCM)





$$|p\rangle = Z\,[\,|p_0\rangle + ... + |MB\rangle + ... + |\Lambda_c \bar{D}_0\rangle + |\Sigma_c^{++} D^-\rangle]$$

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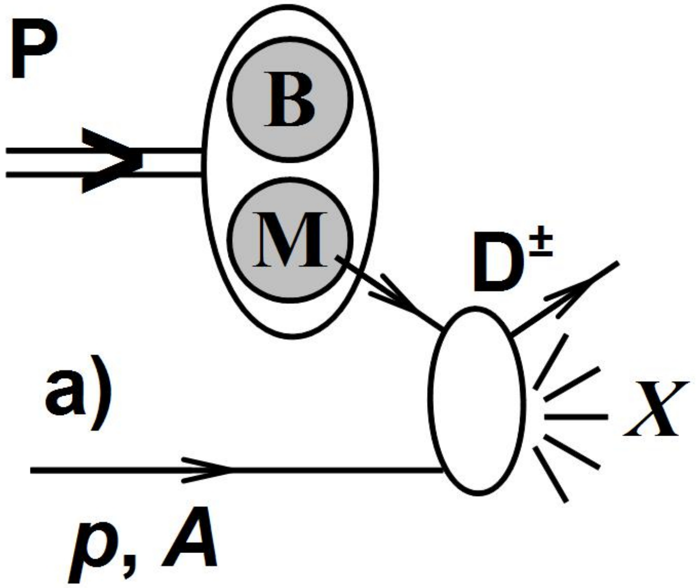
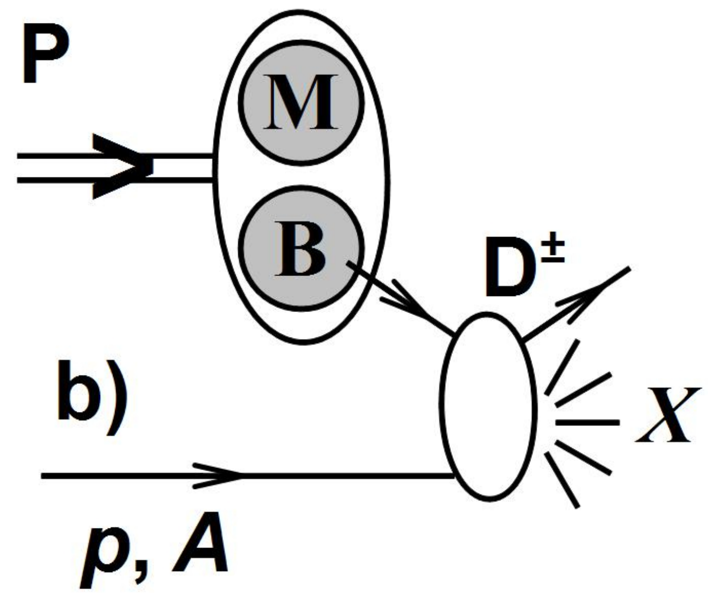
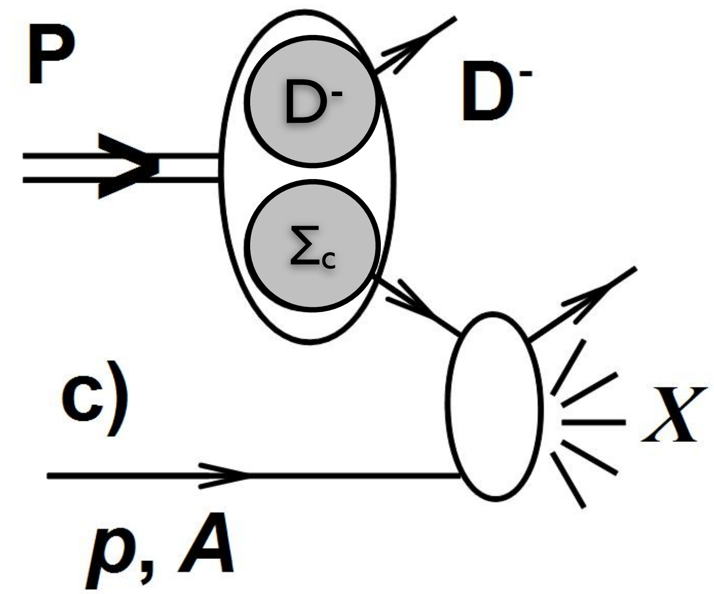
"bare" charm cloud







indirect indirect direct

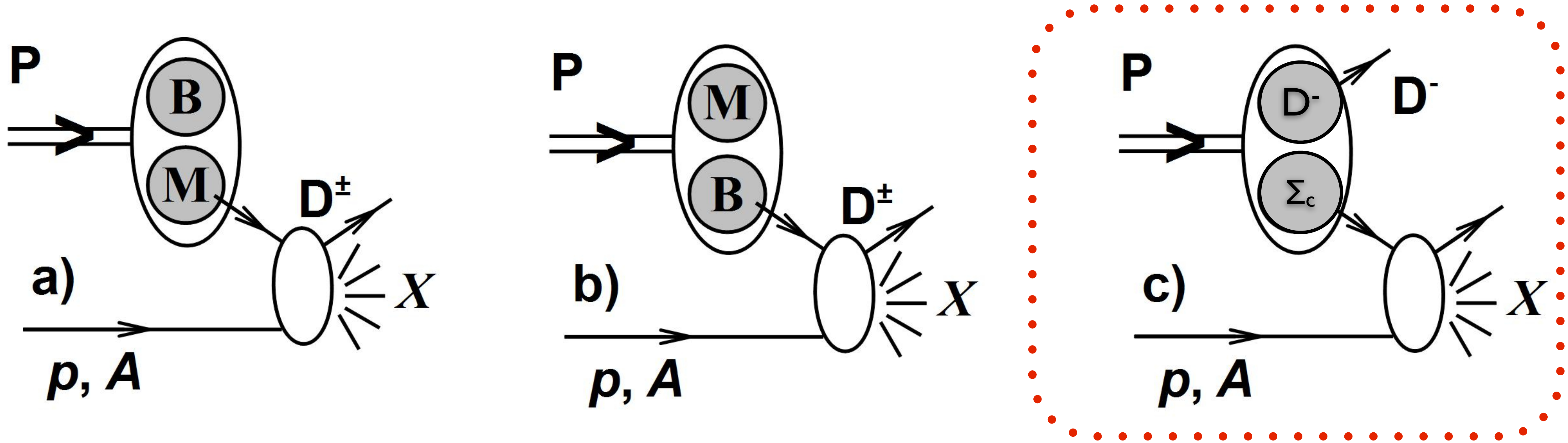
D'Alesio, Pirner, EPJA (2000)

Carvalho, Duraes, Navarra, Nielsen, PRL (2001)

$$\frac{d\sigma^{pp\to DX}}{dx_F} = \Phi_0 \; + \; \Phi_I \; + \; \Phi_D$$

$$|p\rangle = Z\,[\,|p_0\rangle + ... + |MB\rangle + ... + |\Lambda_c \bar{D}_0\rangle + |\Sigma_c^{++} D^-\rangle]$$

"bare" charm cloud



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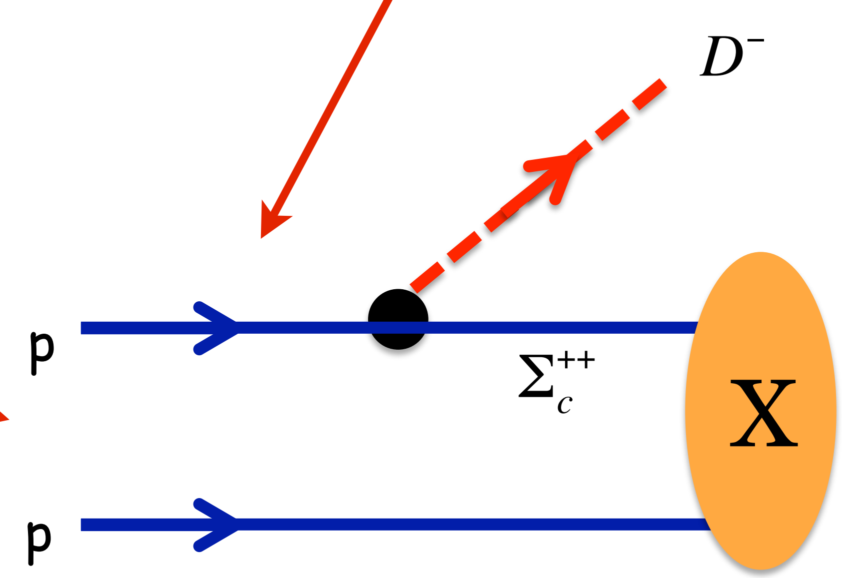

$$\Phi_D = \frac{\pi}{x_F}\, f_D(x_F)\, \sigma^{\Sigma p}$$

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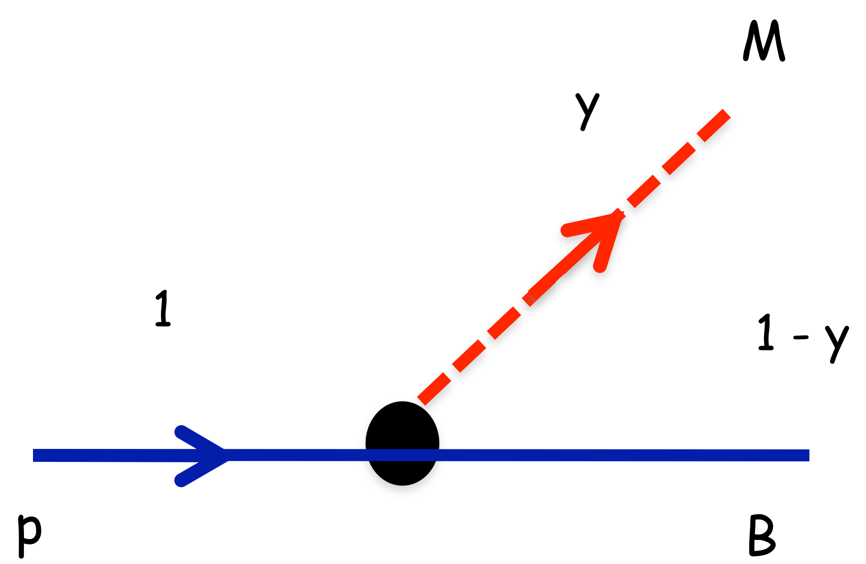
splitting function



$f_M(y)$: probability density of finding a meson with momentum fraction y of the total state $|MB>$

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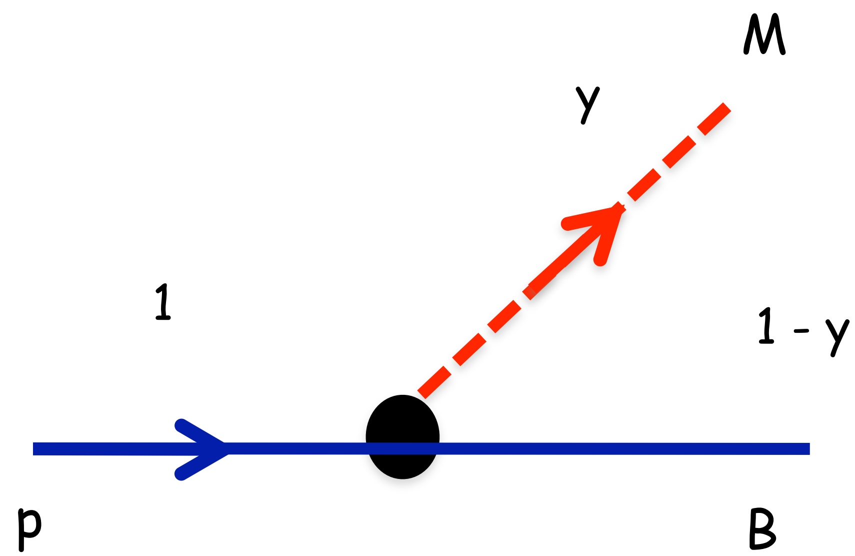
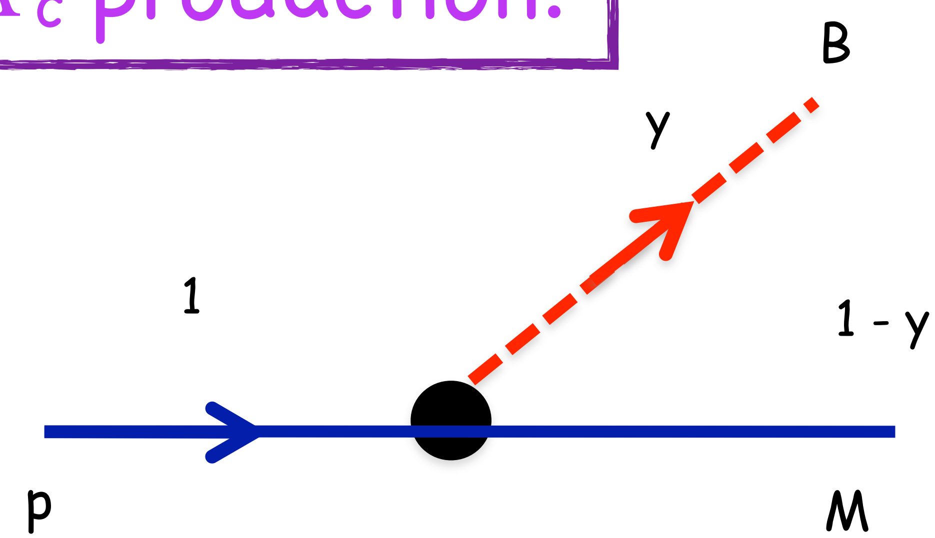


$f_M(y)$: probability density of finding a meson with momentum fraction y of the total state $|MB>$

Similar expression for Λ_c production:

$$\Phi_D = \frac{\pi}{x_F} f_\Lambda(x_F)\, \sigma^{Dp}$$



$$f_M(y) = f_B(1-y)$$

D^+/D^- production asymmetry

$$A^D(x_F) = \frac{\frac{d\sigma^{D^-}(x_F)}{dx_F} - \frac{d\sigma^{D^+}(x_F)}{dx_F}}{\frac{d\sigma^{D^-}(x_F)}{dx_F} + \frac{d\sigma^{D^+}(x_F)}{dx_F}} = \frac{\Phi_D + \Phi_I^{D^-} + \Phi_0^{D^-} - \Phi_I^{D^+} - \Phi_0^{D^+}}{\Phi_D + \Phi_I^{D^-} + \Phi_0^{D^-} + \Phi_I^{D^+} + \Phi_0^{D^+}}$$

$$\simeq \frac{\Phi_D}{\Phi_D + 2\,\Phi_I^D + 2\,\Phi_0^D} \equiv \frac{\Phi_D}{\Phi_T^D}$$

$$\left\{ \begin{aligned} \Phi_T^D &= \frac{d\sigma^{D^-}(x_F)}{dx_F} + \frac{d\sigma^{D^+}(x_F)}{dx_F} \\ &= \sigma_0^D\,[\,(1-x_F)^{n^-} + (1-x_F)^{n^+}\,] \\ &\simeq 2\,\sigma_0^D\,(1-x_F)^{n_D} \qquad (n_D = 5) \\ \Phi_D &= \frac{\pi}{x_F}\, f_D(x_F)\,\sigma^{\Sigma p} \end{aligned} \right.$$

D+/D- production asymmetry

$$A^D(x_F) = \frac{\frac{d\sigma^{D^-}(x_F)}{dx_F} - \frac{d\sigma^{D^+}(x_F)}{dx_F}}{\frac{d\sigma^{D^-}(x_F)}{dx_F} + \frac{d\sigma^{D^+}(x_F)}{dx_F}} = \frac{\Phi_D + \Phi_I^{D^-} + \Phi_0^{D^-} - \Phi_I^{D^+} - \Phi_0^{D^+}}{\Phi_D + \Phi_I^{D^-} + \Phi_0^{D^-} + \Phi_I^{D^+} + \Phi_0^{D^+}}$$

$$\simeq \frac{\Phi_D}{\Phi_D + 2\,\Phi_I^D + 2\,\Phi_0^D} \equiv \frac{\Phi_D}{\Phi_T^D}$$

$$\Phi_T^D = \frac{d\sigma^{D^-}(x_F)}{dx_F} + \frac{d\sigma^{D^+}(x_F)}{dx_F}$$

$$= \sigma_0^D\,[\,(1-x_F)^{n^-} + (1-x_F)^{n^+}\,]$$

$$\simeq 2\,\sigma_0^D\,(1-x_F)^{n_D} \qquad (n_D = 5)$$

$$\Phi_D = \frac{\pi}{x_F}\,f_D(x_F)\,\sigma^{\Sigma p}$$

$$A^D(x_F) = \frac{\pi\,\sigma^{\Sigma p}}{2\,\sigma_0^D}\,\frac{f_D(x_F)}{x_F\,(1-x_F)^{n_D}}$$

energy dependent

$$\Phi_T^D = \frac{d\sigma^{D^+}}{dx_F} + \frac{d\sigma^{D^-}}{dx_F} \simeq 2\sigma_0^D(1-x_F)^5 \Rightarrow \ \sigma^{D^+} + \sigma^{D^-} \simeq \frac{1}{3}\sigma_0^D$$

$$\sigma^{D^+} + \sigma^{D^-} + \sigma^{D^0} + \sigma^{\bar{D}^0} = \sigma_{c\bar{c}} \Rightarrow \sigma^{D^+} + \sigma^{D^-} = \frac{1}{2}\sigma_{c\bar{c}}$$

therefore we have: $\sigma_0^D = \dfrac{3}{2}\sigma_{c\bar{c}}$

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we assume $\sigma^{\Sigma p}$ to be proportional to σ^{pp}: $\sigma^{\Sigma p} = \mathrm{const.}\sigma_{pp}$

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$$A^D(x_F) = \frac{C\pi}{3}\frac{\sigma_{pp}}{\sigma_{c\bar{c}}}\frac{f_D(x_F)}{x_F(1-x_F)^{n_D}}$$

The energy dependence

$$A^D(x_F) = \frac{C\pi}{3}\frac{\sigma_{pp}}{\sigma_{c\bar{c}}}\frac{f_D(x_F)}{x_F(1-x_F)^{n_D}}$$

$$R_A = \frac{A(\sqrt{s_2})}{A(\sqrt{s_1})} = \left(\frac{\sigma_{pp}(s_2)}{\sigma_{pp}(s_1)}\right) \Big/ \left(\frac{\sigma_{c\bar{c}}(s_2)}{\sigma_{c\bar{c}}(s_1)}\right)$$

Energy (GeV)	σ_{pp} (mb)	$\sigma_{c\bar{c}}$ (mb)
40	40	0.04
7000	97	8
14000	110	11

$$R_A = \frac{A(7\ \text{TeV})}{A(40\ \text{GeV})} = \frac{1}{75}$$

The energy dependence

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Energy (GeV)	σ_{pp} (mb)	$\sigma_{c\bar{c}}$ (mb)
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$\sigma_{c\bar{c}}$: Nelson, Vogt, Frawley, arXiv:1210.4610

σ_{pp} : Fagundes, Menon, Silva, arXiv:1208.3456

$$R_A = \frac{A(7\text{ TeV})}{A(40\text{ GeV})} = \frac{1}{75} \qquad R_A = \frac{A(14\text{ TeV})}{A(40\text{ GeV})} = \frac{1}{100}$$

Strong decrease in the asymmetry with increasing energy

Splitting functions

MCM Ansatz :

$$f_M(y) = \frac{g^2_{MBB'}}{16\pi^2}\, y \int_{-\infty}^{t_{max}} dt\, \frac{[-t + (m_{B'} - m_B)^2]}{[t - m_M^2]^2} \quad F^2_{MBB'}(t)$$

Koepf, Frankfurt, Strikman, PRD (1996); Kumano, PR (1998)

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$$F_{MBB'}(t) = \exp\left(\frac{t - m_M^2}{\Lambda^2_{MBB'}}\right)$$

hadronic form factor

Splitting functions

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$\Lambda_{MBB'}$ cutoff parameter

$$F_{MBB'}(t) = \exp\left(\frac{t - m^2_M}{\Lambda^2_{MBB'}}\right)$$

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Splitting functions

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$$F_{MBB'}(t) = \exp\left(\frac{t - m^2_M}{\Lambda^2_{MBB'}}\right)$$

hadronic

form factor

$$A^D(x_F) = \frac{N^D}{(1 - x_F)^{n_D}} \int_{-\infty}^{t_{max}} dt\, \frac{[-t + (m_\Sigma - m_p)^2]}{[t - m^2_D]^2} F^2_{pD\Sigma}(t)$$

Splitting functions

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hadronic form factor

$$A^D(x_F) = \frac{N^D}{(1-x_F)^{n_D}} \int_{-\infty}^{t_{max}} dt\, \frac{[-t+(m_\Sigma-m_p)^2]}{[t-m_D^2]^2}\, F^2_{pD\Sigma}(t)$$

$$t_{max} = m_B^2 x_F - m_{B'}^2 x_F/(1-x_F)$$

$$N^D = \frac{C g^2_{pD\Sigma_c}}{48\pi}\, \frac{\sigma_{pp}}{\sigma_{c\bar{c}}}$$

Splitting functions

MCM Ansatz :

$$f_M(y) = \frac{g^2_{MBB'}}{16\pi^2}\, y \int_{-\infty}^{t_{max}} dt\, \frac{[-t+(m_{B'}-m_B)^2]}{[t-m_M^2]^2}\, F^2_{MBB'}(t)$$

Koepf, Frankfurt, Strikman, PRD (1996); Kumano, PR (1998)

$\Lambda_{MBB'}$ cutoff parameter

$$F_{MBB'}(t) = \exp\left(\frac{t-m_M^2}{\Lambda^2_{MBB'}}\right)$$

hadronic form factor

$$A^D(x_F) = \frac{N^D}{(1-x_F)^{n_D}} \int_{-\infty}^{t_{max}} dt\, \frac{[-t+(m_\Sigma-m_p)^2]}{[t-m_D^2]^2}\, F^2_{pD\Sigma}(t)$$

$$t_{max} = m_B^2 x_F - m_{B'}^2 x_F/(1-x_F)$$

$$N^D = \frac{C g^2_{pD\Sigma_c}}{48\pi}\,\frac{\sigma_{pp}}{\sigma_{c\bar{c}}}$$

$$C = \frac{\sigma^{\Sigma_c p}}{\sigma_{pp}} \sim 0.15$$

Splitting functions

MCM Ansatz :

$$f_M(y) = \frac{g^2_{MBB'}}{16\pi^2}\, y \int_{-\infty}^{t_{max}} dt\, \frac{[-t+(m_{B'}-m_B)^2]}{[t-m_M^2]^2}\, F^2_{MBB'}(t)$$

Koepf, Frankfurt, Strikman, PRD (1996); Kumano, PR (1998)

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$$g_{pD-\Sigma_c^{++}} = g_{p\bar{D}_0\Lambda_c} = 5.6$$

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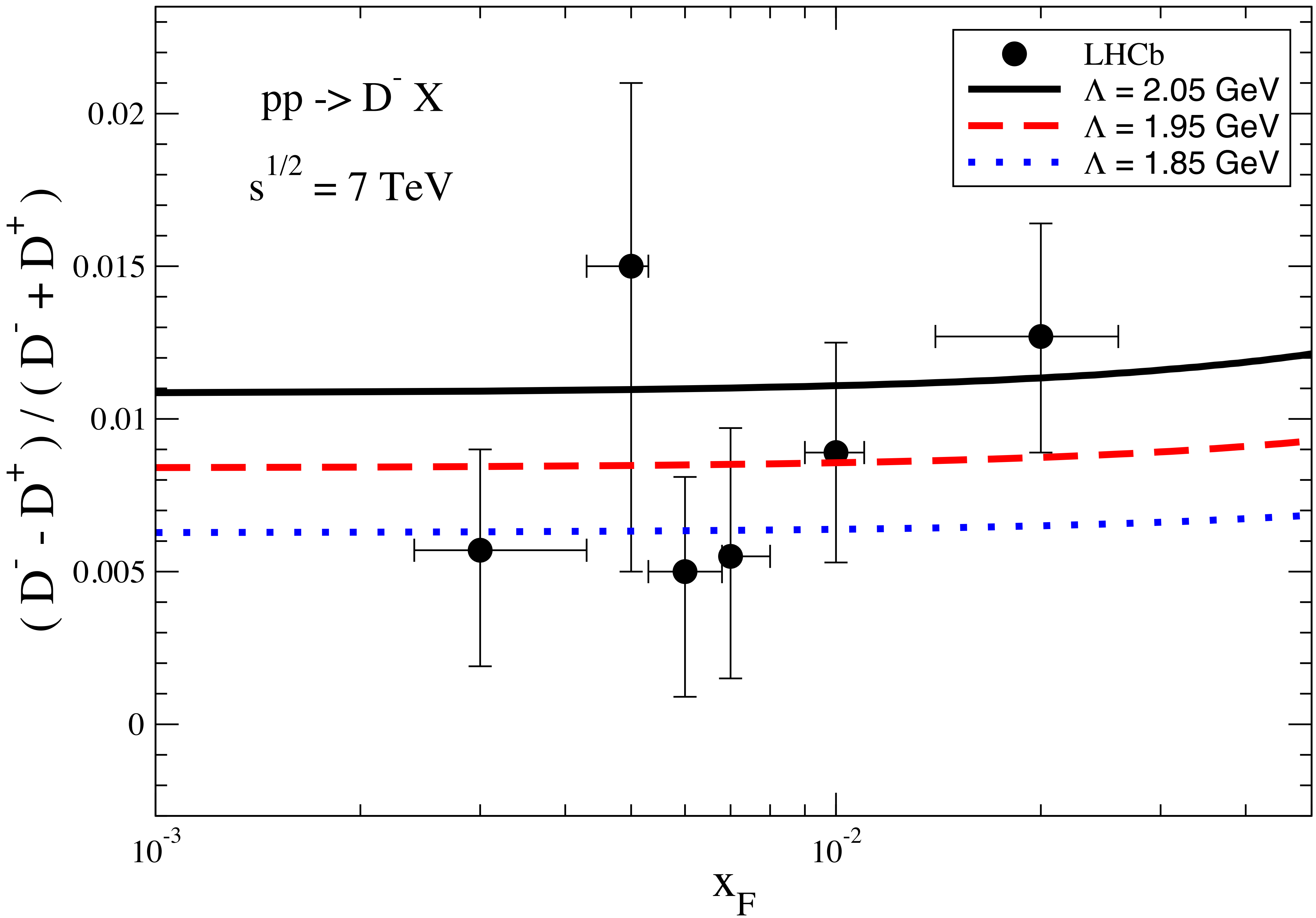
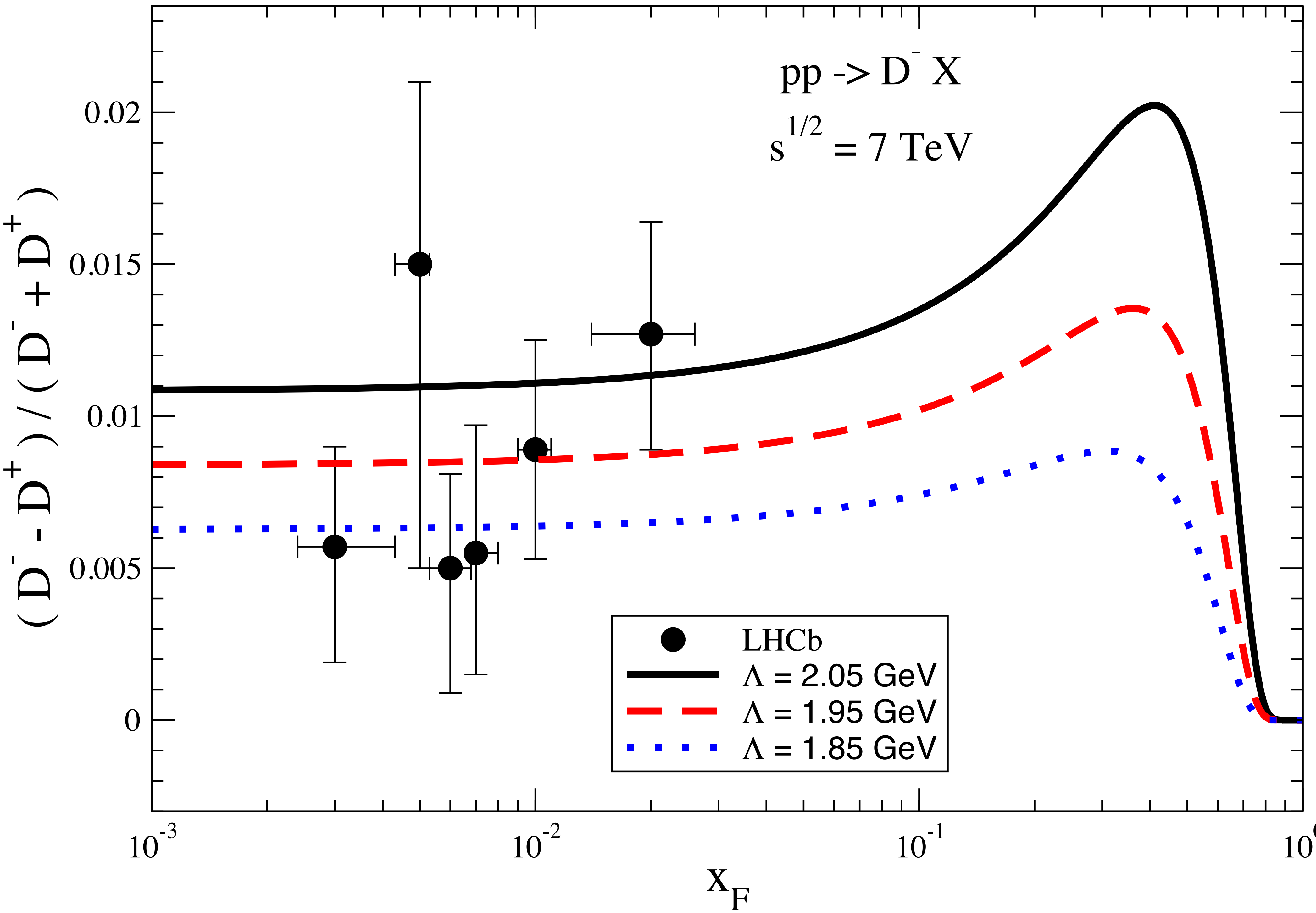
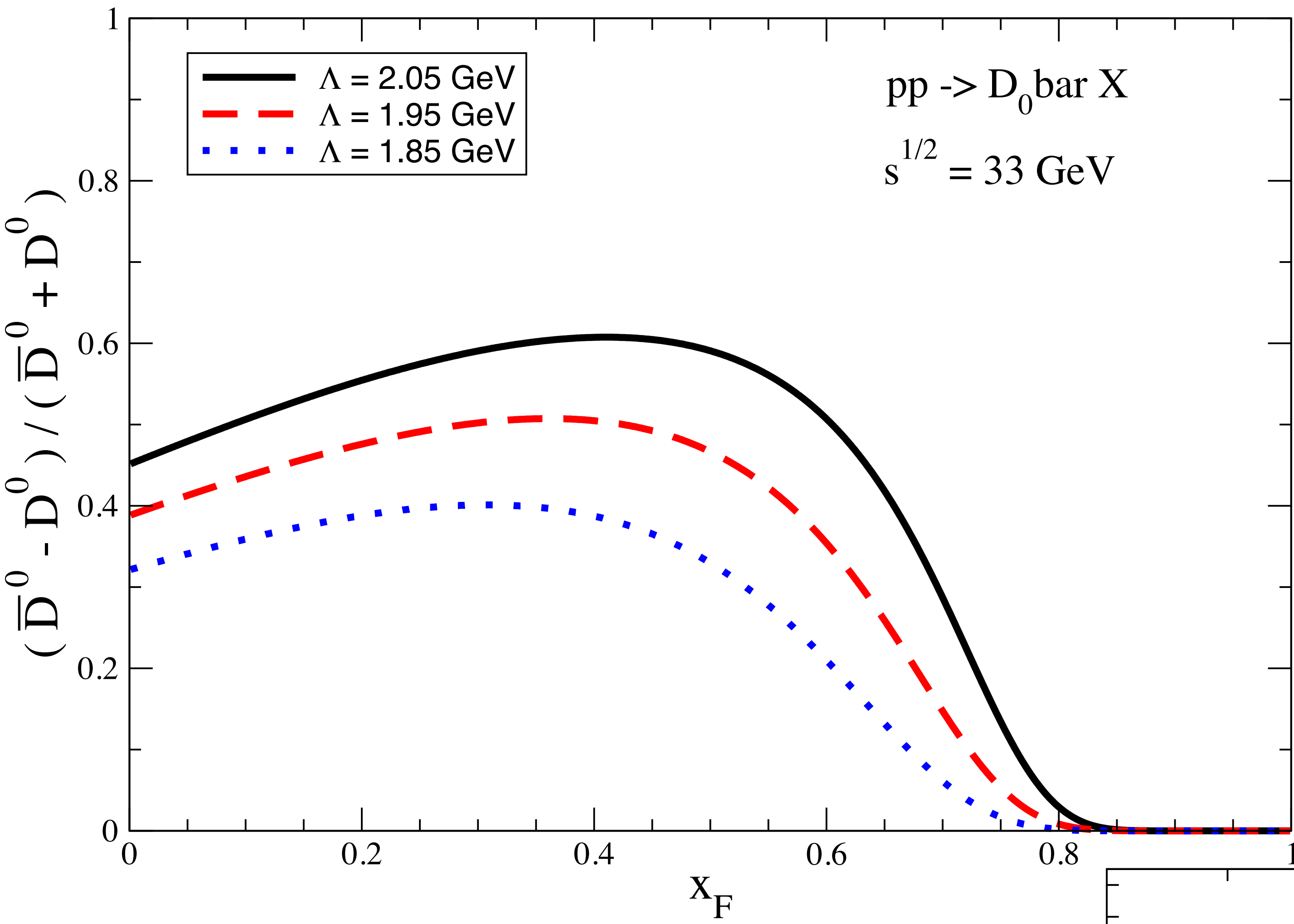
The x_F dependence

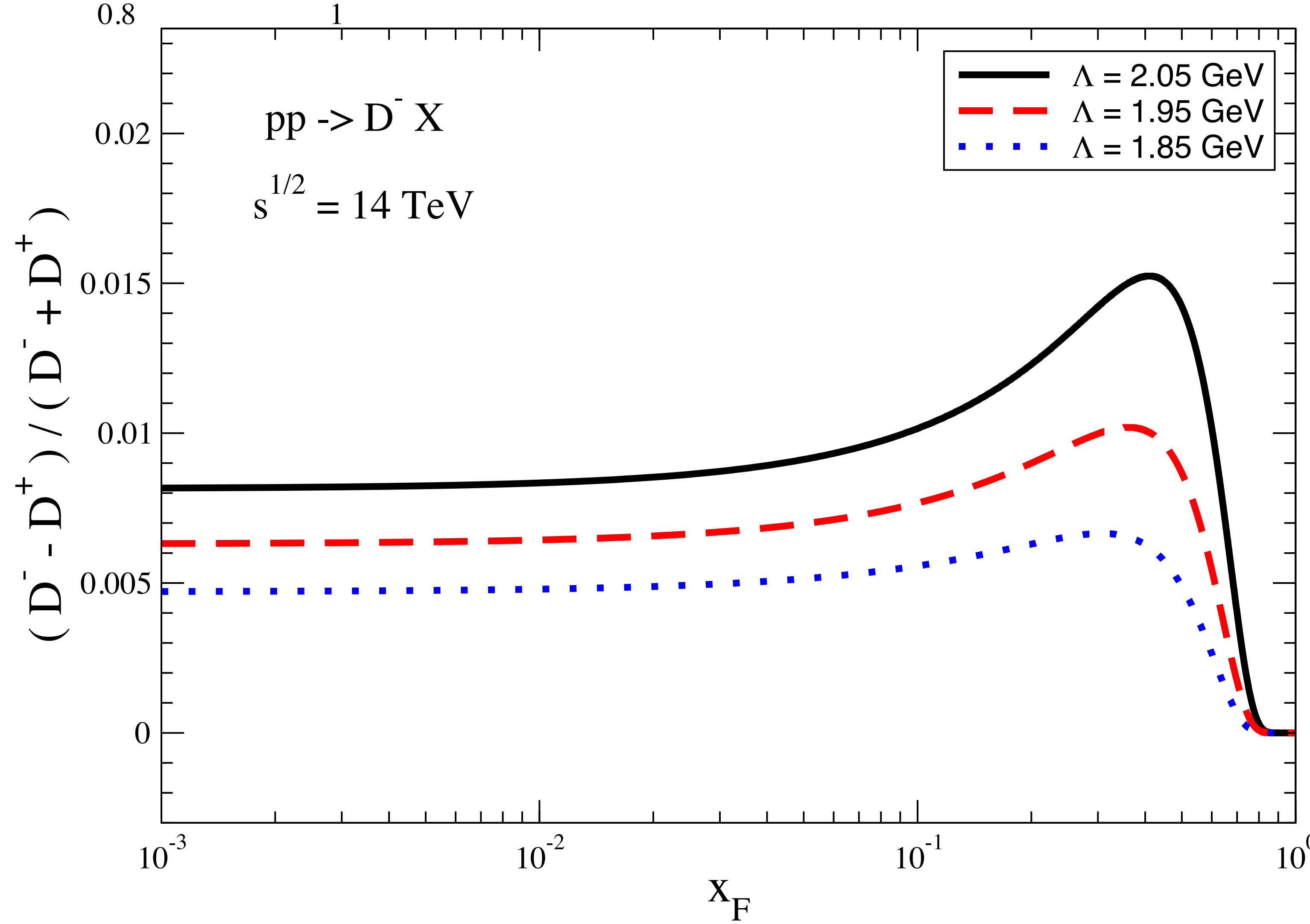


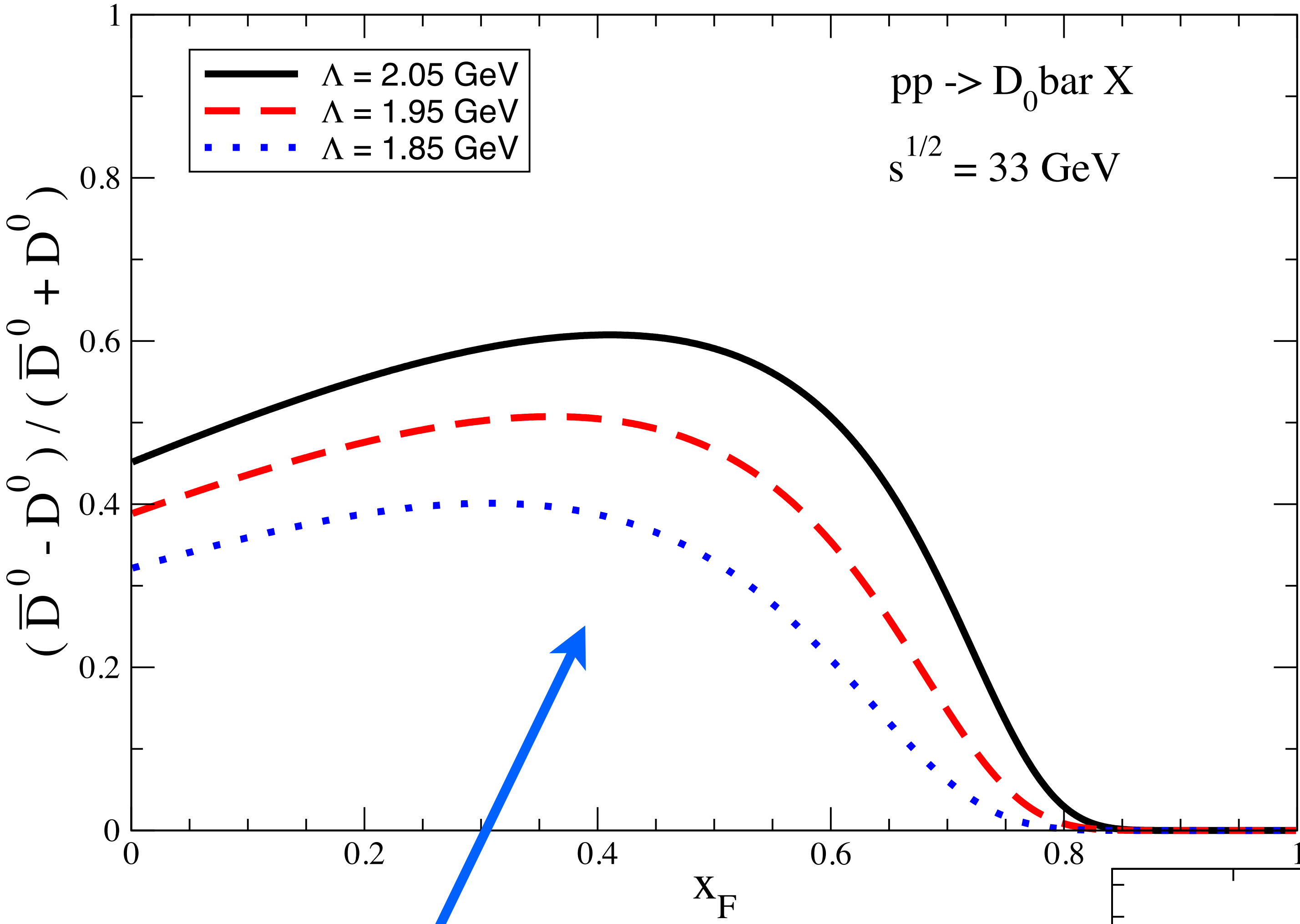
The x_F dependence extended



The x_F dependence for different energies

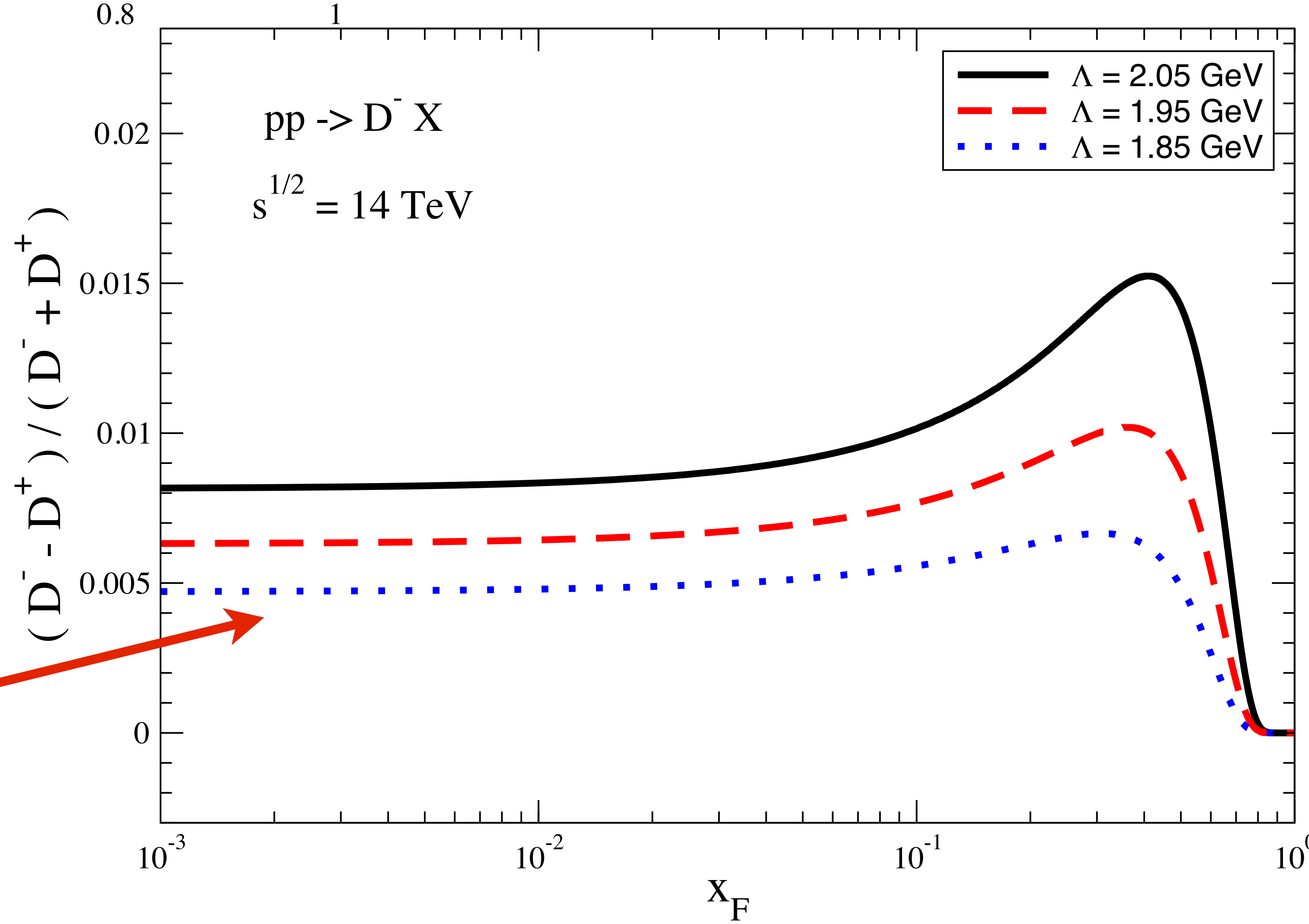






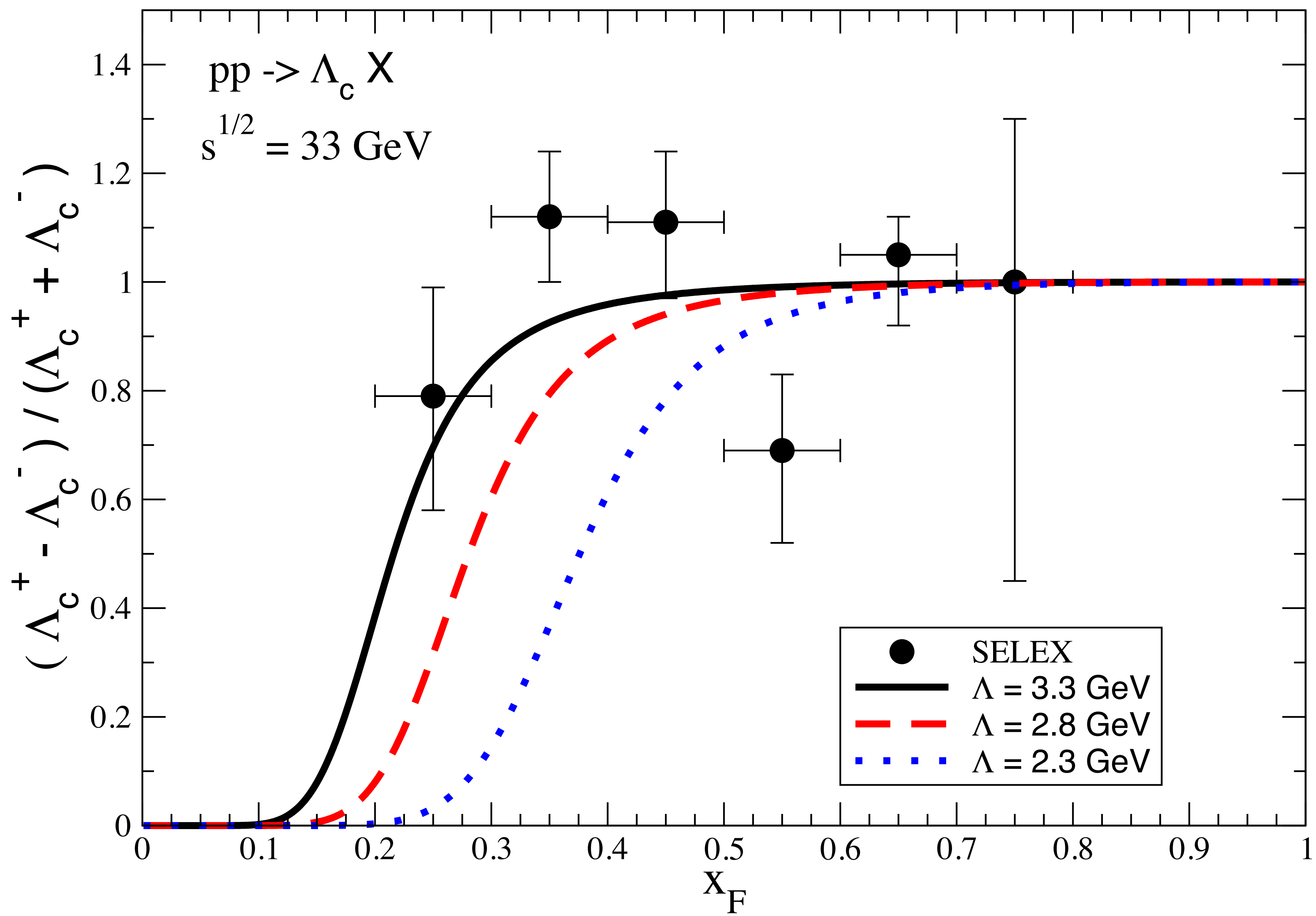
The x_F dependence for different energies

energy of SELEX Coll. for measuring Λ_c^+/Λ_c^- asymmetry

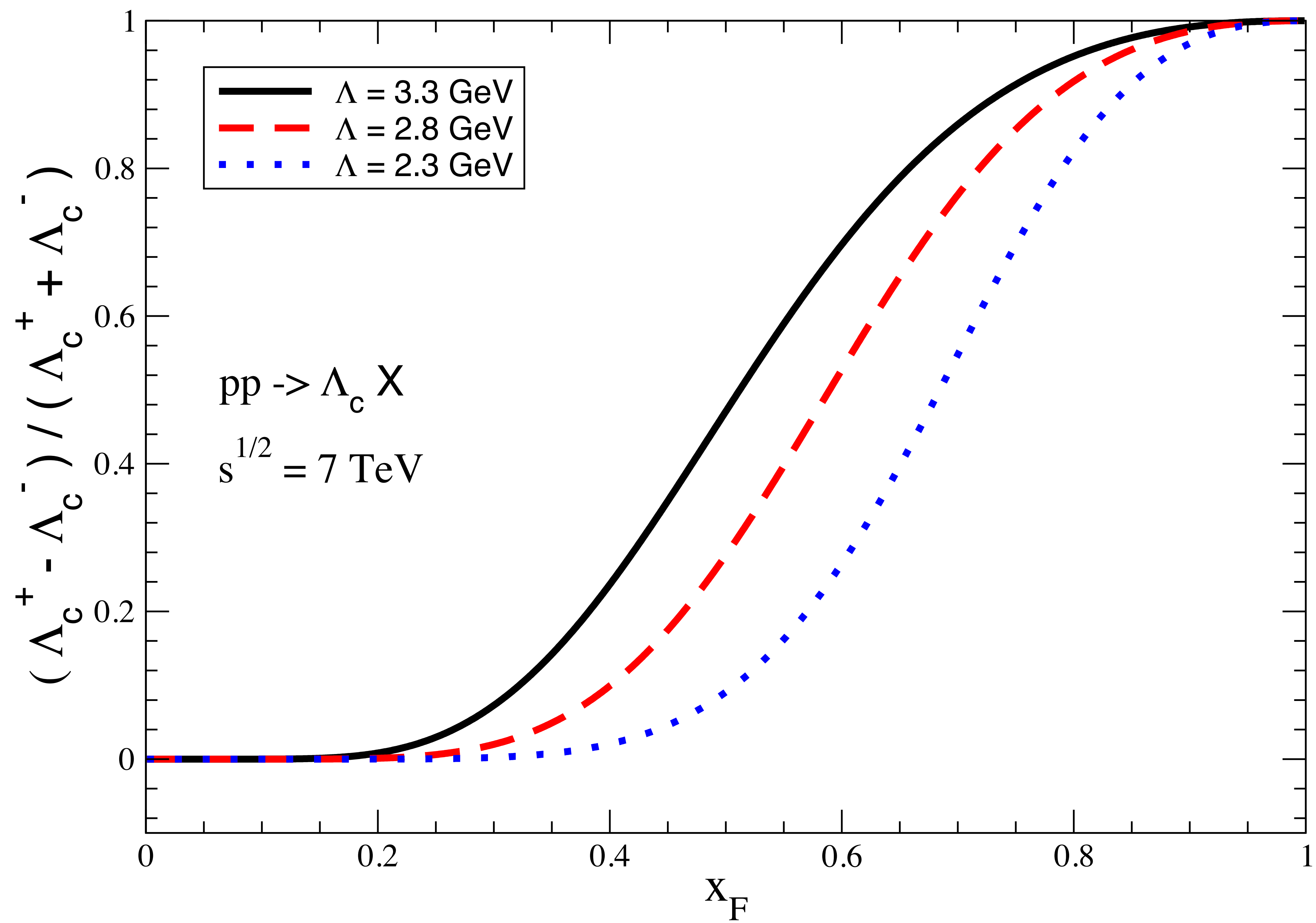


prediction for LHCb

Extension for Λ_c asymmetry



Predicition for Λ_c asymmetry



Summary

Charm asymmetry is a good tool to learn more about the proton structure

It is important to have better data

We know that it is large at low energies

MCM: the asymmetry falls with energy because the partonic cross sections grow faster than the hadronic cross sections

Good qualitative and quantitative understanding of data

Predicition for 14 TeV data

MCM can be systematically improved