Open charm production in Double Parton Scattering processes in the forward kinematics

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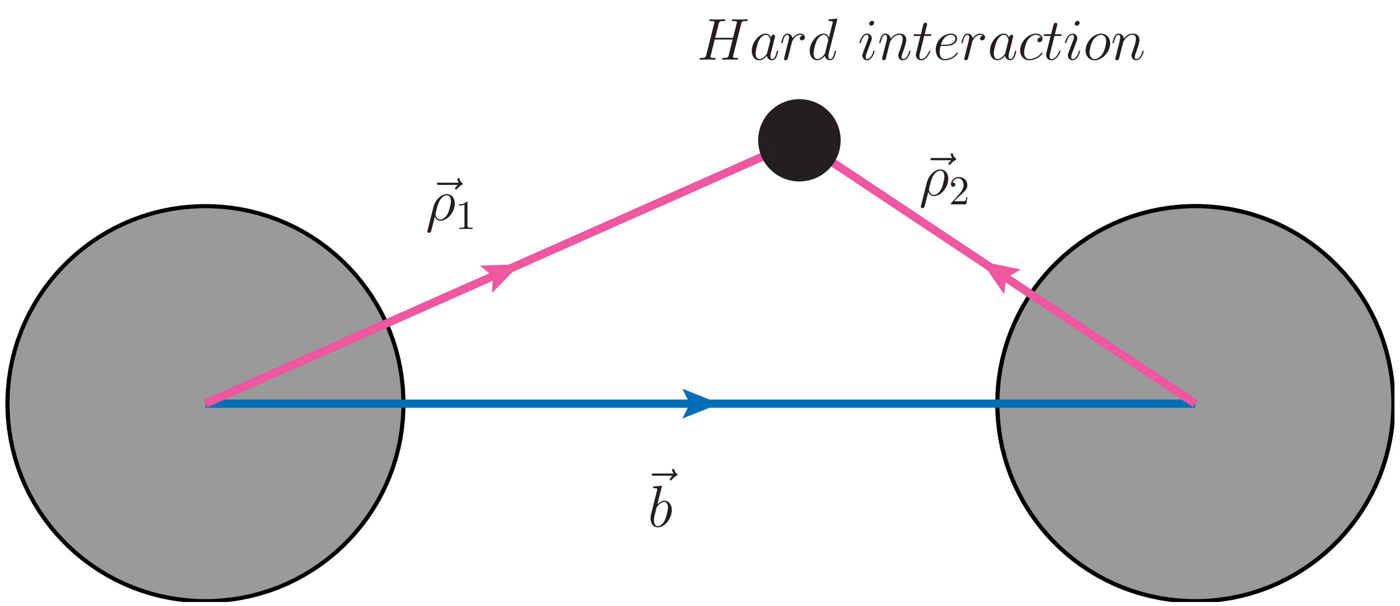
PSU

for Boris Blok

B.Blok, M.Strikman **arXiv:1608.00014; arXiv:1611.03649**

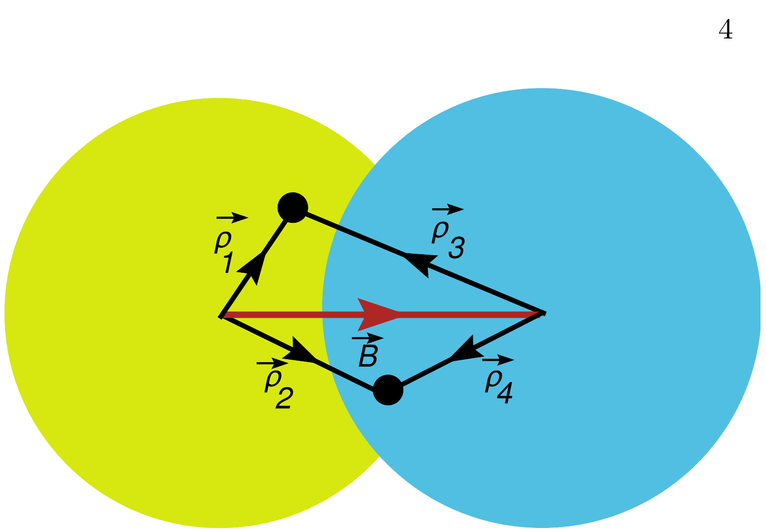
in press

MPI 16

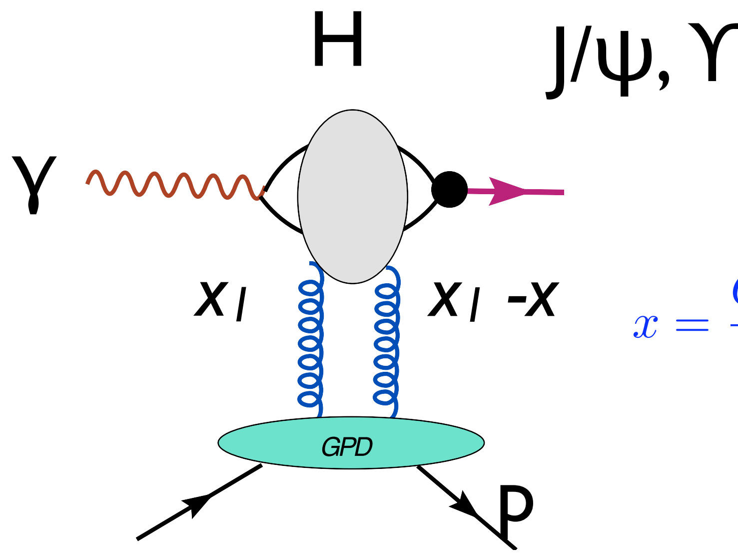


inclusive rate does not depend on transverse size

geometrical picture - 4 → 4



DPI rate ∝ 1/(transverse size)^2



$$x = \frac{Q^2 + m_V^2}{W^2}$$

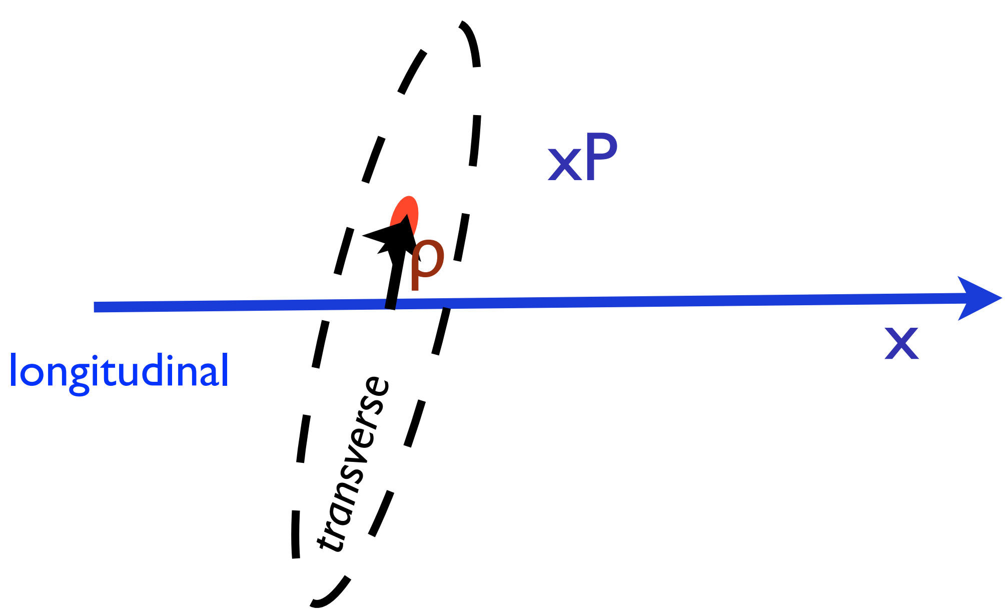
In LT limit x_l -x << x_l

however due to DGLAP evolution skewed GPD kinematics for large Q probes diagonal GPD at Q_0 scale

$$A(\gamma^* + p \to \text{"}Onium\text{"} + p) \propto G(x_1, x_1 - x, t)$$

$$G(x,x,t) \equiv G(x,t) = \int d^2\rho e^{-i\vec{\Delta}_\perp \rho} G(x,\rho)$$

transverse spatial distribution of gluons



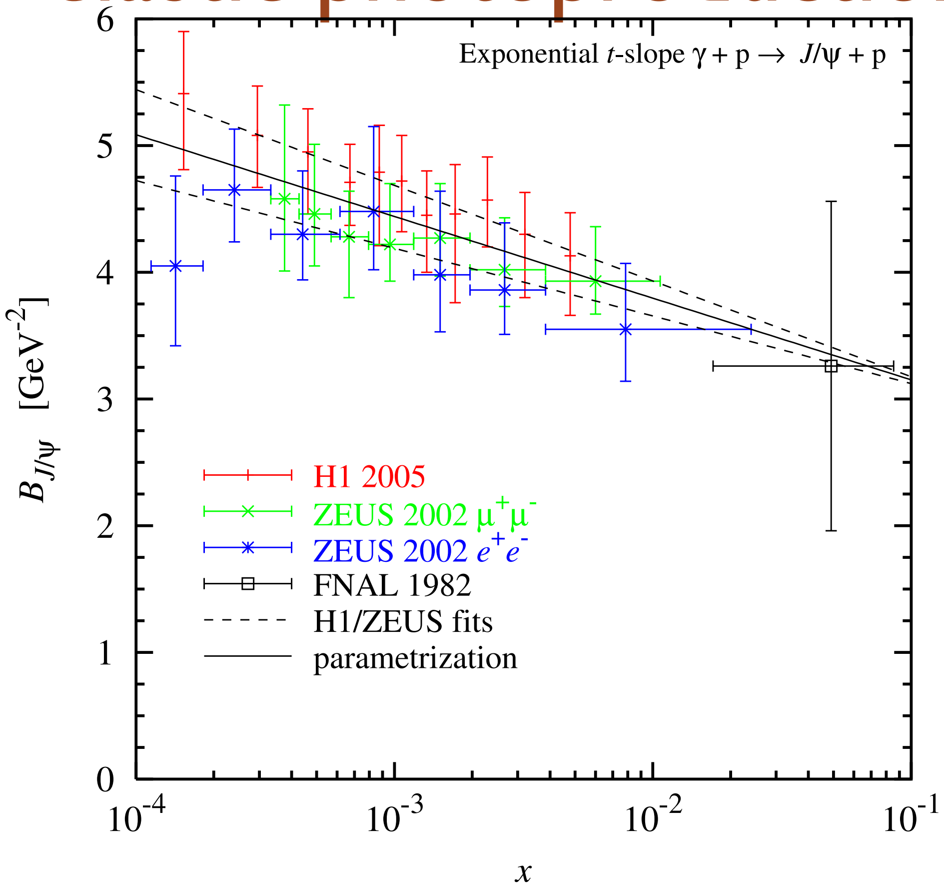
$$\int d^2\rho G(x,\rho) = G(x)$$

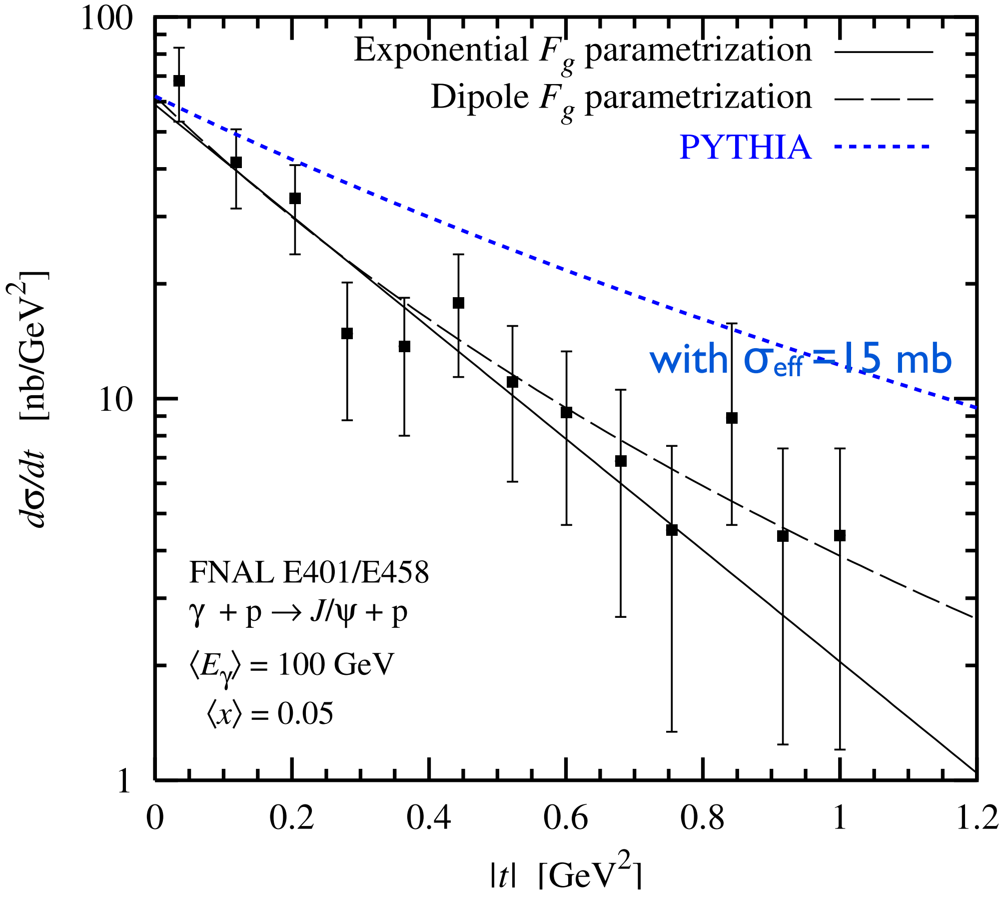
total gluon density

$$G(x,t)/G(x) = F_g(x,t) = 1/(1 - t/m_g(x)^2)$$

$$F_g(x,\rho) = \frac{m_g^2}{2\pi} \left(\frac{m_g \rho}{2}\right) K_1(m_g \rho)$$

J/ψ elastic photoproduction data





$$F_{2g}(x \sim 0.03, t) = (1 - t/m_g^2)^{-2}, m_g^2 \sim 1.1\, GeV^2$$

Independent particle (mean field) approximation

$$\sigma_{eff} = \frac{28\pi}{m_g^2} \sim 34 \text{ mb.}$$

Frankfurt, MS, Weiss 03

For m^2=0.7 GeV^2 ~ 54 mb

$$\frac{1}{\sigma_{eff}} = \int \frac{d^2\Delta}{(2\pi)^2} F_{2g}^4(\Delta) = \frac{m_g^2}{28\pi}.$$

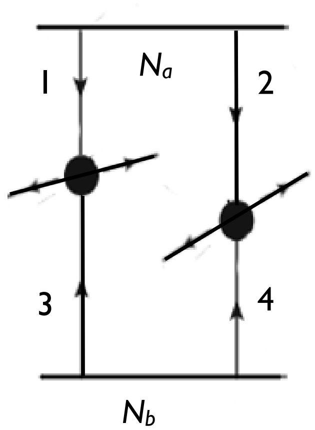
⇨ *Puzzle - need correlations. what is their origin?*

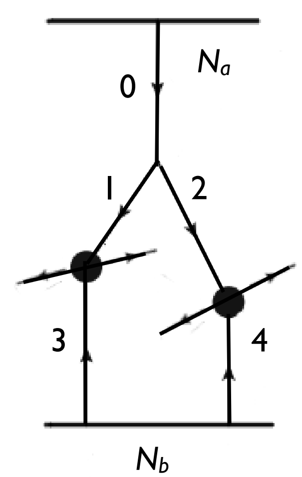
Correlation mechanisms

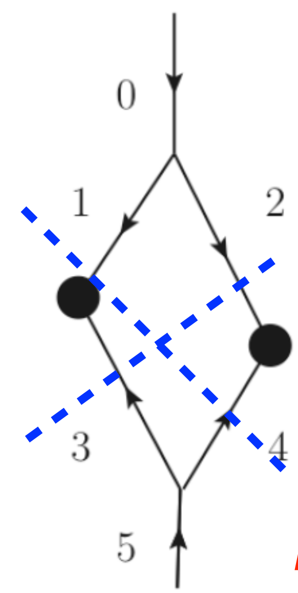
Generated by the pQCD evolution: 3 to 4

parton splits into two partons with close impact parameters in the process of DGLAP Q^2 evolution

Correlation grows with Q^2 (σ_{eff} drops)







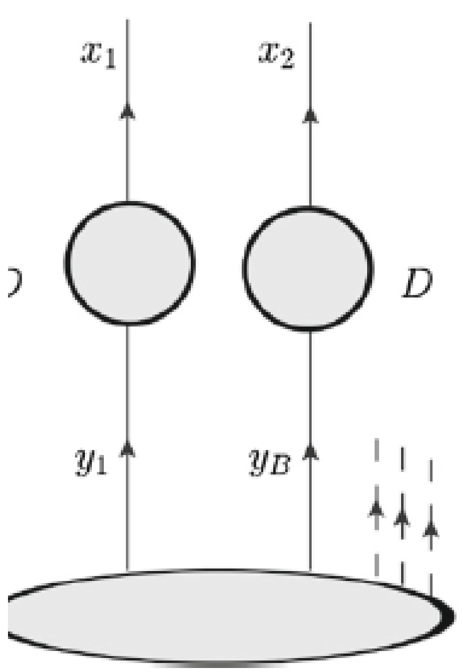
part of 2 to 4

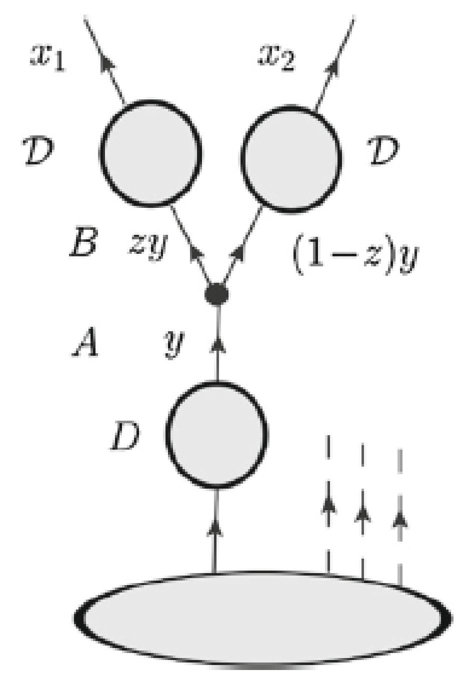
In the boundary condition at low Q

washed out by pQCD evolution (σ_{eff} grows)

$$
{}_{[1]}D_a^{b,c}(x_1, x_2; q_1^2, q_2^2; \vec{\Delta})
= \sum_{a',b',c'} \int_{Q_{\min}^2}^{\min(q_1^2,q_2^2)} \frac{dk^2}{k^2} \frac{\alpha_s(k^2)}{2\pi}
\times \int \frac{dy}{y^2} G_a^{a'}(y; k^2, Q_0^2)
\times \int \frac{dz}{z(1-z)} P_{a'}^{b'[c']}(z) G_{b'}^{b}\left(\frac{x_1}{zy}; q_1^2, k^2\right)
\times G_{c'}^{c}\left(\frac{x_2}{(1-z)y}; q_2^2, k^2\right).
$$

$$
\begin{aligned}
{}_{[2]}D_a^{b,c}(x_1, x_2; q_1^2, q_2^2; \vec{\Delta})
&= S_b(q_1^2, Q_{\min}^2) S_c(q_2^2, Q_{\min}^2)\, {}_{[2]}D_a^{b,c}(x_1, x_2; Q_0^2, Q_0^2; \vec{\Delta}) \\
&+ \sum_{b'} \int_{Q_{\min}^2}^{q_1^2} \frac{dk^2}{k^2} \frac{\alpha_s(k^2)}{2\pi} S_b(q_1^2, k^2) \\
&\times \int \frac{dz}{z} P_{b'}^{b}(z)\, {}_{[2]}D_a^{b',c}\left(\frac{x_1}{z}, x_2; k^2, q_2^2; \vec{\Delta}\right) \\
&+ \sum_{c'} \int_{Q_{\min}^2}^{q_2^2} \frac{dk^2}{k^2} \frac{\alpha_s(k^2)}{2\pi} S_c(q_2^2, k^2) \\
&\times \int \frac{dz}{z} P_{c'}^{c}(z)\, {}_{[2]}D_a^{b,c'}\left(x_1, \frac{x_2}{z}; q_1^2, k^2; \vec{\Delta}\right). \qquad (16)
\end{aligned}
$$





D's are double GPDs

$$
D_a^{b,c}(x_1, x_2; q_1^2, q_2^2; \vec{\Delta}) = {}_{[2]}D_a^{b,c}(x_1, x_2; q_1^2, q_2^2; \vec{\Delta}) + {}_{[1]}D_a^{b,c}(x_1, x_2; q_1^2, q_2^2; \vec{\Delta})
$$

$$\frac{1}{\sigma_{eff}} \equiv \int \frac{d^2\vec{\Delta}}{(2\pi)^2}[\ _{[2]}G_2(x_1,x_3,Q_1^2,Q_2^2;\vec{\Delta})_{[2]}G_2(x_2,x_4,Q_1^2,Q_2^2;-\vec{\Delta})$$

$$+\ _{[1]}G_2(x_1,x_3,Q_1^2,Q_2^2;\vec{\Delta})_{[2]}G(x_2,x_4,Q_1^2,Q_2^2;-\vec{\Delta})$$

$$+\ _{[1]}G_2(x_2,x_4,Q_1^2,Q_2^2;\vec{\Delta})_{[2]}G_2(x_1,x_3,Q_1^2,Q_2^2;-\vec{\Delta})].$$

2G2 and 1G2 are two parts of GPD ,calculated in two different ways. 2G2-in mean field approach, using GPD1 from charmonium photoproduction at HERA

$$_{[2]}GPD_2(x_1,x_3,Q_1^2,Q_2^2,\Delta) = D_q(x_1,Q_1)D_g(x_3,Q_2)F_{2q}(\Delta,x_1)F_{2g}(\Delta,x_3),$$

$$GPD_{q,g}(x,Q^2,\Delta) = D_{q,g}(x,Q)F_{2g,2q}(\Delta,x).$$

We use parametrisation due to Frankfurt,Strikman,Weiss (2011)

1G2 is calculated solving evolution equation for GPD

The final answer for effective cross section is convenient to represent as

$$\sigma_{\rm eff} = \frac{\sigma_{\rm eff}^{(0)}}{1+R},$$

Here $\sigma_{\rm eff}^{(0)}$ *is the 4 to 4 cross section in mean field approximationwhile the function R corresponds to contribution due to 3 to 4 mechanism, and is calculated analytically.*

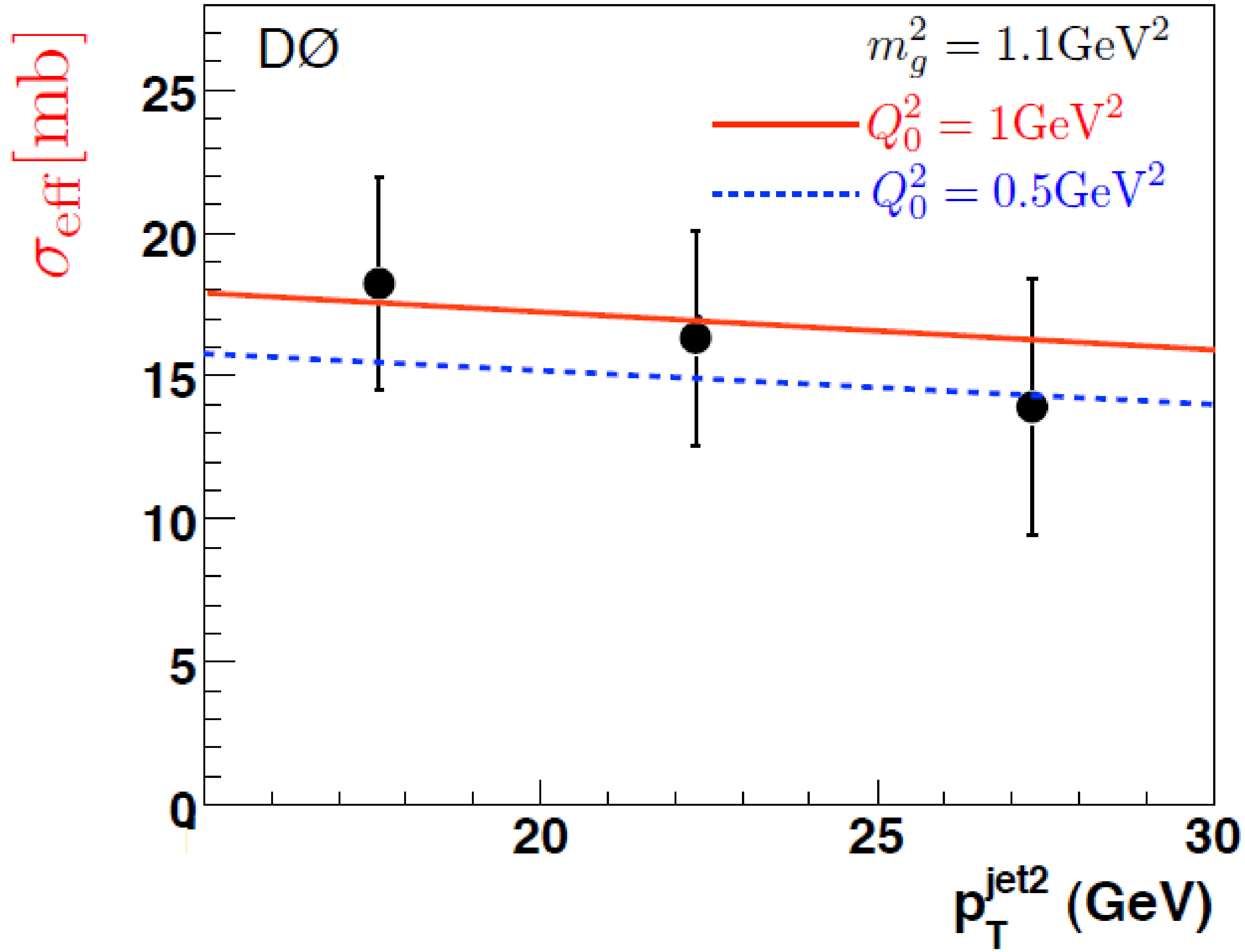
Note: only one unknown paramter-Q0, separating soft and hard scales, so approach is practically model independent.

The total cross sections

$$\frac{d\sigma(x_1,x_2,x_3,x_4)}{d\hat{t}_1\, d\hat{t}_2} = \frac{d\sigma^{13}}{d\hat{t}_1}\,\frac{d\sigma^{24}}{d\hat{t}_2} \times \left\{ \frac{1}{S_4} + \frac{1}{S_3} \right\}.$$

$$\frac{1}{S_4} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2}\, {}_{[2]}D_{h_1}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta})\, {}_{[2]}D_{h_2}(x_3,x_4;q_1^2,q_2^2;-\vec{\Delta}).$$

$$\frac{1}{S_3} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2}\left[{}_{[2]}D_{h_1}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta})\, {}_{[1]}D_{h_2}(x_3,x_4;q_1^2,q_2^2) + {}_{[1]}D_{h_1}(x_1,x_2;q_1^2,q_2^2)\, {}_{[2]}D_{h_2}(x_3,x_4;q_1^2,q_2^2;\vec{\Delta}) \right]$$

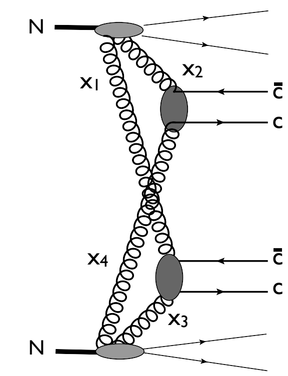


photon + 3 jets

In the LHC energies at central rapidities one typically find an enhancement ~ 2 from pQCD mechanism, which is consistent with the data. Few examples were studied by B.Blok and P. Gunnellini

Challenge are the LHCb double charm data: very accurate , small 2 to 4 background (previous talk)

$\sigma_{eff} \approx 20$ mb



Forward kinematics -- two of x's are small. Gluon radius larger leading to larger σ_{eff} larger than for central region with smaller pQCD effects which hardly can compensate this increase.

Soft correlations and unfactorizable initial conditions.

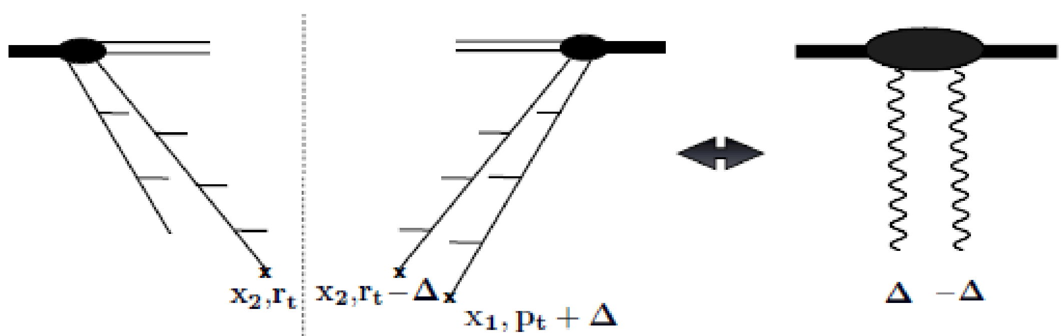
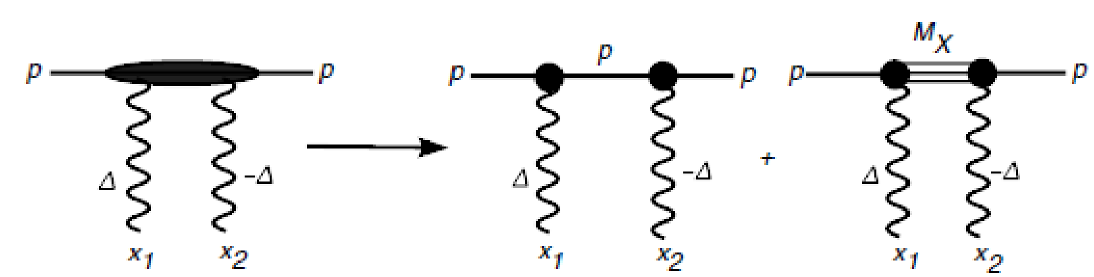


FIG. 3: $_2$GPD as a two Pomeron exchange

BDFS 2012, B.Blok M. Strikman 2016



$2I\!P$ contribution to $_2$D and Reggeon diagrams

For $t = -\Delta^2 = 0$ consider

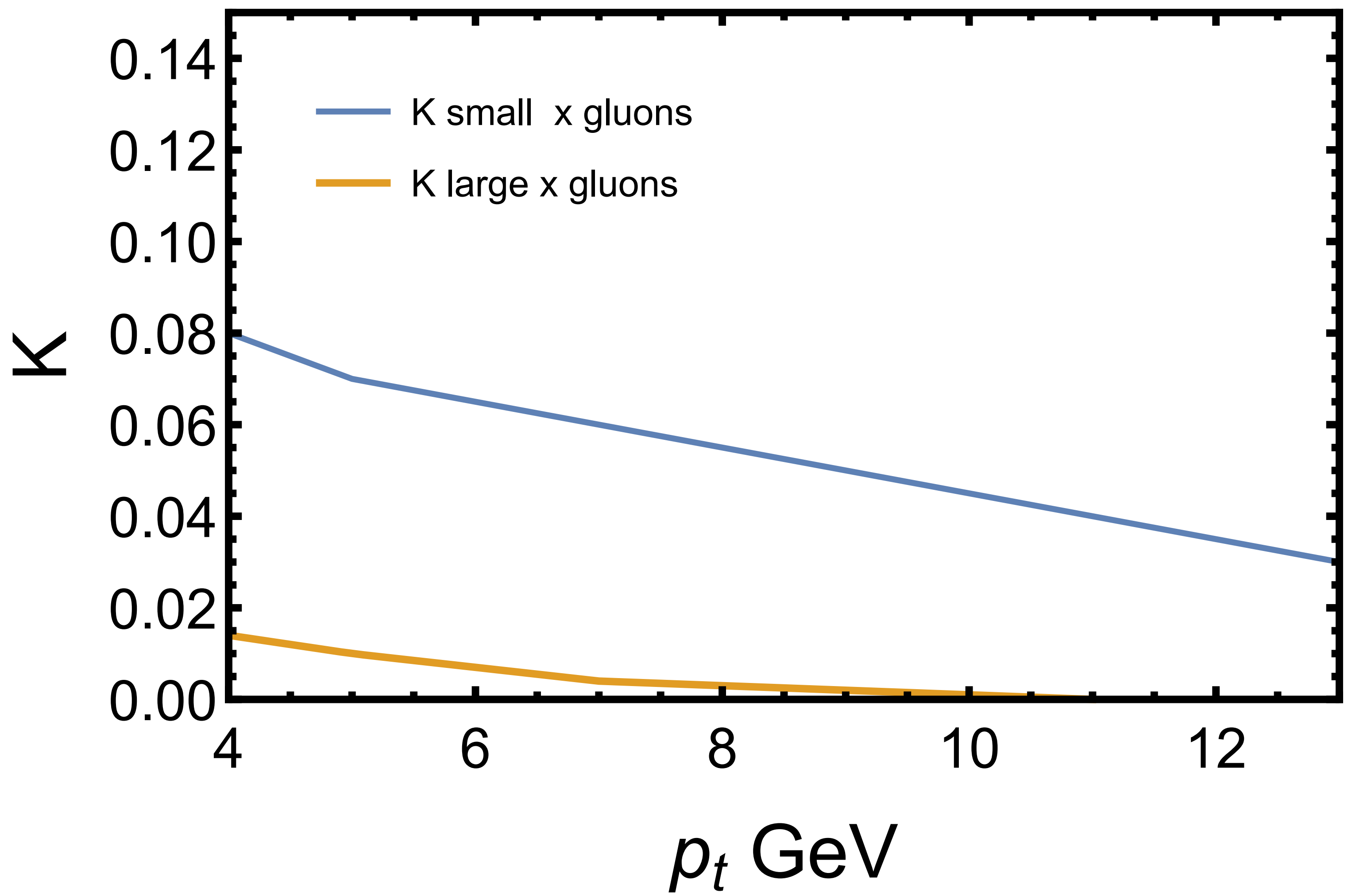
$$\rho(x_1, x_2, Q_0^2) = \frac{{}_2D_{nf}(x_1, x_2, Q_0^2)}{D_f(x_1, x_2, Q_0^2)} = \frac{{}_2D_{nf}(x_1, x_2, Q_0^2)}{D_N(x_1, Q_0^2) D_N(x_2, Q_0^2)}$$

$$\rho(x_1, x_2, Q_0^2) = \int dM^2 S(M^2) \frac{D_N(x_1/x, Q_0^2) D_N(x_2/x, Q_0^2)}{D_N(x_1, Q_0^2) D_N(x_2, Q_0^2)},$$

$$\omega \equiv \frac{\frac{d\sigma_{in.\,dif.}}{dt}}{\frac{d\sigma_{el}}{dt}}\Big|_{t=0} = 0.25 \pm 0.05$$

$${}_2D(x_1, x_2, Q_0^2)_{nf} = c_{3I\!P} \int_{x_m/a}^{1} \frac{dx}{x^{2+\alpha_{I\!P}}} D(x_1/x, Q_0^2) D(x_2/x, Q_0^2)$$

$$K(x_1, x_2, Q_1^2, Q_2^2, Q_0^2) \equiv \frac{D(x_1, x_2, Q_1^2, Q_2^2, Q_0^2)}{D(x_1, Q_1^2) D(x_2, Q_2^2)}$$



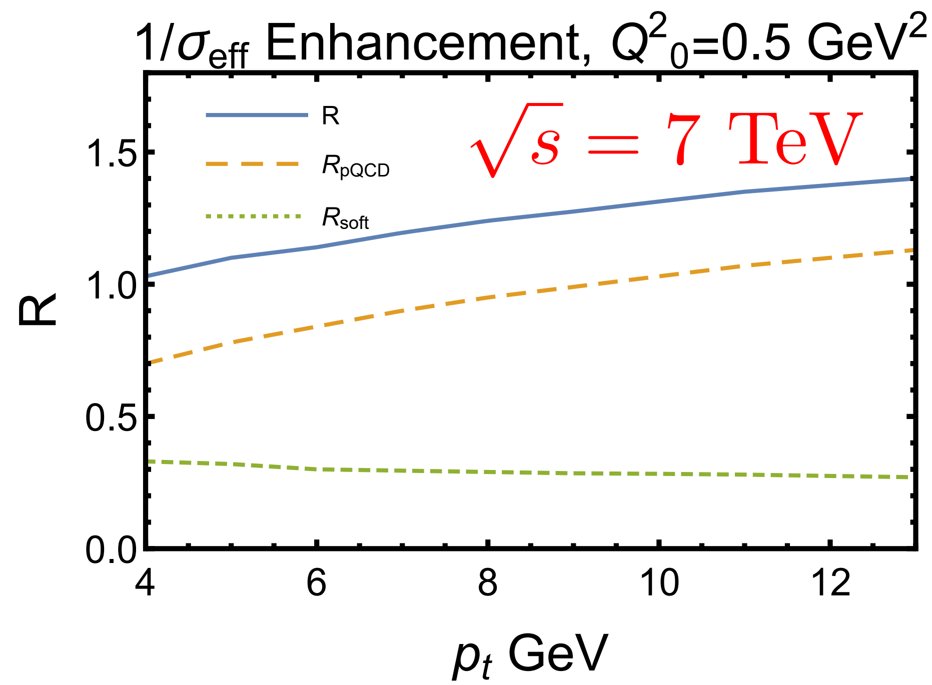
Transverse momentum dependence of K factor for $_2$GPD for regimes of small and large x in kinematics of chapter 2 (Q^2_0 = 0.5 GeV^2)

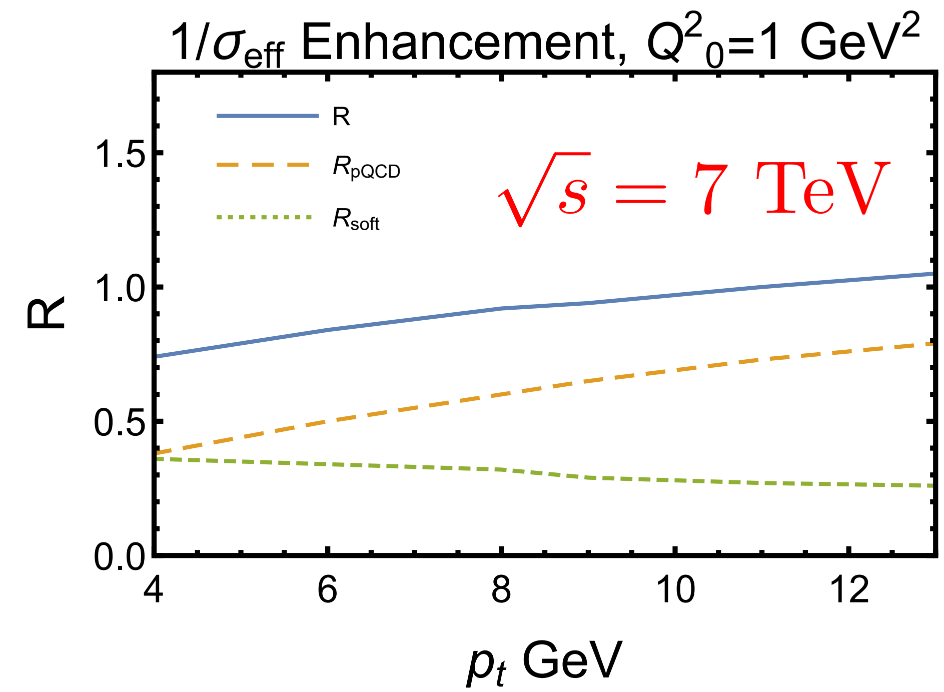
$$R_{\rm tot} = R_{\rm pQCD} + R_{\rm soft}$$

Soft contribution is strongly enhanced due to much smaller t-slope: $B_{inel} << B_{el}$.

$$R_{soft} = K_{12}(\frac{B_{\rm 1el} + B_{\rm 3el}}{B_{\rm 3el} + B_{\rm 1in}} + R_{\rm pQCD}\frac{B_{\rm 1el}}{B_{\rm 1in}})$$

$$\sigma_{\rm eff} \sim 20 - 22mb$$


1/σeff Enhancement, Q²0=0.5 GeV²
R
RpQCD
Rsoft
√s = 7 TeV
R
1.5
1.0
0.5
0.0
4
6
8
10
12
pt GeV


1/σeff Enhancement, Q²0=1 GeV²
R
RpQCD
Rsoft
√s = 7 TeV
R
1.5
1.0
0.5
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4
6
8
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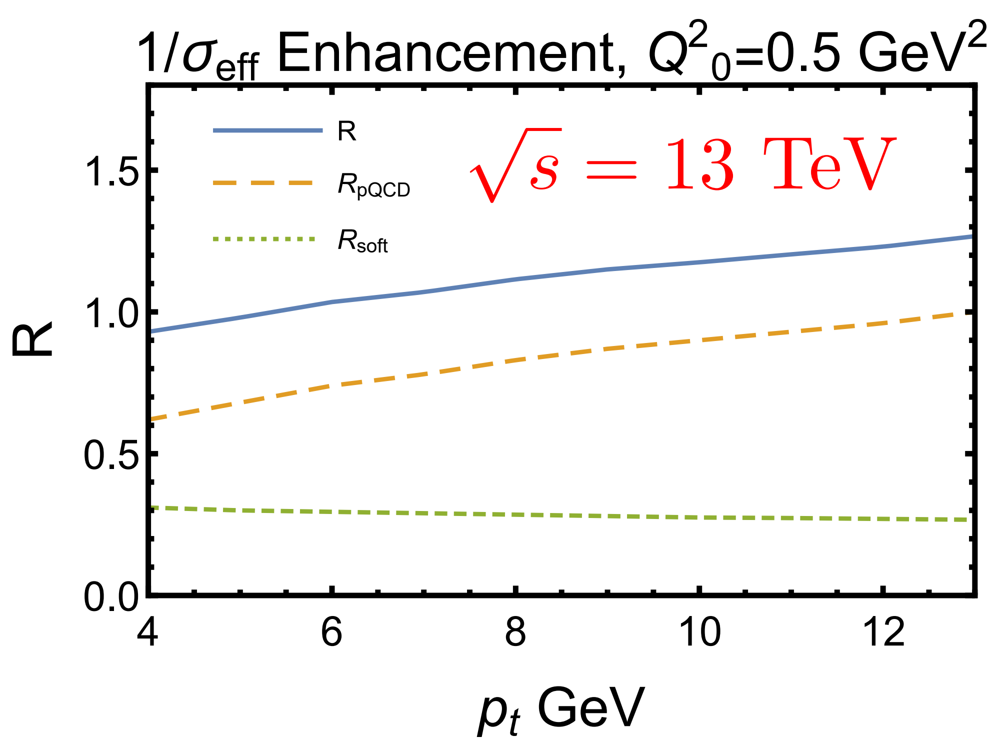
12
pt GeV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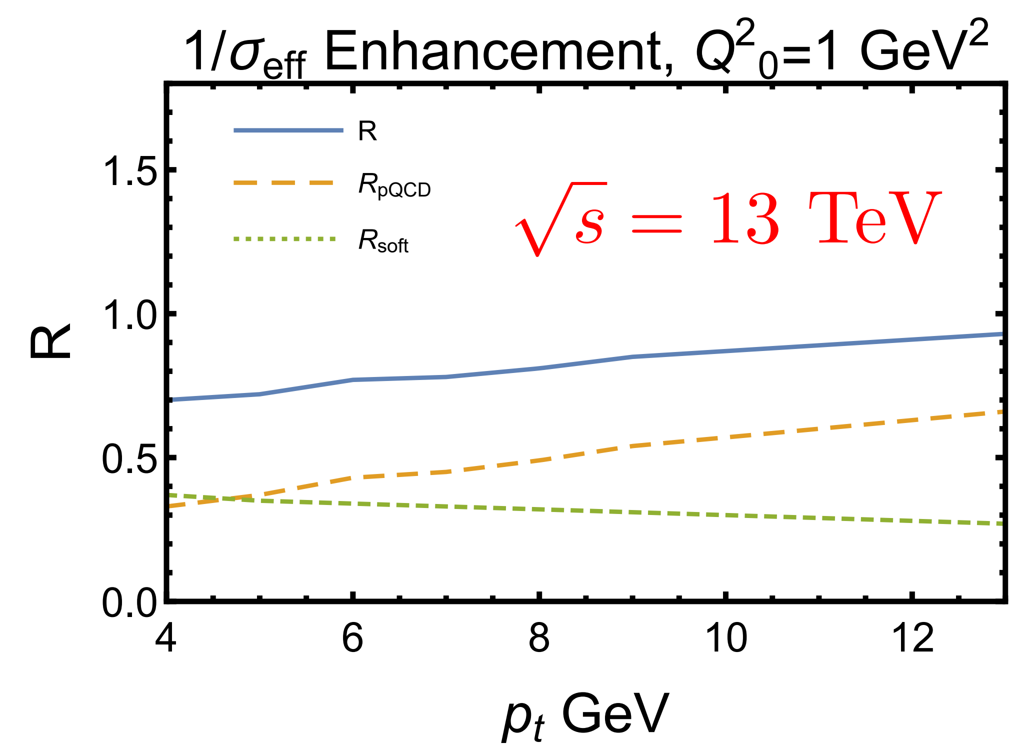
1/σeff Enhancement, Q²0=1 GeV²
R
RpQCD
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√s = 13 TeV
R
1.5
1.0
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4
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8
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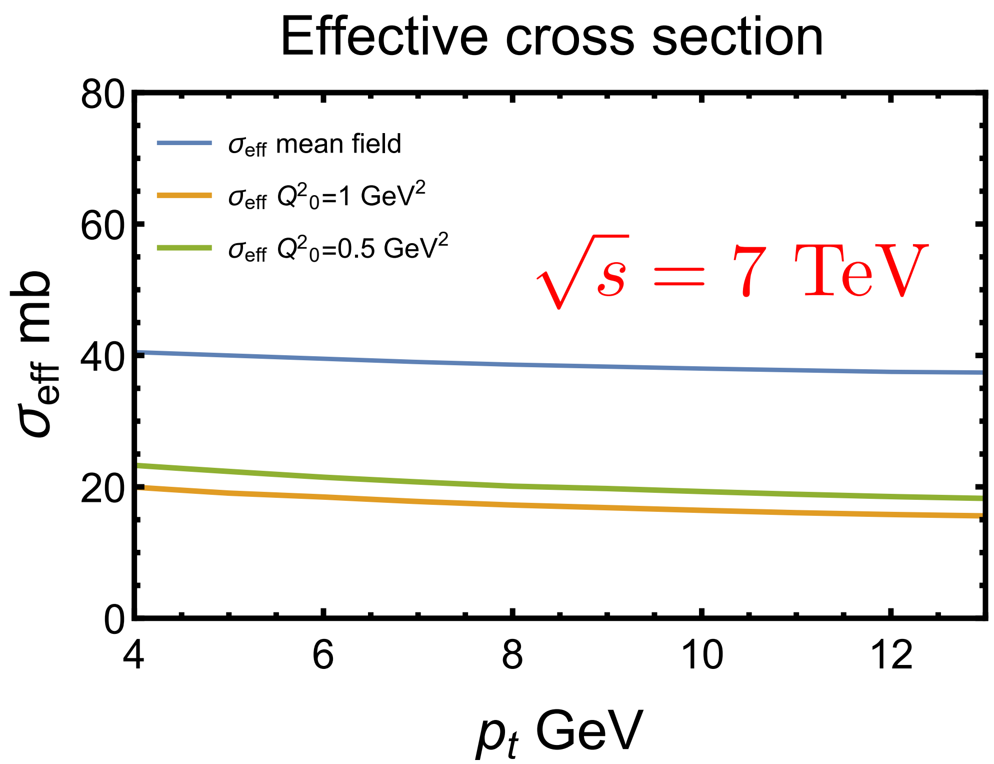
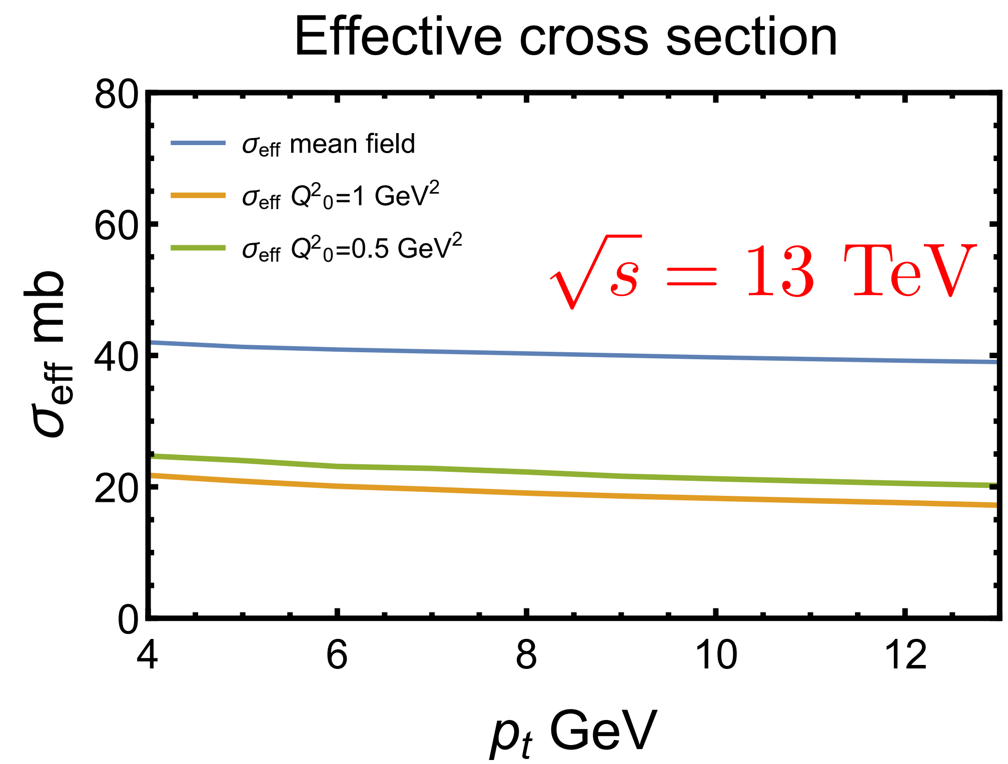
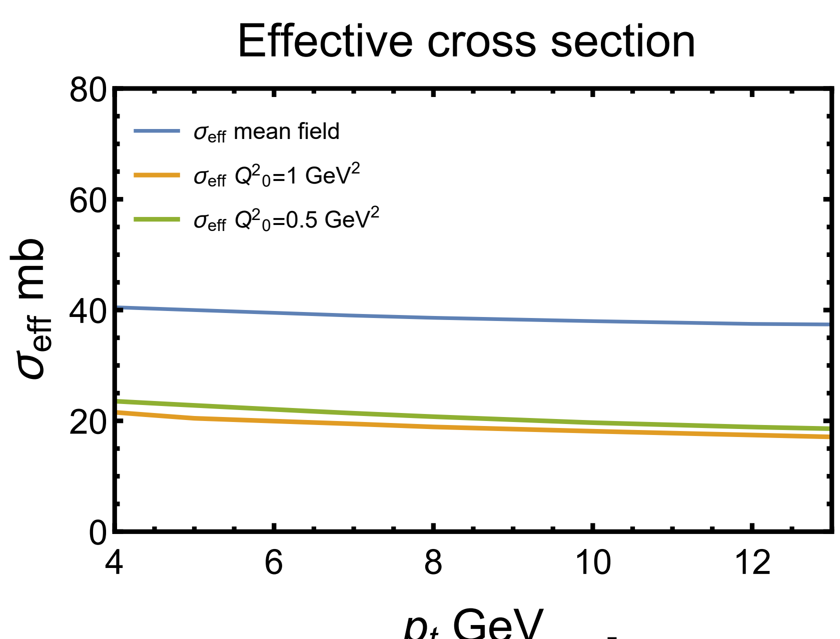
12
pt GeV

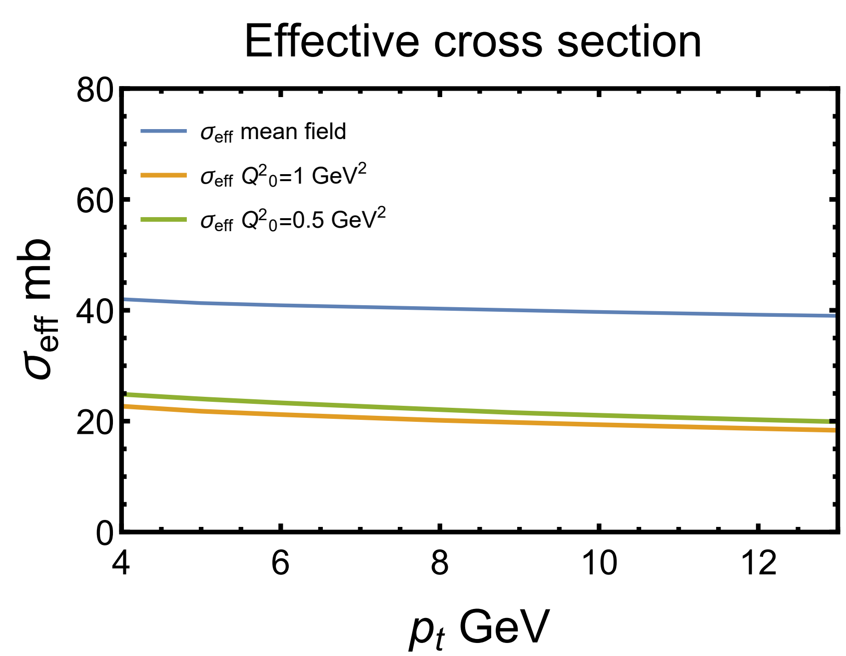
Numerical find: soft mechanism reduces sensitivity to Q_0





$\sigma_{\rm eff}$ as a function of the D meson transverse momentum p_t

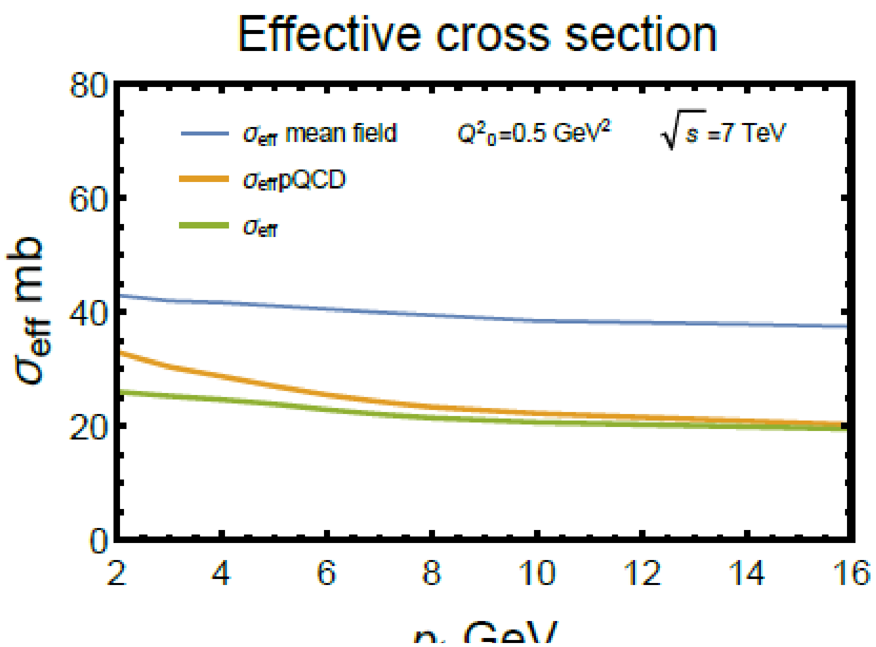


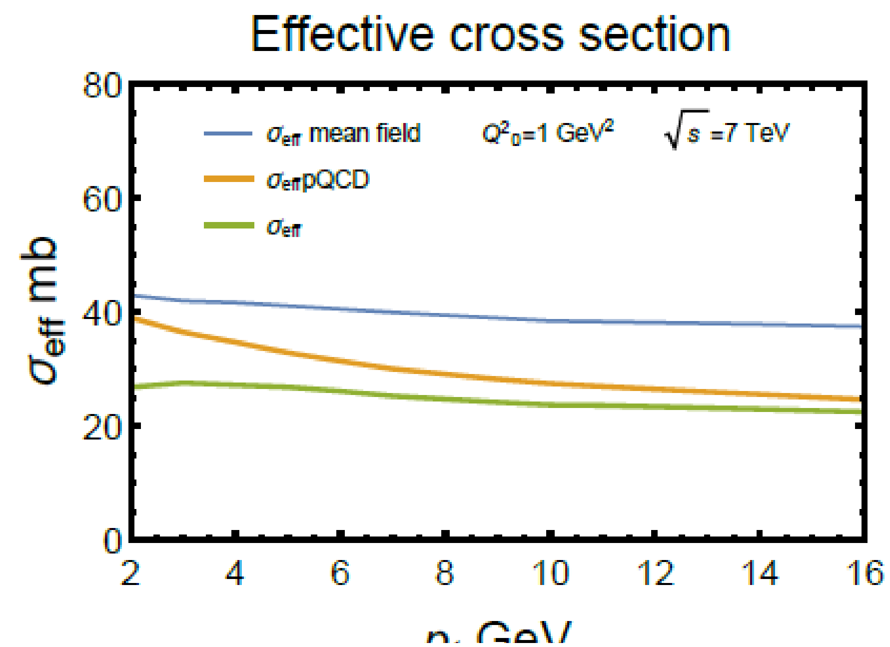


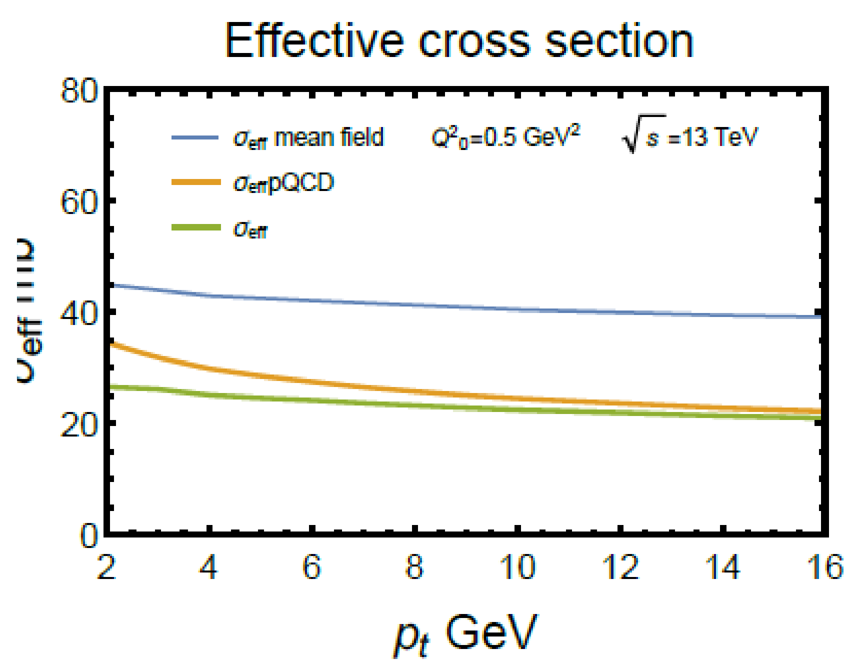
the same for B-mesons

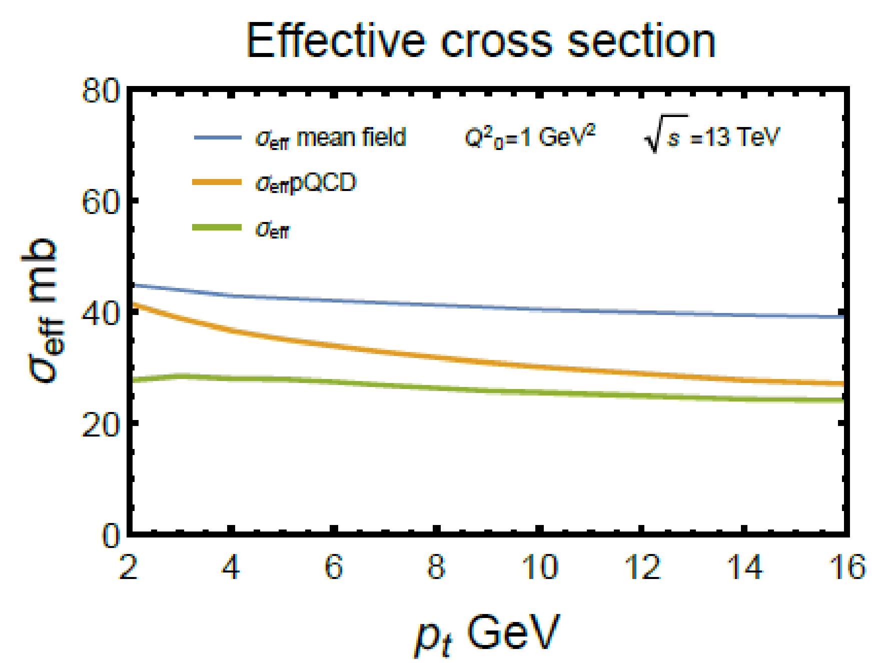
Effect of soft term for central kinematics

Soft correlations are negligible for DPS regime (typical p_T> 10-20 GeV), but maybe important for UE (several GeV scale).









Conclusions

MPI model with pQCD induced correlations and $Q^2 \sim 1$ GeV^2 starting DGLAP evolution scale and soft small x correlations agrees well with the data in most cases (notable exception is double J/psi production and first steps have been done to implement it numerically in MC generators.

Open questions

How unknown mechanism of p_T cutoff affects σ_{eff} at p_T of few GeV.

NLO effects for 3 to 4