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Drell-Yan diffraction in the dipole picture

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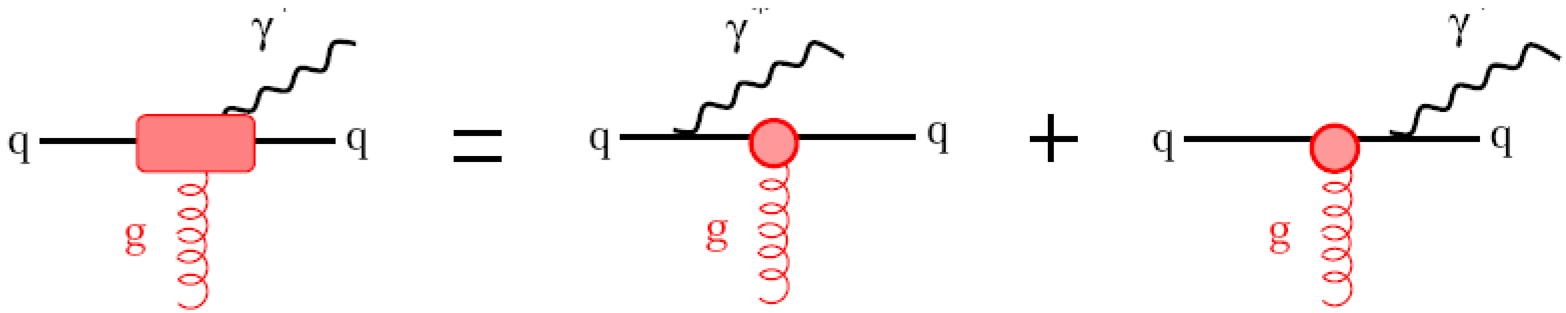
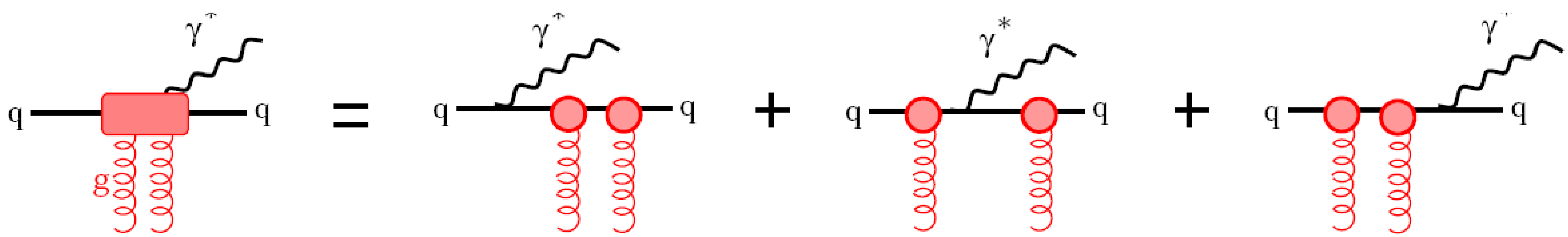
Photon radiation in the forward quark scattering

...in inelastic collision



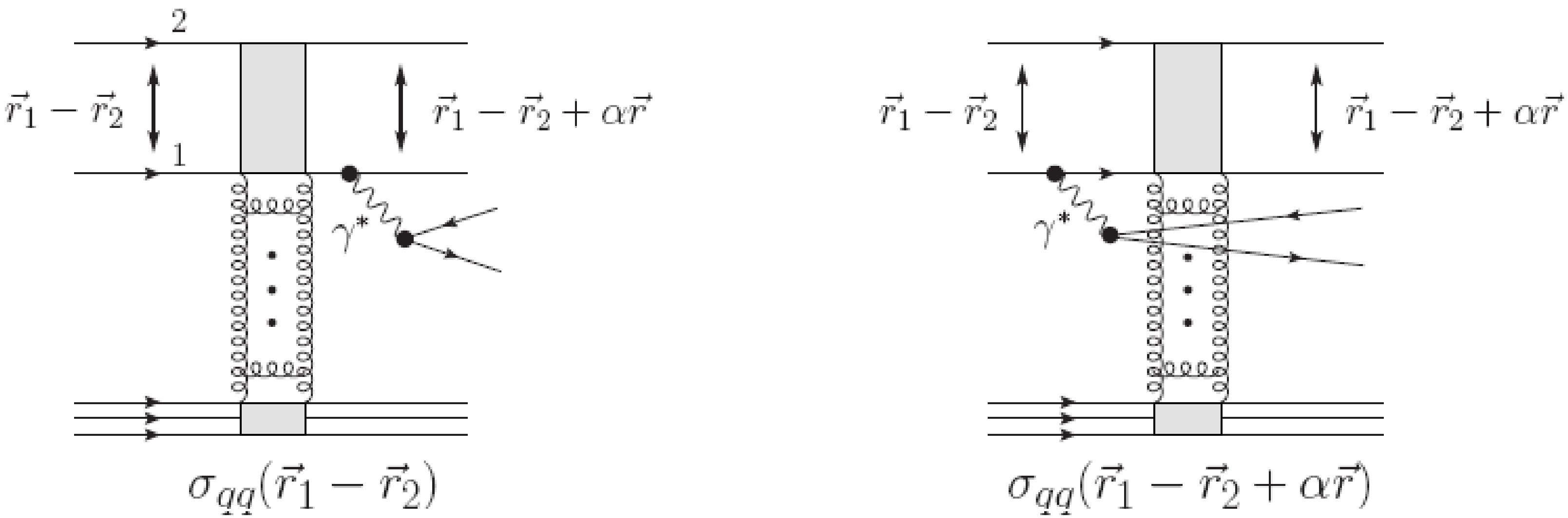
...in elastic collision



Radiation depends on the whole strength of the kick rather on its structure

No radiation from a quark at Pt=0!

Diffractive Drell-Yan in the dipole-target scattering



By optical theorem

$$2i\,\mathrm{Im}\,f_{el}(\vec{b},\vec{r}_p) = \frac{i}{N_c}\sum_X \sum_{c_f c_i} \left| V_q(\vec{b}) - V_q(\vec{b}+\vec{r}_p) \right|^2$$

dipoles with different sizes interact differently!

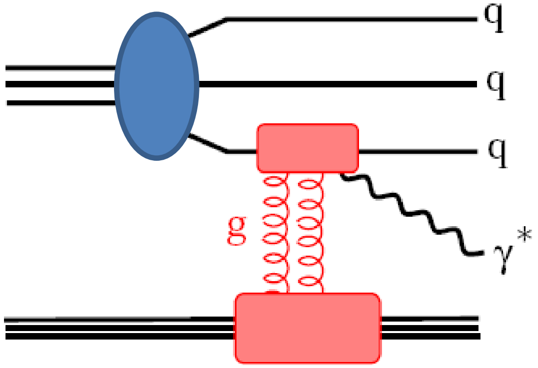
Amplitude of DDY in the dipole-target scattering

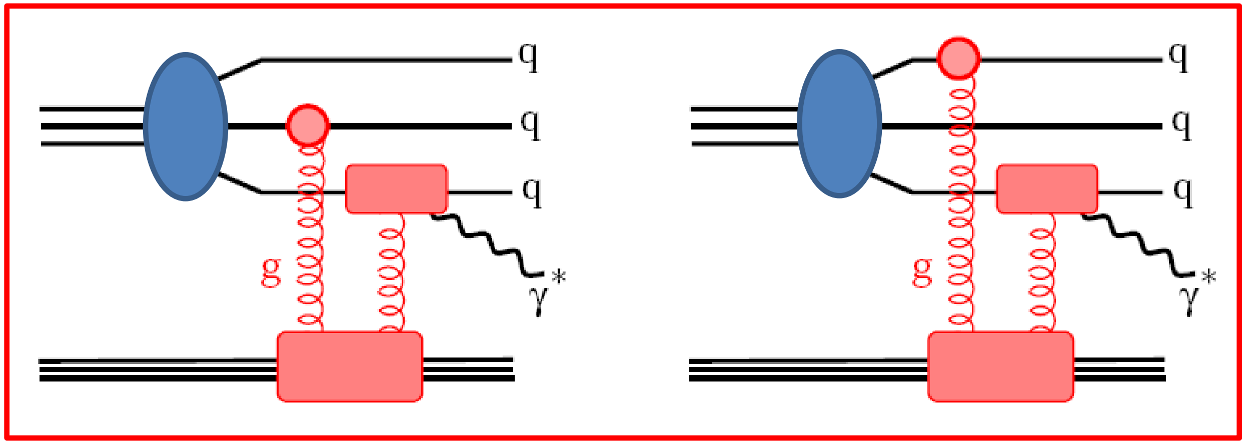
$$M^{(1)}_{qq}(\vec{b},\vec{r}_p,\vec{r},\alpha) = -2ip_i^0\sqrt{4\pi}\,\frac{\sqrt{1-\alpha}}{\alpha^2}\,\Psi^{\mu}_{\gamma^* q}(\alpha,\vec{r})\left[2\mathrm{Im}\,f_{el}(\vec{b},\vec{r}_p) - 2\mathrm{Im}\,f_{el}(\vec{b},\vec{r}_p+\alpha\vec{r})\right]$$

Diffractive Drell-Yan in pp scattering: amplitude

B. Kopeliovich, I. Potashnikova, I. Schmidt and A. Tarasov, Phys. Rev. D74, (2006) 114024

$$p_1 + p_2 \to p_1 + (gap) + \gamma^*(\to l^+ l^-) + X$$





Diffractive DY amplitude ..**probing large distances in the proton**

$$A^{(1)}_{if}(x_\gamma, \vec{k})\Big|_{p_T=0} = \frac{i}{8\pi}\int d^2r_1 d^2r_2 d^2r_3 d^2r\, dx_{q_1} dx_{q_2} dx_{q_3}$$
$$\times \quad \Psi_i(\vec{r}_1, \vec{r}_2, \vec{r}_3; x_{q_1}, x_{q_2}, x_{q_3})\Psi^*_f(\vec{r}_1 + \alpha\vec{r}, \vec{r}_2, \vec{r}_3; x_{q_1} - x_\gamma, x_{q_2}, x_{q_3})$$
$$\times \quad \Sigma^{(1)}(\vec{r}_1, \vec{r}_2, \vec{r}_3, \vec{r}, \alpha)\,\Phi_1(\vec{r}, \alpha)\, e^{-i\vec{k}\cdot\vec{r}} \ .$$

$$\Sigma^{(1)}(\vec{r}_1, \vec{r}_2, \vec{r}_3, \vec{r}, \alpha) = \sigma(\vec{r}_1 - \vec{r}_2) - \sigma(\vec{r}_1 - \vec{r}_2 - \alpha\vec{r}) + \sigma(\vec{r}_1 - \vec{r}_3) - \sigma(\vec{r}_1 - \vec{r}_3 - \alpha\vec{r})$$

QCD factorization breaking in diffractive Drell-Yan

Golec-Biernat-Wuestoff (GBW) dipole cross section

$$\sigma(r) = \sigma_0 \left(1 - e^{-r^2/R_0^2}\right)$$

Difference between two Fock states → **Diffractive DY amplitude**

$$\sigma(\vec{R}) - \sigma(\vec{R} - \alpha\vec{r}) = \frac{2\alpha\,\sigma_0}{R_0^2(x_2)}\, e^{-R^2/R_0^2(x_2)} \underbrace{\left(\vec{r}\cdot\vec{R}\right)} + O(r^2)$$

Interplay between hard and soft scales

$$r \sim 1/M \ll R_0(x_2)$$

Diffractive DIS $\propto r^4$

The QCD factorization holds!

Diffractive DY $\propto r^2$

Dramatic breakdown of the QCD factorization!

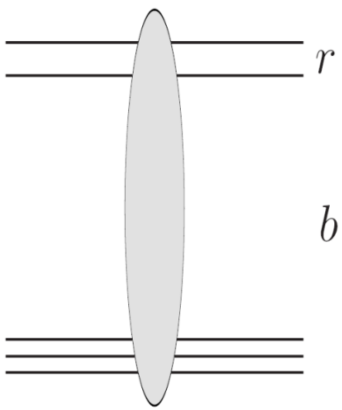
Small and large dipoles

$\boxed{\text{small } x \text{ (large } Q^2)}$

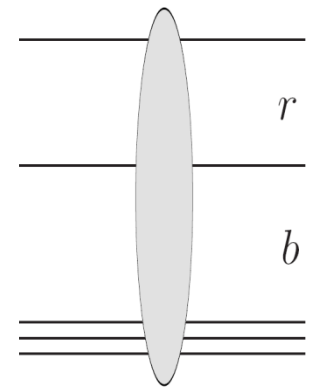
$\boxed{\text{moderate and small } Q^2}$

Fitted to DIS data

Fitted to soft data



$$\mathrm{Im} f_{qq}(\vec{b},\vec{r}) = \frac{\sigma_0}{8\pi\mathcal{B}}\left\{\exp\left[-\frac{[\vec{b}+\vec{r}(1-x_q)]^2}{2\mathcal{B}}\right] + \exp\left[-\frac{[\vec{b}+\vec{r}x_q]^2}{2\mathcal{B}}\right] - 2\exp\left[-\frac{r^2}{R_0^2} - \frac{[\vec{b}+\vec{r}(1/2-x_q)]^2}{2\mathcal{B}}\right]\right\},$$



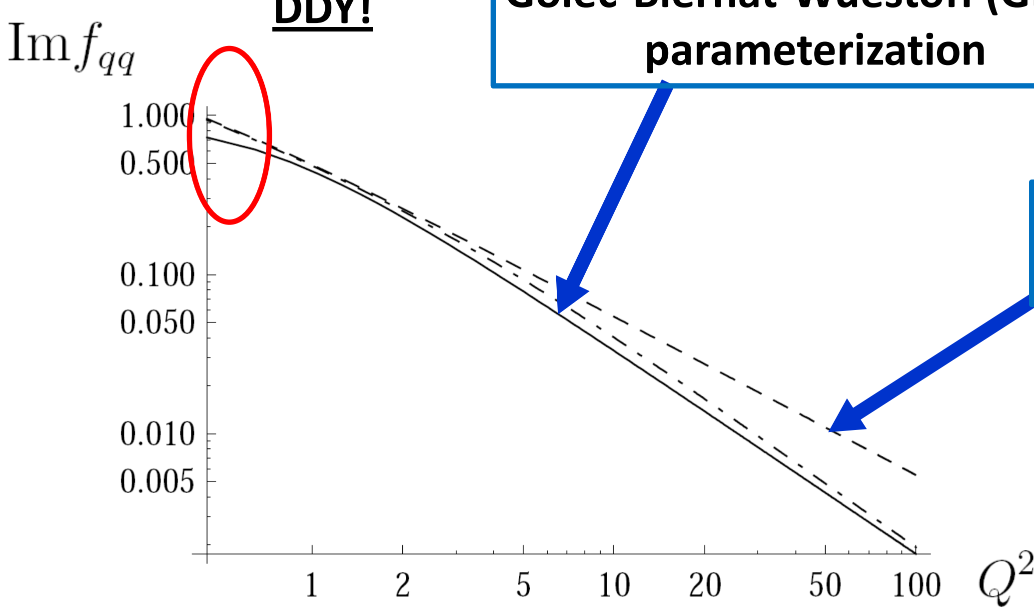
DDY!

Golec-Biernat-Wuestoff (GBW) parameterization

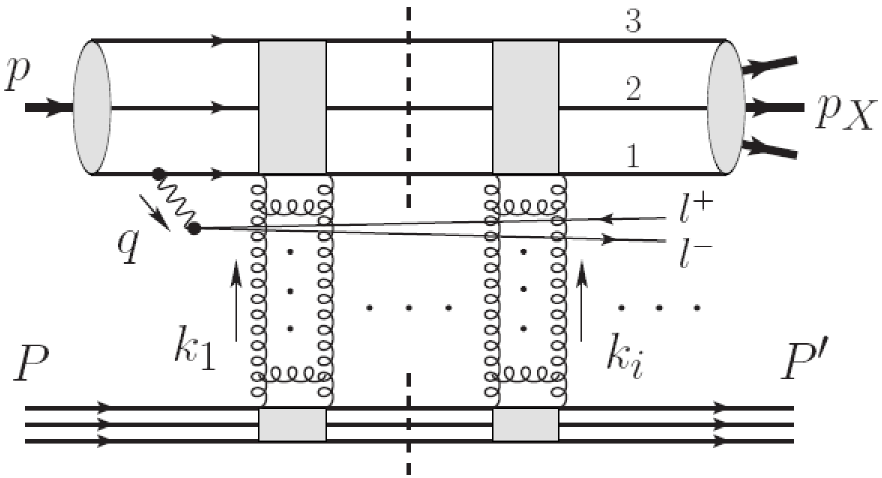
x to s dependence!

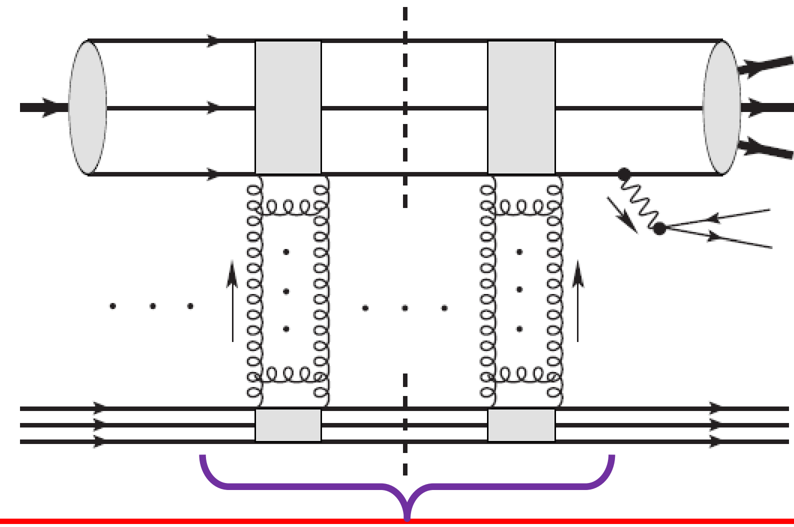
Kopeliovich- Schafer -Tarasov (KST) parameterization

Phys. Rev. D 62 (2000) , 054022



Eikonalization of the diffractive Drell-Yan amplitude





DDY eikonalized amplitude

Accounts for soft and hard components on the same footing!

$$
\begin{aligned}
A^{(1)}_{if}(x_\gamma, \vec{q}_\perp, \lambda_\gamma) \;=\; & \frac{i}{4}\,\alpha^2 \cdot \int d^2r_1 d^2r_2 d^2r_3 d^2r d^2b dx_{q_1} dx_{q_2} dx_{q_3} \\
& \times\; \Psi_i(\vec{r}_1, \vec{r}_2, \vec{r}_3; x_{q1}, x_{q2}, x_{q3}) \Psi^*_f(\vec{r}_1 + \alpha\vec{r}, \vec{r}_2, \vec{r}_3; x_{q_1} - x_\gamma, x_{q_2}, x_{q_3}) \\
& \times\; \Big[M^{\lambda_\gamma}_{qq}(\vec{b}, \vec{r}_1 - \vec{r}_2, \vec{r}, \alpha) + M^{\lambda_\gamma}_{qq}(\vec{b}, \vec{r}_1 - \vec{r}_3, \vec{r}, \alpha) \Big] e^{i\vec{l}_\perp \cdot \alpha\vec{r}} e^{i\vec{\delta}_\perp \cdot \vec{b}}
\end{aligned}
$$

$$
M^{\mu}_{qq}(\vec{b}, \vec{r}_p, \vec{r}, \alpha) = 2ip^0_i \sqrt{4\pi}\, \frac{\sqrt{1-\alpha}}{\alpha^2}\, \Psi^{\mu}_{\gamma^* q}(\alpha, \vec{r}) \left[e^{-2\mathrm{Im}\, f_{el}(\vec{b}, \vec{r}_p)} - e^{-2\mathrm{Im}\, f_{el}(\vec{b}, \vec{r}_p + \alpha\vec{r})} \right]
$$

Diffractive Drell-Yan in pp scattering: cross section

In the forward limit

$$\frac{d^3\sigma_{\lambda_\gamma}(pp \to p\gamma^* X)}{d\ln\alpha\, d\delta_\perp^2}\Big|_{\delta_\perp^2=0} = \frac{\sum_q Z_q^2}{64\pi}\int d^2r_1 d^2r_2 d^2r_3 d^2r\, dx_{q1} dx_{q2} dx_{q3}$$

$$\times |\tilde{\Psi}^{\lambda_\gamma}_{\gamma^* q}(\alpha,\vec{r})|^2 |\Psi_i(\vec{r}_1,\vec{r}_2,\vec{r}_3;x_{q1},x_{q2},x_{q3})|^2 \left[\int d^2b\, \Delta(\vec{r}_1,\vec{r}_2,\vec{r}_3;\vec{b};\vec{r},\alpha)\right]^2$$

$$\Delta = \left[e^{-2\mathrm{Im}\, f_{el}(\vec{b},\vec{r}_1-\vec{r}_2)} - e^{-2\mathrm{Im}\, f_{el}(\vec{b},\vec{r}_1-\vec{r}_2+\alpha\vec{r})} + e^{-2\mathrm{Im}\, f_{el}(\vec{b},\vec{r}_1-\vec{r}_3)} - e^{-2\mathrm{Im}\, f_{el}(\vec{b},\vec{r}_1-\vec{r}_3+\alpha\vec{r})}\right]$$

Proton wave function

$$|\Psi_i(\vec{r}_1,\vec{r}_2,\vec{r}_3;x_{q1},x_{q2},x_{q3})|^2 = \frac{2+a/b}{\pi^2 ab}\exp\left[-\frac{r_1^2}{a} - \frac{r_2^2+r_3^2}{b}\right]\rho(x_{q1},x_{q2},x_{q3})$$
$$\times\ \delta(\vec{r}_1+\vec{r}_2+\vec{r}_3)\delta(1-x_{q1}-x_{q2}-x_{q3})$$

Valence quark distribution

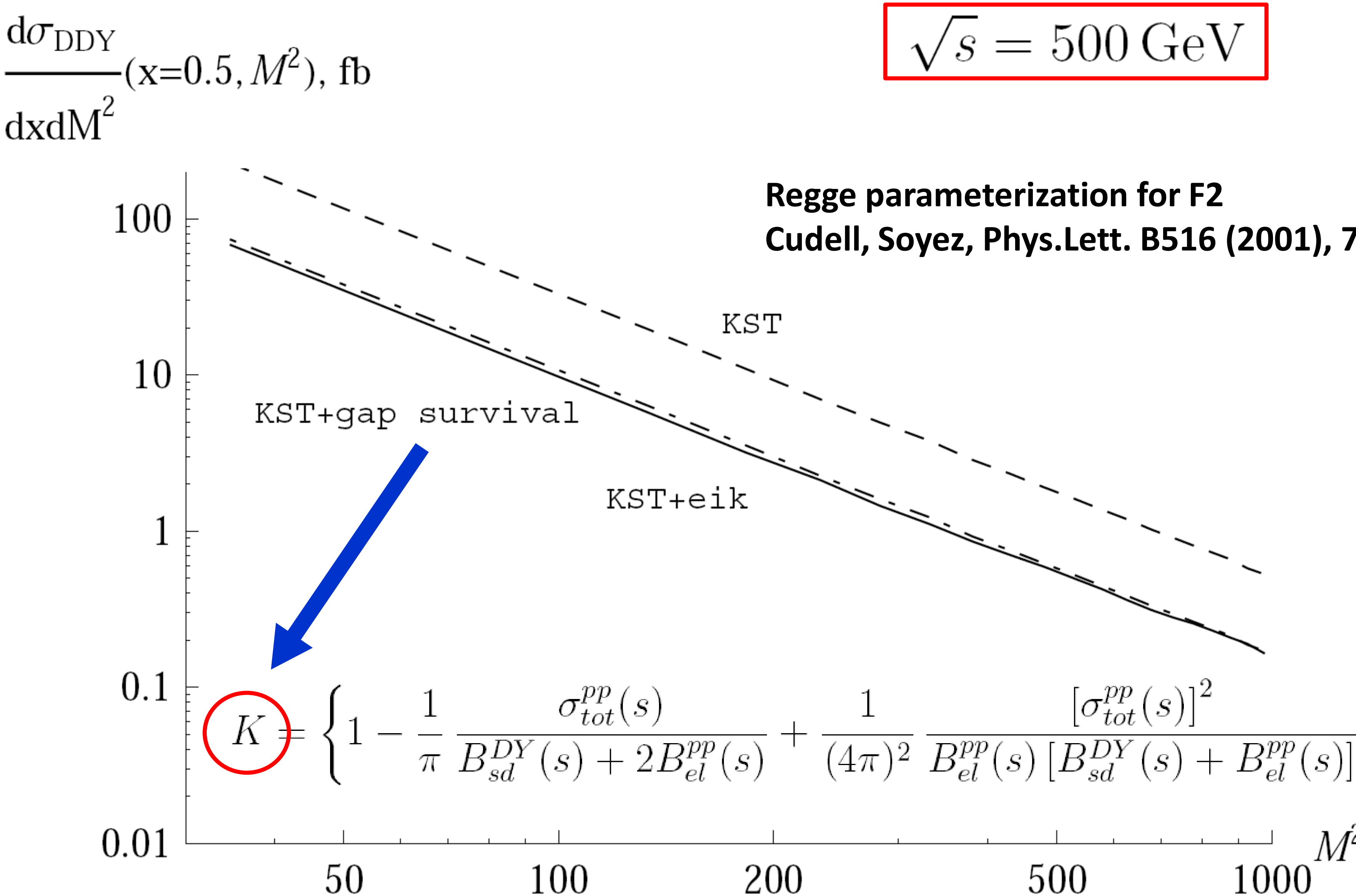
+ antiquarks!

$$\int dx_{q2}dx_{q3}\rho(x_{q1},x_{q2},x_{q3}) = \rho_{q1}(x_{q1}) \quad\Rightarrow\quad \sum_q Z_q^2[\rho_q(x_q) + \rho_{\bar{q}}(x_q)] = \frac{1}{x_q}F_2(x_q)$$

Gap survival vs. eikonalization

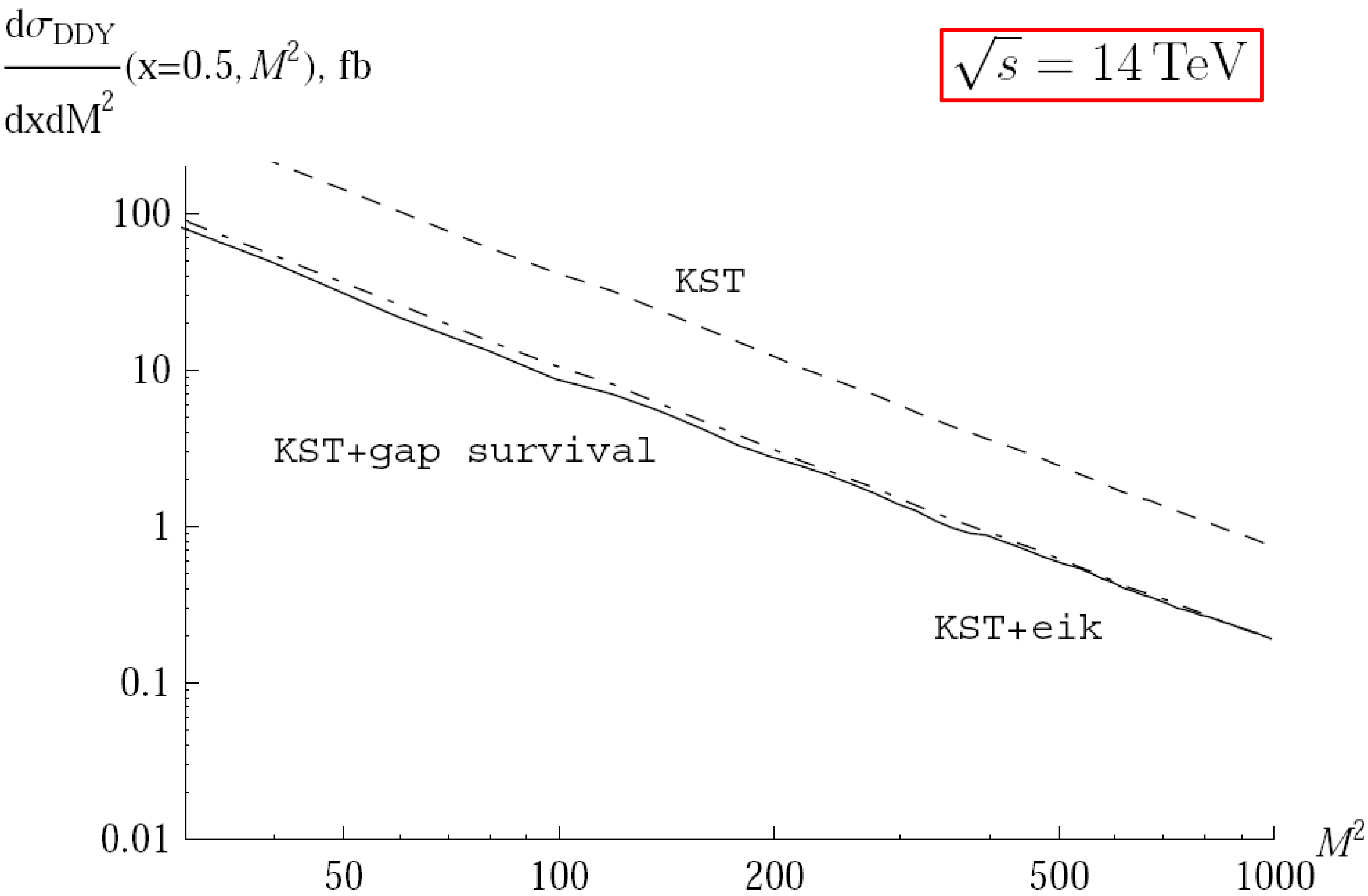
$$\sqrt{s} = 500\,\mathrm{GeV}$$

Regge parameterization for F2
Cudell, Soyez, Phys.Lett. B516 (2001), 77

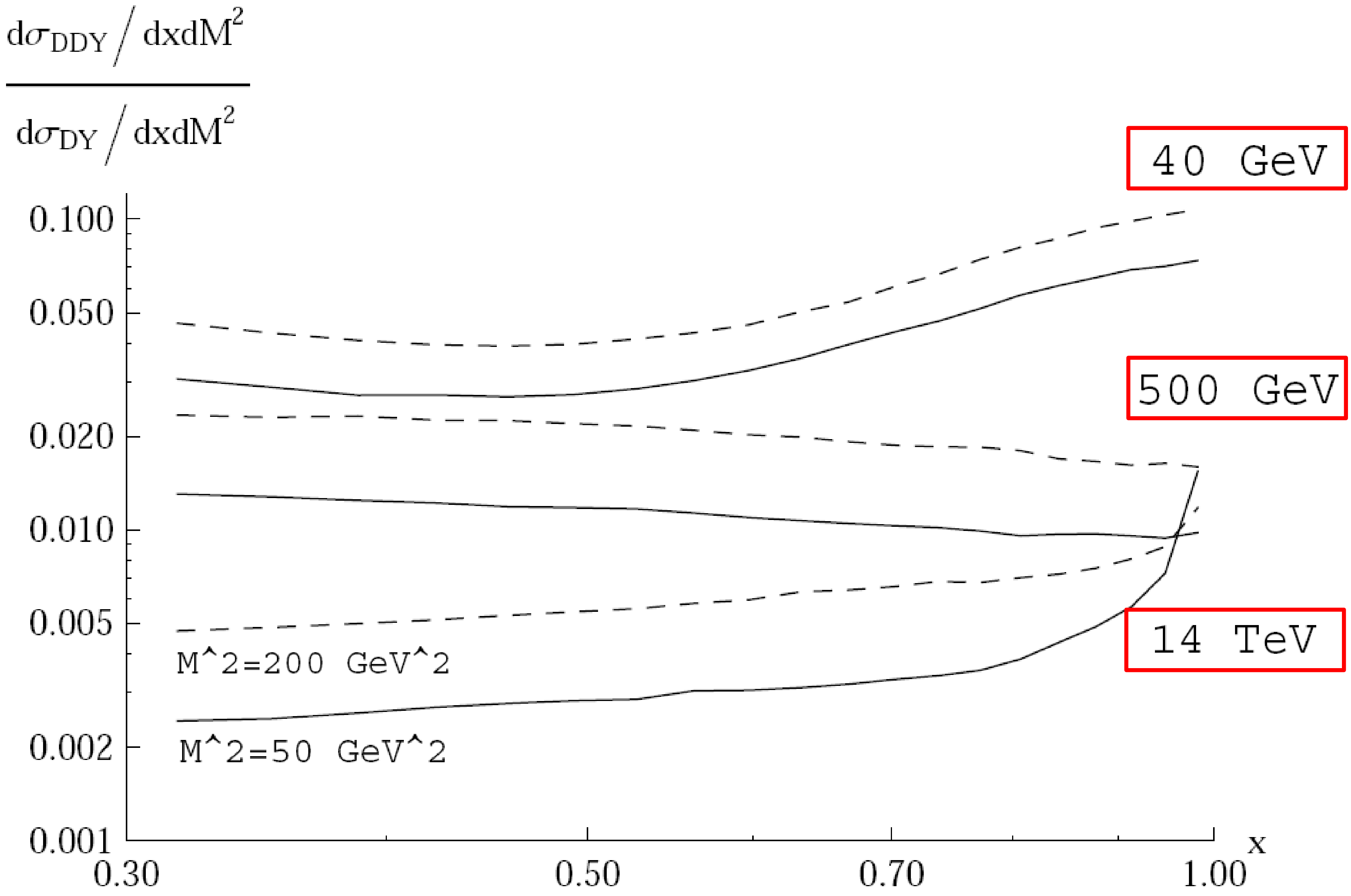


$$K = \left\{1 - \frac{1}{\pi}\frac{\sigma_{tot}^{pp}(s)}{B_{sd}^{DY}(s) + 2B_{el}^{pp}(s)} + \frac{1}{(4\pi)^2}\frac{\left[\sigma_{tot}^{pp}(s)\right]^2}{B_{el}^{pp}(s)\left[B_{sd}^{DY}(s) + B_{el}^{pp}(s)\right]}\right\}$$

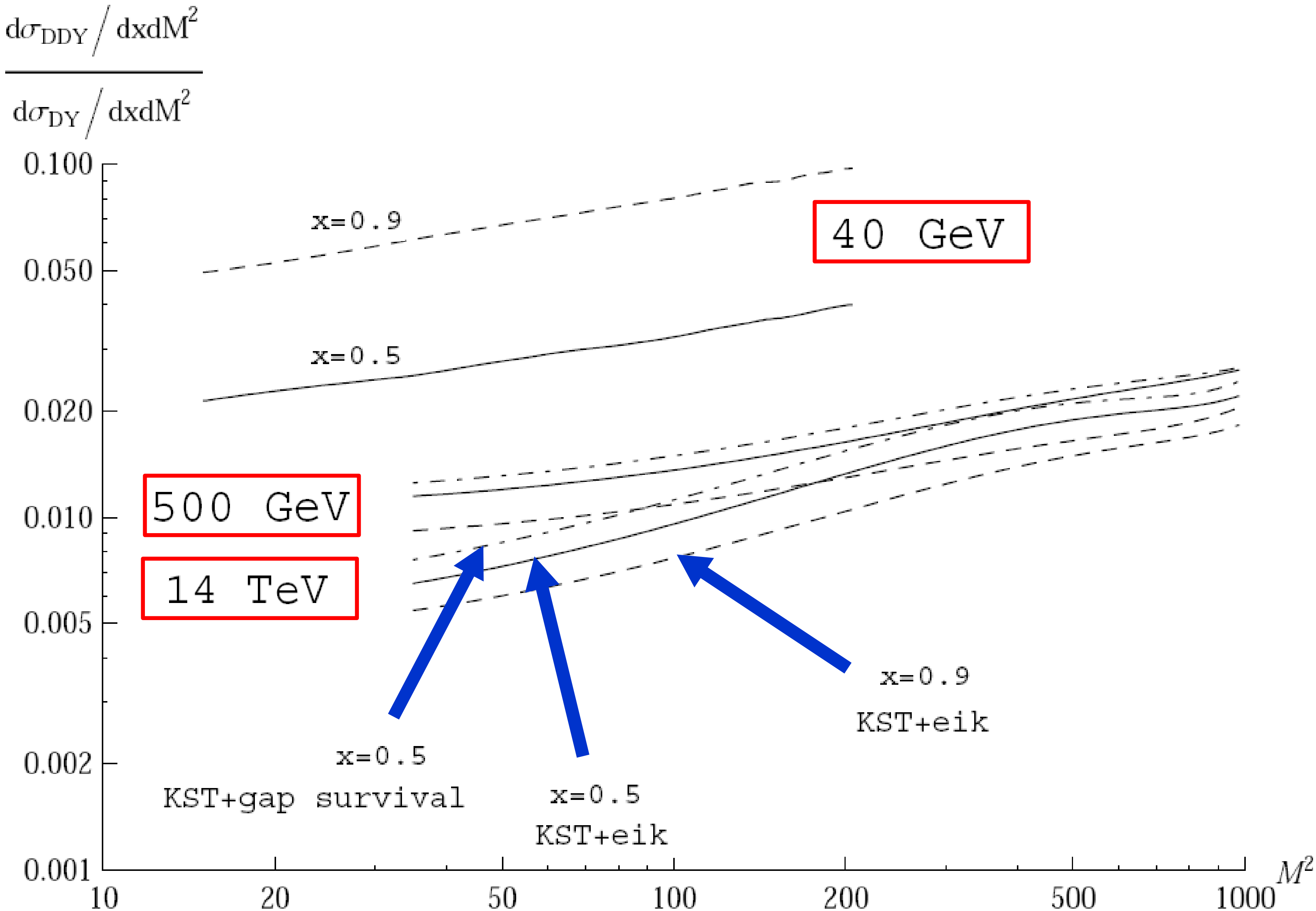
Gap survival vs. eikonalization



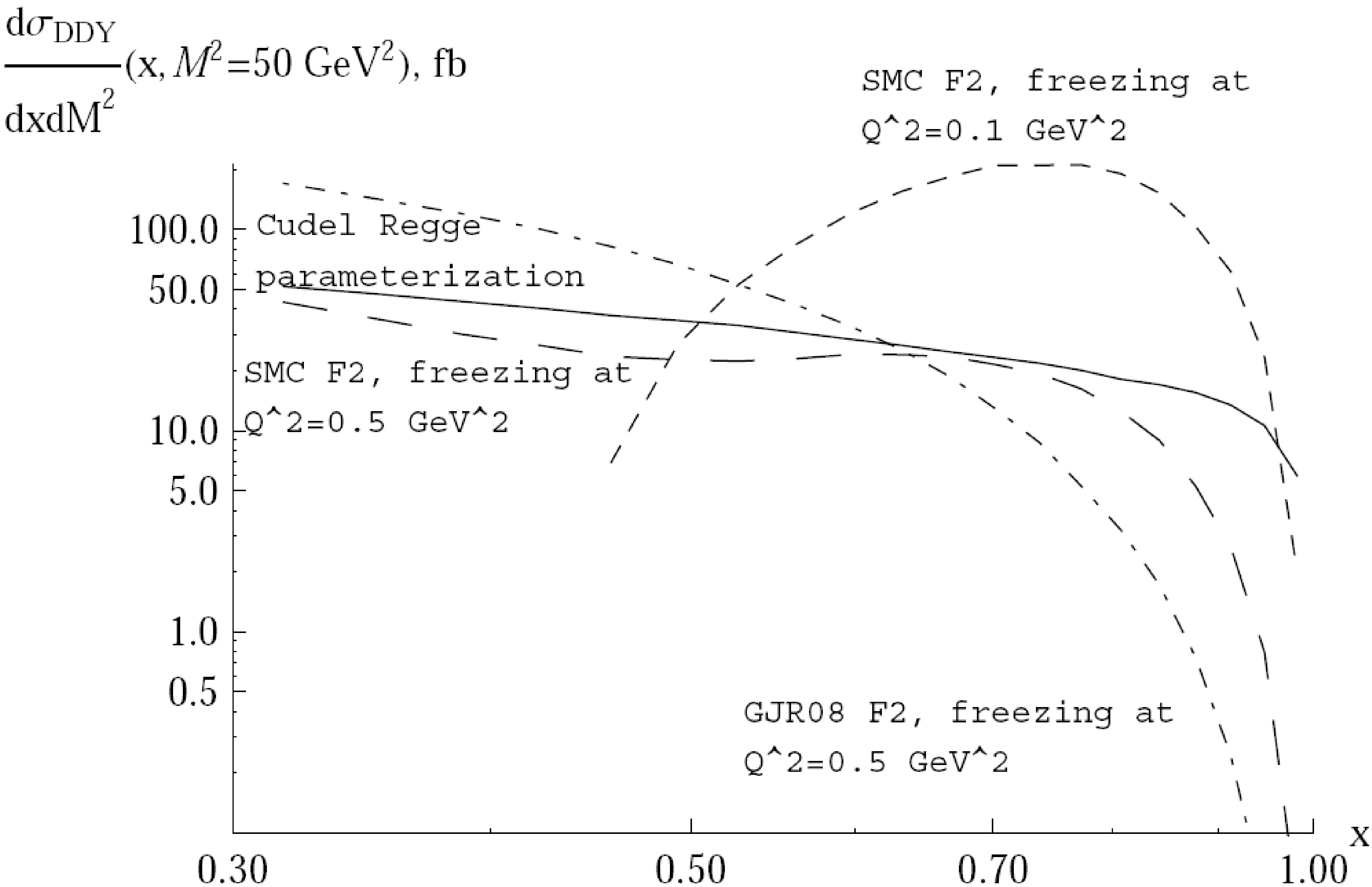
Diffractive vs. inclusive DY



Diffractive vs. inclusive DY



Theory uncertainties



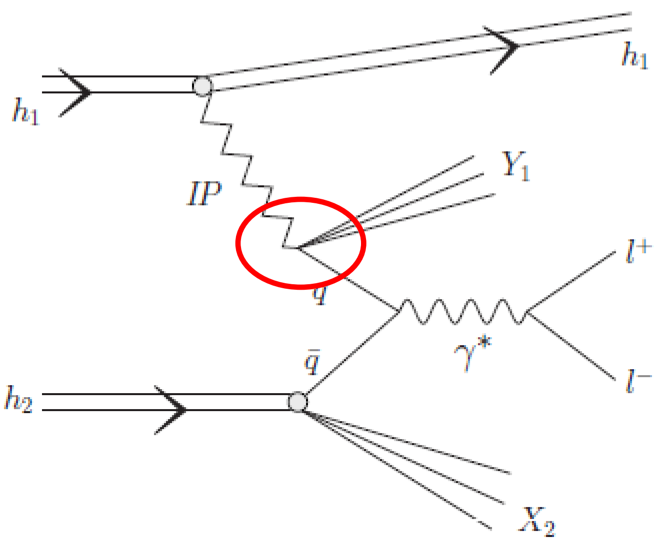
An alternative: Ingelman-Schlein approach

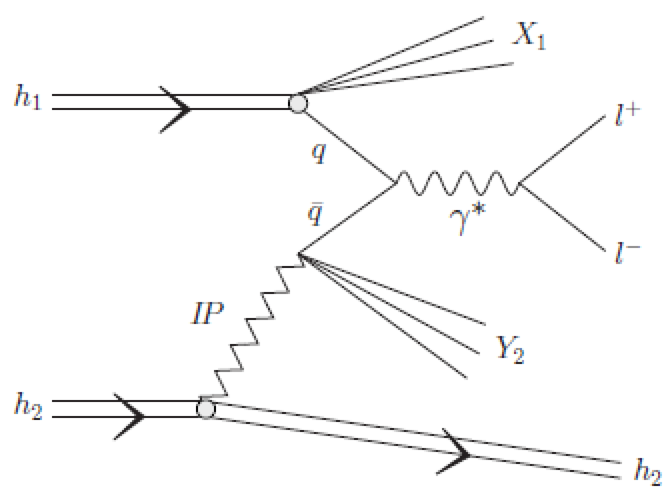
by G. Kubasiak and A. Szczurek

”Inclusive and exclusive diffractive production of dilepton pairs in proton-proton collisions at high energies”,

arXiv:1103.6230

Ingelman-Schein mechanism → Regge factorisation





Conclusions

- A quark **cannot radiate** photon diffractively in the forward direction
- A hadron can radiate photon diffractively in the forward direction because of **the transverse motion of quarks**
- The ratio diffractive/inclusive DY cross sections falls with energy and rises with photon dilepton mass due to **the saturated shape** of the dipole cross section
- Hard and soft interactions contribute to the DDY on the same footing, which is **the dramatic breakdown of the QCD factorisation**
- Main features of Drell-Yan diffraction are valid for other **Abelian processes**
- Experimental measurements of DDY would allow to probe directly the dipole cross section **at large separations**, as well **as the proton structure** function at soft and semihard scales, and large x
- DDY is a good playground for **diffractive production of heavy flavors**