Breakdown of diffractive factorization

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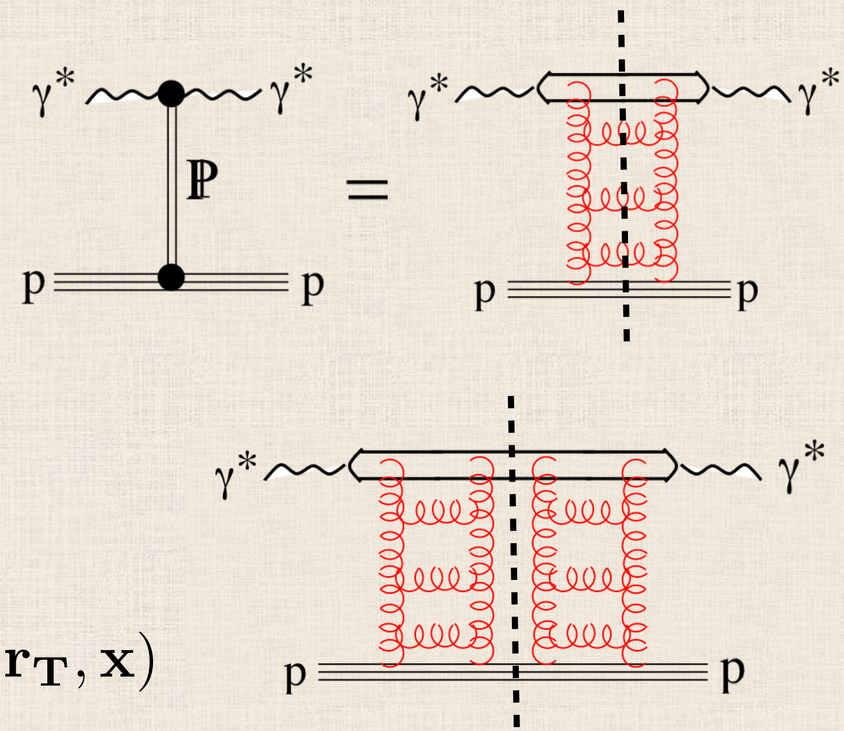
Color dipole description of diffraction

Dipoles are the eigenstates of interaction at high energies. The total and single diffractive cross sections read [B.K., L.Lapidus, A.Zamolodchikov 1981].

$$\sigma_{\mathbf{tot}}^{\mathbf{hp}} = \int \mathbf{d^2 r_T} \left|\Psi_{\mathbf{h}}(\mathbf{r_T})\right|^{\mathbf{2}} \sigma(\mathbf{r_T})$$

$$\mathbf{16\pi} \sum_{\mathbf{h' \neq h}} \left.\frac{\mathbf{d}\sigma_{\mathbf{sd}}^{\mathbf{h \to h'}}}{\mathbf{dt}}\right|_{\mathbf{t=0}} = \langle \sigma^{\mathbf{2}}(\mathbf{r_T}) \rangle - \langle \sigma(\mathbf{r_T}) \rangle^{\mathbf{2}}$$



$$\mathbf{16\pi} \left.\frac{\mathbf{d}\sigma_{\mathbf{sd}}^{\gamma^* \mathbf{p}}(\mathbf{x}, \mathbf{Q^2})}{\mathbf{dt}}\right|_{\mathbf{t=0}} = \int \mathbf{d^2 r_T} \int_{\mathbf{0}}^{\mathbf{1}} \mathbf{d}\alpha \left|\Psi_{\gamma^*}(\mathbf{r_T}, \alpha, \mathbf{Q^2})\right|^{\mathbf{2}} \sigma_{\mathbf{q\bar{q}}}^{\mathbf{2}}(\mathbf{r_T}, \mathbf{x})$$

Even at high Q^2 diffraction is soft-dominated by aligned-jet configurations with $\alpha \sim \mathbf{m_q^2/Q^2}$

$$\langle \mathbf{r_T^2} \rangle = \frac{\mathbf{1}}{\mathbf{Q^2}\alpha(1-\alpha) + \mathbf{m_q^2}}$$

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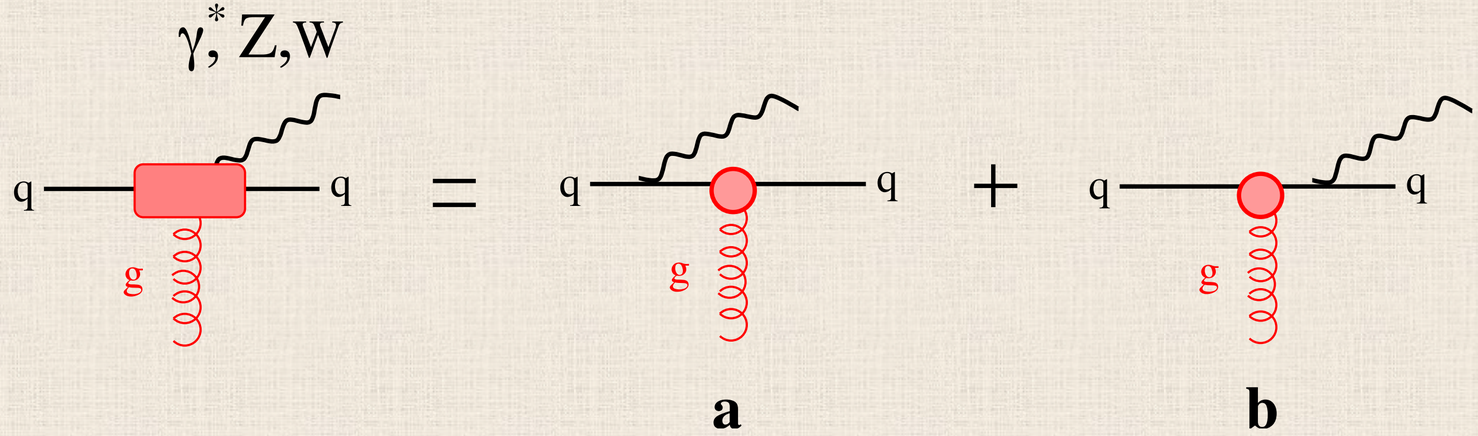
Inclusive Drell-Yan reaction via dipoles

In the rest frame of the target Drell-Yan reaction looks like radiation of a heavy photon (or Z, W) decaying into a dilepton.



The cross section is expressed via the dipoles looks similar to DIS [B.K. 1995]

$$\frac{\mathbf{d}\sigma_{\mathbf{inc}}^{\mathbf{DY}}(\mathbf{qp}\to\gamma^{*}\mathbf{X})}{\mathbf{d}\alpha\,\mathbf{dM^2}}=\int\mathbf{d^2r}\,\left|\mathbf{\Psi_{q\gamma^{*}}}(\tilde{\mathbf{r}},\alpha)\right|^{\mathbf{2}}\,\sigma\left(\alpha\mathbf{r},\mathbf{x_2}\right)\qquad\textbf{where}\;\;\alpha=\mathbf{p}^{+}_{\gamma^{*}}/\mathbf{p}^{+}_{\mathbf{q}}$$

This similarity is the source of universality of the hadron PDFs

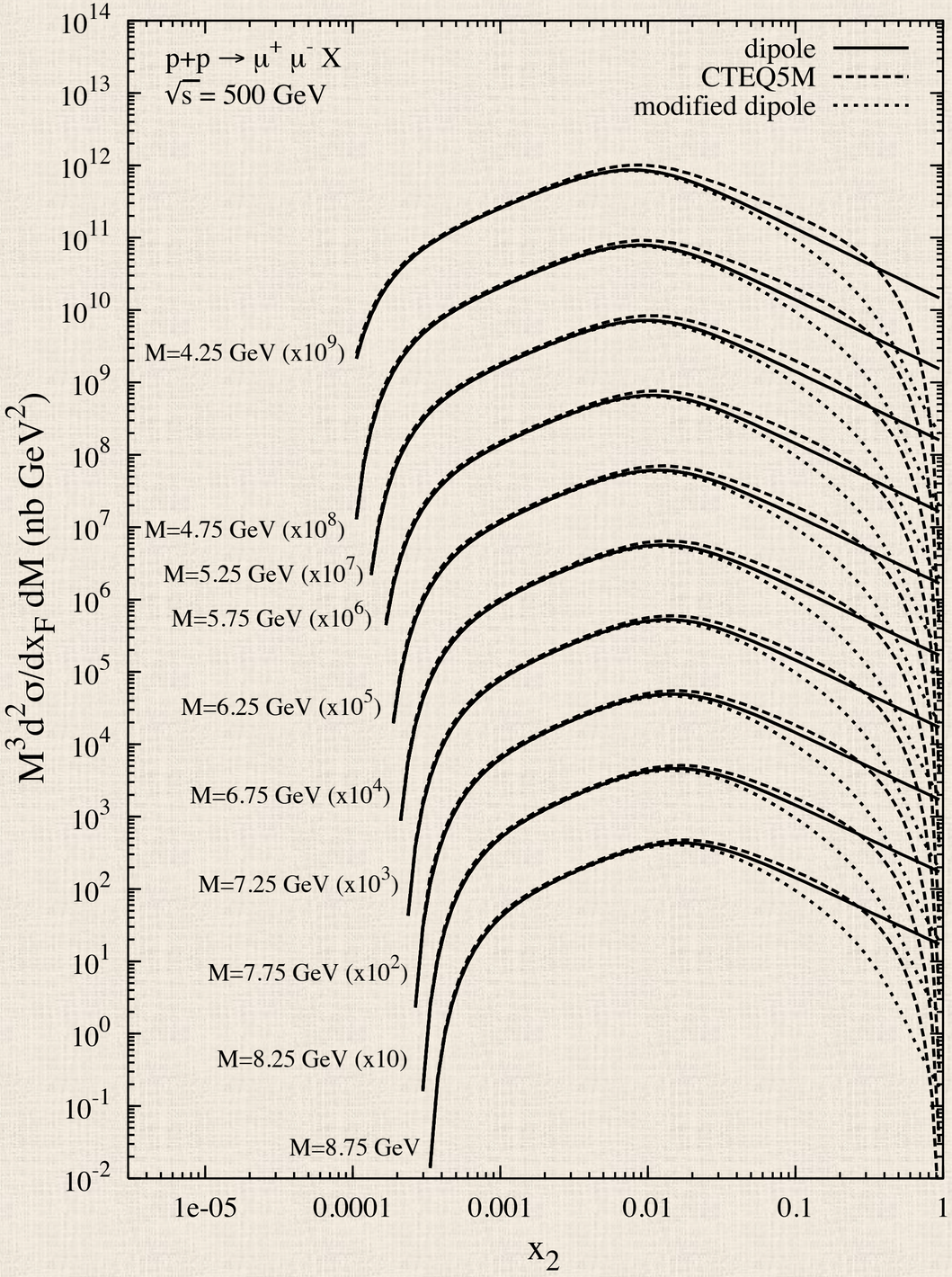
QCD factorization relates inclusive DIS, $\gamma^{*}\to\bar{\mathbf{q}}\mathbf{q}$ with DY, $\mathbf{q}\to\gamma^{*}\mathbf{q}$

Inclusive Drell-Yan reaction via dipoles

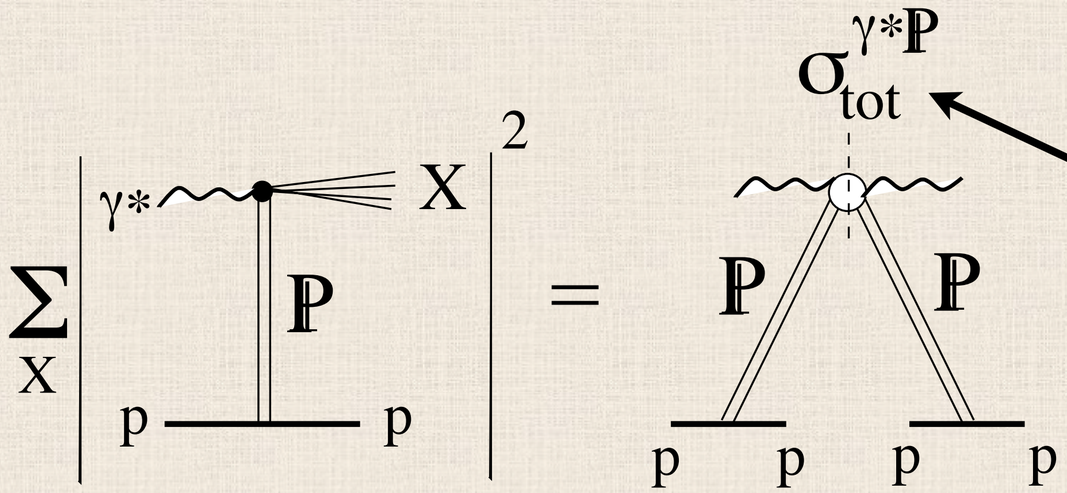
The quark-photon distribution function is calculated perturbatively.
The dipole cross section is fitted to HERA data for $\mathbf{F_2(x, Q^2)}$

Comparison with NLO CTEQ5M

J. Raufeisen, J.C. Peng, G. Nayak, 2002



Diffractive Drell-Yan



Looks like a way to measure the Pomeron PDF

G.Ingelman & P.Schlein, 1985

Once the parton densities in the Pomeron are known, one can predict the cross section of any hard diffractive hadronic reaction.

E.g. for diffractive Drell-Yan: A.Donnachie & P.Landshoff,

$$\sigma_{\mathbf{sd}}^{\mathbf{DY}}(\mathbf{pp} \to \bar{\mathbf{l}}\mathbf{l}\,\mathbf{X}\,\mathbf{p}) = \mathbf{G}_{\mathbf{P/p}} \otimes \mathbf{F}_{\bar{\mathbf{q}}/\mathbf{P}} \otimes \mathbf{F}_{\mathbf{q/p}} \otimes \hat{\sigma}(\bar{\mathbf{q}}\mathbf{q} \to \bar{\mathbf{l}}\mathbf{l})$$

This relation contradicts the basic principles of diffraction.

Diffractive Drell-Yan

According to Good-Walker diffraction vanishes if all Fock components of the hadron interact with the same elastic amplitudes. Then an unchanged Fock state composition emerges from the interaction, i.e. the outgoing hadron is the same as the incoming one, so the interaction is elastic.

Diffractive radiation of a heavy photon (any gauge boson) by a quark vanishes in the forward direction [B.K., A.Schaefer, A.Tarasov 1998]

$$\left.\frac{d\sigma_{inc}^{DY}(qp\to\gamma^* qp)}{d\alpha\, dM^2 dp_T^2}\right|_{p_T=0}=0 \qquad !!!$$

In both Fock components of the quark, $|q\rangle$ and $|q\gamma^*\rangle$, only the quark interacts, so they interact equally (b-integrated), no diffraction is possible

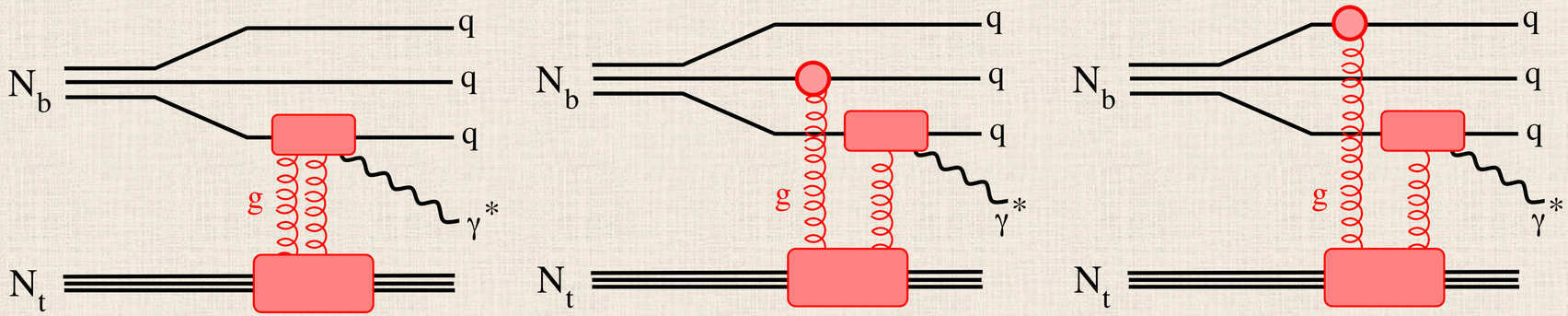
Diffractive factorization is strongly broken

This conclusion holds for any abelian diffractive radiation of γ, W, Z bosons, Higgs.

Diffractive Drell-Yan

Corrections: interaction with the spectators

A simplified example



a **b** **c**

In both Fock components of the proton, $|3q\rangle$ and $|3q\gamma^*\rangle$, only the quark dipoles interact. However these dipoles have different sizes, since the recoil quark gets a shift in impact parameters. So the dipoles interact differently what gives rise to forward diffraction.

Diffractive Drell-Yan

On the contrary to diffractive DIS, dominated by soft interactions, diffractive Drell-Yan gets the main contribution from the interplay of soft and hard scales

B.K., I.Potashnikova, I.Schmidt, A.Tarasov 2006;
R.Pasechnik, B.K. 2011.

The quark radiating the heavy photon gets a shift in its location by $\mathbf{r} \sim 1/\mathrm{M}$

The diffractive amplitude has the Good-Walker structure,

$$\sigma(\mathbf{R}) - \sigma(\mathbf{R} - \alpha\mathbf{r}) \;\propto\; \mathbf{r}\cdot\mathbf{R}$$

hadronic scale — recoil shift — hard-soft

- The diffractive amplitude is not quadratic in r like in DIS, but linear. Therefore, the soft part of the interaction is not enhanced in Drell-Yan diffraction, which is as semi-hard, semi-soft, like inclusive DIS.

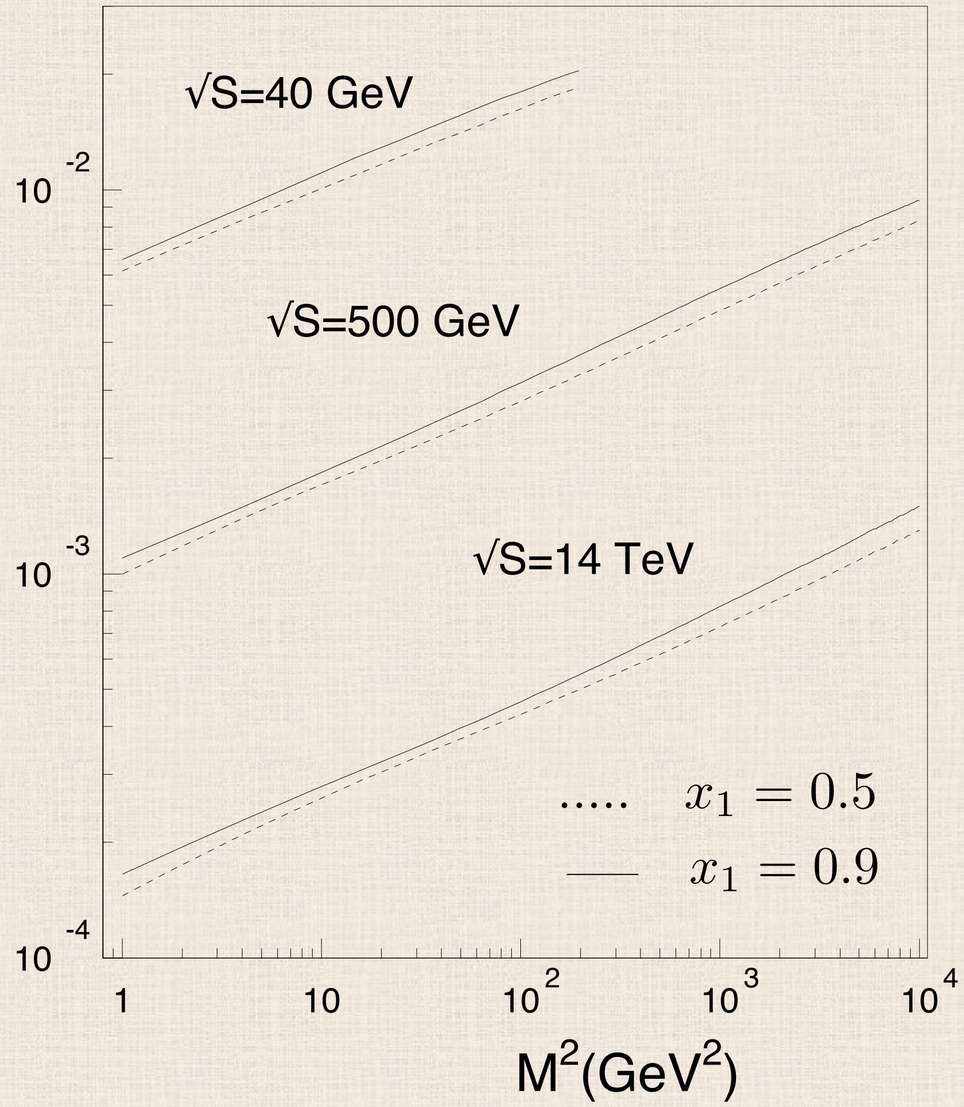
- Such a structure of the diffractive amplitude includes all absorptive corrections (gap survival amplitude), provided that the dipole cross section is adjusted to data.

Diffractive Drell-Yan

The Good-Walker form of the diffractive amplitude and the saturated shape of the dipole cross section, $\sigma(\mathbf{R}) \propto 1 - \exp(-\mathbf{R^2}/\mathbf{R_0^2})$ leads to unusual features of diffractive Drell-Yan,

$$\frac{\sigma_{\mathbf{sd}}^{\mathbf{DY}}}{\sigma_{\mathbf{incl}}^{\mathbf{DY}}} \propto \frac{\exp(-\mathbf{2R^2}/\mathbf{R_0^2})}{\mathbf{R_0^2}}$$

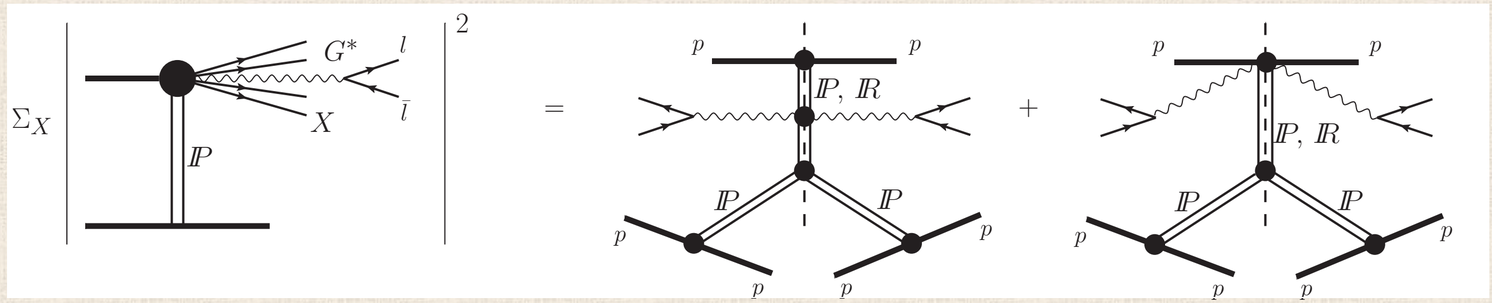
The fraction of diffractive Drell-Yan cross section is steeply falling with energy, but rises with the scale, because of saturation, which scale rises with energy.

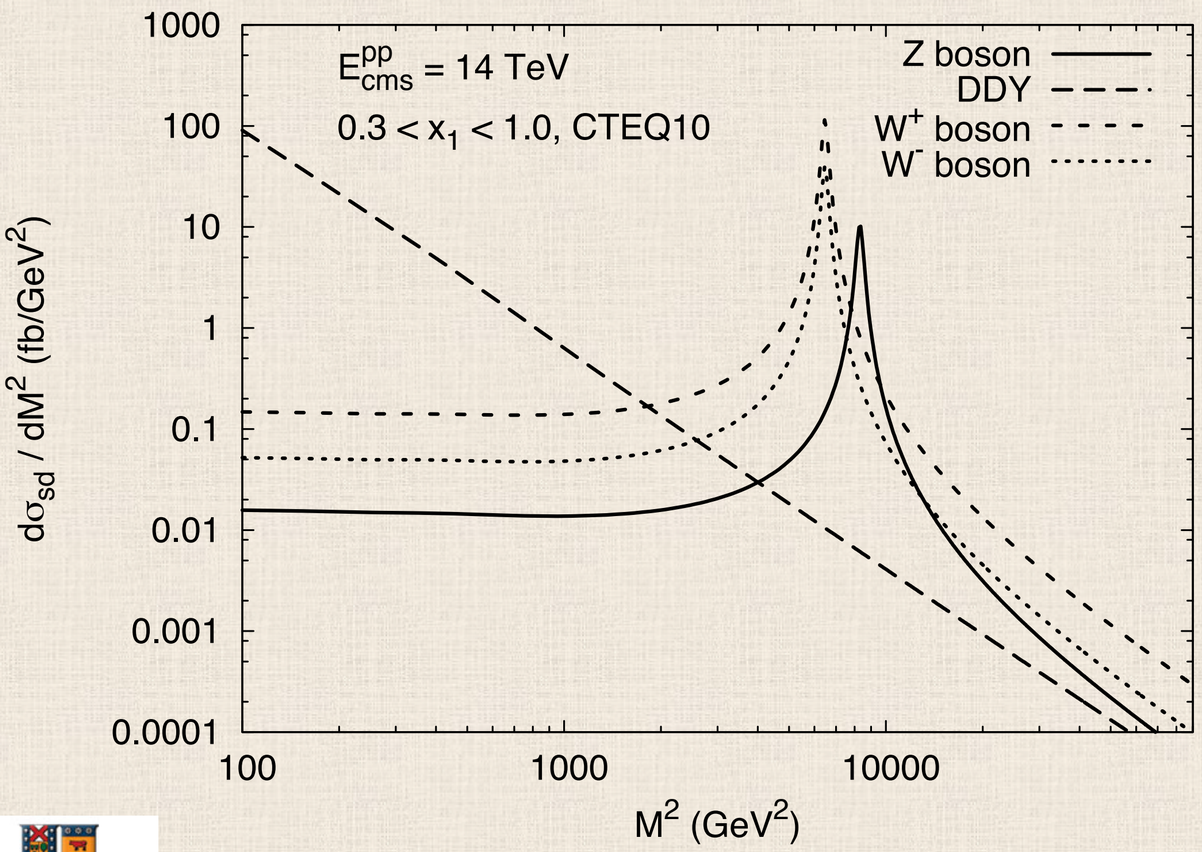


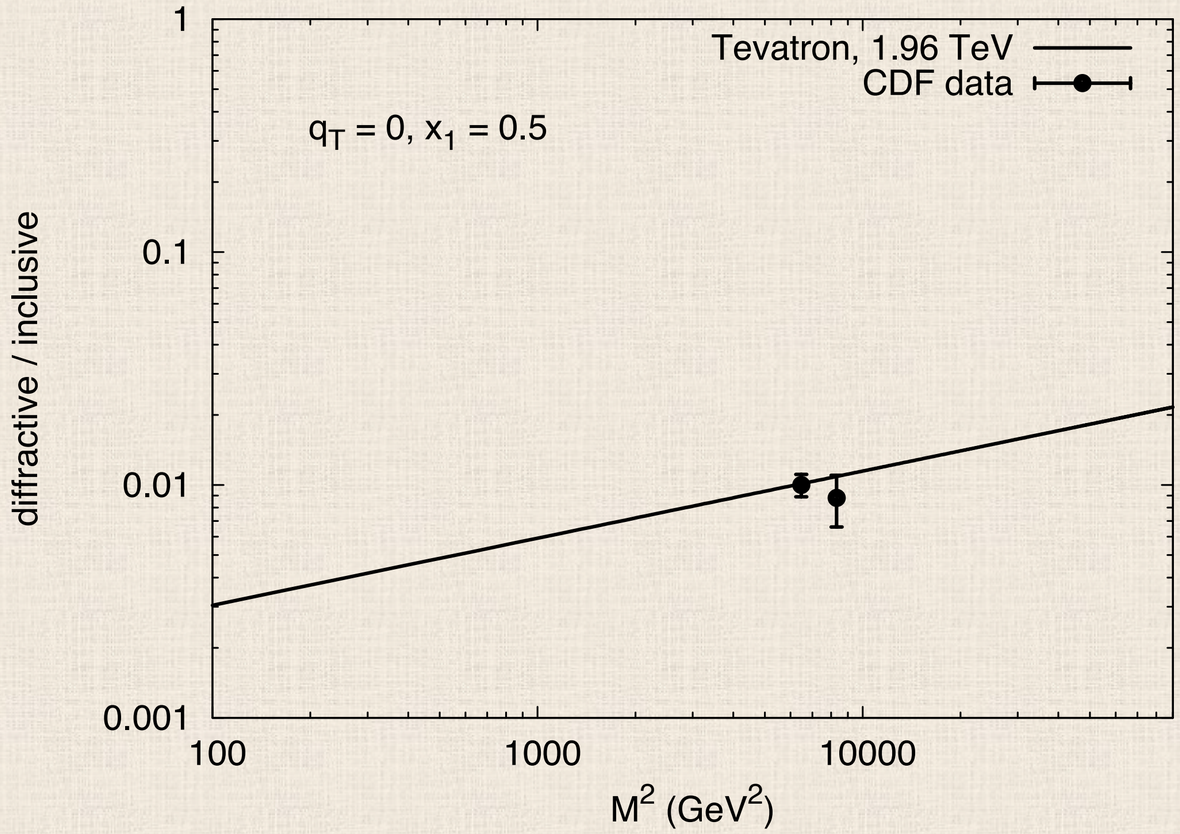
Diffractive Z and W production

Abelian diffractive radiation of any particle is described by the same Feynman graphs, only couplings and spin structure may vary.

R.Pasechnik, B.K., I.Potashnikova 2012.







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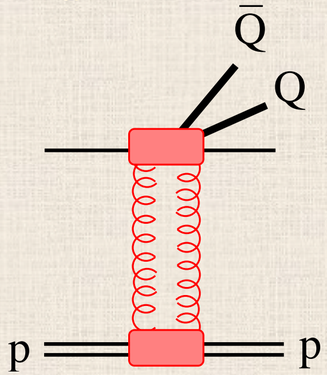
B. Kopeliovich, Diffraction 2014, Primosten

Diffractive heavy flavors

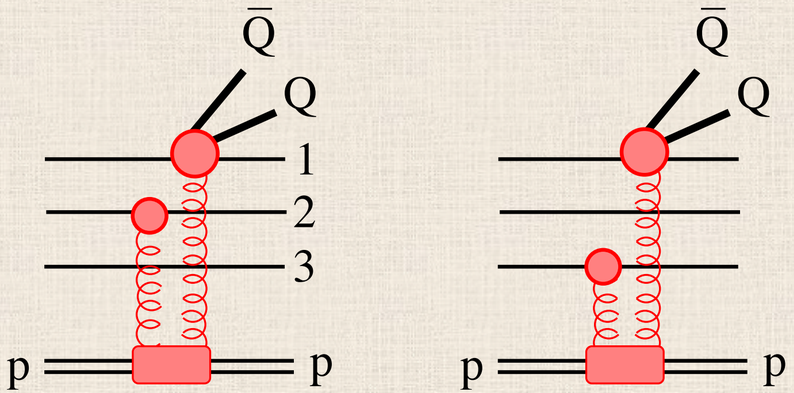
Diffractive production of a heavy quark pair by an isolated parton is not zero, but is a higher twist



$\sigma \sim 1/m_Q^4$

Higher twist

Leading twist mechanism in diffraction:

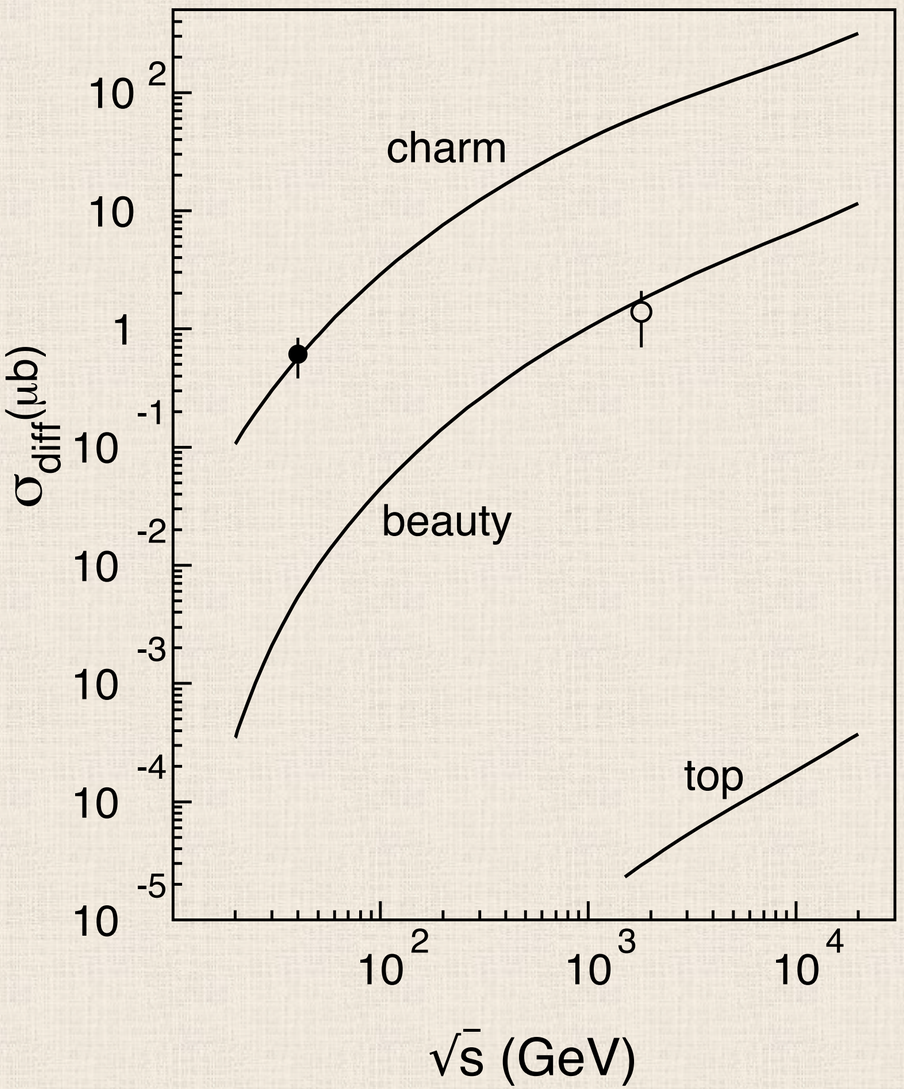


$\sigma \sim 1/m_Q^2$

Leading twist

B.K., I.Potashnikova, I.Schmidt, A.Tarasov 2006

The leading twist behavior, $1/m_Q^2$, is confirmed by CDF data



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Summarizing,

Forward diffractive radiation of direct photons, Drell-Yan dileptons, and gauge bosons Z, W, by a parton is forbidden. A hadron can diffractively radiate in the forward direction due to possibility of soft interaction with the spectators. This breaks down diffractive factorization resulting in a leading twist dependence on the boson mass, $1/\mathrm{M}^2$, well confirmed by data.

Non-abelian forward diffractive radiation of heavy flavors is permitted even for an isolated parton, although it is a higher twist.
The leading twist $1/\mathrm{m}_\mathrm{Q}^2$ comes from the interference between large and small distances.

BACKUPS

• Measurements at ISR led to an amazingly large (probably incorrect) cross section of diffractive charm production (K.L.Giboni et al. 1979), $\sigma \sim 10 - 60$ μb. This experiment was order of magnitude above the subsequent data for inclusive charm production.

• The E653 experiment found no diffractive charm in p – Si collisions at 800 GeV . There is almost no A-dependence between hydrogen and silicon, so $\sigma \leq 26$ μb

• The E690 experiment reported the diffractive charm cross section at $\sigma = 0.61 \pm 0.12 \pm 0.11$ μb at 800 GeV. Agrees well with our calculations.

• The CDF experiment measured the fraction of diffractively produced beauty, $R^{\bar{b}b}_{diff/tot} = (0.62 \pm 19 \pm 16)\%$, at √s = 1.8 TeV . The total cross section of beauty production at this energy has not been measured so far. If to rely on the theoretical prediction (J.Raufeisen & J.C.Peng) $\sigma^{\bar{b}b}_{tot}$ = 200 mb, then $\sigma^{\bar{b}b}_{diff} \approx$ 1.2 mb.

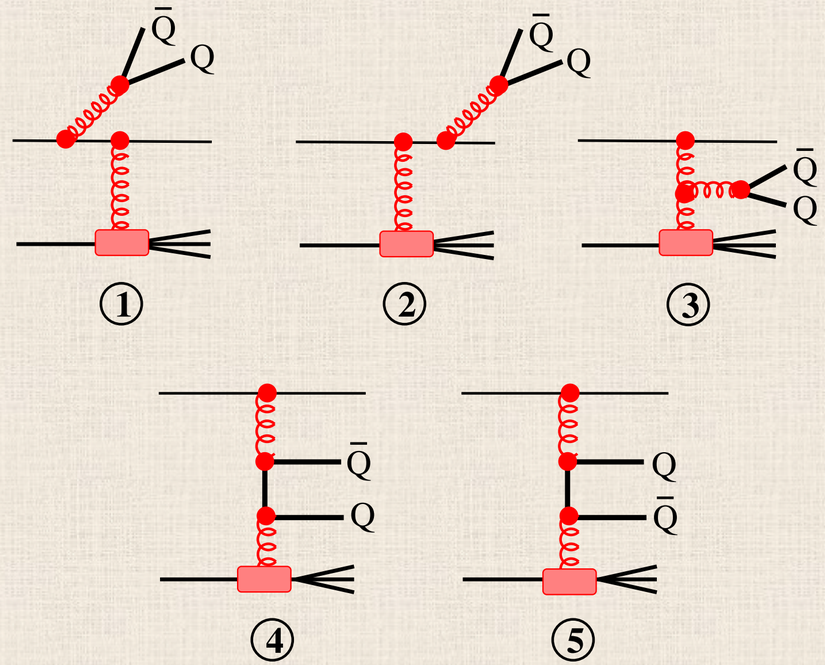
BACKUPS

B.K., I.Potashnikova, I.Schmidt, A.Tarasov 2006

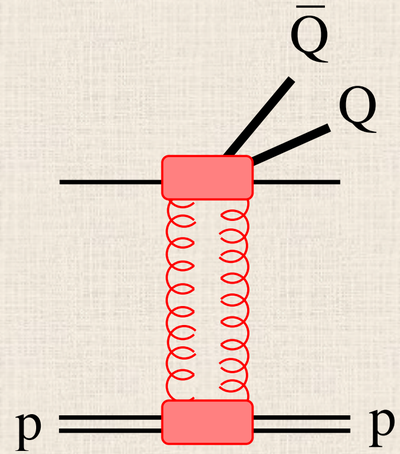
Bremsstrahlung and Production mechanisms in inclusive production of heavy flavors by a projectile parton (quark or gluon)

$$\mathbf{M_{Br} = M_1 + M_2 + \frac{Q^2}{M^2 + Q^2} M_3}$$

$$\mathbf{M_{Pr} = \frac{M^2}{M^2 + Q^2} M_3 + M_4 + M_5}$$



Higher twist Bremsstrahlung mechanism in diffraction: radiation of a $\bar{Q}Q$ pair by an isolated parton.

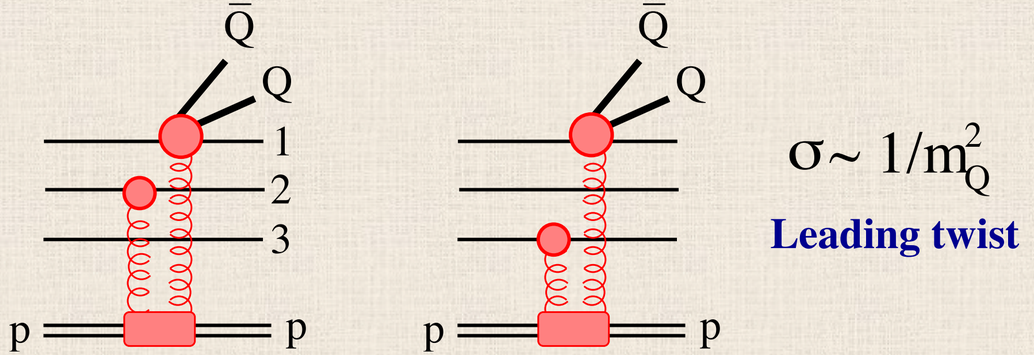


$$\sigma \sim 1/m_Q^4$$

Higher twist

BACKUPS

Leading twist Bremsstrahlung mechanism:



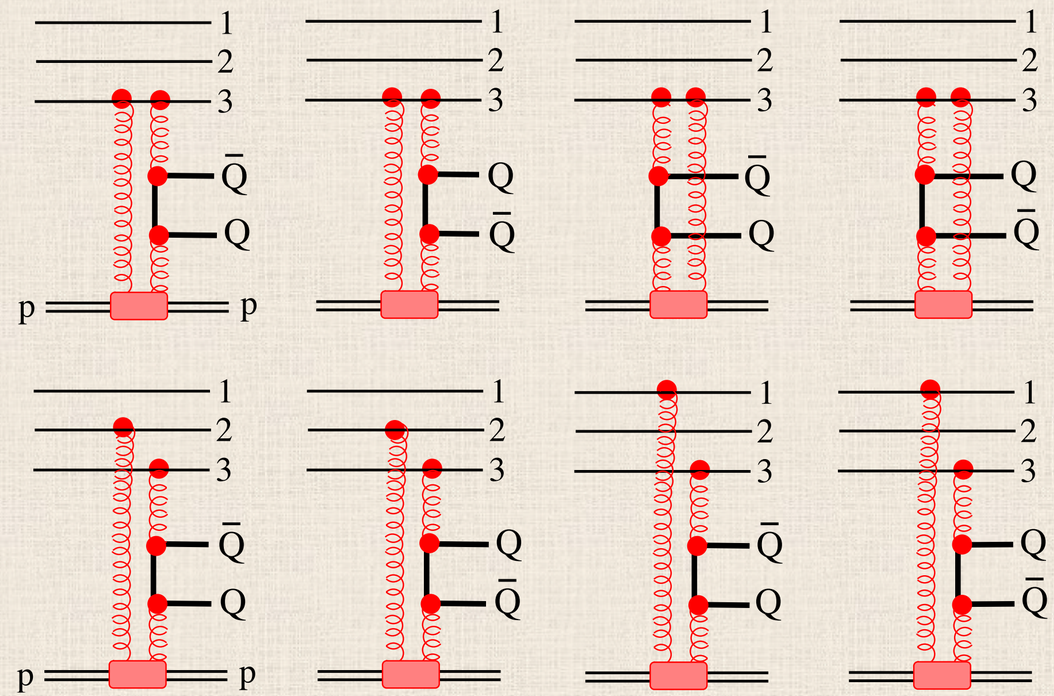
$\sigma \sim 1/m_Q^2$

Leading twist

Production mechanism in diffraction:

$$\sigma \propto 1/\mathbf{m_Q^2}$$

Leading twist



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