# Hard diffraction

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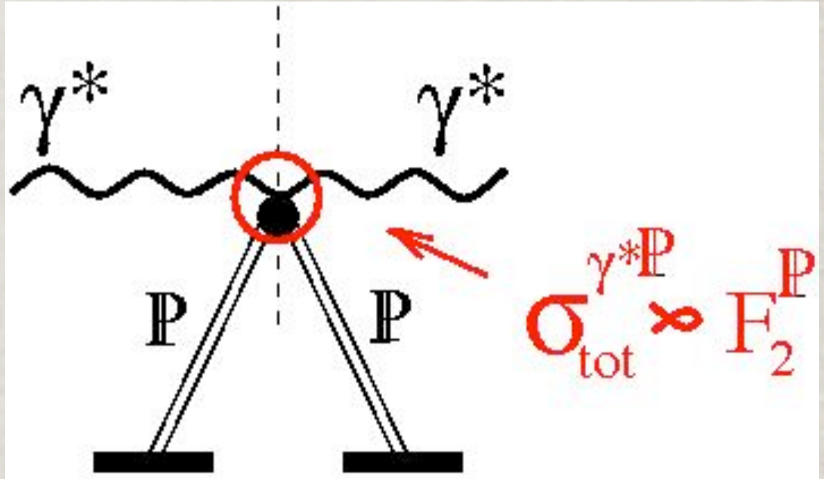
# QCD factorization in diffraction

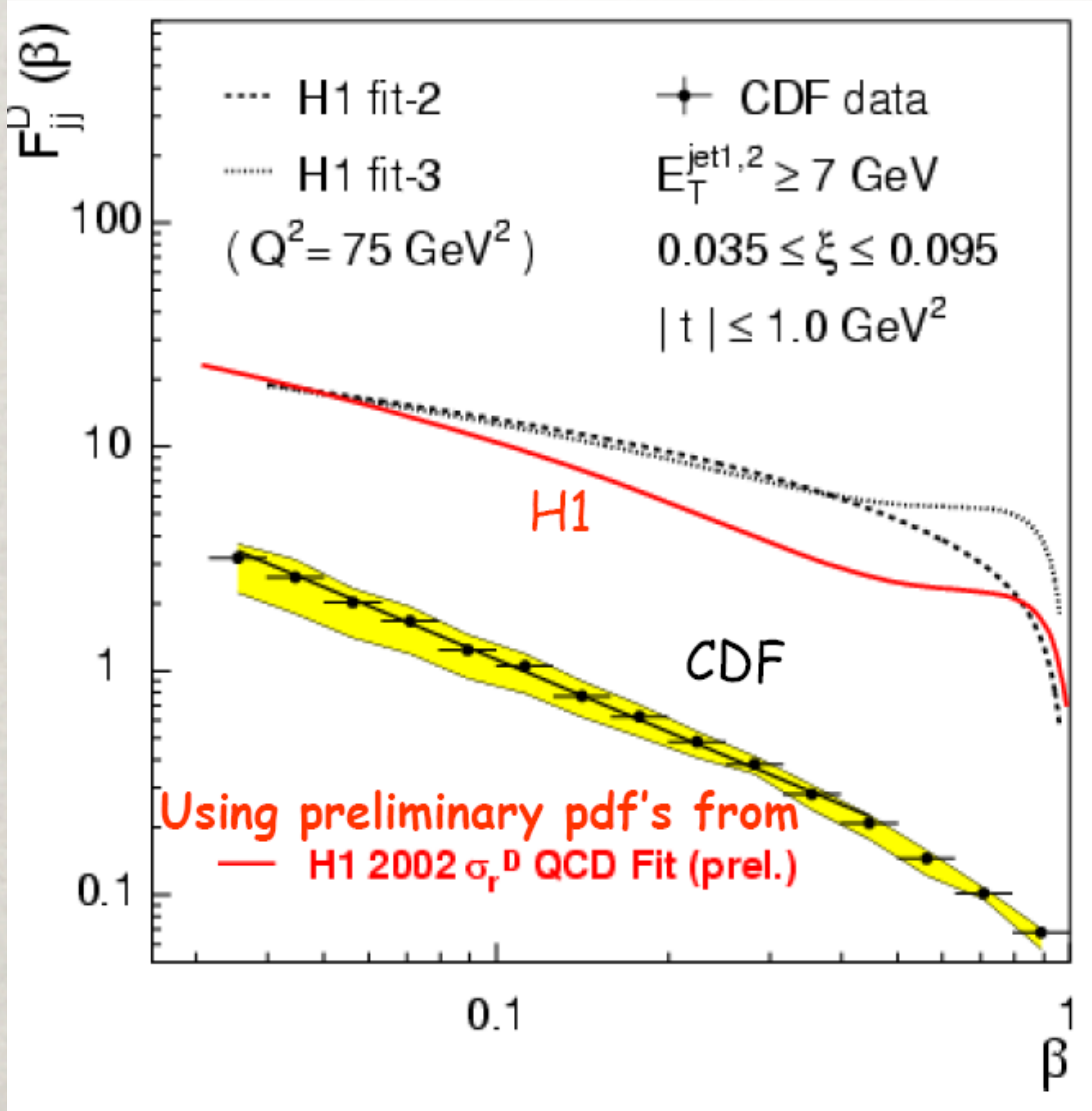
The triple-Regge graphs for diffractive DIS, can be interpreted as a way to measure the structure function (PDFs) of the Pomeron. (Ingelman-Schlein)




Once the parton densities in the Pomeron are known and factorization is at work, one can predict the cross section of any hard hadronic diffraction, A.Donnachie & P.Landshoff

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

However, data from the Tevatron contradict the predictions by an order of magnitude. Diffractive factorization fails for several reasons. The main is interaction with the spectator partons, which suppress large rapidity gaps and considerably modify the scale dependence.



# Outline

- **Diffractive DIS is soft-dominated**

  B.Povh & BK, Z.Phys. A354(1997)467

- **Diffractive Drell-Yan**

  I.Potashnikova, I.Schmidt, A.Tarasov & BK, PRD 74(2006)114024

  R.Pasechnik & BK, EPJ C71(2011)1827

- **Diffractive gauge bosons**

  R.Pasechnik, I.Potashnikova & BK, PRD 86(2012)114039

- **Diffractive heavy flavors**

  I.Potashnikova, I.Schmidt, A.Tarasov & BK, PRD 76(2007)034019

- **Diffractive Higgs production**

  S.Brodsky, I.Schmidt, J.Soffer & BK, PRD 76(2007)034019

  R.Pasechnik, I.Potashnikova & BK, PRD 92(2015)094014

- **Diffractive dijets**

  R.Pasechnik, I.Potashnikova & BK, arXiv:1897.05548

# Diffractive DIS: aligned jets

Mean dipole separation $\langle \mathbf{r^2} \rangle = \frac{\mathbf{1}}{\mathbf{Q^2 z(1-z) + m_q^2}}$

Hard: $\mathbf{z \sim 1 - z}$ ; $\langle \mathbf{r^2} \rangle \sim \mathbf{1/Q^2}$

Soft: $\mathbf{z \sim \mu^2/Q^2 \ll 1}$ ; $\langle \mathbf{r^2} \rangle \sim \mathbf{1/\mu^2}$

| Fluctuation | $W_h^{\gamma*}$ | $\sigma_{tot}^{hN}$ | $W_h^{\gamma*}\sigma_{tot}^{hN}$ (incl) | $W_h^{\gamma*}(\sigma_{tot}^{hN})^2$ (diff) |
|---|---|---|---|---|
| Hard | $\sim 1$ | $\sim 1/Q^2$ | $\sim 1/Q^2$ | $\sim 1/Q^4$ |
| Soft | $\sim \mu^2/Q^2$ | $\sim 1/\mu^2$ | $\sim 1/Q^2$ | $\sim 1/\mu^2 Q^2$ |

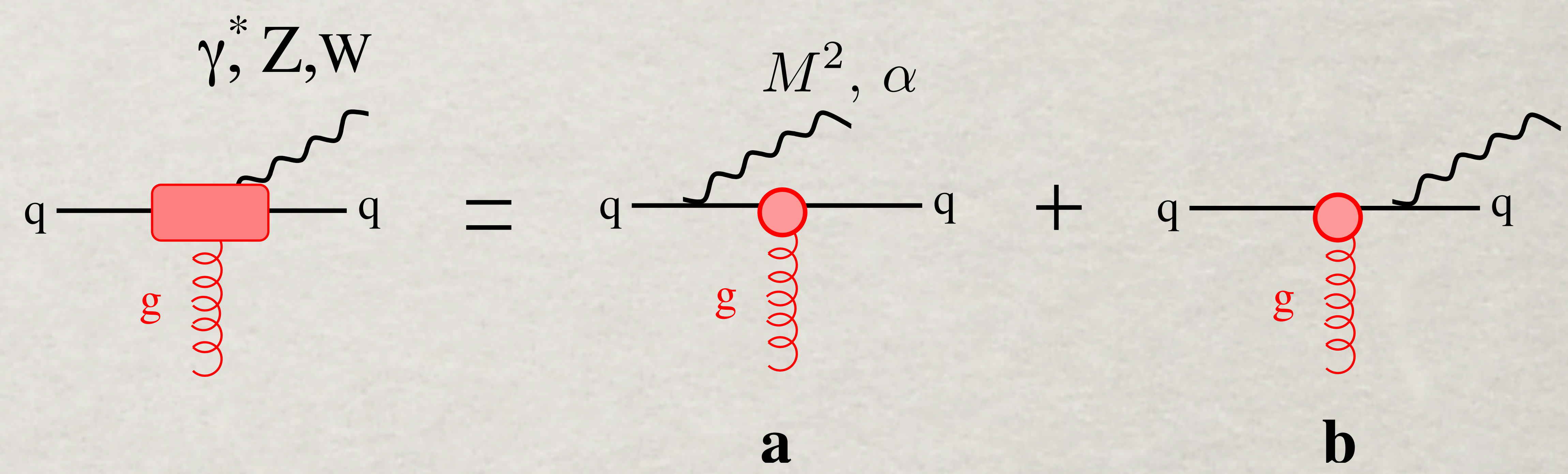
B.Povh & BK, Z.Phys. A354(1997)467

- Naively one could expect $\sigma_{\mathbf{diff}} \propto \mathbf{1/Q^4}$, but it is $\mathbf{1/Q^2}$ , like $\sigma_{\mathbf{incl}}$
- Naively one could expect $\sigma_{\mathbf{diff}} \propto \mathbf{W^{4\Delta}}$ vs $\sigma_{\mathbf{incl}} \propto \mathbf{W^{2\Delta}}$ but in diffraction $\mathbf{\Delta \Rightarrow \Delta_{soft} \sim 0.1}$ , and the two energy dependences turn out to be similar

# Inclusive Drell-Yan via dipoles

Parton model description is not Lorentz invariant.

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

$$\frac{d\sigma^{DY}_{inc}(qp \to \gamma^* X)}{d\alpha\, dM^2} = \int d^2r\, \left|\Psi_{q\gamma^*}(\tilde{r},\alpha)\right|^2 \sigma(\alpha r, x_2)$$

B.K. 1995

where $\alpha = p^+_{\gamma^*}/p^+_q$

$$\frac{d\sigma^{DY}_{incl}(pp \to \gamma^* X)}{dM^2 dx_F} = \frac{\alpha_{em}}{3\pi M^2}\frac{x_1}{x_1+x_2}\int\limits_{x_1}^{1}\frac{d\alpha}{\alpha}F_2^p\left(\frac{x_1}{\alpha}\right)\frac{\sigma(qp \to \gamma^* X)}{d\ln\alpha}$$

J.Raufeisen, A.Tarasov & BK
PLB 503(2001)91

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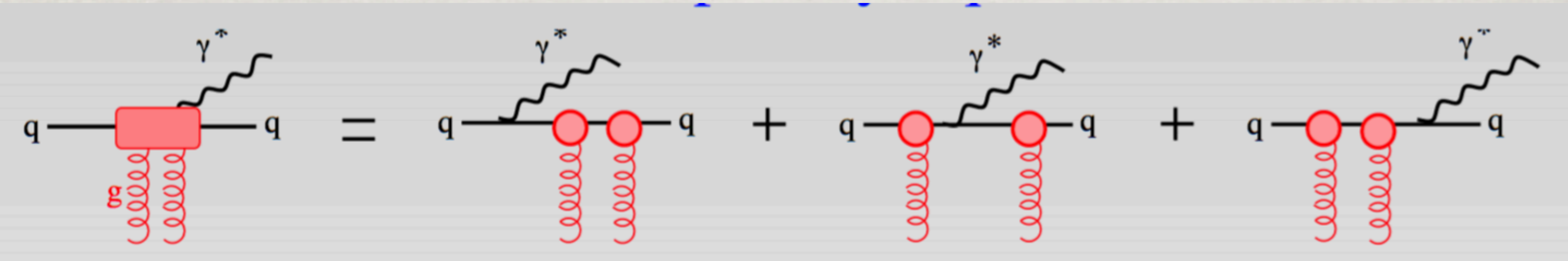
# Diffractive Drell-Yan

Diffractive radiation of a heavy photon by a quark is impossible




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

In both Fock components of the quark, $|q\rangle$ and $|q\gamma^*\rangle$ only quark interacts. No dispersion $\Rightarrow$ no diffraction.

This conclusion holds for any abelian diffractive radiation, like **W, Z bosons, Higgs, etc.**

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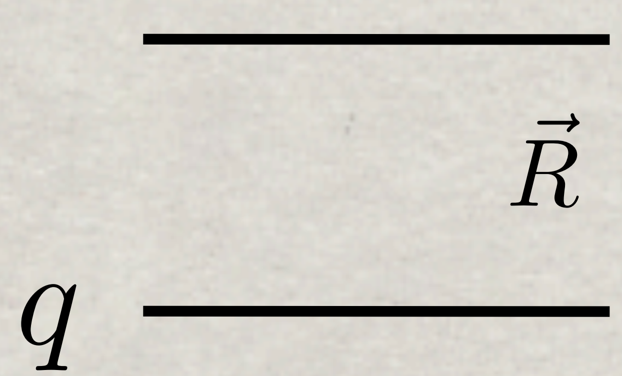
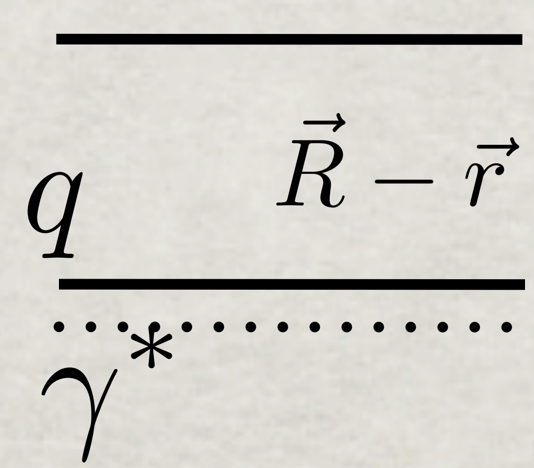
# Diffractive Drell-Yan

The incoming hadron wave function is a linear combination of different Fock states, which are eigenstates of interaction, i.e. can experience only elastic scattering. E.g. dipoles.

Diffractive excitation is possible only due to difference between elastic amplitudes of different Fock states (Good & Walker). Indeed, if all the components interacted equally, the wave packet would remain unchanged, i.e. no new state could be produced.




Large hadronic dipoles without and with a hard DY fluctuation.

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

The diffractive amplitude has the Good-Walker structure,

$$\sigma(\tilde{\mathbf{R}}) - \sigma(\tilde{\mathbf{R}} - \tilde{\mathbf{r}}) = \frac{2\,\sigma_0}{\mathbf{R}_0^2(\mathbf{x}_2)}\, \mathbf{e}^{-\mathbf{R}^2/\mathbf{R}_0^2(\mathbf{x}_2)} \underbrace{\left(\tilde{\mathbf{r}} \cdot \tilde{\mathbf{R}}\right)}_{\text{hard-soft}} + \mathbf{O}(\mathbf{r}^2)$$

GBW: $\sigma(\mathbf{r}) = \sigma_0\left(1 - \mathbf{e}^{-\mathbf{r}^2/\mathbf{R}_0^2}\right)$

# Diffractive Drell-Yan

Differently from DIS diffractive Drell-Yan gets the main contribution from the interplay of soft and hard scales

I.Potashnikova, I.Schmidt, A.Tarasov & BK, PRD 74(2006)114024
R.Pasechnik & BK, EPJ C71(2011)1827

- 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.

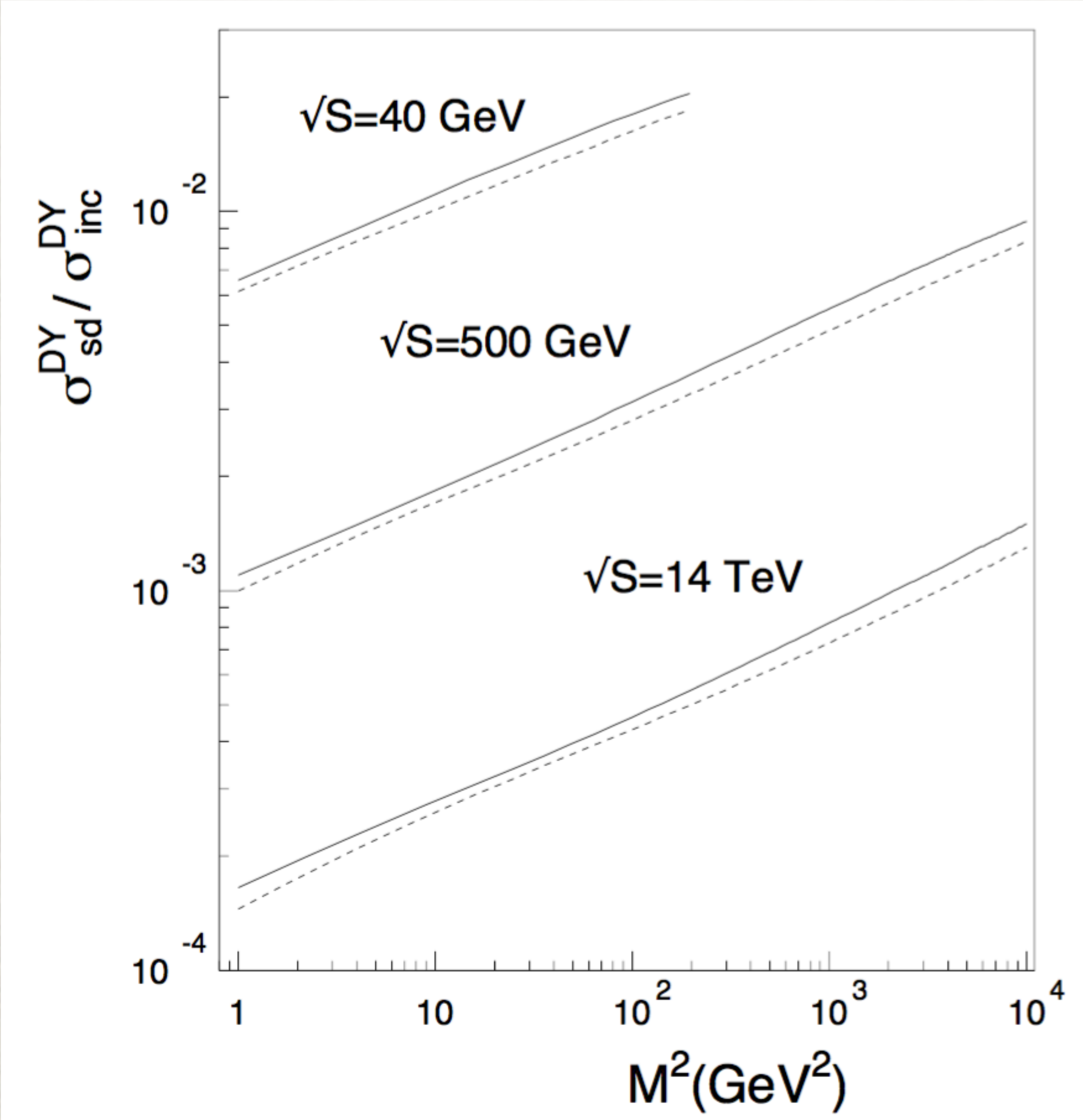
- Such a structure of the diffractive amplitude includes all absorptive corrections (gap survival amplitude), provided that the dipole cross section is adjusted to data.

# Diffractive Drell-Yan

Saturation leads to a peculiar scale dependence of diffractive Drell-Yan.

$$\frac{\sigma^{\mathbf{DY}}_{\mathbf{sd}}}{\sigma^{\mathbf{DY}}_{\mathbf{incl}}} \propto \frac{\exp[-\mathbf{2R^2}/\mathbf{R_0^2(x)}]}{\mathbf{R_0^2(x)}}$$

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

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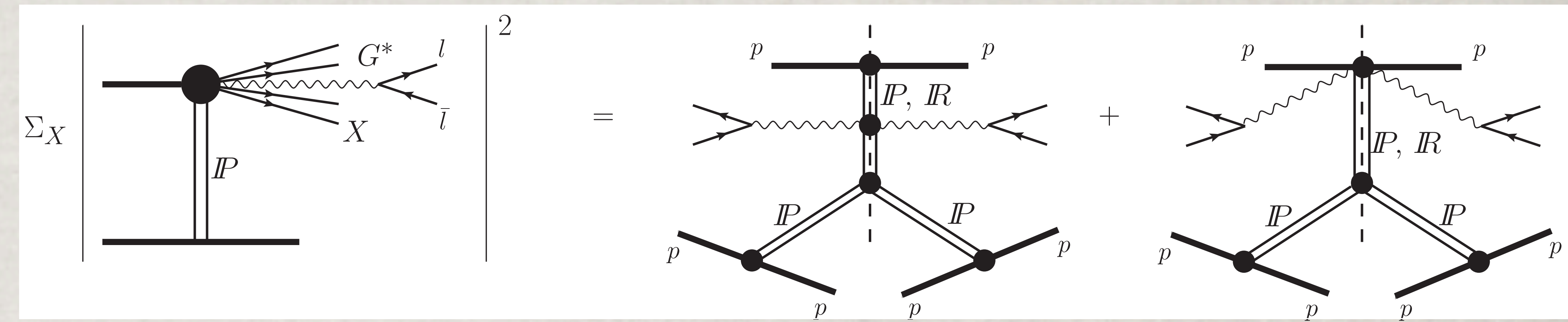
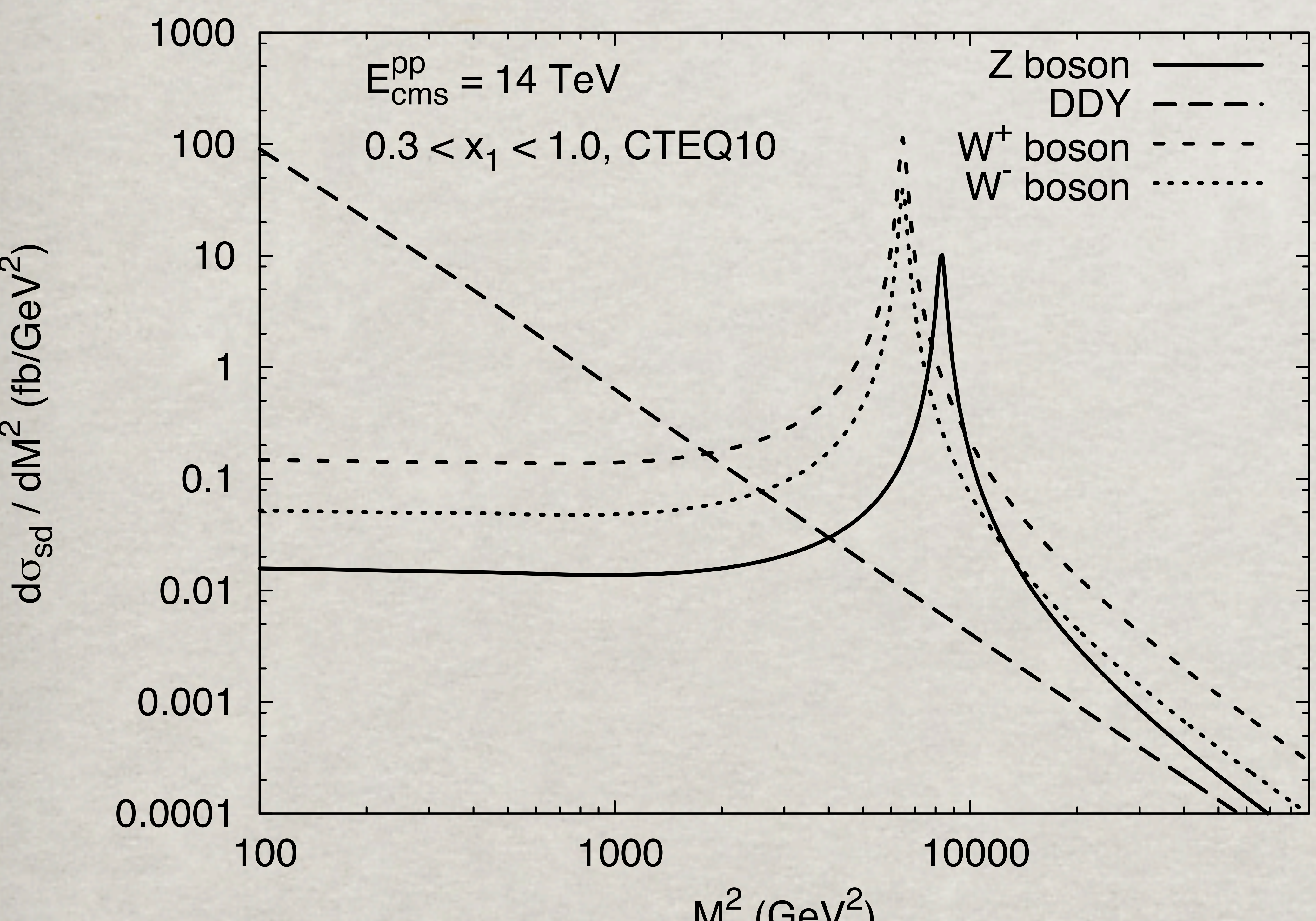
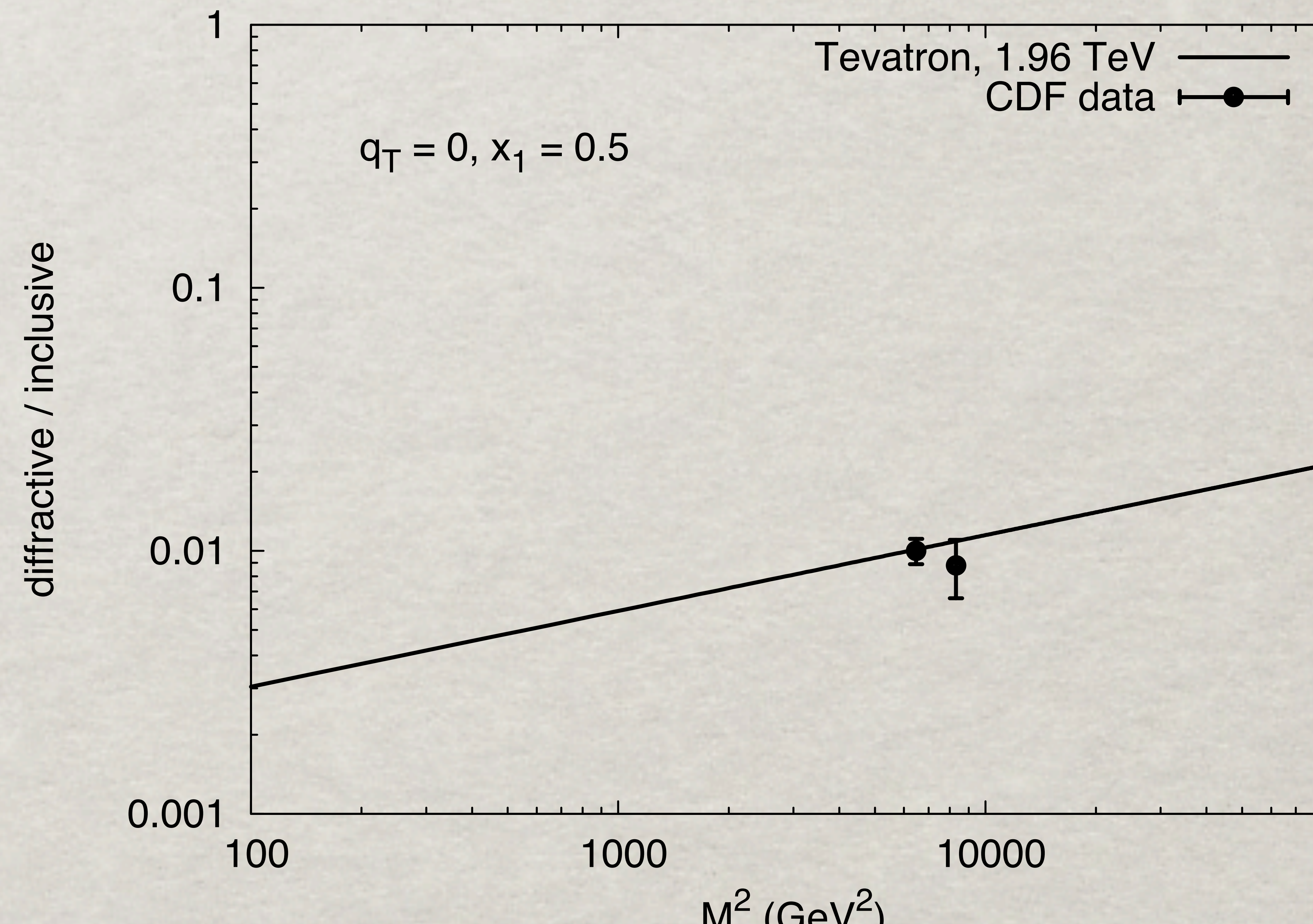
# Another test of scale dependence: diffractive Z and W

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




R.Pasechnik, I.Potashnikova & BK, PRD 86(2012)114039

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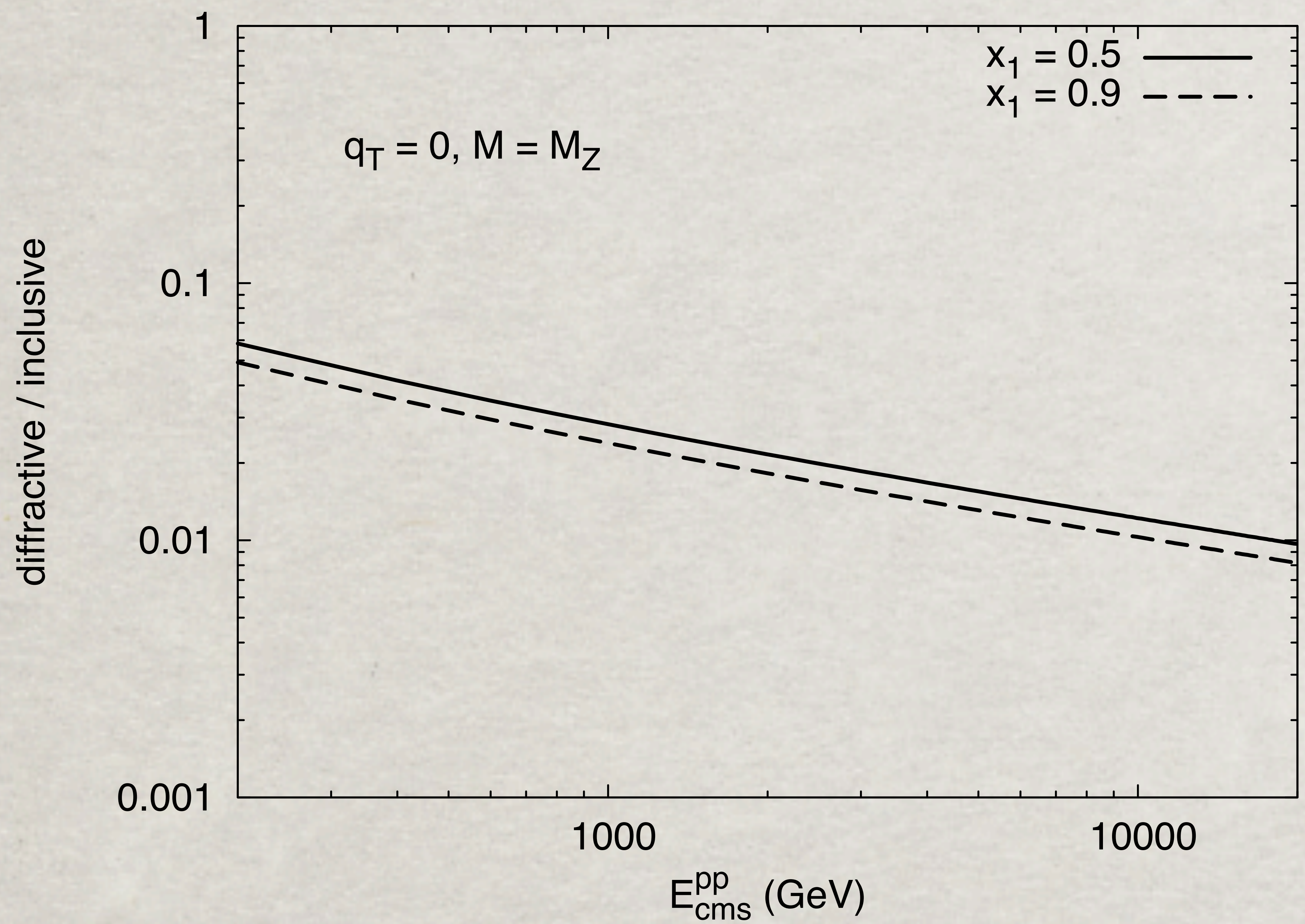
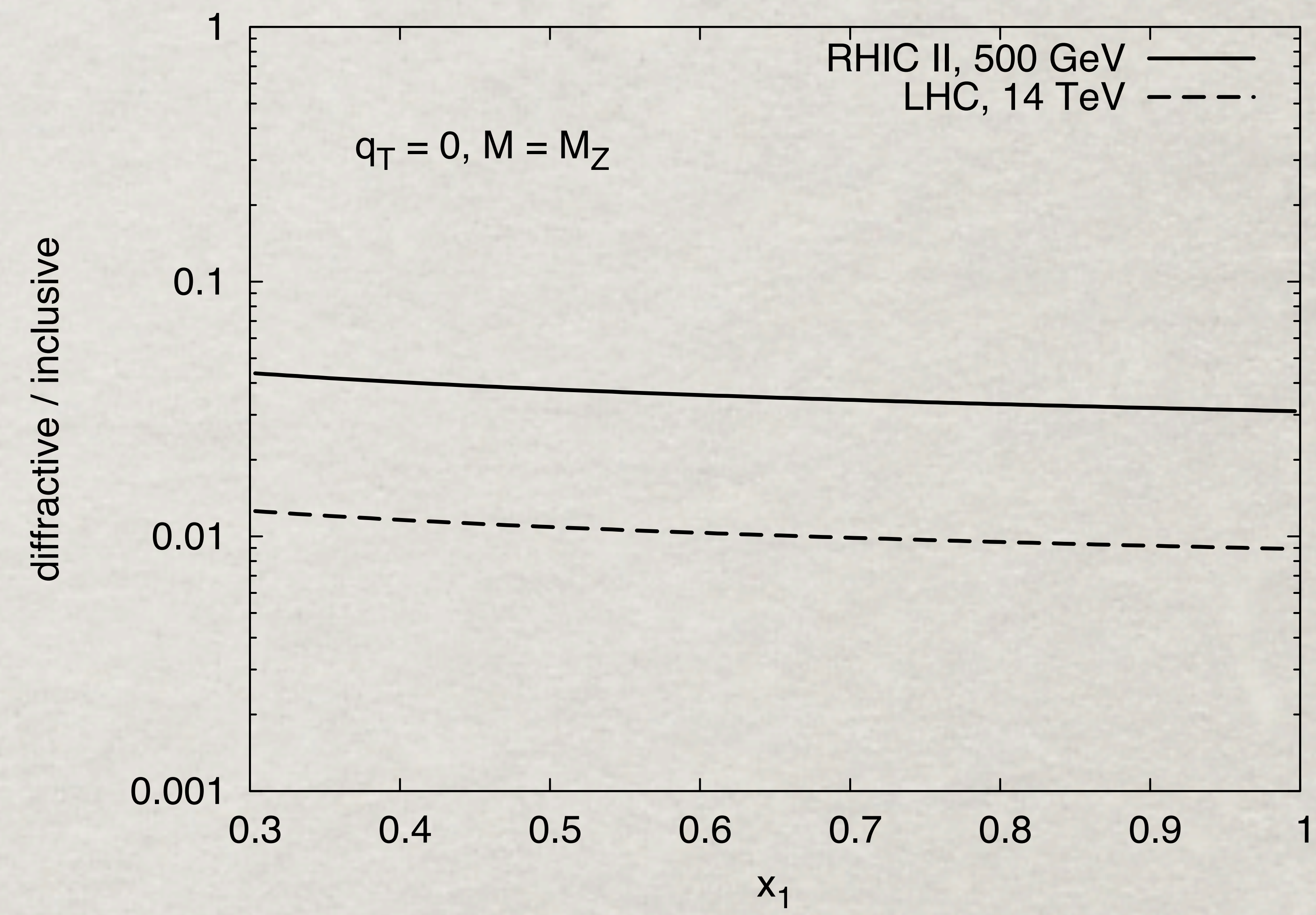
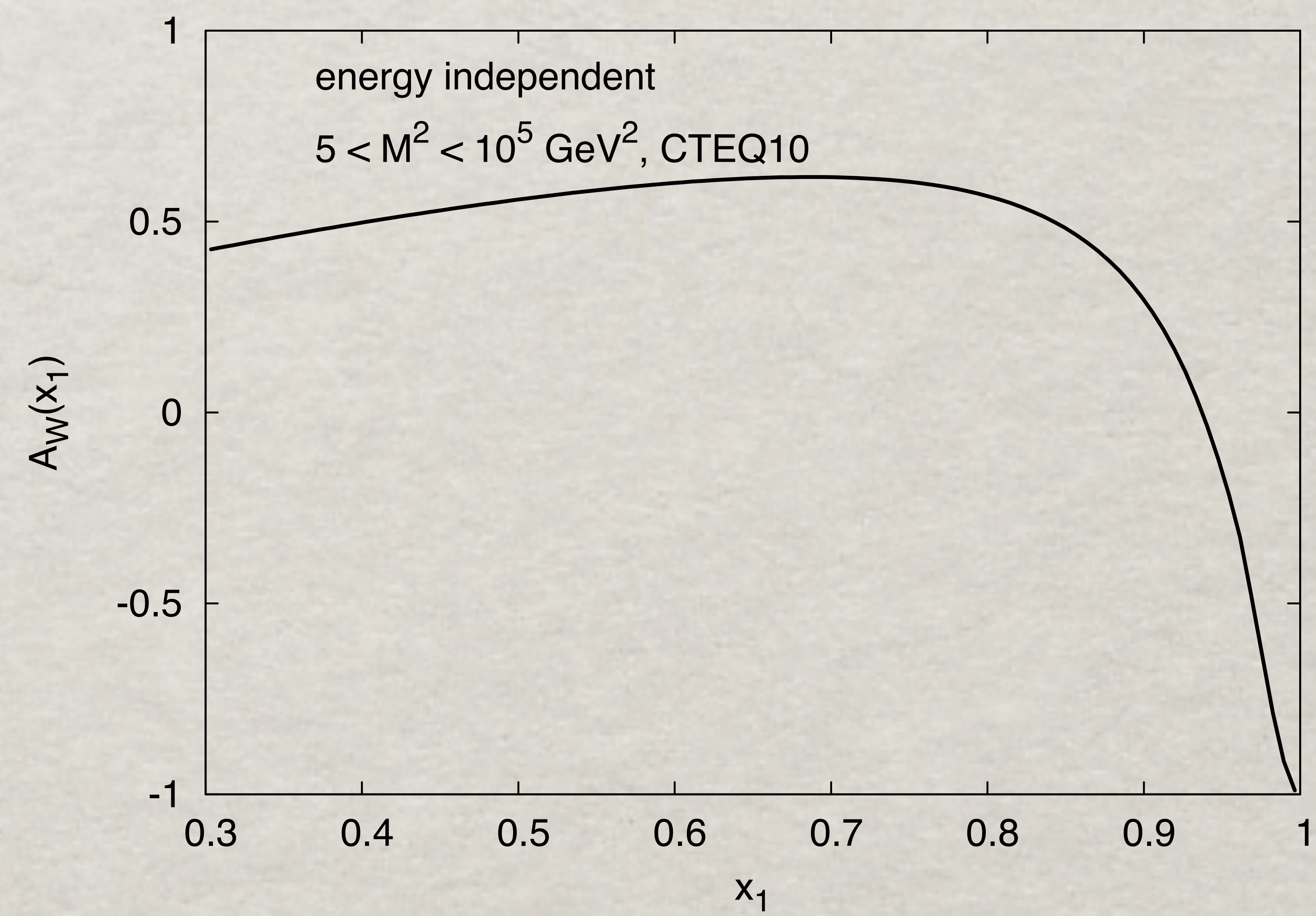
# More of diffractive Z and W




$$\mathbf{A_W(x_1) = \frac{d\sigma_{sd}^{W^+}/dx_1 - d\sigma_{sd}^{W^-}/dx_1}{d\sigma_{sd}^{W^+}/dx_1 + d\sigma_{sd}^{W^-}/dx_1}}$$

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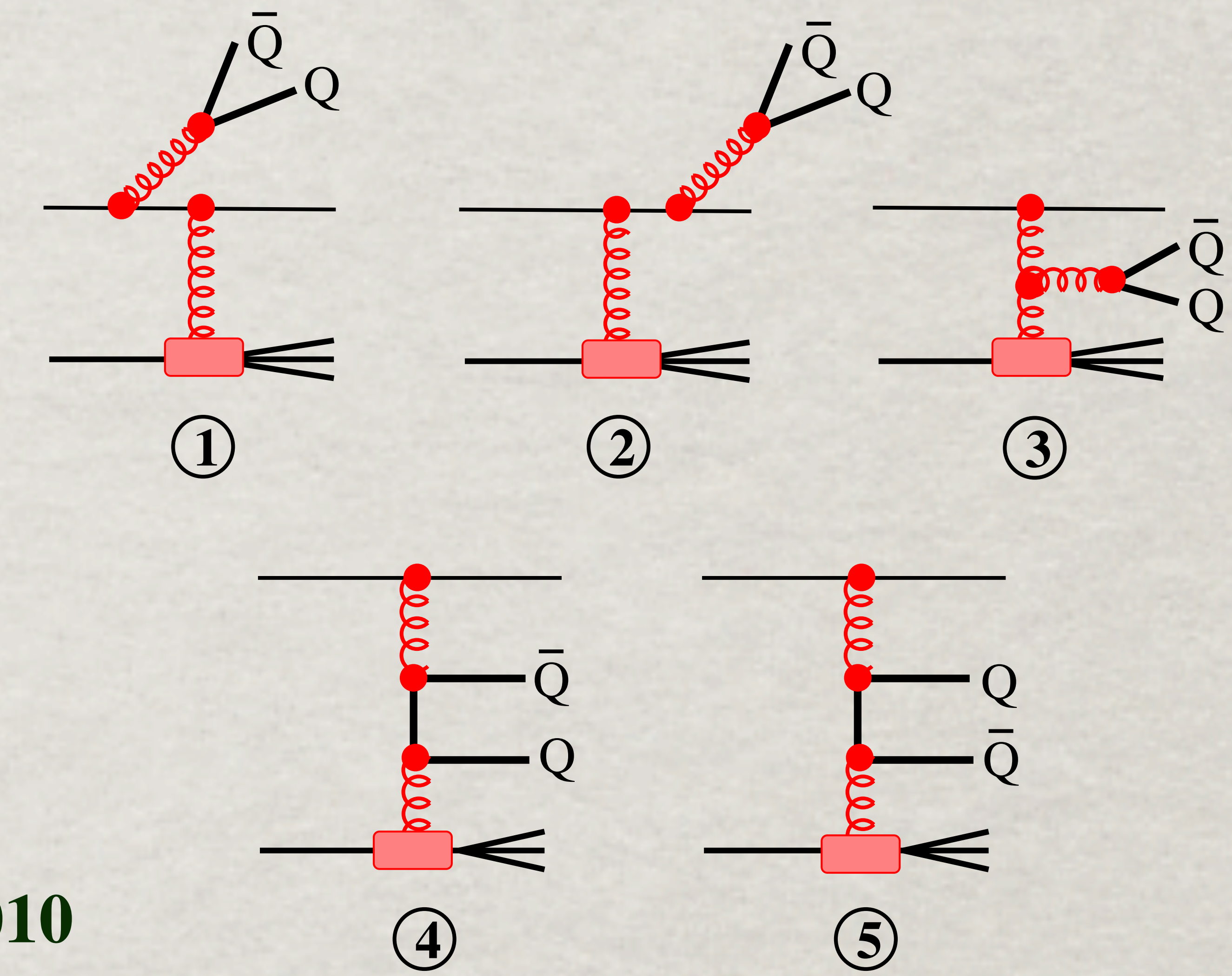
# Diffractive heavy flavors

## Inclusive

Bremsstrahlung (1+2+3) and Production (3+4+5) mechanisms in inclusive production of heavy flavors by a projectile parton (quark or gluon)

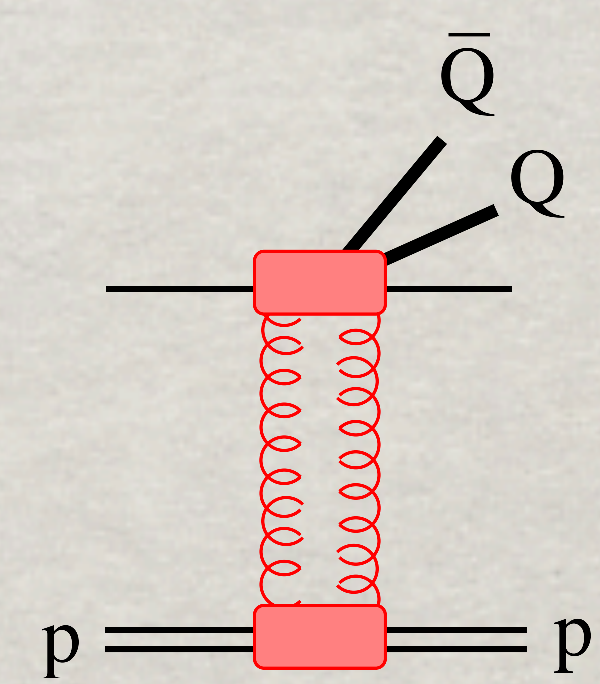



I.Potashnikova, I.Schmidt, A.Tarasov & BK, PRD 76(2007)034019

V.Goncalves, J.Nemchik, R.Pasechnik, I.Potashnikova & BK, PRD 96(2007)014010

## Diffraction

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**

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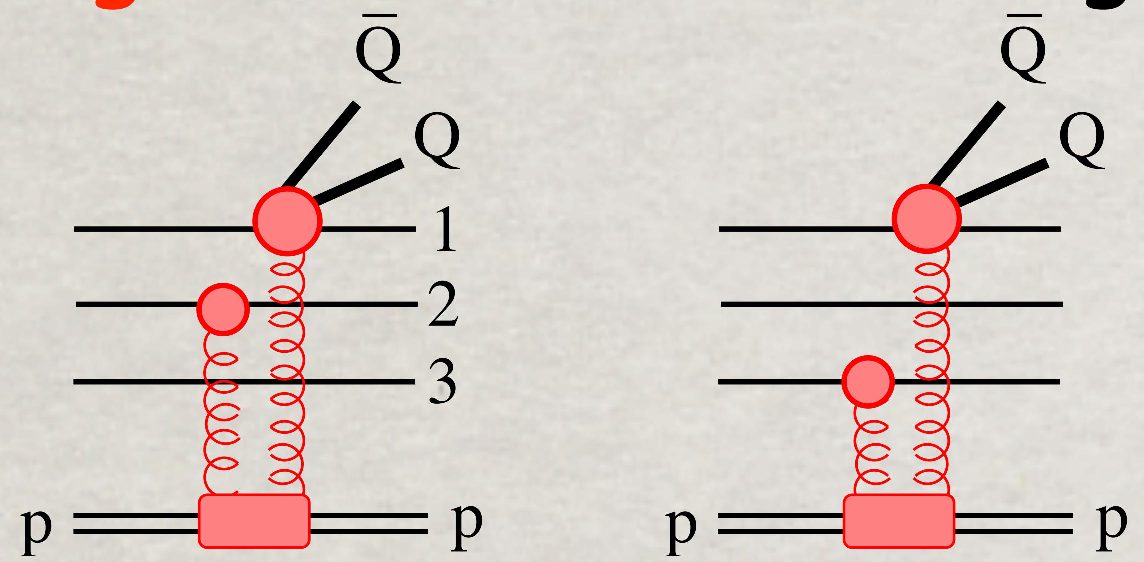
# Diffractive heavy flavors

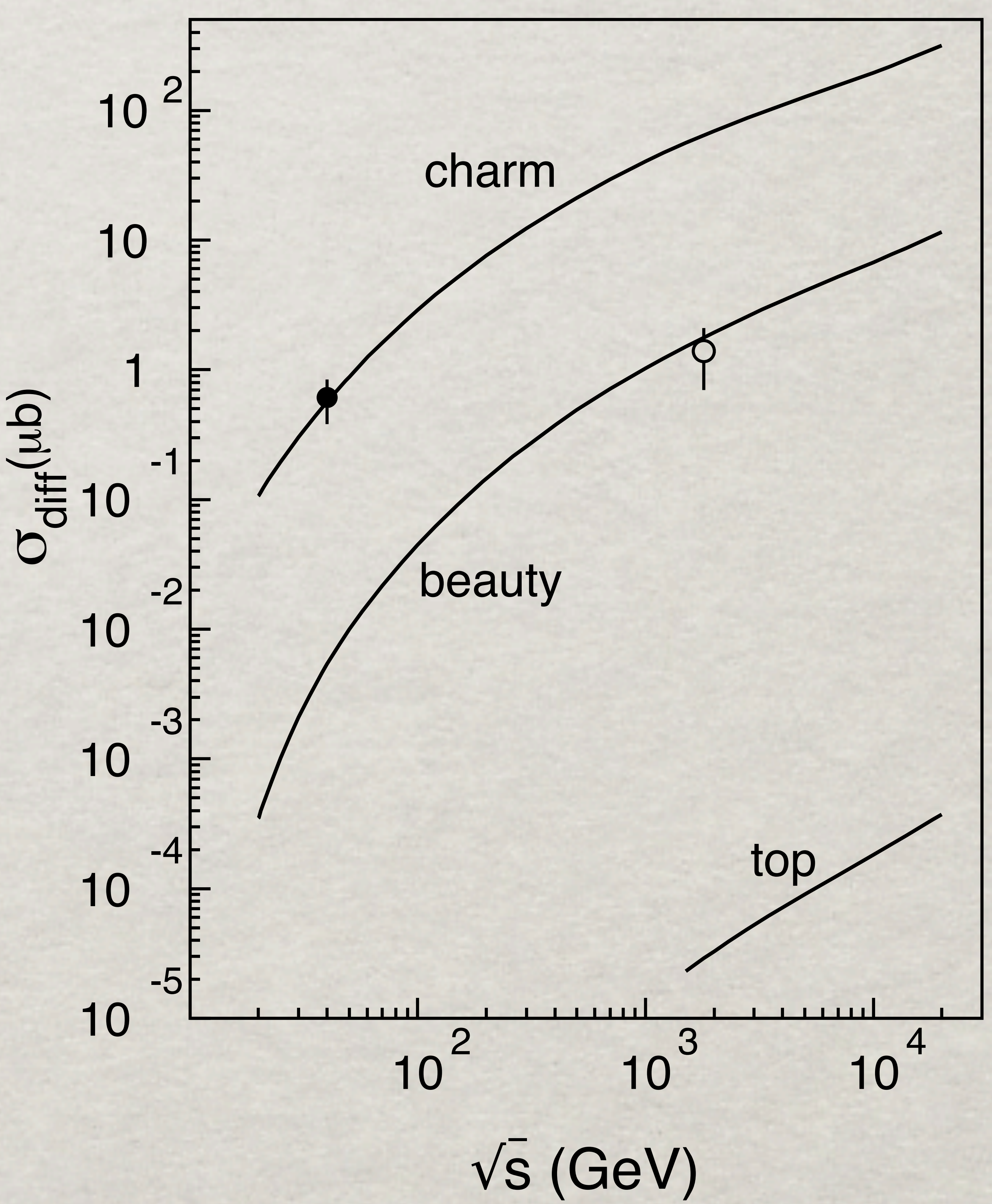
**Leading twist Bremsstrahlung mechanism:**



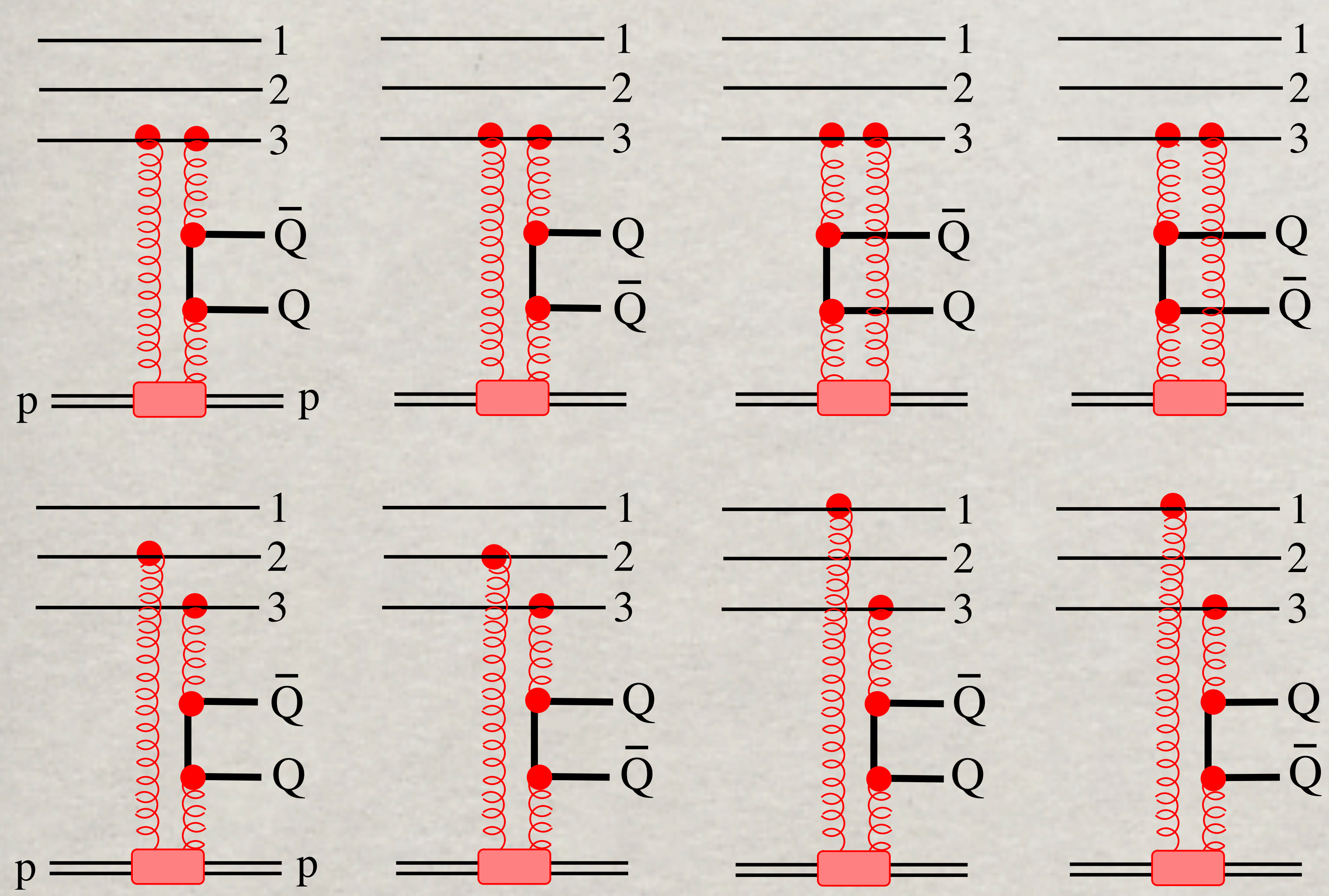

$\sigma \sim 1/m_Q^2$

**Leading twist**

**Test of the scale dependence:**




**Production mechanism in diffraction:**

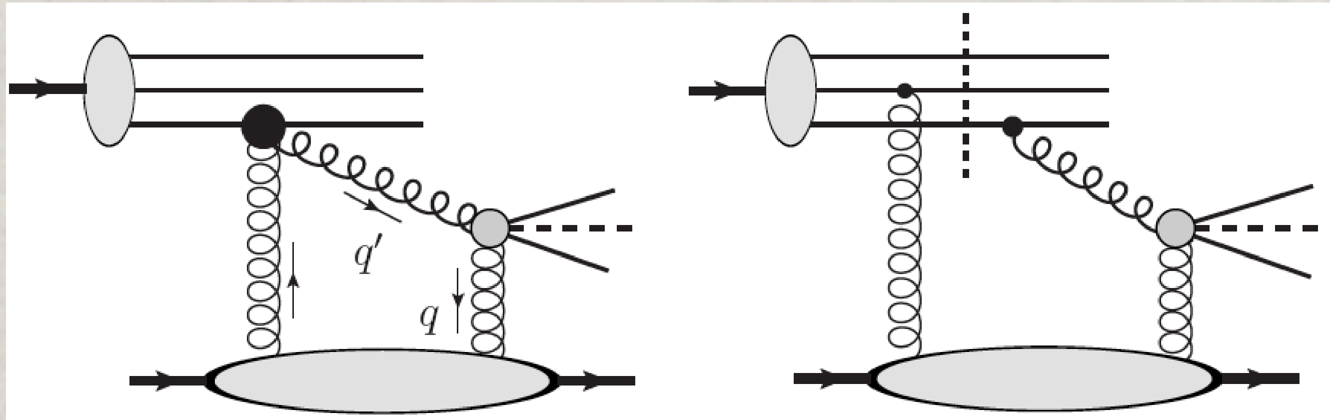


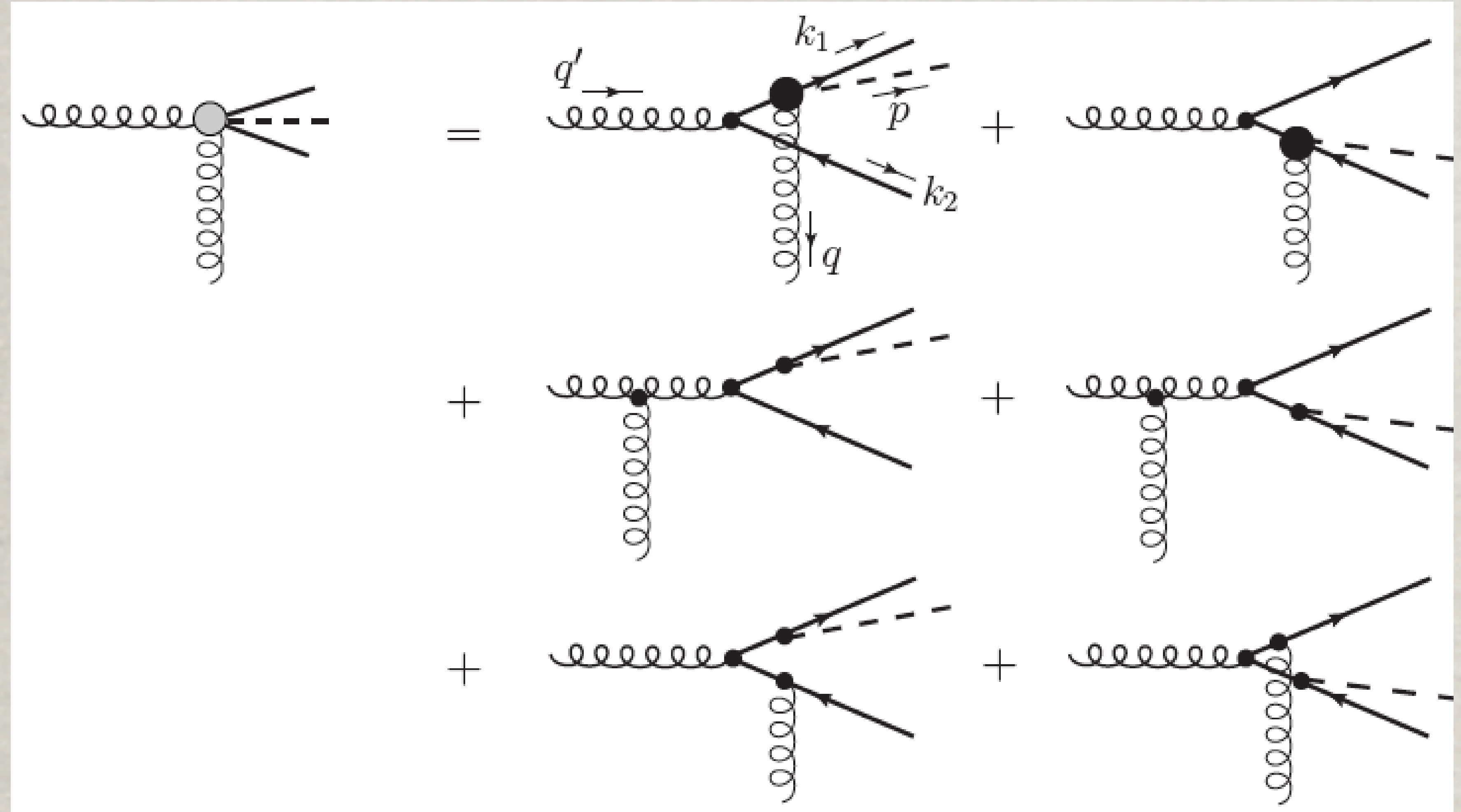

**Leading twist** $\sigma \propto 1/m_Q^2$

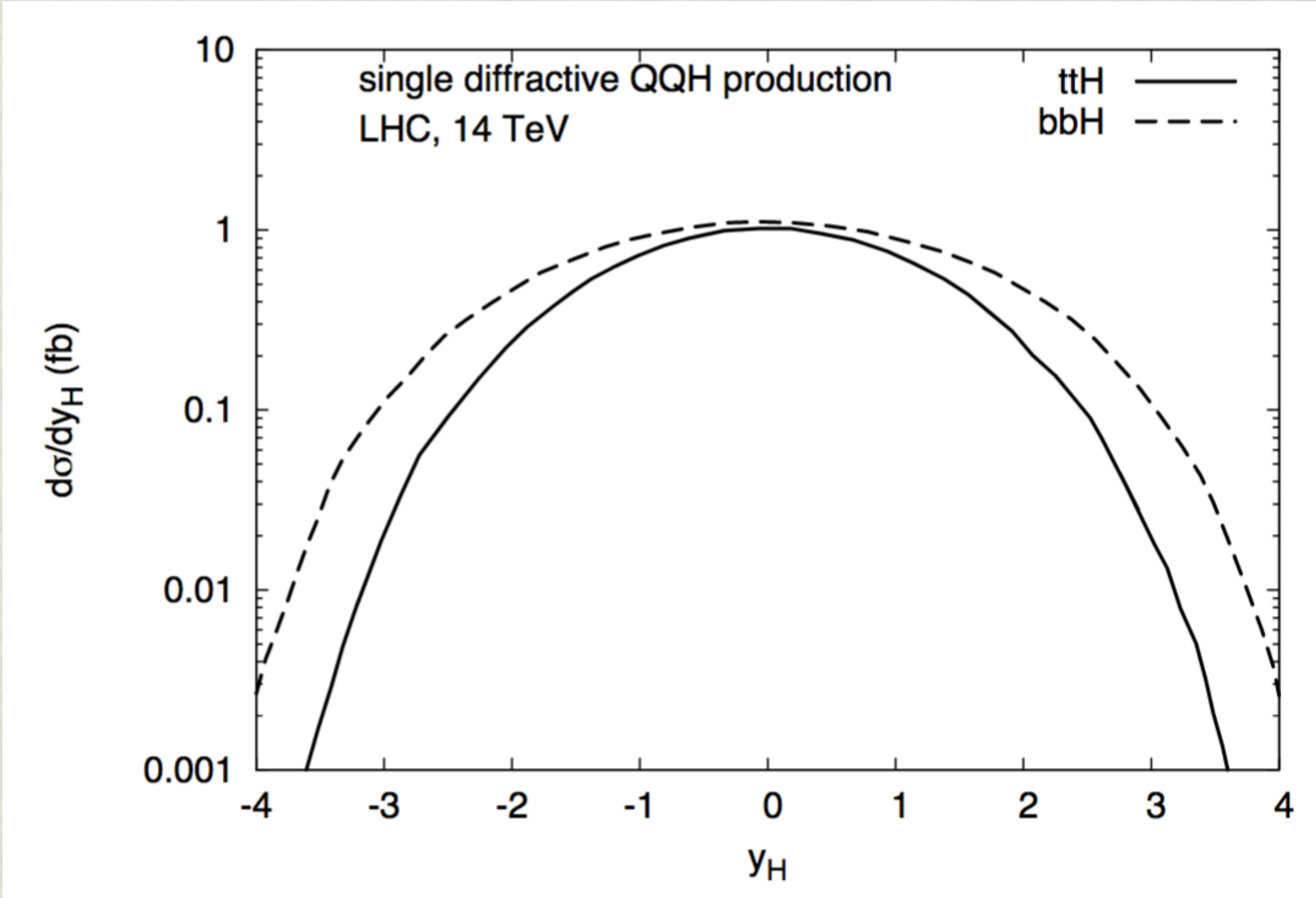
# Diffractive higgsstrahlung

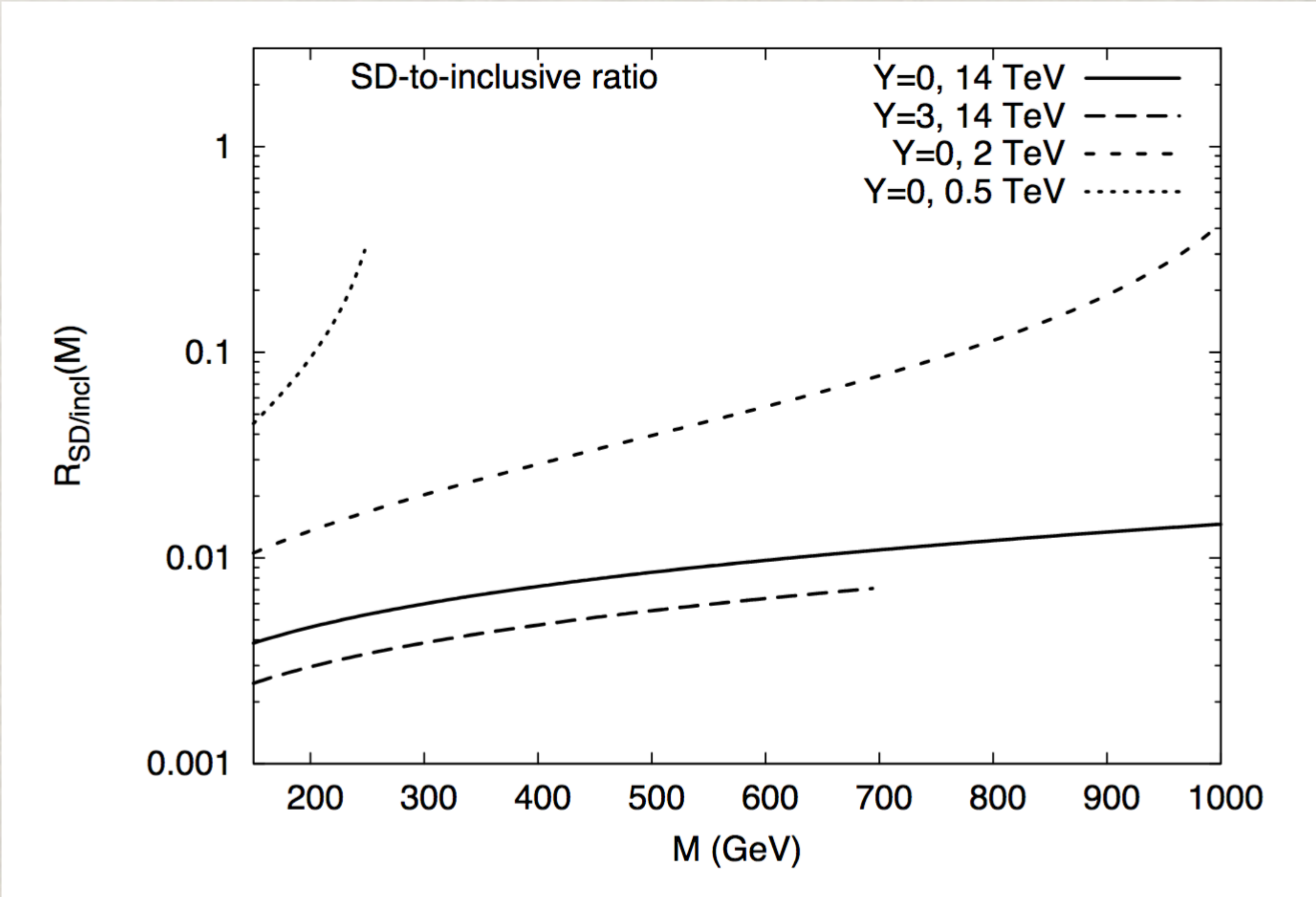
**Light quark do not radiate Higgs directly, only via production of heavy flavors. Therefore the mechanism is the same as for non-abelian diffractive quark production.**

**R.Pasechnik, B.K., I.Potashnikova PRD92 (2015)094014.**

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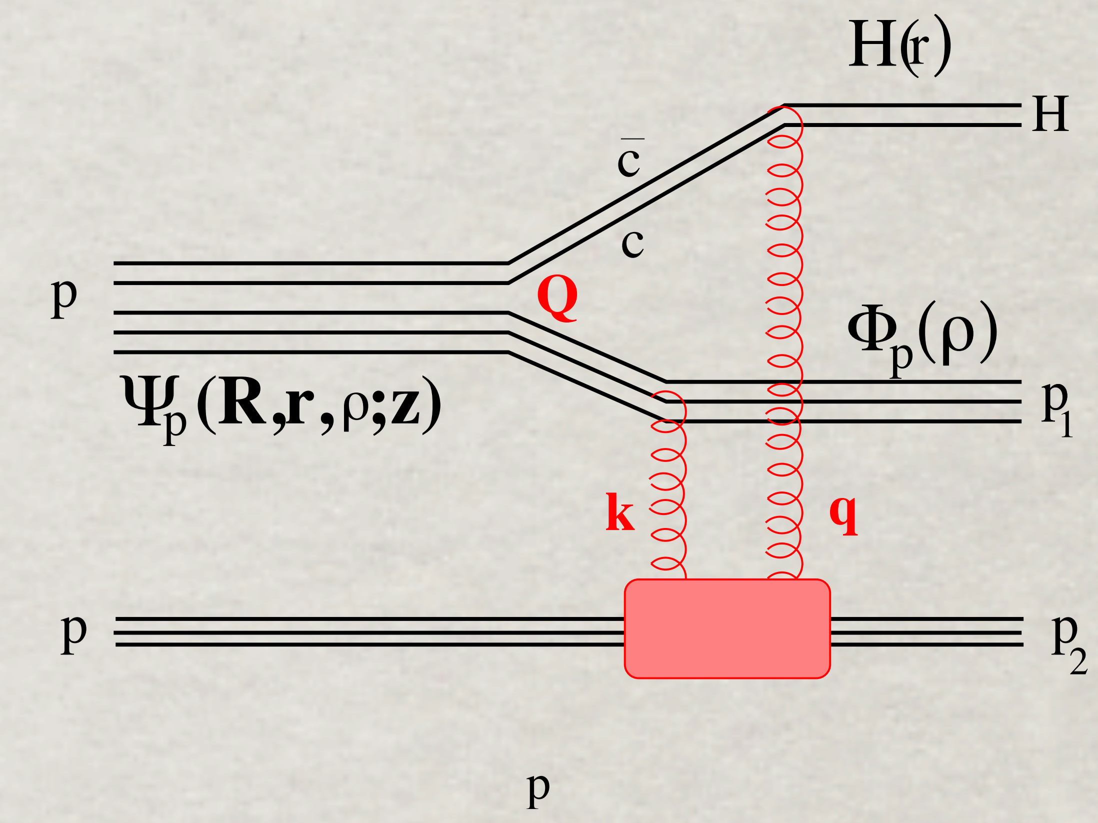
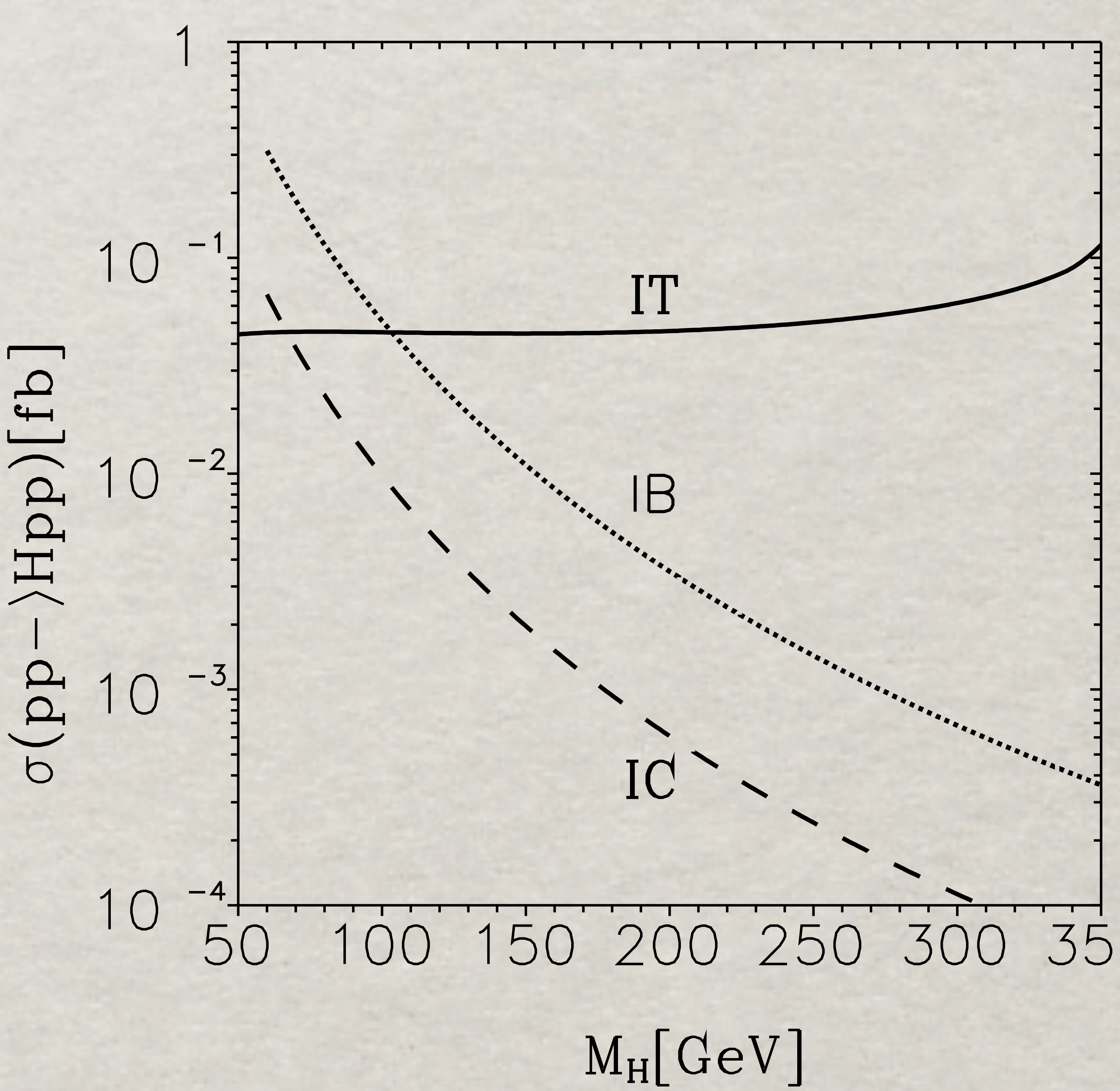
# Diffractive Higgs from heavy flavored sea

A larger cross section may emerge due to admixture of heavy flavors. Exclusive Higgs production, pp→ Hpp, via coalescence of heavy quarks, $Q\bar{Q} \to H$

[S.Brodsky, I.Schmidt, J.Soffer & BK, **PRD73(2006)113005**
S.Brodsky, A.Goldhaber, I.Schmidt & BK, **NP B807 (2009) 334**




The cross section of Higgs production was evaluated assuming 1% of intrinsic charm, and that heavier flavors scale as $1/m_Q^2$ [M.Franz, M.Polyakov, K.Goeke 2000]. At the Higgs mass 125 GeV intrinsic bottom and top give comparable contributions.

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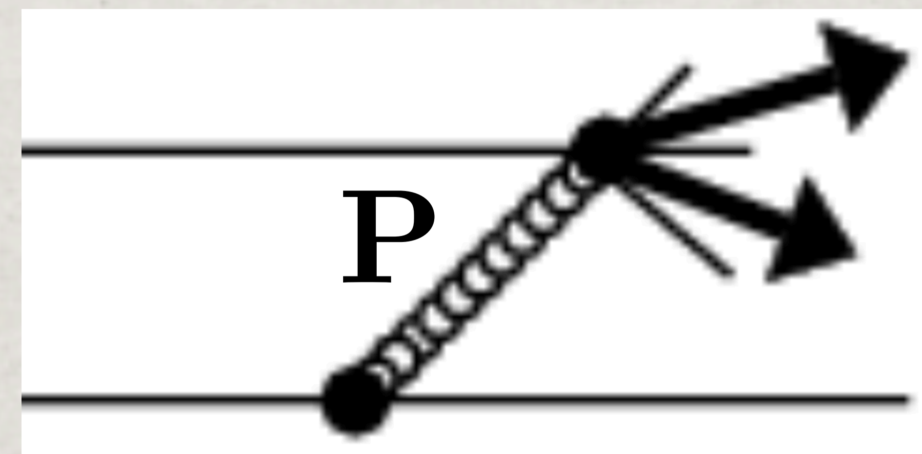
# Diffractive dijets

R.Pasechnik, I.Potashnikova & BK, arXiv:1897.05548




**Notations:**

$$\xi \equiv 1 - x_F = \frac{M_X^2}{s}$$

xF is the fractional longitudinal momentum of the recoil p

$$x_{Bj} = \frac{1}{\sqrt{s}} \sum_{i=1}^{3\,\mathrm{jets}} E_T^i e^{-\eta_i}$$

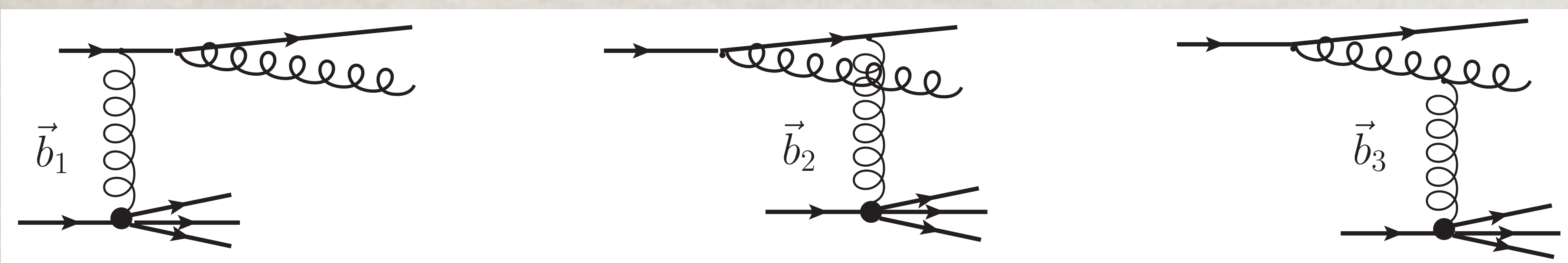
The fractional LC momentum of the target parton (analog of x2 in Drell-Yan)

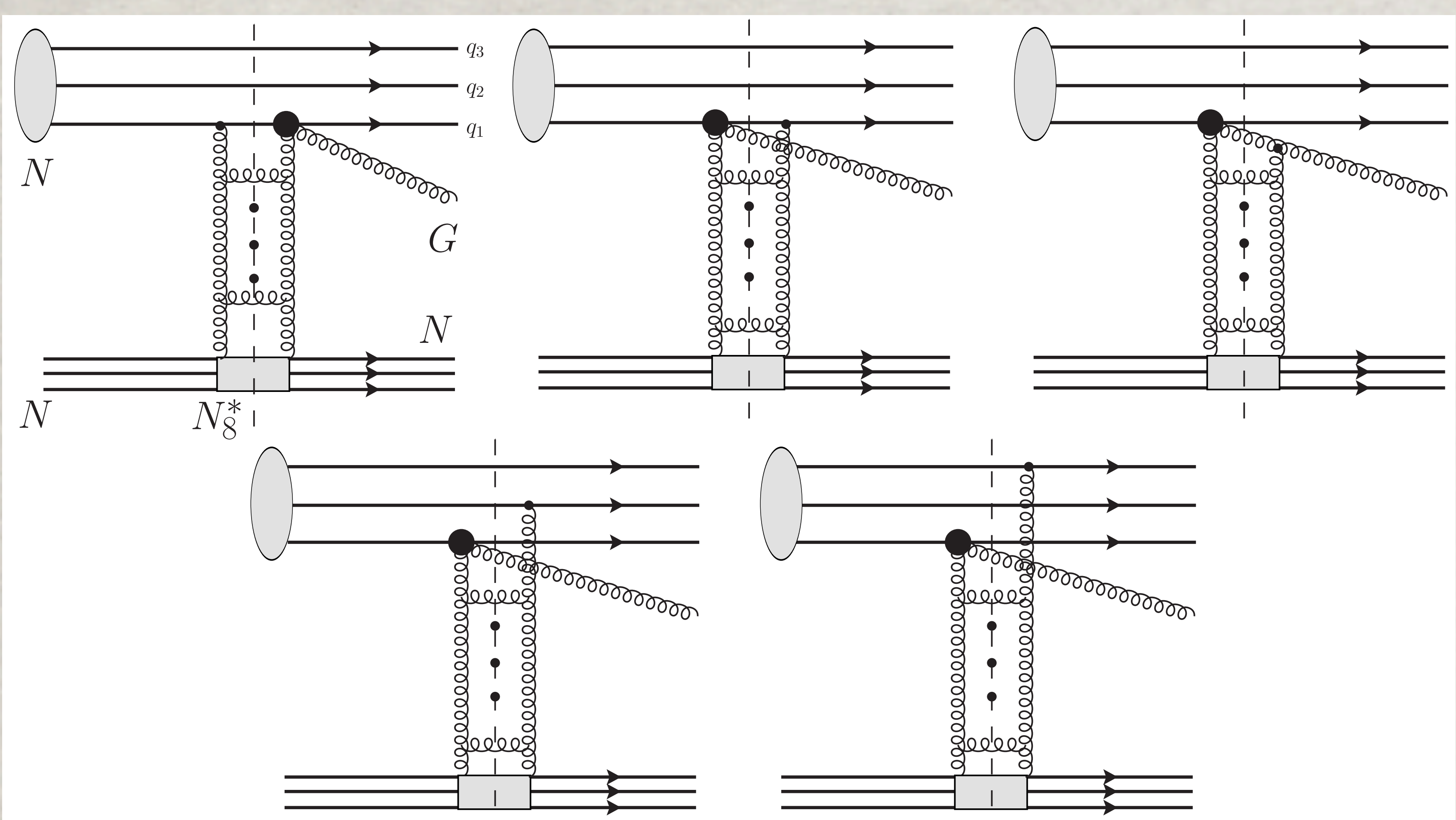
$$Q^2 = \frac{(E_T^1 + E_T^2)^2}{4}$$

The characteristic scale

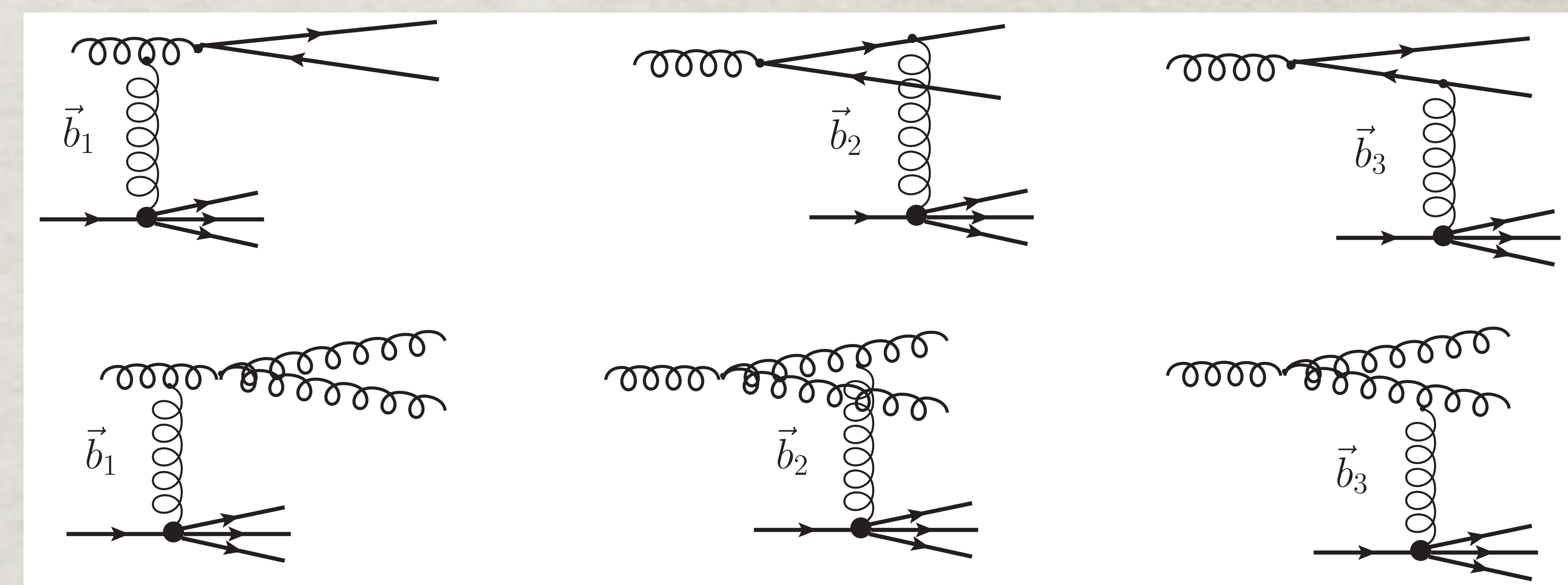
# Diffractive dijets

- quark-gluon dijets



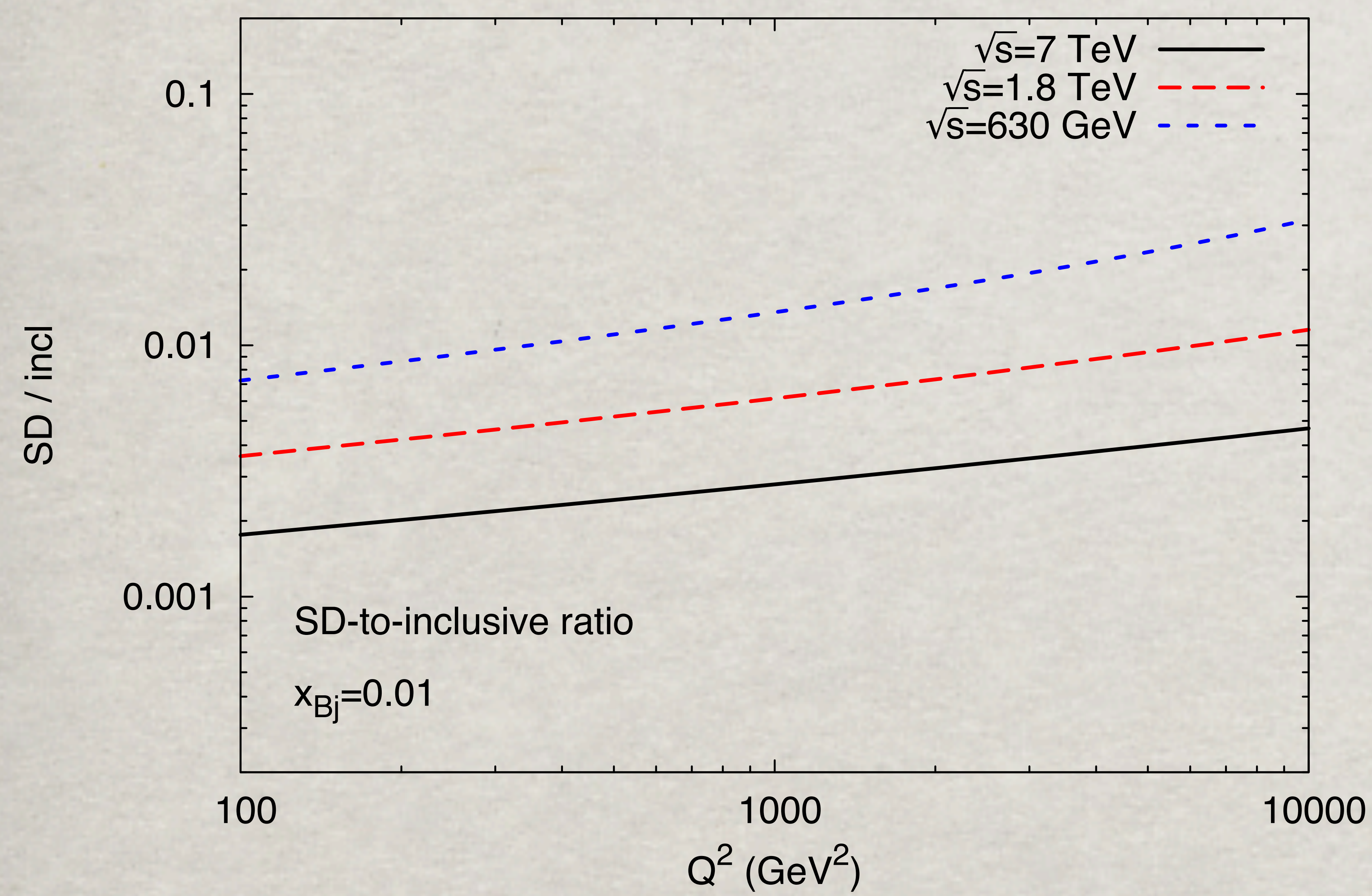




- quark-antiquark dijets

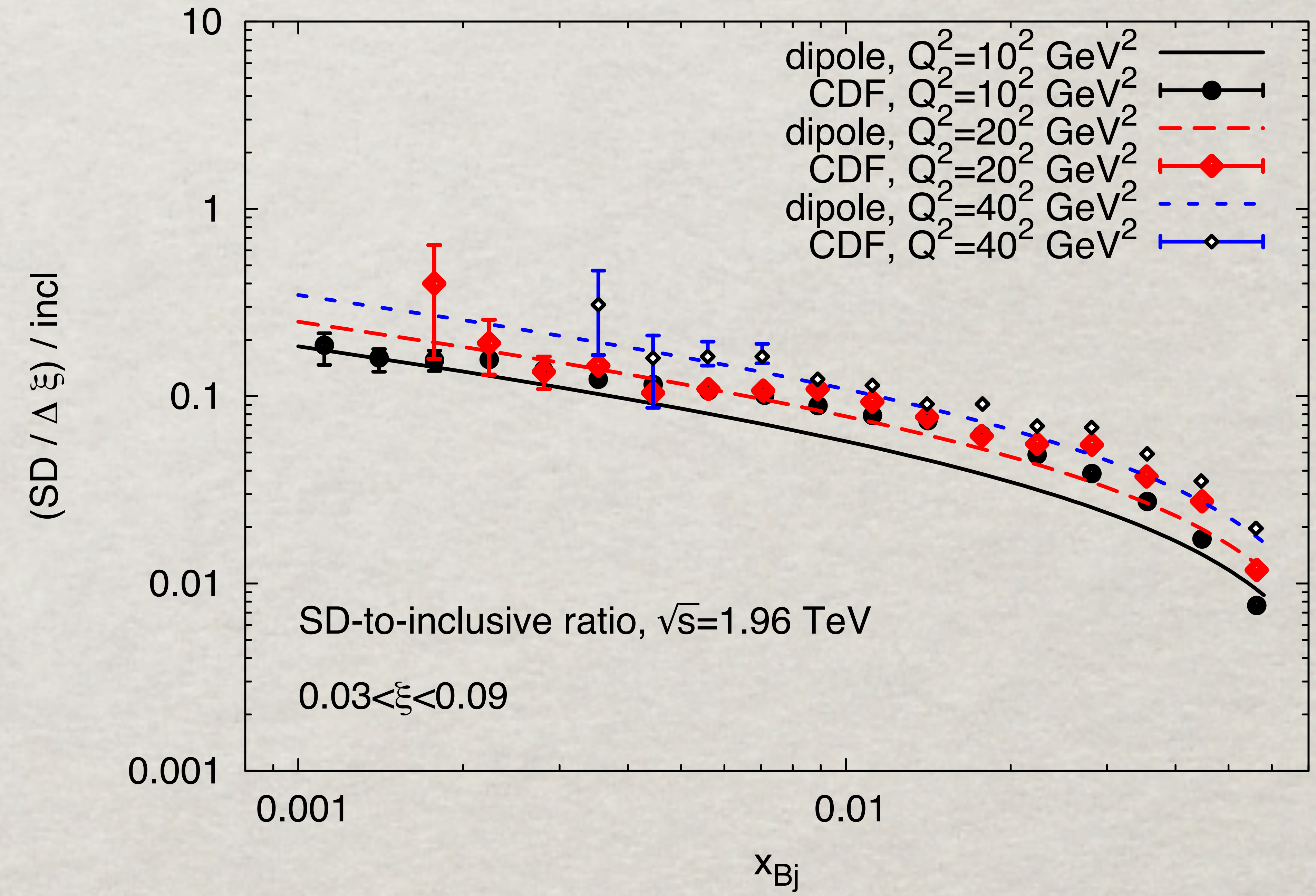


# Diffractive dijets

## Scale dependence




## CDF data



# Conclusions

**Diffractive factorization is heavily broken**

- The concept of parton distribution in the Pomeron cannot be applied to hadronic diffraction.
- Survival probability factor does not exist. The diffractive amplitude is a linear combination of elastic, which have rapidity gaps by default.

- Diffractive Drell-Yan
- Diffractive gauge bosons
- Diffractive heavy flavors
- Diffractive Higgs
- Diffractive dijets

All these hard diffraction processes have common features: they are semi-hard, semi-soft. Have leading twist scale dependence, 1/Q2

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# Conclusions

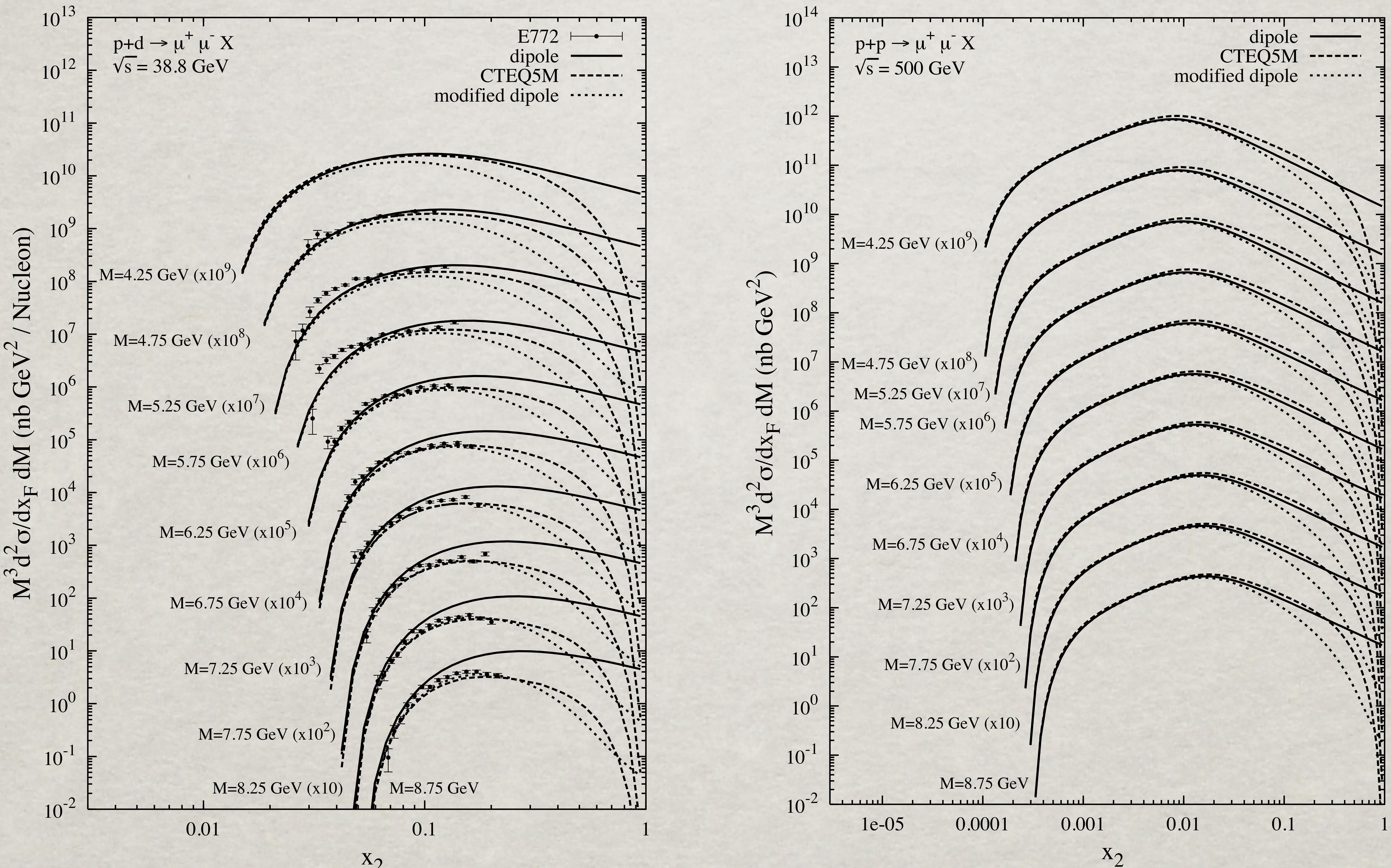
**Diffractive DIS is dominated by soft aligned-jet configuratopns of the q-qbar dipole**

**This explains why the naive expectations, like $\sigma_{\mathbf{diff}} \propto \mathbf{1/Q^4}$, or $\sigma_{\mathbf{diff}} \propto \mathbf{W^{4\Delta}}$ vs $\sigma_{\mathbf{incl}} \propto \mathbf{W^{2\Delta}}$ are not correct.**

**The mechanisms of hadron-induced hard diffraction are different, they are half-hard, half-soft, and have the leading twist behavior.**

# BACKUPS

## Comparison with NLO calculations




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