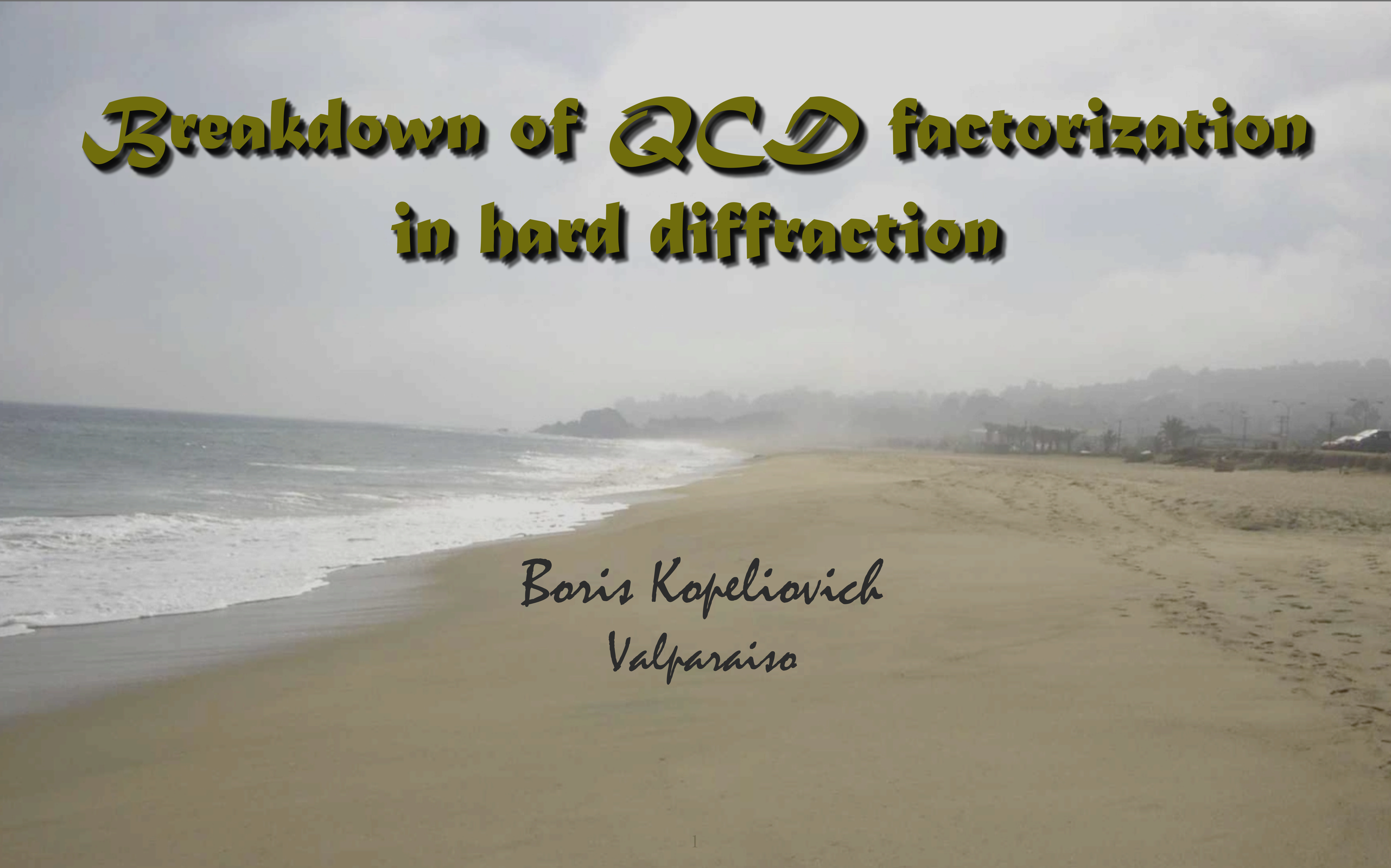
Breakdown of QCD factorization in hard diffraction



Boris Kopeliovich

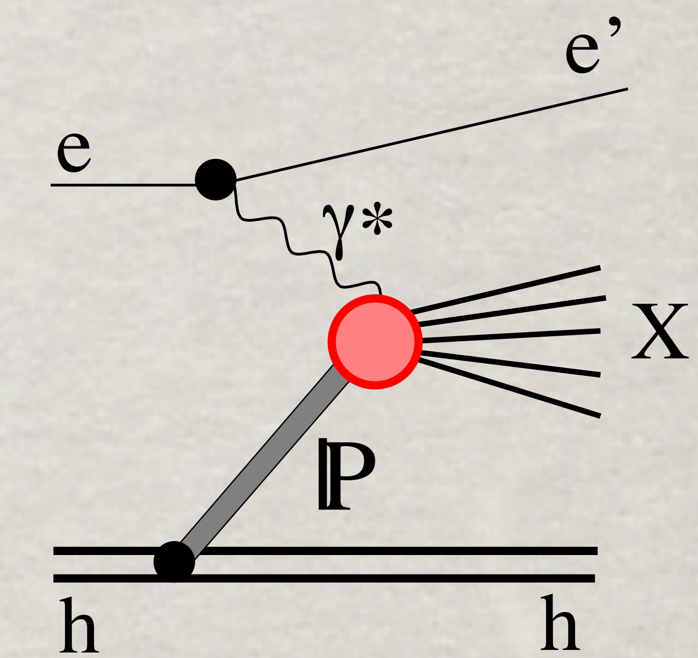
Valparaiso

QCD factorization in diffraction

Ingelman-Schlein picture of diffraction

It looks natural that DIS on the Pomeron probes its PDFs.
Once the parton densities in the Pomeron are known, one can predict any hard diffractive hadronic reaction.

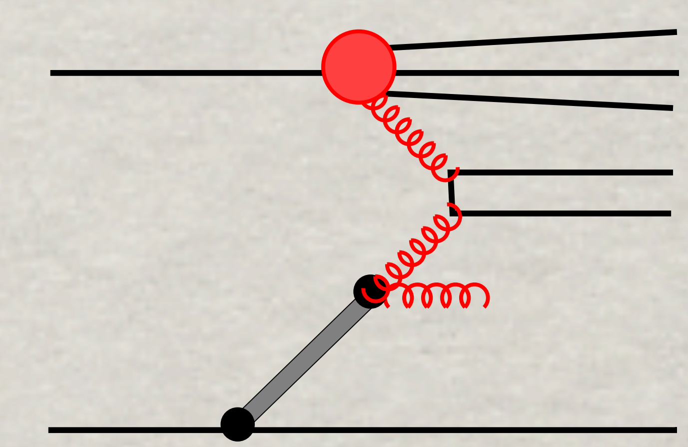
G.Ingelman & P.Schlein 1985



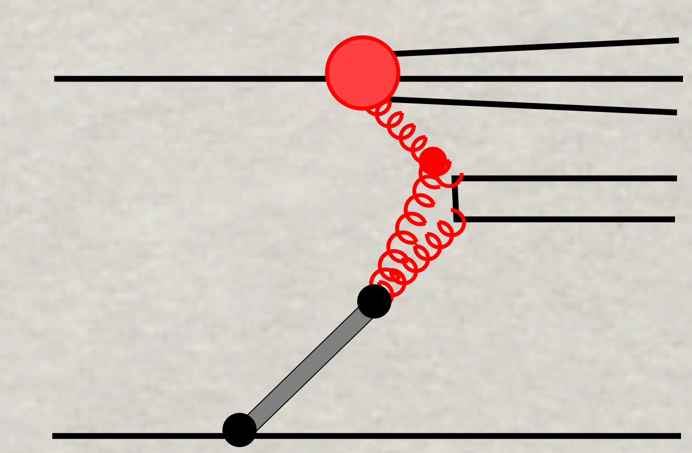
In the Good-Walker mechanism the diffractive amplitude is given by the difference between the elastic amplitudes of different Fock components in the projectile particle. In diffractive DIS

$$\mathbf{A_{diff}} \propto \sigma_{\bar{\mathbf{q}}\mathbf{q}}(\mathbf{r}) \propto \mathbf{r}^2 \sim 1/\mathbf{Q}^2$$

Hard diffraction of a hadron comes from difference of elastic amplitudes of hadronic states with and without a hard fluctuation



$$\mathbf{A^{h}_{diff}} \propto \sigma_{\bar{\mathbf{q}}\mathbf{q}}(\mathbf{R}+\mathbf{r}) - \sigma_{\bar{\mathbf{q}}\mathbf{q}}(\mathbf{R}) \propto \mathbf{r}\mathbf{R} \sim 1/\mathbf{Q}$$



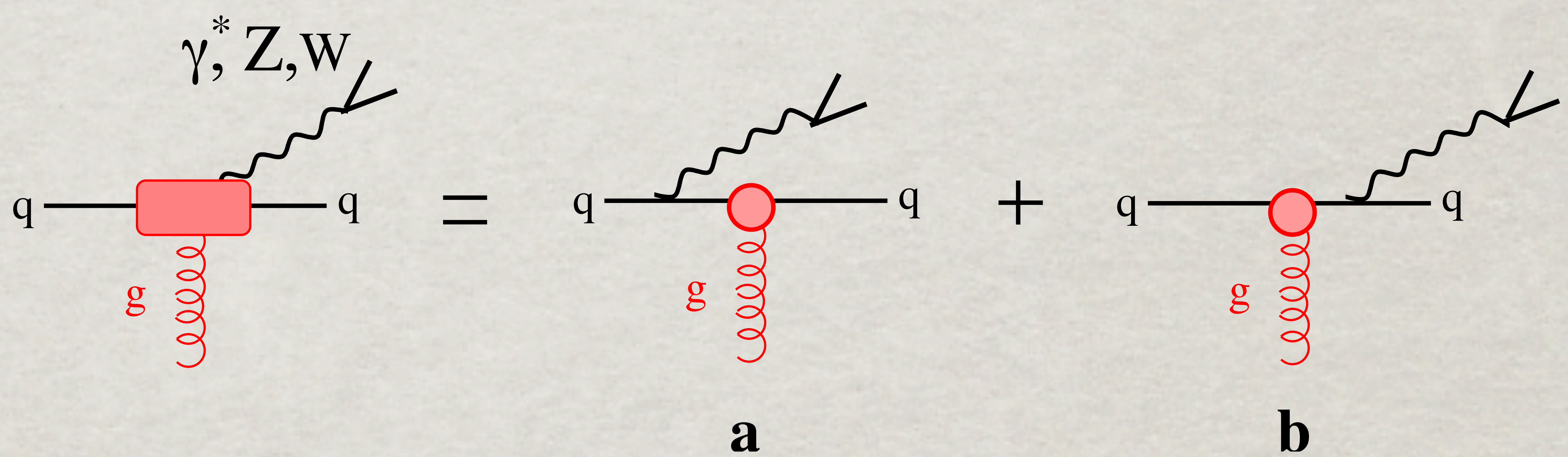
Diffractive factorization also breaks down due to the compositeness of the Pomeron

J.Collins, L.Frankfurt & M.Strikman 1993; G.Alves, E.Levin, A.Santoro 1997

Drell-Yan reaction: annihilation or bremsstrahlung?

Parton model is not Lorentz invariant, interpretation of hard reactions varies with reference frame. E.g. DIS looks like a probe for the proton structure in the Bjorken frame, but looks differently in the target rest frame, as interaction of hadronic components of the photon. Only observables are Lorentz invariant.

Similarly, in the target rest frame the Drell-Yan reaction looks like radiation of a heavy photon (or Z, W), rather than q-qbar annihilation.



The cross section is expressed via the dipoles looks similar to DIS

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

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

B.K. 1994

A.Tarasov, A.Schäfer & B.K. 1999

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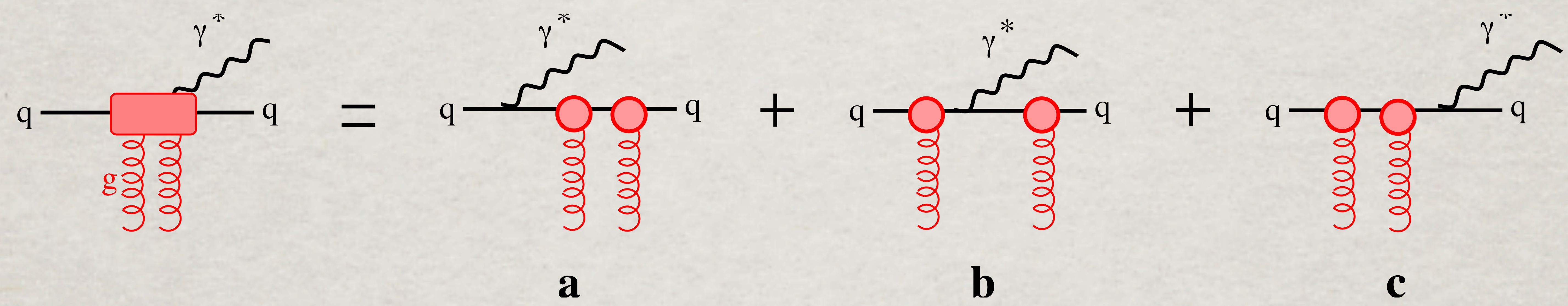
Diffractive Drell-Yan

In DY diffraction the Ingelman-Schlein factorization is broken



Diffractive radiation of a heavy photon by a quark vanishes in the forward direction [A.Schäfer, A.Tarasov & B.K. 1998]

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

In both Fock components of the quark, |q⟩ and |qγ*⟩ only quark interacts, so they interact equally (b-integrated).

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

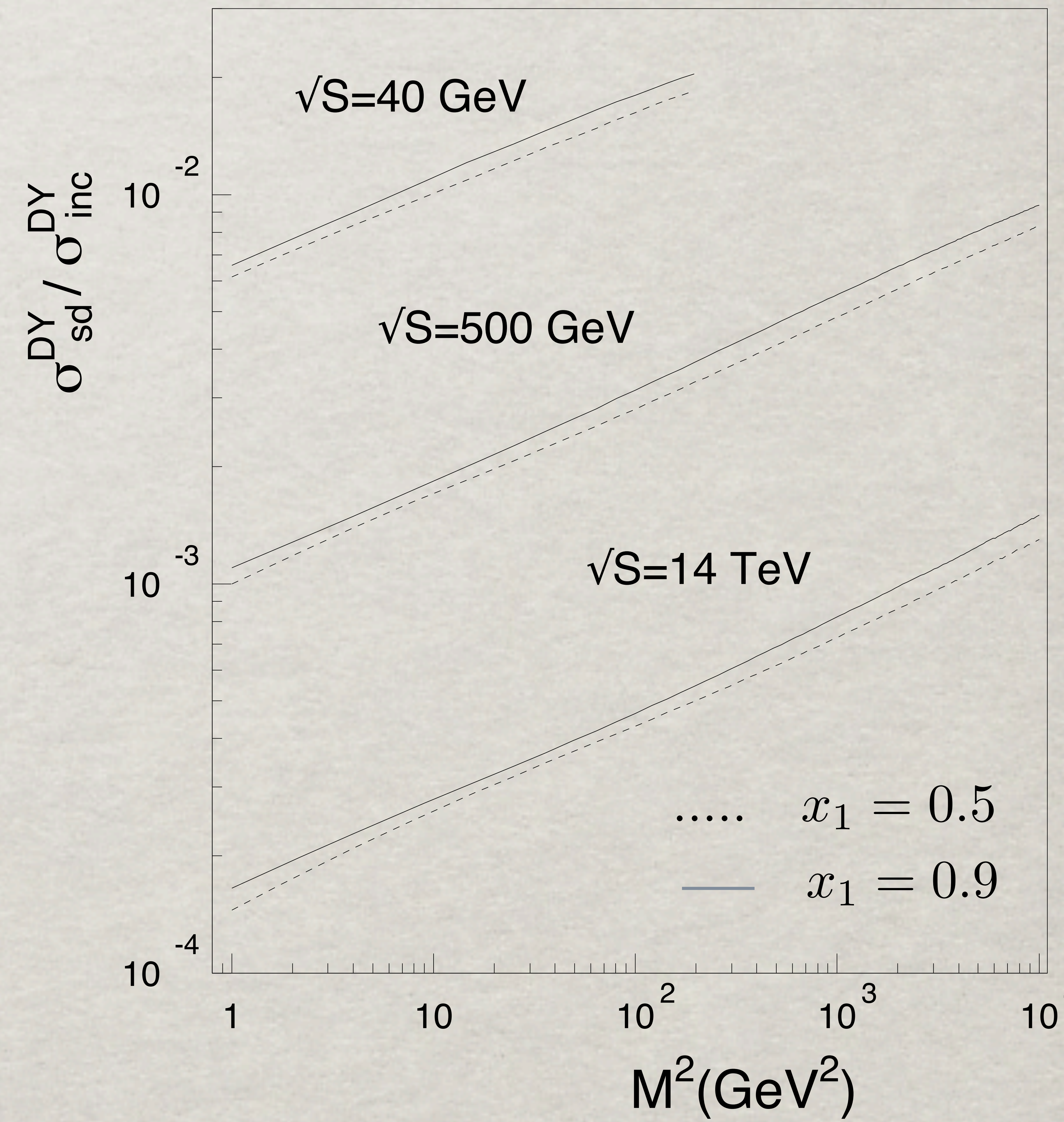
Diffractive Drell-Yan

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

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

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

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

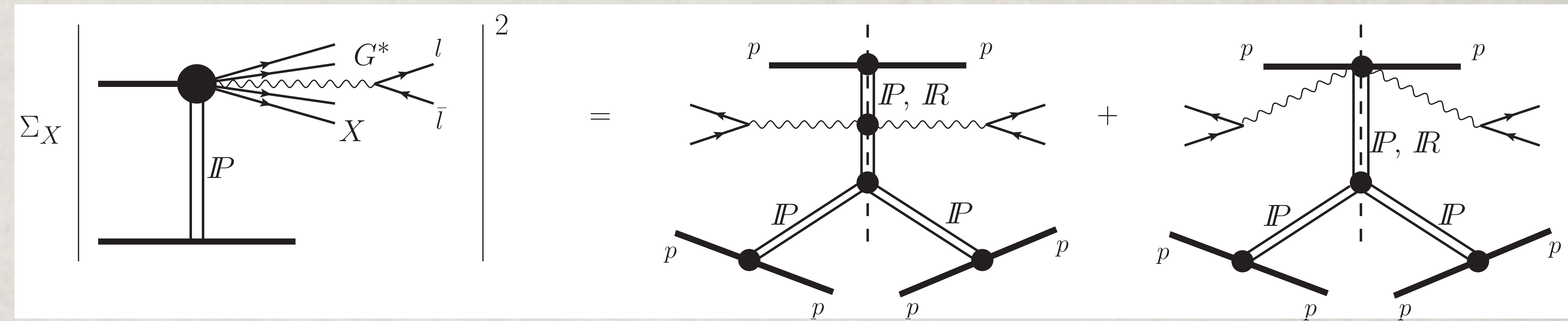


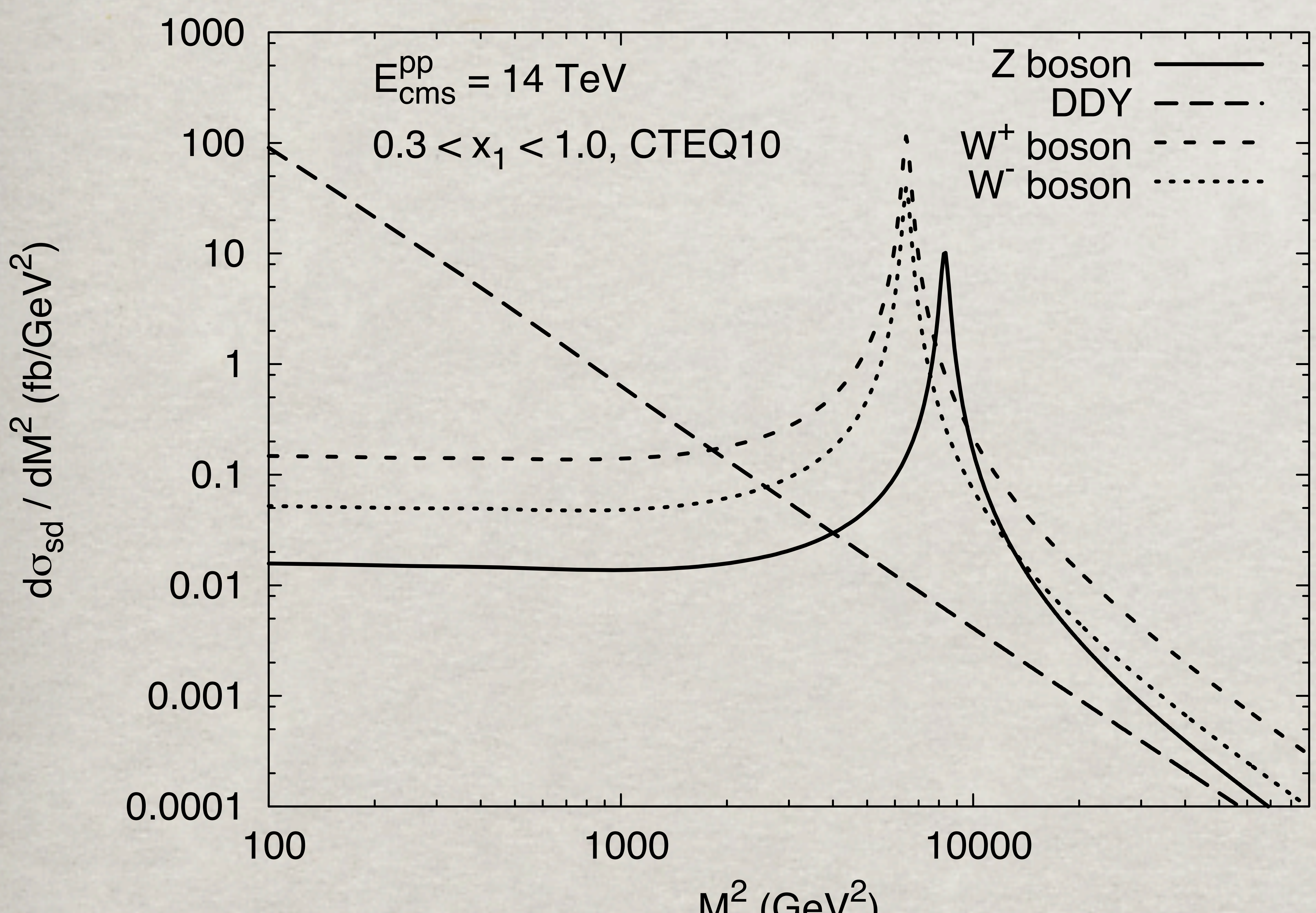
The fraction of diffractive Drell-Yan cross section is steeply falling with energy, but rises with the scale, because of saturation, which scale rises with energy.

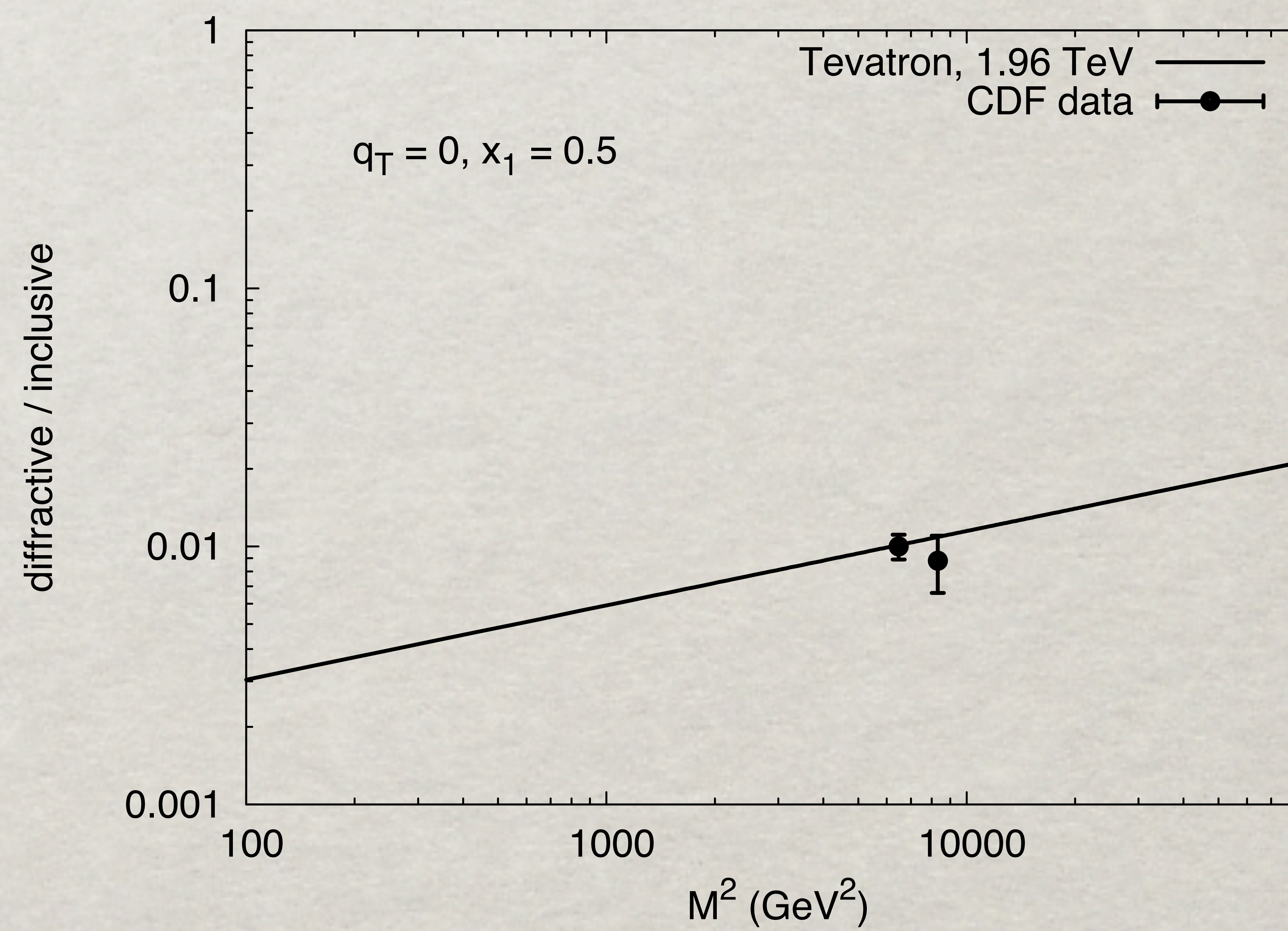
Diffractive Z and W production

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

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







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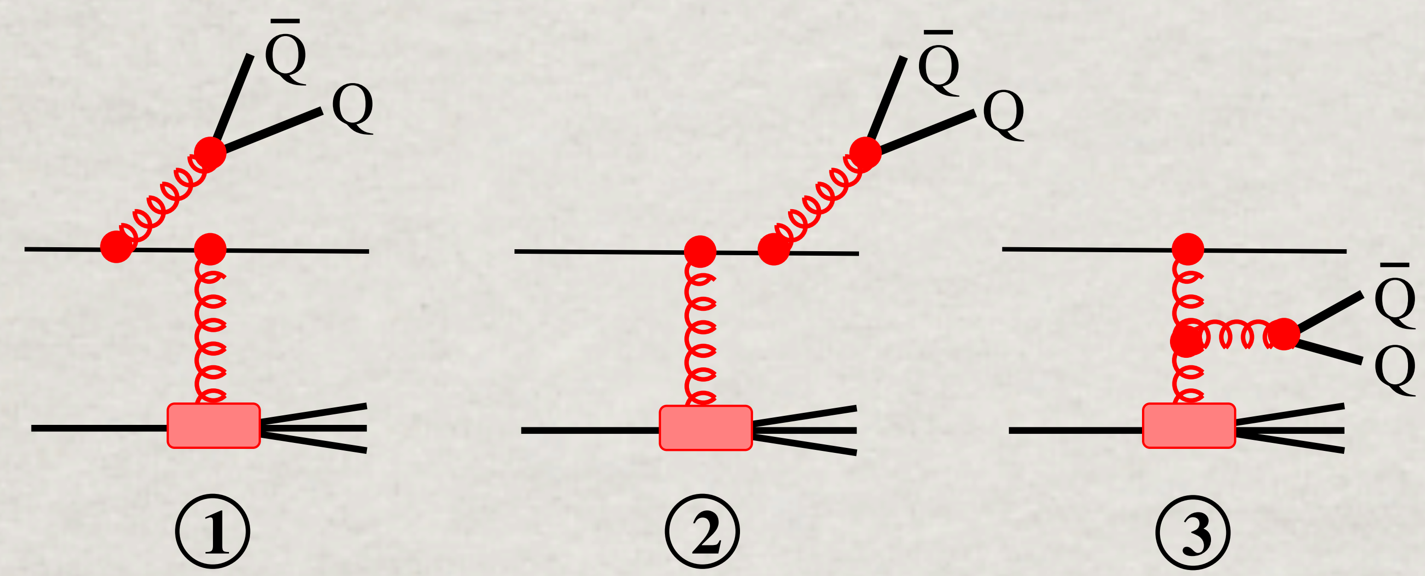
Diffractive heavy flavors

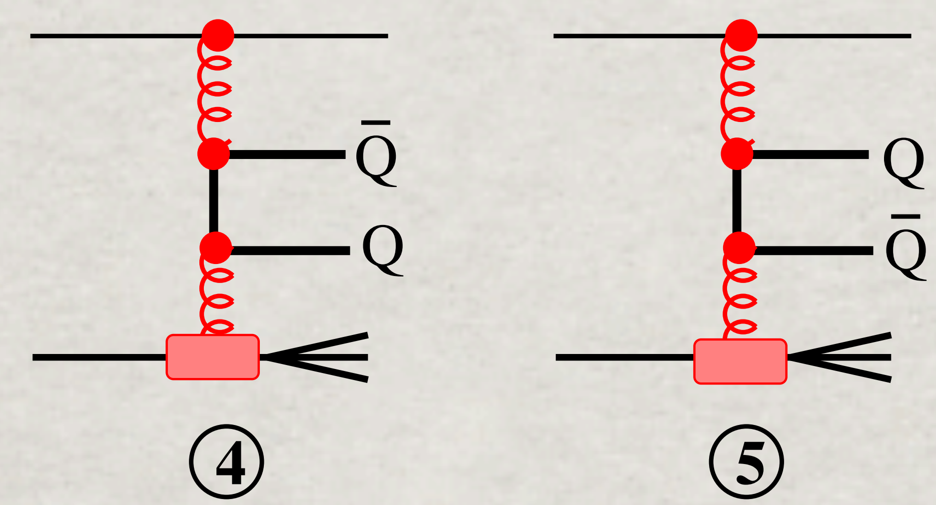
I.Potashnikova, I.Schmidt,
A.Tarasov & B.K. 2006

Inclusive heavy flavors



$$A_{Br} = A_1 + A_2 + \frac{Q^2}{M^2 + Q^2} A_3$$

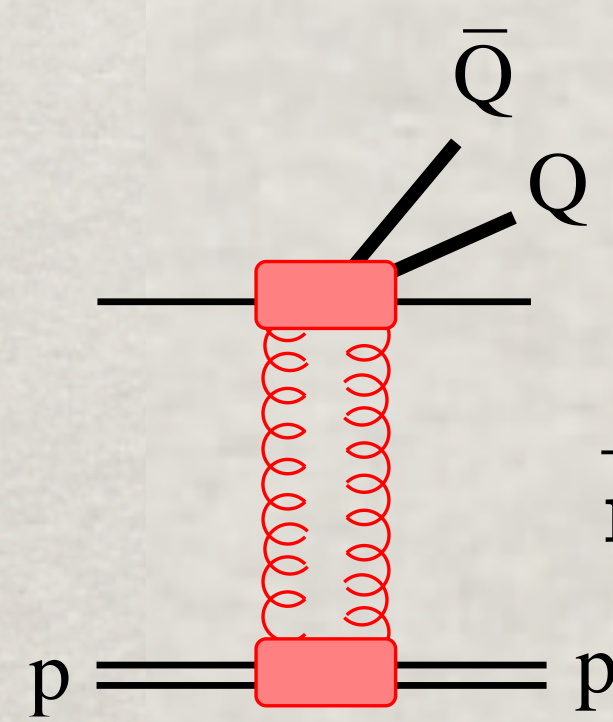
Bremsstrahlung (like in DY)
and production mechanisms



$$A_{Pr} = \frac{M^2}{M^2 + Q^2} A_3 + A_4 + A_5$$

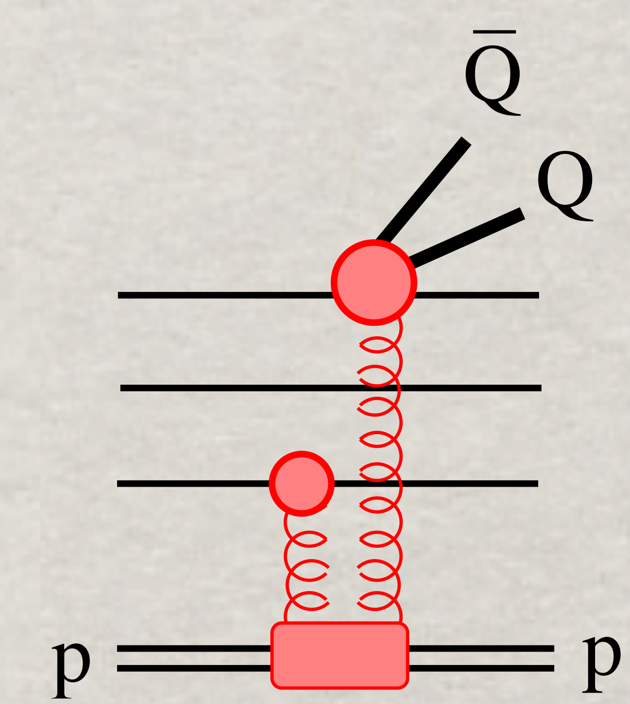
Diffractive heavy flavors

Diffractive bremsstrahlung



$$\frac{1}{m_Q^4}$$

Higher twist
bremsstrahlung



$$\frac{1}{m_Q^2}$$

Leading twist
bremsstrahlung

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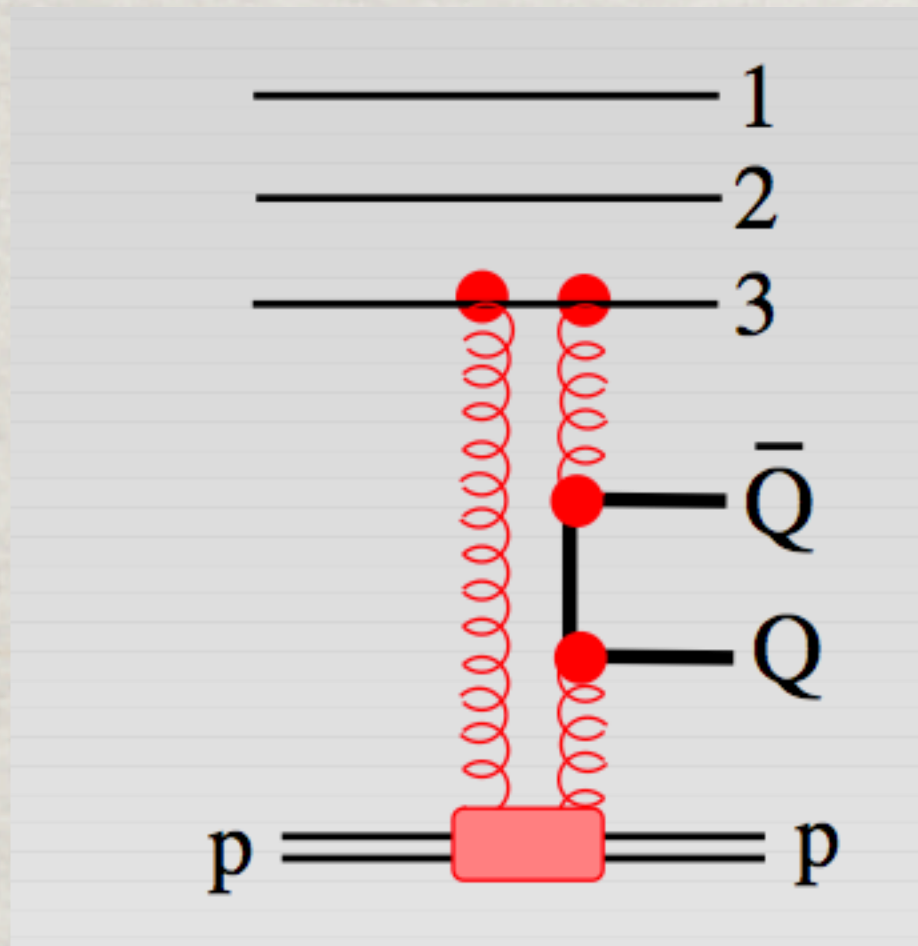
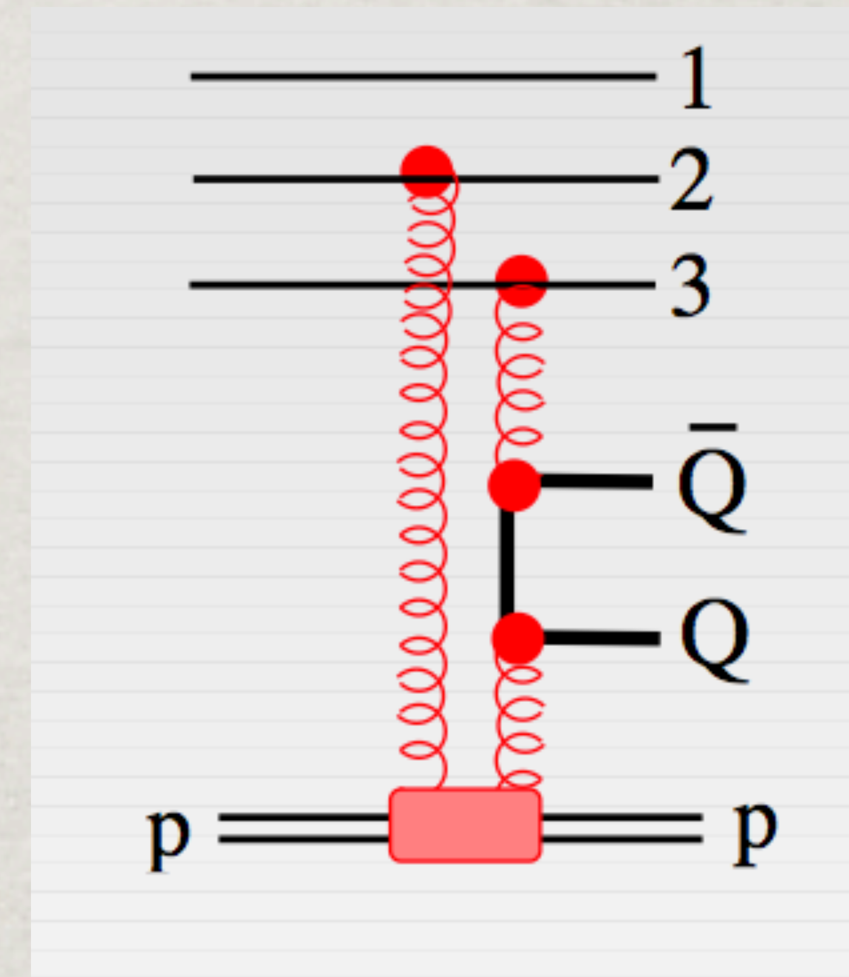
Leading twist production mechanism in diffraction





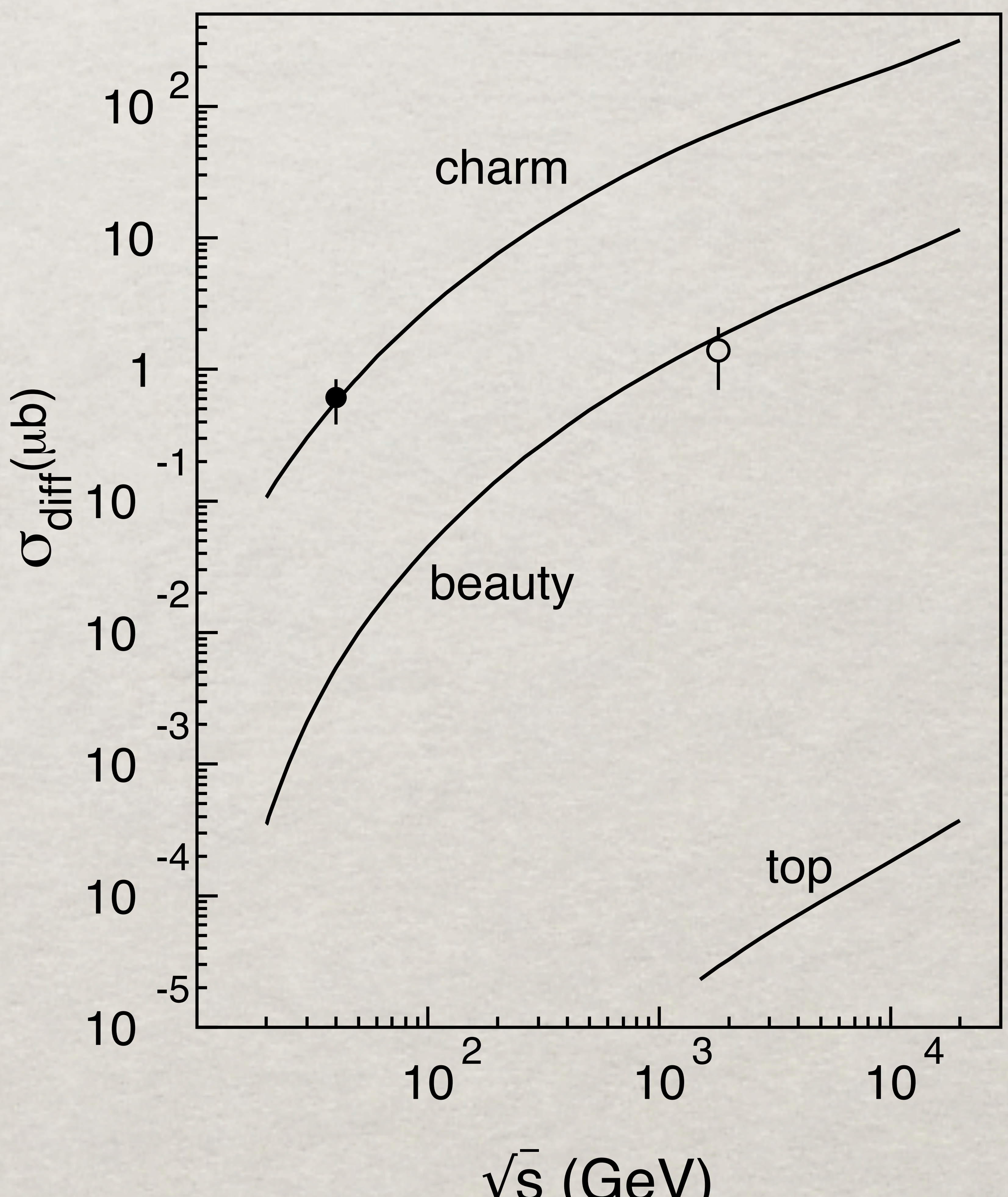
$$\sigma \propto \frac{1}{m_Q^2}$$

Numerically, the leading twist production mechanism is much larger compared with the bremsstrahlung mechanism

Diffractive heavy flavors

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

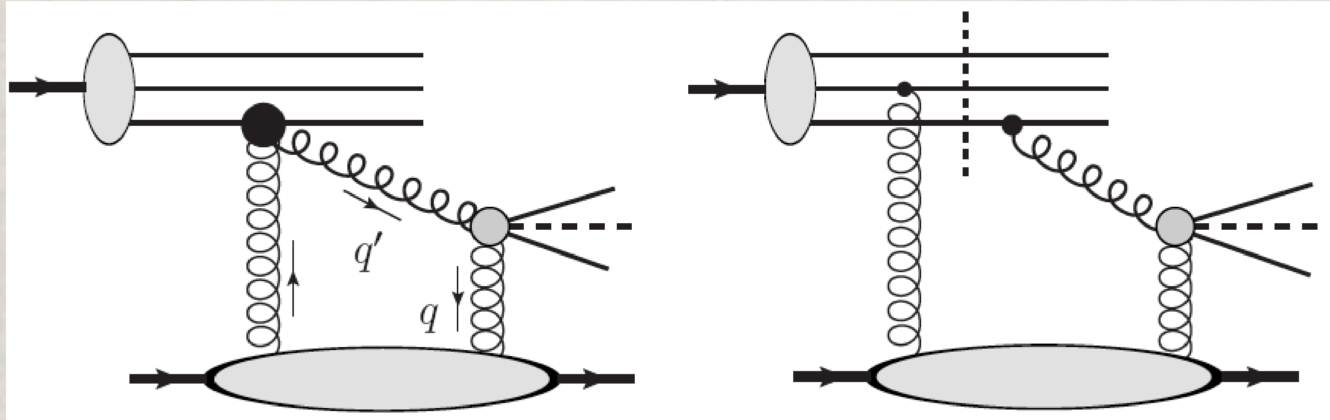
The leading twist behavior $1/m_Q^2$ of the diffractive cross section is confirmed by CDF data.

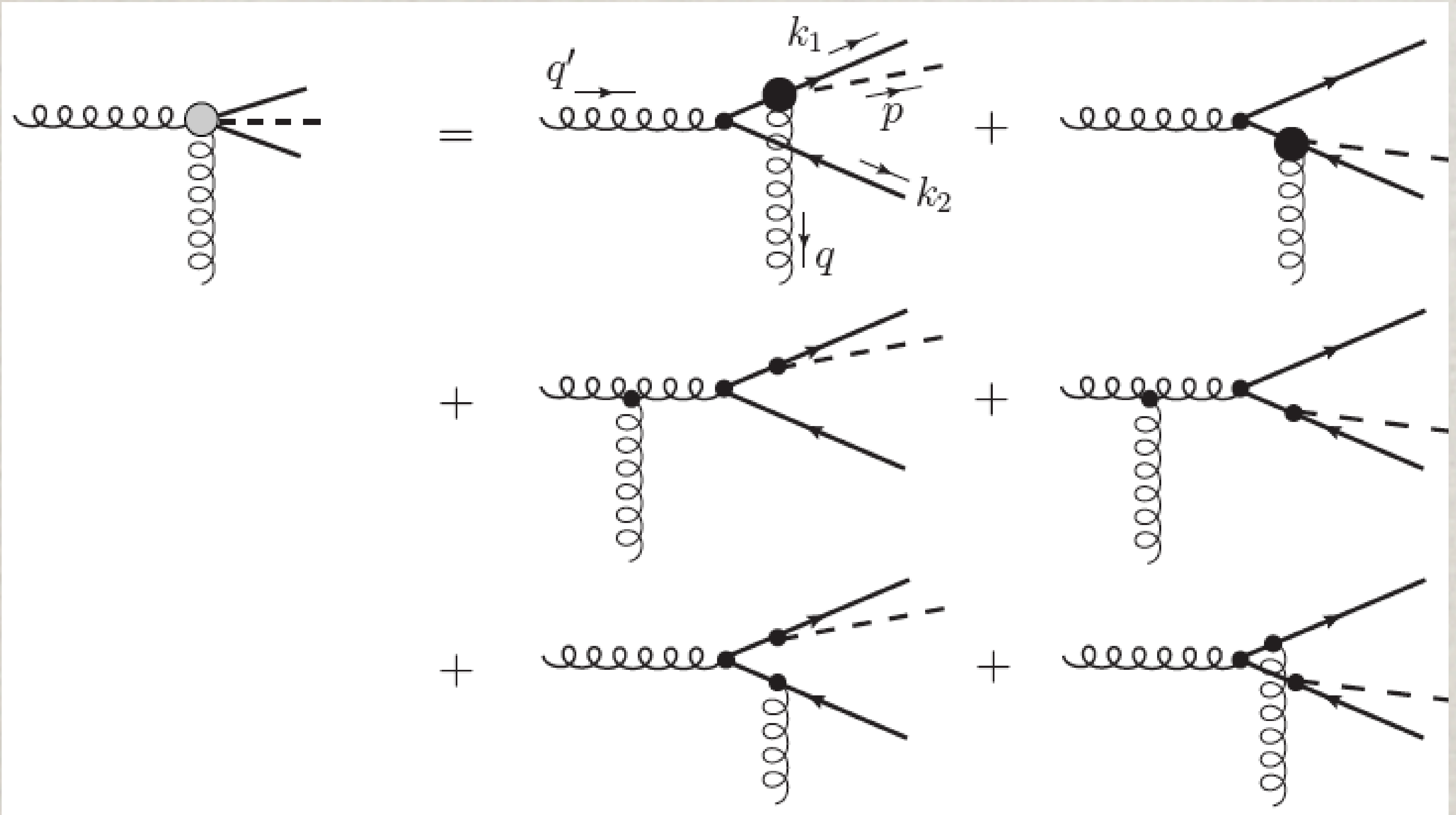


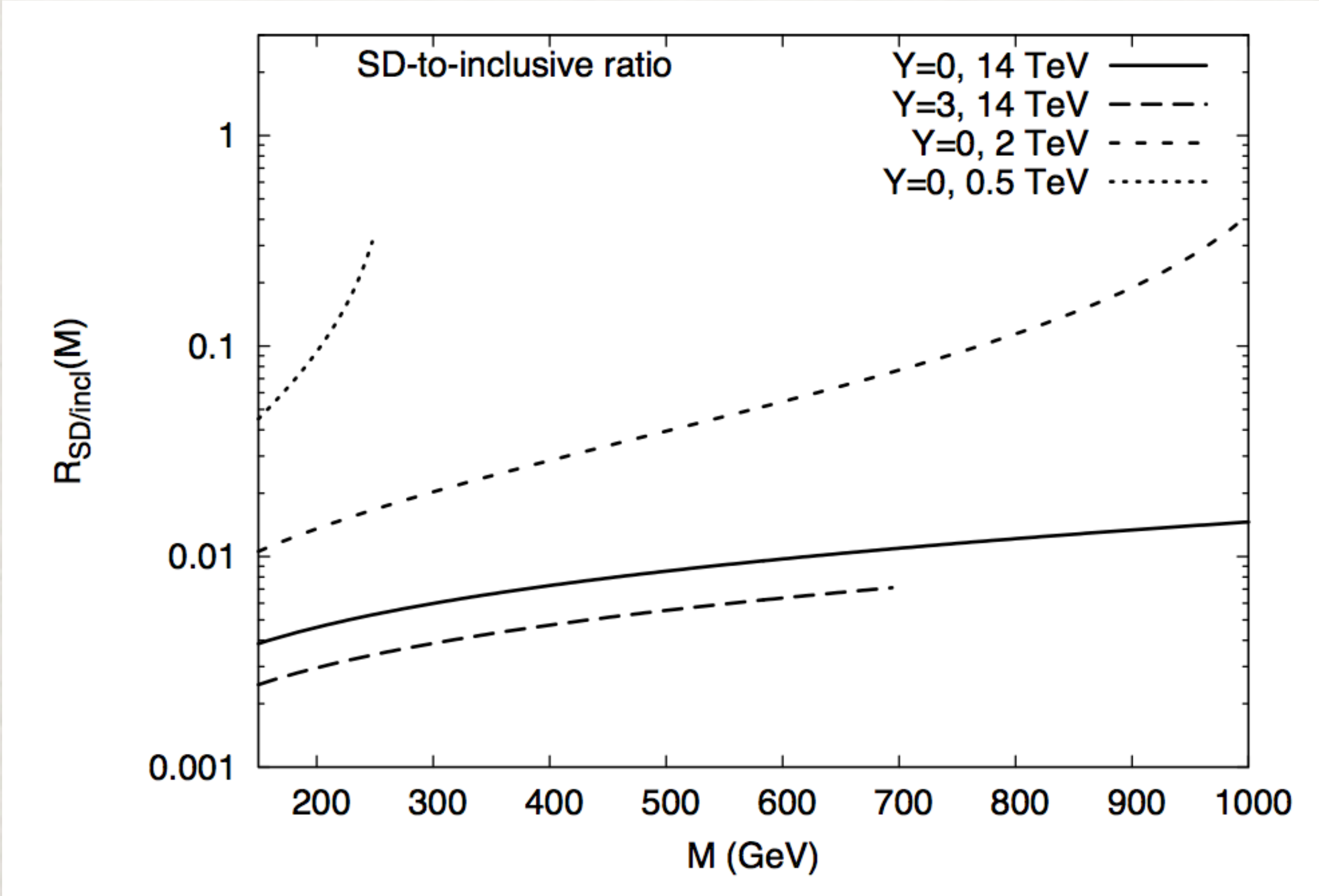
Diffractive Higgsstrahlung

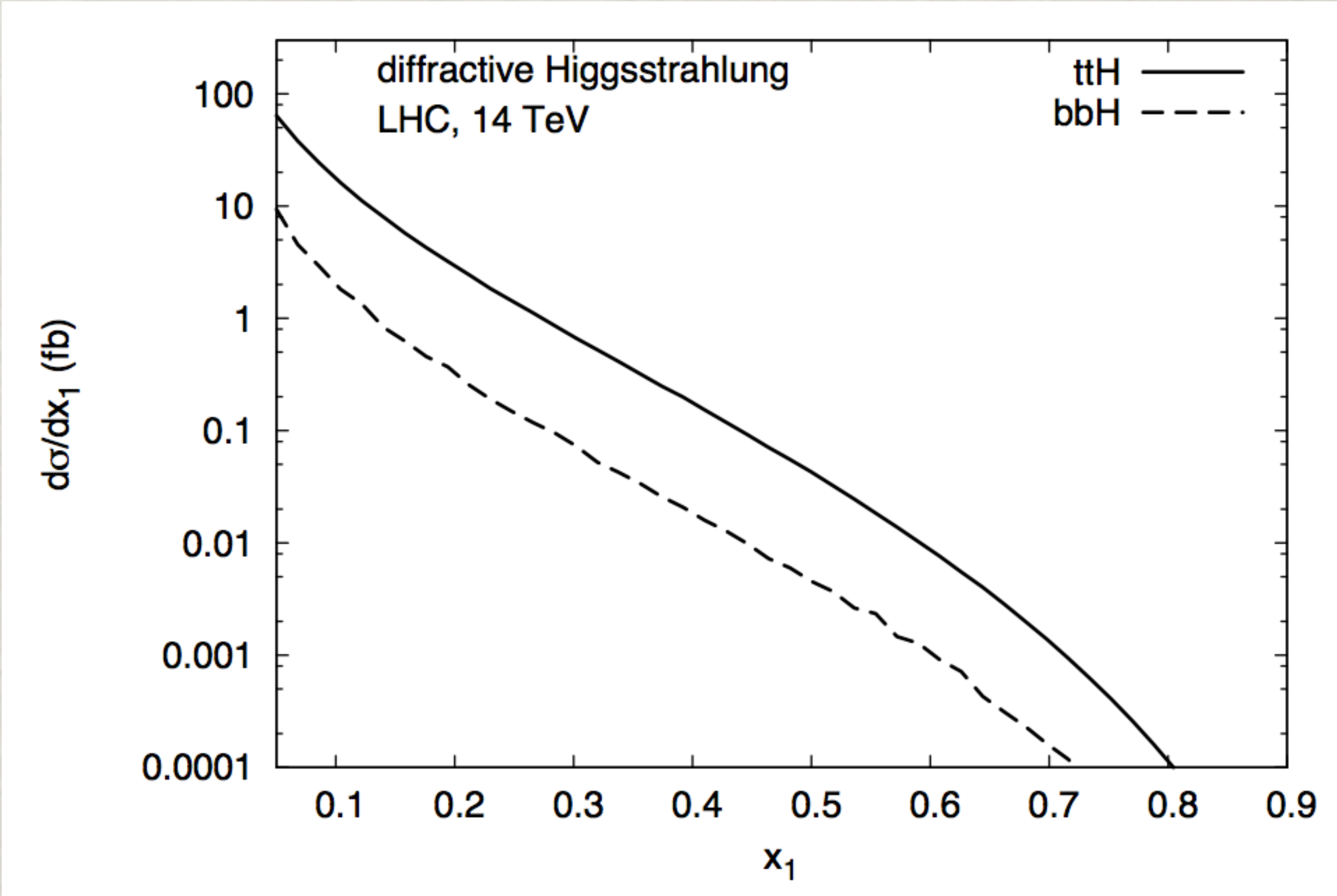
Light quark do not radiate Higgs directly, only via production of heavy flavors. Therefore the mechanism is the same as for non-abelian diffractive quark production.

R.Pasechnik, I.Potashnikova & B.K. 2014



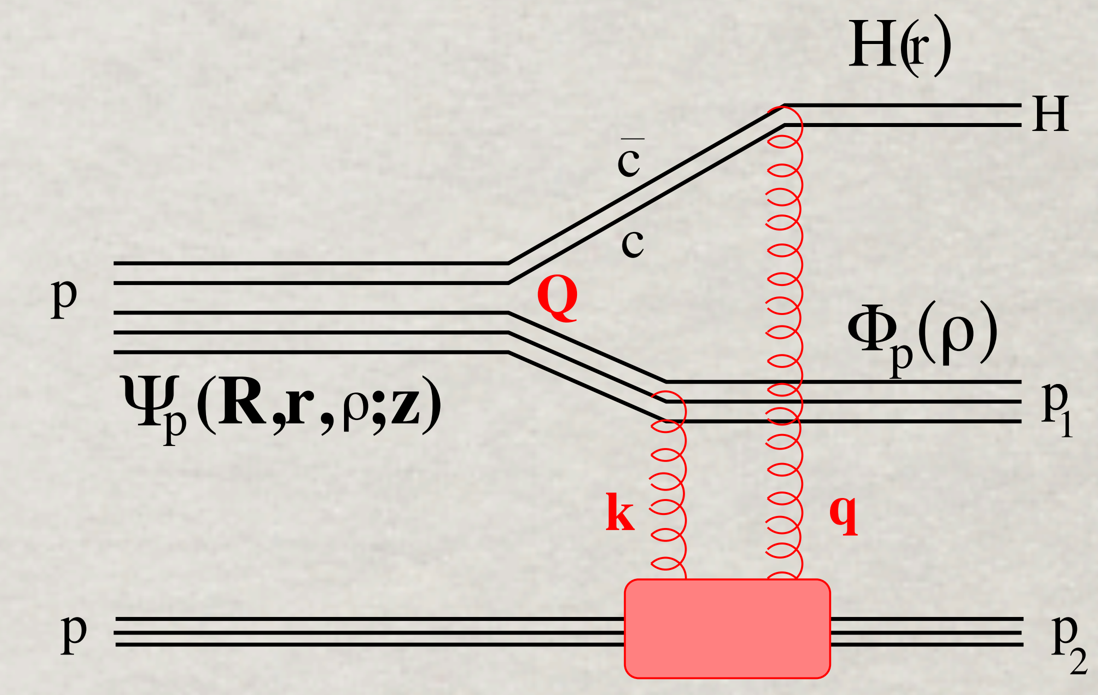






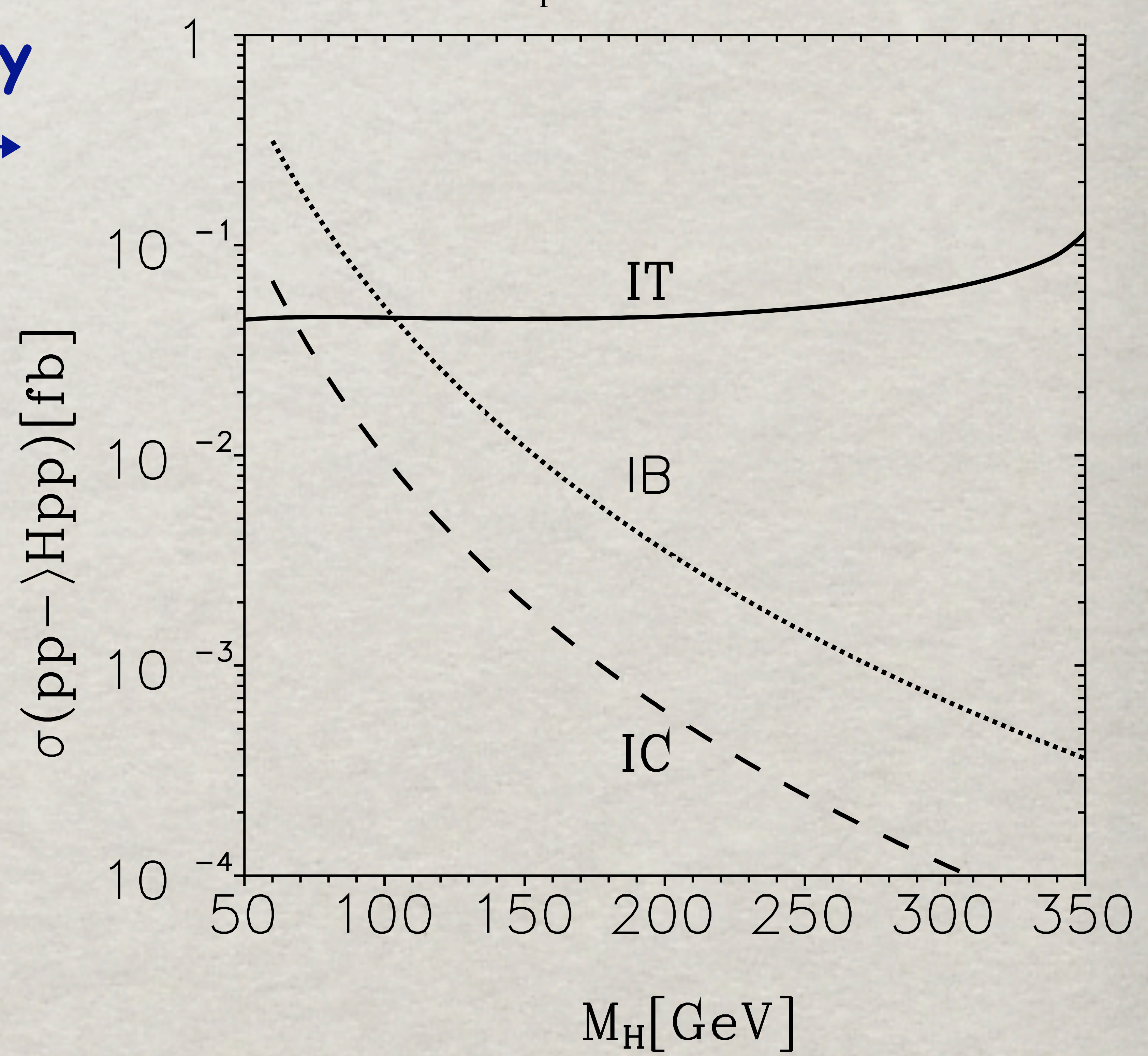
Diffractive Higgs from heavy flavored sea

Diffractive Higgsstrahlung is similar to diffractive DY. Z, W, since in all cases the radiated particle does not participate in the interaction. However, the Higgs decouples from light quarks, so the cross section of higgsstrahlung by light hadrons is small.



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

S.Brodsky, I.Schmidt, J.Soffer & B.K. 2006;
S.Brodsky, A.Goldhaber, I.Schmidt & B.K. 2009



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

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, $\mathbf{1/M^2}$

Non-abelian forward diffractive radiation of heavy flavors is permitted even for an isolated parton. Moreover, this contribution turns out to be a leading twist $\mathbf{1/m_Q^2}$ and dominates the cross section.
It comes from the interference between large and small distances.

Diffractive higgsstrahlung at forward rapidities is much suppressed, and a larger contribution is expected from the coalescence of intrinsic heavy quarks in the proton. For M_H=125 GeV dominance of intrinsic bottom and top is expected.

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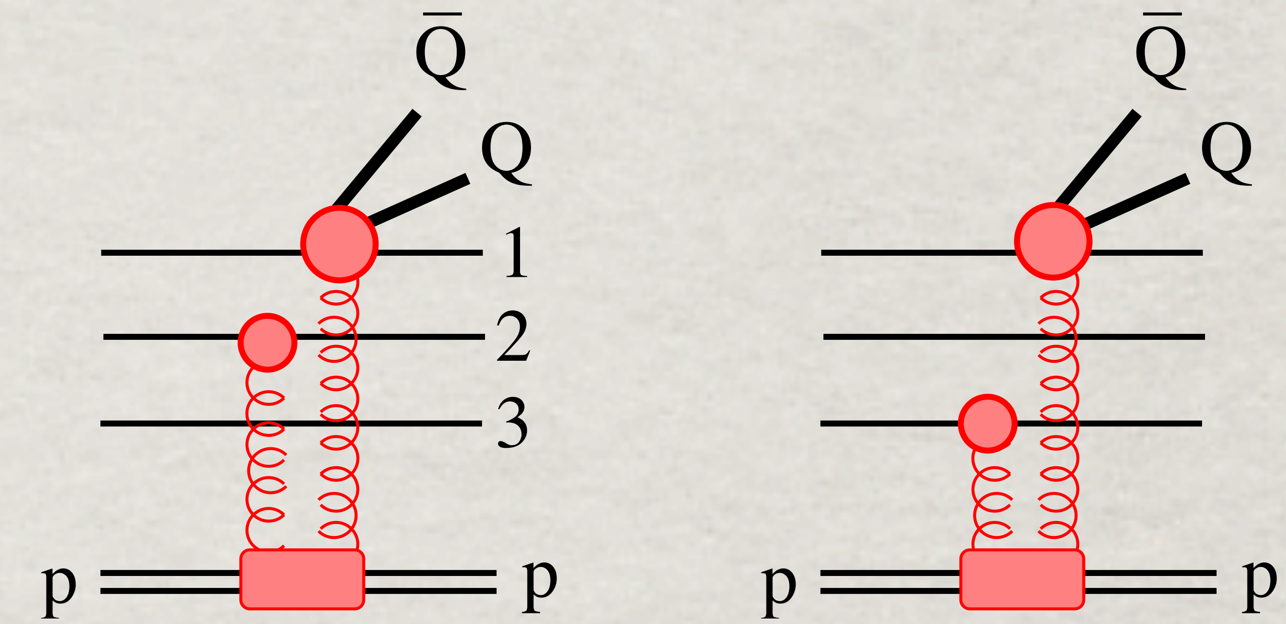
BACKUPS

Leading twist Bremsstrahlung mechanism:



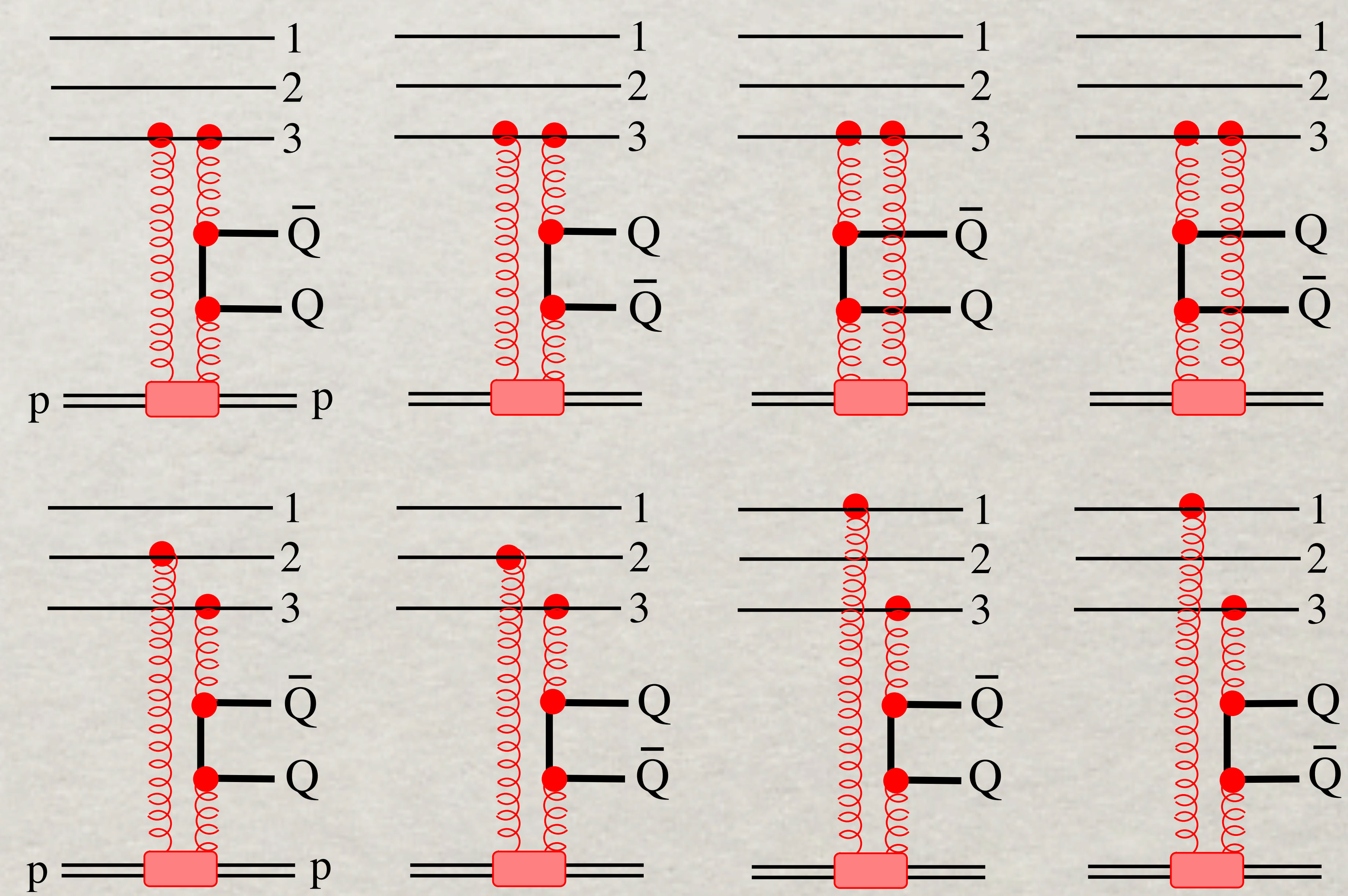
$\sigma \sim 1/m_Q^2$

Leading twist

Production mechanism in diffraction:

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

Leading twist



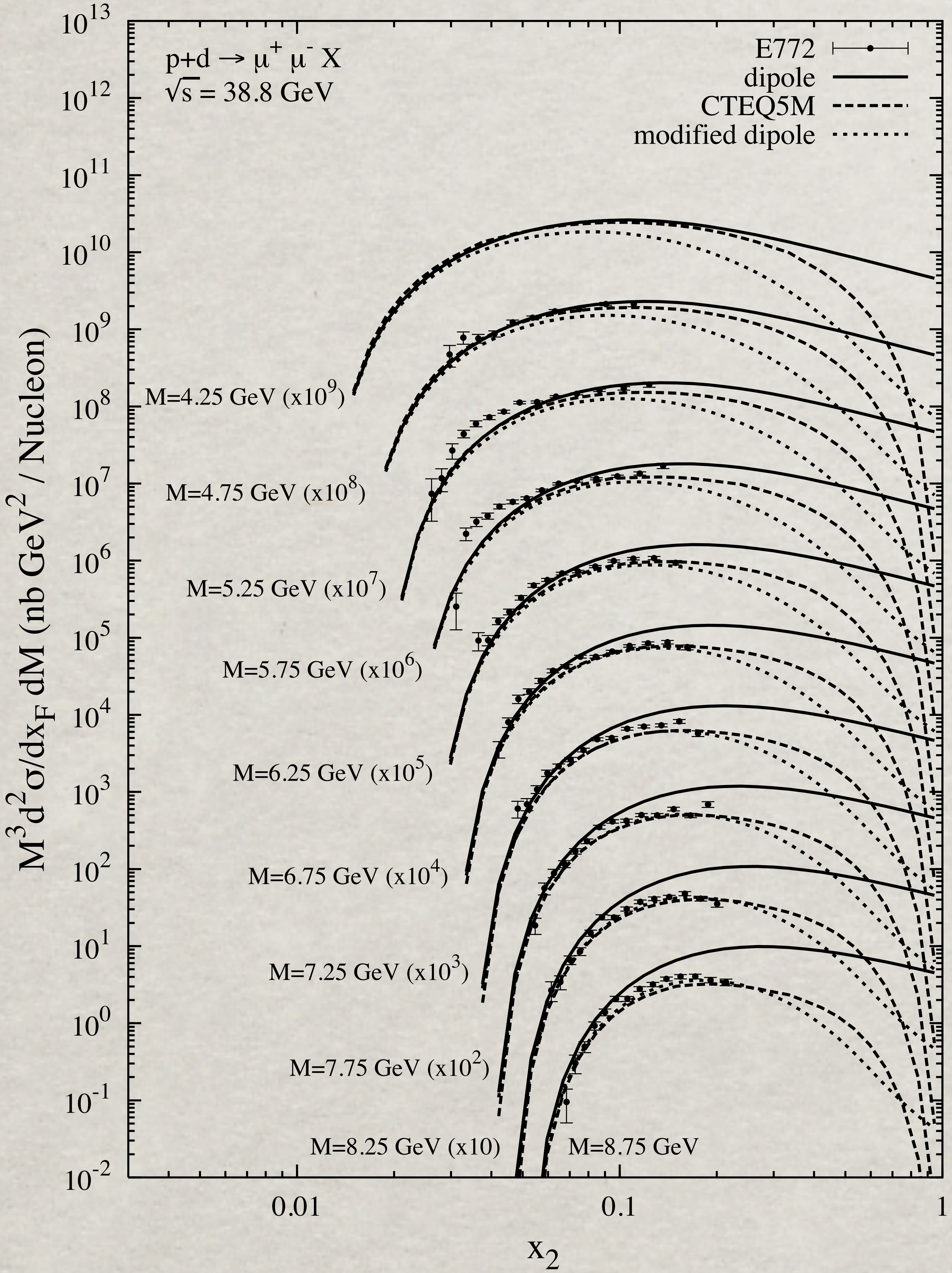
Diffractive heavy flavors: data

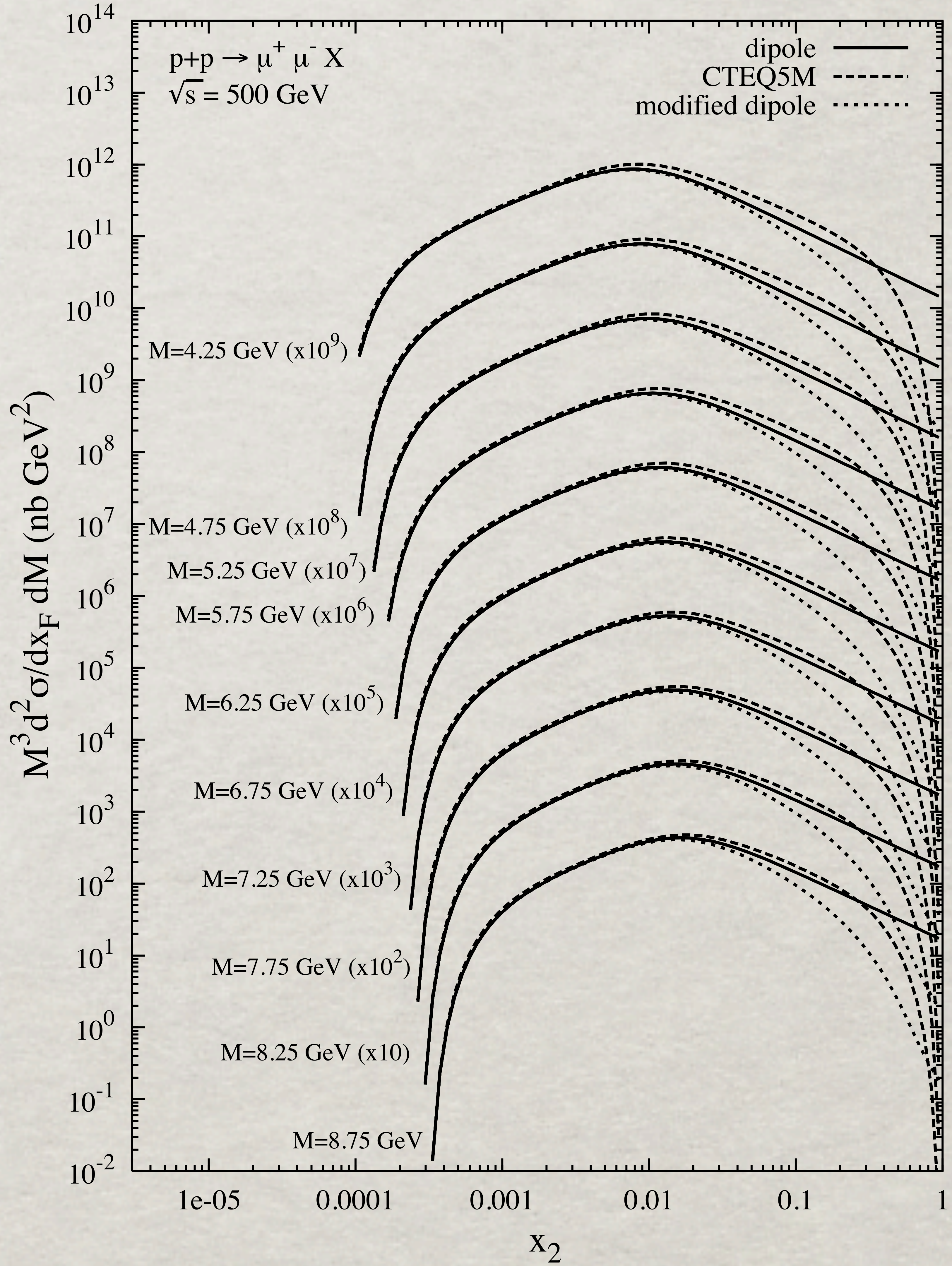
- Measurements at ISR led to an amazingly large (probably incorrect) cross section of diffractive charm production (K.L.Giboni et al. 1979), $\sigma \sim 10 - 60\ \mu b$. This experiment was order of magnitude above the subsequent data for inclusive charm production.

- 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 $\sigma \leq 26\ \mu b$

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

- The CDF experiment measured the fraction of diffractively produced beauty, $\mathbf{R^{\bar{b}b}_{diff/tot}} = (\mathbf{0.62 \pm 19 \pm 16})\%$, at $\sqrt{s}$ = 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) $\sigma^{\mathbf{\bar{b}b}}_{\mathbf{tot}}$ = 200 mb, then $\sigma^{\mathbf{\bar{b}b}}_{\mathbf{diff}} \approx 1.2$ mb.


p+d → μ+ μ- X
√s = 38.8 GeV
E772
dipole
CTEQ5M
modified dipole
M=4.25 GeV (x10^9)
M=4.75 GeV (x10^8)
M=5.25 GeV (x10^7)
M=5.75 GeV (x10^6)
M=6.25 GeV (x10^5)
M=6.75 GeV (x10^4)
M=7.25 GeV (x10^3)
M=7.75 GeV (x10^2)
M=8.25 GeV (x10)
M=8.75 GeV
M^3d^2σ/dx_F dM (nb GeV^2 / Nucleon)
x_2


p+p → μ+ μ- X
√s = 500 GeV
dipole
CTEQ5M
modified dipole
M=4.25 GeV (x10^9)
M=4.75 GeV (x10^8)
M=5.25 GeV (x10^7)
M=5.75 GeV (x10^6)
M=6.25 GeV (x10^5)
M=6.75 GeV (x10^4)
M=7.25 GeV (x10^3)
M=7.75 GeV (x10^2)
M=8.25 GeV (x10)
M=8.75 GeV
M^3d^2σ/dx_F dM (nb GeV^2)
x_2

Color dipole description of diffraction

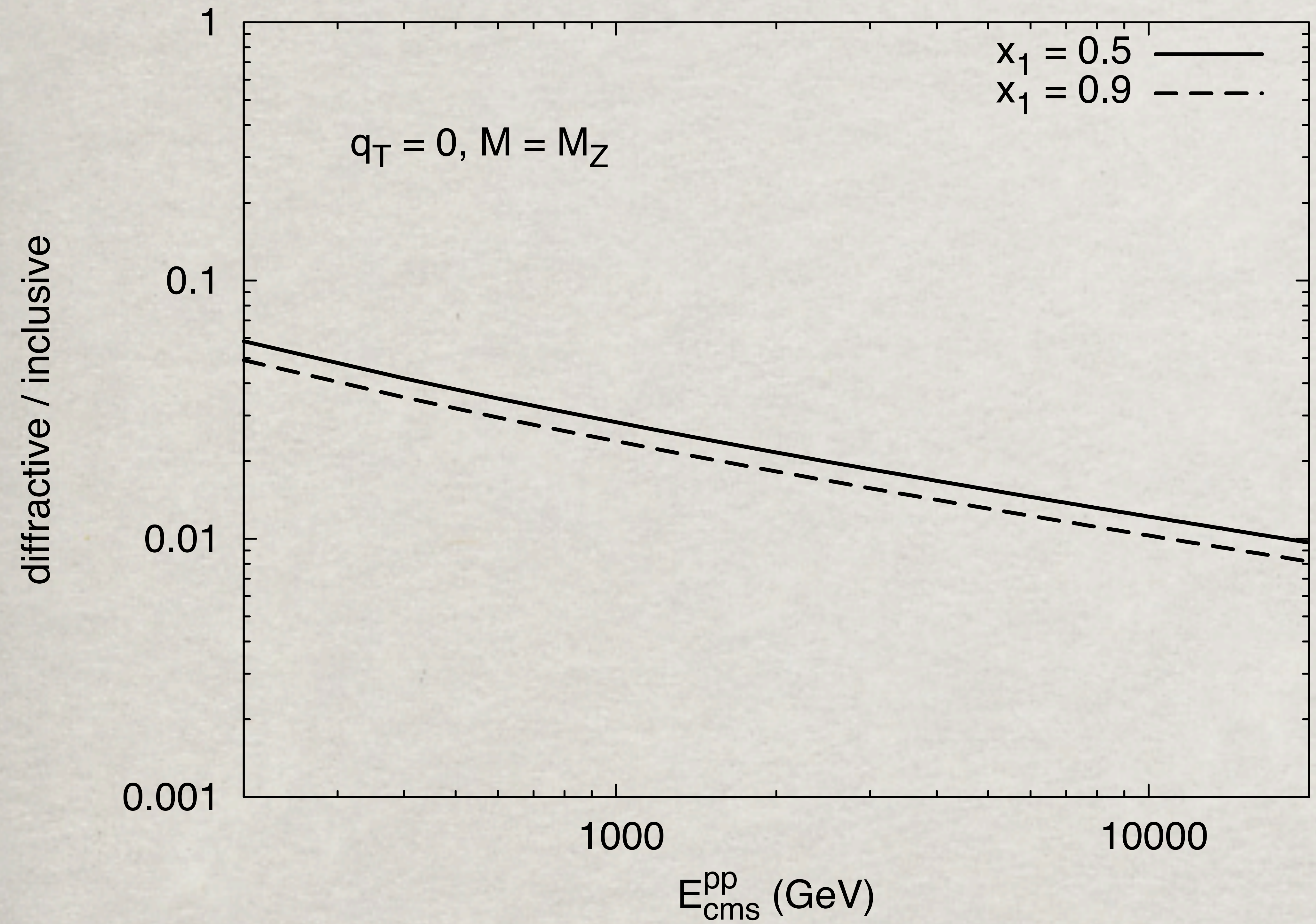
Dipoles are the eigenstates of interaction at high energies

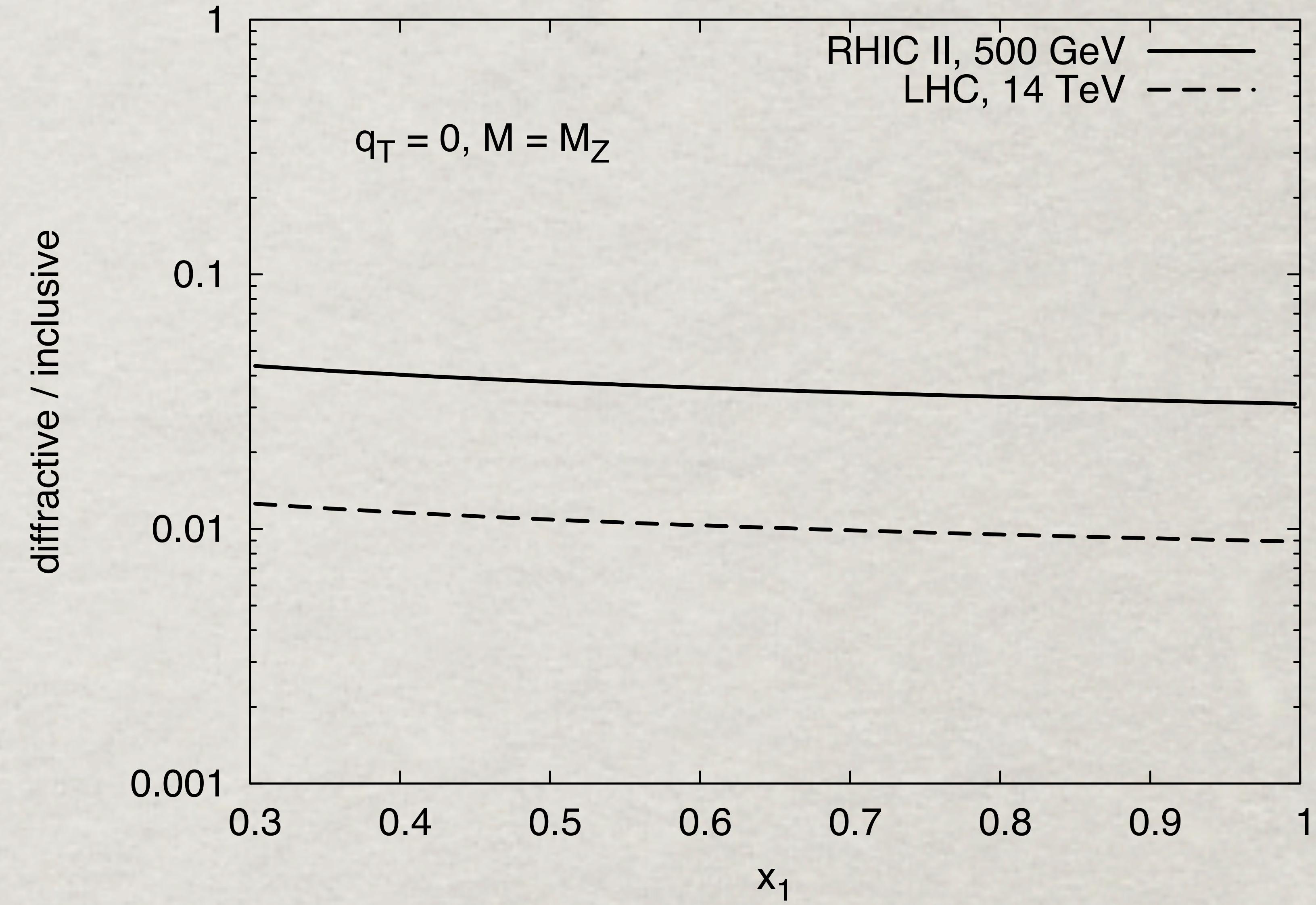
The total and single diffractive cross sections read [L.Lapidus, A.Zamolodchikov & B.K. 1981].

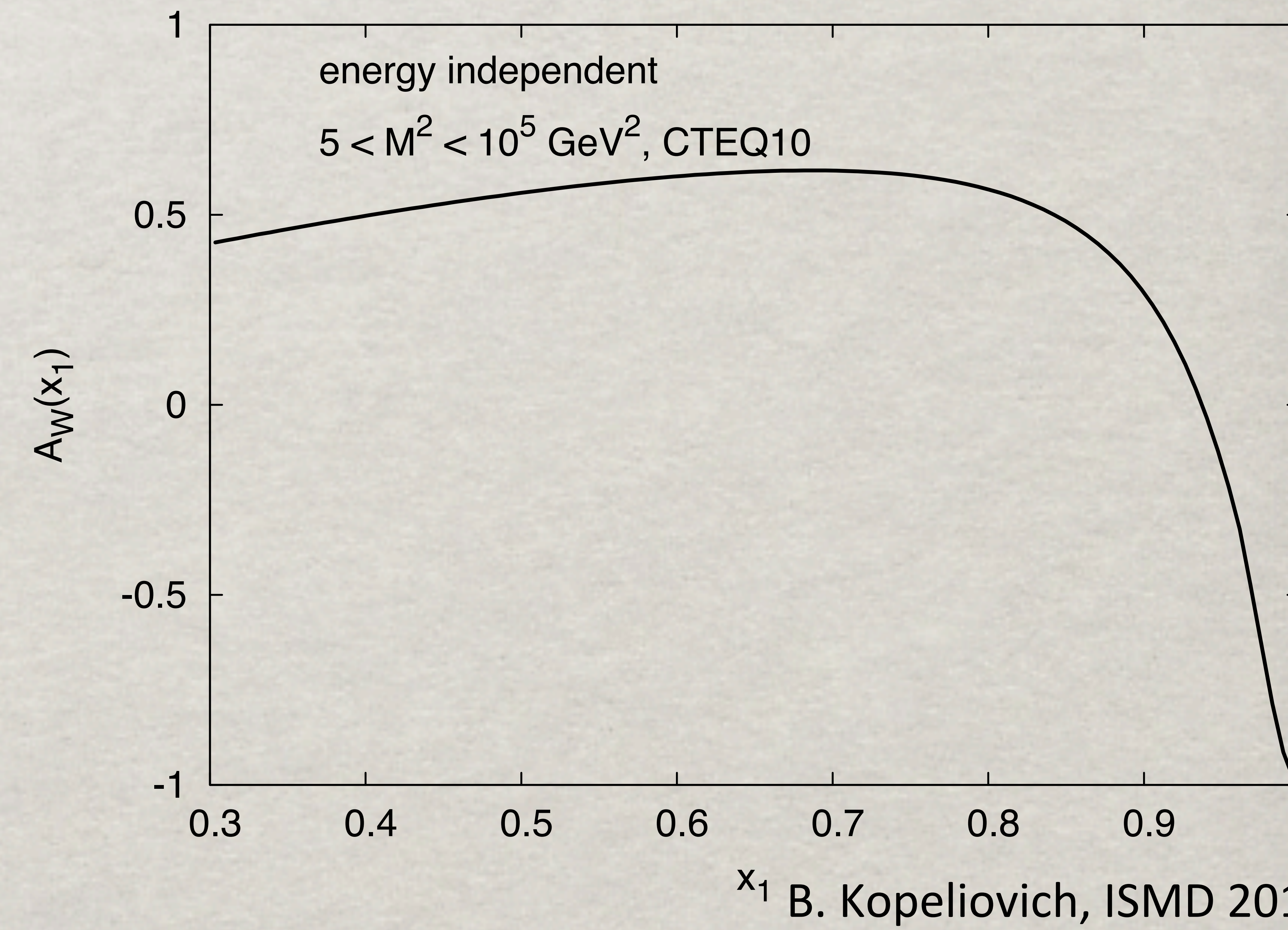
$$\sigma^{\mathbf{hp}}_{\mathbf{tot}} = \int \mathbf{d^2 r_T} \, |\mathbf{\Psi_h}(\mathbf{r_T})|^{\mathbf{2}} \, \sigma(\mathbf{r_T})$$

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

More of diffractive Z and W







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