Breakdown of QCD factorization in hard hadronic diffraction

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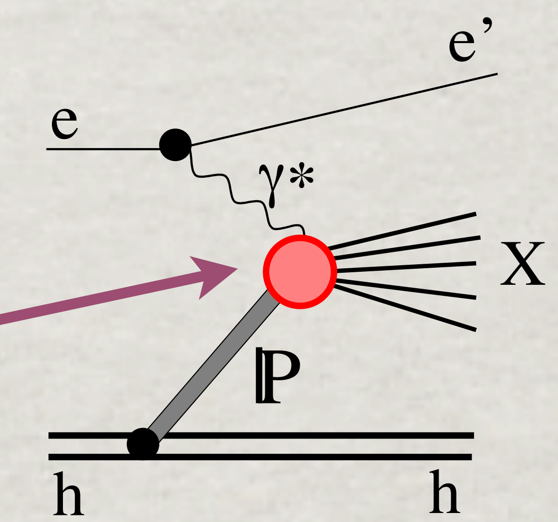
Diffractive factorization

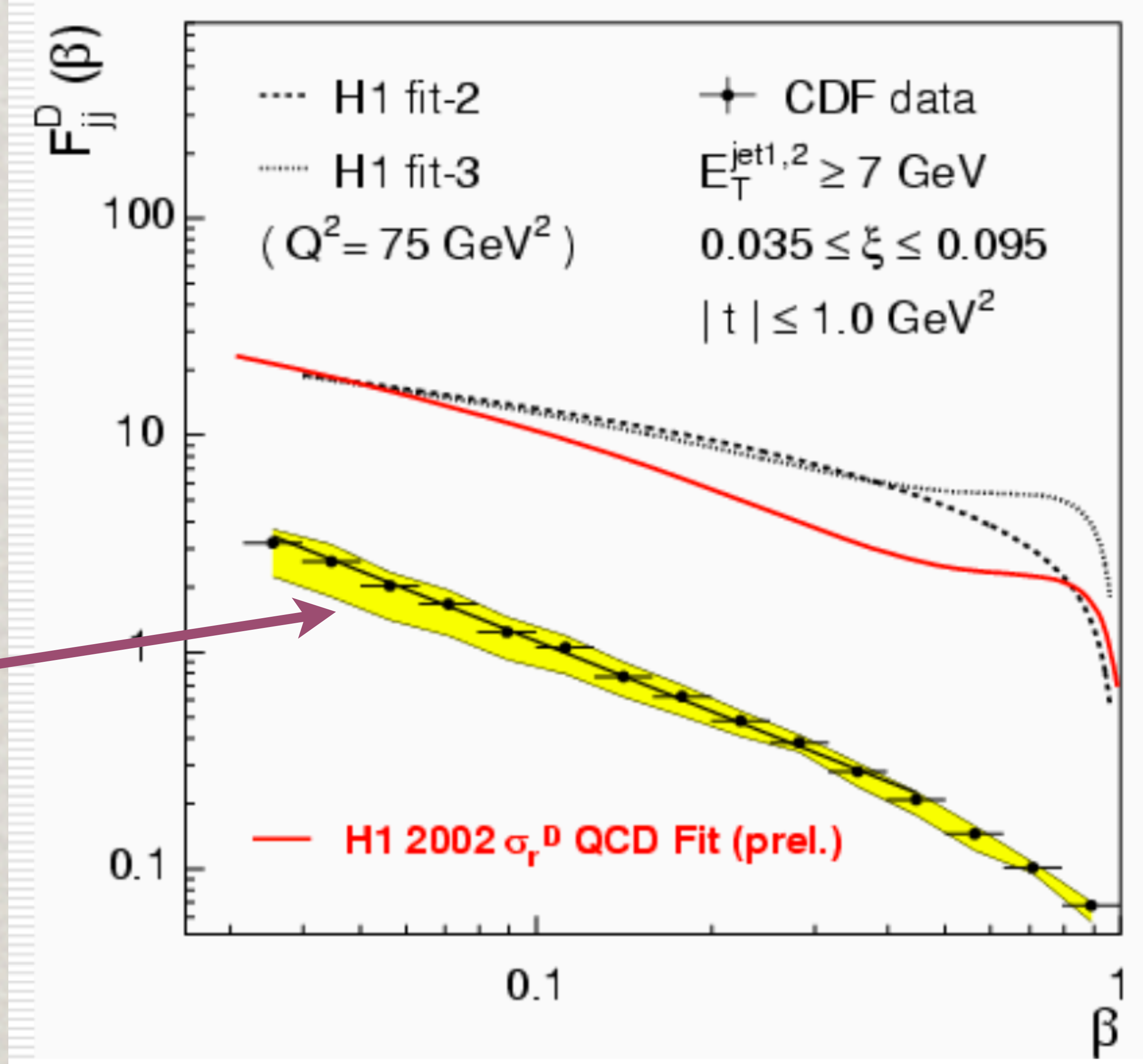
Factorization of short and long distances in inclusive reactions is currently the main theoretical tool, which allows to get around the unsolved problem of infra-red behavior. While only collinear factorization is proven, extensions are possible with either difficult higher order calculations, or making a plausible assumption of kt-factorization.

Ingelman-Schlein picture of diffraction



It looks natural to extend the factorization scheme on diffractive processes. Measuring the the Pomeron PDF in diffractive DIS, one can predict other hard diffractive reactions.

G. Ingelman & P. Schlein, 1985



Fjj(β) measured from SD Dijets suppressed relative to expectation from diffractive DIS

QCD Factorization breakdown

Unfortunately this beautiful idea failed the very first test by CDF, measured diffractive dijet production

Despite of the dramatic breakdown, and theoretical inconsistency the idea of factorization is still alive and popular...

Naively, diffractive factorization is believed to be valid, just needs to be corrected by a gap survival probability factor.

Diffraction is a higher twist

In diffractive DIS the amplitude is

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

So the cross section is a higher twist $\mathbf{\sigma_{diff} \propto 1/Q^4}$

Good-Walker picture of diffraction

The diffractive amplitude is given by the difference between the elastic amplitudes of different Fock components in the projectile hadron.

R.J. Glauber (1955); E. Feinberg & I.Ya. Pomeranchuk (1956); M.L. Good & W.D. Walker (1960)

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

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

Leading twist behavior, compared with the factorization based expectations.

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

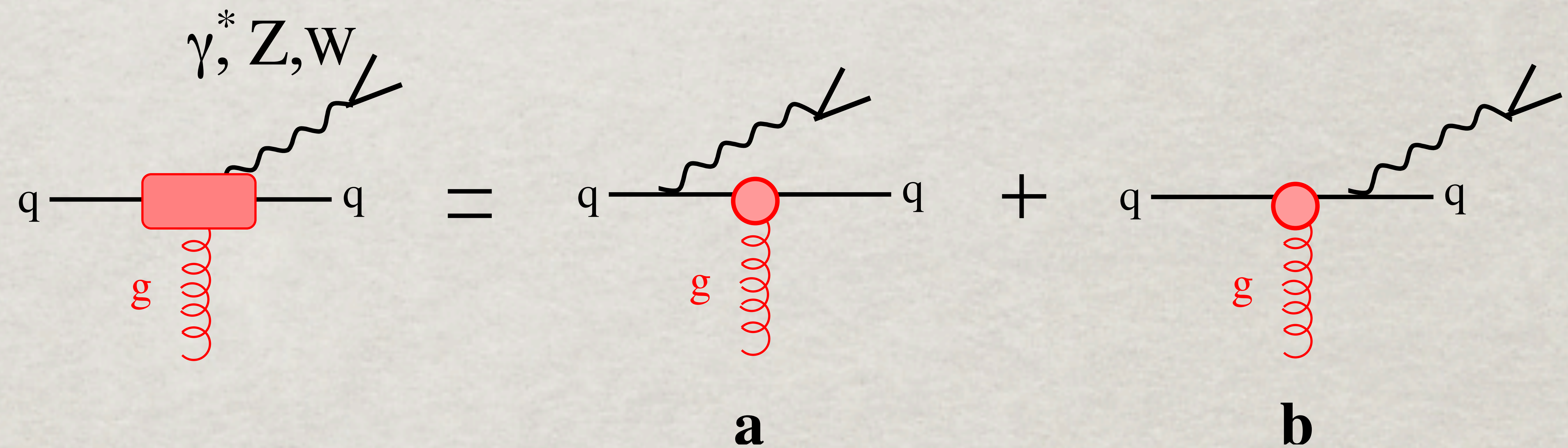
Diffractive factorization also breaks down due to the compositeness of the Pomeron

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

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

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

B.K. 1994

A.Tarasov, A.Schäfer & B.K. 1999

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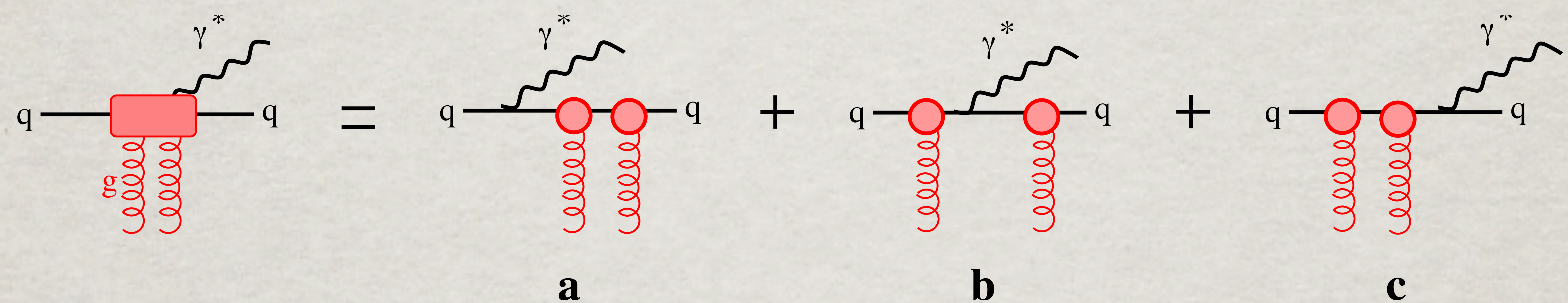
Diffractive Drell-Yan

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, $|q\rangle$ and $|q\gamma^*\rangle$ 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

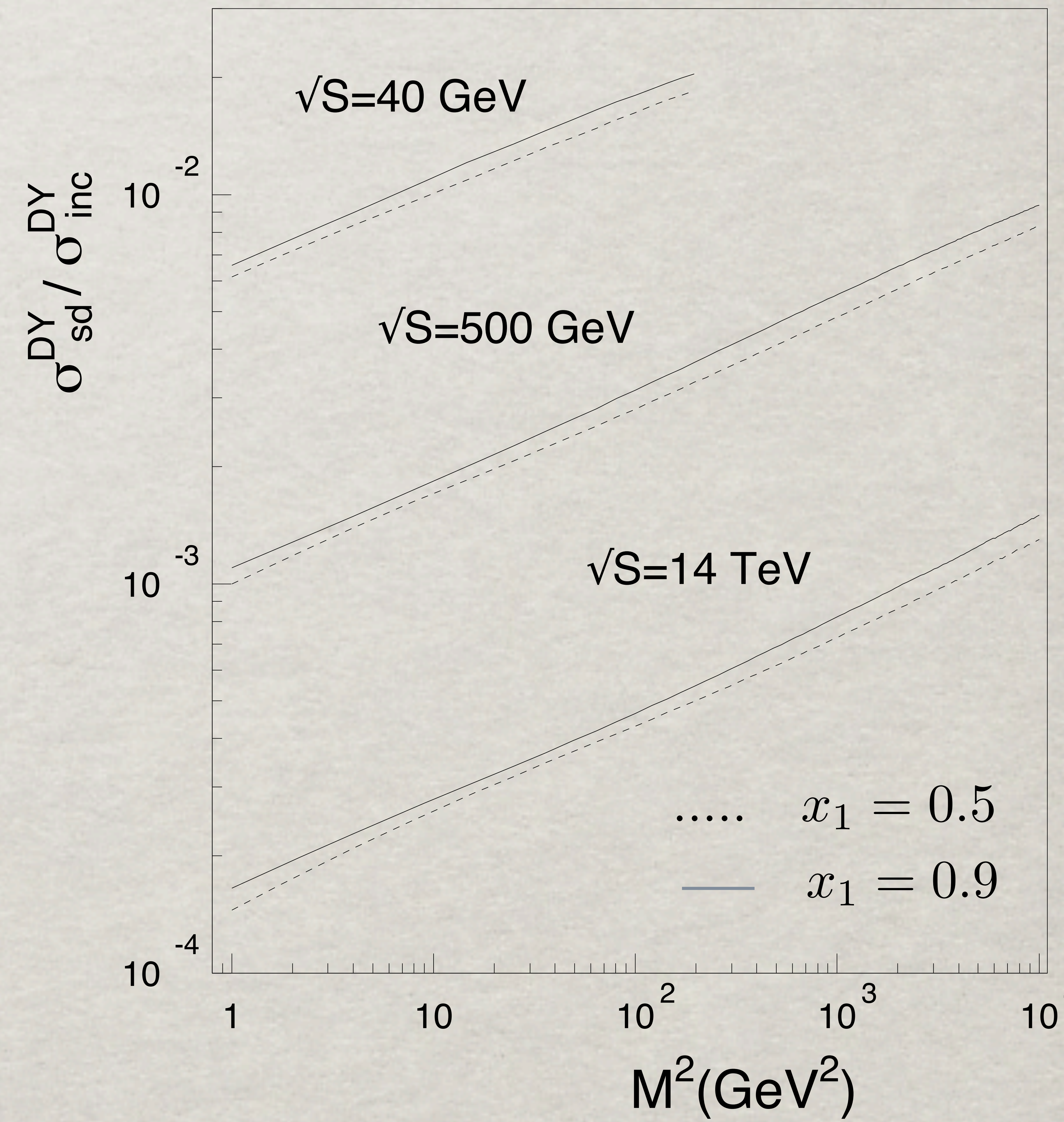
Diffractive DIS is dominated by soft interactions. On the contrary, diffractive Drell-Yan gets the main contribution from the interplay of soft and hard scales

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

The Good-Walker form of the diffractive amplitude and 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,

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

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.



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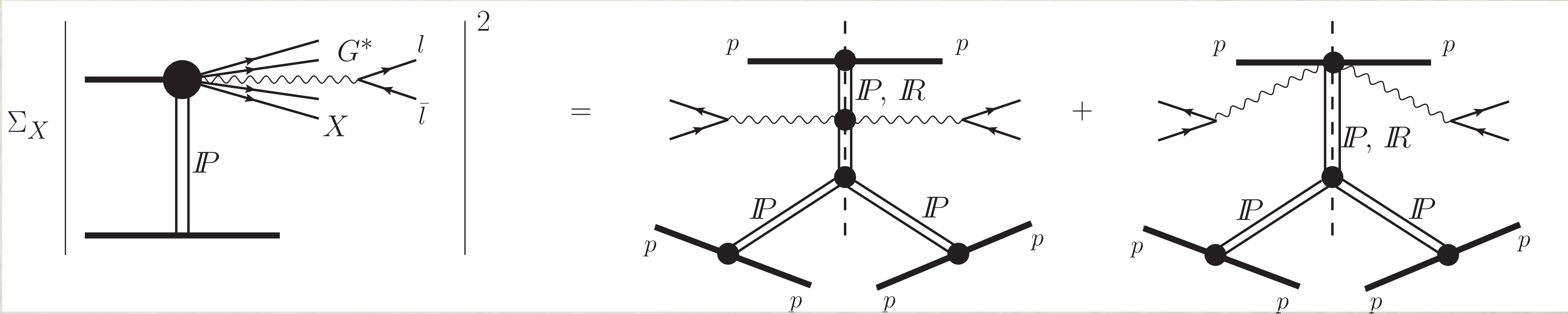
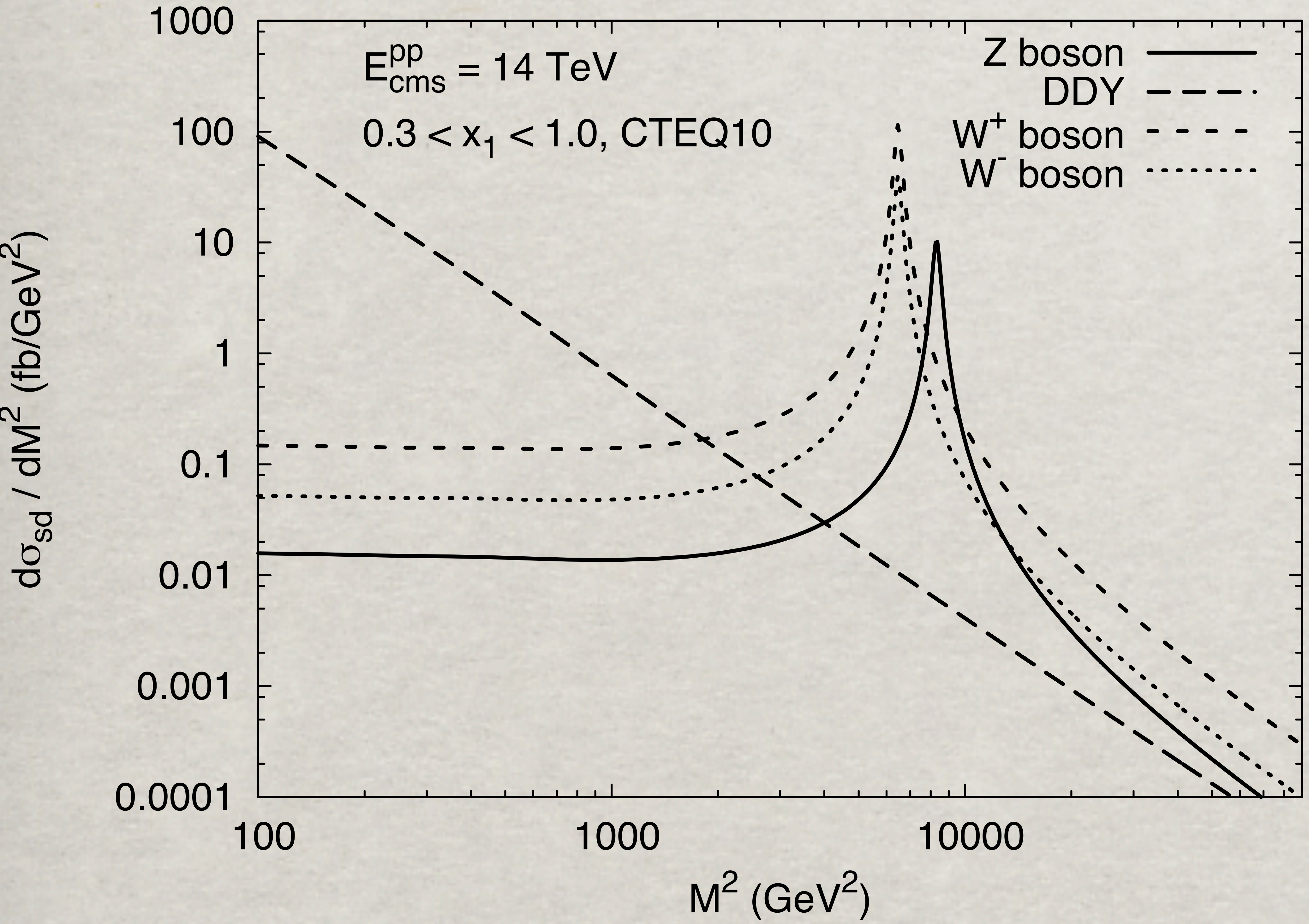
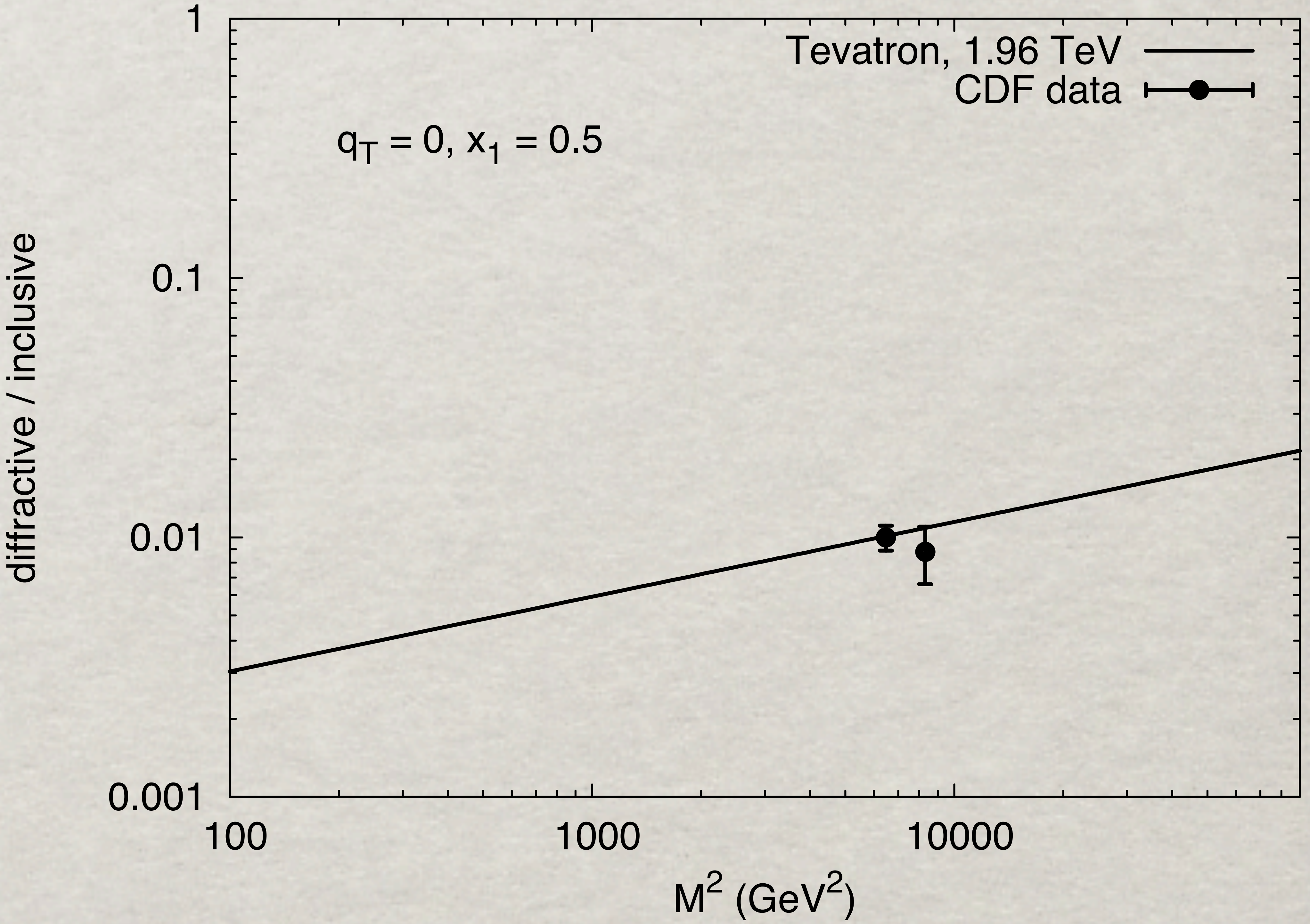
Diffractive Z and W production

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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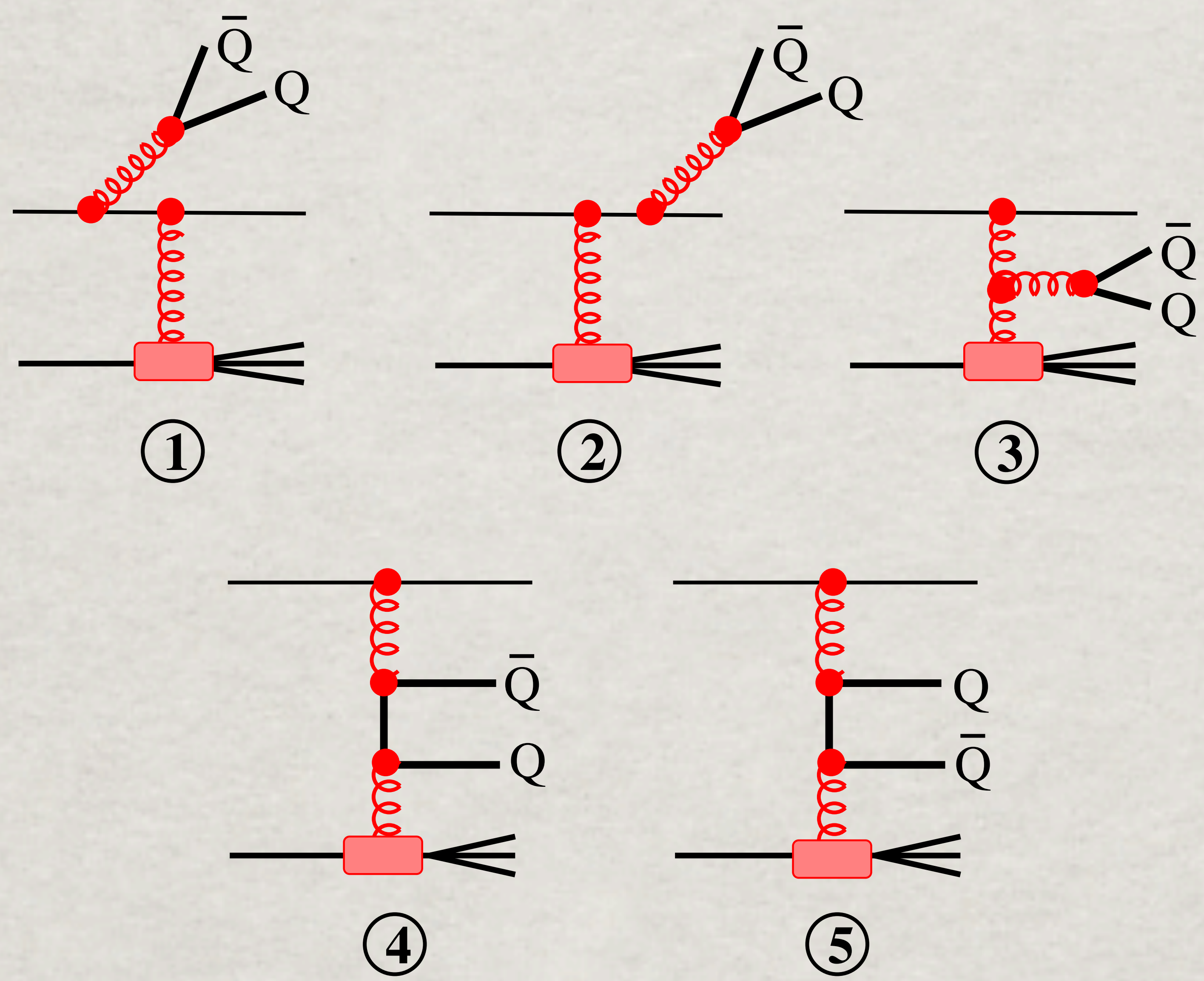
Diffractive heavy flavors

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

Inclusive heavy flavors

Bremsstrahlung (like in DY) and production mechanisms

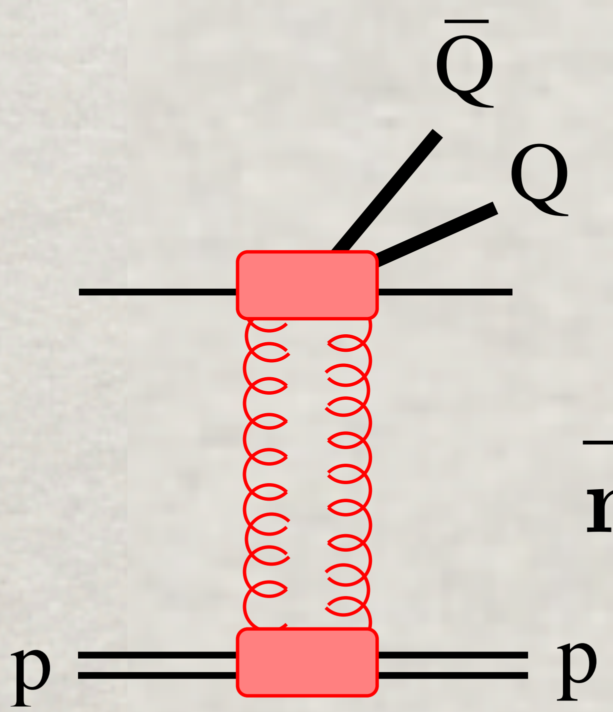


$$A_{Br} = A_1 + A_2 + \frac{Q^2}{M^2 + Q^2} A_3$$

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

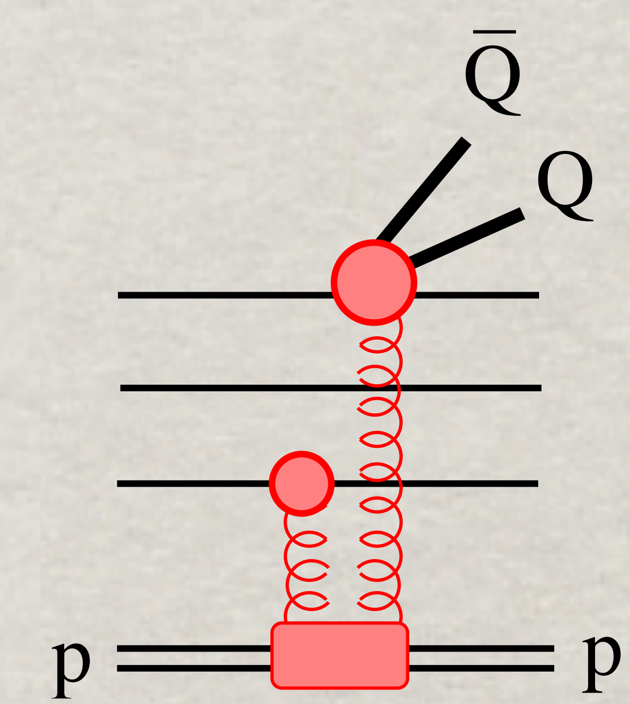
Diffractive heavy flavors

Diffractive bremsstrahlung



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

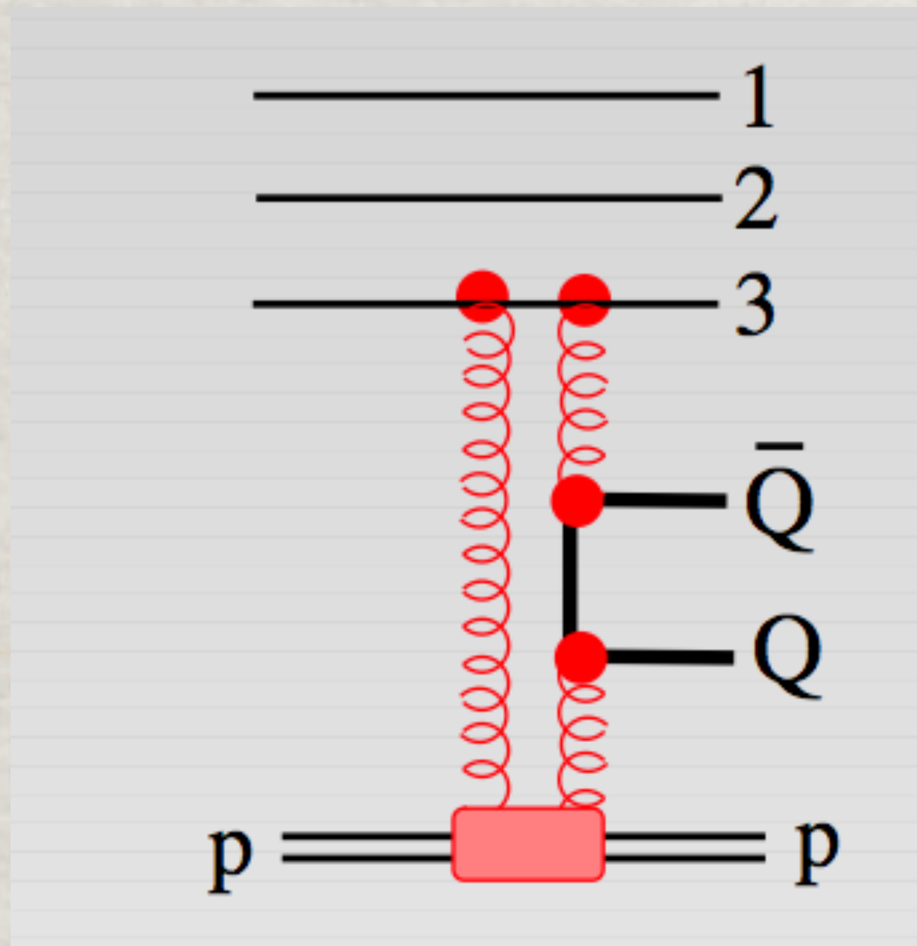
Higher twist bremsstrahlung

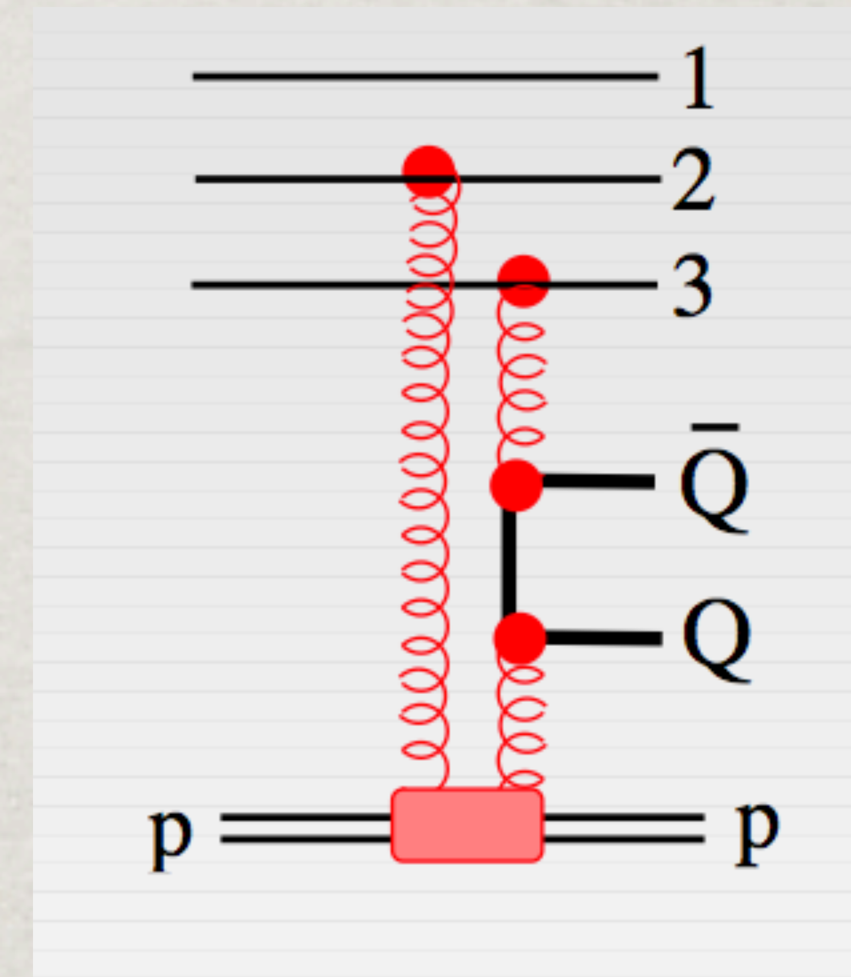


$$\frac{1}{m_Q^2}$$

Leading twist bremsstrahlung

Leading twist production mechanism in diffraction



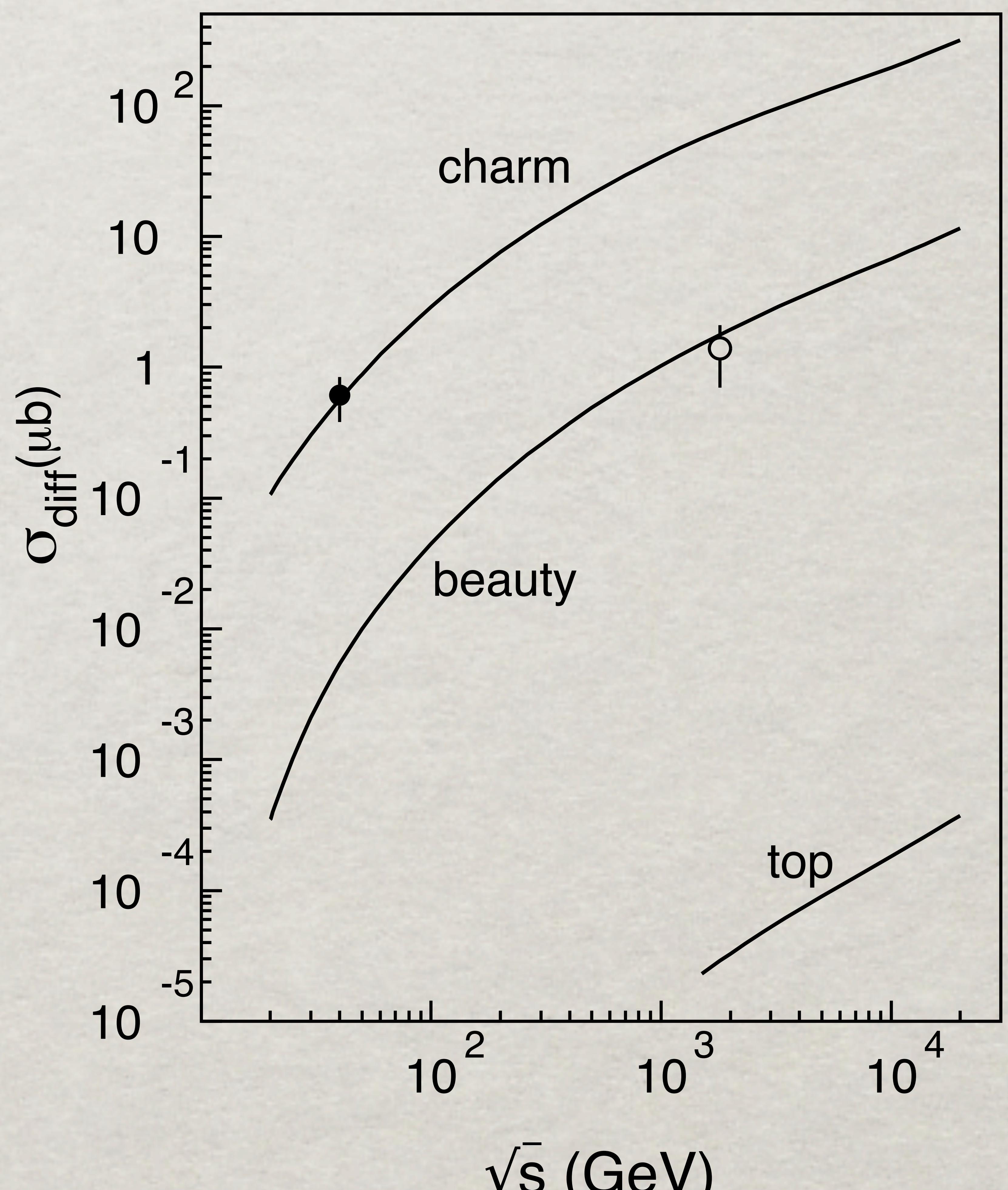


$$\sigma \propto \frac{1}{m_Q^2}$$

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

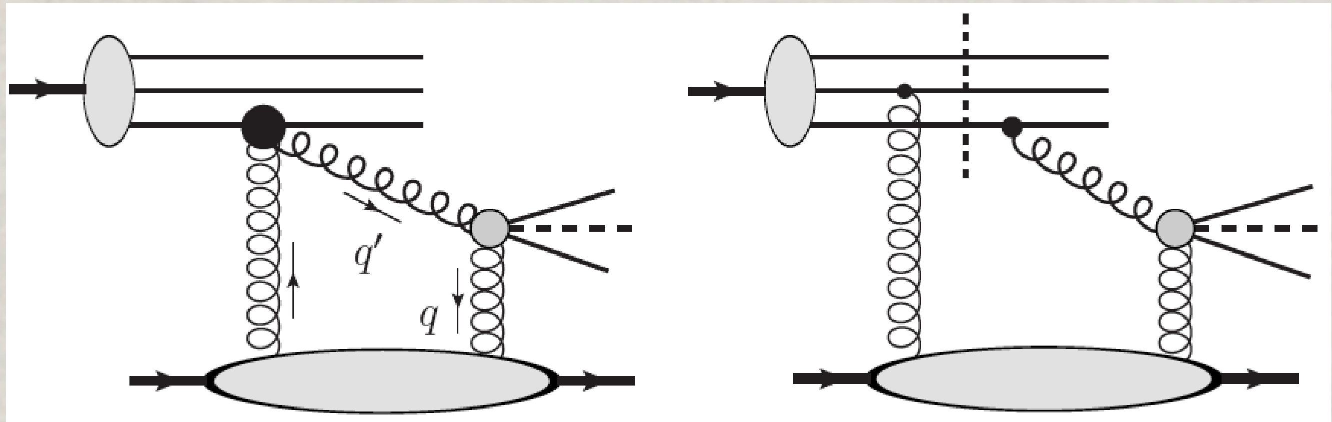


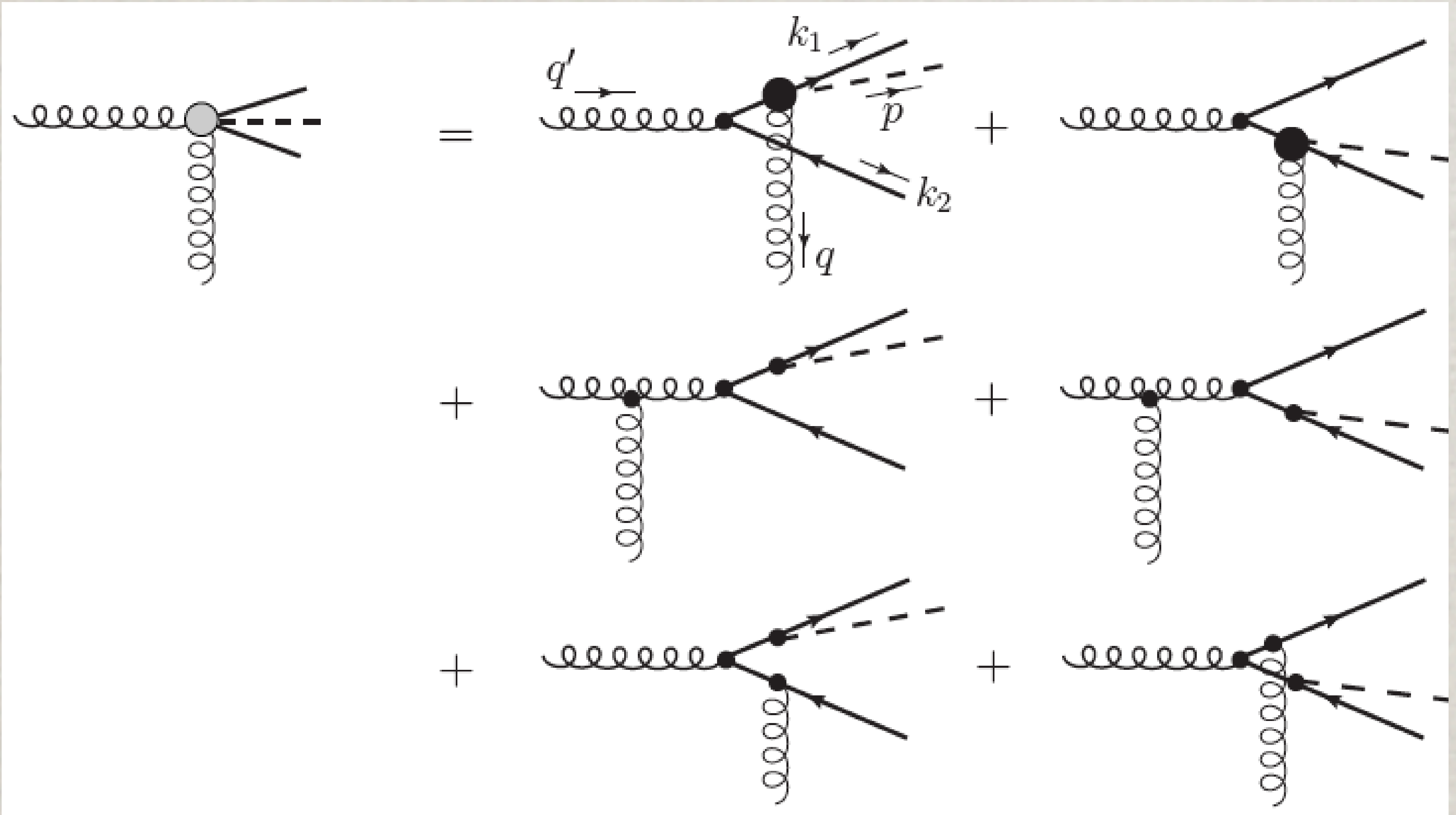
The leading twist behavior $1/m_Q^2$ of the diffractive cross section is confirmed by CDF data.

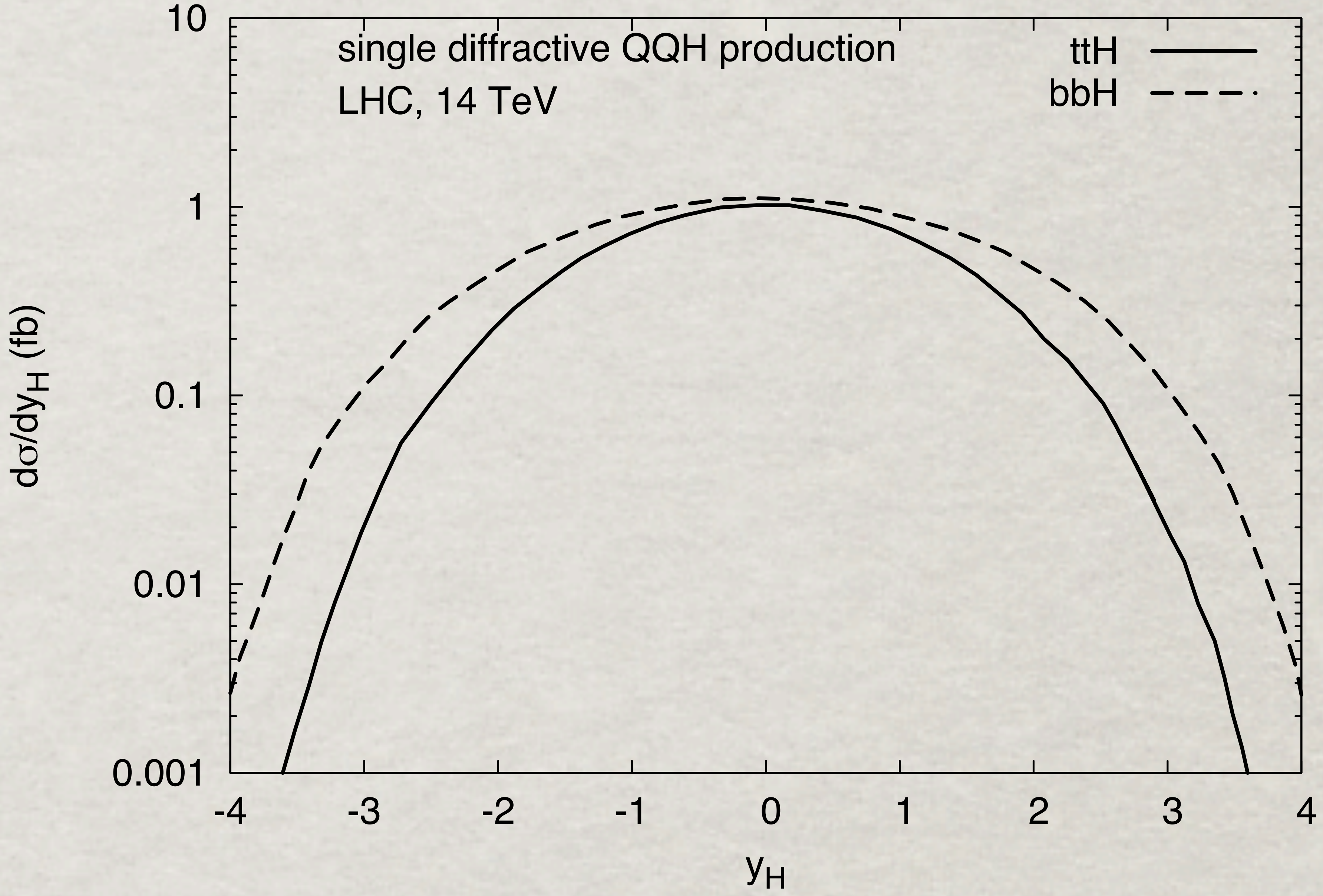
Diffractive Higgsstrahlung

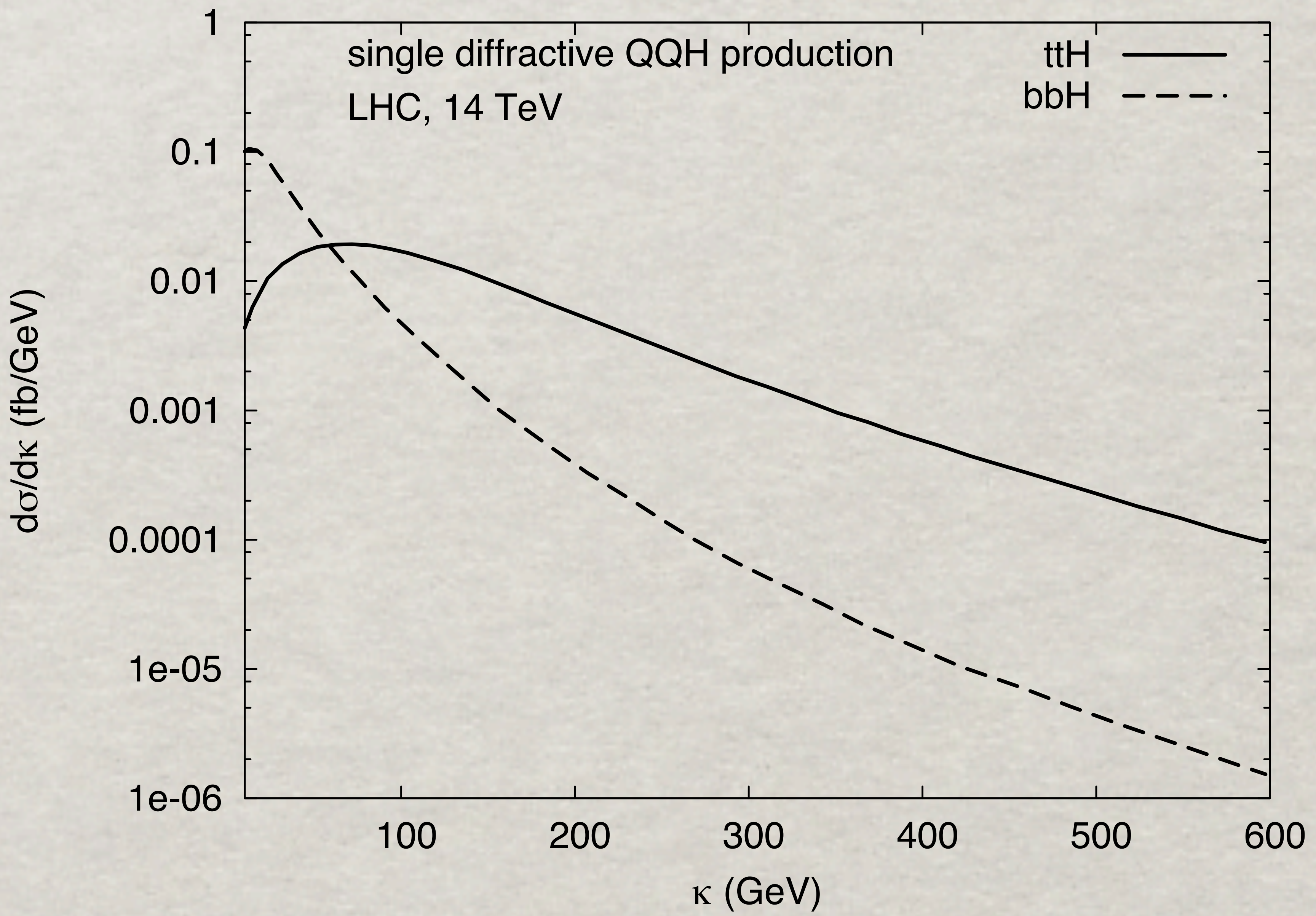
Light quark do not radiate Higgs directly, only via production of heavy flavors. Therefore the mechanism is the same as for non-abelian diffractive quark production.

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









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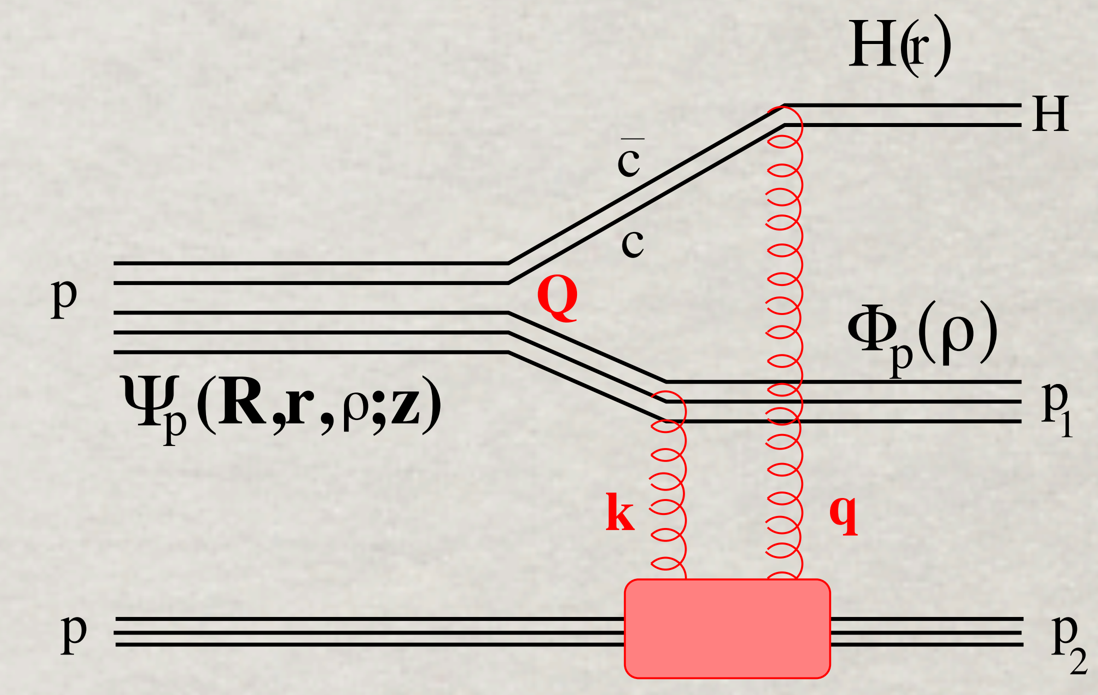
Diffractive Higgs from heavy flavored sea

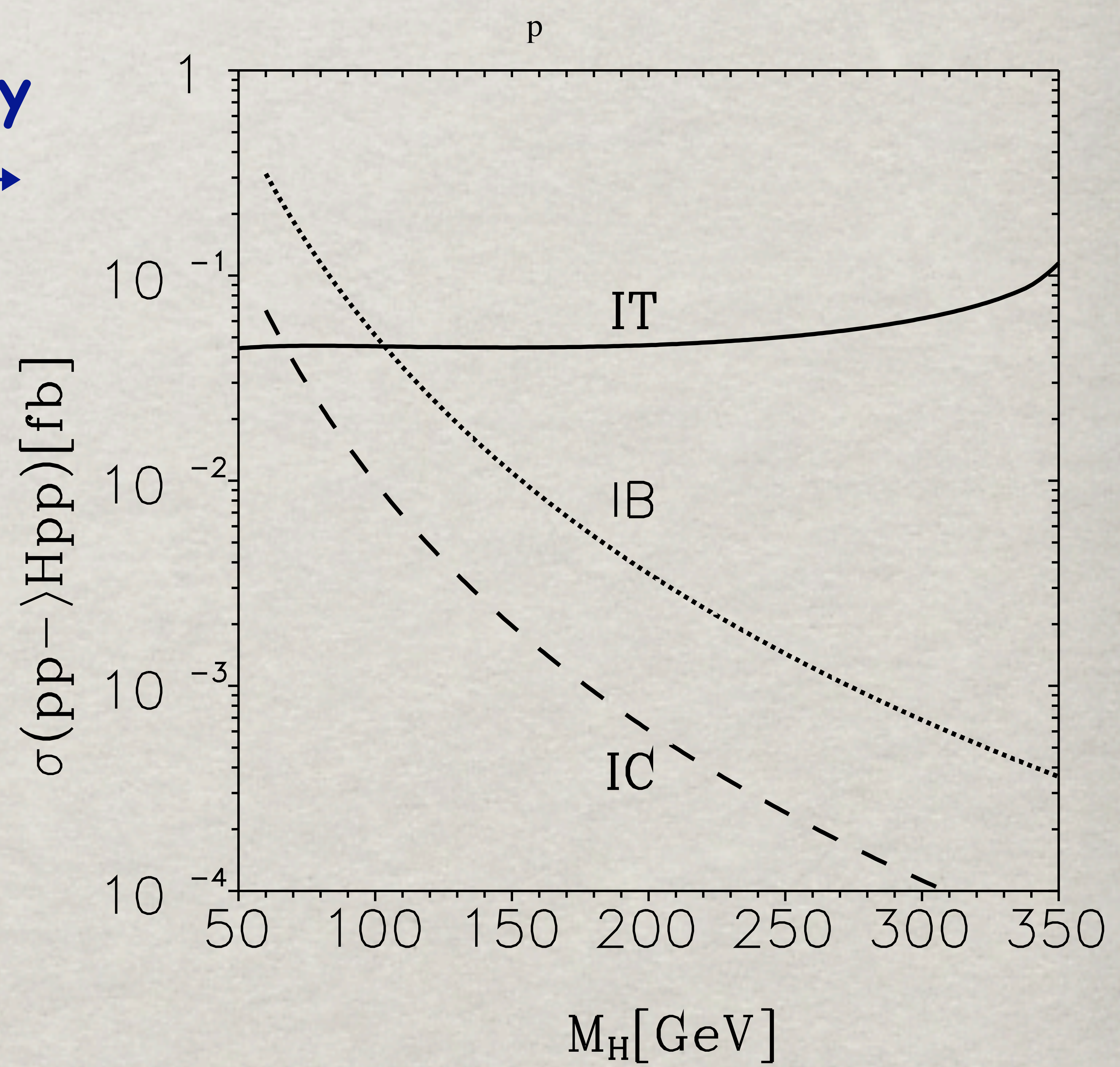
Diffractive Higgsstrahlung is similar to diffractive DY. Z, W, since in all cases the radiated particle does not participate in the interaction. However, the Higgs decouples from light quarks, so the cross section of higgsstrahlung by light hadrons is small.



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

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 $1/m_Q^2$ [M.Franz, M.Polyakov, K.Goeke 2000]. At the Higgs mass 125 GeV intrinsic bottom and top give comparable contributions.

Summarizing:

Universality of the diffractive PDFs is broken in hard hadronic diffraction due to presens of spectator partons.

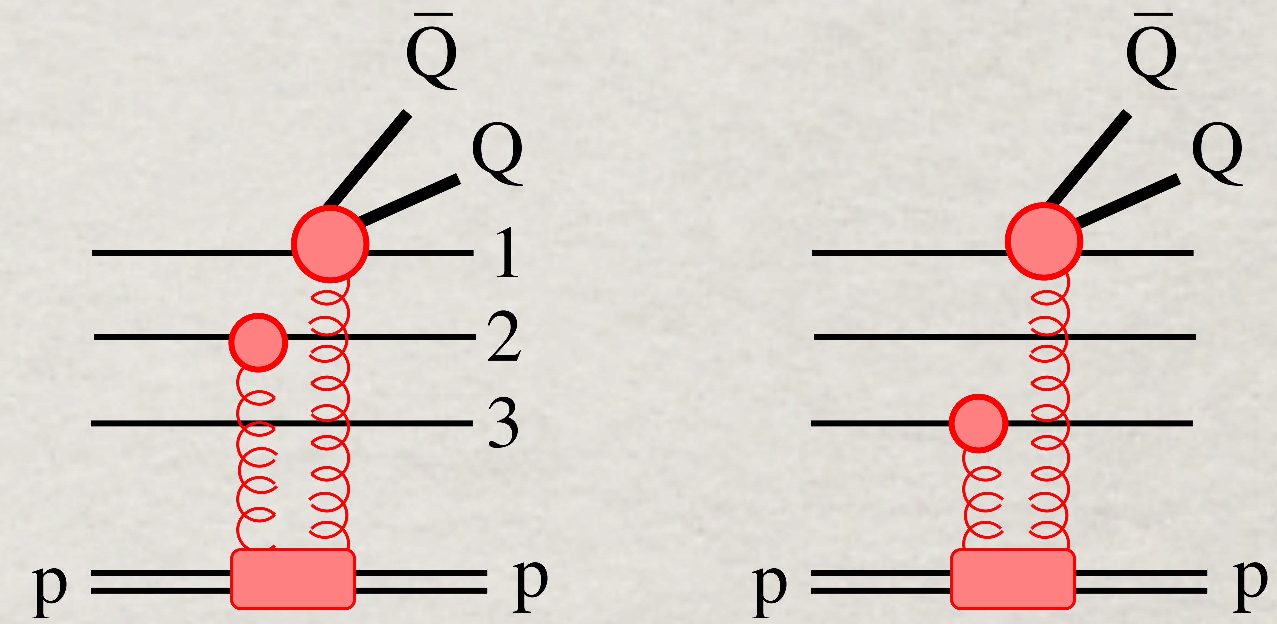
Forward diffractive radiation by a parton of direct photons, Drell-Yan dileptons, and gauge bosons Z, W is forbidden, breaking diffractive factorization. The spectators make it possible and make it leading twist, $1/M^2$

Non-abelian forward diffractive radiation of heavy flavors is permitted. Nevertheless, spectators make diffraction leading twist, $1/m_Q^2$

Diffractive higgsstrahlung at forward rapidities is suppressed, a larger contribution is expected from the coalescence of intrinsic heavy quarks in the proton. Bottom and top are expected to dominate.

BACKUPS

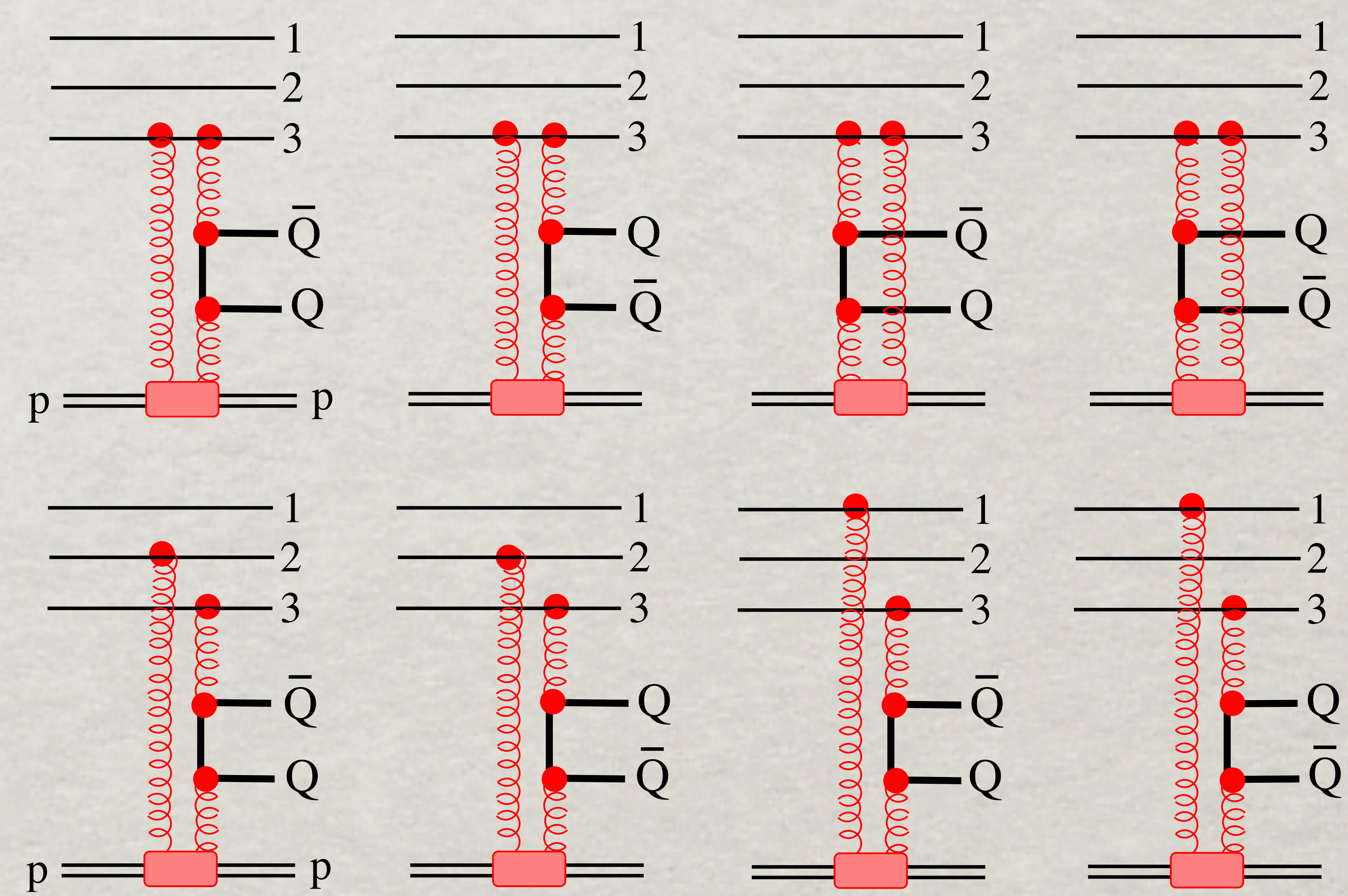
Leading twist Bremsstrahlung mechanism:



$\sigma \sim 1/m_Q^2$

Leading twist

Production mechanism in diffraction:



$$\sigma \propto 1/m_Q^2$$

Leading twist

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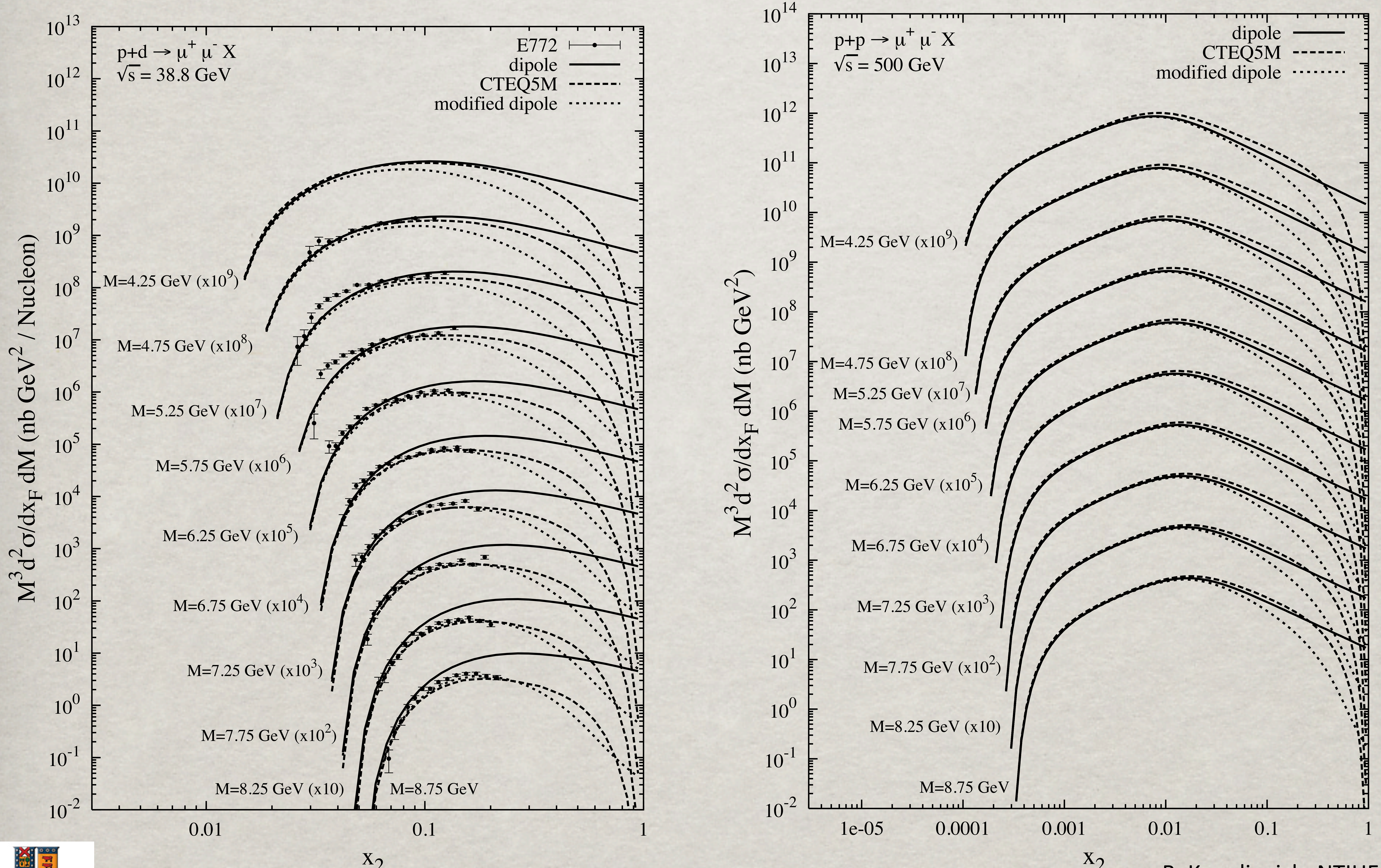
Diffractive heavy flavors: data

• Measurements at ISR led to an amazingly large (probably incorrect) cross section of diffractive charm production (K.L.Giboni et al. 1979), σ ~ 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 σ ≤ 26 μb

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

• The CDF experiment measured the fraction of diffractively produced beauty, $\mathbf{R^{\bar{b}b}_{diff/tot} = (0.62 \pm 19 \pm 16)\%}$, 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) $\sigma^{\mathbf{\bar{b}b}}_{\mathbf{tot}}$ = 200 mb, then $\sigma^{\mathbf{\bar{b}b}}_{\mathbf{diff}}$ ≈ 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^3 d^2σ/dx_F dM (nb GeV^2 / Nucleon)
x_2
p+p → μ⁺ μ⁻ X
√s = 500 GeV
dipole
CTEQ5M
modified dipole
M^3 d^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].

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

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

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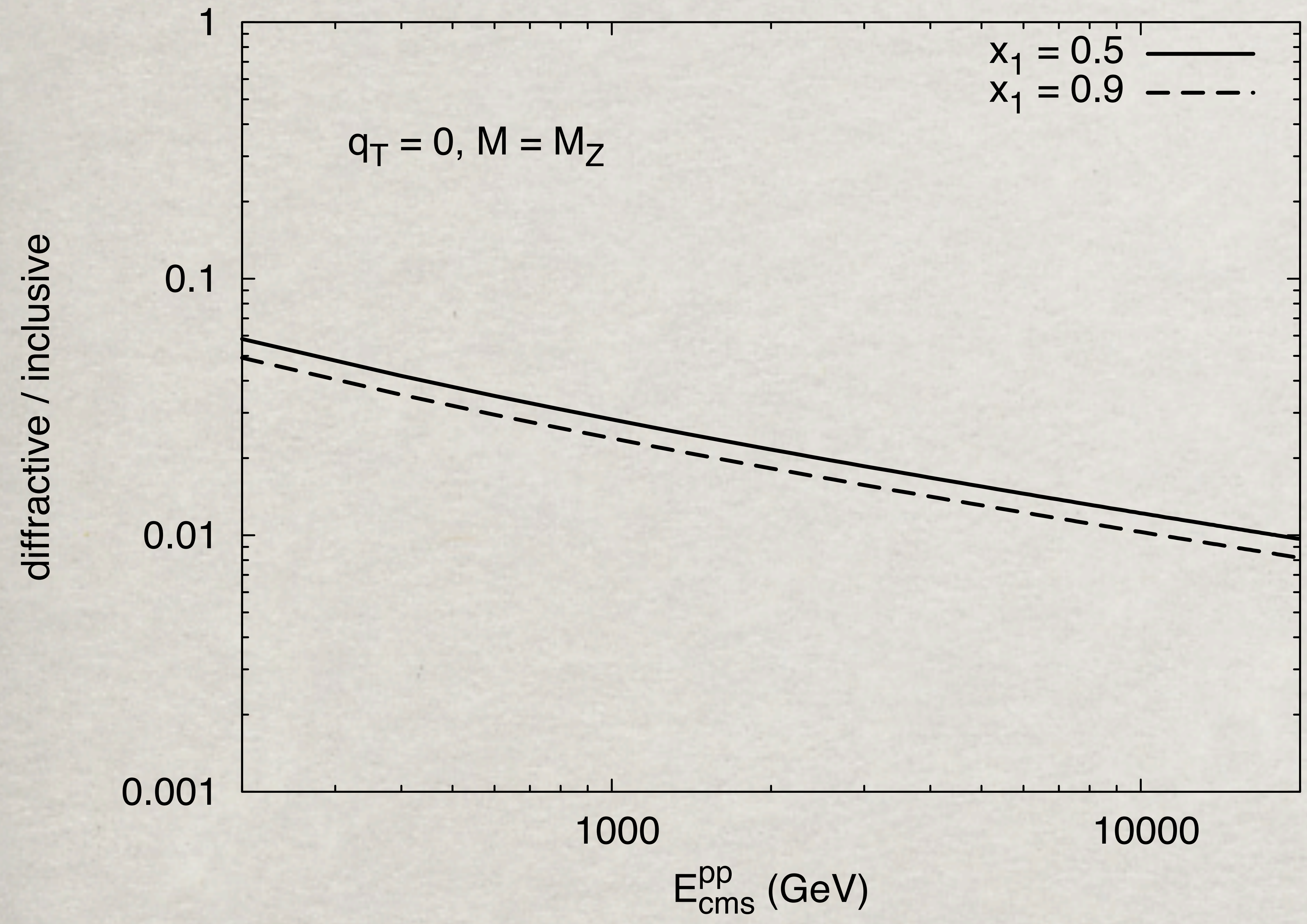
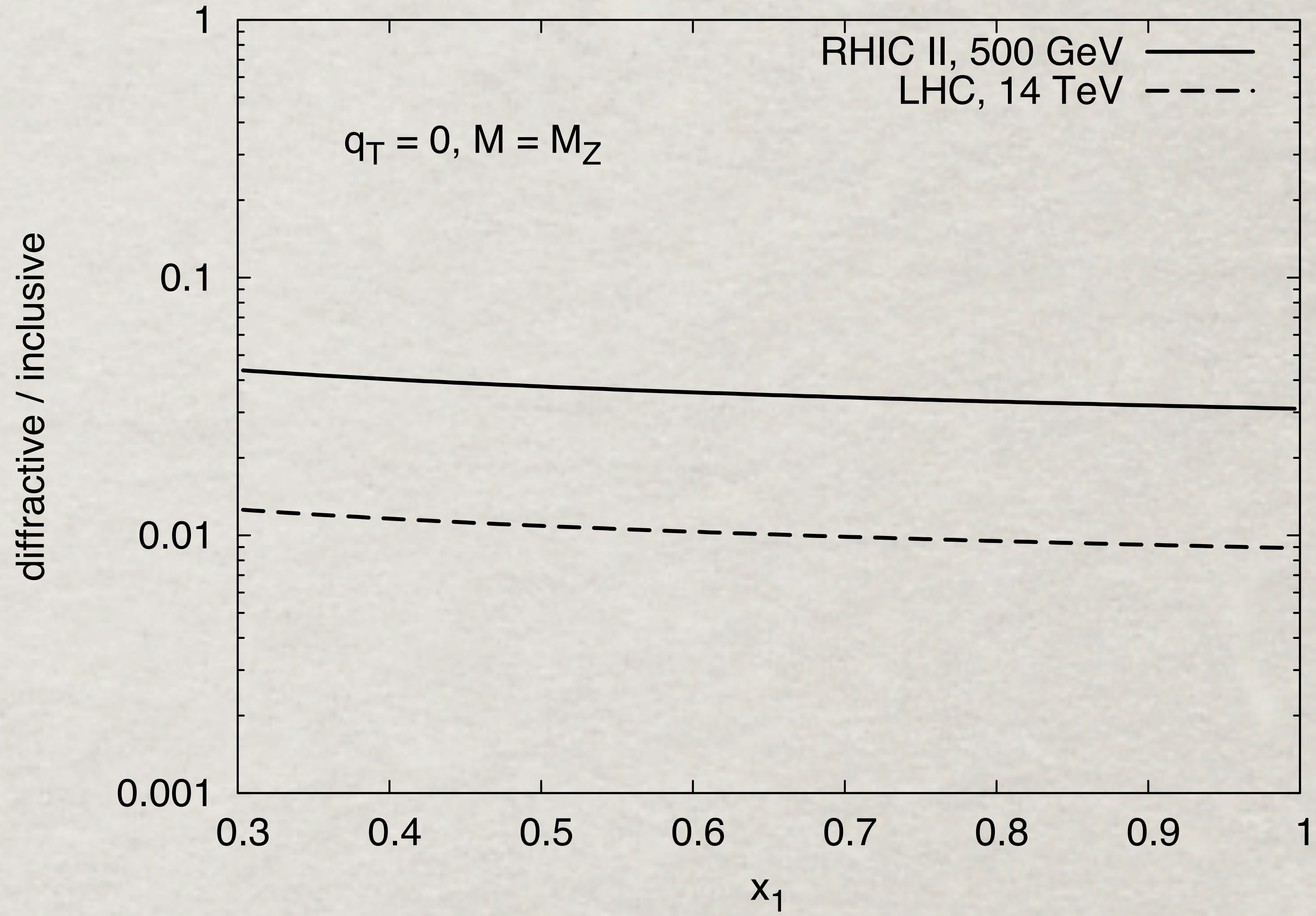
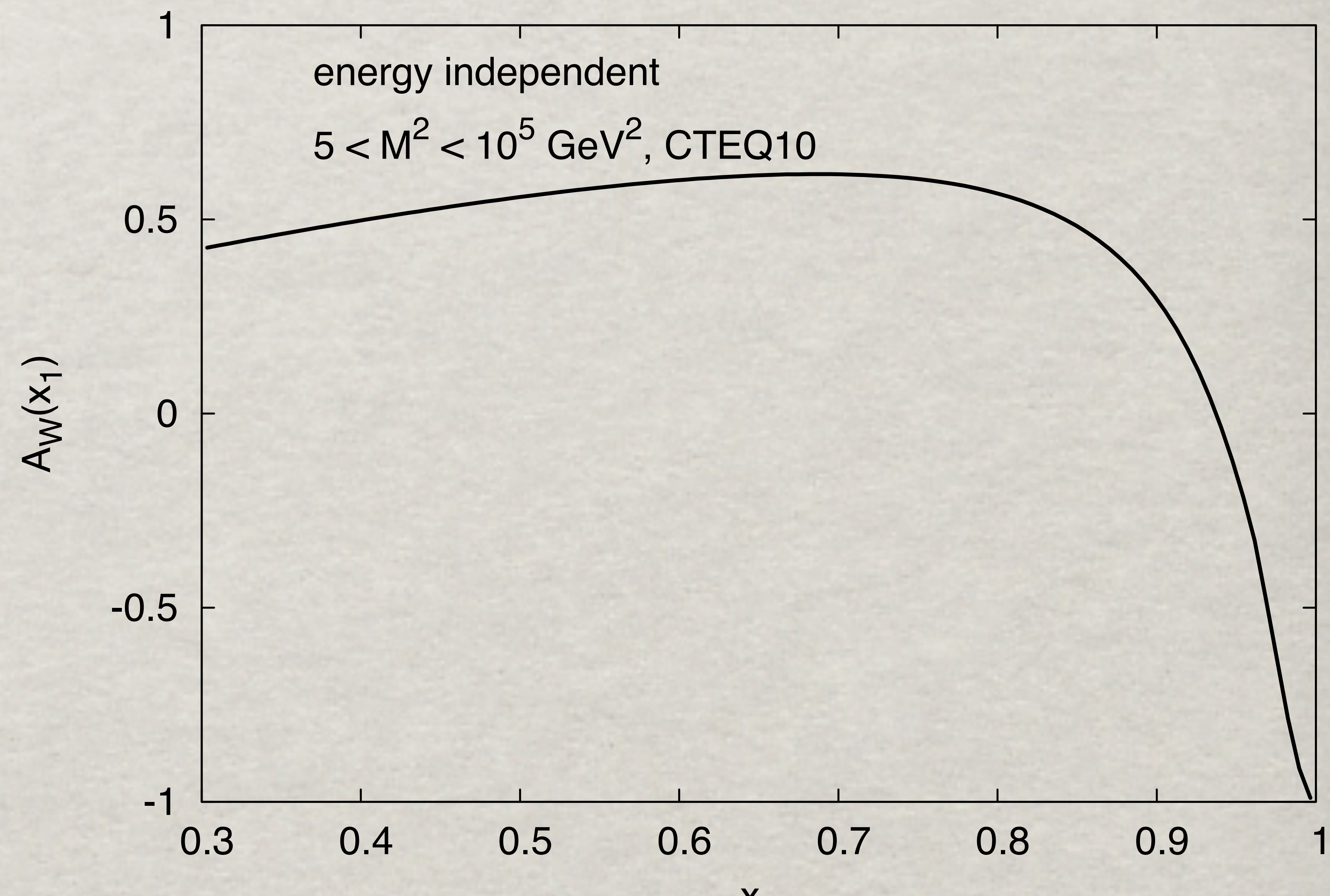
More of diffractive Z and W







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