Diffractive bremsstrahlung of nonabelian fields

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Low-x, 2014, Kyoto

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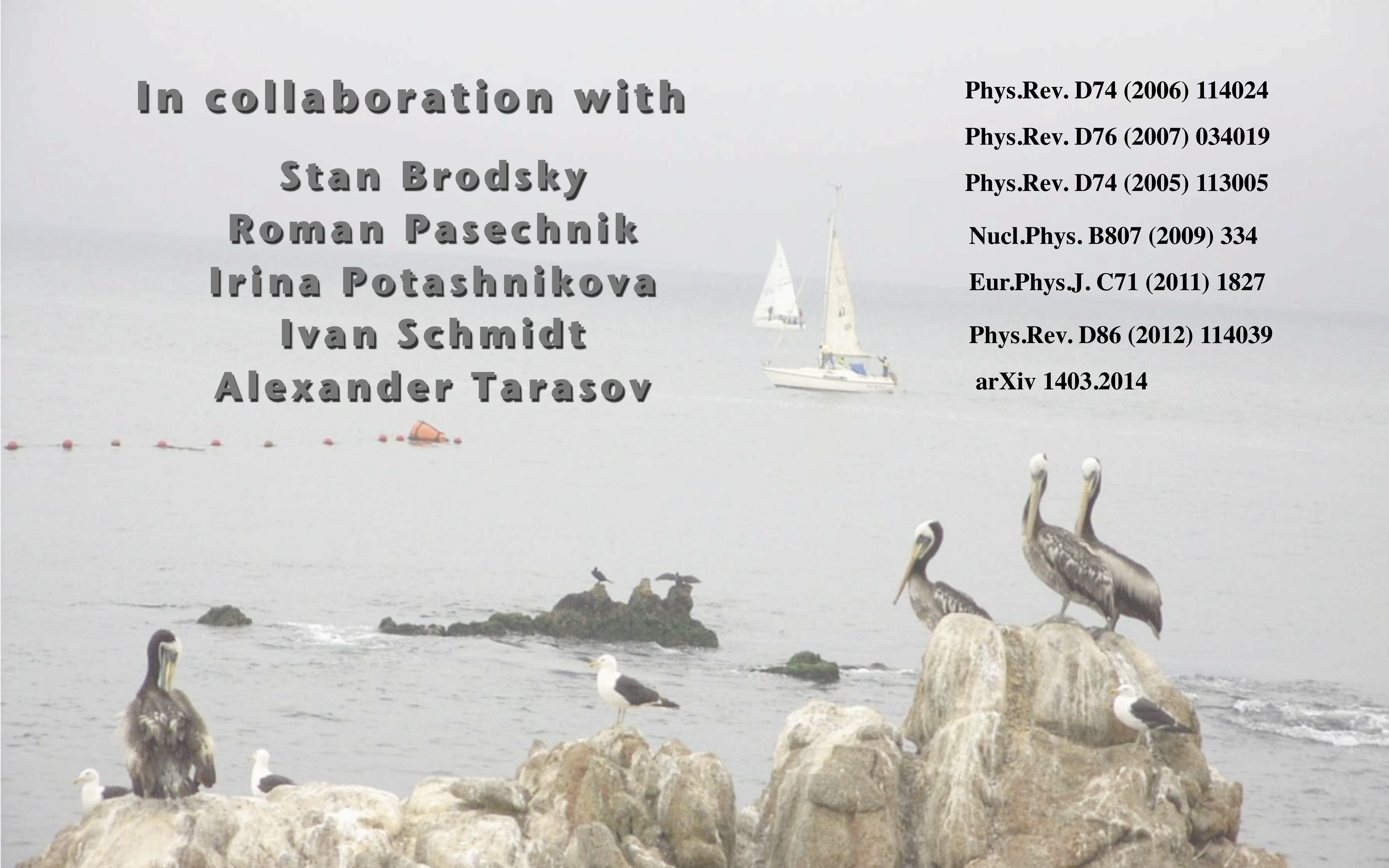Phys.Rev. D74 (2006) 114024

Phys.Rev. D76 (2007) 034019

Phys.Rev. D74 (2005) 113005

Nucl.Phys. B807 (2009) 334

Eur.Phys.J. C71 (2011) 1827

Phys.Rev. D86 (2012) 114039

arXiv 1403.2014

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].

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

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.**

$\gamma^*, \mathbf{Z}, \mathbf{W}$

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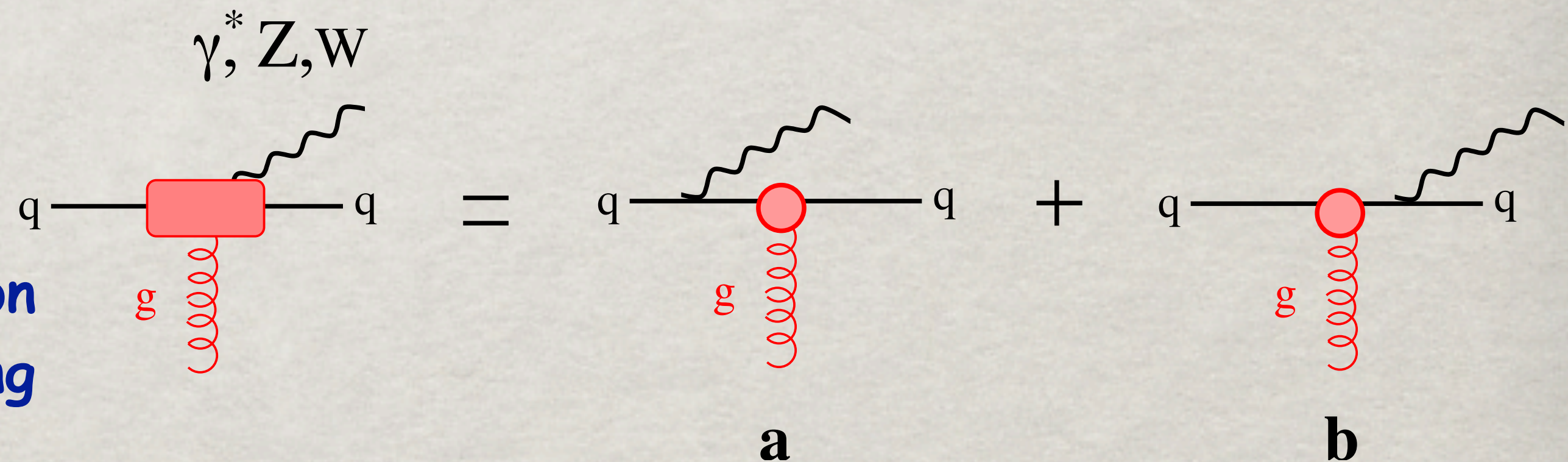
The cross section is expressed via the dipoles looks similar to DIS [B.K. 1995]

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

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

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

In diffraction such a relation (Ingelman-Schlein factorization) is broken

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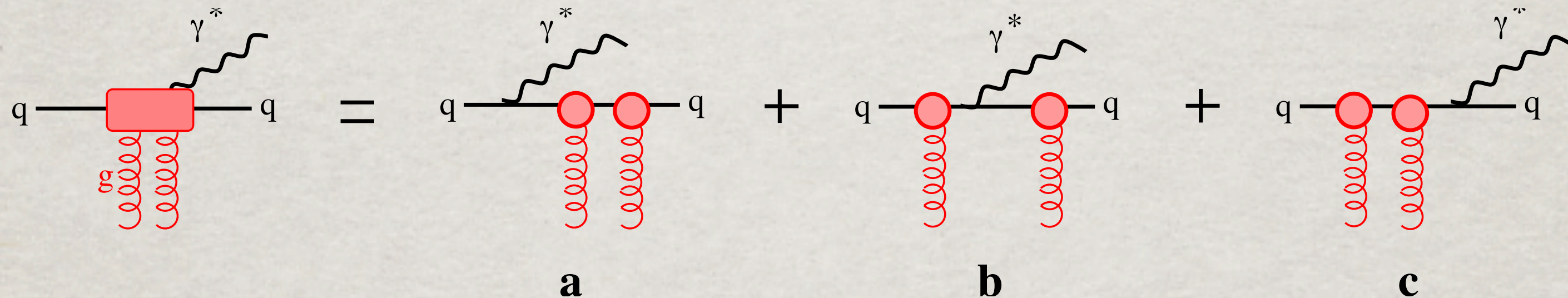
Diffractive radiation of a heavy photon (any gauge boson) by a quark vanishes in the forward direction [B.K., A.Schaefer, A.Tarasov 1998]

$$\frac{d\sigma_{\text{inc}}^{\text{DY}}(qp \to \gamma^* qp)}{d\alpha\, dM^2}\bigg|_{p_T=0} = 0 \quad !!!$$

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.

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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
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 $r \sim 1/M$
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.

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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,

$$\frac{\sigma_{\mathbf{sd}}^{\mathbf{DY}}}{\sigma_{\mathbf{incl}}^{\mathbf{DY}}} \propto \frac{\exp(-2\mathbf{R}^2/\mathbf{R}_0^2)}{\mathbf{R}_0^2}$$

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.
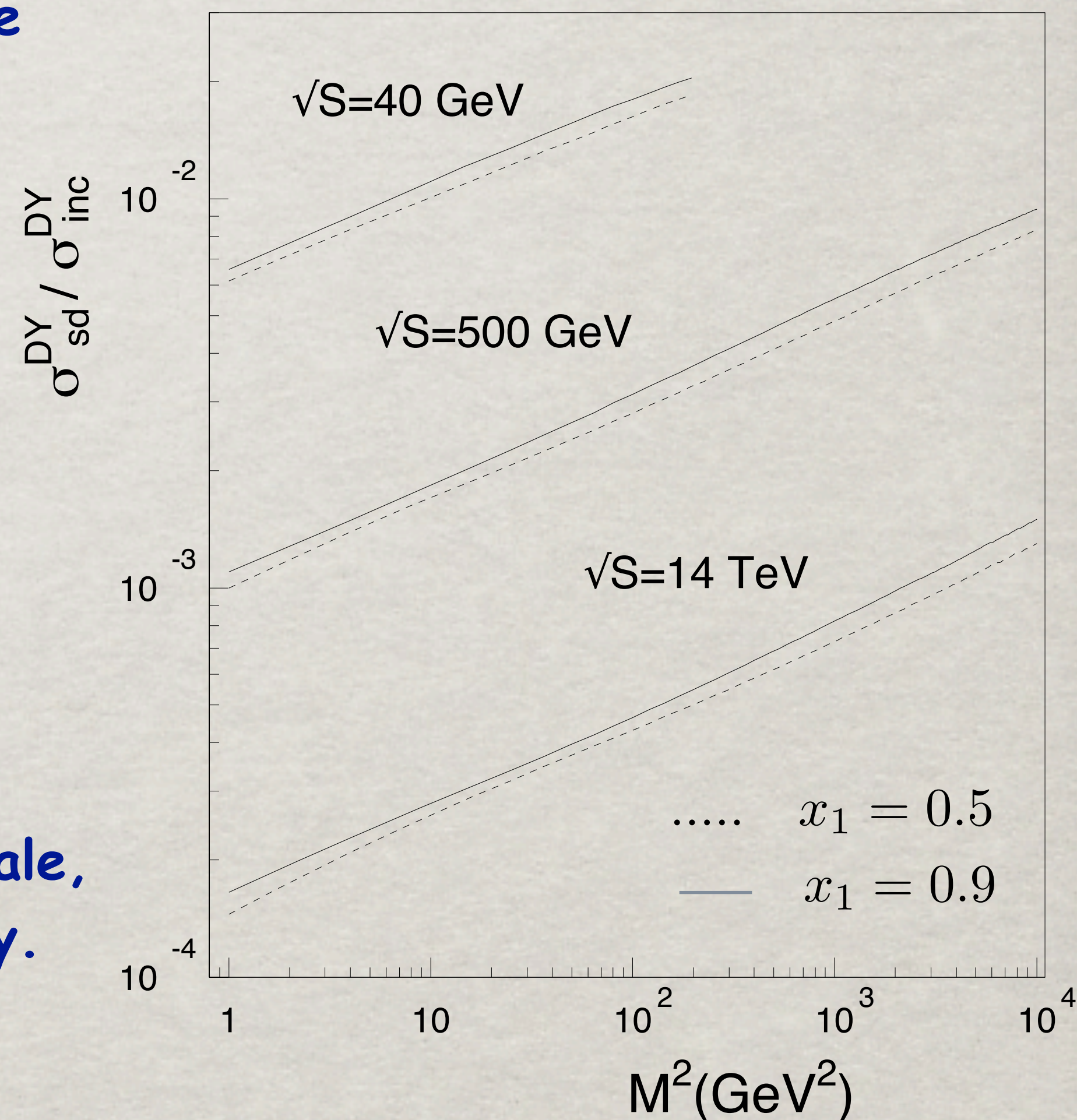
Diffractive Z and W production

Abelian diffractive radiation of any particle is described by the same Feynman graphs, only couplings and spin structure may vary.
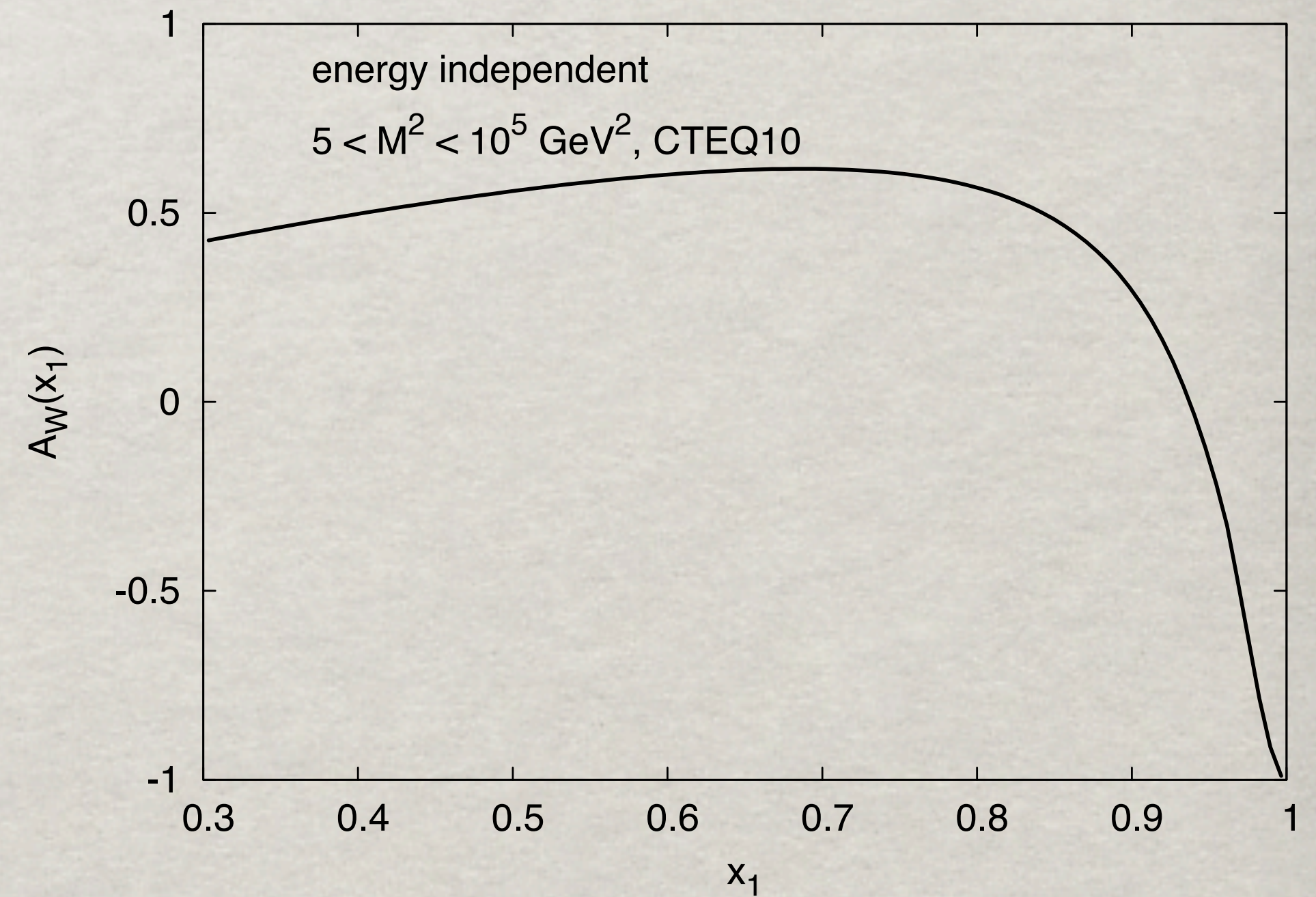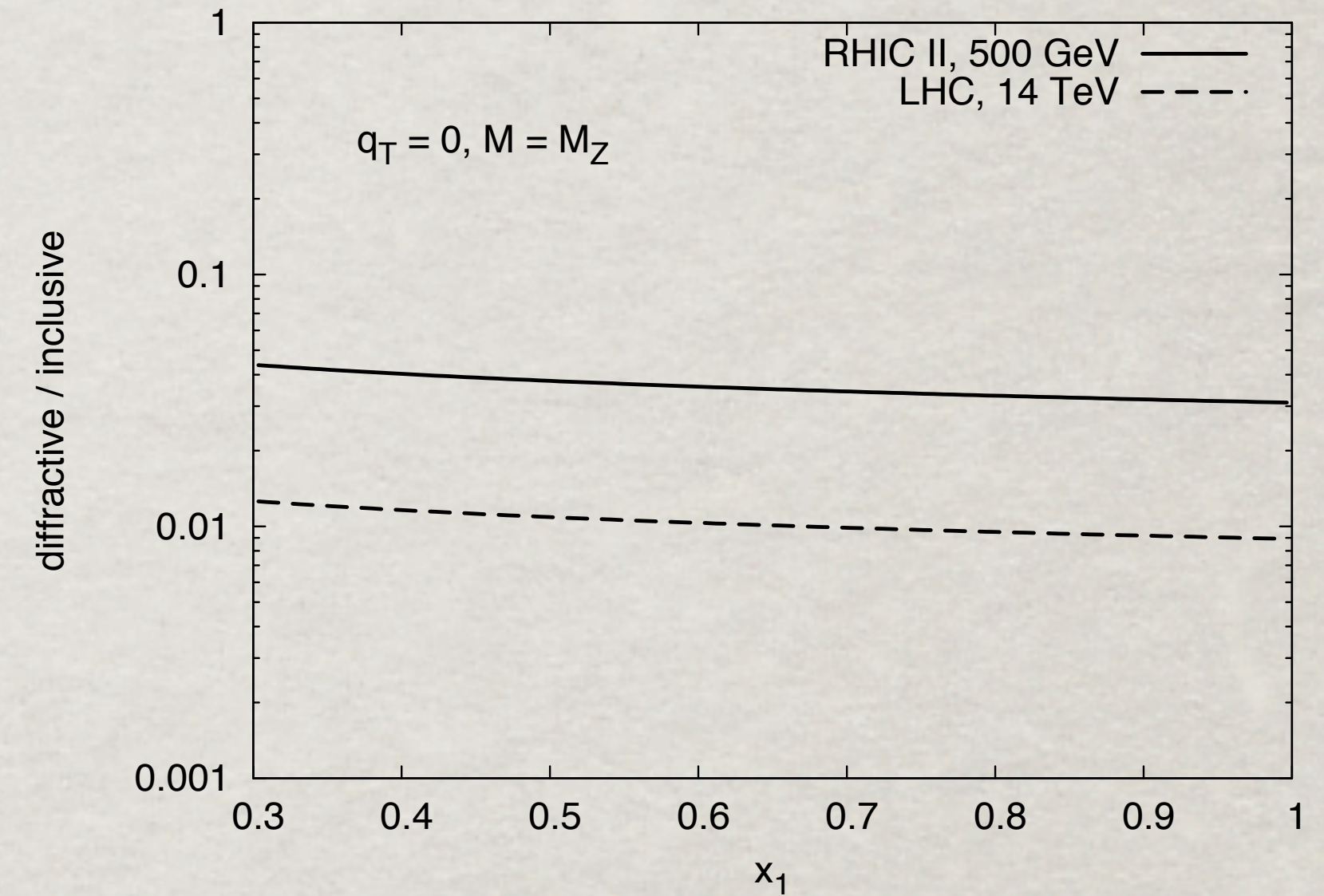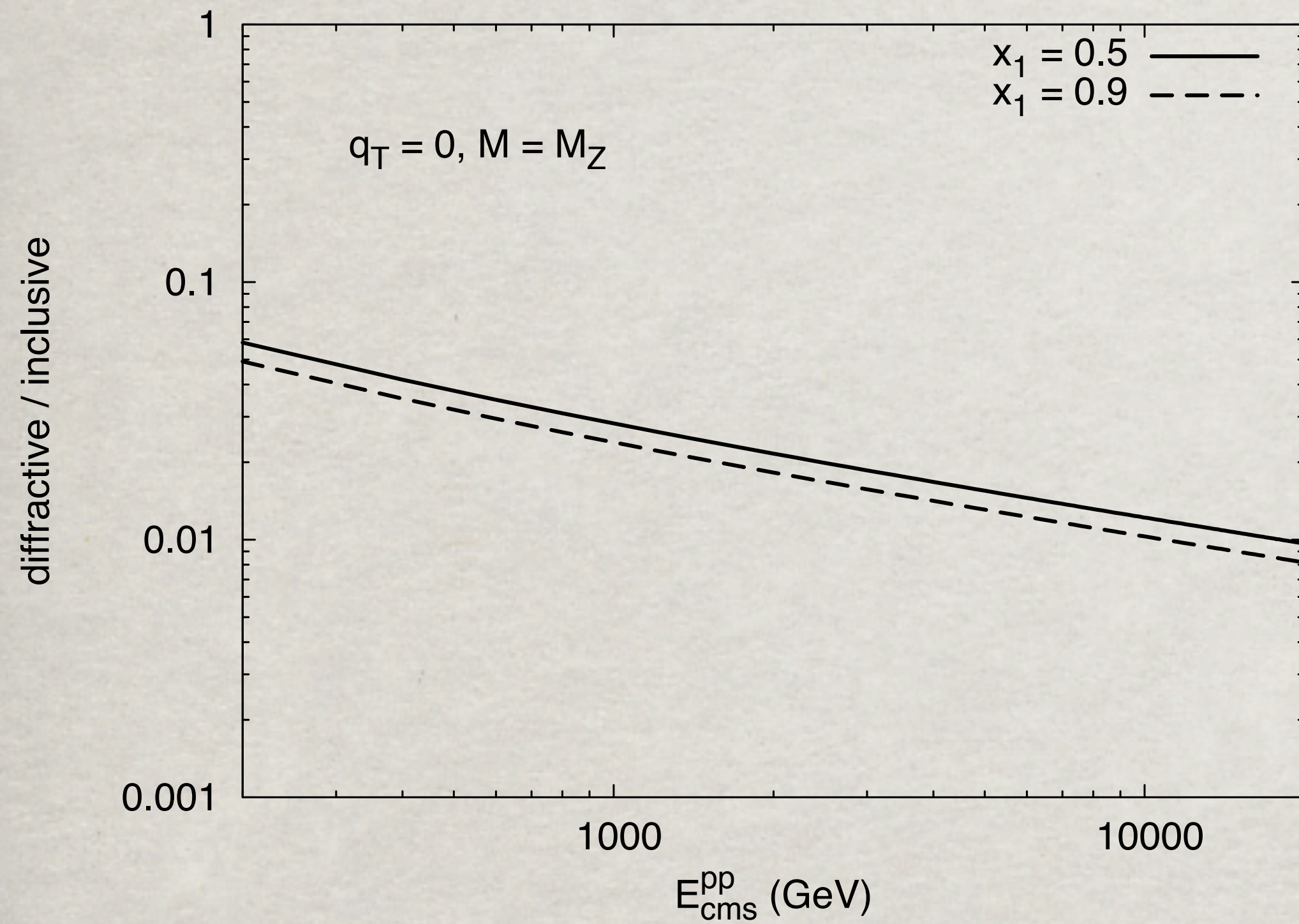
R.Pasechnik, B.K., I.Potashnikova 2012.

B. Kopeliovich, Low-x, 2014, Kyoto
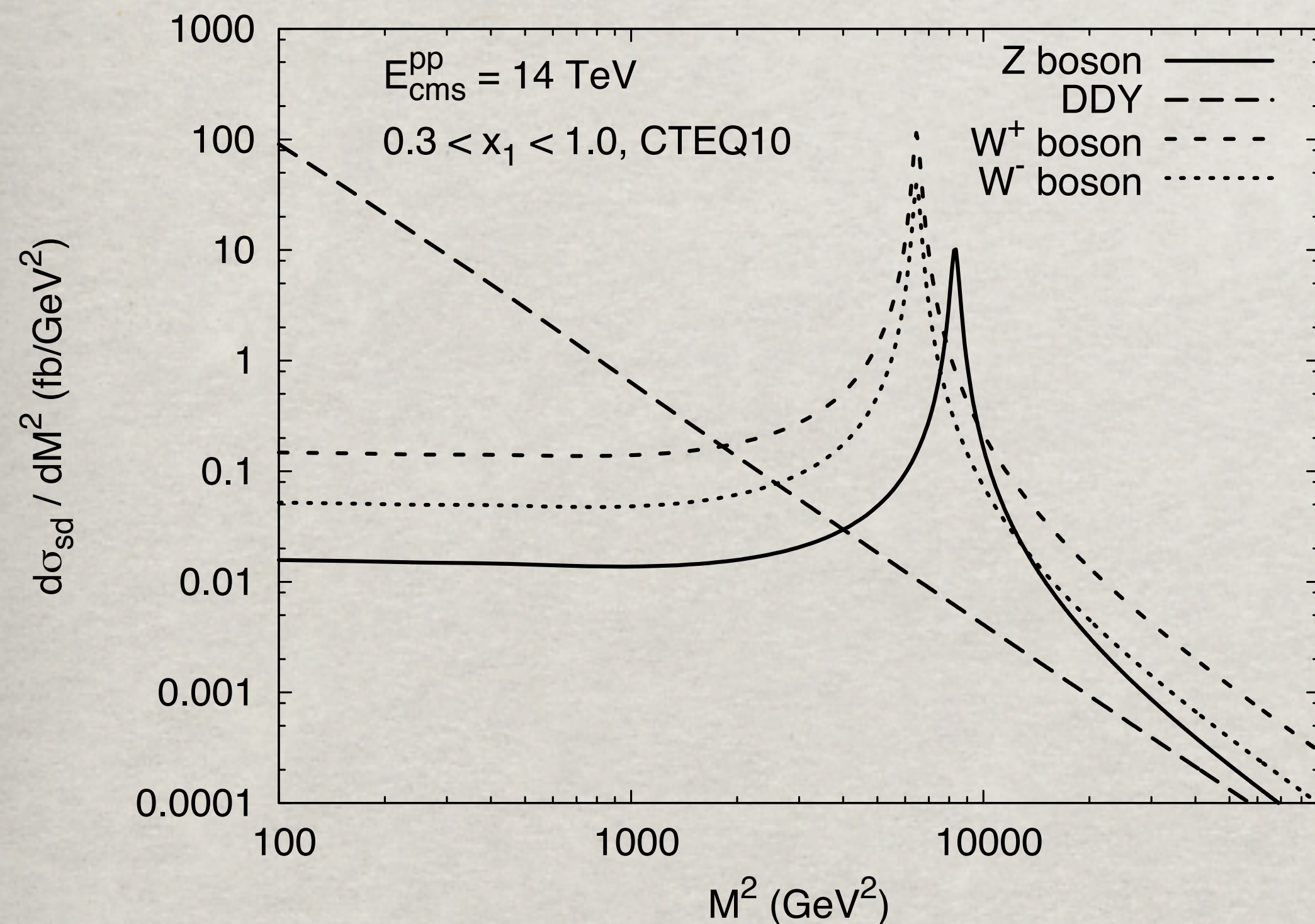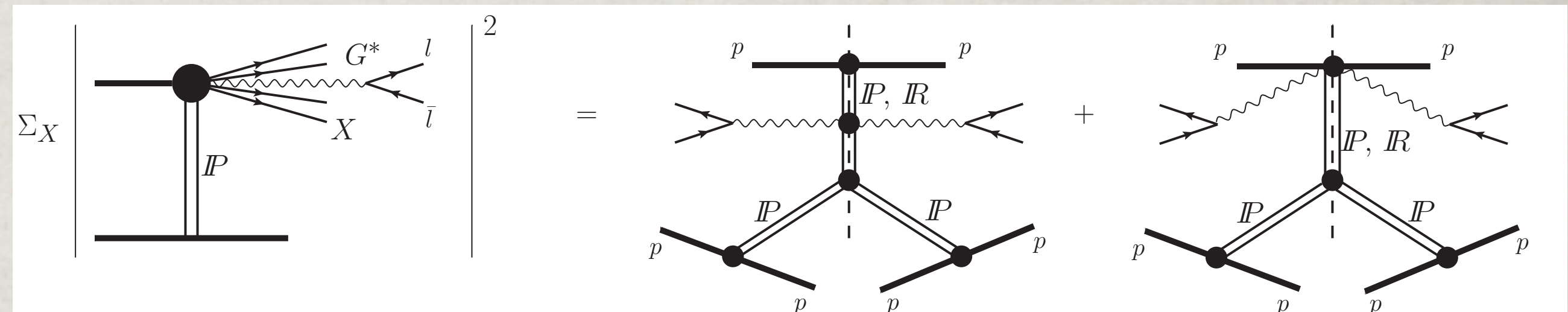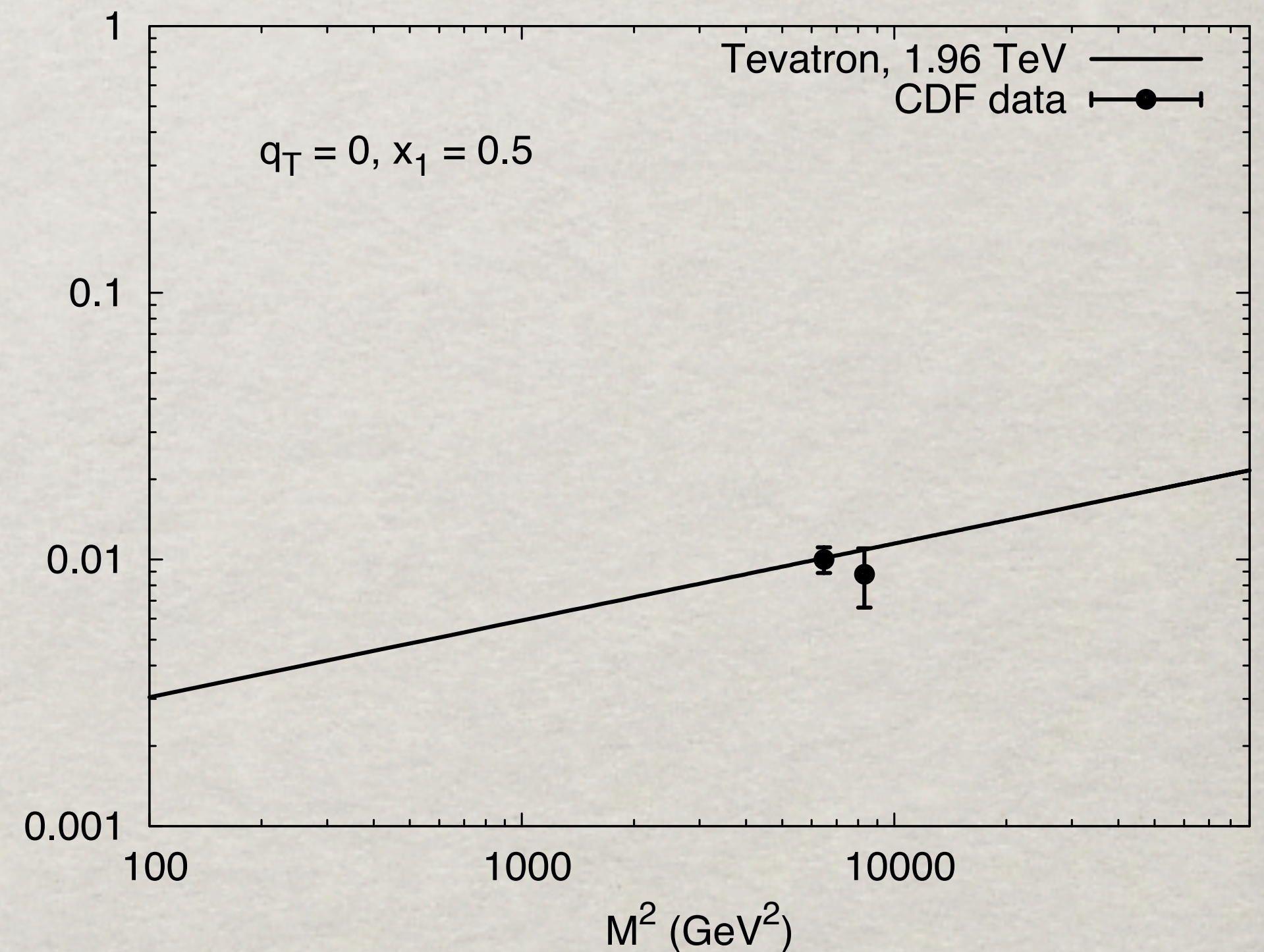
More of diffractive Z and W

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

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Diffractive 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.
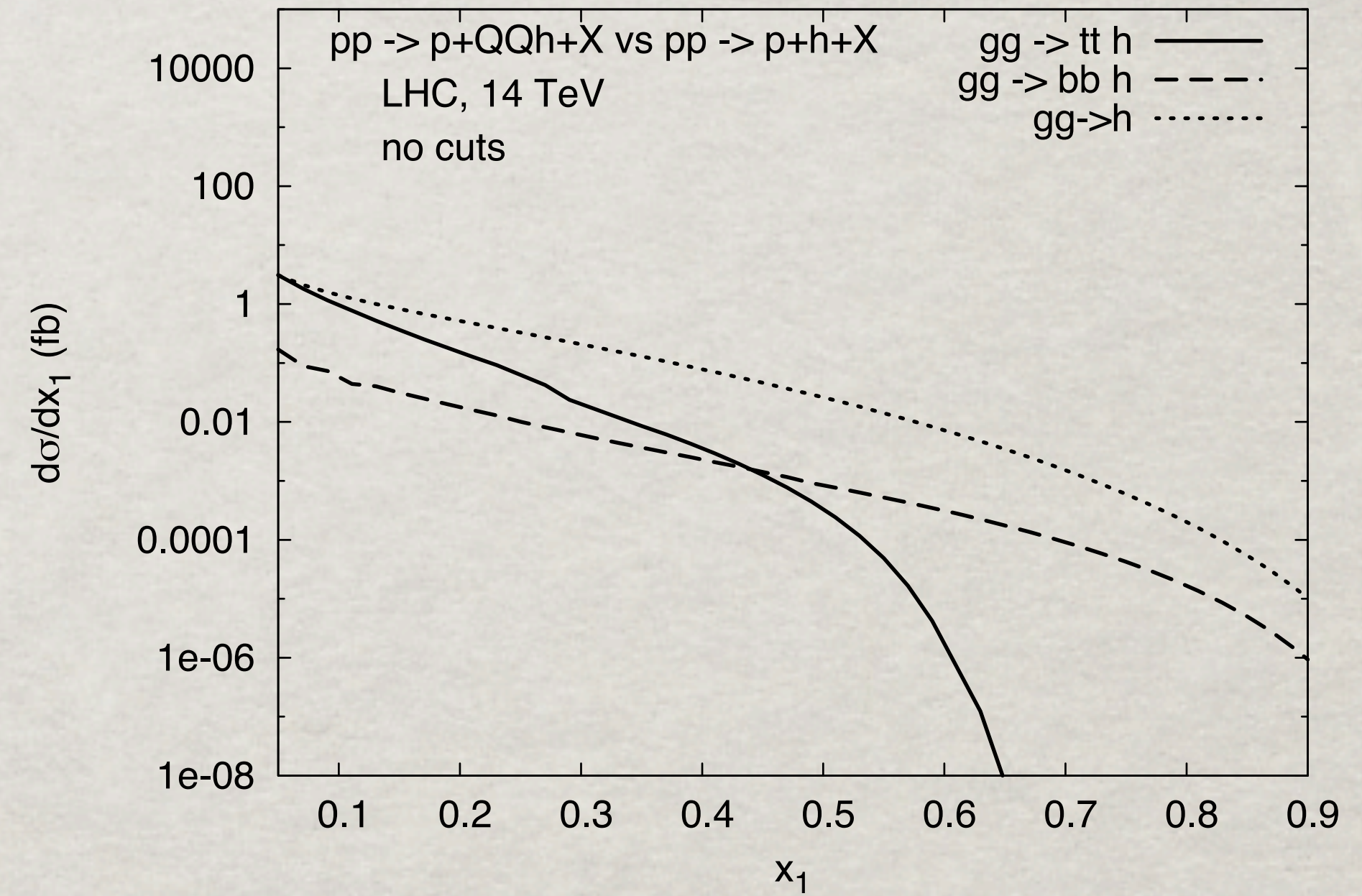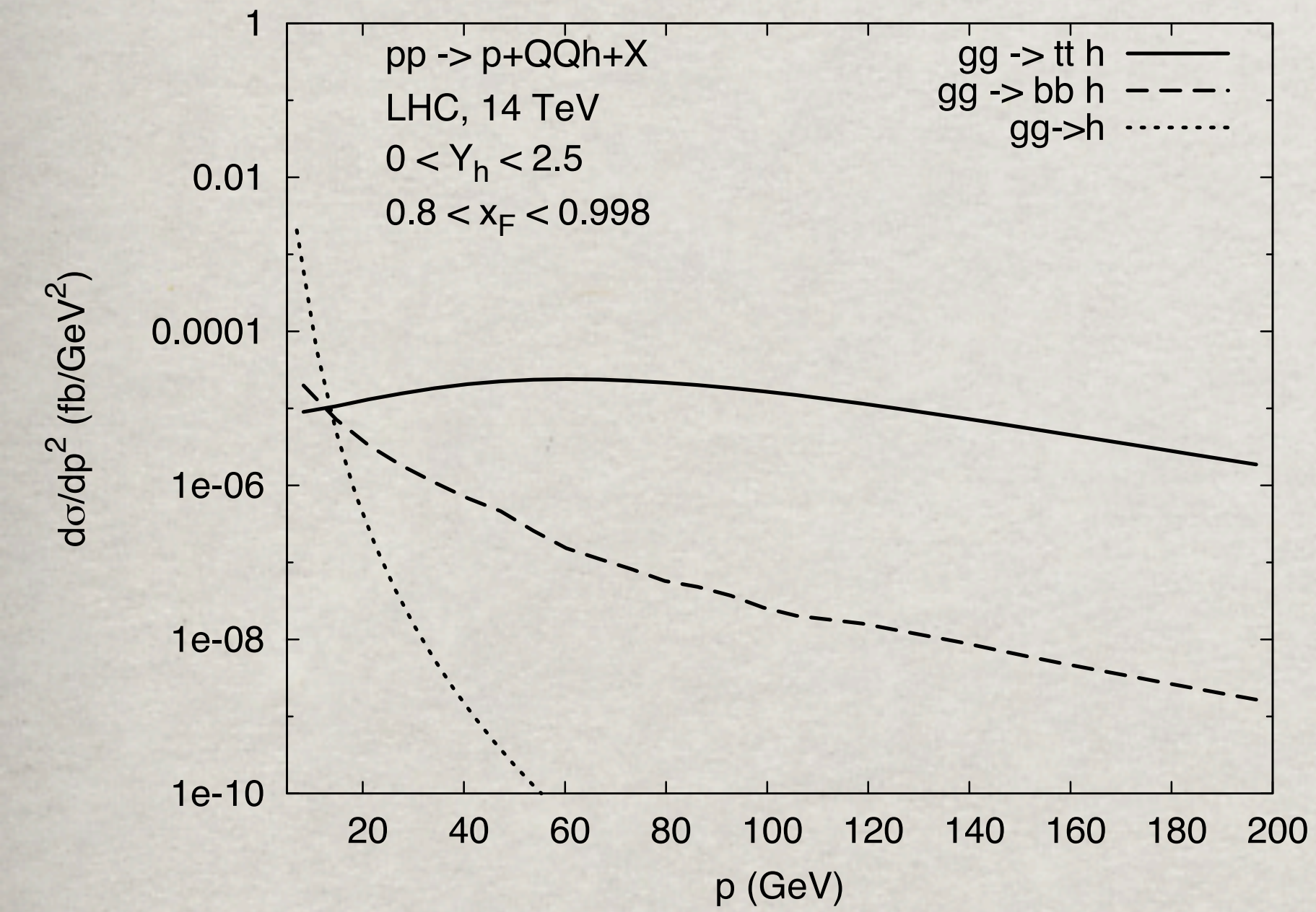**R.Pasechnik, B.K., I.Potashnikova 2014.**

The diffractive cross section is a leading twist, $1/m_Q^2$, confirmed by CDF data

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

Diffractive higgsstrahlung

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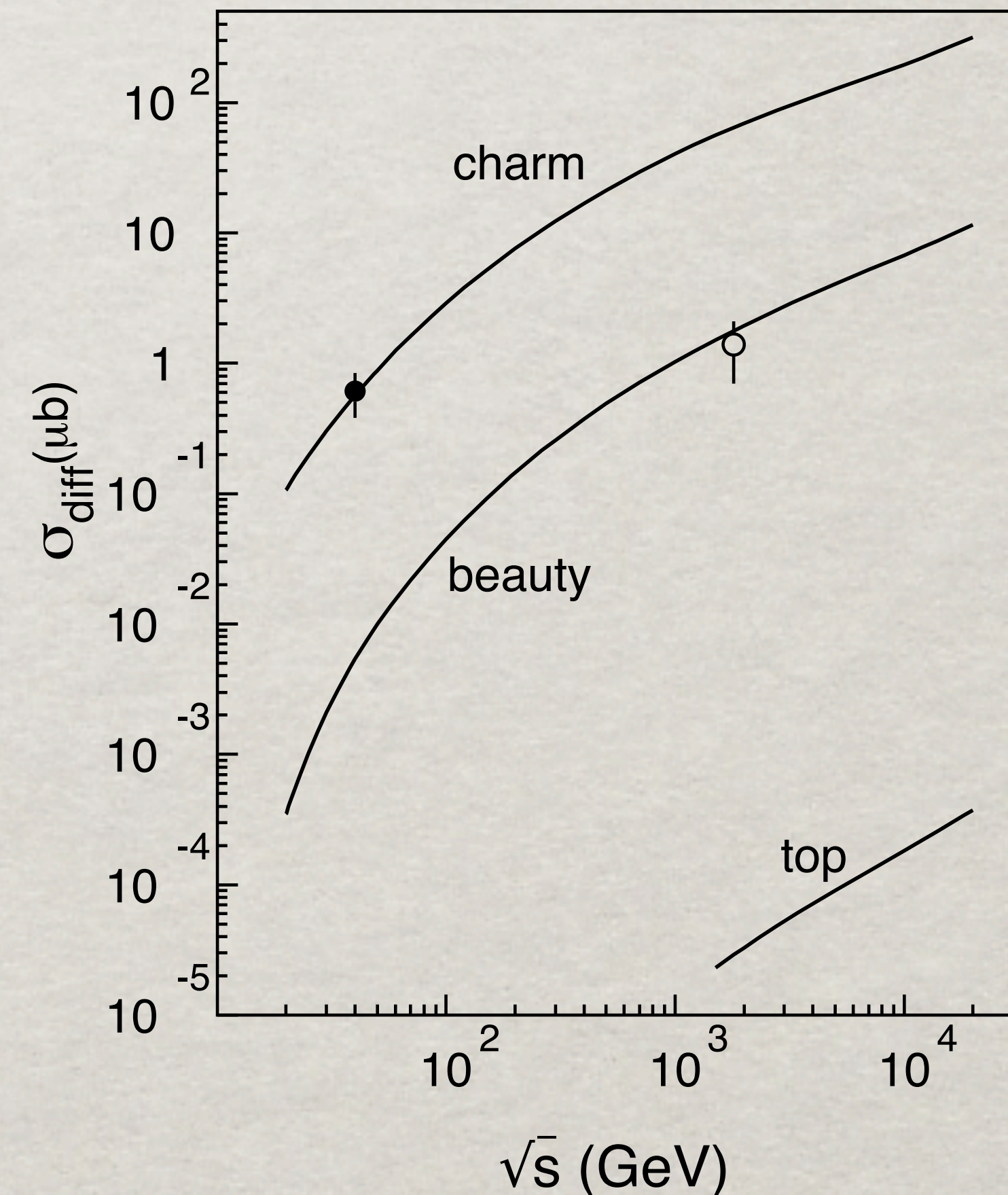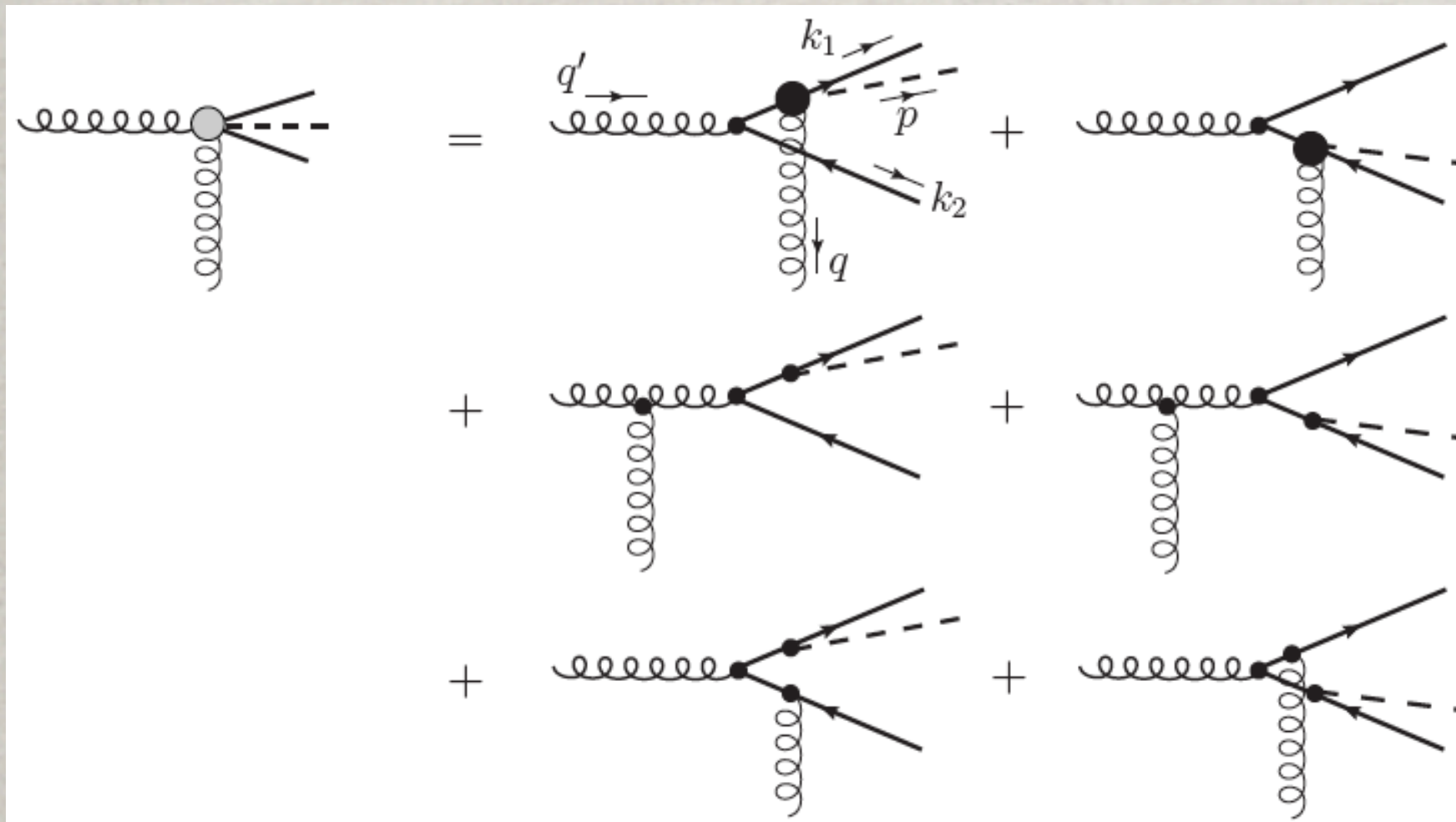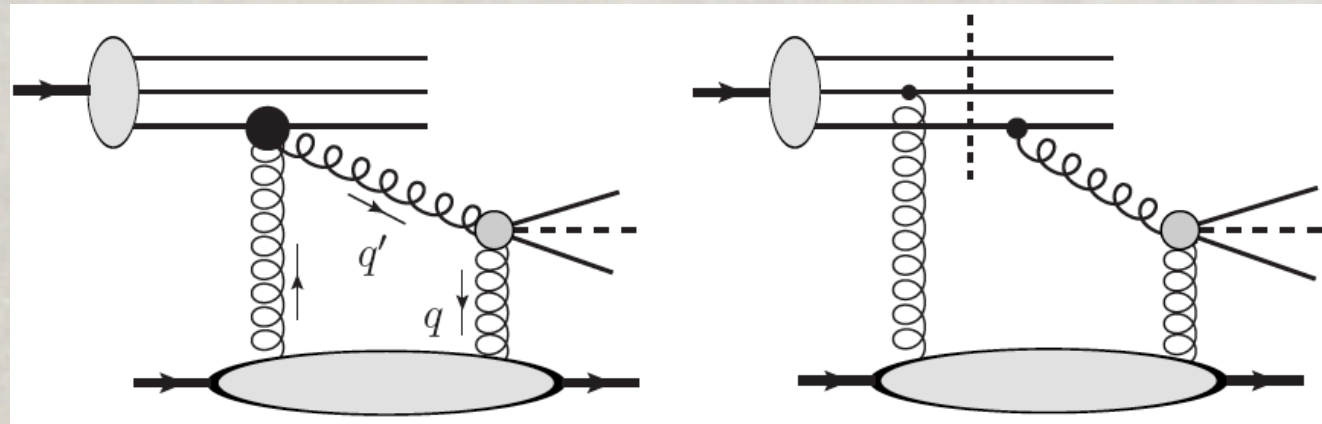
Diffractive higgs from heavy flavored sea

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 admixture of heavy flavors in light hadrons. Exclusive Higgs production, pp→ Hpp, via coalescence of heavy quarks,

$$Q\bar{Q} \rightarrow H$$

[S.Brodsky, B.K., I.Schmidt, J.Soffer 2006;
S.Brodsky, A.Goldhaber, B.K., I.Schmidt 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,
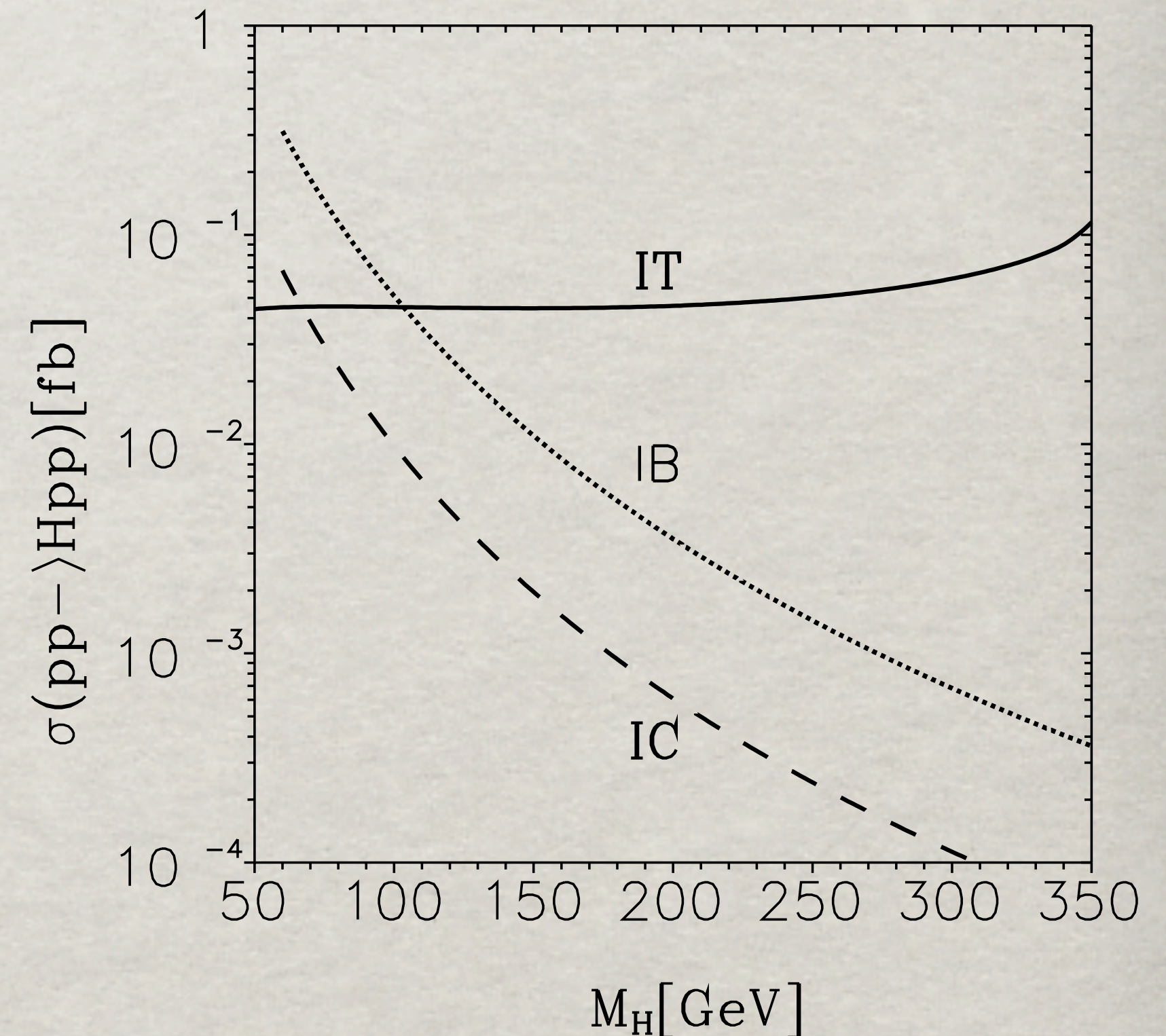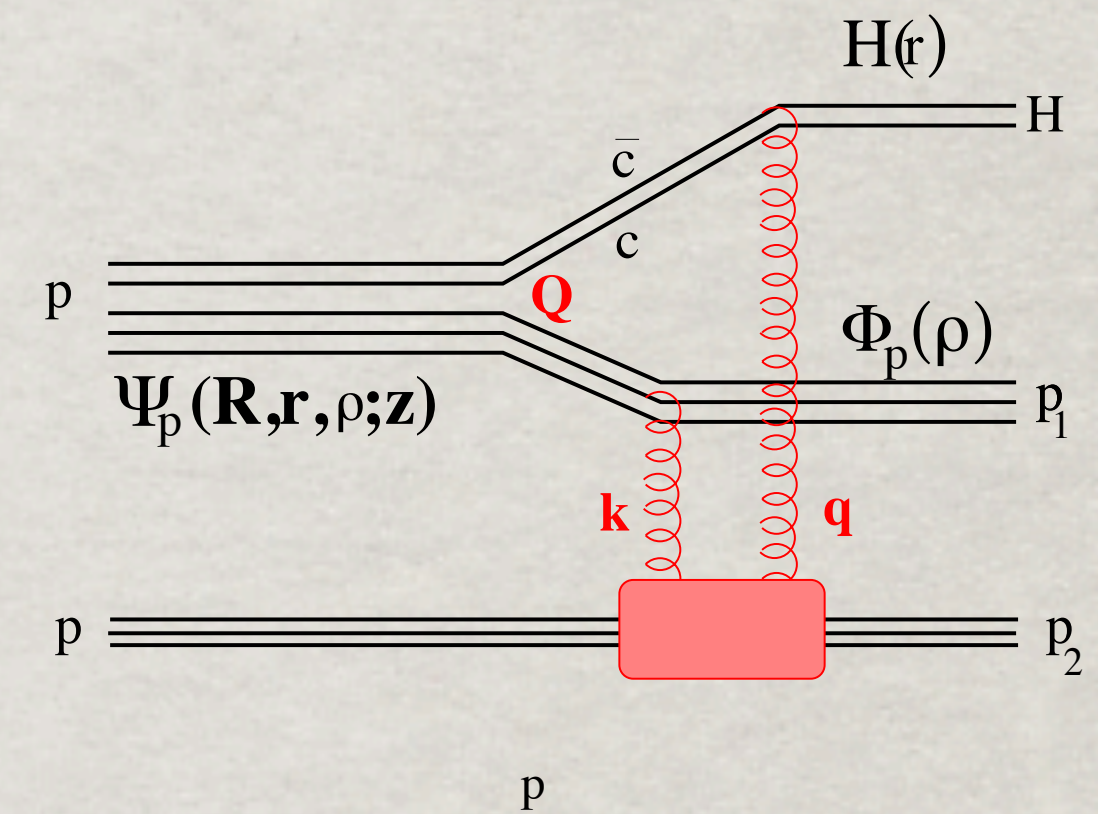
Forward diffractive radiation of direct photons, Drell-Yan dileptons, and gauge bosons Z, W, by a parton is forbidden. A hadron can diffractively radiate in the forward direction due to possibility of soft interaction with the spectators. This breaks down diffractive factorization resulting in a leading twist dependence on the boson mass, $1/M^2$

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 $1/m_Q^2$ 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

Ingelman-Schlein picture of diffraction

DIS on a proton (inclusive γ* + p → X) probes the proton PDF

Therefore, it looks natural that DIS on the Pomeron (diffraction γ* + p → X + p) probes the PDF of the Pomeron. Once the parton densities in the Pomeron are known, one can predict the cross section of any hard diffractive hadronic reaction. E.g. **A.Donnachie & P.Landshoff,**

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

This simple picture fails due to the compositeness of the Pomeron [**J.Collins, L.Frankfurt & M.Strikman 1993; G.Alves, E.Levin, A.Santoro 1997**]. The usual assumption that only one parton participates in the hard interaction, while other partons in the hadron are spectators, apparently is not correct for the Pomeron, which can interact as a whole.
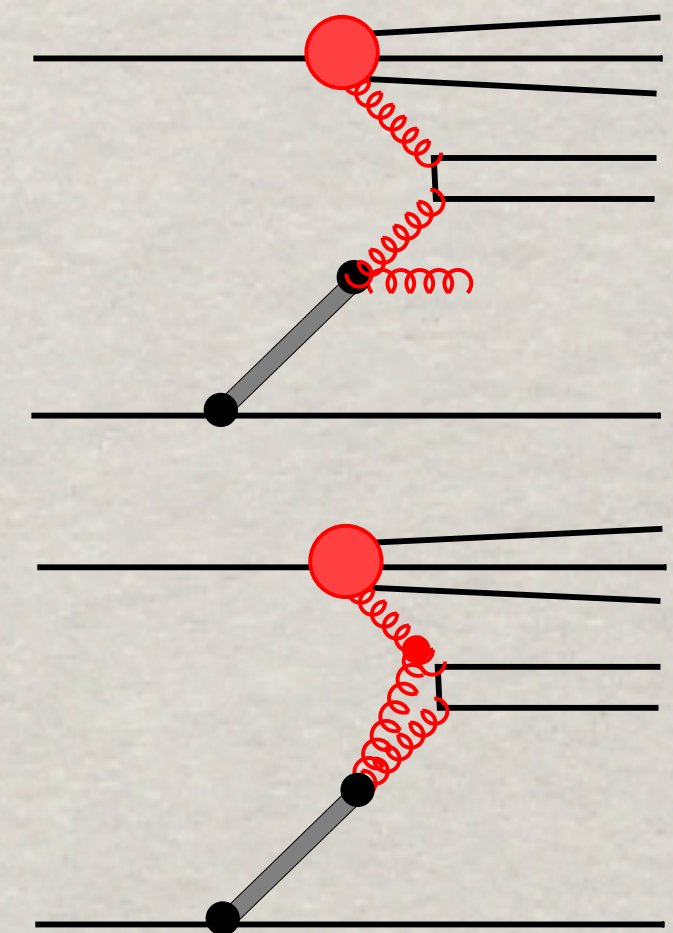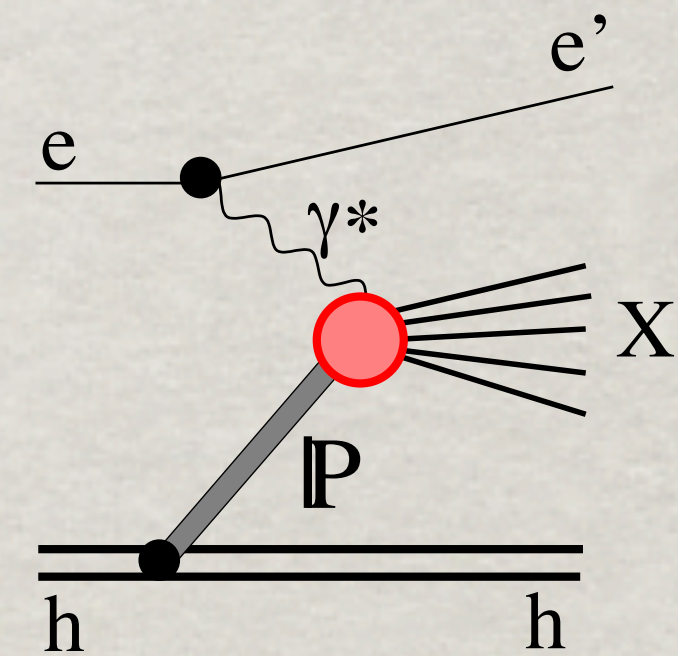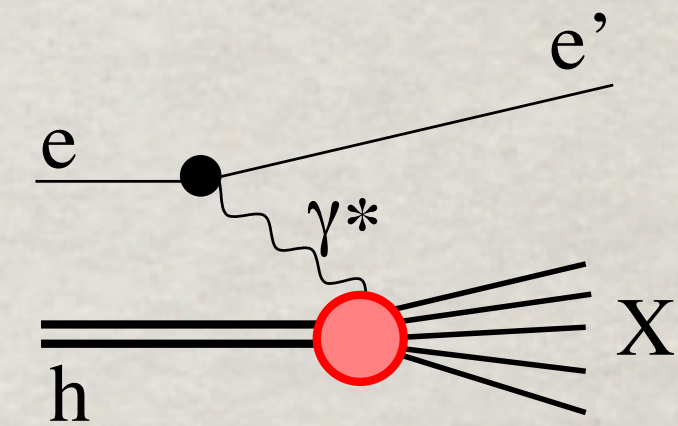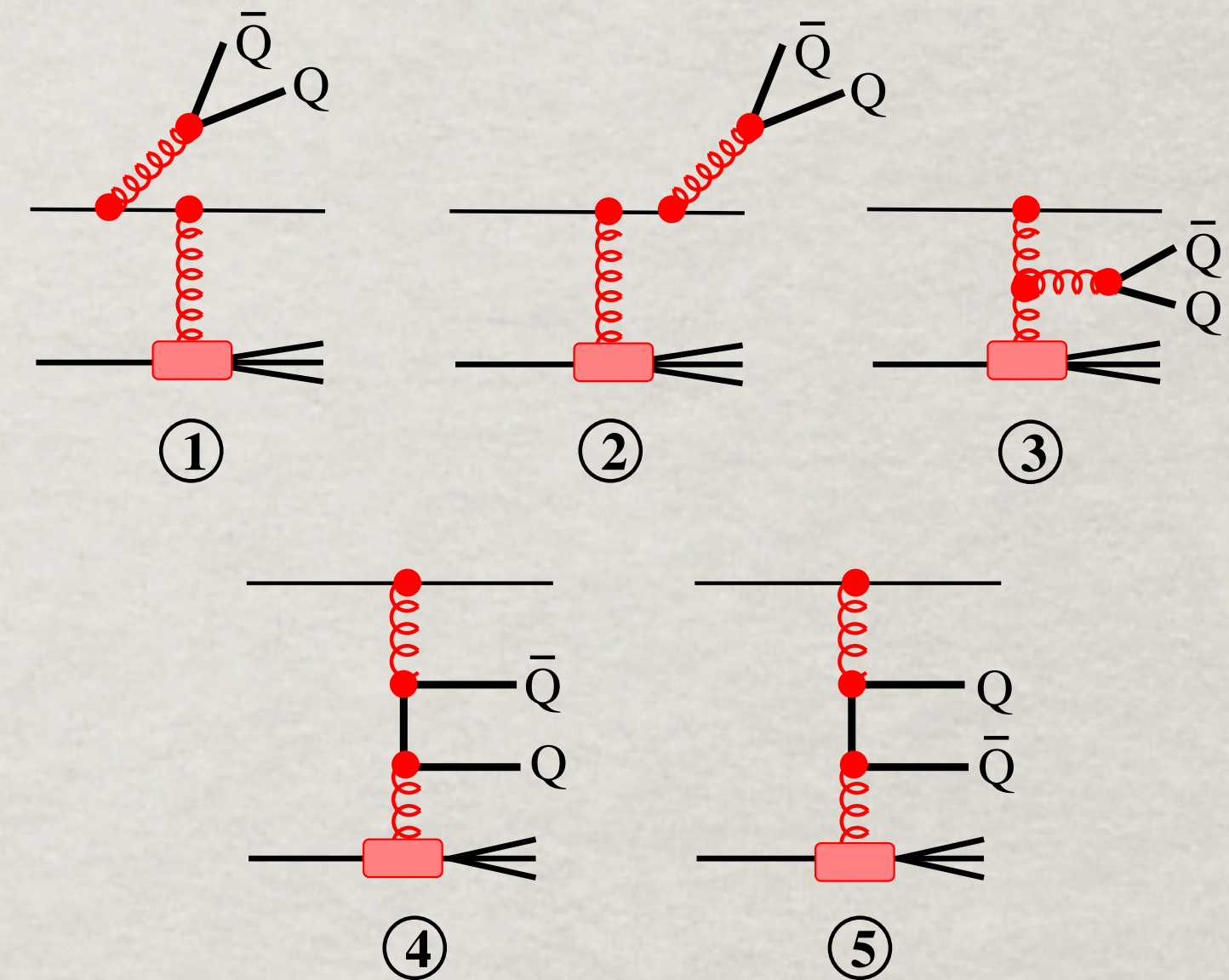
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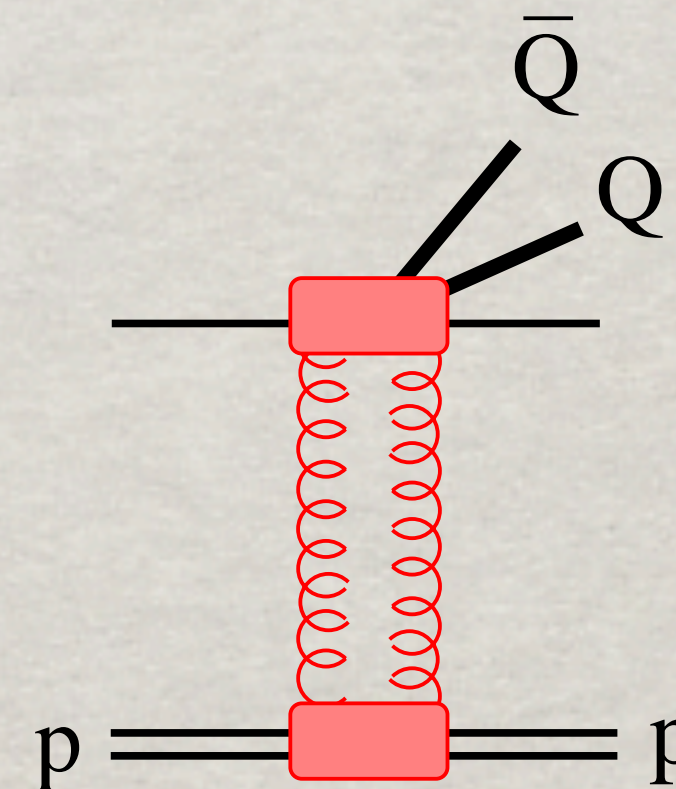**B.K., I.Potashnikova, I.Schmidt, A.Tarasov 2006**

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

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

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

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**Higher twist Bremsstrahlung
mechanism in diffraction: radiation
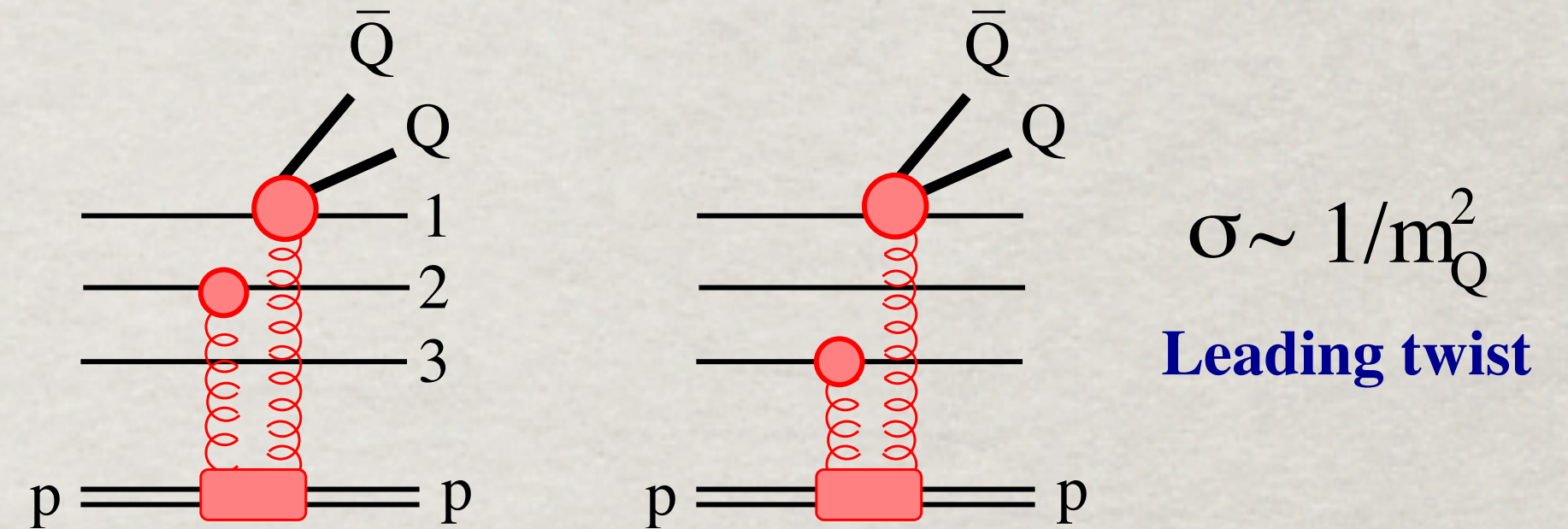of a $\bar{Q}Q$ pair by an isolated parton.**
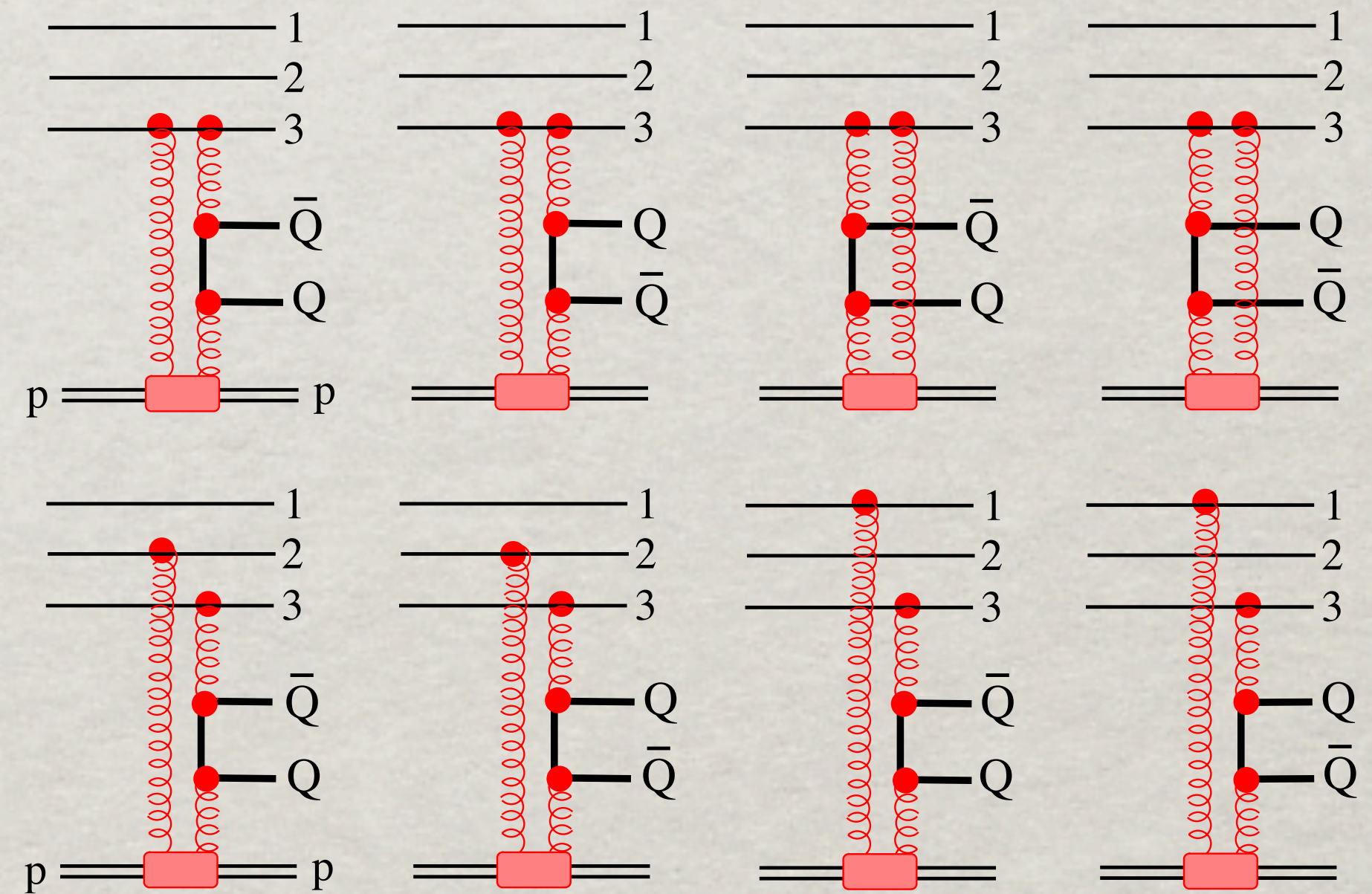
$$\sigma \sim 1/m_Q^4$$

Higher twist

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Leading twist Bremsstrahlung **mechanism:**

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

Leading twist

Production mechanism in diffraction:

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

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), 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, $R^{\bar{b}b}_{\text{diff/tot}} = (0.62 \pm 19 \pm 16)\%$, 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) $\sigma^{\bar{b}b}_{\text{tot}}$ = 200 mb, then $\sigma^{\bar{b}b}_{\text{diff}}$ ≈ 1.2 mb.

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