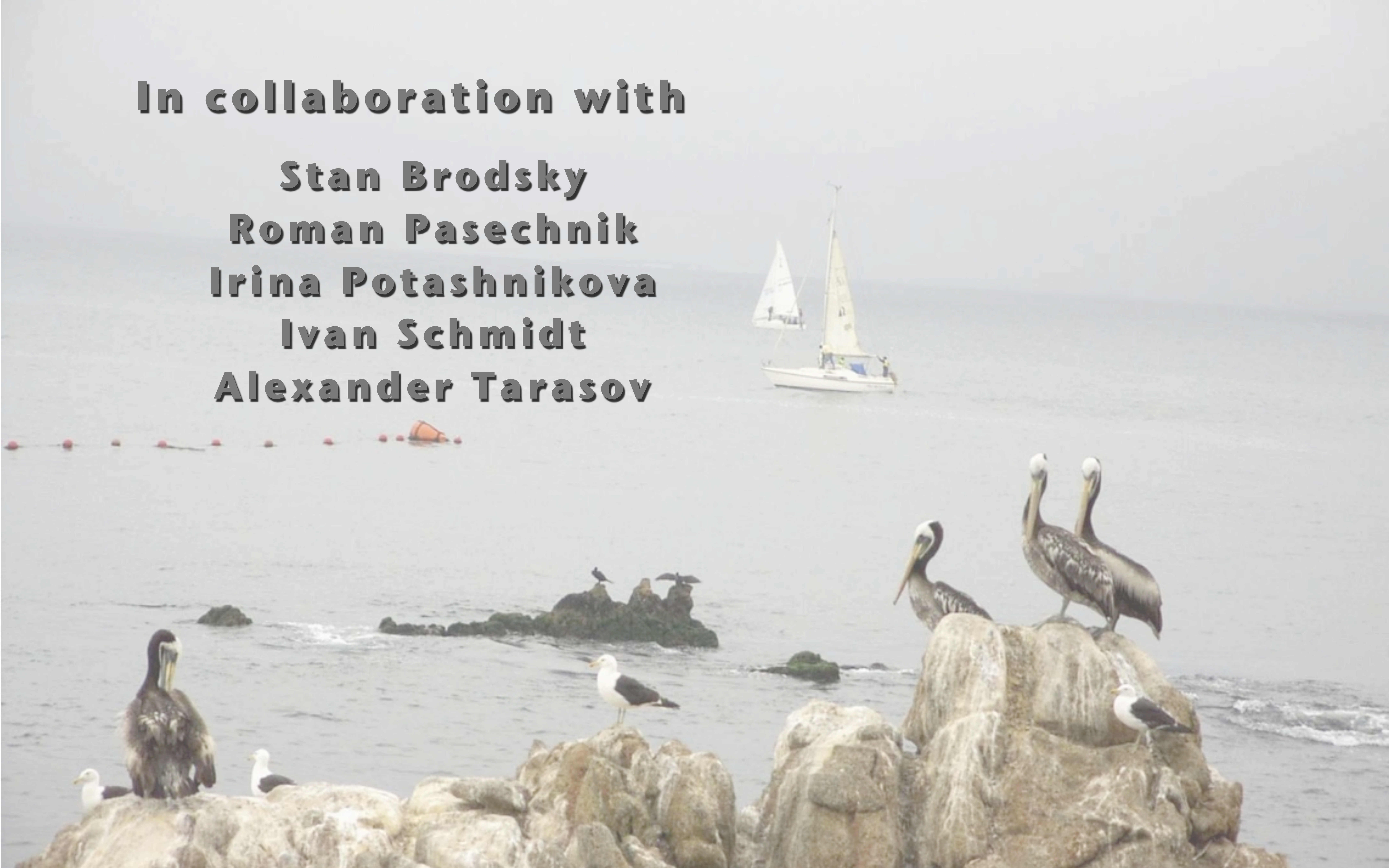
Diffractive production of gauge bosons, higgs, and heavy flavors

Boris Kopeliovich

UTFSM, Valparaiso

LISHEP 2013
Rio de Janeiro

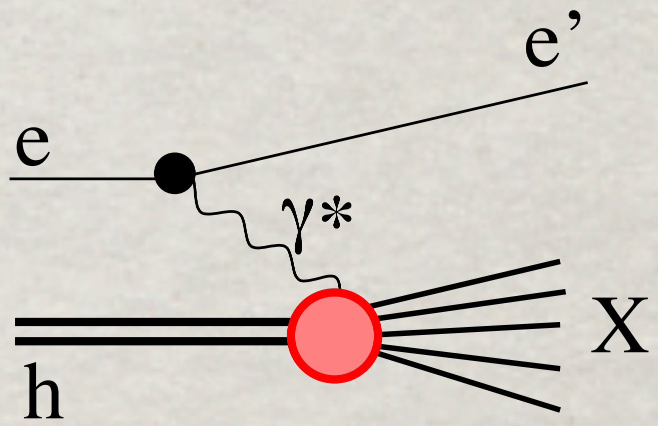


In collaboration with

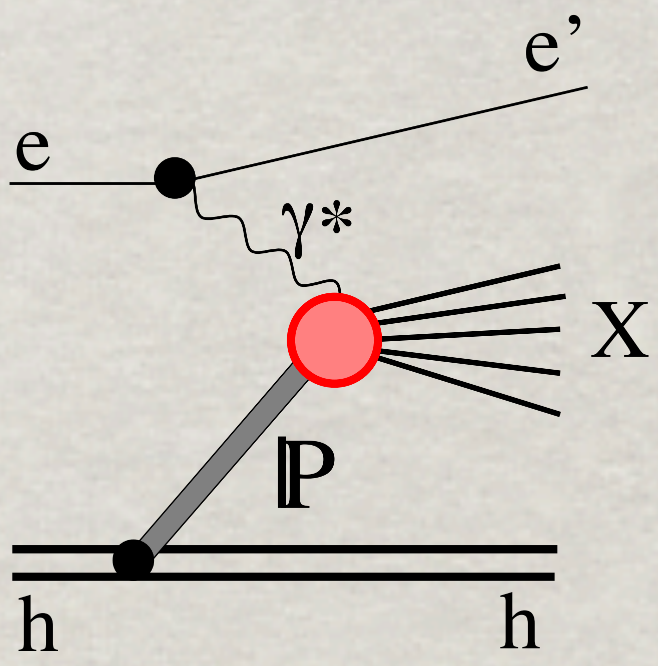
Stan Brodsky
Roman Pasechnik
Irina Potashnikova
Ivan Schmidt
Alexander Tarasov

QCD factorization in diffraction

Ingelman-Schlein picture of diffraction



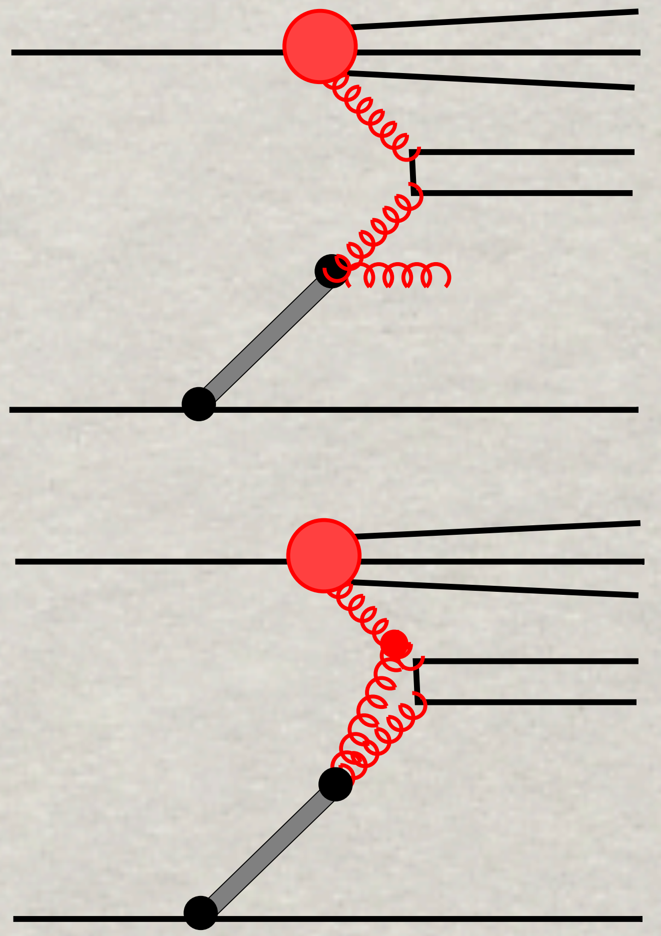
DIS on a proton (inclusive γ^* + p $\to$ X) probes the proton PDF



Therefore, it looks natural that DIS on the Pomeron (diffraction γ^* + p $\to$ 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,

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



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.

Color dipole description

Dipoles are the eigenstates of interaction at high energies [B.K., L.Lapidus & A.Zamolodchikov 1981].

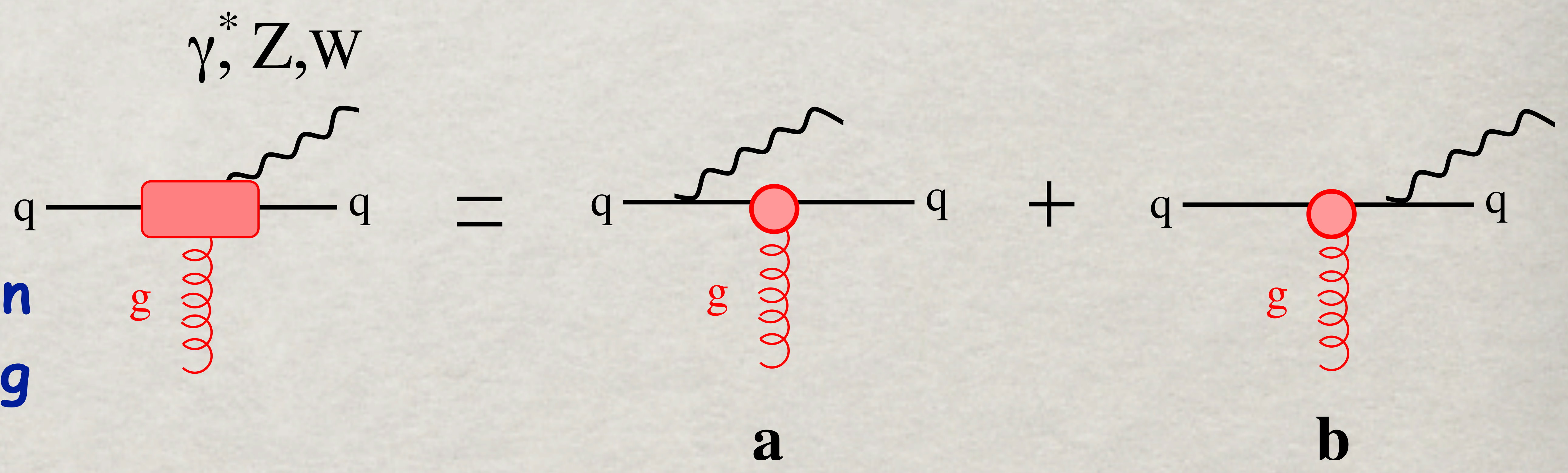
The total and single diffractive cross sections read

$$\sigma^{hp}_{tot} = \sum_{\alpha=1} |C^h_\alpha|^2 \, \sigma_\alpha = \int d^2 r_T \, |\Psi_h(r_T)|^2 \, \sigma(r_T)$$

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

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.



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

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

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

Diffractive Drell-Yan

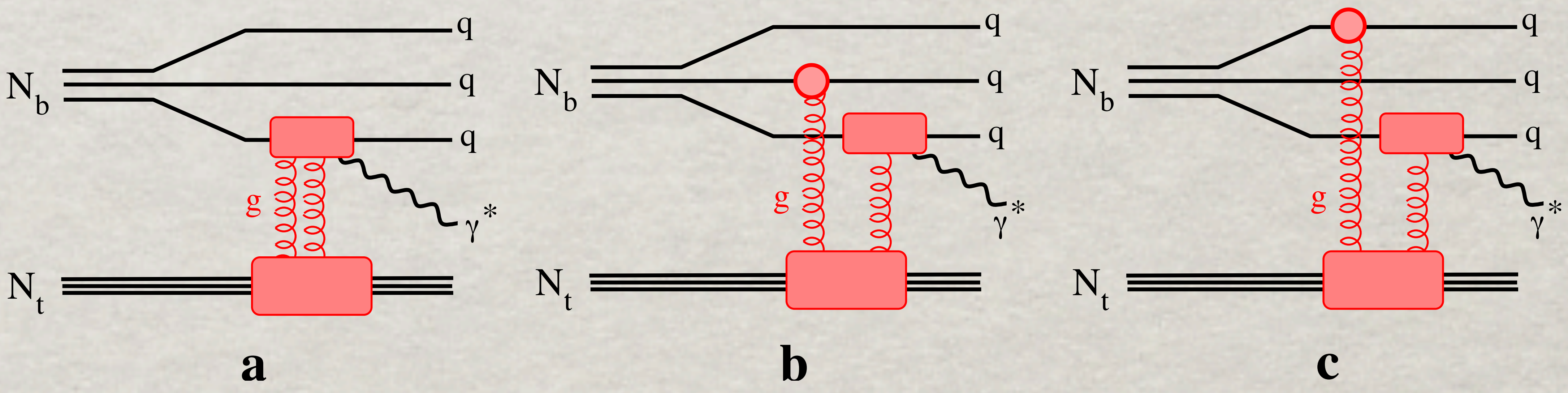
Diffractive radiation of a heavy photon (any gauge boson) by a quark vanishes in the forward direction [B.K., A.Schaefer, A.Tarasov 1998]

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

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, W, Z bosons, Higgs, etc.

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



The two Fock components of the proton, $|3q\rangle$ and $|3q\,\gamma^*\rangle$, have different sizes since the position in impact parameters of the recoil quark is shifted. So the two dipoles interact differently giving rise to diffraction.

Diffractive Drell-Yan

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

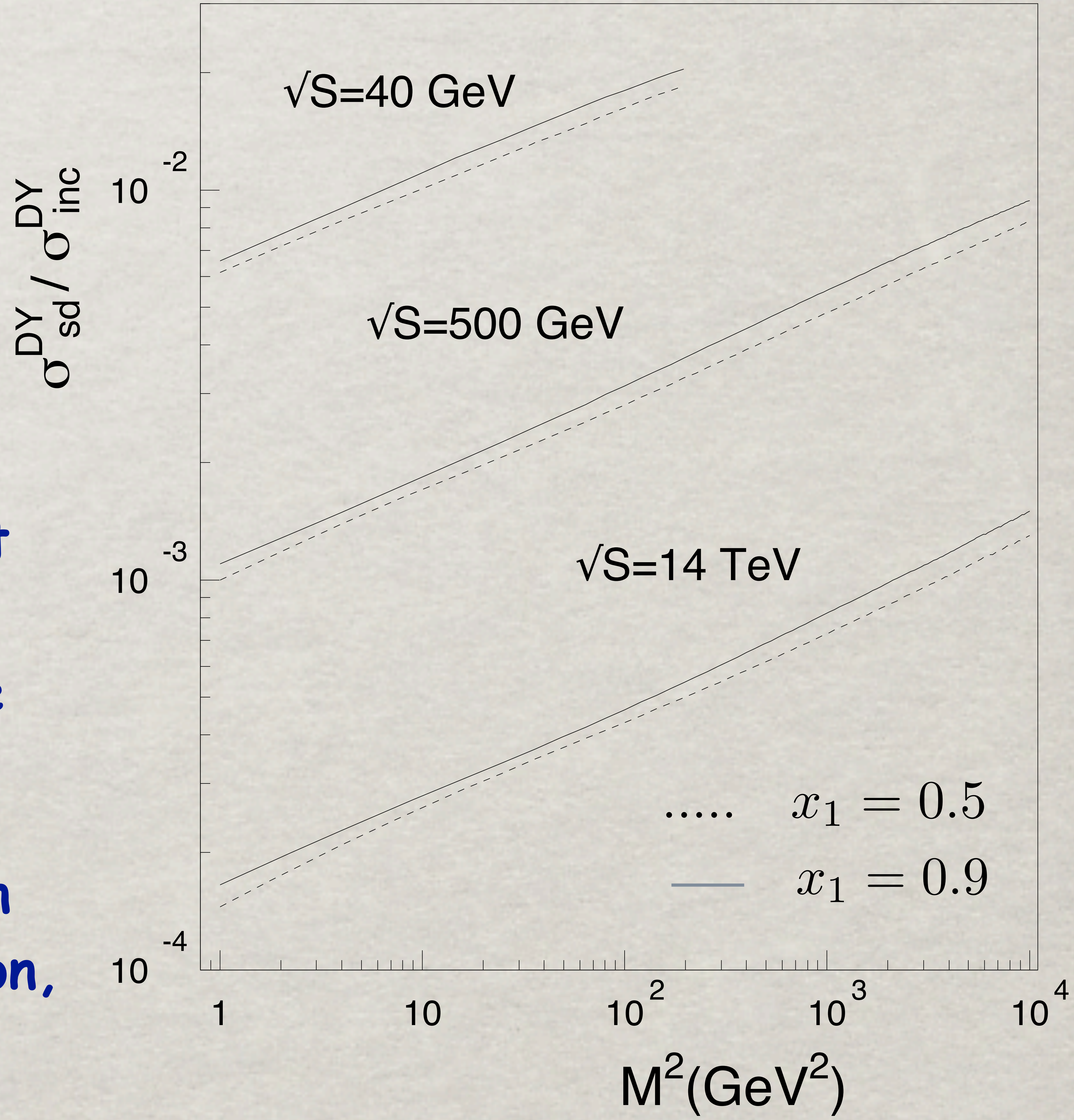
B.K., I.Potashnikova, I.Schmidt, A.Tarasov 2006;
R.Pasechnik, B.K. 2011.

The DY diffractive amplitude reads,

$$\sigma(\underset{\substack{\uparrow\\ \text{hadronic scale}}}{\mathbf{R}}) - \sigma(\mathbf{R} - \alpha\underset{\substack{\uparrow\\ \text{recoil shift}}}{\mathbf{r}}) \;\propto\; \underbrace{\mathbf{r}\cdot\mathbf{R}}_{\text{hard-soft}}$$

Thus, 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 hard/soft, as the inclusive DIS cross section is.

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



Absorptive corrections

Absorptive (unitarity) corrections substantially (by an order of magnitude) reduce diffraction and break down diffractive factorization. They may completely terminate a large rapidity gap process in the limit of unitarity saturation.

$$\mathbf{A_{if}(b) \Rightarrow A_{if}(b)\, S(b) = A_{if}(b)\left[1 - Im f_{el}^{pp}(b)\right]}$$

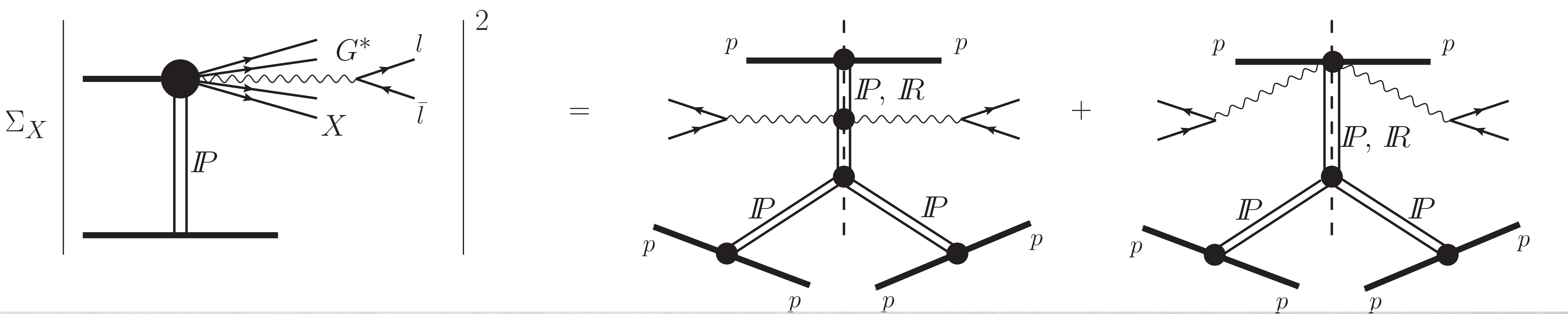
The survival probability factor

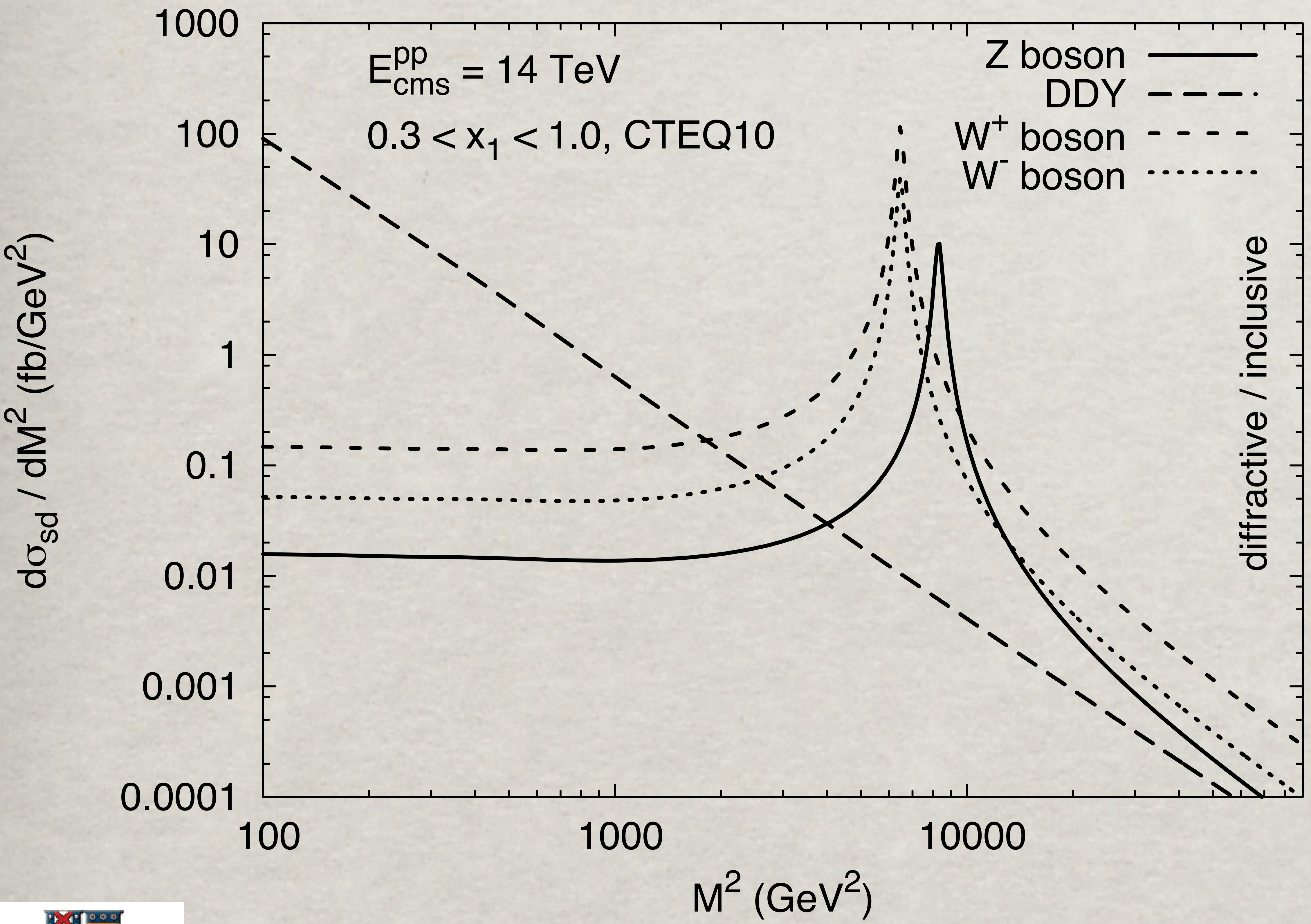
$$\mathbf{S^2 \approx \left\{1 - \frac{1}{\pi}\,\frac{\sigma_{tot}^{pp}(s)}{B_{sd}(s) + 2B_{el}^{pp}(s)} + \frac{1}{(4\pi)^2}\,\frac{\left[\sigma_{tot}^{pp}(s)\right]^2}{B_{el}^{pp}(s)\left[B_{sd}(s) + B_{el}^{pp}(s)\right]}\right\}}$$

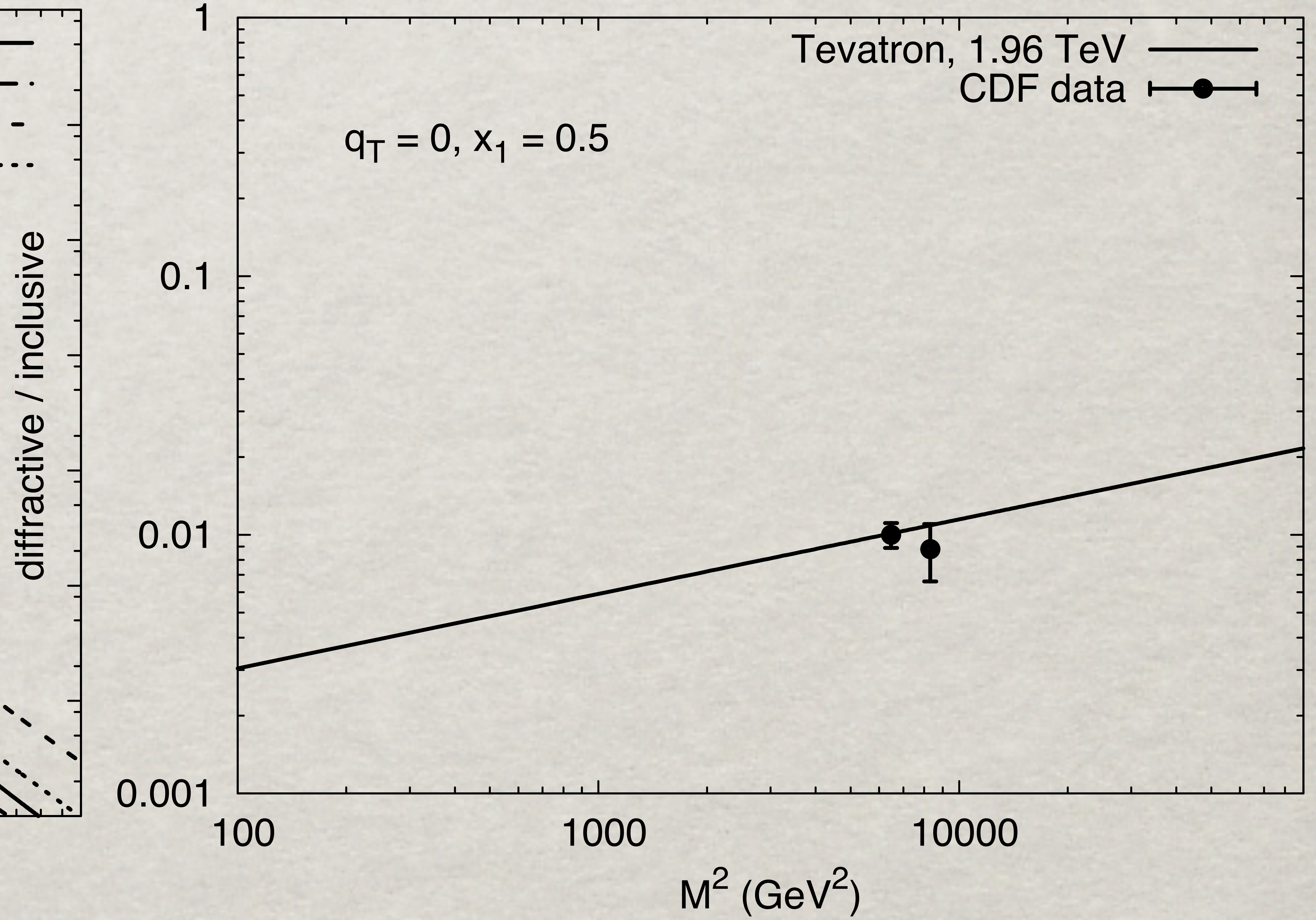
Diffractive Z and W production

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

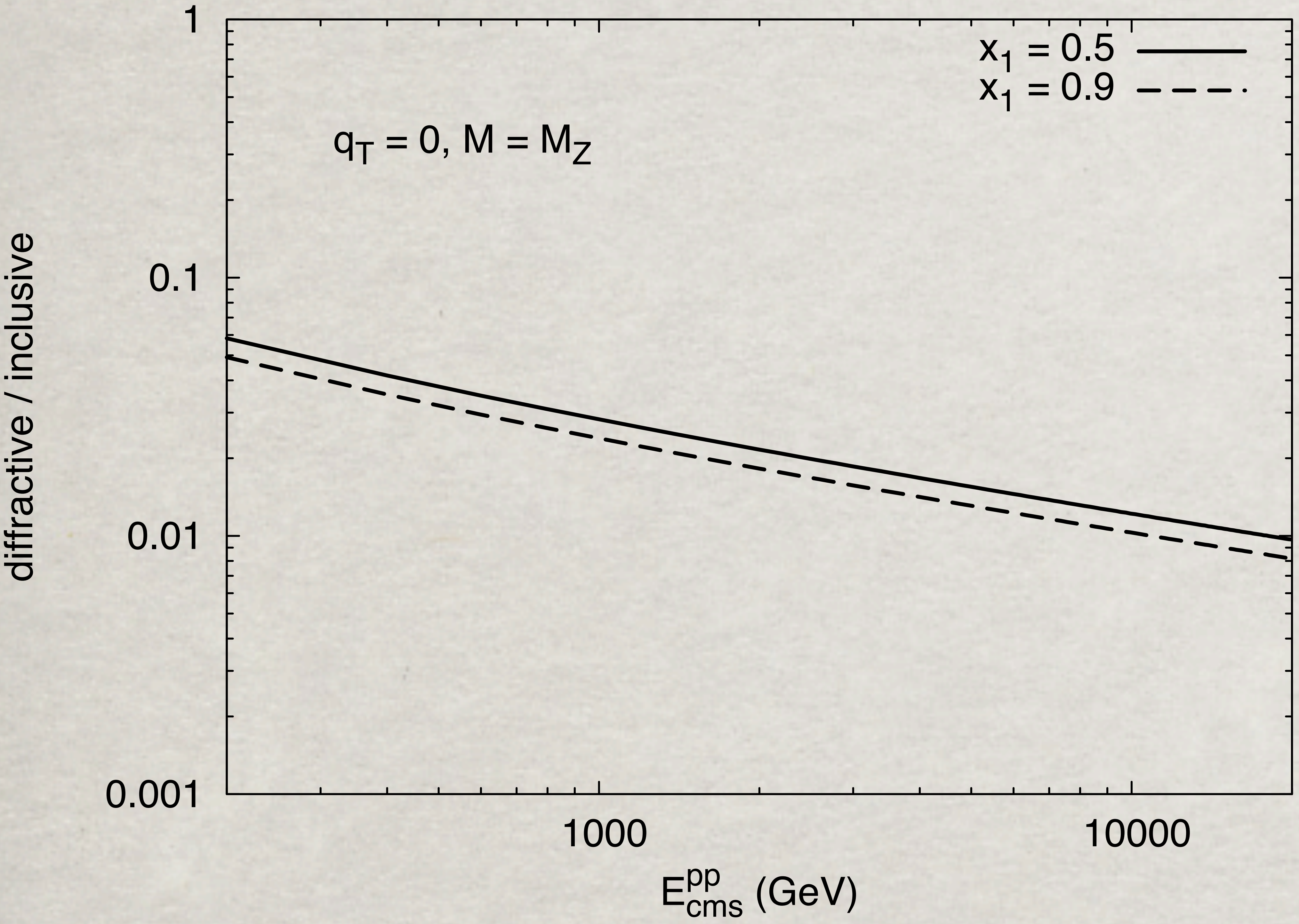
R.Pasechnik, B.K., I.Potashnikova 2012.

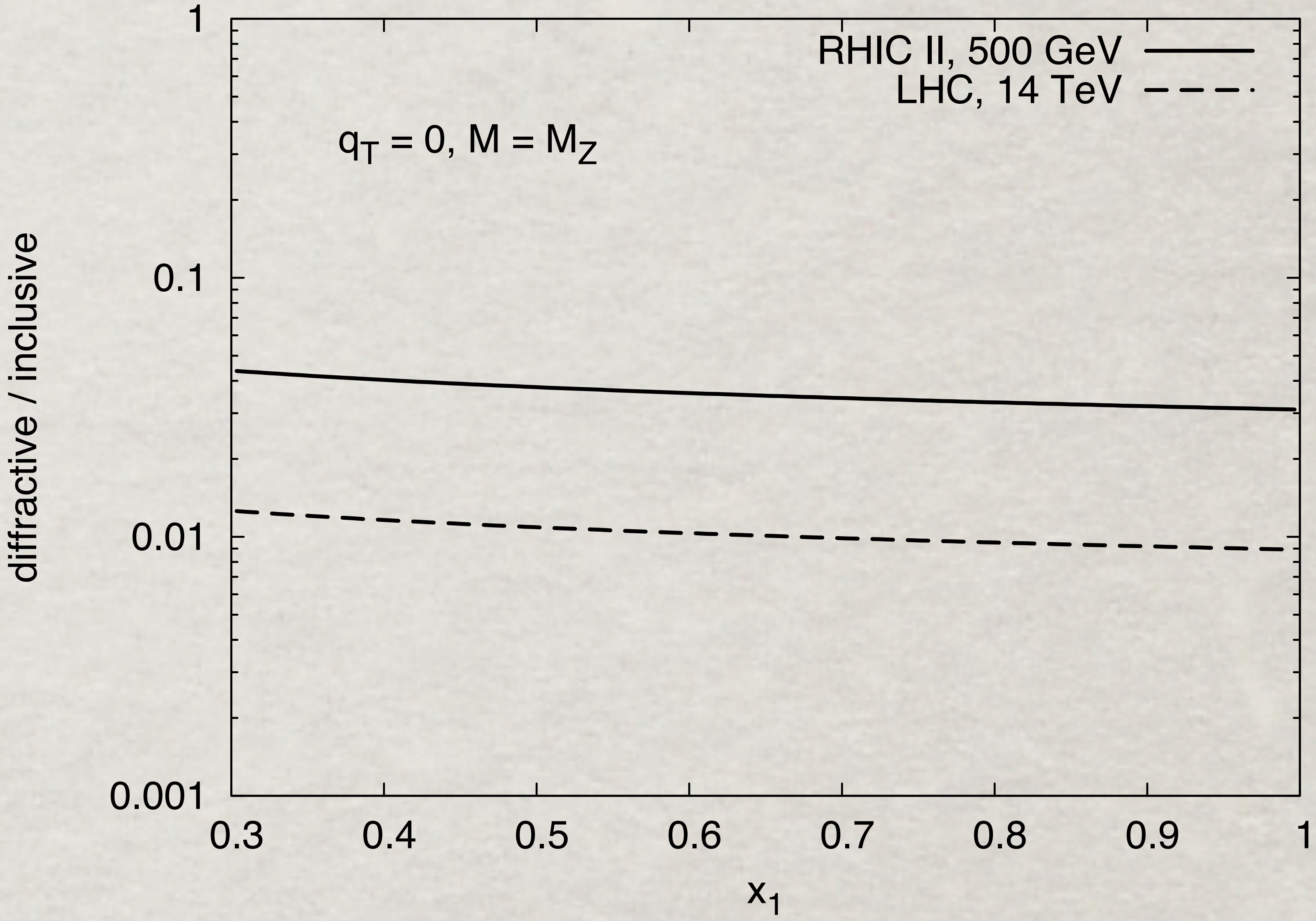




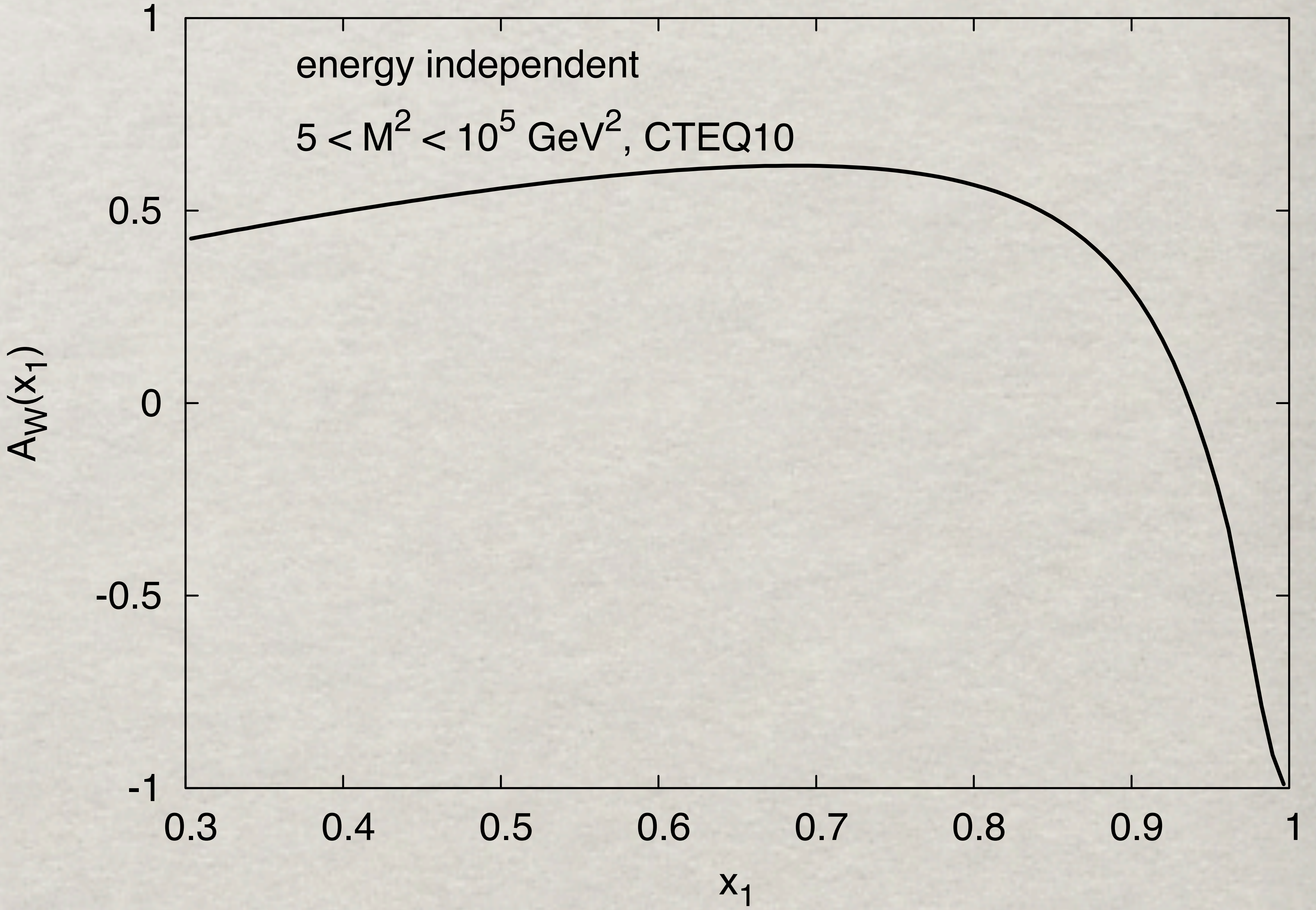


More of diffractive Z and W





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



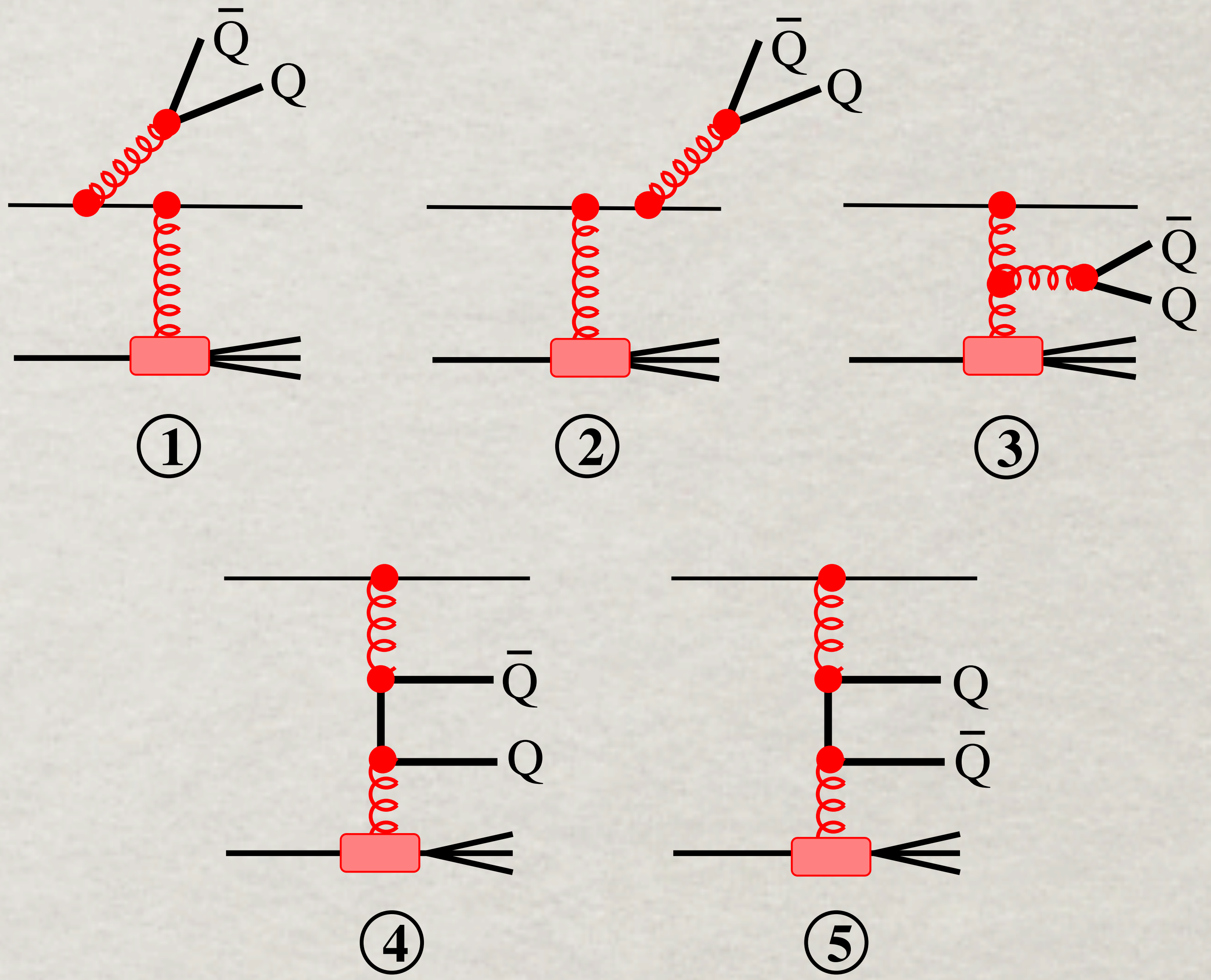
Diffractive production of heavy flavors

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

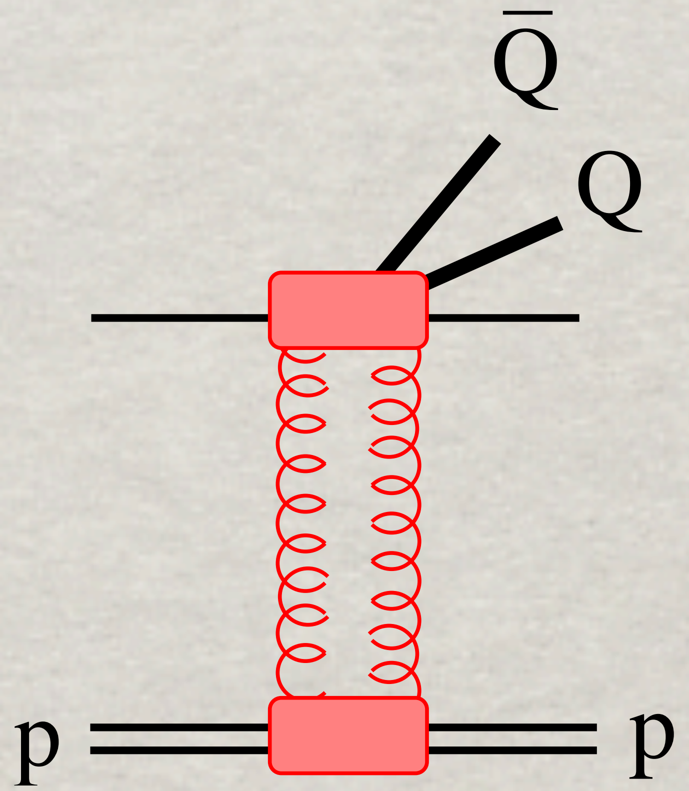
Bremsstrahlung and **Production** mechanisms in inclusive production of heavy flavors by a projectile parton (quark or gluon)

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

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



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

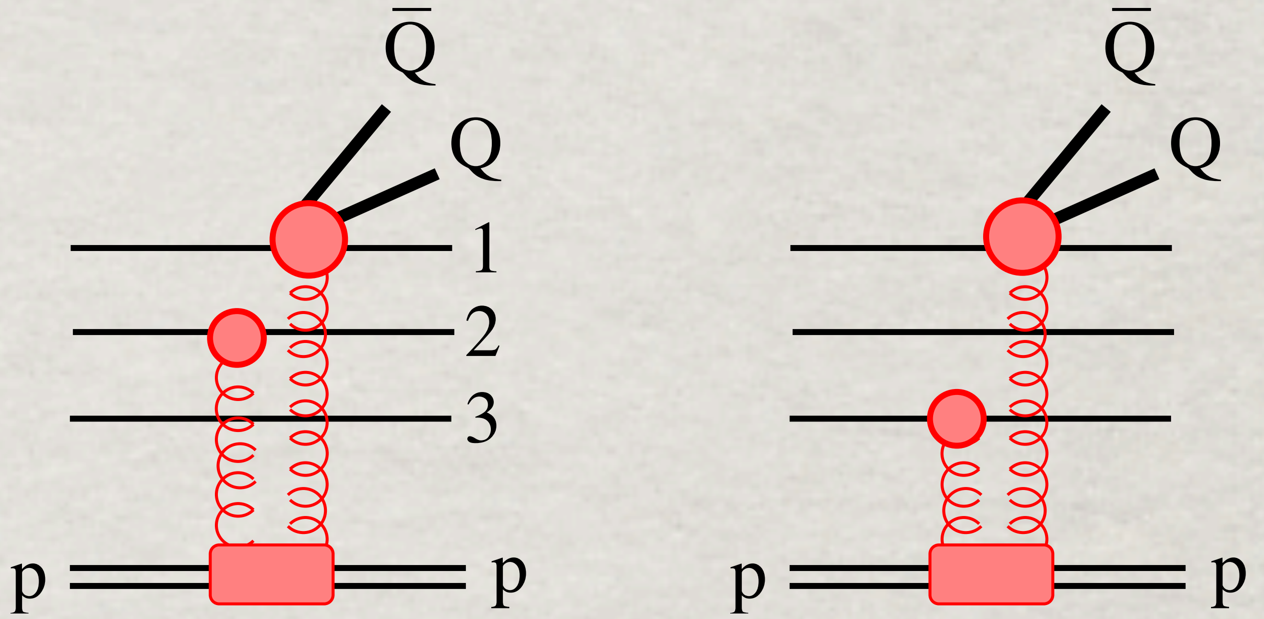


$\sigma \sim 1/m_Q^4$

Higher twist

Diffractive production of heavy flavors

Leading twist **Bremsstrahlung** mechanism:



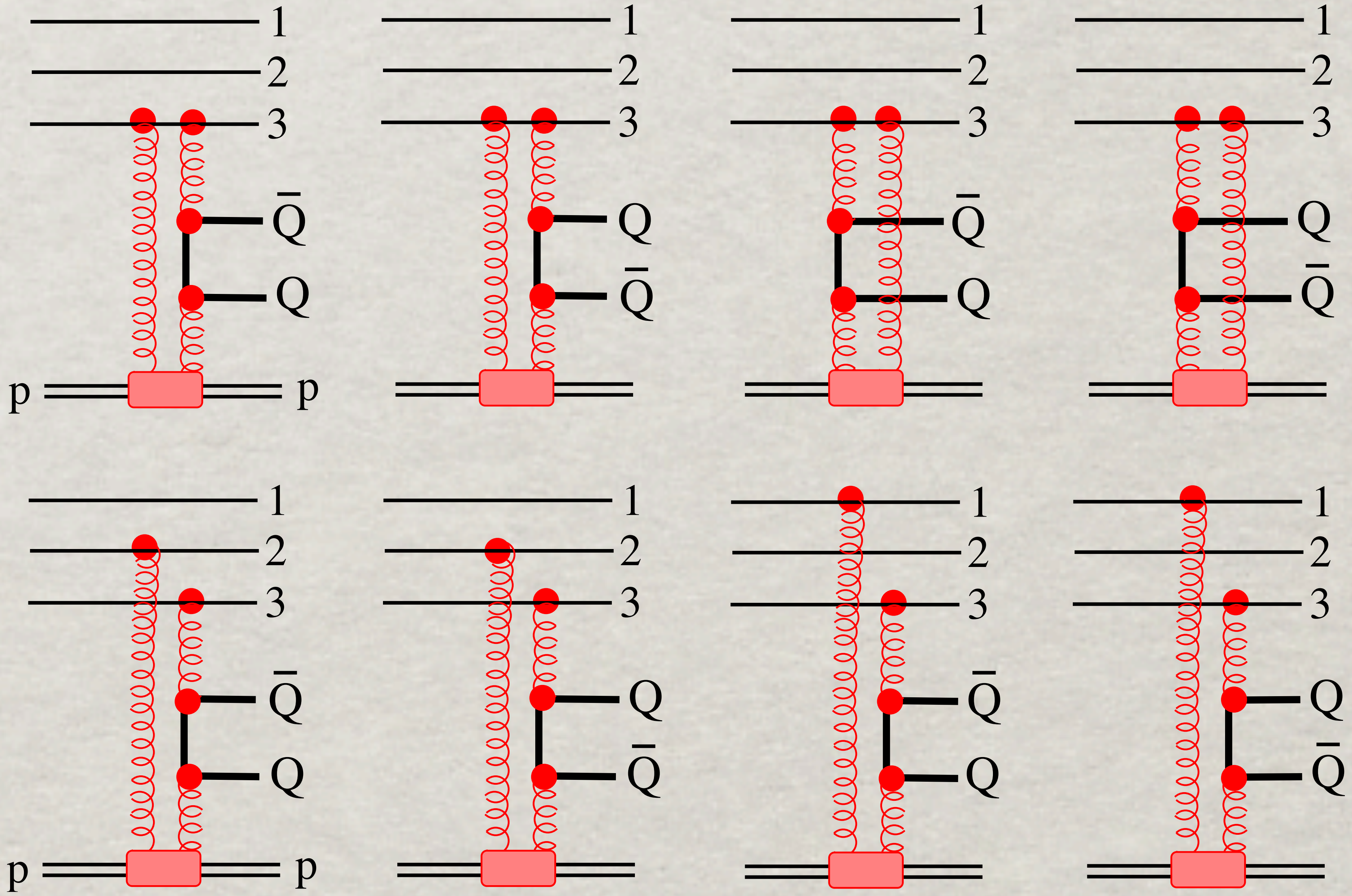
$\sigma \sim 1/m_Q^2$

Leading twist

Production mechanism in diffraction:

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

Leading twist



Diffractive heavy flavors: data

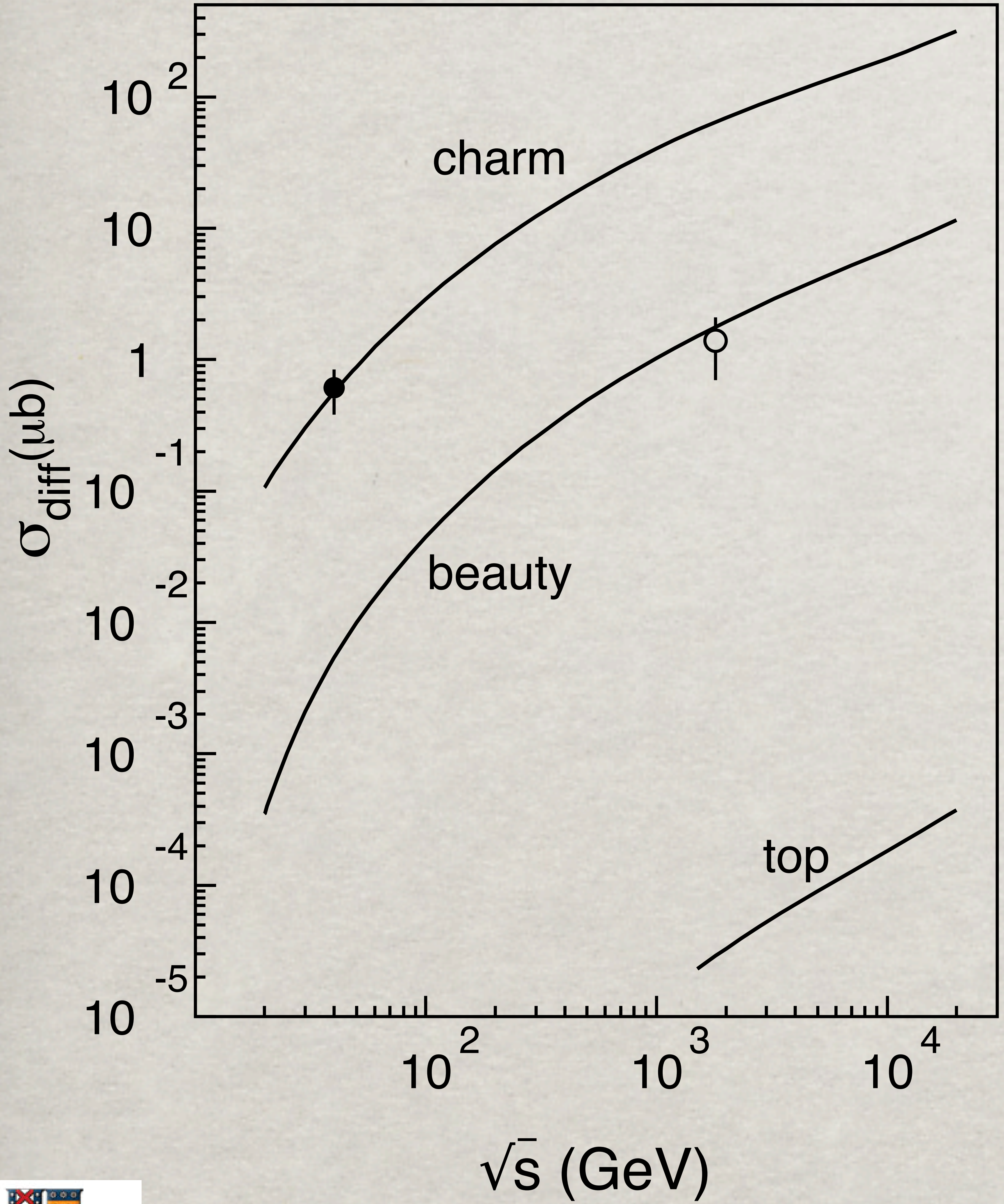
- Measurements at ISR led to an amazingly large (probably incorrect) cross section of diffractive charm production (K.L.Giboni et al. 1979), $\sigma \sim 10 - 60\ \mu\mathrm{b}$. This experiment was order of magnitude above the subsequent data for inclusive charm production.

- 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 $\sigma \leq 26\ \mu\mathrm{b}$

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

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

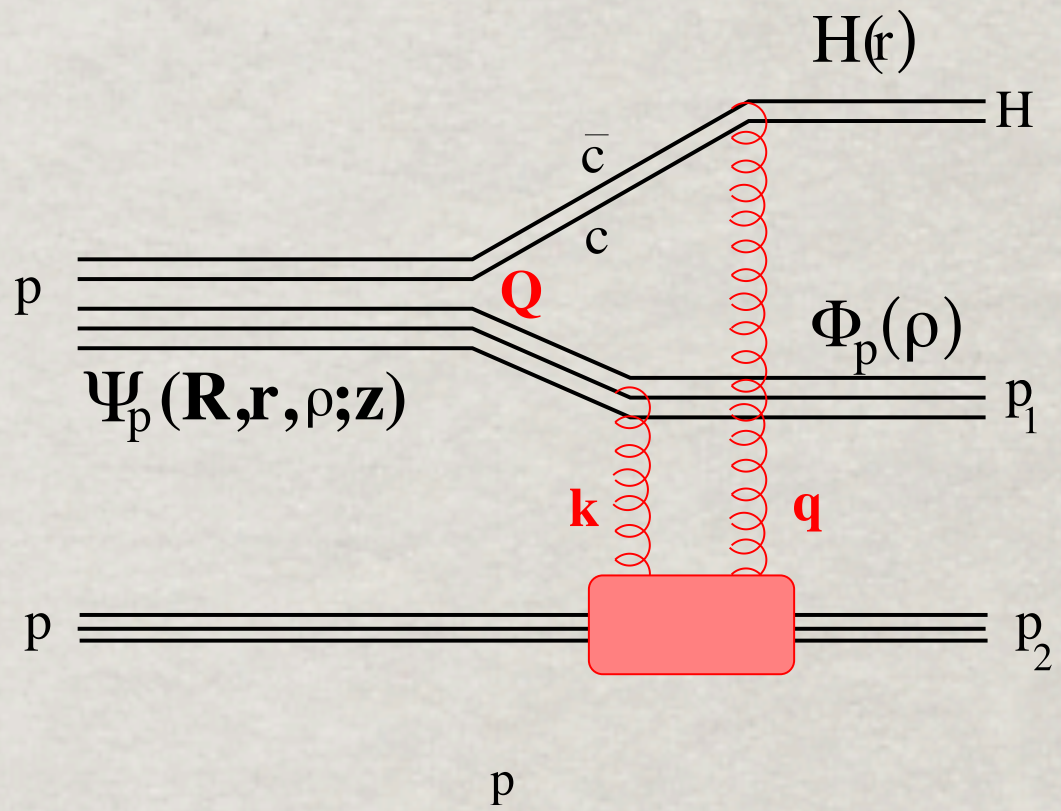
Diffractive heavy flavors: data



Data well agree with our results confirming the leading twist behavior, but contradicts by an order of magnitude the higher twist mass dependence $\sigma_{\mathbf{diff}}^{\mathbf{\bar{b}b}} \propto \mathbf{1/m_Q^4}$, which follows from diffractive factorization.

Diffractive Higgs

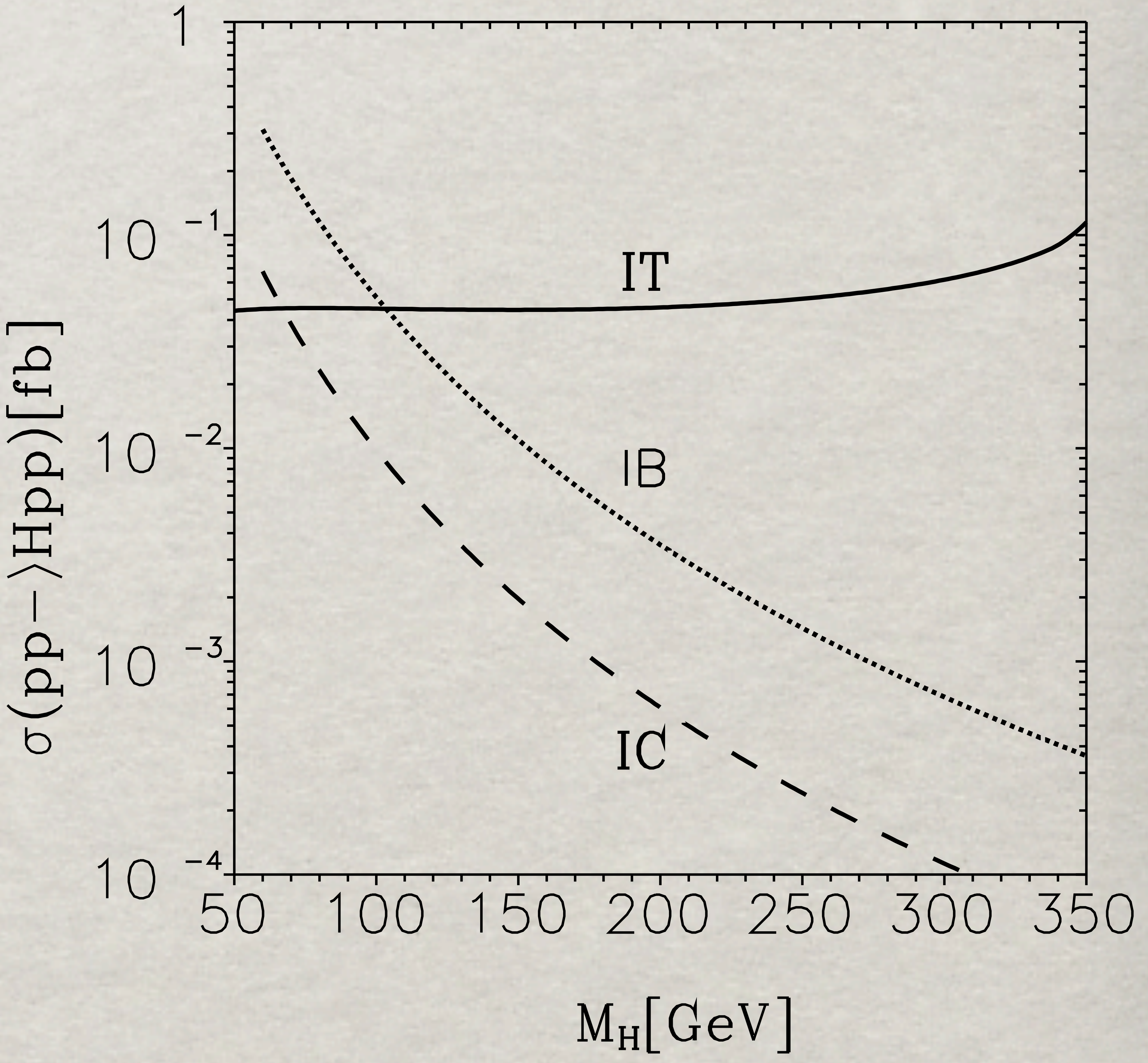
Diffractive Higgsstrahlung is similar to diffractive DY. Z, W, since in all cases the radiated particle does not participate in the interaction. However, the Higgs decouples from light quarks, so the cross section of higgsstrahlung by light hadrons is small.



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

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



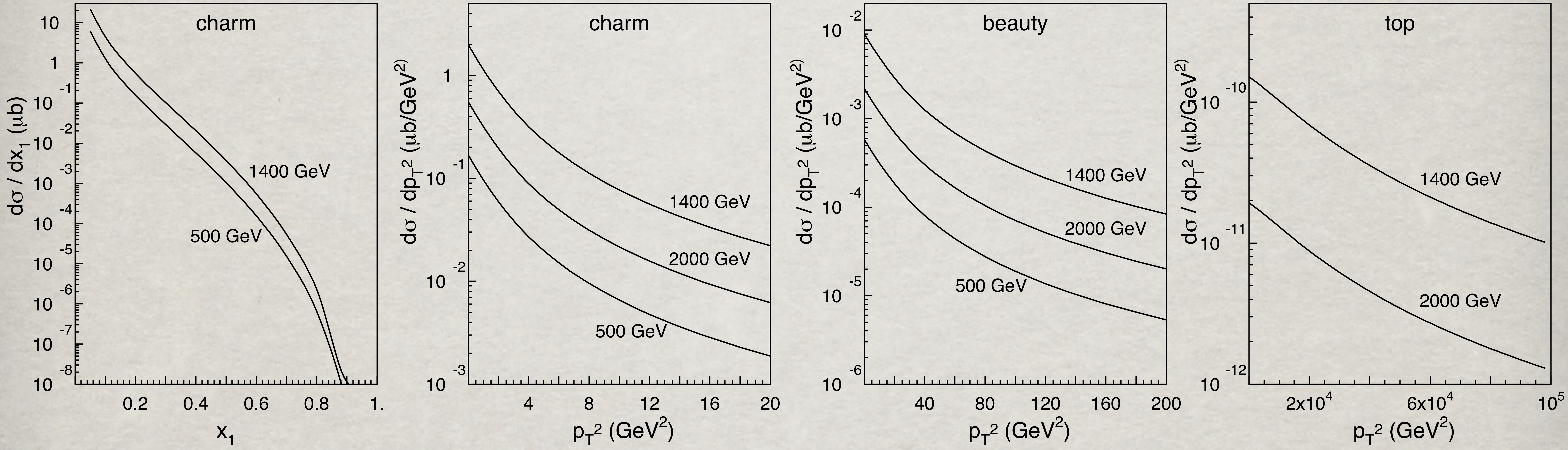
Summarizing,

Forward abelian diffractive radiation of Drell-Yan dileptons, gauge bosons Z, W, and Higgs by a parton is forbidden. A hadron can diffractively radiate in the forward direction due to possibility of soft interaction with the spectators. The latter breaks down diffractive factorization resulting in the 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.

BACKUPS


charm
1400 GeV
500 GeV
dσ / dx$_1$ (μb)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0.2
0.4
0.6
0.8
1.
x$_1$
charm
1400 GeV
2000 GeV
500 GeV
dσ / dp$_T$^{2} (μb/GeV^2)
1
10^{-1}
10^{-2}
10^{-3}
4
8
12
16
20
p$_T$^{2} (GeV^2)
beauty
1400 GeV
2000 GeV
500 GeV
dσ / dp$_T$^{2} (μb/GeV^2)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
40
80
120
160
200
p$_T$^{2} (GeV^2)
top
1400 GeV
2000 GeV
dσ / dp$_T$^{2} (μb/GeV^2)
10^{-10}
10^{-11}
10^{-12}
2x10^4
6x10^4
10^5
p$_T$^{2} (GeV^2)