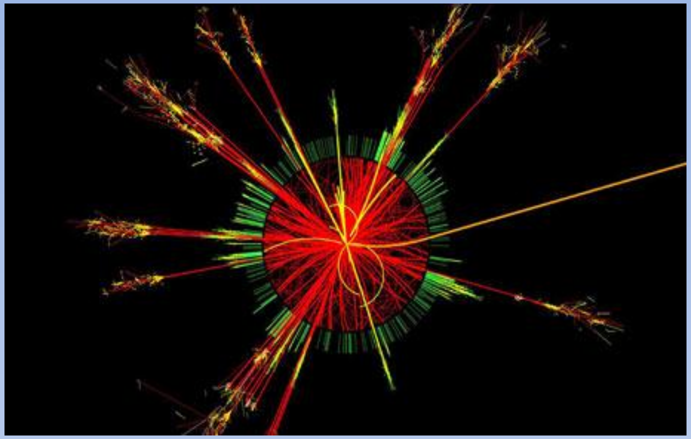


Forward diffractive heavy flavor production

Roman Pasechnik

Lund University, THEP group

In collaboration with:

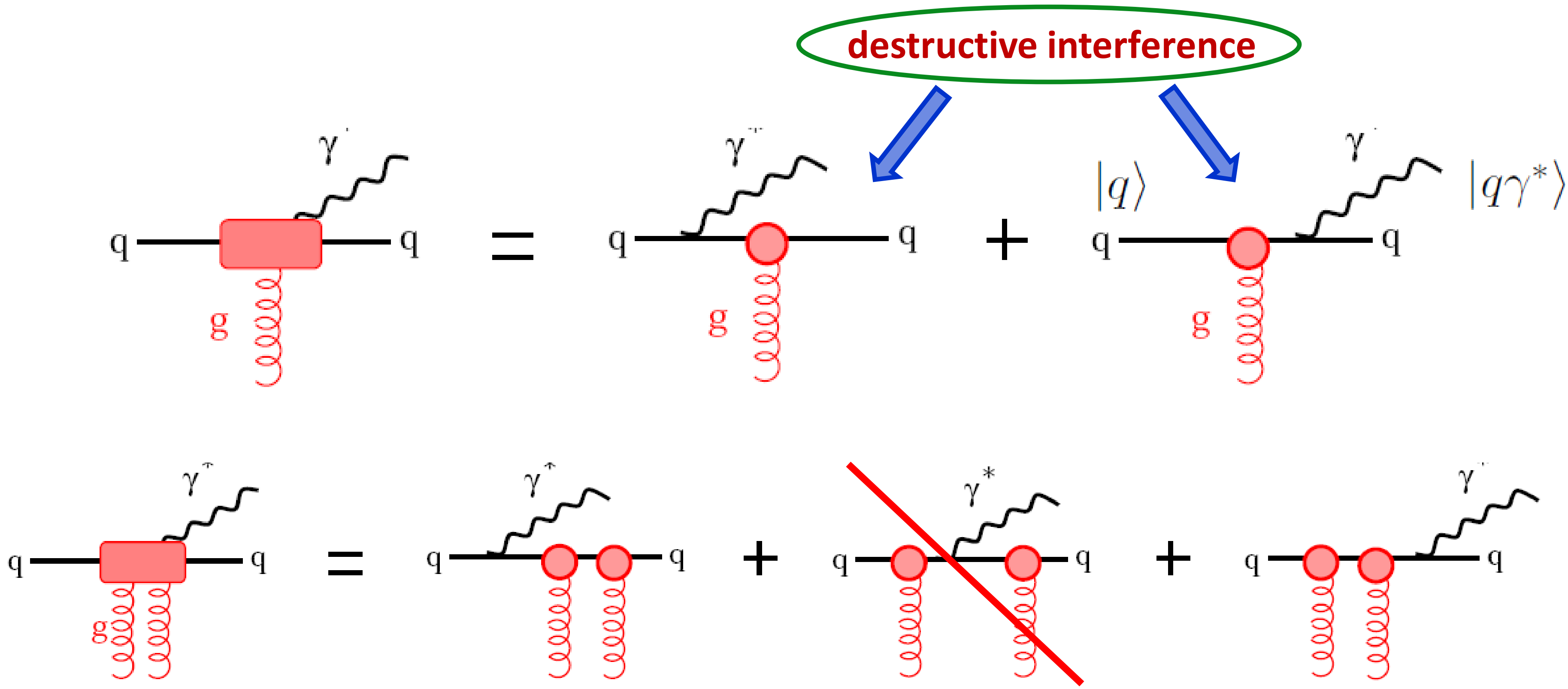
Boris Kopeliovich

EDS Blois 2013, Saariselkä
September 11th, 2013

Contents

- Single diffraction in the Color Dipole Model
- Abelian case: diffractive Drell-Yan
- Absorption
- QCD factorisation breaking
- Non-Abelian case: diffractive gluon Bremsstrahlung
- Results for forward diffractive QQ production
- Conclusions

Abelian Bremsstrahlung off a quark

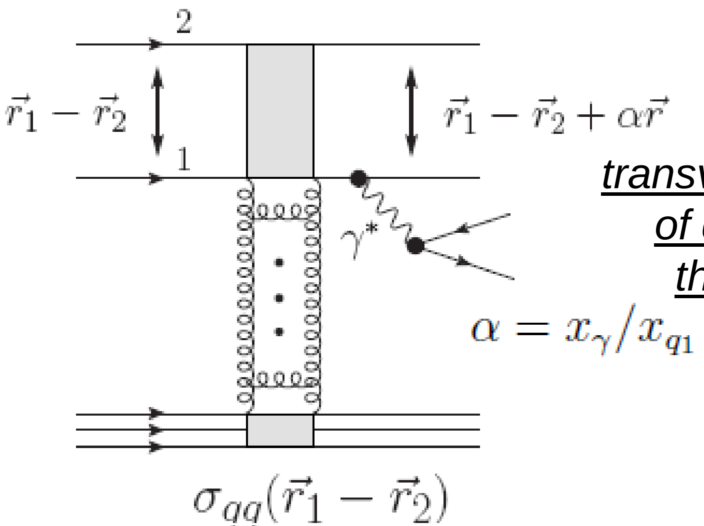


Landau-Pomeranchuk principle: non-accelerated charge does not radiate!

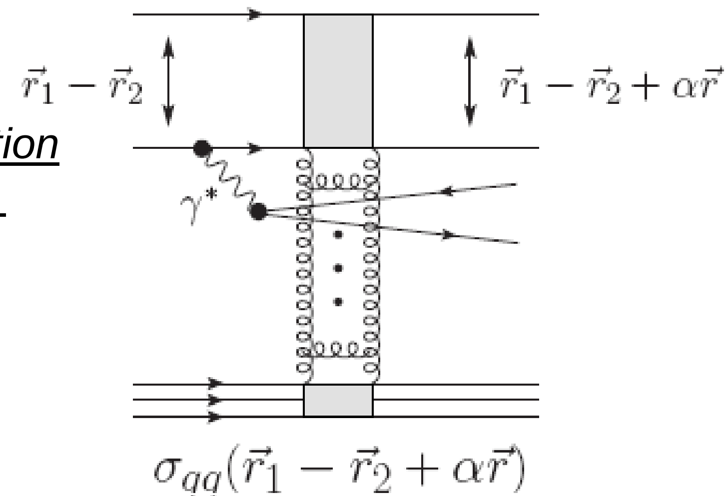
Radiation depends on the whole strength of the kick rather on its structure

No Abelian radiation off a quark at Pt=0!

Abelian Bremsstrahlung off a dipole



transverse motion of quarks in the proton



By optical theorem

$$2i\,\mathrm{Im}\,f_{el}(\vec{b},\vec{r}_p) = \frac{i}{N_c}\sum_X \sum_{c_f c_i} \left|V_q(\vec{b}) - V_q(\vec{b}+\vec{r}_p)\right|^2$$

$$\boxed{\sigma_{\bar{q}q}(r_p) = \int d^2b\, 2\,\mathrm{Im}\,f_{el}(\vec{b},\vec{r}_p)}$$

dipoles with different sizes interact differently!

⇓

The fundamental reason for diffraction!

Amplitude of DDY in the dipole-target scattering

$$M_{qq}^{(1)}(\vec{b},\vec{r}_p,\vec{r},\alpha) = -2ip_i^0\sqrt{4\pi}\,\frac{\sqrt{1-\alpha}}{\alpha^2}\,\Psi^{\mu}_{\gamma^* q}(\alpha,\vec{r})\left[2\mathrm{Im}\,f_{el}(\vec{b},\vec{r}_p) - 2\mathrm{Im}\,f_{el}(\vec{b},\vec{r}_p+\alpha\vec{r})\right]$$

Elastic amplitude and gap survival

Complete dipole elastic amplitude has **eikonal form**:

$$\mathrm{Im}\, f_{el}(\vec{b}, \vec{r}_1 - \vec{r}_2) = 1 - \exp\left[i\chi(\vec{r}_1) - i\chi(\vec{r}_2)\right],$$

$$\chi(b) = -\int\limits_{-\infty}^{\infty} dz\, V(\vec{b}, z),$$

nearly imaginary at high energies!

Diffractive amplitude is proportional to

$$\mathrm{Im}\, f_{el}(\vec{b}, \vec{r}_1 - \vec{r}_2 + \alpha\vec{r}) - \mathrm{Im}\, f_{el}(\vec{b}, \vec{r}_1 - \vec{r}_2) = \boxed{\exp\left[i\chi(\vec{r}_1) - i\chi(\vec{r}_2)\right]} \exp\left[i\alpha\, \vec{r} \cdot \vec{\nabla}\chi(\vec{r}_1)\right]$$

Exactly the soft survival probability amplitude

controlled by soft spectator partons

vanishes in the black disc limit!

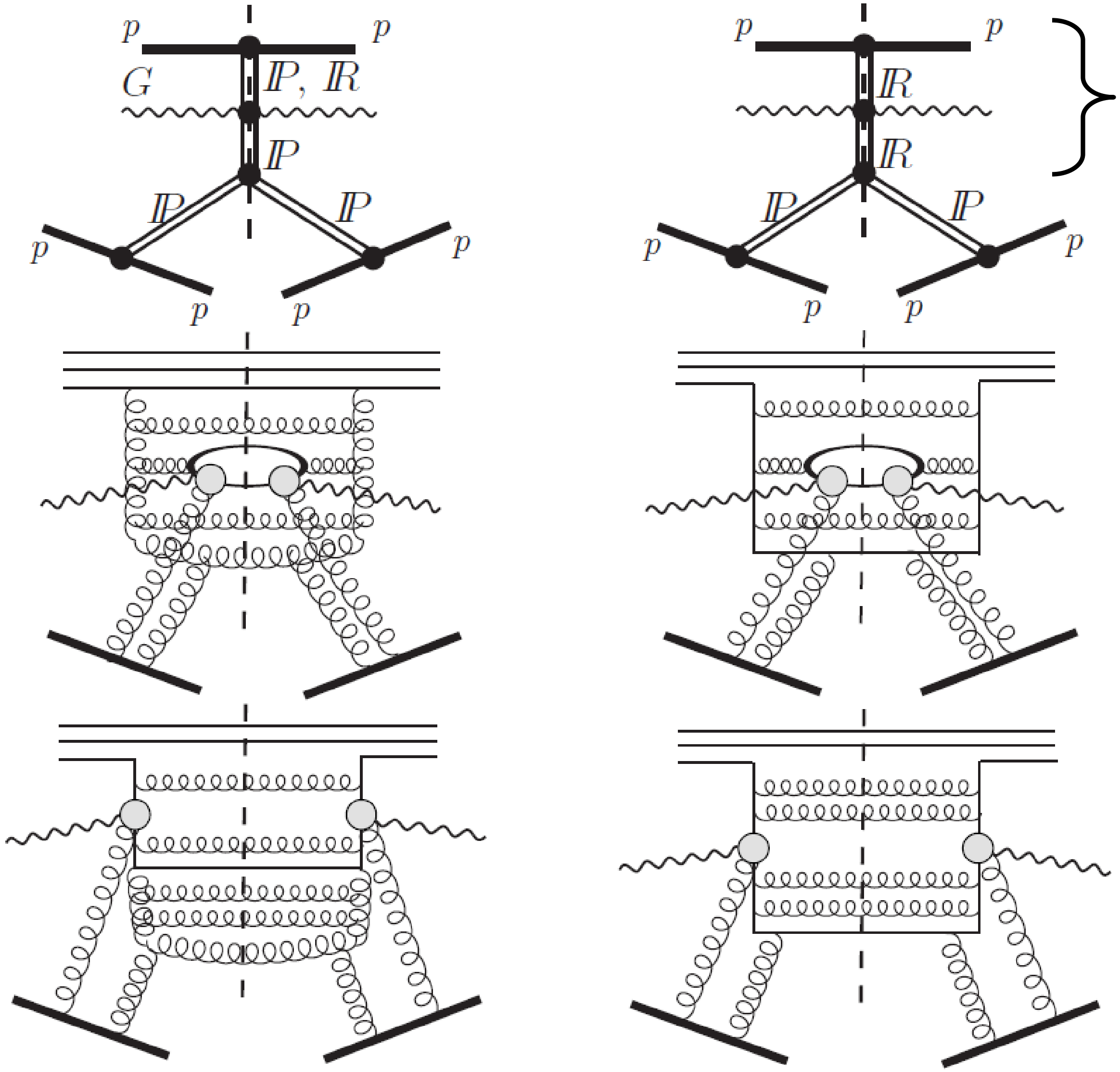
another source of QCD factorisation breaking

Absorption effect should be included into elastic amplitude parameterization (at the amplitude level)

Regge picture of diffractive excitations

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

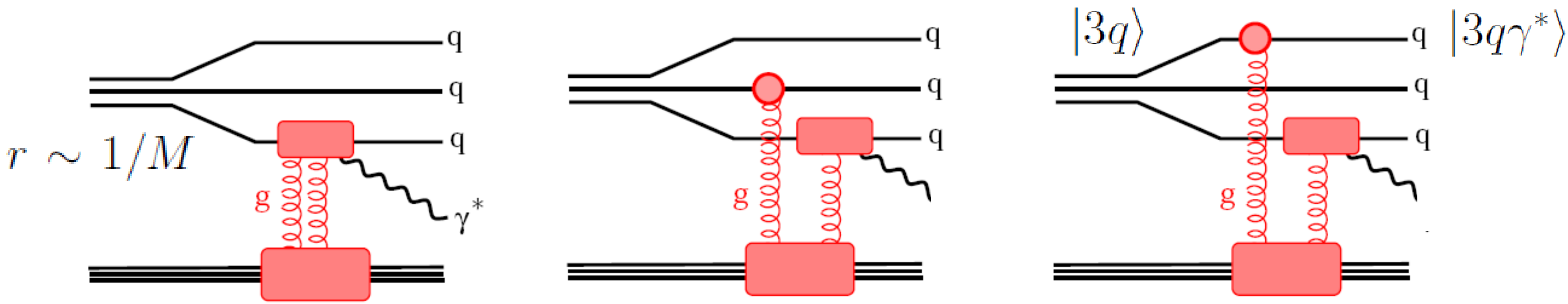
LRG



projectile fragmentation region

Probing large distances in the proton…

R. Pasechnik, B. Kopeliovich, I. Potashnikova, Phys. Rev. D86, 114039, 2012
R. Pasechnik, B. Kopeliovich, Eur. Phys. J. C71: 1827, 2011
B. Kopeliovich, I. Potashnikova, I. Schmidt and A. Tarasov, Phys. Rev. D74: 114024, 2006



GBW dipole (ex.) $\sigma(r) = \sigma_0 \left(1 - e^{-r^2/R_0^2}\right)$

Interplay between hard and soft scales

Amplitude $\propto \sigma(\vec{R}) - \sigma(\vec{R} - \alpha\vec{r}) = \frac{2\alpha\,\sigma_0}{R_0^2(x_2)} e^{-R^2/R_0^2(x_2)} \left(\vec{r} \cdot \vec{R}\right) + O(r^2)$

Diffractive DIS $\propto r^4$

QCD factorization holds!

Higher twist effect!

Diffraction is dominated by soft fluctuations!

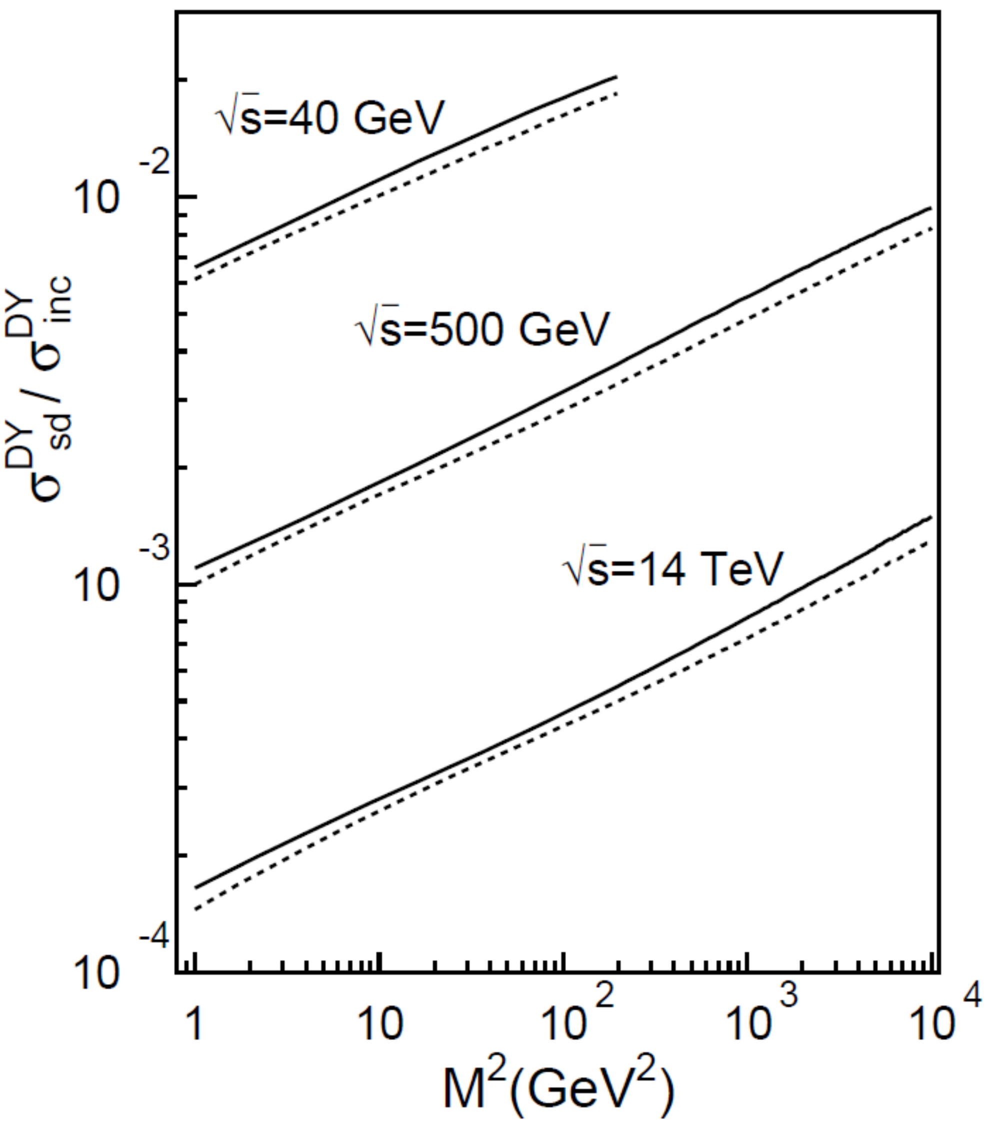
Diffractive DY $\propto r^2$

QCD factorization is broken!

Leading twist effect!

Diffraction is dominated by semisoft-semihard fluctuations!

Signatures for QCD factorisation breaking



saturated shape of the dipole CS

+

unitarity corrections

Fraction of diffractive events

- **steeply falls with energy**
- **grows with the hard scale**

Opposite to QCD factorization-based results (like Ingelman-Schlein)

cf. QCD factorisation-based calculations by

G. Kubasiak, A. Szczurek,
Phys.Rev.D84:014005,2011

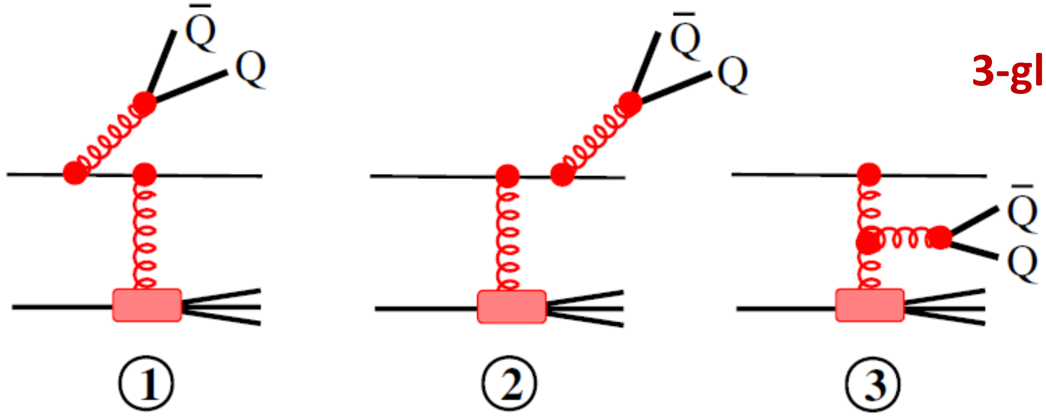
Why go non-Abelian?

- Higher single diffractive cross sections than heavy QQ CEP/Abelian mechanisms (dominates the diffractive heavy flavor production)
- One more promising test of QCD diffraction mechanisms and, in particular, QCD factorisation breaking effects
- More complicated than Abelian but enables to test non-Abelian mechanisms of heavy flavor production vs Abelian ones
- The most important background for intrinsic heavy flavor studies via diffraction
- An important playground for forward Higgsstrahlung studies off heavy flavor/gauge bosons
- One of the cleanest way of Higgs-bottom/Higgs-top Yukawa couplings studies via diffraction

BUT! The pile-up and backgrounds need to be taken under control at high energies!

Non-Abelian Bremsstrahlung off a quark

Non-Abelian couplings

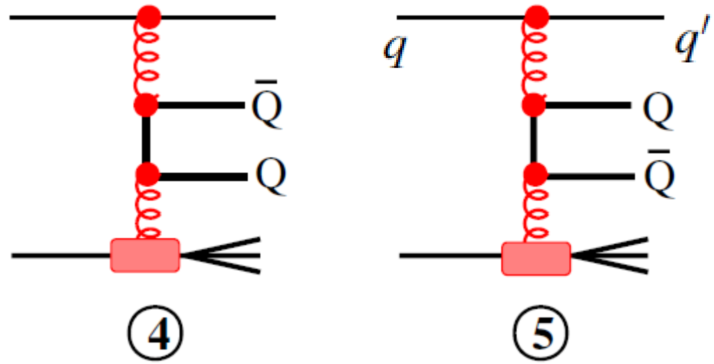


3-gluon coupling

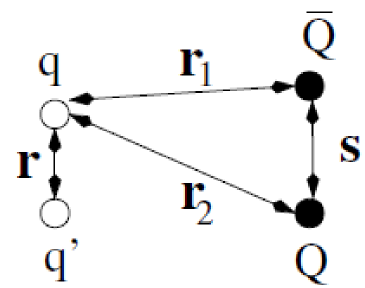
Bremsstrahlung component

$$M^T_{\rm Br} = M^T_1 + M^T_2 + \frac{Q^2}{M^2+Q^2} M^T_3$$

Extra QQ production terms



Impact parameters



Production component

$$M^T_{\rm Pr} = \frac{M^2}{M^2+Q^2} M^T_3 + M^T_4 + M^T_5$$

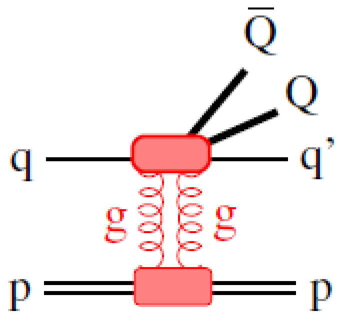
q'-(QQ) distance: $\vec{\rho} = \vec{r} - \beta \vec{r}_1 - (1-\beta)\vec{r}_2$

B. Kopeliovich et al, Phys.Rev.D76, 034019 (2007)

Does not vanish in the forward scattering!

QQ production: diffractive parton-proton scattering

Quark-proton scattering



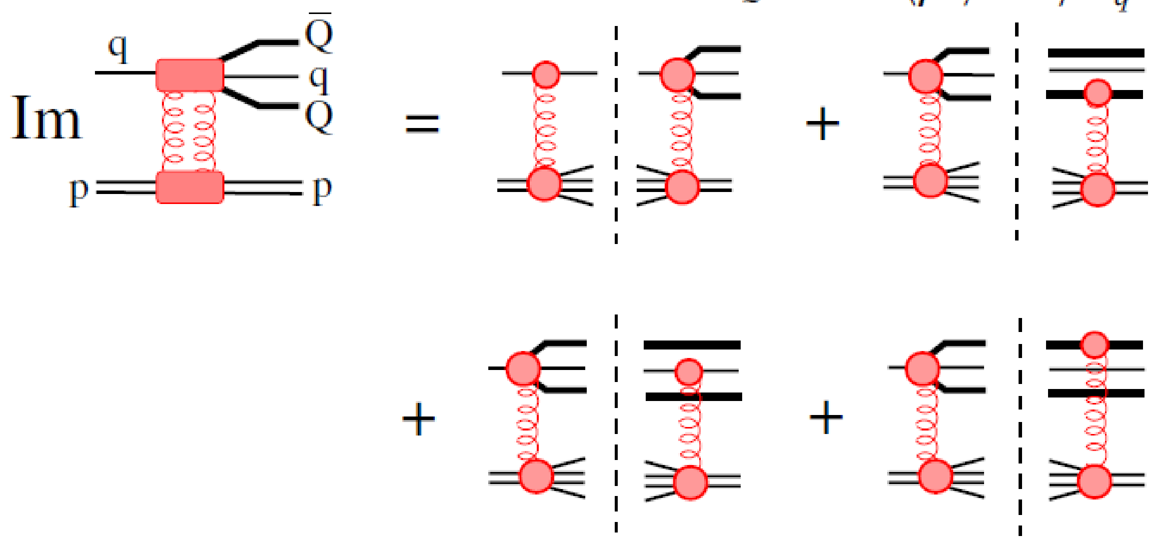
Imaginary amlitude

Cutting rules

$$\langle\rho^2\rangle \sim \langle s^2\rangle \sim \frac{1}{m_Q^2}$$

$$\langle s^2\rangle \sim 1/m_Q^2$$

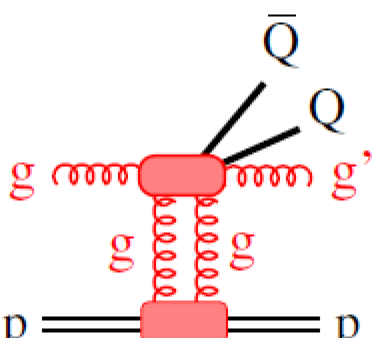
$$\langle\rho^2\rangle \sim 1/m_q^2$$

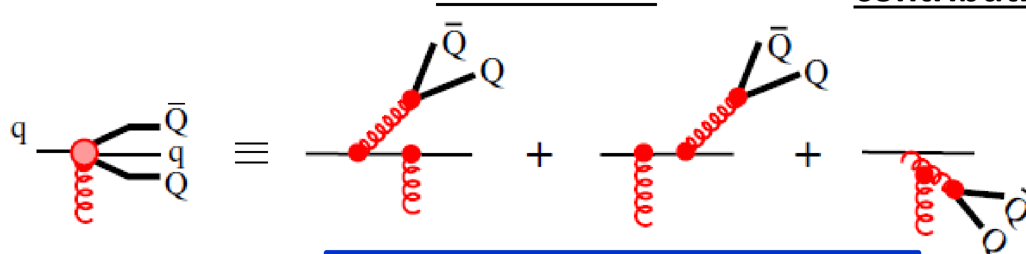


Bremsstrahlung contribution

Production contribution

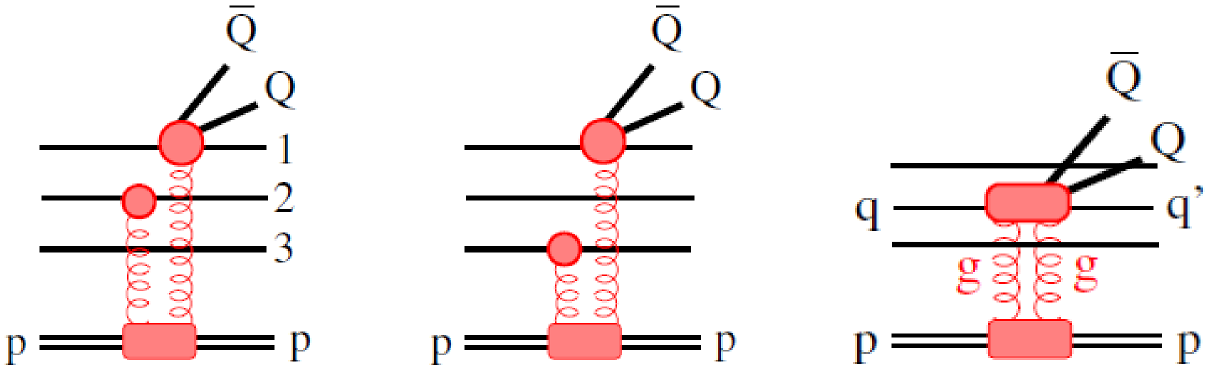
Gluon-proton scattering





Does not vanish in the forward scattering!

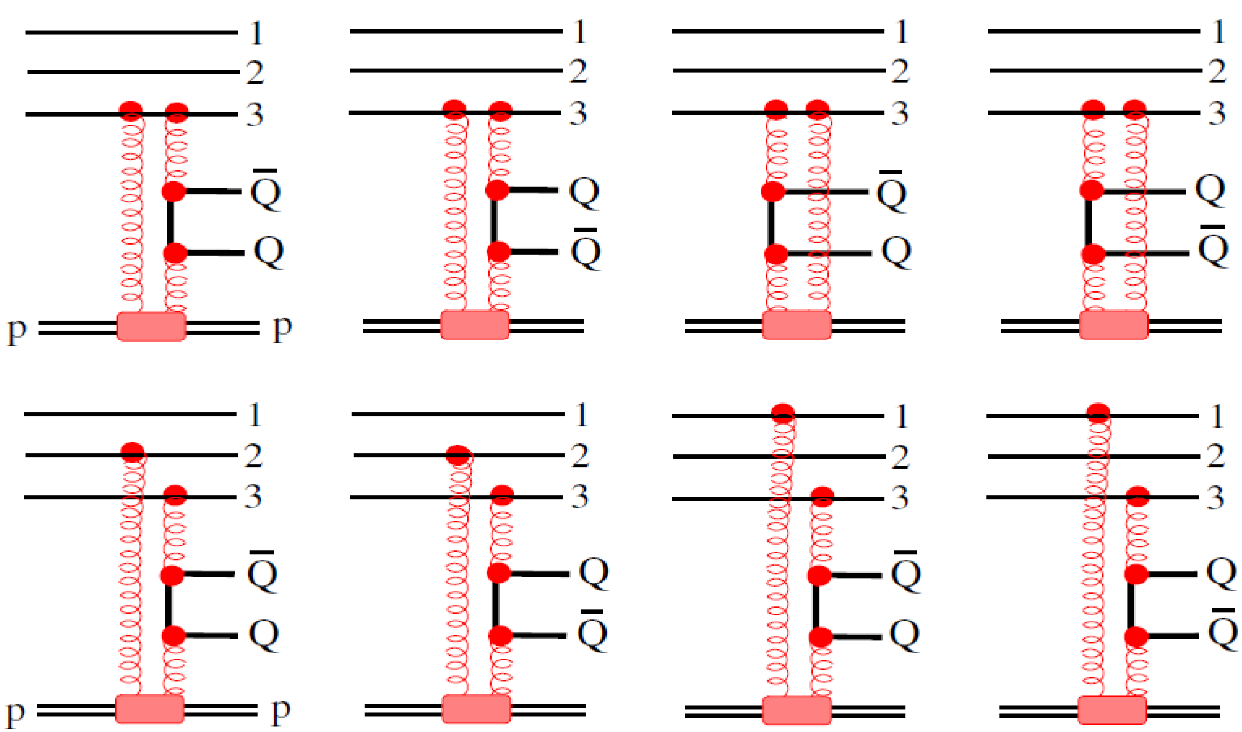
QQ production: diffractive proton-proton scattering



and sea gluons/quarks must be included!

$$|\Psi_{\rm in}(\vec{r}_i, x_i)|^2 \Rightarrow \frac{1}{3}\left[\sum_q q(x) + \bar{q}(x) + \frac{81}{16} g(x)\right]$$

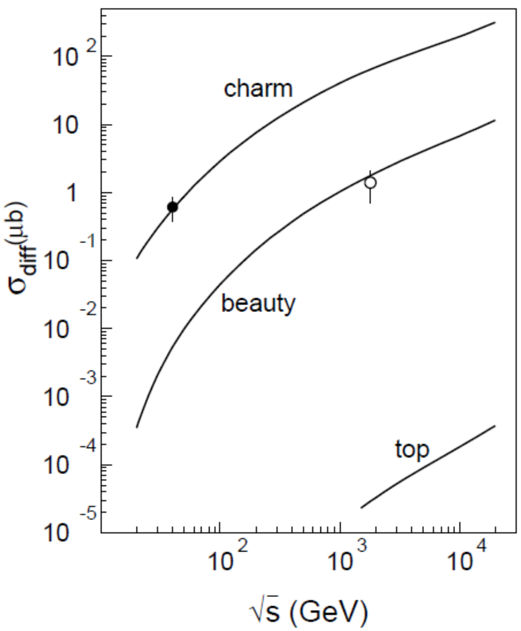
Production component strongly dominates the diffractive cross section!

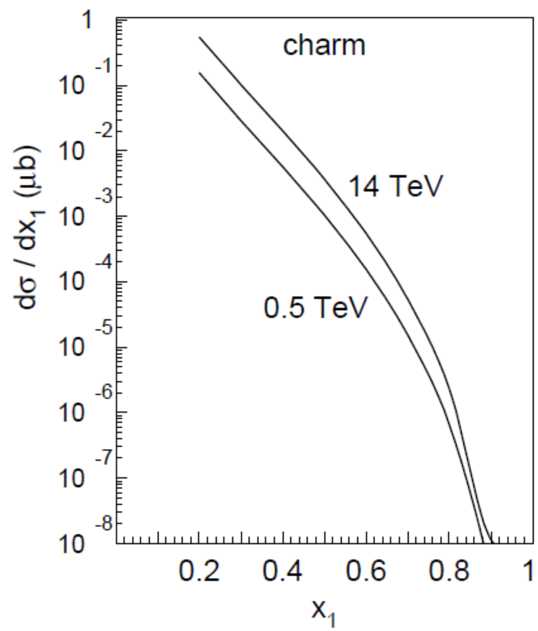


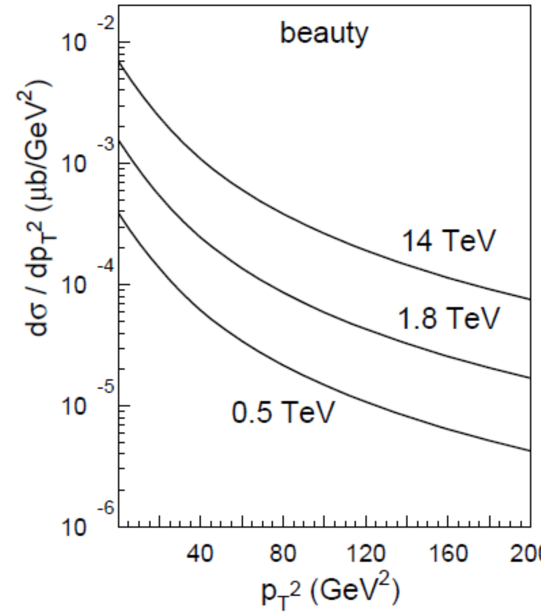
the largest leading-twist contribution

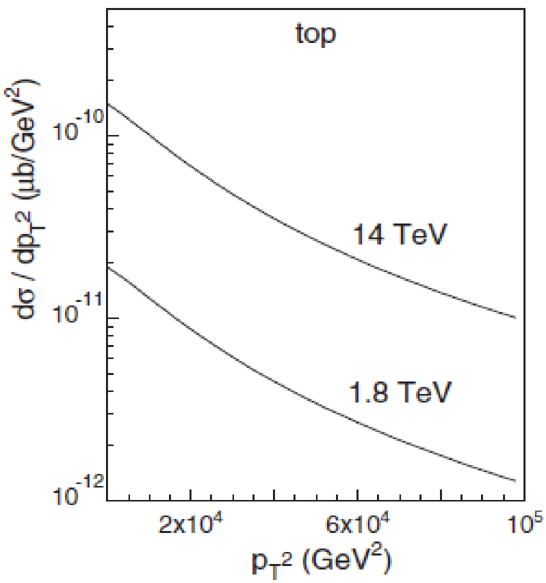
$$\sim 1/m_Q^2$$

Forward diffractive heavy flavor: cross sections









Leading-twist diffractive excitations are proven to be dominated!

QCD factorisation is broken!

cf. *QCD factorisation-based approach* by

M. Luszczak, W. Schafer and A.Szczurek, arXiv:1305.4727 [hep-ph]

Conclusions

- The QCD factorisation is **broken by the presence of transverse motion of spectator quarks at large separations**. The same effect is responsible for the absorption.
- Hard/soft interactions and interplay leads to **dominance of leading-twists mechanisms** in the diffractive heavy flavor (DHF) production
- Experimental measurements of DHF would allow to probe directly the dipole cross section **at large separations**, as well as **the proton structure** function at soft and semi-hard scales, and large x
- The observation of DHF production **provides a good tool for studies of intrinsic heavy flavors**, which could be seen as an excess of DHF compared to the conventional mechanisms