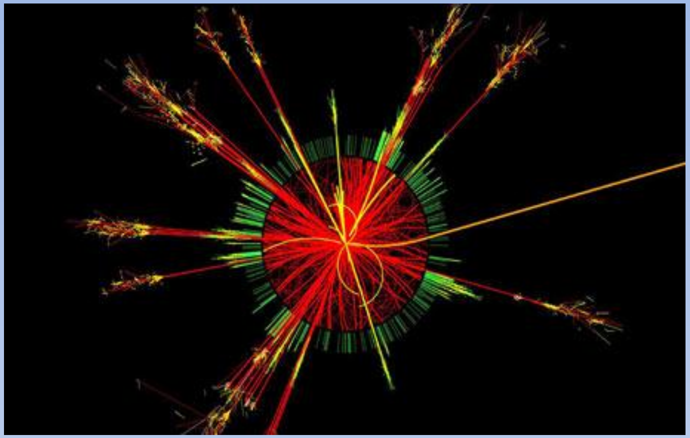

Diffractive gauge bosons production beyond QCD factorisation

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Based on:

RP, B. Kopeliovich and I. Potashnikova
arXiv:1204.6477

Low X 2012, Paphos
June 28th, 2012

In this talk I will touch upon...

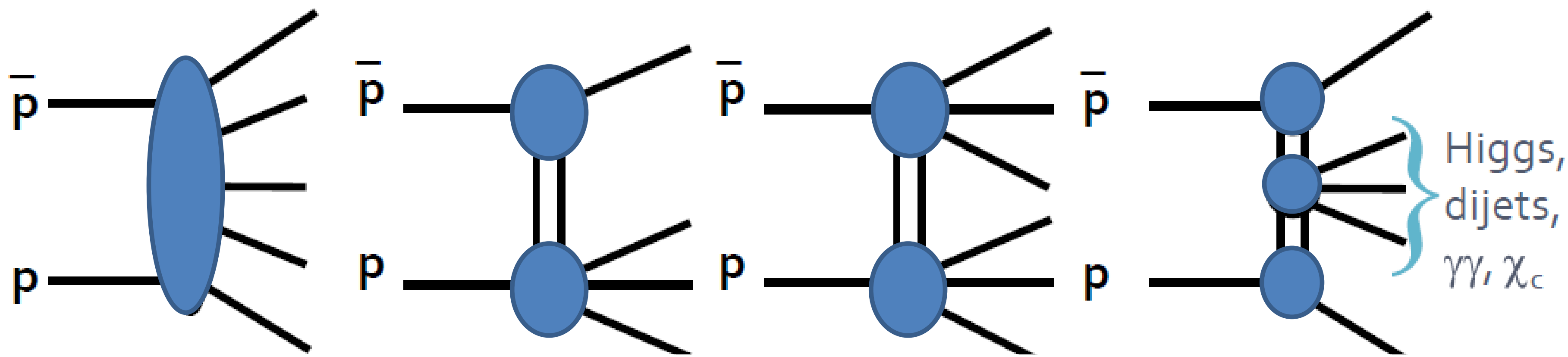
- Diffraction in the Color Dipole Model
- Gauge bosons production at high energies: diffractive vs inclusive
- QCD factorisation breaking in the forward Abelian diffraction
- Absorption effects
- Analytical and numerical results
- Conclusions

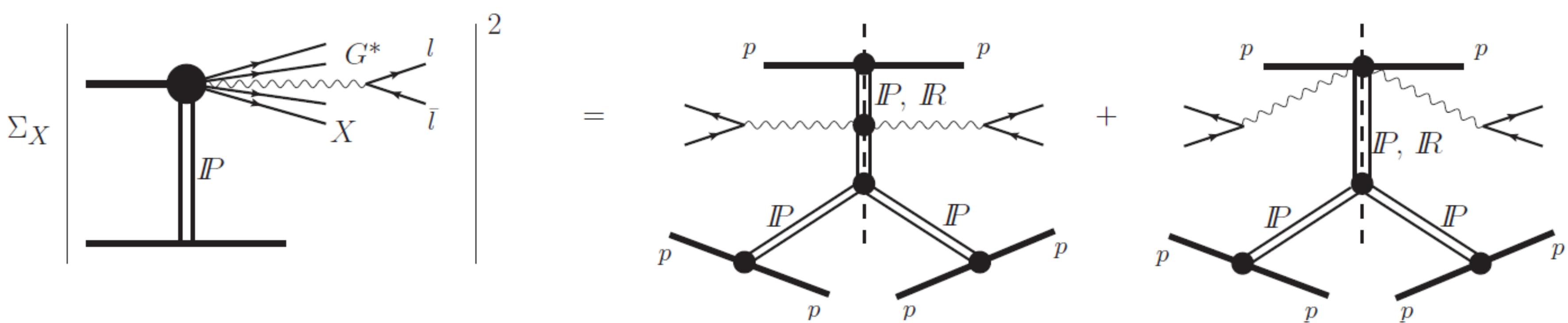
Definition: forward diffractive gauge bosons production

Diffractive reactions – in which:

- no quantum numbers / significant momenta are exchanged
- a new diffractive state is produced

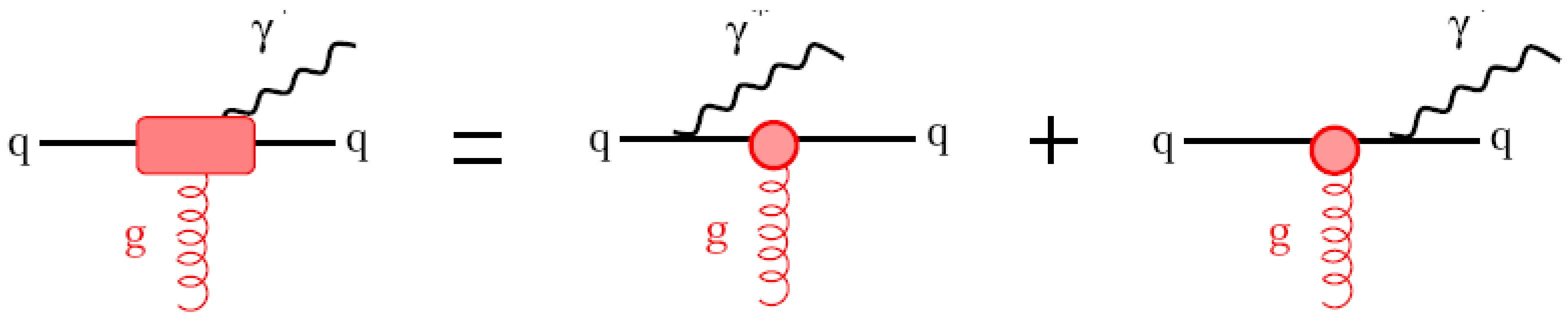
Non-diffractive | Single-diffractive | Double-diffractive | Double-Pomeron exchange



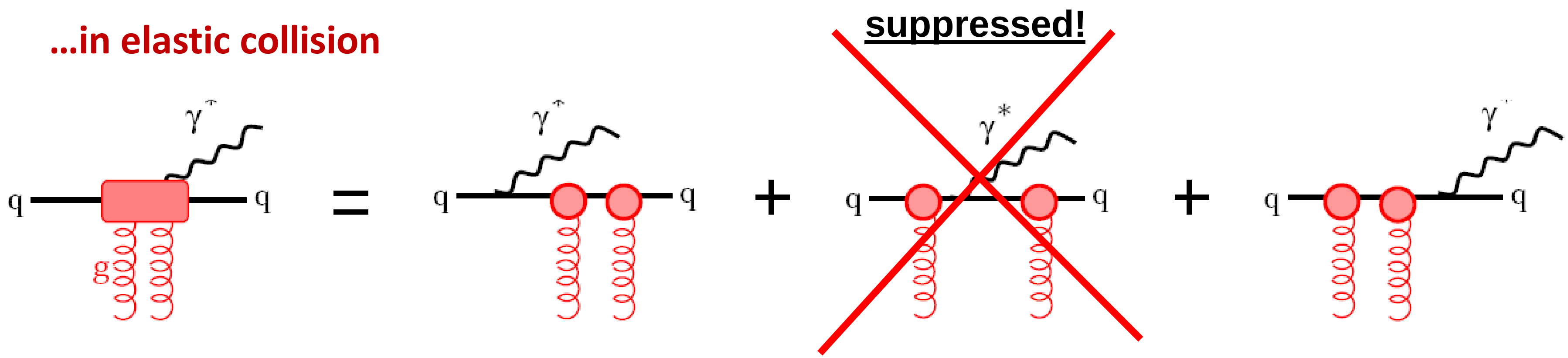


Drell-Yan off a quark: Forward Abelian radiation

...in inelastic collision



...in elastic collision

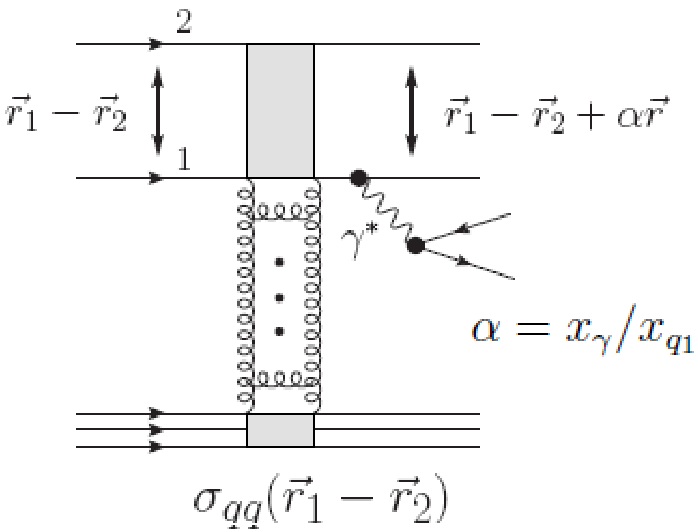


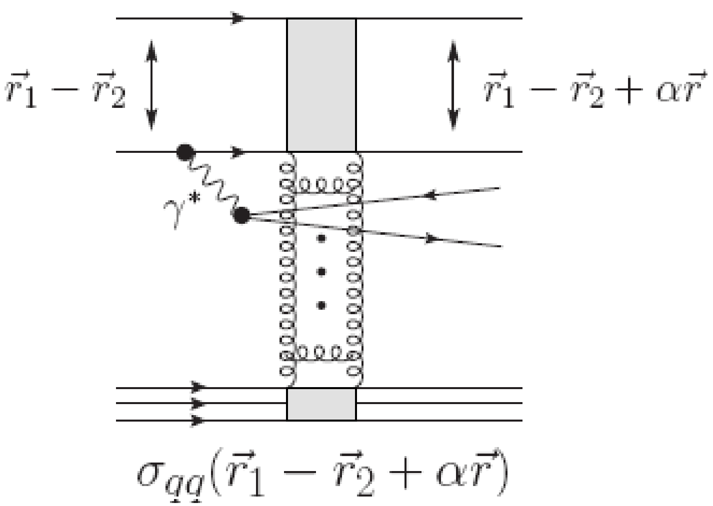
Landau-Pomeranchuk principle: non-accelerated charge does not radiate!

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

No radiation from a quark at Pt=0!

Drell-Yan off a dipole: basics for forward diffraction





By optical theorem

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

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

Dipole:

- cannot be excited
- experience only elastic scattering
- have no definite mass, but only separation
- universal – elastic amplitude can be extracted in one process and used in another

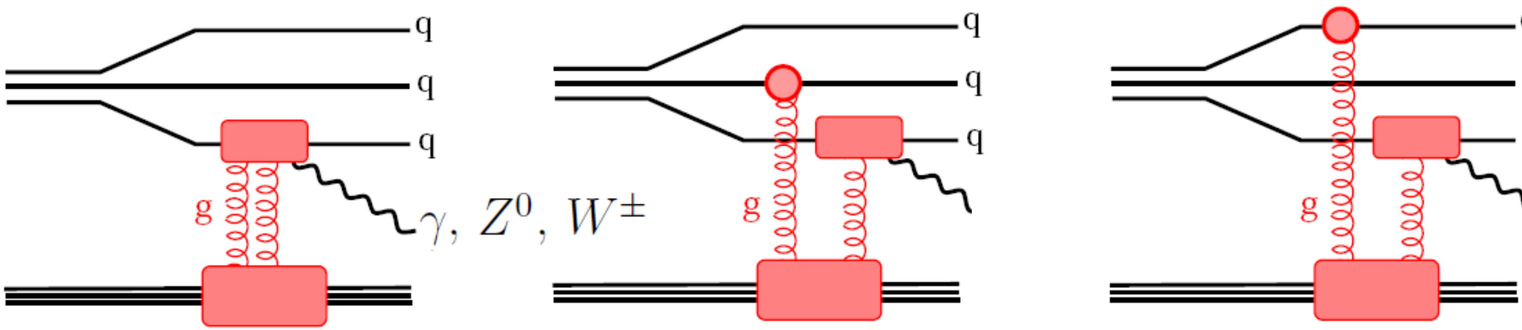
dipoles with different sizes interact differently!

Amplitude of DDY in the dipole-target scattering

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

DY off a hadron: probing large distances in the proton

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

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

Interplay between hard and soft scales

Diffractive DIS $\propto r^4$

Diffractive gauge bosons production $\propto r^2$

QCD factorization holds!

QCD factorization is broken!

Absorption: Elastic amplitude and gap survival

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

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

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

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

vanishes in the black disc limit!

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

Results: Diffractive GB production cross sections

The general result:

$$\frac{d^5\sigma_{\lambda_G}(pp\to pG^*X)}{d^2q_\perp\, d\ln\alpha\, d^2\delta_\perp} = \frac{1}{(2\pi)^2}\frac{1}{64\pi^2}\sum_q \int d^2r_1 d^2r_2 d^2r_3\, d^2r d^2r'\, d^2b d^2b'\, dx_{q_1} dx_{q_2} dx_{q_3}$$
$$\times\, \Psi^{\lambda_G}_{V-A}(\vec r,\alpha,M)\Psi^{\lambda_G *}_{V-A}(\vec r\,',\alpha,M)\,|\Psi_i(\vec r_1,\vec r_2,\vec r_3;x_{q_1},x_{q_2},x_{q_3})|^2$$
$$\times\, \Delta(\vec r_1,\vec r_2,\vec r_3;\vec b;\vec r,\alpha)\Delta(\vec r_1,\vec r_2,\vec r_3;\vec b\,';\vec r\,',\alpha)\, e^{i\vec\delta_\perp\cdot(\vec b-\vec b\,')}\, e^{i\vec l_\perp\cdot\alpha(\vec r-\vec r\,')}$$

$$\Delta = -2\mathrm{Im}\, f_{el}(\vec b,\vec r_1-\vec r_2) + 2\mathrm{Im}\, f_{el}(\vec b,\vec r_1-\vec r_2+\alpha\vec r)$$
$$-2\mathrm{Im}\, f_{el}(\vec b,\vec r_1-\vec r_3) + 2\mathrm{Im}\, f_{el}(\vec b,\vec r_1-\vec r_3+\alpha\vec r)$$

Proton wave function

$$|\Psi_i(\vec r_1,\vec r_2,\vec r_3;x_q,x_{q_2},x_{q_3})|^2 = \frac{3a^2}{\pi^2}e^{-a(r_1^2+r_2^2+r_3^2)}\rho(x_q,x_{q_2},x_{q_3})$$
$$\times\, \delta(\vec r_1+\vec r_2+\vec r_3)\delta(1-x_q-x_{q_2}-x_{q_3})$$

$$a = \langle r_{ch}^2\rangle^{-1}$$

Valence quark distribution

+ sea quarks and antiquarks!

$$\int dx_{q_2}dx_{q_3}\,\delta(1-x_q-x_{q_2}-x_{q_3})\rho(x_q,x_{q_2},x_{q_3}) = \rho_q(x_q)$$

⇒

$$\sum_q Z_q^2[\rho_q(x_q)+\rho_{\bar q}(x_q)] = \frac{1}{x_q}F_2(x_q)$$

In DDY we get an immediate access to the proton structure function at large x!

Results: Diffractive GB production cross sections

In the hard limit r<<R: $\mathrm{Im}\, f_{el}(\vec{b},\vec{R}_{ij}+\alpha\vec{r}) - \mathrm{Im}\, f_{el}(\vec{b},\vec{R}_{ij}) \simeq \frac{\partial \mathrm{Im}\, f_{el}(\vec{b},\vec{R}_{ij})}{\partial \vec{R}_{ij}}\alpha\vec{r}$

Forward diffractive CS:

$$\frac{d^4\sigma_{\lambda_G}(pp\to p\,G^* X)}{d^2q_\perp\, dx_{bos1}\, d\delta_\perp^2}\Big|_{\delta_\perp=0} = \frac{a^2}{24\pi^3}\frac{\sigma_0^2(s)}{R_0^4(s)}\,\frac{1}{A_2}\Big[\frac{2}{(A_2-4A_1)^2}+\frac{A_2^2}{(A_2^2-4A_3^2)^2}\Big]\times$$

$$\sum_q\int_{x_{bos1}}^1 d\alpha\,\Big[\rho_q\Big(\frac{x_{bos1}}{\alpha}\Big)+\rho_{\bar q}\Big(\frac{x_{bos1}}{\alpha}\Big)\Big]\int d^2r d^2r'\,(\vec{r}\cdot\vec{r}\,')\,\Psi^{\lambda_G}_{V-A}(\vec{r},\alpha,M)\Psi^{\lambda_G *}_{V-A}(\vec{r}\,',\alpha,M)\,e^{i\vec{q}_\perp\cdot(\vec{r}-\vec{r}\,')}$$

$$A_1=\frac{2a}{3}+\frac{2}{R_0^2(s)}\,,\qquad A_2=\frac{2a}{3}\,,\qquad A_3=\frac{2a}{3}+\frac{1}{R_0^2(s)}$$

Soft KST parametrization

$$R_0(s) = 0.88\,\mathrm{fm}\,(s_0/s)^{0.14}$$

$$\sigma_0(s) = \sigma^{\pi p}_{tot}(s)\Big(1+\frac{3R_0^2(s)}{8\langle r^2_{ch}\rangle_\pi}\Big)$$

$$\sigma^{\pi p}_{tot}(s) = 23.6(s/s_0)^{0.08}\ \mathrm{mb}$$

$$\langle r^2_{ch}\rangle_\pi = 0.44\ \mathrm{fm}^2$$

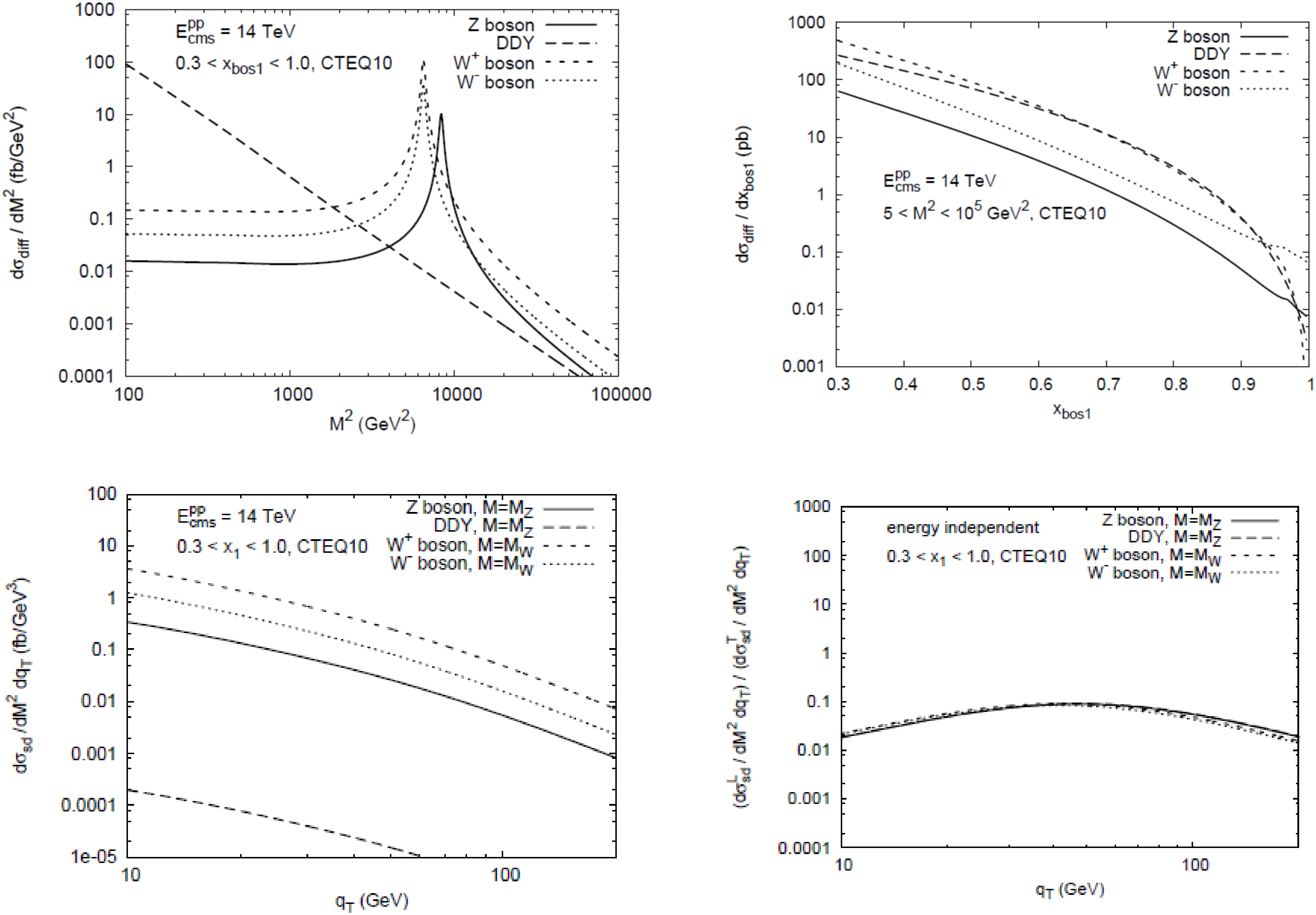
Due to exponential t-dependence

$$\frac{d\sigma(pp\to p\,G^* X)}{d^2q_\perp\, dx_{bos1}} = \frac{1}{B_{sd}(s)}\,\frac{d^3\sigma(pp\to p\,G^* X)}{d^2q_\perp\, dx_{bos1}\, d\delta_\perp^2}\Big|_{\delta_\perp=0}$$

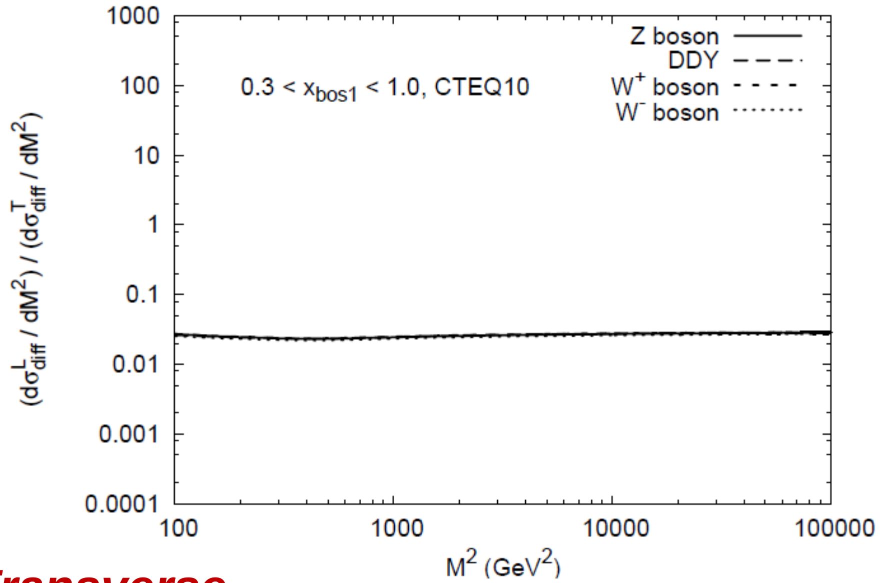
with diffractive (Regge) slope

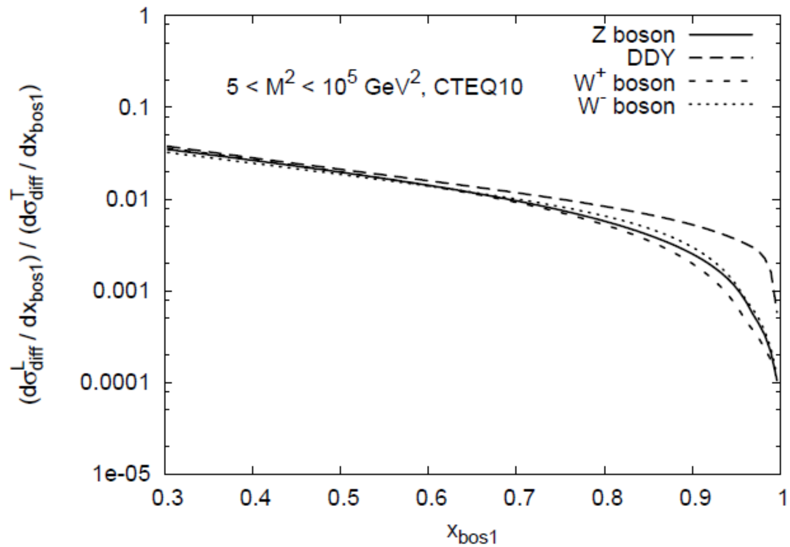
$$B_{sd}(s)\simeq\langle r^2_{ch}\rangle/3+2\alpha'_{I\!P}\ln(s/s_0)$$

Results: diffractive GB production cross sections



Results: longitudinal vs transverse polarisation





Transverse

$$\frac{d^4\sigma_T(pp \to p\,G^* X)}{d^2q_\perp dx_{bos1}} = \frac{1}{B_{sd}(s)}\frac{a^2}{24\pi^3}\frac{\sigma_0^2(s)}{R_0^4(s)}\frac{1}{A_2}\left[\frac{2}{(A_2-4A_1)^2}+\frac{A_2^2}{(A_2^2-4A_3^2)^2}\right]\times$$
$$\sum_q \frac{(\mathcal{C}_q^G)^2}{2\pi^2}\int_{x_{bos1}}^1 d\alpha\left[\rho_q\left(\frac{x_{bos1}}{\alpha}\right)+\rho_{\bar q}\left(\frac{x_{bos1}}{\alpha}\right)\right]\left\{m_q^2\alpha^2\left[(g_{v,q}^G)^2\alpha^2+(g_{a,q}^G)^2(2-\alpha)^2\right]J_1+\right.$$
$$\left.\left[(g_{v,q}^G)^2+(g_{a,q}^G)^2\right]\left[1+(1-\alpha)^2\right]\eta^2 J_2\right\},$$

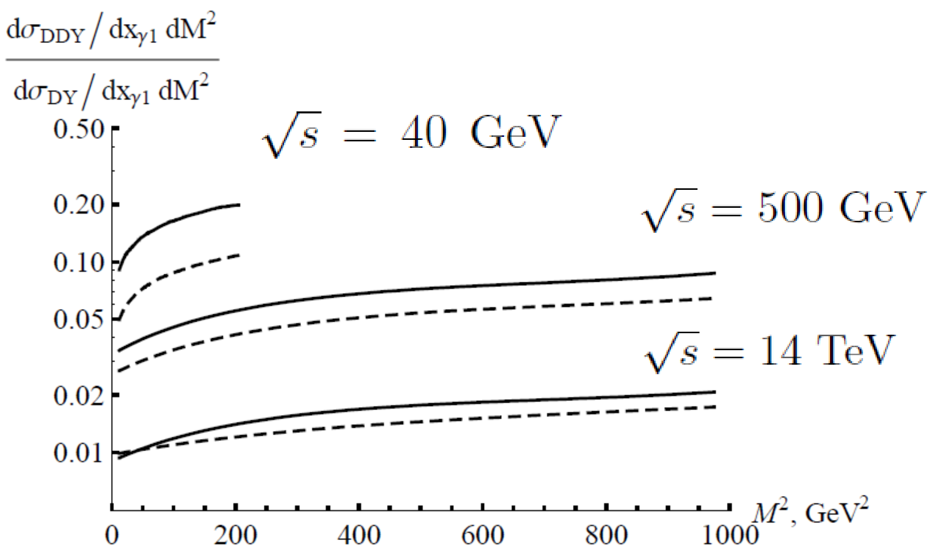
$$J_1(q_\perp,\eta) \equiv 16\pi^2\frac{q_\perp^2}{(\eta^2+q_\perp^2)^4},$$

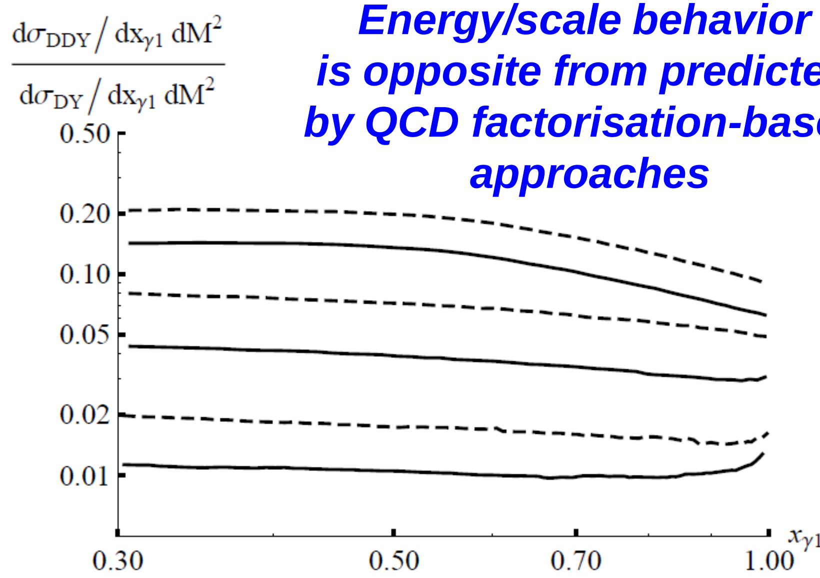
$$J_2(q_\perp,\eta) \equiv 8\pi^2\frac{\eta^4+q_\perp^4}{\eta^2(\eta^2+q_\perp^2)^4}$$

Longitudinal

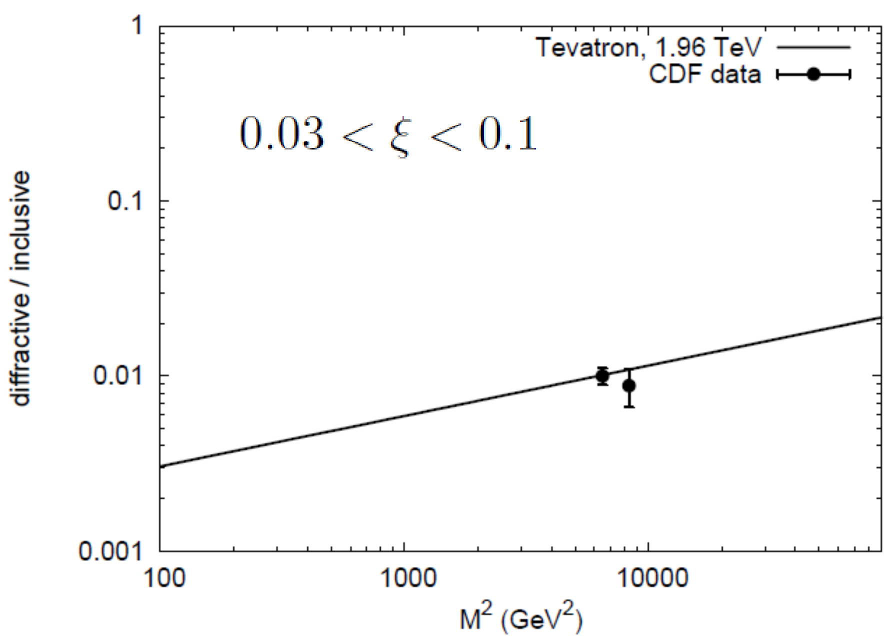
$$\frac{d^4\sigma_L(pp \to p\,G^* X)}{d^2q_\perp dx_{bos1}} = \frac{1}{B_{sd}(s)}\frac{a^2}{24\pi^3}\frac{\sigma_0^2(s)}{R_0^4(s)}\frac{1}{A_2}\left[\frac{2}{(A_2-4A_1)^2}+\frac{A_2^2}{(A_2^2-4A_3^2)^2}\right]\times$$
$$\sum_q \frac{(\mathcal{C}_q^G)^2}{\pi^2}\int_{x_{bos1}}^1 d\alpha\left[\rho_q\left(\frac{x_{bos1}}{\alpha}\right)+\rho_{\bar q}\left(\frac{x_{bos1}}{\alpha}\right)\right]\left\{\left[(g_{v,q}^G)^2M^2(1-\alpha)^2+(g_{a,q}^G)^2\frac{\eta^4}{M^2}\right]J_1+\right.$$
$$\left.(g_{a,q}^G)^2\alpha^2 m_q^2\frac{\eta^2}{M^2}J_2\right\}.$$

Results: diffractive vs inclusive





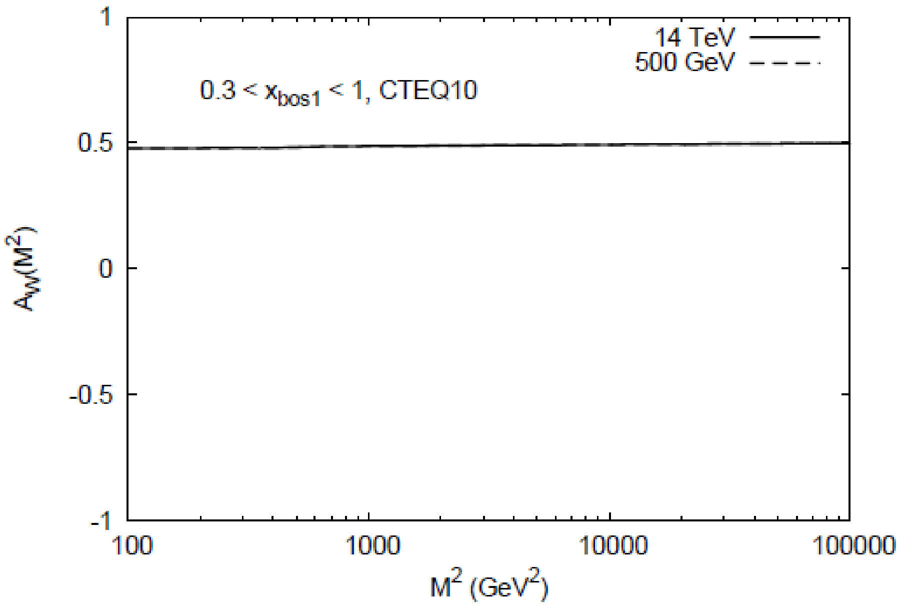
Energy/scale behavior is opposite from predicted by QCD factorisation-based approaches

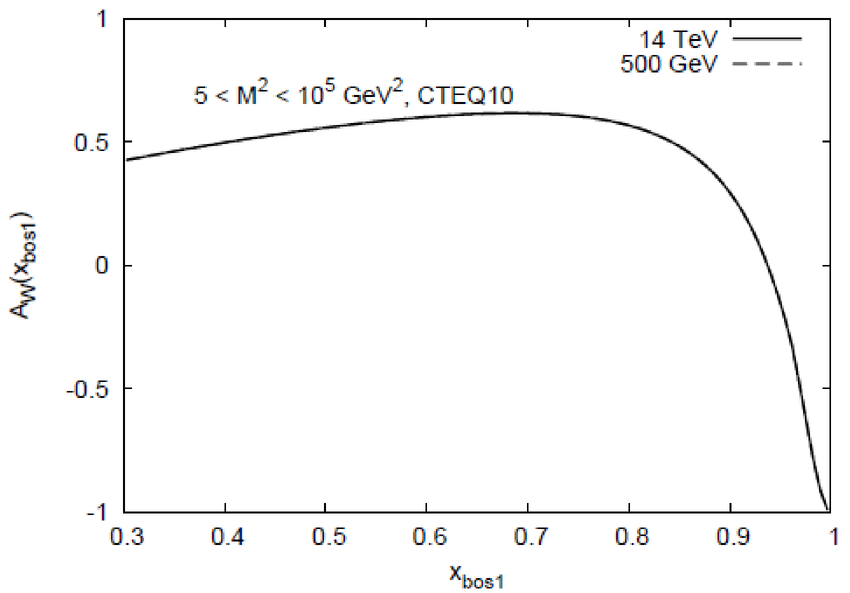


Agrees well with the Tevatron data!

Results: W charge asymmetry

Does not depend on energy and invariant mass!

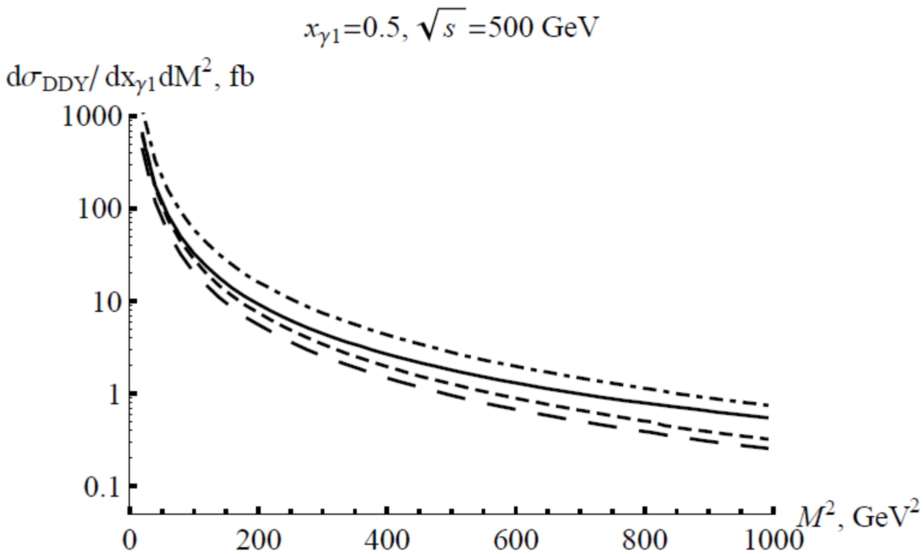


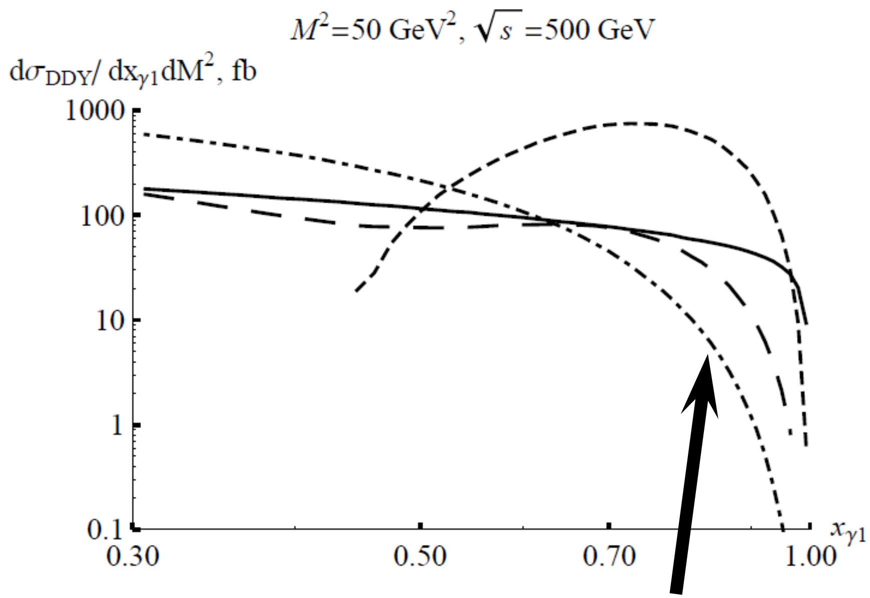


A good probe for QCD diffractive mechanism and soft interactions!

Results: theory uncertainties

Curves are given for different parametrizations of the proton structure function F2





Huge sensitivity to F2 parameterizations at small Q0 and large x!

DDY measurement can improve our understanding of the proton structure in the non-perturbative region

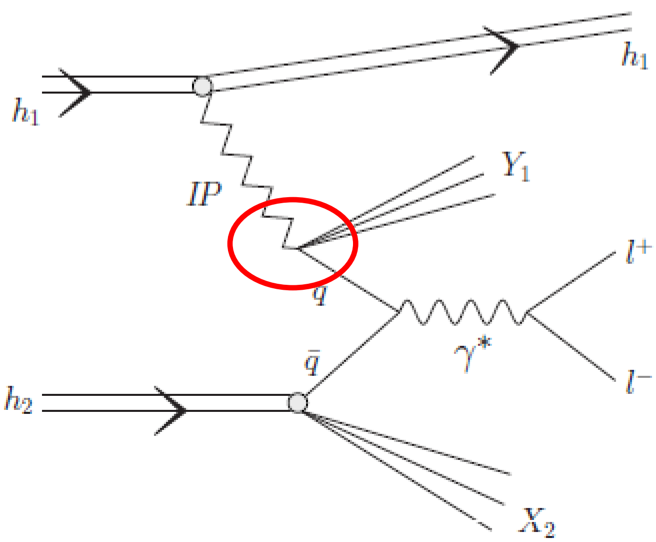
Other models: QCD factorisation approach to diffractive DY

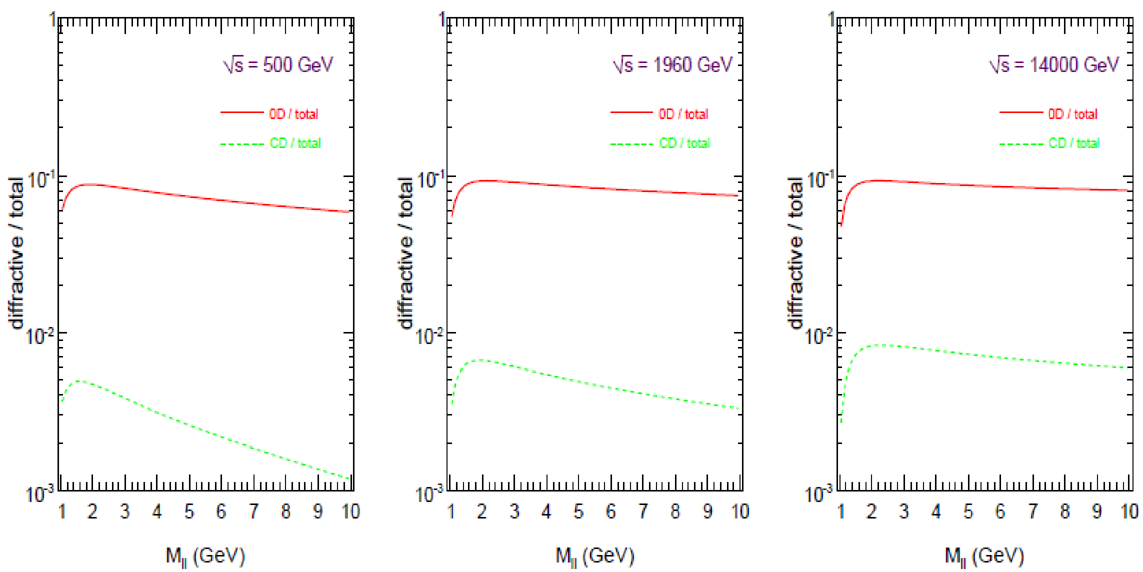
by G. Kubasiak and A. Szczurek, Phys.Rev.D84:014005,2011

Ingelman-Schein mechanism → QCD/Regge factorisation

Diffractive quark density

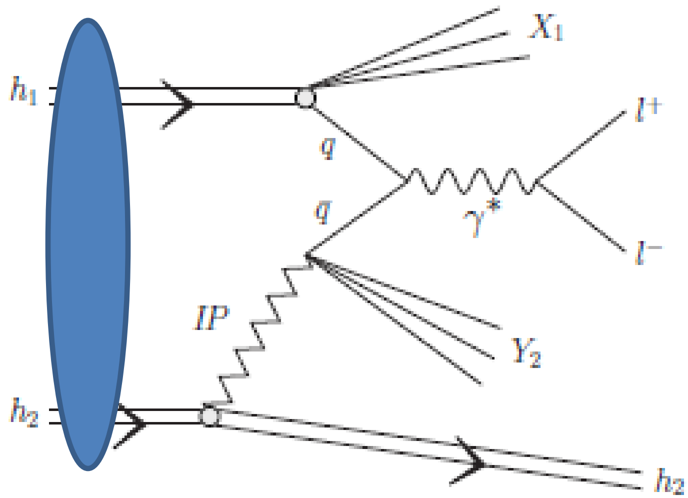
$$q_f^D(x,\mu^2) = \int_x^1 \frac{dx_{\mathbb{P}}}{x_{\mathbb{P}}} f_{\mathbb{P}}(x_{\mathbb{P}}) q_{f/\mathbb{P}}\left(\frac{x}{x_{\mathbb{P}}},\mu^2\right)$$

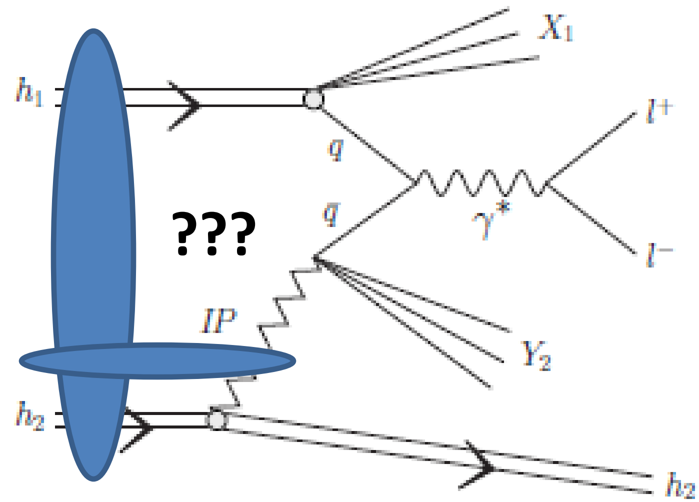




Regge factorization breaking and "enhanced" corrections

Absorptive effects destroy diffractive factorization in hadron-hadron scattering!





without the factorisation breaking:

Diffractive Z,W / Inclusive Z,W **~ 30 %**

with the factorisation breaking:

Diffractive Z,W / Inclusive Z,W **< 1 %**

Gay-Ducati et al Phys. Rev. D75, 114013 (2007)

Conclusions

- A quark **cannot radiate a boson** diffractively in the forward direction
- A hadron can radiate a boson diffractively in the forward direction because of **the transverse motion of quarks**
- The ratio diffractive/inclusive DY cross sections falls with energy and rises with dilepton mass due to **the saturated shape** of the dipole cross section
- Hard/soft interactions contribute to the diffractive gauge bosons production on the same footing leading to **breakdown of QCD factorisation**
- Experimental measurements of DDY 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 diffractive gauge bosons production is a good playground for **diffractive production of heavy flavors**