Diffractive parton density functions

Graeme Watt

DESY Hamburg

Ringberg Workshop: New Trends in HERA Physics 2005

In collaboration with A.D. Martin and M.G. Ryskin

Eur. Phys. J. C **44** (2005) 69 (`hep-ph/0504132`)
Eur. Phys. J. C **37** (2004) 285 (`hep-ph/0406224`)

Outline

- Diffractive deep-inelastic scattering (DDIS) is characterised by a large rapidity gap due to Pomeron (vacuum quantum number) exchange.
- How do we extract diffractive parton density functions (DPDFs) from DDIS data?

1. Demise of the 'Regge factorisation' approach currently used by H1/ZEUS, where the exchanged Pomeron is treated as a hadron-like object.
2. Rise of the 'perturbative QCD' approach, where the exchanged Pomeron is a parton ladder. Treatment of **diffractive** PDFs has more in common with **photon** PDFs than **proton** PDFs.

Outline

- Diffractive deep-inelastic scattering (DDIS) is characterised by a large rapidity gap due to Pomeron (vacuum quantum number) exchange.
- How do we extract diffractive parton density functions (DPDFs) from DDIS data?

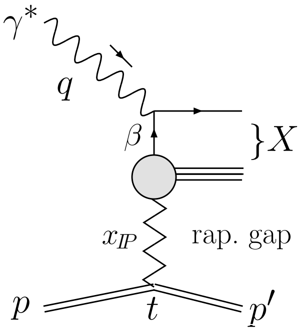
1. Demise of the 'Regge factorisation' approach currently used by H1/ZEUS, where the exchanged Pomeron is treated as a hadron-like object.
2. Rise of the 'perturbative QCD' approach, where the exchanged Pomeron is a parton ladder. Treatment of **diffractive** PDFs has more in common with **photon** PDFs than **proton** PDFs.

Outline

- Diffractive deep-inelastic scattering (DDIS) is characterised by a large rapidity gap due to Pomeron (vacuum quantum number) exchange.
- How do we extract diffractive parton density functions (DPDFs) from DDIS data?

1. Demise of the 'Regge factorisation' approach currently used by H1/ZEUS, where the exchanged Pomeron is treated as a hadron-like object.
2. Rise of the 'perturbative QCD' approach, where the exchanged Pomeron is a parton ladder. Treatment of **diffractive** PDFs has more in common with **photon** PDFs than **proton** PDFs.

Diffractive DIS kinematics



- $q^2 \equiv -Q^2$
- $W^2 \equiv (q+p)^2 = -Q^2 + 2\,p\cdot q$
  $\Rightarrow \quad x_B \equiv \frac{Q^2}{2\,p\cdot q} = \frac{Q^2}{Q^2+W^2}$ (fraction of proton's momentum carried by struck quark)
- $t \equiv (p-p')^2 \approx 0$, $(p-p') \approx x_{\mathbb{P}}\, p$
- $M_X^2 \equiv (q+p-p')^2 = -Q^2 + x_{\mathbb{P}}(Q^2+W^2)$
  $\Rightarrow \quad x_{\mathbb{P}} = \frac{Q^2+M_X^2}{Q^2+W^2}$
  (fraction of proton's momentum carried by Pomeron)
- $\beta \equiv \frac{x_B}{x_{\mathbb{P}}} = \frac{Q^2}{Q^2+M_X^2}$ (fraction of Pomeron's momentum carried by struck quark)

Diffractive structure function $F_2^{\mathrm{D}(3)}$

- Diffractive cross section (integrated over t):

$$\frac{\mathrm{d}^3\sigma^{\mathrm{D}}}{\mathrm{d}x_{\mathbb{P}}\,\mathrm{d}\beta\,\mathrm{d}Q^2} = \frac{2\pi\alpha_{\mathrm{em}}^2}{\beta Q^4}\left[1+(1-y)^2\right]\sigma_r^{\mathrm{D}(3)}(x_{\mathbb{P}},\beta,Q^2),$$

where $y = Q^2/(x_B s)$, $s = 4E_eE_p$, and

$$\sigma_r^{\mathrm{D}(3)} = F_2^{\mathrm{D}(3)} - \frac{y^2}{1+(1-y)^2}F_L^{\mathrm{D}(3)} \approx F_2^{\mathrm{D}(3)}(x_{\mathbb{P}},\beta,Q^2),$$

for small y or assuming that $F_L^{\mathrm{D}(3)} \ll F_2^{\mathrm{D}(3)}$

- Measurements of $F_2^{\mathrm{D}(3)} \Rightarrow$ *diffractive* parton distribution functions (DPDFs)

$$a^{\mathrm{D}}(x_{\mathbb{P}},z,Q^2) = zq^{\mathrm{D}}(x_{\mathbb{P}},z,Q^2) \text{ or } zg^{\mathrm{D}}(x_{\mathbb{P}},z,Q^2),$$

where $\beta \leq z \leq 1$, cf. $x_B \leq x \leq 1$ in DIS.

Collinear factorisation in DDIS

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} + \mathcal{O}(1/Q), \tag{1}$$

where $C_{2,a}$ are the **same** coefficient functions as in inclusive DIS and where $a^{\mathrm{D}} = zq^{\mathrm{D}}$ or zg^{D} satisfy DGLAP evolution in Q^2:

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} \tag{2}$$

"The factorisation theorem applies when Q is made large while x_B, $x_{\mathbb{P}}$, and t are held fixed." [Collins,'98]

- Says **nothing** about the mechanism for diffraction: what **is** the colourless exchange ('Pomeron') which **causes** the large rapidity gap. Assuming a 'QCD Pomeron' we need to modify both (1) and (2).
- Factorisation is broken in hadron–hadron collisions, but hope that same formalism can be applied with extra suppression factor calculable from eikonal models.
- LO diffractive dijet photoproduction: resolved photon contribution should be suppressed. Complications at NLO → talk by M. Klasen.

Collinear factorisation in DDIS

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} + \mathcal{O}(1/Q), \quad (1)$$

where $C_{2,a}$ are the **same** coefficient functions as in inclusive DIS and where $a^{\mathrm{D}} = zq^{\mathrm{D}}$ or zg^{D} satisfy DGLAP evolution in Q^2:

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} \quad (2)$$

"The factorisation theorem applies when Q is made large while x_B, $x_{\mathbb{P}}$, and t are held fixed." [Collins,'98]

- Says **nothing** about the mechanism for diffraction: what **is** the colourless exchange ('Pomeron') which **causes** the large rapidity gap. Assuming a 'QCD Pomeron' we need to modify both (1) and (2).
- Factorisation is broken in hadron–hadron collisions, but hope that same formalism can be applied with extra suppression factor calculable from eikonal models.
- LO diffractive dijet photoproduction: resolved photon contribution should be suppressed. Complications at NLO → talk by M. Klasen.

Collinear factorisation in DDIS

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} + \mathcal{O}(1/Q), \tag{1}$$

where $C_{2,a}$ are the **same** coefficient functions as in inclusive DIS and where $a^{\mathrm{D}} = zq^{\mathrm{D}}$ or zg^{D} satisfy DGLAP evolution in Q^2:

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} \tag{2}$$

"The factorisation theorem applies when Q is made large while x_B, $x_{\mathbb{P}}$, and t are held fixed." [Collins,'98]

- Says **nothing** about the mechanism for diffraction: what **is** the colourless exchange ('Pomeron') which **causes** the large rapidity gap. Assuming a 'QCD Pomeron' we need to modify both (1) and (2).
- Factorisation is broken in hadron–hadron collisions, but hope that same formalism can be applied with extra suppression factor calculable from eikonal models.
- LO diffractive dijet photoproduction: resolved photon contribution should be suppressed. Complications at NLO $\rightarrow$ talk by M. Klasen.

Collinear factorisation in DDIS

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} + \mathcal{O}(1/Q), \tag{1}$$

where $C_{2,a}$ are the **same** coefficient functions as in inclusive DIS and where $a^{\mathrm{D}} = zq^{\mathrm{D}}$ or zg^{D} satisfy DGLAP evolution in Q^2:

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} \tag{2}$$

"The factorisation theorem applies when Q is made large while x_B, $x_{\mathbb{P}}$, and t are held fixed." [Collins,'98]

- Says **nothing** about the mechanism for diffraction: what **is** the colourless exchange ('Pomeron') which **causes** the large rapidity gap. Assuming a 'QCD Pomeron' we need to modify both (1) and (2).
- Factorisation is broken in hadron–hadron collisions, but hope that same formalism can be applied with extra suppression factor calculable from eikonal models.
- LO diffractive dijet photoproduction: resolved photon contribution should be suppressed. Complications at NLO → talk by M. Klasen.

H1 extraction of DPDFs (ZEUS similar)

- Assume Regge factorisation [Ingelman–Schlein,'85]:

$$a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)$$

- Pomeron flux factor from Regge phenomenology:

$$f_{\mathbb{P}}(x_{\mathbb{P}}) = \int_{t_{\mathrm{cut}}}^{t_{\mathrm{min}}} \mathrm{d}t\; \mathrm{e}^{B_{\mathbb{P}}\,t}\; x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)} \qquad (\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}}\,t)$$

"Regge factorisation relates the power of $x_{\mathbb{P}}$ measured in DDIS to the power of s measured in hadron–hadron elastic scattering." [Collins,'98]

- Fit to H1 $F_2^{\mathrm{D}(3)}$ data gives $\alpha_{\mathbb{P}}(0) = 1.17 > 1.08$, the value of the 'soft Pomeron' [Donnachie–Landshoff,'92]. By Collins' definition, Regge factorisation is broken. H1/ZEUS meaning of 'Regge factorisation' is that the $x_{\mathbb{P}}$ dependence factorises as a power law, with the power independent of β and Q^2 (also broken, see later).
- Pomeron PDFs $a^{\mathbb{P}}(z, Q^2) = z\Sigma^{\mathbb{P}}(z, Q^2)$ or $zg^{\mathbb{P}}(z, Q^2)$ are DGLAP-evolved from inputs at $Q_0^2 = 3$ GeV^2:

$$a^{\mathbb{P}}(z, Q_0^2) = \left[A_a + B_a(2z-1) + C_a\left(2(2z-1)^2 - 1\right)\right]^2 \exp(-0.01/(1-z))$$

H1 extraction of DPDFs (ZEUS similar)

- Assume Regge factorisation [Ingelman–Schlein,'85]:

$$a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)$$

- Pomeron flux factor from Regge phenomenology:

$$f_{\mathbb{P}}(x_{\mathbb{P}}) = \int_{t_{\mathrm{cut}}}^{t_{\mathrm{min}}} \mathrm{d}t\; \mathrm{e}^{B_{\mathbb{P}}\, t}\; x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)} \qquad (\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}}\, t)$$

"Regge factorisation relates the power of $x_{\mathbb{P}}$ measured in DDIS to the power of s measured in hadron–hadron elastic scattering." [Collins,'98]

- Fit to H1 $F_2^{\mathrm{D}(3)}$ data gives $\alpha_{\mathbb{P}}(0) = 1.17 > 1.08$, the value of the 'soft Pomeron' [Donnachie–Landshoff,'92]. By Collins' definition, Regge factorisation is broken. H1/ZEUS meaning of 'Regge factorisation' is that the $x_{\mathbb{P}}$ dependence factorises as a power law, with the power independent of β and Q^2 (also broken, see later).
- Pomeron PDFs $a^{\mathbb{P}}(z, Q^2) = z\Sigma^{\mathbb{P}}(z, Q^2)$ or $zg^{\mathbb{P}}(z, Q^2)$ are DGLAP-evolved from inputs at $Q_0^2 = 3$ GeV^2:

$$a^{\mathbb{P}}(z, Q_0^2) = \left[A_a + B_a(2z-1) + C_a\left(2(2z-1)^2 - 1\right)\right]^2 \exp(-0.01/(1-z))$$

H1 extraction of DPDFs (ZEUS similar)

- Assume Regge factorisation [Ingelman–Schlein,'85]:

$$a^{\rm D}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)$$

- Pomeron flux factor from Regge phenomenology:

$$f_{\mathbb{P}}(x_{\mathbb{P}}) = \int_{t_{\rm cut}}^{t_{\rm min}} {\rm d}t\; {\rm e}^{B_{\mathbb{P}}\, t}\; x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)} \qquad (\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}}\, t)$$

"Regge factorisation relates the power of $x_{\mathbb{P}}$ measured in DDIS to the power of s measured in hadron–hadron elastic scattering." [Collins,'98]

- Fit to H1 $F_2^{\rm D(3)}$ data gives $\alpha_{\mathbb{P}}(0) = 1.17 > 1.08$, the value of the 'soft Pomeron' [Donnachie–Landshoff,'92]. By Collins' definition, Regge factorisation is broken. H1/ZEUS meaning of 'Regge factorisation' is that the $x_{\mathbb{P}}$ dependence factorises as a power law, with the power independent of β and Q^2 (also broken, see later).
- Pomeron PDFs $a^{\mathbb{P}}(z, Q^2) = z\Sigma^{\mathbb{P}}(z, Q^2)$ or $zg^{\mathbb{P}}(z, Q^2)$ are DGLAP-evolved from inputs at $Q_0^2 = 3$ GeV^2:

$$a^{\mathbb{P}}(z, Q_0^2) = \left[A_a + B_a(2z-1) + C_a\left(2(2z-1)^2 - 1\right)\right]^2 \exp(-0.01/(1-z))$$

H1 extraction of DPDFs (ZEUS similar)

- Assume Regge factorisation [Ingelman–Schlein,'85]:

$$a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)$$

- Pomeron flux factor from Regge phenomenology:

$$f_{\mathbb{P}}(x_{\mathbb{P}}) = \int_{t_{\mathrm{cut}}}^{t_{\mathrm{min}}} \mathrm{d}t\ \mathrm{e}^{B_{\mathbb{P}}\, t}\ x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)} \qquad (\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}}\, t)$$

"Regge factorisation relates the power of $x_{\mathbb{P}}$ measured in DDIS to the power of s measured in hadron–hadron elastic scattering." [Collins,'98]

- Fit to H1 $F_2^{\mathrm{D}(3)}$ data gives $\alpha_{\mathbb{P}}(0) = 1.17 > 1.08$, the value of the 'soft Pomeron' [Donnachie–Landshoff,'92]. By Collins' definition, Regge factorisation is broken. H1/ZEUS meaning of 'Regge factorisation' is that the $x_{\mathbb{P}}$ dependence factorises as a power law, with the power independent of β and Q^2 (also broken, see later).
- Pomeron PDFs $a^{\mathbb{P}}(z, Q^2) = z\Sigma^{\mathbb{P}}(z, Q^2)$ or $zg^{\mathbb{P}}(z, Q^2)$ are DGLAP-evolved from inputs at $Q_0^2 = 3\ \mathrm{GeV}^2$:

$$a^{\mathbb{P}}(z, Q_0^2) = \left[A_a + B_a(2z-1) + C_a\left(2(2z-1)^2 - 1\right)\right]^2 \exp(-0.01/(1-z))$$

H1 extraction of DPDFs (ZEUS similar)

- Assume Regge factorisation [Ingelman–Schlein,'85]:

$$\boxed{a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, a^{\mathbb{P}}(z, Q^2)}$$

- Pomeron flux factor from Regge phenomenology:

$$\boxed{f_{\mathbb{P}}(x_{\mathbb{P}}) = \int_{t_{\mathrm{cut}}}^{t_{\mathrm{min}}} \mathrm{d}t\; \mathrm{e}^{B_{\mathbb{P}}\,t}\; x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)}} \qquad \left(\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}}\,t\right)$$

"Regge factorisation relates the power of $x_{\mathbb{P}}$ measured in DDIS to the power of s measured in hadron–hadron elastic scattering." [Collins,'98]

- Fit to H1 $F_2^{\mathrm{D}(3)}$ data gives $\alpha_{\mathbb{P}}(0) = 1.17 > 1.08$, the value of the 'soft Pomeron' [Donnachie–Landshoff,'92]. By Collins' definition, Regge factorisation is broken. H1/ZEUS meaning of 'Regge factorisation' is that the $x_{\mathbb{P}}$ dependence factorises as a power law, with the power independent of β and Q^2 (also broken, see later).
- Pomeron PDFs $a^{\mathbb{P}}(z, Q^2) = z\Sigma^{\mathbb{P}}(z, Q^2)$ or $zg^{\mathbb{P}}(z, Q^2)$ are DGLAP-evolved from inputs at $Q_0^2 = 3$ GeV^2:

$$a^{\mathbb{P}}(z, Q_0^2) = \left[A_a + B_a(2z-1) + C_a\left(2(2z-1)^2 - 1\right)\right]^2 \exp(-0.01/(1-z))$$

Recent measurements of DDIS → talk by L. Favart

1. Detect leading proton. No proton dissociation background, but low statistics. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [ZEUS: Eur. Phys. J. C **38** (2004) 43, H1prelim-01-112]
2. Look for large rapidity gap (LRG). (Non-diffractive contribution is exponentially suppressed as a function of the gap size.) Proton dissociation background. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [H1prelim-02-012, H1prelim-02-112, H1prelim-03-011]
3. Use "M_X method". Subtract non-diffractive contribution in each (W, Q^2) bin by fitting:

$$\frac{\mathrm{d}N}{\mathrm{d}\ln M_X^2} = D + \underbrace{c\exp(b\ln M_X^2)}_{\text{non-diffractive}}$$

   Motivated by Regge theory assuming $t = 0$, $\alpha_{\mathbb{P}}(0) \equiv 1$, $Q^2 \ll M_X^2$. (Validity in pQCD?) Proton dissociation background. Only $\mathbb{P}$ contribution. [ZEUS: Nucl. Phys. B **713** (2005) 3]

Are these three methods compatible?

Recent measurements of DDIS → talk by L. Favart

1. Detect leading proton. No proton dissociation background, but low statistics. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [ZEUS: Eur. Phys. J. C **38** (2004) 43, H1prelim-01-112]
2. Look for large rapidity gap (LRG). (Non-diffractive contribution is exponentially suppressed as a function of the gap size.) Proton dissociation background. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [H1prelim-02-012, H1prelim-02-112, H1prelim-03-011]
3. Use "M_X method". Subtract non-diffractive contribution in each (W, Q^2) bin by fitting:

$$\frac{\mathrm{d}N}{\mathrm{d}\ln M_X^2} = D + \underbrace{c\exp(b\ln M_X^2)}_{\text{non-diffractive}}$$

   Motivated by Regge theory assuming $t = 0$, $\alpha_{\mathbb{P}}(0) \equiv 1$, $Q^2 \ll M_X^2$. (Validity in pQCD?) Proton dissociation background. Only $\mathbb{P}$ contribution. [ZEUS: Nucl. Phys. B **713** (2005) 3]

Are these three methods compatible?

Recent measurements of DDIS $\rightarrow$ talk by L. Favart

1. Detect leading proton. No proton dissociation background, but low statistics. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [ZEUS: Eur. Phys. J. C **38** (2004) 43, H1prelim-01-112]
2. Look for large rapidity gap (LRG). (Non-diffractive contribution is exponentially suppressed as a function of the gap size.) Proton dissociation background. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [H1prelim-02-012, H1prelim-02-112, H1prelim-03-011]
3. Use "M_X method". Subtract non-diffractive contribution in each (W, Q^2) bin by fitting:

$$\frac{\mathrm{d}N}{\mathrm{d}\ln M_X^2} = D + \underbrace{c\,\exp(b\ln M_X^2)}_{\text{non-diffractive}}$$

   Motivated by Regge theory assuming $t = 0$, $\alpha_{\mathbb{P}}(0) \equiv 1$, $Q^2 \ll M_X^2$. (Validity in pQCD?) Proton dissociation background. Only $\mathbb{P}$ contribution. [ZEUS: Nucl. Phys. B **713** (2005) 3]

Are these three methods compatible?

Recent measurements of DDIS → talk by L. Favart

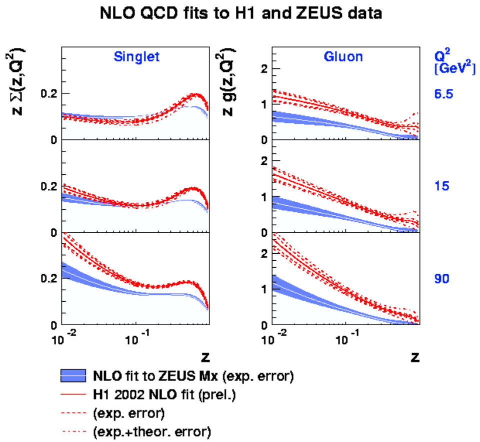
1. Detect leading proton. No proton dissociation background, but low statistics. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [ZEUS: Eur. Phys. J. C **38** (2004) 43, H1prelim-01-112]
2. Look for large rapidity gap (LRG). (Non-diffractive contribution is exponentially suppressed as a function of the gap size.) Proton dissociation background. Both $\mathbb{P}$ and $\mathbb{R}$ contributions. [H1prelim-02-012, H1prelim-02-112, H1prelim-03-011]
3. Use "M_X method". Subtract non-diffractive contribution in each (W, Q^2) bin by fitting:

$$\frac{\mathrm{d}N}{\mathrm{d}\ln M_X^2} = D + \underbrace{c\,\exp(b\ln M_X^2)}_{\text{non-diffractive}}$$

   Motivated by Regge theory assuming $t = 0$, $\alpha_{\mathbb{P}}(0) \equiv 1$, $Q^2 \ll M_X^2$. (Validity in pQCD?) Proton dissociation background. Only $\mathbb{P}$ contribution. [ZEUS: Nucl. Phys. B **713** (2005) 3]

Are these three methods compatible?

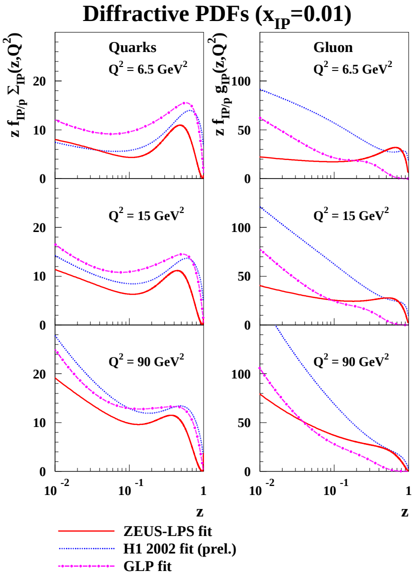
H1 vs. ZEUS M_X DPDFs



Fits and plot by F.-P. Schilling (H1)

- Same procedure used to fit H1 LRG and ZEUS M_X data. (ZEUS M_X data scaled by a constant factor to account for different amount of proton dissociation.)
- Gluon from ZEUS M_X fit $\sim$ factor two smaller than gluon from H1 LRG data, due to different Q^2 dependence of the data sets. H1 2002 fit gives good agreement with (LRG) DDIS dijet and D^* production data.
- N.B. 2-loop α_S fixed by $\Lambda_{\rm QCD} = 200$ MeV for 4 flavours. Gives α_S values much smaller than world average $\Rightarrow$ H1 2002 gluon artificially enhanced. Will be corrected for H1 publication.

H1 vs. ZEUS M_X vs. ZEUS LPS DPDFs



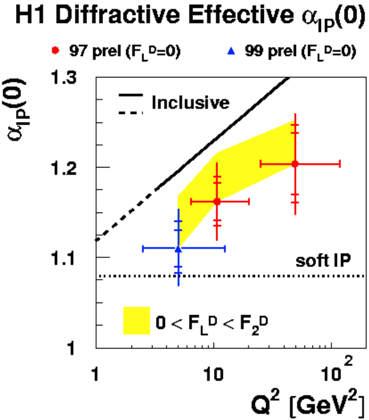
Plot by T. Tawara (ZEUS)

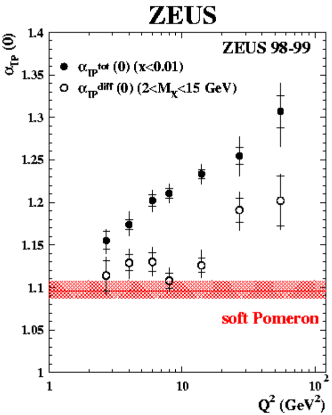
- No correction made for different amounts of proton dissociation.
- GLP = Groys–Levy–Proskuryakov (ZEUS) fit to ZEUS M_X data, gives much too low prediction for ZEUS (LRG) DDIS dijets.
- ZEUS LPS fit describes dijets well, but:

"The shape of the fitted PDFs changes significantly depending on the functional form of the initial parameterisation, a consequence of the relatively large statistical uncertainties of the present sample. ***Therefore, these data cannot constrain the shapes of the PDFs.****"*

[ZEUS: Eur. Phys. J. C **38** *(2004) 43]*

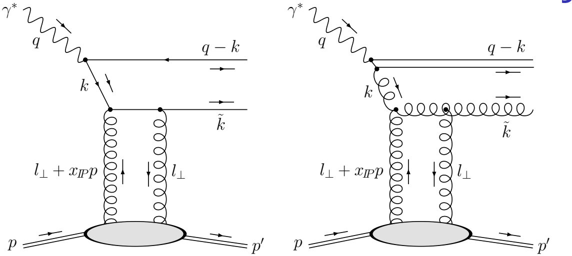
Q^2 dependence of effective Pomeron intercept





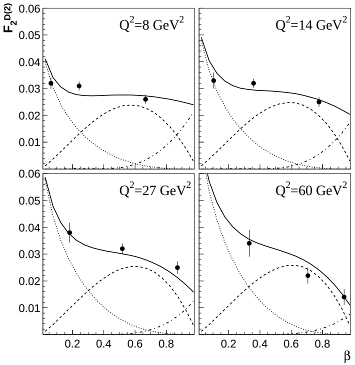
- Recall that 'Regge factorisation' fits assume that $\alpha_{\mathbb{P}}(0)$ is independent of β and Q^2.
- $\alpha_{\mathbb{P}}(0)$ clearly rises with Q^2, but is smaller than in inclusive DIS, indicating that the $x_{\mathbb{P}}$ dependence is controlled by some scale $\mu^2 < Q^2$.
- $\alpha_{\mathbb{P}}(0) > 1.08$ [Donnachie–Landshoff,'92] indicating that the Pomeron in DDIS is not the 'soft' Pomeron exchanged in hadron–hadron collisions $\Rightarrow$ should use pQCD instead of Regge phenomenology. In pQCD, Pomeron exchange can be described by two-gluon exchange.

How to reconcile two-gluon exchange with DPDFs?



Two-gluon exchange calculations are the basis for the colour dipole model description of DDIS (→ talk by G. Shaw).

ZEUS 1994

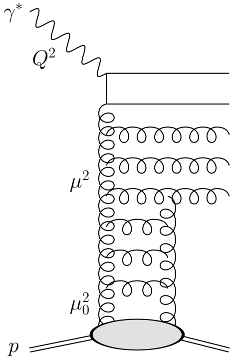


- Right: $x_{\mathbb{P}} F_2^{D(3)}$ for $x_{\mathbb{P}} = 0.0042$ as a function of β [Golec-Biernat–Wüsthoff,'99].
  - dotted lines: $\gamma_T^* \to q\bar{q}g$,
  - dashed lines: $\gamma_T^* \to q\bar{q}$,
  - dot-dashed lines: $\gamma_L^* \to q\bar{q}$,

  important at low, medium, and high β respectively.
- $\gamma_L^* \to q\bar{q}$ is higher-twist, but DPDFs only include leading-twist contributions, therefore H1/ZEUS DPDFs are artificially large at high z.

The QCD Pomeron is a parton ladder

- Generalise $\gamma^* \to q\bar{q}$ and $\gamma^* \to q\bar{q}g$ to arbitrary number of parton emissions [Ryskin,'90; Levin–Wüsthoff,'94].
- Work in Leading Logarithmic Approximation (LLA) $\Rightarrow$ transverse momenta are strongly ordered.



- **New feature:** integral over scale μ^2 (starting scale for DGLAP evolution of Pomeron PDFs).

$$F_2^{\mathrm{D}(3)} = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2} \, f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2) \, F_2^{\mathbb{P}}(\beta, Q^2; \mu^2)$$

$$f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2) = \frac{1}{x_{\mathbb{P}} B_D} \left[R_g \, \frac{\alpha_S(\mu^2)}{\mu} \, x_{\mathbb{P}} g(x_{\mathbb{P}}, \mu^2) \right]^2$$

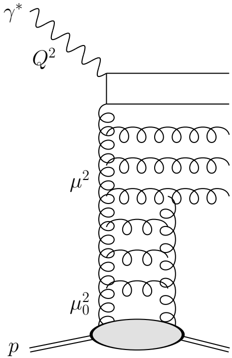
$$F_2^{\mathbb{P}}(\beta, Q^2; \mu^2) = \sum_{a=q,g} C_{2,a} \otimes a^{\mathbb{P}}$$

$\mu_0^2 \sim 1$ GeV^2, B_D from t-integration, R_g from skewedness [Shuvaev *et al.*,'99]

- Pomeron PDFs $a^{\mathbb{P}}(z, Q^2; \mu^2)$ DGLAP-evolved from an input scale μ^2 up to Q^2.

The QCD Pomeron is a parton ladder

- Generalise $\gamma^* \to q\bar{q}$ and $\gamma^* \to q\bar{q}g$ to arbitrary number of parton emissions [Ryskin,'90; Levin–Wüsthoff,'94].
- Work in Leading Logarithmic Approximation (LLA) $\Rightarrow$ transverse momenta are strongly ordered.



- **New feature:** integral over scale μ^2 (starting scale for DGLAP evolution of Pomeron PDFs).

$$F_2^{\mathrm{D}(3)} = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2)\, F_2^{\mathbb{P}}(\beta, Q^2;\mu^2)$$

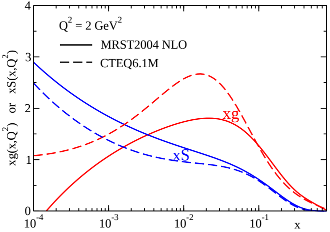
$$f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2) = \frac{1}{x_{\mathbb{P}} B_D}\left[R_g \frac{\alpha_S(\mu^2)}{\mu}\, x_{\mathbb{P}} g(x_{\mathbb{P}},\mu^2)\right]^2$$

$$F_2^{\mathbb{P}}(\beta, Q^2;\mu^2) = \sum_{a=q,g} C_{2,a} \otimes a^{\mathbb{P}}$$

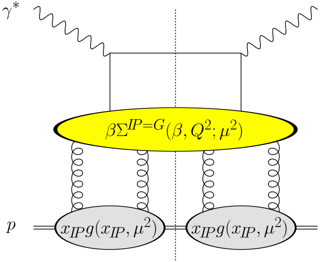
$\mu_0^2 \sim 1$ GeV^2, B_D from t-integration, R_g from skewedness [Shuvaev *et al.*,'99]

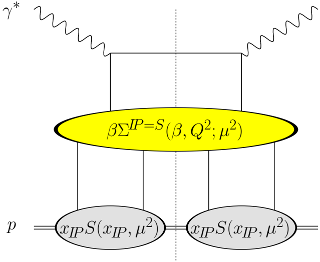
- Pomeron PDFs $a^{\mathbb{P}}(z, Q^2;\mu^2)$ DGLAP-evolved from an input scale μ^2 up to Q^2.

Gluonic and sea-quark Pomeron



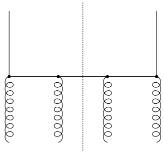
- At low scales, sea-quark density of the proton dominates over gluon density at small x $\Rightarrow$ need to account for sea-quark density in perturbative Pomeron flux factor.





- Pomeron structure function $F_2^{\mathbb{P}}(\beta, Q^2; \mu^2)$ calculated from quark singlet $\Sigma^{\mathbb{P}}(z, Q^2; \mu^2)$ and gluon $g^{\mathbb{P}}(z, Q^2; \mu^2)$ DGLAP-evolved from an input scale μ^2 up to Q^2.
- Input Pomeron PDFs $\Sigma^{\mathbb{P}}(z, \mu^2; \mu^2)$ and $g^{\mathbb{P}}(z, \mu^2; \mu^2)$ are Pomeron-to-parton splitting functions.

LO Pomeron-to-parton splitting functions



- LO Pomeron-to-parton splitting functions calculated in Eur. Phys. J. C **44** (2005) 69.
- **Notation:** '$\mathbb{P} = G$' means gluonic Pomeron, '$\mathbb{P} = S$' means sea-quark Pomeron, '$\mathbb{P} = GS$' means interference between these.

$$z\Sigma^{\mathbb{P}=G}(z,\mu^2;\mu^2) = P_{q,\mathbb{P}=G}(z) = z^3\,(1-z),$$

$$zg^{\mathbb{P}=G}(z,\mu^2;\mu^2) = P_{g,\mathbb{P}=G}(z) = \frac{9}{16}\,(1+z)^2\,(1-z)^2,$$

$$z\Sigma^{\mathbb{P}=S}(z,\mu^2;\mu^2) = P_{q,\mathbb{P}=S}(z) = \frac{4}{81}\,z\,(1-z),$$

$$zg^{\mathbb{P}=S}(z,\mu^2;\mu^2) = P_{g,\mathbb{P}=S}(z) = \frac{1}{9}\,(1-z)^2,$$

$$z\Sigma^{\mathbb{P}=GS}(z,\mu^2;\mu^2) = P_{q,\mathbb{P}=GS}(z) = \frac{2}{9}\,z^2\,(1-z),$$

$$zg^{\mathbb{P}=GS}(z,\mu^2;\mu^2) = P_{g,\mathbb{P}=GS}(z) = \frac{1}{4}\,(1+2z)\,(1-z)^2$$

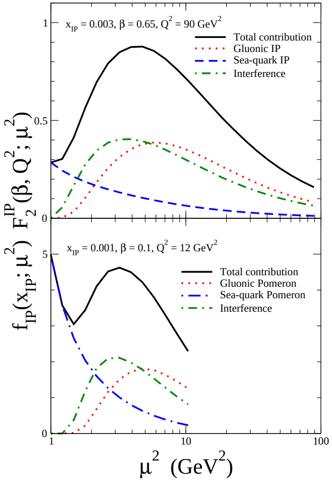
Evolve these input Pomeron PDFs from μ^2 up to Q^2 using NLO DGLAP evolution.

Contribution to $F_2^{\mathrm{D(3)}}$ as a function of μ^2

$$F_2^{\mathrm{D(3)}} = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2)\, F_2^{\mathbb{P}}(\beta,Q^2;\mu^2)$$

$$f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2) = \frac{1}{x_{\mathbb{P}} B_D}\left[R_g \frac{\alpha_S(\mu^2)}{\mu}\, x_{\mathbb{P}} g(x_{\mathbb{P}},\mu^2)\right]^2$$

- Naïvely, $f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2) \sim 1/\mu^2$, so contributions from large μ^2 are strongly suppressed.
- But $x_{\mathbb{P}} g(x_{\mathbb{P}},\mu^2) \sim (\mu^2)^\gamma$, where γ is the anomalous dimension. In BFKL limit $\gamma \simeq 0.5$, so $f_{\mathbb{P}}(x_{\mathbb{P}};\mu^2) \sim$ constant.
- HERA domain is in an intermediate region: γ is not small, but is less than 0.5.
- Plot integrand as a function of μ^2 (using MRST2001 NLO PDFs) $\Rightarrow$ large contribution from large μ^2.
- H1 (ZEUS) fits assume that $\mu^2 < Q_0^2$, where $Q_0^2 = 3$ (2) GeV^2 for H1 (ZEUS) fits.



Inhomogeneous evolution of DPDFs

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}},$$

$$\text{where } a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2) = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2)\, a^{\mathbb{P}}(z, Q^2; \mu^2)$$

$$\Longrightarrow \frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2) \frac{\partial a^{\mathbb{P}}}{\partial \ln Q^2} + f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2)\, a^{\mathbb{P}}(z, Q^2; \mu^2)\Big|_{\mu^2=Q^2}$$

$$= \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2) \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathbb{P}} + f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)\, a^{\mathbb{P}}(z, Q^2; Q^2)$$

$$= \underbrace{\sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}}}_{\text{DGLAP term}} + \underbrace{f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)\, P_{a\mathbb{P}}(z)}_{\text{Extra inhomogeneous term}}$$

Inhomogeneous evolution of DPDFs is **not a new idea**:

*"We introduce a diffractive dissociation structure function and show that it obeys the DGLAP evolution equation, **but**, with an additional inhomogeneous term." [Levin–Wüsthoff,'94]*

Inhomogeneous evolution of DPDFs

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}},$$

$$\text{where } a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2) = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2)\, a^{\mathbb{P}}(z, Q^2; \mu^2)$$

$$\Longrightarrow \frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2) \frac{\partial a^{\mathbb{P}}}{\partial \ln Q^2} + f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2)\, a^{\mathbb{P}}(z, Q^2; \mu^2)\Big|_{\mu^2 = Q^2}$$

$$= \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2) \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathbb{P}} + f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)\, a^{\mathbb{P}}(z, Q^2; Q^2)$$

$$= \underbrace{\sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}}}_{\text{DGLAP term}} + \underbrace{f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)\, P_{a\mathbb{P}}(z)}_{\text{Extra inhomogeneous term}}$$

Inhomogeneous evolution of DPDFs is **not a new idea**:

> *"We introduce a diffractive dissociation structure function and show that it obeys the DGLAP evolution equation, **but**, with an additional inhomogeneous term." [Levin–Wüsthoff,'94]*

Inhomogeneous evolution of DPDFs

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}},$$

$$\text{where } a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2) = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2)\, a^{\mathbb{P}}(z, Q^2; \mu^2)$$

$$\Longrightarrow \frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2) \frac{\partial a^{\mathbb{P}}}{\partial \ln Q^2} + f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2)\, a^{\mathbb{P}}(z, Q^2; \mu^2)\Big|_{\mu^2=Q^2}$$

$$= \int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}\mu^2}{\mu^2}\, f_{\mathbb{P}}(x_{\mathbb{P}}; \mu^2) \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathbb{P}} + f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)\, a^{\mathbb{P}}(z, Q^2; Q^2)$$

$$= \underbrace{\sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}}}_{\text{DGLAP term}} + \underbrace{f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)\, P_{a\mathbb{P}}(z)}_{\text{Extra inhomogeneous term}}$$

Inhomogeneous evolution of DPDFs is **not a new idea**:

> *"We introduce a diffractive dissociation structure function and show that it obeys the DGLAP evolution equation, **but**, with an additional inhomogeneous term." [Levin–Wüsthoff,'94]*

Pomeron structure is analogous to photon structure

Diffractive structure function

$$F_2^{\mathrm{D}(3)}(x_{\mathbb{P}}, \beta, Q^2) = \underbrace{\sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}}}_{\text{Resolved Pomeron}} + \underbrace{C_{2,\mathbb{P}}}_{\text{Direct Pomeron}}$$

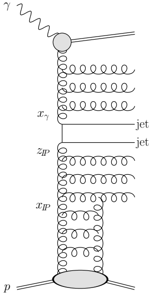
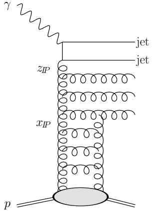
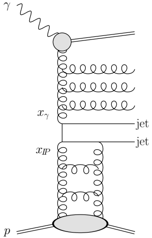
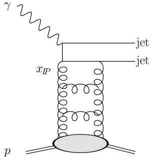
$$\frac{\partial a^{\mathrm{D}}(x_{\mathbb{P}}, z, Q^2)}{\partial \ln Q^2} = \underbrace{\sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}}}_{\text{DGLAP}} + \underbrace{P_{a\mathbb{P}}(z)\, f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)}_{\text{Inhomogeneous}}$$

Photon structure function

$$F_2^{\gamma}(x_B, Q^2) = \underbrace{\sum_{a=q,g} C_{2,a} \otimes a^{\gamma}}_{\text{Resolved photon}} + \underbrace{C_{2,\gamma}}_{\text{Direct photon}}$$

where $$\frac{\partial a^{\gamma}(x, Q^2)}{\partial \ln Q^2} = \underbrace{\sum_{a'=q,g} P_{aa'} \otimes a'^{\gamma}}_{\text{DGLAP}} + \underbrace{P_{a\gamma}(x)}_{\text{Inhomogeneous}}$$

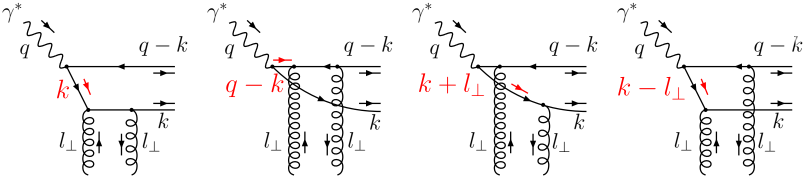
Dijets in diffractive photoproduction

<table>
<tr><th></th><th>Resolved photon
($x_\gamma < 1$)</th><th>Direct photon
($x_\gamma = 1$)</th></tr>
<tr><td>Resolved Pomeron
($z_\mathbb{P} < 1$)</td><td>
</td><td>
</td></tr>
<tr><td>Direct Pomeron
($z_\mathbb{P} = 1$)</td><td>
</td><td>
</td></tr>
</table>

- Effect of direct Pomeron coupling was considered by Kniehl–Kohrs–Kramer [Z. Phys. C **65** (1995) 657], but with Pomeron coupling to quarks like a photon: $\mathcal{L}_{\rm int} = c\,\bar{q}(x)\gamma_\mu q(x)\phi^\mu(x)$.

Need for NLO calculations

- NLO analysis of DDIS data is not yet possible.
- Need $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$ at NLO (help wanted!). Calculable with usual methods, e.g. LO diagrams are:

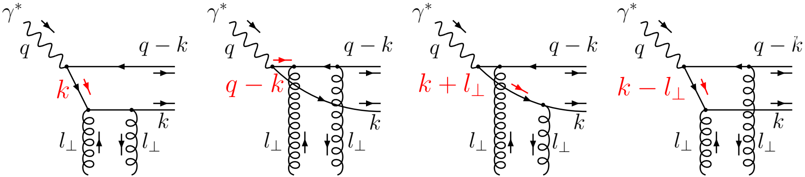


  Dimensional regularisation: work in $4-2\varepsilon$ dimensions, collinear singularity appears as $1/\varepsilon$ pole multiplied by $P_{q\mathbb{P}}$, subtract in e.g. $\overline{MS}$ factorisation scheme to leave finite remainder $C_{2,\mathbb{P}}$.

- **Simplified analysis:** take NLO $C_{2,a}$ and $P_{aa'}$ $(a, a' = q, g)$, but LO $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$.
  - Work in Fixed Flavour Number Scheme (no charm DPDF), with charm production via NLO $\gamma^* g^{\mathbb{P}} \to c\bar{c}$ [Riemersma *et al.*,'95] and LO $\gamma^* \mathbb{P} \to c\bar{c}$ [Levin–Martin–Ryskin–Teubner,'97].
  - For light quarks, include LO $\gamma_L^* \mathbb{P} \to q\bar{q}$ (higher-twist), but not $\gamma_T^* \mathbb{P} \to q\bar{q}$ (leading-twist).

Need for NLO calculations

- NLO analysis of DDIS data is not yet possible.
- Need $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$ at NLO (help wanted!). Calculable with usual methods, e.g. LO diagrams are:

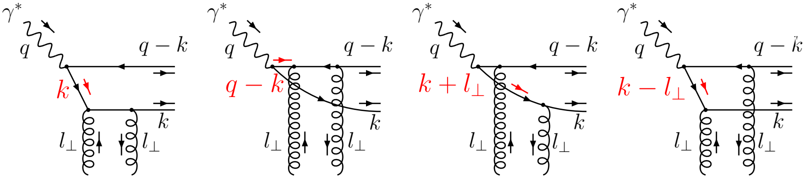


Dimensional regularisation: work in $4-2\varepsilon$ dimensions, collinear singularity appears as $1/\varepsilon$ pole multiplied by $P_{q\mathbb{P}}$, subtract in e.g. $\overline{MS}$ factorisation scheme to leave finite remainder $C_{2,\mathbb{P}}$.

- **Simplified analysis:** take NLO $C_{2,a}$ and $P_{aa'}$ $(a, a' = q, g)$, but LO $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$.
  - Work in Fixed Flavour Number Scheme (no charm DPDF), with charm production via NLO $\gamma^* g^{\mathbb{P}} \to c\bar{c}$ [Riemersma *et al.*,'95] and LO $\gamma^*\mathbb{P} \to c\bar{c}$ [Levin–Martin–Ryskin–Teubner,'97].
  - For light quarks, include LO $\gamma_L^*\mathbb{P} \to q\bar{q}$ (higher-twist), but not $\gamma_T^*\mathbb{P} \to q\bar{q}$ (leading-twist).

Need for NLO calculations

- NLO analysis of DDIS data is not yet possible.
- Need $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$ at NLO (help wanted!). Calculable with usual methods, e.g. LO diagrams are:



Dimensional regularisation: work in $4 - 2\varepsilon$ dimensions, collinear singularity appears as $1/\varepsilon$ pole multiplied by $P_{q\mathbb{P}}$, subtract in e.g. $\overline{MS}$ factorisation scheme to leave finite remainder $C_{2,\mathbb{P}}$.

- **Simplified analysis:** take NLO $C_{2,a}$ and $P_{aa'}$ $(a, a' = q, g)$, but LO $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$.
  - Work in Fixed Flavour Number Scheme (no charm DPDF), with charm production via NLO $\gamma^* g^{\mathbb{P}} \to c\bar{c}$ [Riemersma *et al.*,'95] and LO $\gamma^* \mathbb{P} \to c\bar{c}$ [Levin–Martin–Ryskin–Teubner,'97].
  - For light quarks, include LO $\gamma_L^* \mathbb{P} \to q\bar{q}$ (higher-twist), but not $\gamma_T^* \mathbb{P} \to q\bar{q}$ (leading-twist).

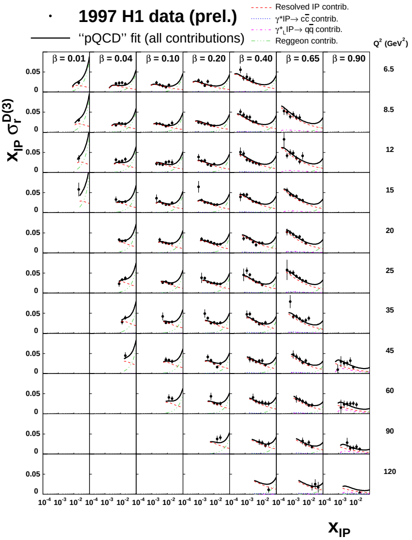
Description of DDIS data

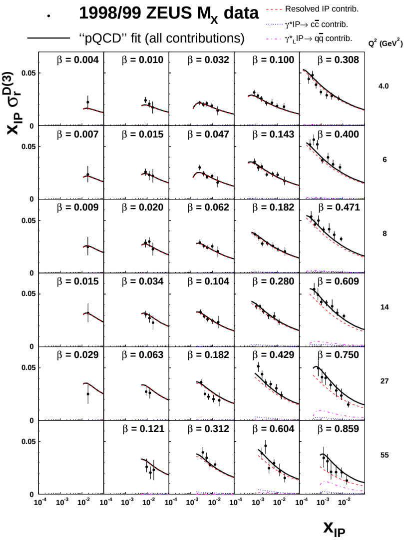
- Take input quark singlet and gluon densities at $Q_0^2 = 3\ \mathrm{GeV}^2$ in the form:

$$z\Sigma^{\mathrm{D}}(x_{\mathbb{P}}, z, Q_0^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, C_q\, z^{A_q}(1-z)^{B_q},$$
$$zg^{\mathrm{D}}(x_{\mathbb{P}}, z, Q_0^2) = f_{\mathbb{P}}(x_{\mathbb{P}})\, C_g\, z^{A_g}(1-z)^{B_g},$$

- Take $f_{\mathbb{P}}(x_{\mathbb{P}})$ as in the H1 2002 fit with $\alpha_{\mathbb{P}}(0)$, C_a, A_a, and B_a ($a = q, g$) as free parameters.
- Treatment of secondary Reggeon as in H1 2002 fit.
- Fit H1 LRG and ZEUS M_X data separately with cuts $M_X > 2$ GeV and $Q^2 > 3\ \mathrm{GeV}^2$. Allow overall normalisation factors of 1.10 and 1.43 respectively to account for proton dissociation.
- Statistical and systematic experimental errors added in quadrature.
- Two types of fits:
    - "Regge" = 'Regge factorisation' approach (i.e. no $C_{2,\mathbb{P}}$ or $P_{a\mathbb{P}}$) as H1/ZEUS do.
    - "pQCD" = 'perturbative QCD' approach with LO $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$.

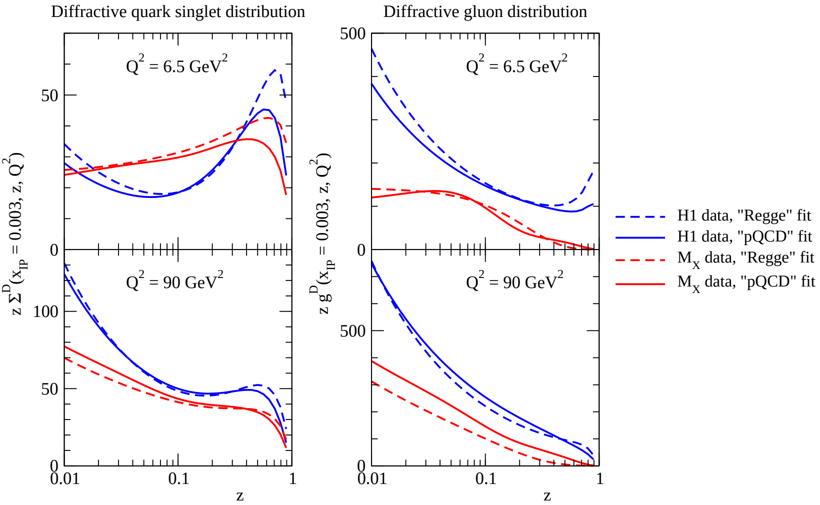
"pQCD" fits to H1 and ZEUS M_X data





- $\chi^2/\mathrm{d.o.f.} = 0.71$ (0.75 for "Regge" fit)
- $\chi^2/\mathrm{d.o.f.} = 0.84$ (0.76 for "Regge" fit)

DPDFs from fits to H1 and ZEUS M_X data

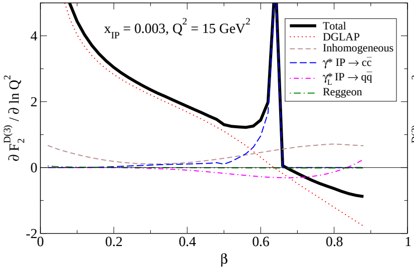


- "pQCD" DPDFs are smaller at large z due to inclusion of the higher-twist $\gamma_L^* \mathbb{P} \to q\bar{q}$.
- "pQCD" DPDFs have slightly more rapid evolution due to the inhomogeneous term.
- Difference between H1 and ZEUS M_X fits remains.

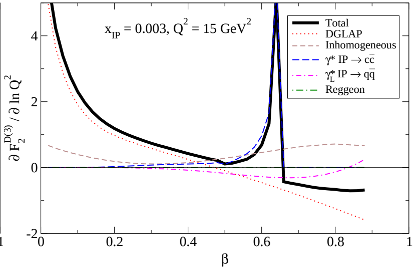
Q^2 slope of H1 vs. ZEUS M_X data

At LO, $$\frac{\partial F_2^{\mathrm{D(3)}}}{\partial \ln Q^2} = \sum_q e_q^2 \left(\sum_{a'=q,g} P_{qa'} \otimes a'^{\mathrm{D}} + P_{a\mathbb{P}} f_{\mathbb{P}} \right) + (\gamma^* \mathbb{P} \to c\bar{c}) + (\gamma_L^* \mathbb{P} \to q\bar{q}) + \mathbb{R}.$$

"pQCD" fit to H1 data



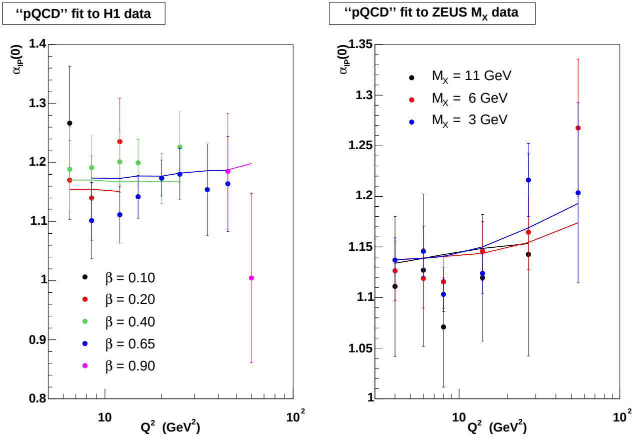
"pQCD" fit to ZEUS MX data



- Peak due to threshold for $\gamma^* \mathbb{P} \to c\bar{c}$ at $\beta = Q^2/(Q^2 + 4m_c^2)$.
- Additional contributions to scaling violations apart from DGLAP contribution.
- All free parameters in 'DGLAP' part: ZEUS M_X data have smaller scaling violations.

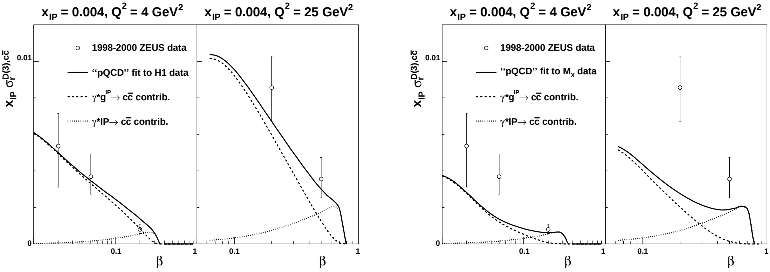
$x_{\mathbb{P}}$ dependence of H1 vs. ZEUS M_X data

- Fit $\sigma_r^{D(3)} \propto f_{\mathbb{P}}(x_{\mathbb{P}})$ in each (β, Q^2) bin with ≥ 4 data points and $y < 0.45$ (additional cut $x_{\mathbb{P}} < 0.01$ for H1 data):



- Inhomogeneous evolution can account for rise of $\alpha_{\mathbb{P}}(0)$ with Q^2.
- Inhomogeneous evolution breaks Regge factorisation.

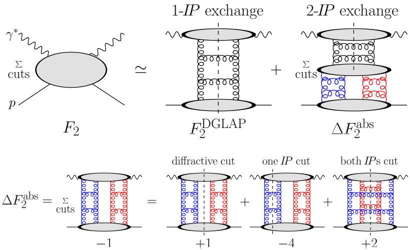
Predictions for diffractive charm production

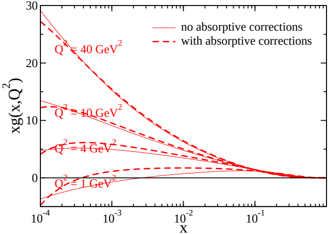


- Data measured using LRG method.
- H1 DPDFs give good description, ZEUS M_X DPDFs too small at low β.
- Direct Pomeron contribution significant at moderate β. These charm data points are included in the ZEUS LPS fit, but only $\gamma^* g^{\mathbb{P}} \to c\bar{c}$ contribution is included and not the $\gamma^* \mathbb{P} \to c\bar{c}$ contribution. Therefore, diffractive gluon from ZEUS LPS fit needs to be artificially large to fit the charm data.

Non-linear evolution of inclusive PDFs

$$\frac{\partial a(x,Q^2)}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a' - \int_x^1 \mathrm{d}x_{\mathbb{P}}\, P_{a\mathbb{P}}(x/x_{\mathbb{P}})\, f_{\mathbb{P}}(x_{\mathbb{P}};Q^2).$$





- Interesting application of DDIS formalism to calculate shadowing corrections to inclusive DIS via AGK cutting rules.
- Inhomogeneous evolution of DPDFs ⇒ non-linear evolution of inclusive PDFs.
- More precise version of GLRMQ equation derived.
- Fit HERA F_2 data similar to MRST2001 NLO fit. Small-x gluon enhanced at low scales.

For more details see Phys. Lett. B **627** (2005) 97.

Summary

- Diffractive DIS is more complicated than inclusive DIS.
- Collinear factorisation holds, but need to account for direct Pomeron coupling:

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} + C_{2,\mathbb{P}}$$

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} + P_{a\mathbb{P}}(z)\, f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)$$

  Analogous to the photon case.

- Outlook
  - Are the LRG and M_X methods compatible?
    (If so, is the amount of proton dissociation Q^2 dependent?)
  - Need $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$ $(a = q, g)$ at NLO.
  - Study sensitivity to form of input parameterisation and starting scale Q_0^2.

Summary

- Diffractive DIS is more complicated than inclusive DIS.
- Collinear factorisation holds, but need to account for direct Pomeron coupling:

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} + C_{2,\mathbb{P}}$$

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} + P_{a\mathbb{P}}(z)\, f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)$$

  Analogous to the photon case.

- Outlook
  - Are the LRG and M_X methods compatible?
    (If so, is the amount of proton dissociation Q^2 dependent?)
  - Need $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$ $(a = q, g)$ at NLO.
  - Study sensitivity to form of input parameterisation and starting scale Q_0^2.

Summary

- Diffractive DIS is more complicated than inclusive DIS.
- Collinear factorisation holds, but need to account for direct Pomeron coupling:

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} \; + \; C_{2,\mathbb{P}}$$

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} \; + \; P_{a\mathbb{P}}(z)\, f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)$$

  Analogous to the photon case.

- Outlook
  - Are the LRG and M_X methods compatible?
    (If so, is the amount of proton dissociation Q^2 dependent?)
  - Need $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$ $(a = q, g)$ at NLO.
  - Study sensitivity to form of input parameterisation and starting scale Q_0^2.

Summary

- Diffractive DIS is more complicated than inclusive DIS.
- Collinear factorisation holds, but need to account for direct Pomeron coupling:

$$F_2^{\mathrm{D}(3)} = \sum_{a=q,g} C_{2,a} \otimes a^{\mathrm{D}} \; + \; C_{2,\mathbb{P}}$$

$$\frac{\partial a^{\mathrm{D}}}{\partial \ln Q^2} = \sum_{a'=q,g} P_{aa'} \otimes a'^{\mathrm{D}} \; + \; P_{a\mathbb{P}}(z)\, f_{\mathbb{P}}(x_{\mathbb{P}}; Q^2)$$

  Analogous to the photon case.

- Outlook
  - Are the LRG and M_X methods compatible?
    (If so, is the amount of proton dissociation Q^2 dependent?)
  - Need $C_{2,\mathbb{P}}$ and $P_{a\mathbb{P}}$ ($a = q, g$) at NLO.
  - Study sensitivity to form of input parameterisation and starting scale Q_0^2.