# Diffraction as a special case of target fragmentation

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## Outline:

- Diffraction as a special case of target fragmentation in DIS
- Open questions in diffraction on the proton
- Diffraction in non-singlet channels

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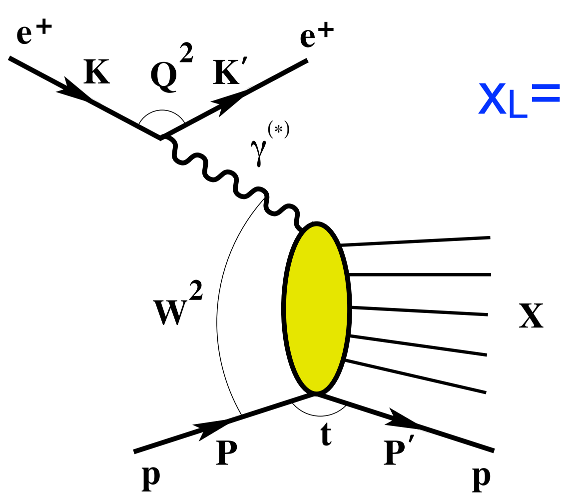
# Target fragmentation in DIS and fracture functions

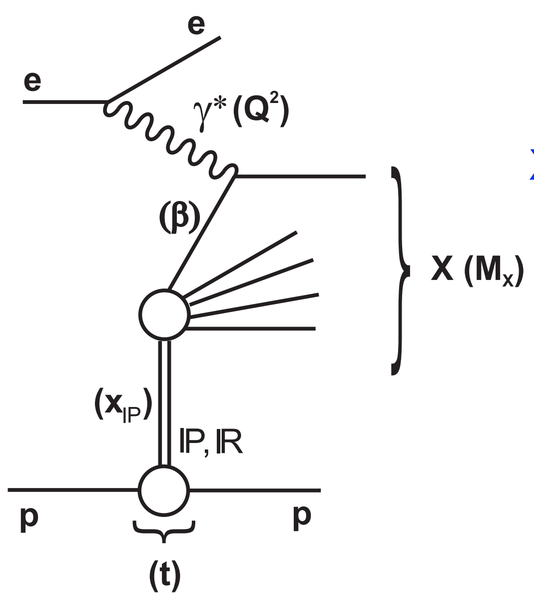
• In collinear QCD factorization, target fragmentation in semi-inclusive hard processes is described in terms of **fracture functions**, Trentadue, Veneziano, PLB 323 (1994) 201

• Fracture functions (FFs) = universal structure functions (parton distributions) of a given target provided it fragmented into another hadron, i.e., conditional probabilities.

• In DIS, FFs provide simultaneous description of leading nucleon production and inclusive diffraction in complimentary regions of $x_L=1-x_P$, de Florian, Sassot, PRD 58 (1998) 054003




$x_L=p'^+/p^+ < 1$




$x_L \sim 1$

# Inclusive diffraction in ep DIS

- Inclusive diffraction is a special case of target fragmentation with $x_L > 0.9$, $x_P < 0.1$ → FFs=diffractive parton distribution function (PDFs)

- QCD factorization theorem for diffraction in DIS, Collins, PRD 57 (1998) 3051; PRD 61 (2000) 019902 (Erratum)

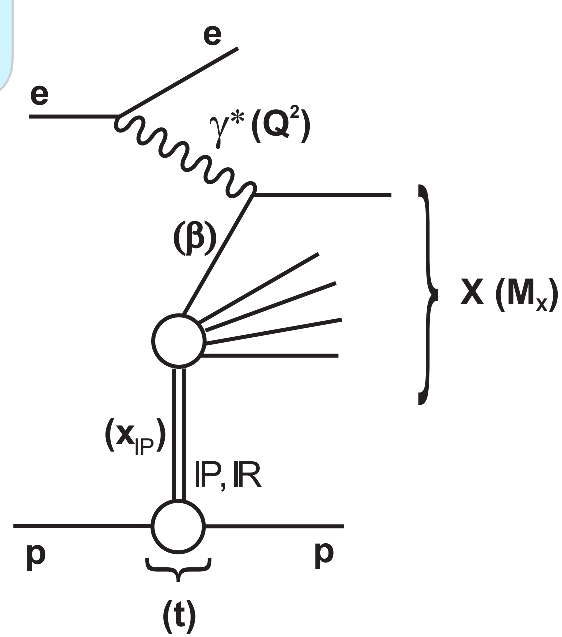
$$\frac{d^4\sigma^D_{ep}}{dx_{\mathbb{P}}\, dt\, dx\, dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[\left(1+(1-y)^2\right) \boxed{F_2^{D(4)}(x, Q^2, x_{\mathbb{P}}, t)} - y^2 \boxed{F_L^{D(4)}(x, Q^2, x_{\mathbb{P}}, t)}\right]$$

$$F_2^{D(4)}(x, Q^2, x_{\mathbb{P}}, t) = \beta \sum_{j=q,\bar{q},g} \int_\beta^1 \frac{dy}{y} C_j\left(\frac{\beta}{y}, Q^2\right) \boxed{f_j^{D(4)}(y, Q^2, x_{\mathbb{P}}, t)}$$

$$t = (p' - p)^2,$$

$$x_{\mathbb{P}} = \frac{q\cdot(p-p')}{q\cdot p} \approx \frac{M_X^2 + Q^2}{W^2 + Q^2},$$

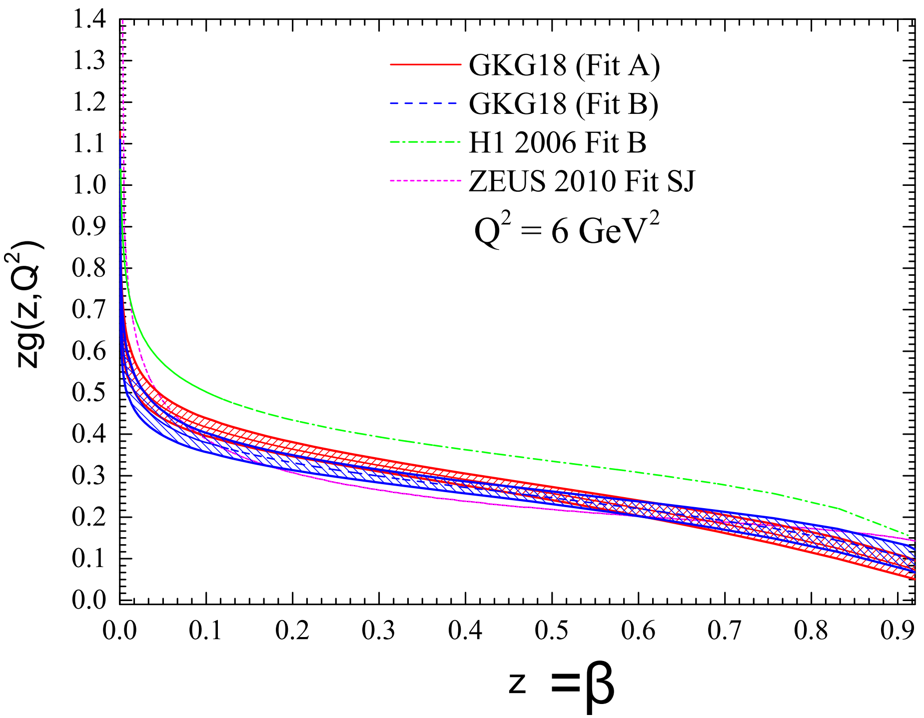
$$\beta = \frac{Q^2}{2q\cdot(p-p')} = \frac{x}{x_{\mathbb{P}}} \approx \frac{Q^2}{Q^2 + M_X^2}$$

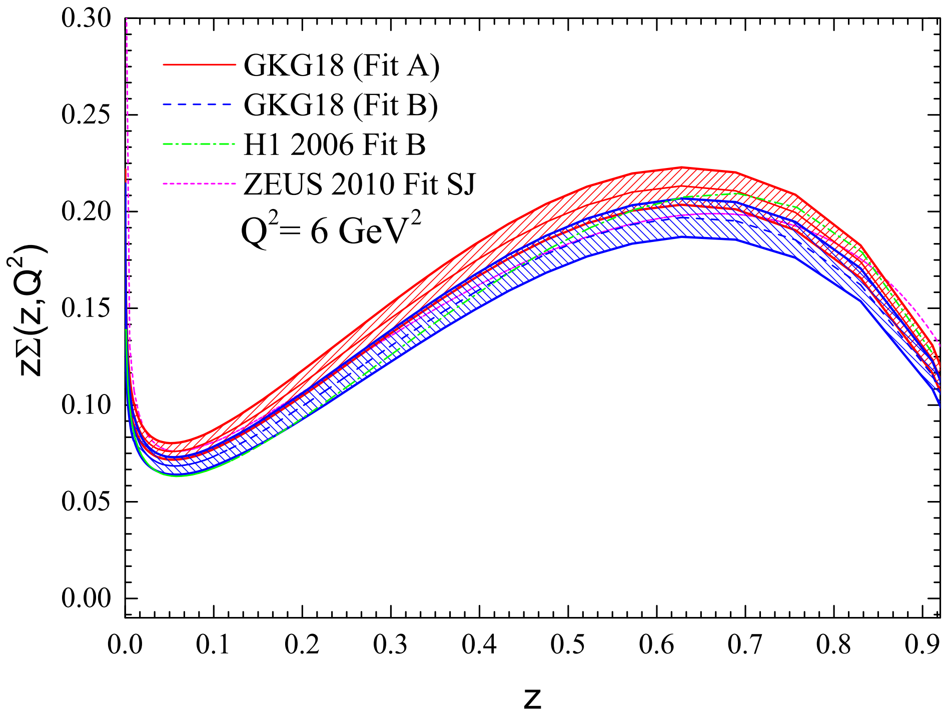


# Inclusive diffraction in ep DIS (2)

• Inclusive diffraction in ep DIS has been expensively measured at HERA by ZEUS and H1 collaborations → 10-15% of the inclusive cross section

• Diffractive PDFs of the proton have been determined by global fits of the data, H1 Coll. EPSC 48 (2006) 715; JHEP 0710 (2007) 042; ZEUS Coll., NPB 831 (2010) 1 (+ diffractive dijets); Goharipour, Khanpour, Guzey, EPJC 78 (2018) 4, 309; Khanpour, PRD 99 (2019) 5, 054007




• Universality of diffractive PDFs has been successfully tested in diffractive dijet and open charm production in ep DIS.

# Open questions in diffraction on the proton: sub-leading contributions

• Diffractive PDFs (FFs) measure the parton structure of the exchanged object without modeling what that object is. In QCD analysis, one assumes Regge factorization at the proton vertex, Ingelman, Schlein, PLB 152 (1985) 256

$$f_{i/p}^{D}(x,Q^2,x_{I\!P},t) = f_{I\!P/p}(x_{I\!P},t)\cdot f_{i/I\!P}(z_{I\!P},Q^2) \;+\; n_{I\!R}\cdot f_{I\!R/p}(x_{I\!P},t)\cdot f_{i/I\!R}(z_{I\!P},Q^2)$$

• The data and its QCD analyses focus on the leading Pomeron contribution, whose emerging parton picture is rather consistent.

• The sub-leading Reggeon contribution is important only for $x_P > 0.01$ and is very poorly constrained (usually taken to be the pion).

• The sub-leading term is important in EIC kinematics because $E_{EIC} < E_{HERA}$. In particular, studies of QCD factorization breaking in diffractive dijet photoproduction at EIC require largest span in $x_P$, Guzey, Klasen, JHEP 05 (2020) 074.

# Open questions in diffraction on the proton: higher-twist

• It is generally expected that at low $Q^2$, higher-twist (HT) effects are larger in diffraction than in the total ep DIS → in global QCD analysis one uses restrictive cuts, e.g. $Q^2_{min} > 8.5$ GeV$^2$, H1 Coll. EPSC 48 (2006) 715

• Explicit phenomenological account of HT contribution leads to a better fit and affects the shape of extracted diffractive PDFs, especially gluons at large $z=\beta$,
Maktoubian, Mehraban, Khanpour, Goharipour, PRD 100 (2019) 5, 054020

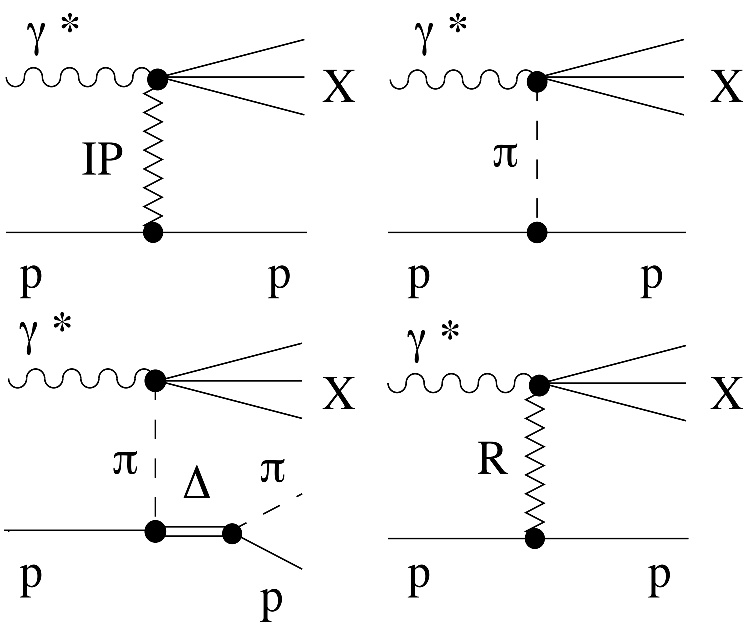
• Another way to include HT effect and describe equally well the available HERA data is provided by the color dipole formalism, Martin, Ryskin, Watt, EPC J 37 (2004) 285, EPJ C 44 (2005) 69; Golek-Biernat, Luszczak, PRD 76 (2007) 114014, PRD 79 (2009) 114010.

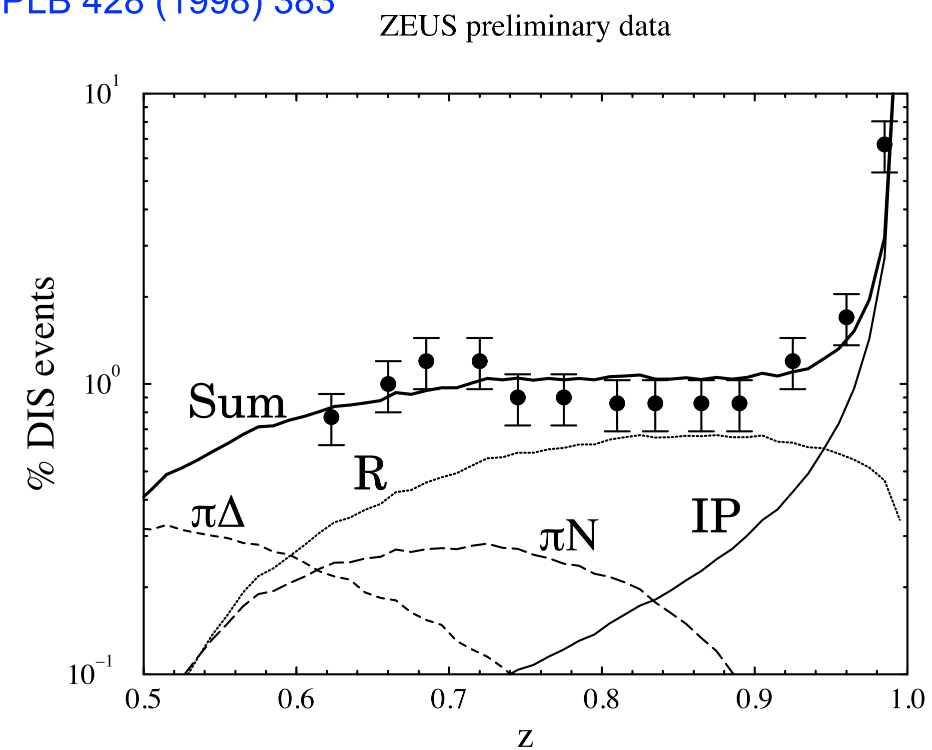
• While the dipole formalism gives an intuitive picture of diffraction and doesn't require new PDFs, to be fully consistent with the collinear factorization (DGLAP evolution) it requires an infinite number of q-anti-q-g…g dipoles.

# Diffraction in non-singlet channels

• Diffraction in non-singlet (non-vacuum) channels comes from Reggeon contribution. While the HERA data on inclusive diffraction in ep DIS very weakly constrains it, it is probed by production of leading particles.

• ZEUS and H1 data on leading proton and neutron production in ep DIS can be successfully explained by models based on t-channel exchanges (peripheral mechanism), Szczurek, Nikolaev, Speth, PLB 428 (1998) 383




• Reggeon contribution from simultaneous measurements of diffraction and leading particle production.

# Diffraction in non-singlet channels (2)

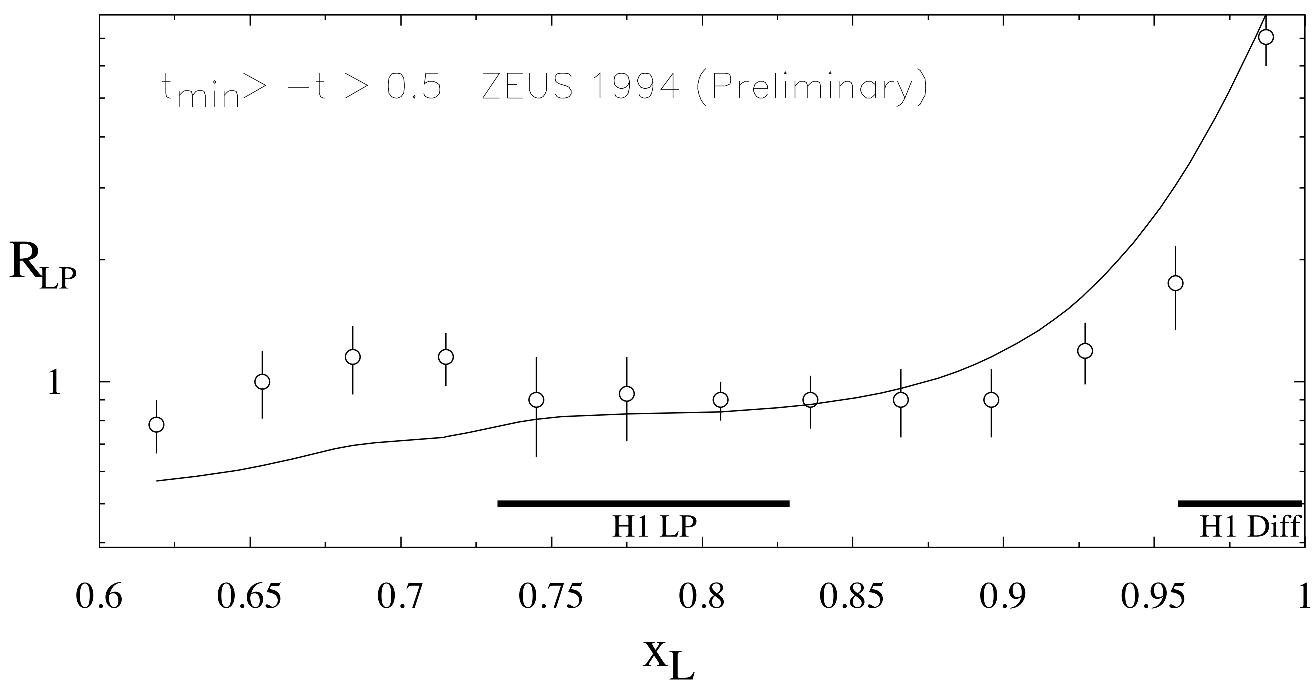
- Or one can use the formalism of FF, de Florian, Sassot, PRD 58 (1998) 054003; Shoeibi, Taghavi-Shahri, Khanpour, Javidan, PRD 97 (2018) 7, 074014.

- While the underlying physical picture is less clear than in Regge exchange model, the formalism is more rigorous (factorization, $Q^2$ evolution, bridge between diffraction and leading-particle production at $x_P \sim 0.1$).

$$xM_q^{p/p}(\beta, Q_0^2, x_{I\!P}) = N_s\, \beta^{a_s}(1-\beta)^{b_s} \times \left\{ C_{I\!P}\, \beta\, x_{I\!P}^{\alpha_{I\!P}} + C_{LP}\,(1-\beta)^{\gamma_{LP}}\,(1 + a_{LP}(1-x_{I\!P})^{\beta_{LP}}) \right\}$$

FFs obtained from fit to H1 data applied to ZEUS data.

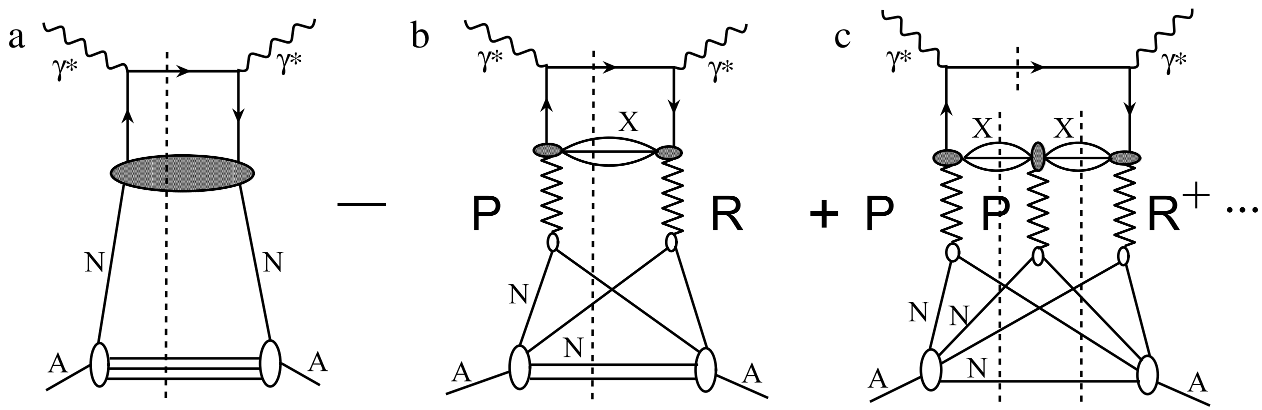
**$R_{LP}$**=fraction of DIS events with leading proton



# Nuclear shadowing of valence quarks

• In the leading twist model of nuclear shadowing, small-x suppression of nuclear PDFs is driven by proton diffractive PDFs, Frankfurt, Strikman, EPJ A 5 (1999) 293; Frankfurt, Guzey, Strikman, Phys. Rept. 512 (2012) 255

• While the Pomeron contribution controls the gluon and sea quark nPDFs, the Pomeron-Reggeon interference gives nuclear shadowing for valence quarks.




• Pomeron and Reggeon contributions have different dependence on $x_P$ ($x_L$) → their overlap is suppressed → suppression of nuclear shadowing in non-vacuum channels (valence quarks, $F_3(x,Q^2)$ structure function, polarized PDFs):

$$\frac{1-V_A/AV_N}{1-F_{2A}/AF_{2N}} \leq 2\sqrt{r_{v/s}} \quad =2*0.1=1/5$$

Estimate from LP spectrum in DIS

# Summary

• Diffraction in DIS is a special case of target fragmentation, where the appropriate framework is that of fracture functions (FFs).

• Diffractive PDFs is a limiting case of FFs at small $x_P < 0.1$

• Quark and gluon diffractive PDFs with uncertainties at LO, NLO, and NNLO have been extracted from HERA data using global QCD fits.

• For the Pomeron contribution, the emerging parton picture is fairly well-constrained.

• The sub-leading Reggion contribution at $x_P > 0.01$, which is more prominent at EIC than at HERA, is much less know.

• The way to constrain it is to fit simultaneously the data on inclusive diffraction and leading nucleon production in DIS.

• Diffraction in non-vacuum channels is responsible for nuclear shadowing of nuclear valence quark distributions, $F_3(x,Q^2)$ structure function, nuclear polarized PDFs, where the shadowing effect is expected to be suppressed.