PROCEEDINGS OF SCIENCE

Diffractive dijets in $e\ p \to e'\ jet\ jet\ p$ reaction using GTMDs

Marta Łuszczak[a,*]

[a] *University of Rzeszów, ul. Pigonia 1, PL-35-959 Rzeszów, Poland*

E-mail: mluszczak@ur.edu.pl

Exclusive (diffractive) dijet production in ep scattering provides direct access to transverse-momentum dependent gluon dynamics at small x. We summarize a momentum-space dipole/GTMD calculation of $ep \to e\,p\,jj$ in which the diffractive amplitude is expressed through off-forward unintegrated gluon distributions (gluon GTMDs). Several GTMD models from the literature are confronted with H1 and ZEUS measurements under the corresponding experimental cuts. With the exception of a GTMD tuned to a subset of H1 observables, the exclusive $q\bar{q}$ channel typically undershoots the measured cross sections; ZEUS data impose the strongest constraints. We also show that sizeable azimuthal modulations between the dijet momentum sum and difference can be generated purely by jet p_T cuts, potentially mimicking signals of elliptic gluon distributions.

The European Physical Society Conference on High Energy Physics (EPS-HEP2025)
7-11 July 2025
Marseille, France

*Speaker

 ISSN 1824-8039 . Published by SISSA Medialab.

PoS(EPS-HEP2025)260

1. Motivation

Diffractive final states at HERA have long been a precision tool to study gluon-dominated dynamics at small Bjorken-x and to test QCD factorization concepts in diffraction [1]. In particular, exclusive ("proton intact") dijet production,

$$ep \to e\, p\, j_1 j_2, \tag{1}$$

is sensitive to the transverse momentum structure of gluons: at sufficiently large jet transverse momenta, the forward diffractive amplitude probes the unintegrated gluon density of the target [4, 5]. In the off-forward case, the relevant object is the gluon GTMD, which is closely related to the gluon Wigner distribution [6, 7].

In this contribution we review a momentum-space dipole approach formulated directly in terms of gluon GTMDs, and confront several GTMD models with the H1 [2] and ZEUS [3] measurements of diffractive dijets.

2. Kinematics and cross section

We use standard DIS variables: the photon momentum is $q = k - k'$ with $q^2 = -Q^2$, and the inelasticity is $y = (q \cdot P)/(k \cdot P)$. Jets carry photon momentum fractions z and $1 - z$, and transverse momenta $\vec{p}_{1\perp}$ and $\vec{p}_{2\perp}$. It is convenient to introduce

$$\vec{\Delta}_\perp = \vec{p}_{1\perp} + \vec{p}_{2\perp}, \qquad \vec{P}_\perp = \frac{\vec{p}_{1\perp} - \vec{p}_{2\perp}}{2}, \tag{2}$$

so that in the exclusive limit $\Delta_\perp$ equals the transverse momentum transfer to the proton. The diffractive mass M_{jj} defines the variables

$$\beta = \frac{Q^2}{Q^2 + M_{jj}^2}, \qquad x_{\mathbb{P}} = \frac{x_{\mathrm{Bj}}}{\beta}, \tag{3}$$

where $x_{\mathbb{P}}$ is the proton momentum fraction transferred through the color-singlet exchange.

To compare with data, we compute the ep cross section through the virtual-photon flux,

$$\frac{d\sigma^{ep}}{dy\, dQ^2\, d\xi} = \frac{\alpha_{\mathrm{em}}}{\pi y Q^2}\left[\left(1 - y + \frac{y^2}{2}\right)\frac{d\sigma_T^{\gamma^* p}}{d\xi} + (1-y)\frac{d\sigma_L^{\gamma^* p}}{d\xi}\right], \tag{4}$$

with $d\xi = dz\, d^2P_\perp\, d^2\Delta_\perp$. The transverse and longitudinal $\gamma^* p \to p\, q\bar{q}$ cross sections are obtained by convoluting a perturbative $\gamma^* \to q\bar{q}$ impact factor with the gluon GTMD.

3. GTMD input

The momentum-space diffractive amplitude can be written as a Fourier transform of the dipole amplitude $N(Y, \vec{r}_\perp, \vec{b}_\perp)$,

$$T(Y, \vec{k}_\perp, \vec{\Delta}_\perp) = \int \frac{d^2b_\perp}{(2\pi)^2}\frac{d^2r_\perp}{(2\pi)^2}\, e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}\, e^{-i\vec{k}_\perp\cdot\vec{r}_\perp}\, N(Y, \vec{r}_\perp, \vec{b}_\perp)\, e^{-\varepsilon r_\perp^2}, \tag{5}$$

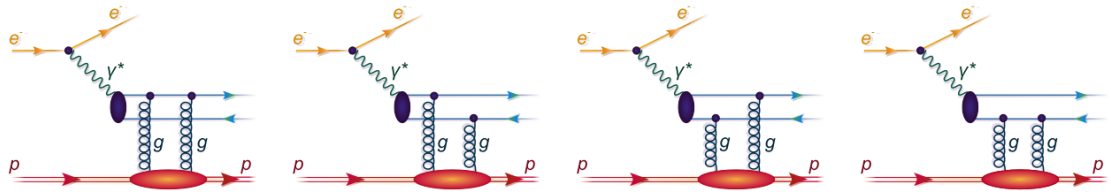

Figure 1: Born-level diagrams for exclusive diffractive dijet production in the momentum-space dipole/GTMD approach.

Table 1: Phase-space cuts used by H1 [2] and ZEUS [3] in the diffractive dijet measurements.

	H1	ZEUS
Q^2	$4 < Q^2 < 110$ GeV^2	$Q^2 > 25$ GeV^2
$x_{\mathbb{P}}$	$x_{\mathbb{P}} < 0.1$	$x_{\mathbb{P}} < 0.01$
y	$0.05 < y < 0.7$	$0.1 < y < 0.64$
jet rapidities	$-1 < \eta_{1,2} < 2.5$	$\eta_{1,2} < 2$
jet p_T	$p_{T1} > 5$ GeV, $p_{T2} > 4$ GeV	$p_{T1,2} > 2$ GeV
other	$\lvert t\rvert < 1$ GeV^2	$M_{jj} > 5$ GeV, $90 < W_{\gamma p} < 250$ GeV

where the Gaussian factor regularizes the $r_\perp$ integral. The GTMD is proportional to T (see, e.g., [8] for a discussion of conventions).

We consider five representative models used in the literature: (i) two off-forward extensions of diagonal UGDs compatible with the GBW saturation model [9] and the MPM UGD [10], with a diffractive slope B, (ii) the bSat model of Kowalski–Teaney [11], and (iii) two models derived from McLerran–Venugopalan inspired dipole amplitudes, including a parametrization by Boer–Setyadi [13, 14] and a model by Iancu–Rezaeian [12] (with a simple $x_{\mathbb{P}}$ dependence added for phenomenology). All results shown below refer to the isotropic part of the GTMD; elliptic components are not included.

4. H1 and ZEUS cuts

The exclusivity requirement is experimentally challenging and the measurements employ different selections. The cuts relevant for our comparison are summarized in Table 1.

5. Results and discussion

A key observable is the Q^2 dependence of the $ep \to e\,p\,jj$ cross section. Figure 2 compares several GTMD models for H1 and ZEUS kinematics. At $Q^2 \gtrsim 20$ GeV^2 the predicted shapes are broadly compatible with data, but the normalization depends strongly on the GTMD. A model tuned to reproduce H1 distributions can significantly overshoot ZEUS data.

Integrated cross sections are summarized in Table 2. For most GTMDs, the exclusive $q\bar{q}$ channel underpredicts the measured cross sections; the discrepancy is more striking for ZEUS,

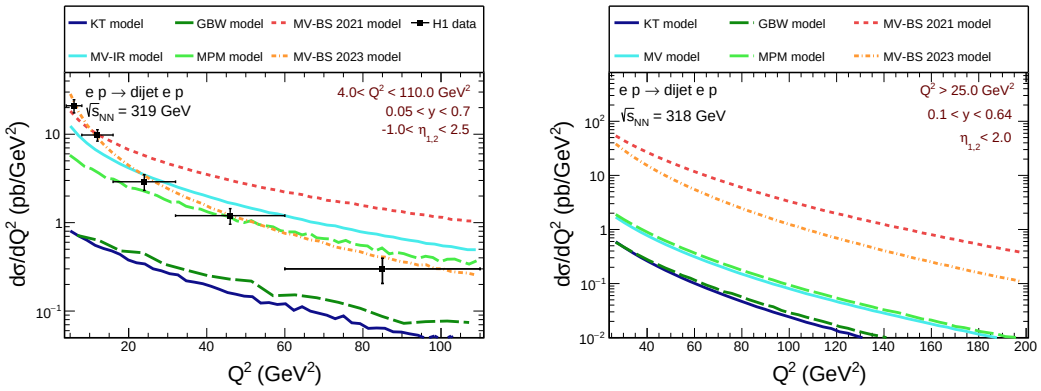

Figure 2: Q^2 dependence of the diffractive dijet cross section for H1 (left) and ZEUS (right) cuts for several GTMD models.

Table 2: Integrated cross sections (pb) for H1 and ZEUS cuts for light $q\bar{q}$ and $c\bar{c}$ dijets. Experimental values are shown for reference.

	H1			ZEUS		
GTMD	$q\bar{q}$	$c\bar{c}$	no p_T cuts	$q\bar{q}$	$c\bar{c}$	no p_T cuts
GBW	26.35	19.91	10900.86	13.57	6.67	337.11
MPM	147.94	108.26	10151.00	43.61	20.47	313.17
MV–BS	404.06	269.75	10999.73	1346.11	624.55	3117.95
KT	21.29	15.20	5957.65	12.57	5.67	52.60
MV–IR	243.20	155.21	11784.75	37.83	17.62	91.18
data	254		–	72		–

which probes smaller $x_{\mathbb{P}}$ where a gluon-driven picture should be most reliable. Including heavy-flavor ($c\bar{c}$) dijets increases the normalization by about 50–70% within the studied cuts, but does not remove the tension.

The distribution in β is particularly constraining. As shown in Fig. 3, the Boer–Setyadi model, which can appear compatible with some H1 observables, strongly overshoots ZEUS data across a broad β range, suggesting that the apparent H1 agreement is not robust. Among the considered options, the KT and GBW-inspired GTMDs yield smaller contributions for H1 and a sizeable but still insufficient contribution at large β in ZEUS kinematics.

Finally, we study the azimuthal angle between $\vec{P}_\perp$ and $\vec{\Delta}_\perp$. Even without elliptic GTMD components, pronounced modulations arise once asymmetric jet p_T cuts are applied. This "cut-induced" effect should be controlled before interpreting azimuthal correlations as evidence for an elliptic gluon distribution.

6. Conclusions and outlook

Diffractive dijets at HERA provide a stringent test of gluon GTMD models. Our comparison to both H1 and ZEUS data shows that the exclusive $q\bar{q}$ channel, evaluated with commonly used GTMD inputs, typically accounts for only a fraction of the measured cross section. ZEUS ob-

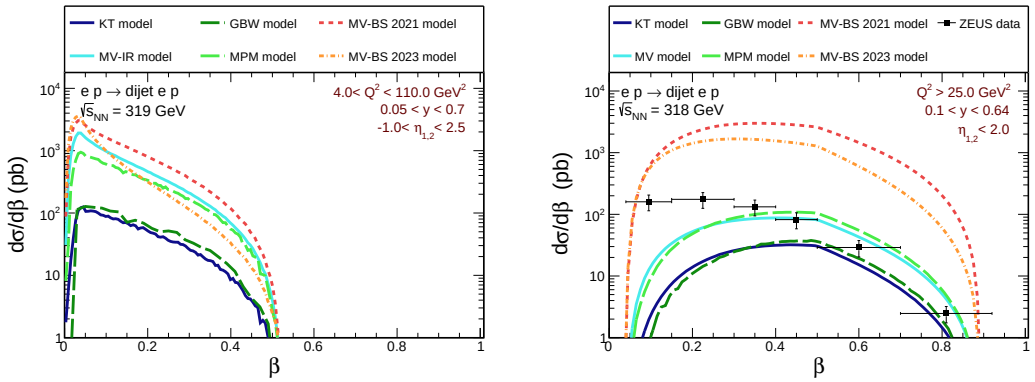

Figure 3: Distribution in the diffractive variable β for H1 (left) and ZEUS (right) cuts for several GTMD models.

servables, in particular the β distribution, impose stronger constraints than H1 and disfavor GTMD parametrizations tuned solely to H1 kinematics.

A realistic description likely requires additional diffractive mechanisms beyond the exclusive $q\bar{q}$ final state, such as a $q\bar{q}g$ component [15] or contributions with a pomeron remnant within a resolved pomeron picture. On the phenomenological side, future studies should combine improved small-x evolution and Sudakov effects [16] with a careful treatment of experimental selections in order to isolate genuine GTMD-induced angular modulations.

7. ACKNOWLEDGMENTS

This work was partially supported by the Polish National Science Center grant// UMO-2023/49/B/ST2/03665.

References

[1] P. Newman and M. Wing, *The hadronic final state at HERA*, *Rev. Mod. Phys.* **86** (2014) 1037.

[2] F. D. Aaron *et al.* [H1 Collaboration], *Measurement of hard diffraction in DIS and photoproduction at HERA*, *Eur. Phys. J. C* **72** (2012) 1970.

[3] H. Abramowicz *et al.* [ZEUS Collaboration], *Diffractive dijet production in DIS at HERA*, *Eur. Phys. J. C* **76** (2016) 16.

[4] N. N. Nikolaev and B. G. Zakharov, *The triple pomeron regime and the structure function F_2 at very small x*, *Phys. Lett. B* **332** (1994) 177.

[5] N. N. Nikolaev, W. Schäfer and G. Schwiete, *The photon wave function in the light cone*, *Phys. Rev. D* **63** (2001) 014020.

[6] R. Boussarie *et al.*, *Status of the gluon Wigner/GTMD program*, arXiv:2304.03302.

[7] R. Pasechnik and M. Taševský, *Gluon Wigner distributions and diffraction*, arXiv:2310.10793.

[8] M. Reinke Pelicer, E. Gräve De Oliveira and R. Pasechnik, *Off-forward UGDs and diffraction*, *Phys. Rev. D* **99** (2019) 034016.

[9] K. J. Golec-Biernat and M. Wüsthoff, *Saturation effects in deep inelastic scattering at low* Q^2, *Phys. Rev. D* **59** (1998) 014017.

[10] L. S. Moriggi, G. M. Peccini and M. V. T. Machado, *Unintegrated gluon distributions from HERA*, *Phys. Rev. D* **102** (2020) 034016.

[11] H. Kowalski and D. Teaney, *An impact parameter dipole saturation model*, *Phys. Rev. D* **68** (2003) 114005.

[12] E. Iancu and A. H. Rezaeian, *Elliptic gluon distributions in the MV model*, *Phys. Rev. D* **95** (2017) 094003.

[13] D. Boer and C. Setyadi, *Gluon GTMDs and diffractive dijets at HERA*, *Phys. Rev. D* **104** (2021) 074006.

[14] D. Boer and C. Setyadi, *Refined GTMD phenomenology*, *Eur. Phys. J. C* **83** (2023) 890.

[15] J. Bartels, H. Jung and M. Wüsthoff, *Three-parton contributions in diffractive DIS*, *Eur. Phys. J. C* **11** (1999) 111.

[16] Y. Hatta, N. Mueller, T. Ueda and F. Yuan, *Sudakov effects in diffractive dijets*, *Phys. Lett. B* **802** (2020) 135211.