Probing gluon saturation via photon-hadron interactions at high energy

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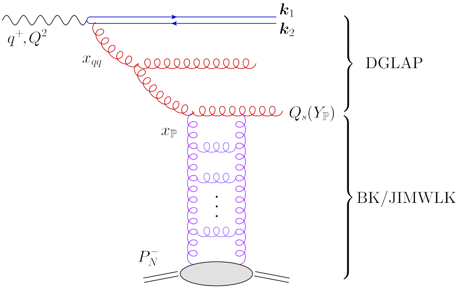
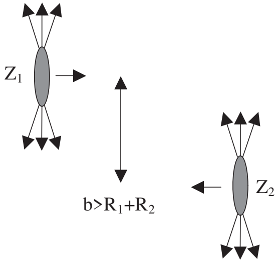




Introduction

- Diffractive γp (or γA) interactions: a unique class of phenomena which remain sensitive to saturation in the hard regime:
  - Q^2, $P_\perp^2$, M^2 ... $\gg Q_s^2(x)$
- Inclusive vs diffractive structure functions at small x:
  - $F_2(x, Q^2)$ sensitive to saturation when $Q^2 \lesssim Q_s^2(x)$ (higher twist), but this sensitivity disappears when $Q^2 \gg Q_s^2(x)$ (leading twist)
  - the leading-twist contribution to $F_2^D(x_{\mathbb{P}}, Q^2)$ at high $Q^2 \gg Q_s^2(x_{\mathbb{P}})$ is still controlled by saturation ("aligned jet")
- Why ? Elastic scattering is controlled by the black disk limit
  - for small enough x/large enough A, such that $Q_s^2(x, A) \gg \Lambda^2$, saturation is the pQCD mechanism for unitarisation
- "High–Q^2 is the realm of the collinear factorisation" ... Indeed !

Introduction (2)

- For DIS diffraction, collinear factorisation emerges via pQCD calculations within the Color Dipole Picture and the CGC effective theory
- TMD factorisation for diffraction has been first identified in this way

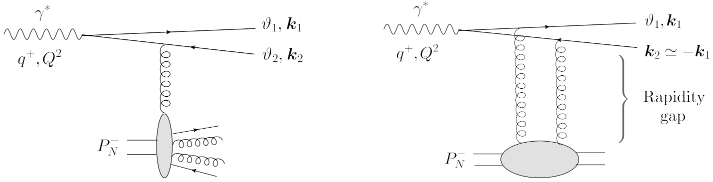
  E.I., A.H. Mueller, D.N. Triantafyllopoulos, Phys.Rev.Lett. 128 (2022) 20

  Y. Hatta, B. Xiao, and F. Yuan, arXiv:2205.08060, PRD
- Explicit results for quark & gluon diffractive TMD, determined by saturation
- Initial conditions for DGLAP from first principles: JIMWLK included
- Not an alternative to fitting diffractive PDFs, but a way to understand them
- This talk: overview & applications to coherent dijet production in AA UPCs

  E.I., A.H. Mueller, D. Triantafyllopoulos, and S.-Y. Wei, 2304.12401, EPJC

Hard dijet production in $\gamma^* A$ at high energy

- Small Bjorken x, hard process: $P_\perp \equiv \frac{1}{2}|\boldsymbol{k}_1 - \boldsymbol{k}_2| \gg Q_s$ and/or $Q^2 \gg Q_s^2$
- Inclusive vs. exclusive/diffractive dijets (elastic vs. inelastic scattering)



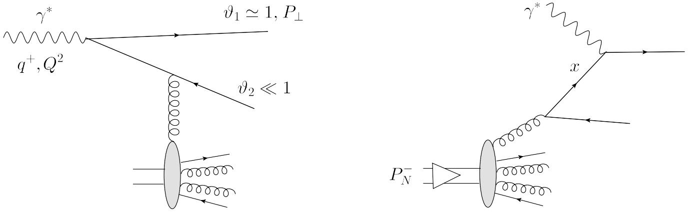
- Symmetric ($\vartheta_1\vartheta_2 \sim 1/4$) vs. aligned-jet ($\vartheta_1\vartheta_2 \ll 1$) configurations
  - this controls the dipole size, hence the typical relative momentum:

$$P_\perp \sim 1/r \sim \bar{Q} \quad \text{with} \quad \bar{Q}^2 \equiv \vartheta_1\vartheta_2 Q^2$$

- Colour dipole picture vs. Target picture: frame & gauge choice
  - $q\bar{q}$ pair: either a part of the γ^* wavefunction, or a part of the target

Inclusive dijets: aligned jet

- Total cross-section (F_2): dominated by the asymmetric configurations
  - $\vartheta_1\vartheta_2 \ll 1 \;\Rightarrow$ large dipoles... but such that $1/Q \ll r \ll 1/Q_s$
  - the scattering is still weak: $Q^2 \gg P_\perp^2 \sim \vartheta_1\vartheta_2 Q^2 \gg Q_s^2$

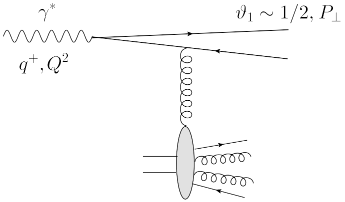


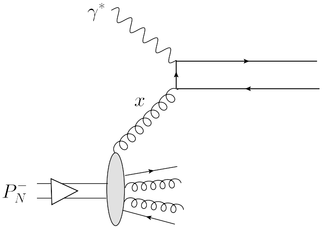
$$T_{q\bar{q}}(r,x) \simeq \begin{cases} r^2 Q_s^2(A,x), & \text{for } rQ_s \ll 1 \;\text{ (color transparency)} \\ 1, & \text{for } rQ_s \gtrsim 1 \;\text{ (black disk/saturation)} \end{cases}$$

- Target picture: a measurement of the sea quark distribution
  - the DGLAP splitting $g \to q\bar{q}$ is typically symmetric: $x \sim 1/2$

Inclusive dijets: symmetric $q\bar{q}$ pairs

- Symmetric configurations: less frequent, but can be harder
  - $\vartheta_1\vartheta_2 \sim 1/4 \;\Rightarrow$ small dipoles, weak scattering: $P_\perp^2 \sim Q^2 \gg Q_s^2$
  - nearly back-to-back jets: $K_\perp \equiv |\boldsymbol{k}_1 + \boldsymbol{k}_2| \ll P_\perp$
- The dijet imbalance $K_\perp$ can be sensitive to multiple scattering

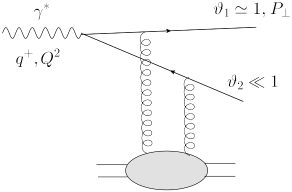


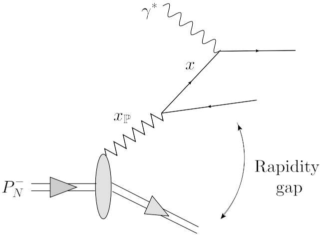


- Target picture: photon-gluon fusion $\Rightarrow$ probing the gluon distribution
  - TMD factorisation: Weizsäcker-Williams gluon TMD (saturation)
- Gluon saturation (target picture) dual to multiple scattering (dipole picture)

Exclusive dijets: aligned jet

- Total cross-section (F_2^D): asymmetric configurations (again): $\vartheta_1\vartheta_2 \ll 1$
  - however, now there are much larger: $r \sim 1/Q_s \Longrightarrow$ strong scattering
  - the final jets are semi-hard: $P_\perp^2 \sim \vartheta_1\vartheta_2 Q^2 \sim Q_s^2$
  - $\sigma_{\rm el} \propto |T_{q\bar q}(r)|^2$ is strongly suppressed when $T \ll 1$ (i.e. $r \ll 1/Q_s$)

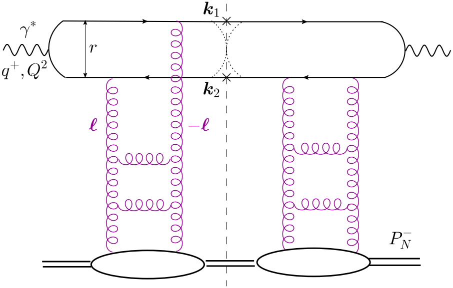




- Target picture: the unintegrated quark distribution of the Pomeron
  - the quark diffractive TMD at $x_{\mathbb{P}} \lesssim 10^{-2}$ from the dipole picture
  - controlled by gluon saturation

Exclusive dijets: symmetric $q\bar{q}$ pairs

- Hard & symmetric ($\vartheta_1\vartheta_2 \sim 1/4$) exclusive dijets are strongly suppressed
  - elastic scattering $\sigma_{\rm el} \propto |T_{q\bar{q}}(r)|^2$ & colour transparency



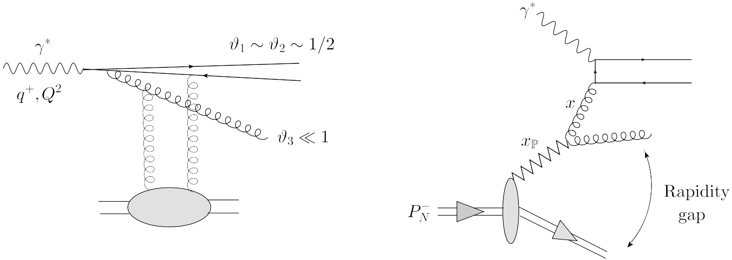
$$\frac{{\rm d}\sigma_{\rm el}^{\gamma^*A\to q\bar{q}A}}{{\rm d}\vartheta_1{\rm d}\vartheta_2{\rm d}^2\boldsymbol{P}} \propto \underbrace{\frac{\alpha_{\rm em}}{P_\perp^2}}_{\gamma^*\to q\bar{q}} \underbrace{\frac{Q_s^4}{P_\perp^4}}_{T_{q\bar{q}}^2}$$

$$Q_s^4 \simeq \left[\frac{\alpha_s}{N_c}\frac{xG(x,P_\perp^2)}{S_\perp}\right]^2$$

- Rare events ("higher twist"), insensitive to saturation
- Target picture: proportional to the square of the gluon distribution
  - gluon distribution probed on the hard scale $P_\perp^2$
- Can one have hard diffractive dijets at leading twist ? ($\sim 1/P_\perp^4$)

Diffractive 2+1 jets

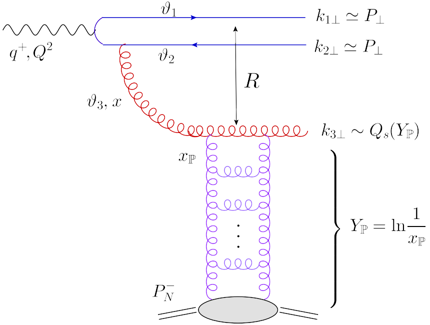
- Two hard jets, $P_\perp \gg Q_s$, and one semi-hard: $k_{3\perp} \sim Q_s \ll P_\perp$
  - the semi-hard jet allows for strong scattering
  - colour configuration with large transverse size $R \sim 1/Q_s$
- $\mathcal{O}(\alpha_s)$, but leading-twist: $r^2 \times r^2 \to 1/P_\perp^4$



- Target picture: photon-gluon fusion ... but a gluon from the Pomeron
  - the gluon diffractive TMD at $x_{\mathbb{P}} \lesssim 10^{-2}$ from the dipole picture
  - controlled by gluon saturation

The gluon-gluon dipole

- Colorless exchange (2 gluons+): Pomeron $\Longrightarrow$ rapidity gap $Y_{\mathbb{P}}$
  - $x_{\mathbb{P}} P_N^-$: target longitudinal momentum taken by the Pomeron
  - $Y_{\mathbb{P}} = \ln \frac{1}{x_{\mathbb{P}}}$: rapidity phase-space for the evolution of the Pomeron
- After emitting the gluon, the small $q\bar{q}$ pair $(r \sim \frac{1}{P_\perp})$ becomes a color octet



$$R \sim \frac{1}{Q_s} \gg r \sim \frac{1}{P_\perp}$$

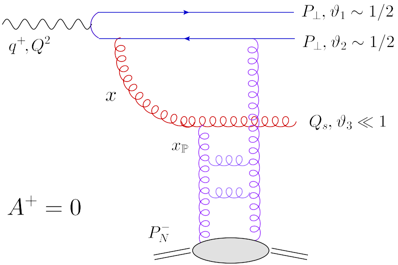
- Gluon-gluon dipole with size R
- Strong scattering: $T_{gg}(R, Y_{\mathbb{P}}) \sim 1$

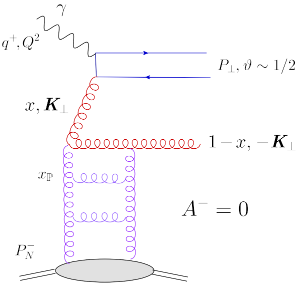
$$Q_s^2(A, Y_{\mathbb{P}})\Big|_{gg} = \frac{N_c}{C_F}\, Q_s^2(A, Y_{\mathbb{P}})\Big|_{q\bar{q}}$$

- The gluon jet also controls the dijet imbalance: $K_\perp \equiv |\boldsymbol{k}_1 + \boldsymbol{k}_2| \simeq k_{3\perp}$

Soft gluon and TMD factorisation

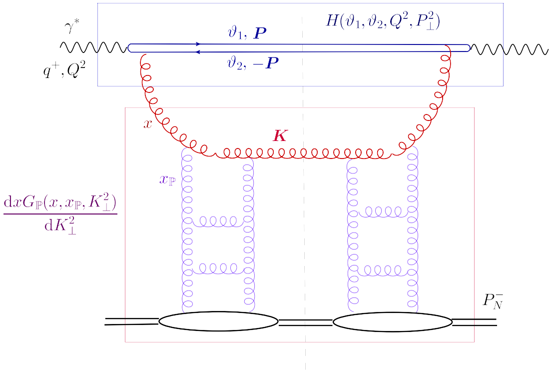
- The third jet is relatively soft: $k_3^+ = \vartheta_3 q^+$ with $\vartheta_3 \sim \frac{Q_s^2}{Q^2} \ll 1$
  - gluon formation time must be small enough to scatter: $\frac{k_3^+}{k_{3\perp}^2} \lesssim \frac{q^+}{Q^2}$
- The soft gluon can alternatively be seen as a part of the Pomeron





- The Pomeron $x_{\mathbb{P}}$ splits into a gluon-gluon pair: $x x_{\mathbb{P}}$ and $(1-x)x_{\mathbb{P}}$
- The t-channel gluon $(x, \boldsymbol{K}_\perp)$ is absorbed by the hard $q\bar{q}$ pair

TMD factorisation for diffractive 2+1 jets

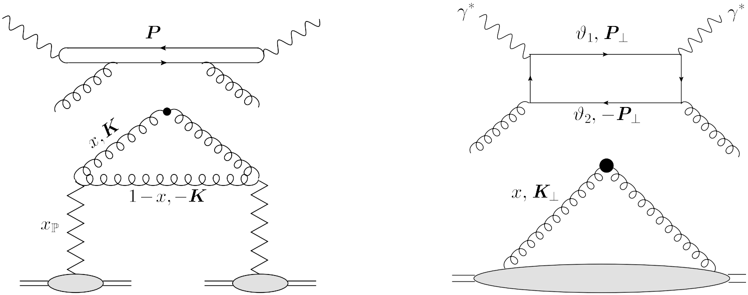


$$\frac{\mathrm{d}\sigma_{2+1}^{\gamma_{T,L}^* A \to q\bar{q}gA}}{\mathrm{d}\vartheta_1 \mathrm{d}\vartheta_2 \mathrm{d}^2\boldsymbol{P} \mathrm{d}^2\boldsymbol{K} \mathrm{d}Y_{\mathbb{P}}} = H_{T,L}(\vartheta_1, \vartheta_2, Q^2, P_\perp^2)\, \frac{\mathrm{d}xG_{\mathbb{P}}(x, x_{\mathbb{P}}, K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}}$$

- Hard factor encoding the kinematics of the $q\bar{q}$ pair
- Gluon diffractive TMD: the unintegrated gluon distribution of the Pomeron
- Valid at $x_{\mathbb{P}} \lesssim 10^{-2}$, but generic values of x and arbitrary high Q^2 and $P_\perp^2$

The hard factor

- The formation of the hard $q\bar{q}$ pair ($\gamma^* \to q\bar{q}$) & the gluon emission



$$H_T = \alpha_{\rm em}\alpha_s \left(\sum e_f^2\right) \vartheta_1\vartheta_2(\vartheta_1^2+\vartheta_2^2)\,\frac{1}{P_\perp^4} \quad \text{when } Q^2 \ll P_\perp^2$$

- The same as for inclusive dijets in the correlation limit
  - the only difference: the origin of the t-channel gluon
- The expected "leading-twist" behaviour $\sim 1/P_\perp^4$

The Pomeron UGD

$$\frac{\mathrm{d}xG_{\mathbb{P}}(x, x_{\mathbb{P}}, K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}} = \frac{S_\perp(N_c^2-1)}{4\pi^3} \underbrace{\Phi_g(x, x_{\mathbb{P}}, K_\perp^2)}_{\text{occupation number}}$$

- A Bessel-Fourier transform of the gg dipole amplitude $T_{gg}(R, Y_{\mathbb{P}})$

$$\Phi_g \propto \left[\mathcal{M}^2 \int \mathrm{d}R\, R\, J_2(K_\perp R) \underbrace{K_2(\mathcal{M}R)}_{\text{virtuality}} \underbrace{T_{gg}(R, Y_{\mathbb{P}})}_{\text{scattering}}\right]^2, \quad \mathcal{M}^2 \equiv \frac{x}{1-x} K_\perp^2$$

- Effective saturation momentum: $\tilde{Q}_s^2(x, Y_{\mathbb{P}}) = (1-x)Q_s^2(Y_{\mathbb{P}})$

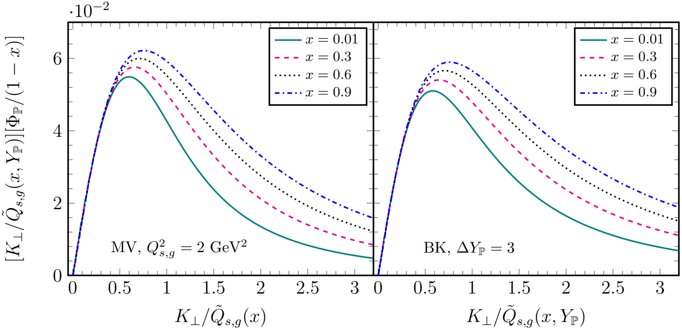
$$\Phi_g(x, x_{\mathbb{P}}, K_\perp^2) \simeq (1-x) \begin{cases} 1, & K_\perp \lesssim \tilde{Q}_s(x) \\ \dfrac{\tilde{Q}_s^4(x)}{K_\perp^4}, & K_\perp \gg \tilde{Q}_s(x) \end{cases}$$

- The bulk of the distribution lies at saturation: $K_\perp \lesssim \tilde{Q}_s(x)$

Numerical results: gluon diffractive TMD

(E.I., A.H. Mueller, D.N. Triantafyllopoulos, S.-Y. Wei, arXiv:2207.06268)

- Left: McLerran-Venugopalan model. Right: BK evolution of T_{gg}
  - multiplied by $K_\perp$ (from the measure $\mathrm{d}^2\boldsymbol{K}_\perp$)
- Pronounced maximum at $K_\perp \simeq \tilde{Q}_s$



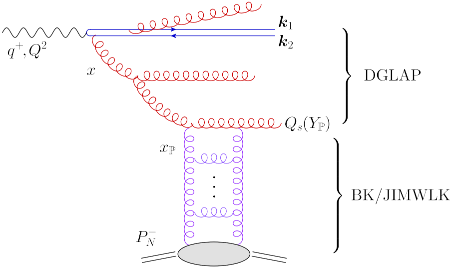
- BK evolution: increasing $Q_s^2(Y_\mathbb{P})$, approximate geometric scaling

The gluon diffractive PDF

- $P_\perp^2 \gg K_\perp^2$: large phase-space for DGLAP evolution & final state radiation
  - emission of gluons with intermediate momenta $K_\perp^2 \ll \ell_\perp^2 \ll P_\perp^2$
- For fixed $K_\perp$: large NLO corrections (Sudakov double log): $\alpha_s \ln^2(P_\perp^2/K_\perp^2)$
- One can avoid that by integrating out the $K_\perp$–distribution

$$xG_{\mathbb{P}}(x, x_{\mathbb{P}}, P_\perp^2) \equiv \int^{P_\perp} \mathrm{d}K_\perp^2\, \Phi(x, x_{\mathbb{P}}, K_\perp^2) \;\propto\; (1-x)^2\, Q_{s,g}^2(Y_{\mathbb{P}})$$

  - integral rapidly converging and effectively cut off at $K_\perp \sim \tilde{Q}_{s,g}(x)$

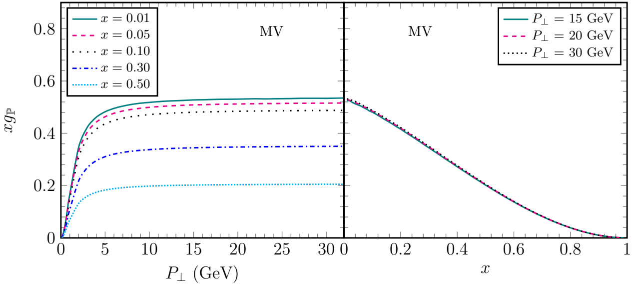


- DGLAP evolution with $\ln P_\perp^2$
- BK evolution with $Y_{\mathbb{P}} = \ln \frac{1}{x_{\mathbb{P}}}$
- The CGC provides the initial condition for DGLAP

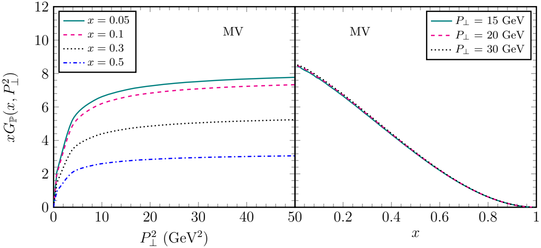
Numerical results: gluon diffractive PDF

$$xG_{\mathbb{P}}(x, x_{\mathbb{P}}, P_\perp^2) \propto S_\perp (1-x)^2 \, Q_{s,g}^2(A, x_{\mathbb{P}}) \propto (1-x)^2 A \left(\frac{1}{x_{\mathbb{P}}}\right)^{\lambda_s}$$

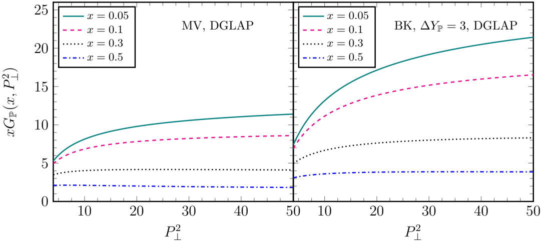
- Hallmarks of saturation: e.g. $\lambda_s \simeq 0.25$ from NLO BK
  - without saturation (confinement): $\propto (1-x)^3 A^{4/3} \Lambda^2$
- Initial condition for BK at $Y_{\mathbb{P}} = 0$: McLerran-Venugopalan model



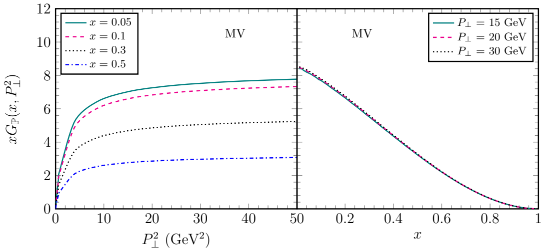
  - flat for $P_\perp > Q_s$, vanishing like $(1-x)^2$



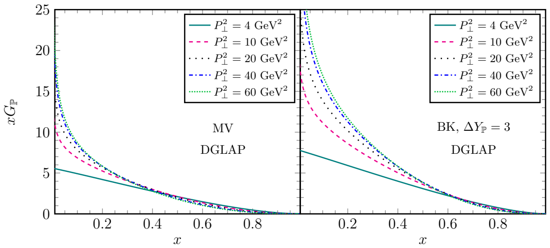
- Adding DGLAP and BK evolutions: $P_\perp$ dependence



  - increase for very small $x \leq 0.01$, slight decrease for $x > 0.05$



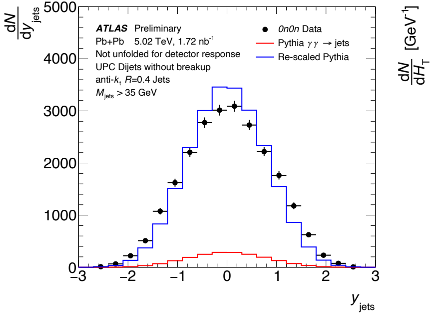
- Adding DGLAP and BK evolutions: x dependence

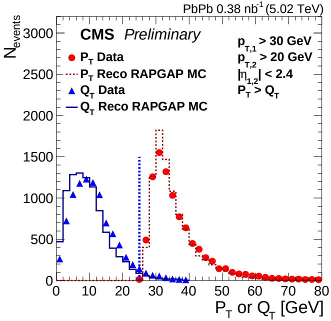


  - when $x \to 1$, the distribution vanishes even faster

Diffractive dijets in Pb+Pb UPCs at the LHC

- Recent measurements: *ATLAS-CONF-2022-021* and *CMS arXiv:2205.00045*

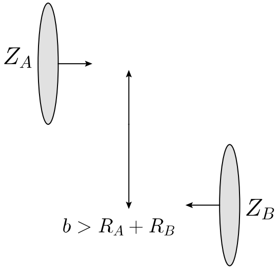


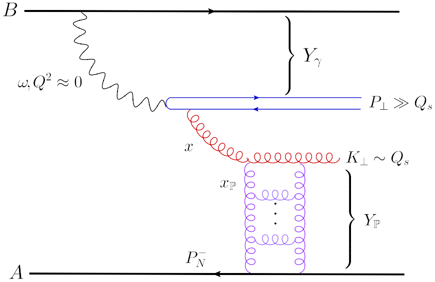


- Several thousands of candidate-events for coherent diffraction
  - no just $\gamma\gamma$ scattering: cross-section would be 10 times smaller
  - no exclusive dijets either: strongly suppressed at such large $P_\perp$
- Most likely: 2+1 jets ... but seing the 3rd jet is tricky in practice!

2+1 diffractive dijets in AA UPCs

- The photo-production limit $Q^2 \to 0$ of the general TMD factorisation



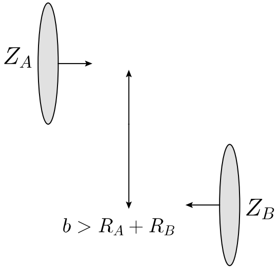


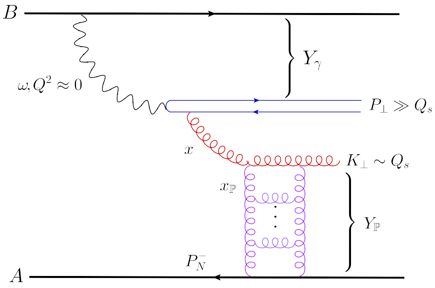
$$\frac{d\sigma_{2+1}^{AB\to q\bar{q}gAB}}{d\eta_1 d\eta_2 d^2\boldsymbol{P} d^2\boldsymbol{K} dY_{\mathbb{P}}} = \underbrace{\omega\frac{dN_B}{d\omega}}_{\gamma\ \text{flux}} \underbrace{H(\eta_1,\eta_2,P_\perp^2)}_{\sim 1/P_\perp^4} \underbrace{\frac{dxG_{\mathbb{P}}^A(x,x_{\mathbb{P}},K_\perp^2)}{d^2\boldsymbol{K}}}_{\text{Gluon DTMD}} + (A \leftrightarrow B)$$

- One nucleus is the source of photons, the other one is the hadronic target

2+1 diffractive dijets in AA UPCs

- The photo-production limit $Q^2 \to 0$ of the general TMD factorisation

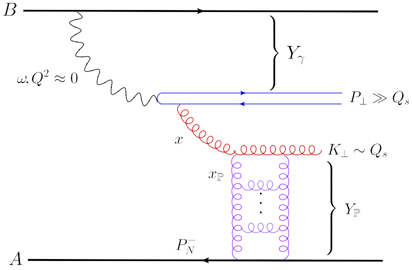


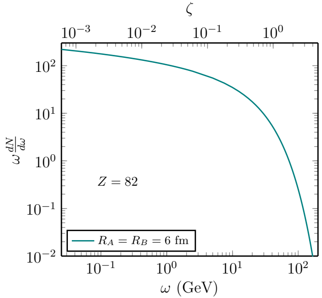


- Coherent diffraction: photon gap + diffractive gap
- Rapidity gaps on both sides: ... but which one is which ??
  - how to distinguish the photon emitter from the nuclear target ?
- By also observing the third jet: it lies between the hard dijet and the target

Why is that difficult ?

- Energy is not that high: exponential cutoff $\omega_{\max} \simeq \frac{\gamma}{2R_A} \simeq 40$ GeV





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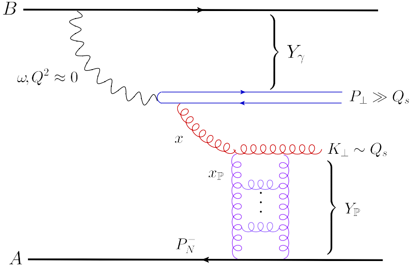


$$\eta_1 \simeq \eta_2 \equiv y$$

$$\omega = P_\perp\, e^y$$

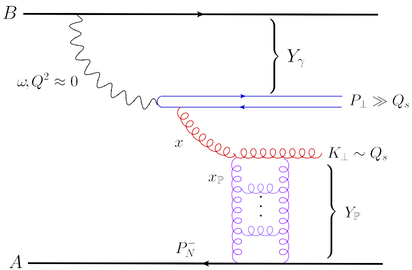
$$P_\perp \sim \omega_{\max} \;\Rightarrow\; y \lesssim 1$$

$$x_{\mathbb{P},\,\min} = \frac{P_\perp}{E_N}\, e^{-y}$$

- Transverse momenta are rather large: $P_\perp \geq 20\,\text{GeV}$
- Rapidity gap is not that large: $Y_{\mathbb{P}} = \ln \frac{1}{x_{\mathbb{P}}} \lesssim 4$
- 3rd jet: $K_\perp \sim Q_{s,g}(Y_{\mathbb{P}}) \sim 1 \div 2\,\text{GeV}$ too soft for the calorimeter
- Measure as a hadron ? The hadron detector is limited in rapidity

Why is that difficult ?

- Energy is not that high: exponential cutoff $\omega_{\max} \simeq \frac{\gamma}{2R_A} \simeq 40$ GeV



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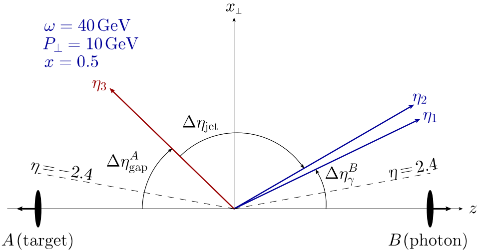
- Rapidity gap is not that large: $Y_{\mathbb{P}} = \ln \frac{1}{x_{\mathbb{P}}} \lesssim 4$
- 3rd jet: $K_\perp \sim Q_{s,g}(Y_{\mathbb{P}}) \sim 1 \div 2$ GeV too soft for the calorimeter
- The third jet lags well behind the hard dijet: $\Delta\eta_{\rm jet} \gtrsim \ln \frac{2P_\perp}{K_\perp} \simeq 2 \div 3$

A favourable event situation

- Largest photon energy, relatively low $P_\perp$
- Assume the photon to be a right mover: it was emitted by nucleus B



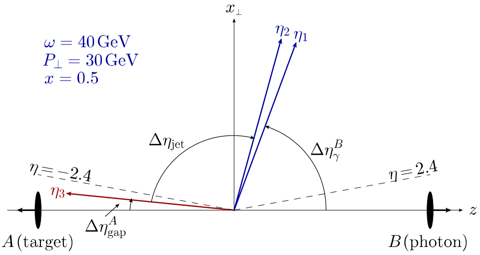
- $\omega = 40\mathrm{GeV}$, $P_\perp = 10\mathrm{GeV}$
- $\eta_{1,2} \simeq 1.4$, $Y_{\mathbb{P}} \simeq 6$

$$\Delta\eta_{\rm jet} \gtrsim \ln\frac{2P_\perp}{Q_s} \simeq 2.3$$

- The hard dijets are forward (towards the photon), the 3rd one is backward (towards the target)
- 3rd jet must lie within the hadronic detector: $|\eta_3| < \eta_0 = 2.4$
- With this kinematics, this seems not to be a problem !

A likely event at CMS

- Dijet events selected by CMS have larger $P_\perp \geq 30\text{GeV}$ *(arXiv:2205.00045)*



- $\omega = 40\text{GeV}$, $P_\perp = 30\text{GeV}$
- $\eta_{1,2} \simeq 0.3$, $Y_{\mathbb{P}} \simeq 4$

$$\Delta\eta_{\text{jet}} \gtrsim \ln\frac{2P_\perp}{Q_s} \simeq 3.4$$

- $|\eta_3| = 3.1 > \eta_0 = 2.4$: the 3rd jet is missed by the detector ☹
- Lessons: Trigger on rare events with high photon energy ω
- Use a hadronic detector with larger rapidity coverage $|\eta_{\max}|$
- Measure jets with lower $P_\perp \leq 15\text{GeV}$

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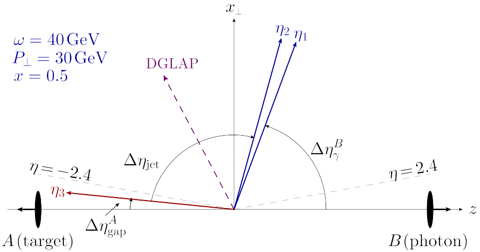

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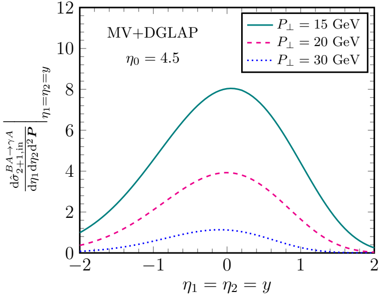
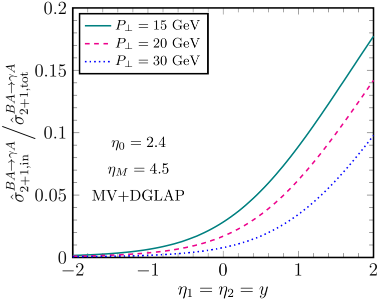
- observe a DGLAP jet ☺

- $|\eta_3| = 3.1 > \eta_0 = 2.4$: the 3rd jet is missed by the detector ☹
- Lessons: Trigger on rare events with high photon energy ω
- Use a hadronic detector with larger rapidity coverage $|\eta_{\max}|$
- Measure jets with lower $P_\perp \leq 15\text{GeV}$

Rapidity distributions

- Left: rapidity distribution of the hard dijets ($\eta_1 \simeq \eta_2 \equiv y$)
  - roughly symmetric around $y = 0$
  - rapidly decreasing when increasing $P_\perp$





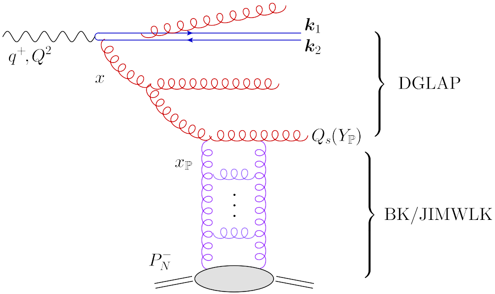
- Right: fraction of events with the 3rd jet inside the detector: $|\eta_3| < \eta_0 = 2.4$
  - rapidly increasing when increasing y, or decressing $P_\perp$

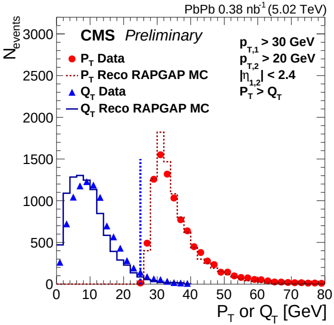
Conclusions & Open questions

- Diffraction in γA (EIC, UPC): good laboratory to study gluon saturation
- Collinear factorisation for hard diffraction emerges from CGC
- Diffractive TMDs and PDFs can be computed from first principles
- Recent progress, many open problems (conceptual & experimental)
- Dijets in AA UPCs (LHC): can one measure the semi-hard, 3rd, jet ?
- What about diffractive hadron production in AA UPCs (ALICE) ?
- What about eA DIS at the EIC ?
- What about next-to-leading order corrections ?
- Possible extensions to inelastic phenomena (e.g. inclusive dijets in DIS) ?
- Towards unifying the DGLAP and the BK/JIMWLK evolutions ?

Final-state radiation

- Dijet momentum imbalance dominated by final-state radiation
  - additional gluons with transverse momenta $Q_s \ll k_\perp \ll P_\perp$

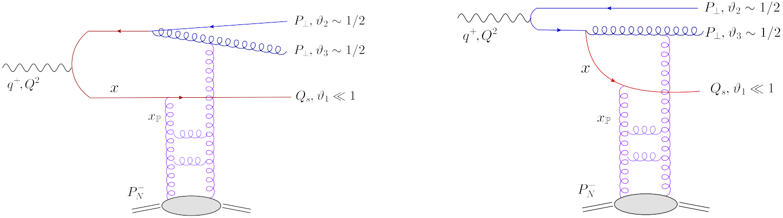




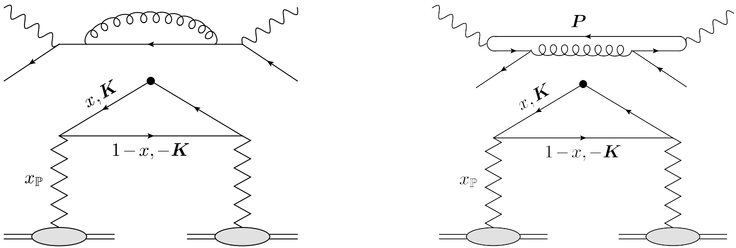
- LHC: dijet imbalance $Q_T = |\boldsymbol{k}_1 + \boldsymbol{k}_2| \sim 10\,\text{GeV} \gg Q_s$
  - consistent with final state radiation *(Hatta et al, 2010.10774)*
  - insensitive to the 3rd jet

2+1 jets with a hard gluon

- The third (semi-hard) jet can also be a quark: same-order



- TMD factorisation: quark unintegrated distribution of the Pomeron



The quark diffractive TMD

$$\frac{\mathrm{d}xq_{\mathbb{P}}(x,x_{\mathbb{P}},K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}} = \frac{S_\perp N_c}{4\pi^3}\underbrace{\Phi_q(x,x_{\mathbb{P}},K_\perp^2)}_{\text{occupation number}}$$

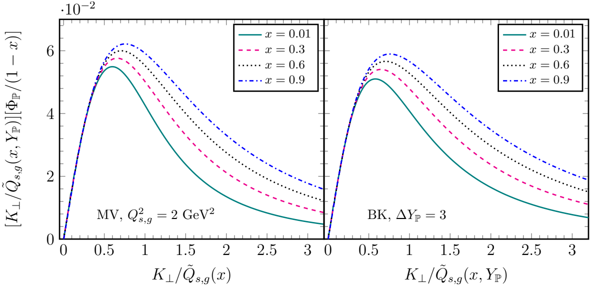
- Bessel-Fourier transform of the $q\bar{q}$ dipole amplitude $T_{q\bar{q}}(R,Y_{\mathbb{P}})$

$$\Phi_q(x,x_{\mathbb{P}},K_\perp^2) \simeq x\begin{cases}1, & K_\perp \lesssim \tilde{Q}_s(x)\\[2mm] \dfrac{\tilde{Q}_s^4(x)}{K_\perp^4}, & K_\perp \gg \tilde{Q}_s(x)\end{cases}$$

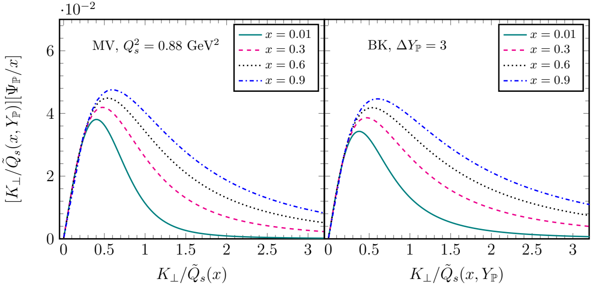
- Like for the gluon diffractive TMD, but with overall factor $1-x \to x$
  - gluons dominate at small x, quarks are more important near $x=1$
- Once again, the bulk of the distribution lies at saturation: $K_\perp \lesssim \tilde{Q}_s(x)$

$$xq_{\mathbb{P}}(x,x_{\mathbb{P}},P_\perp^2) \equiv \int^{P_\perp}\mathrm{d}K_\perp^2\,\Psi(x,x_{\mathbb{P}},K_\perp^2)\,\propto\,x(1-x)\,Q_s^2(Y_{\mathbb{P}})$$

Gluon vs. quark diffractive TMDs

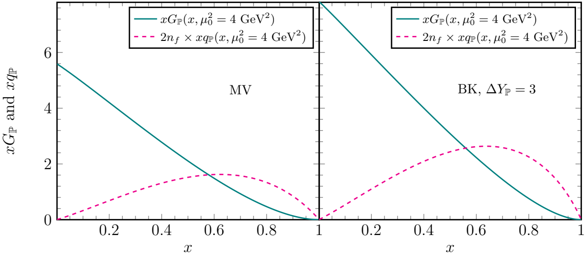


- First line: gluon. Second line: quark

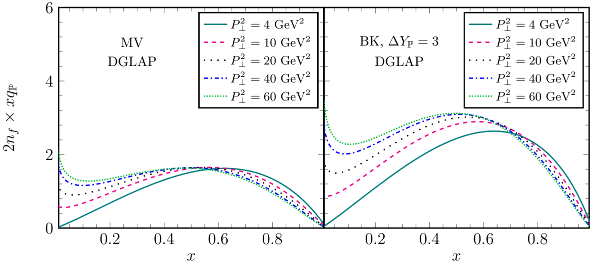


Quark diffractive PDF

- Initial conditions for DGLAP (MV, or MV+BK): gluon & quark



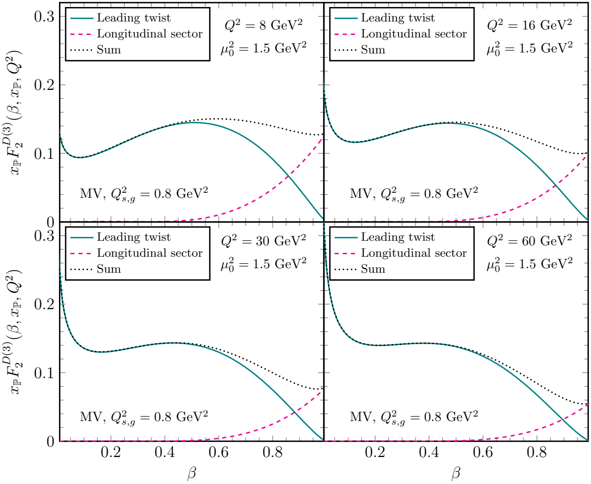
- Quark DPDF with DGLAP: x dependence (gluon-driven at small x)



Diffractive structure function: proton target

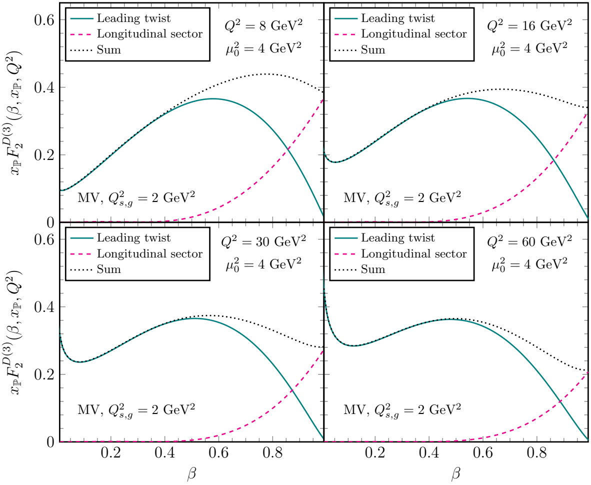
- Quark DPDF (leading-twist, DGLAP) & Longitudinal γ_L^* (higher twists, MV)

$$F_2^{D(3)}(\beta, x_{\mathbb{P}}, Q^2) = 2\sum_f e_f^2\, xq_{\mathbb{P}}(x, x_{\mathbb{P}}, Q^2)\big|_{x=\beta} + F_L^{D(3)}$$



Diffractive structure function: nuclear target

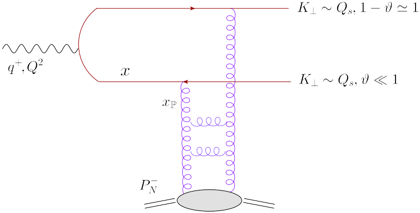
- Larger initial saturation momentum & larger "factorisation" scale μ_0^2

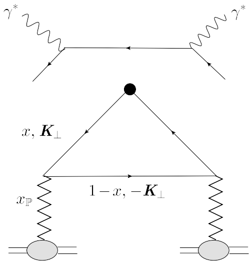


Universality of the quark diffractive TMD

- Diffractive SIDIS in the aligned jet configuration: $\vartheta \ll 1$
- High virtuality: $Q^2 \gg Q_s^2$, but semi-hard transverse momenta:

$$K_\perp^2 \simeq \vartheta(1-\vartheta)Q^2 \sim Q_s^2 \qquad \text{(to have strong scattering)}$$





$$\frac{\mathrm{d}\sigma_{\text{el}}^{\gamma_T^* A \to q\bar{q}A}}{\mathrm{d}^2\boldsymbol{K}\,\mathrm{d}Y_{\mathbb{P}}} = \frac{4\pi^2\alpha_{em}}{Q^2}\,\frac{\mathrm{d}x q_{\mathbb{P}}(x, x_{\mathbb{P}}, K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}}$$

- The hard factor: cross-section for virtual photon absorbtion