Probing gluon saturation via photon-hadron interactions at high energy

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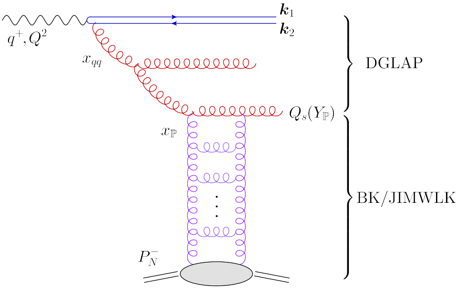
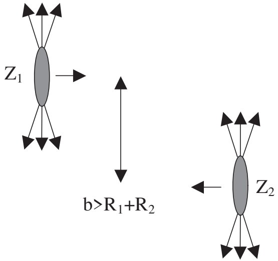


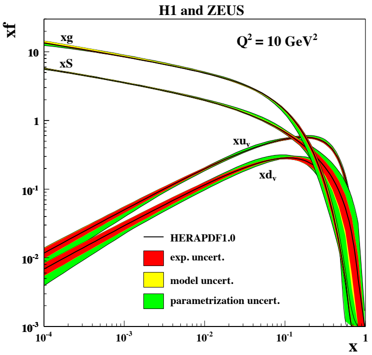


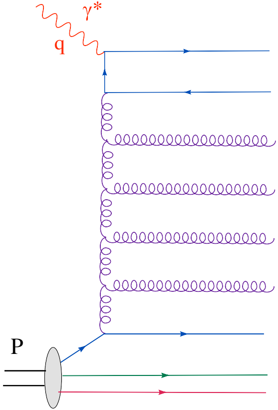
Outline

- Color Dipole Picture for photon-hadron interactions at high energy
    - Gluon Saturation: brief introduction *(cf. talk by Raju Venugopalan)*
    - DIS: from the target picture to the dipole picture
    - Gluon Saturation: Inclusive vs. Diffractive DIS
- Diffractive jets in γ-hadron interactions
    - Exclusive dijets: higher twist
    - 2+1 jets: the dominant channel
    - TMD factorisation from the Color Dipole Picture
    - Unintegrated gluon distribution of the Pomeron
- Diffractive jets in Ultraperipheral Nucleus-Nucleus Collisions
    - opportunities (gluon saturation) & difficulties

Rise of gluon PDF

- Electron-proton DIS at HERA, two invariants: Q^2 and $x = \frac{Q^2}{2P\cdot q}$

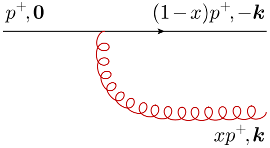




- $xG(x, Q^2) = \#$ of gluons with longitudinal momentum fraction x and transverse momentum $k_\perp \leq Q$
- Dominance of gluons at small $x \leq 0.01$: QCD evolution

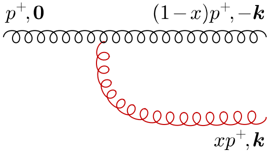
Soft gluons

- Soft gluon emission from a quark



$$\mathrm{d}\mathcal{P} \simeq \frac{\alpha_s}{2\pi} \frac{\mathrm{d}k_\perp^2}{k_\perp^2} \underbrace{P_{g\leftarrow q}(x)\mathrm{d}x}_{\simeq 2C_F/x}$$

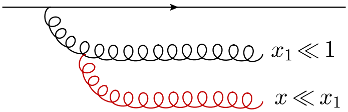
- Soft gluon emission from a gluon



$$\mathrm{d}\mathcal{P} \simeq \frac{\alpha_s}{2\pi} \frac{\mathrm{d}k_\perp^2}{k_\perp^2} \underbrace{P_{g\leftarrow g}(x)\mathrm{d}x}_{\simeq 2N_c/x}$$

- Large emission probability when the gluon is soft/low-energy: $x \ll 1$
- By iterating soft gluon emissions $\Longrightarrow$ Gluon cascades (BFKL evolution)

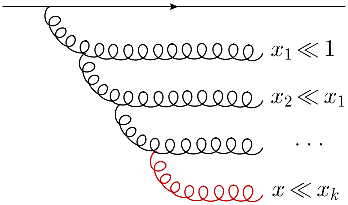
- Two successive gluon emissions, which are strongly ordered



$$\frac{\alpha_s N_c}{\pi}\int_x^1 \frac{\mathrm{d}x_1}{x_1} = \frac{\alpha_s N_c}{\pi}\ln\frac{1}{x}$$

- $Y \equiv \ln(1/x)$: rapidity difference between parent quark and final gluon

- $k+1$ successive emissions, strongly ordered in x



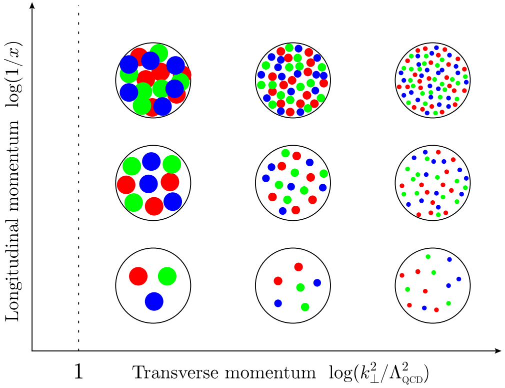
$$\frac{1}{k!}\left(\bar{\alpha}Y\right)^k, \quad \bar{\alpha} \equiv \frac{\alpha_s N_c}{\pi}$$

- Sum over $k \Rightarrow$ an exponential:

$$xG(x, Q^2) \propto \mathrm{e}^{\lambda Y}$$

- Linear evolution: gluons multiply, yet they do not interact

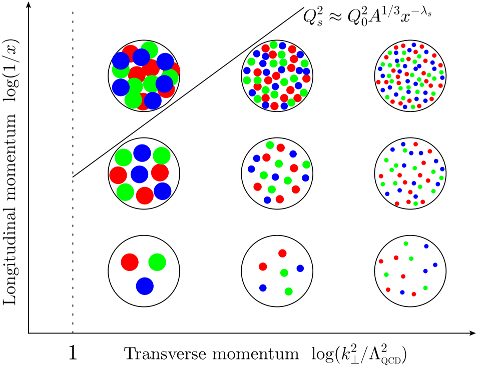
Evolution and the transverse density



- Increase $k_\perp$, or Q^2 (DGLAP) $\Longrightarrow$ many small partons $\Longrightarrow$ low density
- Increase $1/x$ (BFKL) $\Longrightarrow$ many partons of similar size $\Longrightarrow$ high density
- Overlapping gluons can interact with each other

Gluon occupancy

- The relevant quantity: the gluon occupation number in phase space



- gluon area $\times$ gluon density

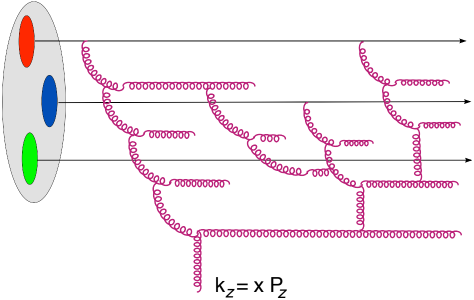
$$n(x,Q^2) \simeq \frac{1}{Q^2} \times \frac{xG_A(x,Q^2)}{\pi R_A^2}$$

- dilute systems have $n \ll 1$

- When $n \gtrsim 1$, gluons overlap, but their interactions are still suppressed by α_s
- Interactions become of $\mathcal{O}(1)$ when $n(x,Q^2) \sim 1/\alpha_s$
- Emergent transverse momentum scale: saturation momentum $Q_s(x,A)$

BK-JIMWLK evolution

- Evolution becomes non-linear (JIMWLK) and gluon occupancy saturates
  (Jalilian-Marian, Iancu, McLerran, Weigert, Leonidov, and Kovner, 97–00)



- schematically ("BK eq.")
  (Balitsky, 95; Kovchegov, 99)

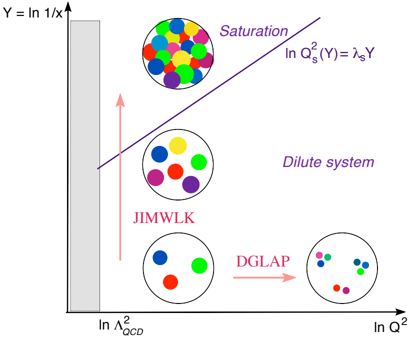
$$\frac{\partial n}{\partial Y} = \alpha_s n - \alpha_s^2 n^2$$

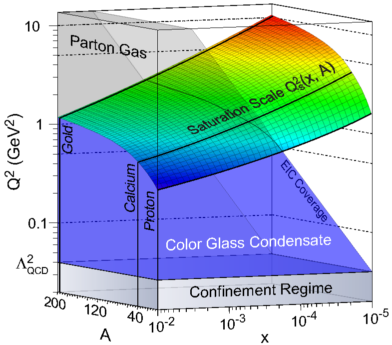
- Fixed point $n \sim 1/\alpha_s$

- Non-linear, functional, generalisation of BFKL: Wilson line operators
  - unitarity for scattering amplitudes, no infrared diffusion
- Known to NLO + collinear resummations *(see talk by Nestor Armesto)*

Saturation momentum

$$Q_s^2(x, A) \simeq \alpha_s \frac{xG_A(x, Q_s^2)}{\pi R_A^2} \sim \frac{A^{1/3}}{x^{\lambda_s}}, \quad \lambda_s \sim 0.3$$

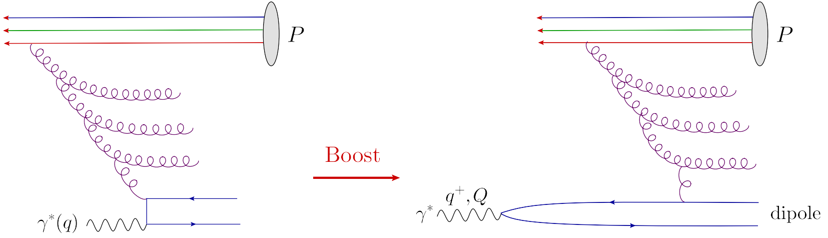




- $x \sim 10^{-3}$ (EIC): $Q_s^2 \sim 2$ GeV^2 for Pb or Au
- $x \sim 10^{-5}$ (LHC): $Q_s^2 \sim 10$ GeV^2 for Pb and ~ 1 GeV^2 for a proton

Dipole picture: Lorentz frame

- Usual parton picture: target infinite momentum frame $P_N^- \to \infty$
- $x \ll 1$: boost to the dipole frame where the photon is energetic: $q^+ \gg Q$
- Goal: transfer the $q\bar{q}$ pair from the target to the projectile

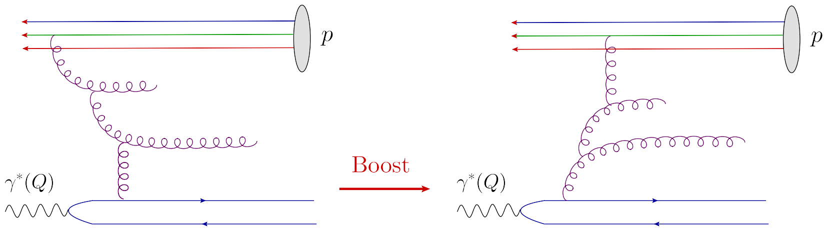


$$x = \frac{Q^2}{2P_N^- q^+} \ll \frac{1}{A^{1/3}} \iff \Delta x^+ \simeq \frac{2q^+}{Q^2} \gg \frac{A^{1/3}}{P_N^-} \sim \frac{R_A}{\gamma}$$

- the virtual photon fluctuates into a $q\bar{q}$ pair long before the scattering
- the $q\bar{q}$ color dipole acts as a probe of the gluon distribution

Dipole picture: gauge choice

- Usual parton picture: target light-cone gauge $A^- = 0$
- $x \ll 1$: change to the light-cone gauge of the projectile (dipole): $A^+ = 0$
- Goal: transfer the high energy evolution & saturation from target to dipole
  - wavefunction of a relativistic system is well defined in its LC gauge



  - building the wavefunction is simpler for a dilute object

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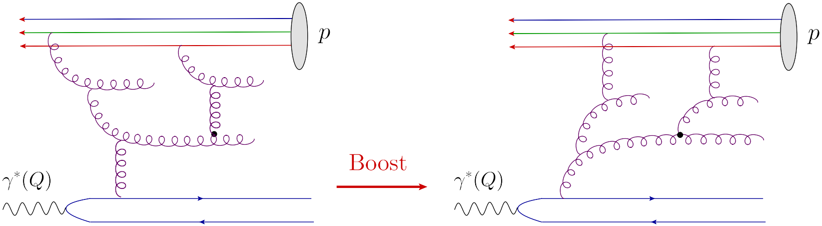
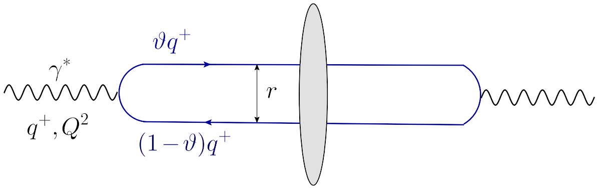


  - building the wavefunction is simpler for a dilute object
  - this becomes obvious after adding non-linear effects
- Gluon saturation in target picture $\Longleftrightarrow$ multiple scattering in dipole picture

Dipole picture for inclusive DIS

- Lorentz contraction: the dipole scatters of a shockwave

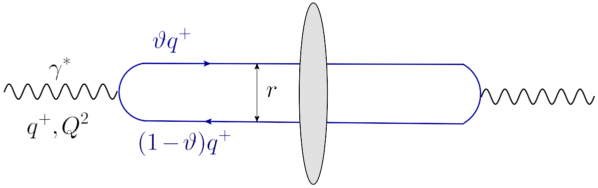


$$\sigma_{\gamma^* A}(Q^2, x) = \int \mathrm{d}^2 r \int_0^1 \mathrm{d}\vartheta \left|\Psi_{\gamma^* \to q\bar{q}}(r, \vartheta; Q^2)\right|^2 \underbrace{\sigma_{\text{dipole}}(r, A, x)}_{2\pi R_A^2\, T_A(r,x)}$$

- All QCD dynamics in the dipole amplitude $T_A(r, x)$
- Solution to BK/JIMWLK eqs, MV model for initial condition at $x_0 \sim 10^{-2}$

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

Dipole picture for inclusive DIS



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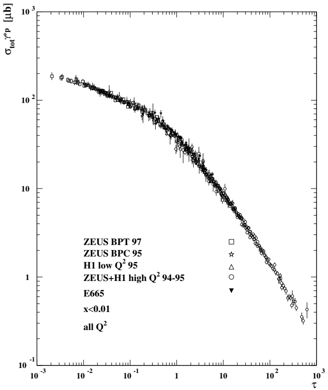
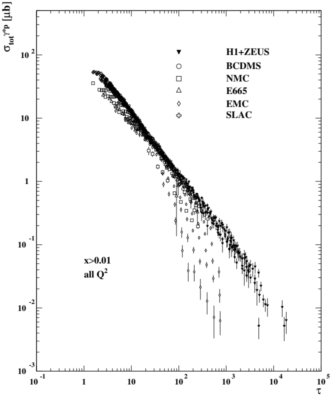
- Virtuality limits large dipoles: $r \lesssim 1/\bar{Q}$ with $\bar{Q}^2 \equiv \vartheta(1-\vartheta)Q^2$
- Saturation requires $r \gtrsim 1/Q_s$, hence $\bar{Q}^2 \lesssim Q_s^2$
- When $Q^2 \gg Q_s^2$, dominant contribution from weak scattering $(rQ_s \ll 1)$
- Even weak scattering can be affected by saturation

Geometric scaling at HERA

(Staśto, Golec-Biernat, Kwieciński, 2000)



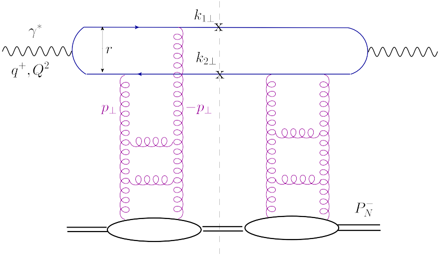


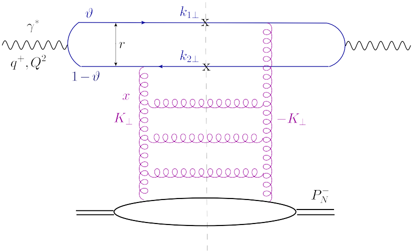
- In general, $\sigma_{\gamma^* p}(x, Q^2)$ involves 2 independent variables
- For $x \leq 10^{-2}$, it depends only upon $\tau \equiv Q^2/Q_s^2(x)$: "scaling"
- For larger $x > 10^{-2}$: no scaling

Diffraction: F_{2D}

- Elastic scattering/diffraction is more sensitive to strong scattering

$$\sigma_{el} \propto |T|^2 \longleftrightarrow \sigma_{tot} \propto 2\mathrm{Im}\, T$$





- Colourless exchange: 2-gluon ladder, (BFKL) Pomeron, rapidity gap
- F_{2D} controlled by the black disk limit ($T \sim 1$) even when $Q^2 \gg Q_s^2$
  - asymmetric $q\bar{q}$ pairs, $\vartheta(1-\vartheta) \ll 1$, with large size $r \sim 1/Q_s$
  - would be non-perturbative, $r \sim 1/\Lambda$, in absence of saturation

One vs two Pomerons... at HERA

- 2-gluon exchange: σ_{el} rises with $\frac{1}{x}$, or with A, like two Pomerons

$$T^2 \simeq \left[r^2 Q_s^2(A,x)\right]^2 \propto \frac{A^{2/3}}{x^{2\lambda_s}} \qquad \text{vs.} \qquad T \simeq r^2 Q_s^2(A,x) \propto \frac{A^{1/3}}{x^{\lambda_s}}$$

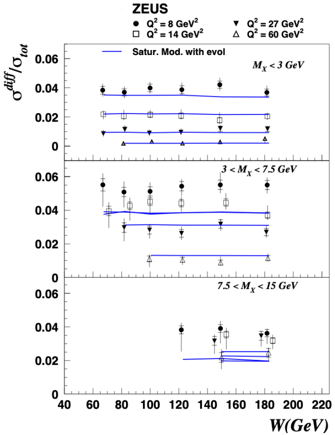


Figure 9: The ratio of $\sigma_{diff}/\sigma_{tot}$ versus the $\gamma^* p$ energy W. The data is from ZEUS and the solid lines correspond to the results of the DGLAP improved model with massless quarks (FIT 2).

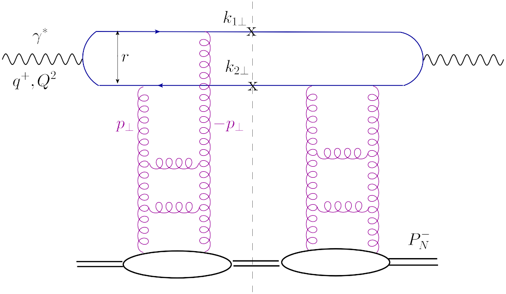
- But it doesn't! Controlled by multiple scattering: $T \sim 1$, or $r \sim 1/Q_s$
- Almost the same scaling as σ_{tot}:

$$\frac{\sigma_{el}}{\sigma_{tot}} \sim \frac{1}{\ln\left(Q^2/Q_s^2\right)}$$

- Weak x-dependence confirmed by HERA *(Bartels, Golec-Biernat, Kowalski, 2002)*
- Would be interesting to also check the A-dependence at the EIC

Exclusive production of hard dijets

- The simplest jet measurement in diffraction: a pair of back-to-back jets
- Leading order: a $q\bar{q}$ pair, which is hard and relatively symmetric:
  - $k_{1\perp} \simeq k_{2\perp} \equiv P_\perp \sim Q \gg Q_s$ & $\vartheta \sim 1/2$
- Hard scale sets dipole size $r \sim 1/P_\perp \ll 1/Q_s \Longrightarrow$ weak scattering



$$\frac{\mathrm{d}\sigma_{\mathrm{el}}^{\gamma^* A \to q\bar{q}A}}{\mathrm{d}\vartheta \mathrm{d}^2\boldsymbol{P}} \propto \underbrace{\frac{\alpha_{\mathrm{em}}}{Q^2}}_{\gamma^* \to q\bar{q}} \underbrace{\frac{Q_s^4}{P_\perp^4}}_{T_A^2}$$

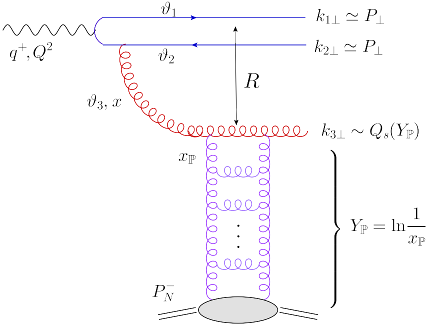
$$\propto \frac{Q_s^4}{P_\perp^6} \quad \text{higher twist}$$

- Rare events ("higher twist"), insensitive to saturation

Diffractive 2+1 jets

(E.I., A.H. Mueller, D.N. Triantafyllopoulos, PRL 128 (2022) 20)

- Can one have diffractive dijets at leading twist ? $(\sim 1/P_\perp^4)$
- Yes, two hard jets $P_\perp \gg Q_s$ and one semi-hard $k_{3\perp} \sim Q_s \ll P_\perp$
- Third, semi-hard, jet provides dijet imbalance: $|\boldsymbol{k}_1 + \boldsymbol{k}_2| = k_{3\perp} \ll P_\perp$



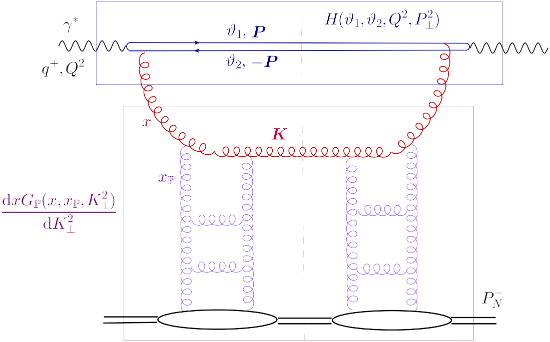
$$R \sim \frac{1}{Q_s} \gg r \sim \frac{1}{P_\perp}$$

- Effective gluon-gluon dipole
- Strong scattering: $T_{gg}(R, Y_{\mathbb{P}}) \sim 1$
- $\mathcal{O}(\alpha_s)$, but leading-twist

- N.B. Saturation momentum evaluated at the rapidity gap $Y_{\mathbb{P}} = \ln \frac{1}{x_{\mathbb{P}}}$

- Scale separation $\Longrightarrow$ Factorisation $\Longrightarrow$ Gluon is part of the Pomeron

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



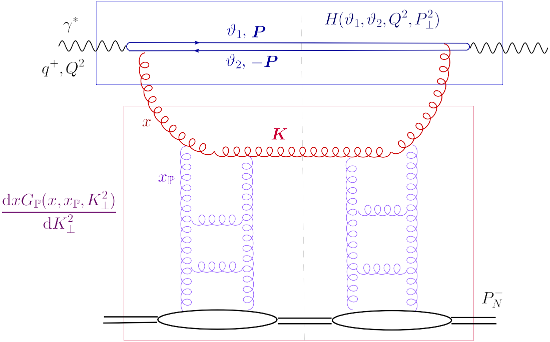
- The hard factor: $\gamma^* \to q\bar{q}$ decay & the gluon emission

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

TMD factorisation

- Scale separation $\Longrightarrow$ Factorisation $\Longrightarrow$ Gluon is part of the Pomeron

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



- Gluon diffractive TMD: unintegrated gluon distribution of the Pomeron
- x: energy fraction of the exchanged gluon with respect to the Pomeron

The Pomeron UGD

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

- Given explicitly in terms of the gluon-gluon dipole amplitude $T_{gg}(R, Y_{\mathbb{P}})$

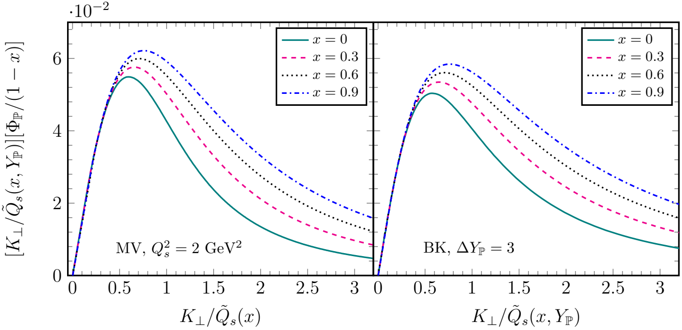
$$\Phi_g(x,x_{\mathbb{P}},K_\perp^2) \simeq (1-x)\begin{cases} 1, & K_\perp \lesssim \tilde{Q}_s(x) \\ \dfrac{\tilde{Q}_s^4(x)}{K_\perp^4}, & K_\perp \gg \tilde{Q}_s(x) \end{cases}$$

- Valid for large gap/small $x_{\mathbb{P}} \lesssim 10^{-2}$ and any $x \leq 1$
- Effective saturation momentum: $\tilde{Q}_s^2(x, Y_{\mathbb{P}}) = (1-x)Q_s^2(Y_{\mathbb{P}})$
- The bulk of the distribution lies at saturation: $K_\perp \lesssim \tilde{Q}_s(x)$
- Gluon saturation in the Pomeron $\longleftrightarrow$ Black disk limit $T_{gg} = 1$

Numerical results

(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 $K_\perp \simeq \tilde{Q}_s$



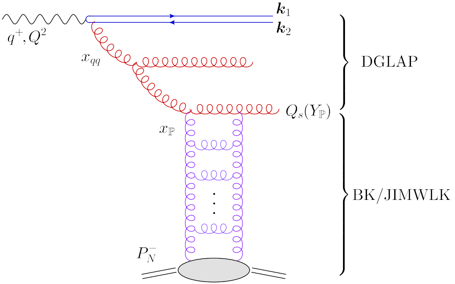
- BK evolution: increasing $Q_s^2(Y_\mathbb{P})$, approximate geometric scaling

From TMD to diffractive PDF

- Sensitivity to saturation persists after integrating out the $K_\perp$–distribution
  - the integral is rapidly converging and effectively cut off at $K_\perp \sim \tilde{Q}_s(x)$

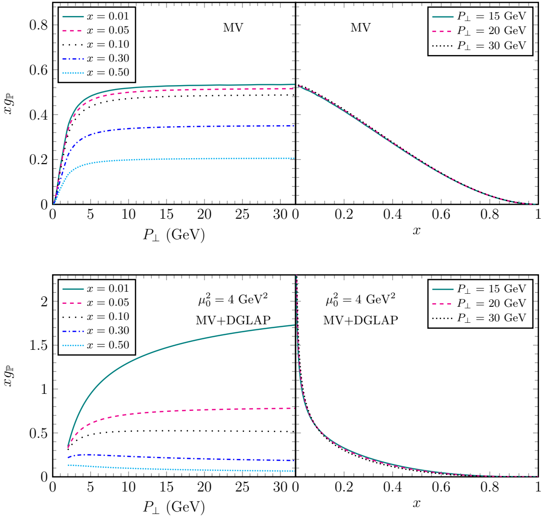
$$xG_{\mathbb{P}}(x, x_{\mathbb{P}}, P_\perp^2) \equiv \int^{P_\perp} \mathrm{d}K_\perp^2 \, \Phi(x, x_{\mathbb{P}}, K_\perp^2) \, \propto \, (1-x)^2 \, Q_s^2(Y_{\mathbb{P}})$$

- Large separation of scales $P_\perp^2 \gg Q_s^2$: one must include DGLAP evolution



- MV model at $x_{\mathbb{P}} = 10^{-2}$
- BK evolution with $Y_{\mathbb{P}} = \ln \frac{1}{x_{\mathbb{P}}}$
- DGLAP evolution with initial condition at $P_\perp^2 \sim Q_s^2(Y_{\mathbb{P}})$
- Collinear factorisation from CGC

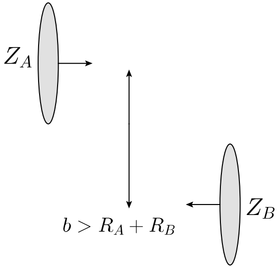
The gluon diffractive PDF

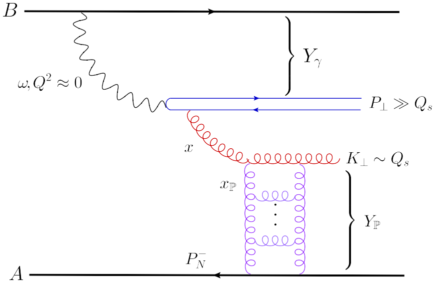


- DGLAP: increase for very small $x \leq 0.01$, slight decrease for $x > 0.05$
- When $x \to 1$, the distribution vanishes even faster

2+1 diffractive dijets in AA UPCs

- $b > R_A + R_B$: interactions mediated by quasi-real photons
- One nucleus source of photons, other nucleus hadronic target
- Coherent diffraction: photon gap + diffractive gap

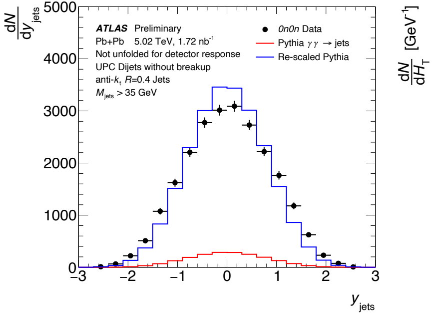


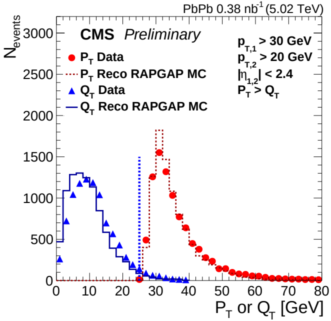


$$\frac{\mathrm{d}\sigma_{2+1}^{AB\to q\bar{q}gAB}}{\mathrm{d}\eta_1 \mathrm{d}\eta_2 \mathrm{d}^2\boldsymbol{P}\mathrm{d}^2\boldsymbol{K}\mathrm{d}Y_{\mathbb{P}}} = \underbrace{\omega\frac{\mathrm{d}N_B}{\mathrm{d}\omega}}_{\text{photon flux}} \underbrace{H(\eta_1,\eta_2,P_\perp^2)}_{\sim 1/P_\perp^4} \underbrace{\frac{\mathrm{d}xG_{\mathbb{P}}^A(x,x_{\mathbb{P}},K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}}}_{\text{Gluon DTMD}}$$

Pb+Pb UPCs at the LHC *(see talk by Brian Cole)*

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

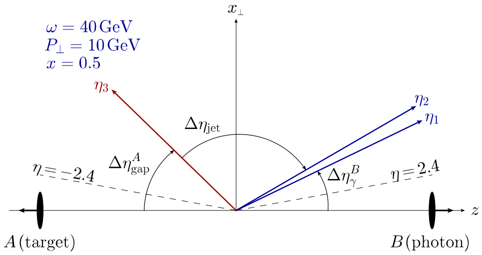




- Several thousands of candidate-events for coherent diffraction
  - no just $\gamma\gamma$ scattering: cross-section would be 10 times smaller
- Most likely: 2+1 jets ... but how to experimentally check ?
  - $K_\perp \sim Q_s \sim 1 \div 2\,$GeV: not really a jet! Measure as a hadron (?)

A favourable event situation

- Assume the photon to be a right mover: it was emitted by nucleus B
- 3rd jet must lie within the hadronic detector: $|\eta_3| < |\eta_{\max}| = 2.4$



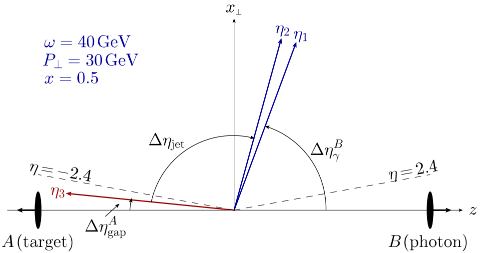
- $\omega = 40$GeV, $P_\perp = 10$GeV
- $\eta_{1,2} \simeq 1.4$, $x_{\mathbb{P}} \simeq 0.002$

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

- Observing the 3rd jet would be extremely useful
  - it propagates towards the nuclear target: lift the A vs. B ambiguity
  - one can measure the diffractive rapidity gap and thus infer $x_{\mathbb{P}}$
  - rapidity separation $\Delta\eta_{\rm jet}$: a measure of the saturation momentum Q_s

A likely event at CMS

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



- $\omega = 40\text{GeV}$, $P_\perp = 30\text{GeV}$
- $\eta_{1,2} \simeq 0.3, \quad x_{\mathbb{P}} \simeq 0.02$

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

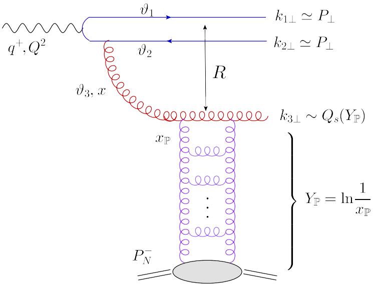
- $|\eta_3| = 3.1 > |\eta_{\max}| = 2.4$: the 3rd jet is missed by the detector ☹
- Lessons: Trigger on rare events with high photon energy ω
- Use a hadronic detector with larger rapidity coverage $|\eta_{\max}|$
- Measure jets with lower $P_\perp \leq 15\text{GeV}$

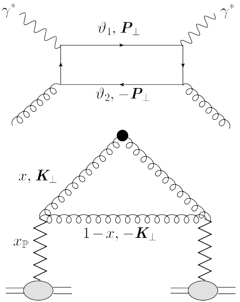
Conclusions

- Diffraction in γA (EIC, UPC): best laboratory to study gluon saturation
- For sufficiently small $x_{\mathbb{P}} \lesssim 10^{-2}$ and/or large $A \sim 200$, diffractive TMDs and PDFs can be computed from first principles
- Collinear factorisation for hard diffraction emerging from CGC
- Due to saturation, diffractive dijets are dominated by (2+1)–jet events
- AA UPCs: Measuring the semi-hard, 3rd, jet is tough, but very useful
  - measure dijets (or dihadrons) with lower $P_{\perp} \leq 10$ GeV
  - hadronic detectors with larger rapidity coverage
  - what about diffractive hadrons in UPCs at ALICE ?
- Kinematical conditions should be more favorable at the EIC

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: $\frac{k_3^+}{k_{3\perp}^2} \lesssim \frac{q^+}{Q^2}$
- Scale separation $\Longrightarrow$ Factorisation $\Longrightarrow$ Gluon is part of the Pomeron

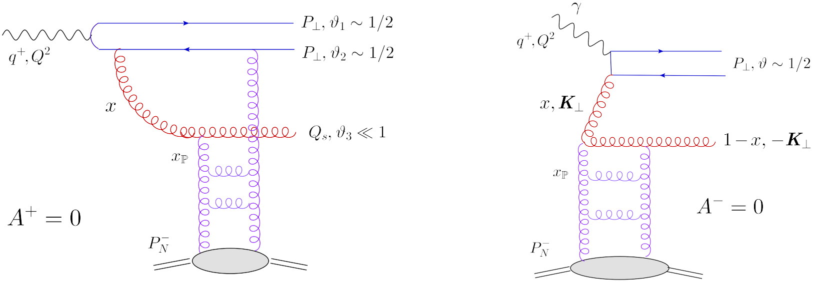




- x: energy fraction of the exchanged gluon with respect to the Pomeron
  - gluon absorption puts the hard dijet system on-shell

Soft gluon and TMD factorisation (2)

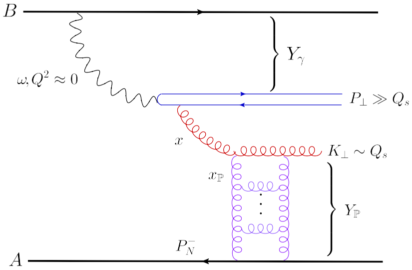
- The strong ordering in both $k_\perp$ and k^+ is essential for factorisation
- The dipole picture holds in the projectile light cone gauge $A^+ = 0$
  - right moving partons couple to the A^- component of the target field

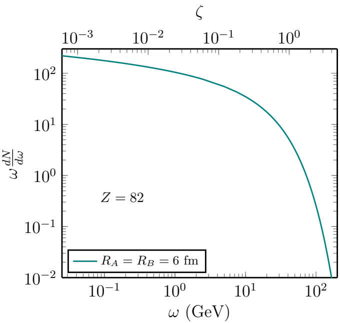


- The TMD picture holds in the target light cone gauge $A^- = 0$
  - only the soft gluon couples to the target field: $v^i A^i$ with $v^i = k^i/k^+$

Energy cutoff

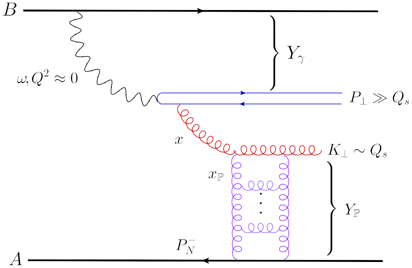
- Energy is not that high:
  - LHC: $\sqrt{s_{NN}} = 2E_N = 5$ TeV, yet $\sqrt{s_{\gamma N}} = \sqrt{4\omega_{\max} E_N} \simeq 650$GeV
  - upper energy cutoff: $b \sim \frac{1}{Q} > 2R_A \;\Rightarrow \omega < \frac{\gamma}{2R_A} \equiv \omega_{\max} \simeq 40$ GeV
  - exponential suppression for $\omega > \omega_{\max}$





$x_{\mathbb{P}}$ is not that small

- Limited energy and relatively hard dijets $P_\perp \geq 15\,\text{GeV}$
  - relatively large $x_{\mathbb{P}}$: $x_{\mathbb{P}} \gtrsim 5 \times 10^{-3}$
  - one cannot probe the high energy evolution of the Pomeron



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

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

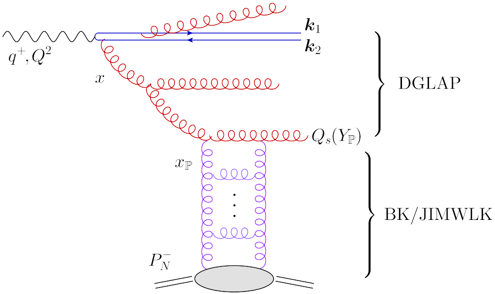
$$\omega = P_\perp\, e^y$$

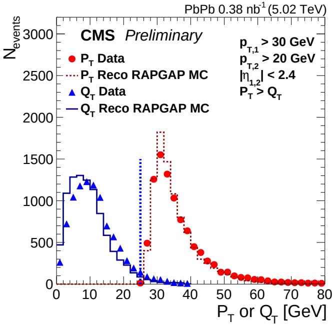
$$P_\perp \sim \omega_{\text{max}} \;\Rightarrow\; y \lesssim 1$$

- Not the ideal "small–$x_{\mathbb{P}}$" set-up! Similar in that sense to the EIC
- Decreasing $P_\perp$ would greatly help !

Final-state radiation

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

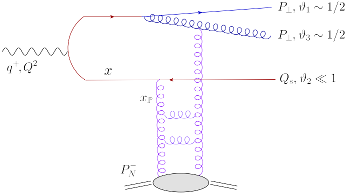


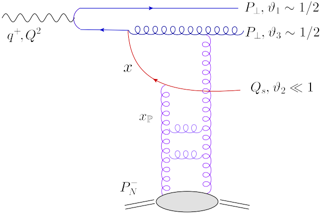


- LHC: dijet imbalance $Q_T = |\boldsymbol{k}_1 + \boldsymbol{k}_2| \sim 10\,\text{GeV} \gg Q_s$
  - consistent with final state radiation *(Hatta et al, 2010.10774)*
  - insensitive to the 3rd jet

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