Diffractive jets in photon-nucleus collisions

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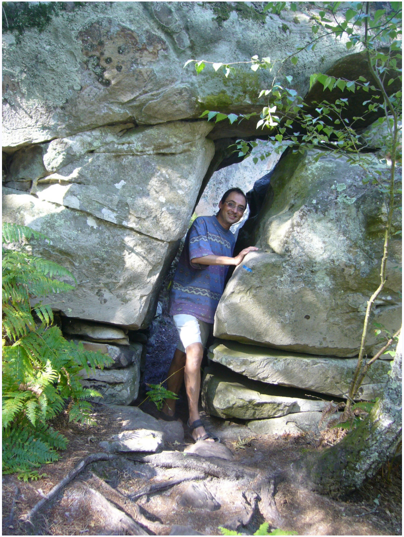
Probing the CGC and QCD Matter at Hadron Colliders
In Celebration of Edmond Iancu's 60th Birthday
GGI Florence, 27 March 2025

- S. Hauksson, E. Iancu, A.H. Mueller, DT, S.Y. Wei: 2402.14748 (JHEP)
  96 PAGES
  [and 2304.12401 (EPJC), 2207.06268 (JHEP) 66 PAGES, 2112.06353 (PRL)]
- B. Rodriguez-Aguilar, DT, S.Y. Wei: 2302.01106 (PRD), 2407.17665 (PRD)

A SURPRISE

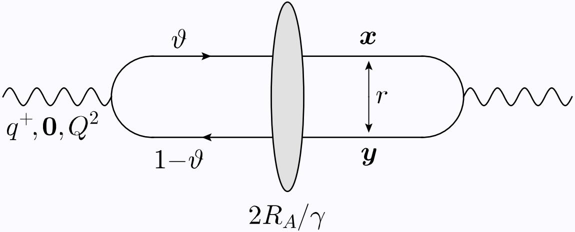
- I don't have many pictures of Edmond
- Because usually he is the one taking pictures
- He is also a tour guide

Beer Sheva 2015

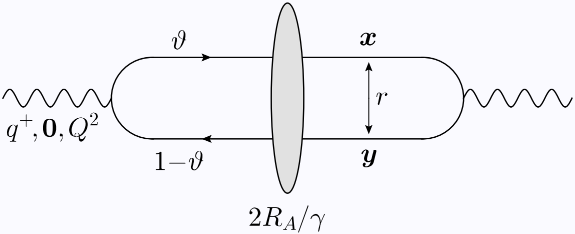


- Met in New York, 2003
- The Cronin paper, EI, K. Itakura, DT, hep-ph/0403103 (NPA), Saclay 2004

- Deep inelastic scattering in the dipole picture
- "$2+1$" jets in coherent diffraction as probes of saturation
- Factorization: Gluon and quark diffractive TMDs
- DTMDs in SIDIS
- 2 and "$2+1$" jets in incoherent diffraction



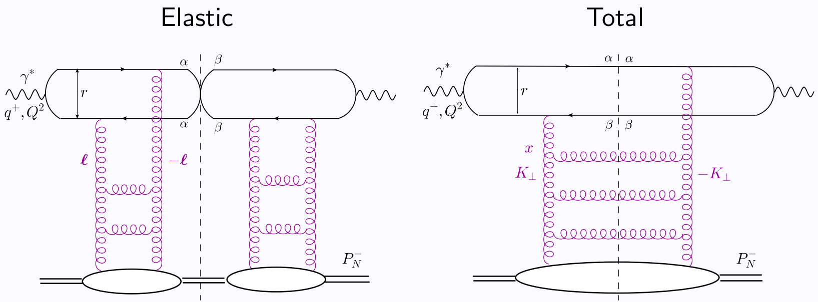
- Right moving off-shell γ^*, $q^\mu = (q^+, \mathbf{0}, -Q^2/2q^+)$
- Left moving nucleus, $p^\mu = (M_N^2/2P_N^-, \mathbf{0}, P_N^-)$ per nucleon
- Projectile lifetime $\tau \sim 2q^+/Q^2$
- Nucleus contracted length $L \sim 2R_A M_N/P_N^- \sim A^{1/3}/P_N^-$
- $L \ll \tau \Longleftrightarrow xA^{1/3} \ll 1$



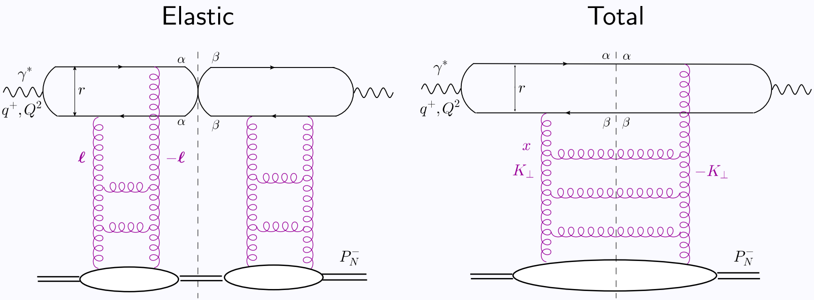
$$\sigma^{\gamma^* A}(x, Q^2) = \int \mathrm{d}^2\boldsymbol{r} \int_0^1 \mathrm{d}\vartheta \left|\Psi_{\gamma^* \to q\bar{q}}(Q^2; \boldsymbol{r}, \vartheta)\right|^2 2\pi R_A^2 T(r, x)$$

- All QCD dynamics in $T(r, x)$
- Virtuality limits large dipoles: $r \lesssim 1/\bar{Q}$, with $\bar{Q}^2 = \vartheta(1-\vartheta)Q^2$
- 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

DIFFRACTION/ELASTIC SCATTERING



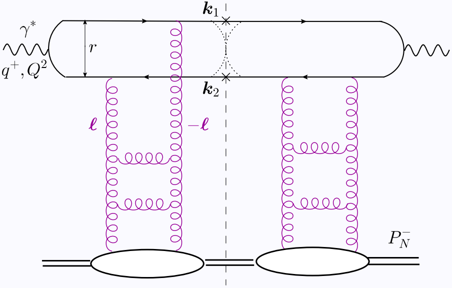
- Rapidity gap: wide angular region void of particles
- Elastic for projectile, no nuclear break-up (coherent reaction)
- Close color at amplitude level
- At least two gluons exchanged at amplitude



$$\sigma_{\rm D}^{\gamma^* A}(x,Q^2) = \int \mathrm{d}^2\boldsymbol{r} \int_0^1 \mathrm{d}\vartheta \left|\Psi_{\gamma^*\to q\bar{q}}(Q^2;\boldsymbol{r},\vartheta)\right|^2 \pi R_A^2 [T(r,x)]^2$$

- T^2 : Diffractive cross section less sensitive to small dipoles
- Even for $Q^2 \gg Q_s^2$ dipoles with $r \gtrsim 1/Q_s$ and $\vartheta \sim Q_s^2/Q^2 \ll 1$ ("aligned jets") dominate diffractive cross section

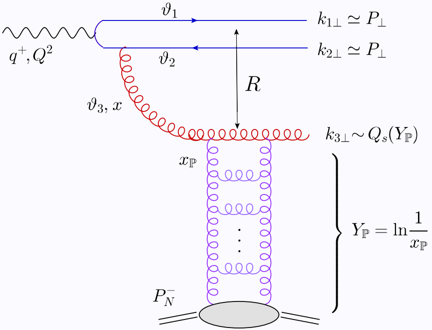
- More exclusive processes? Measured jets or hadrons?
- Hard scale sets dipole size $r \sim 1/P_\perp$, weak scattering
- Hard, symmetric, back to back $q\bar{q}$ pair:
  $k_{1\perp} \simeq k_{2\perp} \equiv P_\perp \sim Q \gg Q_s$, $\vartheta_{1,2} \sim 1/2$



$$\frac{\mathrm{d}\sigma_{\mathrm{D}}^{\gamma^* A \to q\bar{q}A}}{\mathrm{d}\vartheta_1 \mathrm{d}^2\boldsymbol{P}} \propto \pi R_A^2 \, \underbrace{\frac{1}{Q^2}}_{\gamma^* q\bar{q}} \, \underbrace{\frac{Q_s^4}{P_\perp^4}}_{T^2(r)}$$

$\sim \dfrac{1}{P_\perp^6}$ higher twist

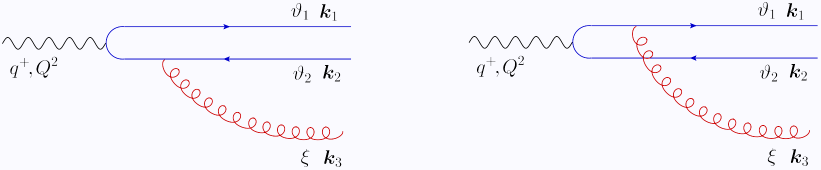
- Diffractive dijet at leading twist $1/P_\perp^4$?
- Yes, two hard jets $P_\perp \gg Q_s$ and one semi-hard $k_{3\perp} \sim Q_s \ll P_\perp$
- Third, semi-hard, jet provides dijet imbalance



- $\mathcal{O}(\alpha_s)$ suppression
- $R \gg r$: gluon dipole
- $T_g(R, Y_{\mathbb{P}}) \simeq \mathcal{O}(1)$
- Hard factor

$$H \propto \underbrace{\frac{1}{Q^2}}_{\gamma^* q\bar{q}} \times \underbrace{r^2}_{\text{gluon emission}} \sim \frac{1}{P_\perp^4}$$

- $x_{\mathbb{P}} P_N^-$ puts trijet on-shell: $x_{\mathbb{P}} \simeq \dfrac{1}{2q^+ P_N^-}\left(\dfrac{P_\perp^2}{\vartheta_1\vartheta_2} + \dfrac{k_{3\perp}^2}{\vartheta_3} + Q^2\right)$

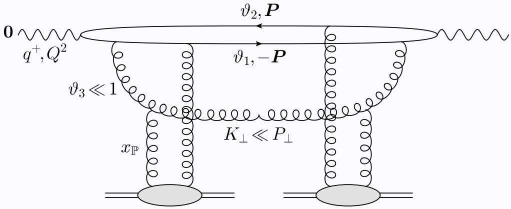


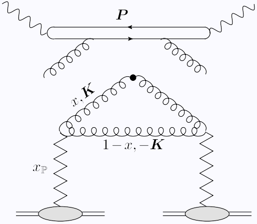
- Gluon formation time must be small enough: $k_3^+/k_{3\perp}^2 \lesssim q^+/Q^2 \rightsquigarrow \vartheta_3 \lesssim k_{3\perp}^2/P_\perp^2 \ll 1$, gluon is soft
- Momentum space LCWF
  - Expand for $k_{3\perp} \ll P_\perp$ and $\xi \ll k_{3\perp}/P_\perp$ (no recoil)
  - Leading terms cancel $\rightsquigarrow$ Non-eikonal emission
  - Scattering is eikonal (Wilson lines)
  - Add instantaneous quark propagator graph

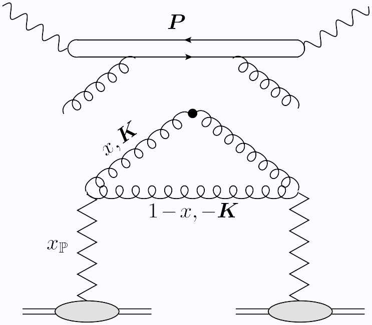
- Scales separation $\rightsquigarrow$ Factorization?
- View gluon as part of Pomeron. Variable change from ξ to x:

$$x = \frac{x_{q\bar{q}}}{x_{\mathbb{P}}} = \frac{\frac{P_\perp^2}{\vartheta_1\vartheta_2} + Q^2}{\frac{P_\perp^2}{\vartheta_1\vartheta_2} + \frac{k_{3\perp}^2}{\vartheta_3} + Q^2} \quad \text{or} \quad x = \beta\,\frac{x_{q\bar{q}}}{x_{\rm Bj}} \simeq \beta\,\frac{\bar{Q}^2 + P_\perp^2}{P_\perp^2}$$

- For given $x_{\rm Bj}$ and hard jets, only one of ξ, $x_{\mathbb{P}}$ and x is independnent







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

- Hard factor as in inclusive $q\bar{q}$ dijet cross section

$$H_T(\vartheta_1,\vartheta_2,Q^2,P_\perp^2) \equiv \alpha_{em}\alpha_s\Big(\sum e_f^2\Big)\,\delta_\vartheta\,\underbrace{(\vartheta_1^2+\vartheta_2^2)}_{2P_{q\gamma}(\vartheta_1)}\,\underbrace{\frac{P_\perp^4+\bar{Q}^4}{(P_\perp^2+\bar{Q}^2)^4}}_{\sim 1/P_\perp^4}$$

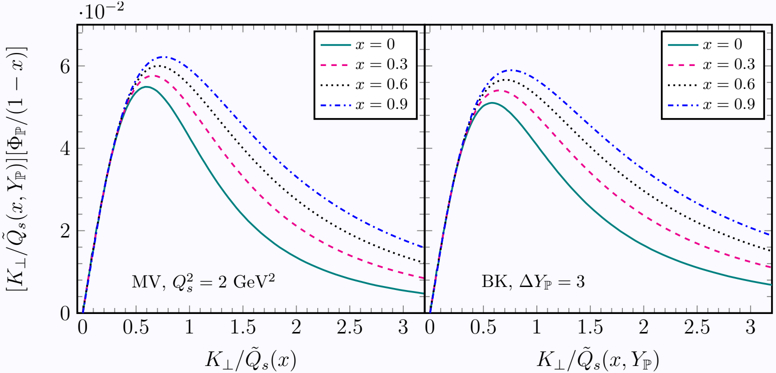
$$\frac{\mathrm{d}xG_{\mathbb{P}}(x, x_{\mathbb{P}}, K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}} = \underbrace{\frac{S_\perp(N_c^2-1)}{4\pi^3}}_{\text{d.o.f.}} \underbrace{\Phi_{\mathbb{P}}(x, x_{\mathbb{P}}, K_\perp^2)}_{\text{occupation number}}$$

- Explicit in terms of elastic amplitude $T_g(R, x_{\mathbb{P}})$

$$\Phi_{\mathbb{P}}(x, x_{\mathbb{P}}, K_\perp^2) \approx \frac{1-x}{2\pi} \begin{cases} 1 & \text{for} \quad K_\perp \ll \tilde{Q}_s(x) \\ \dfrac{\tilde{Q}_s^4(x, Y_{\mathbb{P}})}{K_\perp^4} & \text{for} \quad K_\perp \gg \tilde{Q}_s(x) \end{cases}$$

- Valid for large gaps: $x_{\mathbb{P}} \lesssim 10^{-2}$
- Effective saturation momentum $\tilde{Q}_s^2(x) \equiv (1-x)Q_s^2$
- Bulk of distribution at saturation $K_\perp \ll \tilde{Q}_s(x)$

Gluon Diffractive TMD

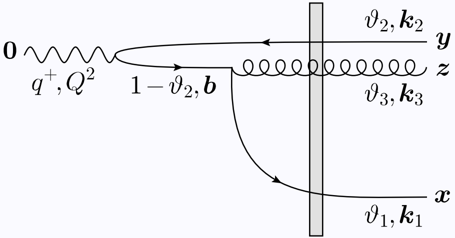


- Multiplied by $K_\perp$ (cf. measure $\mathrm{d}^2\boldsymbol{K}$)
- Pronounced maximum at $K_\perp \sim \tilde{Q}_s(x)$

Can you ever relax with Edmond?

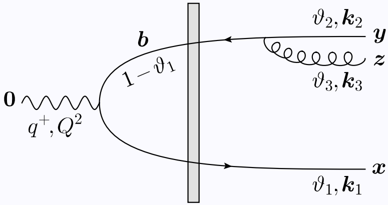
Kavala 2010

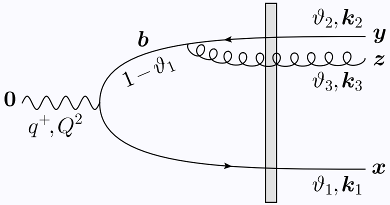
- Hard $\bar{q}$ and g, $P_\perp \gg Q_s$, semi-hard q, $k_{1\perp} \sim Q_s \ll P_\perp$



- $\mathcal{O}(\alpha_s)$ suppression
- Large quark dipole
- $T(R, Y_{\mathbb{P}}) \simeq \mathcal{O}(1)$
- Hard factor $\sim 1/P_\perp^4$

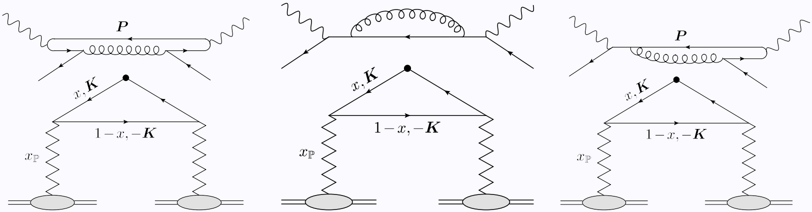
- (NB: Scattering before emission is small, like in soft g case)
- Quark must be soft $\vartheta_1 \lesssim k_{1\perp}^2/P_\perp^2$





- Large initial $q\bar{q}$ pair, hard QCD vertex
- Same scattering before or after gluon emission, fine cancellations
- Also consider interference between these and previous diagram

- Variable change from ϑ_1 to x
- Quark with fraction $1-x$ in final state
- Antiquark "transfers" fraction x and imbalance $\boldsymbol{K}$ to dijet



$$\frac{\mathrm{d}\sigma_{\mathrm{D}}^{\gamma^*_{T,L}A\to q\bar{q}gA}}{\mathrm{d}\vartheta_1\mathrm{d}\vartheta_2\mathrm{d}^2\boldsymbol{P}\mathrm{d}^2\boldsymbol{K}\mathrm{d}Y_{\mathbb{P}}} = \frac{4\pi^2\alpha_{\mathrm{em}}}{Q^2}\Big(\sum e_f^2\Big)H_{T,L}(\vartheta_2,\vartheta_3,Q^2,P_\perp^2)\,\frac{\mathrm{d}xq_{\mathbb{P}}(x,x_{\mathbb{P}},K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}}$$

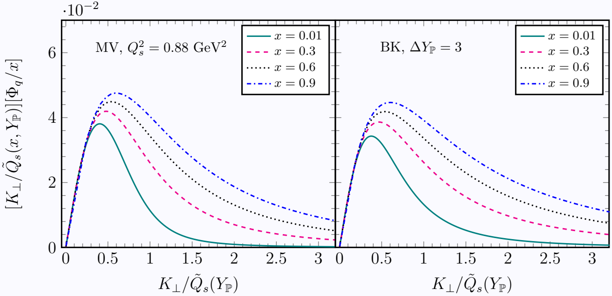
$$H_T(\vartheta_2,\vartheta_3,P_\perp^2,\tilde{Q}^2) = \delta_\vartheta\,\frac{\alpha_s C_F}{\pi^2}\,\frac{1}{2\vartheta_3}\,\frac{\tilde{Q}^2\left[(P_\perp^2+\tilde{Q}^2)^2+\vartheta_2^2\tilde{Q}^4+\vartheta_3^2P_\perp^4\right]}{P_\perp^2(P_\perp^2+\tilde{Q}^2)^3}.$$

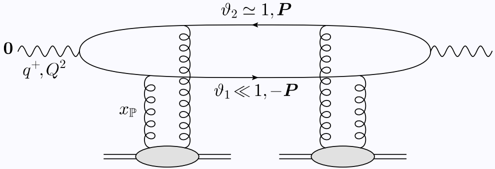
Semi-hard Factor: Quark Diffractive TMD

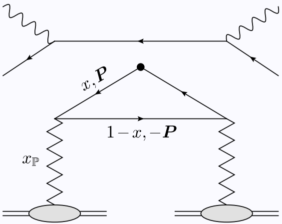
$$\frac{\mathrm{d}xq_{\mathbb{P}}(x,x_{\mathbb{P}},K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}} = \underbrace{\frac{S_\perp N_c}{4\pi^3}}_{\text{d.o.f.}} \underbrace{\Psi_{\mathbb{P}}(x,x_{\mathbb{P}},K_\perp^2)}_{\text{occupation number}}$$

Explicit in terms of elastic amplitude $T(R, x_{\mathbb{P}})$ (fundamental)

$$\Psi_{\mathbb{P}}(x,x_{\mathbb{P}},K_\perp^2) \approx \frac{x}{2\pi} \begin{cases} 1 & \text{for} \quad K_\perp \ll \tilde{Q}_s(x) \\ \dfrac{\tilde{Q}_s^4(x,Y_{\mathbb{P}})}{K_\perp^4} & \text{for} \quad K_\perp \gg \tilde{Q}_s(x) \end{cases}$$







- Consider dijet cross section obtained in the dipole picture
- Integrate one jet keeping β (gap) fixed $\rightsquigarrow$ change from ϑ_1 to β
- If (and only if) aligned jet configuration ($\vartheta_1 \ll 1$) and $P_\perp^2 \ll Q^2$:

$$\frac{\mathrm{d}\sigma^{\gamma_T^* A \to q\bar{q}A}}{\mathrm{d}\ln(1/\beta)\,\mathrm{d}^2\boldsymbol{P}} = \frac{4\pi^2\alpha_{em}}{Q^2}\Big(\sum e_f^2\Big)\, 2\, \frac{\mathrm{d}xq_{\mathbb{P}}(x, x_{\mathbb{P}}, P_\perp^2)}{\mathrm{d}^2\boldsymbol{P}}\bigg|_{x=\beta}$$

- Leading twist result, same quark TMD encountered in 2+1 jets

- Consider hard antiquark-gluon pair and soft quark configuration
- In SIDIS we measure antiquark, integrate the gluon
- Dominant contribution from gluon such that

$$\vartheta_2 \simeq 1 \gg \vartheta_3 \sim \frac{P_\perp^2}{Q^2} \gg \vartheta_1 \sim \frac{k_{1\perp}^2}{Q^2}$$

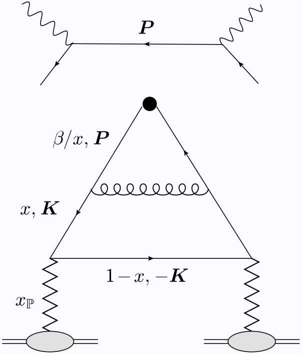
- Integrate at fixed β

$$\frac{\mathrm{d}\sigma^{\gamma_T^* A \to (q)\bar{q}gA}}{\mathrm{d}^2\boldsymbol{P}\,\mathrm{d}\ln(1/\beta)} = \int \mathrm{d}\vartheta_2 \mathrm{d}\vartheta_3 \int \frac{\mathrm{d}x}{x}\,\beta\delta\left(\beta - x\frac{\tilde{Q}^2}{\tilde{Q}^2 + P_\perp^2}\right) \times H_T(\vartheta_2, \vartheta_3, Q^2, P_\perp^2) \int \mathrm{d}^2\boldsymbol{K}\,\frac{\mathrm{d}xq_{\mathbb{P}}(x, x_{\mathbb{P}}, K_\perp^2)}{\mathrm{d}^2\boldsymbol{K}}$$

- $\boldsymbol{K}$-integration gives DPDF

- Hard factor becomes (real part of) DGLAP splitting function

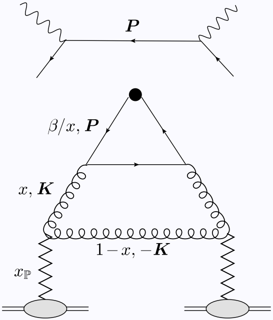
$$\frac{\mathrm{d}\sigma^{\gamma_T^* A\to(q)\bar{q}gA}}{\mathrm{d}^2\boldsymbol{P}\,\mathrm{d}\ln(1/\beta)} = \frac{4\pi^2\alpha_{\rm em}}{Q^2}\left(\sum e_f^2\right) \times \frac{\alpha_s}{2\pi^2}\,\frac{1}{P_\perp^2}\int_{x_{\min}}^1 \frac{\mathrm{d}x}{x}\,\frac{\beta}{x}\,P_{qq}\left(\frac{\beta}{x}\right) xq_{\mathbb{P}}\left(x, x_{\mathbb{P}}, P_\perp^2\right).$$



- Target: gluon emission before γ^* absorption by struck antiquark
- All projectile diagrams contribute to simple target picture

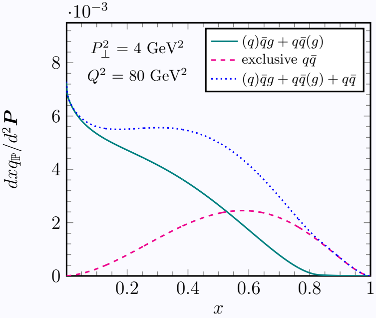
- Consider hard quark-antiquark pair and soft gluon
- Integrate the quark with fixed β to get SIDIS

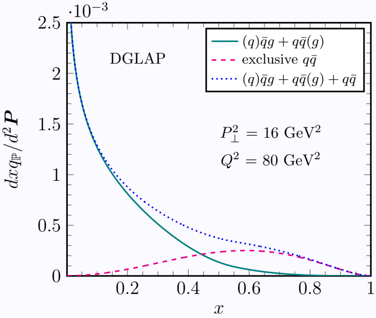
$$\frac{\mathrm{d}\sigma^{\gamma_T^* A\to q\bar{q}(g)A}}{\mathrm{d}^2\boldsymbol{P}\,\mathrm{d}\ln(1/\beta)} = \frac{4\pi^2\alpha_{\mathrm{em}}}{Q^2}\left(\sum e_f^2\right) \times \frac{\alpha_s}{2\pi^2}\,\frac{1}{P_\perp^2}\int_\beta^1 \frac{\mathrm{d}x}{x}\,\frac{\beta}{x}\,P_{qg}\left(\frac{\beta}{x}\right) xG_{\mathbb{P}}\left(x, x_{\mathbb{P}}, P_\perp^2\right).$$



"Total" DTMDs

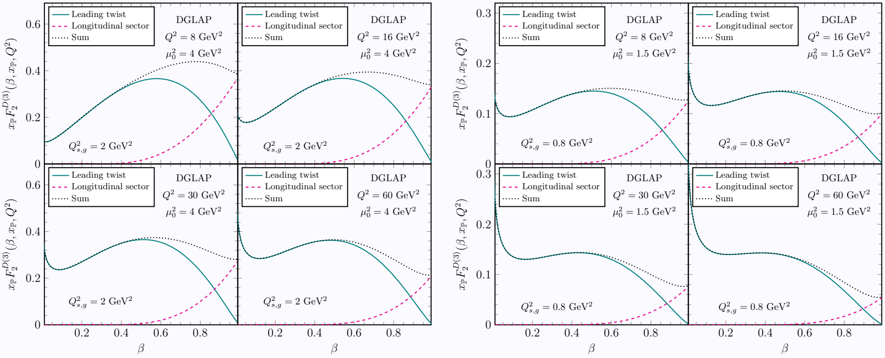
- Absorb 2+1 jet contributions into the quark DTMD
- 2 jets piece: $\sim 1/P_\perp^4$
- 2+1 jets pieces: $\sim \alpha_s/P_\perp^2$
- Similarly for the gluon DTMD (would need an extra step since it does not appear in 2 jets)





Diffractive Structure Function

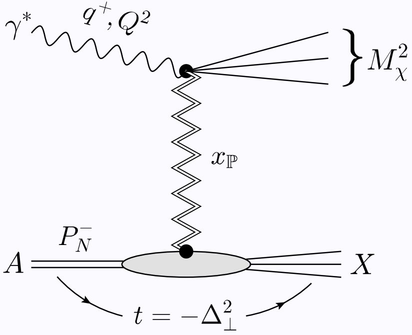
- Integrate over $\mathrm{d}^2\boldsymbol{P} \rightsquigarrow$ Diffractive structure function
- Large nucleus $Q_{sg}^2 = 2\,\mathrm{GeV}^2$, proton $Q_{sg}^2 = 0.8\,\mathrm{GeV}^2$



- Shape difference attributed to starting point μ_0^2, magnitude $\sim Q_s^2$

Copy/paste from Larry's website, anecdotal vita II

Once Edmond visited me in Minnesota for several months. A few years later, one of the visitors in the office next to mine told me the pattern of the encounters he overheard. He said that early in the day, Edmond would come into my office. For a while it would be quiet. Then there would be the sound of chalk scratching on my blackboard, which would continue to get more intense. Then he would hear a loud high pitched voice (Edmond) getting louder, and increasingly violent sounds of chalk pounding on a blackboard. Finally, there would be a deep voice (mine) which would simply say "Bullshit". Then there would be quiet for a while, and the whole sequence would repeat itself. He said this went on for many weeks, and he was never sure what we were really doing.



- Nucleus breaks, associated momentum transfer

Incoherent Diffraction II

Target average to be taken with CGC wave-function

- $\langle T(\boldsymbol{x},\boldsymbol{y})T(\bar{\boldsymbol{y}},\bar{\boldsymbol{x}})\rangle \to$ Total diffraction
- $\langle T(\boldsymbol{x},\boldsymbol{y})\rangle\langle T(\bar{\boldsymbol{y}},\bar{\boldsymbol{x}})\rangle \to$ Coherent diffraction
- $\langle T(\boldsymbol{x},\boldsymbol{y})T(\bar{\boldsymbol{y}},\bar{\boldsymbol{x}})\rangle - \langle T(\boldsymbol{x},\boldsymbol{y})\rangle\langle T(\bar{\boldsymbol{y}},\bar{\boldsymbol{x}})\rangle \to$ Incoherent diffraction

Homogeneous target:

- Coherent diffraction $\sim \delta^2(\boldsymbol{\Delta})$ (smeared to $1/R_A$)
  Negligible momentum transfer from target to projectile
- Momentum transfer conjugate to difference $\boldsymbol{B}$ of impact parameters in DA and CCA $\rightsquigarrow$ non-zero momentum transfer

Incoherent Diffraction III

Variance of scattering amplitude determined by target fluctuations

- Pomeron loops: particle number fluctuations in target
- Hot spots (shape fluctuations)
- $1/N_c^2$ color fluctuations (MV model, JIMWLK)
- $\cdots$

Study color fluctuations

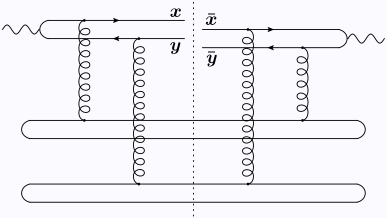
- Q_s sets the scale for color fluctuations
- Expect power-law tail for $\Delta_\perp > Q_s$

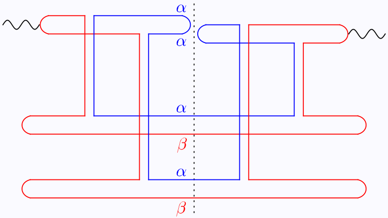
Sinaia 2005

- Duality paper, J.-P. Blaizot, EI, K. Itakura, DT, hep-ph/0502221 (PLB), Saclay 2005
- One of the best emails I ever received

Assume Gaussian CGC WF, only pieces connecting DA with CCA survive

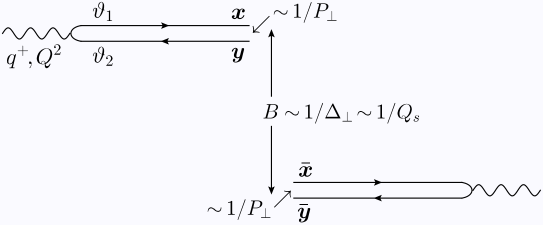
Just for illustration assume 4-gluon exchange





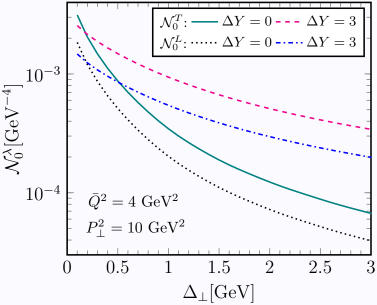
- Projectile can be either quark or gluon dipole
- Elastic on projectile
- Colorless nucleus substructures scatter inelastically
- Exchange of color among them
- Incoherent scattering $\leftrightarrow 1/N_c^2$ suppression

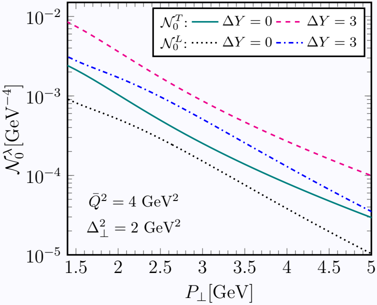
With only two hard jets, pair imbalance is momentum transfer $\boldsymbol{K} = \boldsymbol{\Delta}$
Interested in $P_\perp \gg \Delta_\perp, Q_s \longleftrightarrow r, \bar{r} \ll B, 1/Q_s$



- Correlator known (at finite-N_c)
- Expand for $r, \bar{r} \ll B, 1/Q_s$, other than that B is arbitrary

2 Hard Jets, Averaged (over angle) Cross Section

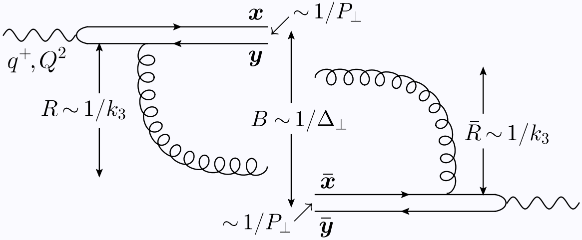




There is angular $\boldsymbol{P}\cdot\boldsymbol{\Delta}$ dependence, focus on averaged cross section

$$\frac{\mathrm{d}\sigma_{\mathrm{D}}^{\gamma_\lambda^* A\to q\bar{q}X}}{\mathrm{d}\vartheta_1\mathrm{d}\vartheta_2\mathrm{d}^2\boldsymbol{P}\mathrm{d}^2\boldsymbol{\Delta}} \propto \frac{\alpha_{\mathrm{em}} S_\perp}{N_c}\,\frac{Q_s^2}{P_\perp^6}\,\underbrace{f(\Delta_\perp/Q_s)}_{\mathrm{dim/less}}$$

$$f(\Delta_\perp/Q_s) \sim \begin{cases} \mathcal{O}(1) & \text{for} \quad \Delta_\perp \ll Q_s \\ Q_s^2/\Delta_\perp^2 & \text{for} \quad \Delta_\perp \gg Q_s \end{cases}$$

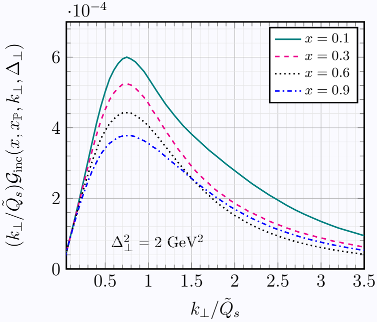


- Pair imbalance determined by momentum transfer $\boldsymbol{\Delta}$ and recoil due to soft jet emission, $\boldsymbol{K} = \boldsymbol{\Delta} - \boldsymbol{k}_3$
- Integrate over $\boldsymbol{k}_3$ with fixed $\boldsymbol{\Delta}$

Interested again in $P_\perp \gg \Delta_\perp, Q_s$, but now:

- Size of scattering dipole $R \sim 1/k_{3\perp} \sim 1/Q_s$ is large
- No expansion in the dipole-dipole QCD correlator

- Incoherent DTMDs at fixed $|t| = \Delta_\perp^2$
- Distribution in $k_{3\perp}$ is peaked at Q_s



Tensor structure $H^{ij}(\boldsymbol{P})\,G^{ij}(\boldsymbol{\Delta})$

- Soft gluon

$$H^{ij}(\boldsymbol{P}) = H(P_\perp)\,\delta^{ij} + H_1(P_\perp)\,\hat{P}^{ij}$$
$$G^{ij}(\boldsymbol{\Delta}) = G(\Delta_\perp)\,\delta^{ij} + 0 \times\ \hat{\Delta}^{ij}$$

- Soft quark

$$H^{ij}(\boldsymbol{P}) = H(P_\perp)\,\delta^{ij} + 0 \times\ \hat{P}^{ij}$$
$$G^{ij}(\boldsymbol{\Delta}) = G(\Delta_\perp)\,\delta^{ij} + G_1(\Delta_\perp)\,\hat{\Delta}^{ij}$$

- No $2\hat{P}^{ij}\hat{\Delta}^{ij} = \cos 2\phi$ coefficient in both cases, no angle dependence
  Valid even before integrating over $\boldsymbol{k}_3$

[NB: $V^{ij} \equiv V^i V^j / V_\perp^2 - \delta^{ij}/2$]

2 +1 Jets Cross Section (and Incoherent DPDFs)

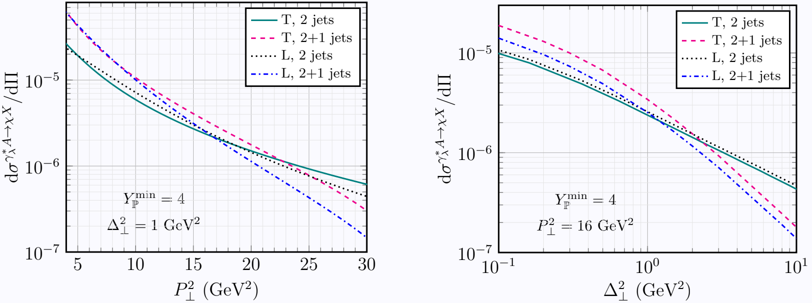
- Integrate $\boldsymbol{B}$, $\boldsymbol{R}$, $\bar{\boldsymbol{R}}$ and $\boldsymbol{k}_3$ $\rightsquigarrow$ incoherent DPDFs and cross section
- Well behaved quantity

$$\frac{\mathrm{d}\sigma_{\mathrm{D}}^{\gamma_\lambda^* A \to q\bar{q}gX}}{\mathrm{d}\vartheta_1 \mathrm{d}\vartheta_2 \mathrm{d}^2\boldsymbol{P}\mathrm{d}^2\boldsymbol{\Delta}} \propto \frac{\alpha_{\mathrm{em}} S_\perp}{N_c} \frac{\alpha_s}{P_\perp^4} \underbrace{f_1(\Delta_\perp/Q_s)}_{\mathrm{dim/less}}$$

$$f_1(\Delta_\perp/Q_s) \sim \begin{cases} \mathcal{O}(1) & \text{for} \quad \Delta_\perp \ll Q_s \\ Q_s^4/\Delta_\perp^4 & \text{for} \quad \Delta_\perp \gg Q_s \end{cases}$$

- Parametrically larger than 2 jets: $\alpha_s(P_\perp)/P_\perp^4$ vs $1/P_\perp^6$
- Natural $1/|t|^2$ fall-off

- Fix Q^2 and s, so that $Y_{\rm Bj} = \ln 1/x_{\rm Bj} = 6.1$ is fixed
- Require a minimum rapidity gap $Y_{\rm gap}^{\rm min} = 4$ (i.e. $x_{\mathbb{P}} \sim 0.02$)
- This implies a $Y_{\beta}^{\rm max}$ or $\beta_{\rm min} = 0.12$
- Fix $\vartheta_1 = \vartheta_2 = 1/2$ and $\Delta_\perp^2 = 2{\rm GeV}^2$
- Then $P_\perp^2$ cannot exceed a max value



Conclusion

- Diffraction at hard momenta in γA collisions in CGC
- Diffractive hard dijet cross sections dominated by 2+1 jets due to scattering near unitarity limit
- Seed of semi-hard jet either a gluon or a quark
- For sufficiently large rapidity gaps and/or large nuclei gluon and quark DTMDs and DPDFs calculated from "first principles"
- CGC as initial condition for DGLAP

(Not) Being Like Edmond and Thanks

Prague 2004

Special thanks to one of the fastest brains for explaining physics to an ordinary one. Happy 60 and be Edmond.