

Exclusive massive photon-pair production in pion-nucleon collisions for extracting generalized parton distributions

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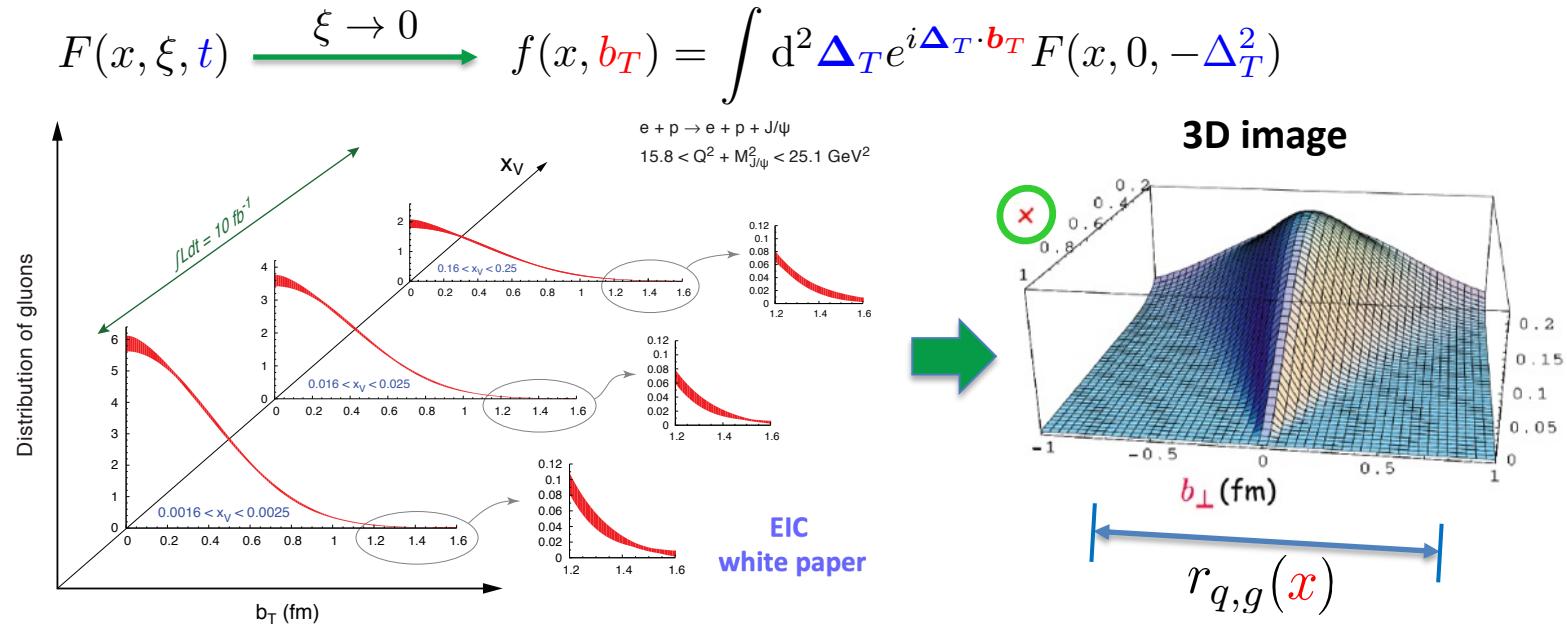
arXiv:2205.xxxxx

**DIS2022 @ Santiago de Compostela
May/4/2022**



Why generalized parton density (GPD)?

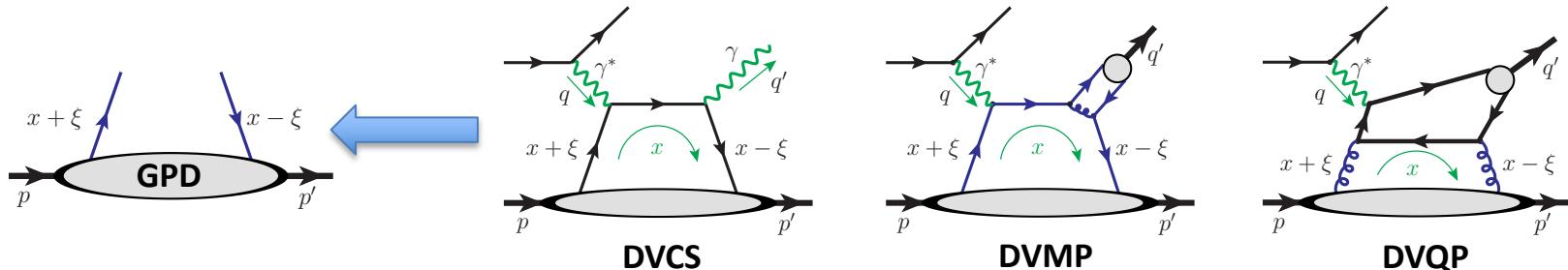
❑ Hadron tomography



→ Precise knowledge of x -dependence is crucial to 3D image.

Why is x -dependence of GPD hard to measure?

- Amplitude nature: exclusive processes

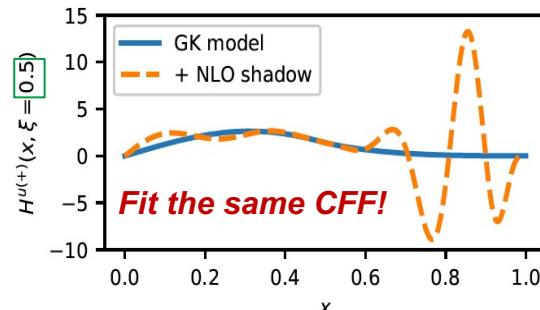


$x \sim \text{loop momentum}$ $i\mathcal{M} \sim \int_{-1}^1 dx F(\textcolor{red}{x}, \xi, t) \cdot C(\textcolor{red}{x}, \xi; Q/\mu)$
never pin down to some x

- Sensitivity to x comes from $C(x, \xi; Q/\mu)$

$$C(x, \xi; Q/\mu) = C_Q(Q/\mu) \cdot C_x(x, \xi) \stackrel{\text{DVCS}}{\propto} \frac{1}{x - \xi + i\varepsilon} \dots$$

→ $i\mathcal{M} \propto \int_{-1}^1 dx \frac{F(\textcolor{red}{x}, \xi, t)}{x - \xi + i\varepsilon} \equiv "F_0(\xi, t)"$



What we can do for x -dependence of GPD

□ More independent processes

More moments...

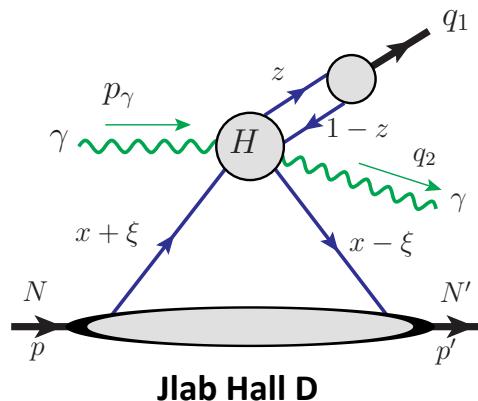
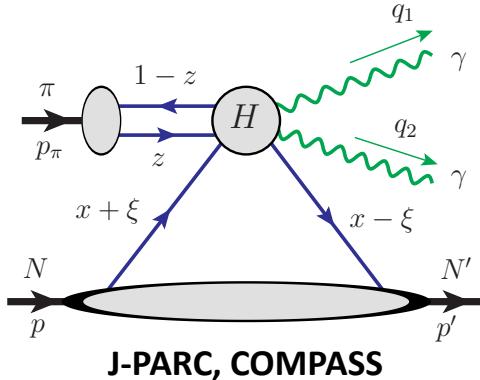
□ A new class of processes

$$C(x, \xi; Q/\mu) \neq C_Q(Q/\mu) \cdot C_x(x, \xi)$$

- Q flow intervenes in the x flow, not point-like
- Two particles in the final state

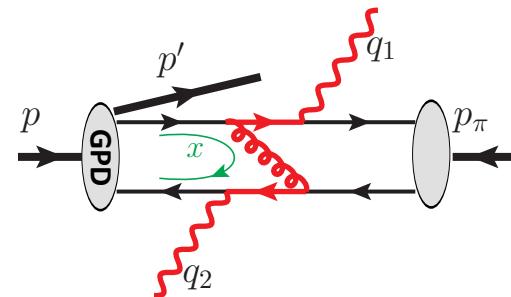
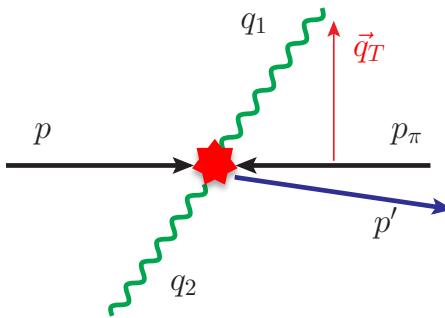
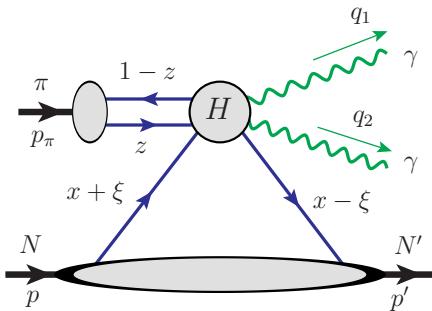


$2 \rightarrow 3$ process



Introduced by G. Duplancic et al.
JHEP 11 (2018) 179

Exclusive massive pair production



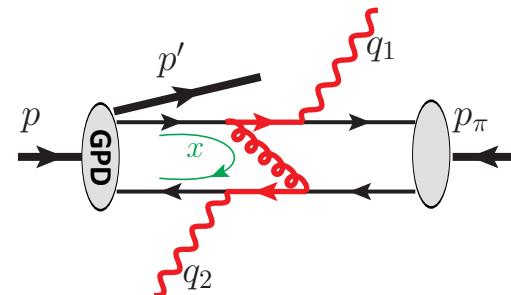
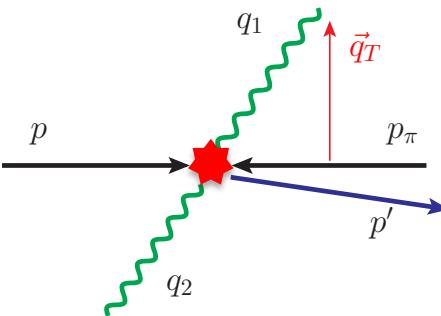
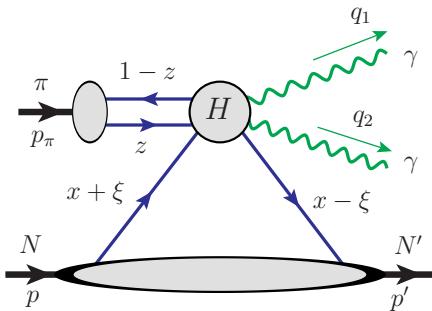
- ❑ Kinematical observables: t, ξ, q_T
- ❑ Factorization

- $t = (p - p')^2$
- $\xi = (p^+ - p'^+)/(\bar{p}^+ + p'^+)$

Hard scale: $q_T \gg \Lambda_{\text{QCD}}$
 Soft scale: $t \sim \Lambda_{\text{QCD}}^2$

$$\mathcal{M}(t, \xi, q_T) = \int_{-1}^1 d\xi F(x, \xi, t; \mu) \cdot C(x, \xi; q_T/\mu) + \mathcal{O}(\Lambda_{\text{QCD}}/q_T) \quad [\text{suppressing DA factor}]$$

Exclusive massive pair production



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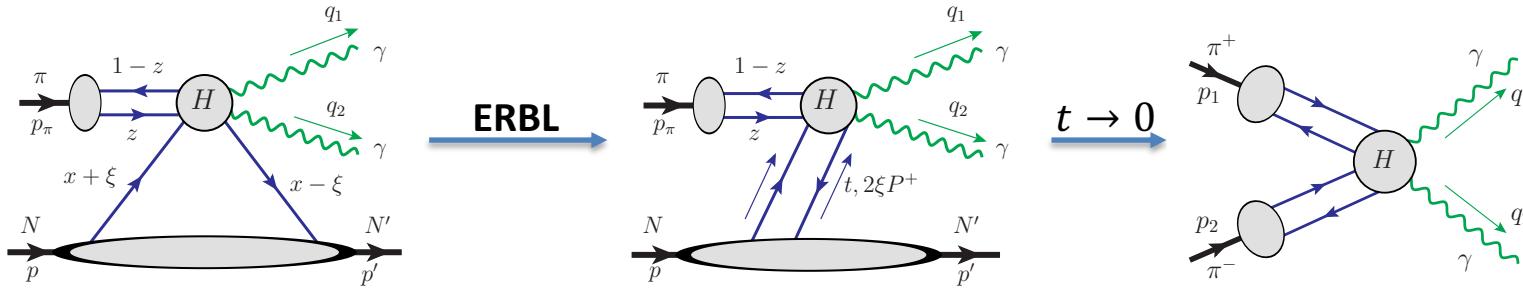
$x \leftrightarrow q_T$

➡ $\frac{d\sigma}{dt \, d\xi \, dq_T} \sim |\mathcal{M}(t, \xi, q_T)|^2$

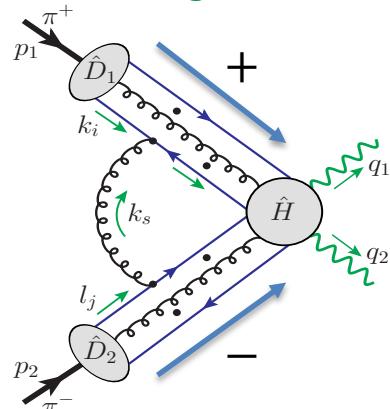


A simplified process: $\pi^+ \pi^- \rightarrow \gamma \gamma$

□ Simplified process



□ Glauber region



$$\lambda \sim m_\pi / q_T$$

$$Q \sim q_T$$

$$k_i = (1, \lambda^2, \lambda) Q,$$

$$l_j = (\lambda^2, 1, \lambda) Q,$$

$$k_s = (\lambda^2, \lambda^2, \lambda) Q$$

No pinch at Glauber region.

$$\frac{1}{(k_i + k_s)^2 + i\varepsilon} \rightarrow \frac{1}{k_s^- + i\varepsilon}$$

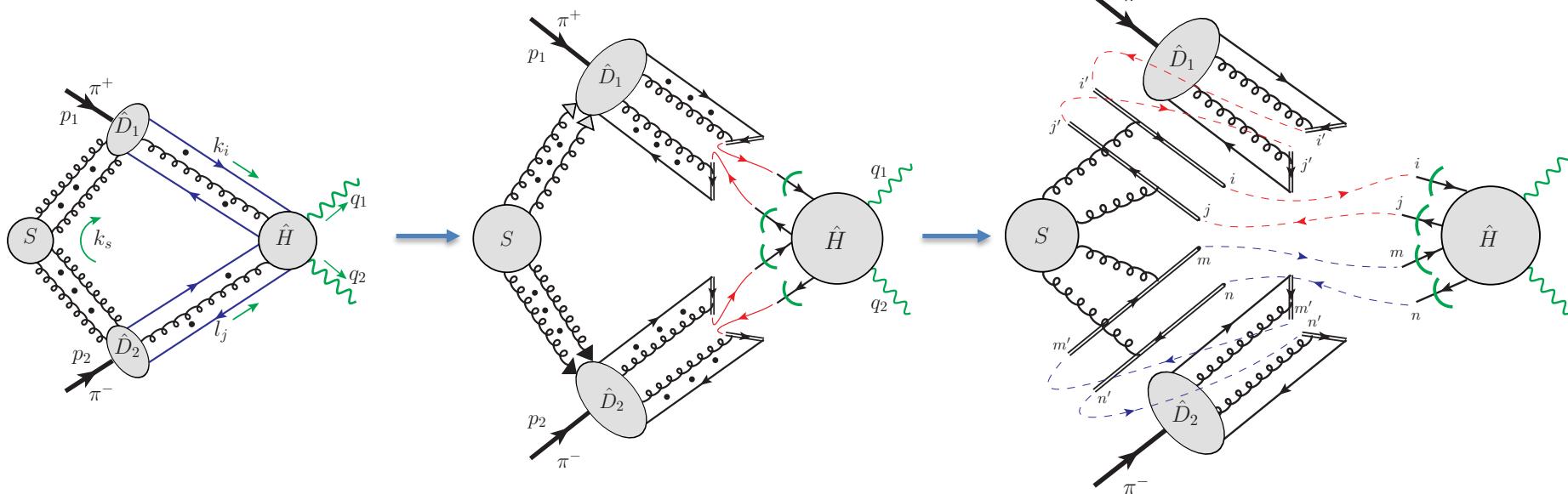
$$\frac{1}{(l_j - k_s)^2 + i\varepsilon} \rightarrow \frac{1}{-k_s^+ + i\varepsilon}$$

$$k_s^+ \rightarrow k_s^+ + i\mathcal{O}(\lambda Q), \quad k_s^- \rightarrow k_s^- - i\mathcal{O}(\lambda Q)$$

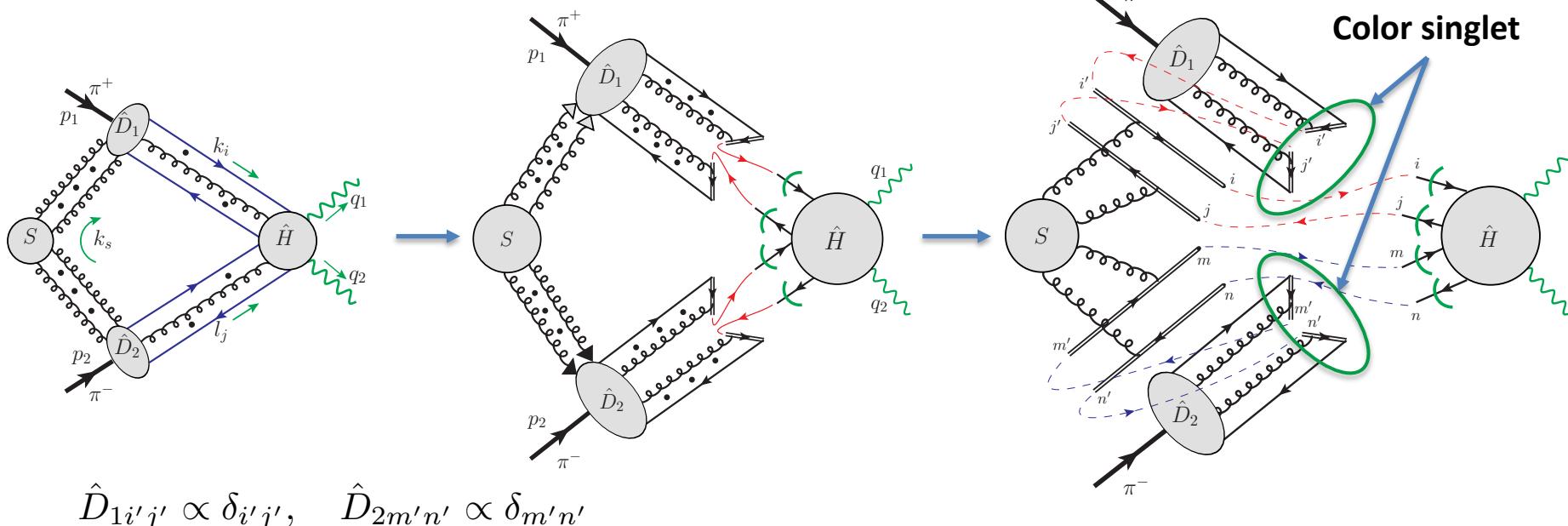
after deformation

$$k_s \sim (\lambda, \lambda, \lambda) Q$$

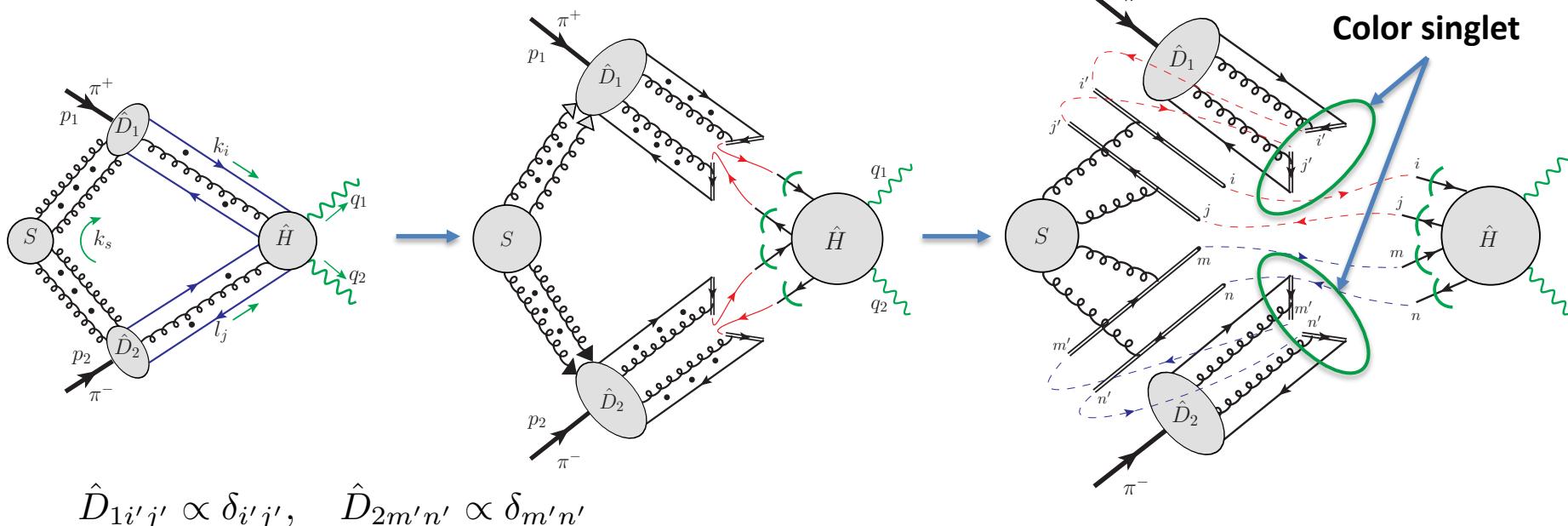
Factorization of the simplified process: $\pi^+ \pi^- \rightarrow \gamma \gamma$



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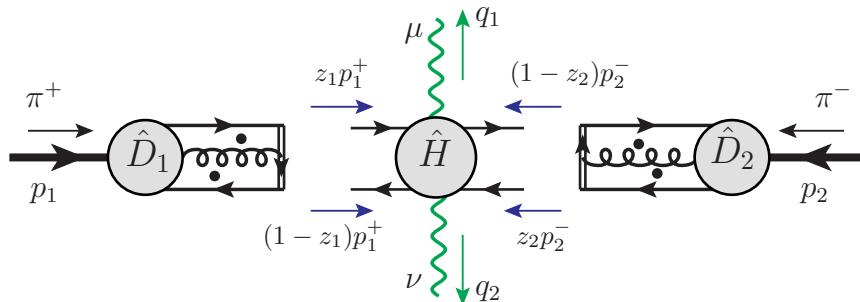


$$\hat{D}_{1i'j'} \propto \delta_{i'j'}, \quad \hat{D}_{2m'n'} \propto \delta_{m'n'}$$

$$\begin{aligned}
 & \delta_{i'j'} \delta_{m'n'} S_{ij,i'j';mn,m'n'} \\
 &= \langle 0 | [\Phi(0, -\infty; n_1) \Phi^\dagger(0, -\infty; n_1)]_{ij} [\Phi(0, -\infty; n_2) \Phi^\dagger(0, -\infty; n_2)]_{mn} | 0 \rangle \\
 &= \delta_{ij} \delta_{mn}
 \end{aligned}$$

Factorization of the simplified process: $\pi^+ \pi^- \rightarrow \gamma \gamma$

$$\mathcal{M}^{\mu\nu} = \int_0^1 dz_1 \int_0^1 dz_2 D_{\pi^+}(z_1) D_{\pi^-}(z_2) C^{\mu\nu}(z_1, z_2; p_1^+, p_2^-, q_T) + \mathcal{O}(\Lambda_{\text{QCD}}/q_T)$$



$$D_{\pi^+}(z_1) = \int \frac{d\xi^-}{4\pi} e^{iz_1 p_1^+ \xi^-} \langle 0 | \bar{d}(0) \gamma^+ \gamma_5 \Phi(0, \xi^-; w_2) u(\xi^-) | \pi^+(p_1) \rangle$$

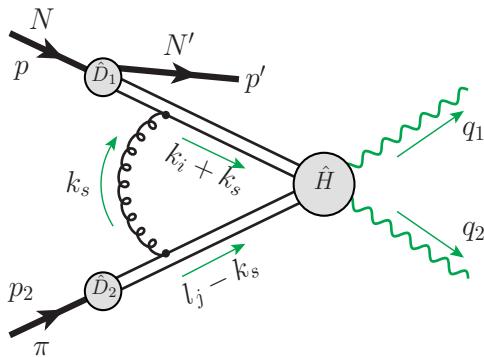
$$D_{\pi^-}(z_2) = \int \frac{d\xi^+}{4\pi} e^{iz_2 p_2^- \xi^+} \langle 0 | \bar{u}(0) \gamma^- \gamma_5 \Phi(0, \zeta^+; w_1) d(\zeta^+) | \pi^-(p_1) \rangle$$

$$C^{\mu\nu}(z_1, z_2; p_1^+, p_2^-, q_T) \equiv \left[\frac{\gamma_5(p_1^+ \gamma^-)}{2} \right]_{\alpha\beta} \hat{H}_{\beta\alpha;\sigma\rho}^{\mu\nu}(\hat{k}_1 = z_1 p_1^+, \hat{k}_2 = z_2 p_2^-; q_T) \left[\frac{\gamma_5(p_2^- \gamma^+)}{2} \right]_{\rho\sigma}$$

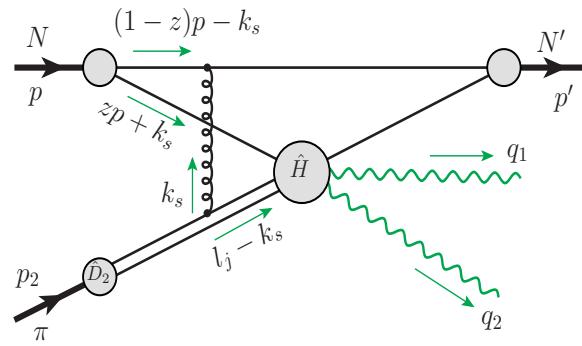


Factorization of $\pi N \rightarrow N' \gamma\gamma$

□ Glauber region



ERBL region: no pinch

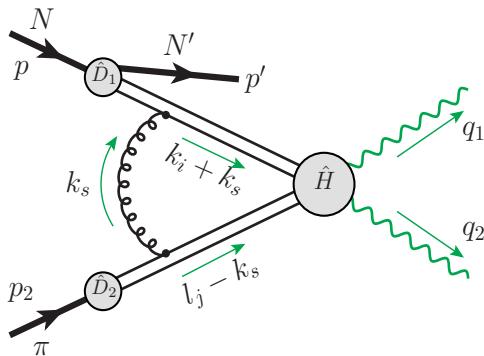


DGLAP region: pinched

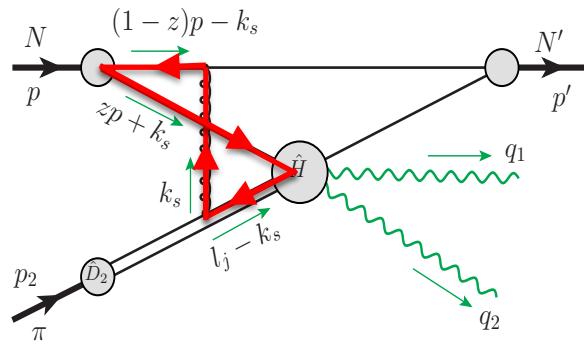


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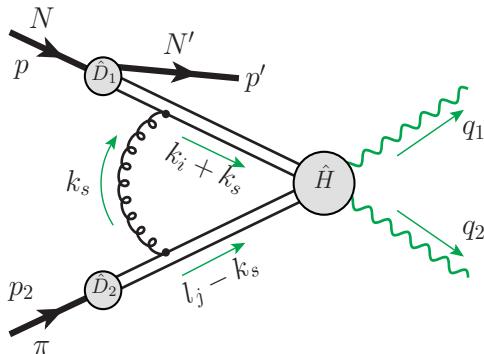


DGLAP region: pinched

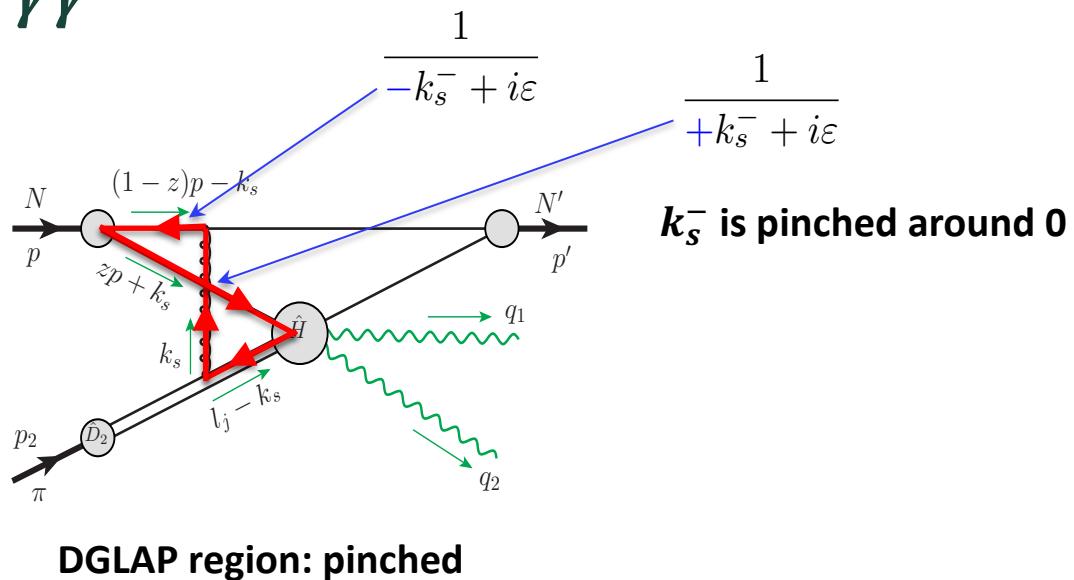


Factorization of $\pi N \rightarrow N' \gamma\gamma$

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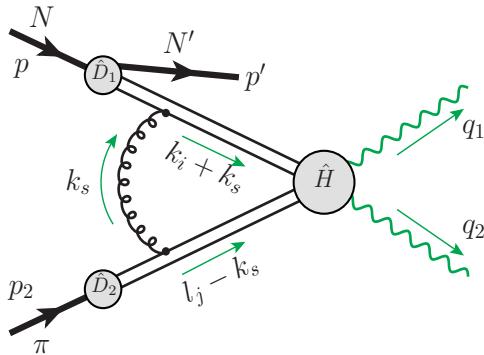


k_s^- is pinched around 0

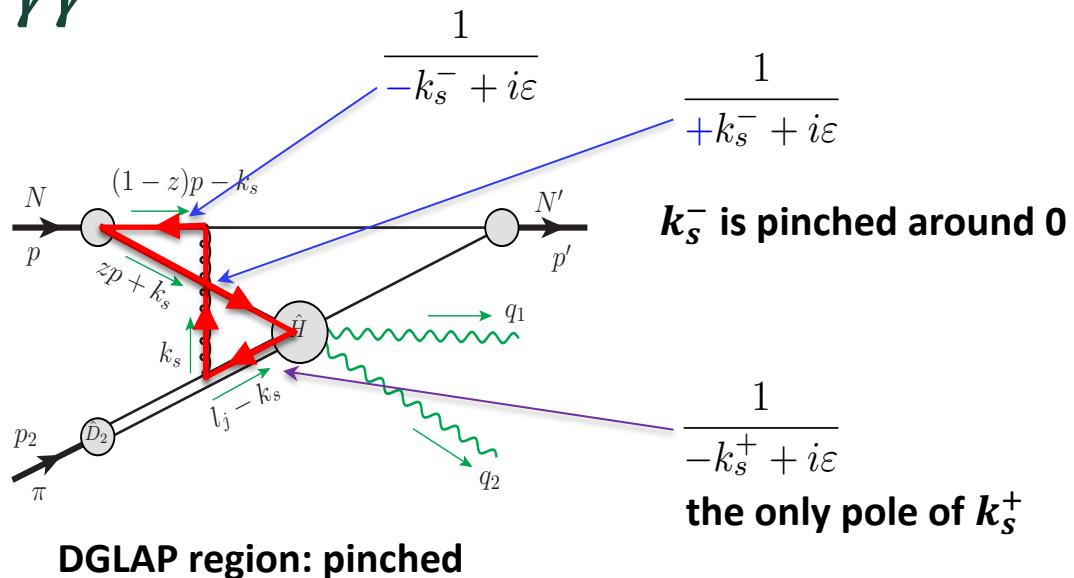


Factorization of $\pi N \rightarrow N' \gamma\gamma$

□ Glauber region

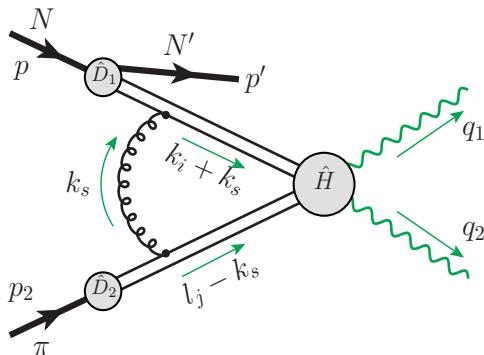


ERBL region: no pinch

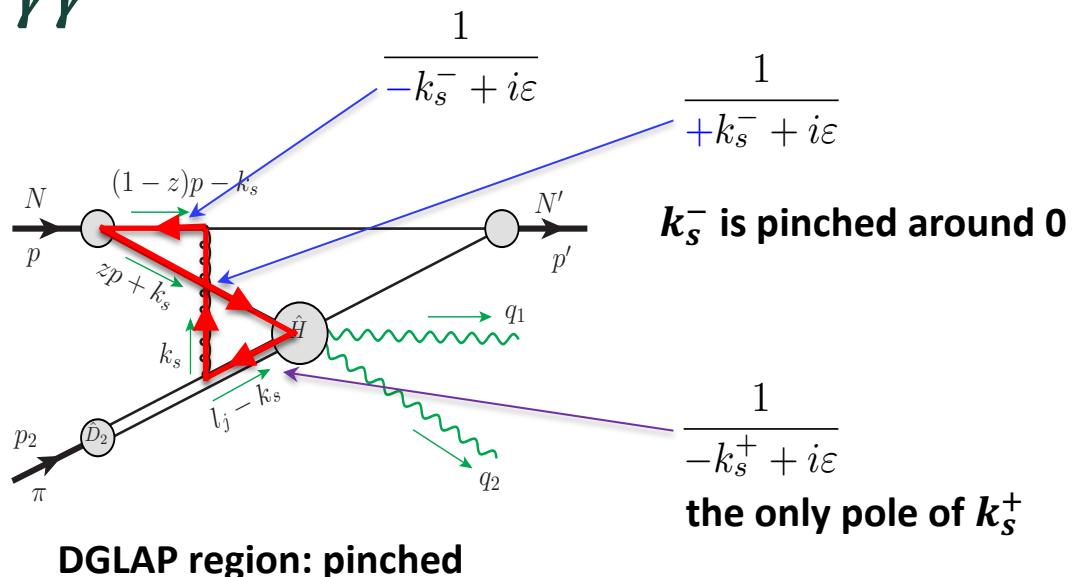


Factorization of $\pi N \rightarrow N' \gamma\gamma$

❑ Glauber region



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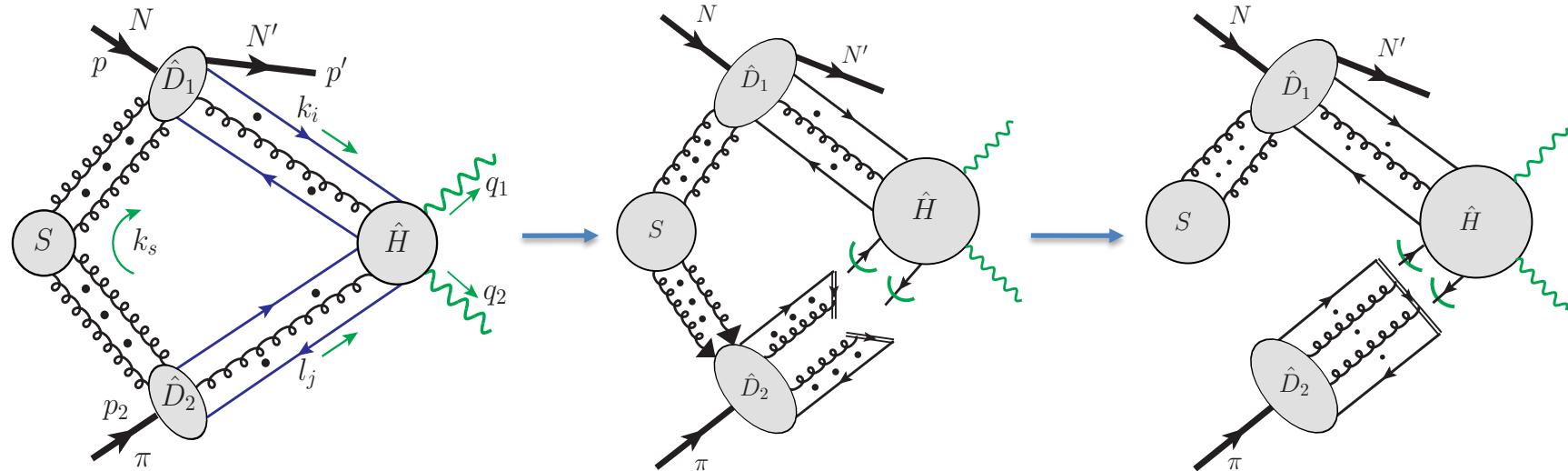
the only pole of k_s^+

Deformation: $k_s^+ \rightarrow k_s^+ - i\mathcal{O}(Q) \longrightarrow k_s \sim (1, \lambda^2, \lambda)Q$ collinear region

Works for both ERBL and DGLAP regions!

Factorization of $\pi N \rightarrow N' \gamma\gamma$

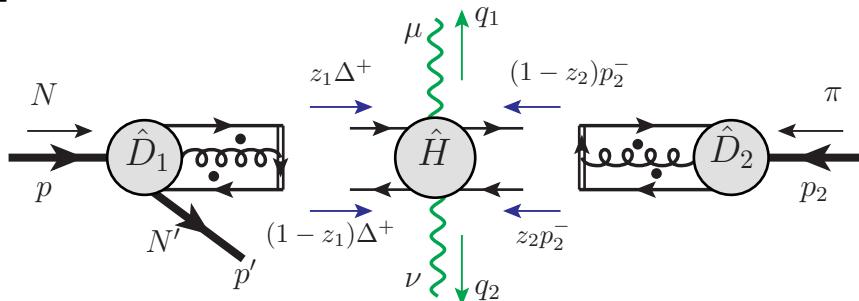
◻ Ward identity



Factorization of $\pi N \rightarrow N' \gamma\gamma$

□ Factorization formula

$$\mathcal{M}^{\mu\nu} = \int dz_1 dz_2 \left[\tilde{\mathcal{F}}_{NN'}^{ud}(z_1, \xi, t) D(z_2) C^{\mu\nu}(z_1, z_2) + \mathcal{F}_{NN'}^{ud}(z_1, \xi, t) D(z_2) \tilde{C}^{\mu\nu}(z_1, z_2) \right] + \mathcal{O}(\Lambda_{\text{QCD}}/q_T)$$



$$\begin{aligned} \mathcal{F}_{NN'}^{ud}(z_1, \xi, t) &= \int \frac{dy^-}{4\pi} e^{iz_1 \Delta^+ y^-} \langle N'(p') | \bar{d}(0) \gamma^+ \Phi(0, y^-; w_2) u(y^-) | N(p) \rangle \\ &= \frac{1}{2P^+} \left[H_{NN'}^{ud}(z_1, \xi, t) \bar{u}(p') \gamma^+ u(p) - E_{NN'}^{ud}(z_1, \xi, t) \bar{u}(p') \frac{i\sigma^{+\alpha} \Delta_\alpha}{2m_p} u(p) \right], \end{aligned}$$

$$\begin{aligned} \tilde{\mathcal{F}}_{NN'}^{ud}(z_1, \xi, t) &= \int \frac{dy^-}{4\pi} e^{iz_1 \Delta^+ y^-} \langle N'(p') | \bar{d}(y^-) \gamma^+ \gamma_5 \Phi(0, y^-; w_2) u(0) | N(p) \rangle \\ &= \frac{1}{2P^+} \left[\tilde{H}_{NN'}^{ud}(z_1, \xi, t) \bar{u}(p') \gamma^+ \gamma_5 u(p) - \tilde{E}_{NN'}^{ud}(z_1, \xi, t) \bar{u}(p') \frac{i\gamma_5 \sigma^{+\alpha} \Delta_\alpha}{2m_p} u(p) \right] \end{aligned}$$



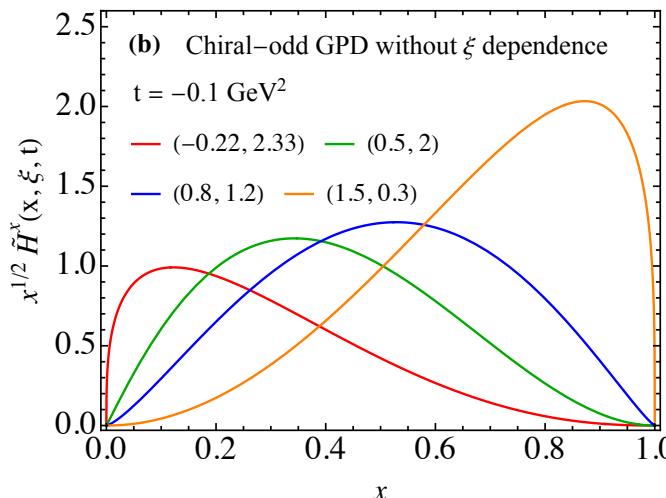
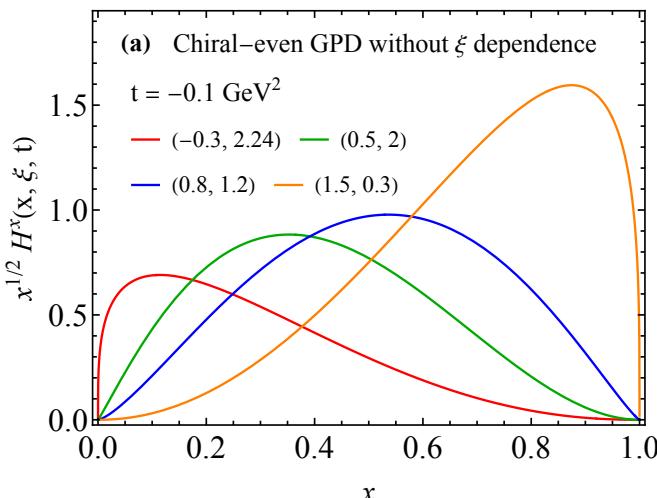
Phenomenology on $\pi^- p \rightarrow n\gamma\gamma$: sensitivity to GPD x

□ GPD models: simplified GK model

$$H_{pn}(x, \xi, t) = \theta(x) x^{-0.9(t/\text{GeV}^2)} \frac{x^\rho(1-x)^\tau}{B(1+\rho, 1+\tau)}$$

$$\tilde{H}_{pn}(x, \xi, t) = \theta(x) x^{-0.45(t/\text{GeV}^2)} \frac{1.267 x^\rho(1-x)^\tau}{B(1+\rho, 1+\tau)}$$

- **Tune (ρ, τ) to control x shape.**
- **Neglect E, \tilde{E} . Neglect evolution effect.**
- **Fix DA: $D(z) = N z^{0.63} (1-z)^{0.63}$**



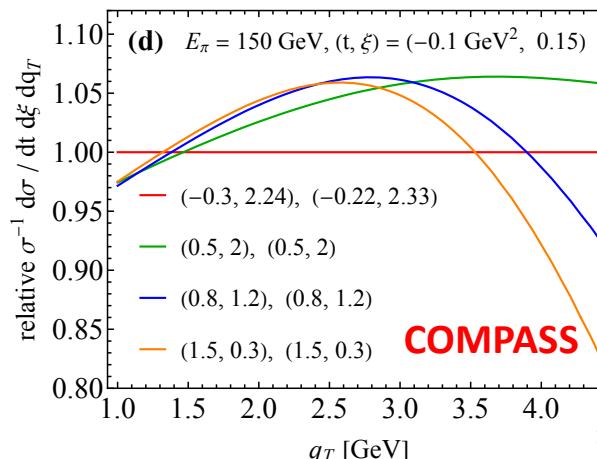
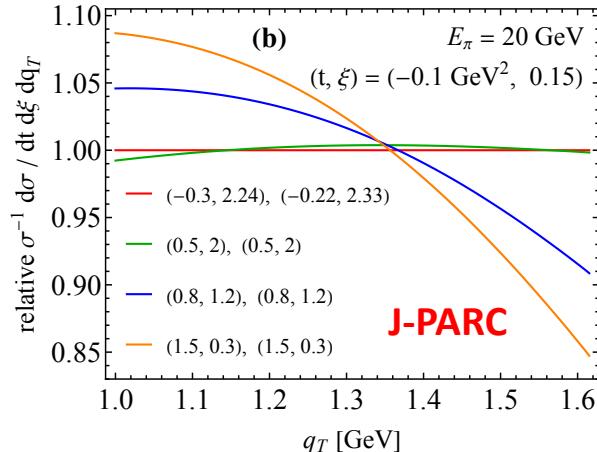
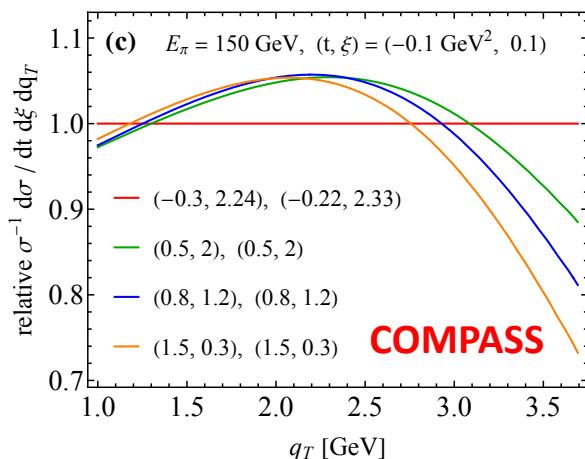
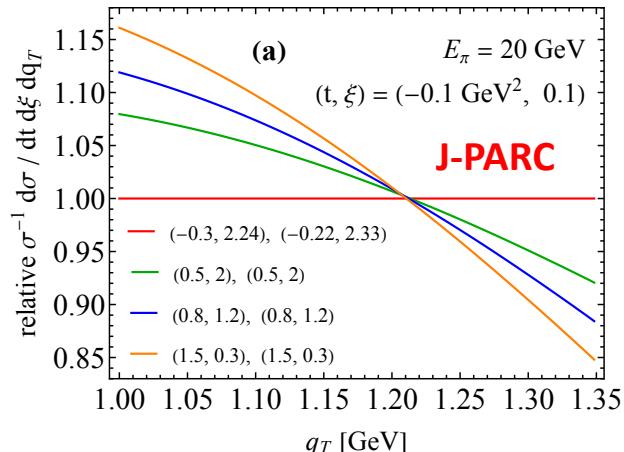
$$\frac{d\sigma}{dt d\xi dq_T} \sim |H(x, \xi, t)|^2$$



Relative q_T shape

$$\frac{\sigma_{\text{tot}}^{-1} d\sigma/dq_T}{\text{some shape func}}$$

$$\sigma_{\text{tot}} = \int_{1 \text{ GeV}}^{\sqrt{s}/2} dq_T \frac{d\sigma}{dt d\xi dq_T}$$



Conclusion

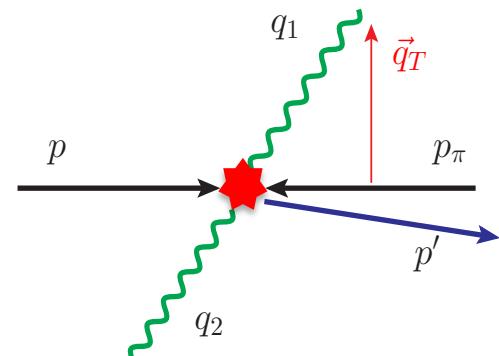
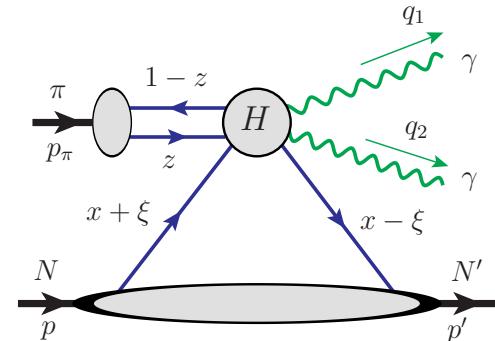
□ Proposed a new type of exclusive processes

- *Exclusive massive pair production*
- *Proved factorization into GPD and DA*
- *Provides sensitivity to x-dependence of GPD*
- *Possible to study at COMPASS, J-PARC*

□ Outlook

- *Similar processes can be proposed*
- *At least two particles come out of the hard interaction*
- *Extra observable to provide sensitivity to GPD*

Thank you!





Backup Slides

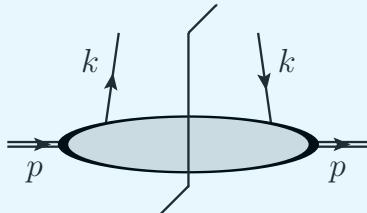


GPD vs. PDF

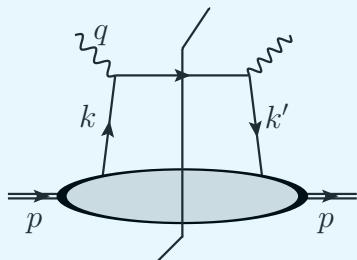
□ Parton Distribution Function (PDF)

$f(x) \sim \text{probability}$
→ cut diagram

$$x = k^+ / p^+$$



Deeply Inelastic Scattering (DIS)



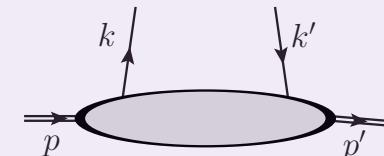
- At LO, $x = x_B$
 - Beyond LO
- $$\int_{x_B}^1 dx f(x) \dots$$

x -dependence is part of measurement.

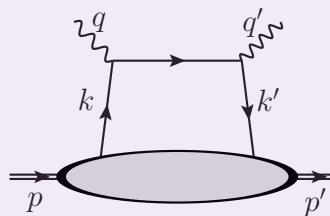
□ Generalized Parton Density (GPD)

$F(x, \xi, t) \sim \text{amplitude}$
→ uncut diagram

$$x = (k + k')^+ / (p + p')^+$$



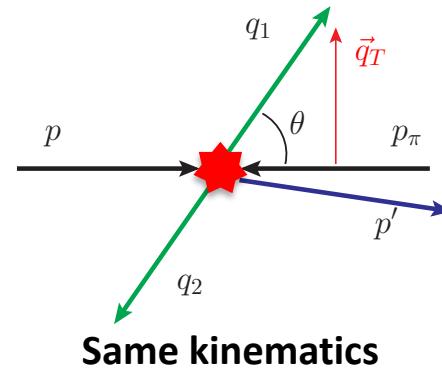
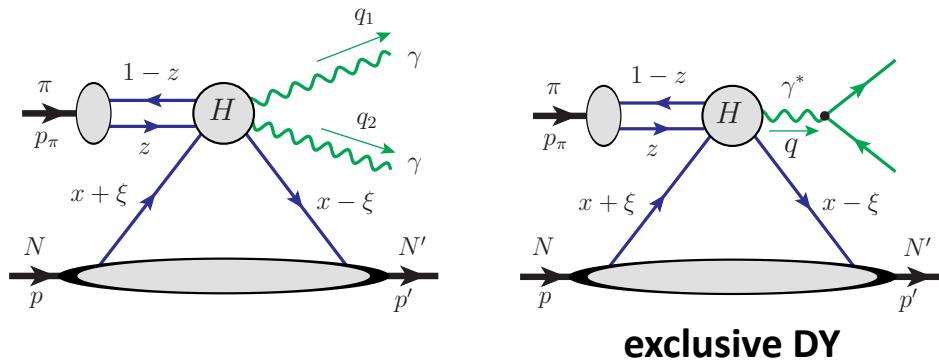
Deeply Virtual Compton Scattering (DVCS)



At any order
 $\int_{-1}^1 dx F(x, \xi, t) \dots$

x -dependence is hard to measure.

Comparison with exclusive Drell-Yan process

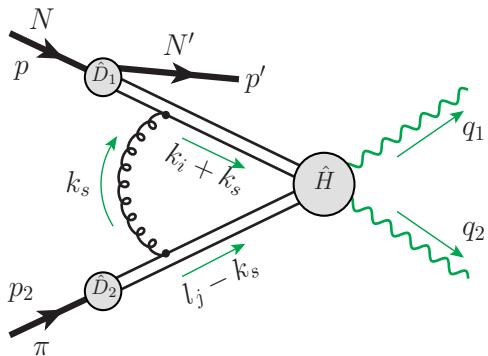


- ❖ Origin of the hard scale is from the production of the pair
- ❖ x -dependence flows through the production of the pair
- ❖ Additional sensitivity from the additional observable

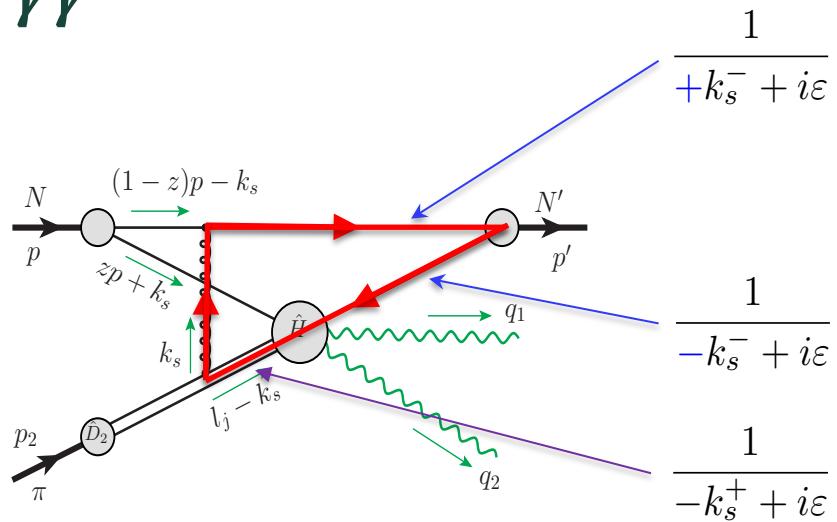


Factorization of $\pi N \rightarrow N' \gamma\gamma$

□ Glauber region



ERBL region: no pinch

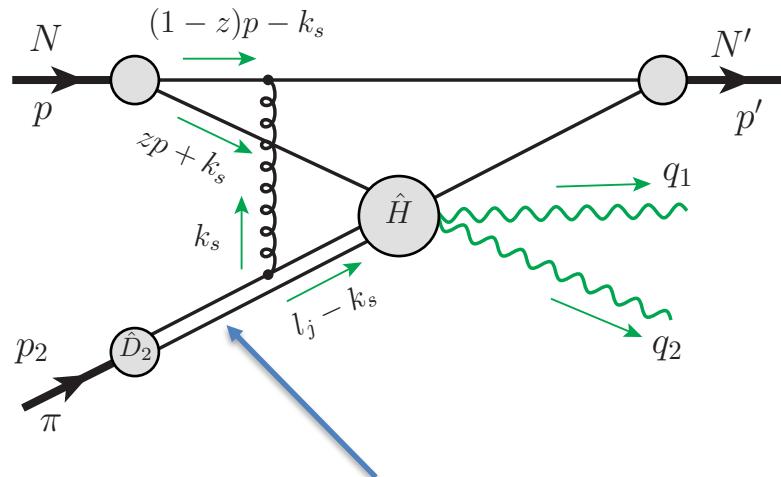


DGLAP region: pinched

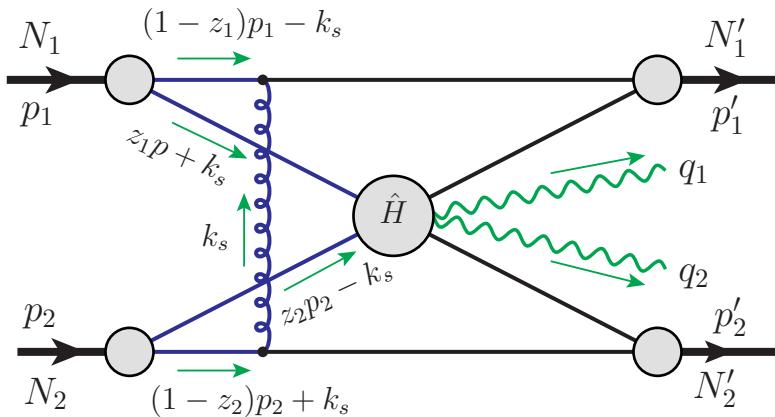
Independent of soft gluon momentum flowing direction.

Remark on double diffractive process

Glauber pinch for diffractive scattering



Factorizable thanks to pion



Non-factorizable even with hard scale