Accessing GPDs through the exclusive photoproduction of a photon-meson pair with a large invariant mass

3DPartons Week

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October 28, 2022

Based on works with S. Wallon, L. Szymanowski, B. Pire, R. Boussarie, G. Duplančić, K. Passek-Kumerički

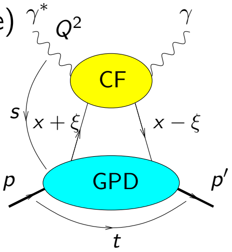
DVCS: exclusive process (non forward amplitude)

Fourier transf.: $t \leftrightarrow$ impact parameter

$(x, \xi, t) \Rightarrow$ 3-dimensional structure

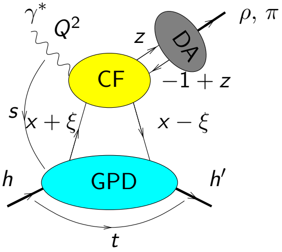
Coefficient Function $\otimes$ Generalized Parton Distribution
(hard) (soft)

[Müller et al. '91 - '94; Radyushkin '96; Ji '97]



DVMP: γ replaced by $\rho,\ \pi, \cdots$

GPD (soft) $\otimes$ CF (hard) $\otimes$ Distribution Amplitude (soft)



[Collins, Frankfurt, Strikman '97; Radyushkin '97]

proofs valid only for some restricted cases

Quark GPDs at twist 2 [Diehl]

without helicity flip (chiral-even Γ matrices): 4 chiral-even GPDs:
(Note: $\Delta = p' - p$)

$$
\begin{aligned}
F^q &= \frac{1}{2}\int \frac{dz^-}{2\pi}\, e^{ixP^+z^-} \langle p'|\, \bar{q}(-\tfrac{1}{2}z)\, \gamma^+ q(\tfrac{1}{2}z)\, |p\rangle \Big|_{z^+=0,\, z_\perp=0} \\
&= \frac{1}{2P^+}\left[H^q(x,\xi,t)\, \bar{u}(p')\gamma^+ u(p) + E^q(x,\xi,t)\, \bar{u}(p')\frac{i\,\sigma^{+\alpha}\Delta_\alpha}{2m} u(p) \right],
\end{aligned}
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$H^q \xrightarrow{\xi=0,t=0}$ PDF q $\qquad$ $\tilde{H}^q \xrightarrow{\xi=0,t=0}$ polarized PDF Δq

with helicity flip (chiral-odd Γ matrices): 4 chiral-odd GPDs:

$$\frac{1}{2}\int \frac{dz^-}{2\pi}\, e^{ixP^+z^-}\langle p'|\,\bar{q}(-\tfrac{1}{2}z)\, i\,\sigma^{+i}\, q(\tfrac{1}{2}z)\;|p\rangle\Big|_{z^+=0,\, z_\perp=0}$$
$$= \frac{1}{2P^+}\bar{u}(p')\left[H_T^q\, i\sigma^{+i} + \tilde{H}_T^q\,\frac{P^+\Delta^i - \Delta^+P^i}{m^2} + E_T^q\,\frac{\gamma^+\Delta^i - \Delta^+\gamma^i}{2m} + \tilde{E}_T^q\,\frac{\gamma^+P^i - P^+\gamma^i}{m}\right]u(p)\,,$$

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$H_T^q \xrightarrow{\xi=0,t=0}$ quark transversity PDFs δq

Note: $\tilde{E}_T^q(x,-\xi,t) = -\tilde{E}_T^q(x,\xi,t)$

Why consider a gamma-meson pair?
Understanding transversity

- Transverse spin content of the proton:

$$\begin{array}{ccc} |\uparrow\rangle_{(x)} & \sim & |\rightarrow\rangle + |\leftarrow\rangle \\ |\downarrow\rangle_{(x)} & \sim & |\rightarrow\rangle - |\leftarrow\rangle \\ \text{spin along } x & & \text{helicity states} \end{array}$$

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- For massless (anti)particles, chirality = (-)helicity
- Transversity GPDs can thus be accessed through chiral-odd Γ matrices.
- Since (in the massless limit) QCD and QED are chiral-even (γ^μ, $\gamma^\mu\gamma^5$), the chiral-odd quantities (1, γ^5, $[\gamma^\mu, \gamma^\nu]$) which one wants to measure should appear in pairs.

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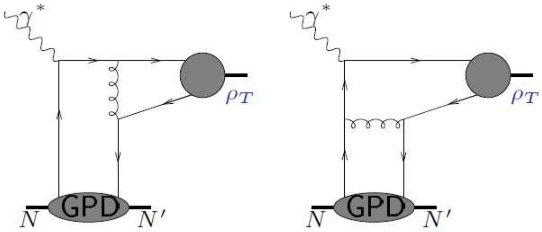
- lowest order diagrammatic argument:



$$\gamma^\alpha[\gamma^\mu, \gamma^\nu]\gamma_\alpha = 0$$

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Go to higher twist?

- This vanishing only occurs at twist 2
- At twist 3 this process does not vanish [Ahmad, Goldstein, Liuti], [Goloskokov, Kroll]

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- This vanishing only occurs at twist 2
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- However processes involving twist 3 DAs may face problems with factorisation (end-point singularities)

  can be made safe in the high-energy k_T-factorisation approach

  [Anikin, Ivanov, Pire, Szymanowski, Wallon]

Why consider a gamma-meson pair?

A convenient alternative solution

- Circumvent this using 3-body final states [Ivanov, Pire, Szymanowski, Teryaev], [Enberg, Pire, Szymanowski], [El Beiyad, Pire, Segond, Szymanowski, Wallon]
- Consider the process $\gamma N \to \gamma M N'$, $M =$meson. Collinear factorisation of the amplitude at large $M^2_{\gamma M}$.

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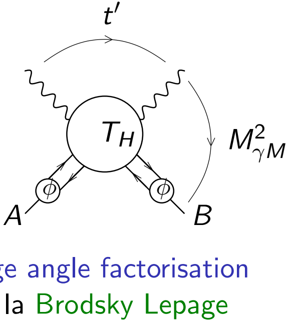

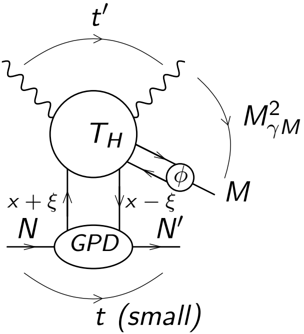

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- Requires large p_T.
- In fact, NLO computation has been performed for $\gamma N \to \gamma\gamma N'$ by Grocholski et al. [2110.00048]. $\Longrightarrow$ See Lech's talk

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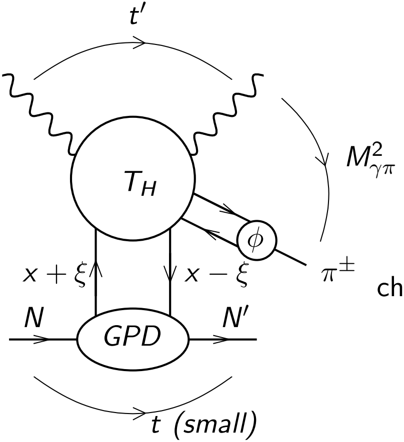
Chiral-even GPDs using $\pi^{\pm}\gamma$ production



chiral-even twist 2 DA

chiral-even twist 2 GPD

[G. Duplančić, K. Passek-Kumerički, B. Pire, L. Szymanowski, S. Wallon]

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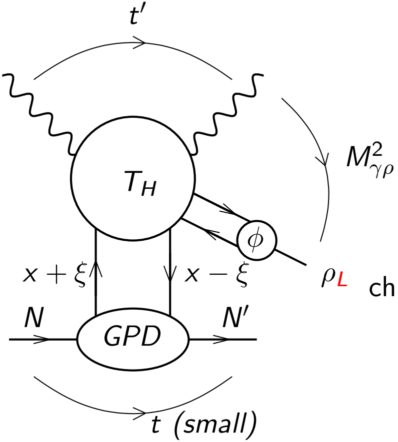
Chiral-even GPDs using $\rho_L \gamma$ production



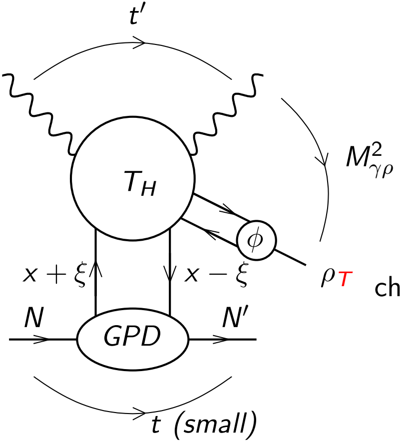
chiral-even twist 2 DA

chiral-even twist 2 GPD

[R. Boussarie, B. Pire, L. Szymanowski, S. Wallon]

Why consider a gamma-meson pair?

Chiral-odd GPDs using $\rho_T\gamma$ production

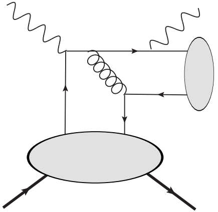


chiral-odd twist 2 DA

chiral-odd twist 2 GPD

[R. Boussarie, B. Pire, L. Szymanowski, S. Wallon]

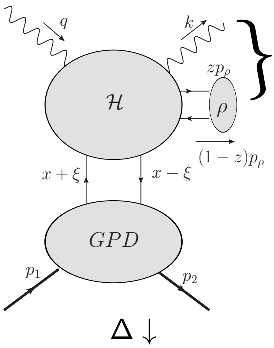
How does it work?



Typical non-zero diagram for a transverse ρ meson

the σ matrices (from either the DA or the GPD) do not kill it anymore!

$$\gamma(q) + N(p_1) \rightarrow \gamma(k) + \rho(p_\rho, \varepsilon_\rho) + N'(p_2)$$



hard scale
$M^2_{\gamma\rho} \propto p_\perp^2$

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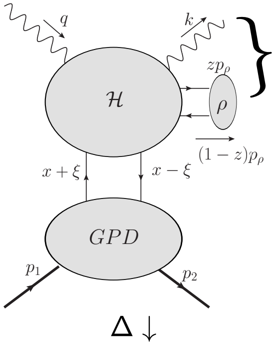

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Useful Mandelstam variables:

$$t = (p_2 - p_1)^2$$

$$u' = (p_\rho - q)^2$$

$$t' = (k - q)^2$$

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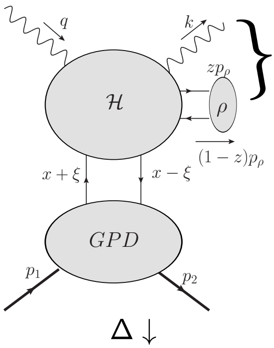

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  $-u' > 1 \text{ GeV}^2$, $-t' > 1 \text{ GeV}^2$ and $(-t)_{\min} \leqslant -t \leqslant .5 \text{ GeV}^2$

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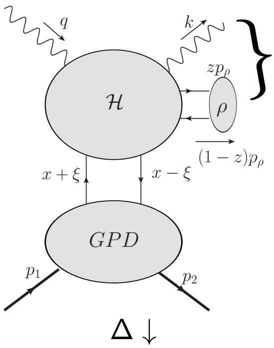

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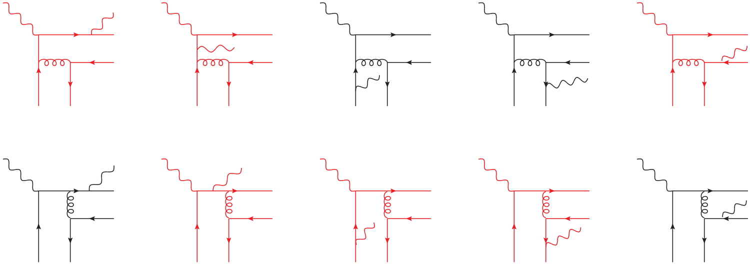
  $-u' > 1\ \mathrm{GeV}^2$, $-t' > 1\ \mathrm{GeV}^2$ and $(-t)_{\min} \leqslant -t \leqslant .5\ \mathrm{GeV}^2$
- Cross-section differential in $(-u')$ and $M^2_{\gamma\rho}$, and evaluated at $(-t) = (-t)_{\min}$.

A total of 20 diagrams to compute



- The other half can be deduced by $q \leftrightarrow \bar{q}$ (anti)symmetry depending on C-parity in $t-$channel
- Red diagrams cancel in the chiral-odd case

We parameterise the GPDs in terms of *double distributions (Radyushkin-type parametrisation)*

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For polarized PDFs (and hence transversity PDFs), two scenarios are proposed for the parameterization:

- “standard” scenario, with flavor-symmetric light sea quark and antiquark distributions.
- “valence” scenario with a completely flavor-asymmetric light sea quark densities.

- We take the simplistic asymptotic form of the DAs

$$\phi_\pi(z) = \phi_{\rho\parallel}(z) = \phi_{\rho\perp}(z) = 6z(1-z)\,.$$

- We also investigate the effect of using a holographic DA (preliminary):

$$\phi_{\text{hol}}(z) = \frac{8}{\pi}\sqrt{z(1-z)}\,.$$

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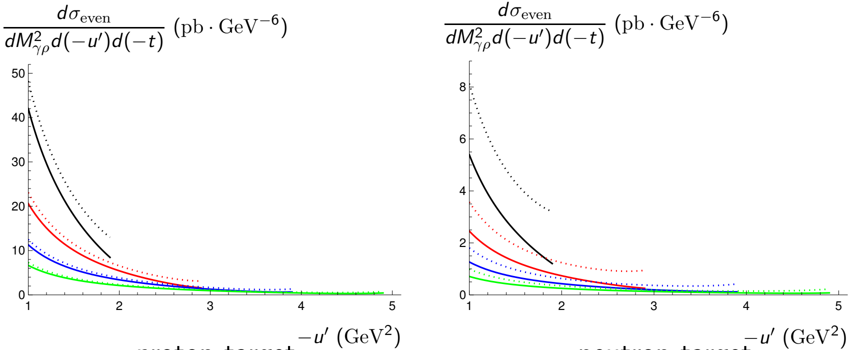
Suggested by AdS/QCD correspondence [Brodsky, de Teramond], dynamical chiral symmetry breaking on the light-front [Shi et al.], and recent lattice results. [Gao et al.]



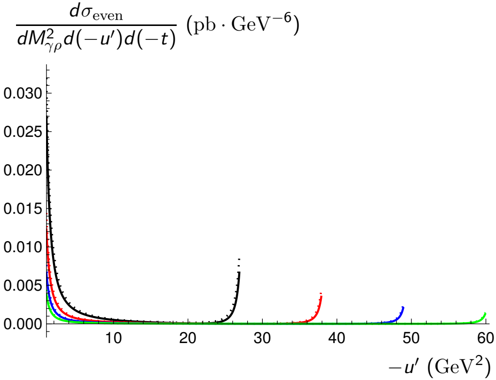
proton target | neutron target

$S_{\gamma N} = 20\ \mathrm{GeV}^2$, at $-t = (-t)_{\min}$, asymptotical DA

$M^2_{\gamma\rho} = 3, 4, 5, 6\ \mathrm{GeV}^2$

dotted: "standard" model

solid: "valence" model



$S_{\gamma N} = 200\ \text{GeV}^2$, at $-t = (-t)_{\text{min}}$, asymptotical DA, proton target

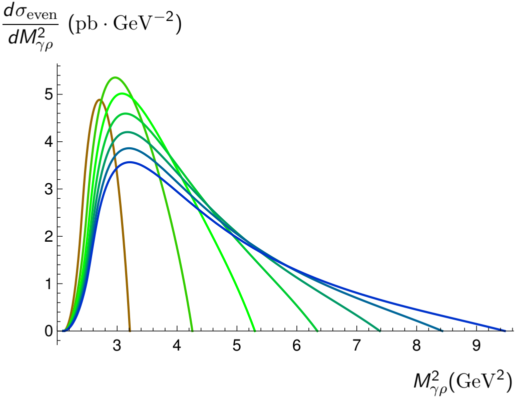
$M^2_{\gamma\rho} = 28, 39, 50, 61\ \text{GeV}^2$

dotted: "standard" model

solid: "valence" model

Results

Single differential cross-section: ρ_L^0 (Chiral even)

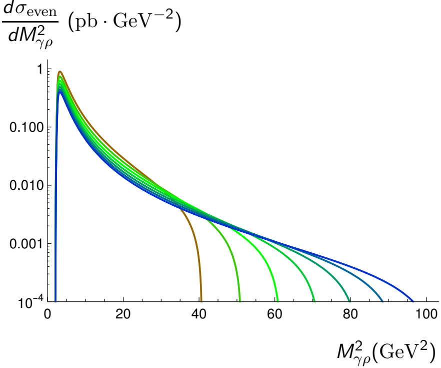


proton target, "valence" scenario, asymptotical DA

$S_{\gamma N} = 8, 10, 12, 14, 16, 18, 20\ \mathrm{GeV}^2$ (typical JLab kinematics)

Results (Preliminary)

Single differential cross-section: ρ_L^0 (Chiral even)



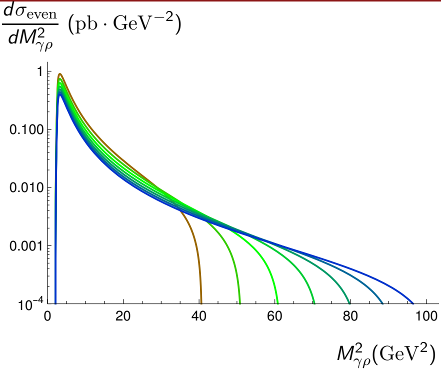
proton target, "valence" scenario, asymptotical DA

$$S_{\gamma N} = 80,\ 100,\ 120,\ 140,\ 160,\ 180,\ 200\ \text{GeV}^2$$

(typical COMPASS kinematics)

Results (Preliminary)

Single differential cross-section: ρ_L^0 (Chiral even)



proton target, "valence" scenario, asymptotical DA

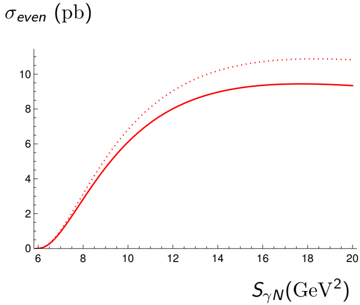
$$S_{\gamma N} = 80, 100, 120, 140, 160, 180, 200 \text{ GeV}^2$$

(typical COMPASS kinematics)

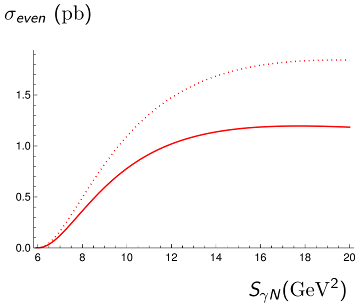
Peak *always* at low $M^2_{\gamma M}$ $\Longrightarrow$ Importance sampling needed for higher $S_{\gamma N}$!

Results

Integrated cross-section: Valence vs Standard: ρ_L^0 (Chiral even)



proton target



neutron target

Asymptotical DA

solid: “valence” scenario

dotted: “standard” one

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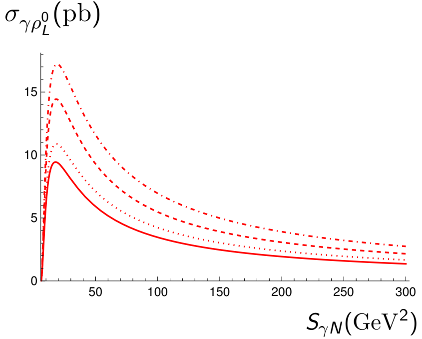
Mapping possible since different sets of $(S_{\gamma N}, M^2_{\gamma M}, -u')$ correspond to the same (α, ξ).

$$\alpha = \frac{-u'}{M^2_{\gamma M}} \,, \qquad \xi = \frac{M^2_{\gamma M}}{2(S_{\gamma N} - M_N^2) - M^2_{\gamma M}} \,.$$

Results (Preliminary)

Fully differential cross-section: Holographic vs Asymptotical DA: ρ_L^0 (Chiral-even)



Dashed: Holographic DA   non-dashed: Asymptotical DA

Dotted: standard scenario   non-dotted: valence scenario

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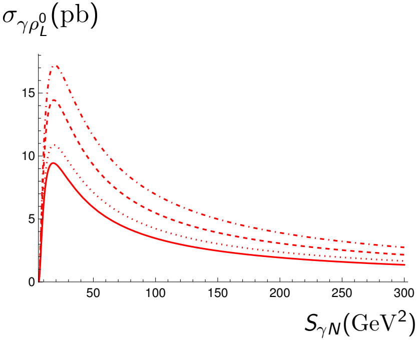

Dashed: Holographic DA non-dashed: Asymptotical DA

Dotted: standard scenario non-dotted: valence scenario

$\Longrightarrow$ DA type has sizable effect, larger than the one due to uncertainties on polarized PDFs

Results (Preliminary)

Polarisation Asymmetries of incoming photon

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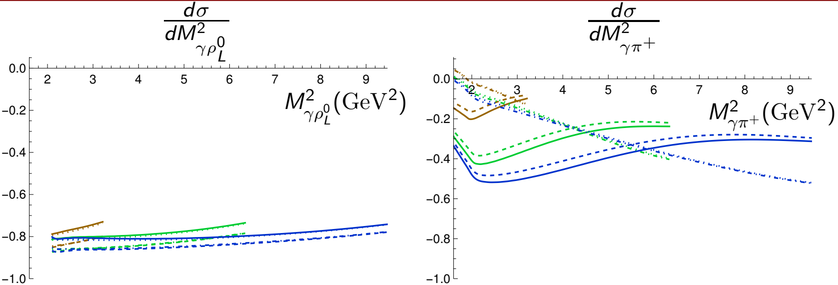
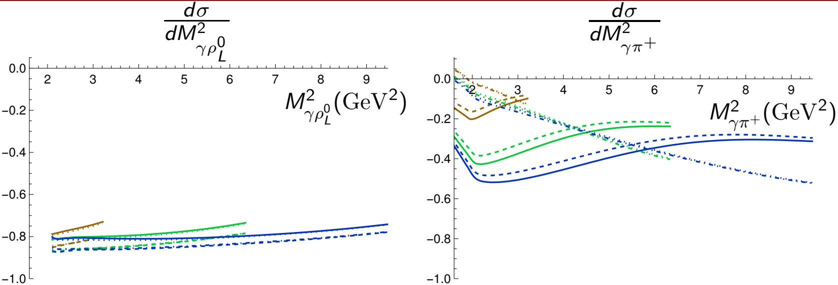
- Circular asymmetry $= 0$ (for unpolarised target).
- Linear asymmetry $= \frac{d\sigma_x - d\sigma_y}{d\sigma_x + d\sigma_y}$, where x is the direction defined by $p_\perp$ (direction of outgoing photon in the transverse plane).
- Kleiss-Sterling spinor techniques used to obtain expressions.



Dashed: Holographic DA non-dashed: Asymptotical DA

Dotted: standard scenario non-dotted: valence scenario

- $S_{\gamma N} = 8, 14, 20$ GeV^2



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Dotted: standard scenario non-dotted: valence scenario

- $S_{\gamma N} = 8, 14, 20$ GeV^2
- ρ^0_L can distinguish between DA model, while π^+ (and π^-) can distinguish between GPD model (valence vs standard).

Good statistics: For example, at JLab Hall B:

- untagged incoming $\gamma \Rightarrow$ Weizsäcker-Williams distribution

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- with an expected luminosity of $\mathcal{L} = 100 \text{ nb}^{-1} s^{-1}$, for 100 days of run:
  - ρ_L^0 (on p) : $\approx 2.4 \times 10^5$
  - ρ_T^0 (on p) : $\approx 7.5 \times 10^3$ (Chiral-odd)
  - ρ_L^+ : $\approx 1.4 \times 10^5$
  - π^+ : $\approx 1.8 \times 10^5$

At COMPASS:

- Taking a luminosity of $\mathcal{L} = 0.1\ \mathrm{nb}^{-1} s^{-1}$, and 300 days of run,
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- Lower numbers due to low luminosity (factor of 10^3 less than JLab!)

Prospects at experiments (Preliminary)
Counting rates: EIC

- At the future EIC, with an expected integrated luminosity of $10\,\mathrm{fb}^{-1}$ (about 100 times smaller than JLab):
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- Small ξ study:

  With $160 < S_{\gamma N} < 20000$, probing $5 \cdot 10^{-5} < \xi < 5 \cdot 10^{-3}$:
  - ρ_L^0 (on p) : $\approx 2.3 \times 10^3$
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For p-Pb UPCs at LHC (integrated luminosity of 1200 nb^{-1}):

- With future data from runs 3 and 4,
  - $\rho_L^0 : \approx 1.6 \times 10^4$
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- Photon flux enhanced by a factor of Z^2, but drops rapidly with $S_{\gamma N} \Longrightarrow$ *Low luminosity not compensated by larger photon flux.*

Conclusion

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- Good statistics in various experiments, particularly at JLab.
- Small ξ limit of GPDs can be investigated by exploiting high energies available at EIC and UPCs at LHC.

Outlook

- Holographic vs Asymptotical DA, polarisation asymmetries of incoming photon and kinematics for COMPASS, EIC and LHC at UPC [to appear!]

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The END

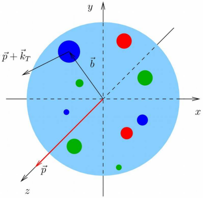
BACKUP SLIDES

What are GPDs?

From Wigner distributions to GPDs and PDFs

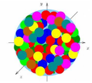
6D/5D

Wigner distributions for hadrons



$W(x, \vec{b}, k_T)$

Experimentally inaccessible directly



perturbative Regge limit

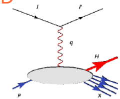
3D

uPDFs (gluons)

Unintegrated parton distributions

$\int d^3\vec{b}$

II



Semi-inclusive processes

TMDs

$f(x, k_T)$

Transverse momentum dependent distributions

$\int d^2k_T \int d\, b_z$

$f(x, b_T)$

Impact parameter distributions

$b_T \Leftrightarrow \Delta$

$H(x, 0, t)$

$t = -\Delta^2$

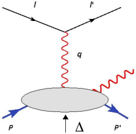
$\int d^2k_T \int Fourier(\vec{b})$

$\xi = 0$

GPDs

$H(x, \xi, t)$

generalised parton distributions



exclusive processes

$\int d^2k_T$

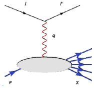
$\int d^2b_T$

$t=0$

$\int dx$

$\int dx\; x^{n-1}$

1D

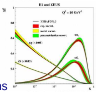


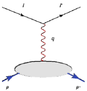
inclusive and semi-inclusive processes

PDFs

$f(x)$

parton distributions



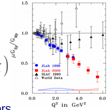


elastic processes

FFs

$G_{E,M}(t)$

form factors



GFFs

generalized form factors

lattices

Computation

Parametrising the GPDs: ρ_L and π case, Chiral-even

$$\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \langle p_2, \lambda_2 | \bar{\psi}_q \left(-\frac{1}{2}z^-\right) \gamma^+ \psi \left(\frac{1}{2}z^-\right) | p_1, \lambda_1 \rangle$$

$$= \frac{1}{2P^+} \bar{u}(p_2, \lambda_2) \left[H^q(x,\xi,t)\gamma^+ + E^q(x,\xi,t) \frac{i\sigma^{\alpha+}\Delta_\alpha}{2m} \right] u(p_1, \lambda_1)$$

$$\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \langle p_2, \lambda_2 | \bar{\psi}_q \left(-\frac{1}{2}z^-\right) \gamma^+ \gamma^5 \psi \left(\frac{1}{2}z^-\right) | p_1, \lambda_1 \rangle$$

$$= \frac{1}{2P^+} \bar{u}(p_2, \lambda_2) \left[\tilde{H}^q(x,\xi,t)\gamma^+\gamma^5 + \tilde{E}^q(x,\xi,t) \frac{\gamma^5 \Delta^+}{2m} \right] u(p_1, \lambda_1)$$

- Take the limit $\Delta_\perp = 0$.
- In that case and for small ξ, the dominant contributions come from H^q and $\tilde{H}^q$.

$$
\begin{aligned}
&\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \langle p_2, \lambda_2 | \bar{\psi}_q \left(-\frac{1}{2}z^-\right) i\sigma^{+i} \psi \left(\frac{1}{2}z^-\right) | p_1, \lambda_1 \rangle \\
= \;& \frac{1}{2P^+} \bar{u}(p_2, \lambda_2) \left[H_T^q(x,\xi,t) i\sigma^{+i} + \tilde{H}_T^q(x,\xi,t) \frac{P^+\Delta^i - \Delta^+ P^i}{M_N^2} \right. \\
+ \;& \left. E_T^q(x,\xi,t) \frac{\gamma^+\Delta^i - \Delta^+\gamma^i}{2M_N} + \tilde{E}_T^q(x,\xi,t) \frac{\gamma^+ P^i - P^+\gamma^i}{M_N} \right] u(p_1, \lambda_1)
\end{aligned}
$$

- Take the limit $\Delta_\perp = 0$.
- In that case and for small ξ, the dominant contributions come from H_T^q.

- GPDs can be represented in terms of Double Distributions [Radyushkin]

$$H^q(x,\xi,t=0) = \int_{-1}^{1} d\beta \int_{-1+|\beta|}^{1-|\beta|} d\alpha\ \delta(\beta+\xi\alpha-x)\, f^q(\beta,\alpha)$$

- ansatz for these Double Distributions [Radyushkin]:
  - chiral-even sector:

$$f^q(\beta,\alpha,t=0) = \Pi(\beta,\alpha)\, q(\beta)\Theta(\beta) - \Pi(-\beta,\alpha)\, \bar{q}(-\beta)\, \Theta(-\beta)\,,$$
$$\tilde{f}^q(\beta,\alpha,t=0) = \Pi(\beta,\alpha)\, \Delta q(\beta)\Theta(\beta) + \Pi(-\beta,\alpha)\, \Delta\bar{q}(-\beta)\, \Theta(-\beta)\,.$$

  - chiral-odd sector:

$$f_T^q(\beta,\alpha,t=0) = \Pi(\beta,\alpha)\, \delta q(\beta)\Theta(\beta) - \Pi(-\beta,\alpha)\, \delta\bar{q}(-\beta)\, \Theta(-\beta)\,.$$

  - $\Pi(\beta,\alpha) = \frac{3}{4}\frac{(1-\beta)^2-\alpha^2}{(1-\beta)^3}$: profile function

- simplistic factorised ansatz for the t-dependence:

$$H^q(x, \xi, t) = H^q(x, \xi, t = t_{\min}) \times F_H(t)$$

with $F_H(t) = \frac{(t_{\min} - C)^2}{(t - C)^2}$ a standard dipole form factor ($C = 0.71 \mathrm{GeV}^2$)

Sets of PDFs used

- $q(x)$: unpolarized PDF [GRV-98]

  and [MSTW2008lo, MSTW2008nnlo, ABM11nnlo, CT10nnlo]

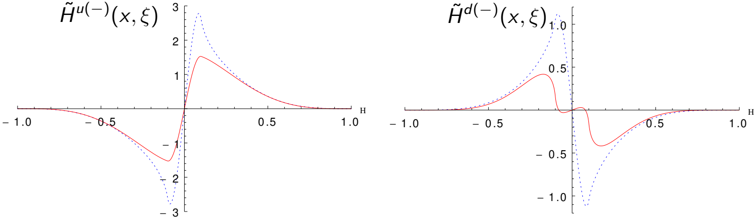
- $\Delta q(x)$ polarized PDF [GRSV-2000]

- $\delta q(x)$: transversity PDF [Anselmino *et al.*]

Effects are not significant! But relevant for NLO corrections!

Typical kinematic point (for JLab kinematics):
$\xi = .1 \;\leftrightarrow\; S_{\gamma N} = 20\ \mathrm{GeV}^2$ and $M^2_{\gamma\rho} = 3.5\ \mathrm{GeV}^2$

$$\tilde{H}^{q(-)}(x,\xi,t) = \tilde{H}^{q}(x,\xi,t) - \tilde{H}^{q}(-x,\xi,t) \quad [C=-1]$$



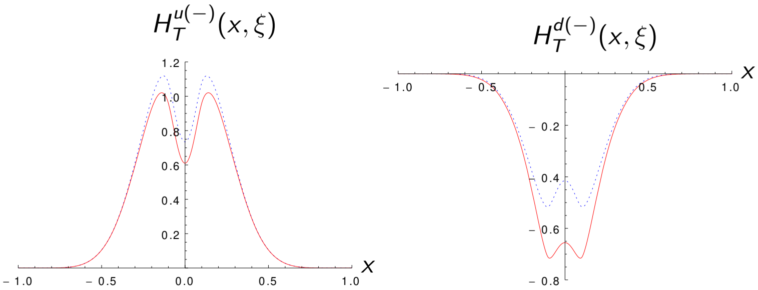
"valence" and "standard": two GRSV Ansätze for $\Delta q(x)$

Computation

Valence vs Standard scenarios in H_T (Chiral-odd)

Typical kinematic point (for JLab kinematics):
$\xi = .1 \leftrightarrow S_{\gamma N} = 20 \text{ GeV}^2$ and $M^2_{\gamma\rho} = 3.5 \text{ GeV}^2$

$$H_T^{q(-)}(x,\xi,t) = H_T^q(x,\xi,t) + H_T^q(-x,\xi,t) \quad [C=-1]$$



"valence" and "standard": two GRSV Ansätze for $\Delta q(x)$

$\Rightarrow$ two Ansätze for $\delta q(x)$

- Helicity conserving (vector) DA at twist 2: ρ_L

$$\langle 0|\bar{u}(0)\gamma^{\mu}u(x)|\rho^0(p,s)\rangle = \frac{p^{\mu}}{\sqrt{2}}f_{\rho}\int_0^1 du\ e^{-iup\cdot x}\phi_{\parallel}(u)$$

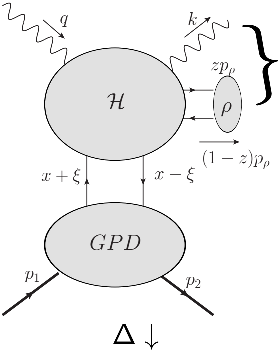
- ρ_T DA at twist 2:

$$\langle 0|\bar{u}(0)\sigma^{\mu\nu}u(x)|\rho^0(p,s)\rangle = \frac{i}{\sqrt{2}}(\epsilon_{\rho}^{\mu}p^{\nu} - \epsilon_{\rho}^{\nu}p^{\mu})f_{\rho}^{\perp}\int_0^1 du\ e^{-iup\cdot x}\ \phi_{\perp}(u)$$

- Work in the limit of:
  - $\Delta_\perp \ll p_\perp$
  - $M^2,\ m_\rho^2 \ll M_{\gamma\rho}^2$
- initial state particle momenta:

$$q^\mu = n^\mu,$$
$$p_1^\mu = (1+\xi)\, p^\mu + \frac{M^2}{s(1+\xi)} n^\mu$$

- final state particle momenta:



hard scale $M_{\gamma\rho}^2 \propto p_\perp^2$

$$p_2^\mu = (1-\xi)\, p^\mu + \frac{M^2 + \vec{p}_t^{\,2}}{s(1-\xi)} n^\mu + \Delta_\perp^\mu$$

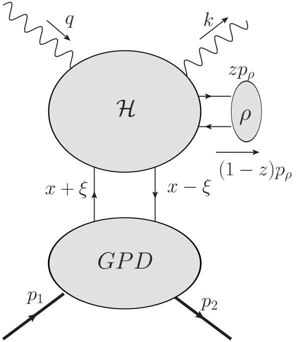
$$k^\mu = \alpha\, n^\mu + \frac{(\vec{p}_t - \vec{\Delta}_t/2)^2}{\alpha s} p^\mu + p_\perp^\mu - \frac{\Delta_\perp^\mu}{2},$$

$$p_\rho^\mu = \alpha_\rho\, n^\mu + \frac{(\vec{p}_t + \vec{\Delta}_t/2)^2 + m_\rho^2}{\alpha_\rho s} p^\mu - p_\perp^\mu - \frac{\Delta_\perp^\mu}{2},$$

$$\mathcal{A} \propto \int_{-1}^{1} dx \int_{0}^{1} dz \; T(x,\xi,z) \; H(x,\xi,t) \; \Phi_\rho(z)$$

- z integration performed analytically using an asymptotic or holographic DA.
- GPD models plugged into expression for amplitude and the integral performed w.r.t. x numerically.
- Differential cross section:

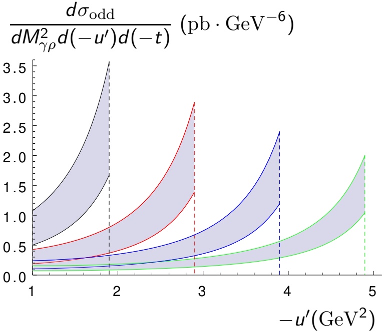
$$\left.\frac{d\sigma}{dt\, du'\, dM^2_{\gamma\rho}}\right|_{-t=(-t)_{min}} = \frac{|\overline{\mathcal{A}}|^2}{32 S^2_{\gamma N} M^2_{\gamma\rho} (2\pi)^3} \,.$$



- Kinematic parameters: $S_{\gamma N}$, $M^2_{\gamma\rho}$ and $-u'$
  Recall: $u' = (p_\rho - q)^2$, $t = (p_2 - p_1)^2$

Results

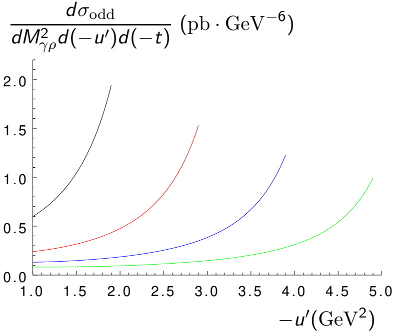
Fully-differential cross-sections: ρ_T^0 (Chiral odd)



proton target

"valence" and "standard" models,

each of them with $\pm 2\sigma$ [S. Melis]



neutron target

"valence" model only

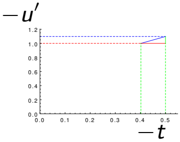
$$S_{\gamma N} = 20\ \mathrm{GeV}^2 \text{ at } -t = (-t)_{\rm min}$$

$$M^2_{\gamma\rho} = 3, 4, 5, 6\ \mathrm{GeV}^2$$

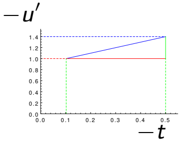
large angle scattering: $M^2_{\gamma\rho} \sim -u' \sim -t'$

$\Longrightarrow$ $-u' > 1~\mathrm{GeV}^2$ and $-t' > 1~\mathrm{GeV}^2$ and $(-t)_{\min} \leqslant -t \leqslant .5~\mathrm{GeV}^2$

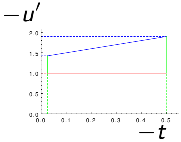
example: $S_{\gamma N} = 20~\mathrm{GeV}^2$



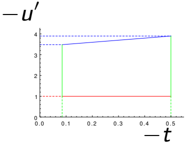
$M_{\gamma\rho} = 2.2~\mathrm{GeV}^2$



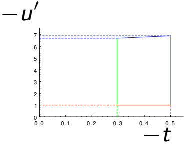
$M^2_{\gamma\rho} = 2.5~\mathrm{GeV}^2$



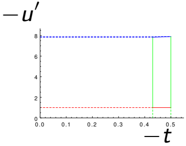
$M_{\gamma\rho} = 3~\mathrm{GeV}^2$



$M_{\gamma\rho} = 5~\mathrm{GeV}^2$

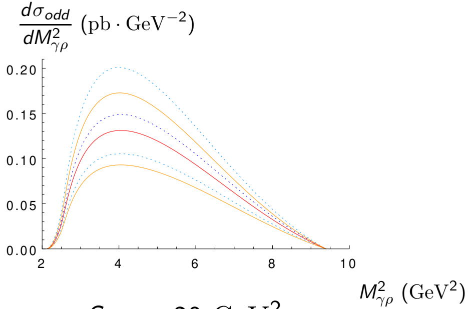


$M_{\gamma\rho} = 8~\mathrm{GeV}^2$



$M_{\gamma\rho} = 9~\mathrm{GeV}^2$

Results



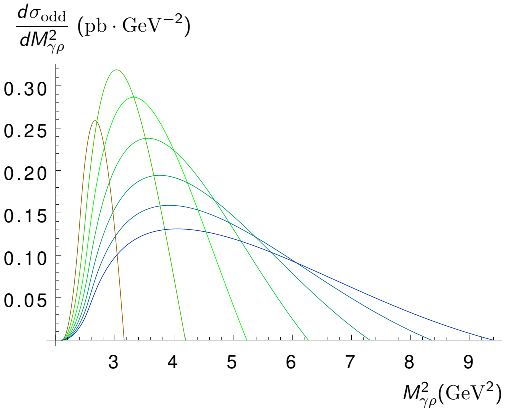
$$S_{\gamma N} = 20 \text{ GeV}^2$$

Various ansätze for the PDFs Δq used to build the GPD H_T:

- *dotted curves*: "standard" scenario
- solid curves: "valence" scenario
- deep-blue and red curves: central values
- light-blue and orange: results with $\pm 2\sigma$.

Results

Single differential cross-section: ρ_T^0 (Chiral odd)

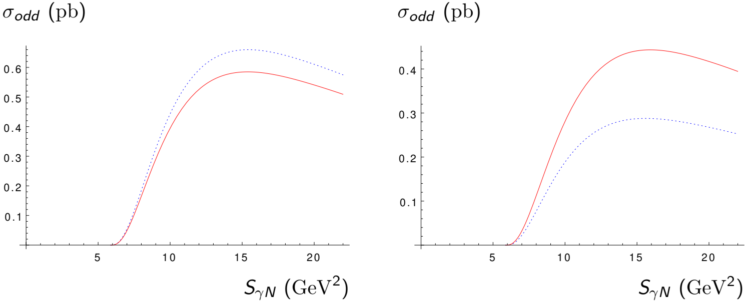


proton target, "valence" scenario

$$S_{\gamma N} = 8,\ 10,\ 12,\ 14,\ 16,\ 18,\ 20\ \text{GeV}^2$$

typical JLab kinematics

Integrated cross-section: Valence vs Standard: ρ_T^0 (Chiral odd)



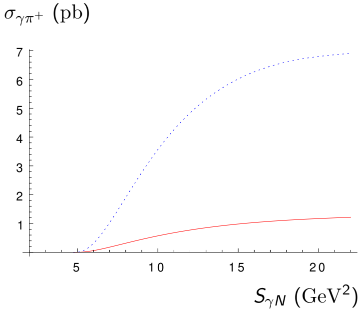
proton target　　　neutron target

solid red: "valence" scenario

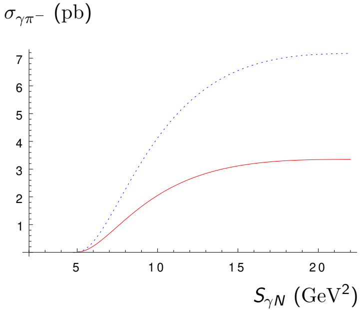
dashed blue: "standard" one

Results

Integrated cross-section: Valence vs Standard: $\pi^{\pm}$ (Chiral even)



proton target



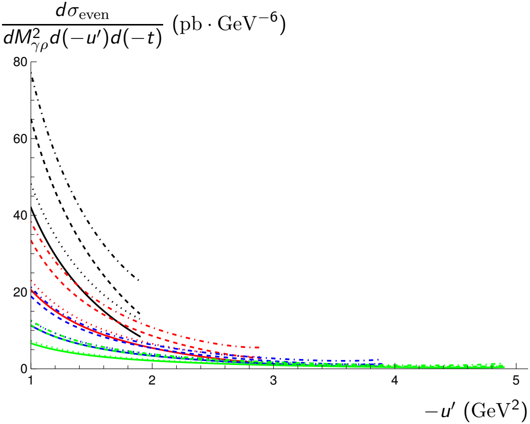
neutron target

solid red: "valence" scenario

dashed blue: "standard" one

Results (Preliminary)

Fully differential X-section: Holographic DA vs Asymptotical DA: ρ_L^0, Chiral-even



dashed dotted:
Hol. DA, "standard" model

dashed:
Hol. DA, "valence" model

dotted:
Asymp. DA, "standard" model

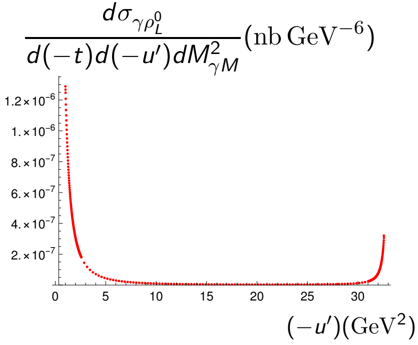
solid:

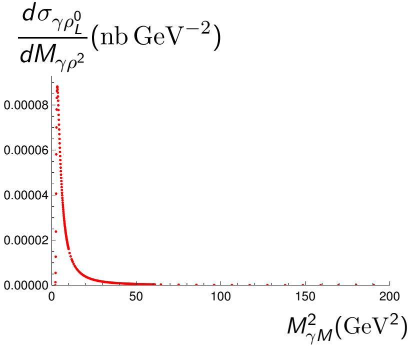
Asymp. DA, "valence" model

$S_{\gamma N} = 20\ \mathrm{GeV}^2$, at $-t = (-t)_{\rm min}$
$M^2_{\gamma\rho} = 3, 4, 5, 6\ \mathrm{GeV}^2$

$\Longrightarrow$ sizable effect, larger than the one due to uncertainties on polarized PDFs

Necessity for Importance Sampling

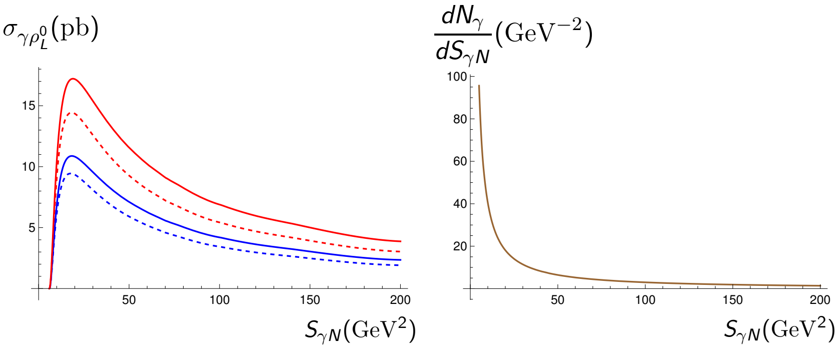




- Need enough points at boundaries for distribution in $(-u')$
- Need enough points to resolve peak (at low $M^2_{\gamma M}$) for distribution in $M^2_{\gamma M}$

Prospects at experiments

Why counting rates lower UPCs at LHC?



Hol. DA vs Asymp. DA Solid: standard vs Dashed: valence

- LHC great for high energy, but JLab better in terms of luminosity.
- Still, LHC gives us access to the small ξ region of GPDs!

Circular asymmetry of incoming photon

Why does it vanish for unpolarised target?

Consider

$$\gamma(q,\lambda_q) + N(p_1,\lambda_1) \to \gamma(k,\lambda_k) + \rho^0(p_\rho,\varepsilon_\rho) + N'(p_2,\lambda_2)\ ,$$

where λ_i represent the helicities of the particles.

QED/QCD invariance under parity implies that [Bourrely, Soffer, Leader]

$$\mathcal{A}_{\lambda_2\lambda_k\,;\,\lambda_1\lambda_q} = \eta\,(-1)^{\lambda_1-\lambda_q-(\lambda_2-\lambda_k)}\mathcal{A}_{-\lambda_2-\lambda_k\,;\,-\lambda_1-\lambda_q}\ ,$$

where η represents phase factors related to intrinsic spin.

Thus, at the cross-section level, it is clear that circular asymmetry will vanish, since

$$\sum_{\lambda_i,\,i\neq q}\left|\mathcal{A}_{\lambda_2\lambda_k\,;\,\lambda_1+}\right|^2 = \sum_{\lambda_i,\,i\neq q}\left|\mathcal{A}_{\lambda_2\lambda_k\,;\,\lambda_1-}\right|^2$$