Probing GPDs through the photoproduction of a rho meson and a photon

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Transversity of the nucleon using hard processes

<p align="center" style="color:red;">What is transversity?</p>

- Transverse spin content of the proton:

$$| \uparrow \rangle_{(x)} \quad \sim \quad | \to \rangle + | \leftarrow \rangle$$
$$| \downarrow \rangle_{(x)} \quad \sim \quad | \to \rangle - | \leftarrow \rangle$$
$$\text{spin along } x \qquad\qquad \text{helicity states}$$

- Observables which are sensitive to helicity flip thus give access to transversity $\Delta_T q(x)$. Poorly known.

- Transversity GPDs are completely unknown experimentally.
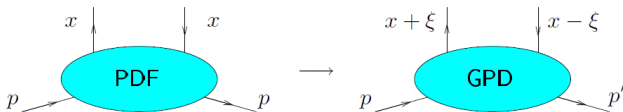
- For massless (anti)particles, chirality = (-)helicity

- Transversity is thus a chiral-odd quantity

- Since (in the massless limit) QCD and QED are chiral even $(\gamma^\mu, \gamma^\mu \gamma^5)$, the chiral odd quantities $(1, \gamma^5, [\gamma^\mu, \gamma^\nu])$ which one wants to measure should appear in pairs

Transversity of the nucleon using hard processes: using a two body final state process?

How to get access to transversity GPDs?

- the dominant DA of ρ_T is of twist 2 and chiral odd ($[\gamma^\mu, \gamma^\nu]$ coupling)
- unfortunately $\gamma^* N^\uparrow \to \rho_T N' = 0$
  - This cancellation is true at any order : such a process would require a helicity transfer of 2 from a photon.

  - lowest order diagrammatic argument:
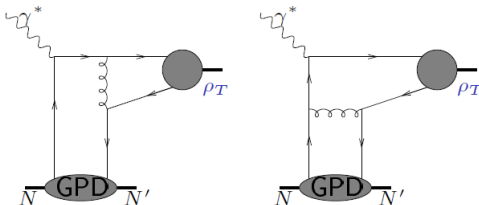
$$\gamma^\alpha [\gamma^\mu, \gamma^\nu] \gamma_\alpha \to 0$$

[Diehl, Gousset, Pire], [Collins, Diehl]

Transversity of the nucleon using hard processes: using a two body final state process?

Can one circumvent this vanishing?

- This vanishing only occurs at twist 2

- At twist 3 this process does not vanish [Ahmad, Goldstein, Liuti], [Goloskokov, Kroll]

- However processes involving twist 3 DAs may face problems with factorization (end-point singularities)

- One can also consider a 3-body final state process [Ivanov, Pire, Szymanowski, Teryaev], [Enberg, Pire, Szymanowski], [El Beiyad, Pire, Segond, Szymanowski, Wallon]

Introduction
○○○

Access to GPDs through a $2 \to 3$ process
●○○○○

Computation
○○○○

Results
○○○○

Conclusion

Probing transversity using ρ meson + photon production

- Processes with 3 body final states can give access to all GPDs
- We consider the process $\gamma\, N \to \gamma\, \rho\, N'$
- Collinear factorization of the amplitude for $\gamma + N \to \gamma + \rho + N'$ at large $M_{\gamma\rho}^2$
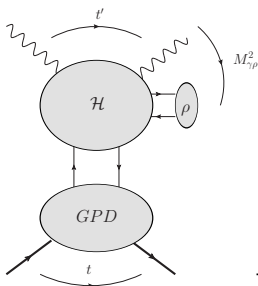

Factorized amplitude
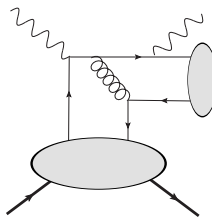
Typical non-zero diagram for a transverse ρ meson

Master formula based on leading twist 2 factorization

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

- Both the DA and the GPD can be either chiral even or chiral odd.
- At twist 2 the longitudinal ρ DA is chiral even and the transverse ρ DA is chiral odd.
- Hence we will need both chiral even and chiral odd non-perturbative building blocks and hard parts.
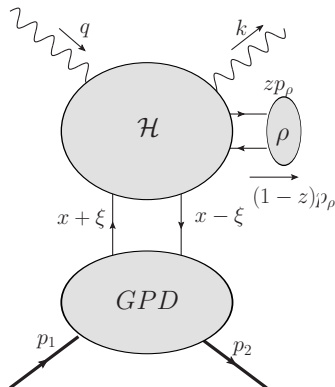
Non perturbative chiral odd building blocks

- Helicity flip GPD at twist 2 :

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

$$= \quad \frac{1}{2P^+} \bar{u}(p_2, \lambda_2) \left[H_T^q(x, \xi, t) i\sigma^{+i} + \tilde{H}_T^q(x, \xi, t) \frac{P^+ \Delta^i - \Delta^+ P^i}{M_N^2} \right.$$

$$+ \quad \left. E_T^q(x, \xi, t) \frac{\gamma^+ \Delta^i - \Delta^+ \gamma^i}{2M_N} + \tilde{E}_T^q(x, \xi, t) \frac{\gamma^+ P^i - P^+ \gamma^i}{M_N} \right] u(p_1, \lambda_1)$$

- We will consider the simplest case when $\Delta_\perp = 0$.
- In that case and in the forward limit $\xi \to 0$ only the H_T^q term survives.

- Transverse ρ DA at twist 2 :

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

Non perturbative chiral even building blocks

- Helicity conserving GPDs at twist 2 :

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

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

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

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

- Helicity conserving (vector) DA at twist 2 :

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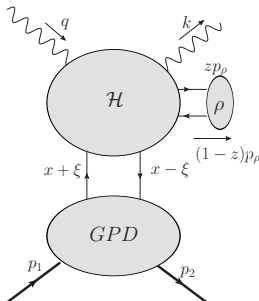
Kinematics

Kinematics to handle GPD in a 3-body final state process

- use a Sudakov basis :
  light-cone vectors p, n with $2p \cdot n = s$
- assume the following kinematics:
  - $\Delta_\perp \sim 0$
  - M^2, $m_\rho^2 \ll M_{\gamma\rho}^2$

- initial state particle momenta:

  $q^\mu = n^\mu$, $p_1^\mu = (1+\xi)\, p^\mu + \frac{M^2}{s(1+\xi)}\, n^\mu$
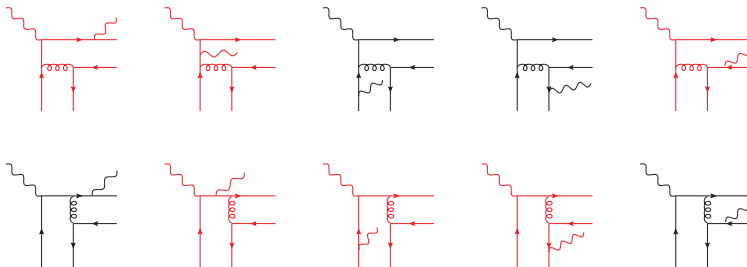
- final state particle momenta:

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

$$k^\mu = \alpha\, n^\mu + \frac{\vec{k}_t^2}{\alpha s}\, p^\mu + k_t^\mu$$

$$p_\rho^\mu = \alpha_\rho\, n^\mu + \frac{\vec{k}_t^2 + m_\rho^2}{\alpha_\rho s}\, p^\mu - k_t^\mu$$

Computation of the hard part

20 diagrams to compute

The other half can be deduced by $q \leftrightarrow \bar{q}$ (anti)symmetry
Red diagrams cancel in the chiral odd case

Chiral odd amplitude

The chiral odd case

The z and x dependence of the amplitude can be factorized

$$\mathcal{A} = \mathcal{N}(z,x)T^i$$

$$
\begin{aligned}
T^i &= (1-\alpha)\left[(\epsilon_{q\perp}.k_\perp)(\epsilon_{k\perp}.\epsilon_{\rho\perp}) - (\epsilon_{k\perp}.k_\perp)(\epsilon_{q\perp}.\epsilon_{\rho\perp})\right]k_\perp^i \\
&- (1+\alpha)(\epsilon_{\rho\perp}.k_\perp)(\epsilon_{k\perp}.\epsilon_{q\perp})k_\perp^i + \alpha\left(\alpha^2-1\right)\xi s\,(\epsilon_{q\perp}.\epsilon_{k\perp})\,\epsilon_\rho^i \\
&- \alpha\left(\alpha^2-1\right)\xi s\left[(\epsilon_{q\perp}.\epsilon_{\rho\perp})\,\epsilon_{k\perp}^i - (\epsilon_{k\perp}.\epsilon_{\rho\perp})\,\epsilon_{q\perp}^i\right]
\end{aligned}
$$

Hence calculating differential cross sections is simple :

$$d\sigma \propto \left|\int_0^1 dz \int_{-1}^1 dx \mathcal{N}(z,x)\phi_\rho(z)H_T^q(x)\right|^2 \sum_{helicities,(i,j)} T^i T^j$$

The chiral even case

The chiral even case
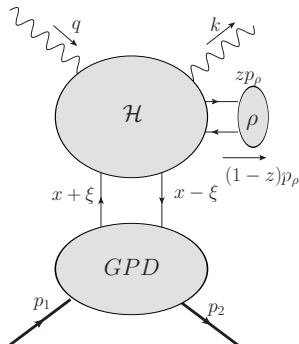
- All 20 (10) diagrams are computed, both with vector and axial coupling

- The z and x dependences do not factorize but they are known.

Final computation

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

- One performs the z integration analytically using an asymptotic DA $\propto z(1 - z)$

- One then plugs a GPD model into the formula and performs the integral wrt x numerically.

A model based on the Double Distribution ansatz

Realistic Parametrization of GPDs

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

  based on the Schwinger representation of a toy model for GPDs which has the structure of a triangle diagram in scalar ϕ^3 theory

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

- ansatz for these Double Distributions [Radyushkin]:

  - $f^q(\beta, \alpha) = \Pi(\beta, \alpha) \, q(\beta)$ in the chiral even case

  - $f_T^q(\beta, \alpha) = \Pi(\beta, \alpha) \, \Delta_T q(\beta)$ in the chiral odd case

  - $q(x)$: PDF (polarized or unpolarized) [MSTW, GRV...]

  - $\Delta_T q(x)$: Chiral odd PDF [Anselmino *et al.*]

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

Differential cross section : the chiral odd case

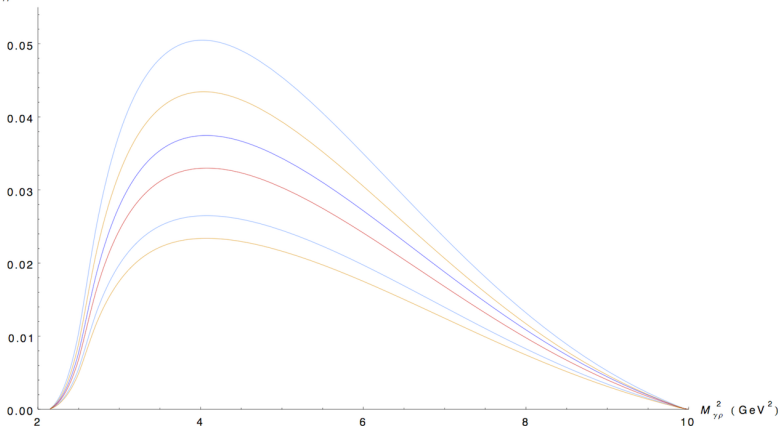
$S_{\gamma N} = 20 \text{ GeV}^2$

H_T^u and H_T^d modelled through double distributions :

based on transversity PDFs δq^u, δq^d which use polarized PDFs Δq^u, Δq^d either

"standard" at $+/-2\sigma$

or "valence" at $+/-2\sigma$

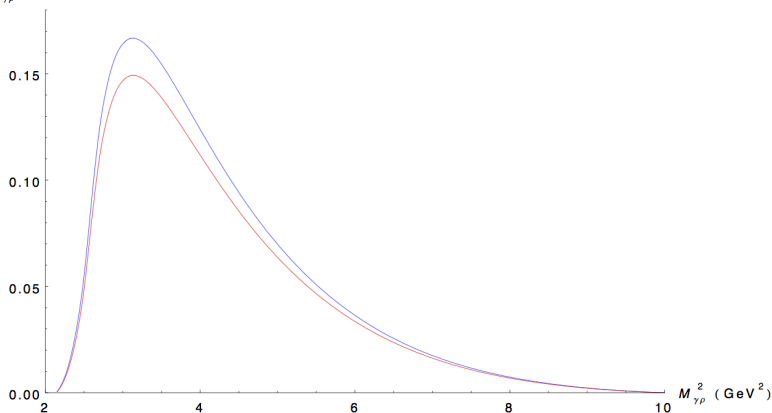## Differential cross section : the chiral even case

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

H^u, H^d, $\tilde{H}^u$, $\tilde{H}^d$ modelled through double distributions:
$\tilde{H}^u$, $\tilde{H}^d$ are based on polarized PDFs Δq^u, Δq^d either
"standard" or "valence"

Counting rates for 100 days

CLAS

Chiral even case : between $4.9 * 10^6$ and $5.4 * 10^6$ events

Chiral odd case : between $1.3 * 10^3$ and $2.7 * 10^3$ events

GLUEX

Chiral even case : between $1.6 * 10^5$ and $1.8 * 10^5$ events

Chiral odd case : between 45 and 90 events

CLAS FT

Chiral even case : between $1.6 * 10^5$ and $1.8 * 10^5$ events

Chiral odd case : between 45 and 90 events

Conclusion

- We gave counting rates for JLAB for our process and we got very promising statistics

- Our result will also be applied to electroproduction ($Q^2 \neq 0$) after adding Bethe-Heitler contributions and interferences.

- This mechanism will give us access to transversity GPDs but also to the usual GPDs by analogy with Timelike Compton Scattering, the $\gamma\rho$ pair playing the role of the γ^*.

- Possible measurement in JLAB and in COMPASS