

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

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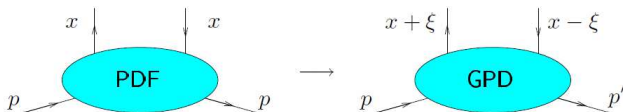
Transversity of the nucleon using hard processes

What is transversity?

- Transverse spin content of the proton:

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

- Observables which are sensitive to helicity flip thus give access to transversity $\Delta_{Tq}(x)$. Poorly known.
- Transversity GPDs are completely unknown experimentally.

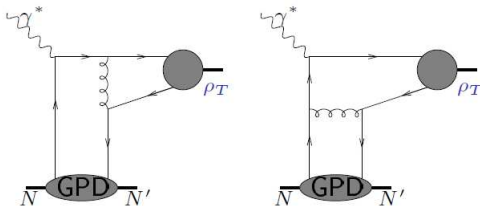


- For massless (anti)particles, chirality = (-)helicity
- Transversity is thus a chiral-odd quantity
- Since (in the massless limit) QCD and QED are chiral even ($\gamma^\mu, \gamma^\mu\gamma^5$), the chiral odd quantities ($1, \gamma^5, [\gamma^\mu, \gamma^\nu]$) which one wants to measure should appear 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 $\gamma^* N^\uparrow \rightarrow \rho_T N' = 0$
 - This cancellation is true at any order : such a process would require a helicity transfer of 2 from a photon.
 - lowest order diagrammatic argument:



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

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

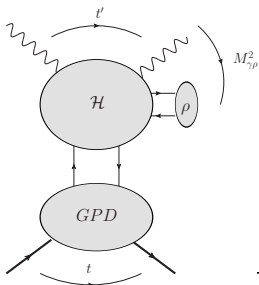
Transversity of the nucleon using hard processes: using a two body final state process?

Can one circumvent this vanishing?

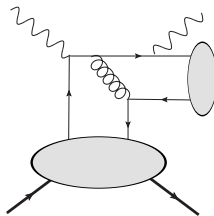
- This vanishing only occurs at **twist 2**
- At twist 3 this process does not vanish [Ahmad, Goldstein, Liuti], [Goloskokov, Kroll]
- However processes involving **twist 3 DAs** may face problems with factorization (end-point singularities)
- One can also consider a 3-body final state process [Ivanov, Pire, Szymanowski, Teryaev], [Enberg, Pire, Szymanowski], [El Beiyad, Pire, Segond, Szymanowski, Wallon]

Probing transversity using ρ meson + photon production

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



Factorized amplitude

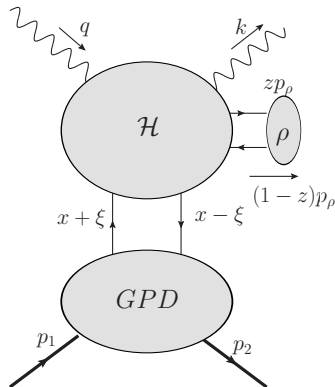


Typical non-zero diagram for a **transverse** ρ meson

Master formula based on leading twist 2 factorization

$$\mathcal{A} \propto \int_{-1}^1 dx \int_0^1 dz T(x, \xi, z) \times H(x, \xi, t) \Phi_\rho(z) + \dots$$

- 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 :

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

- We will consider the simplest case when $\Delta_\perp = 0$.
- In that case and in the forward limit $\xi \rightarrow 0$ 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 :

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

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:

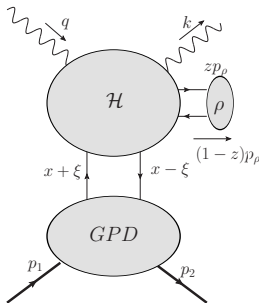
$$q^{\mu} = n^{\mu}, \quad p_1^{\mu} = (1 + \xi) p^{\mu} + \frac{M^2}{s(1 + \xi)} n^{\mu}$$

- final state particle momenta:

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

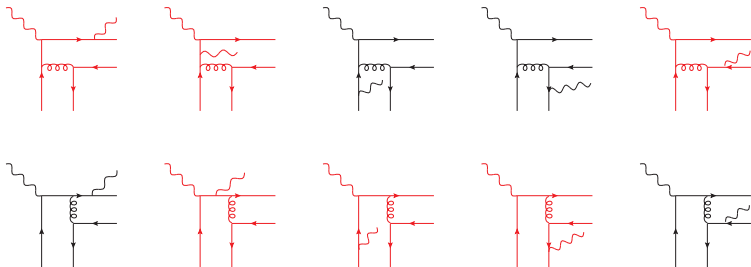
$$k^{\mu} = \alpha n^{\mu} + \frac{\vec{k}_t^2}{\alpha s} p^{\mu} + k_{\perp}^{\mu}$$

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



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

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

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

Hence calculating differential cross sections is simple :

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

The chiral even case

The chiral even case

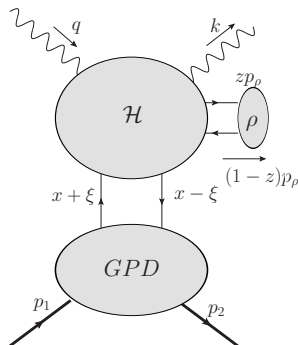
- All 20 (10) diagrams are computed, both with **vector** and **axial** coupling
- The z and x dependences do not factorize but they are known.

Final computation

Final computation

$$\mathcal{A} \propto \int_{-1}^1 dx \int_0^1 dz T(x, \xi, z) \times H(x, \xi, t) \Phi_\rho(z) + \dots$$

- 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

Chiral odd cross section

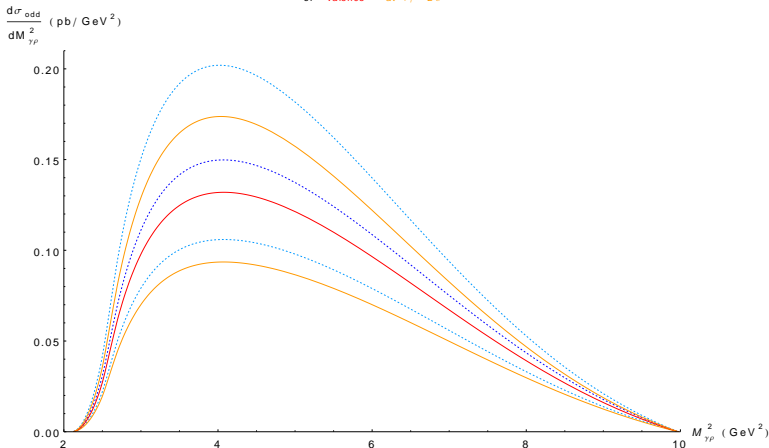
Proton $S_{yN} = 20 \text{ GeV}^2$

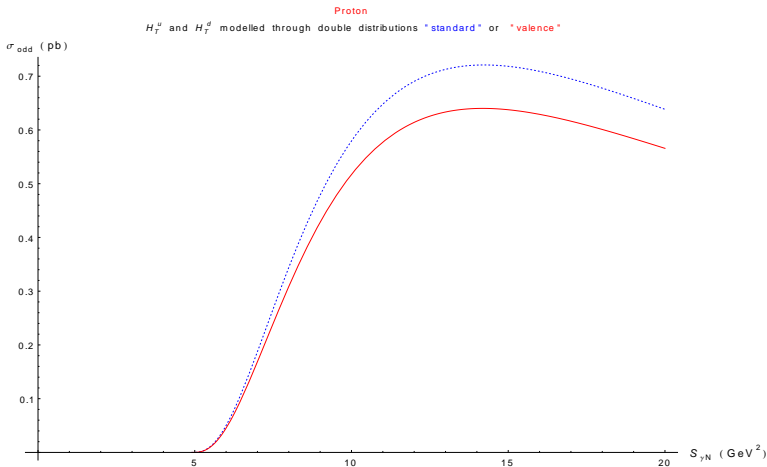
H_T^u and H_T^d modelled through double distributions:

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

standard at $+/- 2\sigma$

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

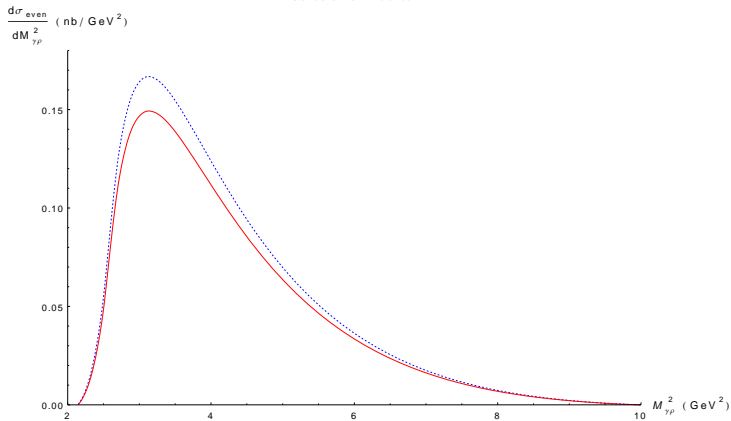


Chiral odd cross section for γp 

Chiral even cross section

Proton $S_{\gamma N} = 20 \text{ GeV}^2$ $H^u, H^d, \tilde{H}^u, \tilde{H}^d$ modelled through double distributions: \tilde{H}^u, \tilde{H}^d are based on polarized PDFs $\Delta q^u, \Delta q^d$ either

standard or *valence*

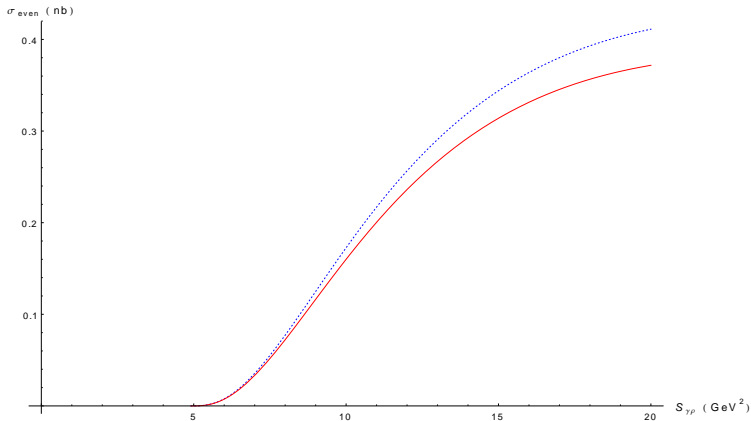


Chiral even cross section

Proton

 $H^u, H^d, \tilde{H}^u, \tilde{H}^d$ modelled through double distributions: \tilde{H}^u, \tilde{H}^d are based on polarized PDFs $\Delta q^u, \Delta q^d$ either

"standard" or "valence"

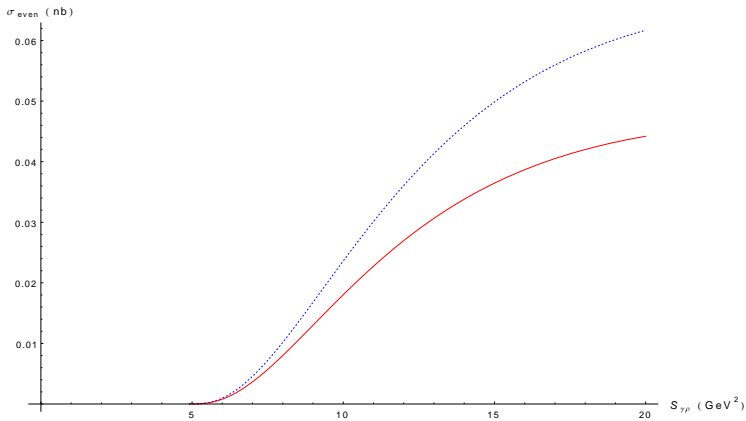


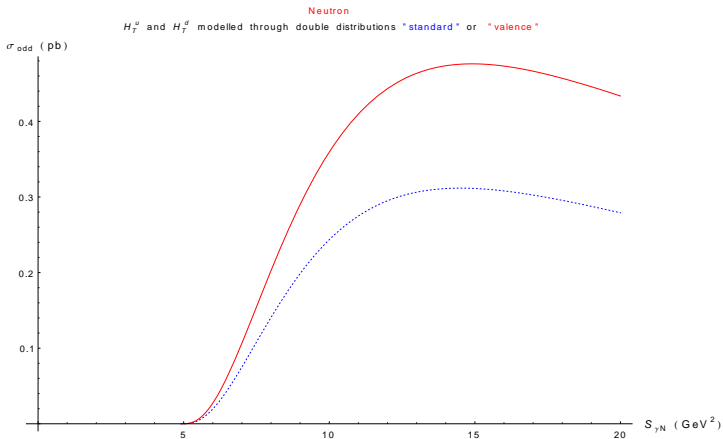
Chiral even cross section for γn

Neutron

 $H^u, H^d, \tilde{H}^u, \tilde{H}^d$ modelled through double distributions: \tilde{H}^u, \tilde{H}^d are based on polarized PDFs $\Delta q^u, \Delta q^d$ either

"standard" or "valence"



Chiral odd cross section for γn 

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

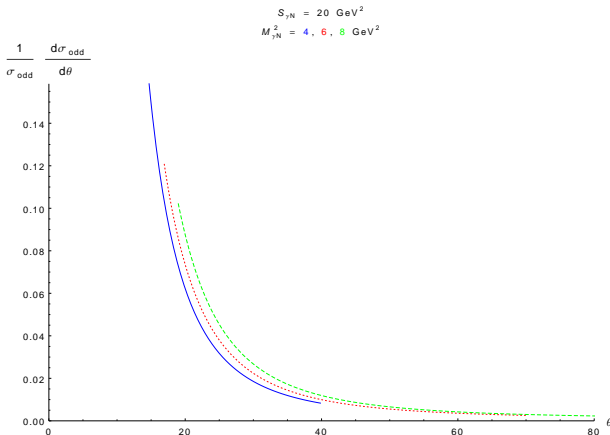
Chiral odd case : between 45 and 90 events

CLAS FT

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

Chiral odd case : between 45 and 90 events

Effects of an experimental angular restriction



A $\theta_{\gamma/\text{beam}} < 35^\circ$ restriction implies a **33% loss** in the **chiral even** cross section and a **18% loss** in the **chiral odd** cross section

Conclusion

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