Revealing transversity GPDs through the production of a rho meson and a photon

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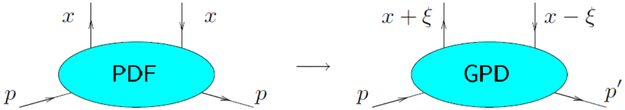
Transversity of the nucleon using hard processes

What is transversity?

- Transverse spin content of the proton:

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

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

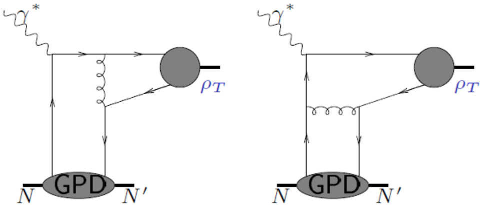


- For massless (anti)particles, chirality = (-)helicity
- Transversity is thus a chiral-odd quantity
- Since (in the massless limit) QCD and QED are chiral even (γ^μ, $\gamma^\mu\gamma^5$), the chiral odd quantities (1, γ^5, $[\gamma^\mu, \gamma^\nu]$) which one wants to measure should appear in pairs

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]

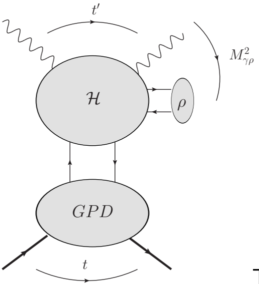
Transversity of the nucleon using hard processes: using a two body final state process?

Can one circumvent this vanishing?

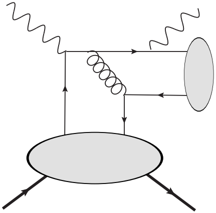
- This vanishing only occurs at twist 2
- At twist 3 this process does not vanish [Ahmad, Goldstein, Liuti], [Goloskokov, Kroll]
- However processes involving twist 3 DAs may face problems with factorization (end-point singularities)
- One can also consider a 3-body final state process [Ivanov, Pire,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

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 $M^2_{\gamma\rho}$



Factorized amplitude

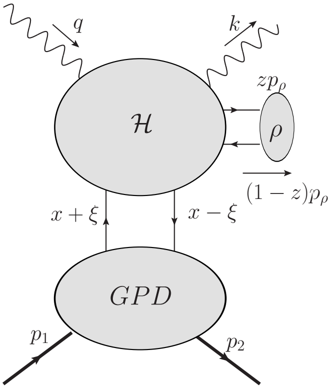


Typical non-zero diagram for a transverse ρ meson

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 :

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

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

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

  - 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 :

$$\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \langle p_2, \lambda_2 | \bar{\psi}_q \left(-\frac{1}{2}z^-\right) \gamma^+ \psi \left(\frac{1}{2}z^-\right) |p_1, \lambda_1\rangle$$
$$= \frac{1}{2P^+} \bar{u}(p_2, \lambda_2) \left[H^q(x,\xi,t)\gamma^+ + E^q(x,\xi,t)\frac{i\sigma^{\alpha+}\Delta_\alpha}{2m} \right]$$

$$\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \langle p_2, \lambda_2 | \bar{\psi}_q \left(-\frac{1}{2}z^-\right) \gamma^+\gamma^5 \psi \left(\frac{1}{2}z^-\right) |p_1, \lambda_1\rangle$$
$$= \frac{1}{2P^+} \bar{u}(p_2, \lambda_2) \left[\tilde{H}^q(x,\xi,t)\gamma^+\gamma^5 + \tilde{E}^q(x,\xi,t)\frac{\gamma^5\Delta^+}{2m} \right]$$

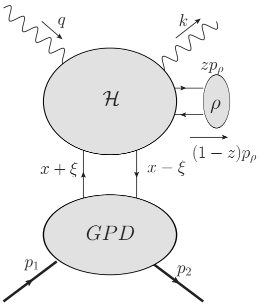
- Helicity conserving (vector) DA at twist 2 :

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

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:
  - $\Delta_\perp \sim 0$
  - $M^2,\ m_\pi^2,\ m_\rho^2 \ll M_{\pi\rho}^2$



- initial state particle momenta:

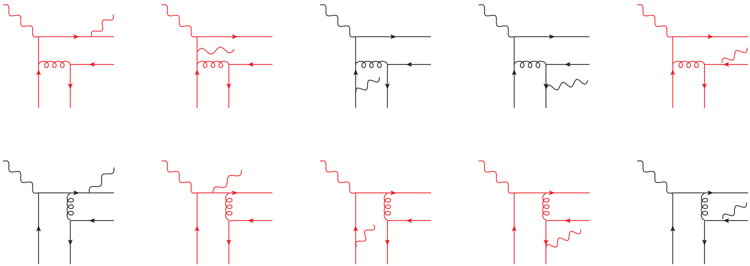
$$q^\mu = n^\mu,\ p_1^\mu = (1+\xi)\, p^\mu + \frac{M^2}{s(1+\xi)} n^\mu$$

- final state particle momenta:

$$
\begin{aligned}
p_2^\mu &= (1-\xi)\, p^\mu + \frac{M^2}{s(1-\xi)} n^\mu \\
k^\mu &= \alpha\, n^\mu + \frac{\vec{k}_t^{\,2}}{\alpha s} p^\mu + k_\perp^\mu \\
p_\rho^\mu &= \alpha_\rho\, n^\mu + \frac{\vec{p}_t^{\,2} + m_\rho^2}{\alpha_\rho s} p^\mu - k_\perp^\mu
\end{aligned}
$$

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

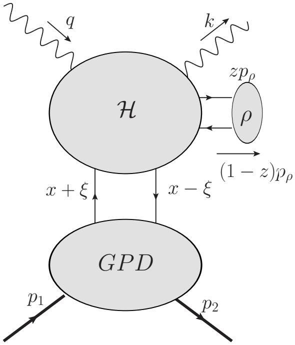
- All 20 (10) diagrams are computed, both with vector and axial coupling
- The z and x dependences do not factorize but they are known.

Final computation

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 Double Distribution

Realistic Parametrization of GPDs

- GPDs can be represented in terms of Double Distribution [Radyushkin]
  based on 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 Distribution [Radyushkin]:
  - $f^q(\beta,\alpha) = \Pi(\beta,\alpha)\, q(\beta)$ in the chiral even case
  - $f^q_T(\beta,\alpha) = \Pi(\beta,\alpha)\, \Delta_T q(\beta)$ in the chiral odd case
  - $q(x)$: PDF [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

Conclusion

- This calculation is still being done but predictions for cross sections and counting rates will be ready very soon.
- 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