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

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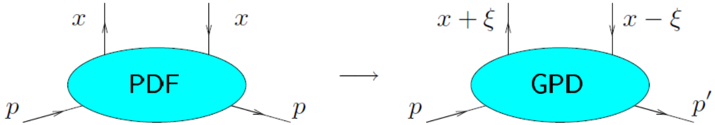
Transversity of the nucleon using hard processes

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

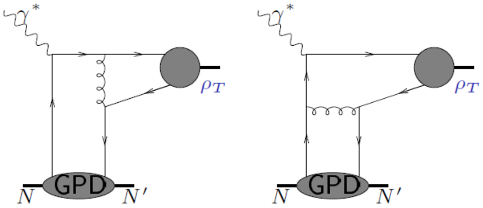


- For massless (anti)particles, chirality = (-)helicity
- Transversity is thus a chiral-odd quantity
- Since QCD and QED are chiral even, the chiral odd quantities which one want to measure should appear in pairs

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:



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

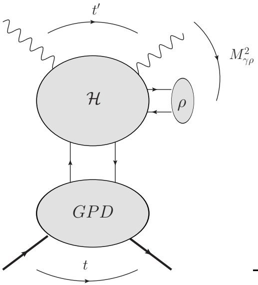
Transversity of the nucleon using hard processes: using a two body final state process?

Can one circumvent this vanishing?

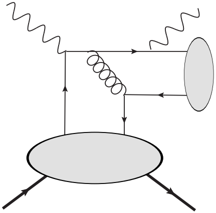
- This vanishing is only occurs at twist 2
- At twist 3 this process does not vanish [Goloskokov, Kroll], [Ahmad, Goldstein, Liuti]
- However processes involving twist 3 DAs may face problems with factorization (end-point singularities)
- One can also consider a 3-body final state process [Ivanov, Pire,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

Probing thansversity using rho meson 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 $M^2_{\gamma\rho}$



Factorized amplitude



Typical non-zero diagram for a transverse ρ meson

Master formula based on leading twist 2 factorization

$$\mathcal{A} = \frac{1}{\sqrt{2}} \int_{-1}^{1} dx \int_{0}^{1} dz \, (T^u(x,z) - T^d(x,z)) \times (H_T^u(x,\xi,t) - H_T^d(x,\xi,t)) \Phi_\rho(z) + \cdots$$

- Both the DA and the GPD can be either chiral even or chiral odd.
- At twist 2 the longitudinal rho DA is chiral even and the transverse rho 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.

- transversity DA at twist 2 :

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

Non perturbative chiral even building blocks

Helicity conserving GPDs at twist 2 :

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

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

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

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

Non perturbative chiral even building blocks

Helicity conserving DAs at twist 2 :

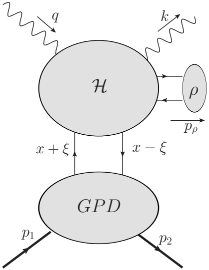
$$\langle 0|\bar{u}(0)\gamma^\mu u(x)|\rho^0(p,s)\rangle = \frac{p^\mu}{\sqrt{2}}\frac{\epsilon.x}{p.x} f_\rho m_\rho \int_0^1 du\ e^{-iup\cdot x}\phi_\parallel(u)$$

$$\langle 0|\bar{u}(0)\gamma^\mu \gamma^5 u(x)|\rho^0(p,s)\rangle = -\frac{1}{4\sqrt{2}}\epsilon^{\mu\nu\sigma\delta}\epsilon_\nu p_\sigma x_\delta f_\rho m_\rho \int_0^1 du e^{-iup\cdot x}\ g_\perp^{(a)}(u)$$

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:

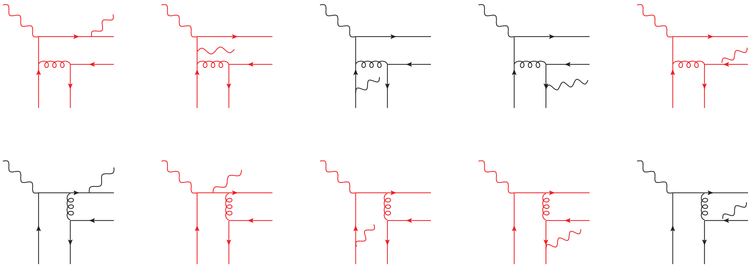
$$p_2^\mu = (1-\xi)\, p^\mu + \frac{M^2}{s(1-\xi)} n^\mu$$

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

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

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 z and x dependence of the amplitude can be factorized

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

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

Hence calculating differential cross sections is simple :

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

A model based on Double Distribution

Realistic Parametrization of H_T^q

- 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

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

- ansatz for these Double Distribution (Radyushkin):
  - $f_T^q(\beta, \alpha) = \Pi(\beta, \alpha) \, \Delta_T q(\beta)$
  - $\Delta_T q(x)$: chiral-odd PDF (Anselmino *et al.*)
  - $\Pi(\beta, \alpha) = \frac{3}{4} \frac{(1-\beta)^2 - \alpha^2}{(1-\beta)^3}$: profile function ($f_T^q(\beta, 0) = \Delta_T q(\beta)$)

- ansatz for the t-dependence:

$$H_T^q(x, \xi, t) = H_T^q(x, \xi, t=0) \times F_H(t)$$

with $F_H(t) = \frac{C^2}{(t-C)^2}$ a standard dipole form factor ($C = .71$ GeV)

The chiral even case

- All 20 (10) diagrams must be computed, both with vector and axial coupling
- The z and x dependence does not factorize
- No problem with integration over GPDs. Results will be available very soon.

Conclusion

- This is still work in progress 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 inteferences.
- 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