Getting access to generalized parton distributions in exclusive photoproduction of a large invariant mass γ-meson pair

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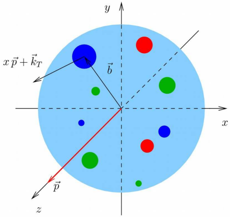
The ultimate picture

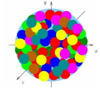
6D/5D

Wigner distributions for hadrons



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

Experimentally inaccessible directly



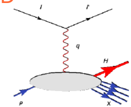
perturbative Regge limit

uPDFs (gluons)

Unintegrated parton distributions

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

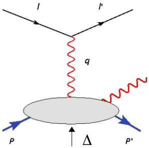
3D



=

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

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



TMDs

$f(x, k_T)$

$b_T \Leftrightarrow \Delta$

$\xi=0$

GPDs

$f(x, b_T) \longleftrightarrow H(x, 0, t) \longleftarrow H(x, \xi, t)$

$t=-\Delta^2$

Semi-inclusive processes

Transverse momentum dependent distributions

Impact parameter distributions

generalised parton distributions

exclusive processes

$\int d^2k_T$

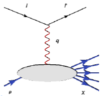
$\int d^2b_T$

$t=0$

$\int dx$

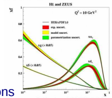
$\int dx\, x^{n-1}$

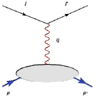
1D



PDFs

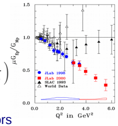
$f(x)$





FFs

$G_{E,M}(t)$



GFFs

generalized form factors

inclusive and semi-inclusive processes

parton distributions

elastic processes

form factors

lattices

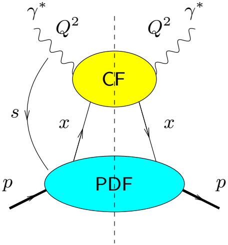
Extensions from DIS

- DIS: inclusive process $\rightarrow$ forward amplitude ($t = 0$) *(optical theorem)*

  (DIS: Deep Inelastic Scattering)

  ex: $e^{\pm}p \rightarrow e^{\pm}X$ at HERA

  $x \Rightarrow$ 1-dimensional structure



Structure Function

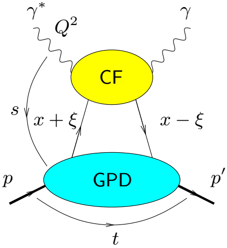
= Coefficient Function (hard) $\otimes$ Parton Distribution Function (soft)

- DVCS: exclusive process $\rightarrow$ non forward amplitude ($-t \ll s = W^2$)

  (DVCS: Deep Vitual Compton Scattering)

  Fourier transf.: $t \leftrightarrow$ impact parameter

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



Amplitude

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

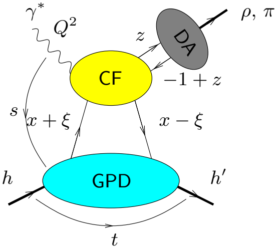
Müller et al. '91 - '94; Radyushkin '96; Ji '97

Extensions from DVCS

- Meson production: γ replaced by $\rho, \ \pi, \cdots$

Amplitude

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



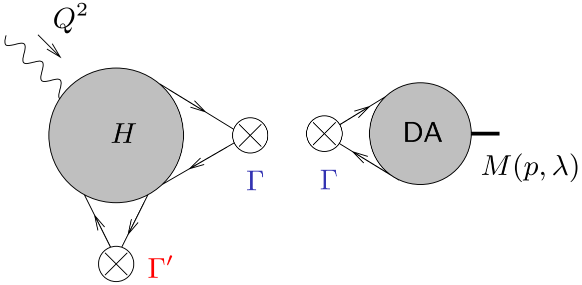
Collins, Frankfurt, Strikman '97; Radyushkin '97

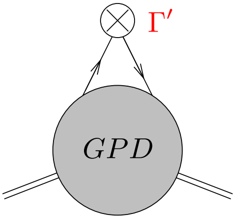
proofs valid only for some restricted cases

Collinear factorization

Meson electroproduction: factorization with a GPD and a DA

The building blocks





Γ, Γ' : Dirac matrices compatible with quantum numbers: C, P, T, chirality

Similar structure for gluon exchange

Collinear factorization

Twist 2 GPDs

Classification of twist 2 GPDs

- For quarks, one should distinguish the exchanges
  - without helicity flip (chiral-even Γ' matrices): 4 chiral-even GPDs:

$H^q \xrightarrow{\xi=0,t=0}$ PDF q, E^q, $\tilde{H}^q \xrightarrow{\xi=0,t=0}$ polarized PDFs Δq, $\tilde{E}^q$

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

$$\tilde{F}^q = \frac{1}{2}\int \frac{dz^-}{2\pi}\, e^{ixP^+z^-} \langle p'|\, \bar{q}(-\tfrac{1}{2}z)\, \gamma^+\gamma_5\, q(\tfrac{1}{2}z)\,|p\rangle\Big|_{z^+=0,\, z_\perp=0}$$
$$= \frac{1}{2P^+}\left[\tilde{H}^q(x,\xi,t)\,\bar{u}(p')\gamma^+\gamma_5 u(p) + \tilde{E}^q(x,\xi,t)\,\bar{u}(p')\frac{\gamma_5\,\Delta^+}{2m}u(p)\right].$$

  - with helicity flip (chiral-odd Γ' mat.): 4 chiral-odd GPDs:

$H_T^q \xrightarrow{\xi=0,t=0}$ quark transversity PDFs δq, E_T^q, $\tilde{H}_T^q$, $\tilde{E}_T^q$

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

Collinear factorization
Twist 2 GPDs

Classification of twist 2 GPDs

- analogously, for gluons:
  - 4 gluonic GPDs without helicity flip:
    $H^g \xrightarrow{\xi=0,t=0}$ PDF $x\,g$
    E^g
    $\tilde{H}^g \xrightarrow{\xi=0,t=0}$ polarized PDF $x\,\Delta g$
    $\tilde{E}^g$
  - 4 gluonic GPDs with helicity flip:
    H_T^g
    E_T^g
    $\tilde{H}_T^g$
    $\tilde{E}_T^g$
    (no forward limit reducing to gluons PDFs here: a change of 2 units of helicity cannot be compensated by a spin 1/2 target)

Chiral-odd sector: Transversity of the nucleon using hard processes

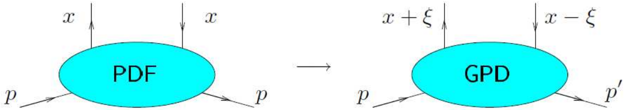
What is transversity?

- 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

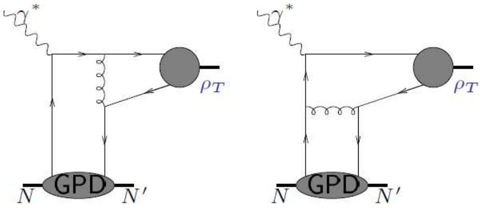
- Transversity is thus a chiral-odd quantity

- 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]

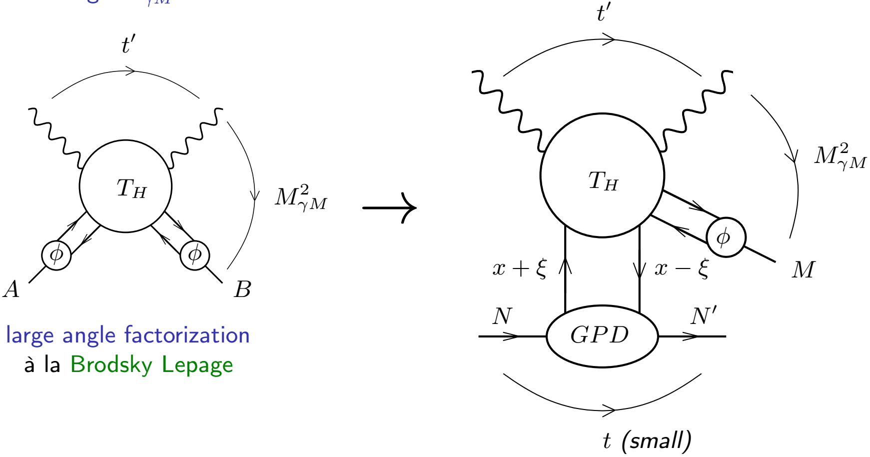
Transversity of the nucleon using hard processes: using a two body final state process?

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)
  can be made safe in the high-energy k_T-factorization approach
  [Anikin, Ivanov, Pire, Szymanowski, S.W.]
- One can also consider a 3-body final state process [Ivanov, Pire, Szymanowski, Teryaev], [Enberg, Pire, Szymanowski], [El Beiyad, Pire, Segond, Szymanowski, S. W.]

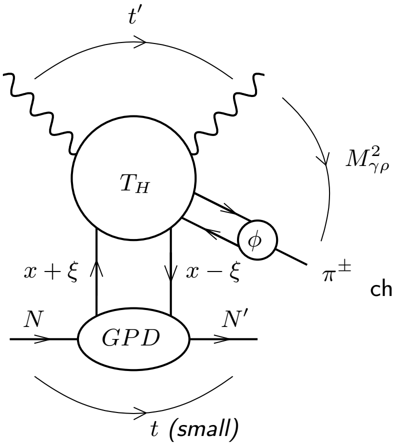
Probing GPDs using ρ or π meson + photon production

- We consider the process $\gamma\, N \to \gamma\, M\, N'$ $\qquad M =$ meson
- Collinear factorization of the amplitude for $\gamma + N \to \gamma + M + N'$ at large $M^2_{\gamma M}$



Probing chiral-even GPDs using π meson + photon production

Processes with 3 body final states can give access to chiral-even GPDs

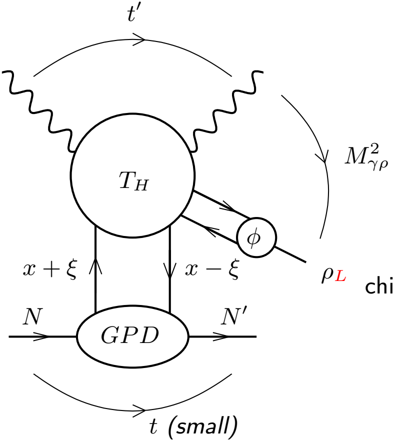


chiral-even twist 2 DA

chiral-even twist 2 GPD

Probing chiral-even GPDs using ρ meson + photon production

Processes with 3 body final states can give access to chiral-even GPDs

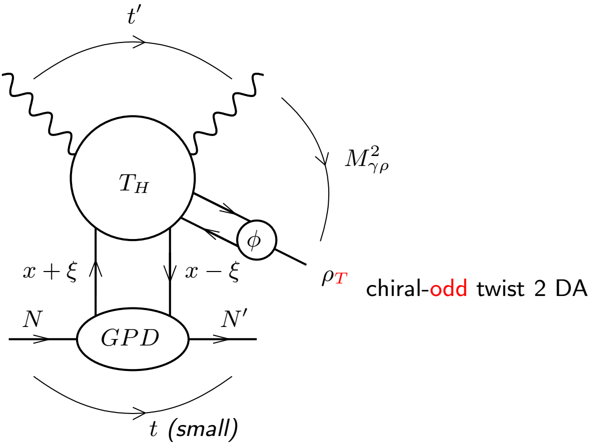


chiral-even twist 2 DA

chiral-even twist 2 GPD

Probing chiral-odd GPDs using ρ meson + photon production

Processes with 3 body final states can give access to chiral-odd GPDs

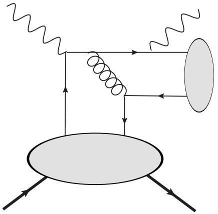


chiral-odd twist 2 GPD

Probing chiral-odd GPDs using ρ meson + photon production

Processes with 3 body final states can give access to chiral-odd GPDs

How did we manage to circumvent the no-go theorem for $2 \to 2$ processes?



Typical non-zero diagram for a transverse ρ meson

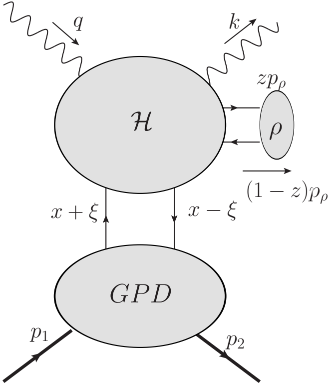
the σ matrices (from DA and GPD sides) do not kill it anymore!

Master formula based on leading twist 2 factorization

The ρ example

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

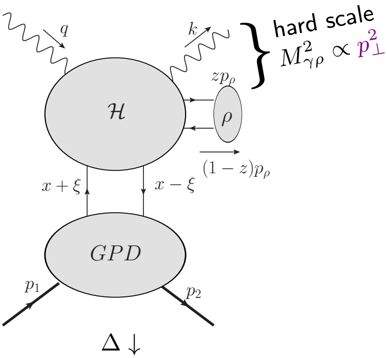
- Both the DA and the GPD can be either chiral-even or chiral-odd.
- At twist 2 the longitudinal ρ DA is chiral-even and the transverse ρ DA is chiral-odd.
- Hence we will need both chiral-even and chiral-odd non-perturbative building blocks and hard parts.



Kinematics

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

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



- 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:

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

Non perturbative chiral-even building blocks

- Helicity conserving GPDs at twist 2 :

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

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

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

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

  - We will consider the simplest case when $\Delta_\perp = 0$.
  - In that case and in the forward limit $\xi \to 0$ only the H^q and $\tilde{H}^q$ terms survive.

- Helicity conserving (vector) DA at twist 2 :

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

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 :

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

Models for DAs

Asymptotical DAs

- We take the simplistic asymptotic form of the (normalized) DAs (i.e. no evolution):

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

- A non asymptotical wave function can be also investigated:

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

(under investigation, see a the end of this talk)

Model for GPDs: 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]:
  - chiral-even sector:

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

  - 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 factorized ansatz for the t-dependence:

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

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

Model for GPDs: based on the Double Distribution ansatz

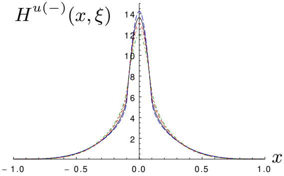
Sets of used PDFs

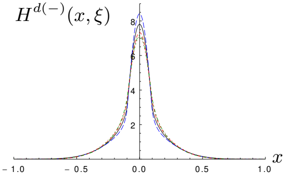
- $q(x)$: unpolarized PDF [GRV-98]
  and [MSTW2008lo, MSTW2008nnlo, ABM11nnlo, CT10nnlo]
- $\Delta q(x)$ polarized PDF [GRSV-2000]
- $\delta q(x)$: transversity PDF [Anselmino *et al.*]

Model for GPDs: based on the Double Distribution ansatz

Typical sets of chiral-even GPDs ($C = -1$ sector)

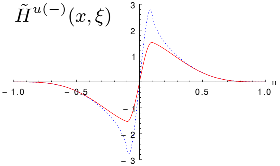
$\xi = .1 \leftrightarrow S_{\gamma N} = 20 \text{ GeV}^2$ and $M^2_{\gamma\rho} = 3.5 \text{ GeV}^2$

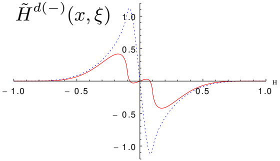




$$H^{q(-)}(x,\xi,t) = H^q(x,\xi,t) + H^q(-x,\xi,t)$$

five Ansätze for $q(x)$: GRV-98, MSTW2008lo, MSTW2008nnlo, ABM11nnlo, CT10nnlo





$$\tilde{H}^{q(-)}(x,\xi,t) = \tilde{H}^q(x,\xi,t) - \tilde{H}^q(-x,\xi,t)$$

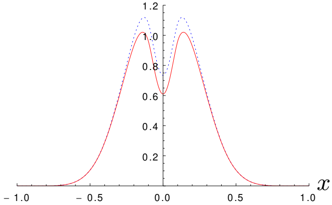
"valence" and "standard" **(flavor-asymmetries in the polarized antiquark sector are neglected)**:
two GRSV Ansätze for $\Delta q(x)$

Model for GPDs: based on the Double Distribution ansatz

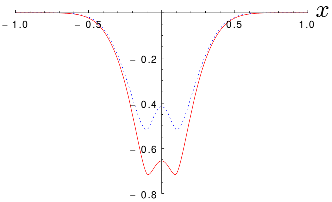
Typical sets of chiral-odd GPDs ($C = -1$ sector)

$$\xi = .1 \leftrightarrow S_{\gamma N} = 20 \text{ GeV}^2 \text{ and } M^2_{\gamma\rho} = 3.5 \text{ GeV}^2$$

$H_T^{u(-)}(x,\xi)$



$H_T^{d(-)}(x,\xi)$

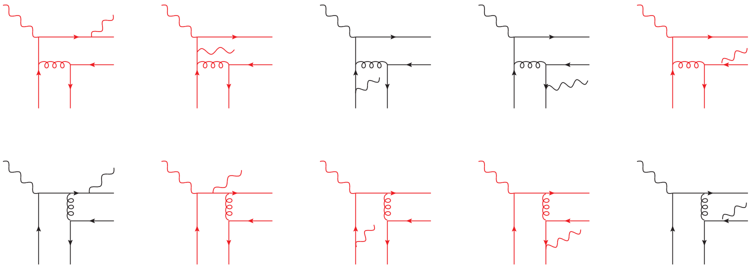


$$H_T^{q(-)}(x,\xi,t) = H_T^q(x,\xi,t) + H_T^q(-x,\xi,t)$$

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

Computation of the hard part

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

Final computation

Final computation

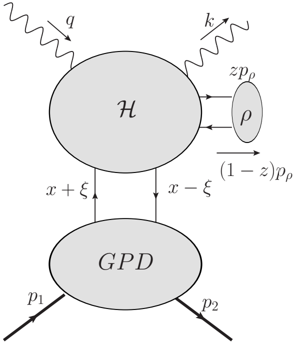
$$\mathcal{A} \propto \int_{-1}^{1} dx \int_{0}^{1} dz \; T(x,\xi,z) \; H(x,\xi,t) \; \Phi_\rho(z)$$

- One performs the z integration analytically using an asymptotic DA $\propto z(1-z)$
- One then plugs our GPD models into the formula and performs the integral w.r.t. x numerically.
- Differential cross section:

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

$|\overline{\mathcal{M}}|^2$ = averaged amplitude squared

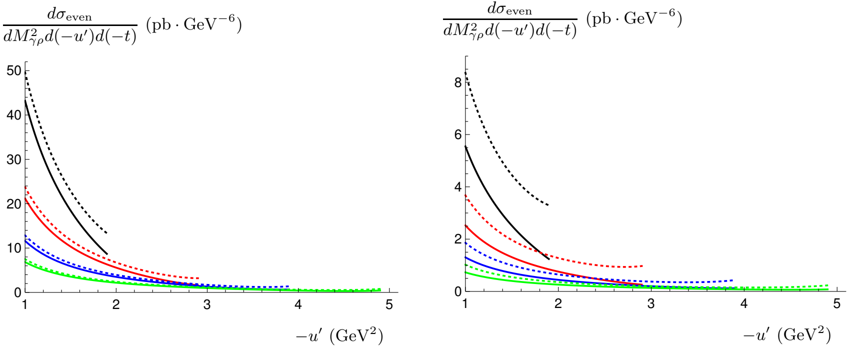
- Kinematical parameters: $S^2_{\gamma N}$, $M^2_{\gamma\rho}$ and $-u'$



Fully differential cross section: ρ_L

Chiral even cross section

at $-t = (-t)_{\min}$



proton target

neutron target

$$S_{\gamma N} = 20 \text{ GeV}^2$$
$$M^2_{\gamma\rho} = 3, 4, 5, 6 \text{ GeV}^2$$

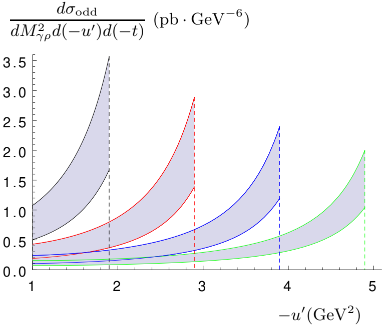
solid: "valence" model

dotted: "standard" model

Fully differential cross section: ρ_T

Chiral odd cross section

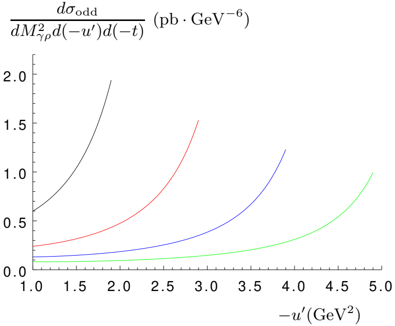
at $-t = (-t)_{\min}$



proton target

"valence" and "standard" models,

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



neutron target

"valence" model only

$$S_{\gamma N} = 20 \text{ GeV}^2$$
$$M^2_{\gamma\rho} = 3, 4, 5, 6 \text{ GeV}^2$$

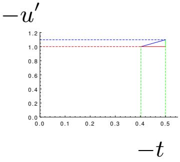
Phase space integration

Evolution of the phase space in $(-t, -u')$ plane

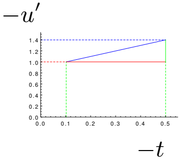
large angle scattering: $M^2_{\gamma\rho} \sim -u' \sim -t'$

in practice: $-u' > 1\ \mathrm{GeV}^2$ and $-t' > 1\ \mathrm{GeV}^2$ and $(-t)_{\min} \leqslant -t \leqslant .5\ \mathrm{GeV}^2$
this ensures large $M^2_{\gamma\rho}$

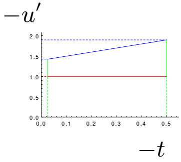
example: $S_{\gamma N} = 20\ \mathrm{GeV}^2$



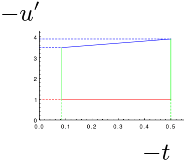
$M_{\gamma\rho} = 2.2\ \mathrm{GeV}^2$



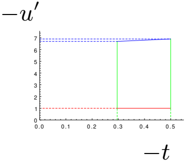
$M^2_{\gamma\rho} = 2.5\ \mathrm{GeV}^2$



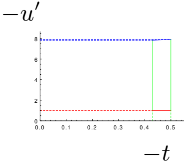
$M_{\gamma\rho} = 3\ \mathrm{GeV}^2$



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



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



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

Variation with respect to $S_{\gamma N}$

Mapping $(S_{\gamma N}, M_{\gamma\rho}) \mapsto (\tilde{S}_{\gamma N}, \tilde{M}_{\gamma\rho})$

One can save a lot of CPU time:

- $\mathcal{M}(\alpha, \xi)$ and $GPDs(\xi, x)$
- In the generalized Bjorken limit:
  - $\alpha = \frac{-u'}{M^2_{\gamma\rho}}$
  - $\xi = \frac{M^2_{\gamma\rho}}{2(S_{\gamma N} - M^2) - M^2_{\gamma\rho}}$

Given $S_{\gamma N}$ $(= 20 \text{ GeV}^2)$, with its grid in $M^2_{\gamma\rho}$, choose another $\tilde{S}_{\gamma N}$.
One can get the corresponding grid in $\tilde{M}_{\gamma\rho}$ by just keeping the same ξ's:

$$\tilde{M}^2_{\gamma\rho} = M^2_{\gamma\rho} \frac{\tilde{S}_{\gamma N} - M^2}{S_{\gamma N} - M^2},$$

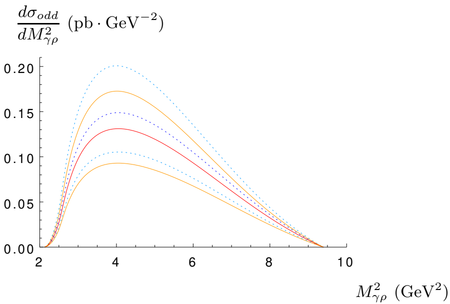
From the grid in $-u'$, the new grid in $-\tilde{u}'$ is given by just keeping the same α's:

$$-\tilde{u}' = \frac{\tilde{M}^2_{\gamma\rho}}{M^2_{\gamma\rho}} (-u').$$

$\Rightarrow$ a single set of numerical computations is required (we take $S_{\gamma N} = 20 \text{ GeV}^2$)

Single differential cross section: ρ_T

Chiral odd cross section



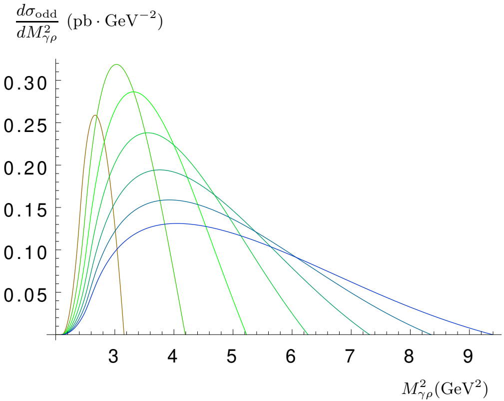
$$S_{\gamma N} = 20 \text{ GeV}^2$$

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 $\pm 2\sigma$.

Single differential cross section: ρ_T

Chiral odd cross section



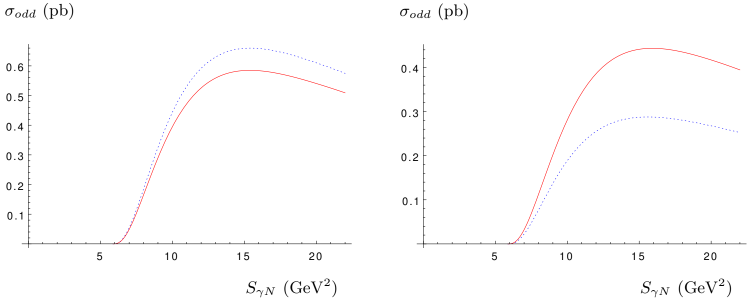
proton target, "valence" scenario

$S_{\gamma N}$ vary in the set 8, 10, 12, 14, 16, 18, 20 GeV^2 (from left to right)

typical JLab kinematics

Integrated cross-section: ρ_T

Chiral odd cross section



proton target　　　　neutron target

solid red: "valence" scenario

dashed blue: "standard" one

Counting rates for 100 days: ρ

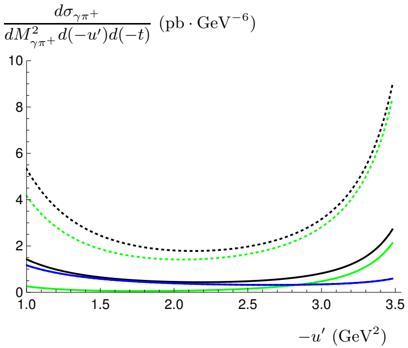
example: JLab Hall B

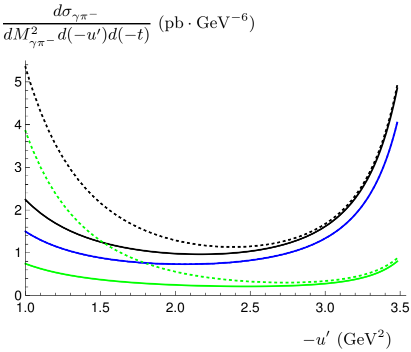
- untagged incoming $\gamma \Rightarrow$ Weizsäcker-Williams distribution
- With an expected luminosity of $\mathcal{L} = 100 \text{ nb}^{-1} s^{-1}$, for 100 days of run:
  - Chiral even case : $\simeq 5.7 \; 10^4 \; \rho_L$.
  - Chiral odd case : $\simeq 7.5 \; 10^3 \; \rho_T$

Fully differential cross section: $\pi^{\pm}$

Chiral even sector: $\pi^{\pm}$

at $-t = (-t)_{\min}$





π^+ photoproduction (proton target) π^- photoproduction (neutron target)

$S_{\gamma N} = 20\ \mathrm{GeV}^2 \qquad M^2_{\gamma\rho} = 4\ \mathrm{GeV}^2$

vector GPD / axial GPD / total result

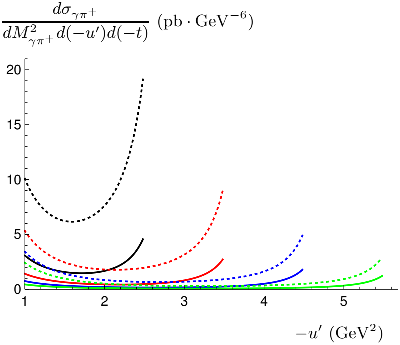
solid: "valence" model

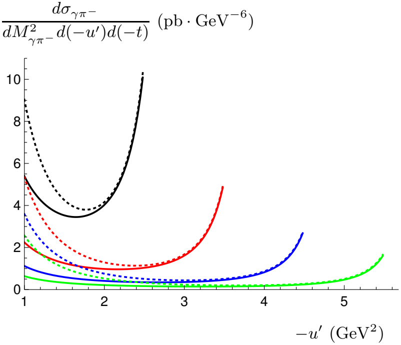
dotted: "standard" model

Fully differential cross section: $\pi^\pm$

Chiral even sector: $\pi^\pm$

at $-t = (-t)_{\min}$





π^+ photoproduction (proton target) π^- photoproduction (neutron target)

$$S_{\gamma N} = 20 \text{ GeV}^2$$
$$M^2_{\gamma\rho} = 3, 4, 5, 6 \text{ GeV}^2$$

solid: "valence" model

dotted: "standard" model

Counting rates for 100 days: $\pi^\pm$

example: JLab Hall B

- untagged incoming $\gamma \Rightarrow$ Weizsäcker-Williams distribution
- With an expected luminosity of $\mathcal{L} = 100\ \mathrm{nb}^{-1} s^{-1}$, for 100 days of run:
  - π^+ : $\simeq 4.5 \times 10^3$
  - π^- : $\simeq 1.8 \times 10^4$

Non asymptotical DA?

Beyond the asymptotical $\mu_F \to \infty$ limit for DAs

Various approaches tells that the ρ and π DAs could be far from being asymptotical:

- AdS/QCD correspondence
- dynamical chiral symmetry breaking on the light-front

$$\phi_{sing}(z) = \frac{8}{\pi}\sqrt{z(1-z)}$$

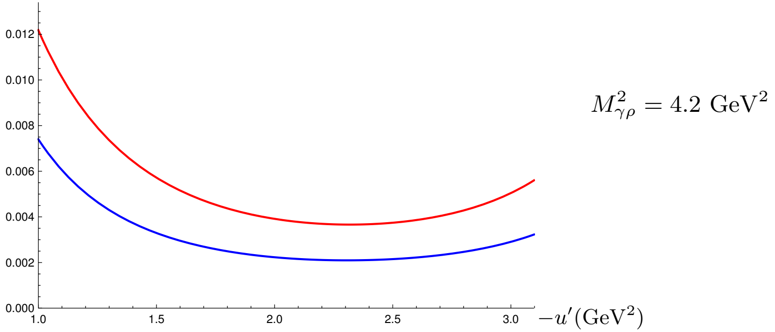
Non asymptotical DA?

Preliminary results: ρ_L^+ photoproduction cross-section

comparing σ with asymptotical DA versus “singular” DA

“valence” model for the polarized PDFs

$$\frac{d\sigma_{\rm even}}{dM^2_{\gamma\rho}d(-u')d(-t)} \; ({\rm nb}\cdot{\rm GeV}^{-6})$$



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

Polarization asymmetries

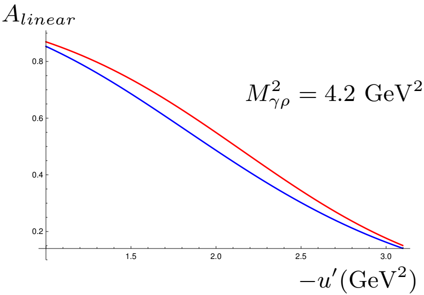
Linear polarization asymmetry of the initial γ

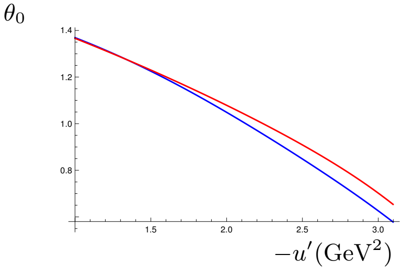
Linear polarization asymmetry

$$\frac{\sigma^x - \sigma^y}{\sigma^x + \sigma^y} = A_{linear} \cos[2(\theta - \theta_0)] \quad \theta = \text{angle between the } x \text{ axis and } p_\perp$$

Preliminary results: ρ_L^+ photoproduction γ asymmetry

asymptotical DA versus "singular" DA   "valence" model for the polarized PDFs





Very sizable asymmetry

Polarization asymmetries

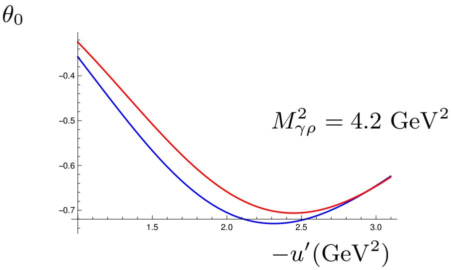
Circular polarization asymmetry of the initial γ

Circular polarization asymmetry

$$\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

Preliminary results: ρ_L^+ photoproduction γ asymmetry

asymptotical DA versus "singular" DA "valence" model for the polarized PDFs



Very sizable asymmetry

Conclusion

Results and experimental perspectives

- High statistics for the chiral-even components: enough to extract H ($\tilde{H}$?) and test the universality of GPDs in ρ^0, $\rho^\pm$ and $\pi^\pm$ channels
- In this chiral-even sector: analogy with Timelike Compton Scattering, the $\gamma\rho$ or $\gamma\pi$ pair playing the role of the γ^*.
- ρ-channel: chiral-even component w.r.t. the chiral-odd one:

$$\sigma_{odd}/\sigma_{even} \sim 1/8.$$

  - possible separation ρ_L/ρ_T through an angular analysis of its decay products
  - Future: study of polarization observables $\Rightarrow$ sensitive to the interference of these two amplitudes: very sizable effect expected, of the order of 30%
- The Bethe Heitler component (outgoing γ emitted from the incoming lepton) is:
  - zero for the chiral-odd case
  - suppressed for the chiral-even case
- Possible measurement at JLab (Hall B, C, D)
- A similar study could be performed at COMPASS. EIC, LHC in UPC?

Conclusion
Future

- For $\gamma\pi^{\pm}$ photoproduction: Effect of twist 3 contributions?
  presumably important for π electroproduction
- Observables sensitive to quantum interferences:
  - γ beam asymmetry
  - Target polarization asymmetries
  - For $\rho^0\gamma$ photoproduction: built from the $\pi^+\pi^-$ decay product angular distribution $\Rightarrow$ chiral odd versus chiral even
- Loop corrections: *in progress*
- Accessing GPDs in light nuclei: spin-0 case using an ^4He target
- Crossed-channel: using the J-PARC π beam (spallation reaction of a proton beam):

$$\pi N \to \gamma\gamma N$$

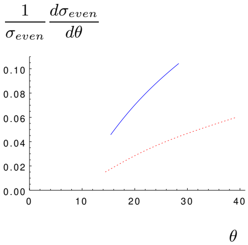
- The processes $\gamma N \to \gamma\pi^0 N'$ and $\gamma N \to \gamma\eta^0 N'$ are of particular interest: they give an access to the gluonic GPDs at Born order.
- Our result can also be applied to electroproduction $(Q^2 \neq 0)$ after adding Bethe-Heitler contributions and interferences.
- New release of *PARTONS* platform

Effects of an experimental angular restriction for the produced γ

Angular distribution of the produced γ

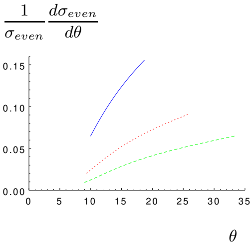
ρ_L photoproduction

after boosting to the lab frame



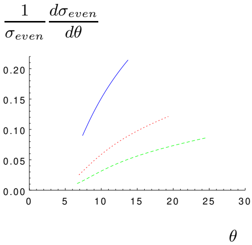
$S_{\gamma N} = 10 \text{ GeV}^2$

$M^2_{\gamma\rho} = 3, 4 \text{ GeV}^2$



$S_{\gamma N} = 15 \text{ GeV}^2$

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



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

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

JLab Hall B detector equipped between 5° and 35°

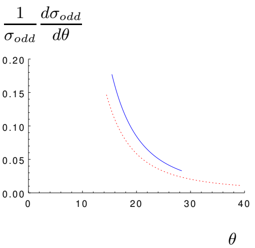
$\Rightarrow$ this is safe!

Effects of an experimental angular restriction for the produced γ

Angular distribution of the produced γ

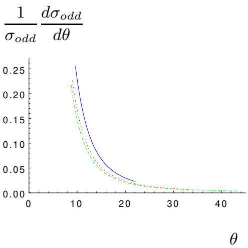
ρ_T photoproduction

after boosting to the lab frame



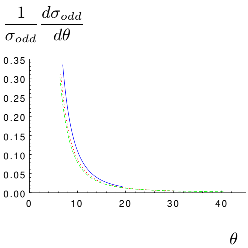
$S_{\gamma N} = 10 \text{ GeV}^2$

$M^2_{\gamma\rho} = 3, 4 \text{ GeV}^2$



$S_{\gamma N} = 15 \text{ GeV}^2$

$M^2_{\gamma\rho} = 3.5, 5, 6.5 \text{ GeV}^2$



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

$M^2_{\gamma\rho} = 4, 6, 8 \text{ GeV}^2$

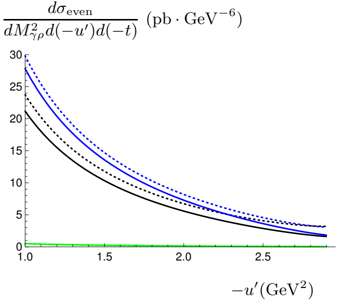
JLab Hall B detector equipped between 5° and 35°

$\Rightarrow$ this is safe!

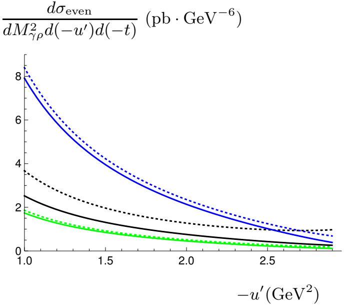
Chiral-even cross section

Contribution of u versus d

ρ_L photoproduction



proton



neutron

$M^2_{\gamma\rho} = 4$ GeV^2. Both vector and axial GPDs are included.

$u + d$ quarks u quark d quark

Solid: "valence" model

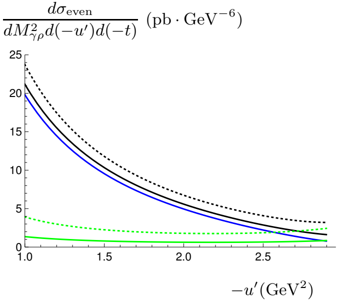
dotted: "standard" model

- u-quark contribution dominates due to the charge effect
- the interference between u and d contributions is important and negative.

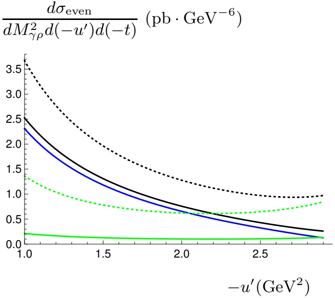
Chiral-even cross section

Contribution of vector versus axial amplitudes

ρ_L photoproduction



proton



neutron

$M^2_{\gamma\rho} = 4 \text{ GeV}^2$. Both u and d quark contributions are included.

vector + axial amplitudes / vector amplitude / axial amplitude

solid: "valence" model

dotted: "standard" model

- dominance of the vector GPD contributions
- no interference between the vector and axial amplitudes