The nucleon's transversity and the photon distribution amplitude probed in lepton pair photoproduction

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Motivation

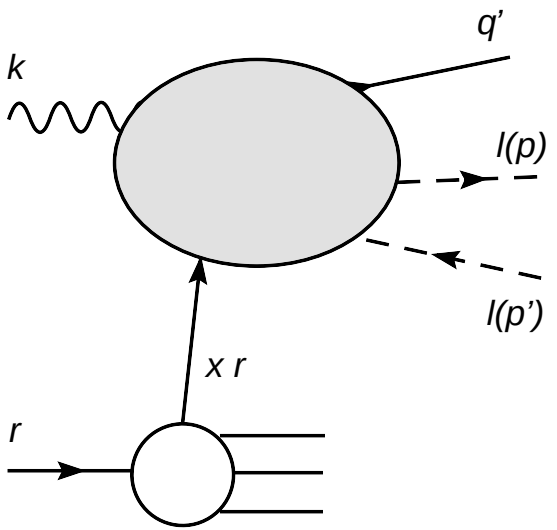
Description of the process of Drell-Yan type

$$\gamma N \to l(p) l(p') X$$

or on the partonic level

$$\gamma(k) q(x\, r) \to l(p) l(p') q(q')$$

in the QCD factorization approach



Real photon components

Two components of a **REAL** photon in (semi-)exclusive processes:

- a "pointlike"or perturbative electromagnetic component
- a "soft"or non-perturbative component
  (familiar from the studies of γ structure function in DIS)

non-perturbative $\longrightarrow$ induced by condensates:

B.L. Ioffe, A.V. Smilga 1984

exist WITHOUT an external field

$\langle 0|\ \bar{q}(0)q(0)\ |0\rangle \neq 0$ "ferromagnetic" type

nonvanishes IN THE PRESENCE of an external e-m field F

$\langle 0|\ \bar{q}(0)\sigma_{\alpha\,\beta}q(0)\ |0\rangle_F = e_q\,\chi\langle\bar{q}q\rangle F_{\alpha\,\beta}$ "paramagnetic" type

$\chi-$ magnetic susceptibility of QCD vacuum

for $z^2 = 0$ $\langle 0|\ \bar{q}(z)\sigma_{\alpha\,\beta}q(-z)\ |0\rangle_F = e_q\,\chi\langle\bar{q}q\rangle \int\limits_0^1 du F_{\alpha\,\beta}((1-2u)z)\phi_\gamma(u)$

Real photon distribution amplitudes

- the perturbative, singular CHIRAL-EVEN with q-$\bar{q}$ pair of opposite (equal) helicities (chiralities)

$$\langle 0|\bar{q}(0)\gamma_+ \frac{1\pm\gamma_5}{2} q(x)|\gamma^{(\lambda)}(q)\rangle = \frac{iN_c e_q}{4\pi^2\mathbf{r}^2}\, q_+ \int\limits_0^1 du e^{-iu(qx)} \left[(\epsilon^{(\lambda)}\cdot\mathbf{r})(2u-1) \pm i\epsilon_{ik}\mathbf{r}_i\epsilon_k^{(\lambda)}\right]$$

- the non-perturbative (due to chiral s.b.), CHIRAL-ODD with q-$\bar{q}$ pair of equal (opposite) helicities (chiralities)

$$\langle 0|\bar{q}(0)\sigma_{\alpha\beta} q(x)|\gamma^{(\lambda)}(k)\rangle = i\, e_q\, \chi\, \langle\bar{q}q\rangle \left(\epsilon_\alpha^{(\lambda)} k_\beta - \epsilon_\beta^{(\lambda)} k_\alpha\right) \int\limits_0^1 dz\, e^{-iz(qx)}\, \phi_\gamma(z)$$

with $\chi\langle\bar{q}q\rangle \approx 40-70\,\text{MeV}$ at $\mu = 1\,\text{GeV}$

χ- **magnetic susceptibility of the QCD vacuum**

Braun et al Phys.Rev.Lett. 89, 172001 (2002); Braun et al Nucl. Phys. B 649, 263 (2003),

P. V. Buividovich et al; Nucl. Phys. B 826 (2010) 313 Dorokhov et al Phys. Rev. D 74, 054023 (2006)

Transversity h_1

- the chiral-odd objects must appear in pairs :
  - Nucleon's transversity parton distribution h_1 is CHIRAL-ODD

$$\langle r, s_T|\bar{q}(-\frac{1}{2}z)\sigma^{+\,i}\gamma^5 q(\frac{1}{2}z)|r, s_T\rangle = \bar{u}(r, s_T)\sigma^{+\,i}\gamma^5 u(r, s_T)\int_0^1 du e^{-iu(rz)}(\delta q(u) - \delta\bar{q}(-u))$$

with quark $\delta q(u) = h_1(u)$

The partonic photoproduction of lepton pair

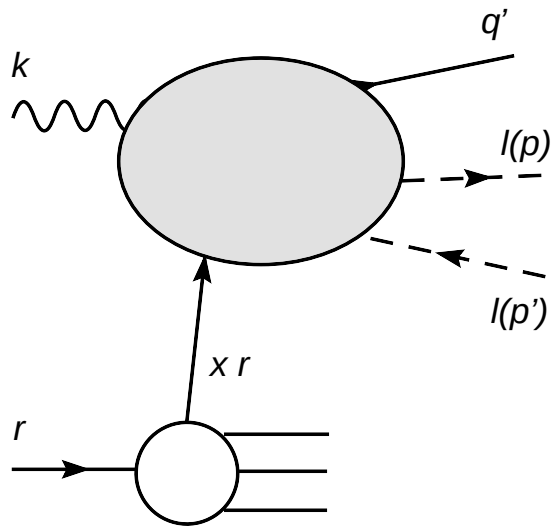
$$\gamma(k)q(x\,r) \to l(p)l(p')q(q')$$

$$q = p + p' = \alpha k + \frac{Q^2+\mathbf{Q}^2}{\alpha s} r + Q_T$$

$$p = \gamma\alpha k + \frac{(\gamma\mathbf{Q_T}+\mathbf{l_T})^2}{\gamma\alpha s} r + \gamma Q_T + l_T$$

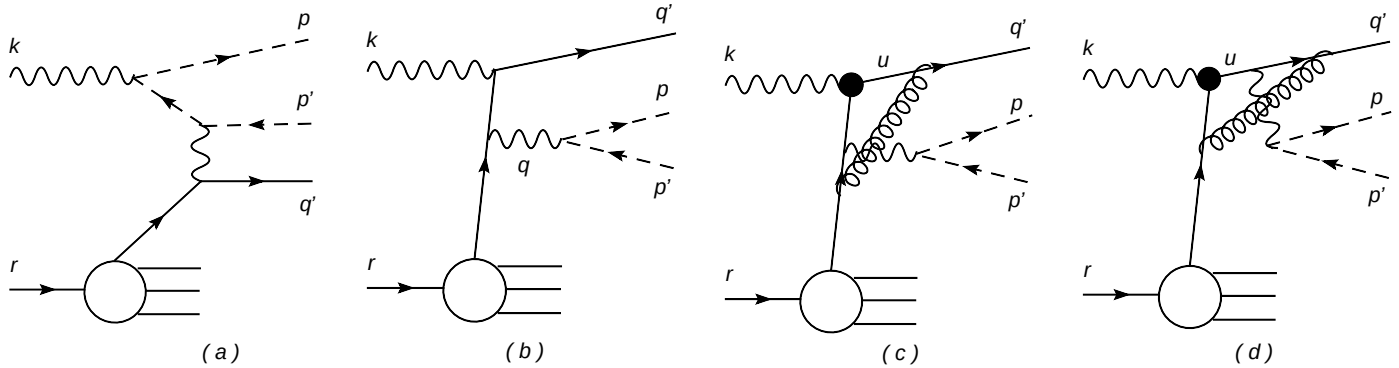
$$p' = \bar{\gamma}\alpha k + \frac{(\bar{\gamma}\mathbf{Q_T}-\mathbf{l_T})^2}{\bar{\gamma}\alpha s} r + \bar{\gamma} Q_T - l_T$$

$$q' = \bar{\alpha} k + \frac{\mathbf{Q_T}^2}{\bar{\alpha} s} r - Q_T$$



$$x = \frac{\bar{\alpha}Q^2+\mathbf{Q_T}^2}{\alpha\bar{\alpha}s} \qquad Q^2 = \frac{\mathbf{l_T}^2}{\gamma\bar{\gamma}} \qquad s = 2r\cdot k \qquad Q_T^2 = -\mathbf{Q_T}^2$$

Contributions to the process



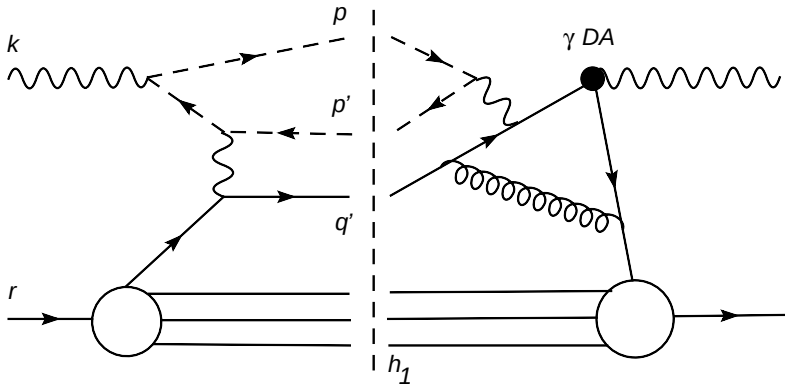
CHIRAL-EVEN: Bethe-Heitler (a) + Drell-Yan (b) AND CHIRAL-ODD (c + d) with γ DA

Crucial observation: the CHIRAL-ODD part has an absorptive part:

e.g. $\sim \int_0^1 du \frac{\phi_\gamma(u)}{u - \frac{Q^2\alpha}{Q^2 + \mathbf{Q_T}^2} - i\epsilon} = PV \int_0^1 du \frac{\phi_\gamma(u)}{u - \frac{Q^2\alpha}{Q^2 + \mathbf{Q_T}^2}} + i\pi\phi_\gamma\left(\frac{Q^2\alpha}{Q^2 + \mathbf{Q_T}^2}\right)$

Interference between CHIRAL-EVEN and CHIRAL-ODD parts

e.g.



+ ....

$$\frac{1}{2}\sum_{\lambda} d\sigma_{\phi BH}(\gamma(\lambda)p \to l^- l^+ X) = \frac{(4\pi\alpha_{em})^3}{4s}\,\frac{C_F 4\pi\alpha_s}{2N_c}\cdot\frac{\chi\,\langle\bar{q}q\rangle}{\vec{Q}_T^2}\int dx \sum_q Q_l^3 Q_q^3 h_1^q(x) 2\mathcal{R}e(\mathcal{I}_{\phi BH})\, dLIPS\,,$$

Result: INTERFERENCE DOESN'T VANISH

$$\sim \quad \chi\,\phi_\gamma\left(\frac{Q^2\alpha}{Q^2+\mathbf{Q_T}^2}\right)\cdot h_1\left(\frac{\bar{\alpha}Q^2+\mathbf{Q_T}^2}{\alpha\bar{\alpha}s}\right)$$

- may be singled out by the lepton azymuthal distribution

- only nucleon is polarized, i.e. SINGLE SPIN EFFECTS

Phenomenological perspectives

- Lepton pair photoproduction cross sec. are $\sim \alpha_{em}^3$: Is it measurable ? It IS NOT a signal of unmeasurability:
  - J. F. Davis *et al.*, "Measurement of muon-pair photoproduction in the deep inelastic region," Phys. Rev. Lett. **29**, 1356 (1972)

- The unpolarized Drell-Yan cross sec. is estimated to be a few picobarns for Q^2 values of a few GeV^2
  R. L. Jaffe, "Photoproduction Of Massive Muon Pairs At High-Energies," Phys. Rev. D **4**, 1507 (1971);

- one needs to carry a detailed numerical analysis of all the kinematical domains in order to perform a judicious partial phase space integration and define less differential observables

- A single spin observable is not necessarily the most easily accessible. A detailed phenomenological analysis should discuss both single spin and double spin observables.

Conclusions

- We propose a new way to access the nucleon's transversity parton distr. $h_1(x)$

  The basic tool is to select observables which selects the interference of the amplitude $\mathcal{A}_\phi$, where the photon couples to quark through its chiral-odd DA with a better known amplitude such as the Bethe-Heitler or the leading Drell-Yan amplitude

  The result - in the exemplary case we have studied - is proportional to $\chi\phi_\gamma(\frac{\alpha Q^2}{Q^2+\vec{Q}_\perp^2})h_1^q(\frac{Q^2}{\alpha s}+\frac{\vec{Q}_\perp^2}{\alpha\bar{\alpha}s})$, which allows to scan both the photon DA and the transversity nucleon distribution
- Experimental prospects cover mostly the future JLab 12 Gev upgrade and in particular its Hall D real photon program
- Experiments at higher energy such as the Compass muon beam at CERN may open another kinematical domain.

  Both set-ups will have polarized quasi real photon beams and transversely polarized nuclear targets.
- A complete phenomenological study is needed to check that the foreseen photon luminosity and a good lepton pair reconstruction will give access to the interference of the chiral odd amplitude driven by the magnetic susceptibility of the QCD vacuum and either the Bethe-Heitler or the usual Drell-Yan amplitudes.

THANK YOU FOR ATTENTION