Transversity and spin–orbit correlations in two–photon DIS

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Transverse target single–spin asymmetry in inclusive $e N(\uparrow) \rightarrow e' X$

- “Pure” two–photon exchange effect!
- Probes helicity–flip amplitudes at quark level $(h, g_T)$
- Approved JLab Hall A experiment PR-07-013 [X. Jiang et al.] Sensitivity $\sim 10^{-4}$ cf. SLAC 1970 $\sim 10^{-2}$
Transverse target spin dependence in $eN \rightarrow e'X$

- Target spin dependence of cross section
  $$\sim S \cdot (k_1 \times k_2) \quad \text{“normal spin”}$$

- Relative asymmetry
  $$A_y = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}$$

- Classical analog: Scattering from magnetic dipole (Lorentz force)
  $$\rightarrow \text{Sign, } p/n \text{ ratio}$$
Spin dependence with two–photon exchange

- Transverse spin dependence zero in one–photon exchange [Christ, Lee 66]
  
  \[ L_{\mu\nu} = L_{\nu\mu} \]

  leptonic tensor symmetric (unpol. beam)

  \[ W_{\mu\nu}(S) = -W_{\mu\nu}(-S) \]

  hadronic tensor antisymmetric (P, T inv.)

- Nonzero at \( O(\alpha^3) \): Two–photon exchange and real emission

- Contributions individually IR-finite
  
  \[ \rightarrow \text{No cancellations (cf. elastic FF)} \]

  \[ \rightarrow \text{Clean two-photon exchange effect} \]
Example: Pointlike target

\[ A_y = \frac{\alpha M}{\sqrt{s}} f(\Theta_{cm}) \quad (\Theta_{cm} \leftrightarrow Q^2/s) \]

- Only imaginary part of two-photon exchange enters; no IR divergences
- Photon virtualities \( -q_1^2, q_2^2 \sim Q^2 \)
- Include strong interactions:
  No QED collinear divergences thanks to gauge invariance

[Barut, Fronsdal 60; …]

[Afanasev, Strikman, CW 07]
Transverse spin dependence in QCD

- Dominance of scattering from same quark (no “anomalous” IR/collinear enhancement)

- Two contributions
  
  I) Quark helicity non-flip and interactions w. spectators
  [Goeke, Metz, Schlegel 06 . . . gauge invariance!]

  II) Quark helicity flip by interaction with vacuum fields:
  Chiral symmetry breaking

  No Sudakov suppression if
  IR cutoff $\sim \mu^2(\text{chiral}) \gg \Lambda_{QCD}^2$
Composite nucleon approximation

- Assume “composite” nucleon

\[ R_N^{-2} \sim \langle p_T^2 \rangle \ll M_q^2 \]

→ Quark helicity flip dominates!
→ Light–front constituent quark model

[cf. Miller 02]

\[
A_y = \frac{\sum e_q^3 h_q(x)}{\sum e_q^2 f_q(x)} \times A_y(\text{quark})
\]

\[ \propto M_q \approx 300 \text{ MeV} \]
Predictions for kinematic dependences

\[ -A_y \, [10^{-4}] \]

\[ s = 10 \text{ GeV}^2 \quad \text{[JLab 6 GeV]} \]

- Asymmetry vanishes in high-energy limit \( A_y \sim s^{-2} \quad (s \gg Q^2) \)
- cf. photon polarizations in \( 2\gamma \) box \quad [Gribov, Lipatov, Frolov 70]
Summary

• Very interesting/challenging problem!
  – Higher–order QED corrections
  – QCD factorization
  – Vacuum structure

• “Cleanest” two–photon exchange observable
  – IR finite — no IR cancellations with real emission
  – How large are finite contributions from real emission?

• Probes helicity–flip amplitudes at quark level
  – Composite Nucleon Approximation $\to h(x)$ transversity
  – How large are helicity–conserving contributions?