Single-spin asymmetry from helicity changing rescattering in semi-inclusive DIS

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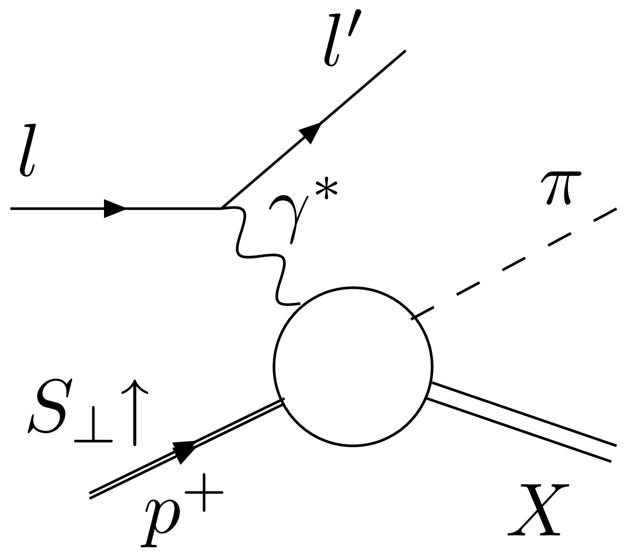
Outline

- Introduction
- Background on transverse spin asymmetries
- Model calculations of SIDIS
  - The BHS model
  - Our calculation (Paul Hoyer and MJ)
- Results and conclusion

Introduction

- Single-spin asymmetry (SSA) = asymmetry in a reaction where the spin of one of the particles is measured
- Parity invariance requires transverse spin (for $2 \to 2$ and $a + b \to c + X$)
- Large transverse spin asymmetries observed, *i.e.*, in $pp \to \Lambda^{\uparrow} X$, $p^{\uparrow} p \to \pi X$ and recently in semi-inclusive DIS, $ep^{\uparrow} \to e\pi X$
- Spin dependent cross sections serve as a sensitive test of our understanding of QCD
- I will discuss dynamical mechanisms for leading twist ($Q^2 \to \infty$) asymmetries in semi-inclusive DIS (SIDIS) with transversely polarized target proton

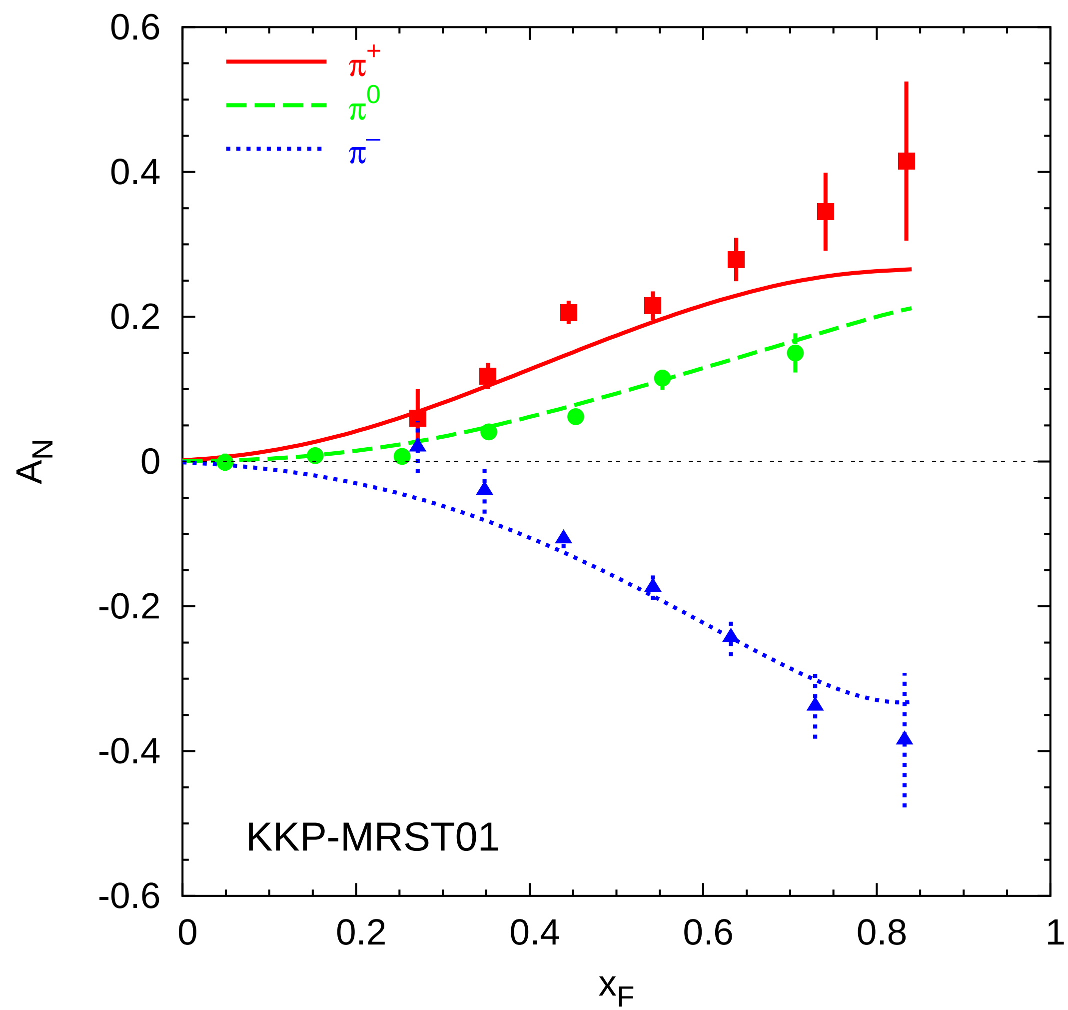


Large transverse asymmetries in $p^{\uparrow}p \to \pi X$

E704 data ($\sqrt{s}$ = 20GeV, $p_{\perp}$ ~1-2GeV):

- Asymmetries large, ~40 % for high x_F
- π^+ and π^- distributions mirror symmetric
- For π^0 the asymmetry is in the same direction as for π^+, but smaller

Recent result from STAR ($\sqrt{s}$ = 200GeV): the asymmetry persists when energy is increased



SIDIS: Theoretical Background

SIDIS can be described using QCD factorization:

Cross section =

Structure functions $\otimes$ Parton cross section $\otimes$ Fragmentation functions

- Transverse asymmetries arising from the hard QCD subprocess are negligible (they are $\propto m_q$)
- Observed, large asymmetries suggest soft rescattering and/or fragmentation effects
- $k_\perp$ dependent factorization for SIDIS was proved recently

[Ji, Ma, and Yuan, PRD71(2005)034005]

Background: Sivers and Collins effects

The asymmetry may arise either from initial (parton distribution) or final (fragmentation distribution) reinteractions:

In the Sivers effect, asymmetry arises due to a T-odd parton distribution ($\Delta^N f_{q^\uparrow/p}$, Sivers function)

$$SSA \sim \Delta^N f(x, k_\perp) \otimes d\sigma \otimes D(z)$$

[Sivers PRD43(1991)83]

In the Collins effect, asymmetry arises due to a T-odd fragmentation function ($\Delta^N D_{h/q^\uparrow}$, Collins function)

$$SSA \sim h_1(x) \otimes d\sigma \otimes \Delta^N D(z, k_\perp)$$

[Collins NPB396(1993)161]

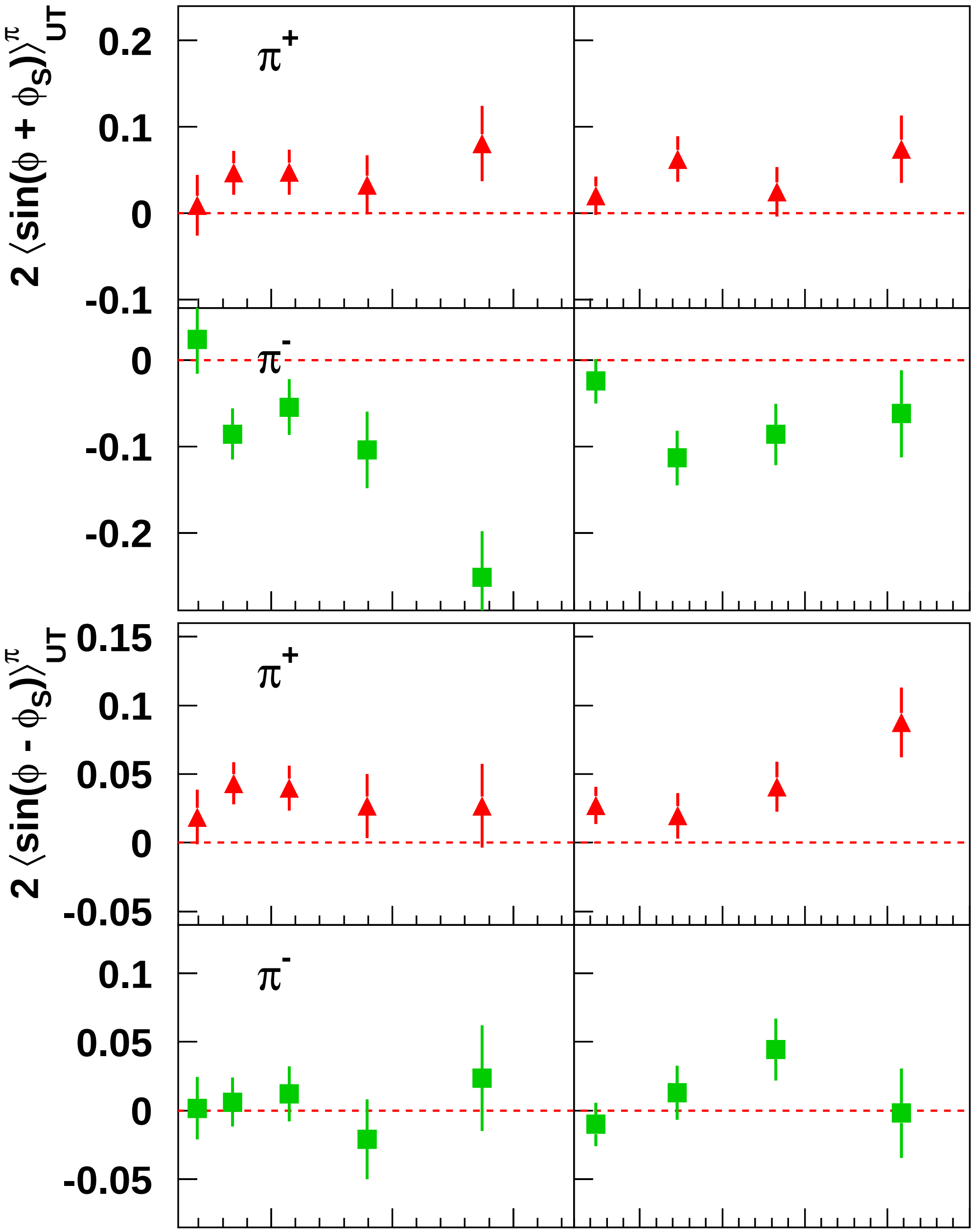
Here h_1 is the transversity distribution.

Experimental results from HERMES

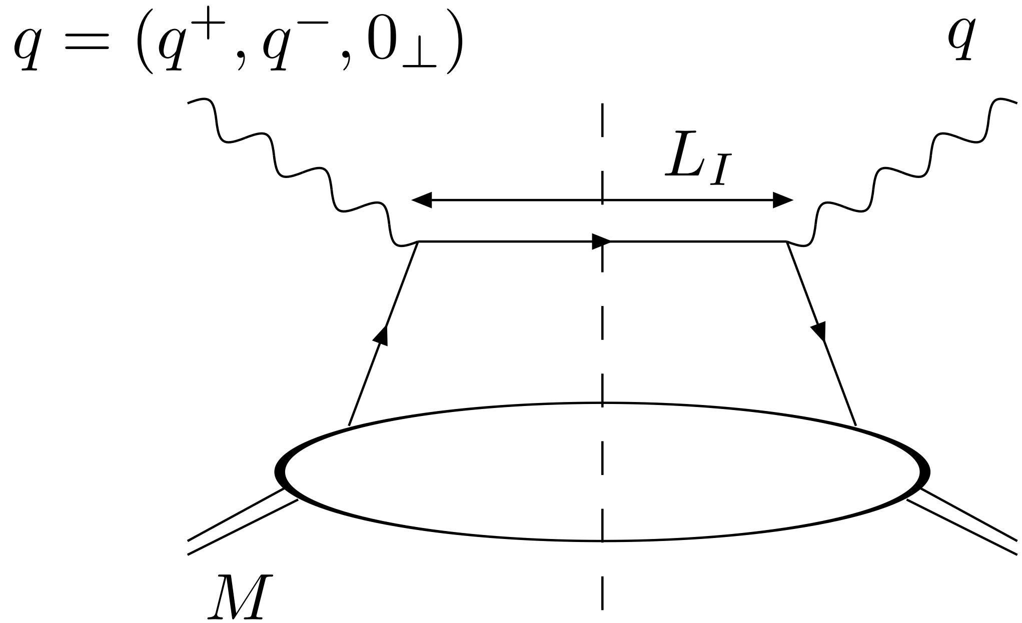
In SIDIS Collins and Sivers mechanisms can be separated through their different dependence on the azimuthal angles (ϕ and ϕ_S).

HERMES collaboration has measured non-vanishing Collins and Sivers effects in SIDIS

[HERMES PRL94(2005)012002]



DIS dynamics



The proper coherence length of the virtual photon is $1/Q$ (expectation from $q^2 = -Q^2$).

However, in the target rest frame we have (if $\vec{q} \uparrow\uparrow +\hat{z}$)

$$\begin{aligned} q^+ &\simeq 2\nu \\ q^- &\simeq -Q^2/2\nu \simeq -x_B M \end{aligned} \qquad \Rightarrow x^+ \sim 1/q^- \sim 1/x_B M$$

i.e., the proper coherence length is Lorentz dilated to the finite Ioffe length

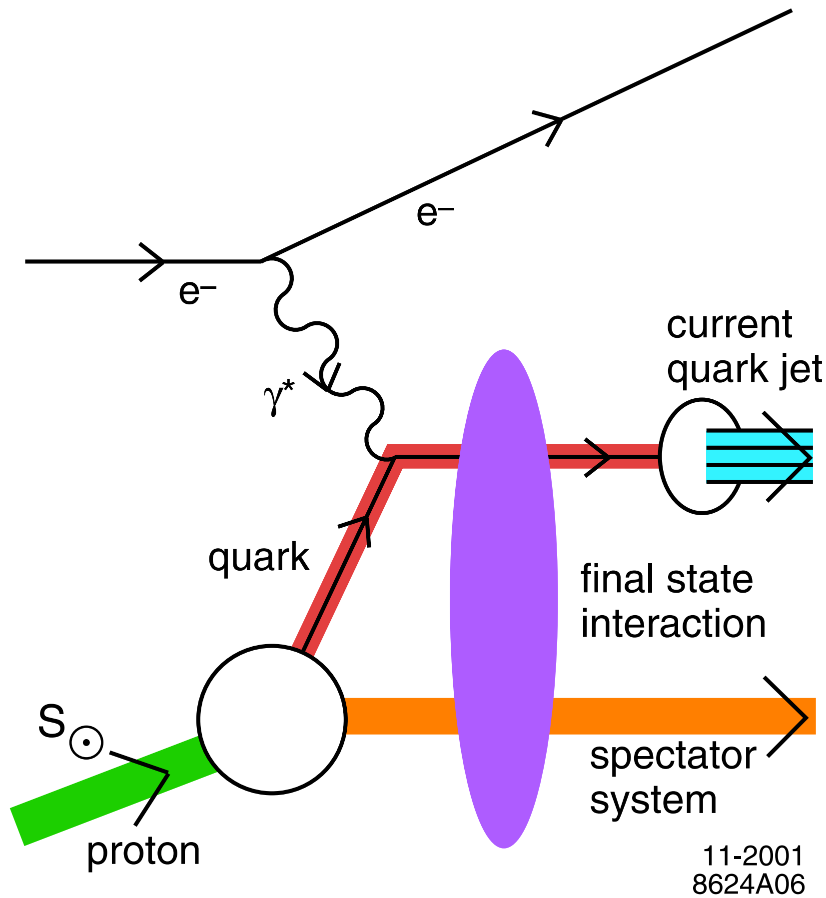
$$L_I \sim \frac{1}{Q} \cdot \frac{\nu}{Q} = \frac{1}{2Mx_B}$$

Rescattering within this length scale is coherent and it can cause leading twist effects.

The BHS model

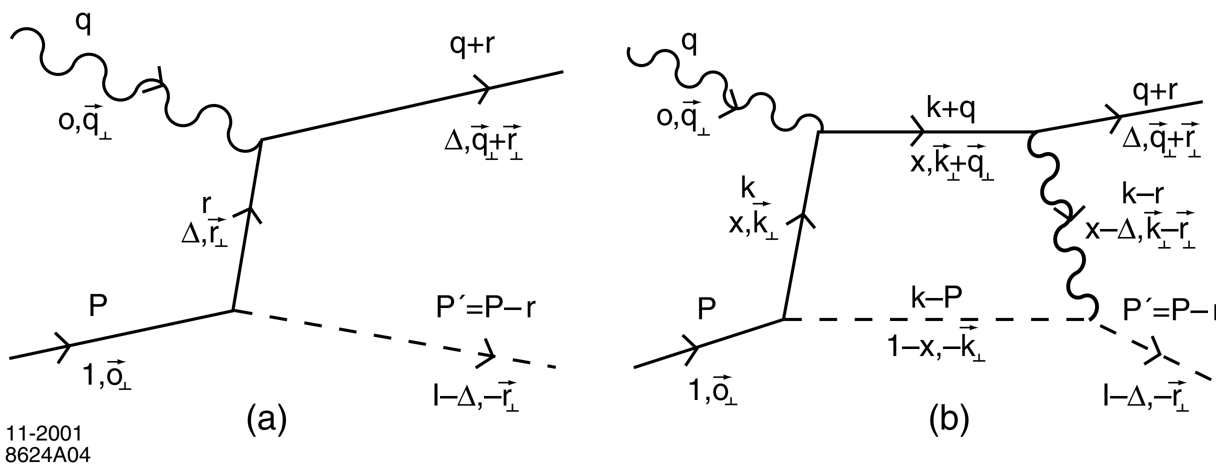
In the BHS model leading twist Sivers effect arises from coherent, soft rescattering between the struck quark and the projectile

[Brodsky, Hwang, and Schmidt, PLB530(2002)99]



Some details of the BHS model

- QCD modelled as abelian gauge theory
- Rescattering from a scalar diquark



- T-odd Sivers function absent at the Born level, but arises due to the soft rescattering

The asymmetry

$$A_N \equiv \frac{\sum_{\{\sigma\}} \left[|\mathcal{M}_{\uparrow,\{\sigma\}}|^2 - |\mathcal{M}_{\downarrow,\{\sigma\}}|^2\right]}{\sum_{\{\sigma\}} \left[|\mathcal{M}_{\uparrow,\{\sigma\}}|^2 + |\mathcal{M}_{\downarrow,\{\sigma\}}|^2\right]} = \frac{2\sum_{\{\sigma\}} \mathrm{Im}\left[\mathcal{M}^*_{\leftarrow,\{\sigma\}}\mathcal{M}_{\rightarrow,\{\sigma\}}\right]}{\sum_{\{\sigma\}} \left[|\mathcal{M}_{\rightarrow,\{\sigma\}}|^2 + |\mathcal{M}_{\leftarrow,\{\sigma\}}|^2\right]}$$

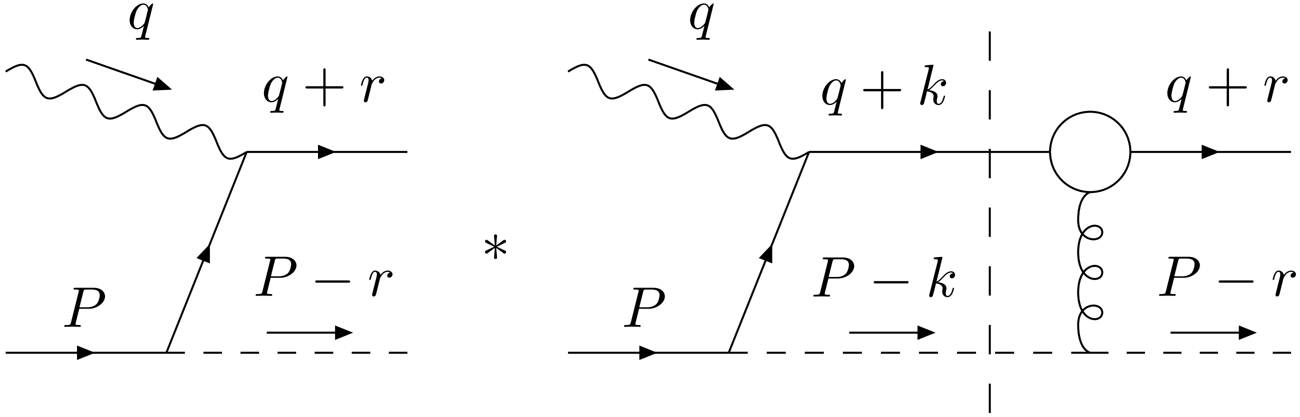
$\Rightarrow$ imaginary amplitudes, or a phase difference, is needed

Our model

We use the BHS model to study the effects of non-perturbative features of QCD on SIDIS.

[Hoyer and MJ, hep-ph/0509058]

We consider the possibility that the non-perturbative, chirality breaking sector of QCD (*e.g.*, instantons) causes a spin-flip in the soft rescattering, giving rise to a leading twist asymmetry.



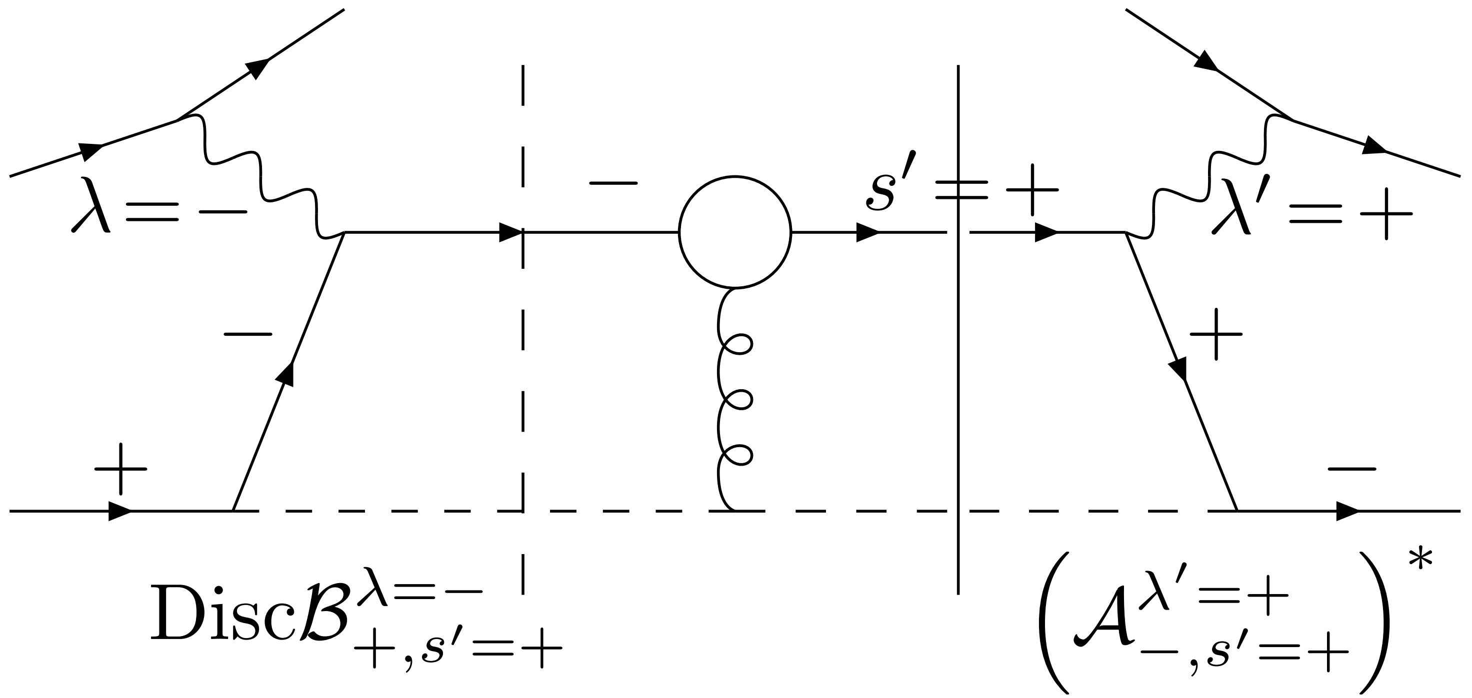
We describe the spin-flip (quark-anomalous magnetic moment) using a Pauli coupling (the blob, $a(p^2)\bar{q}\sigma^{\mu\nu}p_\nu q$). The elastic scattering amplitude with Pauli coupling is $\propto s$, as needed for leading twist asymmetry

Details

The asymmetry is given by

$$A_N \propto \sum_{\lambda,\lambda'} \sum_{s'} \mathrm{Im}\left\{ L^{\lambda,\lambda'} \left[\mathcal{A}^{\lambda}_{+,s'} \left(\mathrm{Disc}\, \mathcal{B}^{\lambda'}_{-,s'} \right)^* + \mathrm{Disc}\, \mathcal{B}^{\lambda}_{+,s'} \left(\mathcal{A}^{\lambda'}_{-,s'} \right)^* \right] \right\}$$

With Pauli coupling $\lambda = -\lambda'$ $\Rightarrow$ asymmetry depends on lepton momenta and the direction of the lepton scattering plane

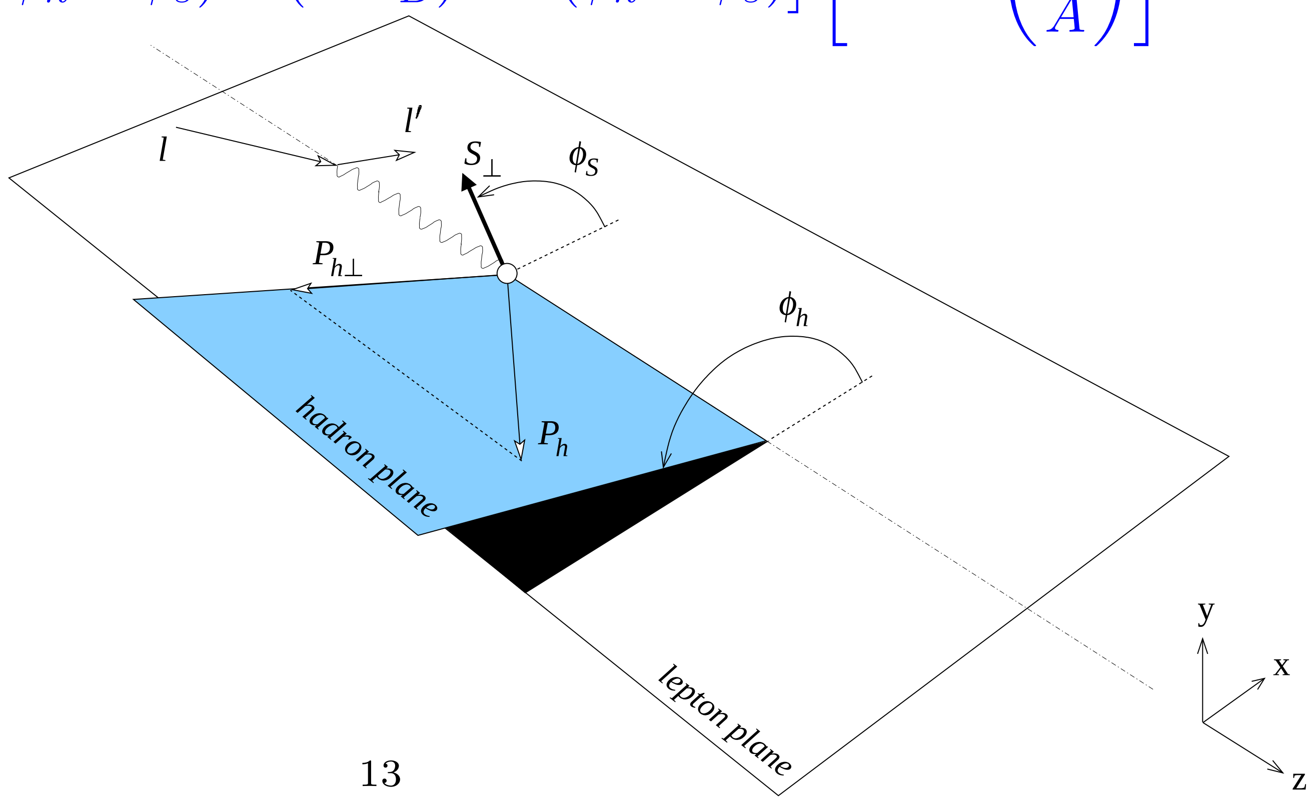


The result

With the "form factor" of the Pauli coupling $a(p^2) = a_0 e^{Ap^2}$, in the limit of large A we find the explicit result for the asymmetry

$$A_N \simeq \frac{e_2 a_0}{2\pi A} \frac{1-y}{1+(1-y)^2} \frac{r_\perp}{\{r_\perp^2 + x_B\left[m_s^2 - (1-x_B)M^2\right]\}\left[r_\perp^2 + (Mx_B)^2\right]}$$
$$\times \left[r_\perp^2 \sin(3\phi_h - \phi_s) - (Mx_B)^2 \sin(\phi_h + \phi_s)\right]\left[1 + \mathcal{O}\left(\frac{1}{A}\right)\right]$$

See figure for angle definitions (here $r_\perp \leftrightarrow P_{h\perp}$)



Conclusion

- Non-perturbative features of QCD may cause a spin-flip of the struck quark in DIS which leads to observable effects.
- The result has the same angular dependence as the Collins effect.
  - However, in our calculation the asymmetry arises from the rescattering of an on-shell struck quark
  - The angular and y dependencies of the result are a direct consequence of the spin-flip
- The effect we have discussed is not expected in PQCD since the anomalous magnetic moment of the initially bare struck quark takes too long to form (we are presently studying this)
- The possibility of an effect also on the $k_\perp$ integrated transversity distribution $h_1(x)$ merits study. It would allow to distinguish the effect discussed here from fragmentation effects.