Higher-Twist Effects in Single-Spin Asymmetries of DIS

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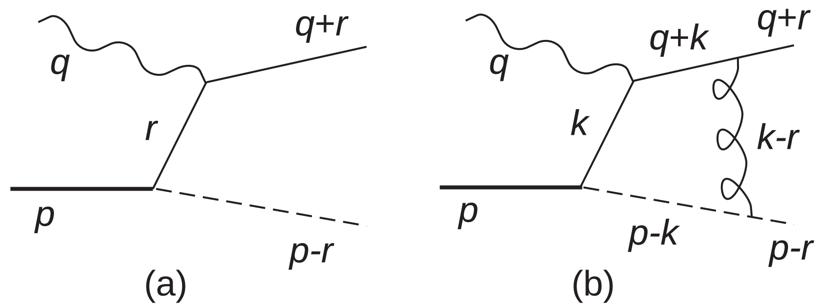
Plan of Talk

- Higher-twist Single-Spin Asymmetries in SIDIS
  - Example of A_{LU}, etc.
  - Issues and outlook
- SSA from two-photon exchange in inclusive DIS
  - Role of transversity
  - Interplay of non-partonic and partonic mechanisms for two-photon exchange; Cancellation of divergences

AA&Carlson on Beam SSA (A_{LU})

hep-ph/0308163

- Assume BHS mechanism for generating single-spin asymmetries, viz.
  - Gluon exchange takes place in the final state, generating both phase differences and transverse-momentum dependence
  - Asymmetry is due to interference between (a) and absorptive part of (b)
  - No assumptions are required on the details of nucleon spin structure



•Concluded: this mechanism is not ~e(x)*Collins fragmentation

•Followed by Yuan (+h_1^{perp}), Gamberg et al., Metz-Schlegel, Bachetta-Mulders-Pijlman (+g^{perp})->jet case

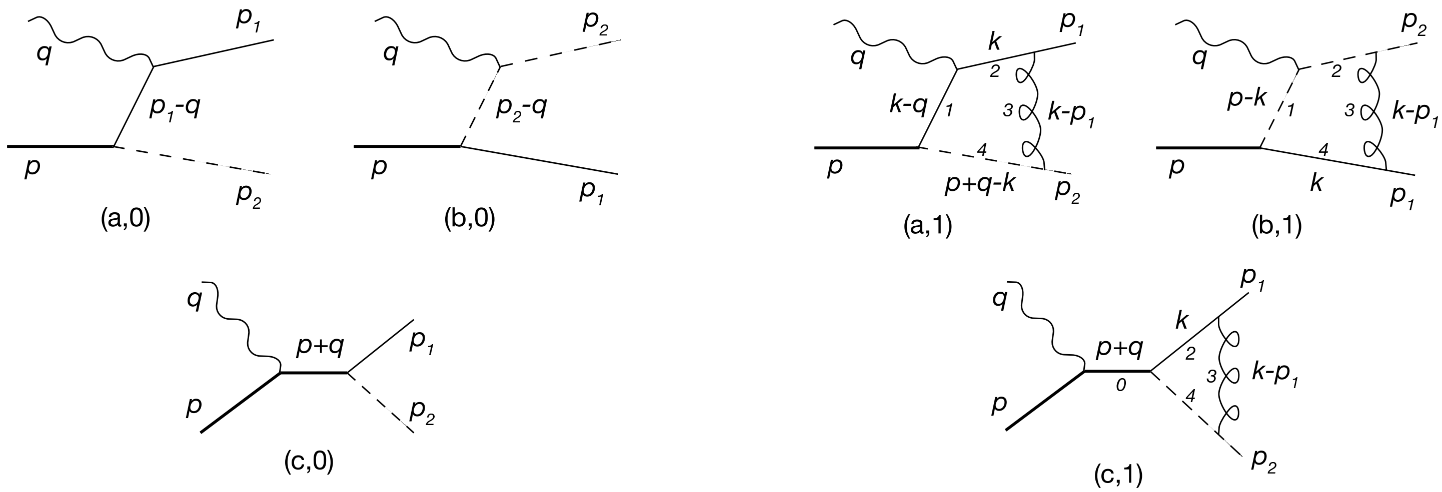
Details of calculation

- NLO contribution is small, neglect terms $O(NLO^2)$
- The asymmetry is proportional to the imaginary part of LT-interference
- The calculation is free of infrared and ultraviolet divergence
- Contributions from soft gluons cancel at the observable asymmetry level
- Assume for this calculation that α_s is frozen (=0.3)
- Assume k_T is small

Electromagnetic gauge invariance

- To ensure (electromagnetic) gauge invariance, the virtual photon couples to all charged particles

(Metz, Schlegel, Eur.Phys.J.A22:489-494, 2004: couple to quark and diquark)



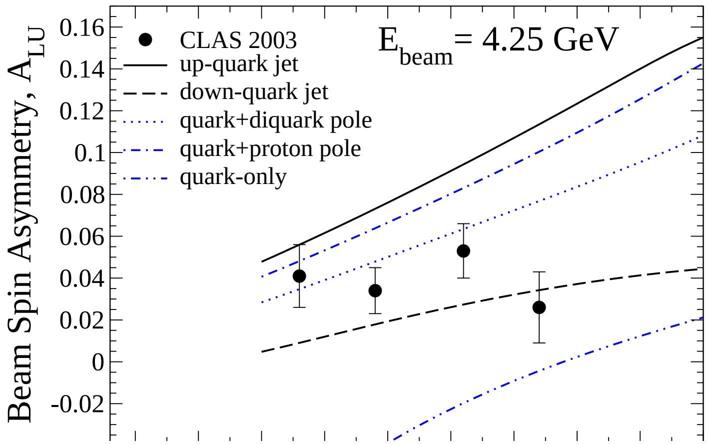
A_{LU} results

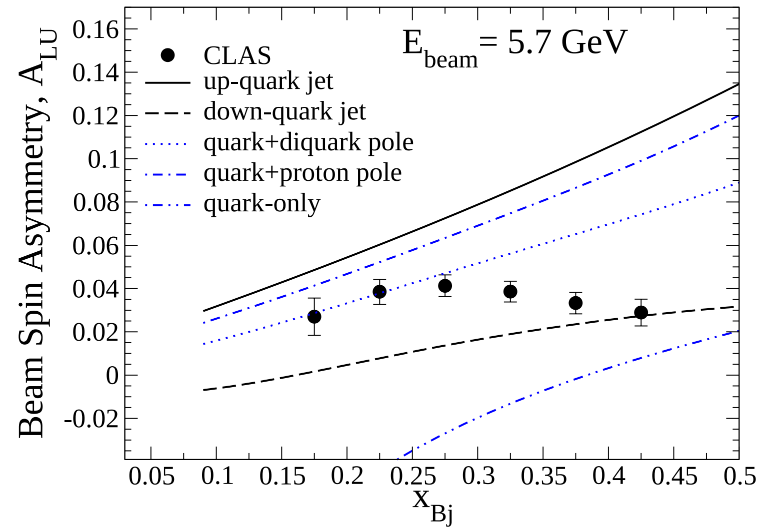
- Electric charges: e_1 (quark), e_2 (di-quark); note the $\log(Q^2)$ dependence

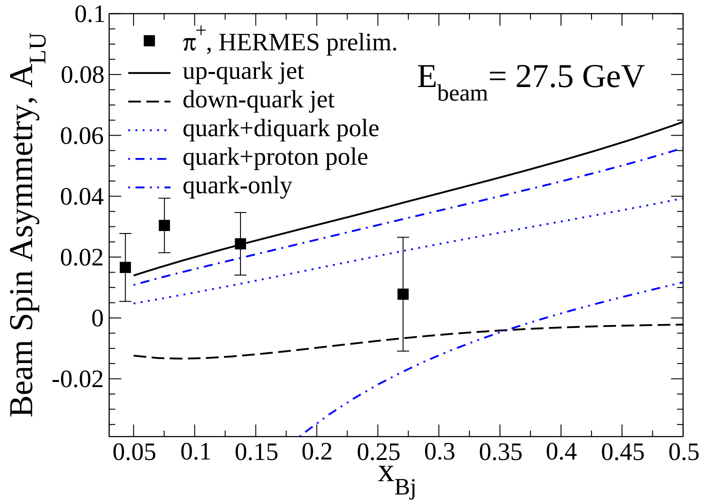
$$A_{LU}^{\sin\phi} = \frac{4\alpha_s}{3}\sqrt{\varepsilon(1-\varepsilon)}\,\frac{\tilde{m}^2+\Delta_\perp^2}{(m+Mx)^2+\Delta_\perp^2}\,\frac{\Delta_\perp}{Q}$$

$$\times\left(\frac{1}{\Delta_\perp^2}\left(M^2x^2-m^2+\frac{2e_1-xe_2}{2e_1(1-x)}\tilde{m}^2\right)\ln\frac{\tilde{m}^2+\Delta_\perp^2}{\tilde{m}^2}+\frac{2e_1+e_2}{2e_1}\frac{x}{1-x}\ln\frac{Q^2(1-x)}{(\tilde{m}^2+\Delta_\perp^2)x}-\frac{e_1+e_2}{e_1}\frac{x}{1-x}\right),$$

$$\tilde{m}^2 = x(1-x)\left(-M^2+\frac{m^2}{x}+\frac{m_s^2}{1-x}\right)$$







- New feature of the calculation: jet flavor dependence
- Lack of suppression at higher *x*
- *Gauge-invariant model in better agreement with experiment*

Extracting g^perp

- Equate the model calculation for A_{LU} with a corresponding expression in terms of parton distributions:

$$A_{LU}^{\sin\phi} = \sqrt{\varepsilon(1-\varepsilon)}\,\frac{\Delta_\perp}{Q}\,\frac{x g^\perp(x,\Delta_\perp)}{f_1(x,\Delta_\perp)}$$

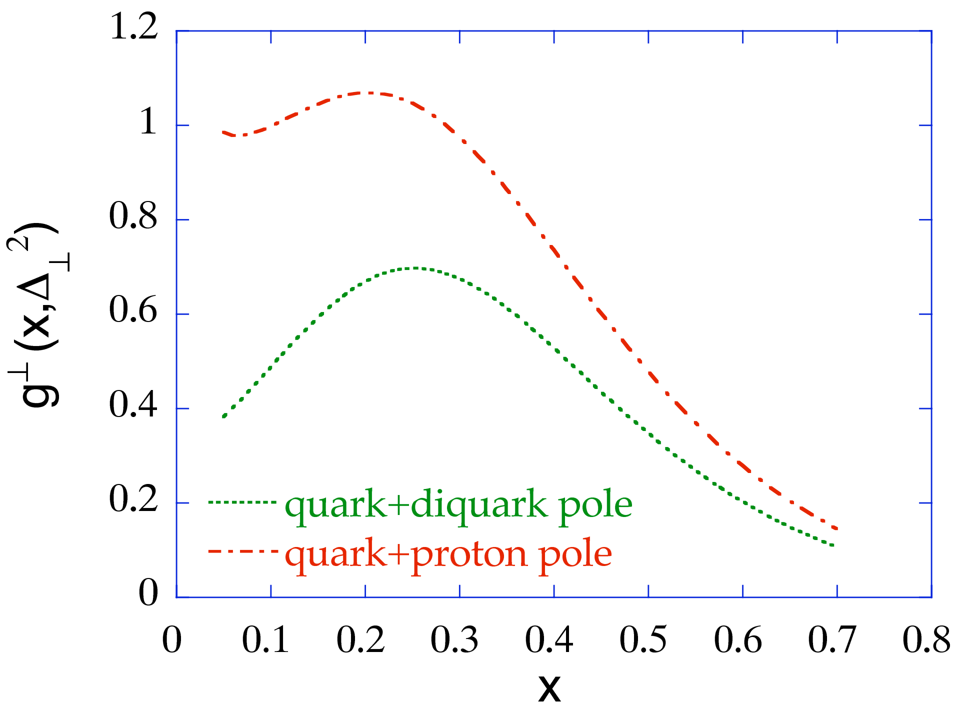
•Obtain the expression for g^perp

$$g^\perp(x,\Delta_\perp) = \frac{g^2}{16\pi^2}\frac{4\alpha_s}{3}\frac{(1-x)^2}{\tilde{m}^2+\Delta_\perp^2}$$

$$\times\left(\frac{1}{\Delta_\perp^2}(M^2x^2 - m^2 + \frac{2e_1 - xe_2}{2e_1(1-x)}\tilde{m}^2)\ln\frac{\tilde{m}^2+\Delta_\perp^2}{\tilde{m}^2} + \frac{2e_1+e_2}{2e_1}\frac{x}{1-x}\ln\frac{Q^2(1-x)}{(\tilde{m}^2+\Delta_\perp^2)x} - \frac{e_1+e_2}{e_1}\frac{x}{1-x}\right),$$

$$\tilde{m}^2 = x(1-x)(-M^2 + \frac{m^2}{x} + \frac{m_s^2}{1-x})$$

Result for g^{perp}



- Additional scaling violation ~ln(Q^2)for the twist-3 observable
- Need proof of factorization for twist-3 case

Summary on beam SSA in SIDIS

- Beam SSA is suppressed by an extra power of 1/Q compared to target SSA, since it is due to LT (photon) interference
- Predictions for beam SSA do not depend on the assumptions of orbital angular momentum contribution to the nucleon light-cone wave function, while the remaining assumption (gluon exchange in the final state) is the same as in the target (Sivers) asymmetry calculations
- Result very sensitive to the method of restoring electromagnetic gauge invariance through adding *non-partonic* contributions
- Both experimental and theoretical effort needed to study factorization for the higher-twist observables

Single-Spin Asymmetries in DIS from 2-photon exchange

AA, C.Weiss

Motivation

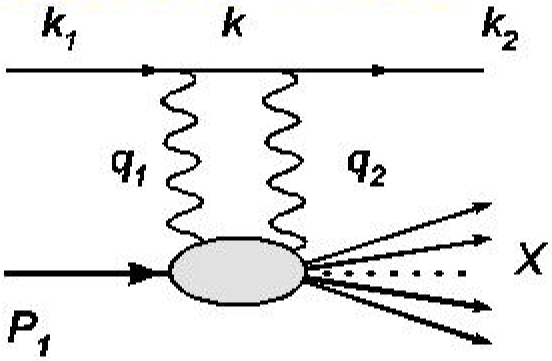
- Motivated by experimental+theoretical two-photon exchange studies at JLab
- Implications for SIDIS: Measured SSA in (e,e'h) are of the order of a few per cent
  - What if higher-order electromagnetic correction is a few per cent?

- **What the … are we (or they) measuring?**

Recent calculation of normal target asymmetry from two-photon exchange in a parton model obtained a divergent result, see

A. Metz, M. Schlegel, K. Goeke (Ruhr U., Bochum) . Oct 2006. 8pp. Published in **Phys.Lett.B643:319-324,2006**. e-Print Archive: **hep-ph/0610112**

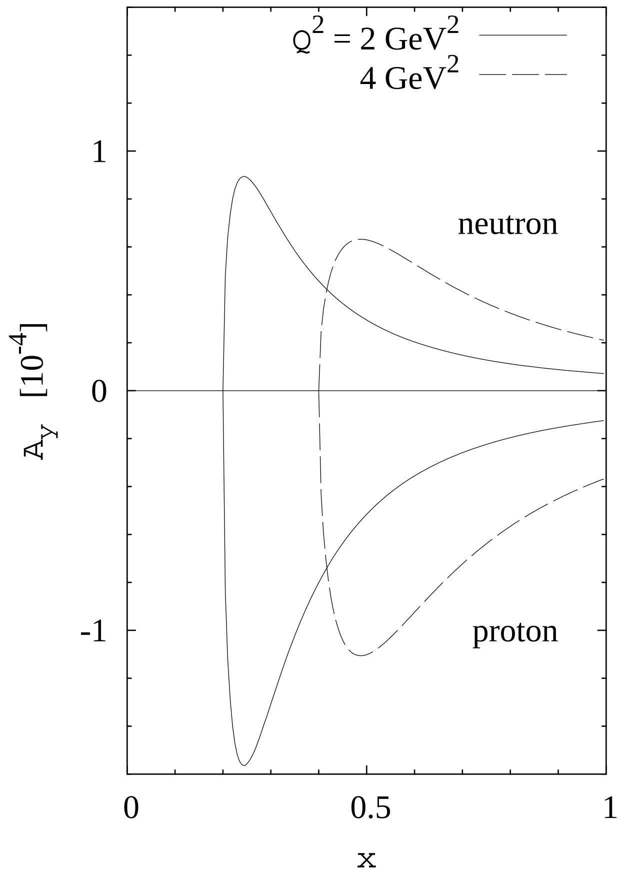
New results from AA, Weiss



- Normal target asymmetry from two-photon exchange is evaluated in a model of a weakly-bound nucleon
  - Asymmetry proportional to quark transversity and a mass scale of chiral symmetry breaking
  - $A_n \sim 10^{-4}$
- Asymmetry is free of infrared and collinear divergence
  - Recent (divergent) result of Metz et al is due to (non)conservation of electromagnetic current in their model

Calculations

- Weakly-bound nucleon model assumes that the main effect of interactions is a dynamical quark mass, Mq;
- An(xs,t)$_{point}$: asymmetry for a pointlike e=1 spinor particle of mass M



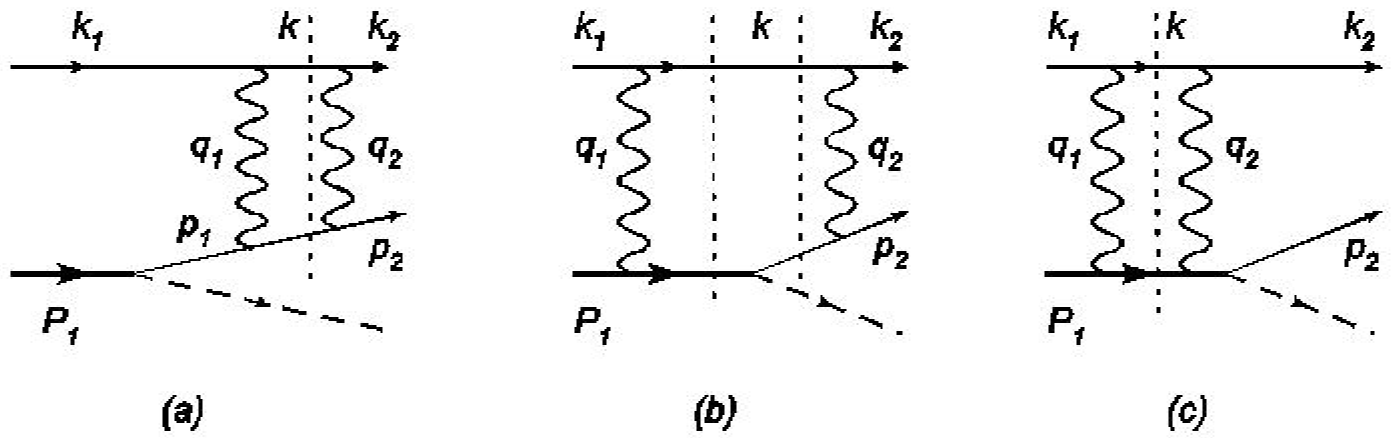
$$A_n(s,t,x)_{comp} = \frac{M_q}{M} \frac{\sum_q e_q^3 h_q(x)}{e_q^2 f_q(x)} A_n(xs,t)_{point}$$

Important observable:
Asymmetry changes from 10^{-2} to 10^{-4} in transition from elastic to deep-inelastic region
(see X.Jiang et al proposal to PAC31)

Divergence cancellation

- Divergence: terms of the type $\ln(Q^2/\lambda^2)$, where λ is a cut-off parameter (`photon mass'); final results should be independent of λ
- Two kinds of divergence appear in two-photon exchange calculation:
  - Infra-red: exchanged photon momentum ->0. Such divergent terms result in a spin-independent common factor appearing in front of one-photon exchange amplitude; the factors cancel in the result for asymmetry
  - Hard collinear: intermediate photon is collinear to the parent electron, while carrying substantial energy: Divergence cancels at the amplitude level; electromagnetic current conservation for the Compton tensor is essential (see AA,Merenkov'04 proof for elastic ep-scattering)

Model example



- Collinear divergence ~ln(Q^2/λ^2) from diagram (a) precisely cancels the divergence of the diagram (b)
- Lesson: To obtain sensible results for the single-spin asymmetry from two-photon exchange, need to work with models that exactly satisfy electromagnetic current conservation for the (inelastic) virtual Compton amplitude

Conclusions

- Electromagnetic current conservation is an requirement is important for higher-twist Single-spin asymmetry calculations
- Neglecting Electromagnetic current conservation results in (unphysical) divergence in spin asymmetries induced by two-photon exchange
- Single-spin asymmetries from two-photon exchange in DIS estimated in a model at 10^{-4} level