

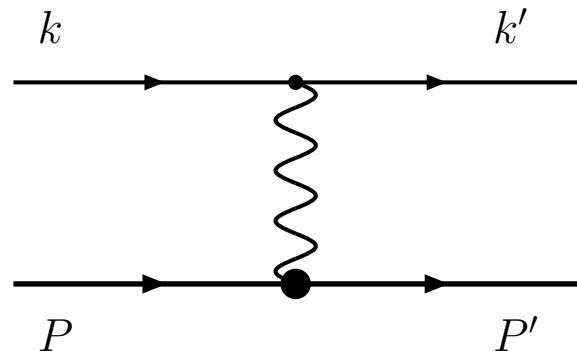
Multi-photon exchange and single spin asymmetries in lepton nucleon scattering

(Andreas Metz, Ruhr-Universität Bochum)

- Introduction
- Single spin asymmetries in elastic lepton nucleon scattering
- Single spin asymmetries in semi-inclusive lepton nucleon scattering
- Single spin asymmetries in inclusive lepton nucleon scattering
(Metz, Schlegel, Goeke, 2006)
- Summary

Elastic lepton nucleon scattering

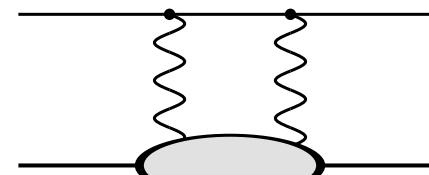
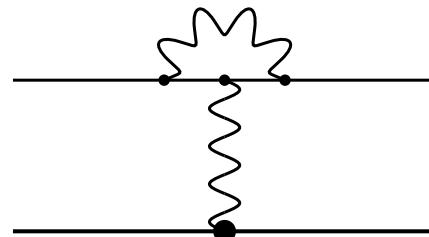
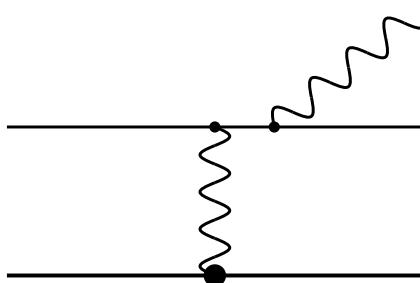
1. One-photon exchange



$$J_{em}^\mu = e \bar{u}(P') \left[\gamma^\mu F_1(Q^2) + \frac{i\sigma^{\mu\nu} q_\nu}{2M} F_2(Q^2) \right] u(P)$$

$$G_E = F_1 - \tau F_2 \quad G_M = F_1 + F_2 \quad \left(\tau = \frac{Q^2}{4M^2} \right)$$

2. Radiative corrections (sample diagrams)



$$\sigma_{1\gamma,2\gamma} \propto (Q_L)^3$$

3. Recent evidence for two-photon exchange

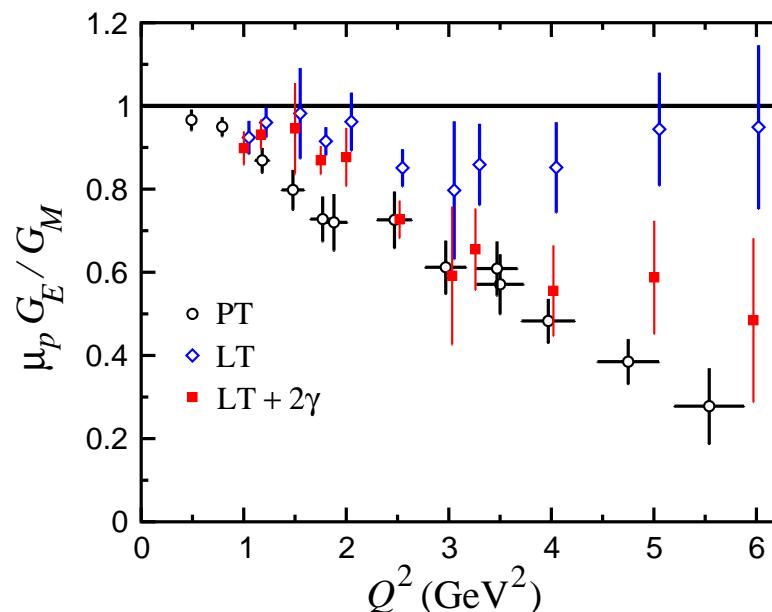
→ Measurement of G_E^p at Jefferson Lab (Jones et al., 2000)

Rosenbluth method

$$\frac{d\sigma}{d\Omega} \propto G_M^2 + \frac{\varepsilon}{\tau} G_E^2$$

Polarization transfer

$$\frac{P_\perp}{P_\parallel} = - \sqrt{\frac{2\varepsilon}{\tau(1+\varepsilon)}} \frac{G_E}{G_M}$$

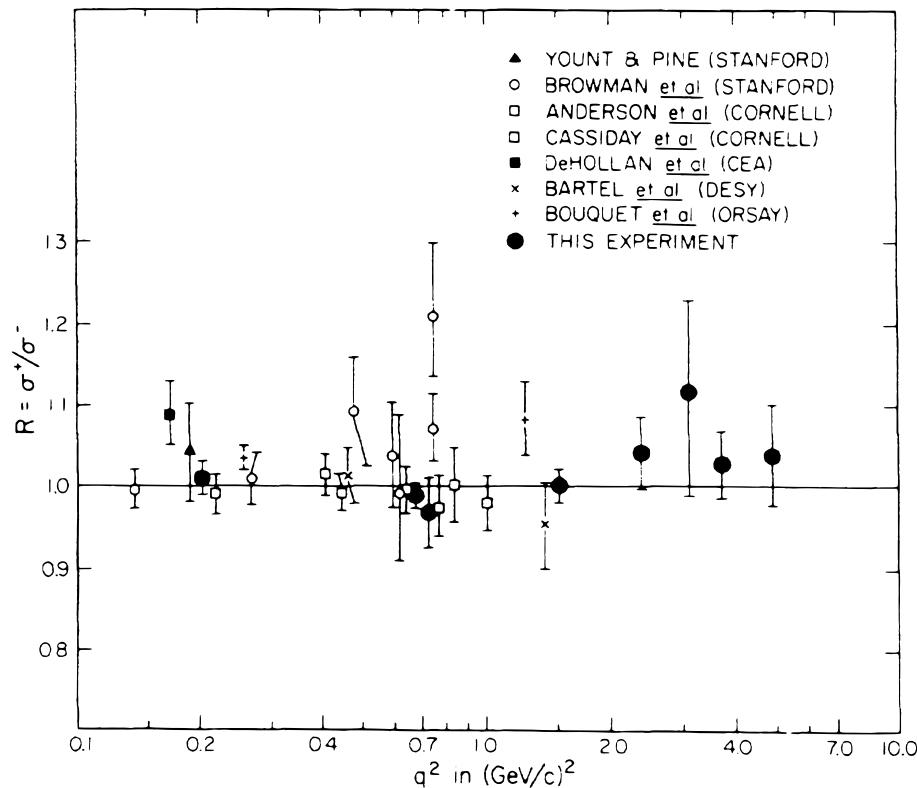


(Carlson, Vanderhaeghen, 2007; on the basis of Blunden, Melnitchouk, Tjon, 2005)

→ Discrepancy between two methods may be due to two-photon exchange

4. Charge asymmetry measurements

- Past



(Mar et al., 1968)

→ Effect consistent with zero within error bars

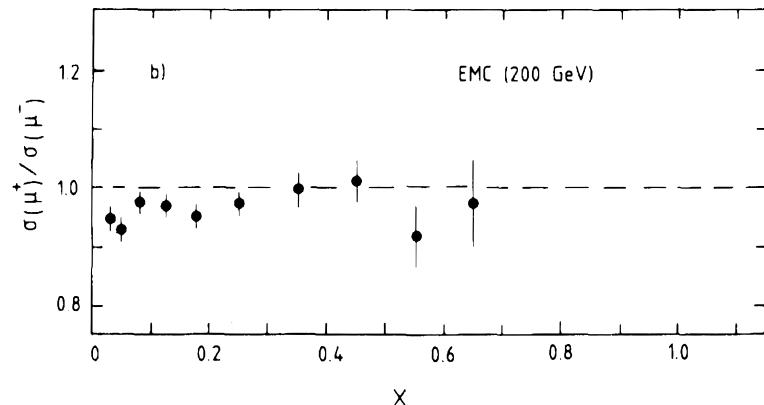
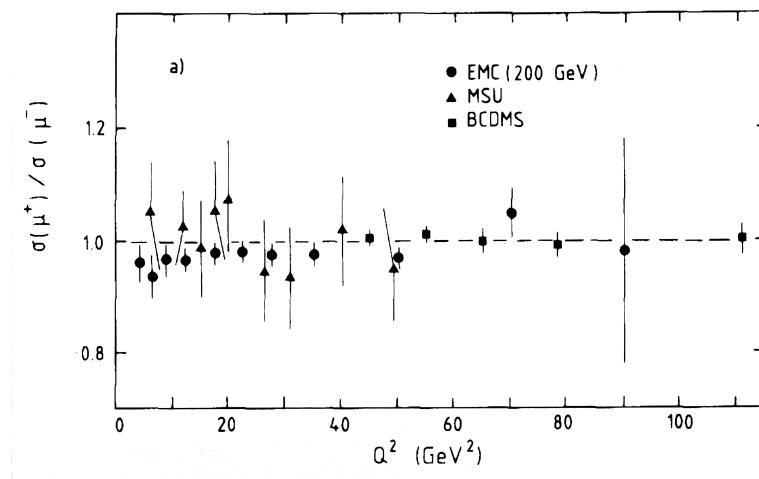
- Future

Jefferson Lab experiment E-04-116; contact person: W. Brooks

→ May provide lower limit on two-photon effect

Charge asymmetry in inclusive DIS

- First measurement: Jöstlein et al., 1974
 - Effect consistent with zero within error bars
 - Upper limit on two-photon effect: 1.7%
- Later measurements: EMC, etc.



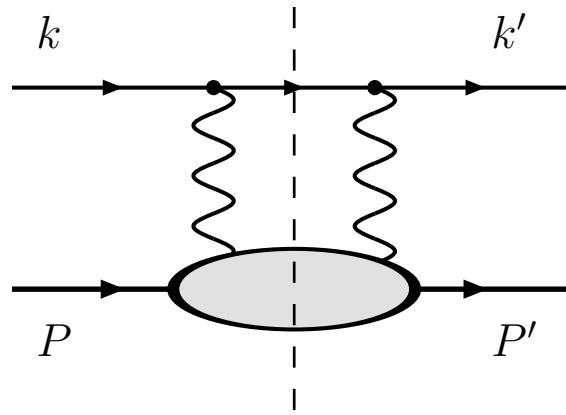
→ Effect consistent with zero within error bars

SSAs in elastic lepton nucleon scattering

1. Mechanism

$$\sigma_{pol} \propto \varepsilon_{\mu\nu\rho\sigma} S^\mu P^\nu k^\rho k'^\sigma \propto \vec{S} \cdot (\vec{k} \times \vec{k}')$$

- Transverse (w.r.t. scattering plane) SSA
- Effect requires imaginary part on the amplitude level



$$A_\perp = \frac{2 T_{1\gamma} \operatorname{Im}(T_{2\gamma})}{|T_{1\gamma}|^2}$$

- Clear signal for two-photon exchange
- First calculation for lepton lepton scattering: Barut, Fronsdal, 1960

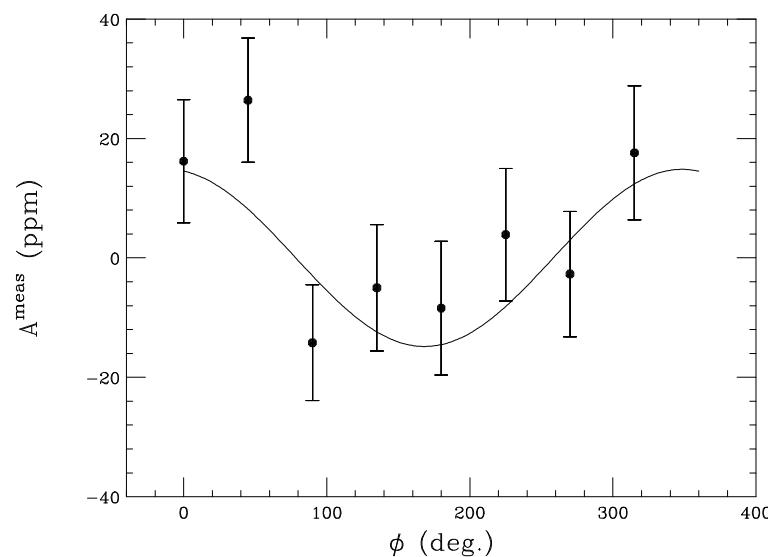
2. Experiments

→ Measurements for polarized electrons

→ Expected effect:

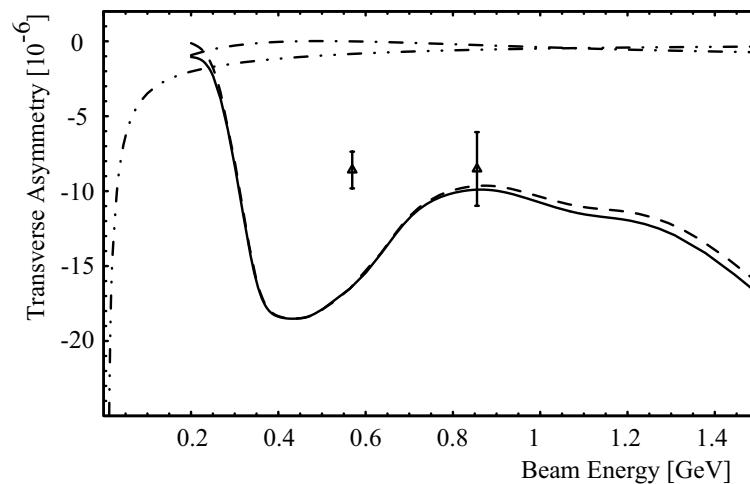
$$A_{\perp} \propto \alpha_{em} \frac{m_e}{Q} \approx 10^{-5}$$

Wells et al., 2000



$$A_{\perp} = (-15.4 \pm 5.4) \text{ ppm}$$

Maas et al., 2004



→ First lower limit on two-photon effect

→ Several other running experiments (preliminary results)

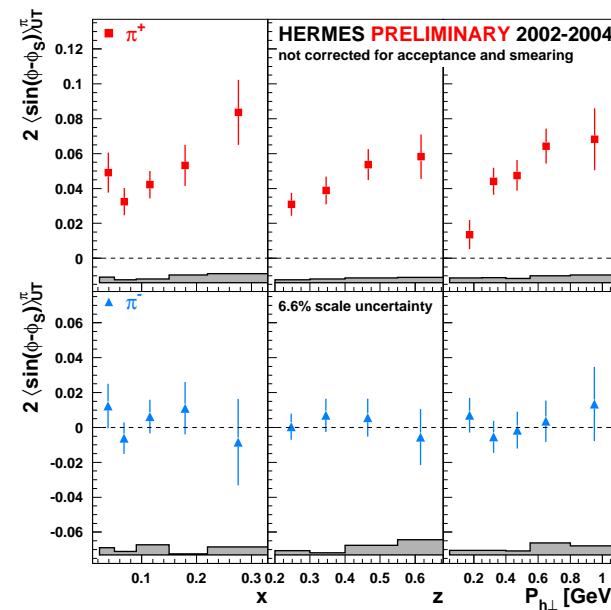
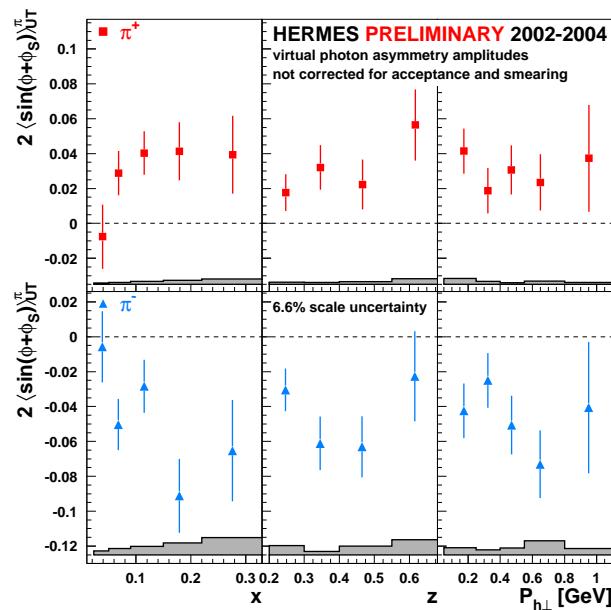
→ Several model calculations (hadronic, partonic picture)

SSAs in semi-inclusive DIS

Transverse target SSA (leading twist)

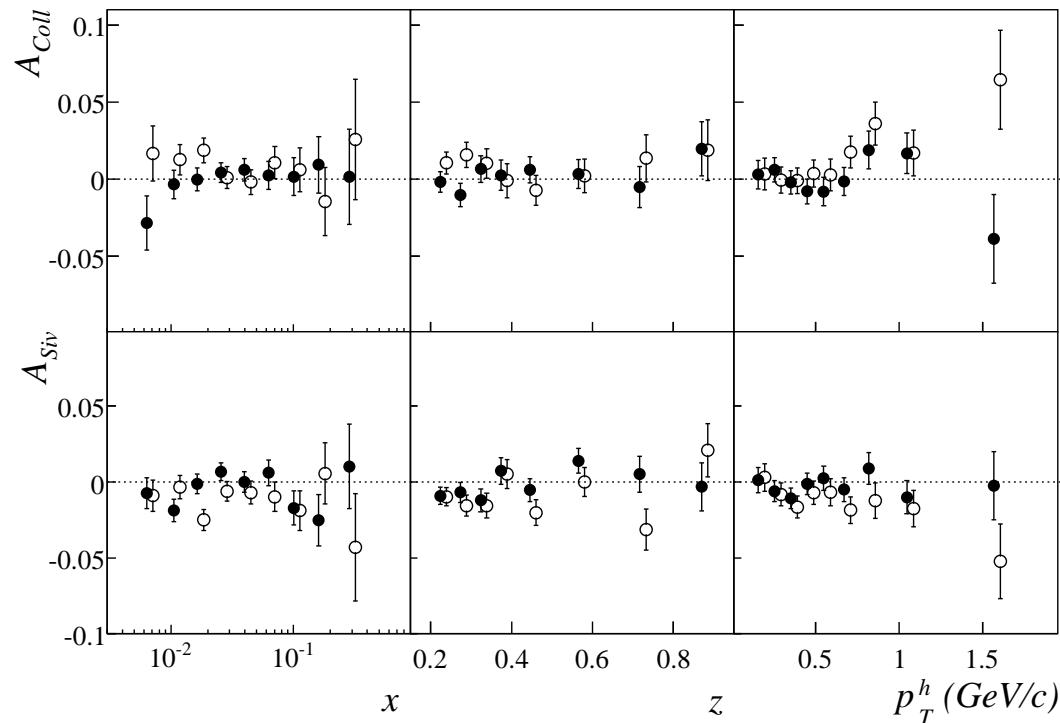
$$A_{UT} \propto \sin(\Phi_h + \Phi_S) h_1(x) H_1^\perp(z) + \sin(\Phi_h - \Phi_S) f_{1T}^\perp(x) D_1(z) + \sin(3\Phi_h - \Phi_S) \dots + \mathcal{O}(1/Q)$$

HERMES data on $l p^\uparrow \rightarrow l' H X$



→ Non-zero Collins and Sivers effect

COMPASS data on $l D^\dagger \rightarrow l' H X$



- Collins and Sivers effect consistent with zero within error bars
- Can be understood on the basis of large N_c result: (Pobylitsa, 2003)

$$f_{1T}^{\perp u/p} = -f_{1T}^{\perp d/p} = -f_{1T}^{\perp u/n}$$

Leading twist TMDs in semi-inclusive DIS

$$\sigma_{UU} : \quad f_1(x) D_1(z) \quad \cos(2\Phi_h) h_1^\perp(x) H_1^\perp(z)$$

$$\sigma_{LL} : \quad g_{1L}(x) D_1(z)$$

$$\sigma_{LT} : \quad \cos(\Phi_h - \Phi_S) g_{1T}(x) D_1(z)$$

$$\sigma_{UL} : \quad \sin(2\Phi_h) h_{1L}^\perp(x) H_1^\perp(z)$$

$$\begin{aligned} \sigma_{UT} : \quad & \sin(\Phi_h - \Phi_S) f_{1T}^\perp(x) D_1(z) & \sin(\Phi_h + \Phi_S) h_1(x) H_1^\perp(z) \\ & \sin(3\Phi_h - \Phi_S) h_{1T}^\perp(x) H_1^\perp(z) \end{aligned}$$

- Complete experiment for p_T -dependent parton densities
- Comparable study also possible in Drell-Yan

SSAs in inclusive DIS

1. One-photon exchange

- Unpolarized case

→ 2 structure functions: $F_1 \quad F_2$

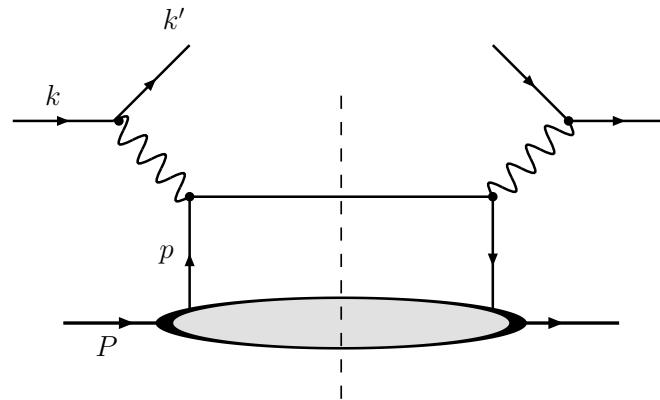
$$k'^0 \frac{d\sigma_{unp}}{d^3\vec{k}'} = \frac{4\alpha_{em}^2}{Q^4} \left(x y F_1(x, Q^2) + \frac{1-y}{y} F_2(x, Q^2) \right)$$

$$y = \frac{P \cdot (k - k')}{P \cdot k} = \frac{\nu_{Lab}}{E_{Lab}}$$

- (Double) polarized case

→ 2 structure functions: $g_1 \quad g_2$

2. Parton model



- Unpolarized case

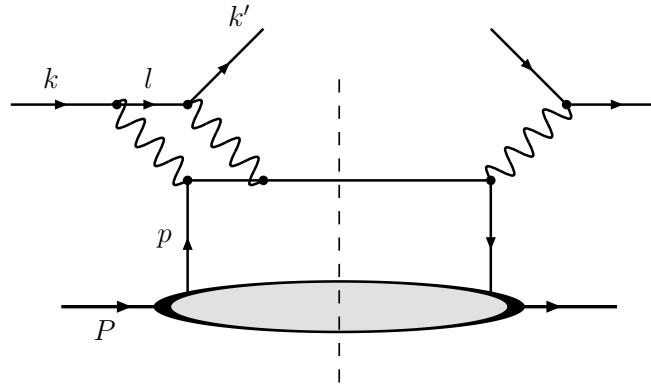
$$F_2(x) = 2x F_1(x) = \sum_q e_q^2 x f_1^q(x)$$

- Polarized case

$$g_1(x) = \frac{1}{2} \sum_q e_q^2 g_1^q(x)$$

$$g_1(x) + g_2(x) = \frac{1}{2} \sum_q e_q^2 g_T^q(x)$$

3. Two-photon exchange and SSAs



- Lepton single spin asymmetry

$$k'^0 \frac{d\sigma_{L,pol}}{d^3 \vec{k}'} = \frac{4 \alpha_{em}^3}{Q^8} m x y^2 \varepsilon_{\mu\nu\rho\sigma} S^\mu P^\nu k^\rho k'^\sigma \sum_q e_q^3 x f_1^q(x)$$

- Target single spin asymmetry

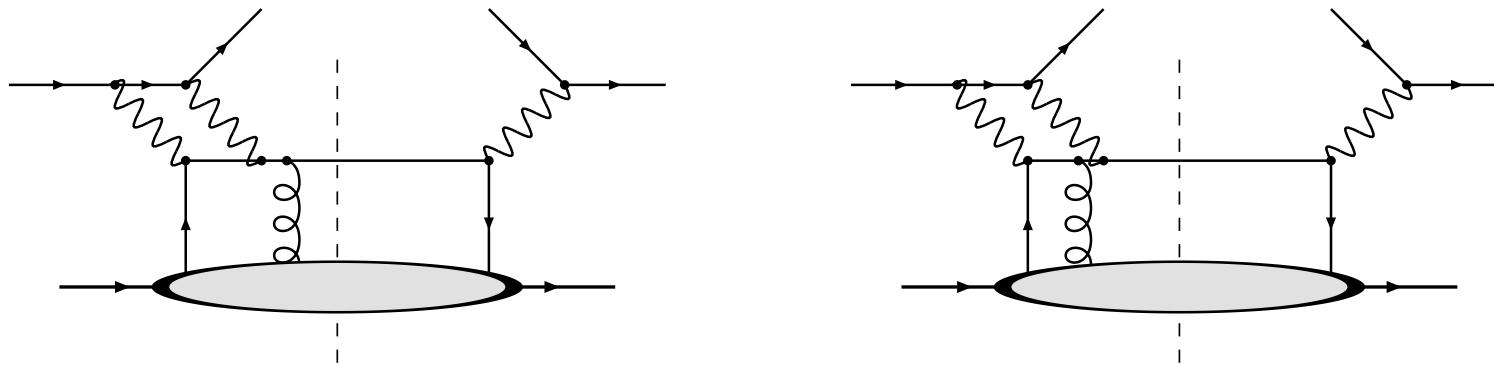
$$\begin{aligned} k'^0 \frac{d\sigma_{N,pol}}{d^3 \vec{k}'} &= \frac{4 \alpha_{em}^3}{Q^8} \frac{M x^2 y}{1 - y} \varepsilon_{\mu\nu\rho\sigma} S^\mu P^\nu k^\rho k'^\sigma \sum_q e_q^3 x g_T^q(x) \\ &\times \left((1 - y)^2 \ln \frac{Q^2}{\lambda^2} + y(2 - y) \ln y + y(1 - y) \right) \end{aligned}$$

→ IR-divergent result

- Allowing for transverse parton momenta

$$\begin{aligned}
 k'^0 \frac{d\sigma_{N,pol}}{d^3 \vec{k}'} &= \frac{4 \alpha_{em}^3}{Q^8} \frac{M x^2 y}{1 - y} \varepsilon_{\mu\nu\rho\sigma} S^\mu P^\nu k^\rho k'^\sigma \\
 &\times \int d^2 \vec{p}_T H(\vec{p}_T^2) \sum_q e_q^3 \left(x g_T^q(x, \vec{p}_T^2) - \frac{\vec{p}_T^2}{2M^2} g_{1T}^q(x, \vec{p}_T^2) \right)
 \end{aligned}$$

- Inclusion of quark-gluon-quark correlations: $\langle P, S | \bar{\psi} A_T \psi | P, S \rangle$



→ IR-finite result may be obtained

4. SSA measurements

- Past

Incident beam	Incident electron energy, E_0 GeV	Four-momentum transfer squared q^2 (GeV/c) 2	Asymmetry value, A(%)			This experiment
			$\Delta(1236)$	$N^*(1512)$	$N^*(1688)$	
e^-	18.0	0.58 ^a	2.8 ± 1.4	-1.3 ± 1.7	0.8 ± 2.1	
e^+	12.0	0.42 ^b	-3.0 ± 1.8	---	---	
e^-	15.0	0.37 ^a	2.3 ± 2.9	3.1 ± 2.2	2.0 ± 3.1	
e^-	18.0	0.96 ^a	-2.8 ± 3.3	-4.8 ± 3.6	-8.2 ± 4.7	
<hr/>						
e^-	3.98	0.23 ^b	3.8 ± 4.3	---	---	Chen et al.
e^-	5.97	0.72 ^a	---	3.6 ± 4.7	-0.5 ± 4.4	
e^-	5.98	0.52 ^a	---	-2.6 ± 8.2	3.6 ± 7.3	

^aAt 1.512-GeV missing mass.

^bAt 1.236-GeV missing mass.

(Rock et al., 1970)

- Effect consistent with zero within error bars
- Indication for charge asymmetry

- Future

- Jefferson Lab experiment E-07-013; contact person: X. Jiang
- COMPASS
- HERMES

Summary

1. Renewed interest in multi-photon exchange in lepton nucleon scattering
2. Sensitive observables
 - Charge asymmetries
 - Transverse single spin asymmetries
3. First lower bound on two-photon exchange by measurement of SSA in elastic electron nucleon scattering
4. Multi-photon exchange generates transverse SSAs in inclusive DIS
 - Reliable result in parton model for lepton spin asymmetry
 - Target spin asymmetry is generic twist-3 effect
→ Requires inclusion of transverse parton momenta and qqq-correlations
 - Order of magnitude estimate:

$$A_{\perp, \text{target}}^{\text{DIS}} \propto \alpha_{em} \frac{M}{Q} \approx 10^{-2}$$

- Worthwhile to study at COMPASS, HERMES, Jefferson Lab