What can we learn from A_{UT} in ρ^0 exclusive electroproduction at HERMES

A.V. Vinnikov

A. von Humboldt fellow, DESY, Zeuthen and research fellow, JINR, Dubna

The physical contents of the A_{UT} asymmetry in ρ^0 exclusive electroproduction is considered. In QCD A_{UT} is described in terms od GPDs. Its measurement gives access to the presently unknown spin-flip GPD E and hence, through Ji's sum rule, to the quark **total** angular momentum in the nucleon. The prospects to obtain constraints on J_u from the HERMES data on A_{UT} in ρ^0 electroproduction are discussed.

Generalised Parton Distributions (GPDs)

$$(x + \xi)\frac{p_1 + p_2}{2} \qquad (x - \xi)\frac{p_1 + p_2}{2}$$

$$p_1 \qquad p_2$$
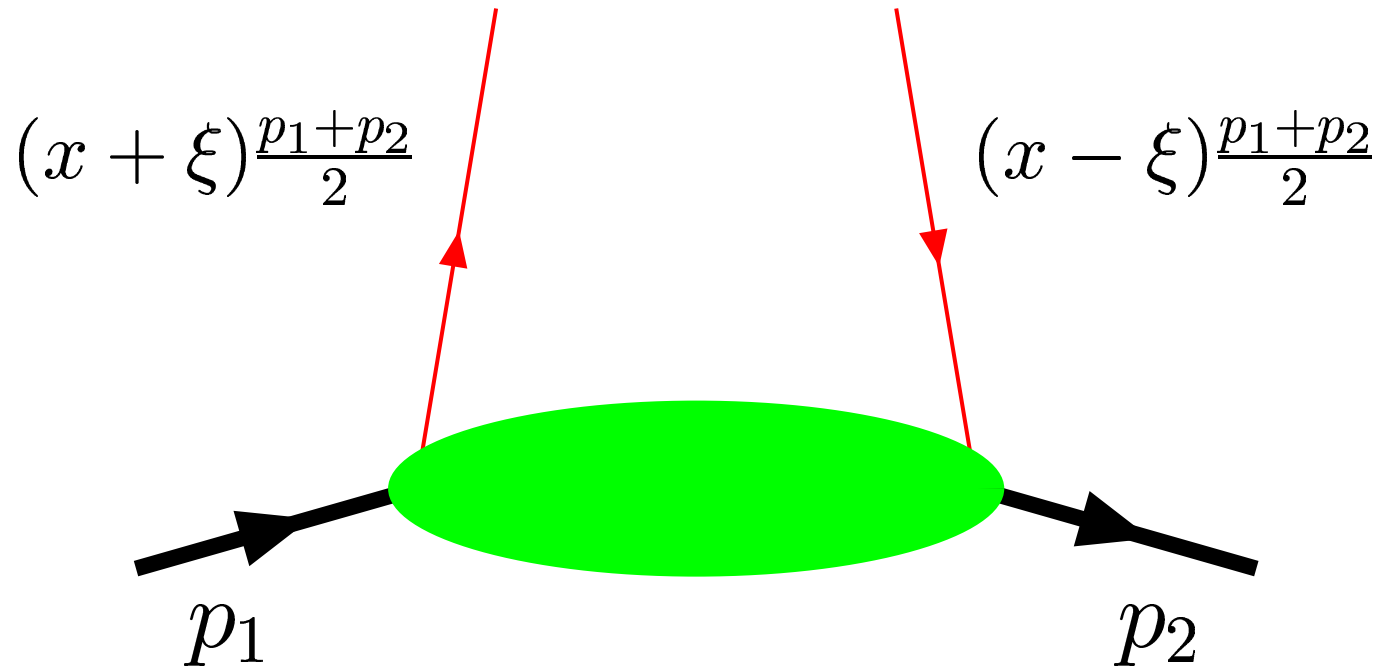
Ji sum rule:

$$J_a(Q^2) = \frac{1}{2}\lim_{t \to 0} \int_{-1}^{1} x\left[H_a(x, \xi, t, Q^2) + E_a(x, \xi, t, Q^2) \right] dx$$

$$H(x, \xi, t) = \frac{4m^2 - 2.8t}{4m^2 - t} \frac{H(x, \xi)}{(1 - t/0.71)^2}$$

$$H(x, \xi) = \int\limits_{-1}^{1} d\beta \int\limits_{-1+|\beta|}^{1-|\beta|} d\alpha \; \delta(x - \beta - \alpha\xi) \, F_q(\beta, \alpha) \,, \quad F_q(\beta, \alpha) = h(\beta, \alpha)q(\beta)$$

$$h(\beta, \alpha) = \frac{\Gamma(2b+2)}{2^{2b+1}\Gamma^2(b+1)} \frac{\left[(1-|\beta|)^2 - \alpha^2\right]^b}{(1-|\beta|)^{2b+1}}$$

$$E_q(x, \xi) = \int\limits_{-1}^{1} d\beta \int\limits_{-1+|\beta|}^{1-|\beta|} d\alpha \delta(x - \beta - \alpha\xi) K_q(\beta, \alpha) \,, \quad K_q(\beta, \alpha) = h(\beta, \alpha)e_q(\beta)$$
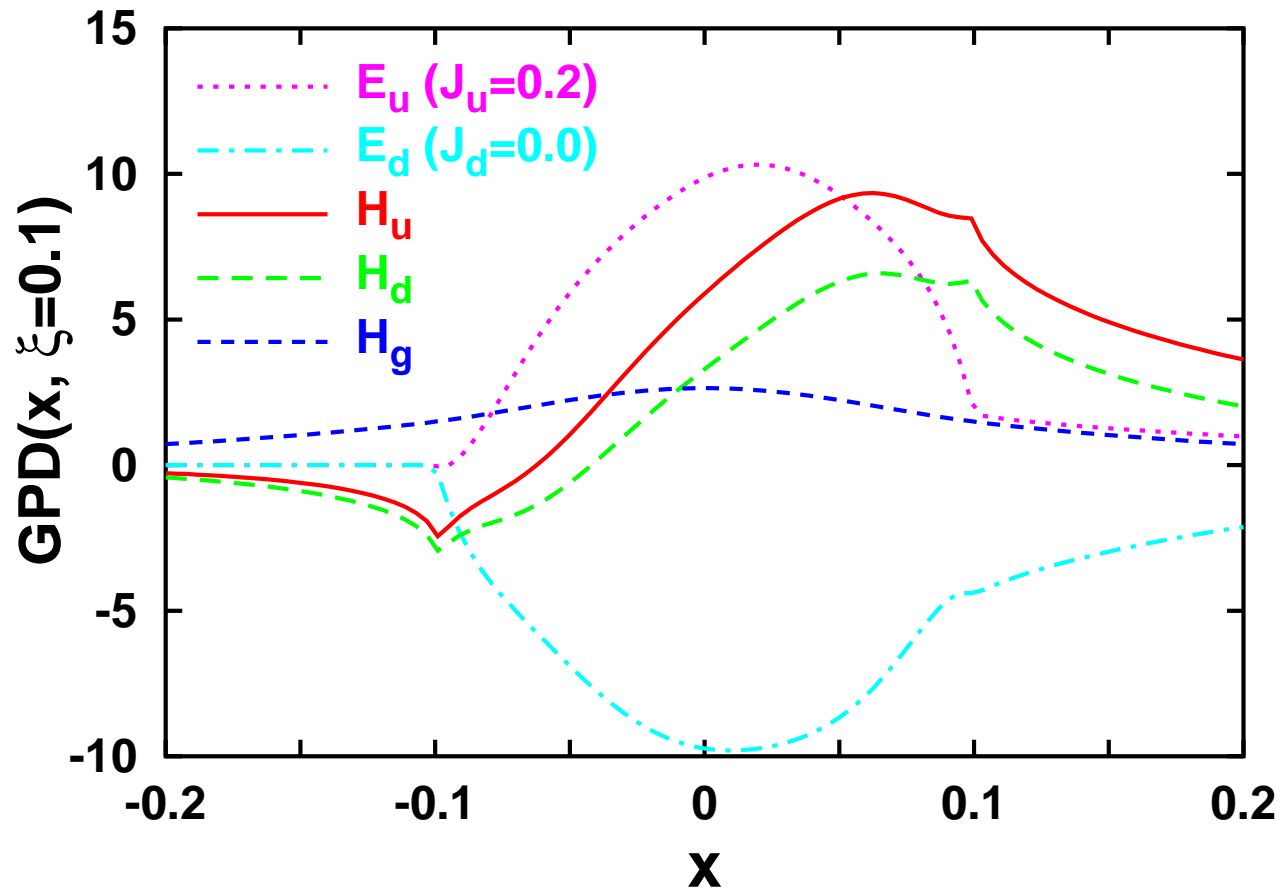
$$e_q(x) = A_q q_{val}(x) + B_q \delta(x)$$

$$\int\limits_{-1}^{+1} e_q(x)dx = \kappa_q \,, \quad \kappa_u = 2\kappa_p + \kappa_n = 1.67, \kappa_d = \kappa_p + 2\kappa_n = -2.03$$

$$A_q = \frac{2\,J_q - M_q^{(2)}}{M_{q_{val}}^{(2)}} \,, \qquad B_u = 2\left[\frac{1}{2}\kappa_u - \frac{2J_u - M_u^{(2)}}{M_{u_{val}}^{(2)}}\right] \,, \qquad B_d = \kappa_d - \frac{2J_d - M_d^{(2)}}{M_{d_{val}}^{(2)}}$$

What about E_g? From Ji sum rule and momentum sum rule $\sum\limits_{a} \int\limits_{-1}^{1} x H_a dx = 1$:

$$\lim_{t \to 0} \int_{-1}^{1} x \left(E_u(x,\xi,t) + E_d(x,\xi,t) + E_g(x,\xi,t) \right) dx = 0$$

as E_u and E_d about compensate each other, E_g is expected to be small

CROSS SECTION AND ASYMMETRY IN TERMS OF GPDS

The GPDs-based description of vector meson exclusive electroproduction requires both the virtual photon and the vector meson to be longitudinal. The present calculations thus cover only the longitudinal part of the cross section.

$$\frac{d\sigma_L}{dt} = \frac{1}{8m\pi(W^2 - m^2)|\vec{q}_1|}\left(|\mathcal{T}_A|^2 + |\mathcal{T}_B|^2\right)$$

$\vec{q}_1$ is the momentum of the virtual photon in the center of mass system of this photon and the initial proton, W is their invariant mass.

$$\mathcal{T}_A = -i\pi\mathcal{A}\frac{4\sqrt{2}e\alpha_s}{9Q}\int\limits_0^1 dz\frac{\Phi(z)}{z}, \qquad \mathcal{T}_B = -i\pi\mathcal{B}\frac{|\Delta_T|}{m}\frac{2\sqrt{2}e\alpha_s}{9Q}\int\limits_0^1 dz\frac{\Phi(z)}{z}$$

$$\mathcal{A} = \int\limits_{-1}^1 \left(e_u H_u(x,\xi,t) - e_d H_d(x,\xi,t) + \frac{3}{8}\frac{H_g(x,\xi,t)}{x}\right)\left(\frac{1}{x-\xi+i\epsilon} + \frac{1}{x+\xi-i\epsilon}\right) dx$$

$$\mathcal{B} = \int\limits_{-1}^1 \left(e_u E_u(x,\xi,t) - e_d E_d(x,\xi,t) + \frac{3}{8}\frac{E_g(x,\xi,t)}{x}\right)\left(\frac{1}{x-\xi+i\epsilon} + \frac{1}{x+\xi-i\epsilon}\right) dx$$

$$A_{UT}(\phi - \phi_S) = \frac{d\sigma(\phi - \phi_S) - d\sigma(\phi - \phi_S + \pi)}{d\sigma(\phi - \phi_S) + d\sigma(\phi - \phi_S + \pi)} = A_{UT}^{\sin(\phi - \phi_S)} \cdot \sin(\phi - \phi_S)$$

In the exclusive VM photo and electroproduction
there is only one (namely, $\sin(\phi - \phi_S)$) moment of the asymmetry

$$A_{UT}^{\sin(\phi - \phi_S)} = \frac{Im(\mathcal{A}\mathcal{B}^*)|\Delta_T|/m}{(1 - \xi^2)|\mathcal{A}|^2 - (\xi^2 + \frac{t}{4m^2})|\mathcal{B}|^2 - 2\xi^2 Re(\mathcal{A}\mathcal{B}^*)}$$

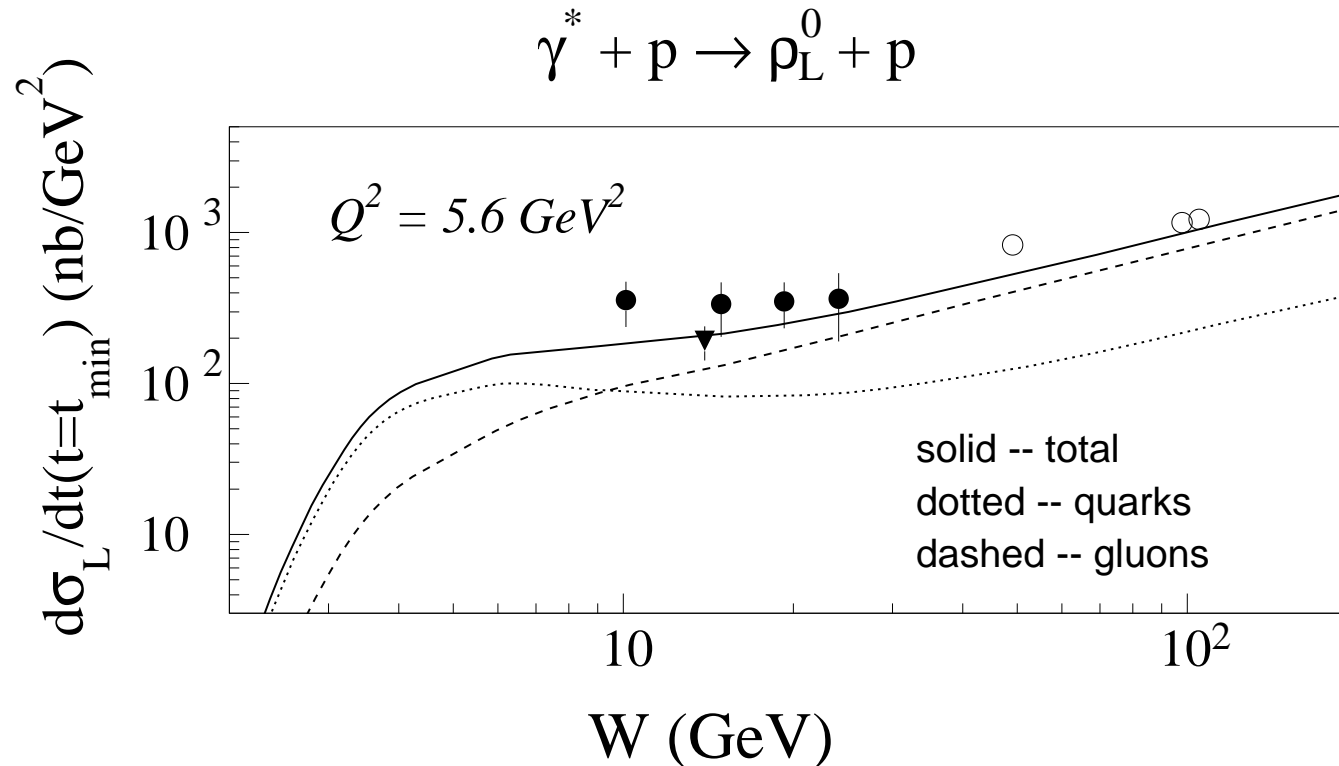The imaginary part comes from the Cauchy integral

$$\int_{a<x_0}^{b>x_0} \frac{f(x)}{x - x_0 - i\epsilon} dx = \fint_a^b \frac{f(x)}{x - x_0} dx + i\pi f(x_0)$$

Very strongly simplifying and neglecting E_g,

$$A_{UT}^{\sin(\phi - \phi_S)} \sim \frac{E}{H} = \frac{2/3E_u + 1/3E_d}{2/3H_u + 1/3H_d + 3/(8\xi)H_g}$$

ρ^0 CROSS SECTION: GLUONIC CONTRIBUTION

Guichon, Guidal, Vanderhaeghen [PRD60]: very small gluonic contribution at HERMES energies

$$\gamma^* + p \rightarrow \rho^0_L + p$$

$Q^2 = 5.6 \, GeV^2$

solid -- total
dotted -- quarks
dashed -- gluons

$d\sigma_L/dt(t=t_{min})$ (nb/GeV^2)

W (GeV)

Strong suppression of gluons comes from the effects of transverse motion of quarks in the vector meson and the proton, which are unknown. It comes out that gluons are suppressed much stronger than quarks. But VGG took the pion's parameters for describing transverse motion in vector meson and proton. Is it correct?

No, it is quite incorrect. The VGG model does not describe the $\sigma_\phi/\sigma_{\rho^0}$ ratio.

Simple phenomenological estimate

PRELIMINARY

2/9
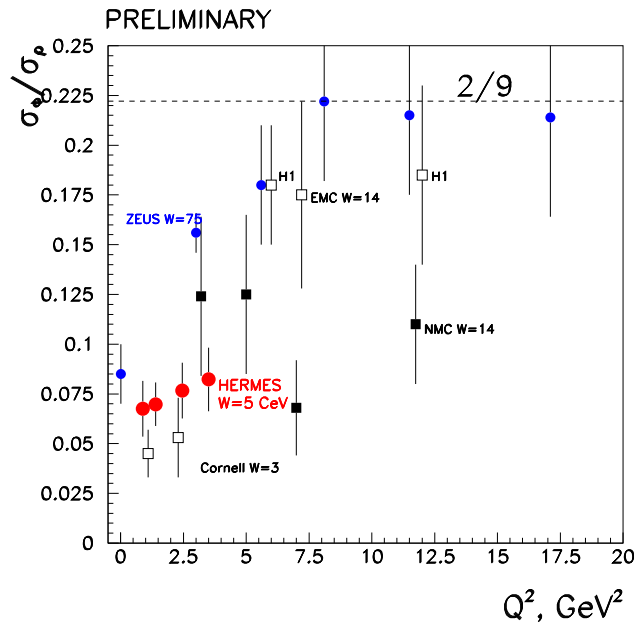
$$\sigma_{\rho^0} = C|q + g|^2 = C(|q|^2 + 2|q||g|\cos(\varphi_{qg}) + |g|^2)$$

$$\sigma_\phi = \frac{2}{9}C|g|^2$$

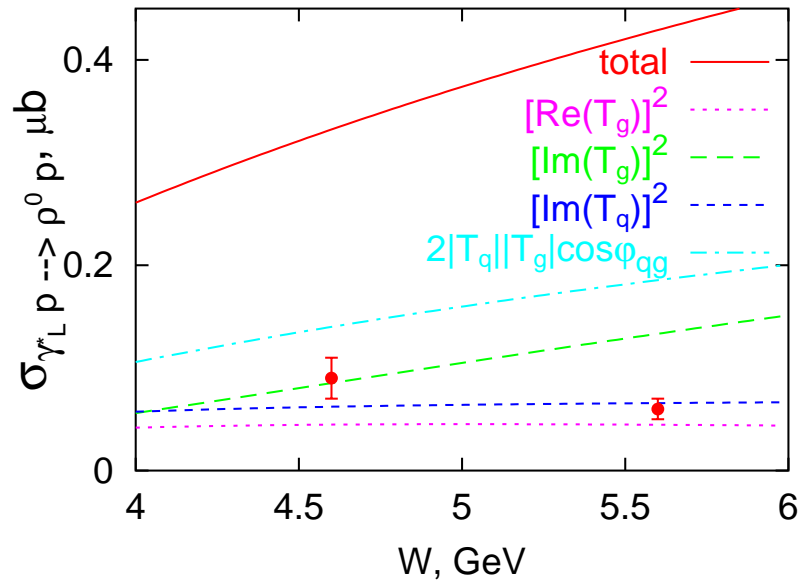$$\frac{\sigma_\phi}{\sigma_{\rho^0}} = \frac{2}{9}\frac{|g|^2}{|q|^2 + 2|q||g| + |g|^2}$$

Using the value of $\sigma_\phi/\sigma_{\rho^0}$ measured at HERMES, we get

$$\frac{|q|}{|g|}\bigg|_{HERMES} \approx 0.7$$

In strong contradiction to VGG result $|q|/|g| = 3$. Probably assuming proton internal transverse motion exact copy of the pion's is far from the reality.
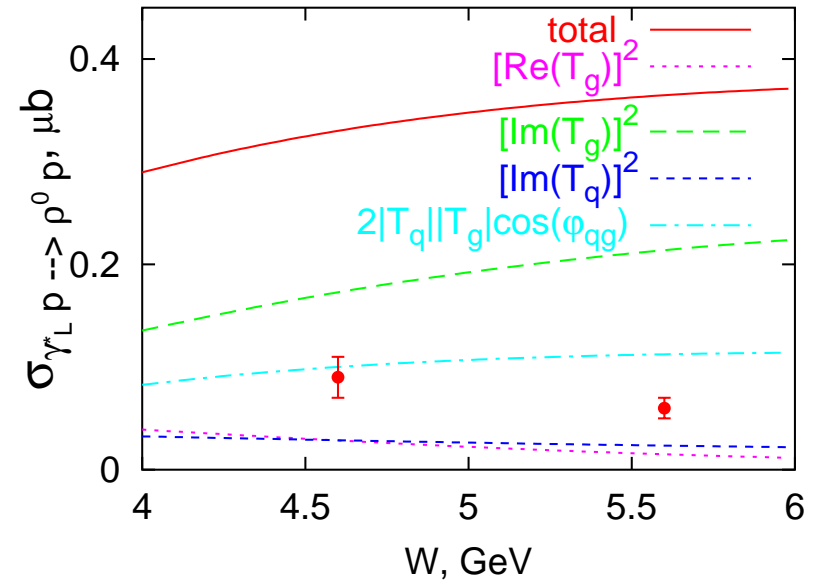
GPDs-based calculation without transverse motion suppression [AV]

Factorized
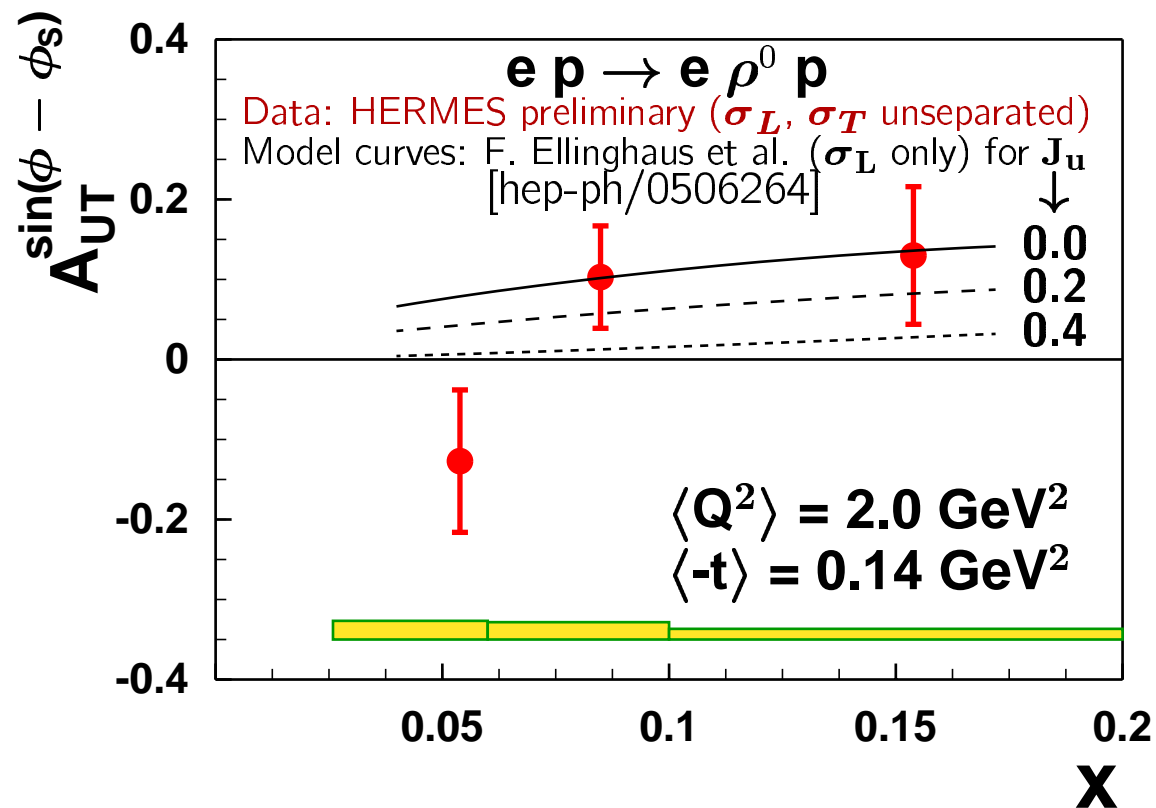

$$\frac{|q|}{|g|} = 0.8 \ .. \ 0.5$$

Reggeized

$$\frac{|q|}{|g|} = 0.5 \ .. \ 0.3$$

The overall normalization depends on the higher twist contributions and the meson wave function normalization. As a simple example, choosing $\Phi(z) = \delta(\frac{1}{2})$ instead of the asymptotic WF $\Phi(z) = 6z(1-z)$ used here provides a factor of $\frac{4}{9}$ suppression for the cross section.

Comparison of VGG vs. AV: GPDs-based description without (unknown) transverse motion effects appears to describe experimental data better than VGG [PRD60]

THE ASYMMETRY

$e\,p \rightarrow e\,\rho^0\,p$

Data: HERMES preliminary (σ_L, σ_T unseparated)
Model curves: F. Ellinghaus et al. (σ_L only) for $\mathbf{J_u}$
[hep-ph/0506264]

0.0
0.2
0.4

$\langle Q^2 \rangle = 2.0\ \text{GeV}^2$
$\langle -t \rangle = 0.14\ \text{GeV}^2$

- $\Delta J_u = 0.4$ corresponds only to 0.1 difference in $A_{UT}^{sin(\phi - \phi_S)}$. The reason is the gluonic dilution of the asymmetry and partial cancellation between E_u and E_d.

- Events with small x probably have $Q^2 < 2\ \text{GeV}^2$. Large higher twist contributions at small Q^2 (say, in σ_T)?

- What happens if σ_L and σ_T are separated? $\rightarrow$ HERMES report 05-044
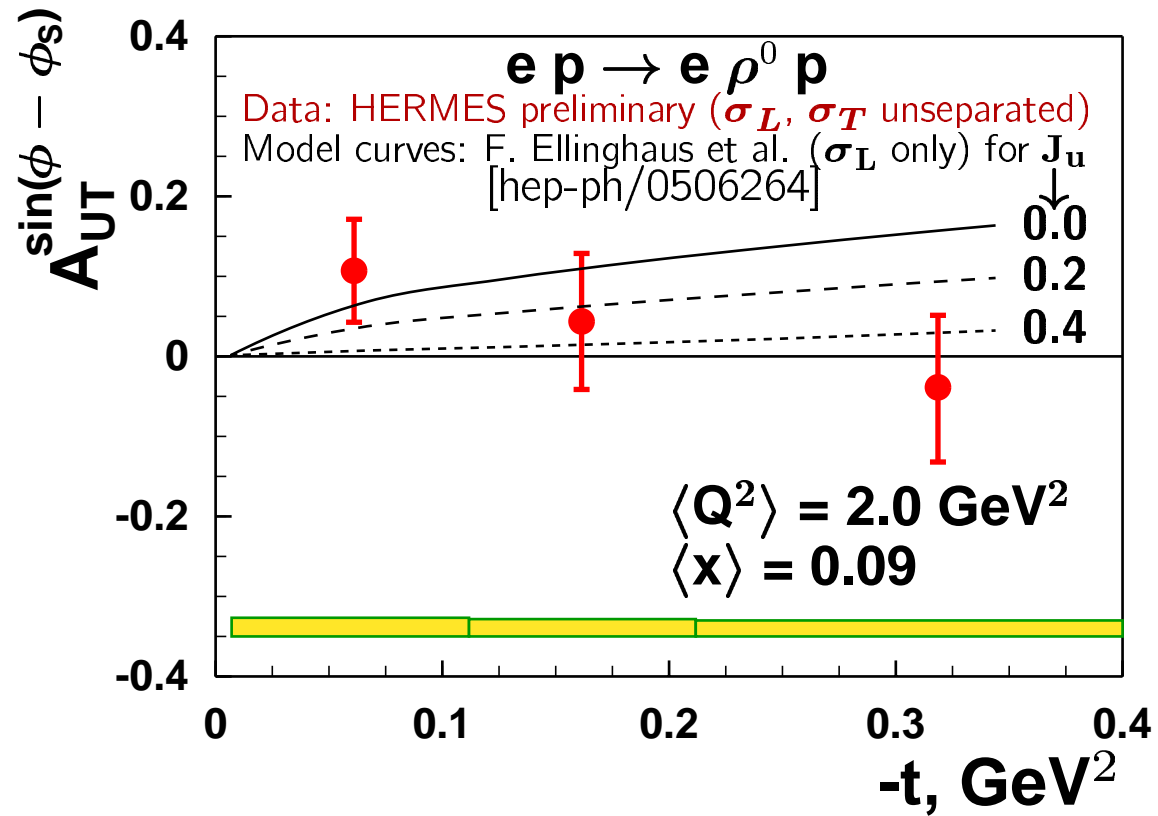
- The observed t-dependence contradicts the expected $\sqrt{-t}$ shape.

- The asymmetry **must** be zero at $t = 0$.

CONCLUSIONS

1. The sensitivity of the $A_{UT}^{sin(\phi-\phi_S)}$ moment of the asymmetry in exclusive ρ^0 electroproduction to the quark total momentum in the proton is not expected to be strong. In particular, the model used in the present calculation gives an estimate: 0.4 difference in J_u results in 0.1 difference in $A_{UT}^{sin(\phi-\phi_S)}$. The reason is the large dilution of the asymmetry by the gluons.

2. NOTE: the significance of the gluonic contribution can be cross-checked by measurement (at least upper limit) of the ρ^+ cross section (as there is no gluonic contribution in ρ^+ production.

3. The low-x behavior of $A_{UT}^{sin(\phi-\phi_S)}$ indicates that higher twist contributions may be significant. A possible source is σ_T.

4. The observed t-dependence contradicts the expected $\sqrt{-t}$ shape. Model-independent statement: $A_{UT}^{sin(\phi-\phi_S)}(t=0)=0$.