Recent HERMES Results in Exclusive ρ and ϕ Transverse Target Spin Asymmetries

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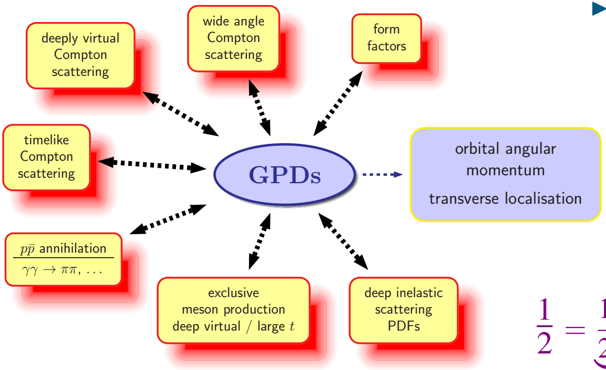
Outline

I. Background and Motivation

Exclusive Reactions and GPDs



- GPDs offer most complete description available of quark-gluon structure of hadrons

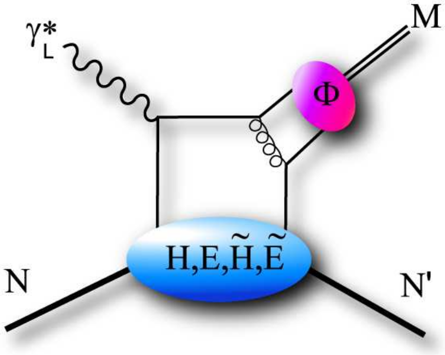
Nucleon Helicity:

$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_q}_{J_q} + \underbrace{\Delta G + L_g}_{J_g}$$

- $\Delta\Sigma = 0.330 \pm 0.011^{(theo.)} \pm 0.025^{(exp.)} \pm 0.028^{(evol.)}$ *[hep-ex/0609039]*
- $\Delta G =$ small (?)
- Measure $J_q = \frac{1}{2}\Delta\Sigma + L_q$

Ji Sum Rule: $J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} x \left(H_q(x, \xi, t) + E_q(x, \xi, t) \right) dx$

Vector Mesons and GPDs



- Soft hadronization process given by meson form factor Φ
- Factorization Theorem for Vector Meson production proven only for longitudinal photons.*

**Collins, Frankfurt, Strikman arXiv:hep-ph/9709336*

- Approximate *s*-channel helicity conservation (SCHC):

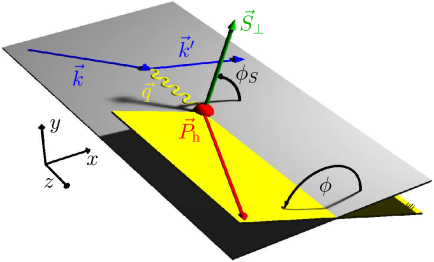
$$\rho \text{ SCHC at } 96.4 \pm 1.6\%^{**}\text{; similar for } \phi^{***}.$$

- Assume exact SCHC
- ρ^0_L/ρ^0_T & ϕ_L/ϕ_T separation can be mapped into γ^*_L/γ^*_T separation
- Meson production sensitive to flavor dependencies of GPDs

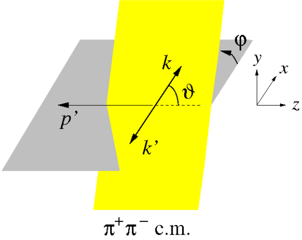
***(HERMES ρ SDMEs, arXiv:hep-ex/0002016)*

****(HERMES φ SDMEs, arXiv:0808.0669)*

Cross-section and A_{UT} Moments



Lab frame



Meson rest frame

[M. Diehl, arXiv:0704.1565]

- For $ep \to e'p'h,\, h \to h'^+h'^-$, the cross-section is proportional to

$$d\sigma(\phi,\phi_s,\varphi) \propto \sigma_{UU}\left[1 + A_{UU}(\phi,\vartheta) + P_T A_{UT}(\phi,\phi_s,\vartheta) + \ldots\right]$$

- L–T separation

$$1 + A_{UU}(P_T,\phi,\vartheta) + P_T A_{UT}(\phi,\phi_s,\vartheta) \propto$$
$$\Big[\cos^2\vartheta \quad r^{04}_{00} \qquad \Big(1 + A_{UU,L}(\phi) + P_T A_{UT,L}(\phi,\phi_s)\Big)$$
$$+\frac{1}{2}\sin^2\vartheta(1-r^{04}_{00})\Big(1 + A_{UU,T}(\phi) + P_T A_{UT,T}(\phi,\phi_s)\Big)\Big]$$

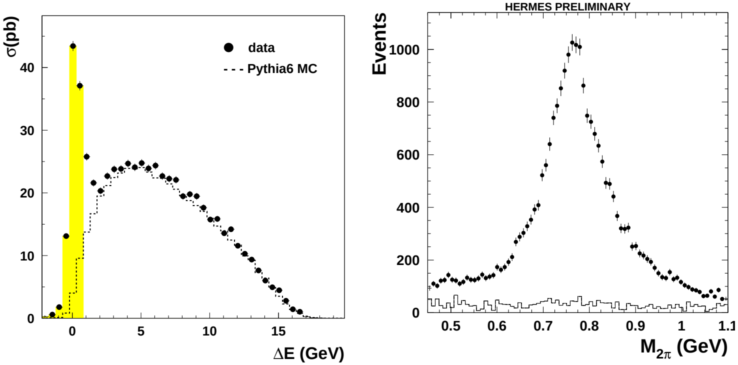
Transverse Target Spin Asymmetry

- Transverse Target Spin Asymmetry defined as
$$\frac{1}{P_T}\frac{d\sigma(\phi,\phi_s)-d\sigma(\phi,\phi_s+\pi)}{d\sigma(\phi,\phi_s)+d\sigma(\phi,\phi_s+\pi)}=\frac{A_{UT}(\phi,\phi_s,\vartheta)}{1+A_{UU}(\phi,\vartheta)}$$
- Instead, extract $A_{UT}(\phi,\phi_s,\vartheta)$ using MLE
- Fix $A_{UU}(\phi,\vartheta)$ using SDME values
- $A_{UT,L}$ and $A_{UT,T}$ parametrized as
$$A_{UT,X}(\phi,\phi_s) \quad = \quad A_{UT,X}^{\sin(\phi-\phi_s)}\sin(\phi-\phi_s)+\text{five other terms.}$$
- Note:*
$$\begin{aligned} A_{UT,L}^{\sin(\phi-\phi_s)} &= \frac{\sqrt{t_0-t}}{m_p}\frac{\sqrt{1-\xi^2}\mathrm{Im}(\mathcal{E}_V{}^*\mathcal{H}_V)}{(1-\xi^2)|\mathcal{H}_V|^2-(t/(4m_p^2)+\xi^2)|\mathcal{E}_V|^2-2\xi^2\mathrm{Re}(\mathcal{E}_V{}^*\mathcal{H}_V)} \\ &\approx \frac{\sqrt{t_0-t}}{m_p}\left|\frac{\mathcal{E}_V}{\mathcal{H}_V}\right|\sin\delta_V \end{aligned}$$
- Assume $\mathcal{E}_V \ll \mathcal{H}_V$ in above approximation
- GPD E not suppressed in exclusive meson production, as it is in DVCS & other processes

*arXiv:0708.1121

Exclusive $\boldsymbol{\rho^0}$: Analysis and Results

Hard Exclusive ρ_L^0 Production

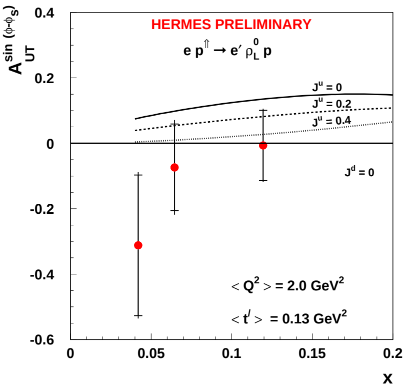


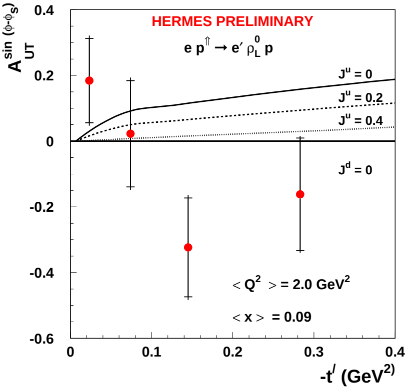
- Exclusive events determined by $\Delta E < 0.6$ GeV
- ρ^0 identified by peak in the mass of two-pion system distribution.
- Note: subtle difference between defining angles w.r.t. virtual photon or incident electron*
  - $P_T A_{UT}^{e^\pm} = S_T(\theta_\gamma, \phi_s) A_{UT}^{\gamma^*} + S_L(\theta_\gamma, \phi_s) A_{UL}^{\gamma^*}$
  - $|\frac{S_L}{S_T}| < 0.15 \implies P_T A_{UT}^{e^\pm} \sim S_T(\theta_\gamma, \phi_s) A_{UT}^{\gamma^*}$ at HERMES

Diehl & Sapeta, arXiv:hep-ph/0503023

Results with Ellinghaus, et al., Model

$$A_{UT}^{\sin(\phi-\phi_s)} \propto \frac{\mathcal{E}}{\mathcal{H}} \propto \frac{\mathcal{E}_q + \mathcal{E}_g}{\mathcal{H}_q + \mathcal{H}_g}$$

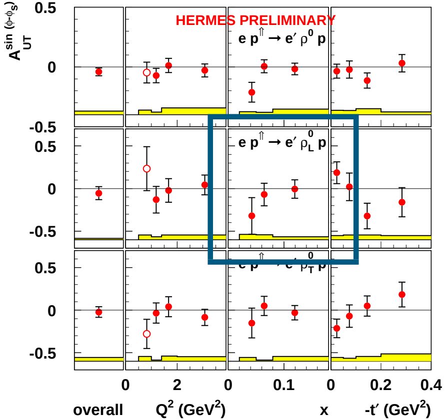




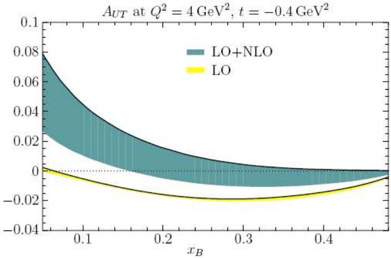
- F. Ellinghaus, W.D. Nowak, A.V. Vinnikov, Z.Ye, hep-ph/0506264
- Uses all transverse data, 2002-2005!
- Assume $J_d = 0$ for above plots
- Constraint on J_u, J_d in progress

Results with Diehl/Kugler Model

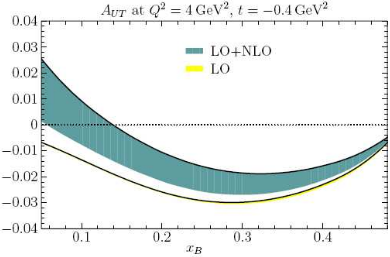
arXiv:0708.1121



$$\langle Q^2 \rangle = 2.0\ \mathrm{GeV}^2$$
$$\langle -t' \rangle = 0.14\ \mathrm{GeV}^2$$



Model 1: $e_{\bar{q}} \approx e_{q_v}$

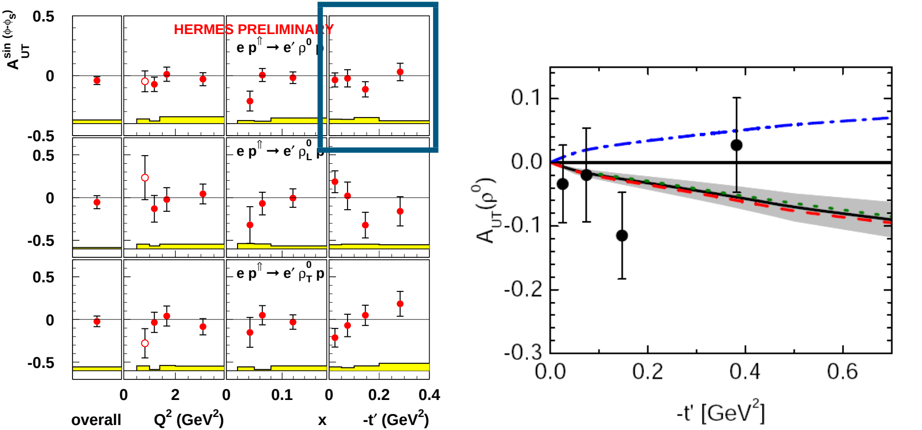


Model 2: $e_{\bar{q}} \approx e_g$

Model 2 slightly preferred; Model params. yield $J_u \approx 0.2$, $J_d \approx 0$

Results with Goloskokov/Kroll Model

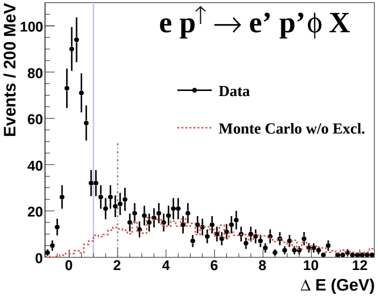
arXiv:0809.4126

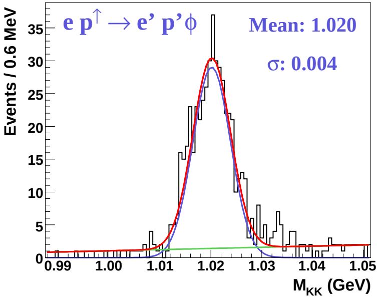


- H taken from previous electro-production cross-sections
- E taken computed with double distributions, constrained by Pauli nucleon form factors, positivity bounds and sum rules.
- Four variants on the model parameters considered
- Agreement between data and model within uncertainties

Exclusive ϕ: Analysis and Results

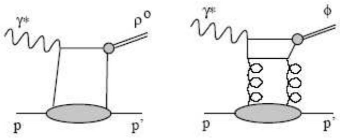
Hard Exclusive ϕ_L Production



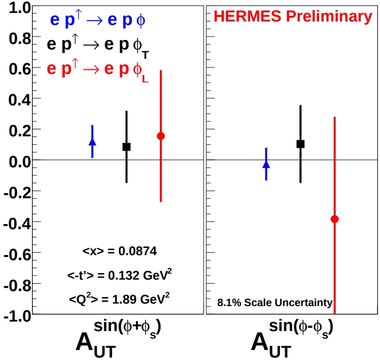


- Identify exclusive ϕ in similar manner as identified exclusive ρ^0
- ΔE cut now placed at 1.0 GeV.
- Note: ϕ is $s\bar{s}$ pair, while ρ^0 is $(u\bar{u} - d\bar{d})/\sqrt{2}$ combination
- Predicted that ϕ A_{UT} sensitive to gluon GPDs

$$A_{UT}^{\sin(\phi-\phi_s)} \propto \frac{\mathcal{E}_q + \mathcal{E}_g}{\mathcal{H}_q + \mathcal{H}_g}$$

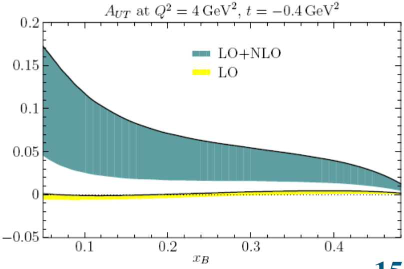


Results



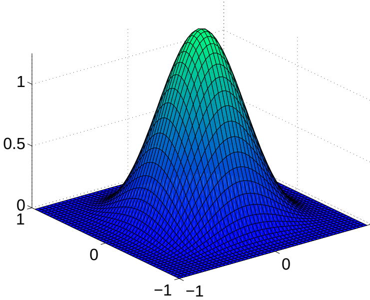
- Only fully integrated moments shown, as limited statistics
- Newer approach using Kernel Density Estimation may allow extraction of kinematic dependencies

- Model prediction by Diehl/Kugler *arXiv:0708.1121*
- First theoretical treatment for excl. ϕ A_{UT}
- Model at higher Q^2 and $-t'$
- Uncertainty on extracted value too large to make strong conclusions



IV. Conclusion and Outlook

Kernel Density Estimation



- Given:
  - Data set $\mathbb{X} = \left\{x^{(i)}\right\}_{i=1}^{N}$ in D dimensions
  - Normalized, centered kernel function K
  - Bandwidth Matrix H
- The Kernel Density Estimate (KDE) of the probability density function (PDF) is

$$\hat{p}(x|\mathbb{X}) = \frac{1}{N}\sum_{i=1}^{N} K\left(H^{-1}(x - x^{(i)})\right)$$

Clara Kernel:

$$K \propto \prod_{k=1}^{D}\left[1 - \left(\frac{x_k - x_k^{(i)}}{h_k}\right)^2\right]^{\gamma}\Theta(\cdot)$$

- KDEs are non-parametric, continuous density estimators
- Optimal asymptotic convergence $\rightarrow$ minimal information loss
  - More accurate and precise than histograms for given statistics
  - Scales better with small statistics and/or high dimensions
- No more extracting parameters per kinematic bin! (No more bins!)
- Can yield continuous, non-parametric estimates of A_{UT} moments

Conclusion

- A_{UT} for exclusive ρ_L^0
  - Successful ρ_L^0/ρ_T^0 separation
  - Possible constraint on J_u, J_d
  - Many recent
  - Great progress on paper draft

- A_{UT} for exclusive ϕ
  - First theoretical paper including exclusive ϕ A_{UT} in August, 2007
  - A_{UT} ϕ_L/ϕ_T separated moments released
  - High uncertainty currently limits interpretation

- KDEs under investigation for many analyses:
  - Exclusive π^+ paper—may be able to resolve existence of node
  - Color Transparency—need both l_c and Q^2 dependence
  - Kinematic dependencies with low statistics
    - Exclusive ϕ and Exclusive ω A_{UT}
  - Unfolding Acceptance and Smearing effects
    - SIDIS A_{UU}, A_{UT}, A_{LT} moments
    - Exclusive ϕ and Exclusive ω A_{UT}