HERMES Transverse Target Measurements of Hard Exclusive Processes

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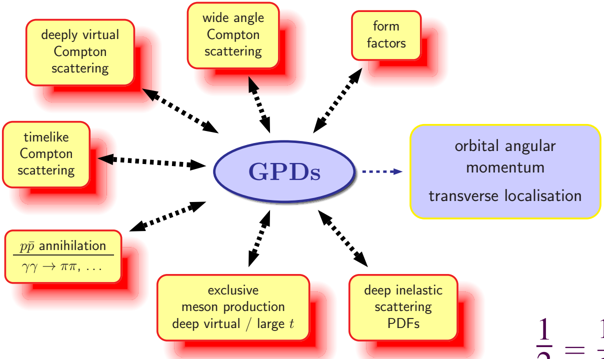
Outline

- Background and Motivation
  - General Parton Distribution Functions (GPDs)
- Deeply Virtual Compton Scattering (DVCS)
  - Analysis of Transverse Target Spin Asymmetry (TTSA)
  - TTSA Results
- TTSA in Exclusive ρ^0 production
  - *L*-*T* Separation
  - Results
- Conclusion and Outlook

Exclusive Reactions and GPDs



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

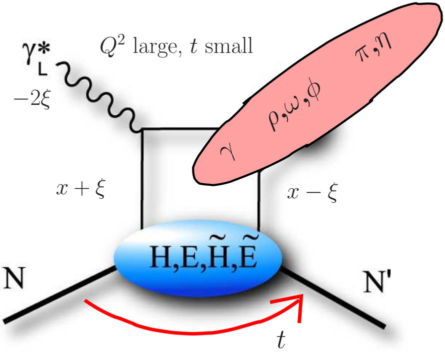
Nucleon Helicity:

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

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

Generalized Parton Distribution Functions

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



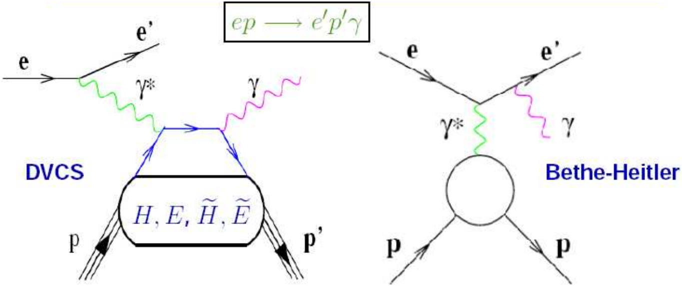
$x \pm \xi$ longitudinal momentum fraction of the quark

-2ξ exchanged longitudinal momentum fraction

t squared momentum transfer

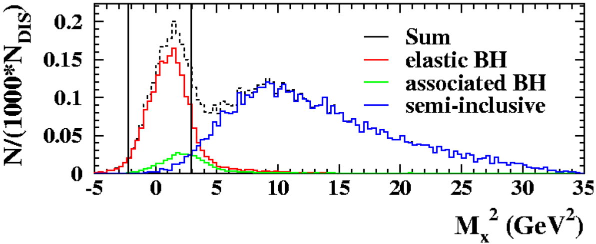
- Soft quark-gluon correlations given by GPDs $H, E, \tilde{H}, \tilde{E}$
- Experimental access: Compton Form Factors $(\mathcal{H}, \mathcal{E}, \tilde{\mathcal{H}}, \tilde{\mathcal{E}})$ convolution of GPDs with hard scattering kernel

DVCS and Bethe-Heitler Diagrams

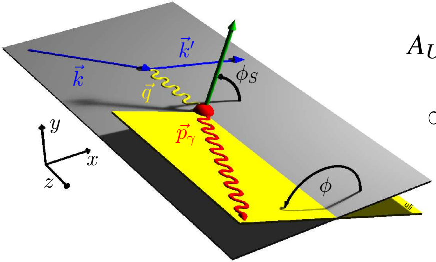


- $d\sigma \propto |A_{DVCS}|^2 + |A_{BH}|^2 + |A^*_{DVCS}A_{BH} + A^*_{BH}A_{DVCS}|^2$
- Bethe-Heitler (BH) term dominates at HERMES kinematics
- Yet interference term yields non-zero azimuthal asymmetries
  $\Longrightarrow$ Transverse Target Asymmetry (A_{UT}) sensitive to $\mathcal{E}$ and $\widetilde{\mathcal{E}}$
- DVCS Beam Charge (A_C), Beam Spin (A_{LU}), and Long. Target (A_{UL}) asymmetries most sensitive to $\mathcal{H}$ and $\widetilde{\mathcal{H}}$, not $\mathcal{E}$ or $\widetilde{\mathcal{E}}$

DVCS Transverse Target Spin Asymmetry



- Transverse Target Spin Asymmetry



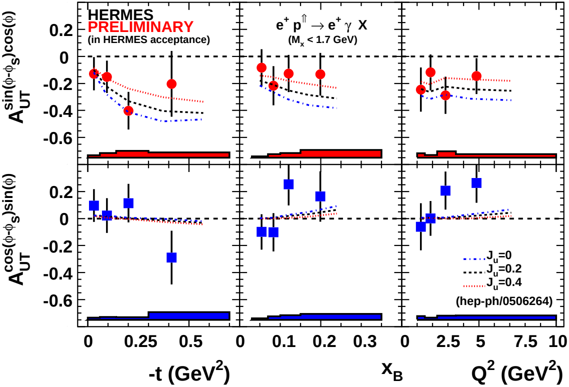
$$A_{UT}(\phi, \phi_s) = \frac{\sigma(\phi, \phi_s) - \sigma(\phi, \phi_s + \pi)}{\sigma(\phi, \phi_s) + \sigma(\phi, \phi_s + \pi)}$$

$$\propto \quad \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \sin(\phi - \phi_s)\cos(\phi)$$
$$+\mathrm{Im}[F_2\widetilde{\mathcal{H}} - \xi F_1\widetilde{\mathcal{E}}] \cos(\phi - \phi_s)\sin(\phi)$$
$$+\text{other terms}\ldots$$

$$\xi = \frac{x}{2-x}$$

Transverse Target Results

$$A_{UT}(\phi,\phi_s) \propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]\sin(\phi-\phi_s)\cos(\phi) + \mathrm{Im}[F_2\widetilde{\mathcal{H}} - \xi F_1\widetilde{\mathcal{E}}]\cos(\phi-\phi_s)\sin(\phi) + \ldots$$



Analyzed 50% of Data Sample (2002-2004)

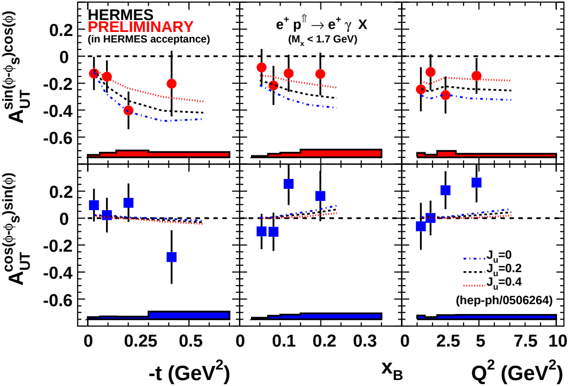
Predictions by

- Ellinghaus et al., Eur. Phys. J. C46 (2006) 729-739
- Based on Goeke et al., Prog. Part. Nucl. Phys. 47 (2001), 401

- For theoretical lines assume $J_d = 0$ and vary J_u

Transverse Target Results

$$A_{UT}(\phi,\phi_s) = A_{UT}^{\sin(\phi-\phi_s)\cos(\phi)} \sin(\phi-\phi_s)\cos(\phi) + A_{UT}^{\cos(\phi-\phi_s)\sin(\phi)} \cos(\phi-\phi_s)\sin(\phi) + \ldots$$



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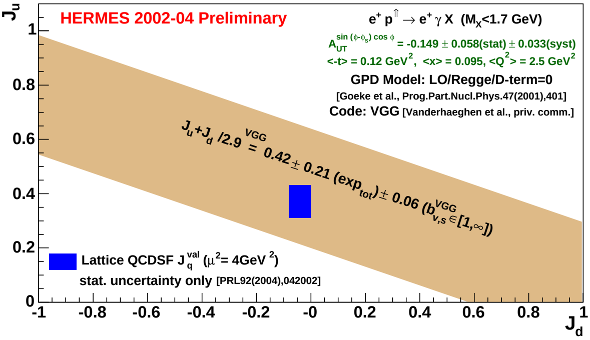
A_{UT} Sensitivity to J_u

$$\chi^2(J_u, J_d) = \sum_i^{\#\,\text{bins}} \frac{\left(A_{UT,i}^{\sin(\phi-\phi_s)\cos(\phi)}\Big|_{exp} - A_{UT,i}^{\sin(\phi-\phi_s)\cos(\phi)}\Big|_{VGG(J_u,J_d)} \right)^2}{\delta A^2_{stat,i} + \delta A^2_{syst,i} + \delta A^2_{accept.,i}}$$

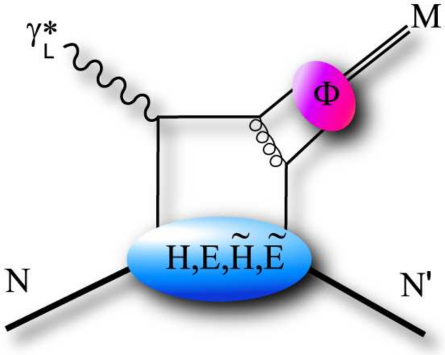
- Calculate $A_{UT}^{\sin(\phi-\phi_s)\cos(\phi)}$ with VGG-based model
- J_u, J_d kept free in fit
- Via χ^2 minimization determine 1σ area for J_u, J_d.

More details in Z. Ye et al., hep-ex/0606061



First constraint on J_u, J_d, ALBEIT model dependent

Vector Mesons and GPDs



- Factorization Theorem for Vector Meson production proven only for longitudinal photons

  -Collins, Frankfurt, Strikman (1997)-

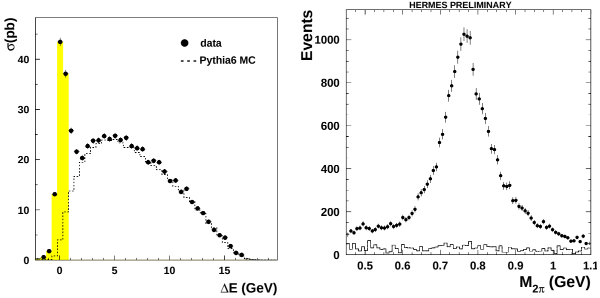
- Soft hadronization process given by meson form factor Φ

- As with DVCS, soft quark-gluon correlations given by GPDs H, E, $\tilde{H}$, $\tilde{E}$
- Meson products sensitive to quark flavor dependencies of GPDs
- Approximate s-channel helicity conservation $(96.4 \pm 1.6\%)^*$

  $\Longrightarrow$ ρ^0_L/ρ^0_T separation can be mapped into γ_L/γ_T separation

*(HERMES ρ SDMEs, hep-ex/0002016)

Hard Exclusive ρ^0_L Production

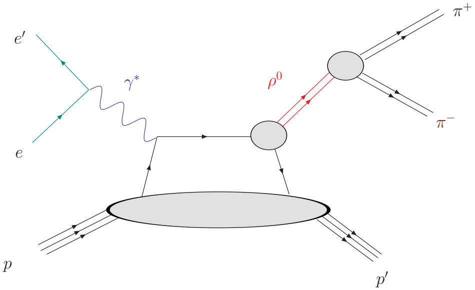


- ρ^0 A_{UT} parametrized as

$$A_{UT}(\phi,\phi_s) \quad = \quad A_{UT}^{\sin(\phi-\phi_s)}\sin(\phi-\phi_s) + \text{five other terms.}$$

- $A_{UT}^{\sin(\phi-\phi_s)} \propto \frac{\mathcal{E}}{\mathcal{H}} \propto \frac{\mathcal{E}_q+\mathcal{E}_g}{\mathcal{H}_q+\mathcal{H}_g}$
- $A_{UT}^{e^\pm}(\phi,\phi_s) = \frac{1}{P_T}\frac{d\sigma(\phi,\phi_s)-d\sigma(\phi,\phi_s+\pi)}{d\sigma(\phi,\phi_s)+d\sigma(\phi,\phi_s+\pi)}, \quad A_{UT}^{\gamma^*}(\phi,\phi_s) = \frac{1}{S_\perp}\frac{d\sigma(\phi,\phi_s)-d\sigma(\phi,\phi_s+\pi)}{d\sigma(\phi,\phi_s)+d\sigma(\phi,\phi_s+\pi)}$
- $P_T A_{UT}^{e^\pm} = S_T(\theta_\gamma,\phi_s)A_{UT}^{\gamma^*} + S_L(\theta_\gamma,\phi_s)A_{UL}^{\gamma^*}$
    - $\left|\frac{S_L}{S_T}\right| < 0.15 \implies P_T A_{UT}^{e^\pm} \sim S_T(\theta_\gamma,\phi_s)A_{UT}^{\gamma^*}$ at HERMES

Hard Exclusive ρ_L^0 Production



- ρ^0 A_{UT} parametrized as

$$A_{UT}(\phi,\phi_s) \quad = \quad A_{UT}^{\sin(\phi-\phi_s)} \sin(\phi-\phi_s) + \text{five other terms.}$$

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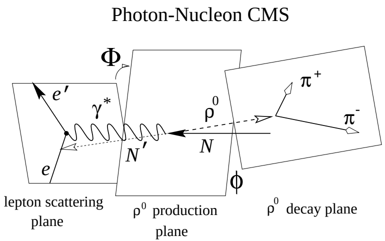
- $A_{UT}^{e^{\pm}}(\phi,\phi_s) = \frac{1}{P_T}\frac{d\sigma(\phi,\phi_s)-d\sigma(\phi,\phi_s+\pi)}{d\sigma(\phi,\phi_s)+d\sigma(\phi,\phi_s+\pi)}, \quad A_{UT}^{\gamma^*}(\phi,\phi_s) = \frac{1}{S_\perp}\frac{d\sigma(\phi,\phi_s)-d\sigma(\phi,\phi_s+\pi)}{d\sigma(\phi,\phi_s)+d\sigma(\phi,\phi_s+\pi)}$
- $P_T A_{UT}^{e^{\pm}} = S_T(\theta_\gamma,\phi_s)A_{UT}^{\gamma^*} + S_L(\theta_\gamma,\phi_s)A_{UL}^{\gamma^*}$
  - $\left|\frac{S_L}{S_T}\right| < 0.15 \implies P_T A_{UT}^{e^{\pm}} \sim S_T(\theta_\gamma,\phi_s)A_{UT}^{\gamma^*}$ at HERMES

ρ^0_L, ρ^0_T Separation

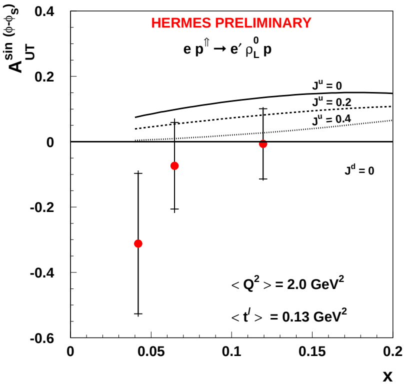


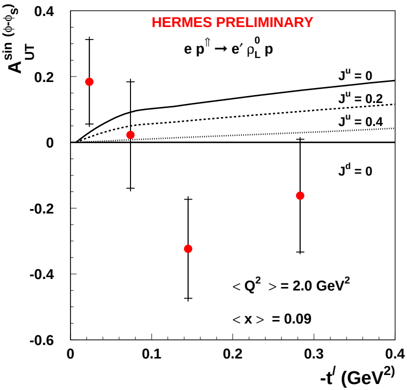
- Each ρ^0 polarization state has a characteristic decay angular distribution
- Can use ρ^0 CM angle $\theta_{\pi\pi}$ of π-meson to separate ρ^0_L, ρ^0_T
- Use HERMES measured value of Spin Density Matrix Elements
  - Note: SDME paper in preparation.

$$A_{UT}(P_T, \cos\theta_{\pi\pi}, \phi, \phi_s) \propto$$
$$\Big[\cos^2\theta_{\pi\pi}\; r^{04}_{00} \left(1 + P_T\sigma_{UT,\rho_L}(\phi,\phi_s) + \sigma_{UU,\rho_L}(\phi)\right) +$$
$$\frac{1}{2}\sin^2\theta_{\pi\pi}\; (1 - r^{04}_{00})\left(1 + P_T\sigma_{UT,\rho_T}(\phi,\phi_s) + \sigma_{UU,\rho_T}(\phi)\right) \Big]$$

Results

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





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

Conclusion and Outlook

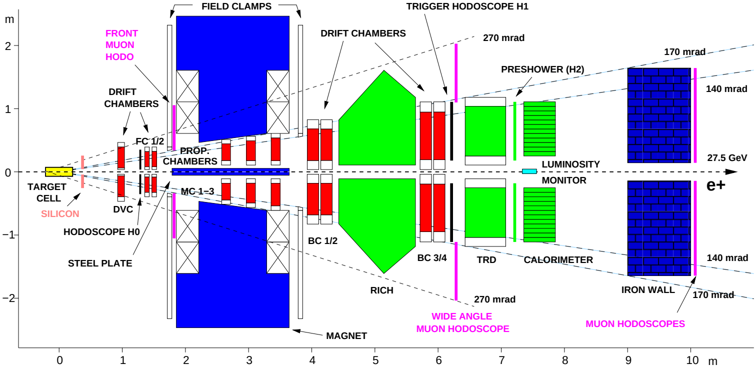
- A_{UT} for DVCS
  - Constraints on GPD models
  - First model dependant constraint on J_u, J_d
  - Still 2005 data set to include
- A_{UT} for exclusive ρ^0_L
  - Successful ρ^0_L/ρ^0_T separation
  - Possible constraint on J_u, J_d

Year	Target Pol.	Mil. DIS
'02-'04	Trans.	3.2
'05	Trans.	4.2
'06	Unpol.	8.1
'07	Unpol.	lots

- A_{UT} for exclusive ϕ
  - Working with theorists for exact relation between ϕ A_{UT} and GPDs
  - A_{UT} ϕ_L/ϕ_T separated moments to be released soon
  - Provides access to gluons and strange quark sea
- HERMES Recoil Detector Data coming soon
  - Improved kinematic resolution
  - Large Statistics
  - All polarized beam, unpolarized target

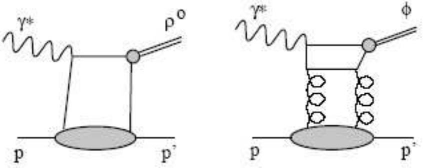
Extra Slides

HERMES Experiment



- 27.6 GeV $e^{\pm}$ (polarized) beam on fixed polarized target
- Deepely Virtual Compton Scattering (DVCS): $\gamma^* p \to \gamma p$
- Exclusive diffractive ρ^0 production: $\gamma^* p \to \rho^0 p$

ϕ-meson A_{UT}



- Significantly different production process
- Should directly access gluon portion of GPDs
- Ongoing discussion with theorists about relating ϕ A_{UT} with GPDs
- HERMES ϕ A_{UT} results available soon, including L-T separation