Final HERMES Results on DVCS Transverse Target Spin Asymmetries

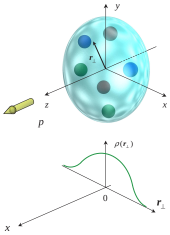
Eduard Avetisyan

PANIC08, Eilat

From Flat to 3D

Form factors

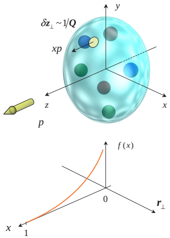
$ep \longrightarrow e'p'$



transverse charge

Parton density

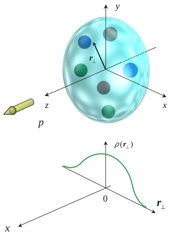
$ep \longrightarrow e'X$

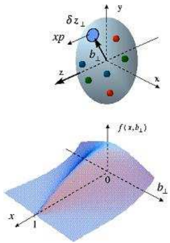


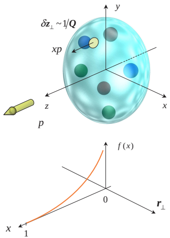
longitudinal momentum and helicity

From Flat to 3D

Form factors	GPDs	Parton density
$ep \longrightarrow e'p'$	$ep \longrightarrow e'Xp'$	$ep \longrightarrow e'X$





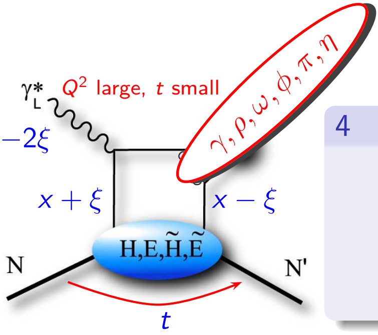


transverse charge

correlated momentum, helicity distribution in transverse space

longitudinal momentum and helicity

Generalized Parton Distributions



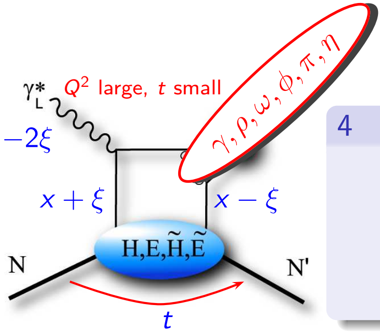
-Collins, Frankfurt, Strikman (1997)-

4 Generalized Parton Distributions

H	$\widetilde{H}$
E	$\widetilde{E}$
$\downarrow$	$\downarrow$
unpolarized	polarized

- Quantum numbers of final state selects different GPDs
  - ⊛ DVCS (γ): all GPDs H, E, $\widetilde{H}$, $\widetilde{E}$
  - ⊛ vector mesons (ρ, ω, ϕ): unpolarized GPDs H, E
  - ⊛ pseudoscalar mesons (π, η): polarized GPDs $\widetilde{H}$, $\widetilde{E}$

Generalized Parton Distributions



-Collins, Frankfurt, Strikman (1997)-

4 Generalized Parton Distributions

H	$\widetilde{H}$
E	$\widetilde{E}$ $\Rightarrow$ nucleon helicity flip
$\downarrow$	$\downarrow$
unpolarized	polarized

- Quantum numbers of final state selects different GPDs
  - ⊛ DVCS (γ): all GPDs H, E, $\widetilde{H}$, $\widetilde{E}$
  - ⊛ vector mesons (ρ, ω, ϕ): unpolarized GPDs H, E
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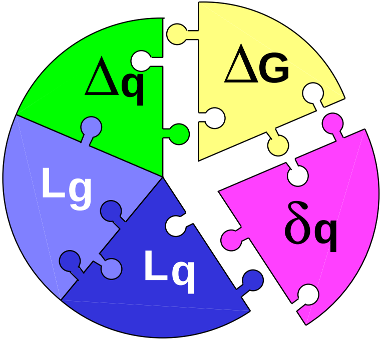
What can we learn from GPDs?



Proton Spin (HERMES, Phys. Rev. D 75 (2007) 012007)

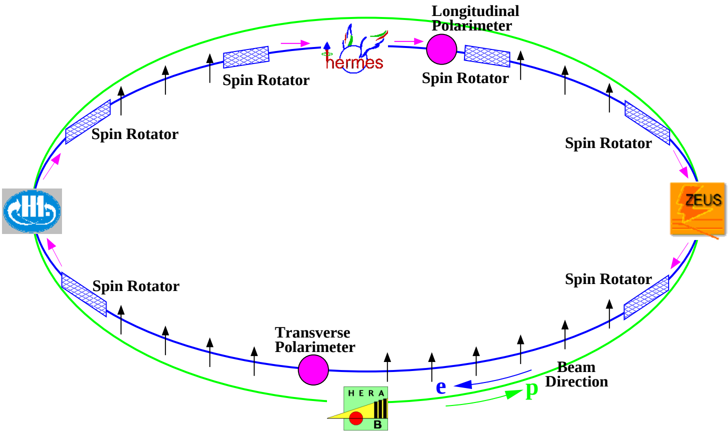
$$\frac{1}{2} = \underbrace{\frac{1}{2}(\overbrace{\Delta u + \Delta d + \Delta s}^{\sim 33\%} + L_q}_{J_q} + J_g$$

Δq: well known from DIS & SIDIS

GPDs allow access to J_q, J_g through Ji's sum rule:

$$J_{q,g} = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \cdot x \cdot [H_{q,g}(x,\xi,t) + E_{q,g}(x,\xi,t)]$$

The HERA Accelerator

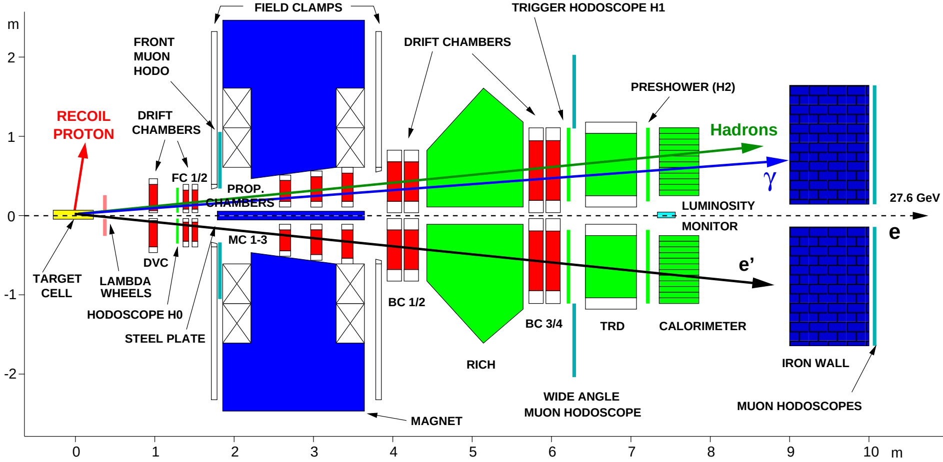


Possibility of e^+ and e^- beams with $E_{beam} = 27.5 GeV$

Naturally polarised! $\langle P_{beam} \rangle \approx 30 - 60\%$

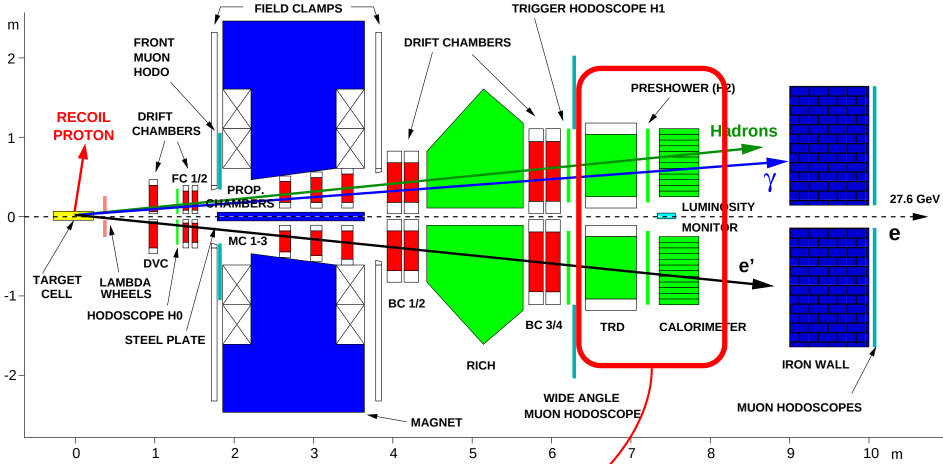
Spin rotators used to obtain longitudinal polarisation

Spectrometer



Fixed target (**H,D**,N,Ne,Kr,Xe), high longitudinal/transverse polarisation!

Spectrometer



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$e^{\pm}$: EM-Calorimeter, TRD, Preshower

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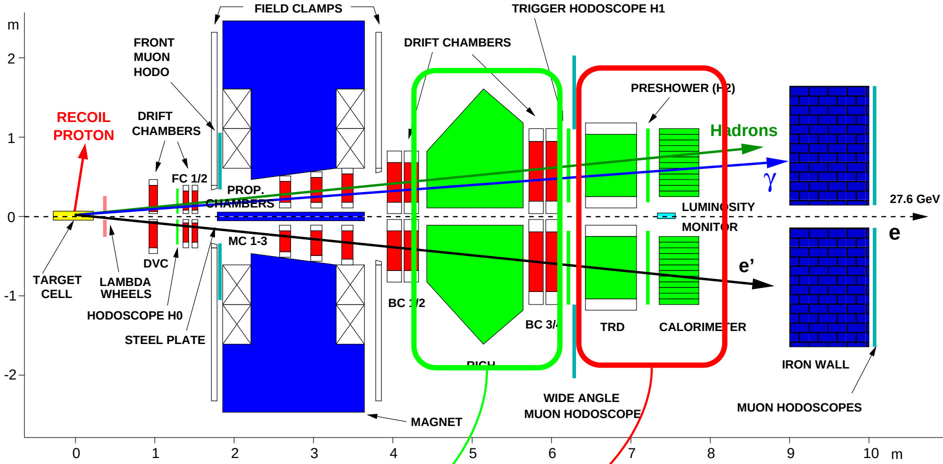

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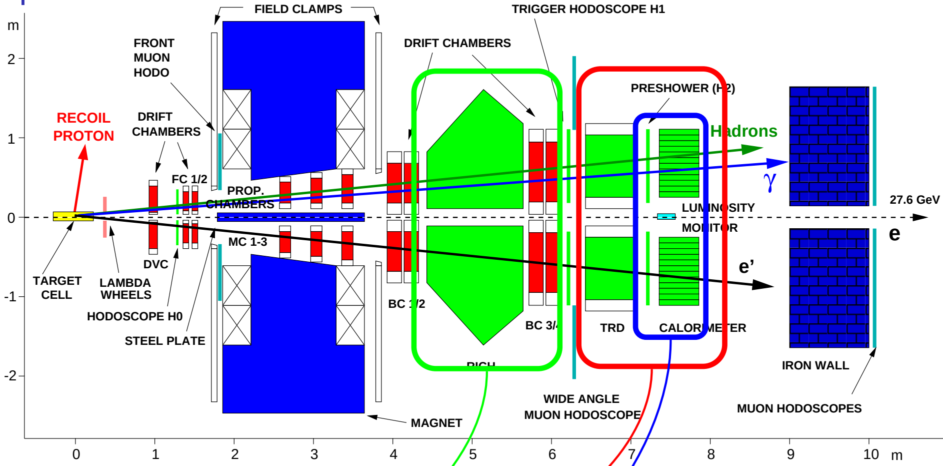
hadron PID: RICH

Spectrometer



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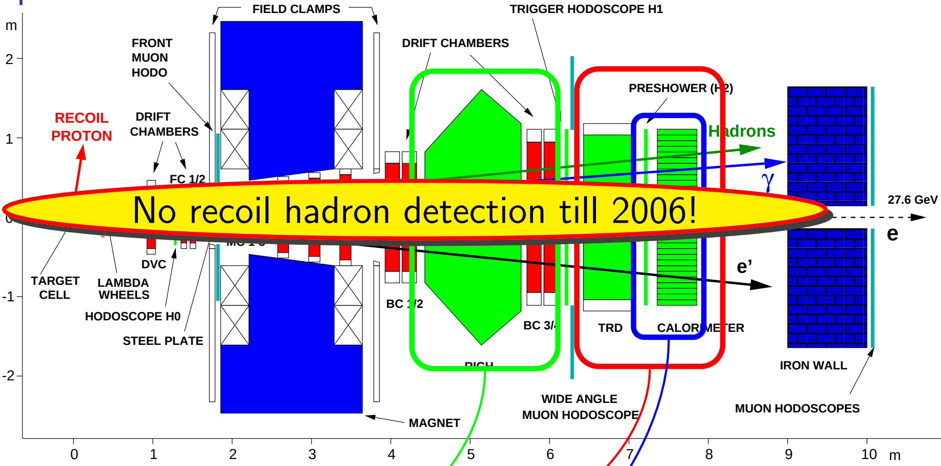
Spectrometer



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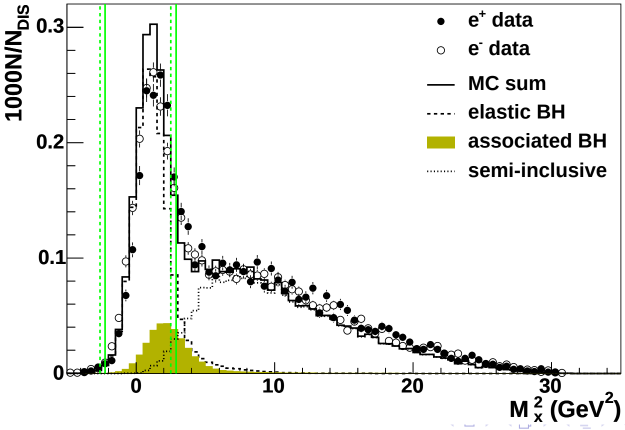
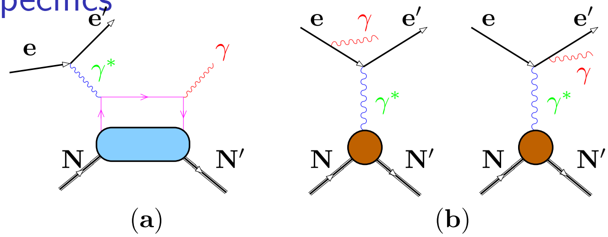
Measurement of DVCS

- No recoil proton detection (1996-2005) $\Rightarrow$ missing mass technique used
- $M_x^2 = (P_e + P_p - P_{e'} - P_\gamma)^2$
- SIDIS (π^0) Background contribution $\sim$ 5% estimated from MC



DVCS - Specifics



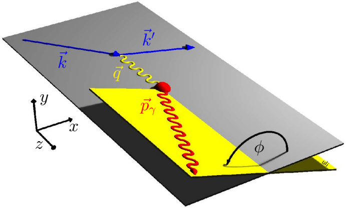
$$e + N \rightarrow e' + \gamma + N'$$

- The simplest probe of GPDs (no gluons in the leading order)
- Same final state in DVCS and Bethe-Heitler ⇒ Interference!
- $d\sigma(\mathrm{eN} \rightarrow \mathrm{eN}\gamma) \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}}_{\mathcal{I}}$
- $|\mathcal{T}_{BH}|^2 >> |\mathcal{T}_{DVCS}|^2$ at HERMES → no direct X-section measurement
- Good news: $\mathcal{I}$ interference term allows access to (certain) GPD combinations through asymmetries!

All the glory of the asymmetries!

Interference term $\mathcal{I}$ induces azimuthal asymmetries in cross-section:

- Beam-charge asymmetry $A_C(\phi)$:
  $d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto \mathrm{Re}[F_1\mathcal{H}] \cdot \cos\phi$
- Beam-spin asymmetry $A_{LU}(\phi)$:
  $d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}[F_1\mathcal{H}] \cdot \sin\phi$
- Long. target-spin asymmetry $A_{UL}(\phi)$:
  $d\sigma(\overset{\Leftarrow}{P},\phi) - d\sigma(\overset{\Rightarrow}{P},\phi) \propto \mathrm{Im}[F_1\widetilde{\mathcal{H}}] \cdot \sin\phi$



- Transverse target-spin asymmetry $A_{UT}(\phi,\phi_s)$

$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S)\cos\phi + \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S) + \ldots$$

$\Rightarrow$ TTSA is the only DVCS asymmetry where $\mathcal{E}$ enters in leading order
As models for $\mathcal{E}$ depend on $J_q \Longrightarrow \mathrm{A}_{\mathrm{UT}}^{\sin(\phi-\phi_S)\cos\phi}$ is sensitive to J_q !

(F_1, F_2 are the Dirac and Pauli form factors, calculable in QED)
($\mathcal{H},\mathcal{E},\widetilde{\mathcal{H}},\widetilde{\mathcal{E}}$ are the Compton form factors, moments of corresponding GPDs)

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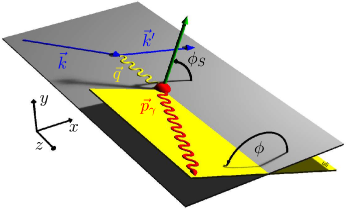

$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S)\cos\phi$$
$$+ \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S) + \ldots$$

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Extraction Procedure

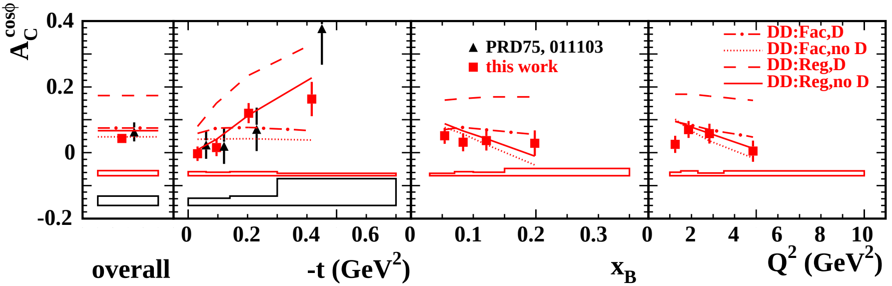
Used Maximum Likelihood method with simultaneous extraction of Beam-charge and Target-Spin Asymmetry amplitudes by minimizing

$$-\ln L(\boldsymbol{\eta}_{\mathrm{UT}}^{\mathrm{DVCS}}, \boldsymbol{\eta}_{\mathrm{C}}, \boldsymbol{\eta}_{\mathrm{UT}}^{\mathrm{I}}) = \widetilde{\mathcal{N}}_{\mathrm{par}}(\boldsymbol{\eta}_{\mathrm{UT}}^{\mathrm{DVCS}}, \boldsymbol{\eta}_{\mathrm{C}}, \boldsymbol{\eta}_{\mathrm{UT}}^{\mathrm{I}}) - \sum_{i=1}^{N_{\mathrm{o}}} \ln\Big[1 + S_{\perp}^{i} \mathcal{A}_{\mathrm{UT}}^{\mathrm{DVCS}}(\phi^{i}, \phi_{S}^{i}; \boldsymbol{\eta}_{\mathrm{UT}}^{\mathrm{DVCS}}) + e_{l}^{i} \mathcal{A}_{\mathrm{C}}(\phi^{i}; \boldsymbol{\eta}_{\mathrm{C}}) + e_{l}^{i} S_{\perp}^{i} \mathcal{A}_{\mathrm{UT}}^{\mathrm{I}}(\phi^{i}, \phi_{S}^{i}; \boldsymbol{\eta}_{\mathrm{UT}}^{\mathrm{I}})\Big]$$

Allows separation of **DVCS** and **Interference** terms with same harmonic signature.

A_C: Beam Charge Asymmetry

$$A_c(\phi) = \frac{d\sigma(e^+,\phi) - d\sigma(e^-,\phi)}{d\sigma(e^+,\phi) + d\sigma(e^-,\phi)} \propto \mathrm{Re}[F_1 \mathcal{H}] \cdot \cos\phi$$



- **DD** model for proton from M.Vanderhaeghen et al (PRD 60 (1999) 094017)
- data taking years 2002-2005 with transverse target

HERMES, JHEP 06 (2008) 066

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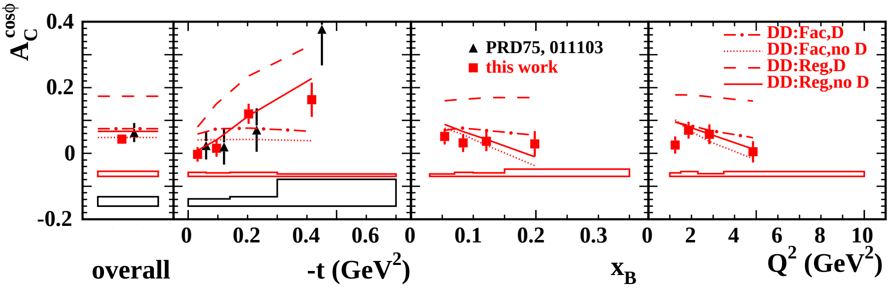

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HERMES, JHEP 06 (2008) 066

Regge model without D-term favoured by the *t*-dependence of the BCA

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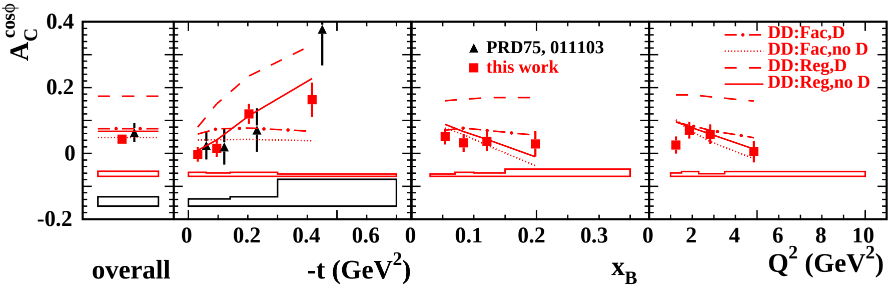

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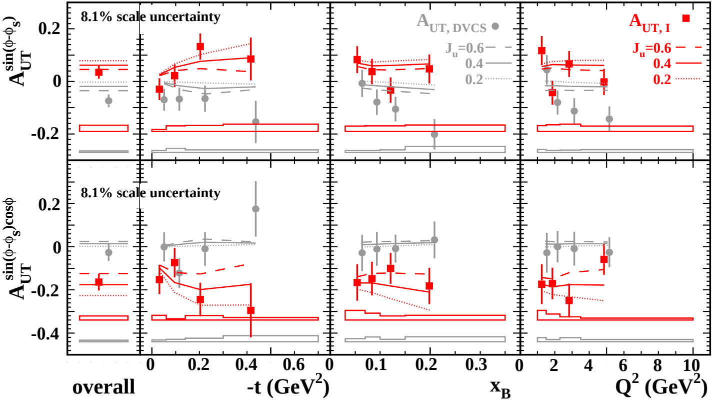
more data on tape! Updates coming soon!

Transverse Target Spin Asymmetry A_{UT}

$$A_{UT}(\phi,\phi_S) = \frac{1}{P_T}\cdot\frac{d\sigma(P^{\Uparrow},\phi,\phi_S)-d\sigma(P^{\Downarrow},\phi,\phi_S)}{d\sigma(P^{\Uparrow},\phi,\phi_S)+d\sigma(P^{\Downarrow},\phi,\phi_S)}$$

$$\propto \mathrm{Im}[F_2\mathcal{H}-F_1\mathcal{E}]\sin(\phi-\phi_S)\cos\phi+\mathrm{Im}[F_2\mathcal{H}-F_1\mathcal{E}]\sin(\phi-\phi_S)$$

$$+ \mathrm{Im}[\mathcal{H}\mathcal{E}^*-\mathcal{E}\mathcal{H}^*+\xi\widetilde{\mathcal{E}}\widetilde{\mathcal{H}}^*-\widetilde{\mathcal{H}}\xi\widetilde{\mathcal{E}}^*]\sin(\phi-\phi_S)+\ldots$$



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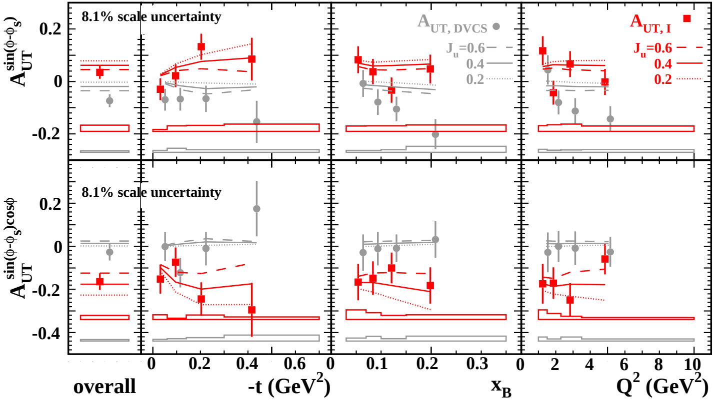
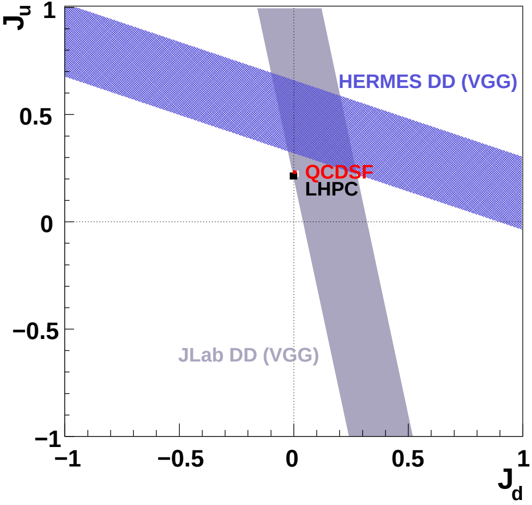


- $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ found much more sensitive to J_u than others
- insensitive to J_d, assumed $J_d = 0$ (supported by lattice QCD)
- allows a model-dependent constraint
- systematics controlled through Monte Carlo with 5 different model variants

Total Angular Momentum - Ji sum rule



- Final transverse data fitted against the model
- J_u and J_d as free parameters
- Model-dependent constraints on linear comnbination of J_u, J_d

Conclusions and Outlook

Conclusions

- Full statistics ($\sim$ 170 pb^{-}1) with transverse polarization analyzed
- Pure hydrogen target with high polarization $\Rightarrow$ low systematics!
- Extracted DVCS azimuthal asymmetries from Beam Charge and Transverse Target Spin $\Rightarrow$ access GPDs H and E.
- Used the best knowledge available to construct a model dependent constraint on total angular momentum J_q of the quarks in proton

Outlook

- More data being analyzed for A_C to better constraint models
- Similar studies using exclusive ρ^0 and π^+ underway
- Other models currently being investigated and developed
- Another step towards solving of the spin puzzle

Backups

Forward limits (link to PDFs): $(t \to 0, \xi \to 0)$

for quarks:	$H^q(x,0,0) = q(x)$	$\widetilde{H}^q(x,0,0) = \Delta q(x)$
for antiquarks:	$H^q(x,0,0) = -\bar{q}(-x)$	$\widetilde{H}^q(x,0,0) = \Delta \bar{q}(-x)$
for gluons:	$H^g(x,0,0) = xg(x)$	$\widetilde{H}^g(x,0,0) = x\Delta g(x)$

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No corresponding relation for polarised $(E, \widetilde{E})$ GPDs $\Rightarrow$ accessible ONLY in exclusive processes!

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Sum rules (link to Form Factors):

$$\int_{-1}^{+1} H^q(x,\xi,t)dx = F_1^q(t) \qquad \int_{-1}^{+1} E^q(x,\xi,t)dx = F_2^q(t)$$

$$\int_{-1}^{+1} \widetilde{H}^q(x,\xi,t)dx = g_A^q(t) \qquad \int_{-1}^{+1} \widetilde{E}^q(x,\xi,t)dx = h_2^q(t)$$

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Ji sum rule - relation to total angular momentum! *- Ji,PRL 78 (1997) 610 -*

$$\frac{1}{2}\int_{-1}^{1} dx\ x\ [H^q(x,\xi,t) + E^q(x,\xi,t)] \stackrel{t\rightarrow 0}{=} J_q = \frac{1}{2}\Delta\Sigma + L_q$$

Kinamatical Coverage of Experimental Data

collider experiments:

$10^{-4} < x_B < 0.021$: probing gluons

fixed target experiments:

- Compass $0.006 < x_B < 0.3$: gluons and quarks $(q_v + q_s)$
- HERMES $0.02 < x_B < 0.3$: gluons and quarks $(q_v + q_s)$
- JLAB (@6GeV)$0.13 < x_B < 0.6$: quarks (valence)