The Virtual Photon-Proton Asymmetry A_2 and the Spin Dependent Structure Function xg_2 at HERMES

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Outline

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- Experiment HERMES
- Raw Asymmetries
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Polarized Inclusive DIS

$$e(k,s) + p(P,S) \longrightarrow e'(k') + X(P_X)$$

$$Q^2 = -q^2 = -(k-k')^2, \quad x_B = \frac{Q^2}{2P\cdot q}, \quad y = \frac{P\cdot q}{P\cdot k}, \quad W^2 = (P+q)^2$$

$$\frac{d^2\sigma(s,S)}{dx\,dQ^2} = \frac{2\pi\alpha^2 y^2}{Q^6} L_{\mu\nu}(s) W^{\mu\nu}(S)$$

$W^{\mu\nu}$ parameterized in terms of Structure Functions $F_{1,2}$ and $g_{1,2}$

QPM:

$$F_1(x) = \frac{1}{2}\sum_q e_q^2 f_1^q(x) \qquad F_2(x) = x\sum_q e_q^2 f_1^q(x)$$

$$g_1(x) = \frac{1}{2}\sum_q e_q^2 g_1^q(x) \qquad g_2(x) = 0$$

OPE: $g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2), \quad g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$.

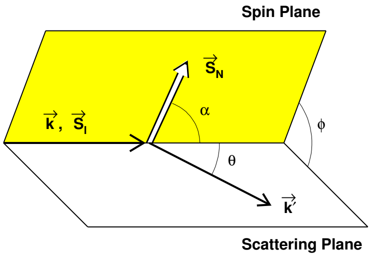
$$A_1 = \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \frac{g_1 - \gamma^2 g_2}{F_1}, \qquad A_2 = \frac{2\sigma^{TL}_{1/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \gamma\,\frac{g_1 + g_2}{F_1}$$

$$\gamma = \frac{2Mx}{\sqrt{Q^2}}$$

Polarized Inclusive DIS

$$\frac{d^3\sigma}{dx\,dy\,d\phi} \propto \frac{y}{2}F_1(x,Q^2) + \frac{1-y-\gamma^2y^2/4}{2xy}F_2(x,Q^2)$$
$$-P_l \cdot P_T \cos\alpha\left[\left(1-\frac{y}{2}-\frac{\gamma^2y^2}{4}\right)g_1(x,Q^2) - \frac{\gamma^2 y}{2}g_2(x,Q^2)\right]$$
$$+P_l \cdot P_T \sin\alpha\cos\phi\,\gamma\sqrt{1-y-\frac{\gamma^2y^2}{4}}\left(\frac{y}{2}g_1(x,Q^2)+g_2(x,Q^2)\right)$$

$$\gamma = \frac{2Mx}{\sqrt{Q^2}}$$

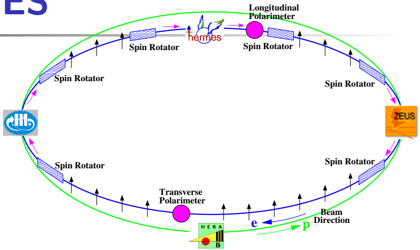


Measurements of A_2^p, g_2^p:

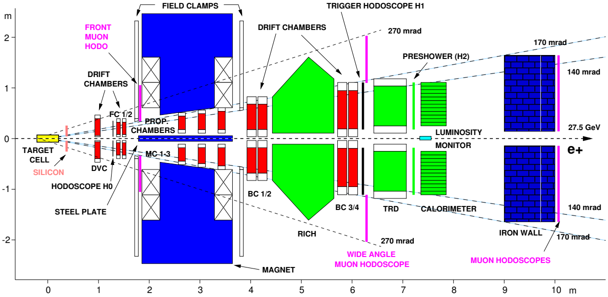
- SMC (D.Adams et al., Phys.Rev. D56, 5330 (1997))
- E143 (K.Abe et al., Phys.Rev. D58, 112003 (1998))
- E155 (P.L.Anthony et al., Phys.Lett. B553, 18 (2003))
- JLAB (resonanse region)

HERMES has measured $A_1^{p,d}$, $g_1^{p,d}$ (A.Airapetian et al., Phys.Rev. D75, 012007 (2007))

Experiment HERMES



27.5 GeV polarized e^+/e^- beam of HERA



Internal gas Target:
polarized - $H^{\uparrow}$

Angular acceptance:
$40 < \theta < 220$ mrad

- e/h rejection: TRD, Preshower, Calorimeter, RICH
- magnetic spectrometer: $\Delta p/p < 2.5\%$ and $\Delta\theta < 0.6$ mrad

Experimental Data

- 2002 - 2005 : data taking with transversely polarized hydrogen target.
- 2002 - essentially unpolarized beam.
- Flip of the target polarisation direction every 90 sec in 0.5 sec;
- Electron beam polarization reversed every few months.

The following kinematic requirements were imposed on the data:
$0.023 < x < 0.70$, $1 < Q^2 < 15$ GeV^2, $W > 2$ GeV, $0.1 < y < 0.85$
6.9 million events were accepted.

The target polarization $\langle P_T \rangle = 0.708 \pm 0.064$
The beam polarization $\langle P_B \rangle = 0.338 \pm 0.013$
$P_B > 0$: $\langle |P_B \cdot P_T| \rangle = 0.266 \pm 0.024$
$P_B < 0$: $\langle |P_B \cdot P_T| \rangle = 0.222 \pm 0.024$

$A_\perp$ Measurement

Four independent cross-sections, $\sigma^{\leftarrow\Uparrow}$, $\sigma^{\leftarrow\Downarrow}$, $\sigma^{\rightarrow\Uparrow}$, $\sigma^{\rightarrow\Uparrow}$.
One may construct two independent definitions of asymmetrty $A_\perp$:

$$
\begin{aligned}
\mathbf{A}_\perp(\phi, \mathbf{x}, \mathbf{Q}^2) &= +\frac{\sigma^{\leftarrow\Uparrow}(\phi, \mathbf{x}, \mathbf{Q}^2) - \sigma^{\leftarrow\Downarrow}(\phi, \mathbf{x}, \mathbf{Q}^2)}{\sigma^{\leftarrow\Uparrow}(\phi, \mathbf{x}, \mathbf{Q}^2) + \sigma^{\leftarrow\Downarrow}(\phi, \mathbf{x}, \mathbf{Q}^2)} \\
&= -\frac{\sigma^{\rightarrow\Uparrow}(\phi, \mathbf{x}, \mathbf{Q}^2) - \sigma^{\rightarrow\Downarrow}(\phi, \mathbf{x}, \mathbf{Q}^2)}{\sigma^{\rightarrow\Uparrow}(\phi, \mathbf{x}, \mathbf{Q}^2) + \sigma^{\rightarrow\Downarrow}(\phi, \mathbf{x}, \mathbf{Q}^2)} \\
&= \mathbf{A}_\mathbf{T}(\mathbf{x}, \mathbf{Q}^2) \cdot \cos\phi
\end{aligned}
$$

$$
\mathbf{A}_\mathbf{T}(\mathbf{x}, \mathbf{Q}^2) = \frac{-\gamma\sqrt{1 - \mathbf{y} - \frac{\gamma^2 \mathbf{y}^2}{4}}\left(\frac{\mathbf{y}}{2}\mathbf{g}_1(\mathbf{x}, \mathbf{Q}^2) + \mathbf{g}_2(\mathbf{x}, \mathbf{Q}^2)\right)}{\frac{\mathbf{y}}{2}\mathbf{F}_1(\mathbf{x}, \mathbf{Q}^2) + \frac{1}{2\mathbf{x}\mathbf{y}}(1 - \mathbf{y} - \gamma^2\mathbf{y}^2/4)\mathbf{F}_2(\mathbf{x}, \mathbf{Q}^2)}
$$

Extraction of A_T provides an access to g_2.

$A_\perp$ Measurement

Azimuthal angle ϕ is defined by vectors $\vec{k}$, $\vec{k}'$, and $\vec{S}_N$:

$$\phi = \frac{(\vec{k} \times \vec{S}_N) \cdot \vec{k}'}{|(\vec{k} \times \vec{S}_N) \cdot \vec{k}'|} \arccos \frac{(\vec{k} \times \vec{k}') \cdot (\vec{k} \times \vec{S}_N)}{|\vec{k} \times \vec{k}'||\vec{k} \times \vec{S}_N|}$$

Asymmetries for two beam polarization directions:

$$\mathbf{A}_\perp^{\rightarrow}(\phi_\mathbf{i}, \mathbf{x_j}) = \frac{-\mathbf{1}}{\langle|\mathbf{P_B P_T}|\rangle^{\rightarrow}} \frac{\frac{\mathbf{n}^{\rightarrow\Uparrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\rightarrow\Uparrow}} - \frac{\mathbf{n}^{\rightarrow\Downarrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\rightarrow\Downarrow}}}{\frac{\mathbf{n}^{\rightarrow\Uparrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\rightarrow\Uparrow}} + \frac{\mathbf{n}^{\rightarrow\Downarrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\rightarrow\Downarrow}}}$$

$$\mathbf{A}_\perp^{\leftarrow}(\phi_\mathbf{i}, \mathbf{x_j}) = \frac{\mathbf{1}}{\langle|\mathbf{P_B P_T}|\rangle^{\leftarrow}} \frac{\frac{\mathbf{n}^{\leftarrow\Uparrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\leftarrow\Uparrow}} - \frac{\mathbf{n}^{\leftarrow\Downarrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\leftarrow\Downarrow}}}{\frac{\mathbf{n}^{\leftarrow\Uparrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\leftarrow\Uparrow}} + \frac{\mathbf{n}^{\leftarrow\Downarrow}(\phi_\mathbf{i}, \mathbf{x_j})}{\mathbf{N}^{\leftarrow\Downarrow}}}$$

$A_\perp^{\rightarrow}$ and $A_\perp^{\leftarrow}$ measure the same physical quantity - can be averaged.

Unfolding of the Asymmetry

- Raw asymmetries have to be corrected for:
  - QED radiative effects
  - detector smearing
- Event migration is simulated by Monte Carlo which includes a full detector description and a model for the cross section.
- The approach is independent on the model for the asymmetry in the measured region.

Unfolding procedure as in HERMES g_1 paper (A.Airapetian et al., Phys.Rev. D75, 012007 (2007))

$$\mathbf{A}_{\perp}^{\mathbf{B}}(\mathbf{j}) = -\mathbf{1} + \frac{\mathbf{2}}{\mathbf{N}_{\mathbf{B}}^{\mathbf{unpMC}}(\mathbf{j})} \sum_{\mathbf{i=1}}^{\mathbf{n_{bins}}} \left[\mathbf{S}^{\rightarrow\Downarrow} + \mathbf{S}^{\rightarrow\Uparrow}\right]^{-\mathbf{1}}(\mathbf{j},\mathbf{i}) \times$$

$$\left[\mathbf{A}_{\perp}^{\mathbf{obs}}(\mathbf{i}) \cdot \mathbf{N}_{\mathbf{obs}}^{\mathbf{unpMC}}(\mathbf{i}) - \mathbf{n}_{\mathbf{bg}}^{\mathbf{MC}}(\mathbf{i}) + \sum_{\mathbf{k=1}}^{\mathbf{n_{bins}}} \mathbf{S}^{\rightarrow\Uparrow}(\mathbf{i},\mathbf{k}) \cdot \mathbf{N}_{\mathbf{B}}^{\mathbf{unpMC}}(\mathbf{k})\right]$$

Here, $S(i,j)$ is the smearing matrix.
Unfolding procedure produces a correlation between data points.
The covariance matrix should be used for any further analysis of the data.

$A_2(x)$ and $g_2(x)$ Extraction

Asymmetries $A_\perp^B(\phi, x)$ were used to get $A_T(x)$: $A_\perp^B(\phi, x) = A_T(x) \cdot \cos\phi$.

$$A_T \implies \begin{aligned} \mathbf{A_2} &= \frac{1}{1+\gamma\xi}\left(\frac{\mathbf{A_T}}{\mathbf{d}} + \xi(1+\gamma^2)\,\frac{\mathbf{g_1}}{\mathbf{F_1}}\right), \\ \mathbf{g_2} &= \frac{\mathbf{F_1}}{\gamma(1+\gamma\xi)}\left(\frac{\mathbf{A_T}}{\mathbf{d}} - (\gamma-\xi)\,\frac{\mathbf{g_1}}{\mathbf{F_1}}\right) \end{aligned}$$

Here, $F_1(x, Q^2) = \dfrac{1+\gamma^2}{2x(1+R(x, Q^2))} F_2(x, Q^2)$

The following parameterizations were used:

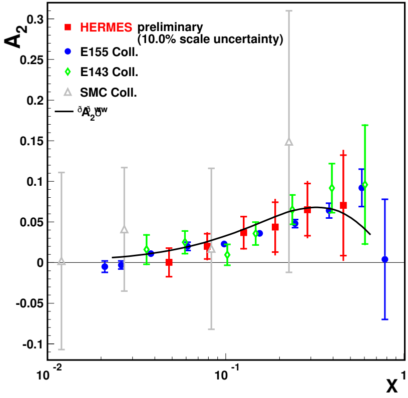
$R(x, Q^2) = \sigma_L/\sigma_T$ – R1998 (E143 Coll. K. Abe et al., Phys.Lett. B452, 194 (1999))
$F_2(x, Q^2)$ – ALLM07 (D.Gabbert, L. De Nardo, hep-ph/0708.3196 (2007))
$g_1/F_1(x, Q^2)$ – (E155 Coll. P.L. Anthony et al., Phys.Lett. B493, 19 (2000))

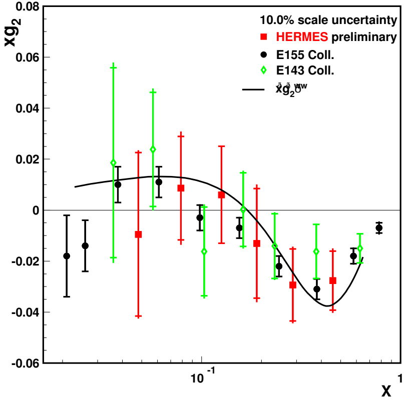
Systematic uncertainties were estimated to be much less then statistical ones.

Uncertainties in the beam and target polarization values produce 10% scale uncertainty on the results.

$A_2(x)$ and $xg_2(x)$ Results

Statistical uncertainties of HERMES data correspond to the diagonal elements of the covariance matrix obtained from the unfolding procedure.





$$g_2(x, Q^2) = g_2^{WW}(x, Q^2) + \bar{g}_2(x, Q^2),$$

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_x^1 \frac{dy}{y} g_1(x, Q^2)$$

Summary

• Virtual photon-proton asymmetry $A_2(x)$ and the spin dependent structure function $g_2(x)$ are measured at HERMES.

• The results are consistent with (sparse) world data and compatible with Wandzura-Wilczek relation.

• Statistical uncertainty of the data is relatively large due to low beam polarization during HERA II.

• A comparison of the HERMES statistical uncertainty with existing data from other experiments (e.g. as in previous slide) is somewhat misleading due to the unfolding procedure. The full covariance matrix is meaningful only.

• This is the first result of HERMES obtained with longitudinally polarized leptons and transversely polarized target.