Measurements of the Nucleon Spin Structure

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for the HERMES collaboration

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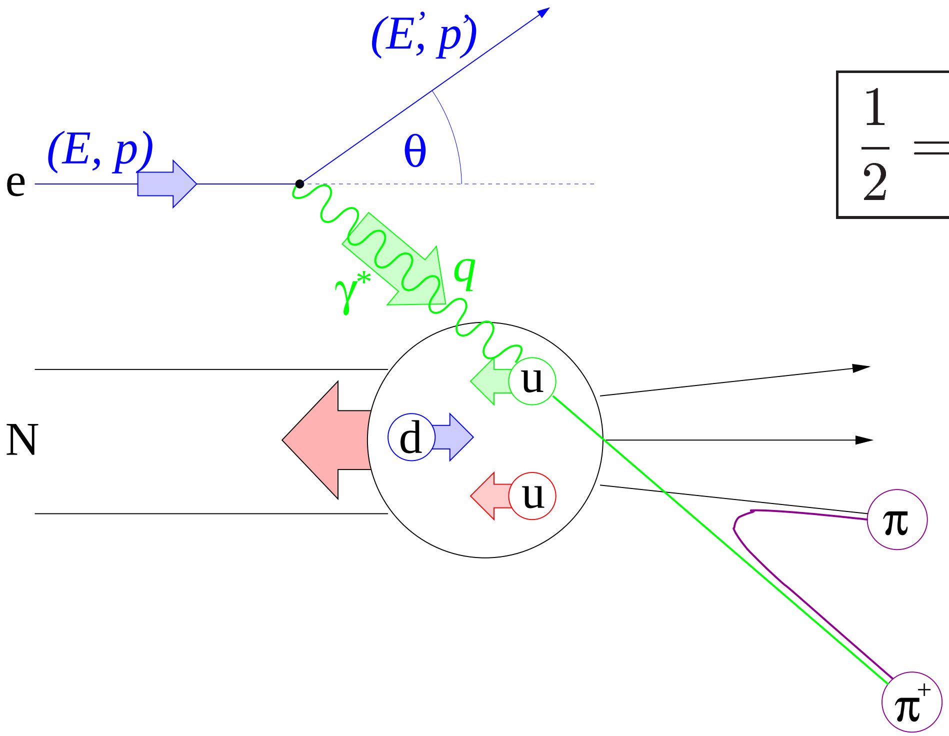
- Polarized Deep Inelastic Scattering
- The HERMES Experiment at HERA
- Inclusive Measurements
- Semi-Inclusive Measurements
- Exclusive Measurements
- Conclusion and Outlook

Polarized Deep Inelastic Scattering



$$\boxed{\frac{1}{2} = \frac{1}{2}\,\Delta\Sigma + \Delta G + (L_q + L_g)}$$

$$Q^2 \overset{\text{lab}}{=} 4EE'\sin^2\frac{\theta}{2}$$

$$\nu \overset{\text{lab}}{=} E - E'$$

$$x = Q^2/(2M\nu)$$

$$W^2 \overset{\text{lab}}{=} M^2 + 2M\nu - Q^2$$

- Inclusive DIS: $e + N \to e' + X$

  $$\Delta\Sigma = (\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s})$$

- Semi-inclusive DIS: $e + N \to e' + h + X$

  $$\Delta u,\ \Delta\bar{u},\ \Delta d,\ \Delta\bar{d},\ \Delta s,\ \Delta\bar{s}$$

- Exclusive, e.g. DVCS: $e + N \to e' + N' + \gamma$

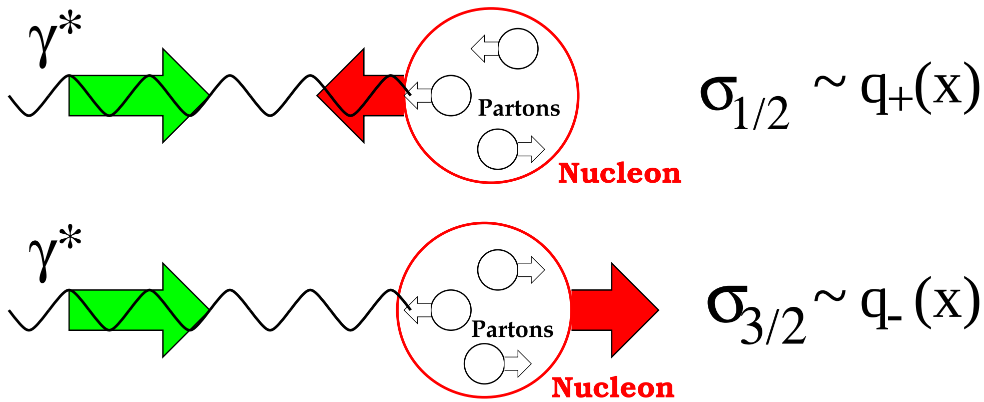
  $(L_q + L_g)$ **??**

Electron-nucleon asymmetry $A_{\|}$:

$$A_{\|} = \frac{1}{\langle P_B P_T \rangle} \frac{(N/L)^{\uparrow\downarrow} - (N/L)^{\uparrow\uparrow}}{(N/L)^{\uparrow\downarrow} + (N/L)^{\uparrow\uparrow}}$$

Virtual photon-nucleon asymmetry A_1:

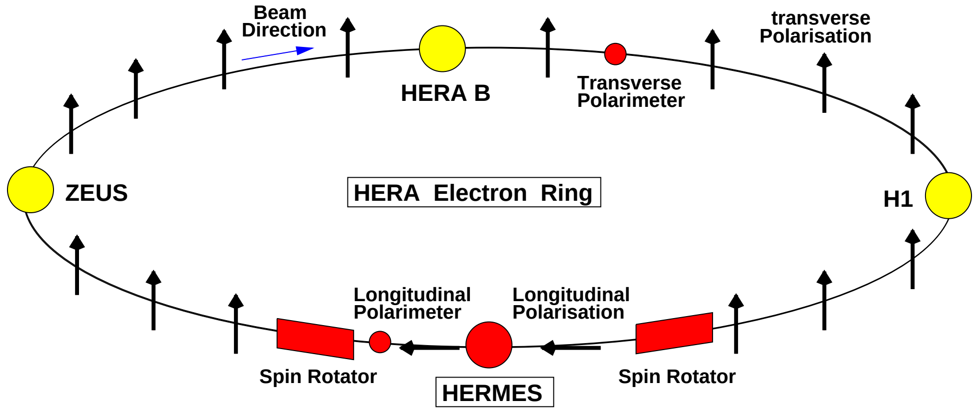
$$A_1(x, Q^2) = A\|(x, Q^2) / \left[(1 + \eta\gamma)\ D(x, Q^2)\right]$$



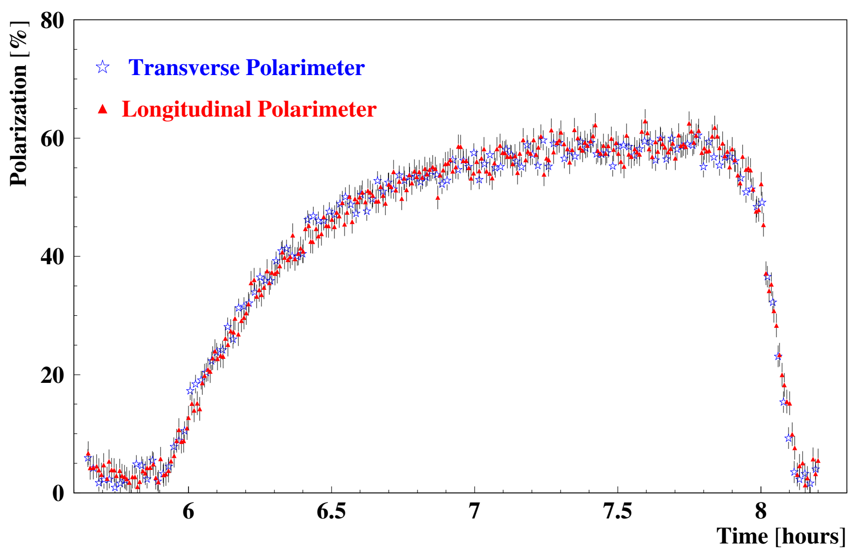
$$\boxed{\begin{aligned} \Delta q &= q_+ - q_- \\ q &= q_+ + q_- \end{aligned}}$$

$$A_1(x, Q^2) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \overset{g_2=0}{\simeq} \frac{g_1(x, Q^2)}{F_1(x, Q^2)} = \frac{\frac{1}{2}\sum_f e_f^2\ \Delta q_f(x, Q^2)}{\frac{1}{2}\sum_f\ e_f^2\ q_f(x, Q^2)}$$

HERA at DESY (Hamburg)

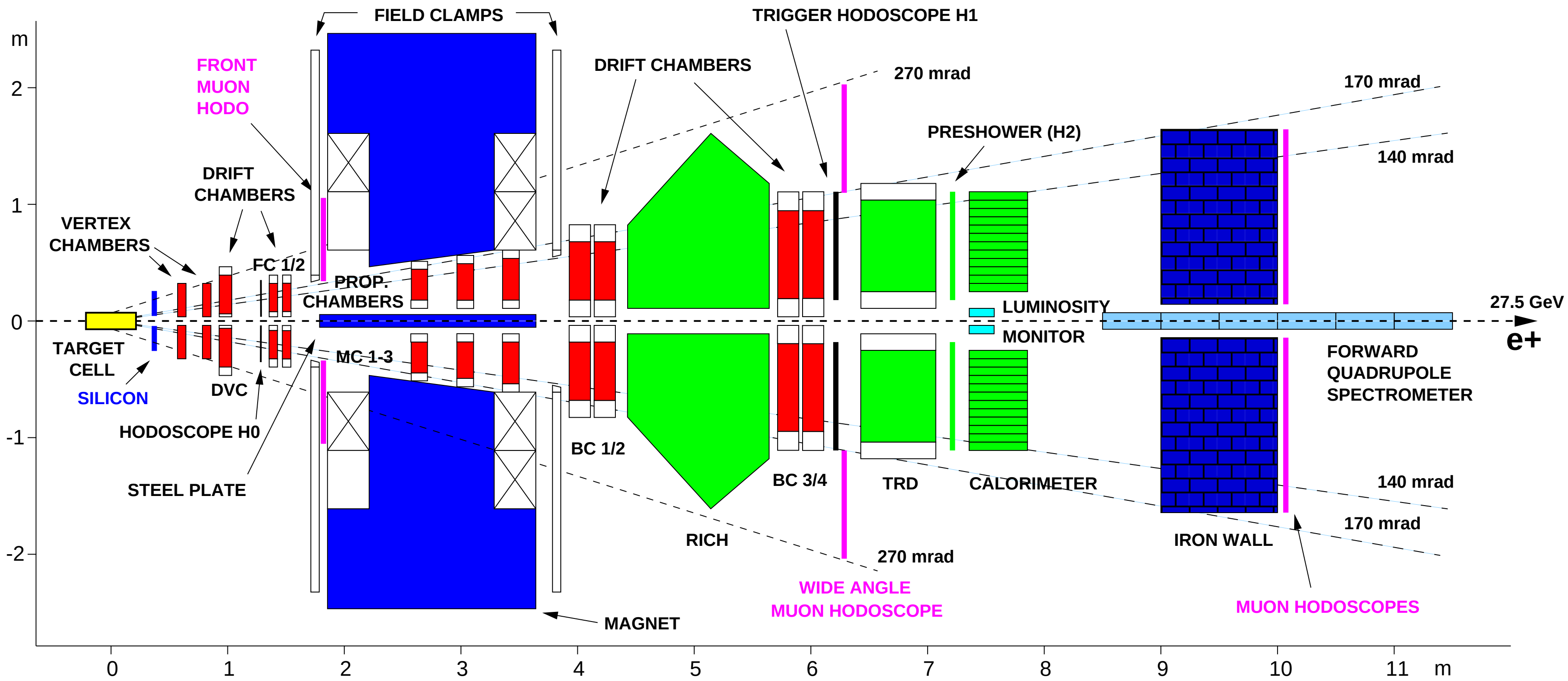


- Self-polarizing electron beam through the Sokolov Ternov effect (small asymmetry in the emission of synchrotron radiation)
- Longitudinal polarization at HERMES
- Average beam polarization: 55%



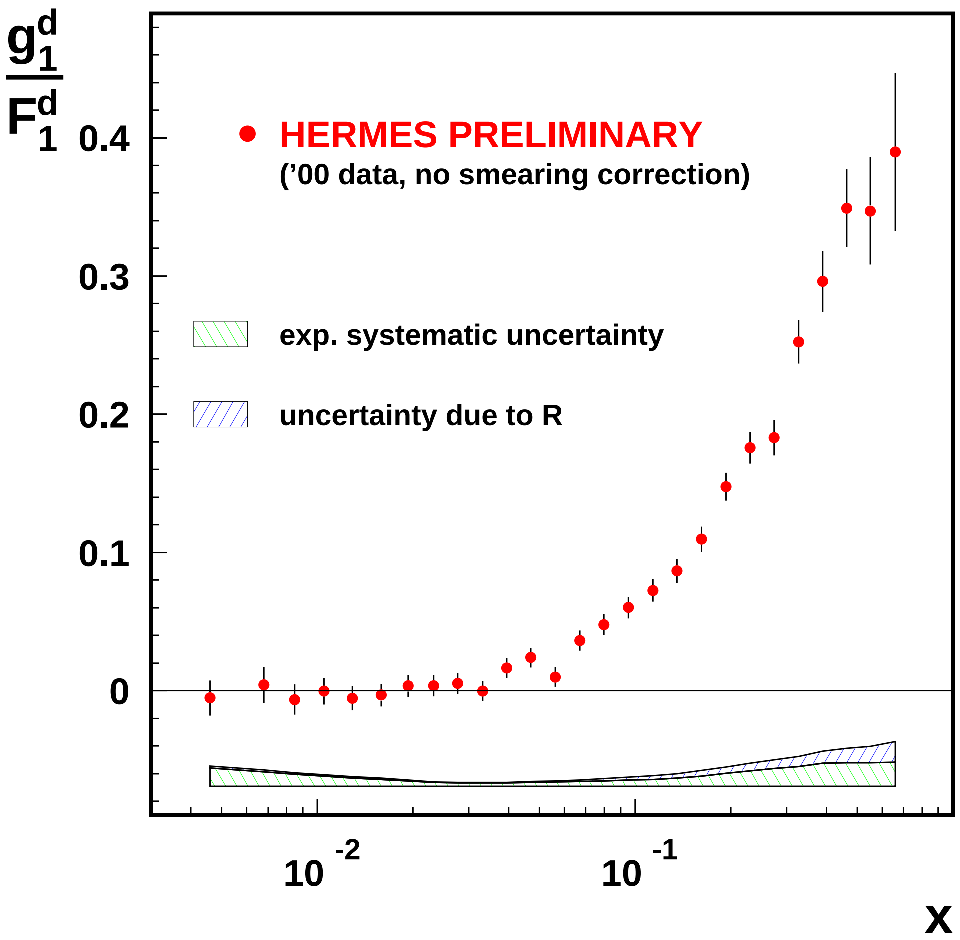
- Beam polarization measured through Compton backscattering

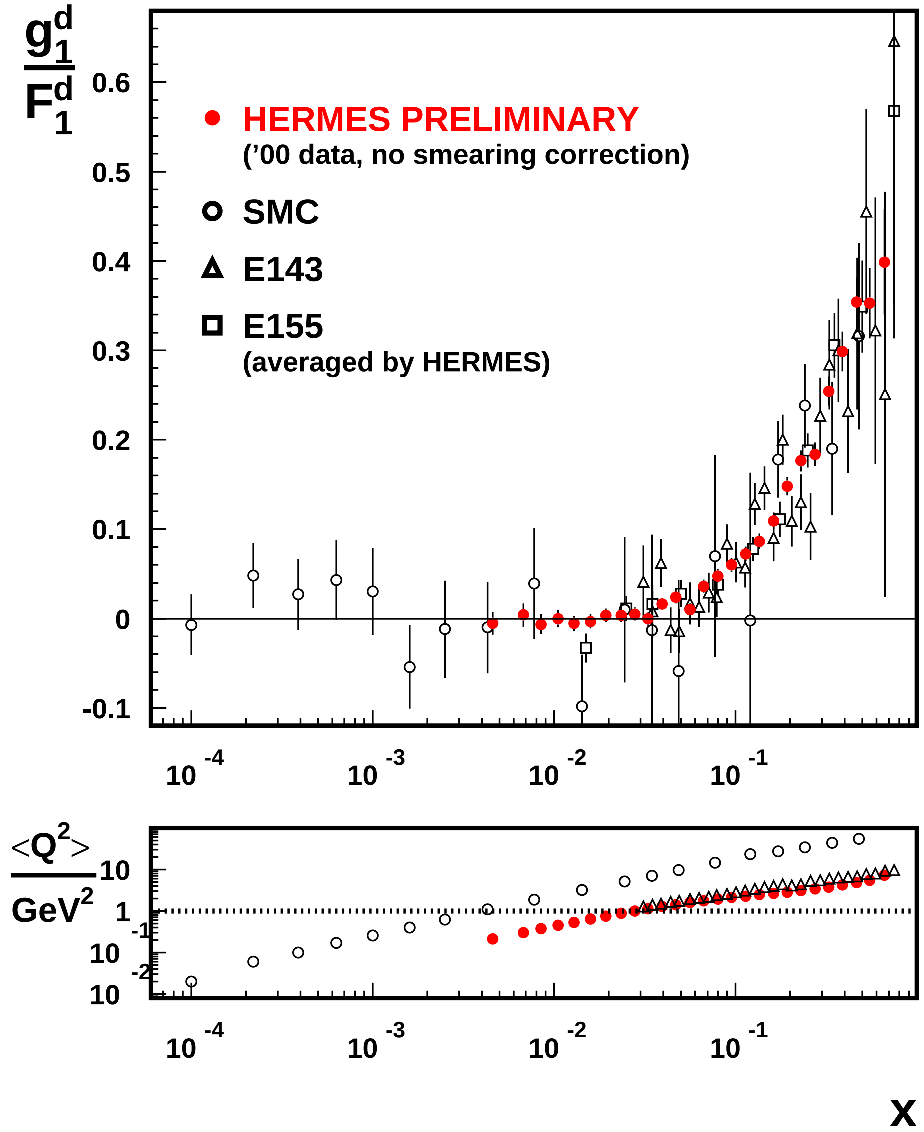
The HERMES Spectrometer



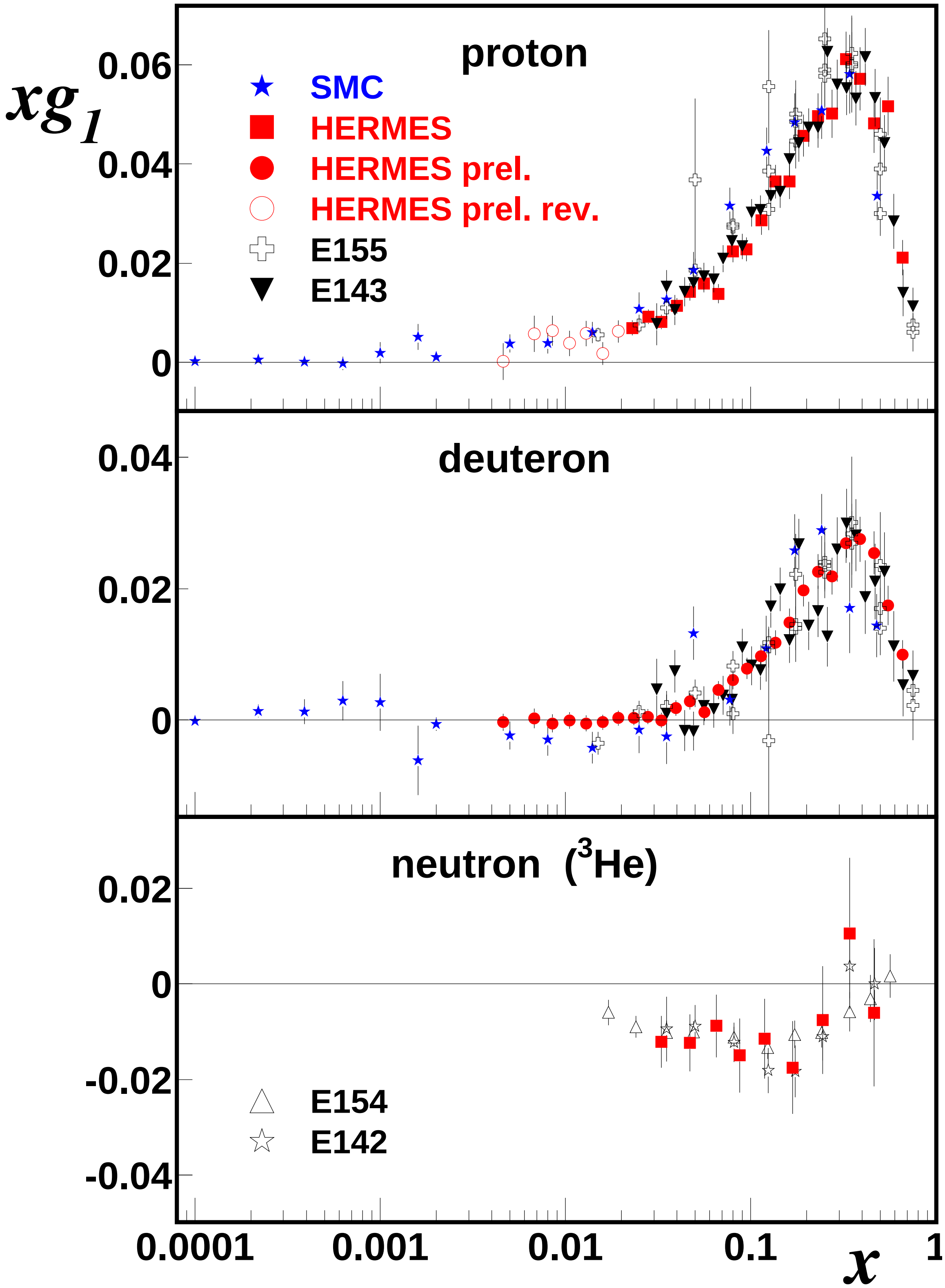
- Angular resolution $\Delta\theta < 0.6$mrad, momentum resolution $\Delta p/p = 0.7\ldots1.3\%$
- Lepton identification efficiency $\sim 98\%$ with hadron contaminations $< 1\%$
- Čerenkov counter replaced by a RICH detector in 1998

The Deuteron Double Spin Asymmetry A_1^d





World Data on Spin Structure Functions



In leading order:

$$F_1(x,Q^2) = \frac{1}{2}\sum_f e_f^2\; q_f(x,Q^2) \qquad g_1(x,Q^2) = \frac{1}{2}\sum_f e_f^2\; \Delta q_f(x,Q^2)$$

Semi-inclusive asymmetry of hadron h:

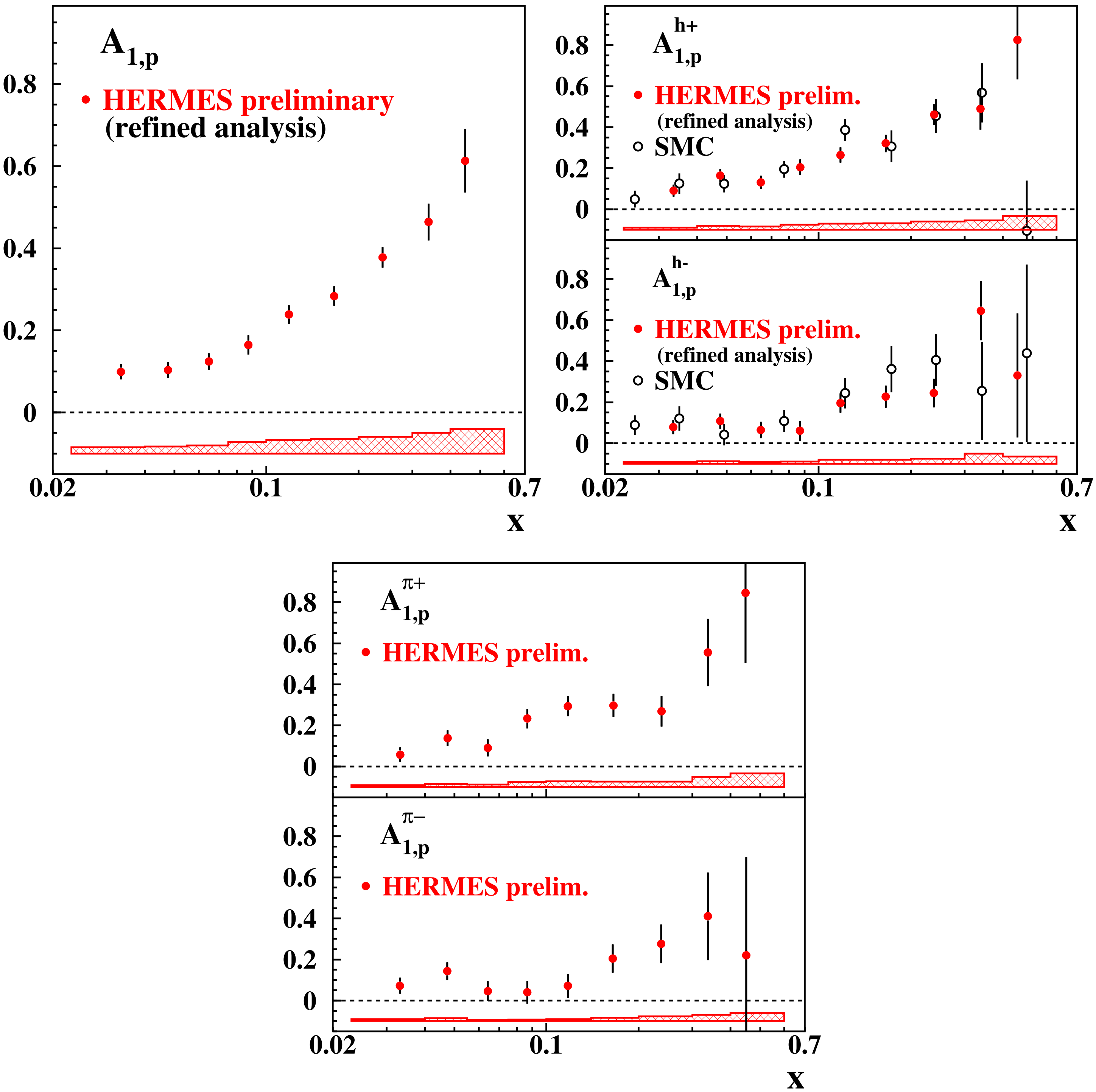
$$A_1^h(x) \overset{g_2=0}{\simeq} \frac{\sum_f e_f^2\; \Delta q_f(x)\; \int \mathrm{d}z\; D_f^h(z)}{\sum_{f'} e_{f'}^2\; q_{f'}(x)\; \int \mathrm{d}z\; D_{f'}^h(z)}$$

$$= \sum_f \underbrace{\frac{e_f^2\; q_f(x) \int \mathrm{d}z\; D_f^h(z)}{\sum_{f'} e_{f'}^2\; q_{f'}(x)\; \int \mathrm{d}z\; D_{q_{f'}}^h(z)}}_{\equiv\, \mathcal{P}_f^h(x) \;\ldots\; \text{Purity}} \frac{\Delta q_f(x)}{q_f(x)}$$

Solve system of linear equations $\vec{A}$:

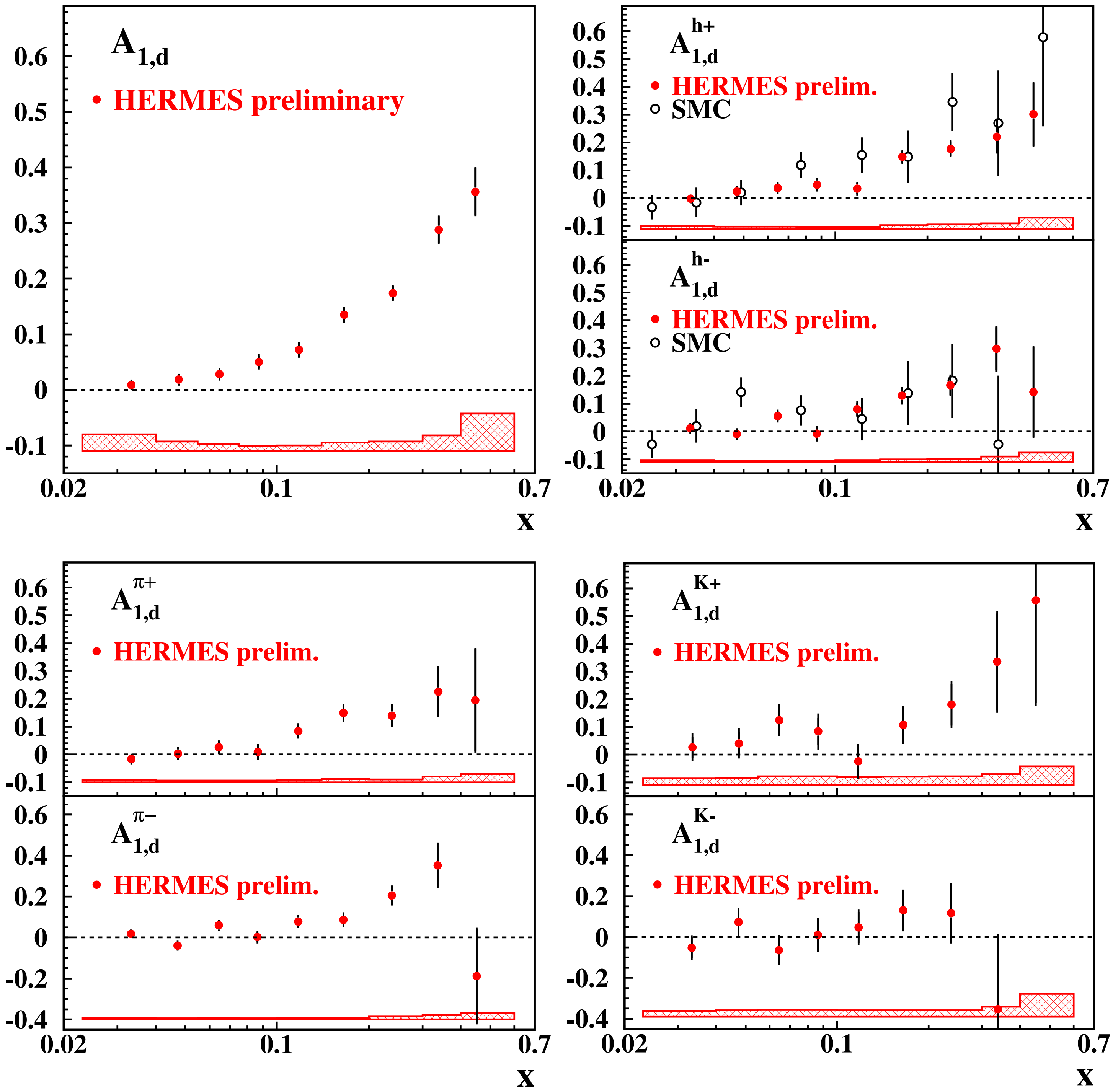
$$\boxed{\vec{A}(x) = \mathbf{P}_f^h(x) \cdot \vec{Q}(x)} \qquad \vec{Q} = \left(\frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta \bar{d}}{\bar{d}}, \frac{\Delta s + \Delta \bar{s}}{s + \bar{s}}\right)$$

Asymmetries On The Proton



Threshold Čerenkov counter allows measurement of $\pi^{\pm}$ asymmetries.

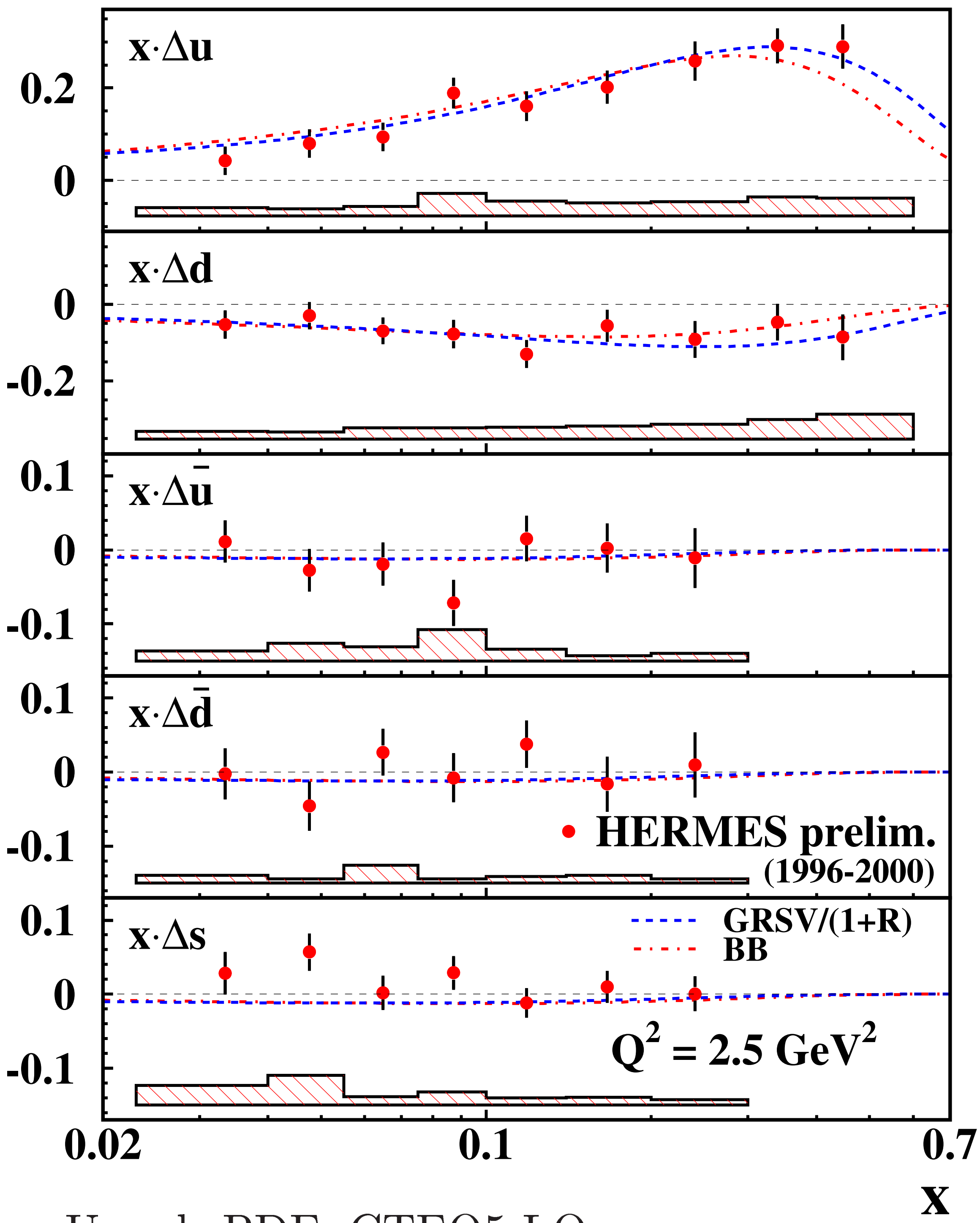
Asymmetries On The Deuteron



RICH detector allows measurement of

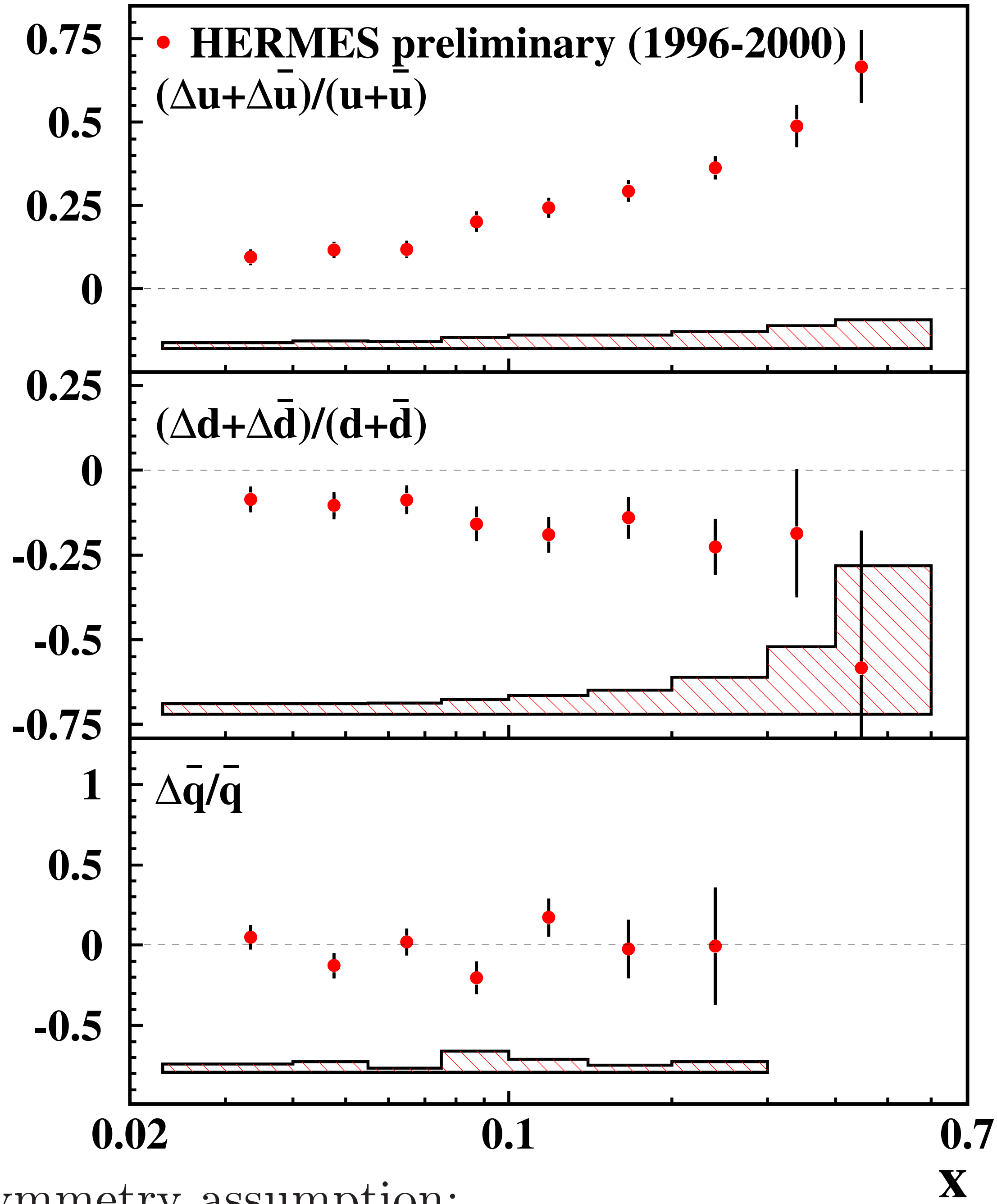
$\pi^{\pm}$ and $K^{\pm}$ asymmetries.

Polarized Quark Densities



- Unpol. PDF: CTEQ5 LO
- Strange sea polarization: $\Delta s \gtrsim 0$

Quark Polarizations

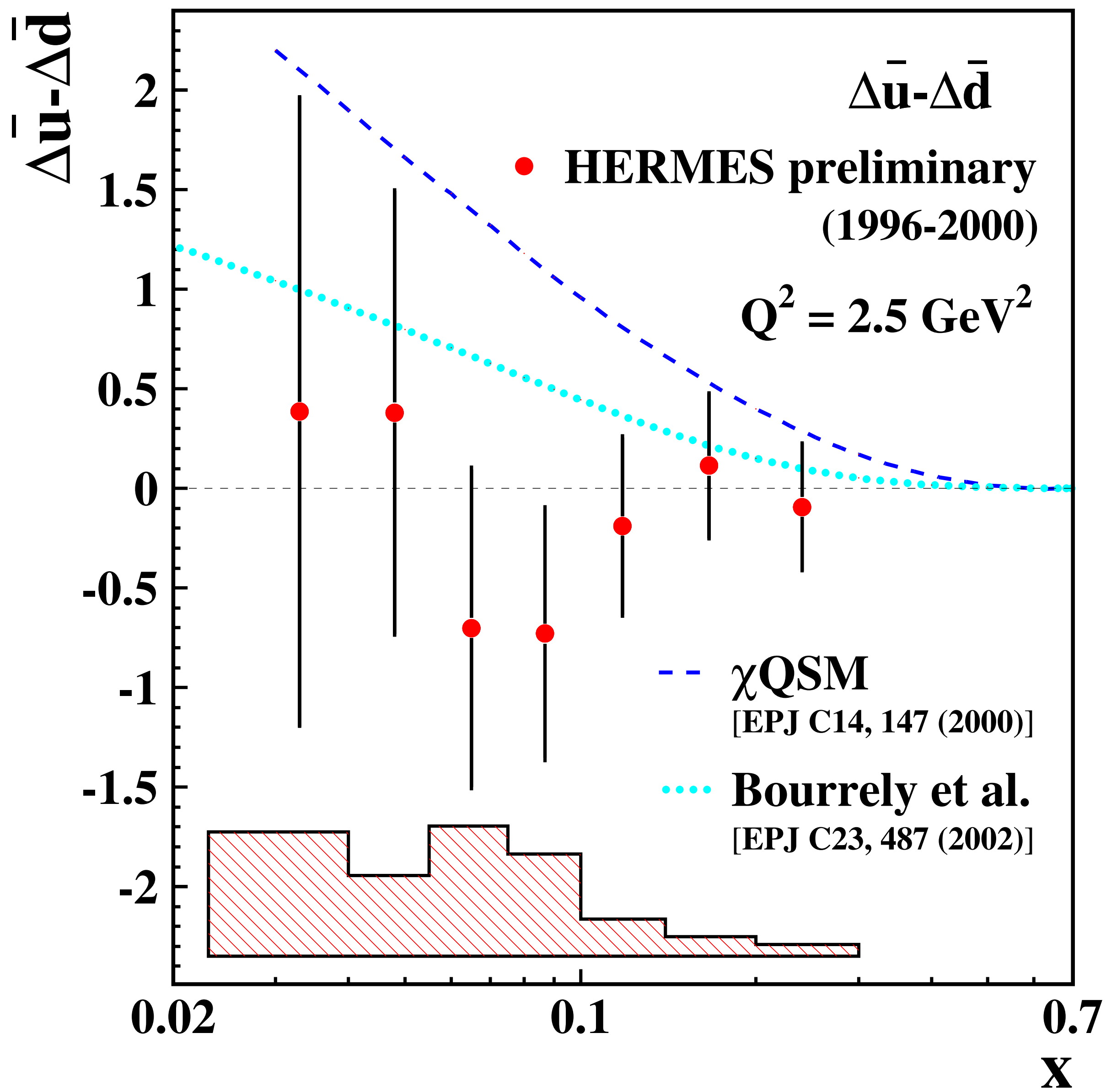


Symmetry assumption:

$$\frac{\Delta\bar{q}}{\bar{q}} \equiv \frac{\Delta\bar{u}}{\bar{u}} = \frac{\Delta u_s}{u_s} = \frac{\Delta\bar{d}}{\bar{d}} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta\bar{s}}{\bar{s}}$$

$\Delta\bar{q}(x)/\bar{q}(x)$ dominated by u-quarks

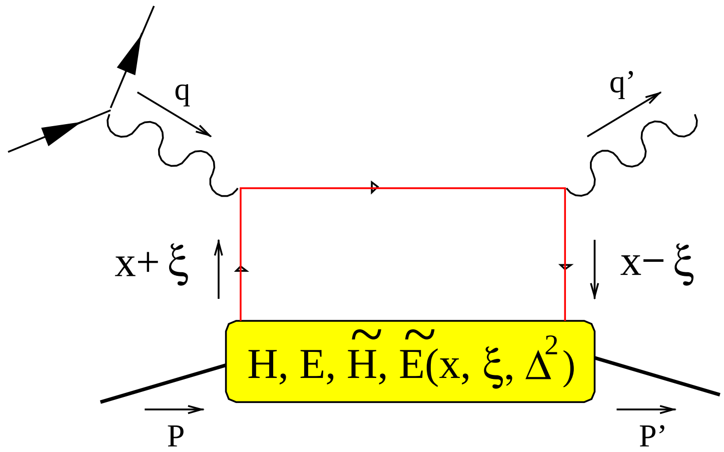
Symmetry of the Polarized Light Sea



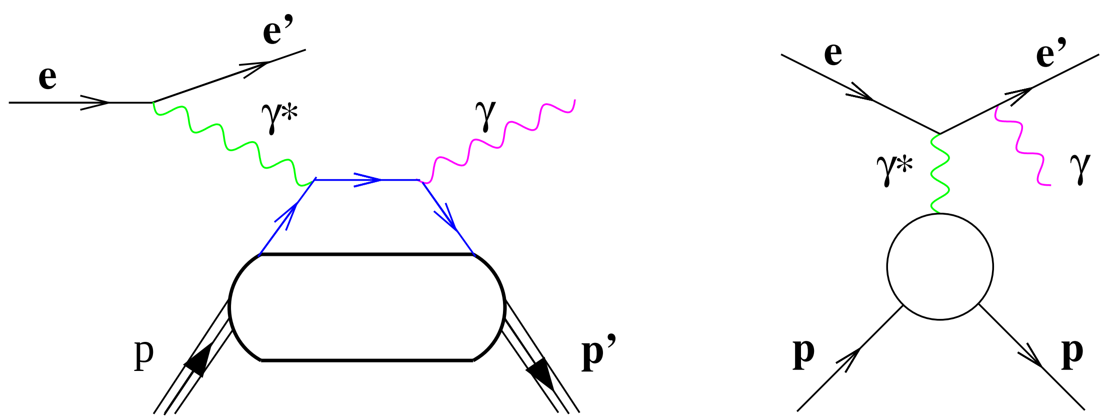
- No significant breaking of flavor symmetry
- Data do not favor χQSM

Deeply Virtual Compton Scattering

Generalized Parton Distributions: $H, E, \tilde{H}, \tilde{E}$



Exclusive lepto-production of photons:



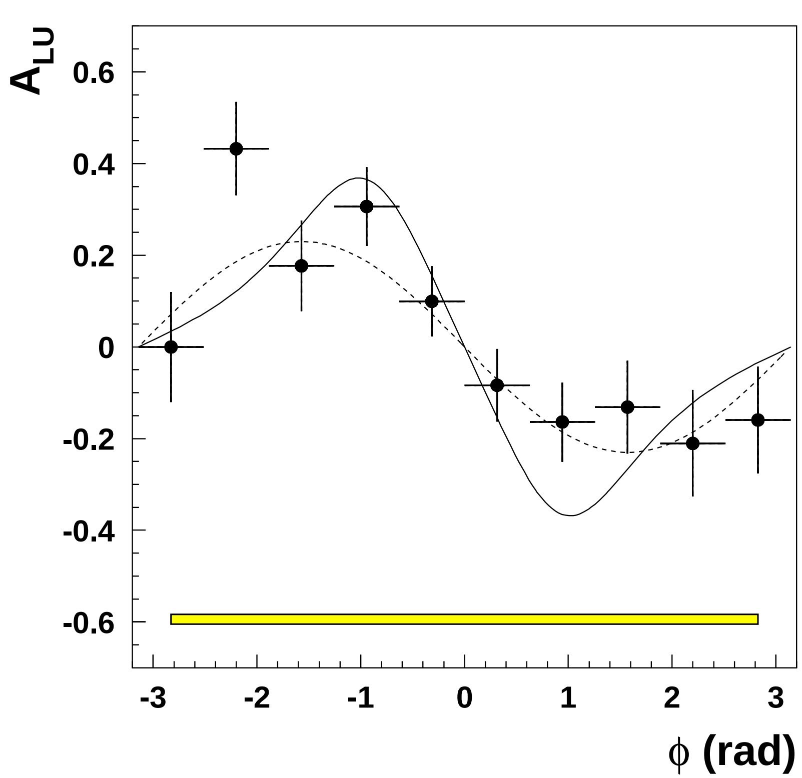
Interference term is beam helicity dependent,

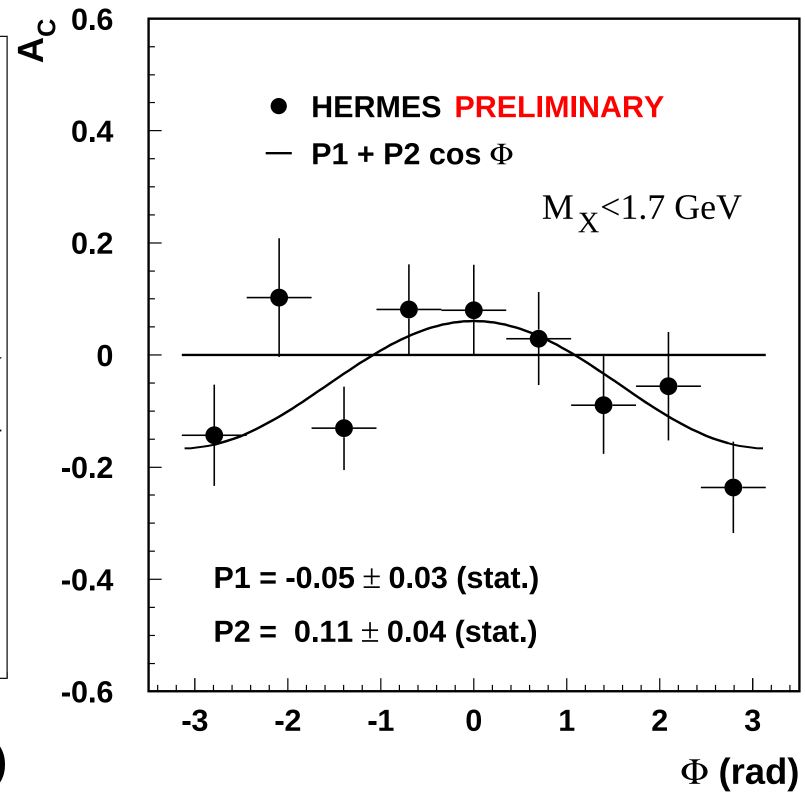
$$(\tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}} + \tau_{\mathrm{BH}}\tau^*_{\mathrm{DVCS}}) \;\propto\; -e_l\, P_l \sin\phi\, \mathrm{Im}(\tilde{M}^{1,1})$$

and beam charge dependent:

$$(\tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}} + \tau_{\mathrm{BH}}\tau^*_{\mathrm{DVCS}}) \;\propto\; \pm\cos\phi\, \mathrm{Re}(\tilde{M}^{1,1})$$

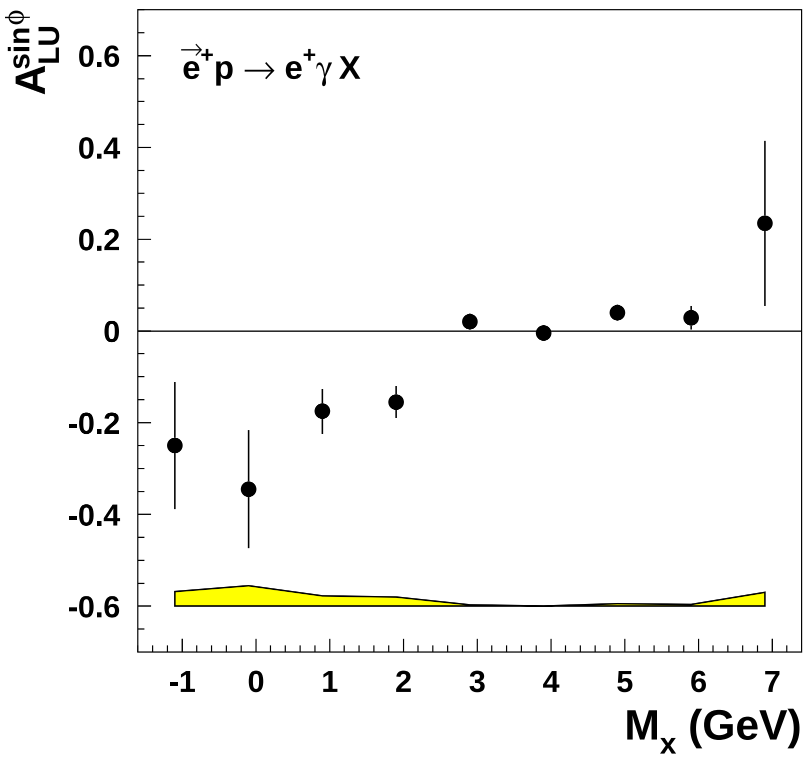
Beam Spin and Beam Charge Asymmetries

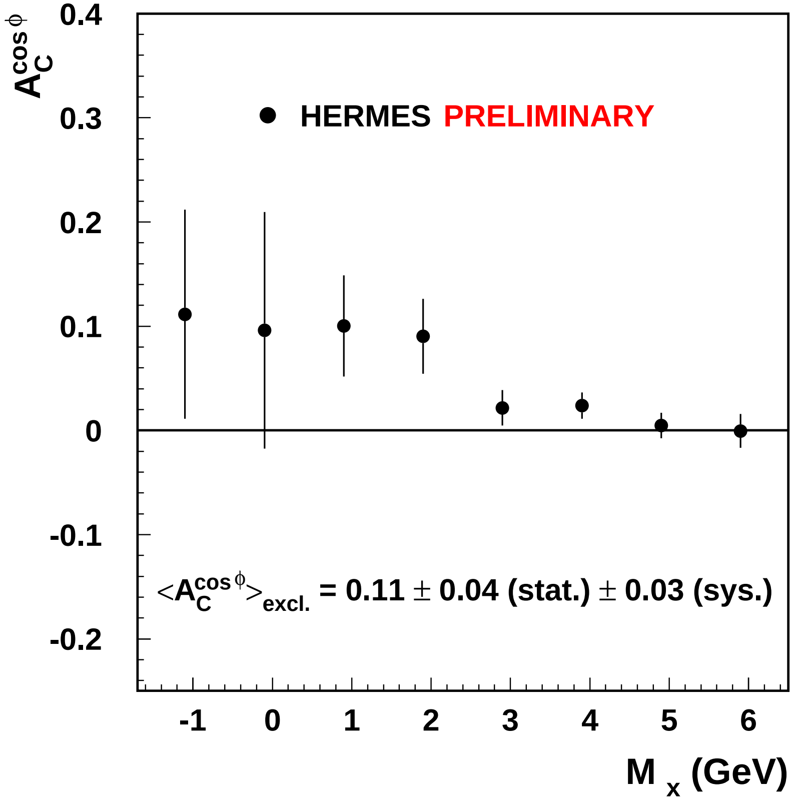




$$A_{LU}(\phi) = \frac{1}{\langle |P_l| \rangle} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \qquad A_C(\phi) = \frac{N^{e^+}(\phi) - N^{e^-}(\phi)}{N^{e^+}(\phi) + N^{e^-}(\phi)}$$

Beam Helicity and Beam Charge Moments





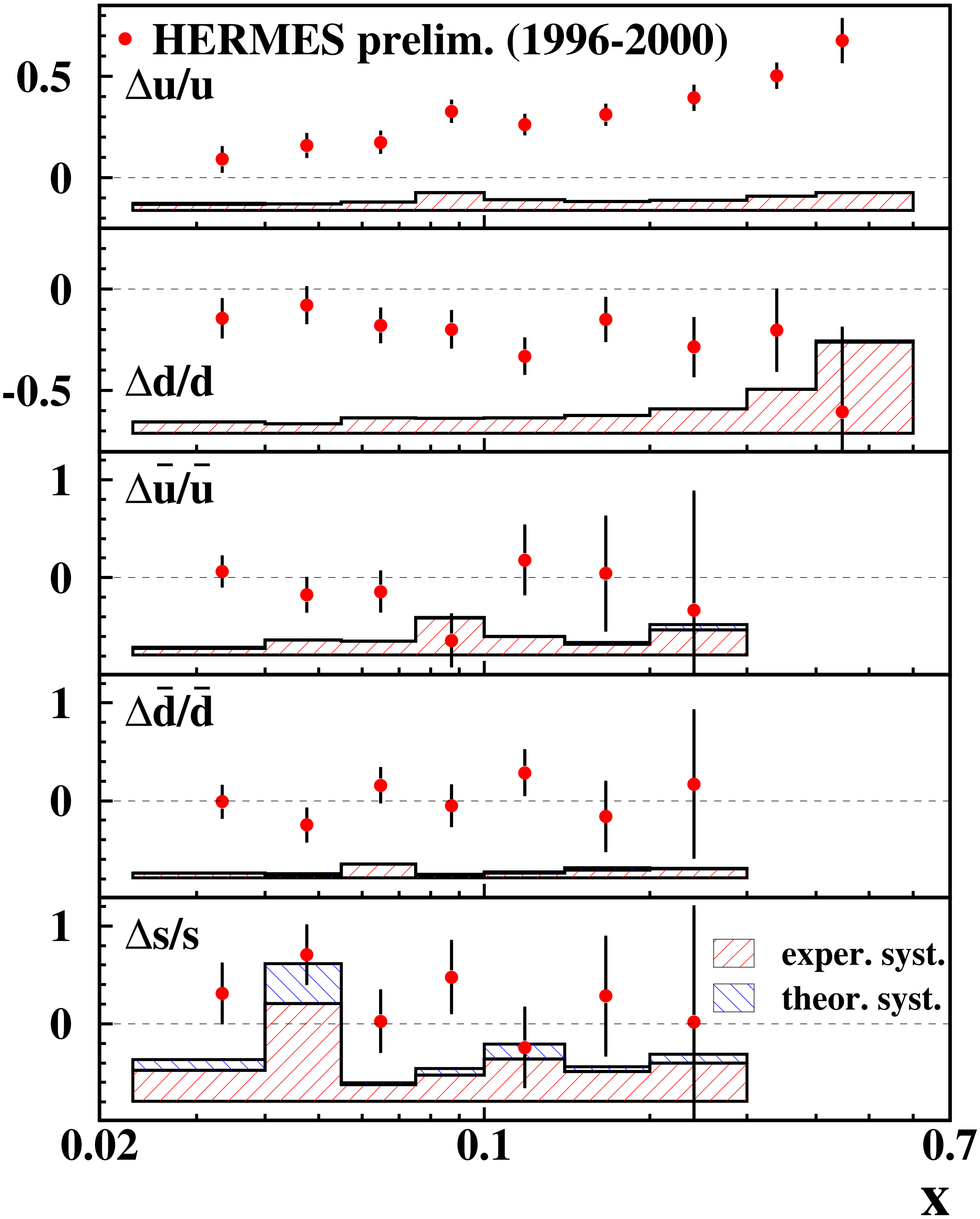
$$A_{LU}^{\sin\phi} = \frac{2}{N} \sum_{i=1}^{N} \frac{\sin\phi_i}{(P_l)_i}$$

$$A_C^{\cos\phi} = \sum_{i=1}^{N^{e^+}} \frac{\cos\phi_i}{N^{e^+}} - \sum_{i=1}^{N^{e^-}} \frac{\cos\phi_i}{N^{e^-}}$$

Conclusion

- Inclusive asymmetries measured with *high statistical precision*
  - ➨ $g_1^{p,d,n}$ confirm world data
- Asymmetries of pions and kaons measured for the first time
- Polarized quark distributions obtained in LO analysis
  - ➨ Precise results for Δu, Δd
  - ➨ First decomposition of sea polarization
- First extraction of strange polarization
  - ➨ Within statistics: $\Delta s \gtrsim 0$
- First measurements of DVCS promise more exciting results
  - ➨ *Total angular momentum??*
- Recoil detector upgrade will improve exclusive measurements

Quark Polarizations



DVCS – The Azimuthal Angle ϕ