Measurement of the proton spin structure function $\mathbf{g_2^p}$ *and asymmetry* $\mathbf{A_2^p}$ *at the* HERMES *experiment*

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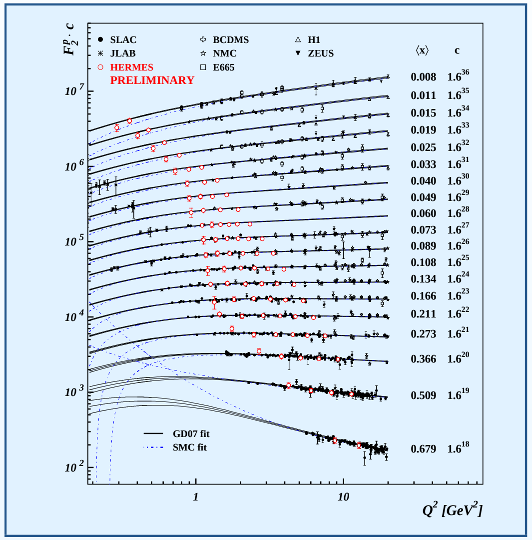
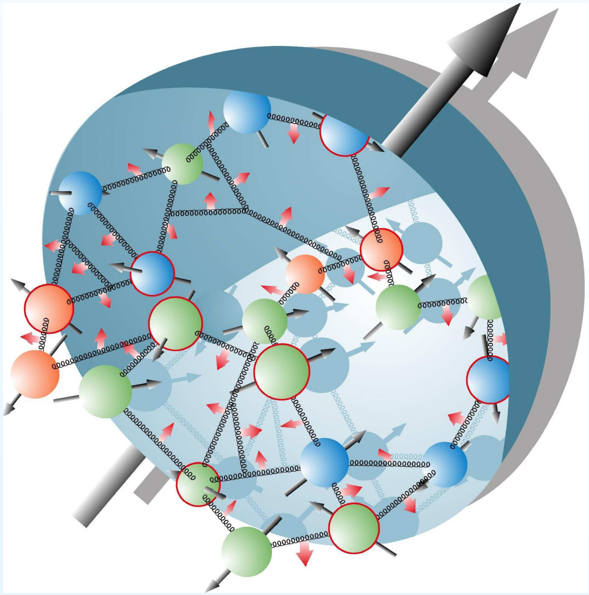
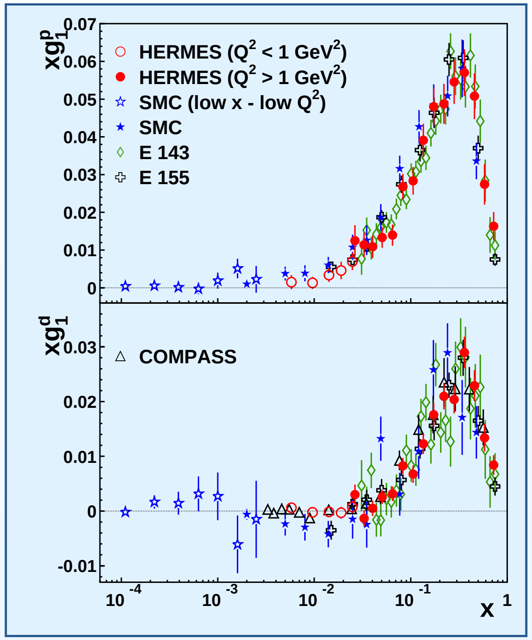
on behalf of the hermes collaboration

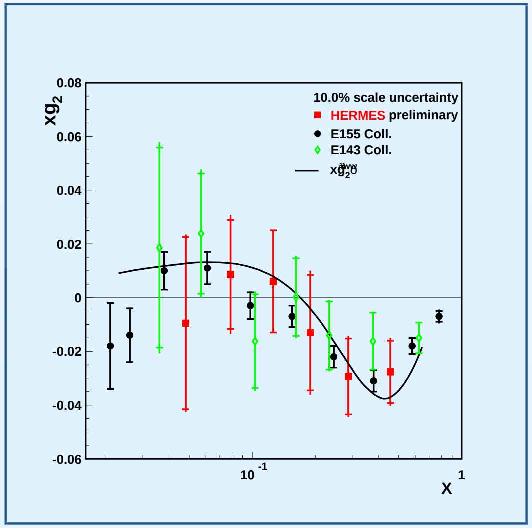
The HERA legacy:



$$F_2(x) = 2xF_1(x)$$

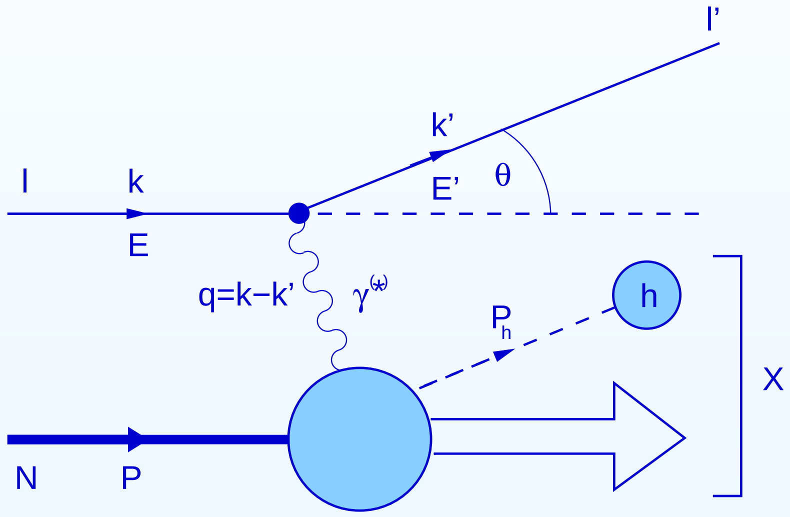






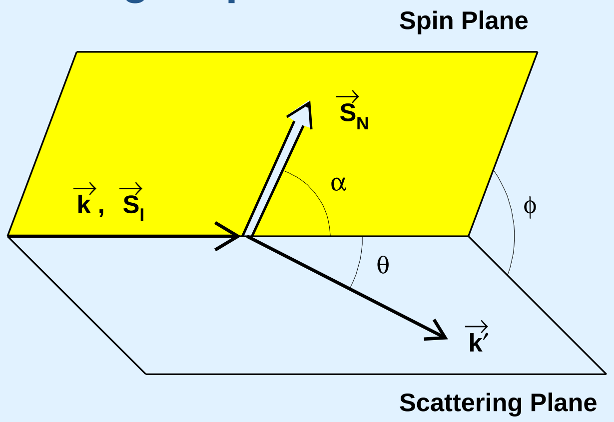
The polarised deep-inelastic scattering process:

- **inclusive measurement ($lN \to l'X$):**



$$Q^2 \equiv -q^2, \quad x = Q^2/(2P \cdot q)$$

target spin orientation:



- longitudinal: $\alpha = 0°, 180°$
- transverse: $\alpha = 90°, 270°$

- **spin-dependent cross-section contribution:**

$$\frac{d^3\left(\sigma(\alpha) - \sigma(\alpha+\pi)\right)}{dx\,dy\,d\phi_S} = \frac{e^4}{2\pi^2 Q^2}\left\{\cos\alpha\left[\left(1 - \frac{y}{2} - \frac{y^2\gamma^2}{4}\right)\mathbf{g_1}\left(\mathbf{x},\mathbf{Q^2}\right) - \left(\frac{y}{2}\gamma^2\right)\mathbf{g_2}\left(\mathbf{x},\mathbf{Q^2}\right)\right]\right.$$

$$\left. - \sin\alpha\cos\phi_S\gamma\sqrt{1 - y - \frac{y^2\gamma^2}{4}}\left[\frac{y}{2}\mathbf{g_1}\left(\mathbf{x},\mathbf{Q^2}\right) + \mathbf{g_2}\left(\mathbf{x},\mathbf{Q^2}\right)\right]\right\}$$

The structure function $\mathbf{g_2}$:

- **Wandzura-Wilczek decomposition:**

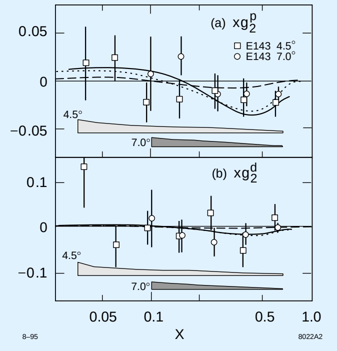
$$g_2\left(x,Q^2\right) = g_2^{\mathrm{WW}}\left(x,Q^2\right) + \bar{g}_2\left(x,Q^2\right)$$

  - $g_2^{\mathrm{WW}}\left(x,Q^2\right) = -g_1\left(x,Q^2\right) + \int_x^1 \frac{dy}{y} g_2\left(y,Q^2\right)$
  - pure **twist-three contribution $\bar{\mathbf{g}}_2$**
    - **probing quark-gluon correlations**
    - $\int_0^1 dx\, x^n \bar{g}_2\left(x,Q^2\right) = \frac{n}{4(n+1)} d_n\left(Q^2\right)$
    - d_2: Lorentz-force acting on quark

- **Burkhardt-Cottingham sum rule:**

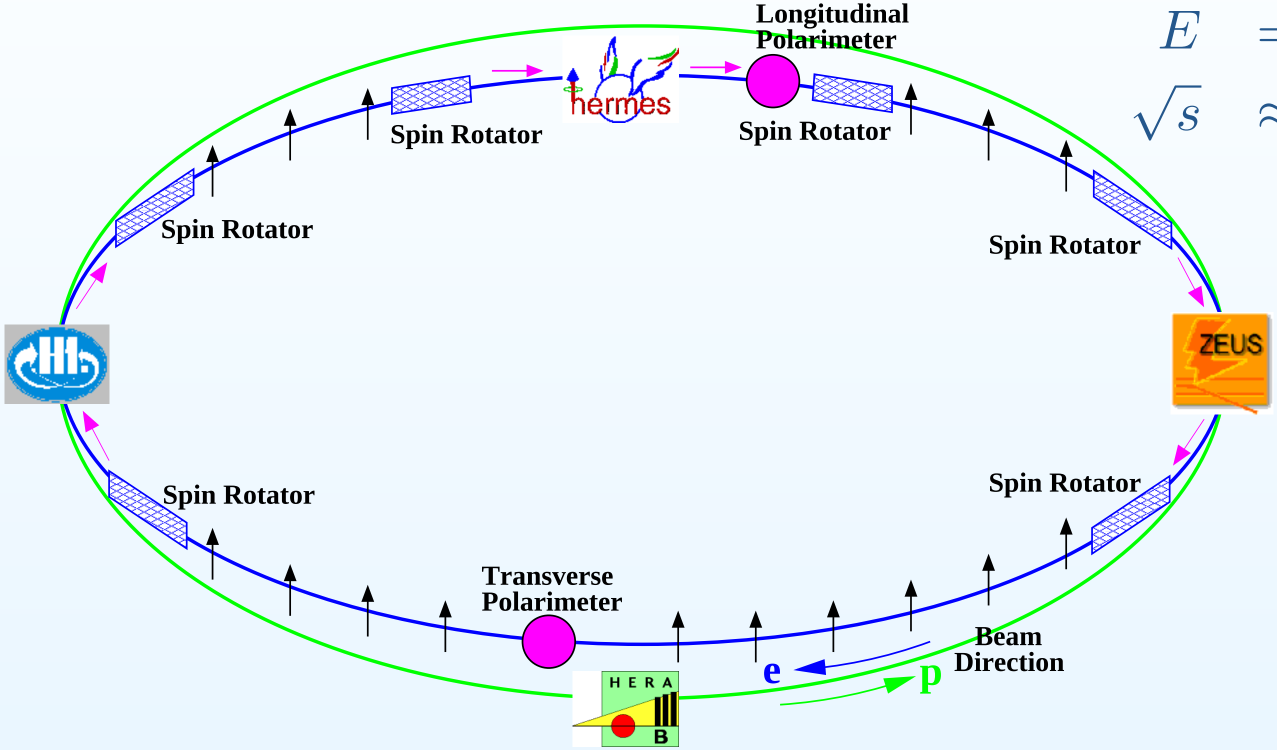
$$\int_0^1 dx\, g_2\left(x,Q^2\right) = 0$$

➥ nodes? (besides $x = 1$ and perhaps $x = 0$)



(E143 data)

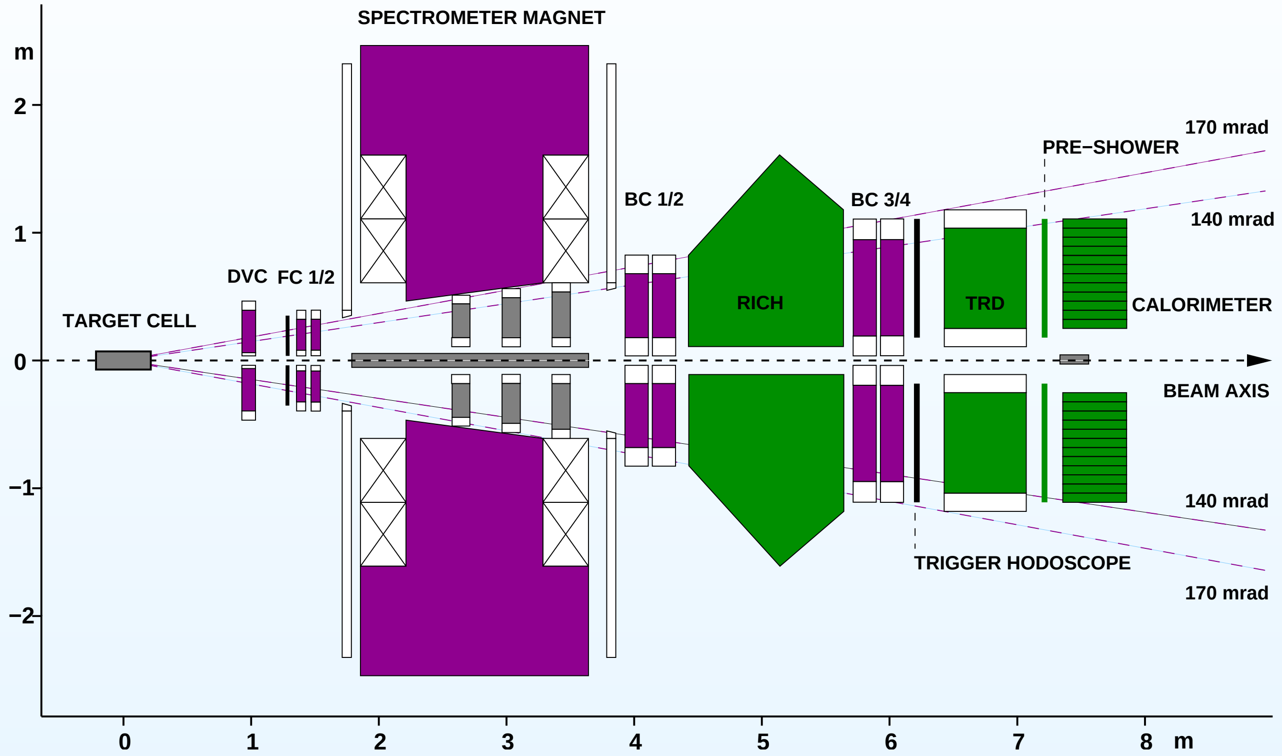
The HERMES polarised DIS scattering experiment:



$$E = 27.6\,\text{GeV}$$
$$\sqrt{s} \approx 7\,\text{GeV}$$

- **Sokolov-Ternov mechanism**
  ➥ transverse beam polarisation
- **spin rotators:**
  ➥ longitudinal beam polarisation: $\langle P_B \rangle = 0.34 \pm 0.01$

The HERMES spectrometer:



- polarised **hydrogen target** internal to the HERA storage ring
  ➥ background-free measurements from highly polarised protons
  ➥ substantial reduction of time-dependent systematics
- very clean lepton-hadron separation
- 2003–2005: **transversely polarised target**: $\langle P_T \rangle = 0.71 \pm 0.06$

The measurement of double-spin asymmetries:

- **lepton-beam asymmetries:**

$$A_{\parallel} = \frac{\sigma^{\rightarrow\Leftarrow} - \sigma^{\rightarrow\Rightarrow}}{\sigma^{\rightarrow\Leftarrow} + \sigma^{\rightarrow\Rightarrow}} = D\left(A_1 + \eta A_2\right)$$

$$A_{\perp} = \frac{\sigma^{\rightarrow\Uparrow} - \sigma^{\rightarrow\Downarrow}}{\sigma^{\rightarrow\Uparrow} + \sigma^{\rightarrow\Uparrow}} = d\left(A_2 - \zeta A_1\right)$$

- **virtual-photon asymmetries:**

$$A_1 = \frac{\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}}{\sigma_{\frac{1}{2}} + \sigma_{\frac{3}{2}}} = \frac{g_1 - \gamma^2 g_2}{F_1}$$

$$A_2 = \frac{\sigma_{\mathrm{LT}}}{\sigma_{\mathrm{T}}} = \frac{\gamma\left(g_1 + g_2\right)}{F_1}$$

The measurement of $A_\perp$:

- HERA beam facility: $\sigma^{\rightarrow\Uparrow},\ \sigma^{\rightarrow\Downarrow}$ and $\sigma^{\leftarrow\Uparrow},\ \sigma^{\leftarrow\Downarrow}$

$$
\begin{aligned}
A_1\left(\phi_S, x, Q^2\right) &= \frac{\sigma^{\rightarrow\Uparrow}\left(\phi_S, x, Q^2\right) - \sigma^{\rightarrow\Downarrow}\left(\phi_S, x, Q^2\right)}{\sigma^{\rightarrow\Uparrow}\left(\phi_S, x, Q^2\right) + \sigma^{\rightarrow\Uparrow}\left(\phi_S, x, Q^2\right)} \\
&= -\frac{\sigma^{\leftarrow\Uparrow}\left(\phi_S, x, Q^2\right) - \sigma^{\leftarrow\Downarrow}\left(\phi_S, x, Q^2\right)}{\sigma^{\leftarrow\Uparrow}\left(\phi_S, x, Q^2\right) + \sigma^{\leftarrow\Uparrow}\left(\phi_S, x, Q^2\right)} \\
&= cos\phi_S\ A_\perp\left(x, Q^2\right)
\end{aligned}
$$

- $A_\perp$ reconstructed from luminosity-normalised count-rates:

$$
A_\perp^{\overset{(\leftarrow)}{\rightarrow}}\left(\phi_S, x, Q^2\right) = \frac{1}{|P_B\, P_T|} \frac{N^{\overset{(\leftarrow)}{\rightarrow}\Uparrow}\left(\phi_S, x, Q^2\right) - N^{\overset{(\leftarrow)}{\rightarrow}\Downarrow}\left(\phi_S, x, Q^2\right)}{N^{\overset{(\leftarrow)}{\rightarrow}\Uparrow}\left(\phi_S, x, Q^2\right) + N^{\overset{(\leftarrow)}{\rightarrow}\Uparrow}\left(\phi_S, x, Q^2\right)}
$$

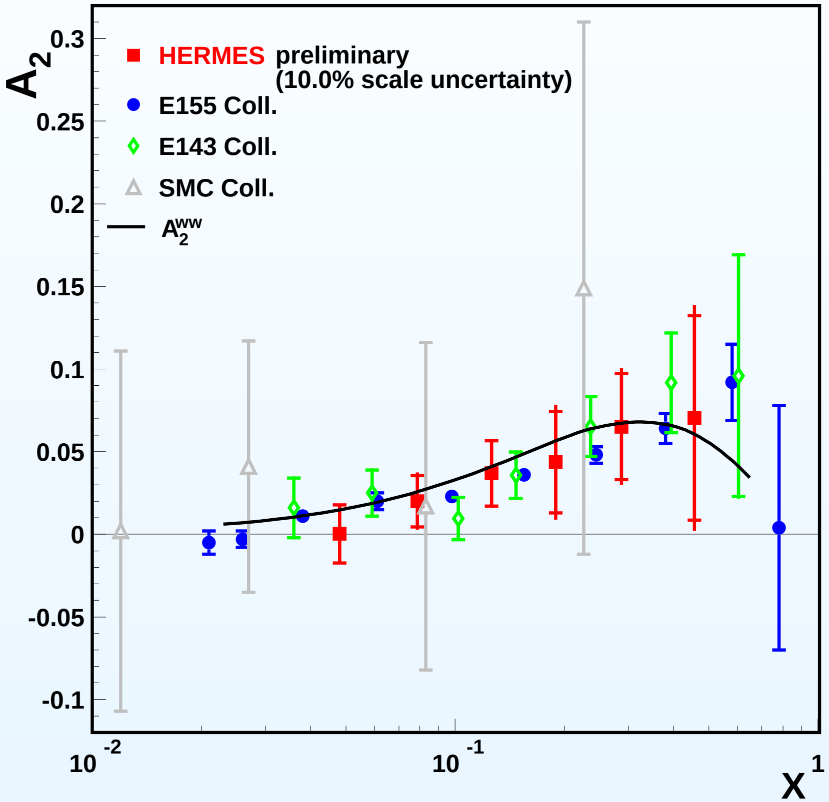
Correction for kinematic smearing effects:

- $A'_\perp\left(\phi_S, x, Q^2\right)$ measurement affected by
  - **higher order QED processes**
  - finite detector resolution ➥ **kinematic smearing**
- resulting bin migration studied in Monte Carlo (MC)
  ➥ smearing matrix S
  ➥ (model-independent) **unfolding algorithm**

$$A_\perp(j) = -1 + \frac{2}{N_{\text{MC, unpol}}(j)} \sum_{i=1}^{n_{\text{bins}}} \left(S^{\rightarrow\Uparrow} + S^{\rightarrow\Downarrow}\right)^{-1}(j,i) \times$$
$$\left(A'_\perp(i)\, N'_{\text{MC, unpol}}(i) - n_{\text{MC, bg}}(i) + \sum_{k=1}^{n_{\text{bins}}} S^{\rightarrow\Uparrow}(i,k)\, N_{\text{MC, unpol}}(k)\right)$$

➥ statistical correlation of $A_\perp\left(\phi_S, x, Q^2\right)$

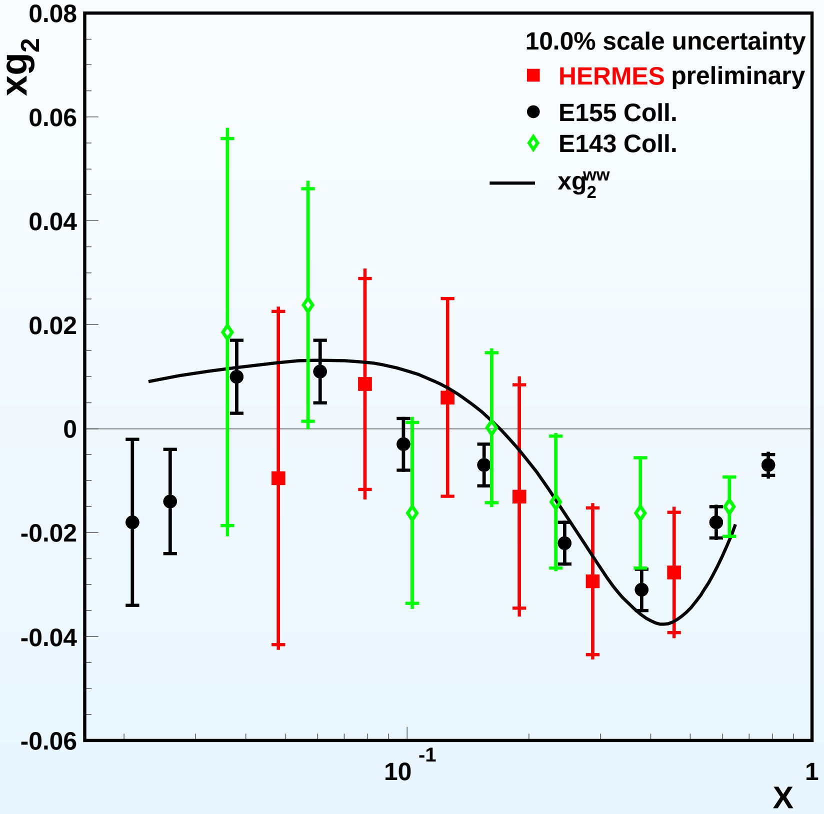
HERMES extraction of $A_2^p(x)$:



$$A_2^p = \frac{1}{1+\eta\,\zeta}\left(\frac{A_\perp^p}{d} + \frac{\eta\,\zeta}{\gamma}\left(1+\gamma^2\right)\frac{g_1^p}{F_1^p}\right)$$

R	R1998
F_2^p	GM07
$\frac{g_1^p}{F_1^p}$	E155

HERMES extraction of $g_2^p(x)$:



$$0.0041 < x < 0.9$$

$$0.18\,\text{GeV}^2 < Q^2 < 20\,\text{GeV}^2$$

$$g_2^p = \frac{F_1^p}{\gamma(1+\eta\zeta)}\left(\frac{A_\perp^p}{d} - \left(\gamma - \frac{\eta\zeta}{\gamma}\right)\frac{g_1^p}{F_1^p}\right)$$

R	R1998
F_2^p	GM07
$\frac{g_1^p}{F_1^p}$	E155

In a nutshell:

- extraction of $A_2^p\left(x,Q^2\right)$ in
$$0.0041 < x < 0.9 \text{ and } 0.18\,\text{GeV}^2 < Q^2 < 20\,\text{GeV}^2$$
- extraction of $g_2^p\left(x,Q^2\right)$
  - consistent with SMC, E143 and E155
    ➥ important check of *transverse data*
  - consistent with $g_2^p\left(x,Q^2\right) \approx g_2^{p,\text{WW}}\left(x,Q^2\right)$
    ➥ no sensitivity to $\bar{g}_2^p\left(x,Q^2\right)$?
    ➥ probing quark-gluon correlation?
- in preparation for final publication
- including a more detailed analysis of $g_2^p\left(x,Q^2\right)$