# *Search for a 2-photon exchange signal at HERMES*

..and a bonus: ***$A_2$ and $xg_2$ measurement***

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..on behalf ***HERMES Collaboration***

Transverse Partonic Structure of Hadrons

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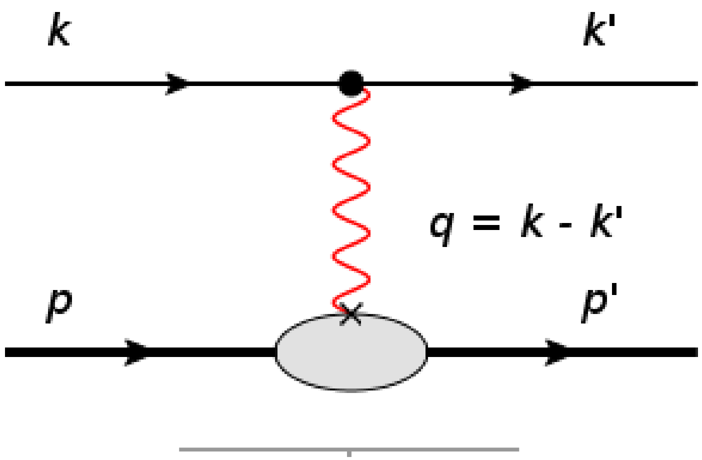
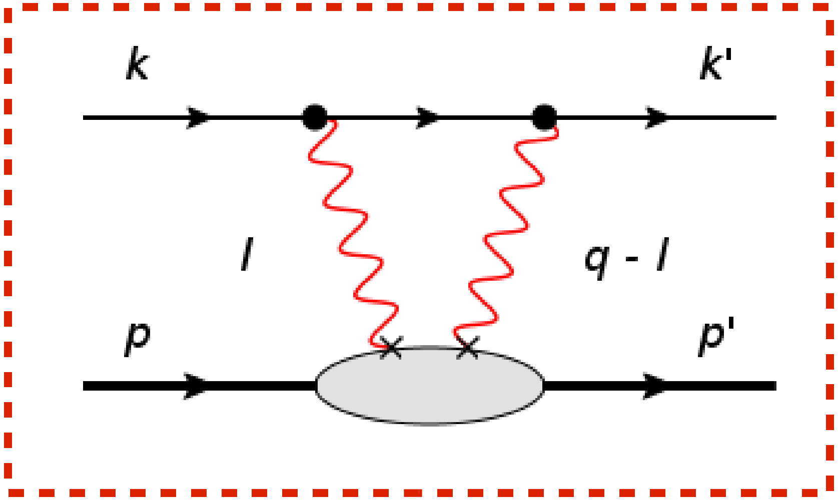
# 1. 2-photon exchange

*.. In lepton-nucleon scattering:*

standard **one-photon** exchange
(Born) approximation




***two-photon*** exchange
contribution to 1-loop corrections
to the scattering amplitude




$$\mathcal{M} = \mathcal{M}^0 + \mathcal{M}^1$$

# 1. 2-photon exchange

*.. Why is it interesting?*

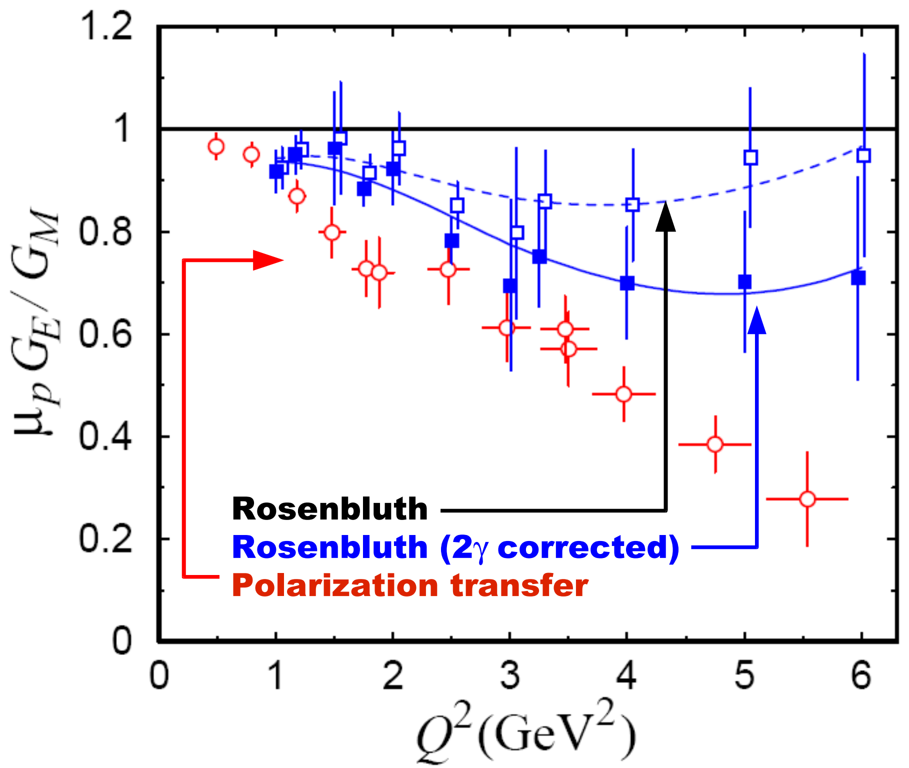
➔ **Strong Impact on *ep* scattering:**

1. Partially solves the discrepancy in GE/GM between unpolarized (Rosenbluth) and polarization transfer methods.

[P. G. Blunden et al., Phys. Rev. Lett. 91, 142304 (2003).]

2. Sizeable effect on parity-violating electron-proton scattering asymmetry:

[A. V. Afanasev and C. E. Carlson, Phys. Rev. Lett. 94,]




*.. Where else to look for?*

2-photon exchange process could lead to sizeable effects on certain observables. → 

*Beam charge asymmetries (BCA).

****Single Spin Asymmetries (SSA).***

# 1. 2-photon exchange

## *Experimental results*

***(for Single spin asymmetries)***

### ***Elastic*** *scattering*

$l + N \to l' + N'$

***Transversely polarized $e^-$ off unpolarized protons***

Non-Zero ***asymmetries***: **~ $10^{-5}$**

* **SAMPLE:**
[S.. P. Wells et al., Phys.Rev.C63, 064001]

* **A4:**
[F. E. Maas et al., Phys.Rev Lett.94, 082001]

* **G0:**
[D. S. Armstrong et al., Phys.Rev.Lett. 99, 092301]

### ***Inelastic*** *scattering*

$l + N \to l' + X$

***Unpolarized $e^-$ off transversely polarized protons.***

Zero ***asymmetries***: **0**

* **Cambridge electron accel:**
[J. A. Appel et al., Phys. Rev. D1, 1285]
[J. R. Chen et al., Phys. Rev. Lett. 21, 1279]

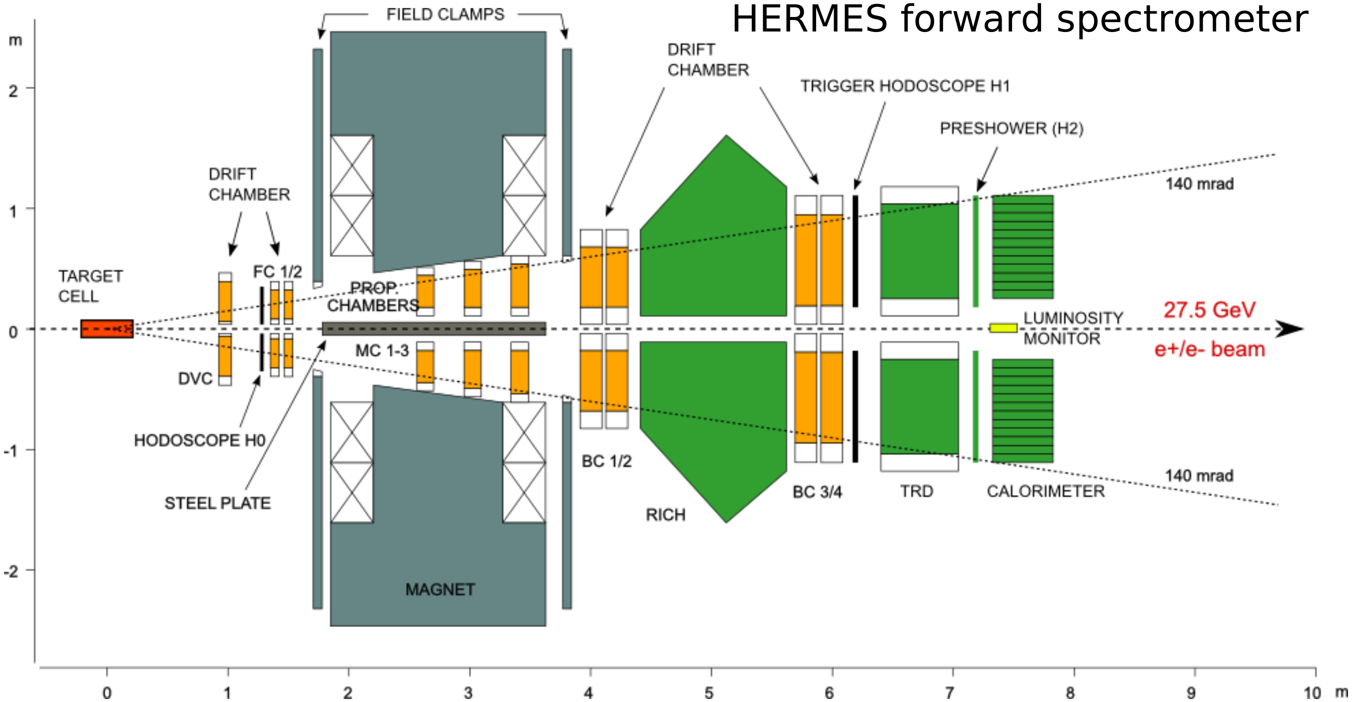
* **SLAC:**
[S. Rock et al., Phys. Rev. Lett. 24, 748]

### ***Deep Inelastic*** *scattering*

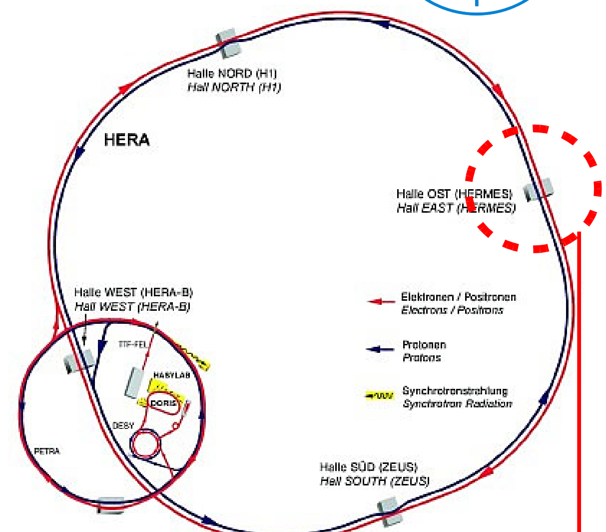
? hermes !

# 2. The HERMES experiment

schematic side view of the
HERMES forward spectrometer



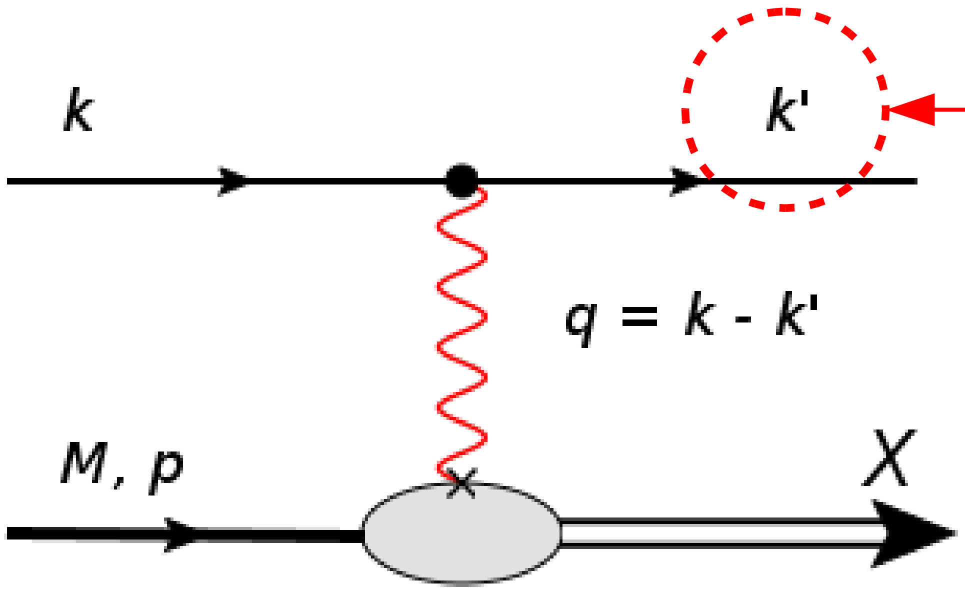

HERA accelerator at DESY




* *Lepton ($e^+/e^-$) beam at **27.5 GeV**.*
* *Transversely polarized H target:*
  *Polarization state reversed every 1-3 min.*
* *Particle ID (RICH + TRD + Pre-Shower + CALO)*
  *Provide superb lepton/hadron separation.*
* *Tracking system:*
  *Resolution on kinematics ~ 1%*

# 2. inclusive DIS

*Deep*
*Inelastic*
*Scattering*




$$l + p \rightarrow l' + X$$

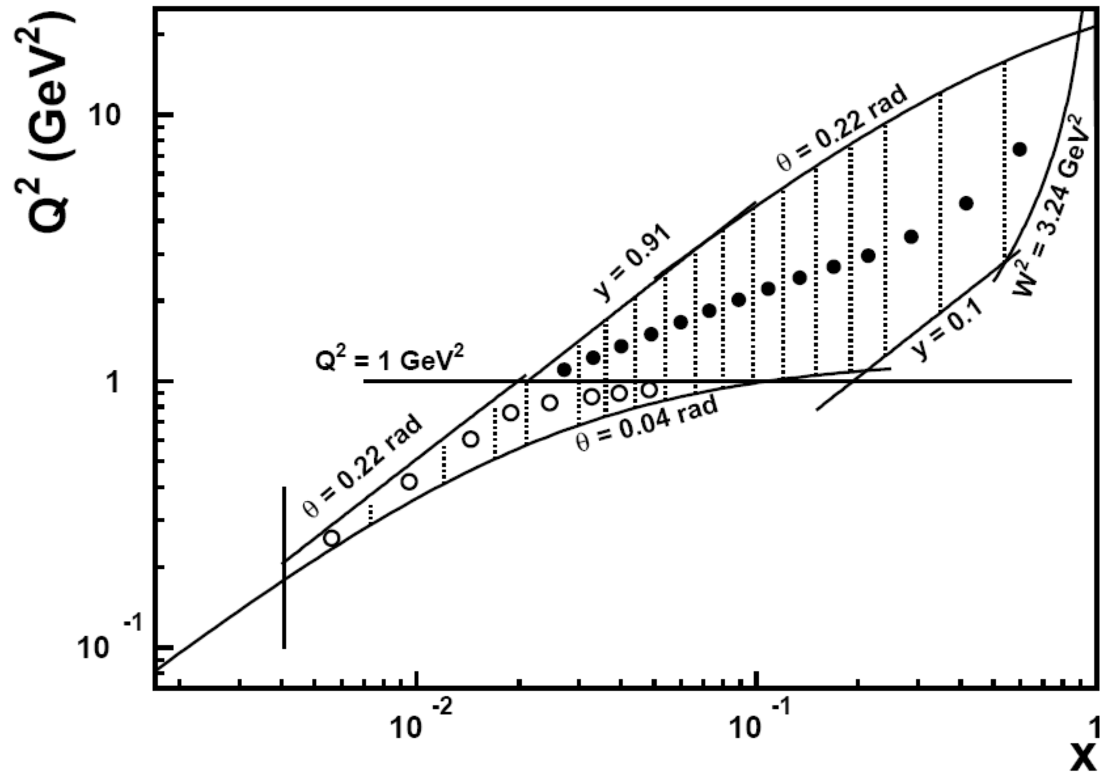
**inclusive DIS:**
Only de scattered lepton is detected

* $x = Q^2 / 2M(E-E')$
  Scaling Bjorken variable

* $Q^2 = -(k-k')^2 = 2EE'(1-\cos\theta)$
  negative squared of momentum transfer

# 2. inclusive DIS

**_Kinematic Plane_**




*Deep Inelastic Scattering*

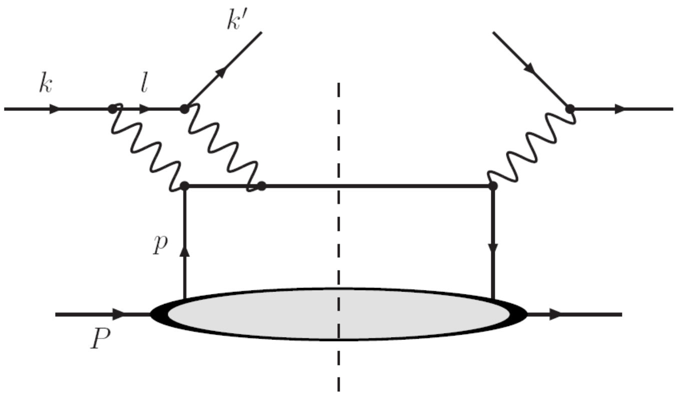
*$0.004 < x < 0.9$*
*$0.1 < Q^2 < 20$ GeV$^2$*
*$W^2 > 3.24$ GeV$^2$*

at HERMES

# 2. 2-photon contribution

* ***1-photon exchange approximation:***
  Forbids any SSA in inclusive DIS due to parity and time reversal invariance

* ***2-photon exchange contribution:***
  Leads to a SSA arising from the interference of 1-photon and 2-photon exchange:
  [A.. Metz, M. Schlegel, and K. Goeke, Phys. Lett. B643, 319.]



1-photon & 2-photon Interference diagram.

correlation between polarization vector S of the nucleon as well as the 4-momenta of the nucleon and of the leptons

Opposite sign for $e^-$ and $e^+$

$$\sigma_{\mathrm{UT}} \propto e_l \alpha_{em} \frac{M}{Q} \varepsilon_{\mu\nu\rho\sigma} S^\mu p^\nu k^\rho k'^\sigma C_T .$$

Higher-twist term arising from quark-quark and quark-gluon-quark correlations.

Scale as 1/Q in respect with the unpolarized cross section.

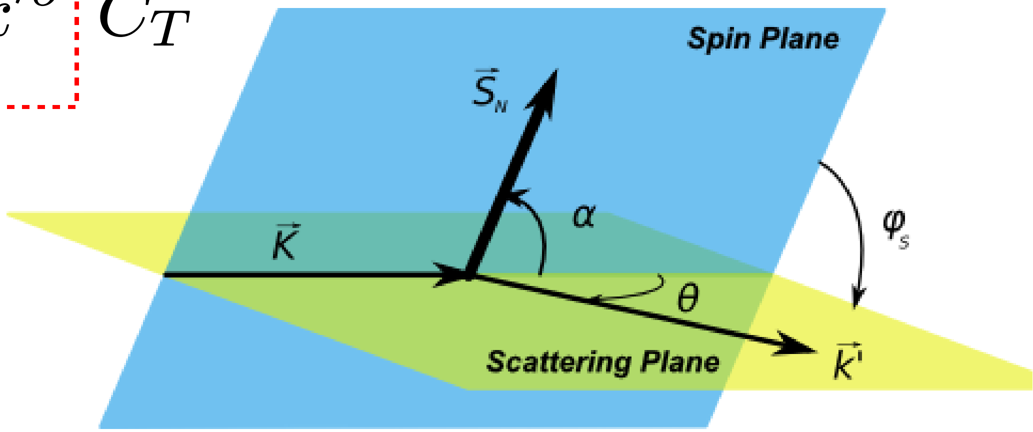
**Spin dependent** part of cross section. for and **Unpolarized beam** on a **Transversely polarized target**

→ *non-**ZERO** azimuthal SSA*

# 3. the Asymmetry

$$\sigma_{\rm UT} \propto e_l \alpha_{em} \frac{M}{Q} \varepsilon_{\mu\nu\rho\sigma} S^\mu p^\nu k^\rho k'^\sigma C_T$$

$$\propto \vec{S} \cdot (\vec{k} \times \vec{k'})$$




Largest asymmetry when the spin vector S is perpendicular to the lepton scattering plane defined by the three-momenta k and k′ .

**Azimuthal asymmetry**

**Asymmetry amplitude**

$$A(x,Q^2,\phi_s) = \frac{\sigma_{\rm UT}(x,Q^2,\phi_s)}{\sigma_{\rm UU}(x,Q^2)} = A_{\rm UT}^{\sin\phi}(x,Q^2) \sin\phi_s$$

**Left-Right asymmetry**

*(in respect to the spin direction)*

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

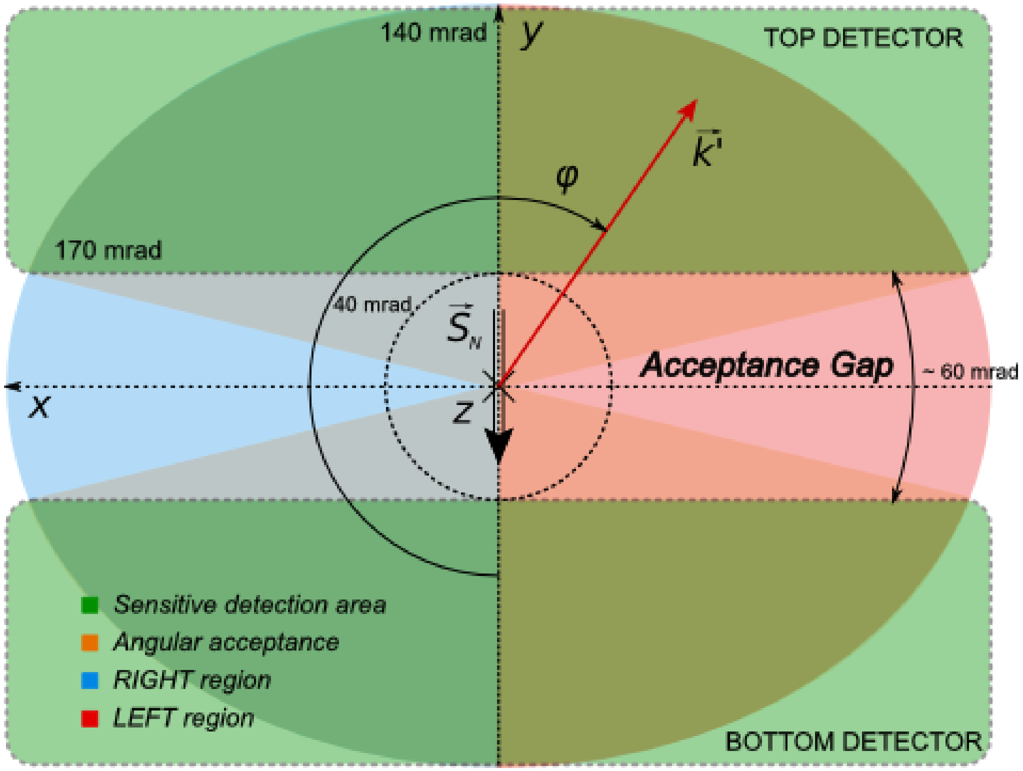
# 3. the Left-Right Asymmetry

Experimentally:

$$A_N = \frac{(\sigma_L^{\downarrow} - \sigma_R^{\downarrow}) - (\sigma_L^{\uparrow} - \sigma_R^{\uparrow})}{(\sigma_L^{\downarrow} + \sigma_R^{\downarrow}) + (\sigma_L^{\uparrow} + \sigma_R^{\uparrow})}$$

**R**ight det. side: $0 < \phi < \pi$
**L**eft det. side: $\pi < \phi < 2\pi$

Here, R and L refer to the right and left sides of the spectrometer in the HERMES coordinate system: independent of target spin state.




Experimental yields:

$$N_R^{\uparrow} = (L^{\uparrow}\sigma_{UU} + L_P^{\uparrow}\sigma_{UT})\chi_R/2$$
$$N_L^{\uparrow} = (L^{\uparrow}\sigma_{UU} - L_P^{\uparrow}\sigma_{UT})\chi_L/2$$
$$N_R^{\downarrow} = (L^{\downarrow}\sigma_{UU} - L_P^{\downarrow}\sigma_{UT})\chi_R/2$$
$$N_L^{\downarrow} = (L^{\downarrow}\sigma_{UU} + L_P^{\downarrow}\sigma_{UT})\chi_L/2$$

$$A_N^{meas} = \frac{\sqrt{\frac{N_L^{\downarrow}}{L_P^{\downarrow}}\frac{N_R^{\uparrow}}{L_P^{\uparrow}}} - \sqrt{\frac{N_R^{\downarrow}}{L_P^{\downarrow}}\frac{N_L^{\uparrow}}{L_P^{\uparrow}}}}{\sqrt{\frac{N_L^{\downarrow}}{L^{\downarrow}}\frac{N_R^{\uparrow}}{L^{\uparrow}}} + \sqrt{\frac{N_R^{\downarrow}}{L^{\downarrow}}\frac{N_L^{\uparrow}}{L^{\uparrow}}}}$$

# 3. the Acceptance factor

*The HERMES detector is top-bottom symmetric, with a gap in the horizontal direction, and thus it does not cover the full 2π range in φ.*

$$A_N^{meas} = \frac{\int_{acc.} d\phi \; \sigma_{UU} \; A_{UT}^{\sin\phi} \; \sin\phi}{\int_{acc.} d\phi \; \sigma_{UU}}$$

*Measured asymmetry needs to be corrected by the angular acceptance:*

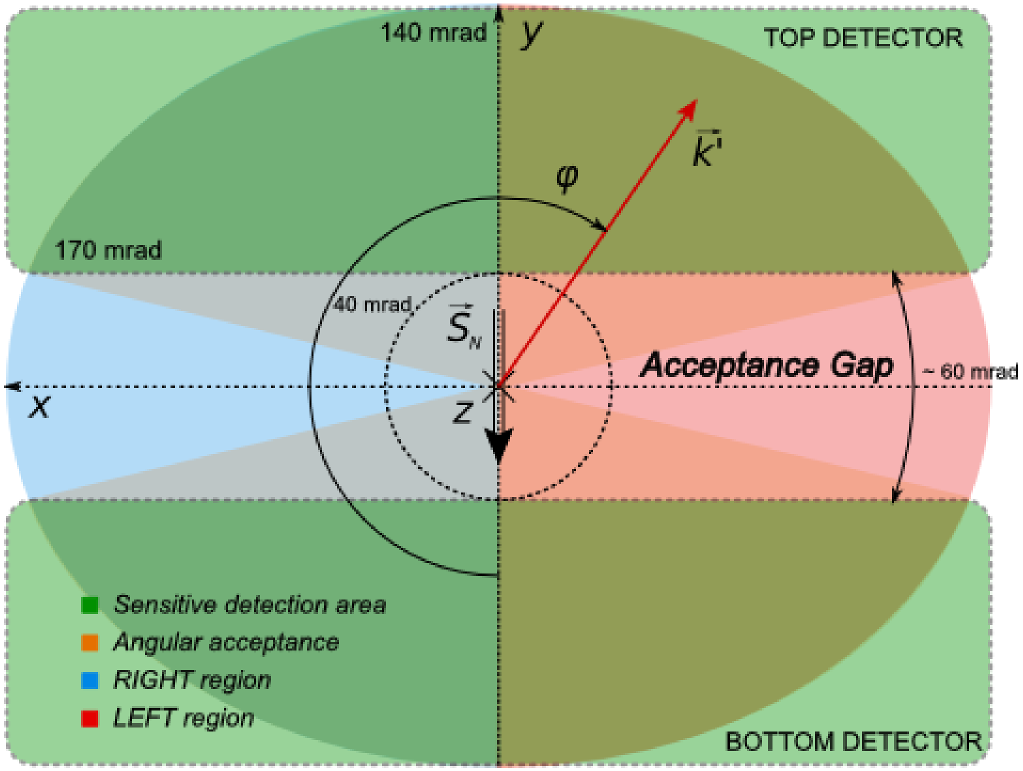
$$A_N^{meas} = \chi^H A_{UT}^{\sin\phi}$$

HERMES acceptance factor

*To extract the real Left-Right asymmetry:*

$$A_N = \frac{\chi^{2\pi}}{\chi^H} A_N^{meas}$$

For an ideal 2π detector: $\chi^{2\pi} = \frac{2}{\pi}$

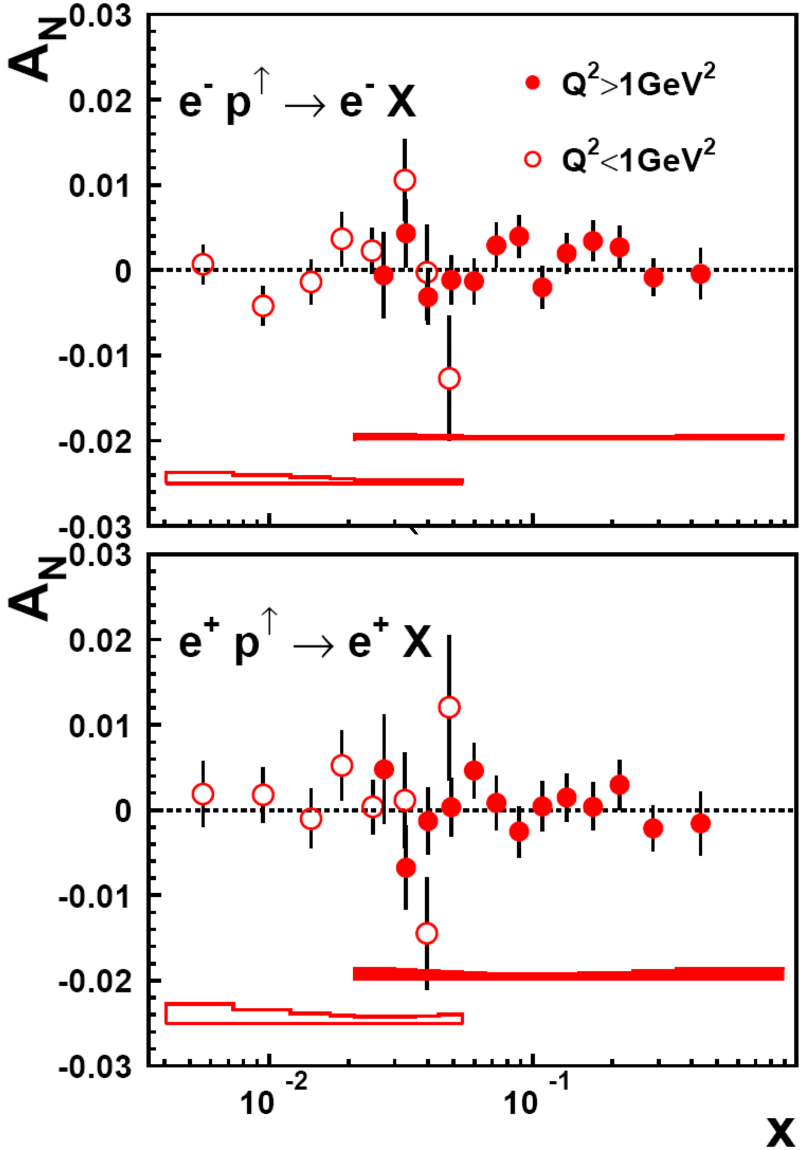


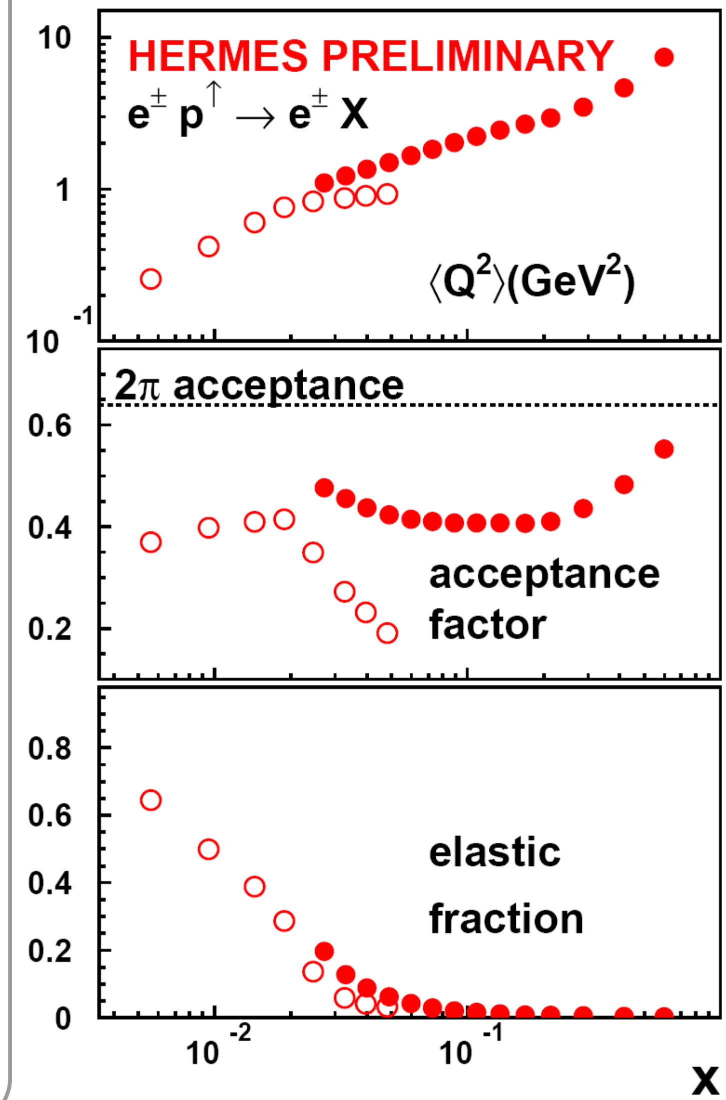

* Calculation based on MC:

1. Introduce an artificial $A_{UT}^{\sin\phi}$
2. Measure the asymmetry $A_N^{meas}$
3. Extract proportionality factor $\chi^H$

# 4. Results

### *Measured Asymmetries*




Average x and Q2 variables for every kinematic beam

To calculate the real left-right asymmetry.

To estimate the contribution from elastic scattering.

# 4. Conclusions

* *Inclusive Single Spin Asymmetries have been measured at HERMES on a transversely polarized target.*

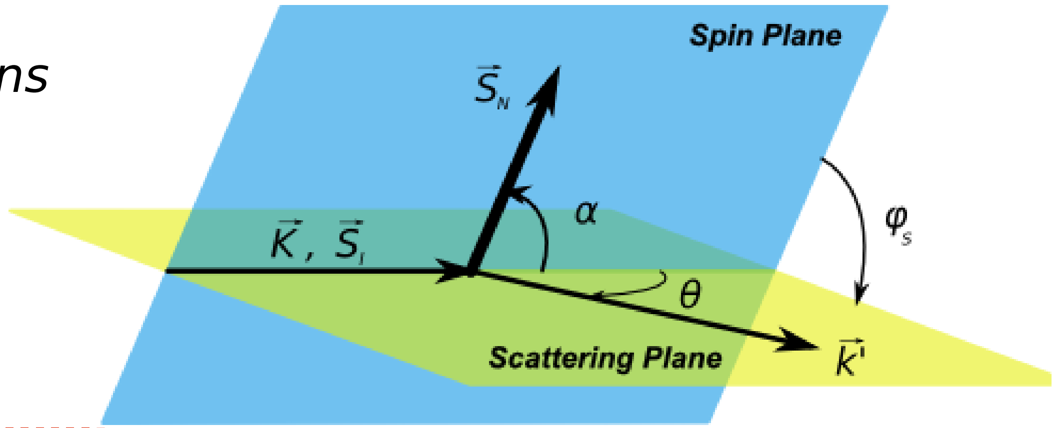
* *No evidence of 2-photon exchange has been observed within the experimental uncertainties of the order $10^{-3}$.*

* *This sets up the most precise limit on inclusive DIS up to now.*

# 5. $A_2$ and $xg_2$

.. *inclusive DIS of longitudinally polarized electrons on transversely polarized protons*

$$\mathbf{e}^{\leftrightarrow} + \mathbf{p}^{\Updownarrow} \rightarrow \mathbf{e}' + \mathbf{X}$$




*The cross section:*

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

Lepton tensor

Hadron tensor:
*Parametrized in terms of*

***Structure Functions***

$$\propto \quad \frac{y}{2} F_1(x,Q^2) + \frac{1 - y - \gamma^2 y^2/4}{2xy} F_2(x,Q^2)$$

$$-P_l P_T \cos\alpha \left[ \left( 1 - \frac{y}{2} - \frac{\gamma^2 y^2}{4} \right) g_1(x,Q^2) - \frac{\gamma^2 y}{2} g_2(x,Q^2) \right]$$

$$+P_l P_T \sin\alpha \cos\phi \gamma \sqrt{1 - y - \frac{\gamma^2 y^2}{4}} \left( \frac{y}{2} g_1(x,Q^2) + g_2(x,Q^2) \right)$$

# 5. $A_2$ and $xg_2$ extraction

*..How do we access to spin dependent structure functions?*

$$\sigma = \bar{\sigma} - h_l \Delta\sigma \quad (h_l = \pm 1) \qquad \Delta\sigma = \cos\alpha\Delta\sigma_{\parallel} + \sin\alpha\Delta\sigma_T$$

spin-dependent cross section can be split in parallel and **transverse** components

$$\frac{d^3\Delta\sigma_{\parallel}}{dx\,dy\,d\phi} = \frac{e^4}{4\pi^2 Q^2}\left[\left(1 - \frac{y}{2} - \frac{\gamma^2 y^2}{4}\right) g_1(x, Q^2) - \frac{\gamma^2 y}{2} g_2(x, Q^2)\right]$$

$$\frac{d^3\Delta\sigma_T}{dx\,dy\,d\phi} = -\cos\phi \frac{e^4}{4\pi^2 Q^2}\gamma\sqrt{1 - y - \frac{\gamma^2 y^2}{4}}\left(\frac{y}{2} g_1(x, Q^2) + g_2(x, Q^2)\right)$$

➔***Double spin azimuthal asymmetry:***

$$\frac{\sigma^{\rightarrow\Downarrow}(\phi) - \sigma^{\rightarrow\Uparrow}(\phi)}{\sigma^{\rightarrow\Downarrow}(\phi) + \sigma^{\rightarrow\Uparrow}(\phi)} = \frac{\Delta\sigma_T}{\bar{\sigma}} = \underbrace{\frac{-\gamma\sqrt{1 - y - \frac{\gamma^2 y^2}{4}}\left(\frac{y}{2} g_1(x, Q^2) + g_2(x, Q^2)\right)}{\left[\frac{y}{2} F_1(x, Q^2) + \frac{1}{2xy}\left(1 - y - \frac{\gamma^2 y^2}{4}\right) F_2(x, Q^2)\right]}}_{A_T} \cos\phi$$

# 5. $A_2$ and $xg_2$ extraction

*..azimuthal Double Spin Asymmetry:*

$$\frac{\sigma^{\rightarrow\Downarrow(\leftarrow\Uparrow)} - \sigma^{\rightarrow\Uparrow(\leftarrow\Downarrow)}}{\sigma^{\rightarrow\Downarrow(\leftarrow\Uparrow)} + \sigma^{\rightarrow\Uparrow(\leftarrow\Downarrow)}}$$

Measured and fitted to:

$$f(\phi) = A_T \cos\phi$$

Input to $A_2$ and $g_2$ calculation

$$A_2 = \frac{1}{d(1+\gamma\xi)} A_T + \frac{\xi(1+\gamma^2)}{1+\gamma\xi} \frac{g_1}{F_1}$$

$$g_2 = \frac{F_1}{\gamma d(1+\gamma\xi)} A_T - \frac{F_1(\gamma - \xi)}{\gamma(1+\gamma\xi)} \frac{g_1}{F_1}$$

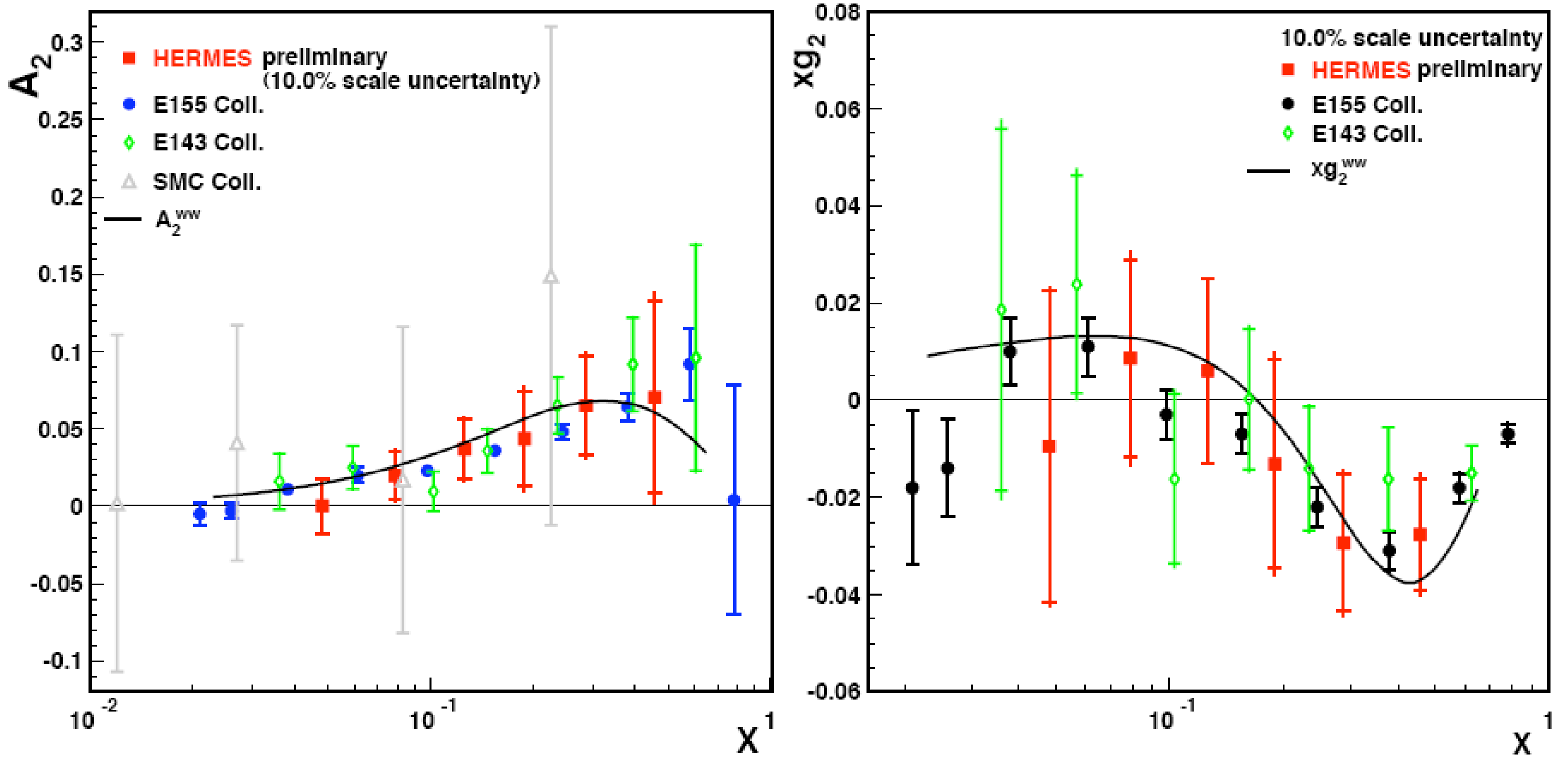
$$F_1 = \frac{1+\gamma^2}{2x(1+R)} F_2$$

$$R = \sigma_L / \sigma_T$$

Additional Input from world data:

* Fit to $\frac{g_1}{F_1}$ : P.L.Anthony et al. (E155 Coll.) PL B493,19.
  g1/F1= x0.7(0.817 + 1.014x – 1.489x2)(1- 0.04/$Q^2$).
* Fit to $R(x, Q^2)$ : K.Abe et al. (E143 Coll.) PL B452,194.
* Fit to $F_2(x, Q^2)$ : D.Gabbert and L.De Nardo, hep-ph 0708.3196

# 5. $A_2$ and $xg_2$ results




- *Consistent with world data*
- *Suffers from low beam polarization during HERA-II*

# Back-up

# Wandzura-Wilczek

In the simplest quark-parton model the spin-dependent structure function g1(x) describes a distribution of longitudinal polarization of quarks inside the longitudinally polarized nucleon. The polarized structure function g2(x) has no clear probabilistic interpretation in the framework of the quark-parton model and is exactly zero in the naive parton model, where the nucleon is considered to be made of collinear, free constituents. Properties of the structure function g2(x,Q2) have been well established in the framework of the OPE analysis within QCD. Generally, ignoring quark mass effects, g2(x,Q2) can be written as the sum of two terms

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

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

The first, Wandzura-Wilczek term $g_2^{WW}$(x,Q2), is the twist-2 part, while the second term, $g_2$'(x,Q2), is the genuine twist-3 part which measures quark-gluon correlations in the nucleon.