Search for a two-photon exchange contribution to inclusive deep-inelastic scattering

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Outline

- Motivation: 2-γ exchange in elastic ep scattering
- 2-γ exchange in inelastic ep scattering: $e + p^{\uparrow} \rightarrow e' + X$ with transversely polarised target
- HERMES
- Results

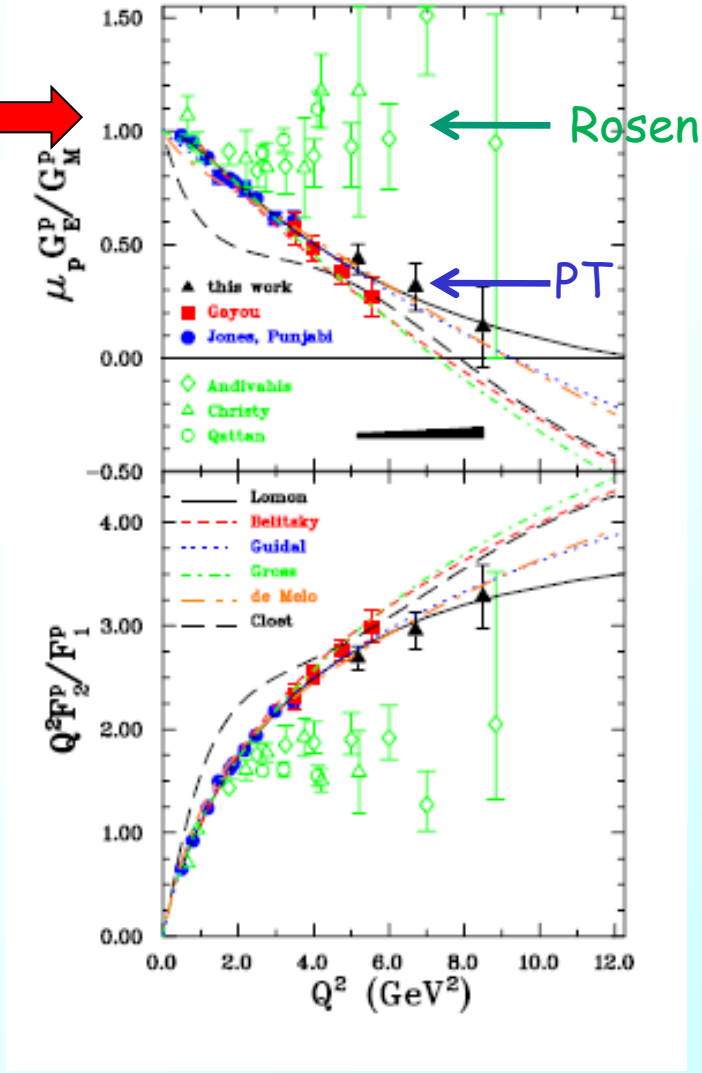
2-γ exchange in elastic ep scattering

- 2-γ exchange best candidate to explain discrepancy in measurements of $\mu_p G_E/G_M$ [Rosenbluth ↔ polarisation transfer (PT)]

- 2-γ exchange has sizeable effect on parity-violating asymmetry
(A.V. Afanasev and C.E. Carlson, Phys. Rev. Lett. 94 (2005) 212301)

- 2-γ exchange produces transverse-beam single-spin asymmetries (SSA) of order 10^{-5} – 10^{-6} in $e^{\uparrow}p \rightarrow e'p'$
SAMPLE: S.P. Wells et al., Phys. Rev. C 63 (2001) 064001
A4: F. Maas et al., Phys. Rev. Lett. 94 (2005) 082001
G0: D.S. Armstrong et al., Phys. Rev. Lett. 99 (2007) 092301

A.J.R. Puckett et al., Phys. Rev. Lett. 104 (2010) 242301

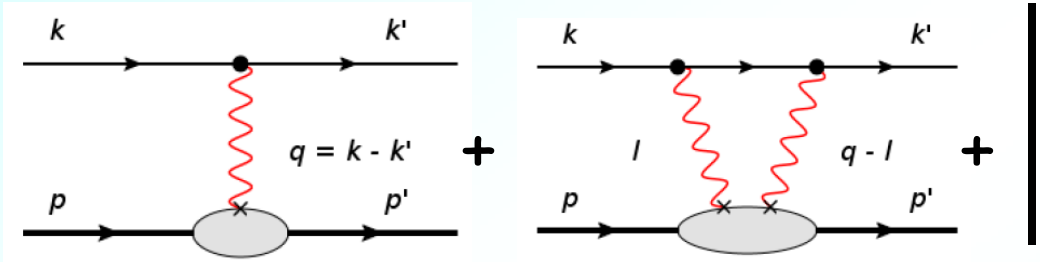


2-γ exchange in elastic ep scattering

Precise determination of 2-γ-exchange contribution: $\sigma(e^+p)/\sigma(e^-p)$

CLAS, VEPP-3, OLYMPUS

$$\sigma \sim \left| \; + \; + \; \right|^2$$

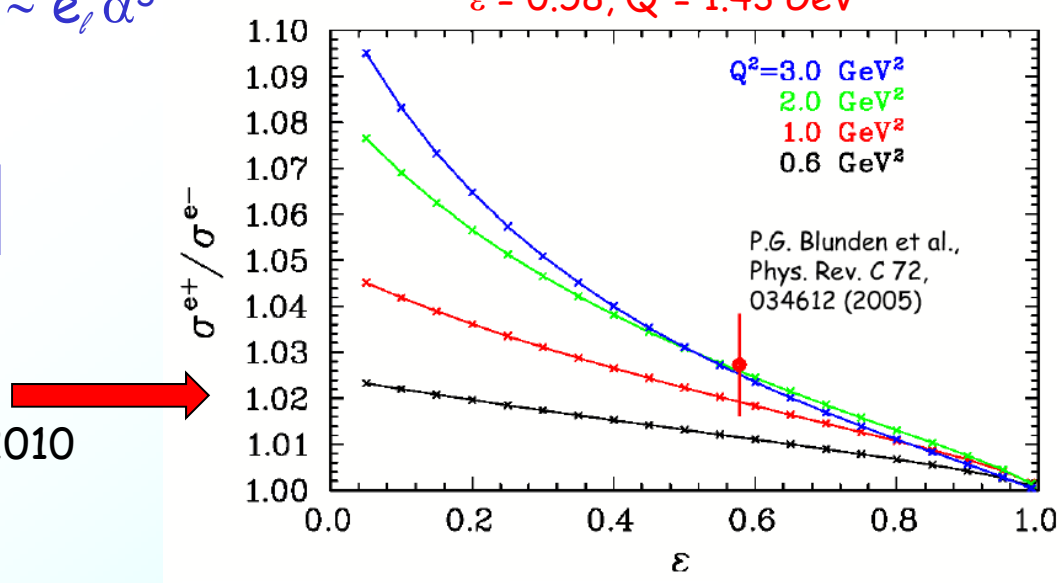


$\mathcal{A}_{1\gamma} \sim \alpha$ $\qquad$ $\mathcal{A}_{2\gamma} \sim \alpha^2$

Interference term $\sim \mathcal{A}_{1\gamma} \times \mathcal{A}_{2\gamma} \sim e_\ell \, \alpha^3$

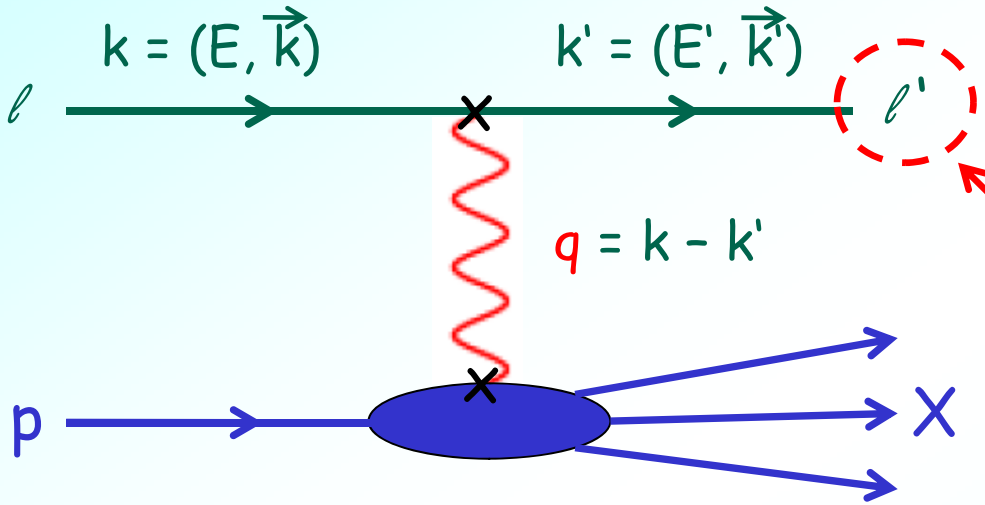
$$\sigma(e^+p)/\sigma(e^-p) \approx 1 + 2\,\mathcal{A}_{2\gamma}/\mathcal{A}_{1\gamma}$$

VEPP-3, preliminary data
Presented by D. Nikolenko at ICHEP 2010



$\varepsilon = 1/[1+2(1+Q^2/4M^2)\tan^2(\theta/2)]$

Inelastic ep scattering



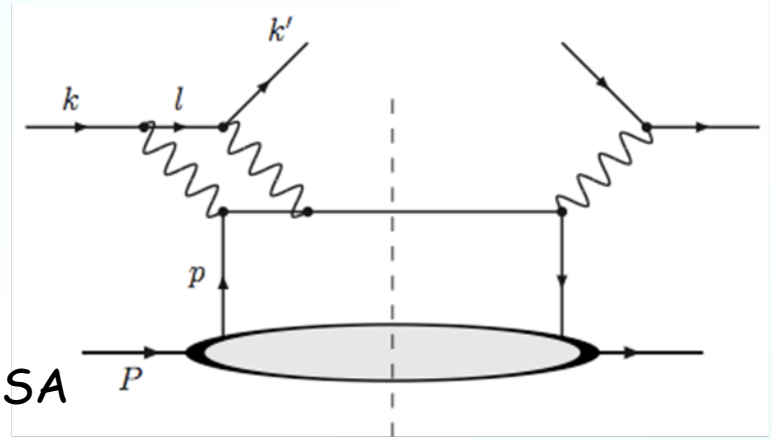
Inclusive DIS:
Only the scattered lepton ℓ' is detected

$$\ell + p \rightarrow \ell' + X$$

- $Q^2 = -q^2 = 2EE'(1-\cos\theta)$
  negative squared four-momentum transfer
- $x = Q^2/2M(E - E')$
  Bjorken scaling variable

2-γ exchange in inelastic ep scattering

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



- 2-γ exchange contribution:
  Leads to a transverse-target and/or beam SSA arising from the interference of 1-γ and 2-γ exchange

(A. Metz, M. Schlegel and K. Goeke, Phys. Lett. B643 (2006) 319,
A. Afanasev, M. Strikman, and C. Weiss, Phys. Rev. D77 (2008) 014028

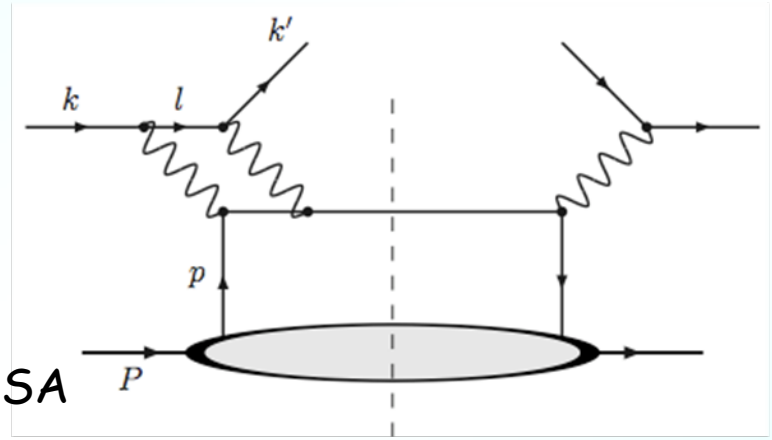
$$\sigma_{UT} \propto e_\ell \, \alpha \, \frac{m_{pol}}{Q} \, \varepsilon_{\mu\nu\rho\sigma} \, S^\mu \, p^\nu \, k^\rho \, k'^\sigma \, C_T$$

Spin dependent part of cross section for Unpolarised beam on a Transversely polarized target

2-γ exchange in inelastic ep scattering

- 1-γ exchange approximation:

Forbids any SSA in inclusive DIS due to parity and time reversal invariance



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beam charge

mass and spin of polarized particle

$$\sigma_{UT} \propto e_\ell \alpha \frac{m_{pol}}{Q} \varepsilon_{\mu\nu\rho\sigma} S^\mu p^\nu k^\rho k'^\sigma C_T$$

Spin dependent part of cross section for Unpolarised beam on a Transversely polarized target

Higher-twist term arising from q-q and q-g-q correlations, presently not yet calculable

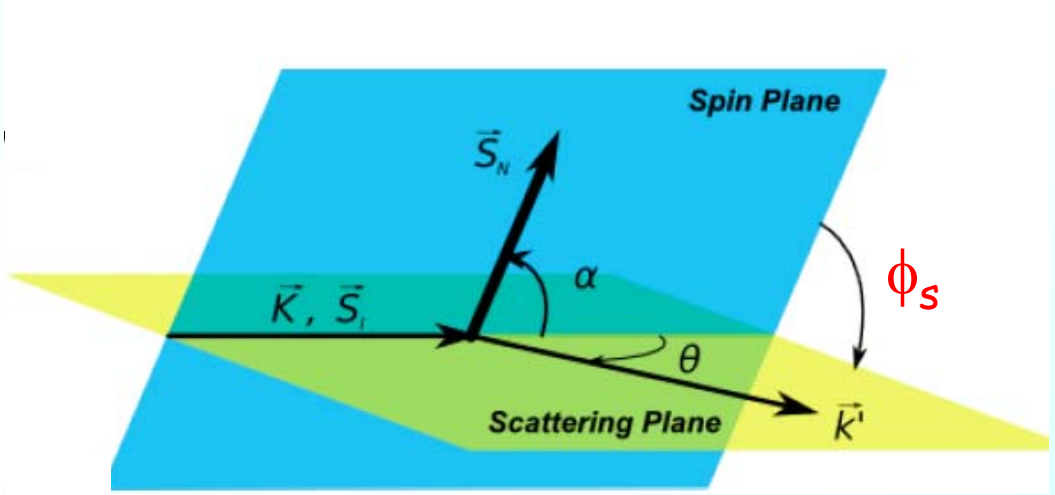
non-zero azimuthal SSA

2-γ exchange in inelastic ep scattering

$$\sigma_{UT} \propto e_\ell\, \alpha\, (m_{pol}/Q)\, \varepsilon_{\mu\nu\rho\sigma}\, S^\mu\, p^\nu\, k^\rho\, k'^\sigma\, C_T$$

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

Largest asymmetry when the spin vector $\vec{S}$ is perpendicular to the lepton scattering plane



Azimuthal asymmetry:

Asymmetry amplitude

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

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{2}{\pi} A_{UT}^{\sin\phi_s} \text{ (left-right asymmetry)}$$

2-γ exchange in inelastic ep scattering

Early measurements:

- $\sigma(e^+p)/\sigma(e^-p)$

DESY: H. Jostlein et al., Phys. Lett. B 52 (1974) 485
DESY: S. Hartwig et al., Lett. Nuovo Cim. 15 (1976) 429
SLAC: D.L. Fancher et al., Phys. Rev. Lett. 37 (1976) 1323
SLAC: L.S. Rochester et al., Phys. Rev. Lett. 36 (1976) 1284
DESY: S. Hartwig et al., Phys. Lett. B 82 (1979) 297

- $\sigma(\mu^+p)/\sigma(\mu^-p)$

CERN-BCDMS:A. Argento et al., Phys. Lett. B 140 (1984) 142
CERN-EMC: J.J. Aubert et al., Nucl. Phys. B 272 (1986) 158

- A_N in $e^- + p^{\uparrow} \rightarrow e^{-\prime} + X$

(region of nucleon resonances; search for violation of time-reversal invariance)

CEA: J.A. Appel et al., Phys. Rev. D 1 (1970) 1285
CEA: J.R. Chen et al., Phys. Rev. Lett. 21 (1968) 1279
SLAC: S. Rock et al., Phys. Rev. Lett. 24 (1970) 748

No effect within statistical accuracy of a few percent

HERMES Experiment

Data taking: 1995-2007

27.6 GeV e+/e- beam of HERA
polarisation ≤ 60 %

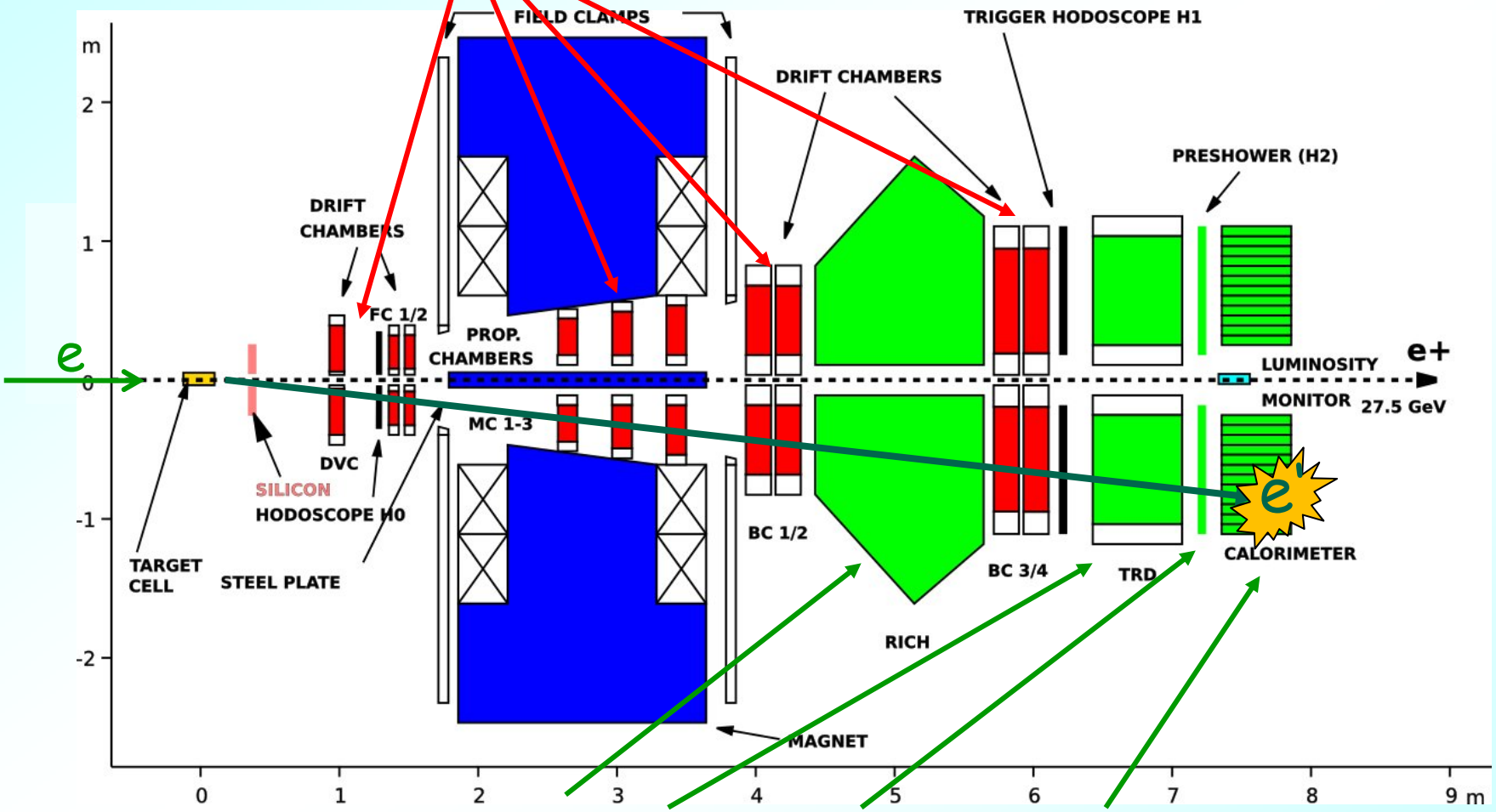
Internal gas targets

polarized : $\vec{}^{1}H$, $\vec{}^{1}H^{\uparrow}$, $\vec{}^{2}H$, $\vec{}^{3}He$

unpolarized: ^{1}H, ^{2}H, ^{3}He, ^{4}He,
N, Ne, Kr, Xe

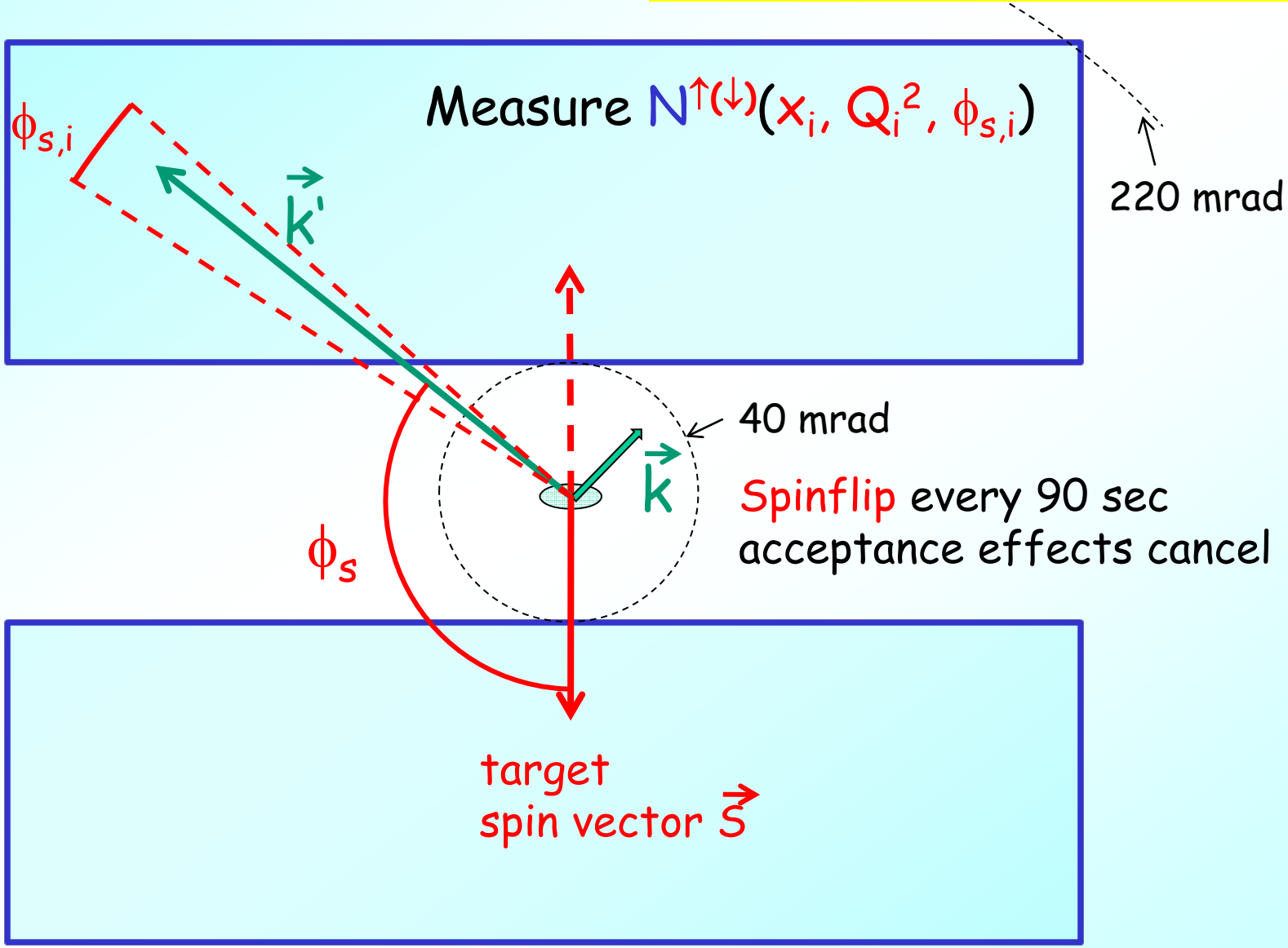
HERMES Spectrometer

- tracking: $\delta p/p \sim 2\%$, $\delta\Theta < 0.6$ mrad, 40-220 mrad

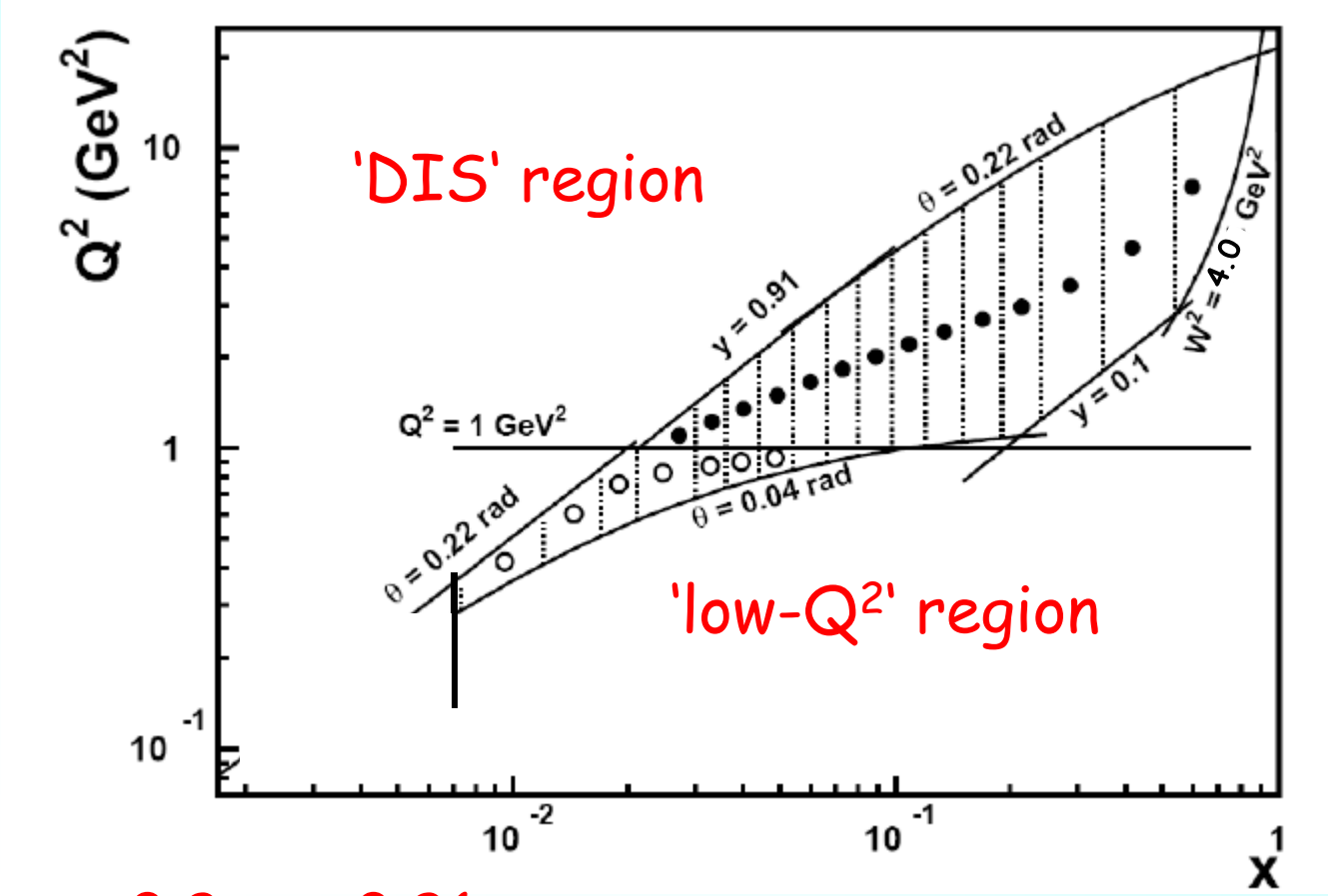


- PID: RICH, TRD, Preshower, Calorimeter
  hadron contamination in lepton sample for these data < 10^{-4} ,
  with lepton detection efficieny of 94%

HERMES front view



HERMES kinematic plane



$0.007 < x < 0.9,\ y < 0.91$

$0.25\ GeV^2 < Q^2 < 20\ GeV^2$

$W^2 > 4\ GeV^2$

Single-spin azimuthal asymmetry

luminosity — polarisation-weighted luminosity — acceptance

$$\frac{d^3N^{\uparrow(\downarrow)}}{dx\,dQ^2\,d\phi_s} = [\,L^{\uparrow(\downarrow)}\,d^3\sigma_{UU} + (-)\,L_P^{\uparrow(\downarrow)}\,d^3\sigma_{UT}\,]\,\Omega(x, Q^2, \phi_s)$$

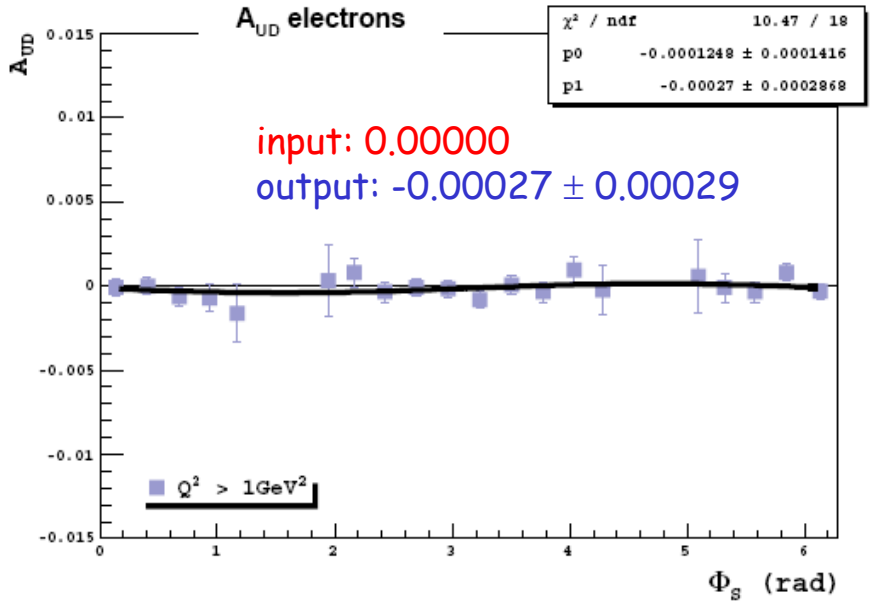
$$= d^3\sigma_{UU}\,[\,L^{\uparrow(\downarrow)} + (-)\,L_P^{\uparrow(\downarrow)}\,A_{UT}^{\sin\phi_S}(x,Q^2)\,\sin\phi_s\,]\,\Omega(x, Q^2, \phi_s)$$

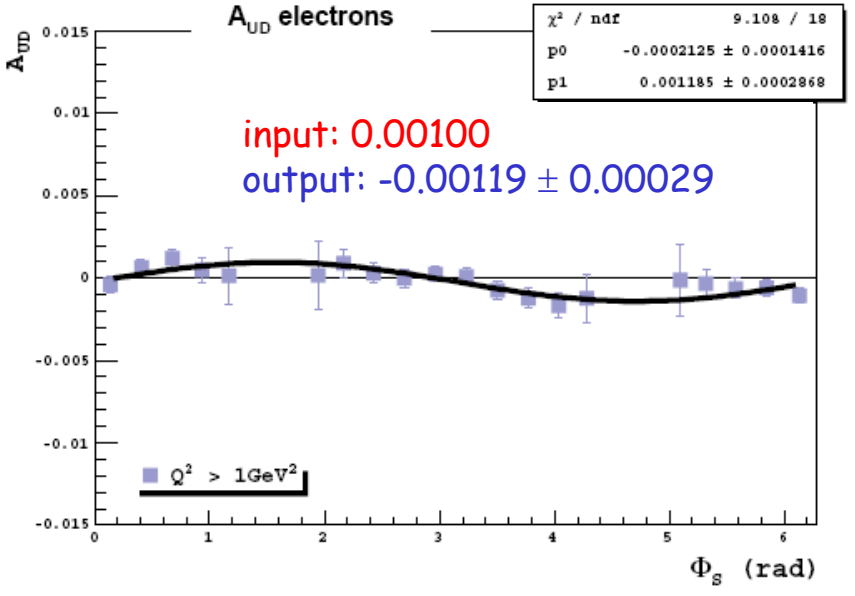
$$A_{UT}(x,Q^2,\phi_s) = \frac{N^{\uparrow}/L_P^{\uparrow} - N^{\downarrow}/L_P^{\downarrow}}{N^{\uparrow}/L^{\uparrow} + N^{\downarrow}/L^{\downarrow}} \cong A_{UT}^{\sin\phi_S}(x,Q^2)\,\sin\phi_s$$

Acceptance effects cancel for small bin size or asymmetry

Systematic uncertainties

- Possible apparative sources of false asymmetries:
  - misalignement of the detectors,
  - beam position and slope at the interaction point,
  - bending of e and e' in transverse holding field of target magnet
- MC studies with artificial $A_{UT}^{\sin\phi_S}$ implemented
- Examples:





- Syst. uncertainty: max[δ^{MC}(stat), (input-output)]

Results

	⟨P⟩	Events
e+	0.75	2.9 M
e-	0.71	4.8 M

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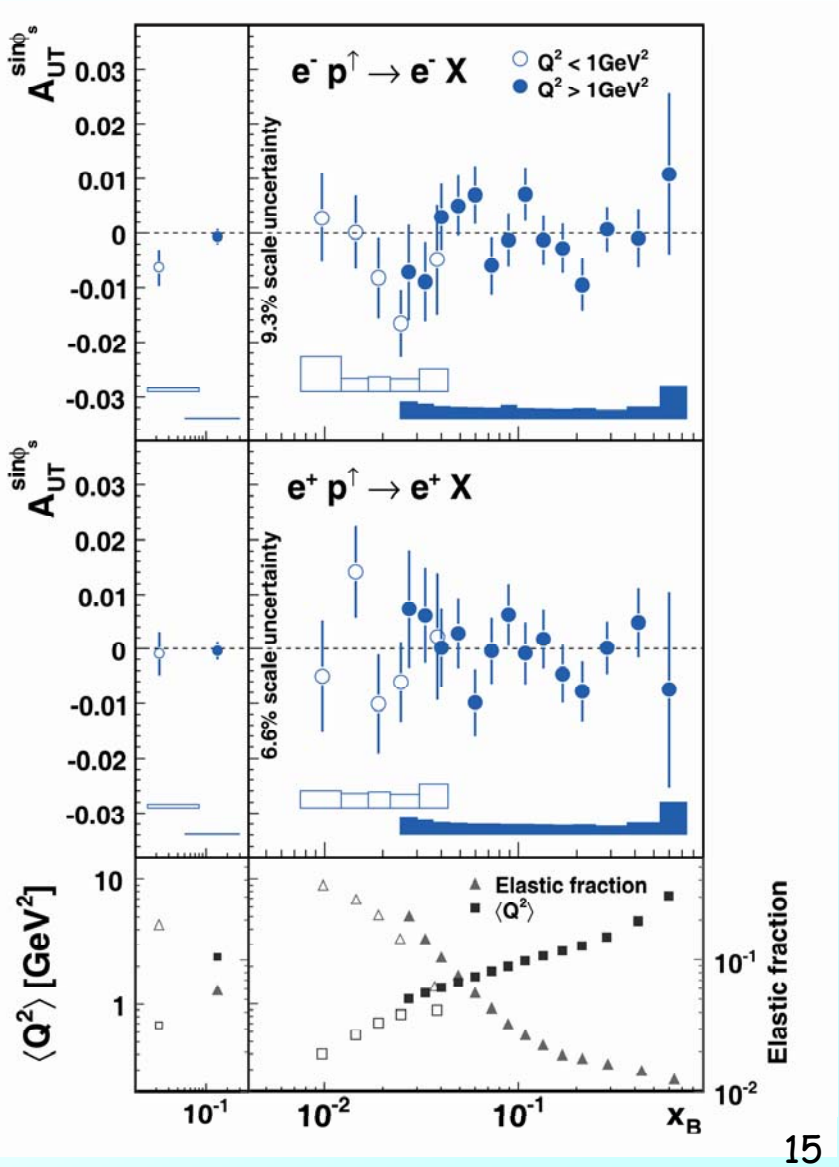
beam	$A_{UT}^{\sin\phi_S}$ $\times 10^{-3}$	$\delta A_{UT}^{\sin\phi_S}$(stat.) $\times 10^{-3}$	$\delta A_{UT}^{\sin\phi_S}$(syst.) $\times 10^{-3}$	$\langle x_B \rangle$	$\langle Q^2 \rangle$ [GeV^2]
e^+	-0.61	3.97	0.63	0.02	0.68
e^-	-6.55	3.40	0.63		
e^+	-0.60	1.70	0.29	0.14	2.40
e^-	-0.85	1.50	0.29		



$A_N = 2/\pi\, A_{UT}^{\sin\phi_S} = O(10^{-3})$

same for e+ and e-

No sign for 2-photon exchange in DIS

Conclusion

- HERMES has measured with high precision single-spin asymmetries in inclusive DIS $e + p^{\uparrow} \rightarrow e' + X$ from a transversely polarised proton target

- No evidence for a 2-photon-exchange contribution to the cross section has been observed within the experimental uncertainties of the order of 10^{-3}

- This sets the so far most precise limit of 2-photon exchange in DIS