The Tensor Structure Function b1 at HERMES

- Why b1?
- The HERMES experiment
- Tensor asymmetries and smearing unfolding
- Systematic uncertainties
- Result and comparison with theory (status: 2005).

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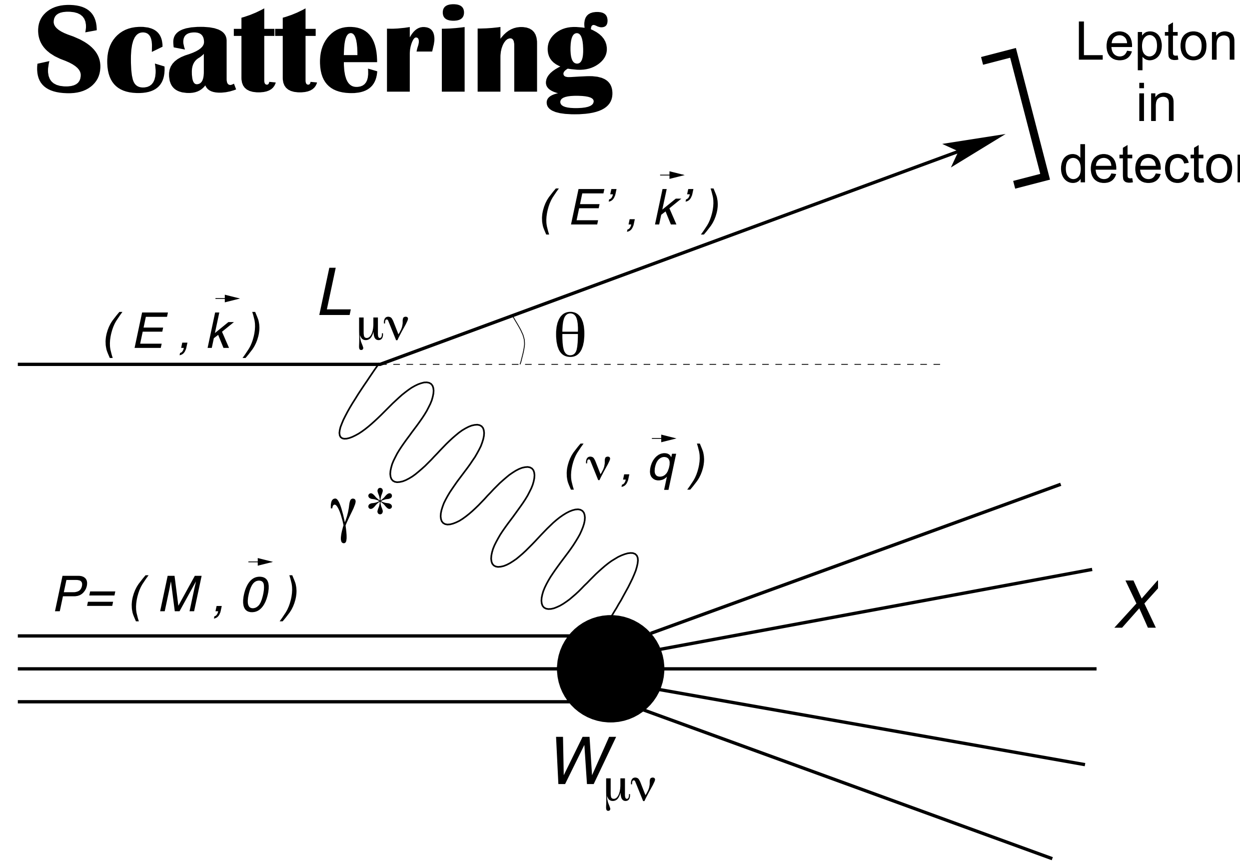
Newport News, VA

Inclusive Deep-Inelastic Scattering



$$\left.\frac{\mathrm{d}^2\sigma}{\mathrm{d}E'\mathrm{d}\Omega}\right|_{1\gamma^*} = \frac{\alpha^2}{2MQ^4}\frac{E'}{E}\underline{L_{\mu\nu}W^{\mu\nu}}$$

$W^{\mu\nu}$ of the target hadron parameterized by independent structure functions:
4 for the **proton, spin ½**
8 for the **deuteron, spin 1**

spin-averaged, symmetric part **+** spin-dependent, anti-symmetric part

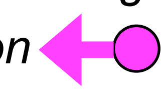
$$L_{\{\mu\nu\}}W^{\{\mu\nu\}}(F_1, F_2; \boxed{b_1, b_2, \Delta, b_3}) + iL_{[\mu\nu]}W^{[\mu\nu]}(g_1, g_2)$$

- Only for spin-1 target.
- Implicitly dependent on target spin through momentum terms.
- Not sensitive to lepton spin.

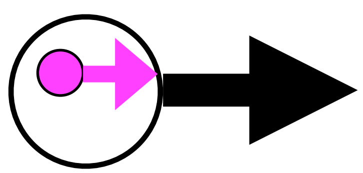
- F_1, F_2, g_1, b_1, b_2, Δ of leading twist
- $F_1 \leftrightarrow F_2$ and $b_1 \leftrightarrow b_2$: Callan-Gross relation

Structure Functions in the Quark Parton Model

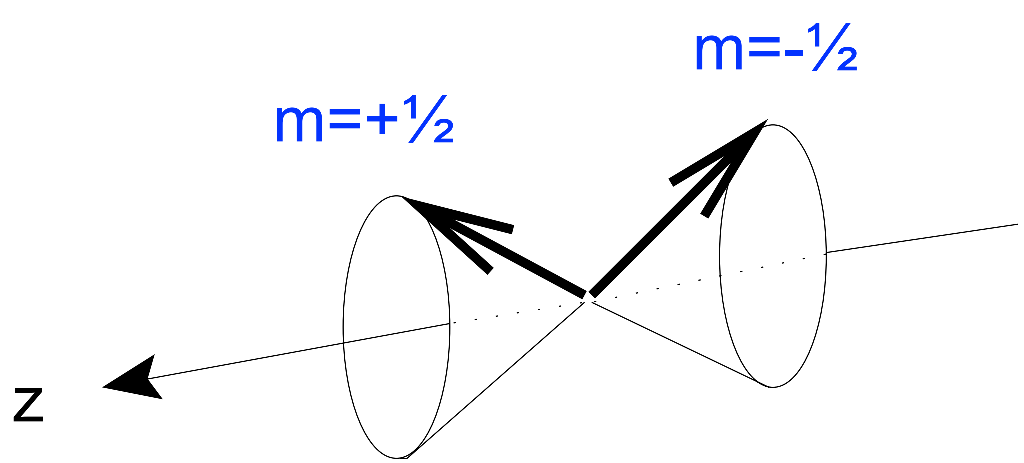
spin-½ target

here and following: configuration  *skipped for simplicity*

$$q^+(x, Q^2) \quad q^-(x, Q^2)$$



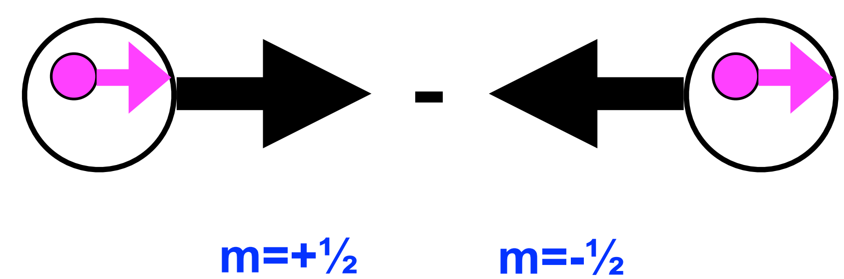
*= probability of finding a **quark** with same / opposite spin orientation as the **parent hadron***



orientation of target spin

$$F_1 = \frac{1}{2} \sum_q e_q^2 (q^+ + q^-)$$

$$g_1 = \frac{1}{2} \sum_q e_q^2 (q^+ - q^-)$$

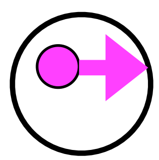


spin structure function

Structure Functions in the Quark Parton Model

spin-1 target

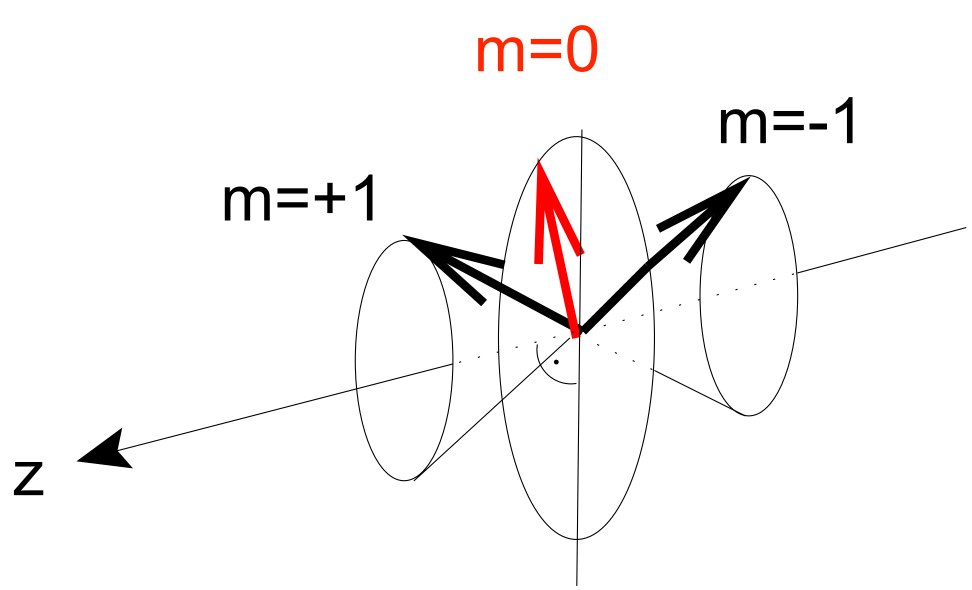
$$q^0(x, Q^2)$$



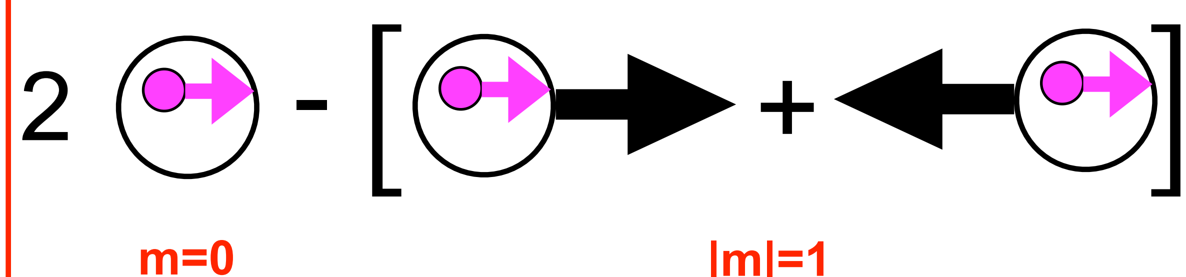
= *probability of finding a quark in a hadron with m=0*

$$F_1 = \frac{1}{3}\sum_q e_q^2(q^+ + q^- + q^0)$$

$$g_1 = \frac{1}{2}\sum_q e_q^2(q^+ - q^-)$$



$$b_1 = \frac{1}{2}\sum_q e_q^2(2\,q^0 - [q^+ + q^-])$$



tensor structure function

Early b1 Models (late 1980s, early 1990s)

- The deuteron: $|\psi^{\mathrm{d}}\rangle = 0.98|^3S_1\rangle + 0.20|^3D_1\rangle$
  Binding energy of proton and neutron = 2.2 MeV

- b1=0 if spin-1 hadron made up of spin-½ constituents at rest or a relative S-wave

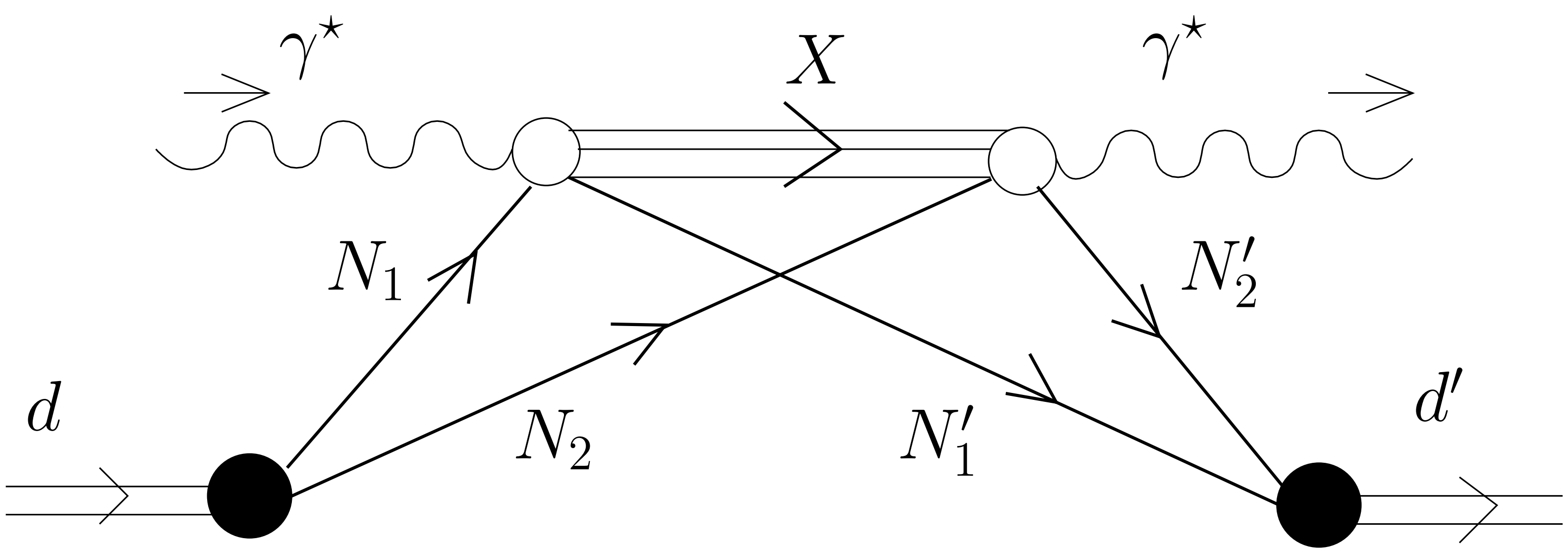
- Turn on D-state admixture + non-relativistic Fermi-motion +
  binding energy: b1 still only order(10^{-4})
  ☞ b1(ρ-meson) = relativistic system: b1 can be large, up to order(F1)

Early models predict b1(deuteron) = negligible.

- b1 as measure of the deviation from "deuteron = proton + neutron":
  study non-nucleonic degrees of freedom in the nucleus,
  e.g. meson exchange currents
  ☞ large b1 as measure for extra degrees of freedom possessed by partons

  in a nucleus relative to the nucleon

Double-Scattering Interpretation of b1
(late 1990s)



Probe deuteron as spin-1 object and not as compound of two spin-1/2 objects

Diffractive double scattering

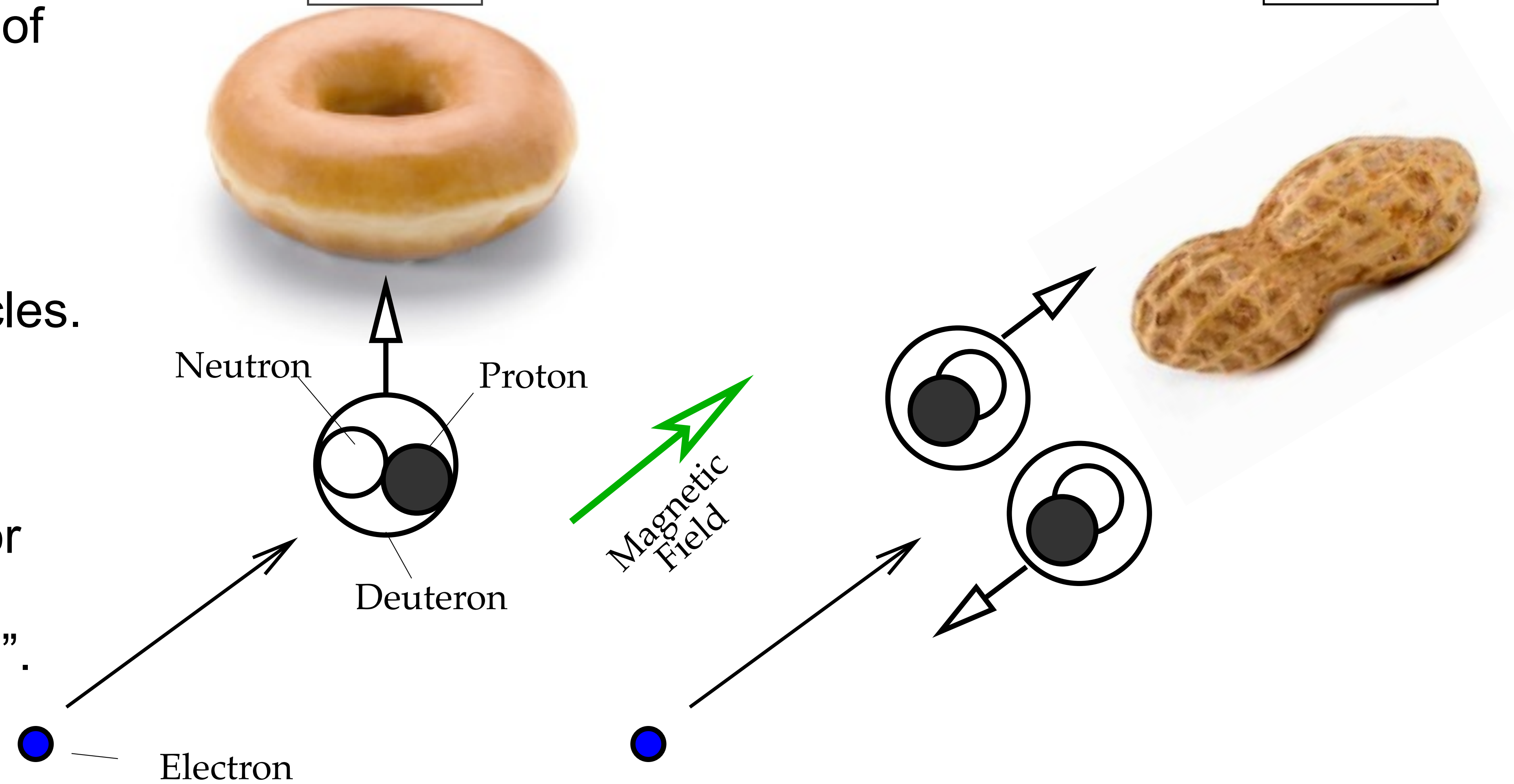
$$\lambda \simeq \frac{1}{xM}\left(\frac{Q^2}{M_X^2+Q^2}\right)$$

Double scattering expected to be enhanced for x<0.03, where the γ* coherence length is large enough to allow for successive scattering off both nucleons (d≈4fm)

S-D Interference of the Polarized Deuteron

- **Nuclear shadowing** depends on alignment of nucleons in the hadron
- **Single scattering:** nucleons seen as individual spin-½ particles. b1 absent.
- **Double scattering:** sensitivity for the tensor structure = “coherent feature of the deuteron”.

m=0 ***versus*** **|m|=1**



S-D interference different for m=0 and |m|=1 states

Tensor Structure Function b1

- **Close-Kumano sum rule for b1:**
  Phenomenological expectation about **tensor polarization of sea quarks** in the naïve QPM

$$\int_0^1 \mathrm{d}x\, b_1(x) = \boxed{\frac{1}{9}\theta Q_s} \equiv 0$$

with $\theta q = \frac{1}{2}(2q^0 - [q^+ + q^-])$

(@ fixed Q^2)

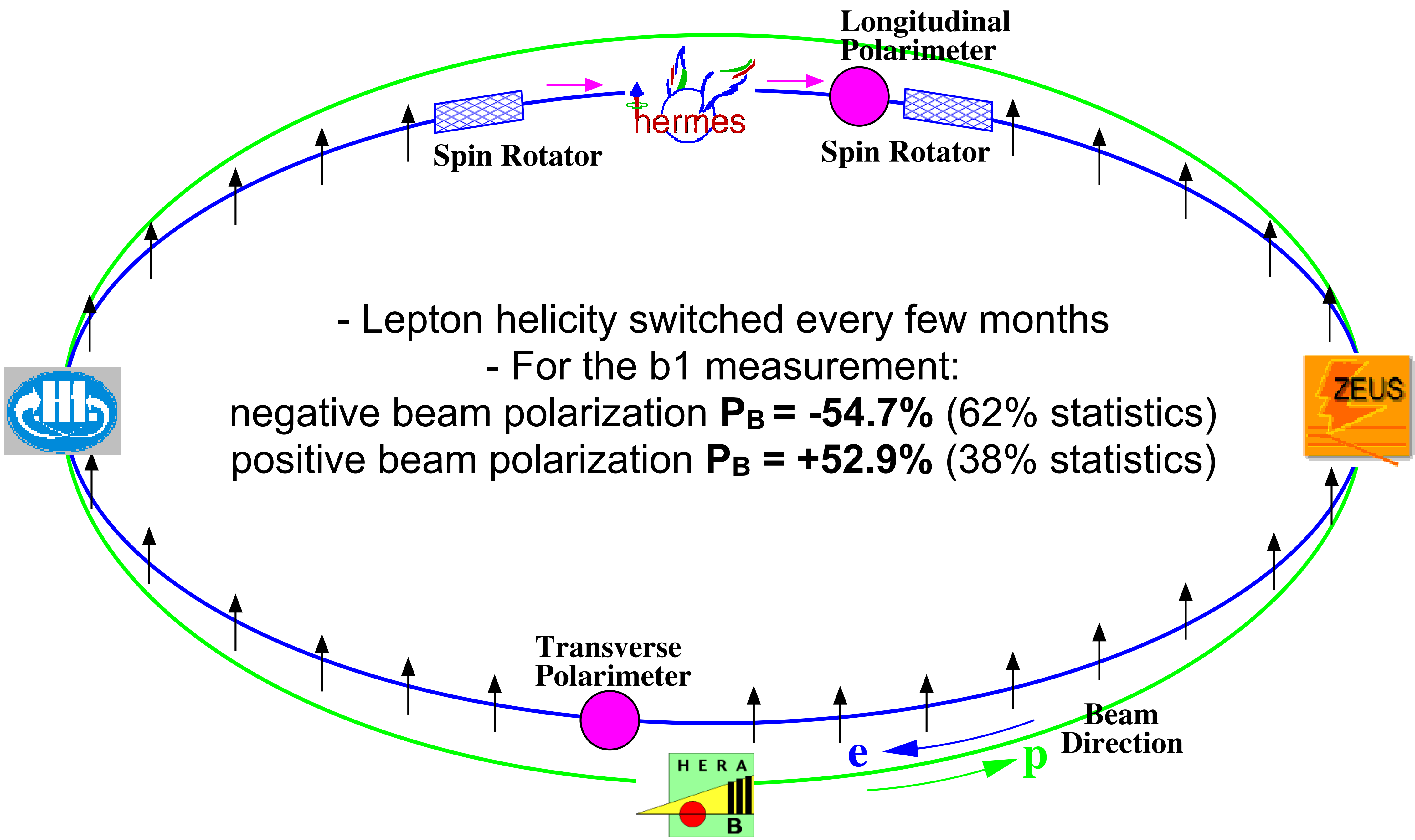
  Diffractive nuclear shadowing can be a source of tensor polarization of sea quarks and lead to a violation of the phenomenological sum rule.

- **b1 as "border crosser" between nuclear and quark physics:**
  - Accessible only in DIS - however does not probe quark spin, but spin of embedding hadron
  - Access to information on nuclear binding effects at parton level.

The Experiment

The Lepton Beam: HERA at DESY

- HERA retired June 30, 2007
- Self-polarized e+ and e- beams of 27.6 GeV (proton beam not employed by HERMES)
- At HERMES: longitudinal beam polarization



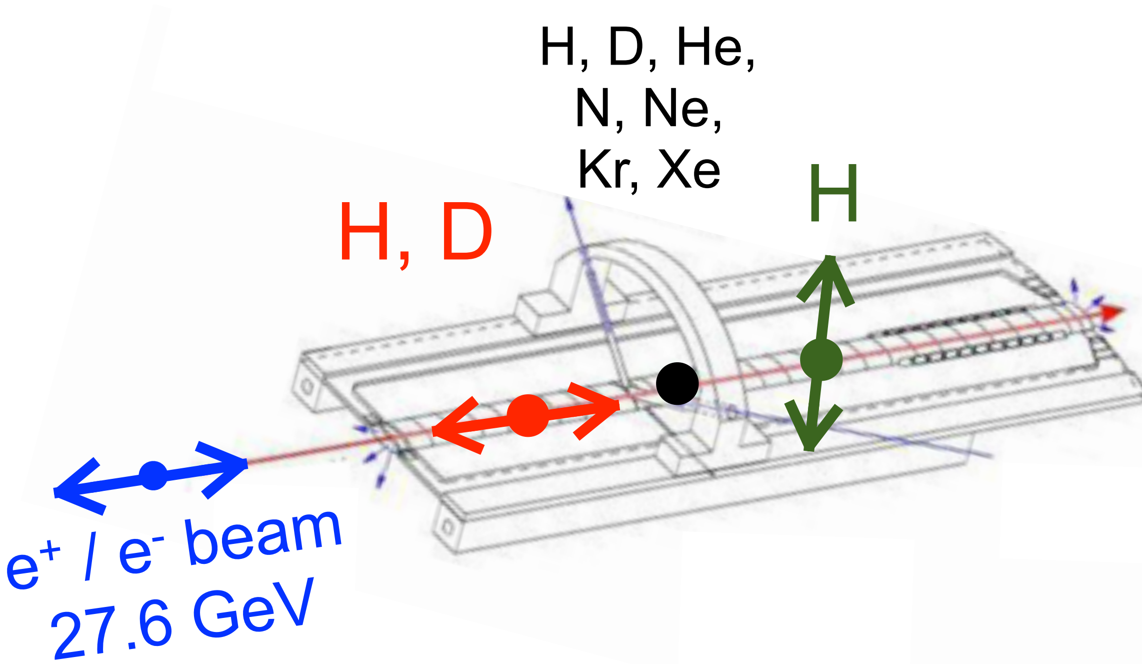
- Lepton helicity switched every few months
- For the b1 measurement:

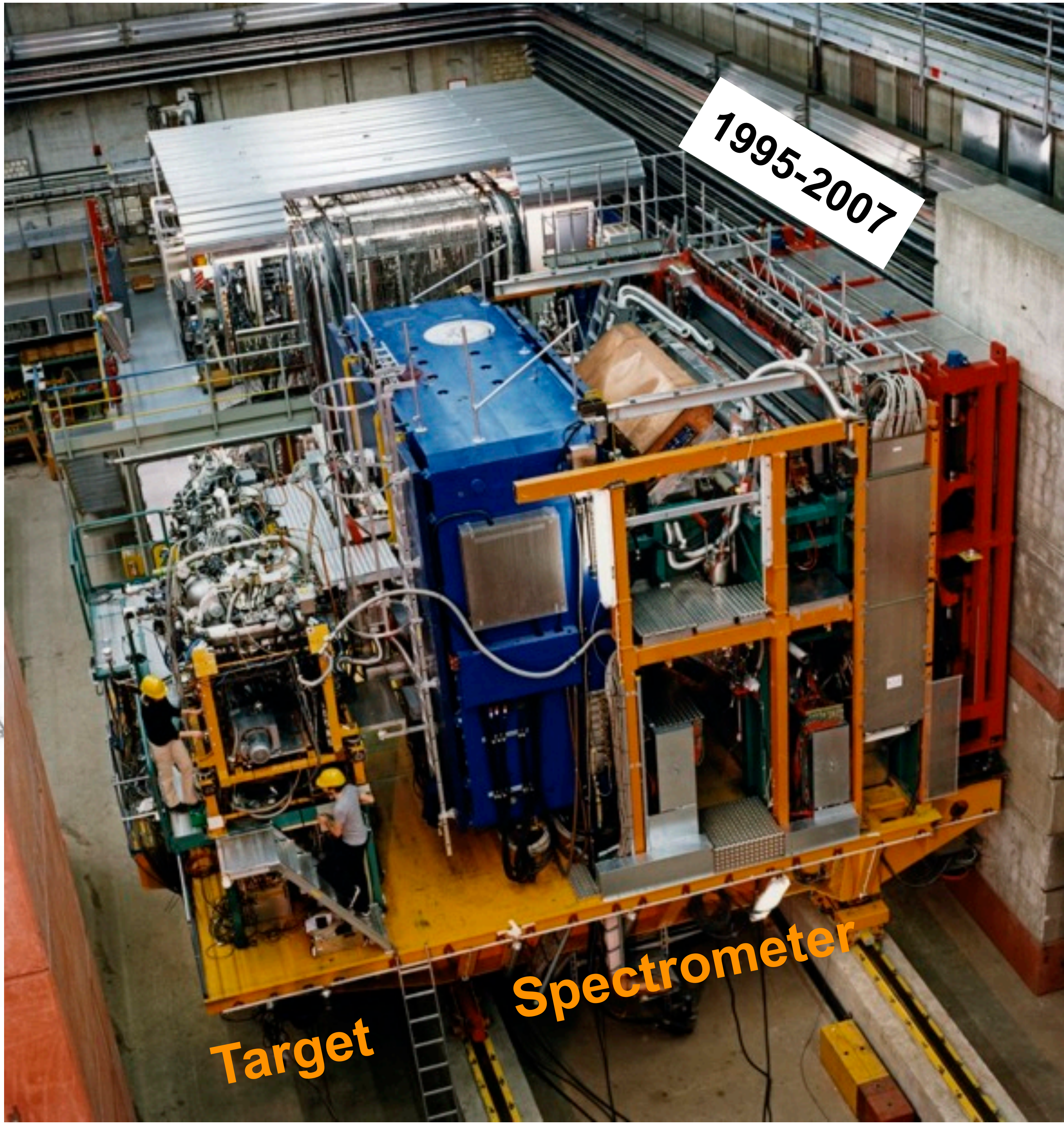
negative beam polarization **P_B = -54.7%** (62% statistics)
positive beam polarization **P_B = +52.9%** (38% statistics)

HERMES

Gas target internal to lepton ring

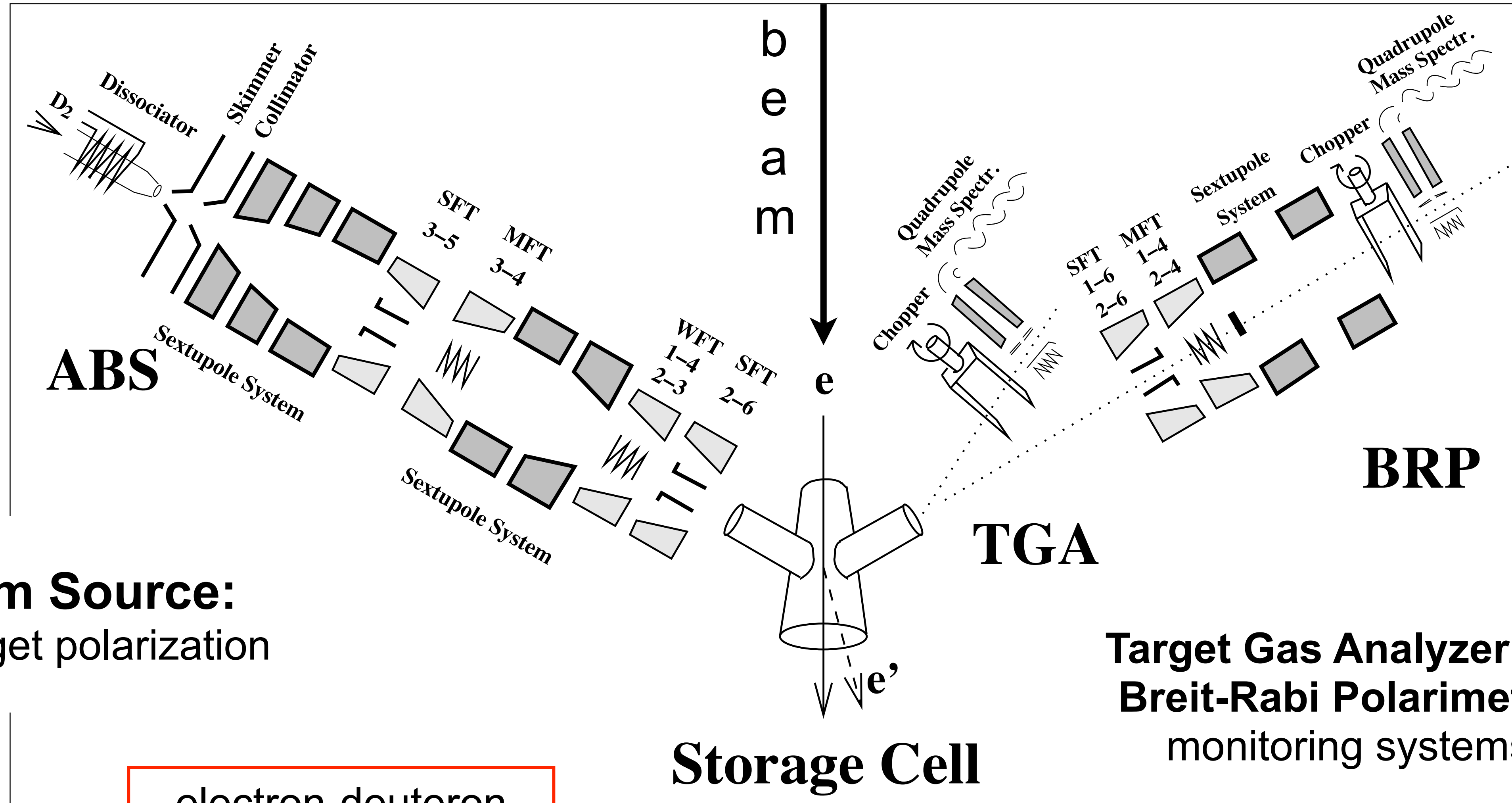
No dilution from unpolarizable material





Longitudinally polarized deuterium
1998-2000 with dedicated 6 weeks
of data with high tensor polarization
in July / August 2000

Polarized Gas Target



Atomic Beam Source:
generation of target polarization

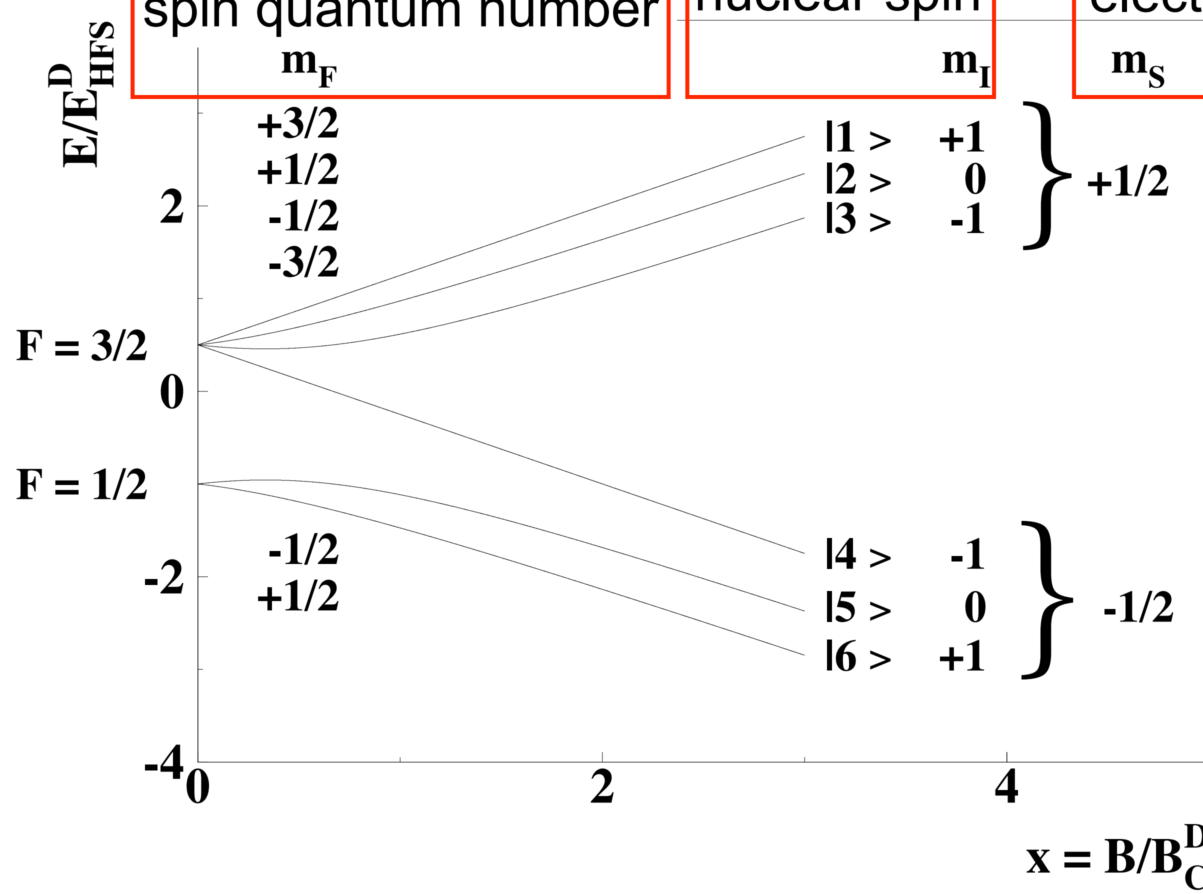
Target Gas Analyzer and **Breit-Rabi Polarimeter:**
monitoring systems

electron-deuteron spin quantum number

nuclear spin

electron spin

Breit-Rabi diagram for deuterium



Stern-Gerlach separation of hyperfine states

Vector and Tensor Polarizations

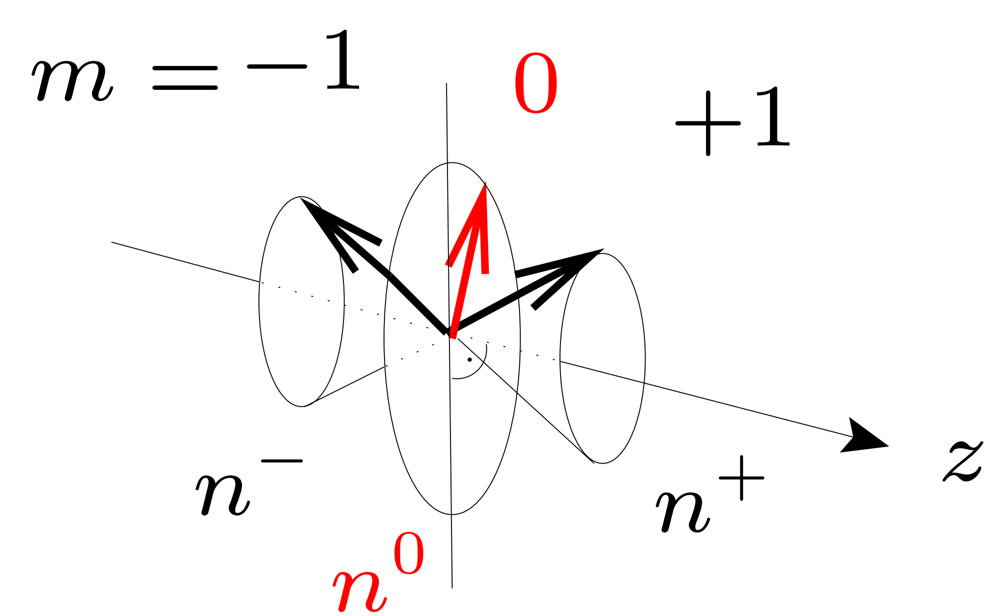
target mode *changed every 90s, randomly*

	inj. hyper-fine states	injected particles	vector polarization P_z ideal	vector polarization P_z measured	tensor polarization P_{zz} ideal	tensor polarization P_{zz} measured
+	$\|1>+\|6>$	n^+	$P_z^+ = +1$	$+0.851 \pm 0.029$	$P_{zz}^+ = +1$	$+0.800 \pm 0.025$
−	$\|3>+\|4>$	n^-	$P_z^- = -1$	-0.840 ± 0.026	$P_{zz}^- = +1$	$+0.853 \pm 0.027$
⇔	$\|3>+\|6>$	$n^+ + n^-$	$P_z^{\Leftrightarrow} = 0$	-0.010 ± 0.003	$P_{zz}^{\Leftrightarrow} = +1$	$+0.891 \pm 0.027$
0	$\|2>+\|5>$	n^0	$P_z^0 = 0$	-0.010 ± 0.005	$P_{zz}^0 = -2$	-1.656 ± 0.049

(numbers for b1 measurement)

$$P_z = \frac{n^+ - n^-}{n^+ + n^- + n^0}$$ vector polarization

$$P_{zz} = \frac{(n^+ + n^-) - 2n^0}{n^+ + n^- + n^0}$$ tensor polarization



Tensor Asymmetries

Measured Asymmetry Extraction

- Cross section for polarized leptons off vector- and tensor-polarized spin-1 target:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E\,\mathrm{d}\Omega} \equiv \sigma_{\mathrm{meas}} = \sigma^{\mathrm{U}}\left[1 - P_B P_z A_\parallel + \frac{1}{2} P_{zz} A_{zz}\right] = \sigma^{\mathrm{U}} + \sigma^{\mathrm{P}}$$

$$\boxed{\sigma_{\mathrm{meas}} = \frac{N}{L}}$$

$$\boxed{A_\parallel := \frac{\sigma^{\overset{\rightleftarrows}{\Leftarrow}} - \sigma^{\overset{\rightrightarrows}{\Rightarrow}}}{2\sigma^{\mathrm{U}}}}$$

vector asymmetry

$$\boxed{A_{zz} := \frac{2\sigma^1 - 2\sigma^0}{3\sigma^{\mathrm{U}}}}$$

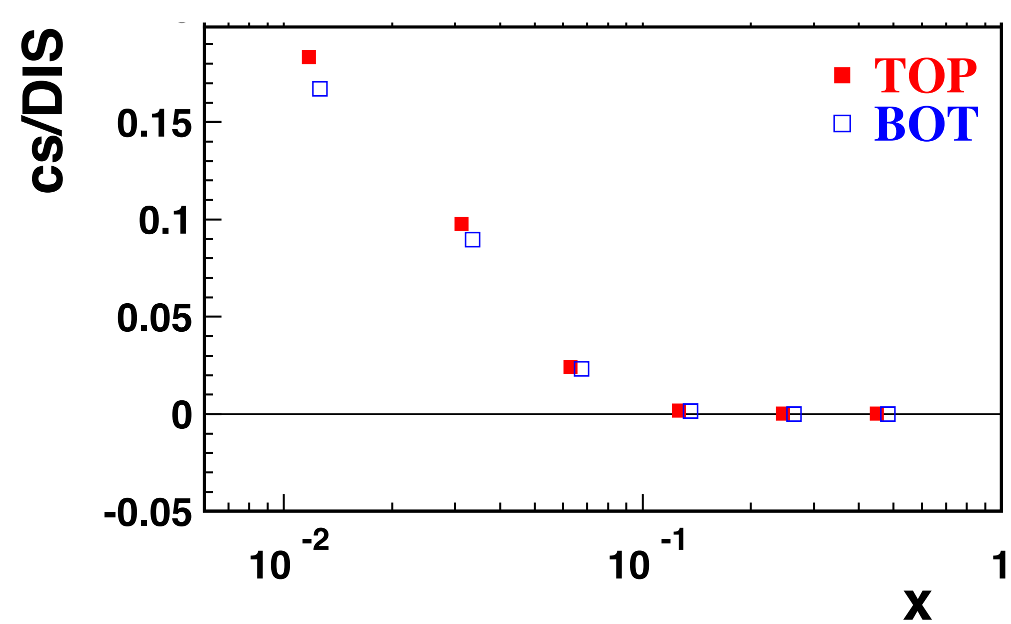
tensor asymmetry

- Integrated, dead-time corrected luminosity:

$$L := \int_{\Delta\mathcal{T}} \mathrm{d}t\ \epsilon(t)\ \mathcal{L}(t) = \sum_i \Delta\tau_i \epsilon_i \mathcal{L}_i$$

coincidence rate [Hz] in
luminosity monitor

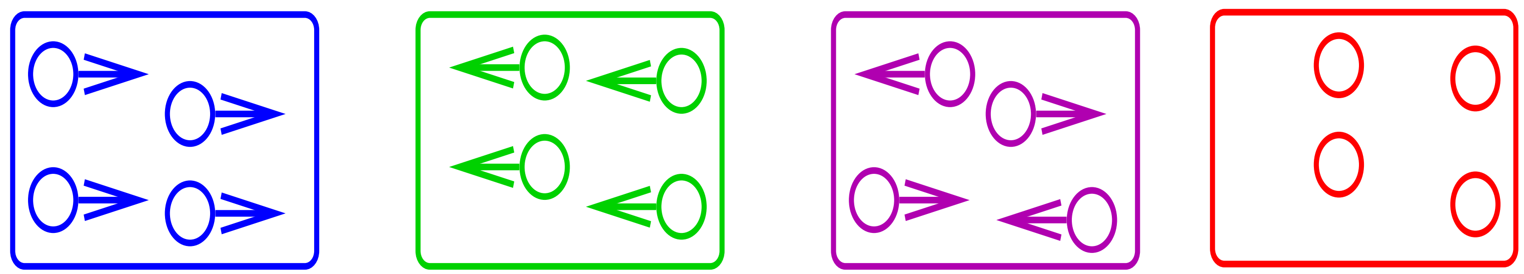
- Correction for charge-symmetric background:
subtract # of events with wrong lepton charge



Tensor and Vector Asymmetry

HERMES target mode

+	−	⇔	0
$P_z = +1$	$P_z = -1$	$P_z = 0$	$P_z = 0 \quad P_{zz} = -2$



randomly cycled through, switched every 90 s

6 weeks of data taking in 2000

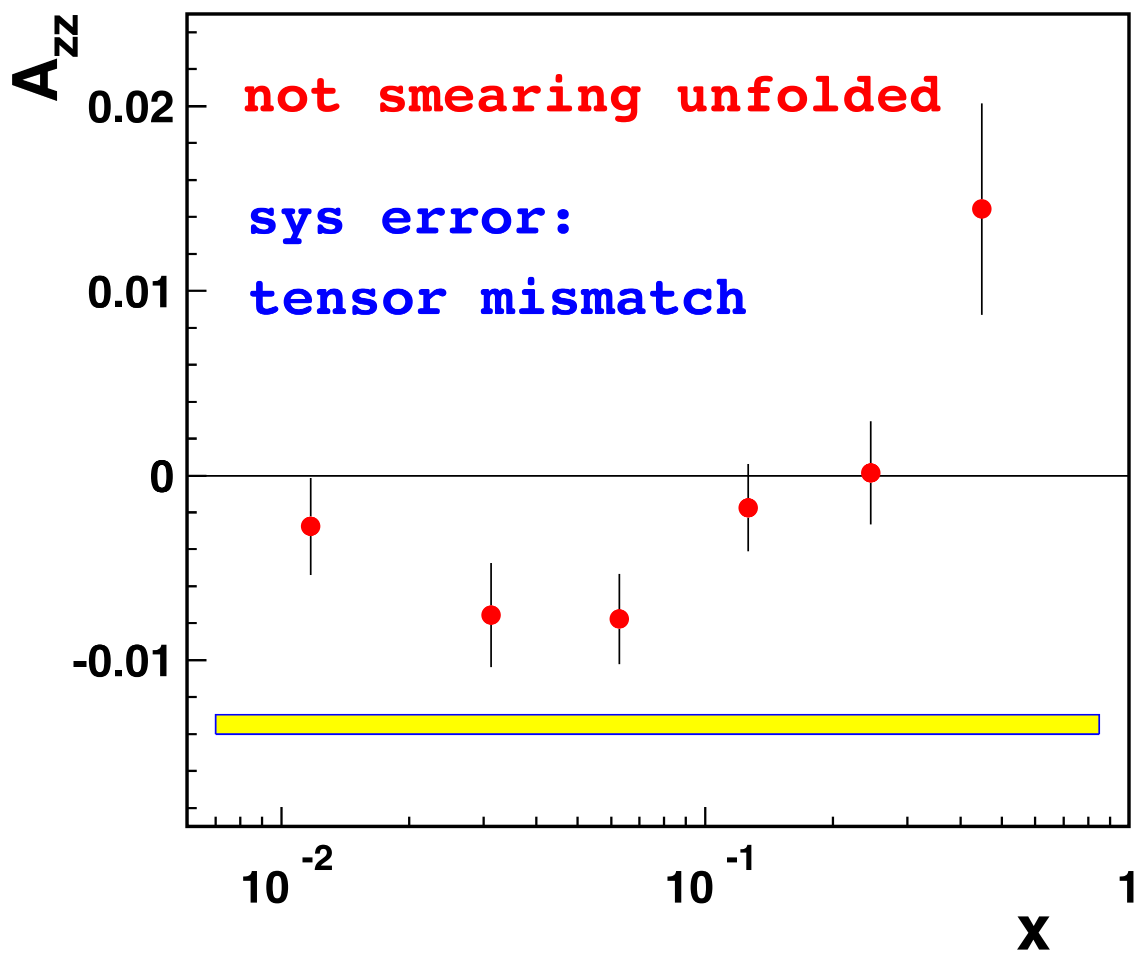
vector modes **consistency-check mode** **tensor mode**

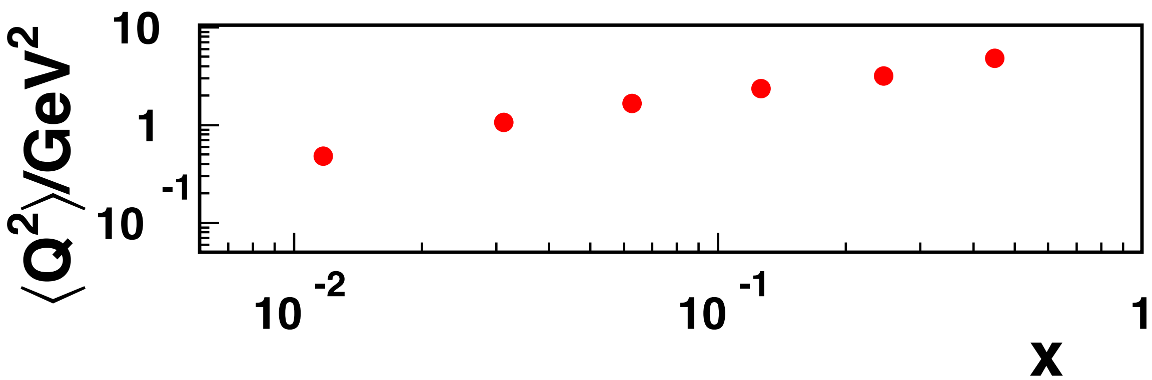
$$A_{zz} = \frac{1}{\langle P_{zz} \rangle} \cdot \frac{\frac{2}{3}\left(\frac{N^{\stackrel{\rightarrow}{\Leftarrow}}}{L^{\stackrel{\rightarrow}{\Leftarrow}}} + \frac{N^{\stackrel{\rightarrow}{\Rightarrow}}}{L^{\stackrel{\rightarrow}{\Rightarrow}}} + \frac{N^{\Leftrightarrow}}{L^{\Leftrightarrow}}\right) - 2\left(\frac{N^0}{L^0}\right)}{\frac{2}{3}\left(\frac{N^{\stackrel{\rightarrow}{\Leftarrow}}}{L^{\stackrel{\rightarrow}{\Leftarrow}}} + \frac{N^{\stackrel{\rightarrow}{\Rightarrow}}}{L^{\stackrel{\rightarrow}{\Rightarrow}}} + \frac{N^{\Leftrightarrow}}{L^{\Leftrightarrow}}\right) + \left(\frac{N^0}{L^0}\right)} = -\frac{2}{3}\frac{b_1}{F_1}$$

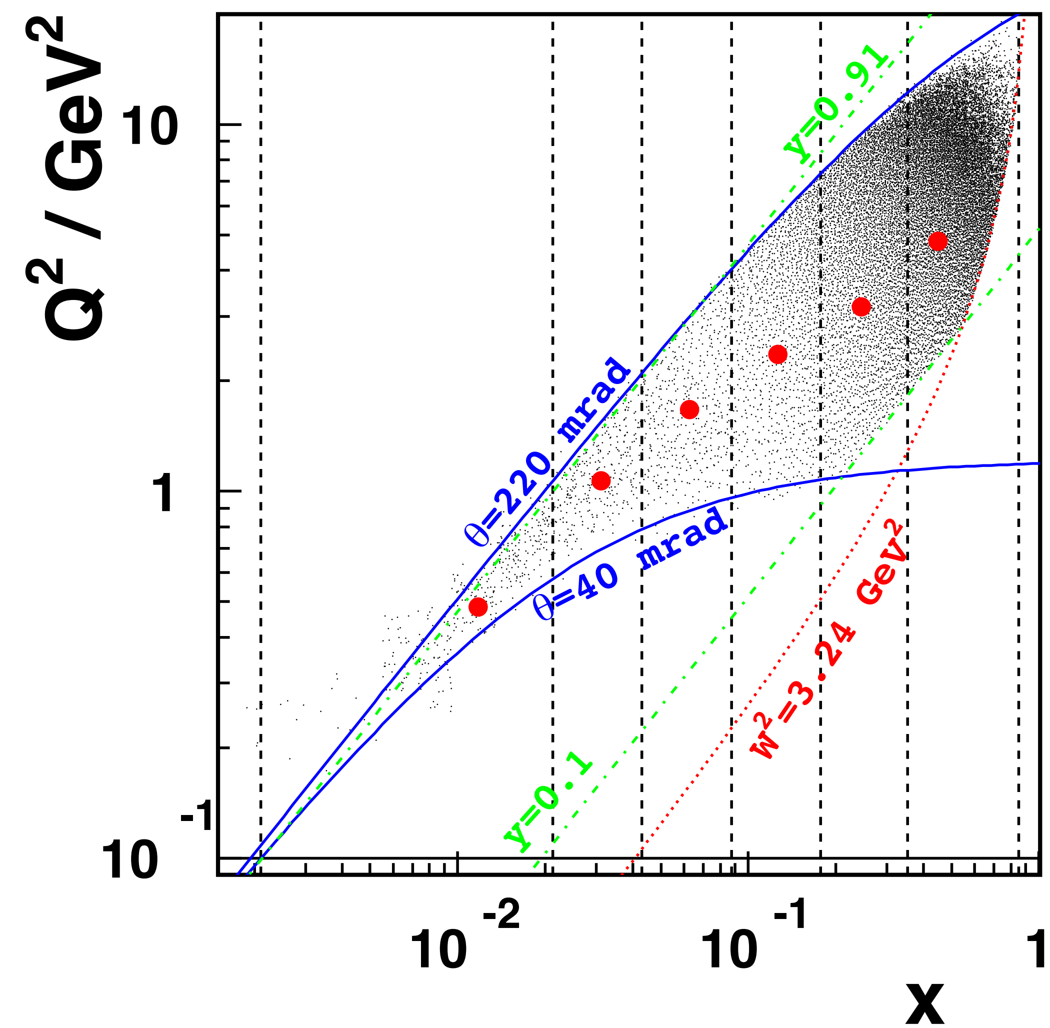
$$A_{\parallel} = \frac{1}{\langle P_B P_z \rangle} \cdot \frac{\left(\frac{N^{\stackrel{\rightarrow}{\Leftarrow}}}{L^{\stackrel{\rightarrow}{\Leftarrow}}}\right) - \left(\frac{N^{\stackrel{\rightarrow}{\Rightarrow}}}{L^{\stackrel{\rightarrow}{\Rightarrow}}}\right)}{\left(\frac{N^{\stackrel{\rightarrow}{\Leftarrow}}}{L^{\stackrel{\rightarrow}{\Leftarrow}}}\right) + \left(\frac{N^{\stackrel{\rightarrow}{\Rightarrow}}}{L^{\stackrel{\rightarrow}{\Rightarrow}}}\right)} \sim D\frac{g_1}{F_1}$$

deuteron structure functions

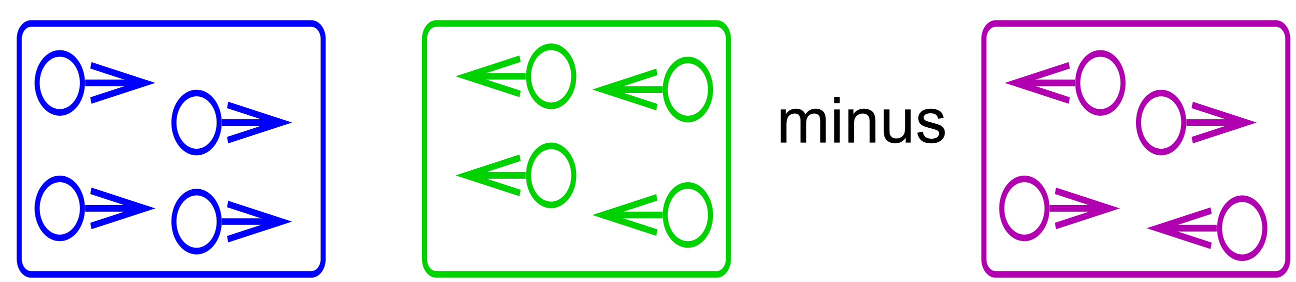
Measured Tensor Asymmetry



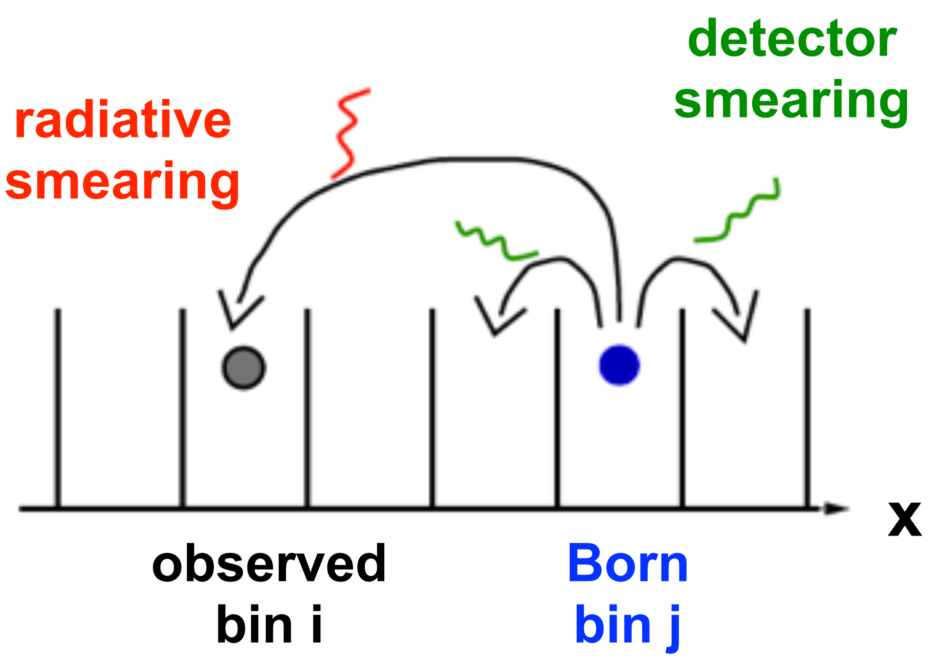


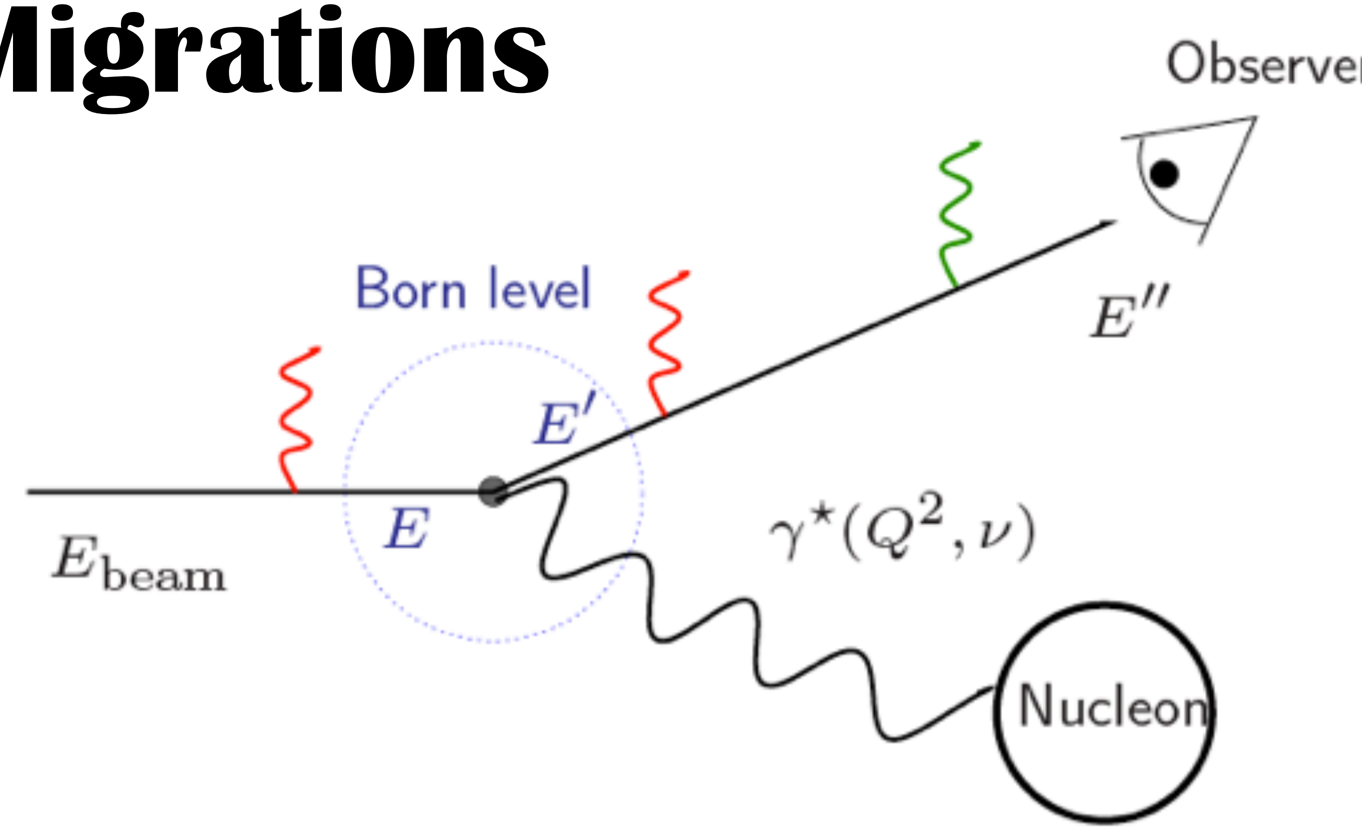


Half of “tensor mismatch”: 0.0021±0.0010 assigned as systematic uncertainty



Kinematic Bin Migrations

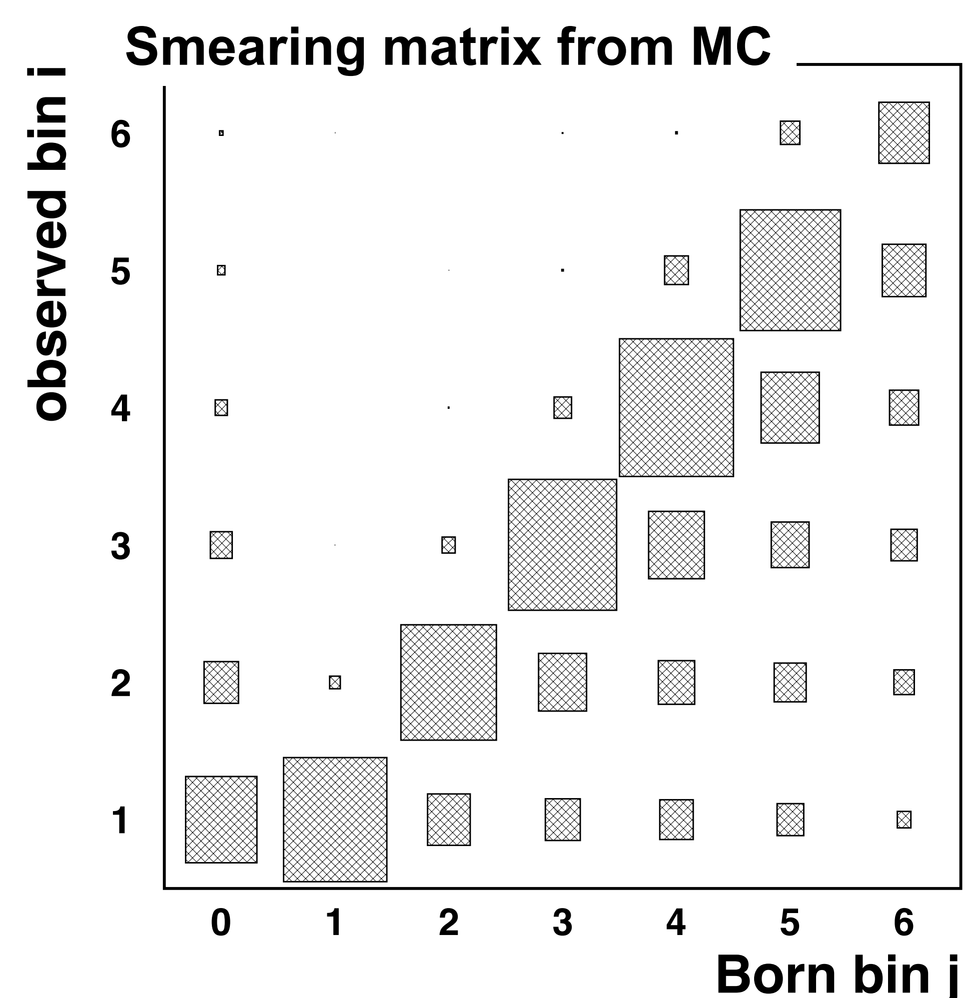




Monte-Carlo simulation
(PEPSI generator for DIS)

Input parameterizations:
- F_2(ALLM)
- $R=\sigma_L/\sigma_T$(1990)
- A_{zz}(Born) from fit to HERMES data

9 times higher statistics than real data
Subject to same cuts as experimental data



Kinematic Unfolding

$$A_{\mathrm{Born}} = A_{\mathrm{X}} \cdot \left(1 + \frac{\Delta\sigma^{\mathrm{U}}}{\sigma^{\mathrm{U}}_{\mathrm{Born}}}\right) - \frac{\Delta\sigma^{\mathrm{P}}}{\sigma^{\mathrm{U}}_{\mathrm{Born}}}$$

Unfolding of measured asymmetry A_X

- bin-wise, not event-wise
- no iteration needed
- close to model-independent

Δσ = background not belonging to Born bin
U = spin-independent contribution
P = spin-dependent contribution

eXperimental MC: $\Delta\sigma^{\mathrm{P(U)}}$

- Observed cross section
- Radiative corrections (RADGEN)
- Tracking through detector (GEANT)
- Migration matrix $M(i,j)$
- Background from outside acceptance $\Delta\overset{\frown}{\sigma}$

Born MC: $\sigma^{\mathrm{U}}_{\mathrm{Born}}$

- Born cross section within acceptance
- No radiative corrections, no tracking

Smearing matrix from MC

$$S(i,j) \equiv \frac{M(i,j)}{\sigma_{\mathrm{Born}}(j)}$$

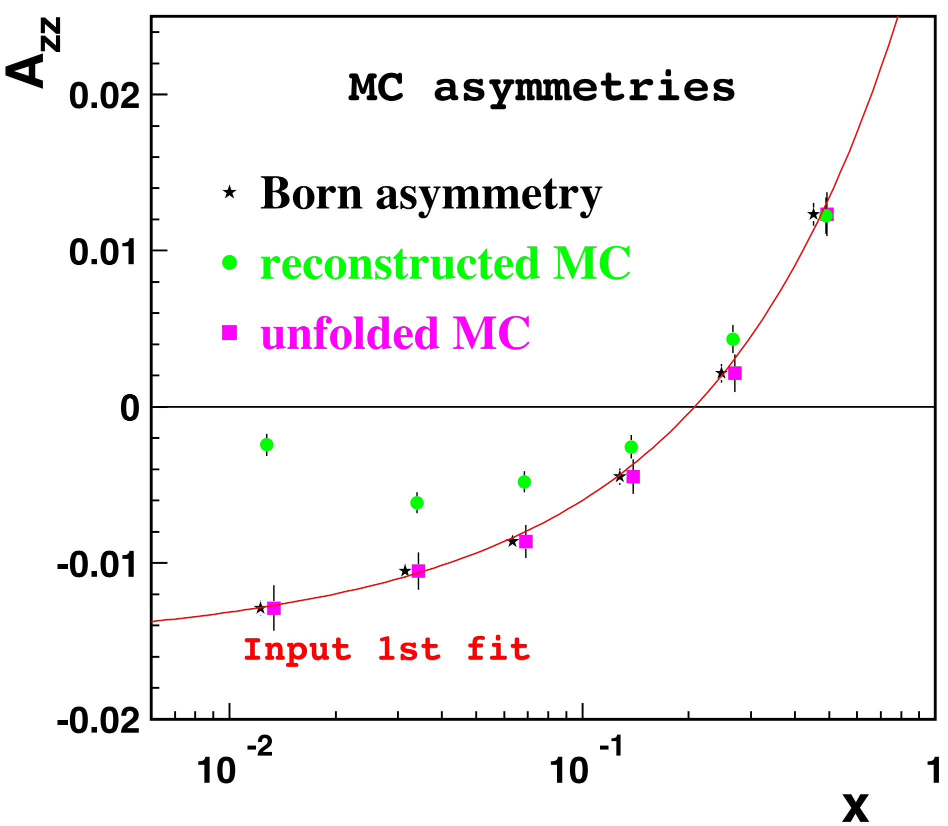
$$A_{\mathrm{Born}}(j) = -2 + \frac{6}{\sigma^{\mathrm{U}}_{\mathrm{Born}}(j)} \cdot \sum_{i=1}^{n} [S']^{-1}(j,i) \times$$
$$\left[\frac{1}{2} A_{\mathrm{X}}(i)\sigma^{\mathrm{U}}_{\mathrm{X}}(i) - \frac{1}{2}\Delta\overset{\frown}{\sigma}^{\mathrm{P}}(i) + \sum_{k=1}^{n} S^{-}(i,k)\sigma^{\mathrm{U}}_{\mathrm{Born}}(k)\right]$$

eXperimental MC corrected for tracking inefficiencies caused by electromagnetic showers

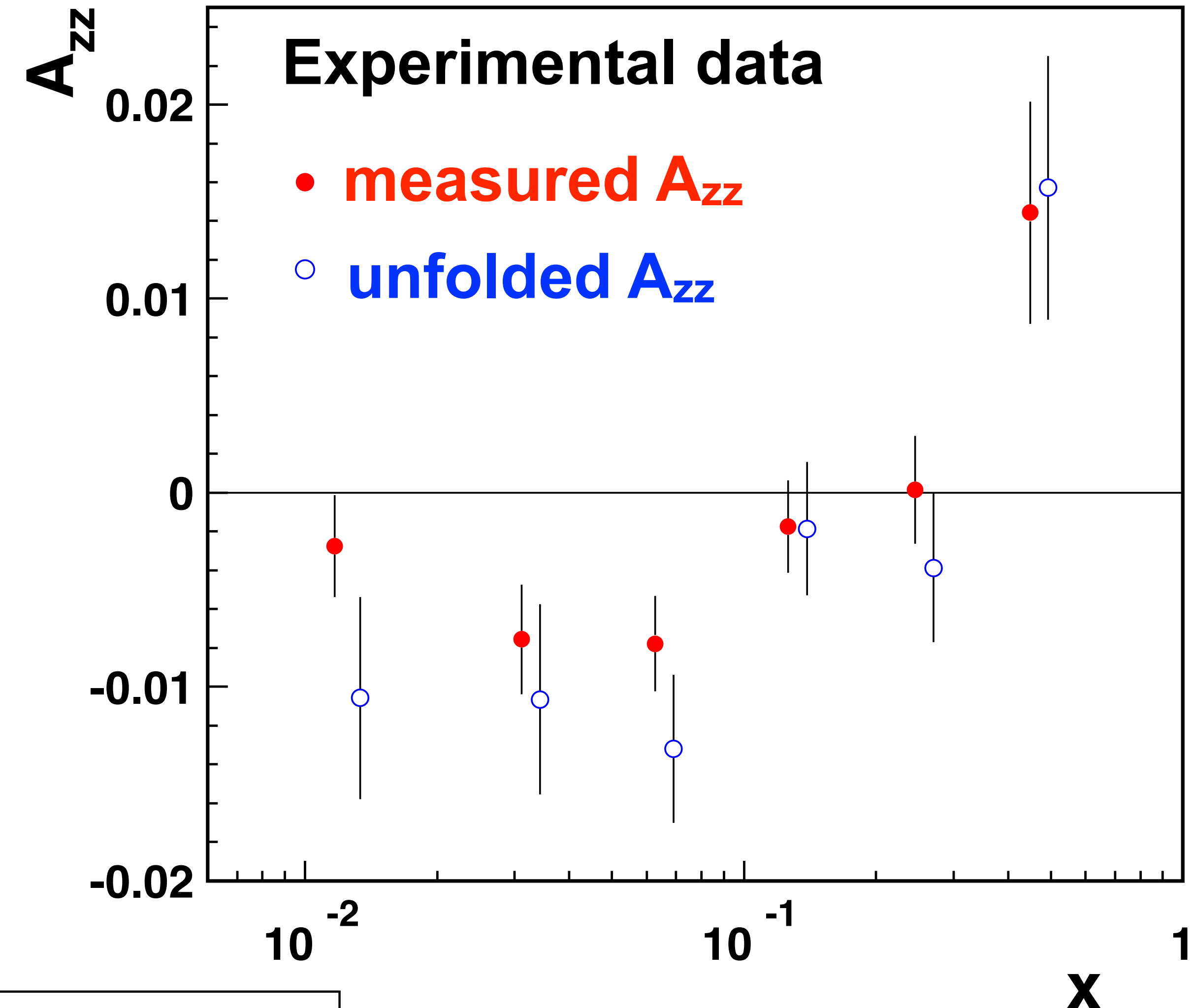
Unfolded Tensor Asymmetry

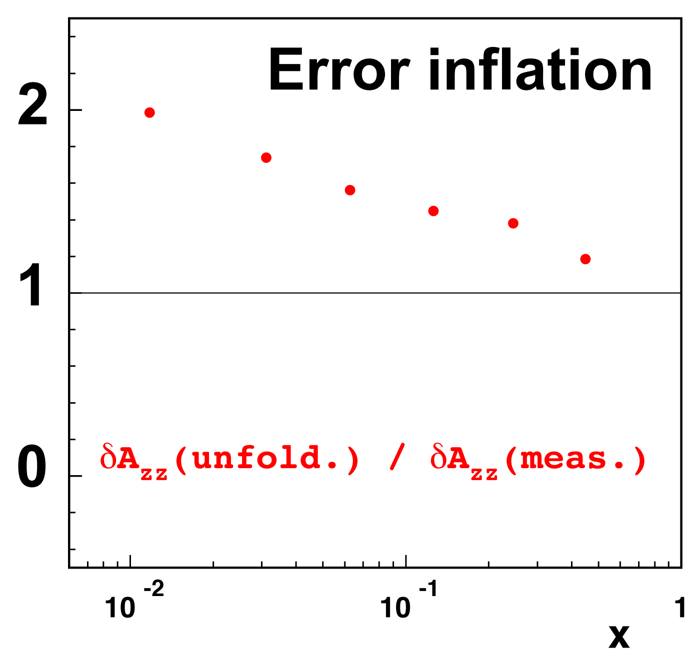
Consistency check with Monte Carlo

✔ Unfolded asymmetry lies on input fit



"PEPSI challenge"





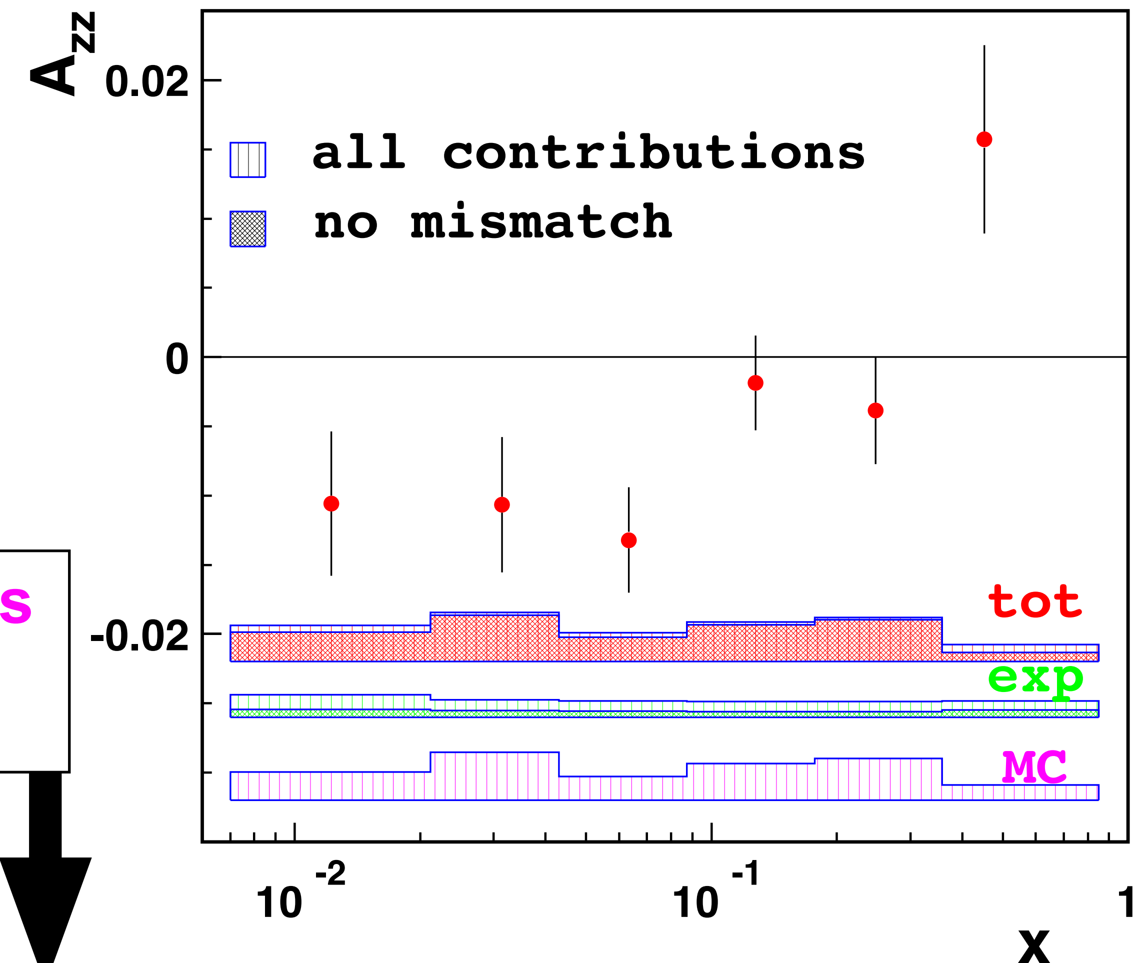
- Systematic correlations between bins removed
- Statistical correlations introduced
- Covariance matrix of statistical errors must be employed for integrals or fits

Systematic Uncertainties

Tensor asymmetry is small, of order $(1\pm0.3[\mathrm{stat}])\cdot10^{-2}$, need to control systematics well!

Uncertainties from experimental data analysis

- Tensor mismatch 10^{-3}
- Target polarization $10^{-6} \ldots 10^{-4}$
- Target density $3\cdot10^{-4}$
- Residual electron polarization $2\cdot10^{-4}$
- Hadron contamination $0 \ldots 10^{-6} \ldots 10^{-5}$



Uncertainties from MC studies

- Radiative corrections $10^{-5} \ldots 10^{-3}$
- Detector misalignment $10^{-4} \ldots 10^{-3}$

Separate **error inflation** by unfolding procedure

Assumed to be 100% correlated between bins (except for had. cont.)

Add **δ(exp)'s** in quadrature

Add **δ(MC)'s** in quadrature

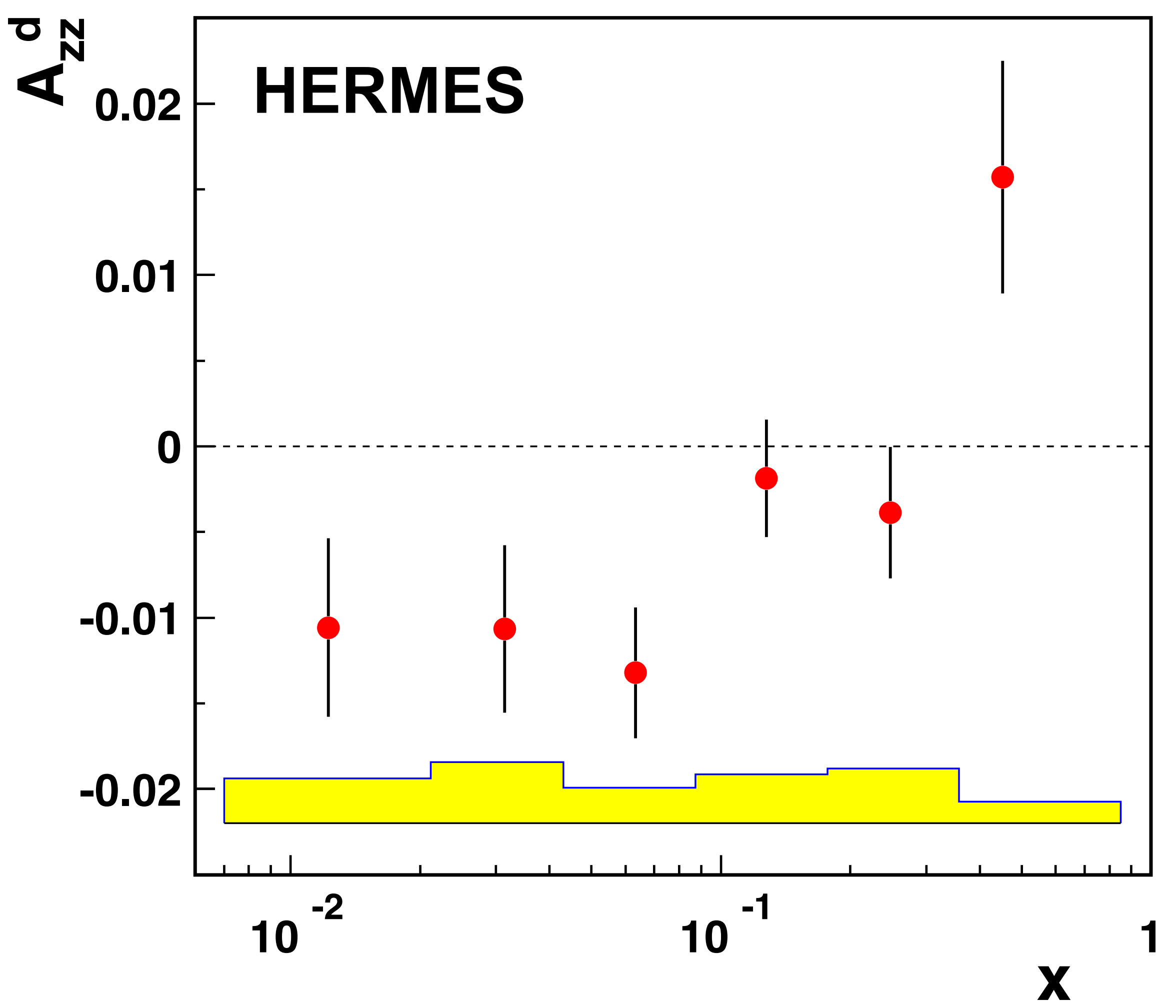
Add in quadrature for total sys. uncertainty

Propagate total systematic uncertainty of A_{zz} to **b1**

Tensor Structure Function

Extraction of b1

Unfolded tensor asymmetry



$$\boxed{b_1^{\mathrm{d}}(x,Q^2) \;=\; -\frac{3}{2}A_{zz}(x)F_1^{\mathrm{d}}(x,Q^2)}$$

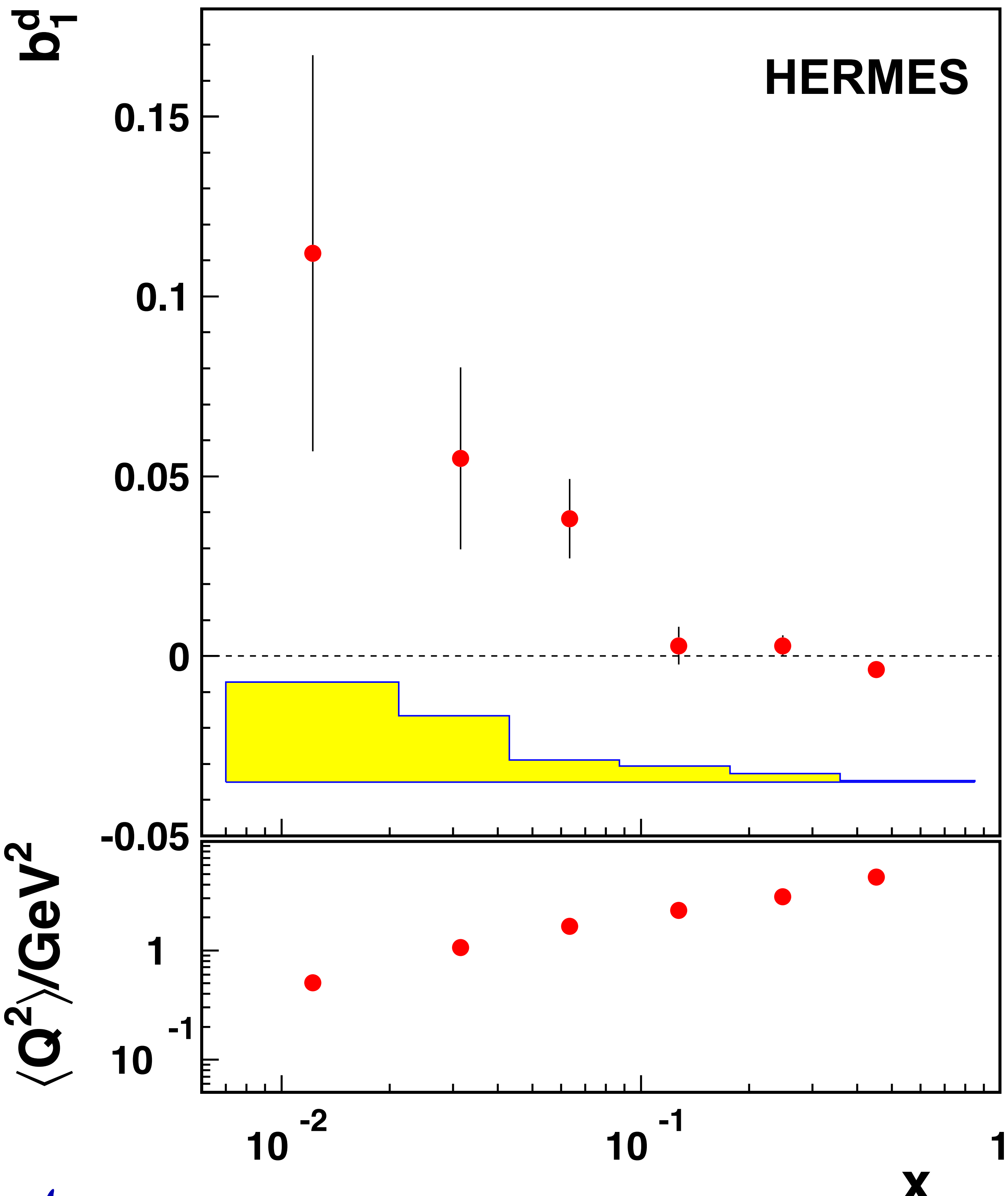
$$F_1^{\mathrm{d}}(x,Q^2) = F_2^{\mathrm{d}}(x,Q^2)\left(\frac{1+\gamma^2}{2x(1+R(x,Q^2))}\right)$$

$$F_2^{\mathrm{d}} = \frac{1}{2}F_2^{\mathrm{p}}\left(1+\frac{F_2^{\mathrm{n}}}{F_2^{\mathrm{p}}}\right) \equiv (F_2^{\mathrm{p}})_{\mathrm{ALLM}}\cdot\left(\frac{F_2^{\mathrm{d}}}{F_2^{\mathrm{p}}}\right)_{\mathrm{NMC}}$$

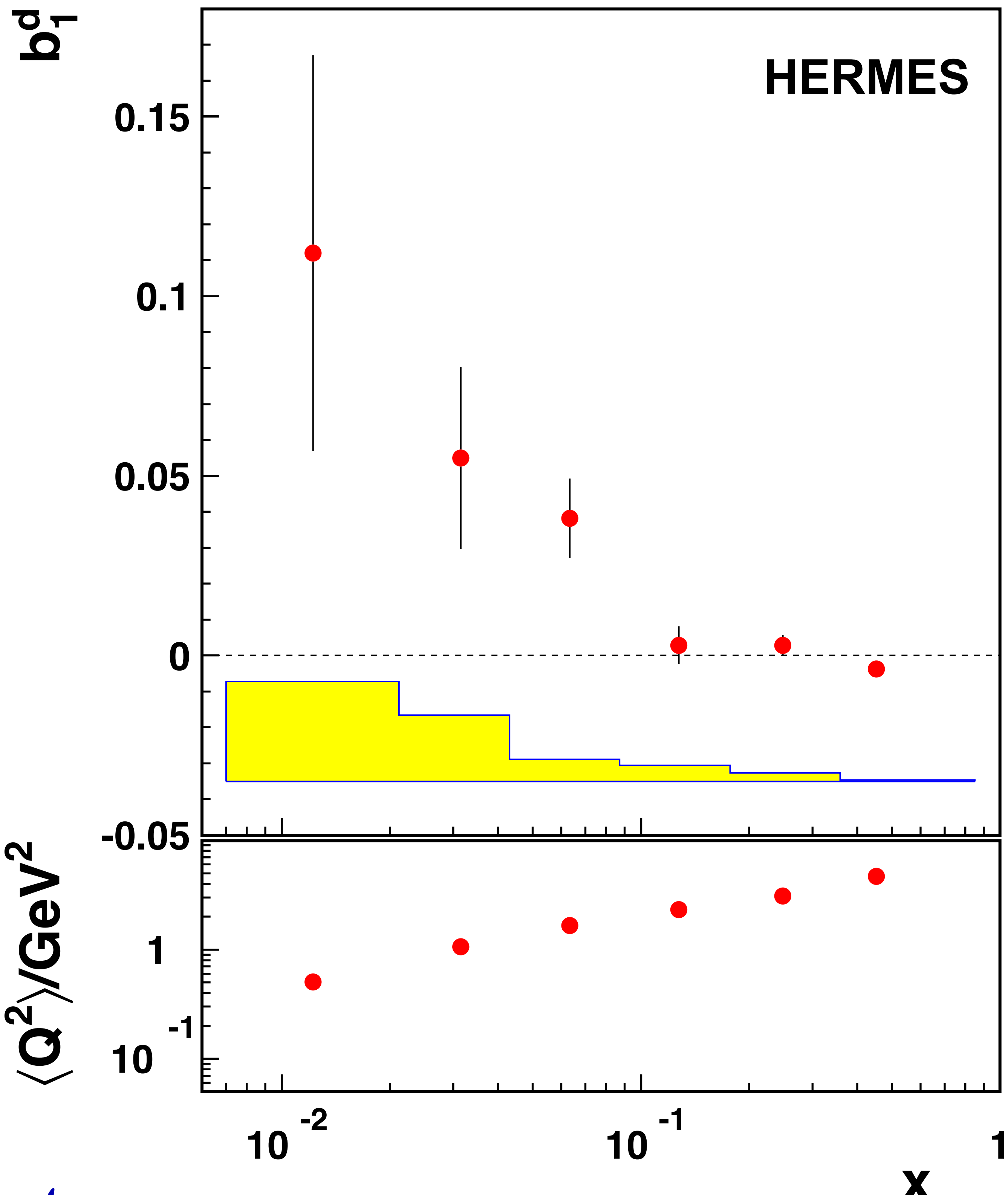
$$x \equiv \langle x\rangle$$
$$Q^2 \equiv \langle Q^2\rangle$$
$$\gamma^2 \equiv \langle \gamma^2\rangle$$

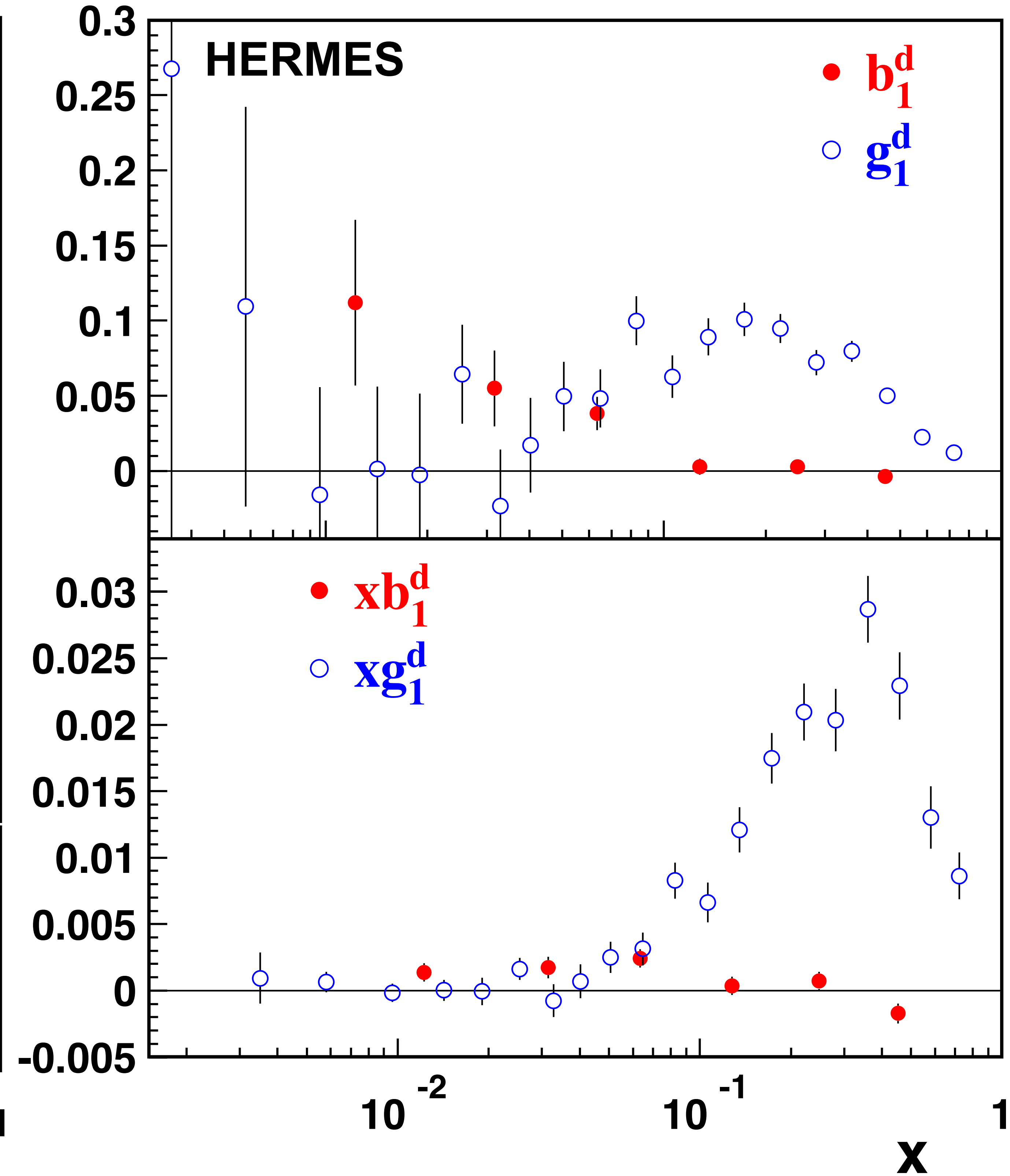
average kinematics in HERMES bin

To be one or not to be one...

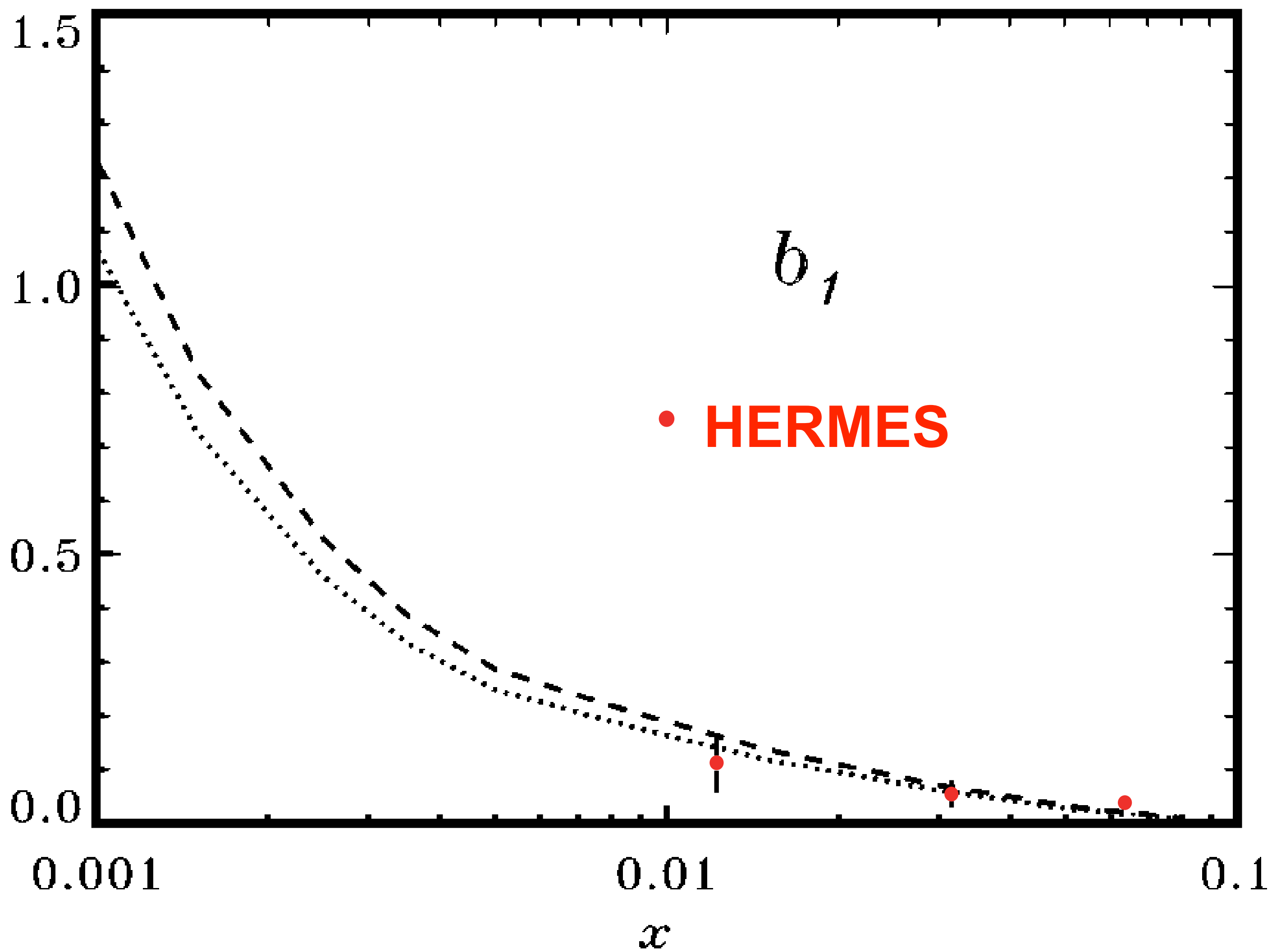


To be one or not to be one...

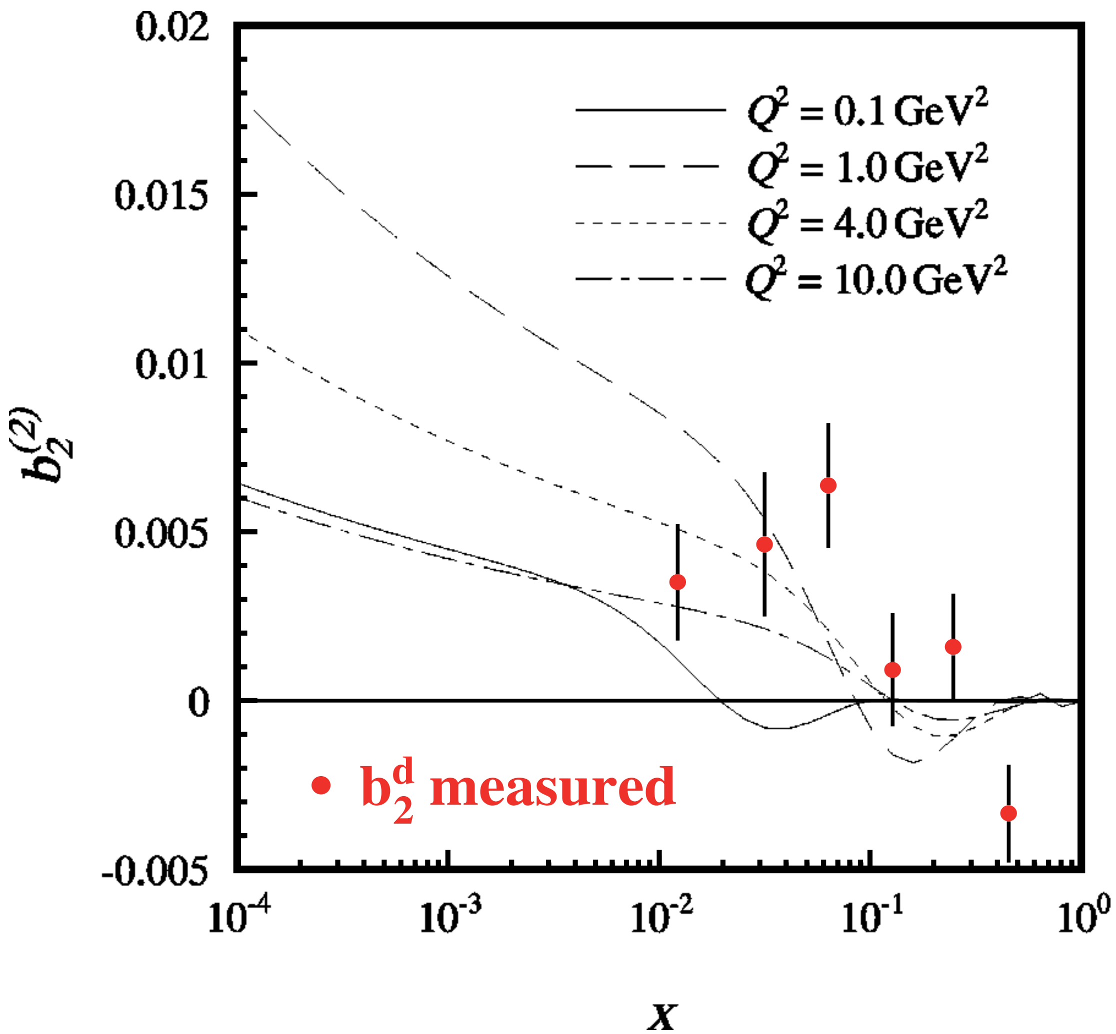




Comparison with Theory



From double-scattering model [17]
(Edelmann, Piller, Weise 1998)

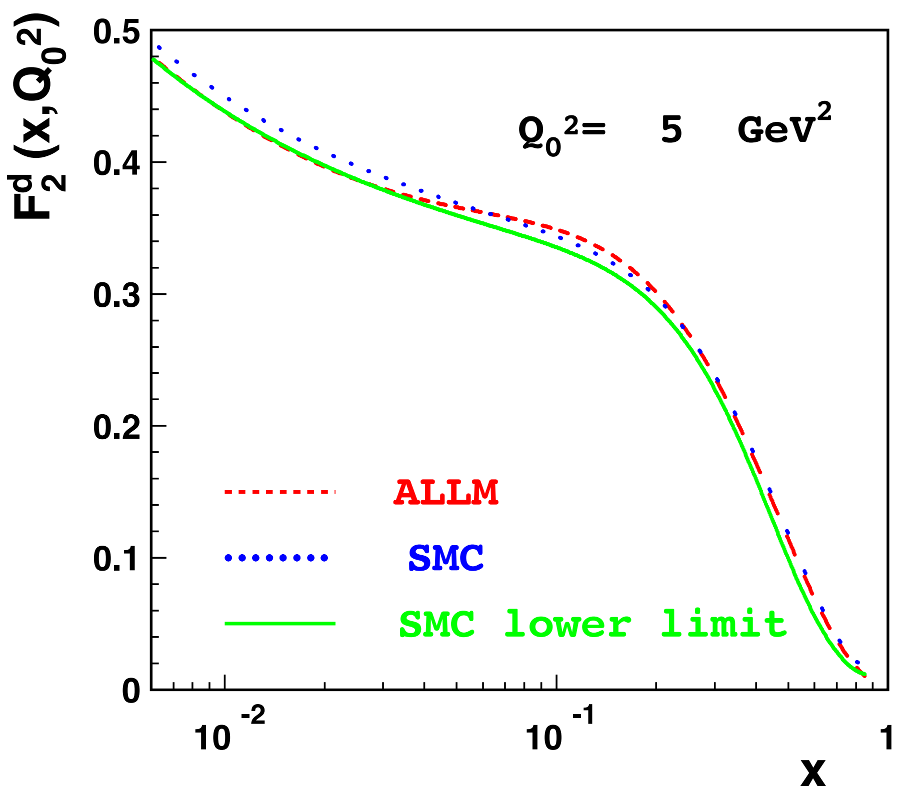


From [41] (Bora, Jaffe 1998)

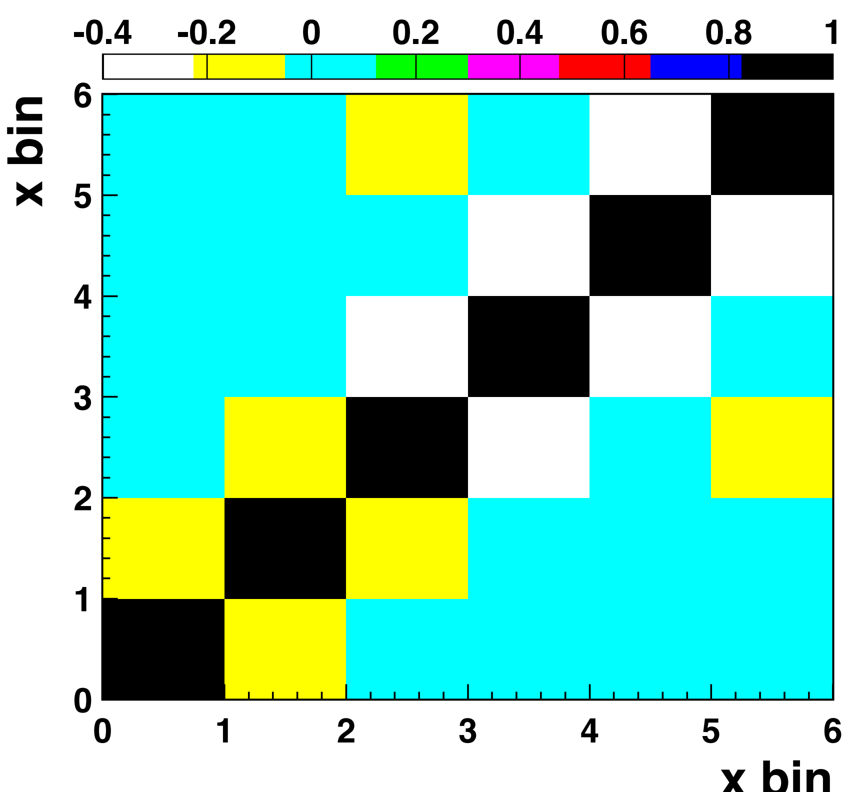
First Moment of b1 in Measured Range

$$M = \int_{x_{\min}}^{x_{\max}} b_1(x, Q_0^2)\mathrm{d}x = -\frac{3}{2}\sum_{i=i_1}^{\mathrm{n}} A_{zz}(\langle x_i \rangle) \int_{x_i}^{x_{i+1}} F_1^{\mathrm{d}}(x, Q_0^2)\mathrm{d}x$$

$$\delta M = \frac{9}{4}\sum_{i=i_1}^{\mathrm{n}}\sum_{j=j_1}^{\mathrm{n}} \mathrm{cov}(i,j) \int_{x_i}^{x_{i+1}} F_1^{\mathrm{d}}(x, Q_0^2)\mathrm{d}x \int_{x_j}^{x_{j+1}} F_1^{\mathrm{d}}(x, Q_0^2)\mathrm{d}x$$



$x_{\min}$	$x_{\max}$	M
0.002	0.85	$0.0105 \pm 0.0034(\mathrm{stat}) \pm 0.0035(\mathrm{sys})$
0.02	0.85	$0.0035 \pm 0.0010(\mathrm{stat}) \pm 0.0018(\mathrm{sys})$



After unfolding: statistical uncertainties correlated between bins due to un-smearing. Need **covariance matrix** for correct interpretation and usage of error bars.

$$\mathrm{cov}(i,j) = \sum_{k=1}^{n} \frac{\partial A_{\mathrm{Born}}(i)}{\partial A_{\mathrm{X}}(k)} \frac{\partial A_{\mathrm{Born}}(j)}{\partial A_{\mathrm{X}}(k)} \delta A_{\mathrm{X}}^2(k)$$

Summary: b1@HERMES

- Pioneering measurement
- Inclusive tensor asymmetry different from zero for x<0.1
  Other spin asymmetries are known to vanish for x→0!
- Tensor structure function shows steep rise for x<0.1,
  2% of F_1 magnitude @x=0.01
- Behavior in qualitative agreement with coherent double scattering models
- Diffractive nuclear shadowing as one source of tensor polarization of sea quarks.
  HERMES extraction of first b1 moment:

$$\int_{0.0021}^{0.85} b_1^{\mathrm{d}}(x, Q_0^2 = 5\,\mathrm{GeV}^2)\mathrm{d}x = 0.0105 \pm 0.0034(\mathrm{stat}) \pm 0.0035(\mathrm{sys}).$$

Outlook: Tensor-Polarized DVCS ☛

Tensor signatures in Deeply Virtual Compton Scattering

9 chiral-even quark **GPDs** at leading twist

Spin-1	H_1, H_2, H_3, H_4, H_5 $\tilde{H}_1, \tilde{H}_2, \tilde{H}_3, \tilde{H}_4$

$b_1(x)$
tensor structure function

H_3, H_5 associated with the D-wave component of deuteron wave function

4 chiral-even quark **GPDs** at leading twist

Spin-½	flips nucleon helicity	conserves nucleon helicity
does not depend on quark helicity	E	H
depends on quark helicity	$\tilde{E}$	$\tilde{H}$

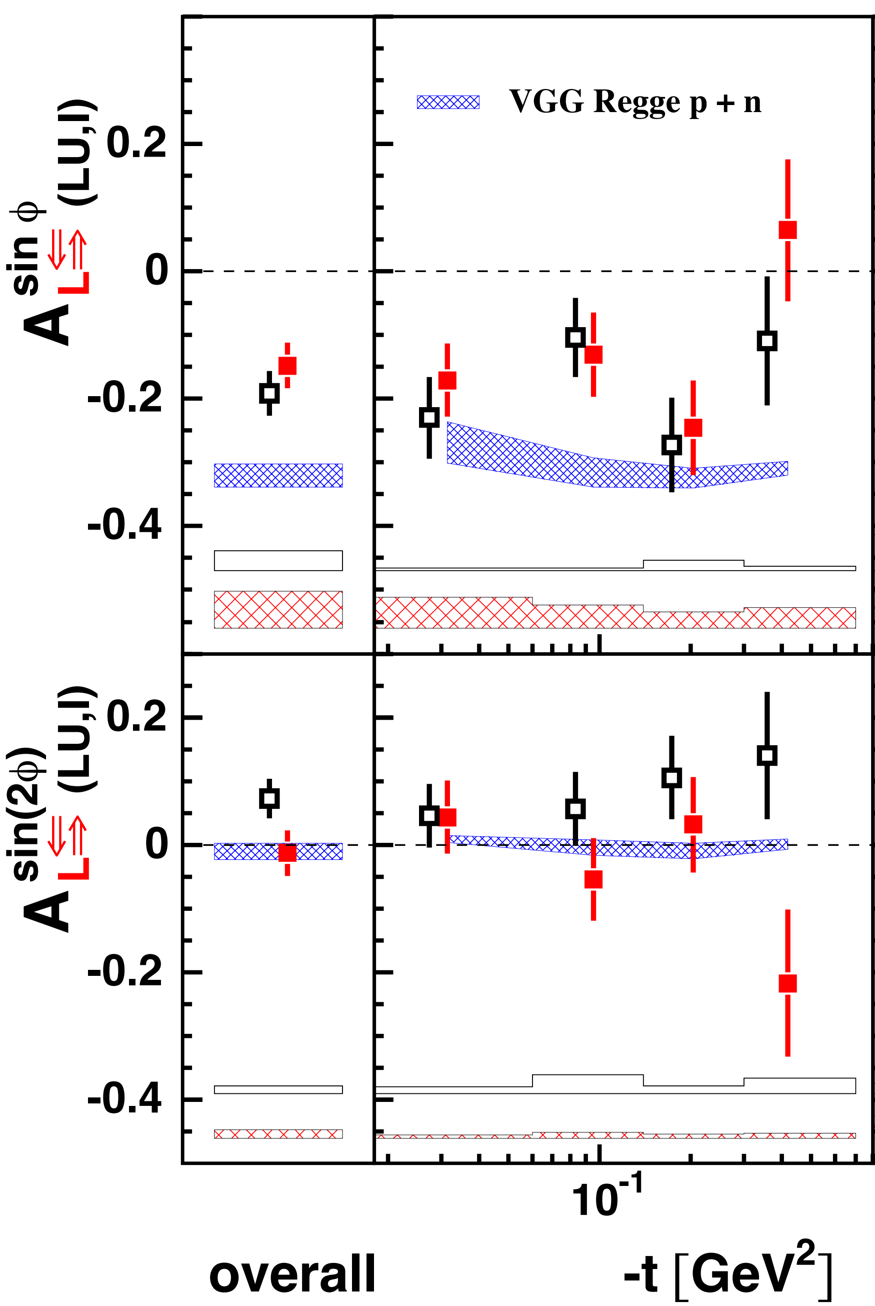
$q^+ + q^-$

forward limit
$\xi \to 0, t \to 0$

$q^+ - q^-$

HERMES: DVCS off tensor-polarized deuterons

Search for tensor signature in beam-helicity asymmetry



□ **unpolarized**

$\mathcal{R}e(\mathcal{H}_1)$

■ **tensor-polarized**

$\mathcal{R}e(\mathcal{H}_1 - \frac{1}{3}\mathcal{H}_5)$

- Vector polarization $P_z \approx 0.85$
- Tensor polarization $P_{zz} \approx 0.83$

- If deuterons are tensor-polarized: A_{LU} becomes, for coherent scattering at low-t, sensitive to CFF H_5 (≡ tensor structure function in the forward limit)

DVCS A_{LZZ} (tensor asymmetry) sinϕ amplitude:
(no plot shown)

0.074 ± 0.196 ± 0.022

-t<0.06 GeV^2, 40% coherent,
dedicated data set with $P_{zz}=-1.656$ && $P_z \approx 0$

HERMES collaboration, Nucl. Phys. B 842 (2011) 265-298

References

- HERMES b1 publication: PRL 95, 242001 (2005).
- C. Riedl, PhD thesis: DESY-THESIS-2005-027 (2005).

a = early b1
b = delta spin flip
c = double-scattering models
d = Close-Kumano sum rule

a [14] P. Hoodbhoy, R. L. Jaffe and A. Manohar, Nucl. Phys. B**312** (1989) 571

c [17] J. Edelmann, G. Piller and W. Weise, Z. Phys. A**357** (1997) 129, Phys. Re (1998) 3392

a d [29] S. Kumano, The ELFE project, an Electron Laboratory For Europe, Conference Proceedings of the Italian Physical Society Vol. **44**, Mainz (1993) p. 371

a [35] H. Khan and P. Hoodbhoy, Phys. Rev. C**44** (1991) 1219

a [36] G. A. Miller, in *Electronuclear Physics with Internal Targets*, ed. R. G. Arnold (World Scientific, Singapore 1989) p. 30

a [37] L. Mankiewicz, Phys. Rev. D**40** (1989) 255

b [38] R. L. Jaffe and A. Manohar, Phys. Lett. B**223** (1989) 218

b [39] E. Sather and C. Schmidt, Phys. Rev. D**42** (1990) 1424

c [40] N. N. Nikolaev and W. Schäfer, Phys. Lett. B**398** (1997) 245

c [41] K. Bora and R. L. Jaffe, Phys. Rev. D**57** (1998) 6906

c [42] G. Niesler, G. Piller and W. Weise, Z. Phys. A**358** (1997) 407

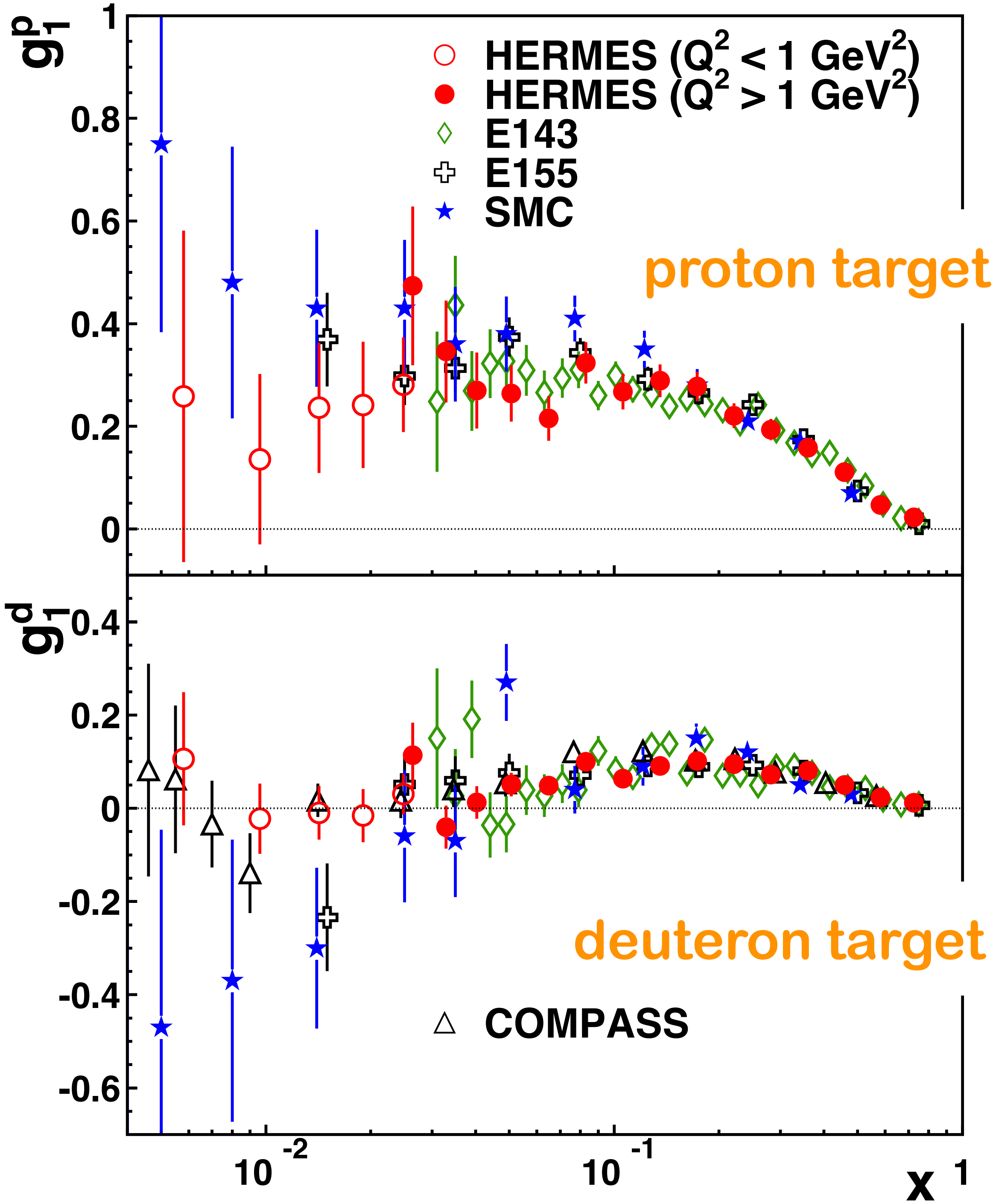
c [43] H. Khan and P. Hoodbhoy, Phys. Lett. B**298** (1993) 181

d [49] F. E. Close and S. Kumano, Phys. Rev. D**42** (1990) 2377

Backup

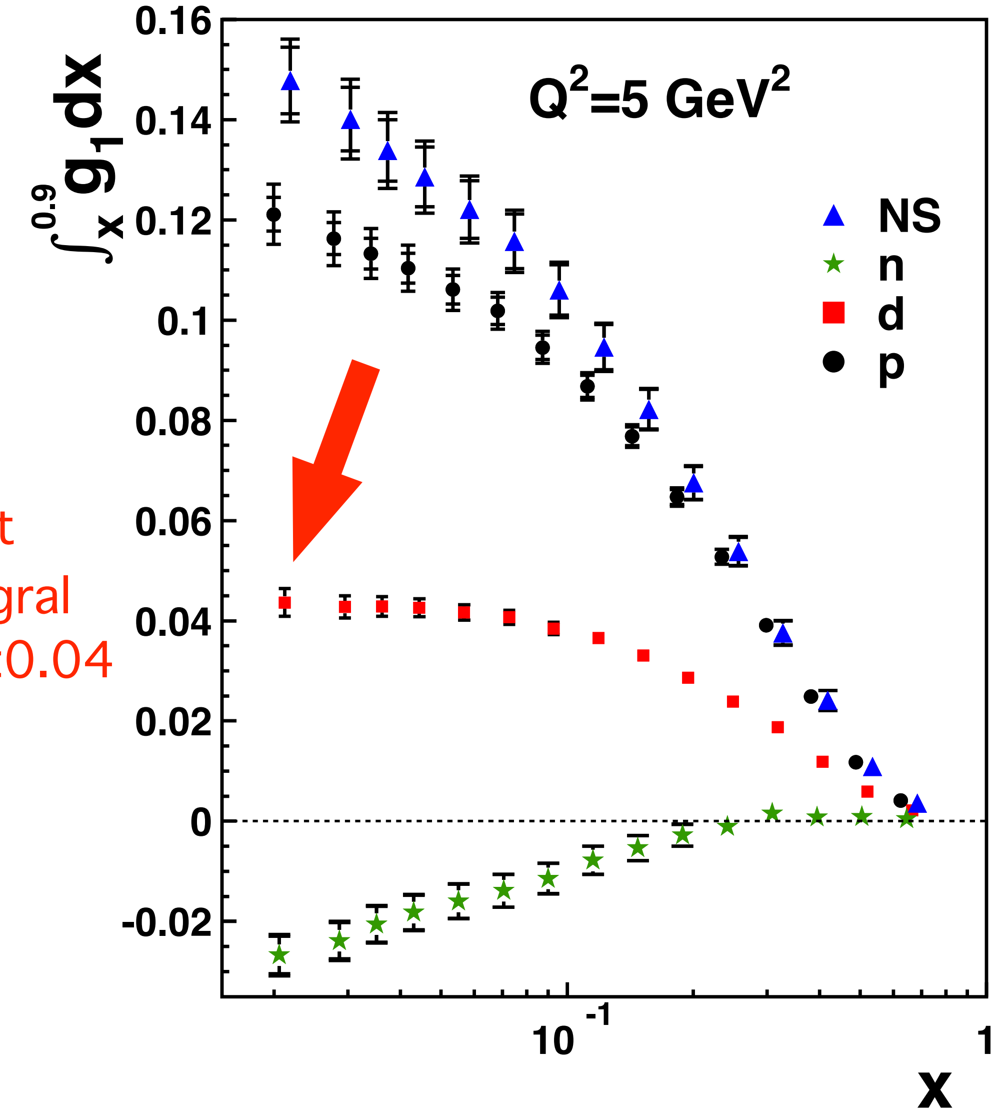
Spin Structure Function g1

A. Airapetian et al. [HERMES], Phys. Rev. D 75 (2007) 012007



$$A_\parallel \sim \frac{g_1}{F_1}$$

assume that deuteron integral saturates for x<0.04



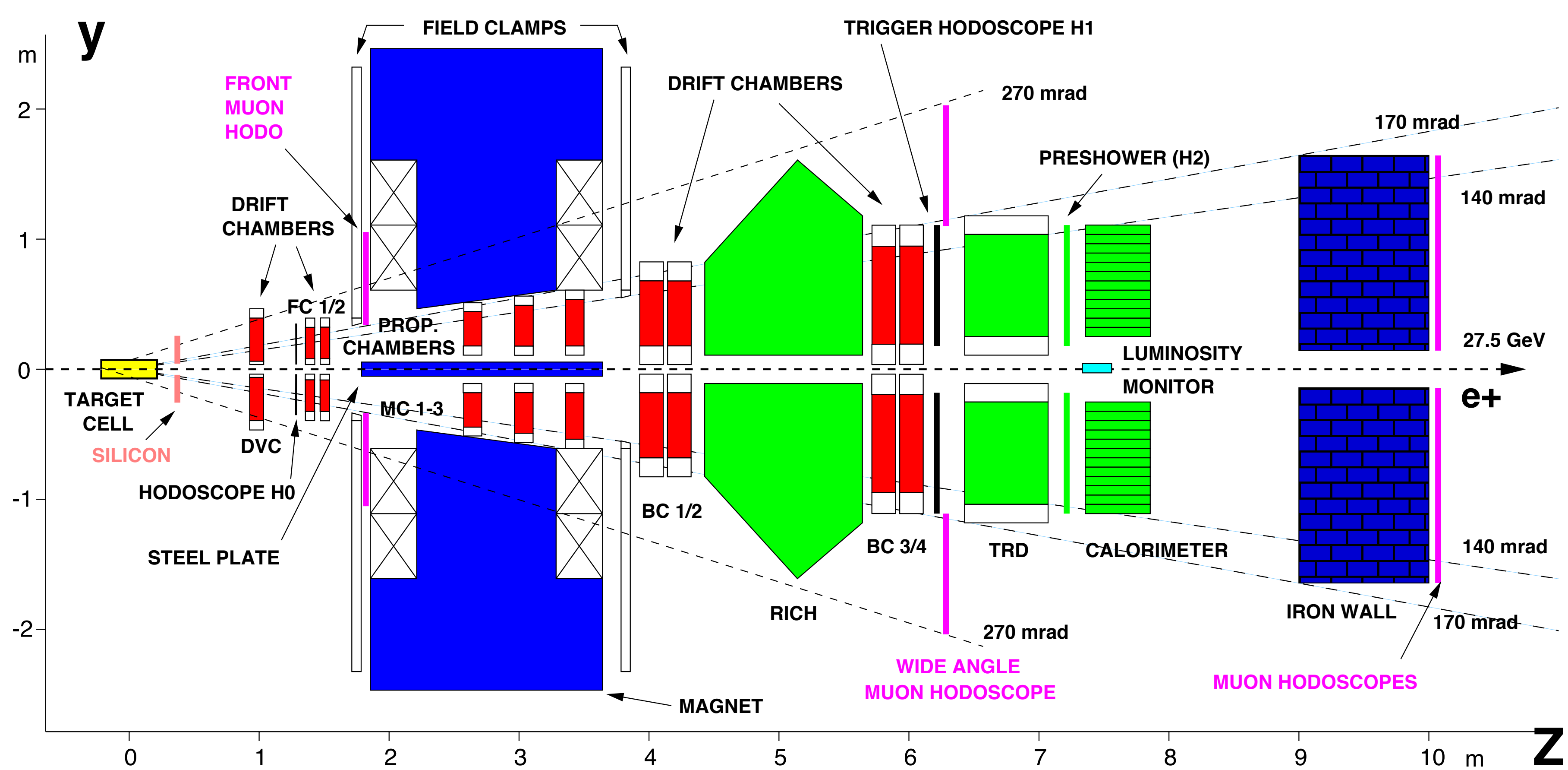
$$\Delta\Sigma^{\overline{MS}} = \frac{1}{\Delta C_S^{\overline{MS}}}\left[\frac{9\Gamma_1^d}{(1-\frac{3}{2}\omega_D)} - \frac{1}{4}a_8\Delta C_{NS}^{\overline{MS}}\right]$$

$\boxed{\Delta\Sigma = 0.330 \pm 0.011(\text{theo}) \pm 0.025(\text{exp}) \pm 0.028(\text{evol})}$

Double-spin flip structure function $\Delta(x,Q^2)$

- Arises for spin-1 target. Of leading twist. No interpretation in QPM.
- Corresponds to the Compton amplitude that flips both photon and target helicity by 2 units each.
  ⇒ Cannot receive contributions from nucleons or pions bound in the hadron
  ⇒ Probes gluon contributions not assigned to *individual* nucleons within the hadron
- Kinematically suppressed for a longitudinally polarized target.
- Can be determined by measuring the azimuthal asymmetry of the scattered lepton wrt the direction of the transversely polarized spin-1 target.

The HERMES Spectrometer

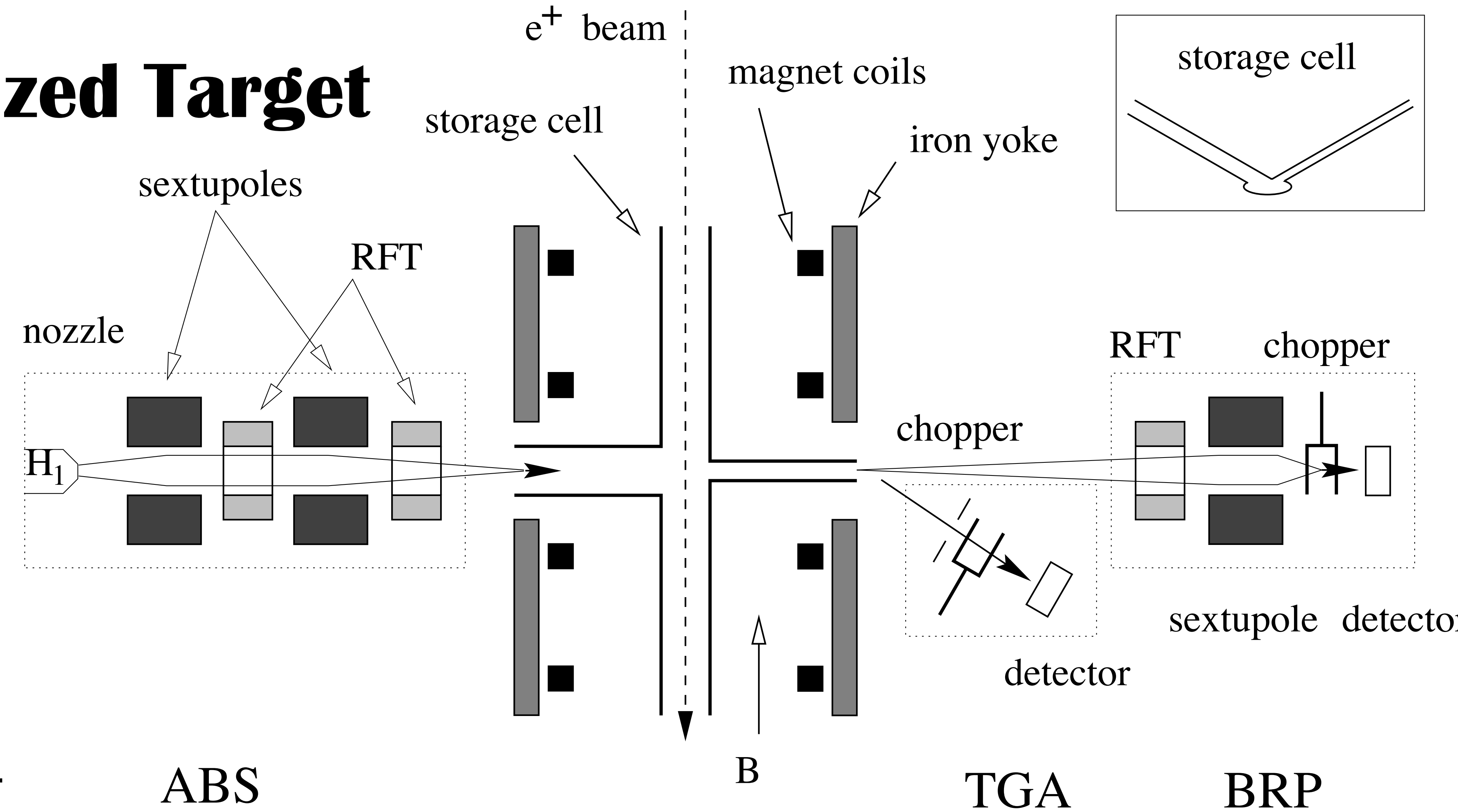


- Acceptance: $40 < \theta < 220$ mrad
- Momentum resolution: $\frac{\delta p}{p} \approx 2\%$;
  Angular resolution: $0.3 - 0.6$ mrad;
- Calorimeter: $\frac{\delta E}{E} \approx \frac{(5.1 \pm 1.1)}{\sqrt{E[\mathrm{GeV}]}}\%$

- PID: RICH, TRD, preshower, calo
- Efficiency of electron ID: 98-99 %
- Hadron contamination: $< 1\%$

HERMES Polarized Target

The storage cell, inside the HERA beam pipe, is a windowless 40 cm long elliptical tube, coaxial to the beam, with 75 μm thick Al walls coated to inhibit surface recombination and depolarization. The use of the storage cell technique results in a typical areal density increase of about two orders of magnitude compared to a free jet target.



A sample of gas (ca. 5%) diffuses from the middle of the cell into a Breit-Rabi Polarimeter (BRP), which measures the atomic polarization, or into a Target Gas Analyzer (TGA), which measures the atomic and the molecular content of the sample.

A magnet surrounding the storage cell provides a holding field defining the polarization axis and prevents spin relaxation via spin exchange or wall collisions by effectively decoupling the magnetic moments of electrons and nucleons.

A gaseous helium cooling system keeps the cell temperature at the lowest value for that atomic recombination and spin relaxation during wall collisions are minimal.

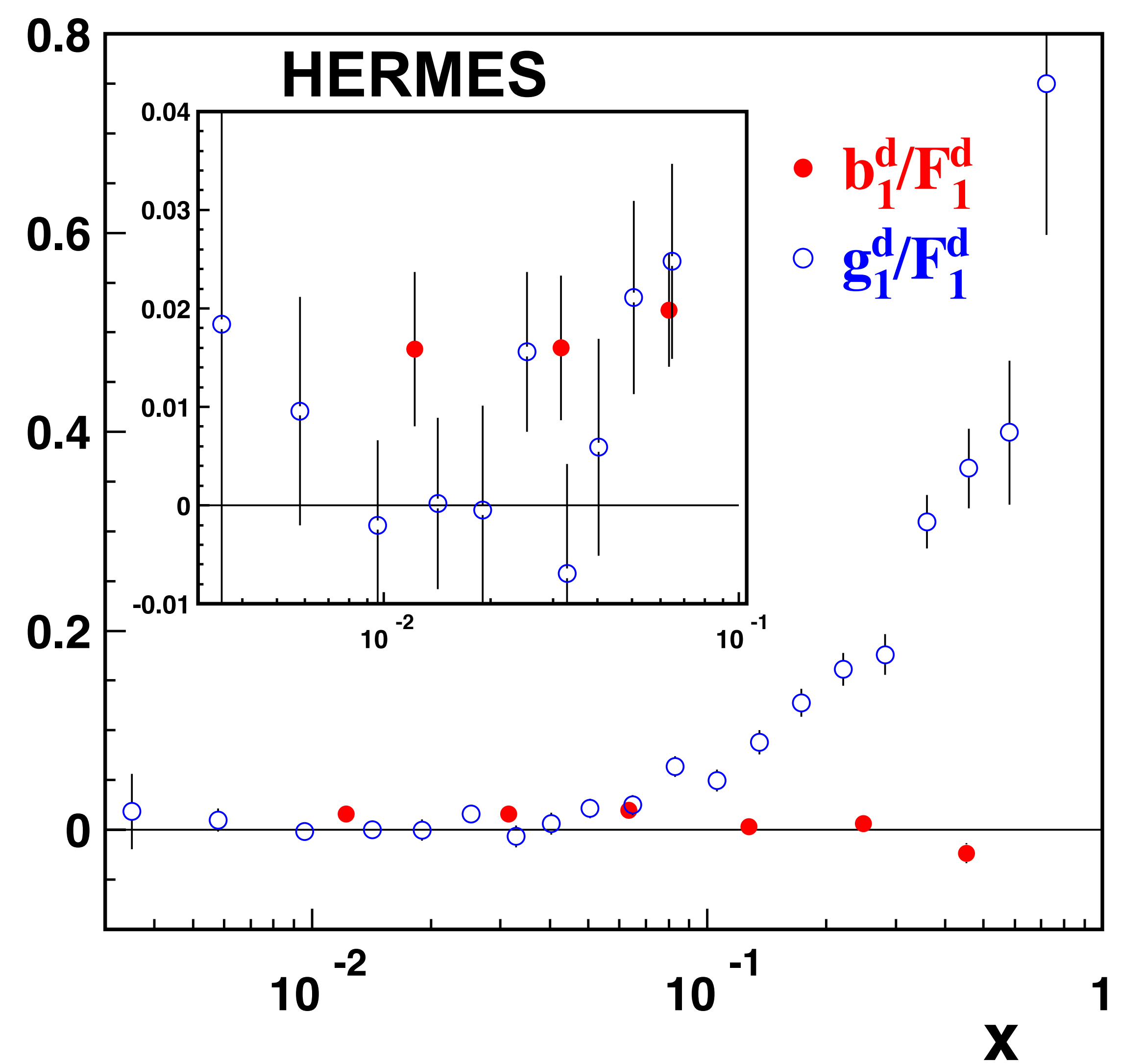
This text: Precise determination of the spin structure function g_1 of the proton, deuteron and neutron
HERMES collaboration, Phys. Rev. D 75 (2007) 012007.
For more details, see: The HERMES Polarized Hydrogen and Deuterium Gas Target in the HERA Electron Storage Ring
HERMES collaboration, Nucl. Instr. and Meth. A540 (2005) 68.

Cross Contaminations in DIS off Spin-1 Target

- Vector contamination in tensor-asymmetry measurement:
  If beam is polarized, preferably have equal portions of both helicities to avoid contamination by g1. Small @ HERMES small because
  - luminosities for different beam helicities are approximately balanced out (ΔL/L = 0.22)
  - |Pz+| approx. equal |Pz-|

- Tensor contamination in vector-asymmetry measurement (1%):
  corrected for in HERMES g1 publication

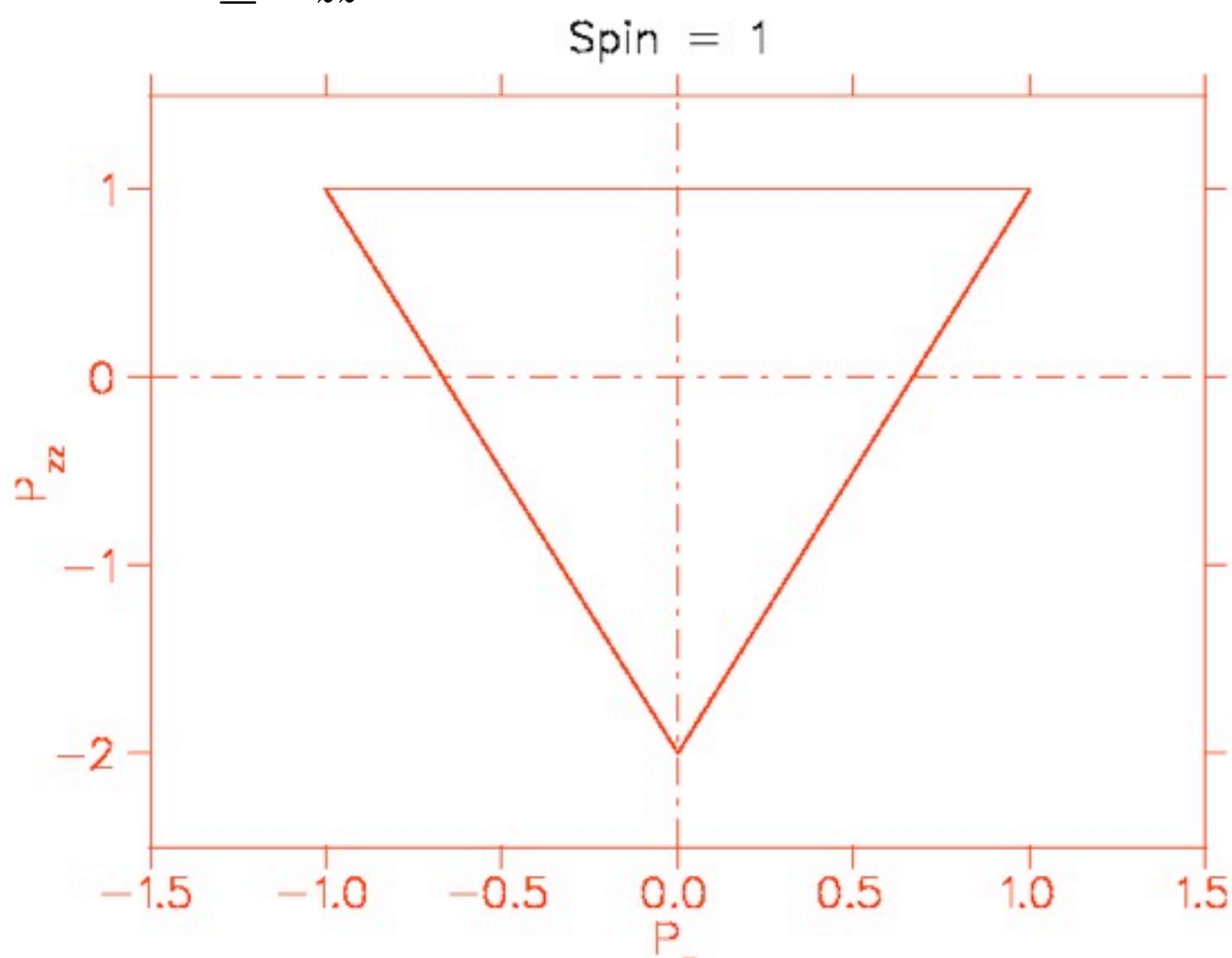
$$A_{\|} = A \cdot (1 + \frac{1}{2} P_{zz} A_{zz})$$



Relation between Vector and Tensor Polarization

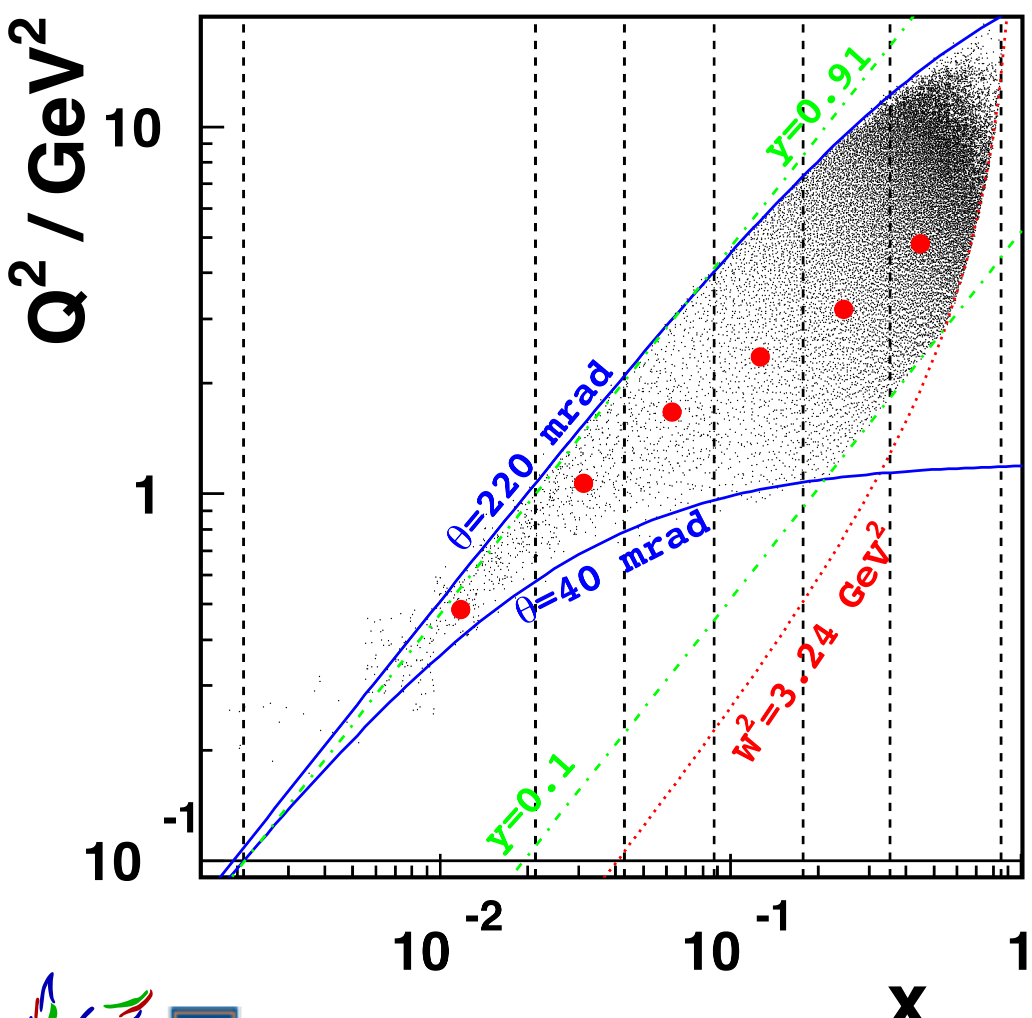
$$P_z = \frac{n^+ - n^-}{n^+ + n^- + n^0}, \qquad |P|_z \leqq 1.$$

$$P_{zz} = \frac{(n^+ + n^-) - 2n^0}{n^+ + n^- + n^0}, \qquad -2 \leqq P_{zz} < 1.$$



Average kinematics for the HERMES tensor analysis

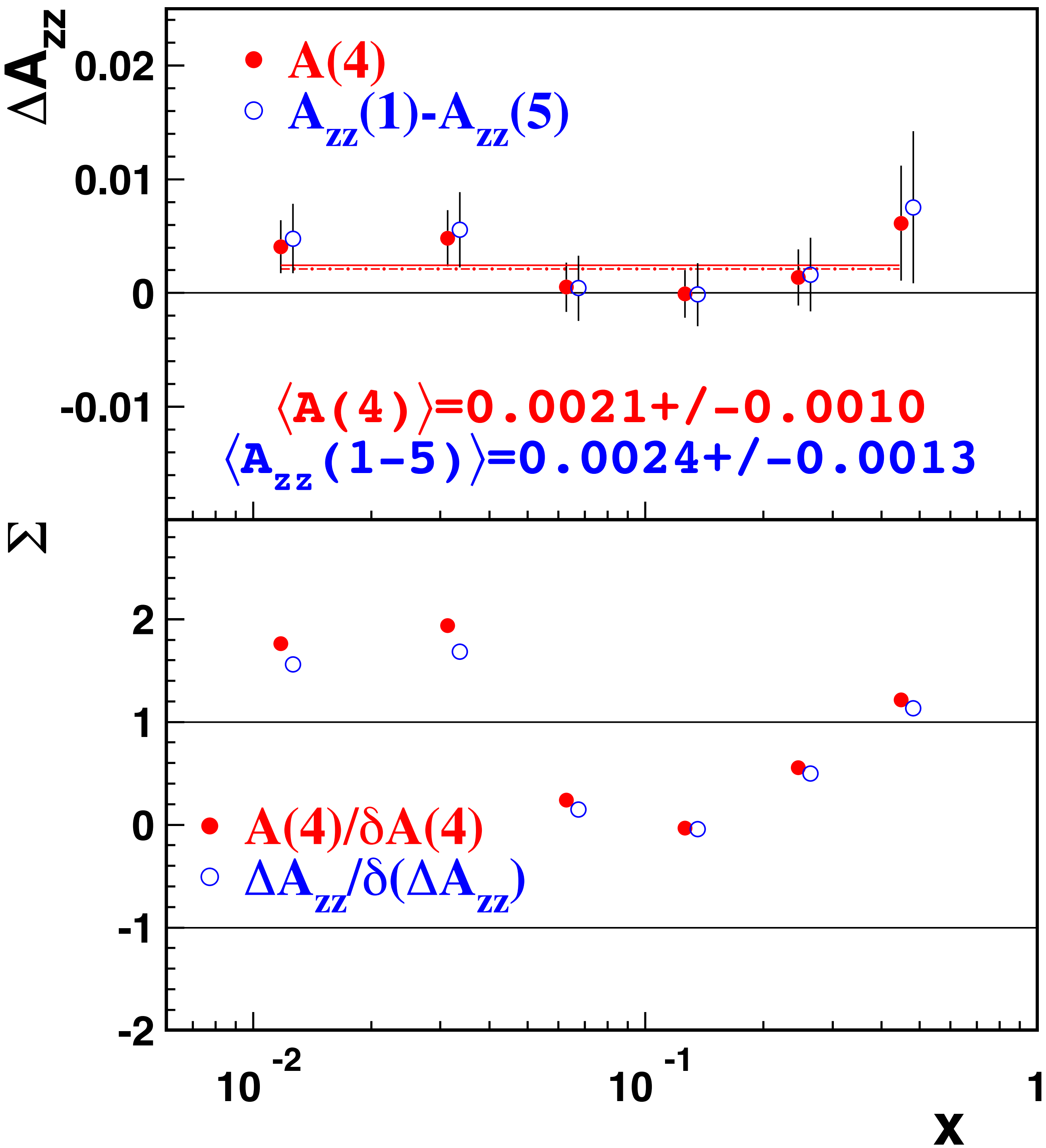
Binning in x-BJØRKEN		
bin	$x_{\min}$	$x_{\max}$
1	0.0021	0.0212
2	0.0212	0.0430
3	0.0430	0.0872
4	0.0872	0.1770
5	0.1770	0.3580
6	0.3580	0.8500

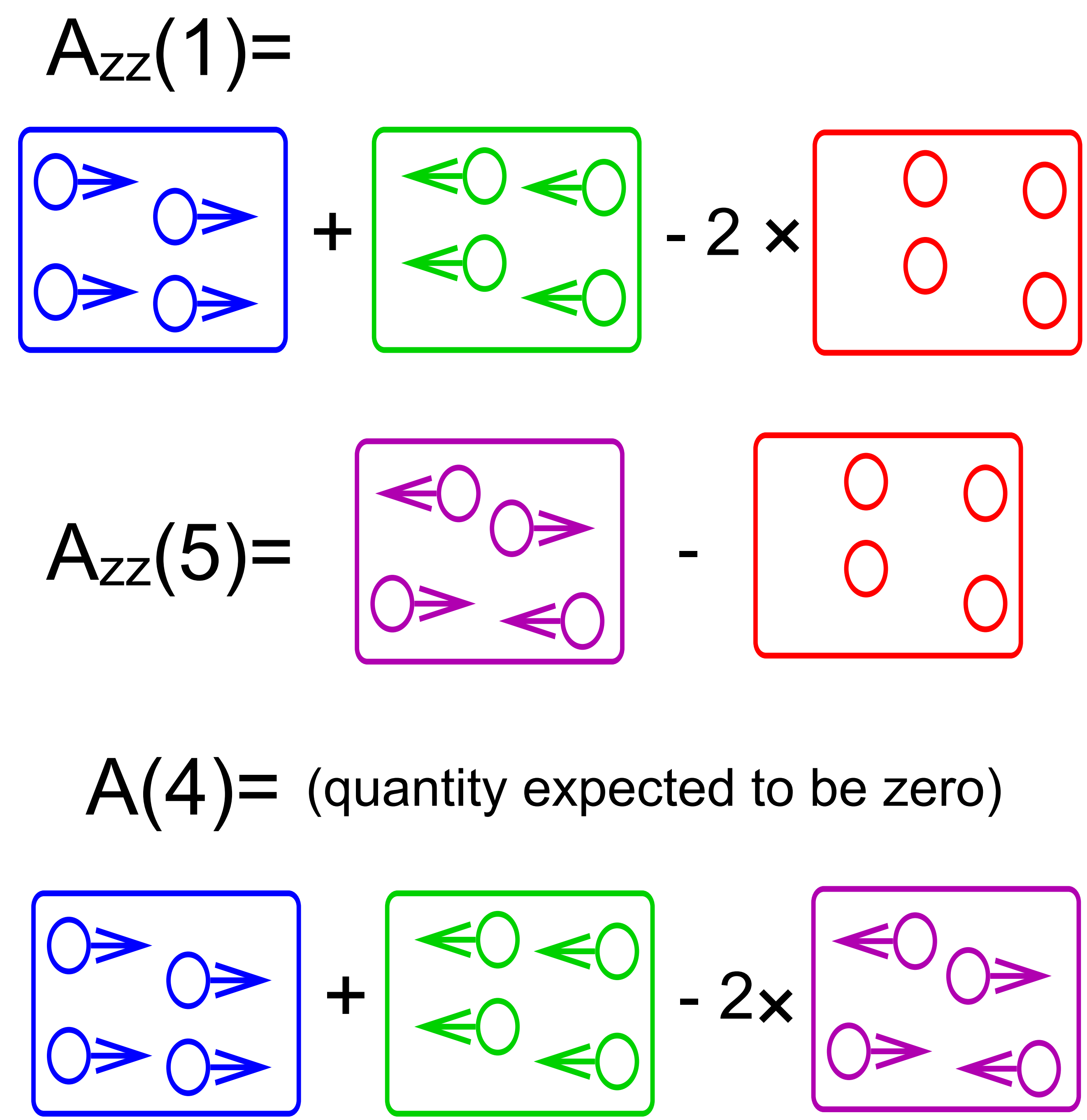


A_{zz} on BORN level					
$\langle x\rangle$	$\langle Q^2\rangle$	A_{zz}	δA_{zz}(stat)	δA_{zz}(sys)	δ(MC)
0.0122	0.5075	-0.0106	0.0052	0.0026	0.0015
0.0315	1.0641	-0.0107	0.0049	0.0036	0.0013
0.0635	1.6542	-0.0132	0.0038	0.0021	0.0012
0.1277	2.3319	-0.0019	0.0034	0.0029	0.0012
0.2481	3.1066	-0.0039	0.0039	0.0032	0.0014
0.4521	4.6923	0.0157	0.0068	0.0013	0.0016

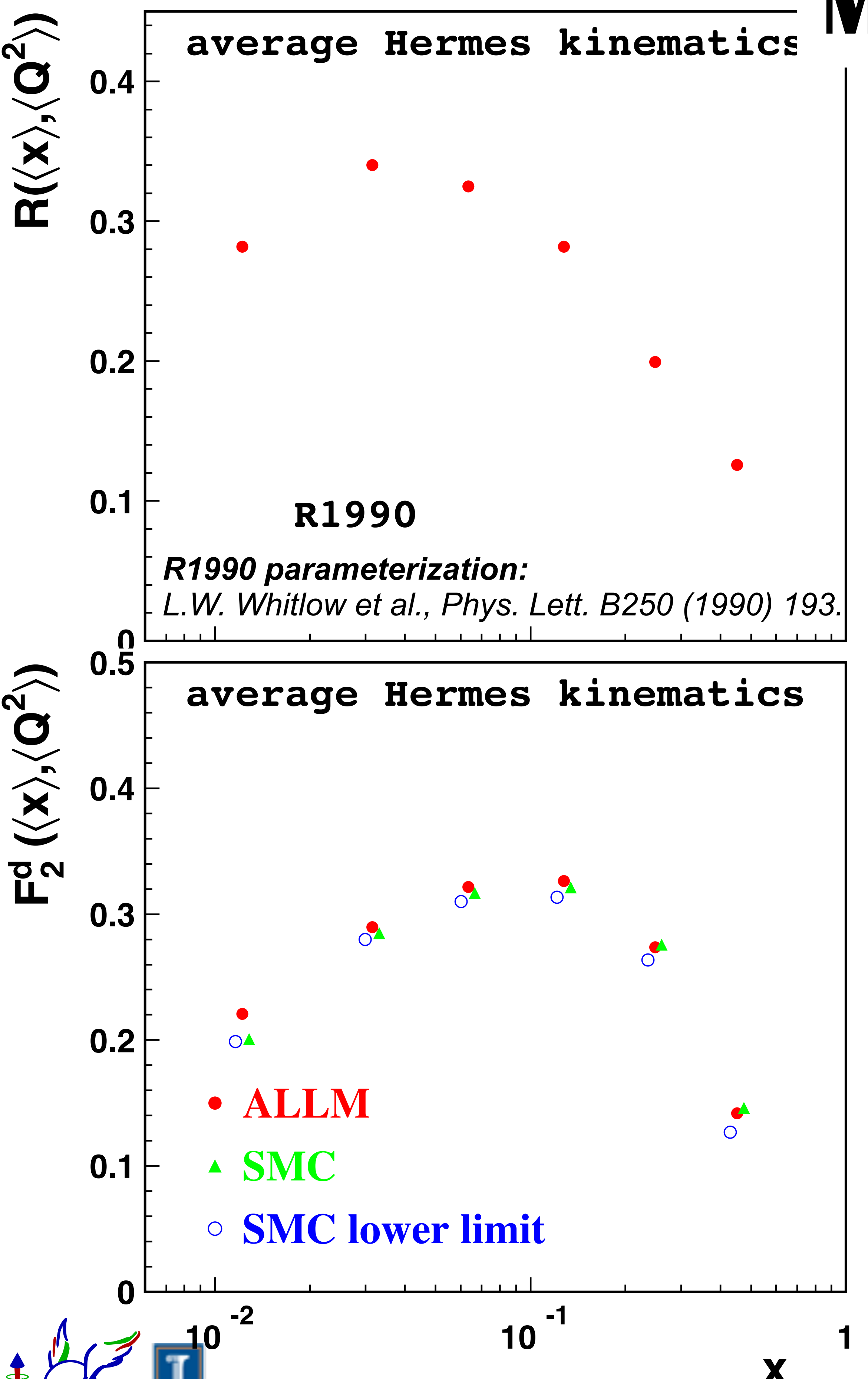
Kinematic cuts
$0.0021 < x < 0.8500$
$0.1\ \mathrm{GeV}^2 < Q^2$
$W^2 > 3.24\ \mathrm{GeV}^2$
$\nu > 1$ GeV
$0.10 < y < 0.91$

Tensor Mismatch





MC Input Parameterizations



- Unfolding tested with modified input parameterizations:
  - R(x,Q2): low-Q2 fixed to constant instead of linear
  - F2(x,Q2): 15-parameter fit of SMC collaboration P15, and its lower limit P15l
  - alternative A_{zz} fit from HERMES data

- Unfolding expected to be close-to-model independent:

$$S(i,j) \equiv \frac{M(i,j)}{\sigma_{\text{Born}}(j)}$$

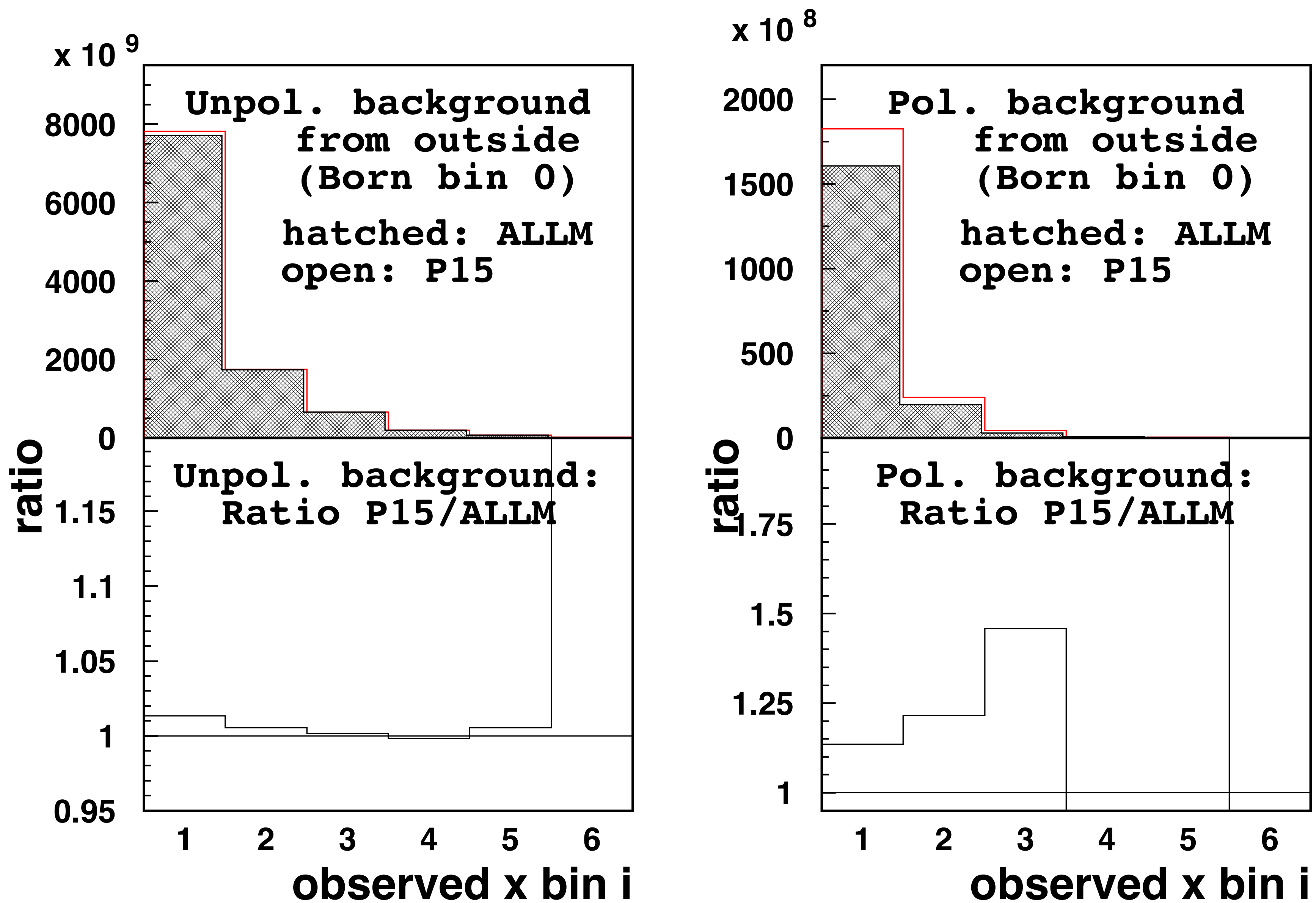
- Both • and • scale with # of generated events in Born bin j
- # of generated events controlled by input parameterizations

$\Rightarrow$ algorithm is independent of MC input parameterization except for polarized background entering acceptance $\Delta \overset{\frown}{\sigma}^{\mathrm{P}}$

ALLM F2p from world data fit *(H1, ZEUS, E665, BCMDS, NMC, SLAC): H. Abramowicz and A. Levy, hep-ph/9712415,* ***rescaled by NMC F2n/F2p****: P. Amaudruz et al., Nucl. Phys. B371 (1992) 3.*

Impact of MC Input Parameterizations

- Compare $\Delta \overset{\curvearrowright}{\sigma}$ from F_2(ALLM) and F_2(SMC)

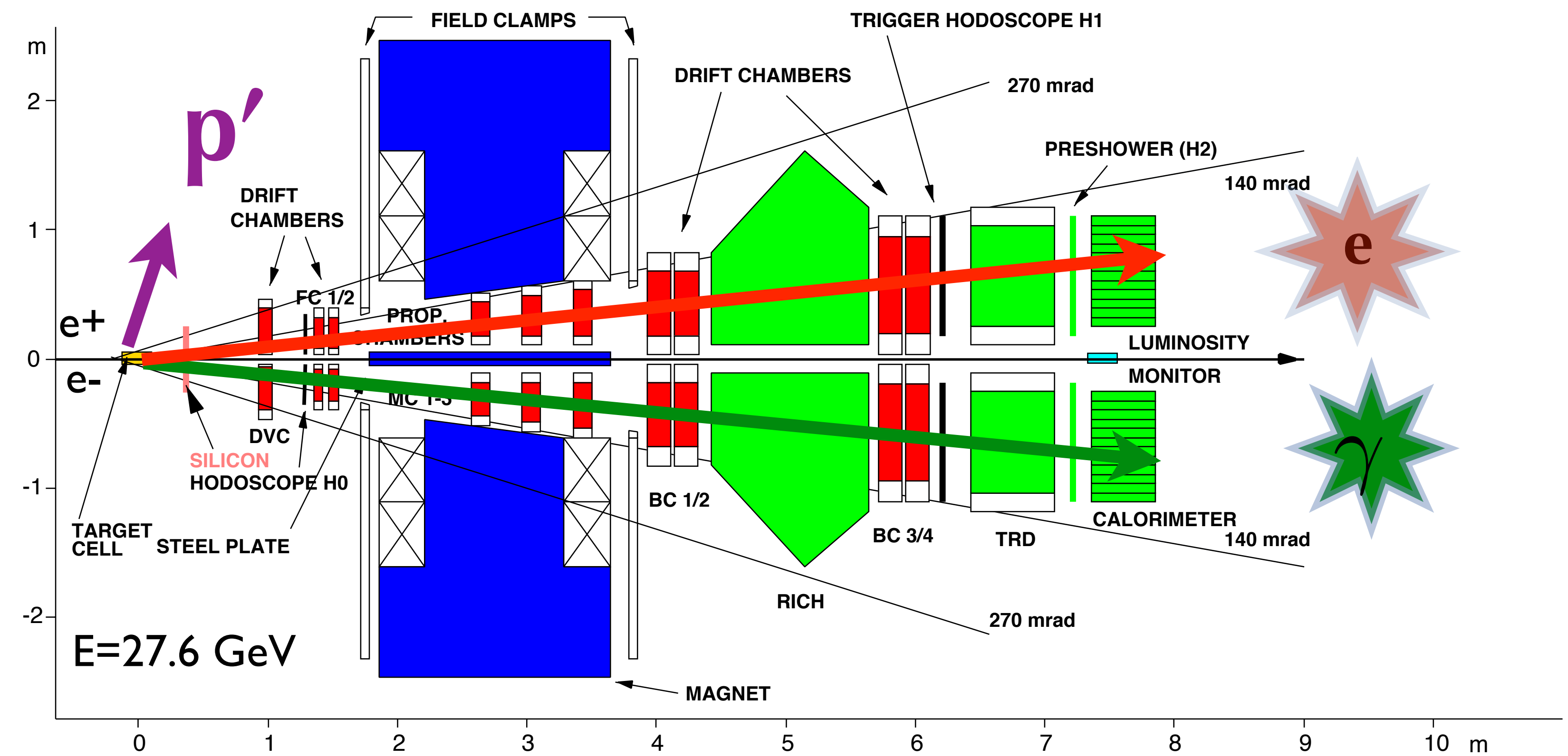


- Unfolding results compatible within statistics
- No systematic error assigned

DVCS at HERMES 1996-2005

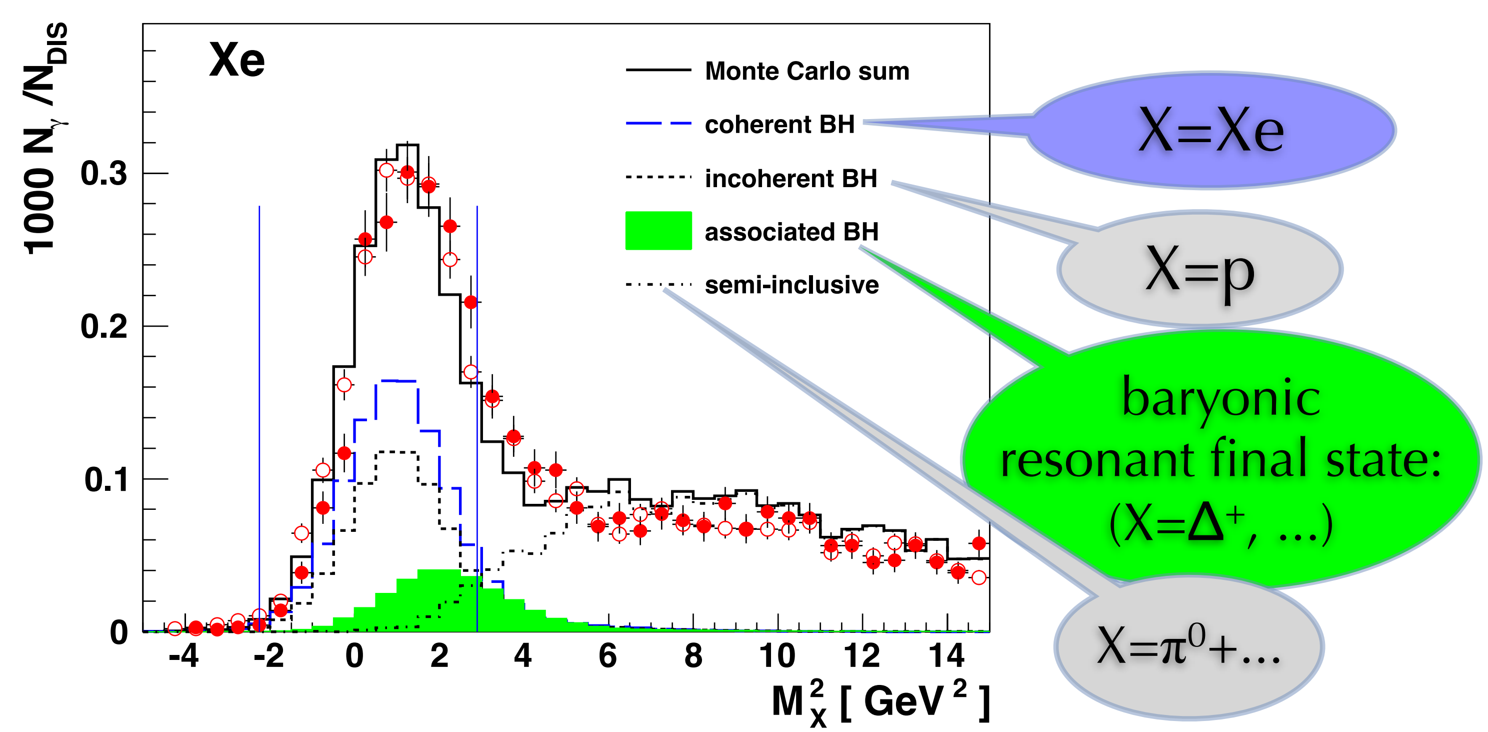
2006/2007: **recoil proton** detected

Hydrogen target:
400 pb^{-1}
unpolarized Deuterium:
300 pb^{-1}
L-polarized Deuterium:
200 pb^{-1}
`Heavier Nuclear targets:
He, N, Ne, Kr, Xe
300pb^{-1}



Missing mass technique for
ep→eXγ

$$M_X^2 = (k + p - k' - q')^2$$

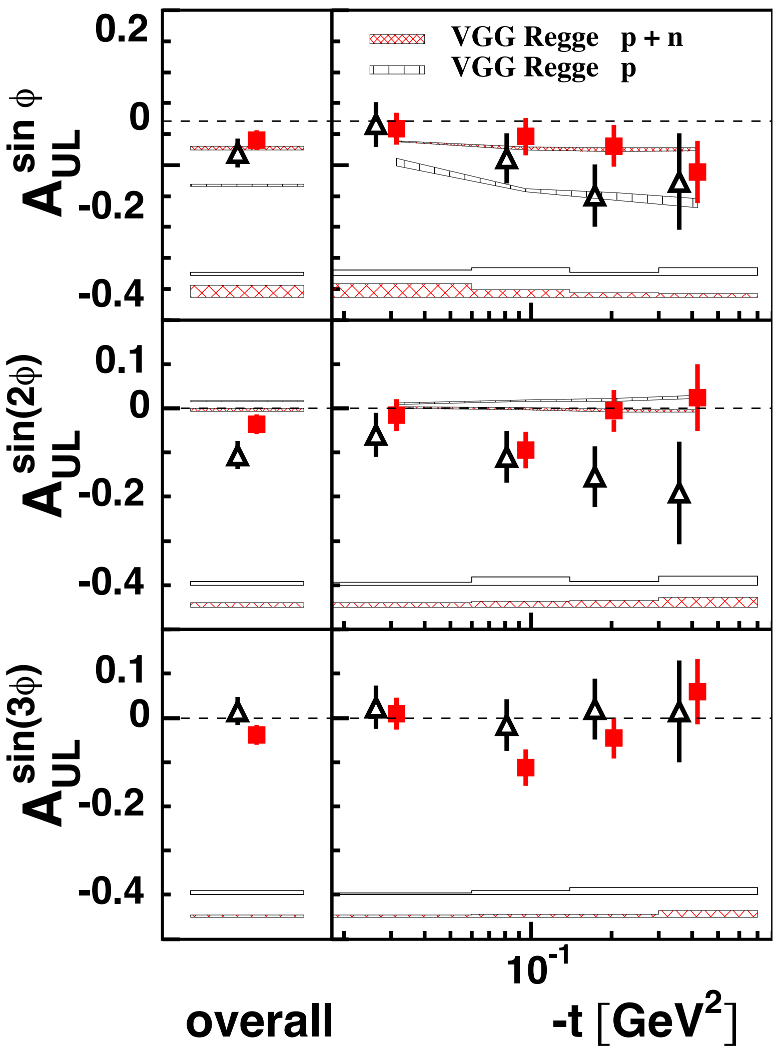


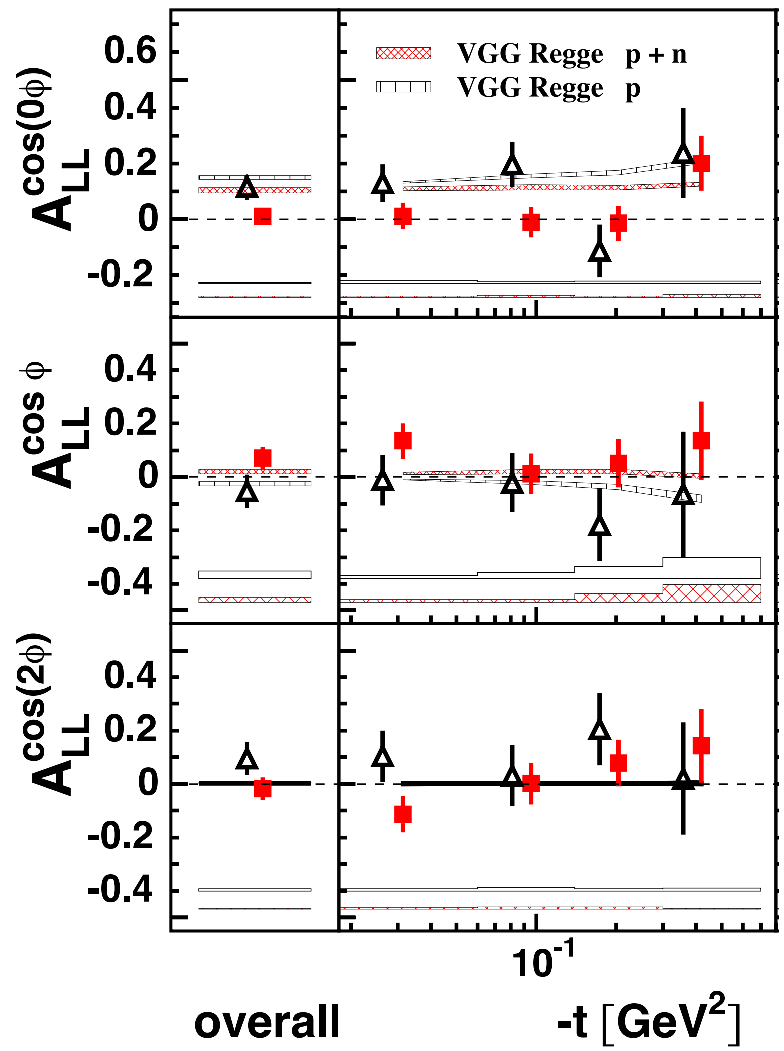
GPD $\tilde{H}_1$

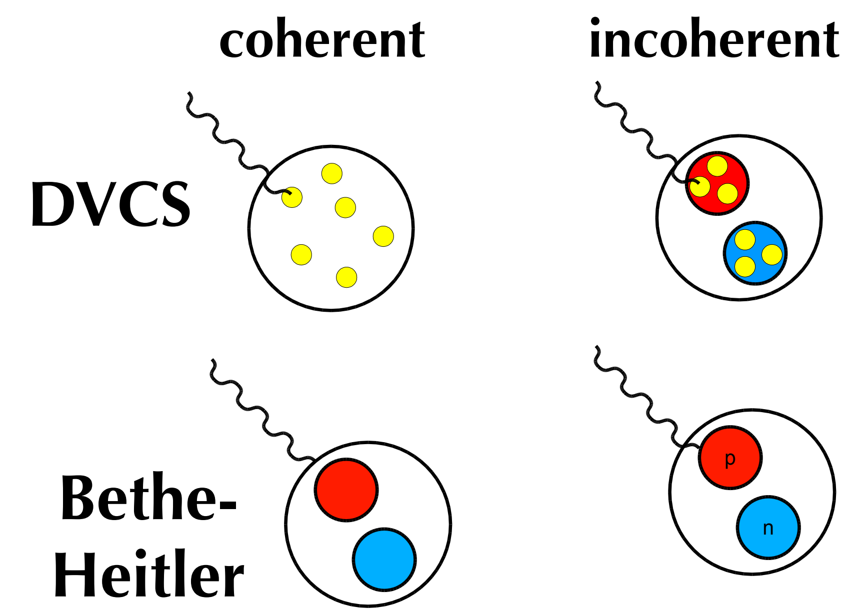
DVCS Target-Spin Asymmetry on p and d

1998–2000 longitudinally polarized deuteron data

Search for coherent signature







Deuteron: probe spin-1 object

Nucleon: probe spin-1/2 object

□ **Proton:**

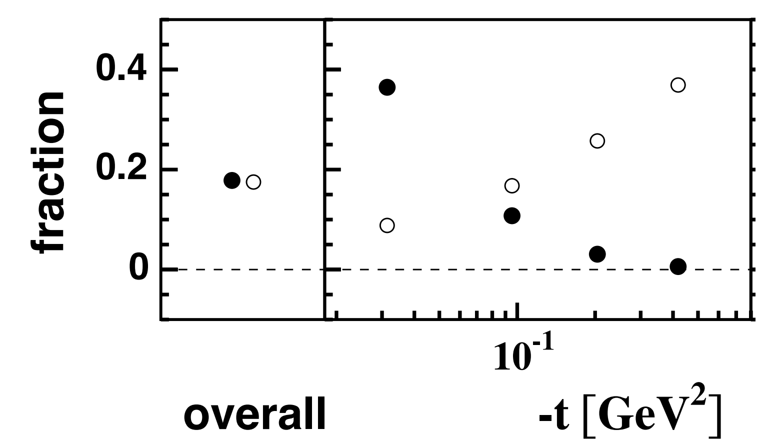
$\mathcal{R}e(\tilde{\mathcal{H}})$ (incoherent)

■ **Deuteron:**

$\mathcal{R}e(\tilde{\mathcal{H}}_1)$ (coherent @low -t)

$\mathcal{R}e(\tilde{\mathcal{H}})$ (incoherent @larger -t)

● coherent fraction
o resonant fraction



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