Consideration of a polarized internal gas target experiment at the EIC Electron Storage Ring

- Overview of experiments with polarized gas targets internal to electron storage rings
- Focus on BLAST and HERMES experiments.

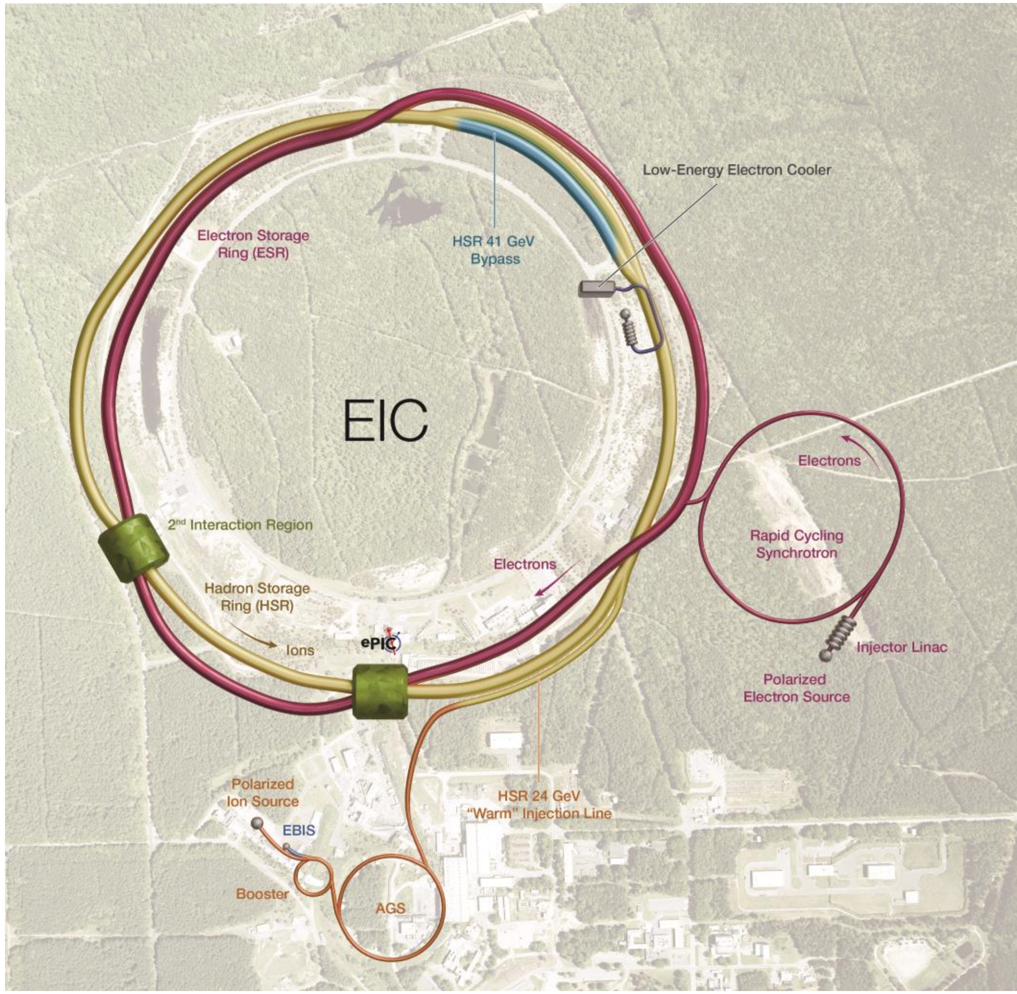
HERMES - a fixed target experiment in the electron ring of a collider

- Polarized internal gas targets
- Some perspective on fixed target experiment in EIC ESR.

Present EIC Concept (2025)

Ultimate EIC Performance Parameters:

- High Luminosity: L= $10^{33} - 10^{34} cm^{-2} sec^{-1}$
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: Ecm = 28 – 140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Forward Acceptance and Low-Background Conditions
- Possibility to Implement a Second Interaction Region (IR)



Accelerator Status in a glance:

- ✓ Polarized ion/proton source
- ✓ Ion injection and initial acceleration systems – Linac (200 MeV), Booster (1.5 GeV), AGS (25 GeV)
- UPGRADE Hadron Storage Ring (40-275 GeV) – HSR
- NEW Electron Pre-Injector (750 MeV linac) – EPI
- NEW Electron Rapid Cycling Synchrotron (0.75 GeV – top energy) – RCS
- NEW Electron Storage Ring (5 GeV – 18 GeV) – ESR
- NEW Interaction Region(s) – IR
- NEW Hadron Injection Cooling System

Polarized Internal Gas Target Experiments in Electron Storage Rings

Experiment	Location	Energy (GeV)	Beam current (mA)	Polarized Targets
BLAST	MIT-Bates, MA, USA	0.85	250	^{1}H, ^{2}H
AmPs	AmPs, NIKHEF, The Netherlands	0.7	100	^{1}H, ^{2}H, ^{3}He
VEPP-3	Novosibirsk, Russia	3	50	^{2}H
HERMES	DESY, Germany	27.5	40	^{1}H, ^{2}H, ^{3}He

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VEPP-3	Novosibirsk, Russia	3	50	^{2}H
HERMES	DESY, Germany	27.5	40	^{1}H, ^{2}H, ^{3}He
	EIC ESR, BNL, NY, USA	10-18	2500	^{1}H, ^{2}H, ^{3}He, ^{6}Li, ^{7}Li

BLAST Collaboration

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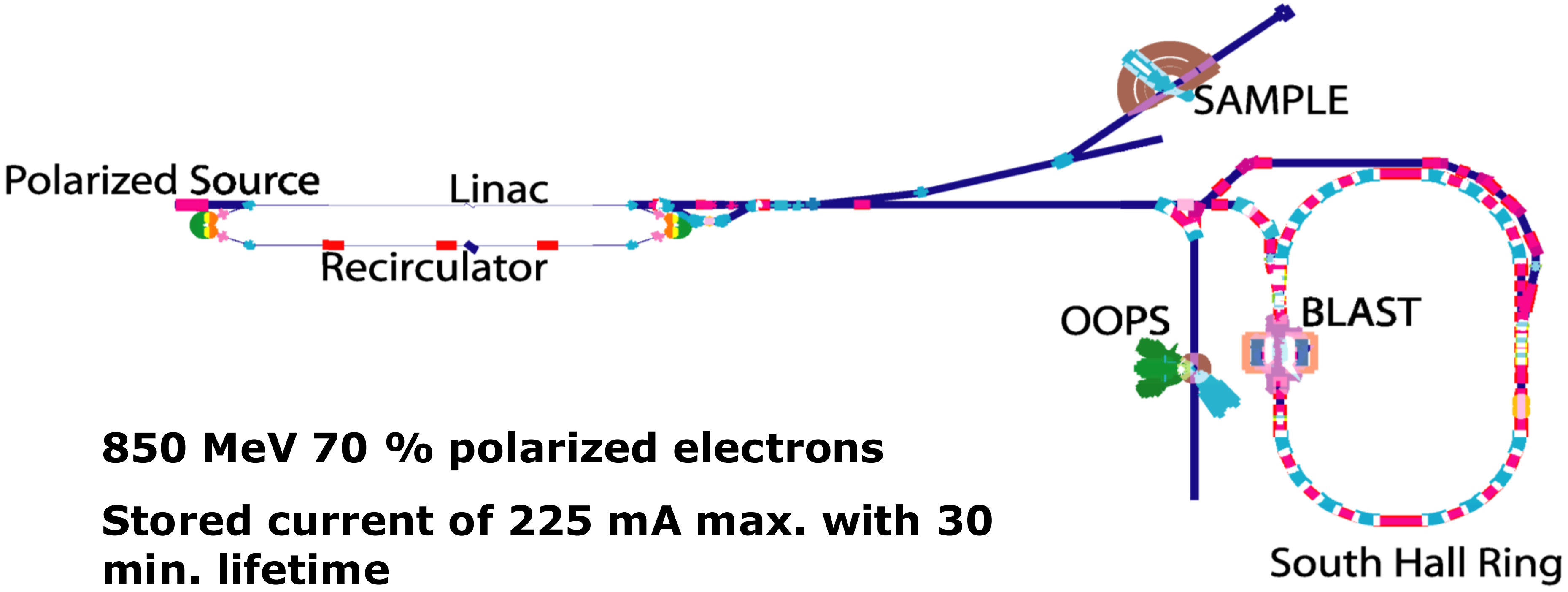
MIT-Bates Linear Accelerator Laboratory



850 MeV 70 % polarized electrons

Stored current of 225 mA max. with 30 min. lifetime

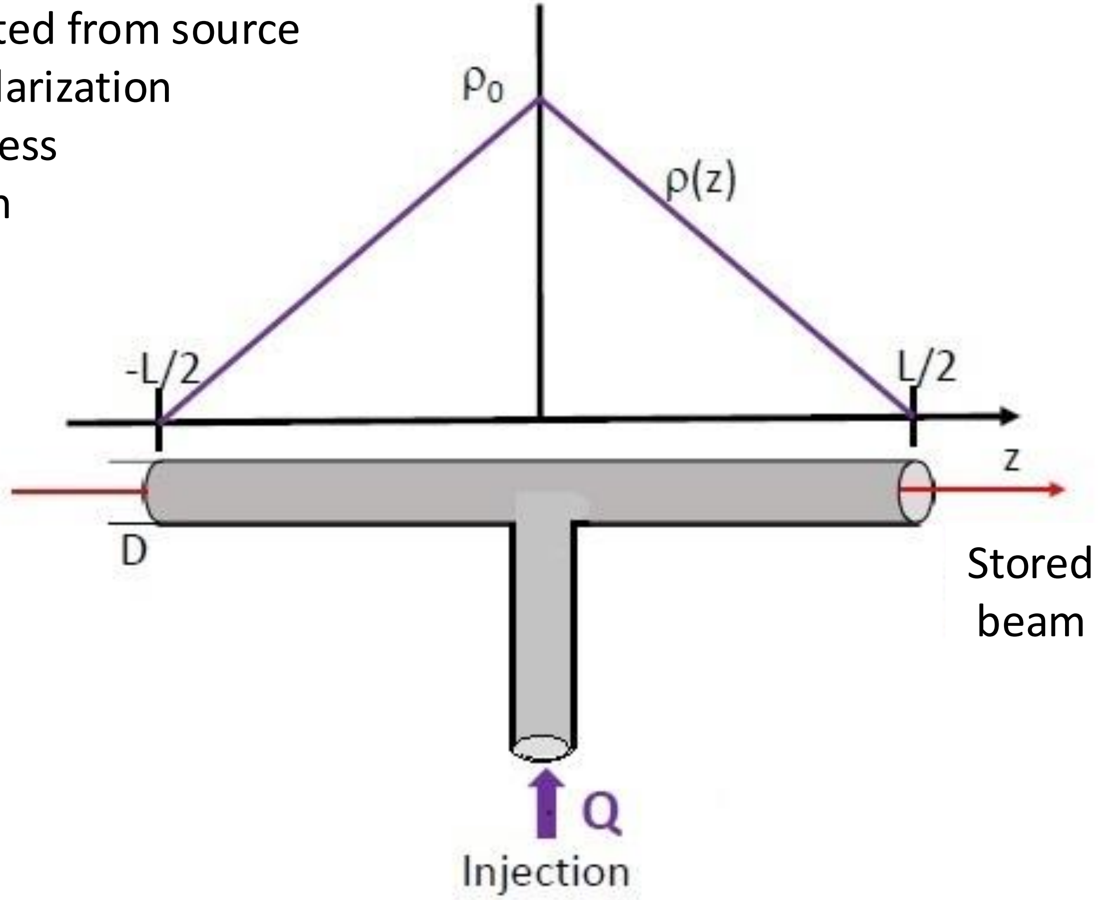
Siberian snake

Spin flipper

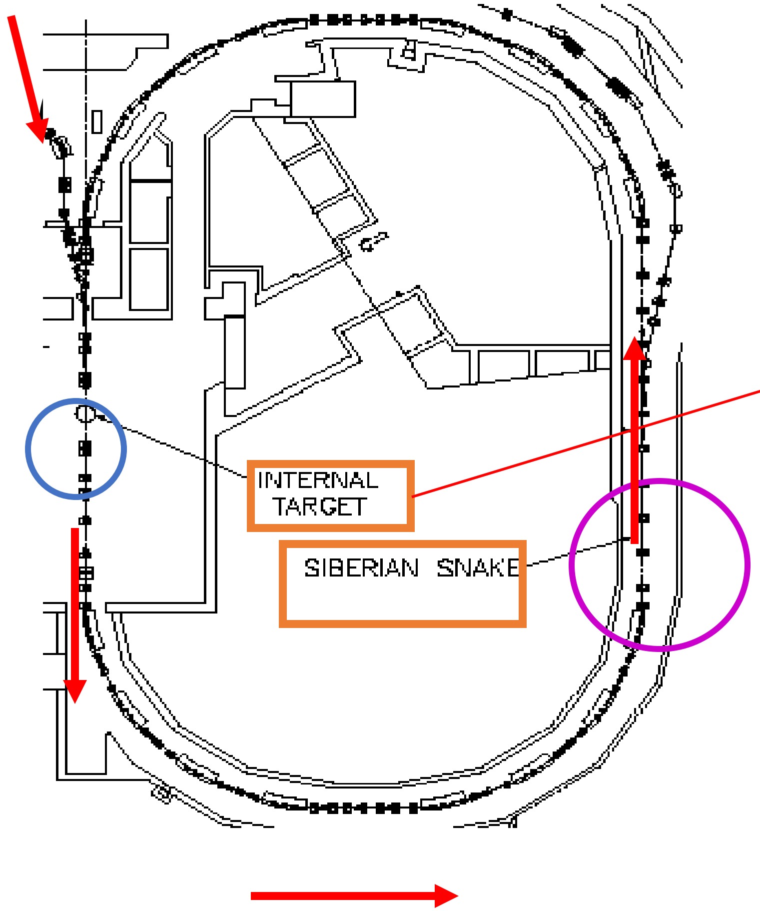
Compton polarimeter

Polarized Internal Gas Target

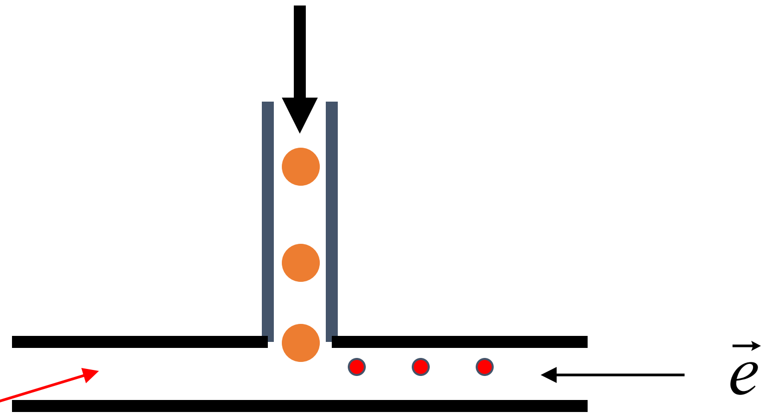
- Polarized neutral atoms injected from source
- Cell coated to minimize depolarization
- Cell cooled to increase thickness
- Triangular density distribution



Internal Target Concept



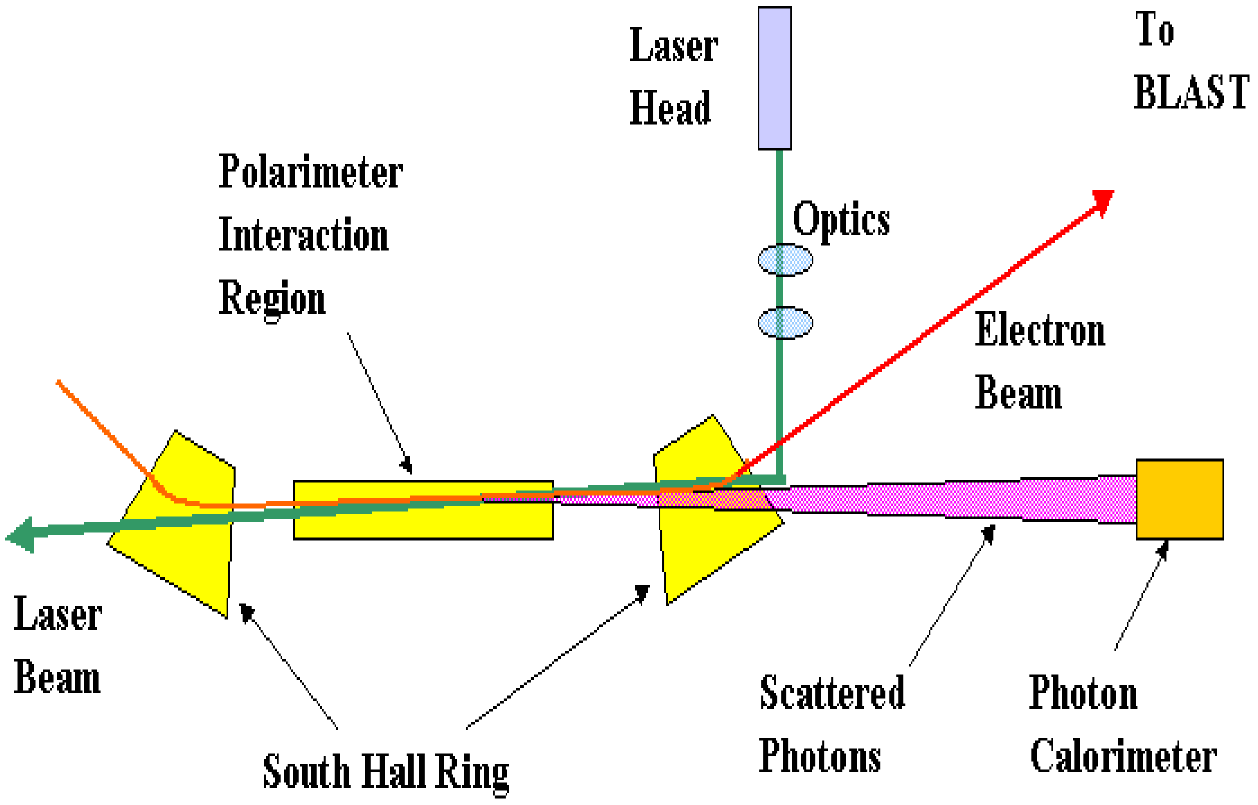
South Hall Ring



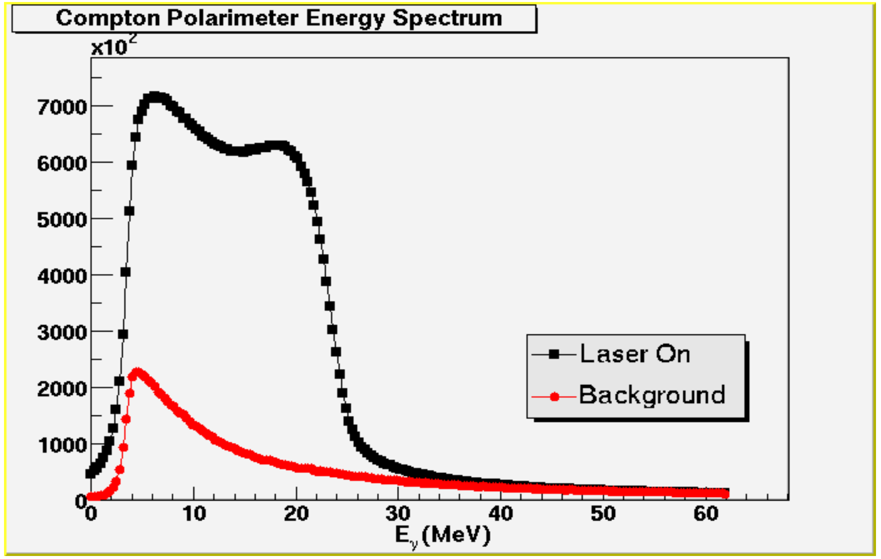
pure target
high polarization
thin cell walls
low holding field

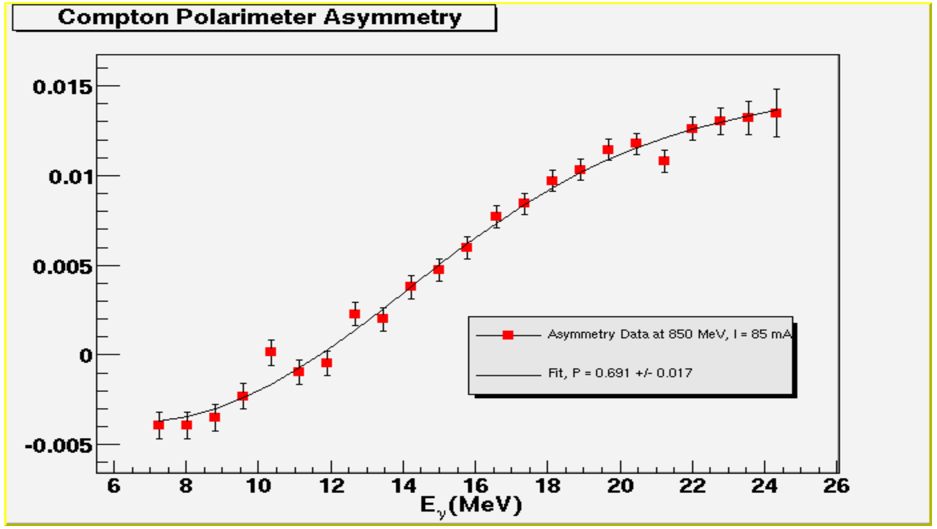
L = 10^{31}-10^{33} atoms cm^{2}s^{-1}

Compton Polarimetry



Compton Polarimeter





Polarization about 0.7 typical

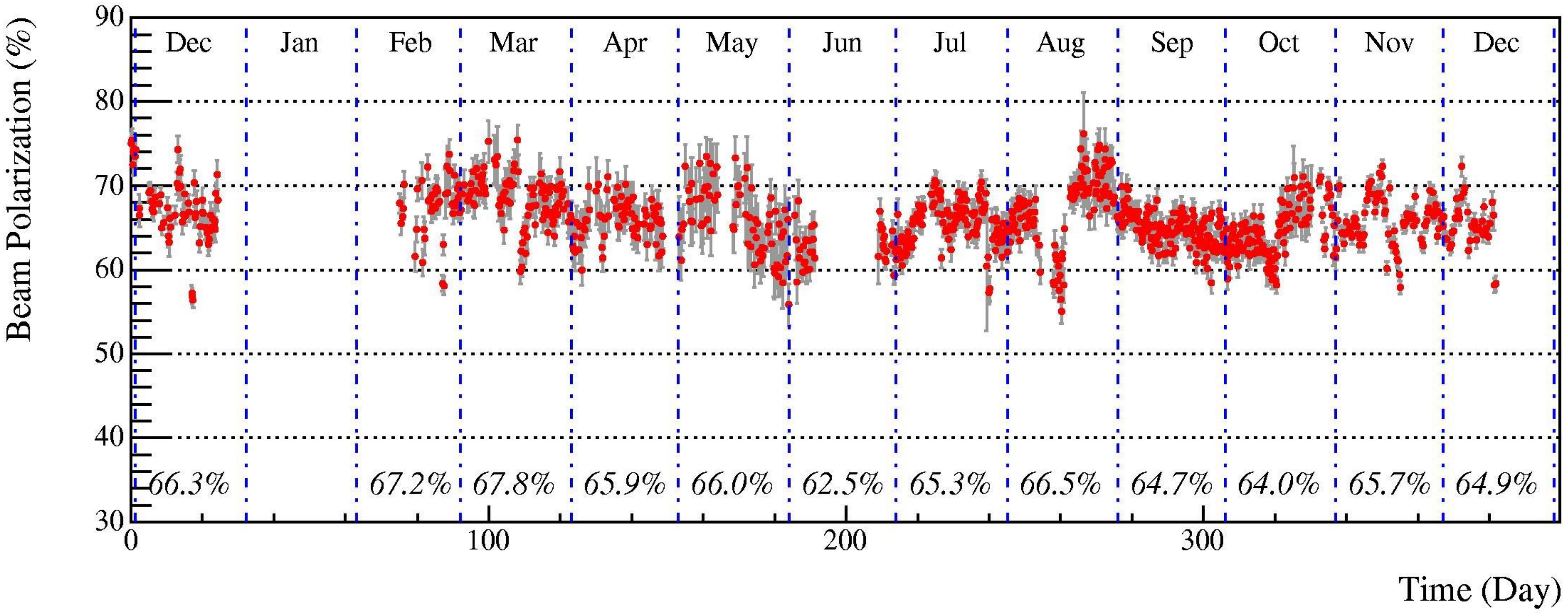
Typical precision of 1-2% per hour.

Systematic errors estimated at 5% level at present

Full photon energy spectrum measured as function of laser helicity

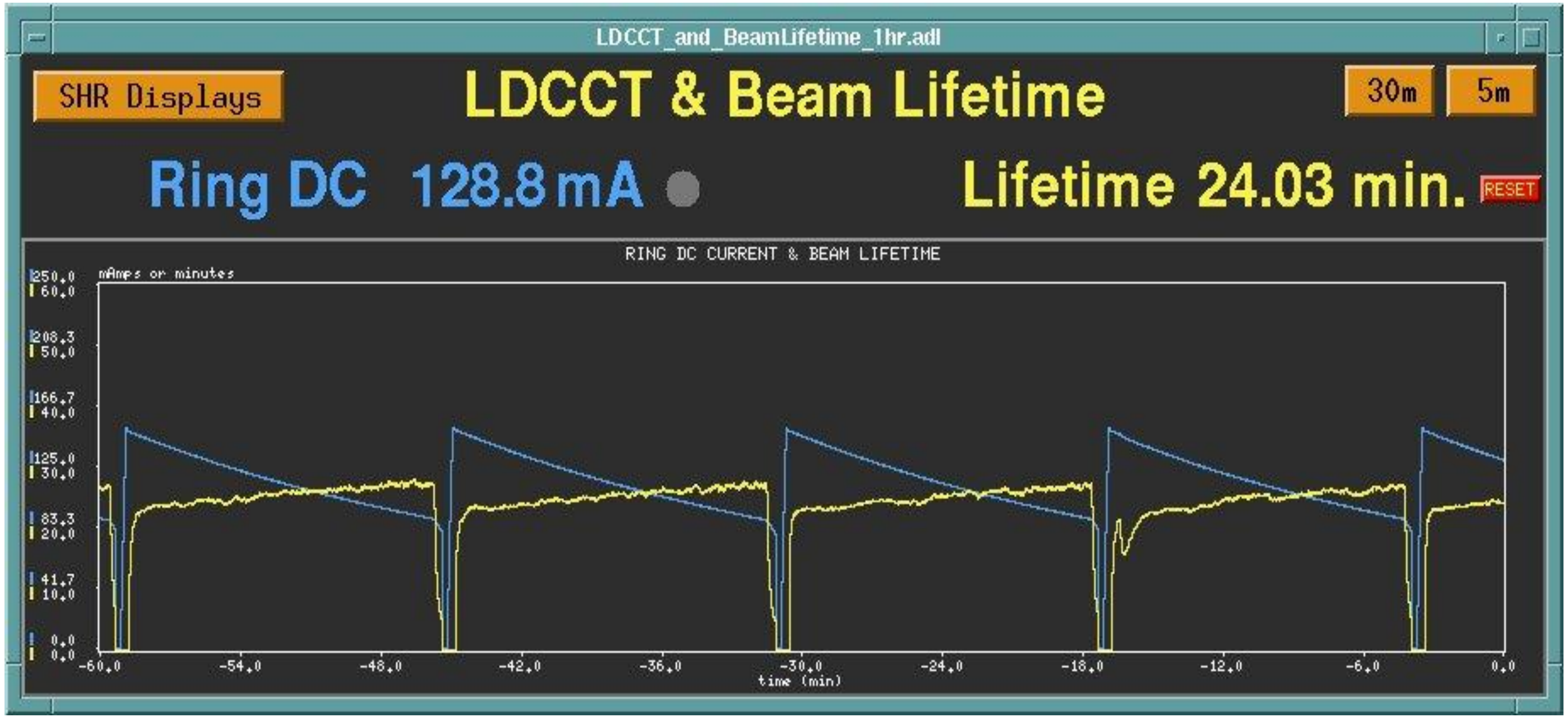
Polarization measurements made at currents up to 225 mA

South Hall Ring Polarization



Compton polarimeter data from Dec. 2003 – Dec. 2004
Mean polarization of 66% measured

Stored beam for BLAST

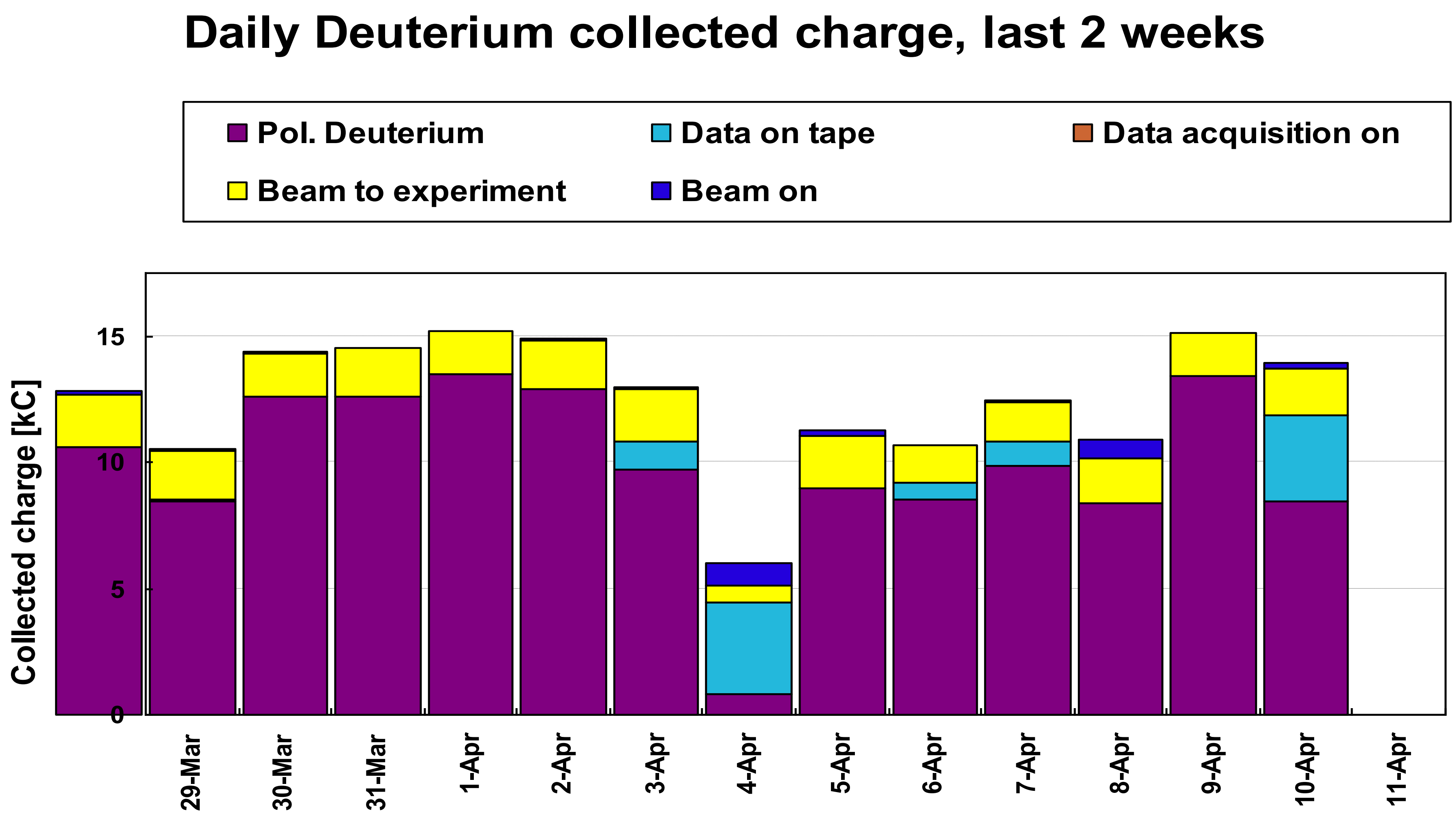


Accelerator complex and BLAST experiment fully automated

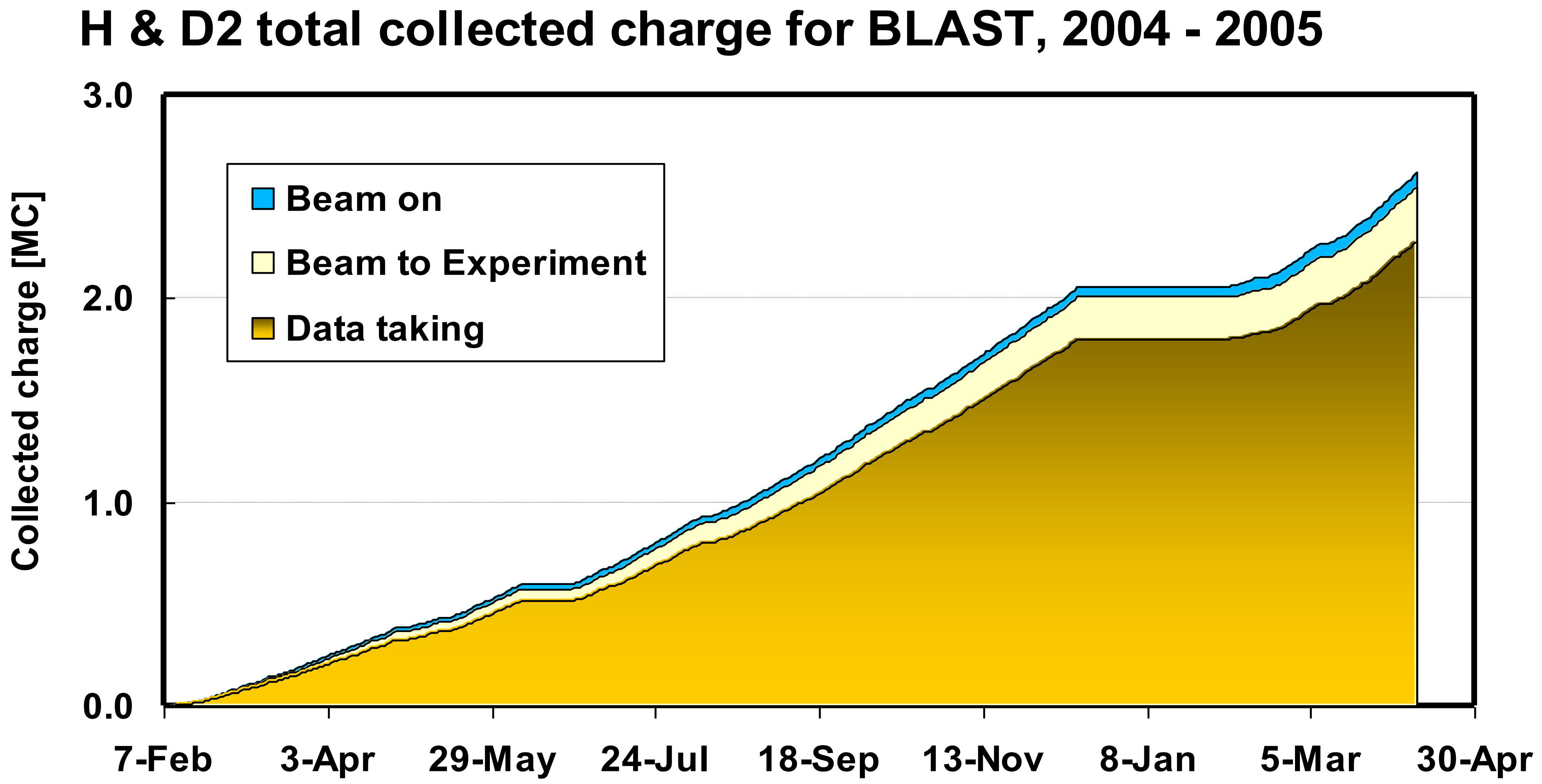
Stored currents: routinely fill to 225 mA, lifetime of ~ 35 minutes at 100mA

Beam Polarization: ~65% with possibility of rapid reversal (flipper)

Performance

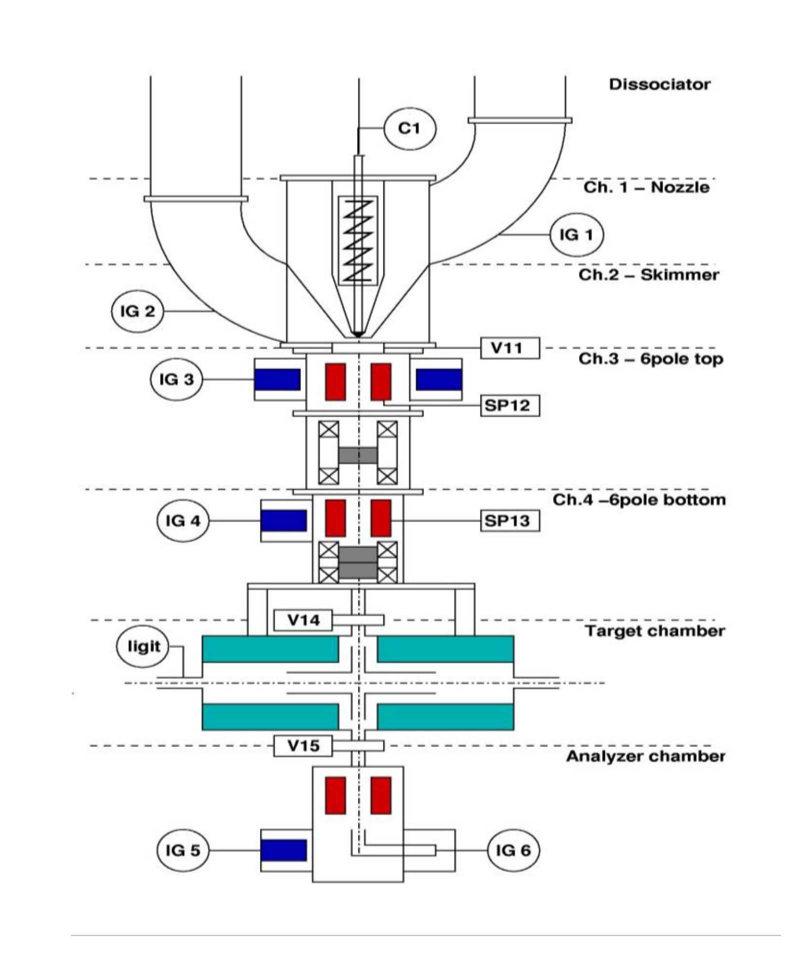


Integrated charge delivered



Polarized ^1H and ^2H Gas Target

- Received from NIKHEF in 2000
- Has to fit inside of two BLAST coils
- Operates in high BLAST toroidal field
- Operations must be reliable and stable over a long period of time
- Improvement of figure-of-merit
- Rapid switching between various spin states and deuterium and hydrogen gases



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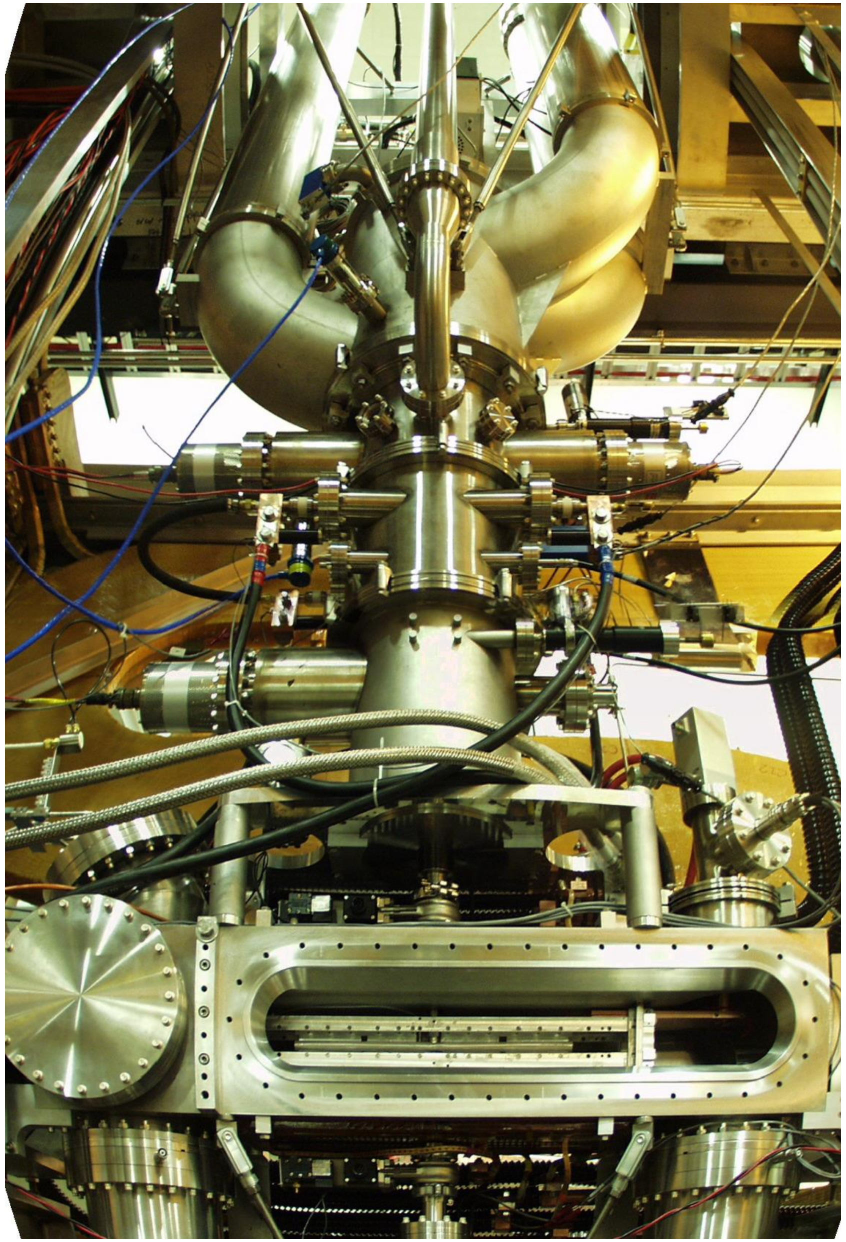


Focusing in the Sextupole System

- The force on atom in sextupole in absence of external magnetic field

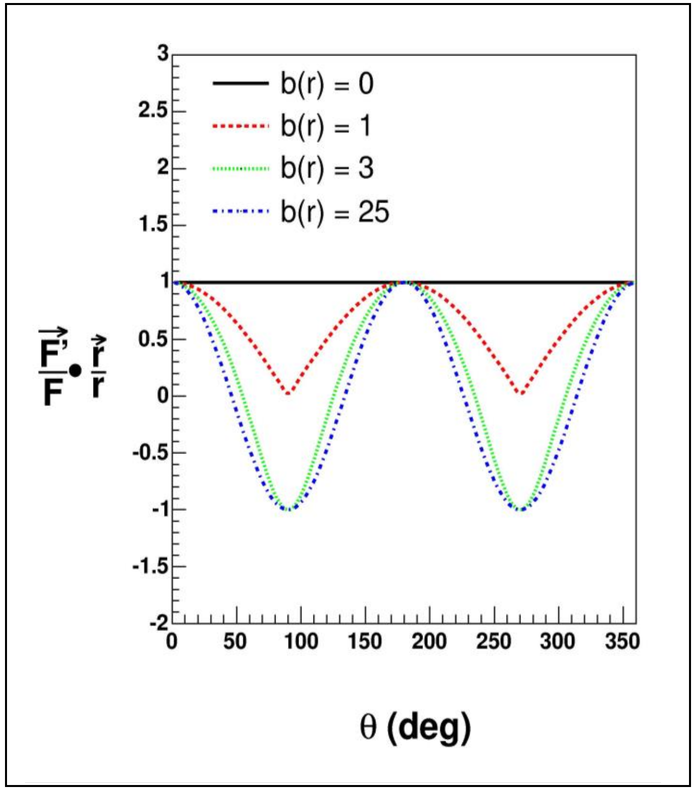
$$\vec{F} = 2\mu B_0 \frac{\vec{r}}{r_0^2}$$

- In presence of external magnetic field

B_x^{ext}

$$\frac{\vec{F'}}{F} \cdot \frac{\vec{r}}{r} = \frac{1+b\frac{r_0^2}{r^2}cos(2\theta)}{\sqrt{1+2b\frac{r_0^2}{r^2}cos(2\theta)+b^2\frac{r_0^4}{r^4}}}$$

- Parameter $b=B^{ext}/B_0$ is a function of external magnetic field, pole-tip field strength
- Force magnitude remains the same, while the direction changes
- In a weak b regime the force is the weaker but in the right direction
- In a strong b regime F_x remains the same, while F_y completely reverses direction

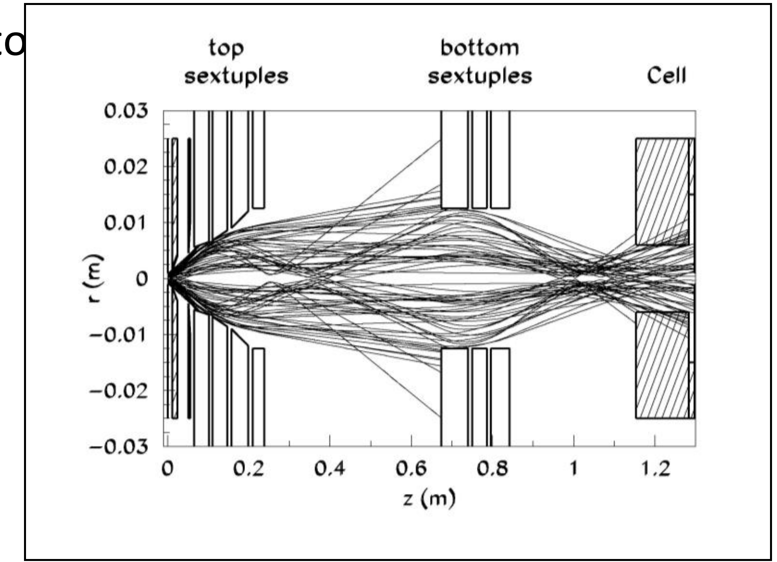


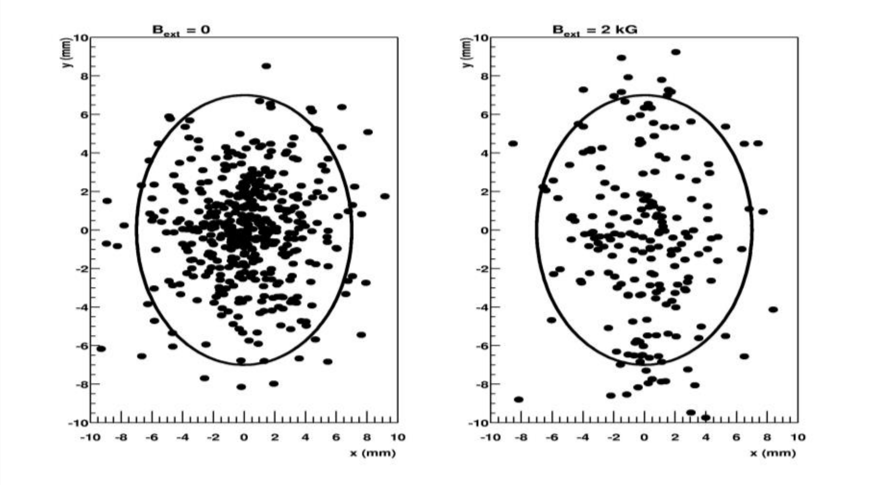
Focusing Simulation

- The effect of the external magnetic field was put into the ray tracing program

- The atomic beam has a Maxwellian velocity distribution:

$$f(v) = \frac{\alpha}{v}\left(\frac{mv^2}{2k_BT}\right)^2 e^{-\frac{m(v-v_0)^2}{2k_BT}}$$



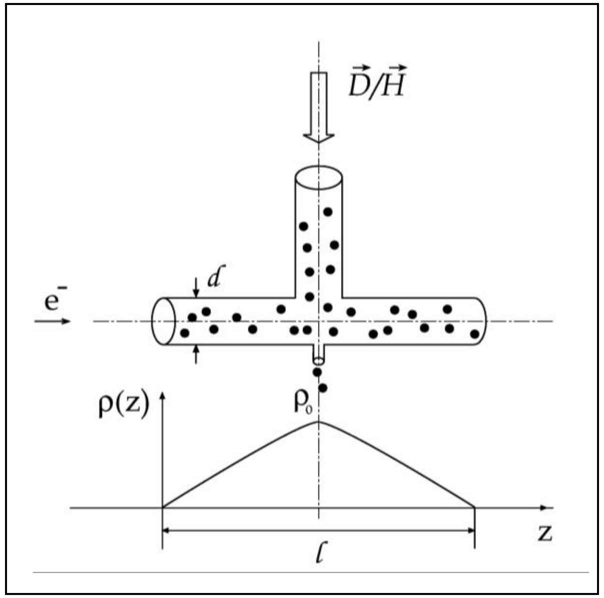


The external field reduces the intensity almost a factor of two

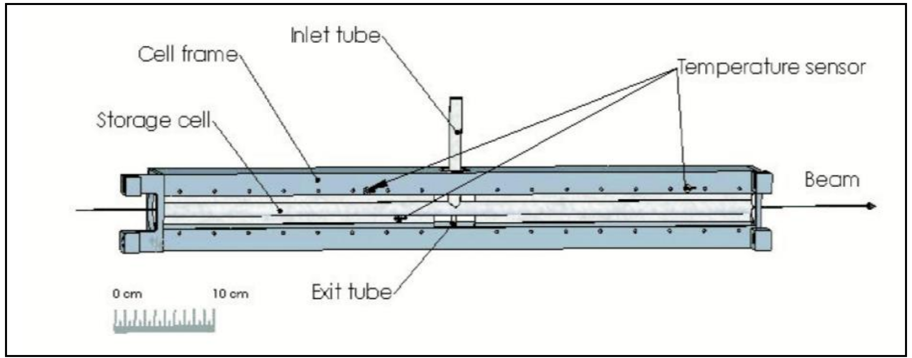
Polarized Gas in the Storage Cell

- Triangular distribution

$$\rho(z) = \begin{cases} \frac{2\rho_0}{l}(z + l/2) & , \ z < 0 \\ \frac{2\rho_0}{l}(l/2 - z) & , \ z > 0 \end{cases}$$
$$\rho_0 = I_0/C_{tot},$$



- Drifilm coating
- Beam Collimator to protect the cell
- Cooled to 90 K



- Polarization loss is due to
  1. *Recombination on the walls*
  2. *Wall depolarization*
  3. *Spin-exchange collisions*

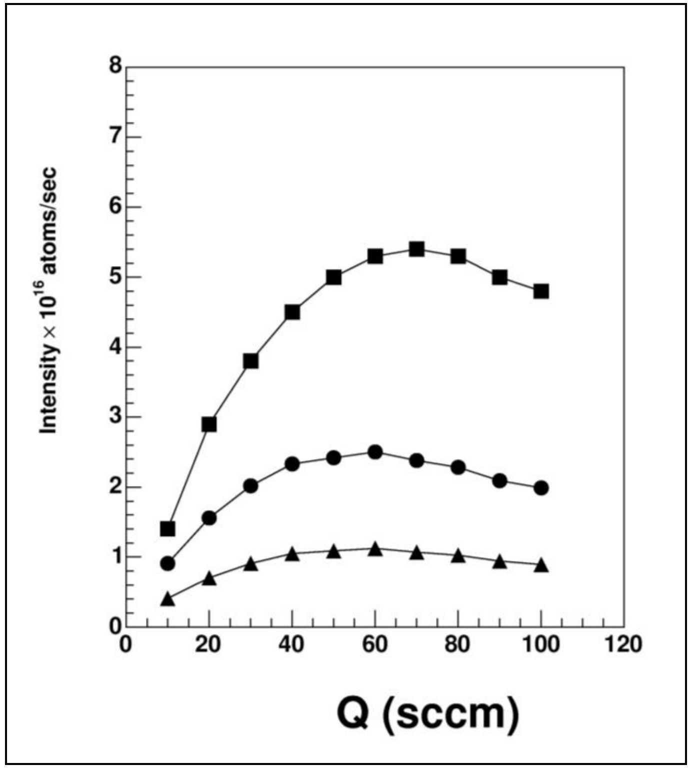
Performance (Atomic Beam Intensity)

- The intensity is limited by the rest gas scattering

$$I(Q) = I_0 \cdot Q \cdot e^{-Q/Q_0}$$

where Q is the flow into the dissociator.

- I_0 is a function of focusing in sextupoles, fraction of dissociation, etc.
- Q_0 is a function of vacuum in the ABS
- I_{ave} =2.5 x 10^{16} atoms/sec
- r_{ave} =4.5 x 10^{13} cm^{-2}
- L_{ave} =2.7 x 10^{31} $cm^{-2}s^{-1}$



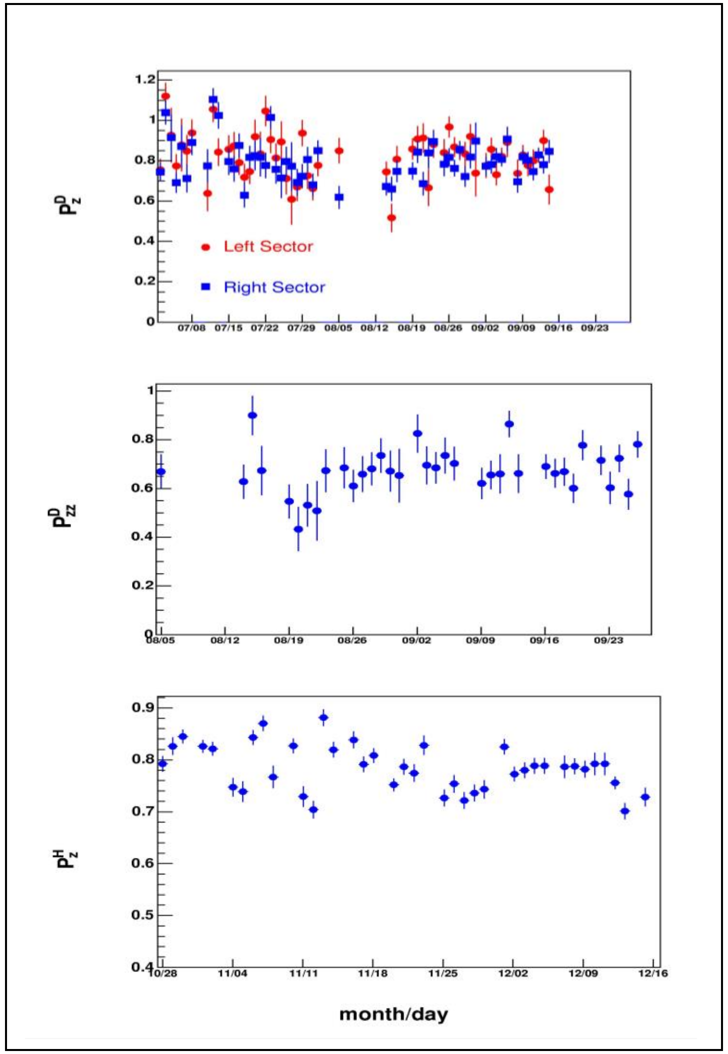
Performance (Polarization)

- Polarization is measured in nuclear reaction, $^2\vec{H}(e,e'p)n$ for $\vec{P}_z$ and $^2\overleftrightarrow{H}(e,e'd)$ for P_{zz}

- Polarization remained stable over the course of the experiments

- Average polarizations in deuterium:
  $P_z = 80 \pm 4$ %
  $P_{zz} = 68 \pm 6$ %

- Average polarization in hydrogen:
  $P_z = 80 \pm 4$ %



Summary of BLAST operating parameters

	design	routinely achieved
beam polarization	0.6	0.65
average beam current (mA)	80	120
ABS H-flux (atoms/sec)	6×10^{16}	4.5×10^{16}
^{2}H vector polarization	0.75	0.8
^{2}H tensor polarization	0.7	0.7
^{1}H polarization	0.5	0.8

Note: BLAST run of 80 mA for 1000 hours requires delivery of 288 kC

Neutron Form Factors

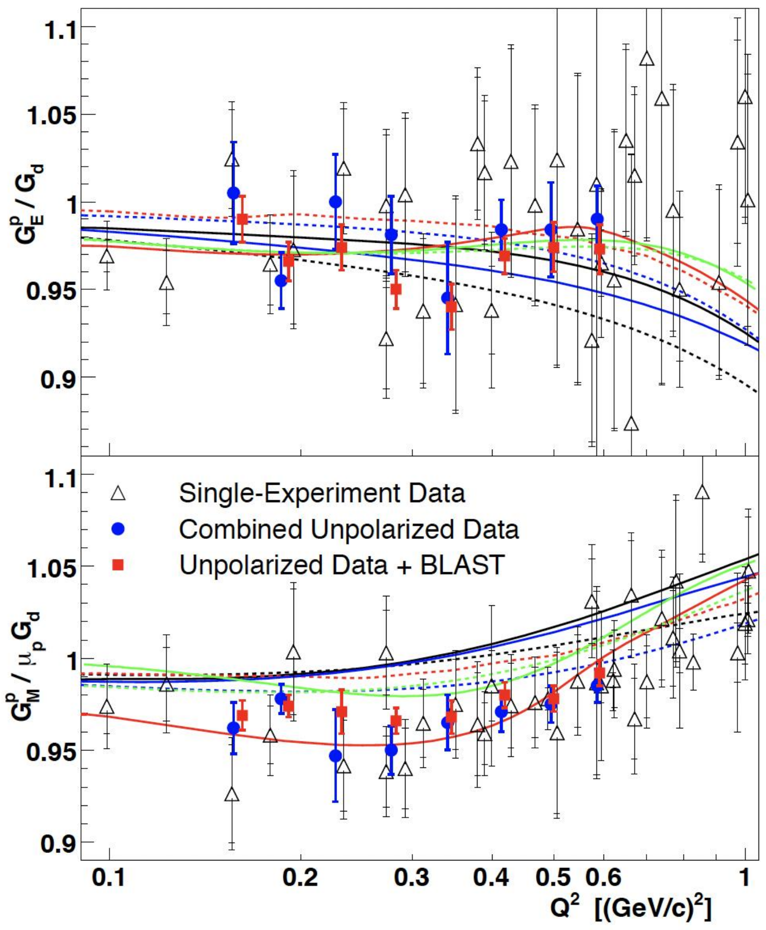


Figure 5: Compilation of world data on G_E^p/G_D and $G_M^p/\mu_p G_D$ at BLAST kinematics with (red) and without (blue) BLAST input, shown with total uncertainties. The curves are the same as in Figure 4.

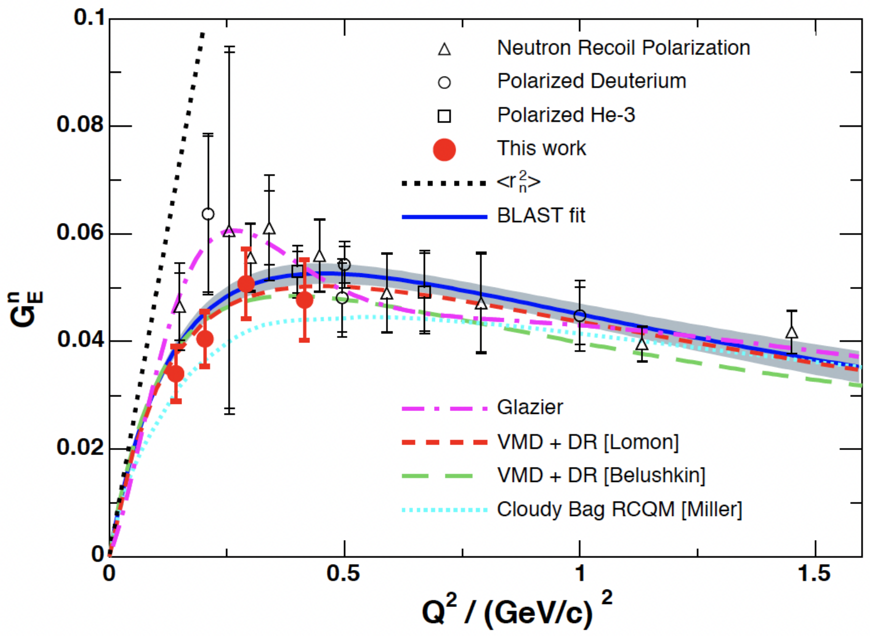


Figure 7: World data on G_E^n from double-polarization experiments. The curves are described in the text.

Tensor Polarization in Elastic e-d Scattering

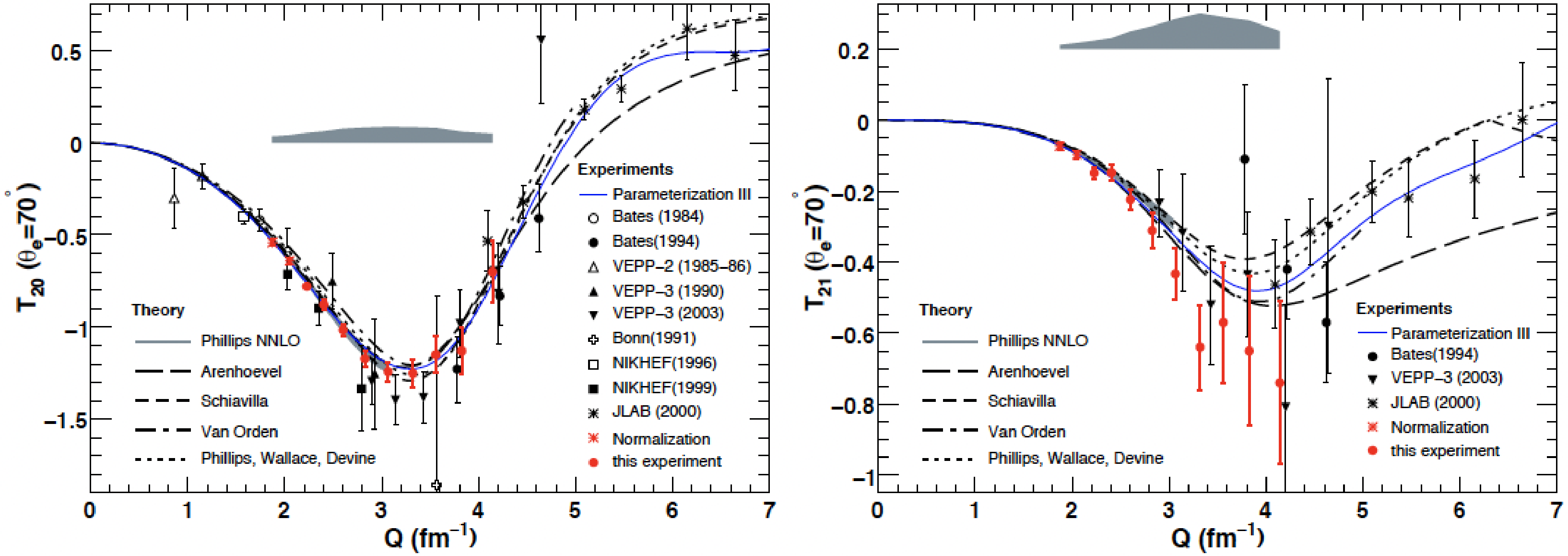


Figure 10: Results for the tensor analyzing powers T_{20} and T_{21} (red dots) in comparison to previous data and various theoretical predictions.

Vector and Tensor Asymmetries in Quasielastic (e,e'p) Scattering

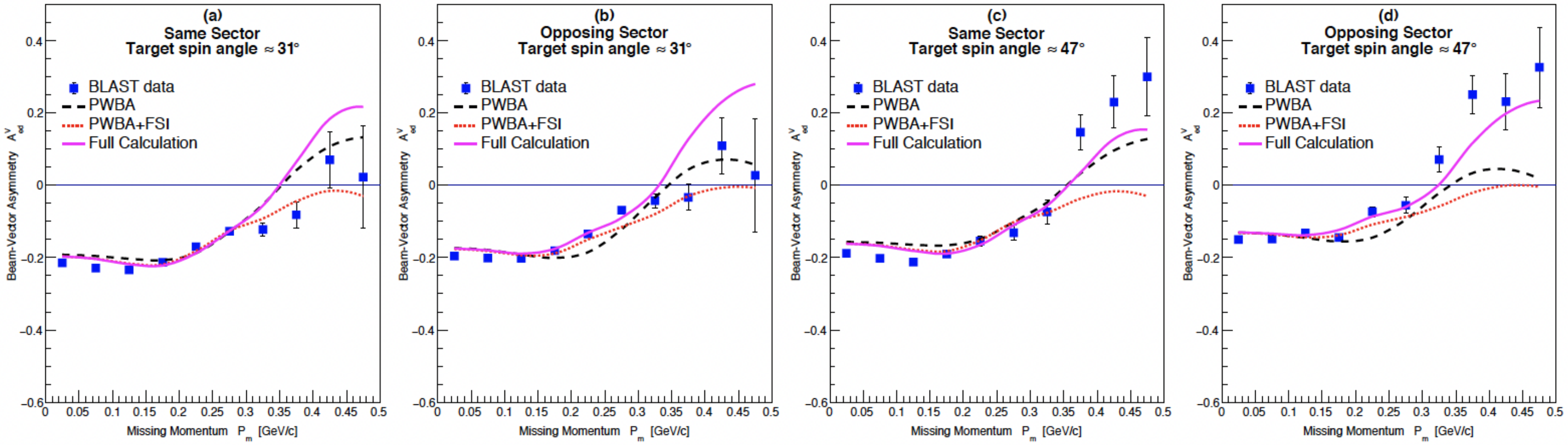


FIG. 2. Beam vector asymmetries A_{ed}^{V} for $0.1 < Q^2 < 0.5$ (GeV/c)^2 vs. p_m. Panels (a) and (c) refer to *same sector* kinematics for target spin angles ≈ 31° and ≈ 47°. Panels (b) and (d) refer to *opposing sector* kinematics for the same target spin angles.

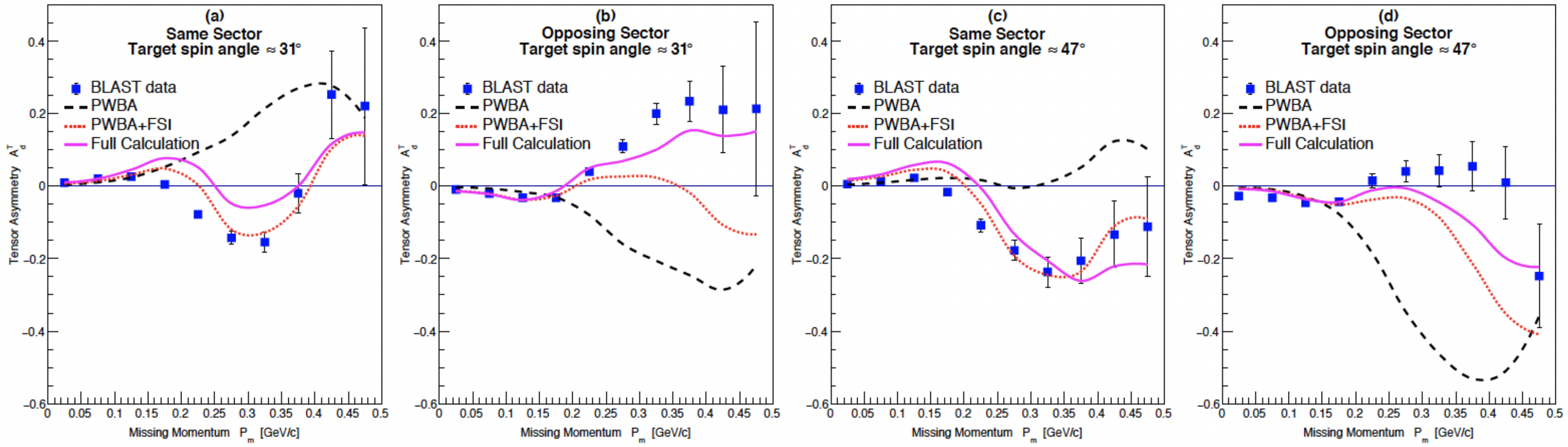
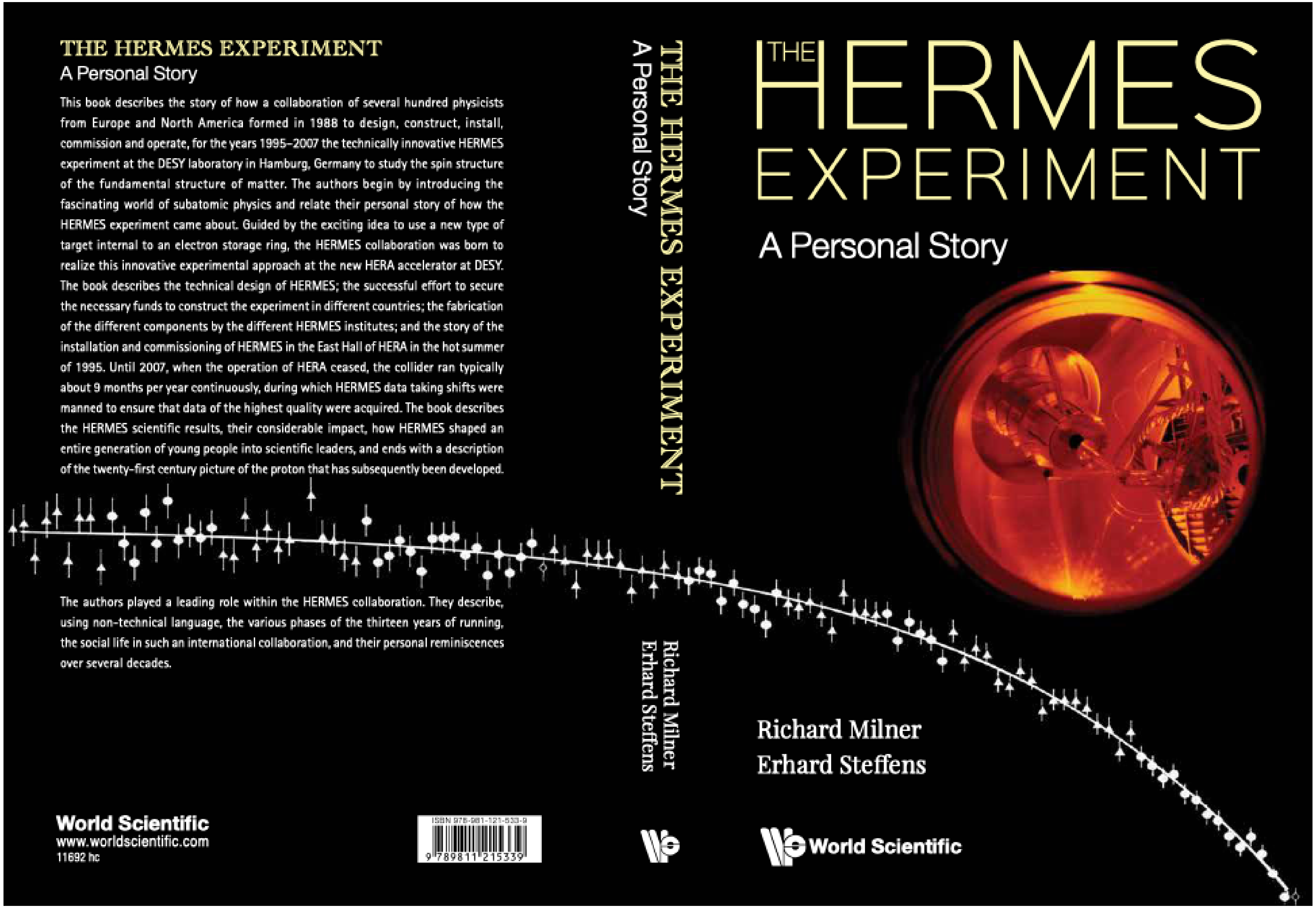


FIG. 3. Tensor asymmetries A_d^T for $0.1 < Q^2 < 0.5$ (GeV/c)^2 vs. p_m. Panels (a) and (c) refer to *same sector* kinematics for target spin angles ≈ 32° and ≈ 47°. Panels (b) and (d) refer to *opposing sector* kinematics for the same target spin angles.


hermes



THE HERMES EXPERIMENT
A Personal Story

This book describes the story of how a collaboration of several hundred physicists from Europe and North America formed in 1988 to design, construct, install, commission and operate, for the years 1995–2007 the technically innovative HERMES experiment at the DESY laboratory in Hamburg, Germany to study the spin structure of the fundamental structure of matter. The authors begin by introducing the fascinating world of subatomic physics and relate their personal story of how the HERMES experiment came about. Guided by the exciting idea to use a new type of target internal to an electron storage ring, the HERMES collaboration was born to realize this innovative experimental approach at the new HERA accelerator at DESY. The book describes the technical design of HERMES; the successful effort to secure the necessary funds to construct the experiment in different countries; the fabrication of the different components by the different HERMES institutes; and the story of the installation and commissioning of HERMES in the East Hall of HERA in the hot summer of 1995. Until 2007, when the operation of HERA ceased, the collider ran typically about 9 months per year continuously, during which HERMES data taking shifts were manned to ensure that data of the highest quality were acquired. The book describes the HERMES scientific results, their considerable impact, how HERMES shaped an entire generation of young people into scientific leaders, and ends with a description of the twenty-first century picture of the proton that has subsequently been developed.

The authors played a leading role within the HERMES collaboration. They describe, using non-technical language, the various phases of the thirteen years of running, the social life in such an international collaboration, and their personal reminiscences over several decades.

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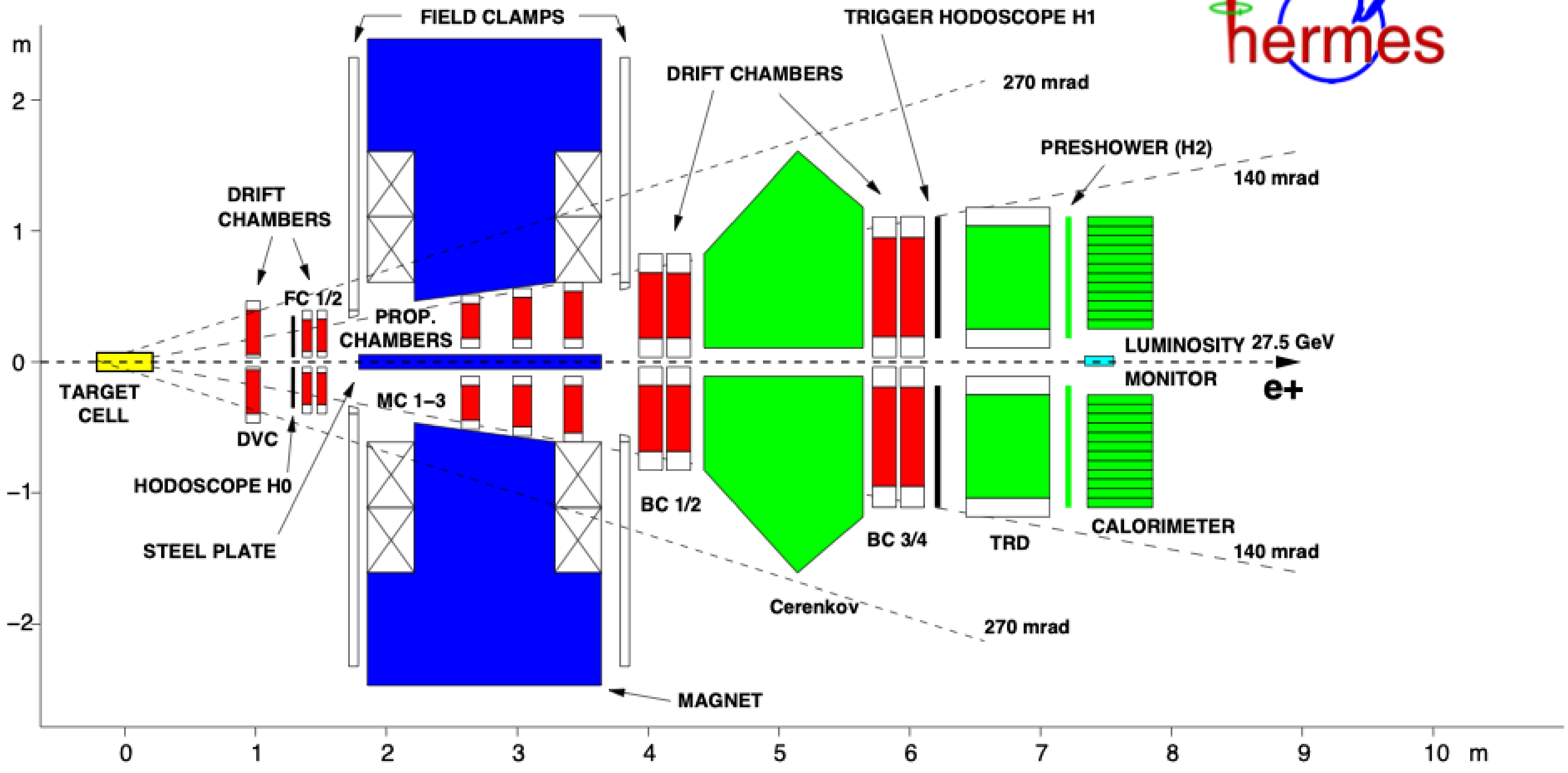
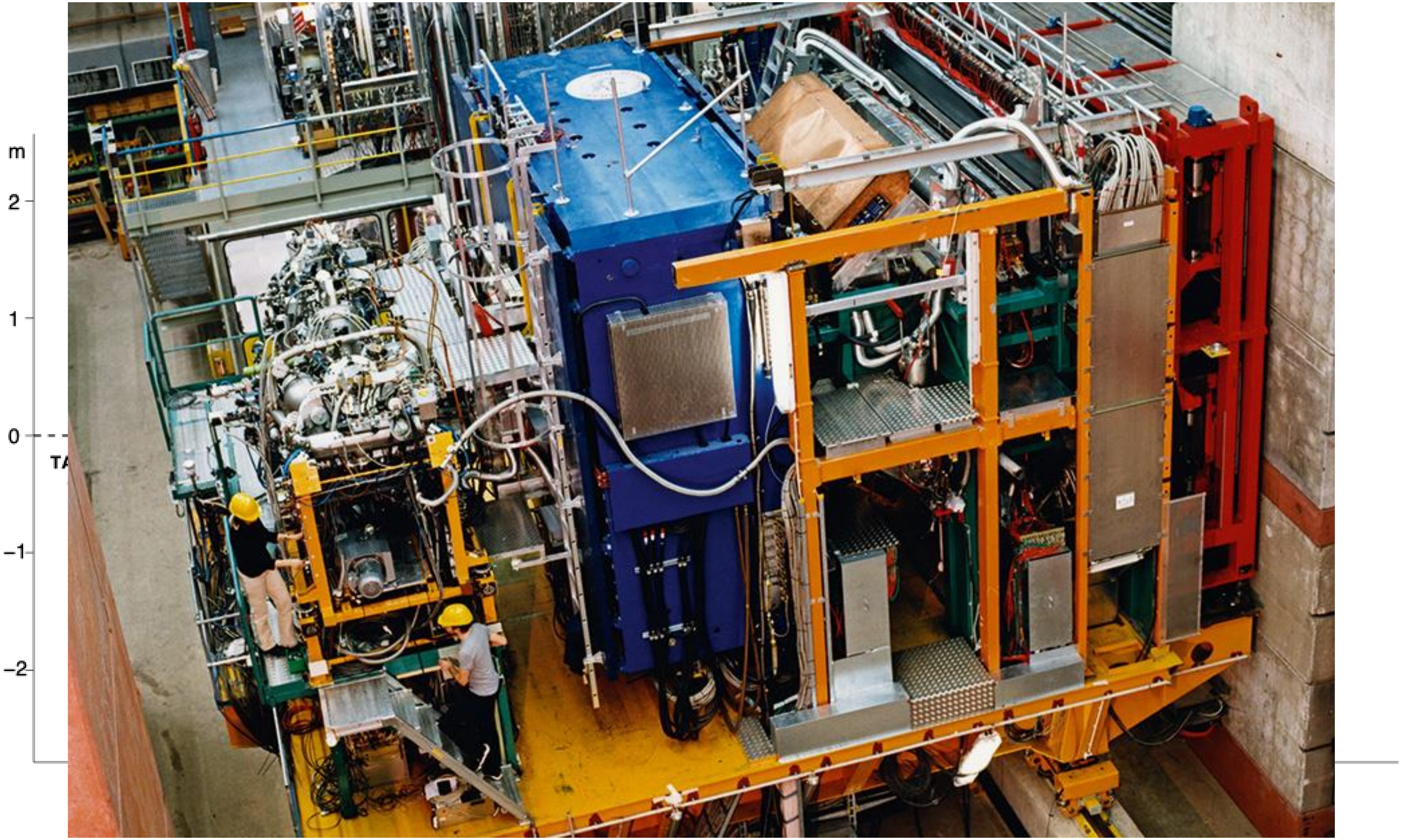
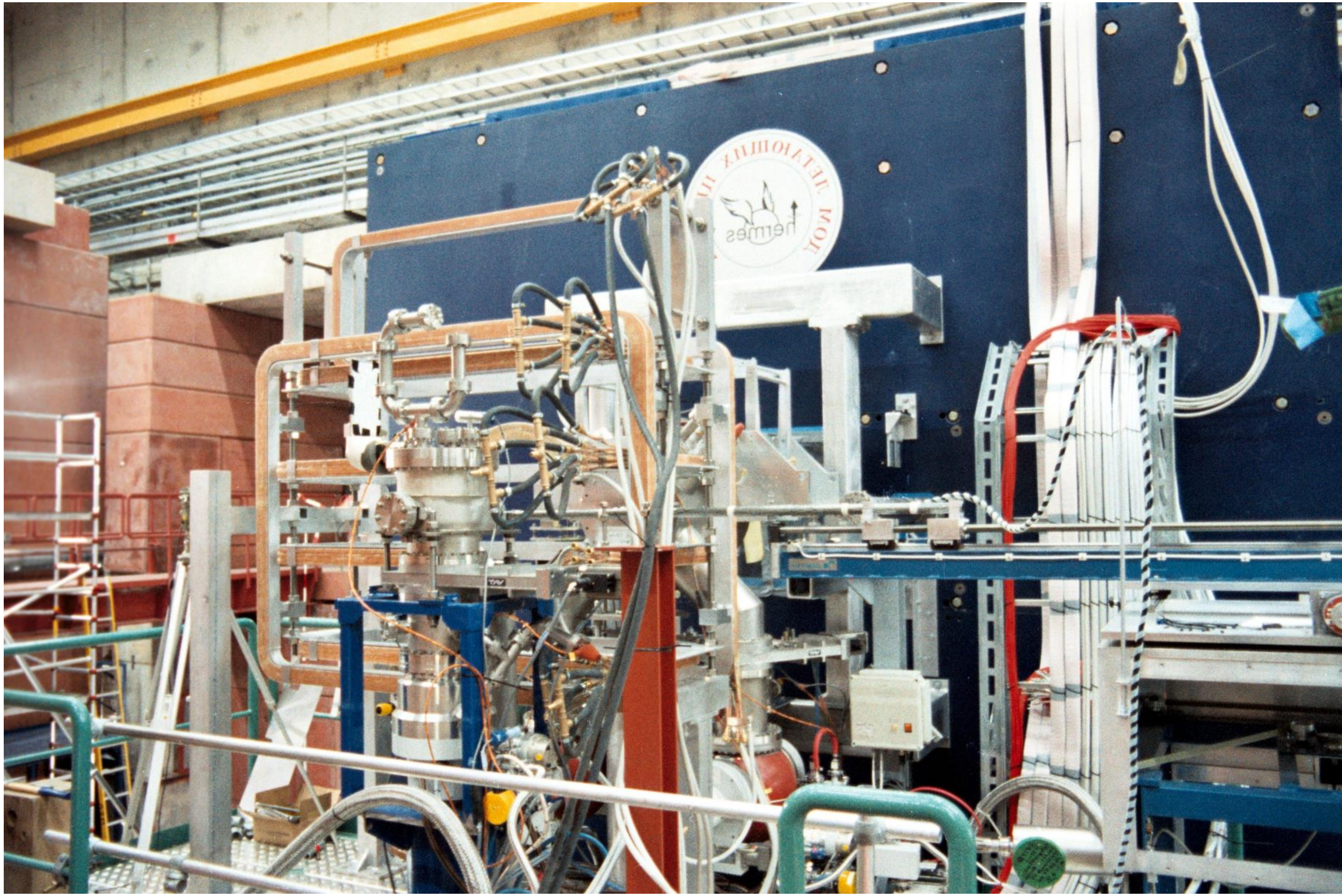


HERMES Experiment

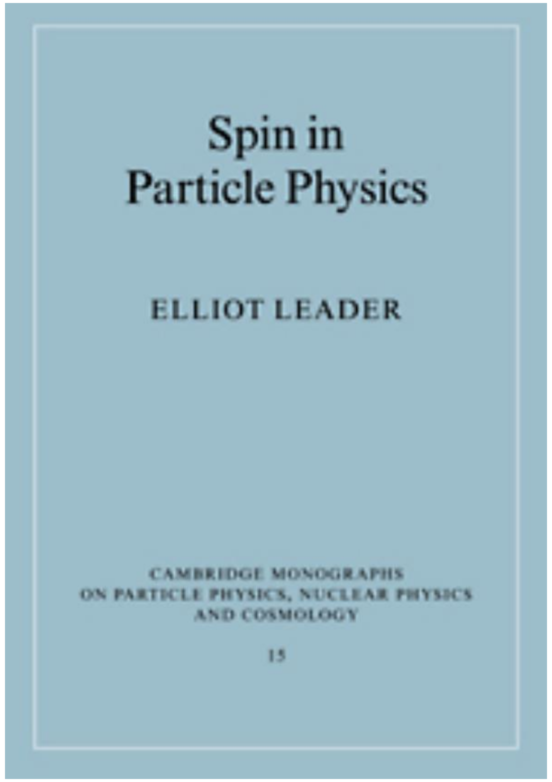


HERMES Polarized ^{3}He Target 1995



D. DeSchepper *et al.*, NIM A **419,** 16 (1998)

Pumping cell polarization vs. Target Optical Monitor polarization



142 *6 The production of polarized hadrons*

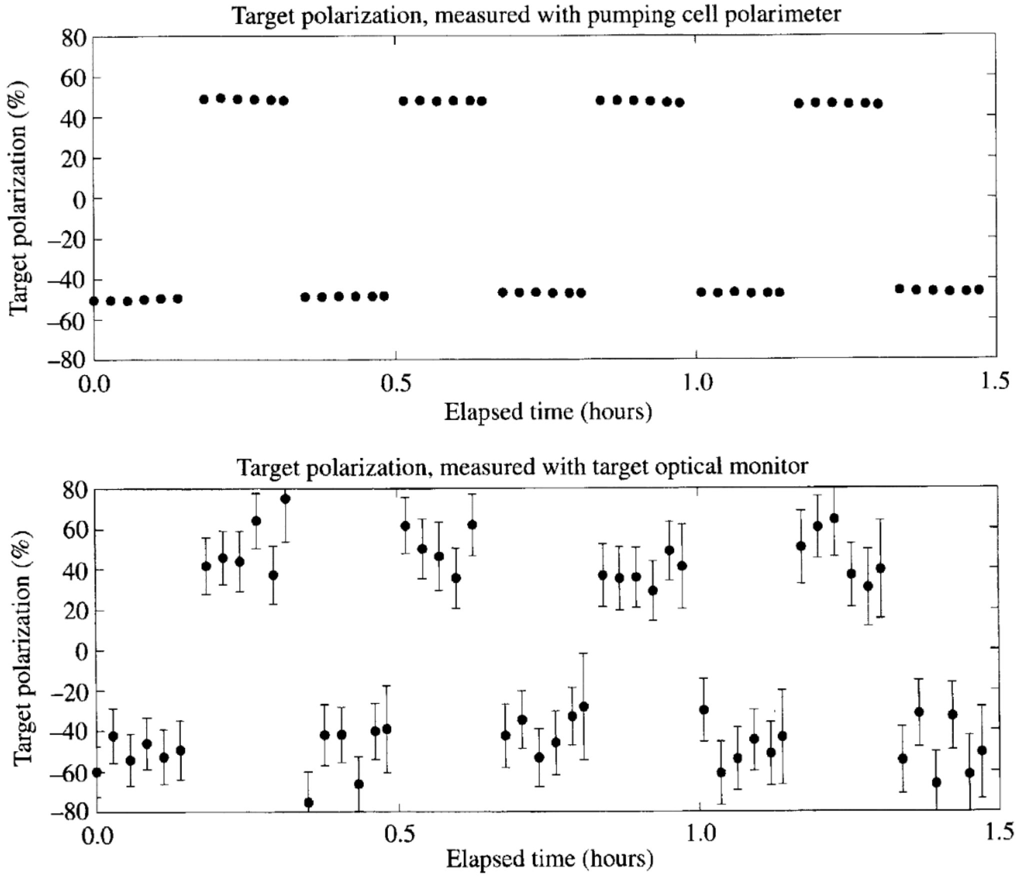


Fig. 6.8 Polarization of ^3He in the HERMES gas cell as a function of time, measured by two methods (courtesy of W. Lorenzon).

Neutron spin structure function from polarized ^{3}He at SLAC and DESY

- Data taken in 1995-96.
- E-142 had higher precision.
- Power of HERMES was coincident hadron detection as demonstrated on proton and deuteron.
- HERMES-like program on ^{3}He – > CLAS12

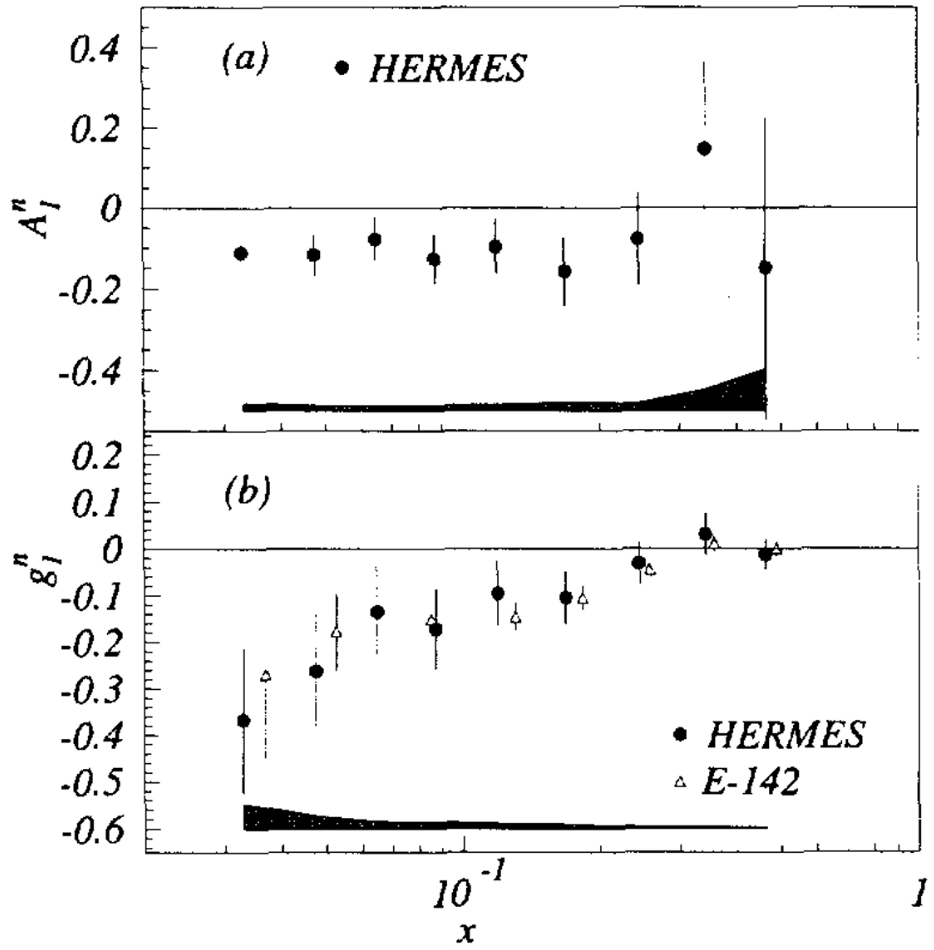


Fig. 2. The spin asymmetry A_1^n (a) and the spin structure function g_1^n (b) of the neutron as a function of x. The values are given for the measured $\langle Q^2 \rangle$. The error bars are statistical uncertainties. The error bands show the systematic uncertainties. The data points from E-142 have been displaced slightly in x for comparison with the present experiment.

HERMES Polarized H/D Target

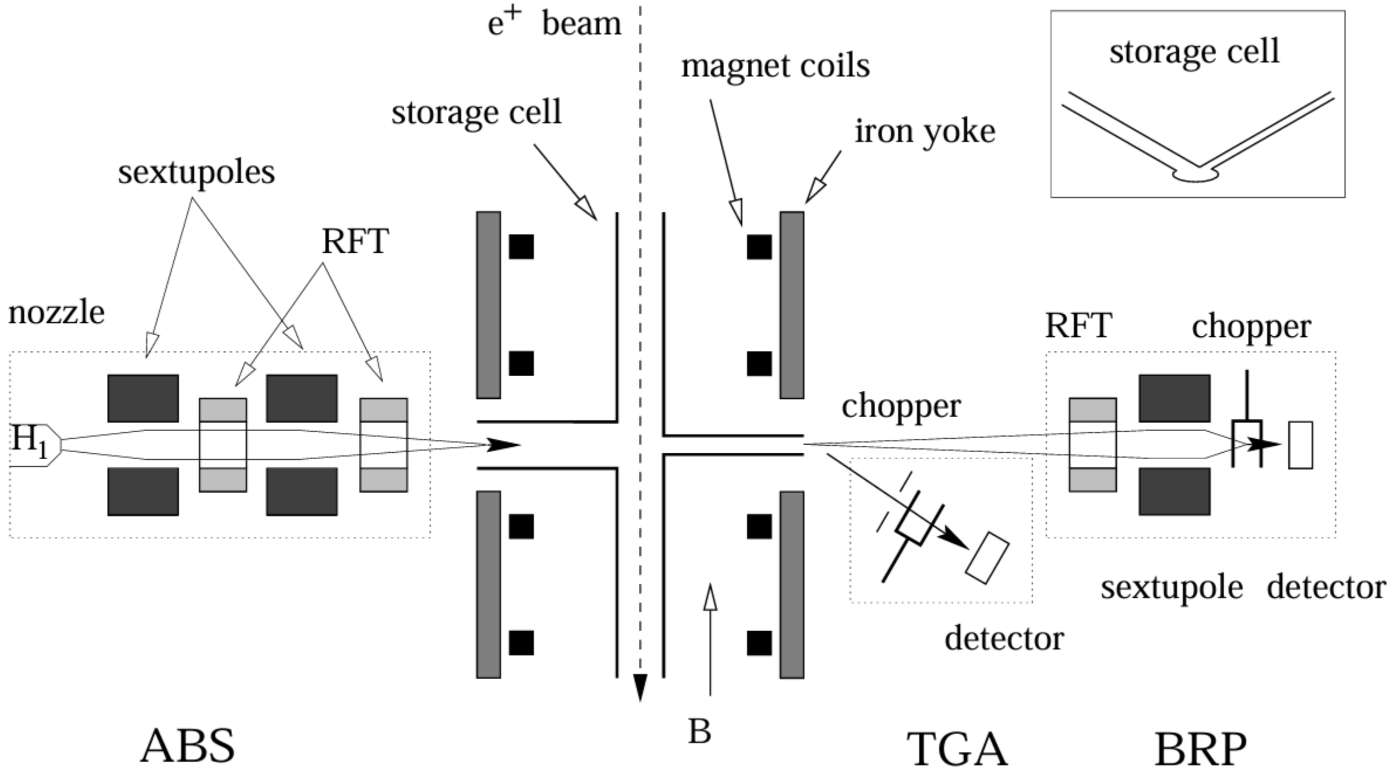


Fig. 1. Schematic view of the HERMES longitudinally polarized target. From left to right: Atomic Beam Source (ABS), target chamber with cell and magnet, and diagnostic system composed by Target Gas Analyzer (TGA) and Breit-Rabi Polarimeter (BRP). The locations of the radio-frequency transition (RFT) units are indicated.

A. Airapetian *et al.*, NIM A **540**, 68 (2005)

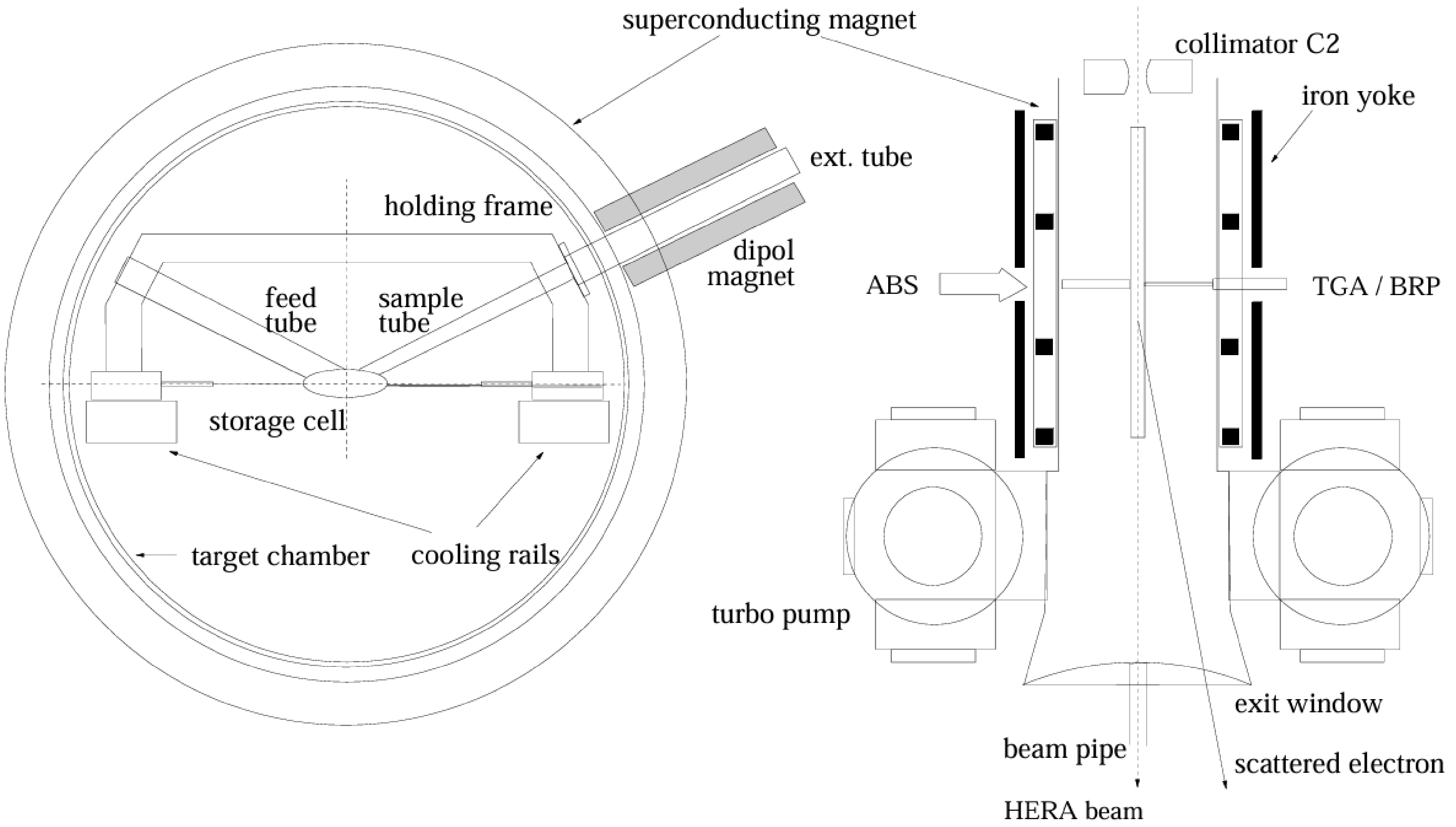


Fig. 2. Longitudinal target chamber and superconducting magnet viewed from downstream with respect to the HERA beam direction (left), and from above (right).

HERMES H/D Storage Cell

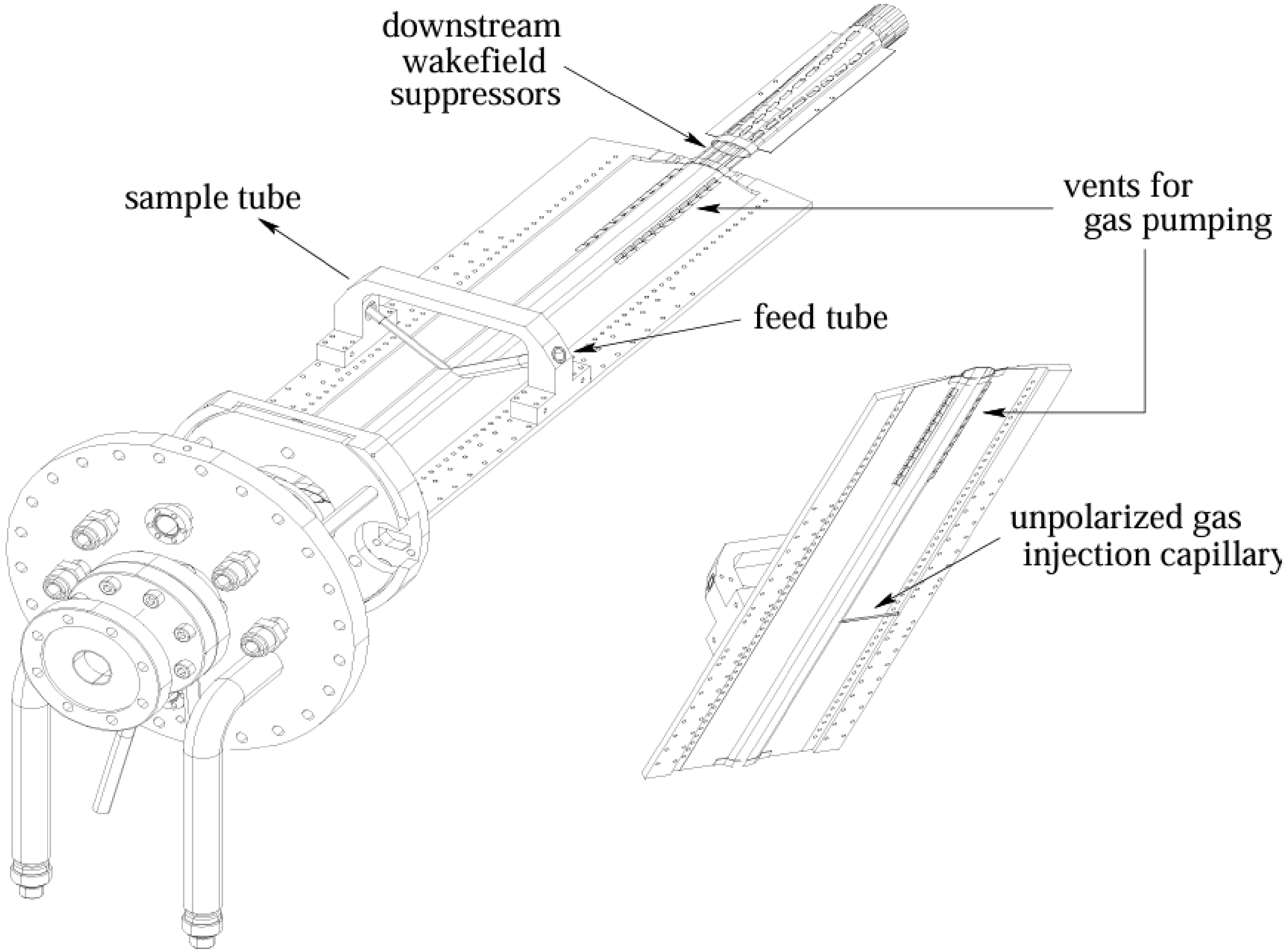


Fig. 4. The storage cell and its support flange.

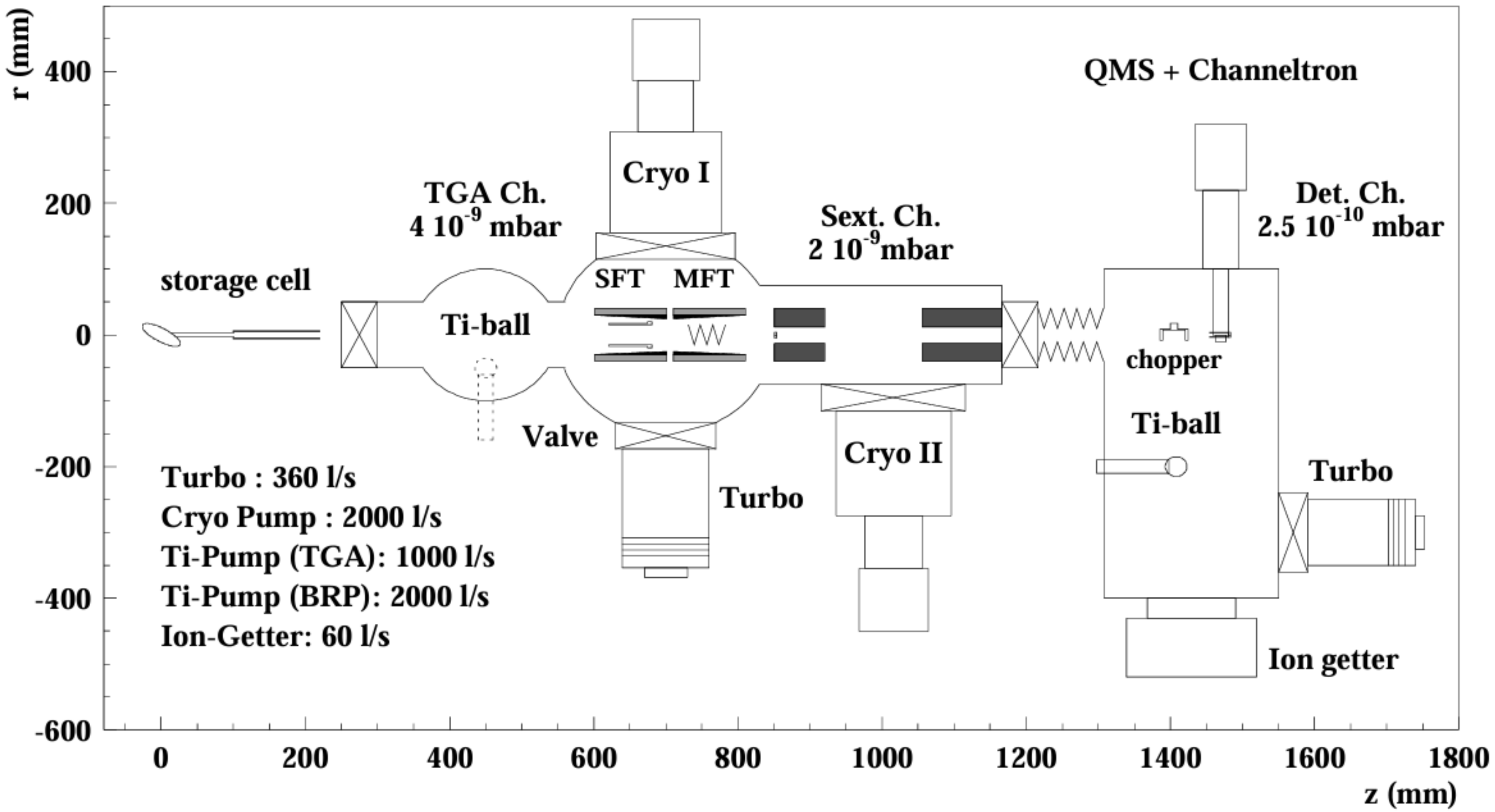
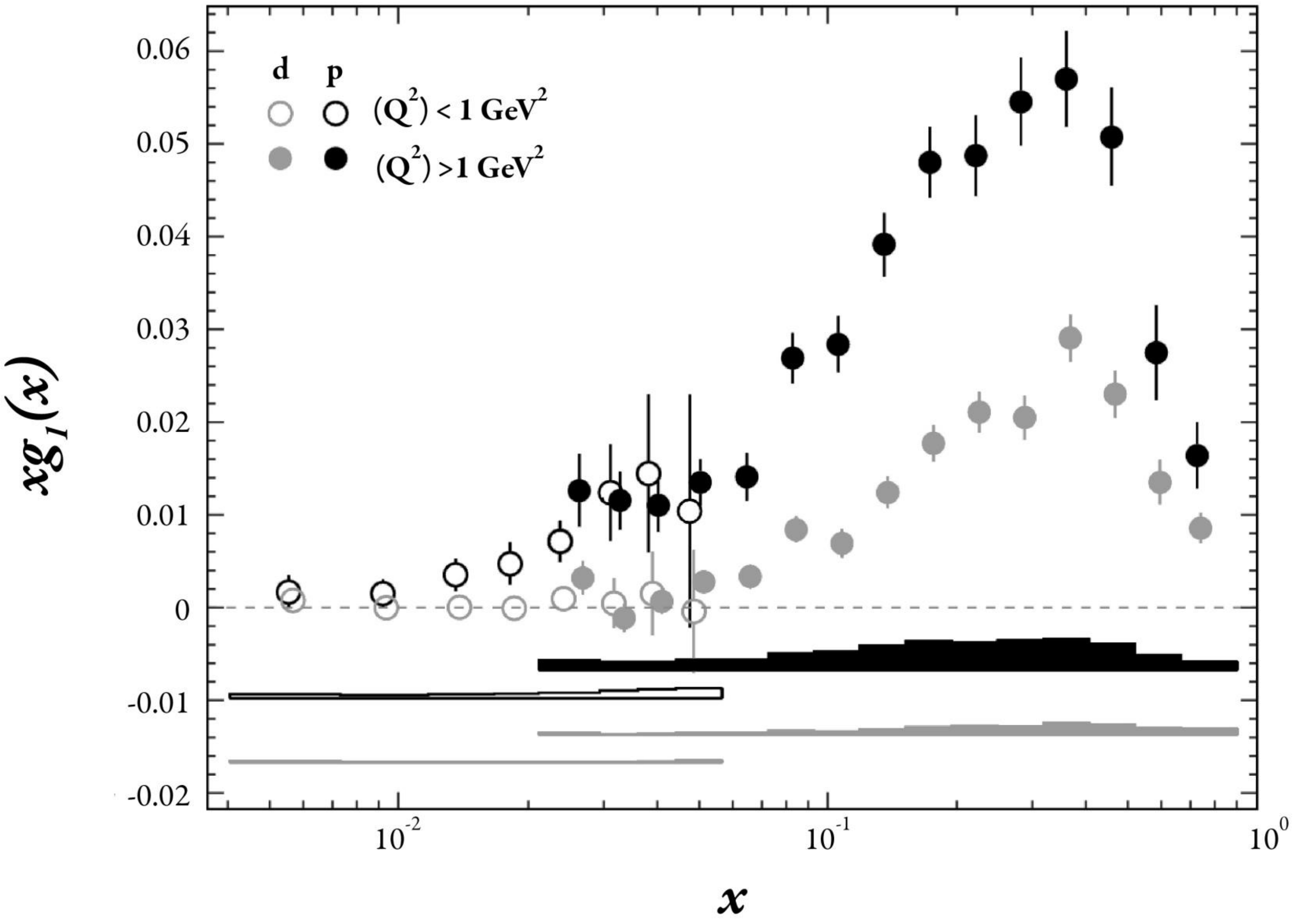


Fig. 8. Schematic view of the BRP/TGA vacuum system.

Summary of H/D Target Performance

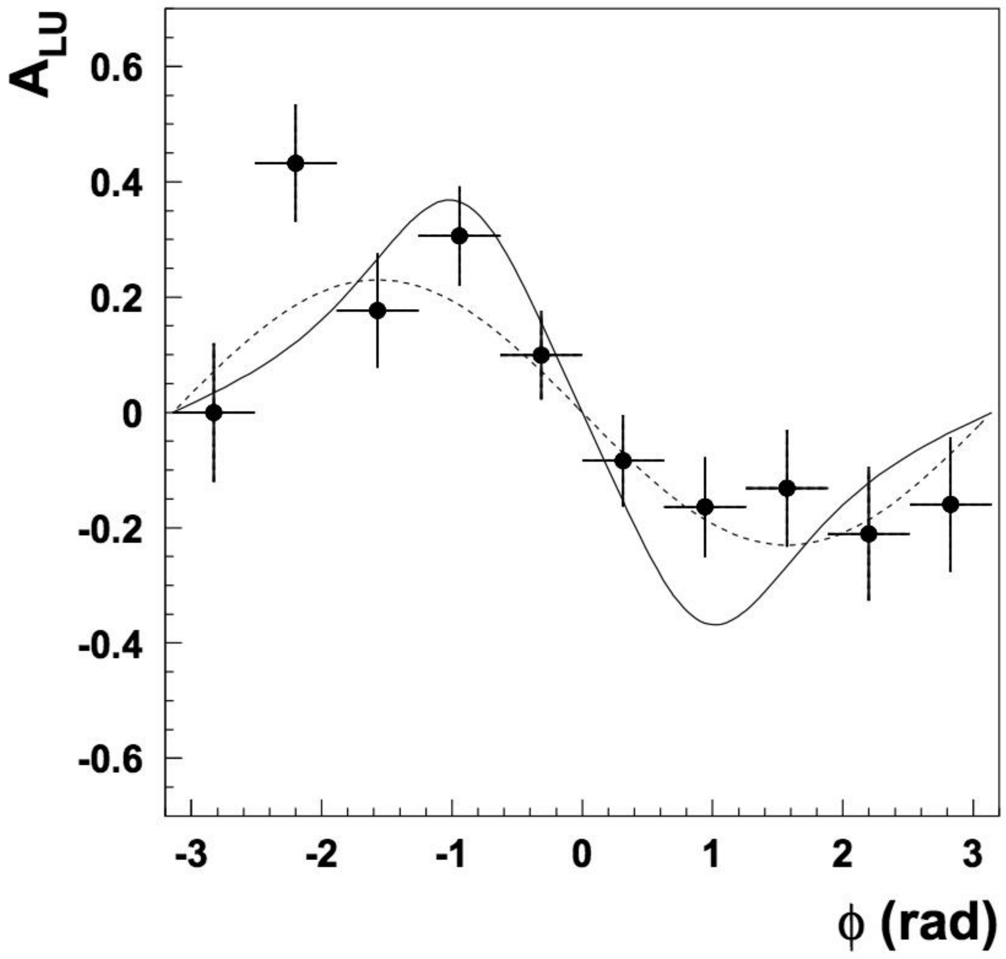
Target/year	$H_{\|\|}$(1997)	$D_{\|\|}$(2000)
P_z	0.851 ± 0.033	0.845 ± 0.028
$\Delta\alpha_r$	0.055	0.003 (absent)
ΔP_{SE}	0.035	≤0.001 (absent)
ΔP_{WD}	0.02	≤0.01 (absent)
ΔP_{BI}	-	-
t(10^{14} nucl/cm^2)	0.7	2.1
FOM ($P^2 t$)	0.5	1.5



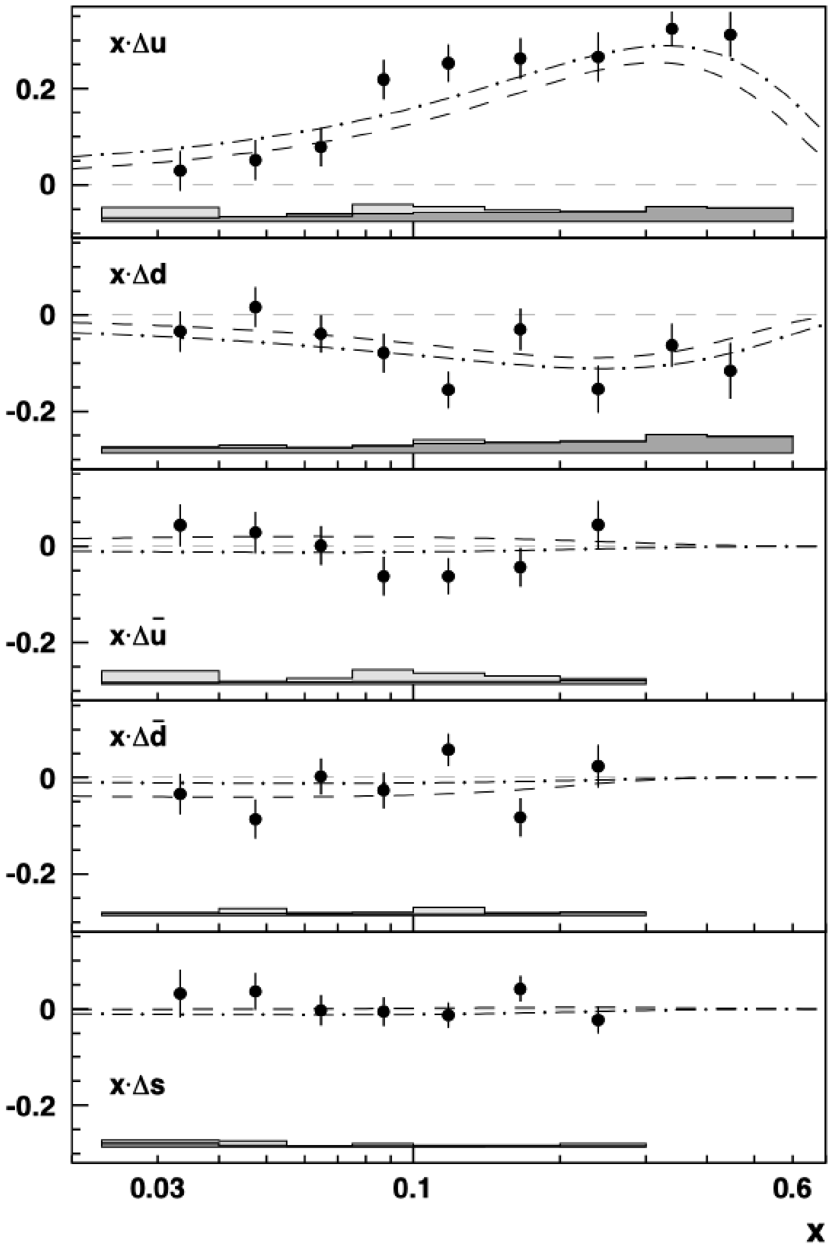
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
d p
(Q2) < 1 GeV2
(Q2) >1 GeV2
$xg_1(x)$
10^{-2}
10^{-1}
10^{0}
x

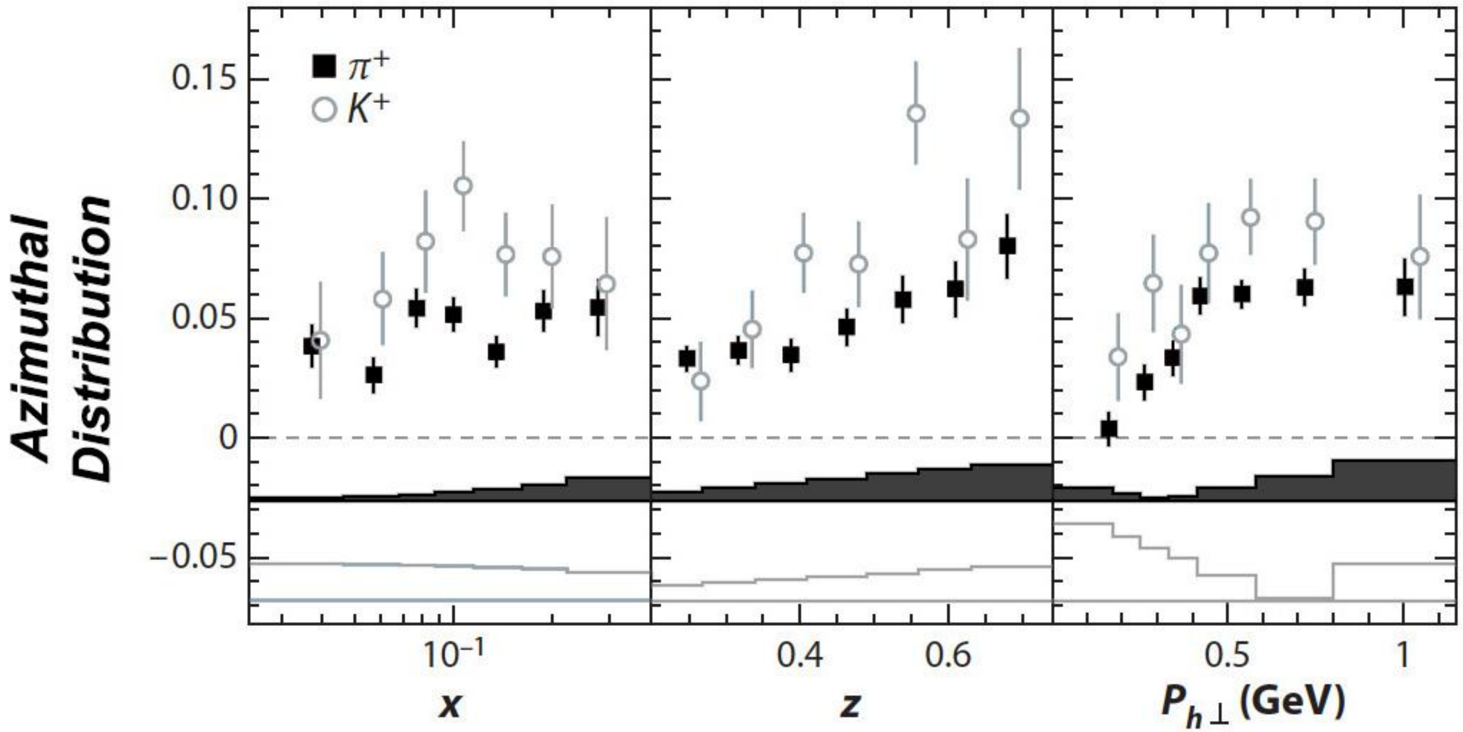
First Measurement of DVCS

A. Airapetian et al., Phys. Rev. Lett. 87, 182001 (2001)



Quark Polarizations
Sivers Effect





Tensor Structure Function

A. Airapetian *et al.*, Phys. Rev. Lett. **95**, 242001 (2005)

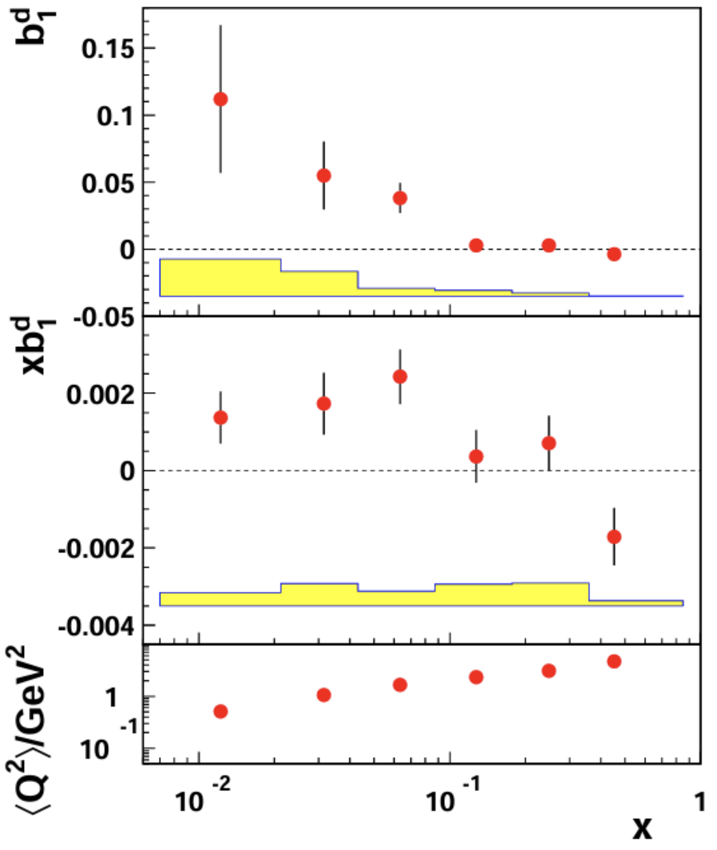


FIG. 2: The tensor structure function presented as (top) $b_1^{\mathrm{d}}(x)$ and (middle) $xb_1^{\mathrm{d}}(x)$. The error bars are statistical and the shaded bands show the systematic uncertainty. The bottom panel shows the average value of Q^2 in each x-bin.

Possible fixed target experiment in EIC ESR

- Science motivation:

  electron scattering in valence quark region from polarized nucleons and nuclei
- Luminosity significantly higher (~ X 100) than HERMES
- CLAS12 like detector required
- Note that polarized ion sources will be developed for EIC – these can be used to feed internal gas targets
- Realization requires careful discussion with EIC accelerator physicists.

Realizing the Scientific Program with Polarized Ion Beams at EIC

(The EPIOS Scientific Consortium)

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(Dated: September 29, 2025)

EIC **P**olarized **IO**n **S**ource Scientific Consortium

- We identify the AGS as a very valuable platform to carry out beam studies of polarized sources, polarized beams and spin manipulators in the era when RHIC is dark. We recommend that EPIOS and the BNL-CAD together consider the possibilities and develop a plan that takes advantage of the AGS.

- Finally, we point out that the polarized atom sources required for the production of EIC polarized ion beams can also be utilized to feed windowless gas targets internal to a charged particle storage ring. If desired, this would make possible a program of fixed target physics at one of the storage rings in the EIC accelerator complex.