The Deuteron Polarized Tensor Structure Function b_1

PAC 40 Defense

PR12-13-11 Spokespeople

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b_1 Collaboration

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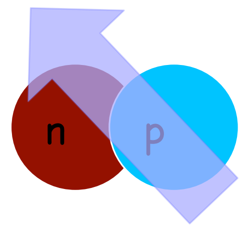
DESY

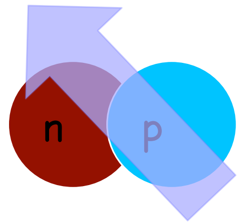
Deuteron



Spin-1 system

Simple testing ground for nuclear physics
Reasonably “easy” to polarize

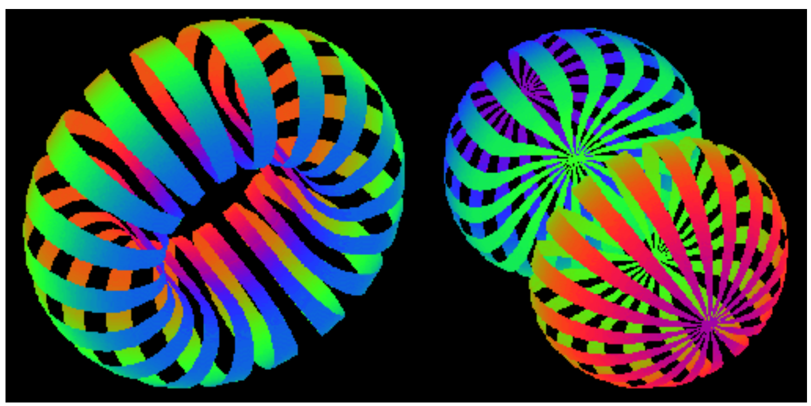
Deuteron



Spin-1 system

Simple testing ground for nuclear physics
Reasonably "easy" to polarize

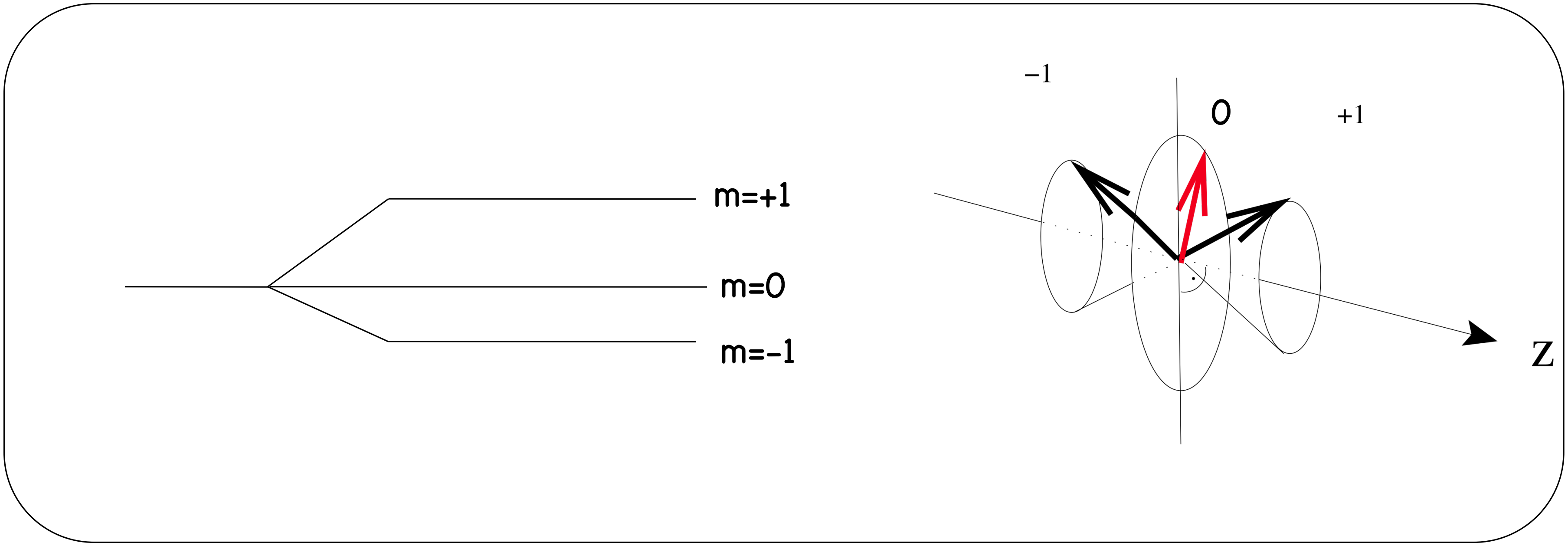
Spatial distribution depends on the spin state



M = 0 M = ±1

Spin-1 System

Spin-1 in B-field leads to 3 Zeeman sublevels



<u>Vector Polarization</u> P_z : $(n^+ - n^-)$ $(-1 < P_z < +1)$

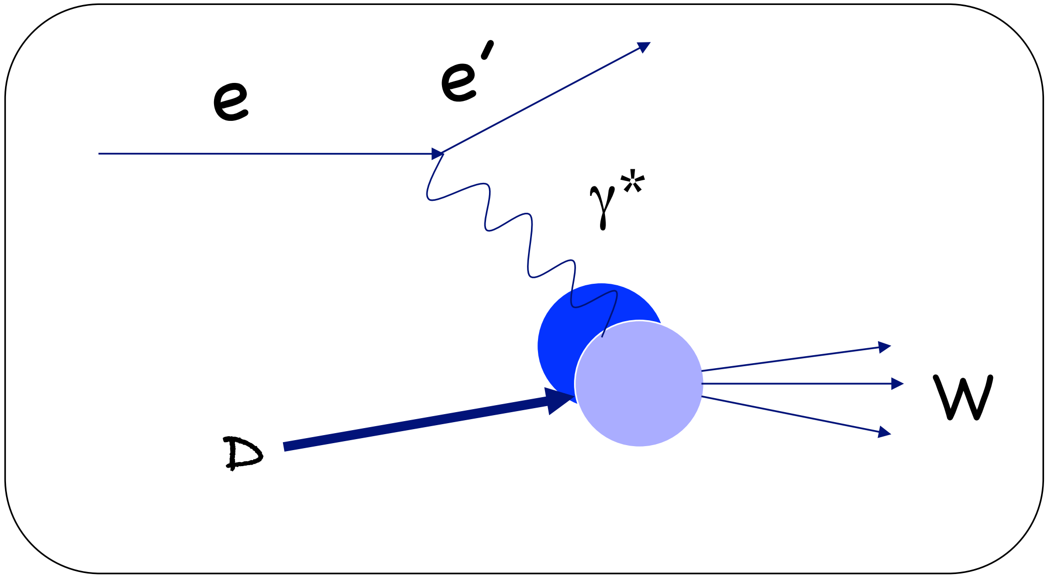
and

<u>Tensor polarization</u> P_{zz} : $(n^+ - n^0) - (n^0 - n^-)$ $(-2 < P_{zz} < +1)$

<u>Normalization</u>

$(n^+ + n^- + n^0) = 1$

Inclusive Scattering from Deuteron



Construct the most general Tensor W consistent with Lorentz and gauge invariance

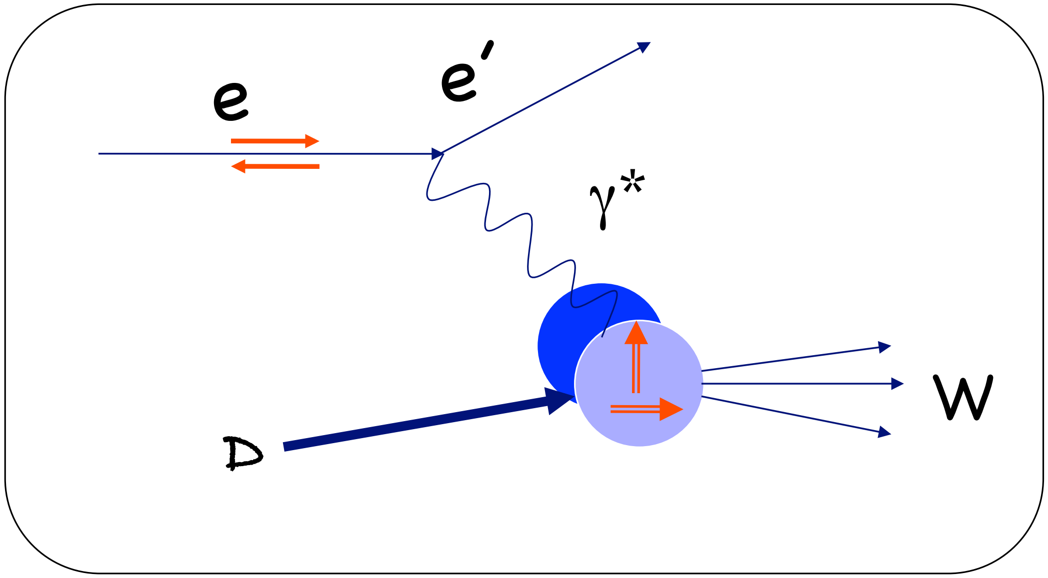
Frankfurt & Strikman (1983)

Hoodbhoy, Jaffe, Manohar (1989)

$$
\begin{aligned}
W_{\mu\nu} \quad = \quad & -F_1 g_{\mu\nu} + F_2 \frac{P_\mu P\nu}{\nu} \\
& -b_1 r_{\mu\nu} + \frac{1}{6} b_2 (s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) \\
& + \frac{1}{2} b_3 (s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2} b_4 (s_{\mu\nu} - t_{\mu\nu}) \\
& + i \frac{g_1}{\nu} \epsilon_{\mu\nu\lambda\sigma} q^\lambda s^\sigma + i \frac{g_2}{\nu^2} \epsilon_{\mu\nu\lambda\sigma} q^\lambda (p \cdot q s^\sigma - s \cdot q p^\sigma)
\end{aligned}
$$

Unpolarized Scattering

Inclusive Scattering from Deuteron



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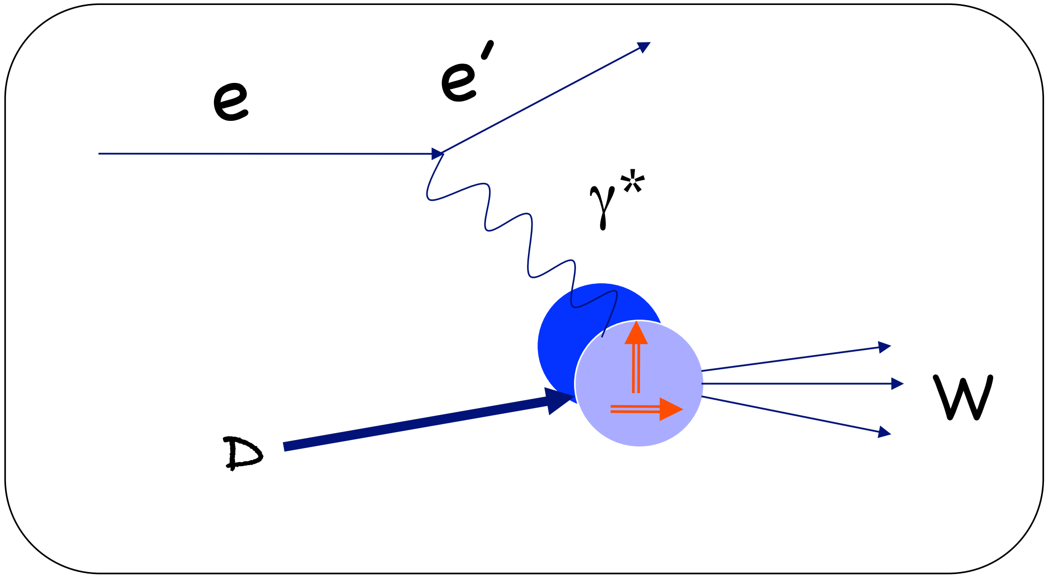
$$

Doubly Polarized Scattering

Inclusive Scattering from Deuteron



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\end{aligned}
$$

Unpolarized beam
&
Polarized Target

b_1 Structure Function

Focus on b_1 in this experiment:

Leading twist

Simplest to access experimentally.

Probe the tensor polarization of the sea quarks.

Signature of "exotic" effects in nuclei.
i.e. deviation of proton from simple system of two bound nucleons.

b_1 Structure Function

$$b_1(x) = \frac{q^0(x) - q^1(x)}{2}$$

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q^0 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state m=0

q^1 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state |m| = 1

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q^1 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state |m| = 1

<u>Nice mix of nuclear and quark physics</u>

measured in DIS (so probing quarks), but depends solely on the deuteron spin state

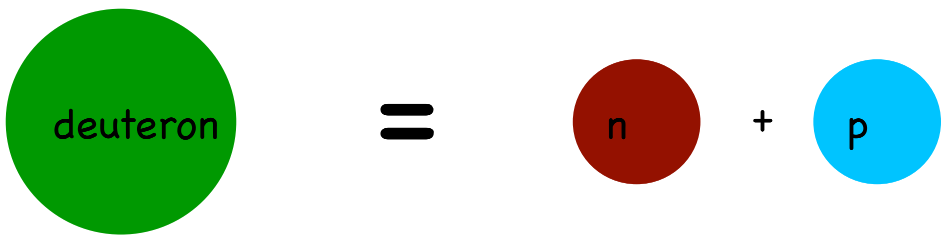
Investigate nuclear effects at the level of partons!

b_1 Structure Function

<u>Hoodbhoy, Jaffe and Manohar (1989)</u>

b_1 vanishes in the absence of nuclear effects

i.e. if...



Proton Neutron in relative S-state

Even accounting for D-State admixture <u>b_1 expected to be vanishingly small</u>

Khan & Hoodbhoy, PRC 44 ,1219 (1991) : $b_1 \approx O(10^{-4})$
Relativistic convolution model with binding

Umnikov, PLB 391, 177 (1997) : $b_1 \approx O(10^{-3})$
Relativistic convolution with Bethe-Salpeter formalism

It is a unique opportunity at JLab to develop this new field of spin physics.

S. Kumano (KEK)

I'm glad to hear that b1 is not forgotten in all the excitement about other spin dependent effects.

Robert Jaffe (MIT)

I am particularly interested in signatures of novel QCD effects in the deuteron. The tensor charge could be sensitive to hidden color (non-nucleonic) degrees of freedom at large x. It is also interest- ing that antishadowing in DIS in nuclei is not universal but depends on the quark flavor and spin. One can use counting rules from PQCD to predict the $x \to 1$ dependence of the tensor structure function.

Stanley Brodsky (SLAC)

I am certainly interested in the experimental development to find the novel QCD phenomena from the hidden color component of deuteron.

Chueng-Ryong Ji (NCSU)

Surely this is of real interest the spin community!

Leonard Gamberg (Penn State Berks)

I find the proposal well written, well justified, sound, and exciting.

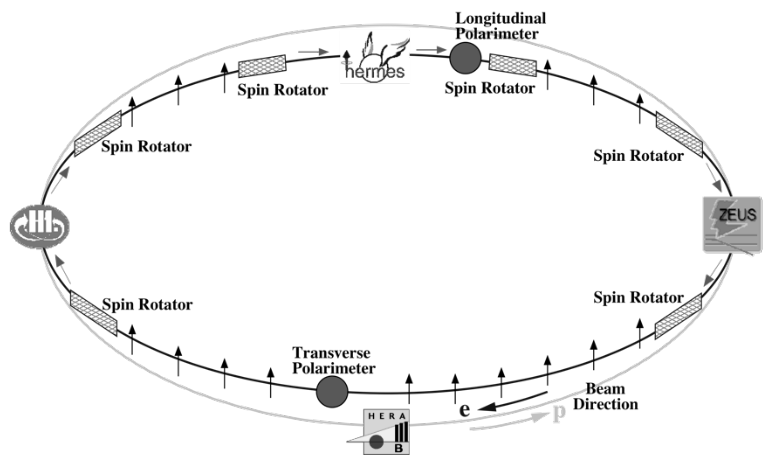
Alessandro Bacchetta (Universita di Pavia)

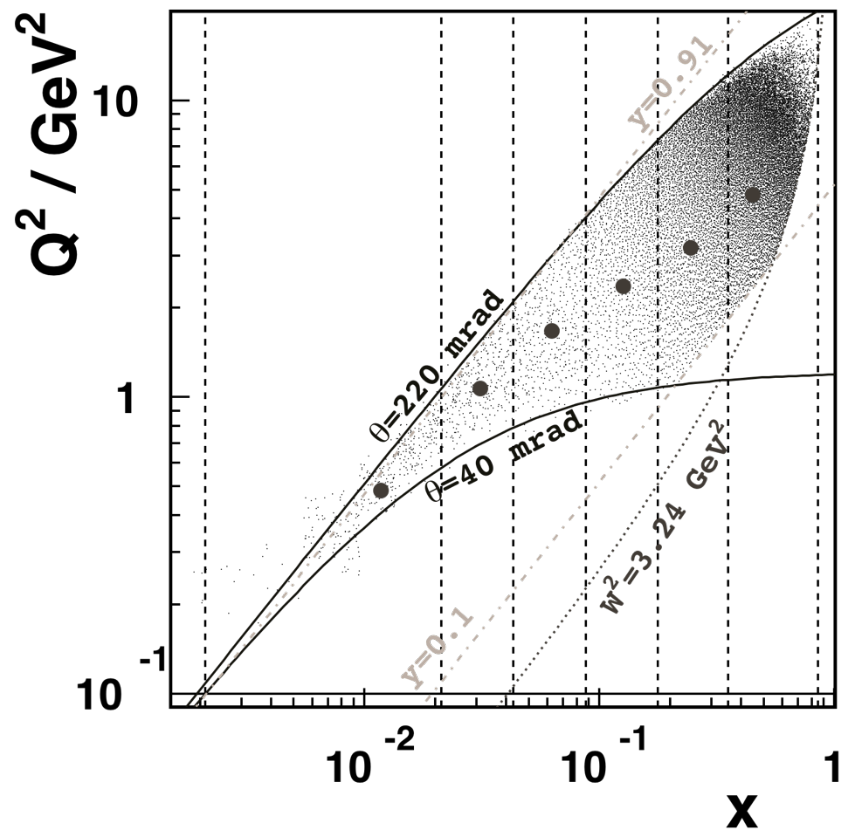
It is certainly an interesting quantity, precisely because it vanishes in the independent nucleon picture of the deuteron.

Elliot Leader (Imperial College of London)

WORLD DATA

First Data from HERMES





27.6 GeV positrons

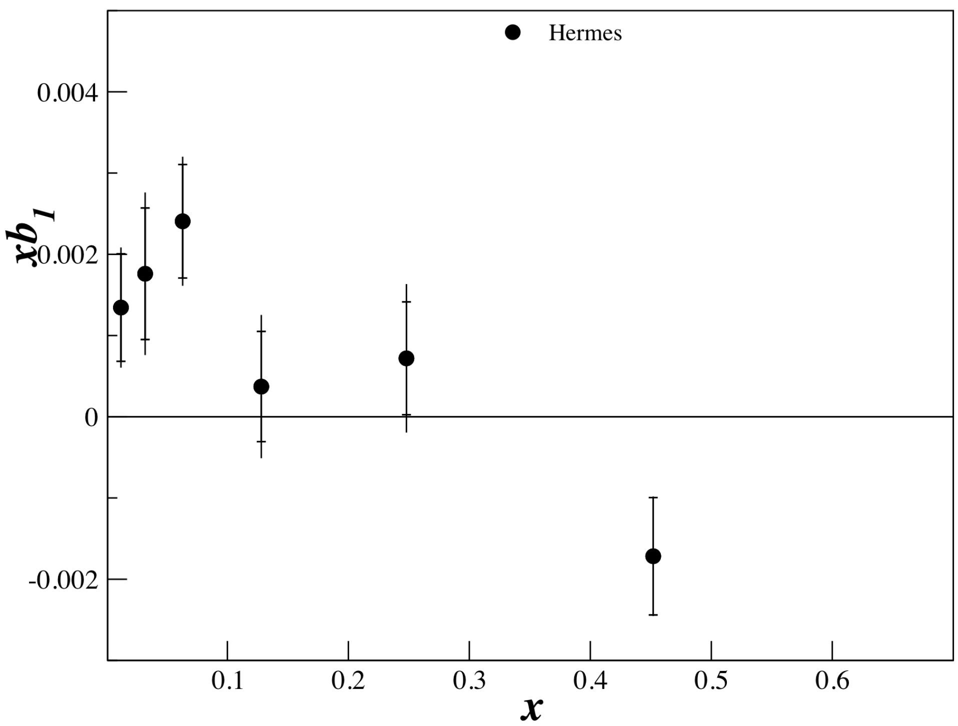
Internal gas target

~Pure tensor polarization
with little vector component

$0.01 < \langle x \rangle < 0.45$

$0.5 < \langle Q^2 \rangle < 5$ GeV^2

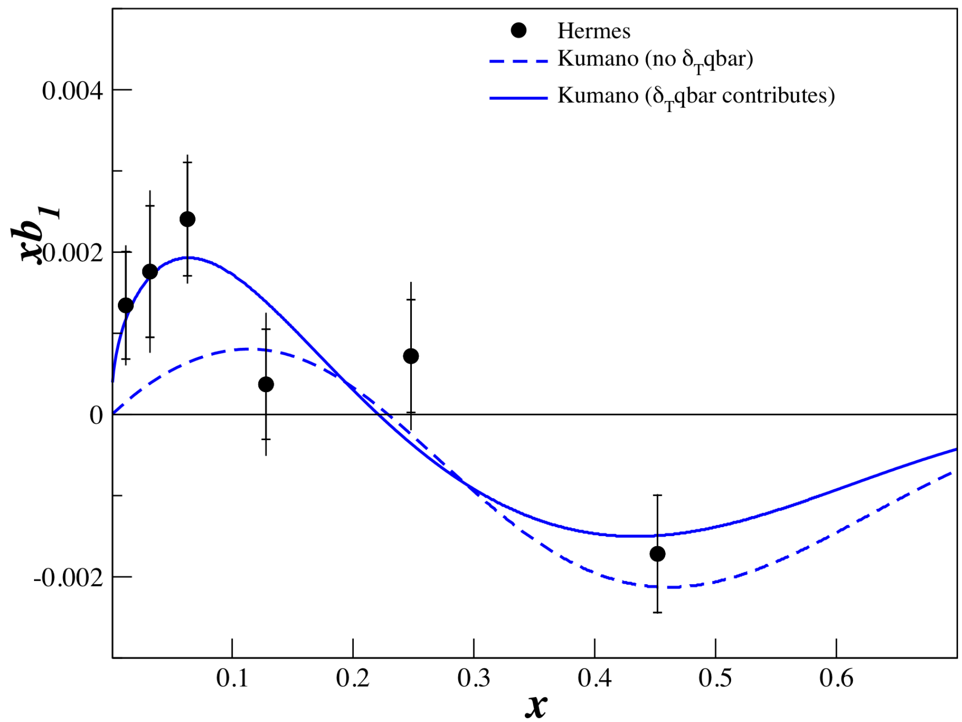
First Data from HERMES



PRL **95**, 242001 (2005)

$$b_1 = -\frac{3}{2} F_1 A_{zz}$$

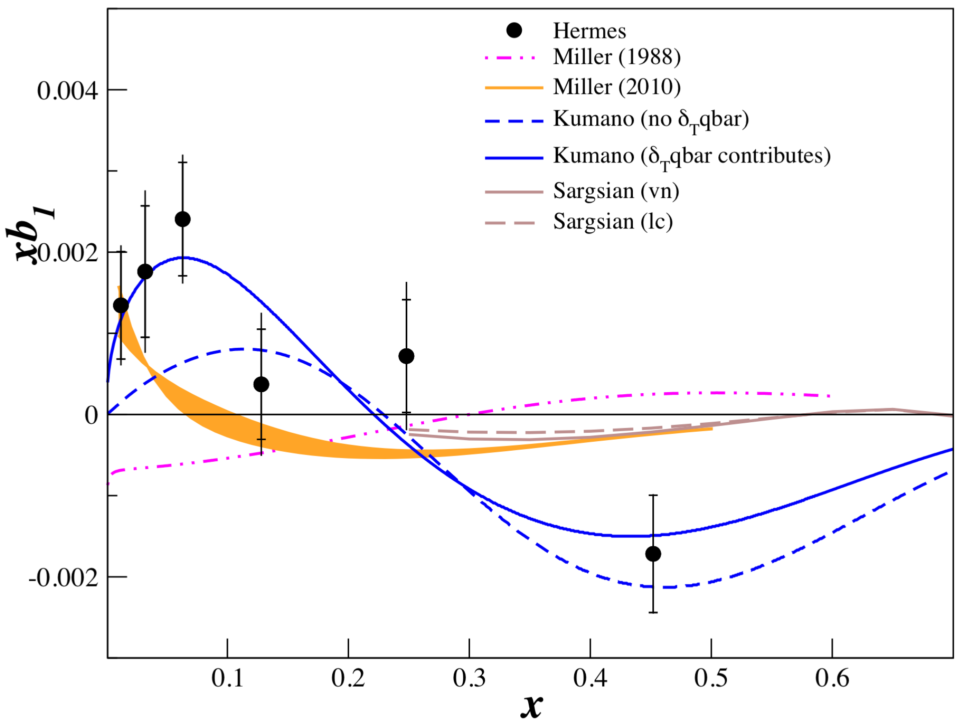
Model Predictions



Kumano Fit to the Data

Requires tensor polarized sea for best fit.

Model Predictions



All Conventional Models predict small or vanishing values of b1 in contrast to the HERMES data

Close-Kumano Sum Rule

$$\int b_1(x)dx = 0$$

Satisfied for an unpolarized sea.

Deviations from zero : good signature of exotic effects in the Deuteron Wave Function.

Khan & Hoodbhoy, PRC 44 ,1219 (1991) :
Relativistic convolution model with binding : -6.7E10^{-4}

Hermes result

$$\int_{0.02}^{0.85} b_1(x)dx = 0.0105 \pm 0.0034 \pm 0.0035$$

2.2 σ difference from zero

Jefferson Lab Experimental Set-up

JLab

- Unpolarized Beam
  - Polarized beam will be spin-averaged to isolate b_1
- UVa/JLab Polarized Target
  - Longitudinal field

JLab

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- Ratio Method

$$\frac{N_{Pol}}{N_u} - 1 = f\frac{1}{2}A_{zz}P_{zz}$$

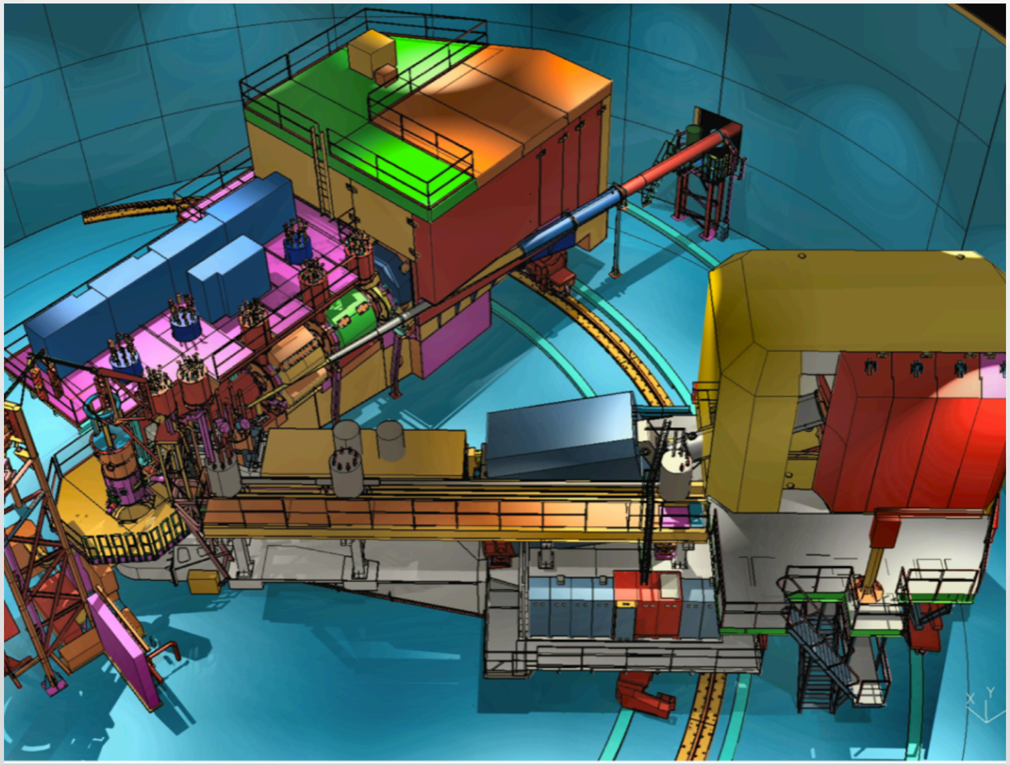
$$A_{zz} = \frac{2}{f \cdot P_{zz}}\left(\frac{N_{Pol}}{N_u} - 1\right)$$

$$b_1 = -\frac{3F_1}{f \cdot P_{zz}}\left(\frac{N_{Pol}}{N_u} - 1\right)$$

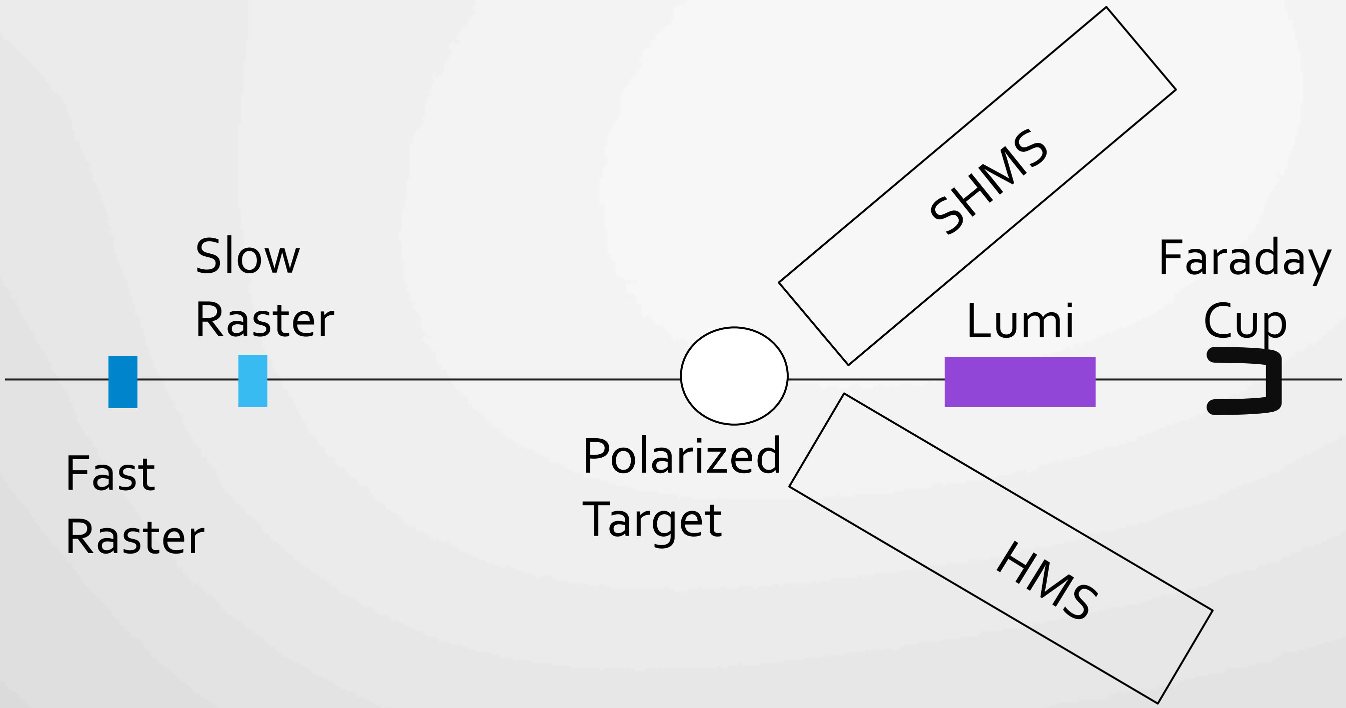
Hall C Configuration

Detector	x	Q^2 (GeV^2)	W (GeV)	$E_{e'}$ (GeV)	$\theta_{e'}$ (deg.)	θ_q (deg.)	Rates (kHz)	Time (Days)
SHMS	0.15	1.21	2.78	6.70	7.35	11.13	1.66	6
SHMS	0.30	2.00	2.36	7.45	8.96	17.66	0.79	9
SHMS	0.45	2.58	2.00	7.96	9.85	23.31	0.38	15
HMS	0.55	3.81	2.00	7.31	12.50	22.26	0.11	30

$I_{beam} = 115$ nA



Hall C Beamline



Polarized Target

- Dynamic Nuclear Polarization of ND_3
- 5 Tesla at 1 K
- SLAC, G_E^n (1&2), RSS, SANE, g2p
- 3cm Target Length
- $p_f \sim 0.65$
- $f_{dil} \sim 0.27$
- Development of a highly-polarized (30%+) tensor deuteron target has far-reaching effects

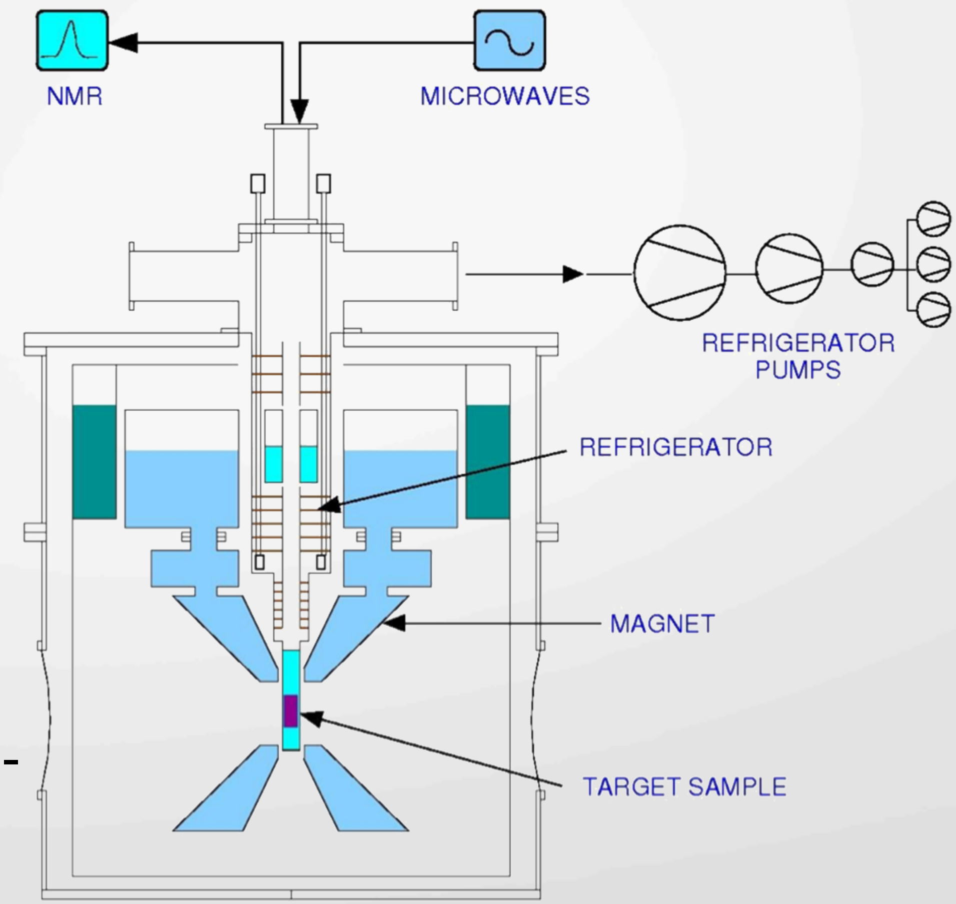


Figure courtesy of C. Keith

Polarization With Hole-Burning

- (Waiting for Dustin's slides…)

$$P_{zz}^{HB} \approx \frac{A^{NMR}}{A^{I}} \Big(P_{zz}^{I} + r_0 (P^{I} - P_{zz}^{I}) \Big)$$

Polarization Cycle

- Each day will consist of 10 hours of polarized beam, depolarization using destructive NMR and DPR, and 10 hours of unpolarized beam with 4 hours spent switching between states
- Each pol/unpol cycle is an independent measurement
  - Any issues from annealing, bead dropping, or luminosity drift will be isolated to a single cycle and not effect the rest of the data
- For the lowest SHMS setting, the time spent in each state will be halved

Kinematics

Detector	x	Q^2 (GeV^2)	W (GeV)	$E_{e'}$ (GeV)	$\theta_{e'}$ (deg.)	θ_q (deg.)	Rates (kHz)	Time (Days)
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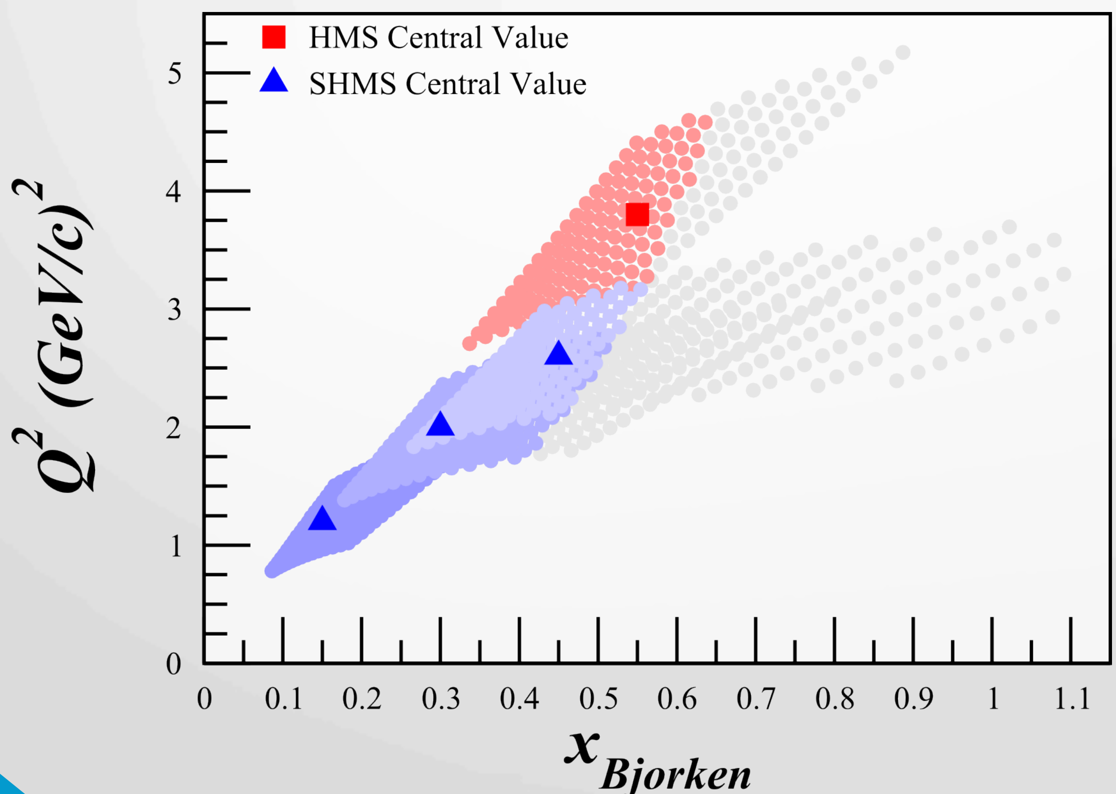
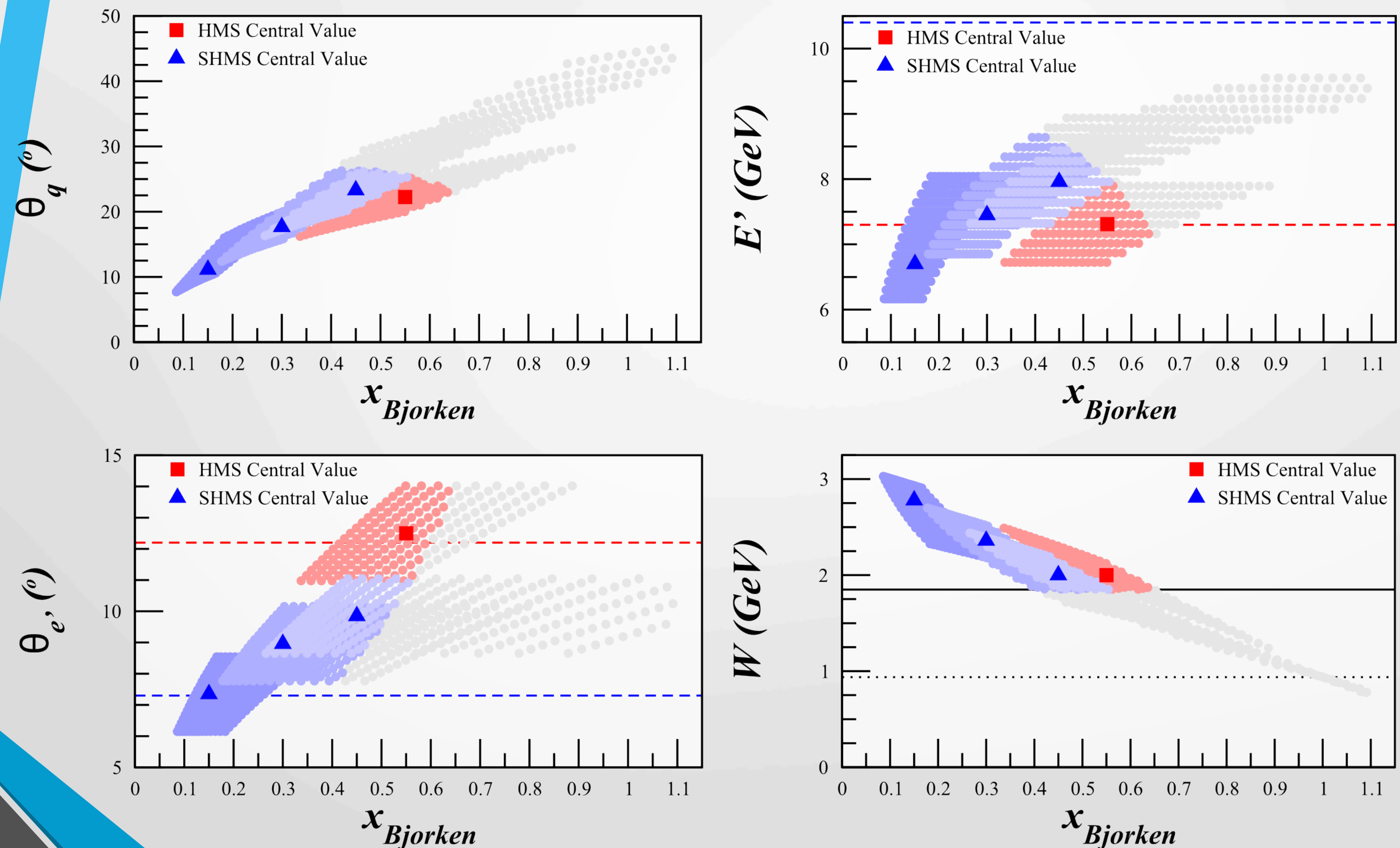
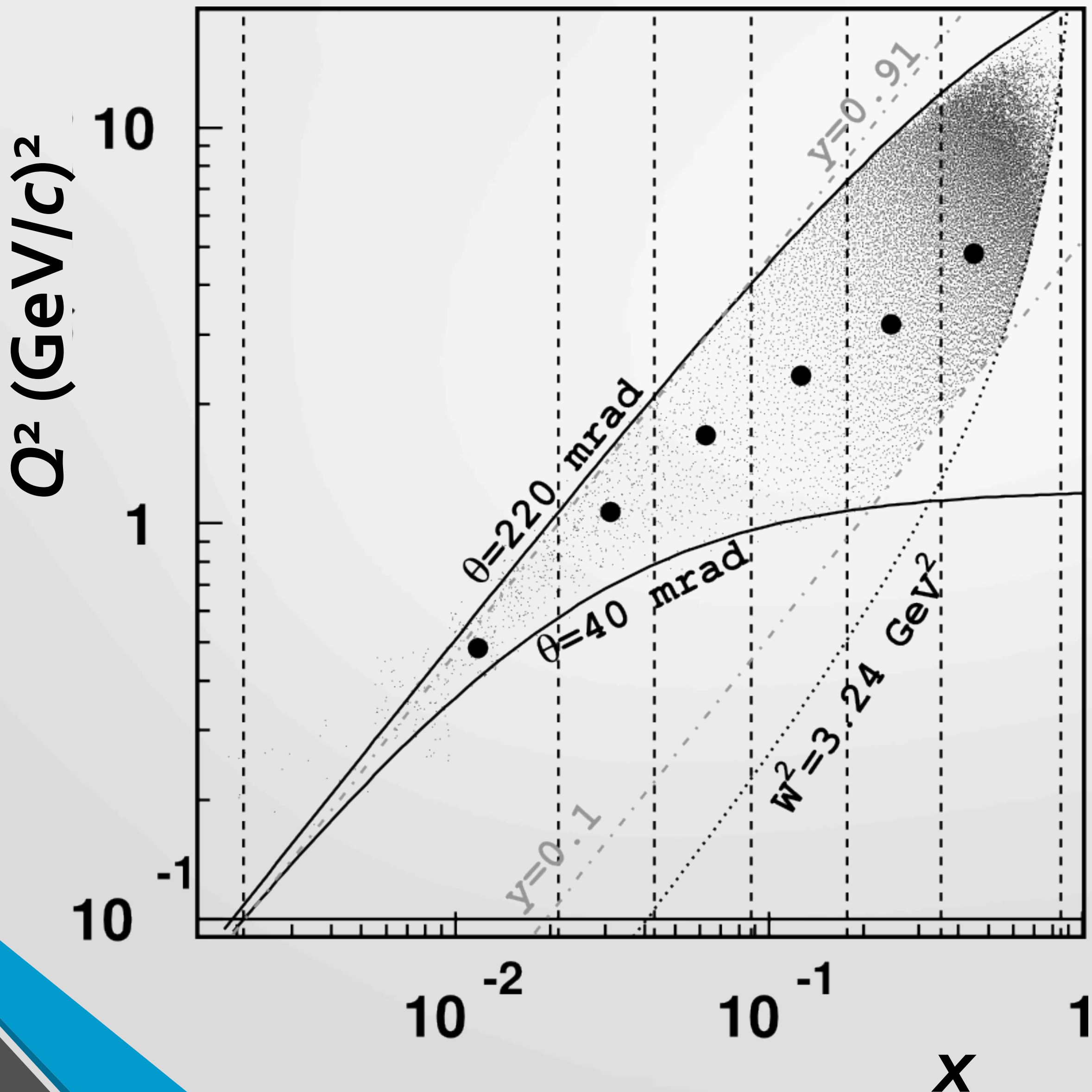


Kinematics



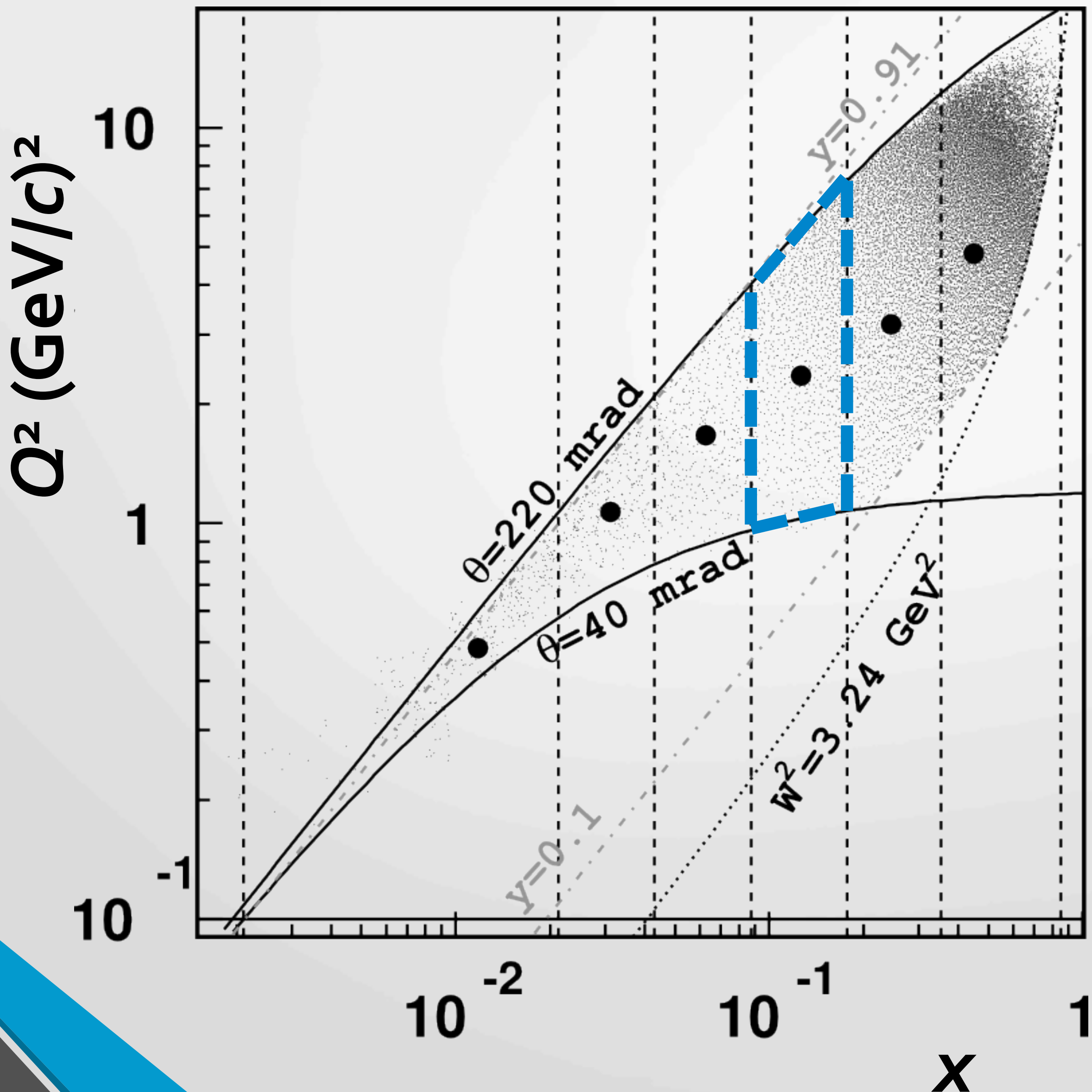
HMS Central Value
SHMS Central Value
θq (°)
xBjorken
E' (GeV)
θe' (°)
W (GeV)

HERMES Kinematics



- Logarithmic Scale

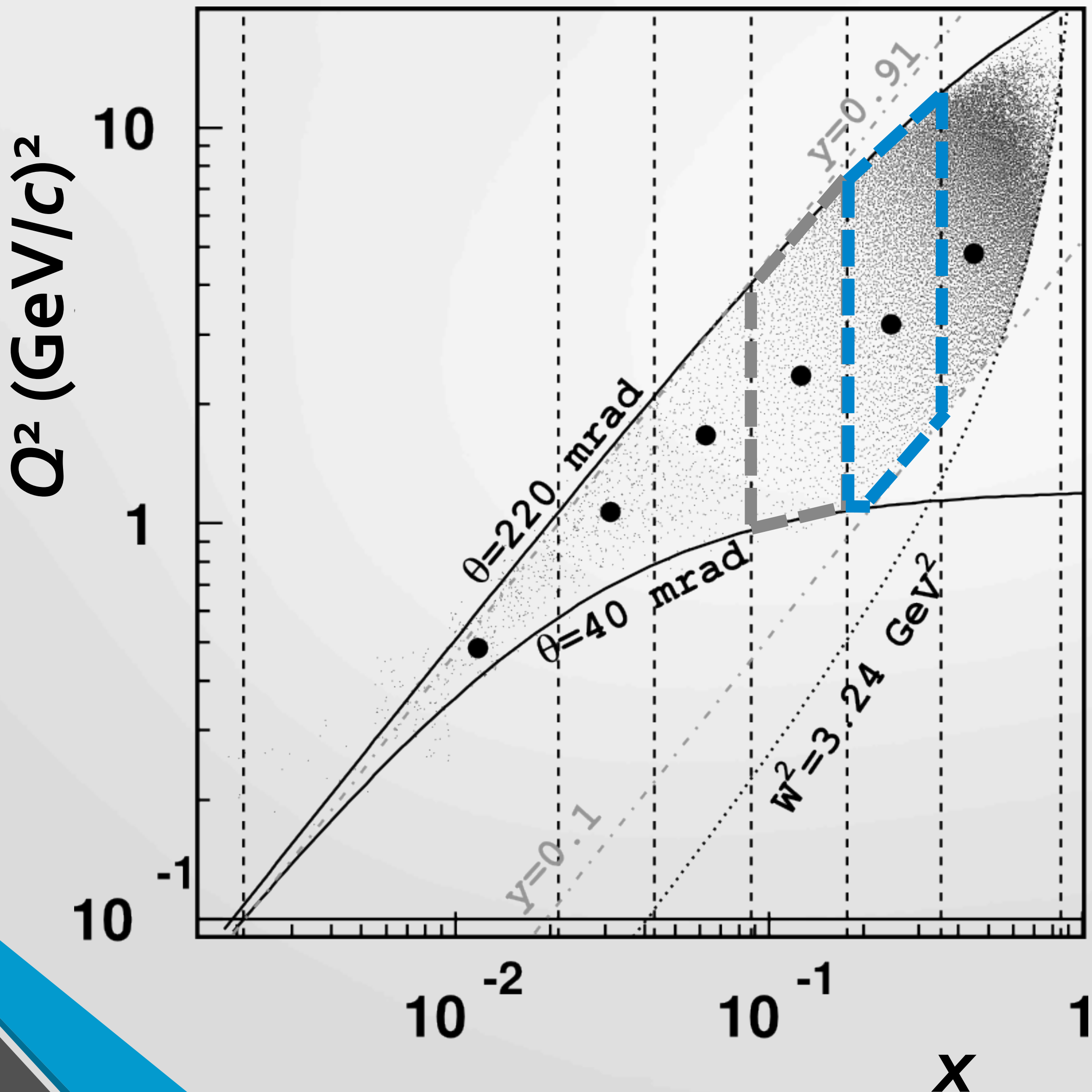
HERMES Kinematics



Approximate

- $0.09 < x < 0.18$
- $0.8 < Q^2 < 7$

HERMES Kinematics



Approximate

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- $0.18 < x < 0.35$
- $1 < Q^2 < 9$

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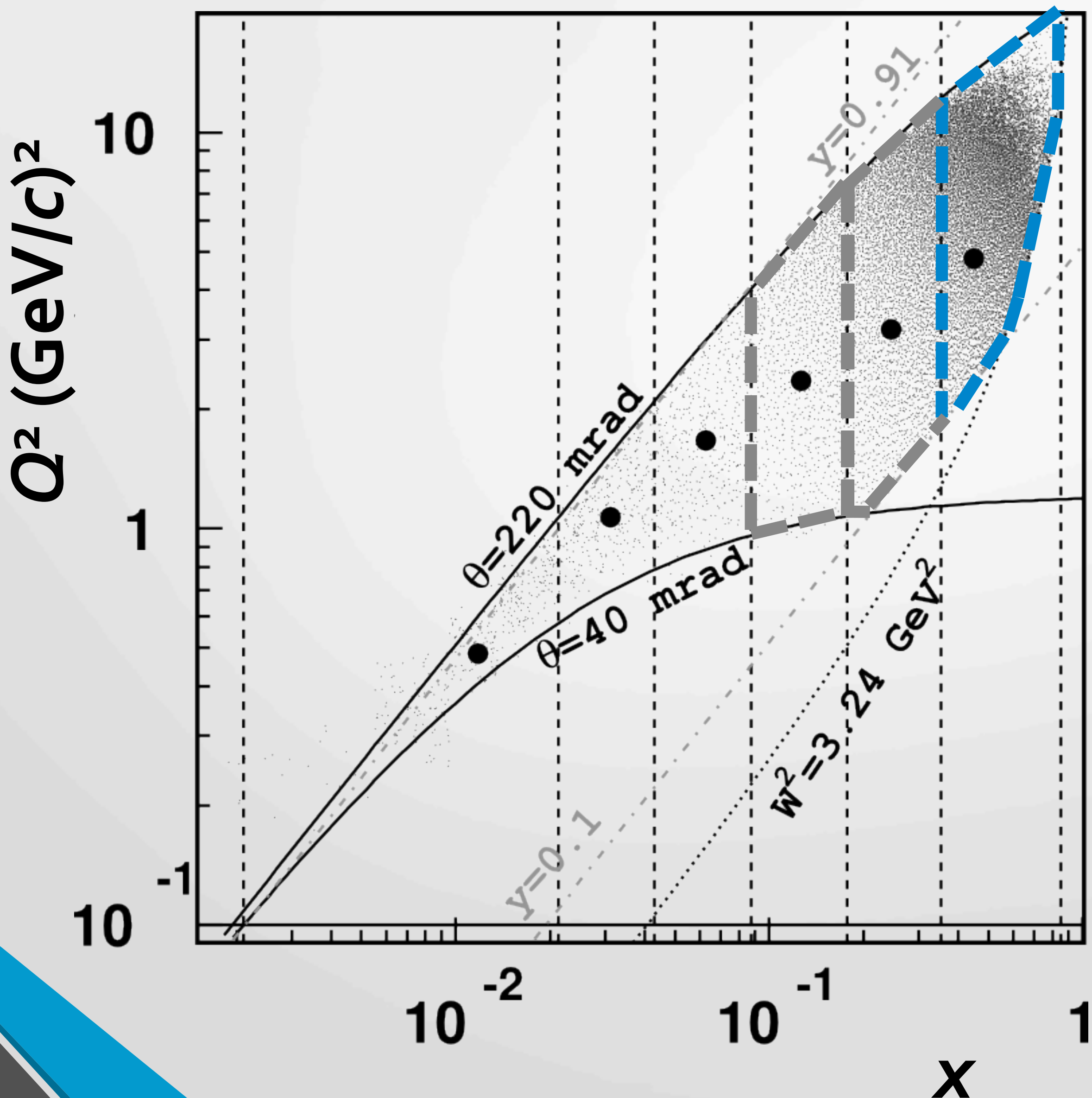

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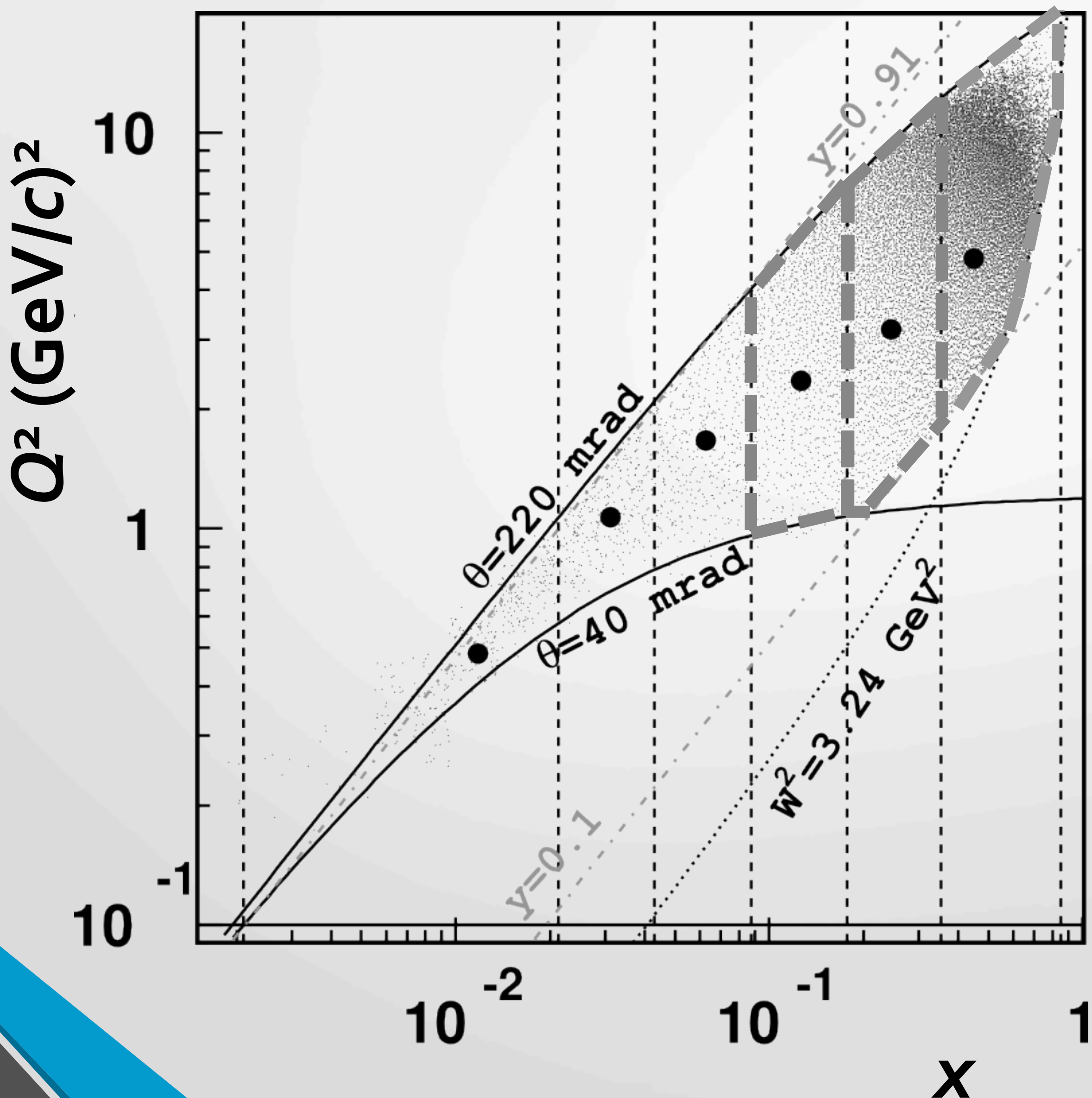
- $0.35 < x < 0.85$
- $2 < Q^2 < 18$

HERMES Kinematics



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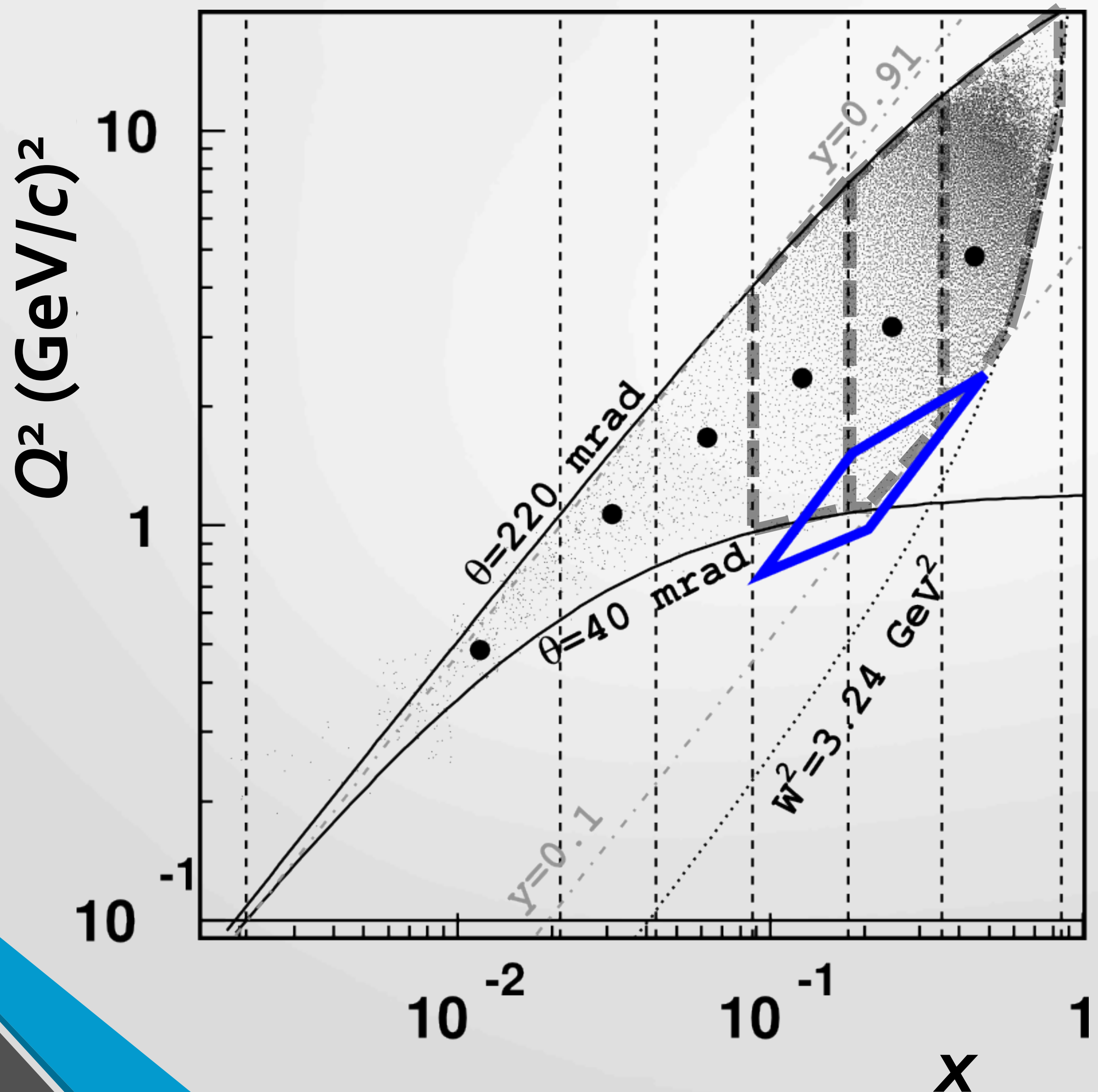
This experiment

HERMES Kinematics



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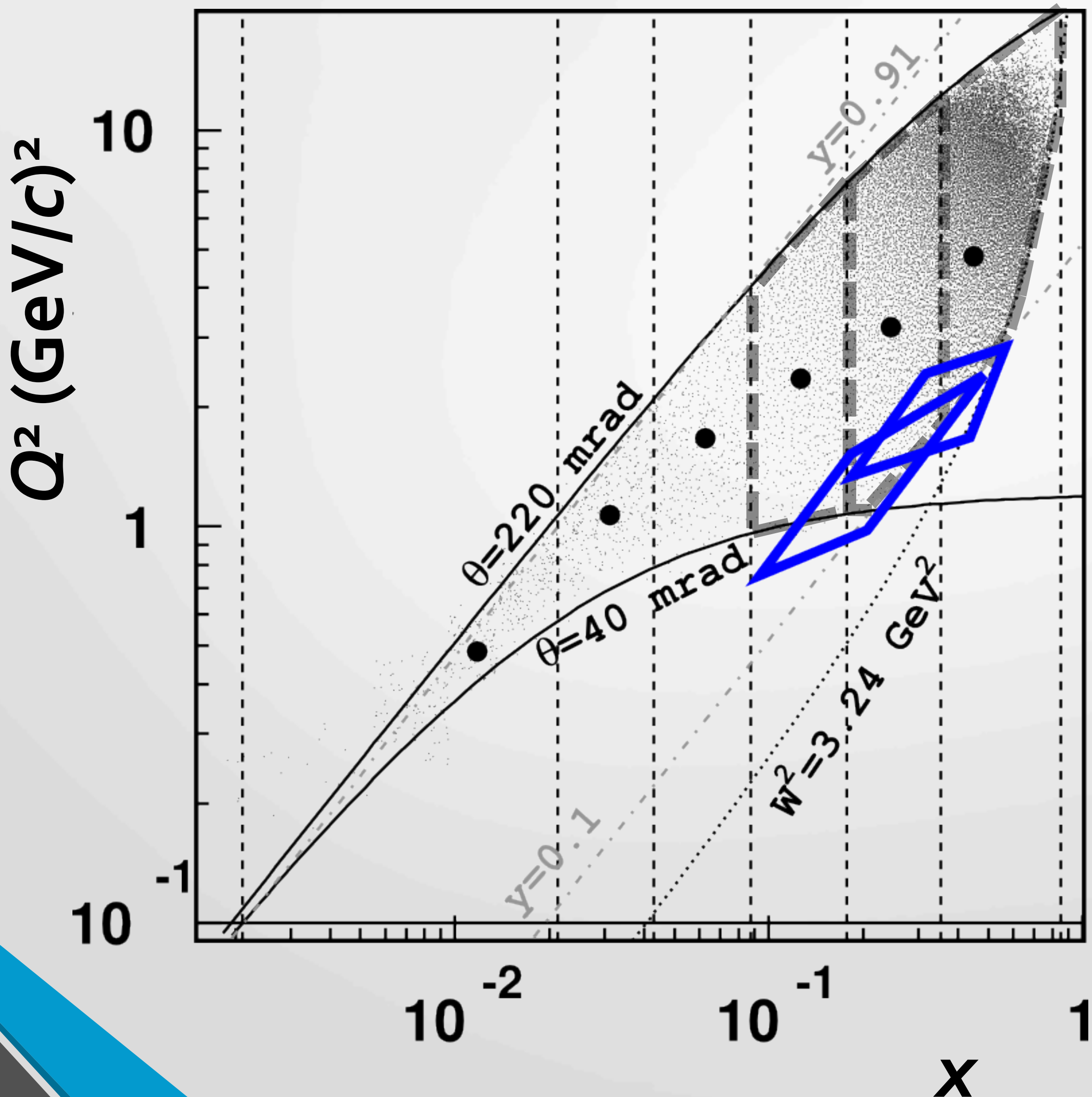

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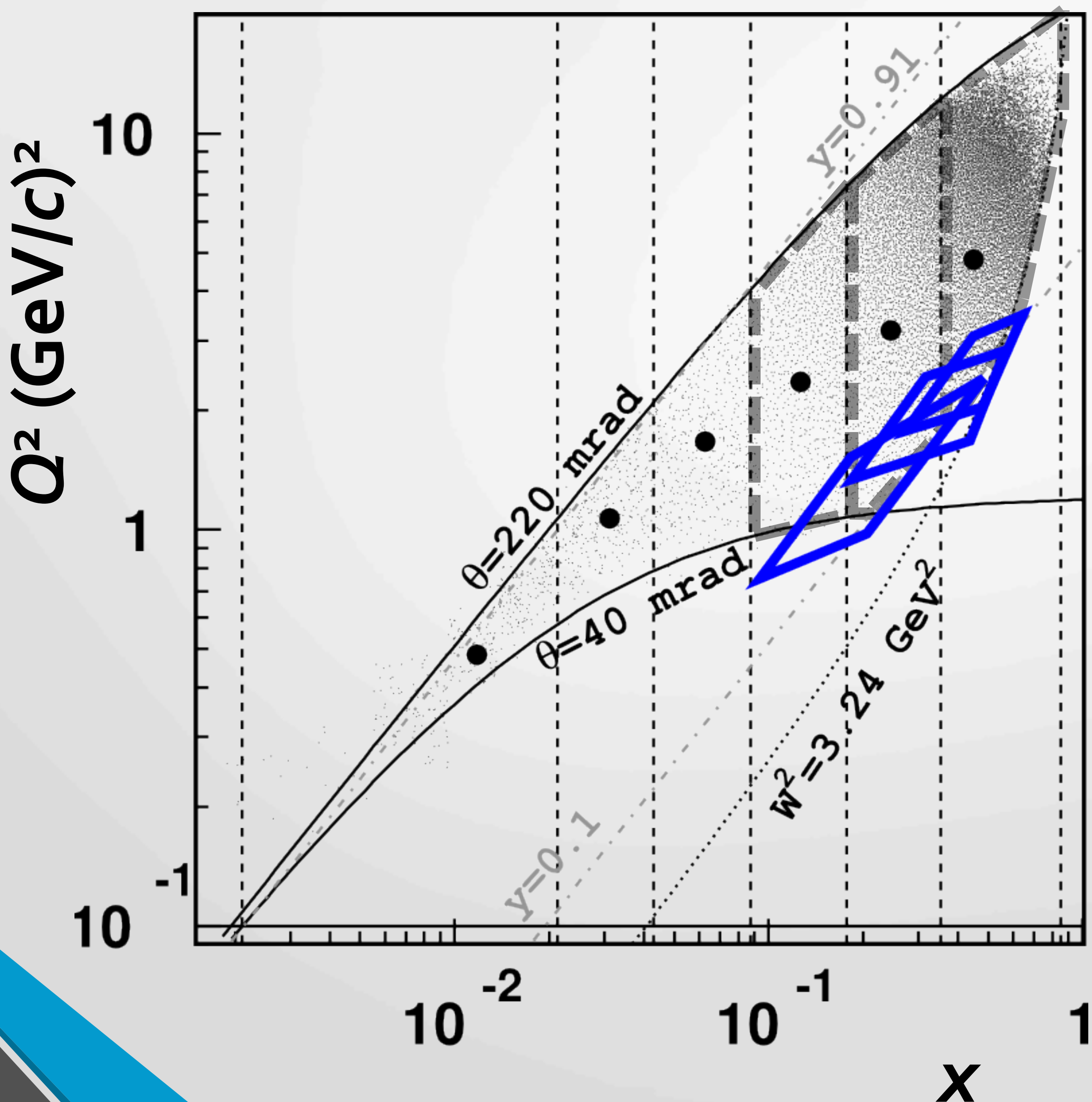

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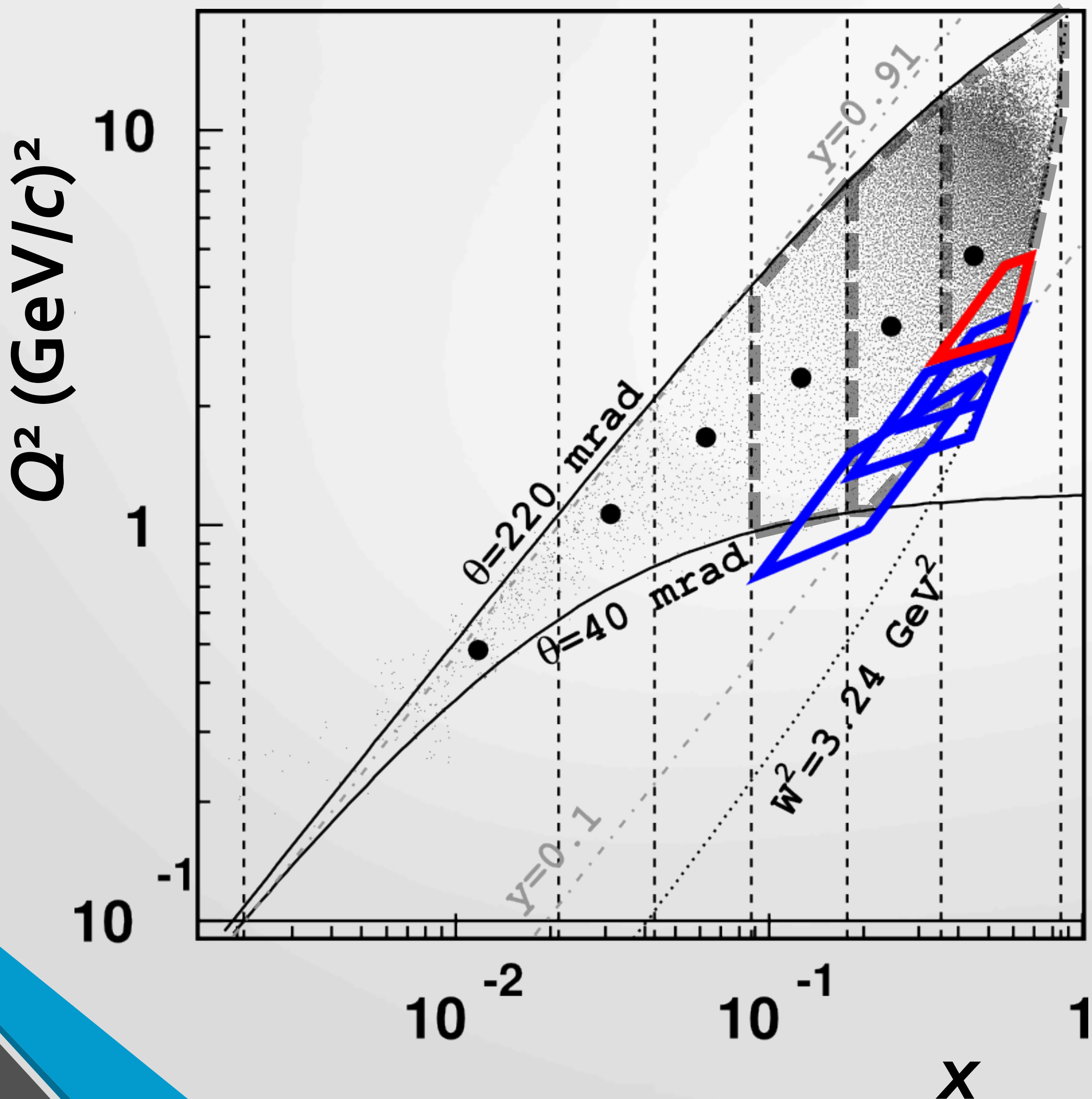
HERMES Kinematics



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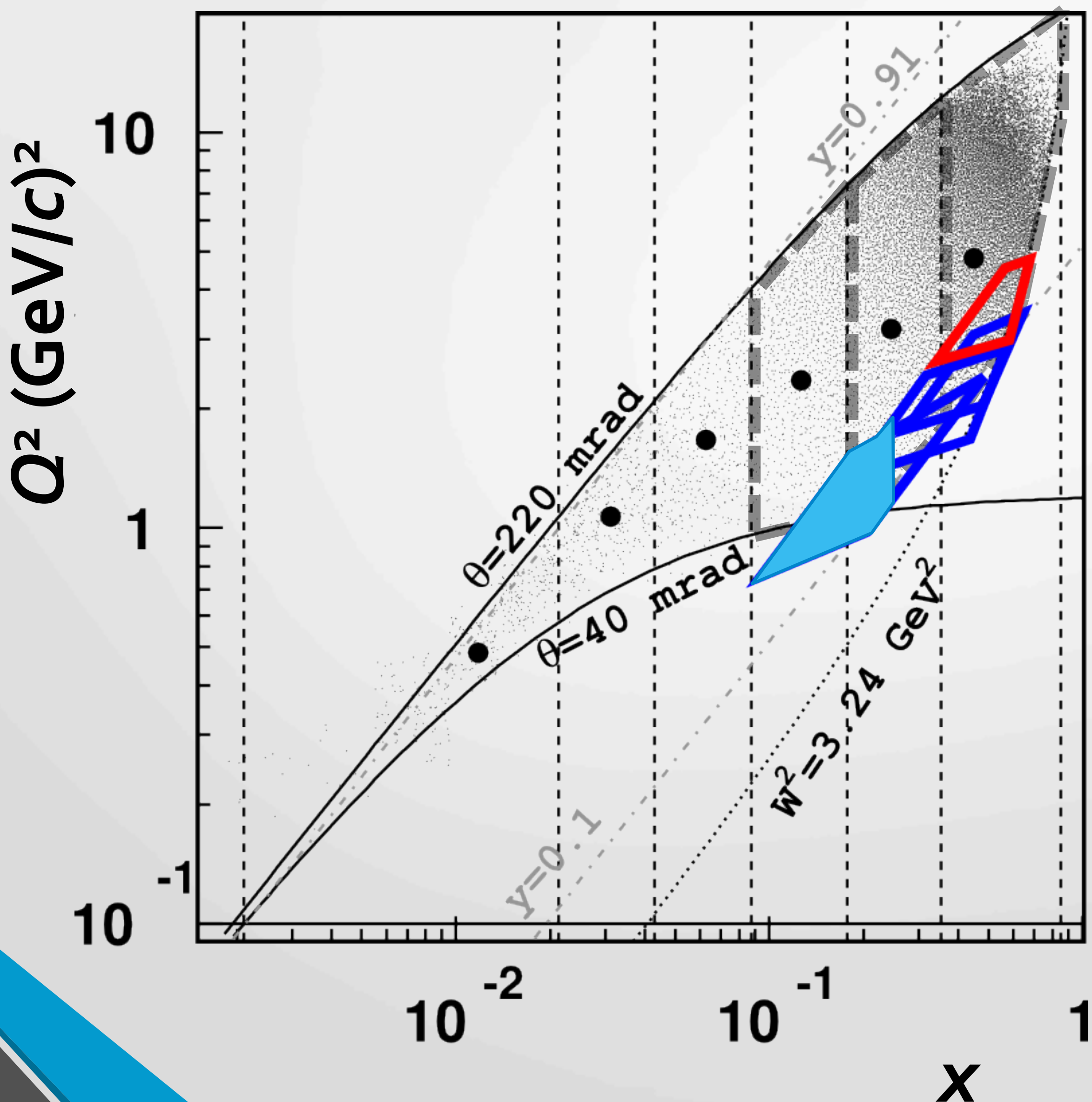

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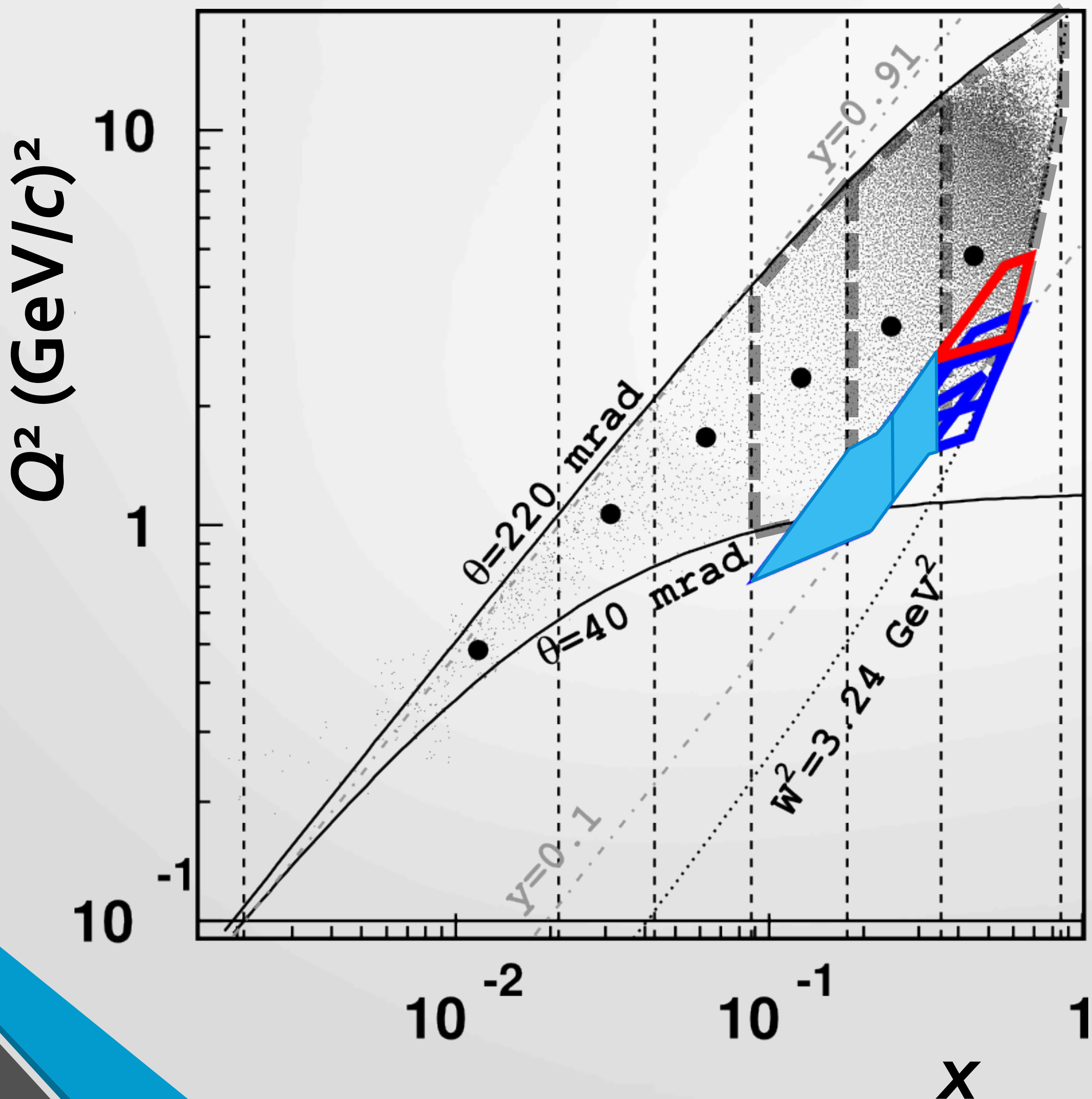
<u>This experiment</u>

- $0.09 < x < 0.23$
- $0.75 < Q^2 < 1.1$

HERMES Kinematics



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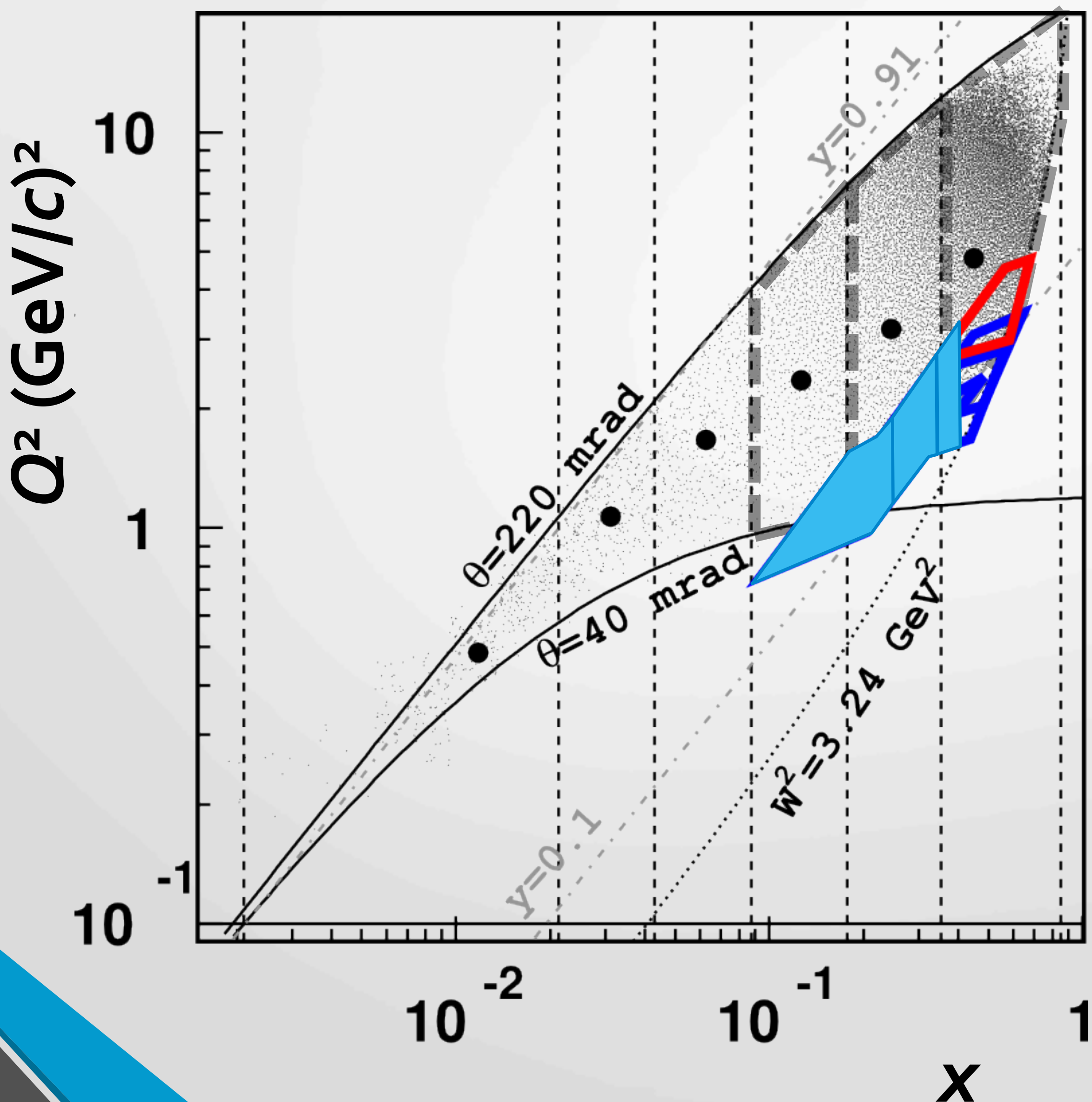
- $0.09 < x < 0.23$
- $0.75 < Q^2 < 1.1$
- $0.23 < x < 0.32$
- $1.1 < Q^2 < 2.6$

HERMES Kinematics



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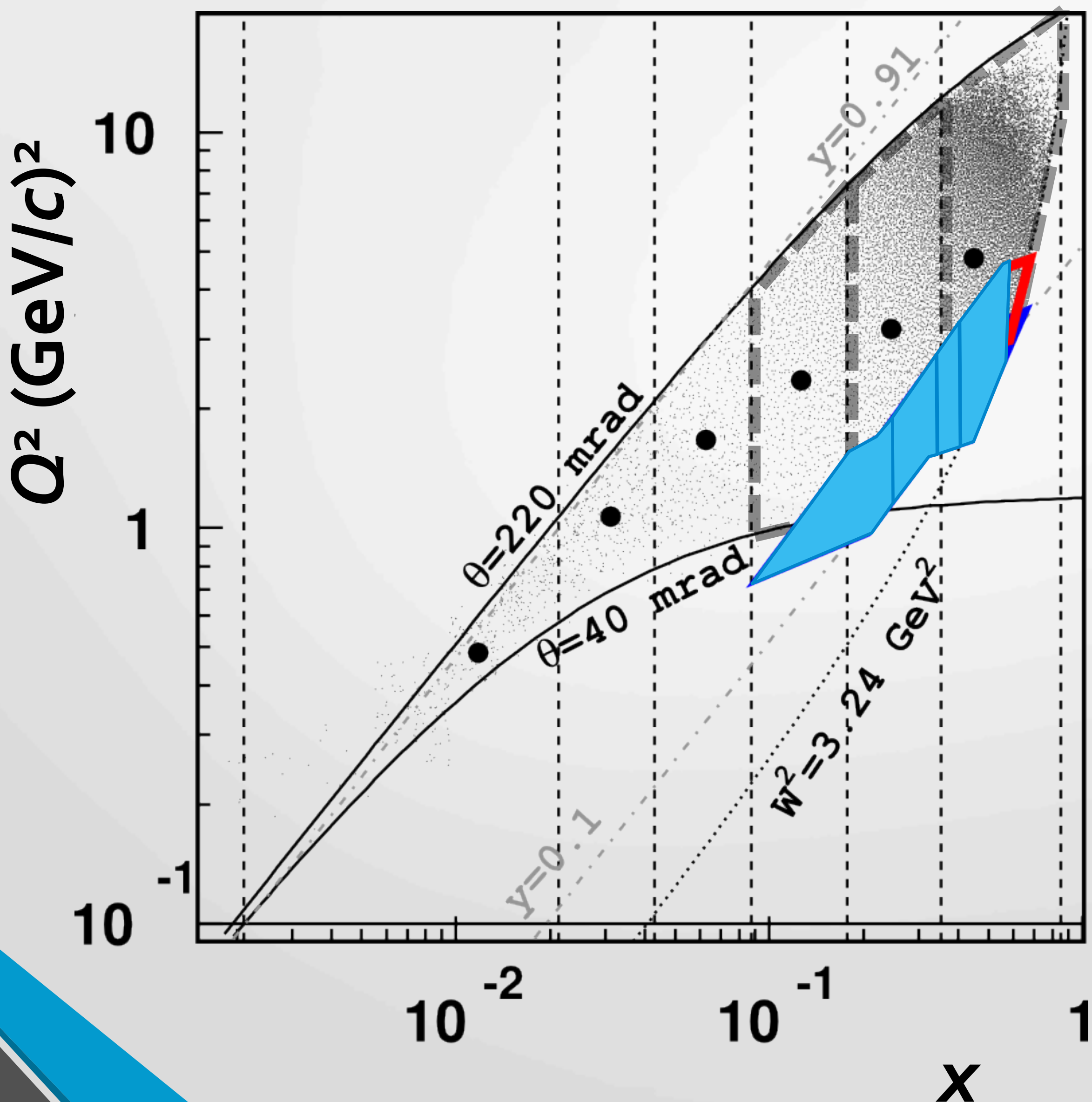
This experiment

- $0.09 < x < 0.23$
- $0.75 < Q^2 < 1.1$
- $0.23 < x < 0.32$
- $1.1 < Q^2 < 2.6$
- $0.32 < x < 0.40$
- $2.6 < Q^2 < 3.1$

HERMES Kinematics



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- $2 < Q^2 < 18$

This experiment

- $0.09 < x < 0.23$
- $0.75 < Q^2 < 1.1$
- $0.23 < x < 0.32$
- $1.1 < Q^2 < 2.6$
- $0.32 < x < 0.40$
- $2.6 < Q^2 < 3.1$
- $0.40 < x < 0.58$
- $3.1 < Q^2 < 4.3$

Addressing Systematics

- Charge drift
  - $< 2 \times 10^{-4}$, mitigated by thermal isolation of BCMs and addition of new low-power Faraday Cup (comparable to E06-010 and E08-027
- Beam drift
  - $< 6 \times 10^{-4}$/cycle, mitigated by taking multiple cycles
- Trigger and tracking drift
  - $< 2.2 \times 10^{-4}$, similar to Transversity in Hall A
- Target dilution and length
  - $\sim 1 \times 10^{-4}$,
- Luminosity
  - $\sim 1 \times 10^{-4}$, monitored with the Hall C Lumi
- Unpolarized measurement with polarized beam
  - $\sim 2.2 \times 10^{-5}$, using parity feedback

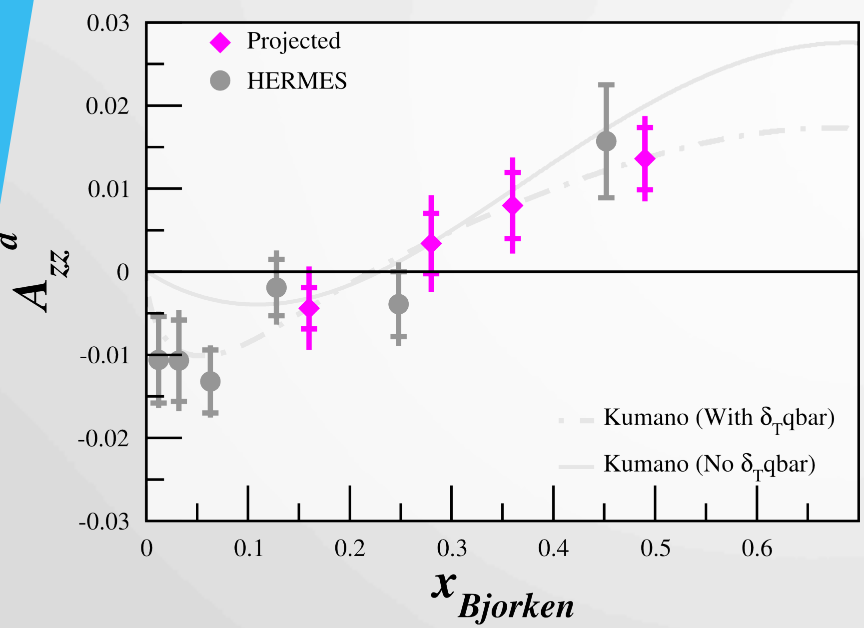
Systematic Contributions

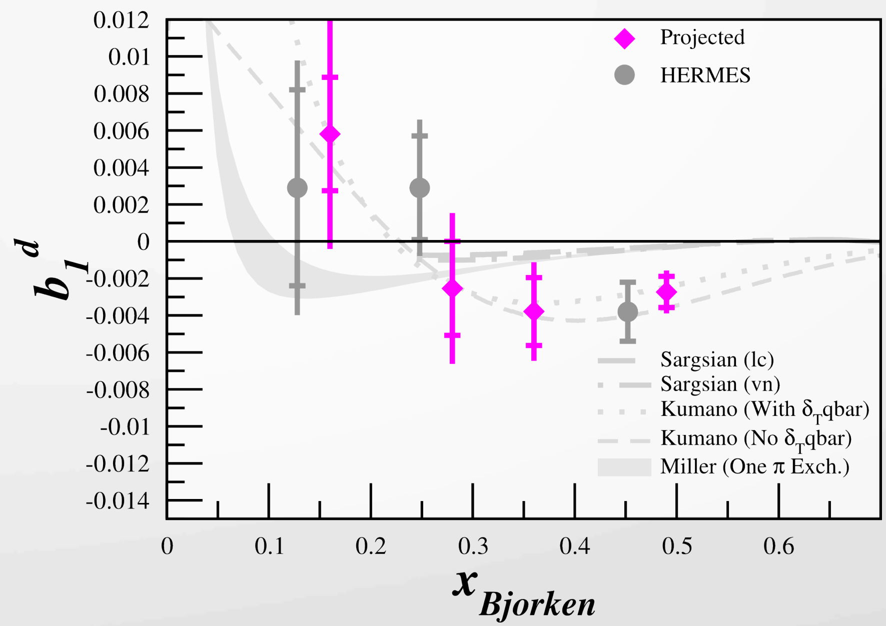
Source	Relative Uncertainty
Polarimetry	8.0%
Dilution/Packing Fraction	4.0%
Radiative Corrections	1.5%
Charge Determination	1.0%
Detector Resolution and Efficiency	1.0%
Total	9.2%

Spec. $\langle x \rangle$	Hours	Stat. Err ($\times 10^{-3}$)	Cycles	Drift Error ($\times 10^{-3}$)
0.15	144	2.6	12	4.3
0.30	216	3.0	9	4.9
0.45	360	3.7	15	3.8
0.55	720	4.1	36	2.4

Projected Results

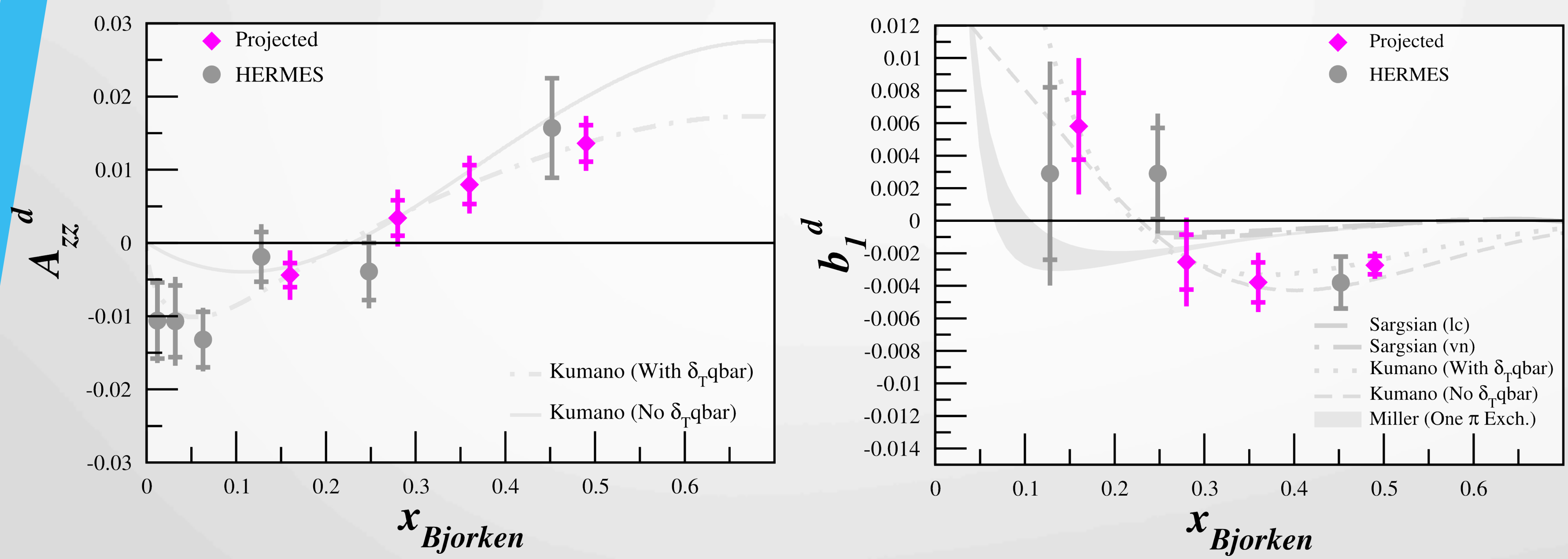
- Assuming P_{zz}=20%





Projected Results

- Assuming P_{zz}=30%



Summary

- All conventional models predict b_1~0 at moderate x
- Large, non-zero values of b_1 in this region would serve as clean signatures of exotic effects in nuclei
- First data showed intriguing behavior, but are only ~2σ from zero
- HMS/SHMS from Hall C

Summary

- All conventional models predict b_1~0 at moderate x
- Large, non-zero values of b_1 in this region would serve as clean signatures of exotic effects in nuclei
- First data showed intriguing behavior, but are only ~2σ from zero
- HMS/SHMS from Hall C
- Novel type of experiment at Jefferson Lab
- With 30 days of beam-time we can perform a very precise measurement of b_1 for $0.1 < x < 0.6$ with much smaller kinematic binning than HERMES
  - 2.7σ for P_{zz}=20%, 3.6σ for P_{zz}=30% at x=0.49

Back-Ups

Close-Kumano Sum Rule Calculations

- Integrating model calculations in the x range we will measure
- Miller ($0.15 < x < 0.5$)
  - -0.0001
- Sargsian ($0.245 < x < 0.5$)
  - -0.0002

Polarization Without Hole-Burning

- UVA has achieved vector polarization > 50%
- Polarization measured using line shape fitting
  - Vector polarization from NMR signal

$$P = C \int \frac{\omega_d S(\omega)}{\omega} d\omega$$

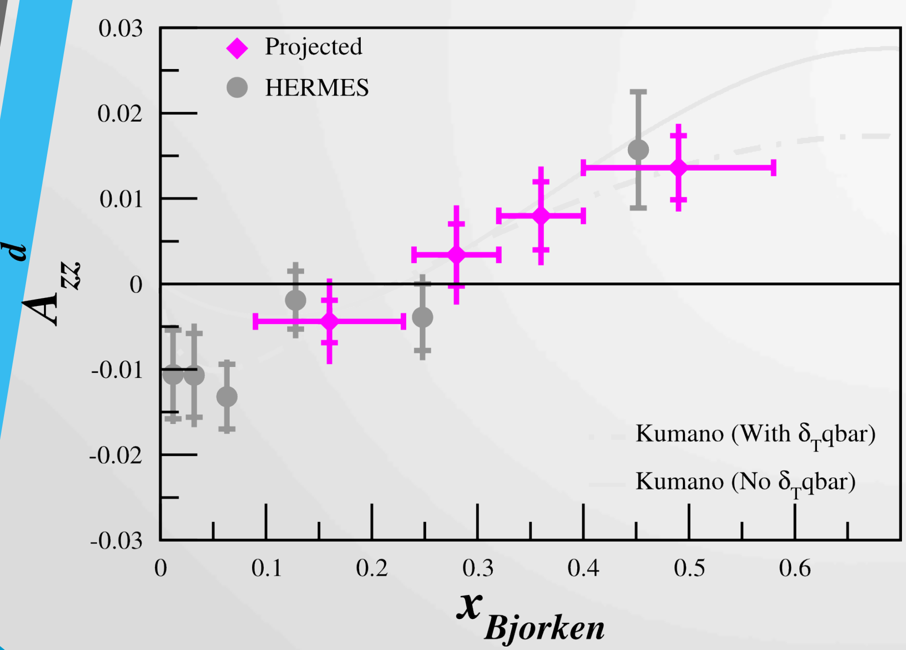
  - Determine tensor polarization from vector polarization

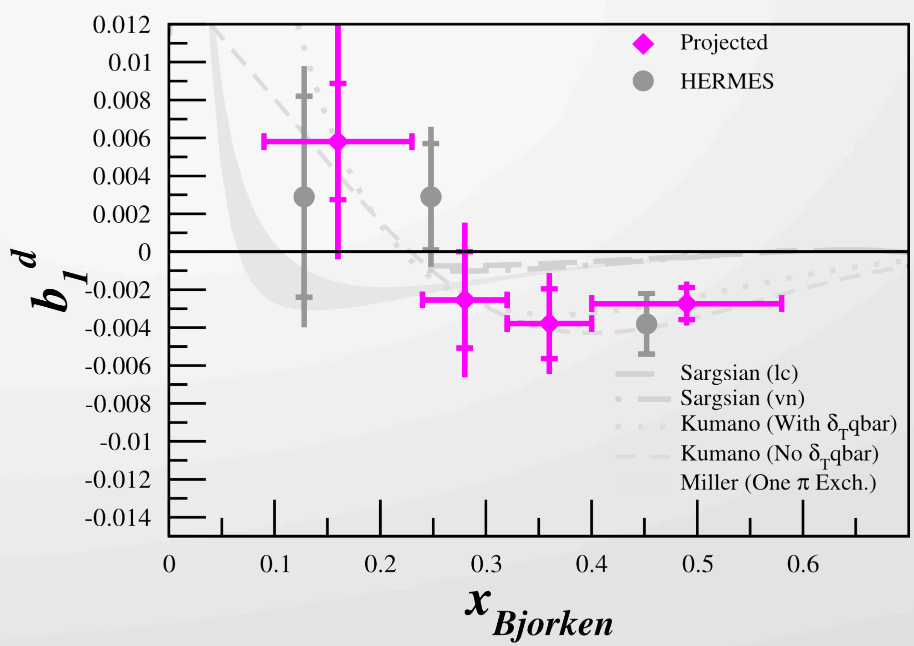
$$P_{zz} = 2 - \sqrt{4 - 3P^2}$$

- With development, we expect to achieve P_{zz} ~ 20%

Projected Results

- Assuming P_{zz}=20%





Projected Results

- Assuming P_{zz}=30%