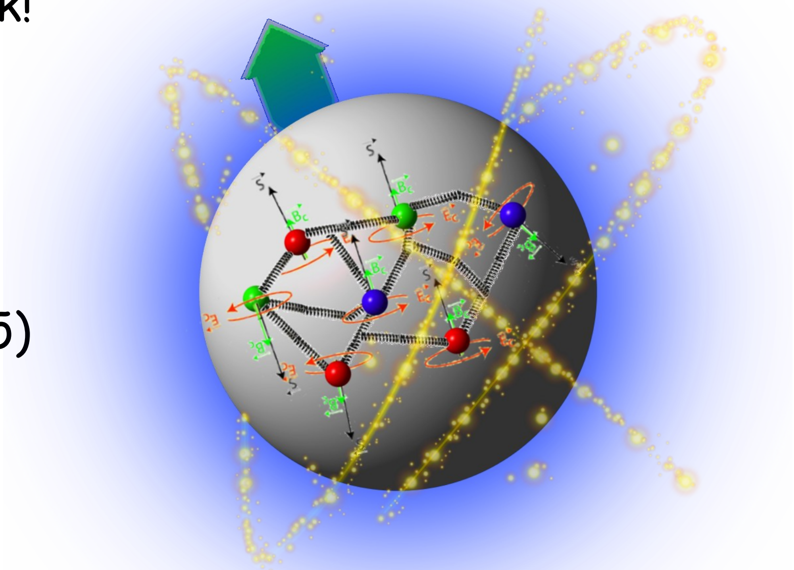
E12-06-121
Measuring the Neutron g_2 and d_2 at 12 GeV

- A cross section measurement on a *polarized* ^{3}He target in Hall C

- Directly measure the Q^2 dependence of the neutron $d_2^n(Q^2)$ at $Q^2 \approx 3, 4, 5, 6$ GeV^2 with the new polarized ^{3}He target.
  - ➡ d_2 integrals will involve data at fixed Q^2 for the first time.
  - ➡ The SHMS is ideally suited to this task!

- Doubles number of precision data points for $g_2^n(x, Q^2)$ in DIS region.
  - ➡ Q^2 evolution of g_2^n over $(0.23 < x < 0.85)$



- Spokespeople: T. Averett, W. Korsch, Z.E. Meziani, B. Sawatzky

d_2: A clean probe of quark-gluon correlations

- d_2 is a clean probe of quark-gluon correlations / higher twist effects

$$d_2(x,Q^2) = \int_0^1 x^2 [2g_1(x,Q^2) + 3g_2(x,Q^2)]\, dx$$

  ➡ d_2 is the 2nd moment of a sum of the spin structure functions

  ➡ matrix element in the Operator Product Expansion

    ↳ *it is cleanly computable using Lattice QCD*

- Connected to the *color Lorentz force* acting on the struck quark (Burkardt)

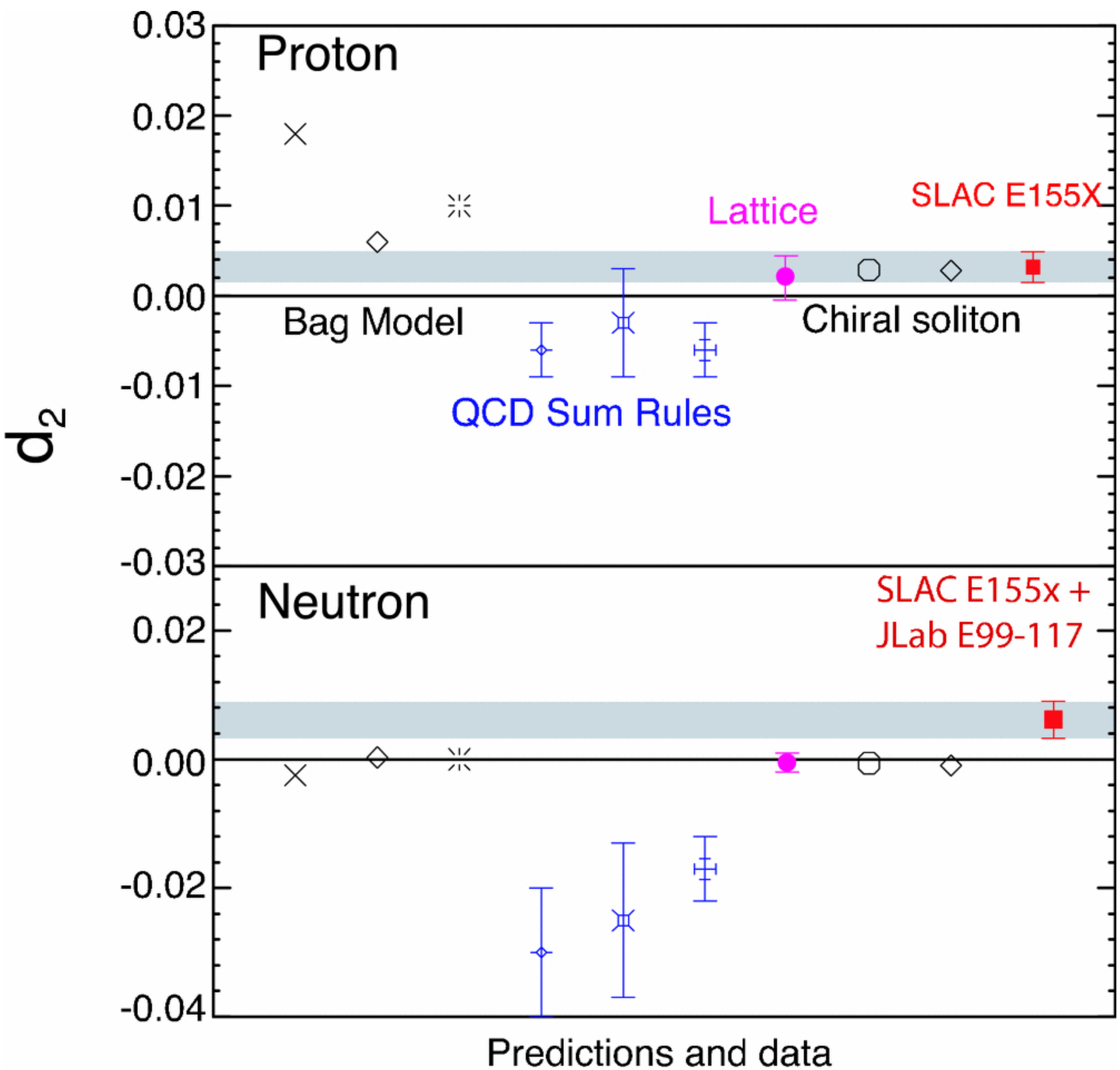
  ➡ same underlying physics as in SIDIS $k_\perp$ studies

- Investigate the present discrepancy between data and theories for the neutron d_2

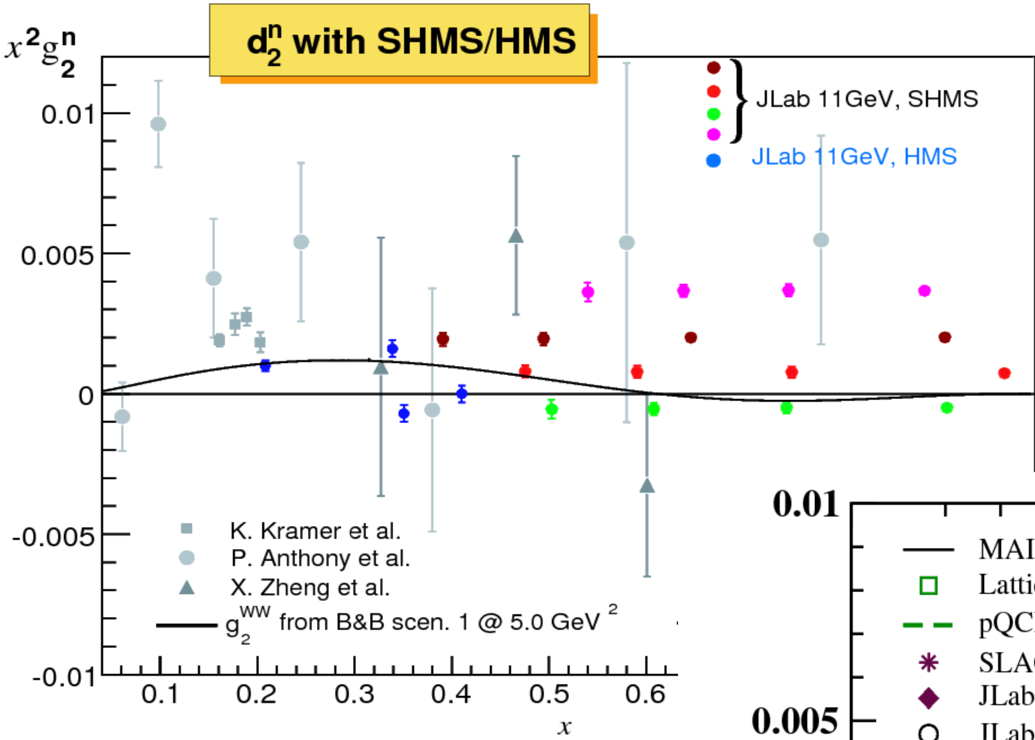
  ➡ Theory calcs consistent but have wrong sign, wrong value.

    - Spokespeople: T. Averett, W. Korsch, Z.E. Meziani, B. Sawatzky

Model evaluations of d_2

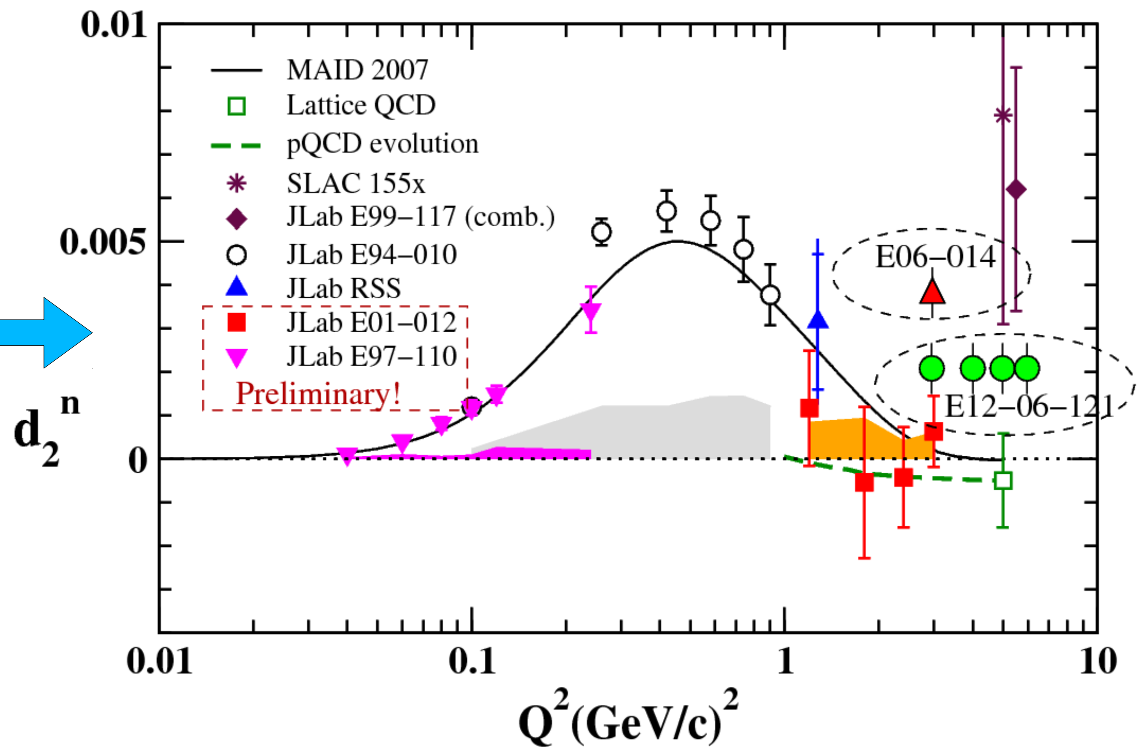


Projected results for E12-06-121



Projected g_2^n points are vertically offset from zero along lines that reflect different (roughly) constant Q^2 values from 2.5—7 GeV^2.

- Q2 evolution of d_2^n in a region where models are thought to be accurate.
- Direct overlap with 6 GeV Hall A measurement point.



E12-06-121 for Hall C and SHMS/HMS

- A polarized electron beam of 11.0 GeV and *new* polarized ^{3}He target
  - ➡ Measure $\Delta\sigma_\perp = \sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}$, $\Delta\sigma_\parallel = \sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}$ for $^3\vec{\mathrm{He}}(\vec{e},e')$ reaction using both the SHMS and HMS running in parallel for 4 kinematic settings of *125 hours* each
    - SHMS: (7.5 GeV/c, 11.0°), (7.0 GeV/c, 13.3°), (6.3 GeV/c, 15.5°), *(5.6 GeV/c, 18.0°)*
    - HMS: (4.3 GeV/c, 13.5°), (5.1 GeV/c, 16.4°), (4.0 GeV/c, 20.0°), *(2.5 GeV/c, 25.0°)*
- Polarized target will also be used with 12 GeV A1n (Hall A & C), and GeN-II experiments
- Determine d_2^n and g_2^n using the relations:

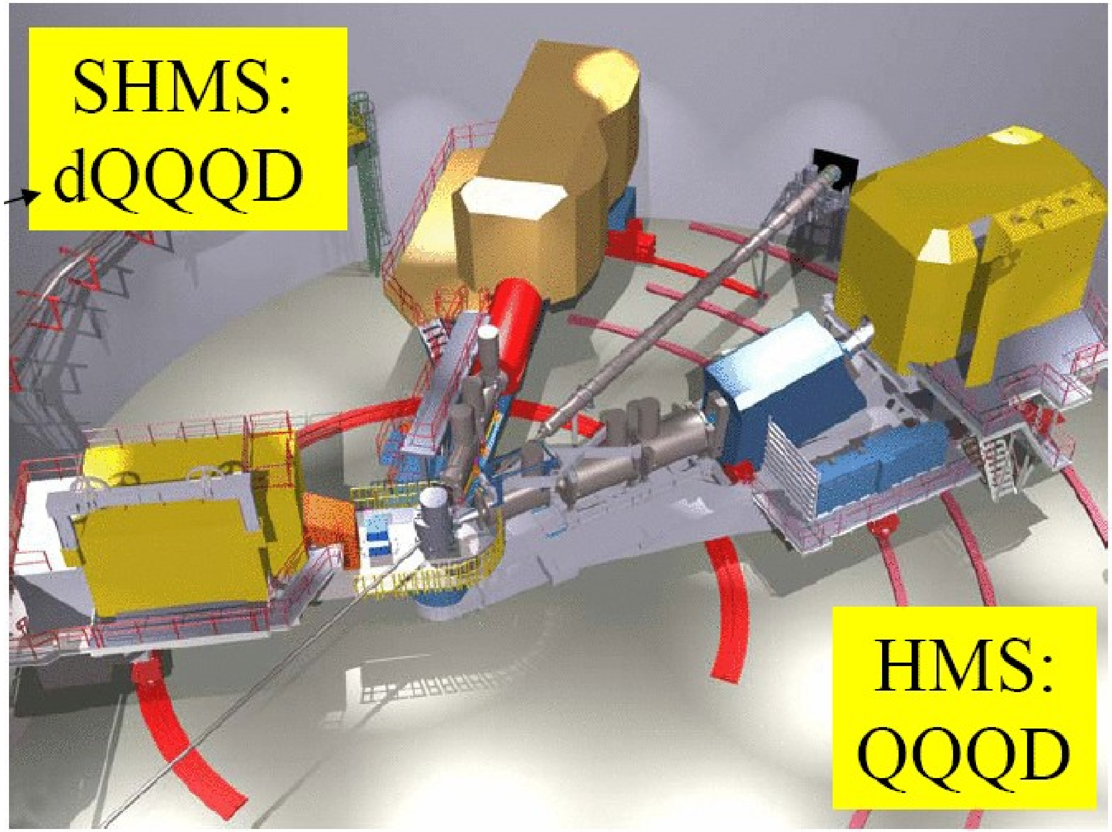
$$\tilde{d}_2 = x^2(2g_1+3g_2) = \frac{MQ^2\nu}{8\alpha_e^2}\frac{E}{E'}\frac{x^2(4-3y)}{(E+E')}\left[\Delta\sigma_\parallel + \left(\frac{4-y}{(1-y)(4-3y)\sin\theta_e} - \cot\theta_e\right)\Delta\sigma_\perp\right]$$

$$g_2 = \frac{MQ^2\nu^2}{4\alpha_e^2}\frac{1}{2E'(E+E')}\left[-\Delta\sigma_\parallel + \frac{E+E'\cos\theta_e}{E'\sin\theta_e}\Delta\sigma_\perp\right]$$

where $\Delta\sigma_\parallel = \sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}$, $\Delta\sigma_\perp = \sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}$ and $y = \nu/E$.

I_{beam} = 30 μA
P_{beam} = 0.8
P_{targ} = 0.55

Floor layout for Hall C

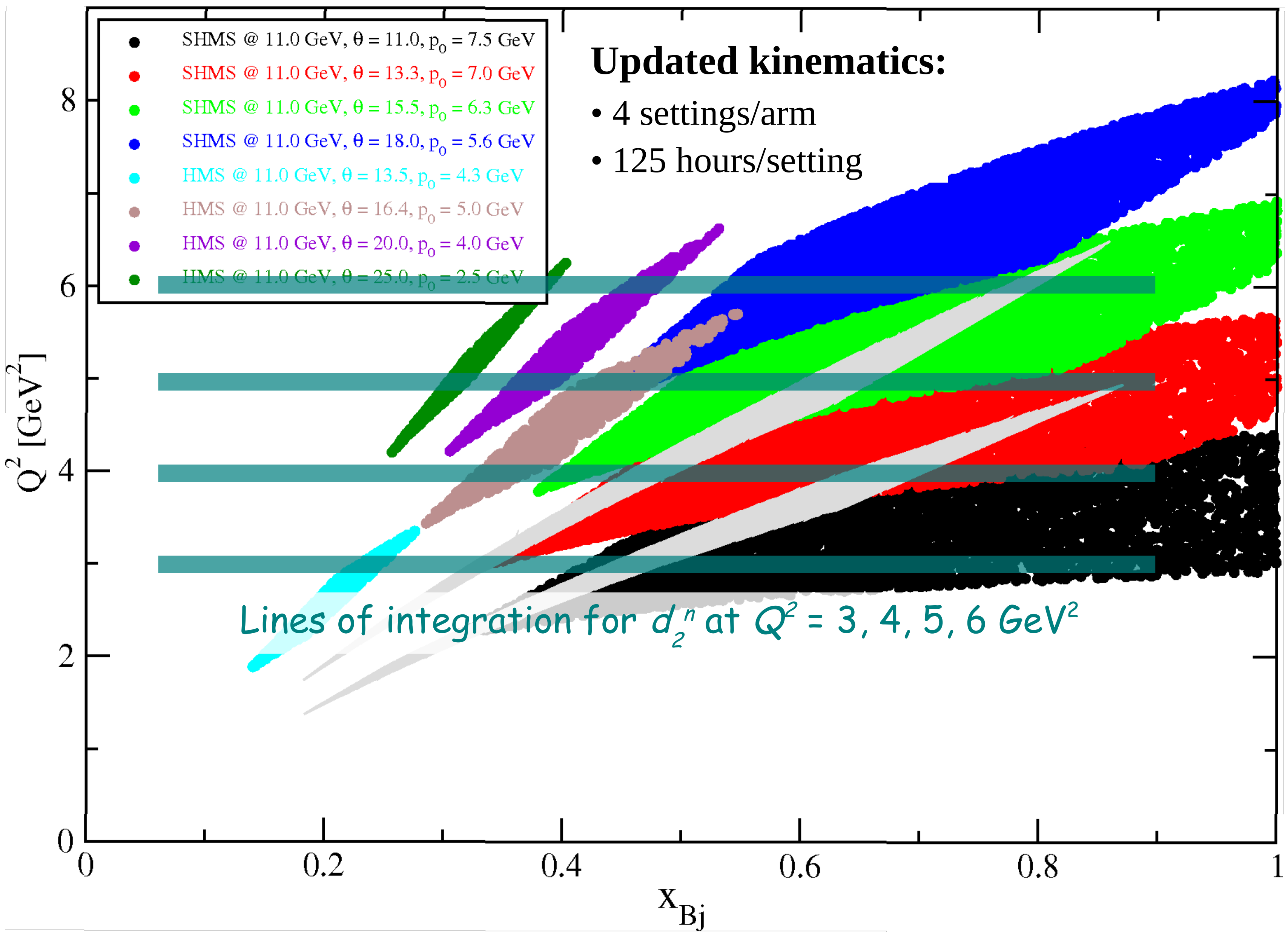


Hall C

- One beam energy
  - ➡ 11 GeV
- Each arm measures a total cross section independent of the other arm.
- Experiment split into four pairs of 125 hour runs with spectrometer motion in between.

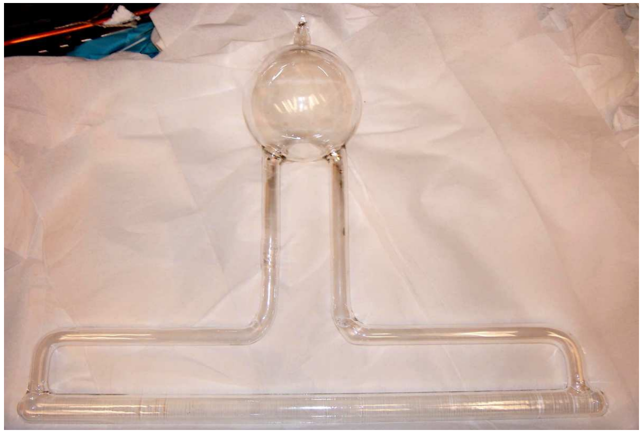
- SHMS collects data at Θ = 11°, 13.3°, 15.5° and 18.0° for 125 hrs each
  - ➡ data from each setting divided into 4 bins
- HMS collects data at Θ = 13.5°, 16.4°, 20.0° and 25.0° for 125 hrs each
- Calibration + Overhead: 200 hrs

Updated Kinematics



Impact of Planned ^{3}He Target Upgrade

- Polarized ^{3}He target group has developed a new target design
  - "high-luminosity GEN-II" target cell
  - 60cm long target cell (2008 cell was 40cm)
  - dual transfer tube allowing active convective circulation of polarized gas
  - *Ultimate goal* for this design is to reach 60% polarization @ 60 μA (critical for GEN-II)

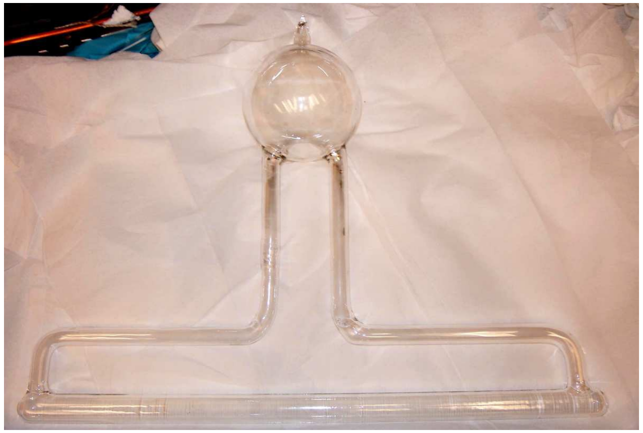


Prototype cell bench tested in 2010 (UVa)

- E12-06-121 collaboration assumed 55% polarization @ 30 μA for PAC36 (a "grading PAC" in Summer 2010)
  - 55% polarization @ 15 uA is sufficient to achieve original (PAC30) goals (even with original 40cm cell)
  - Extended cell + 30 μA operation allows significant extension of experimental reach. Additional kinematic points were added to take advantage of new design.
    - This measurement would be a good commissioning run for new target!
    - Moderate luminosity goal. Easily adapts to accommodate unforeseen issues, or add additional points if target perform to final spec.

Impact of Planned ^{3}He Target Upgrade

- Polarized ^{3}He target group has developed a new target design
  - "high-luminosity GEN-II" target cell
  - 60cm long target cell (2008 cell was 40cm)
  - dual transfer tube allowing active convective circulation of polarized gas
  - *Ultimate goal* for this design is to reach 60% polarization @ 60 μA (critical for GEN-II)



Prototype cell bench tested in 2010 (UVa)

- E12-06-121 collaboration assumed 55% polarization @ 30 μA for PAC36 (a "grading PAC" in Summer 2010)
  - 55% polarization @ 15 uA is sufficient to achieve original (PAC30) goals (even with original 40cm cell)
  - Extended cell + 30 μA operation allows significant extension of experimental reach (FOM increase ~4—5x). Additional kinematic points were added to take advantage of new design.
    - This measurement would be a good commissioning run for new target!
    - Moderate luminosity goal. Easily adapts to accommodate unforeseen issues, or add additional points if target perform to final spec.

Misc slide

Updated Kinematics

Table 3: Kinematic bins and expected rates for the SHMS. The uncertainties for $A_{||}$ and $A_{\perp}$ are *statistical* only.

SHMS Setting	E'_{bin} [GeV]	Q^2 [GeV^2]	x	W [GeV]	e^- rate [Hz]	π^- rate [Hz]	$t_{\|\|}$ [hrs]	$t_{\perp}$ [hrs]	$\Delta A_{\|\|}$ [$\cdot 10^{-4}$]	$\Delta A_{\perp}$ [$\cdot 10^{-4}$]
$\theta_0 = 11^\circ$	7.112	2.875	0.394	2.305	1058	11	12	113	2.0	0.5
	7.709	3.116	0.504	1.988	708	3.1	12	113	2.3	0.7
$E'_{cent} = 7.5$	8.304	3.357	0.663	1.610	259	0.83	12	113	3.7	0.1
GeV	8.900	3.597	0.912	1.109	2.7	0.21	12	113	36	10
$\theta_0 = 13.3^\circ$	6.647	3.922	0.480	2.267	268	3.1	12	113	3.5	1.0
	7.203	4.250	0.596	1.941	139	0.8	12	113	4.8	1.5
$E'_{cent} = 7.0$	7.758	4.578	0.752	1.548	31.6	0.16	12	113	10	3.1
GeV	8.314	4.906	0.972	1.012	0.10	0.033	12	113	173	55
$\theta_0 = 15.5^\circ$	5.997	4.798	0.511	2.342	96	1.9	12	113	5.7	1.8
	6.496	5.197	0.614	2.037	49	0.47	12	113	7.8	2.5
$E'_{cent} = 6.3$	6.995	5.597	0.744	1.677	13.5	0.11	12	113	15	4.7
GeV	7.494	5.996	0.911	1.215	0.29	0.025	12	113	98	33
$\theta_0 = 18.0^\circ$	5.348	5.756	0.542	2.397	35	1.1	12	113	9.5	3.1
	5.790	6.235	0.637	2.106	17	0.25	12	113	13	4.4
$E'_{cent} = 5.6$	6.233	6.711	0.749	1.769	5.1	0.05	12	113	24	8.1
GeV	6.675	7.187	0.885	1.350	0.38	0.01	12	113	87	30

Table 4: Expected rates for the three HMS settings. The uncertainties for $A_{||}$ and $A_{\perp}$ are *statistical* only.

θ_0 [$\circ$]	E'_{cent} [GeV]	Q^2 [GeV^2]	x	W [GeV]	e^- rate [Hz]	π^- rate [Hz]	$t_{\|\|}$ [hrs]	$t_{\perp}$ [hrs]	$\Delta A_{\|\|}$ [$\cdot 10^{-4}$]	$\Delta A_{\perp}$ [$\cdot 10^{-4}$]
13.5	4.305	2.617	0.208	3.293	954	765	8	117	2.0	0.6
16.4	5.088	4.555	0.410	2.727	218	15	12	113	3.9	1.2
20.0	4.000	5.31	0.404	2.951	76	66	10	115	6.0	1.8
25.0	2.500	5.15	0.323	3.417	20	84	13	112	10.7	3.1

Systematic Error Contributions to g_2^n and d_2^n

Item description	Subitem description	Relative uncertainty
Target polarization		1.5 %
Beam polarization		3 %
Asymmetry (raw)		
	• Target spin direction (0.1°)	$< 5 \times 10^{-4}$
	• Beam charge asymmetry	$<$ 50 ppm
Cross section (raw)		
	• PID efficiency	$<$ 1 %
	• Background Rejection efficiency	$\approx$ 1 %
	• Beam charge	$<$ 1 %
	• Beam position	$<$ 1 %
	• Acceptance cut	2-3 %
	• Target density	$<$ 2%
	• Nitrogen dilution	$<$ 1%
	• Dead time	$<$1%
	• Finite Acceptance cut	$<$1%
Radiative corrections		$\leq$ 5 %
From ^{3}He to Neutron correction		5 %
Total systematic uncertainty (for both $g_2^n(x,Q^2)$ and $d_2(Q^2)$)		$\leq$ 10 %
Estimate of contributions to d_2 from unmeasured region	$\int_{0.003}^{0.23} \tilde{d}_2^n \, dx$	4.8×10^{-4}
Projected absolute statistical uncertainty on d_2		$\Delta d_2 \approx 5 \times 10^{-4}$
Projected absolute systematic uncertainty on d_2 (*assuming* $d_2 = 5 \times 10^{-3}$)		$\Delta d_2 \approx 5 \times 10^{-4}$

- Radiative correction uncertainty cross-checked with E01-012 (Spin Duality) experiment
  - ➡ worst case: 4.4%
- Pion rejection ratio of ~10^4:1 should be achievable with standard SHMS/HMS detectors (~10^3:1 would be adequate)

Older Stuff

(OLD/PAC30) Kinematics in Hall C

Spec.	p0 [GeV/c]	E[GeV]	theta[deg]	Q2[GeV^2]	x	W[GeV]	total_e-[Hz]	Pi-[Hz]	e+/e-
SHMS	**8**	11	**11**	2.74	0.34	2.47	257.6	4.88	<0.0001
				3.04	0.46	2.1	194.1	1.05	<0.0001
				3.34	0.65	1.65	77.72	0.21	<0.0001
				3.63	0.96	1.01	0.21	0.04	<0.0001
HMS	**4.2**	11	**13.5**	2.62	0.21	3.29	268.8	282	0.04
SHMS	**7**	11	**13.3**	3.65	0.4	2.5	79.98	2.06	<0.0001
				4.05	0.52	2.14	51.4	0.38	<0.0001
				4.45	0.69	1.71	17.75	0.06	<0.0001
				4.85	0.93	1.13	0.14	0.01	<0.0001
HMS	**3.5**	11	**20**	4.68	0.33	3.2	25.7	28.64	0.04
SHMS	**6.3**	11	**15.5**	4.6	0.47	2.48	28.63	0.83	<0.0001
				5.1	0.59	2.12	15.31	0.15	<0.0001
				5.6	0.74	1.68	3.89	0.02	<0.0001
				6.1	0.96	1.07	0.02	<0.01	<0.0001
HMS	**5.1**	11	**16.4**	4.56	0.41	2.73	78.14	6.38	<0.0001

Rates/backgrounds computed using multiple parametrizations: MRST2001LO, CTEQ61, H12000LO, and Wiser fit of SLAC data.

Results cross-checked against previous JLab data.

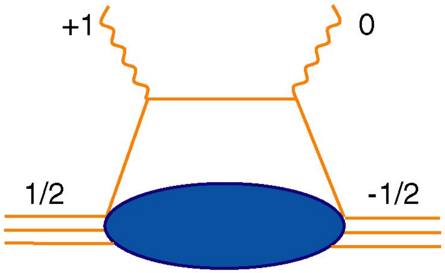
- SHMS collects data at Θ = 11°, 13.3° and 15.5° for 200 hrs each
  - ➡ data from each setting divided into 4 bins
- HMS collects data at Θ = 13.5°, 16.4° and 20.0° for 200 hrs each
- Ratio of Transverse to Parallel hours is ~11:1

➡ Hall C: SHMS and HMS collect data *in parallel*

Total time: 600 hours

g_2 and Quark-Gluon Correlations

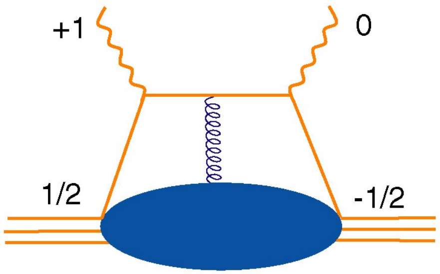
twist-2



Carry one unit of orbital angular momentum

QCD allows the helicity exchange to occur in two principle ways

twist-3



Couple to a gluon

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

- a twist-2 term (Wandzura & Wilczek, 1977):

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

- a twist-3 term with a suppressed twist-2 piece (Cortes, Pire & Ralston, 92):

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left(\frac{m_q}{M}h_T(y,Q^2) + \xi(y,Q^2)\right)\frac{dy}{y}$$

transversity → h_T

quark-gluon correlation → ξ