Probing the Spin Structure of the Neutron:

E12-06-121: d_2 and g_2 for the Neutron

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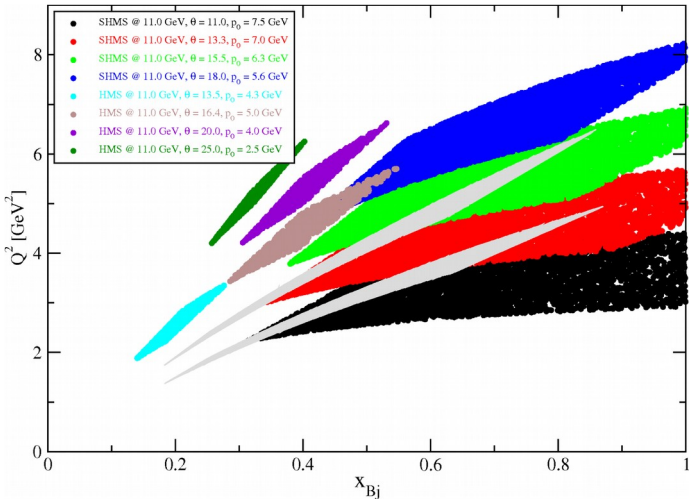
E12-06-121: d_2^n, g_2^n

- Hall C: SHMS + HMS
- Two beam energies:
  - → 11 GeV/c (production)
  - → 2.2 GeV/c (calib.)
- Beam Current
  - → 30 uA (production)
  - → 60 uA (max, calib.)
- Target: 40 cm Polarized 3He
- Each arm measures an absolute polarized cross section independent of the other arm (g_1, g_2)
  - → $d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$
- 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

SHMS Production		
Setting	P_0	Angle
A	7.5	11.0°
B	7.0	13.3°
C	6.3	15.5°
D	5.6	18.0°

HMS Production		
Setting	P_0	Angle
A'	4.3	13.5°
B'	5.1	16.4°
C'	4.0	20.0°
D'	2.5	25.0°



Nominal Beam Time Allocation

- PAC 36 approved E12-06-121 for requested 700 PAC hours (29 PAC days)
  - → 5-pass beam (nominal 11.0 GeV/c) for ~ 676 PAC hours
  - → 1-pass beam (nominal 2.2 GeV/c) for ~ 20 PAC hours + pass change → 5-pass
    - » Requested 3 calendar days at 1 pass during d2n period to accommodate our 1-pass checks + a nominal PAC day for the proposed Pol 3He Elastic measurement

      * Some of the 1-pass data below will already be in the can from the A1n 1-pass.
- 1-pass Running (Calibrations) [~20 PAC hours]
  - → Optics [2 PAC hours*]
  - → H(e,e'p) elastics, C, ^{3}He elastic, QE calibrations [15 PAC hours*]
  - → BCM, BPM calibrations [2 PAC hours*]
- Pass change 1→ 5 [~4 PAC hours*]
- 5-pass Running (Production) [~676 PAC hours]
  - → Production [~600 PAC hours]
  - → Optics , BCM, Misc. [18 PAC hours]
  - → Target polarization measurements (4% of production) [24 PAC hours]
  - → Reference cell runs (N_2, ^{3}He, vacuum) [8 PAC hours]
  - → Positive polarity [16 PAC hours]
  - → Moller measurements (x4) [12 PAC hours]

5-Pass Running

- **5-pass beam allocation**
  - → 54 calendar days
  - → 162 shifts

- For each kinematic "pair" (X, X')
  - → 1+1 hr Nitrogen
  - → 1+1 hr Empty cell
  - → 8 hrs Optics (C-foil + Sieve)
  - → 8 hrs Pressure curves
    - » 4 hrs He-3
    - » 4 hrs N2
  - → 8 hrs Positive polarity runs
    - » 4 hrs optics
    - » 4 hrs production
  - → Target NMR sweep
    - » 1–2 / shift (?)
  - → Production runs (125 PAC hrs)
    - » 31 shifts

SHMS Production		
Setting	P_0	Angle
A	7.5	11.0°
B	7.0	13.3°
C	6.3	15.5°
D	5.6	18.0°

HMS Production		
Setting	P_0	Angle
A'	4.3	13.5°
B'	5.1	16.4°
C'	4.0	20.0°
D'	2.5	25.0°

- Summing up time in left list:
  - → 35 shifts: production + optics + pos. pol. running
- Moller runs: roughly 1/week
  - → 2 shift / setting
- Allow ~10% overhead = ~3–4 shifts

- **Total: ~40 shifts / setting**
  - → 160 shifts out of a nominal
    162 calendar shifts at 5-pass

5-Pass Running

- **5 Pass running**
  - → 54 days = 162 shifts total
  - → 160 shifts of "Kinematically tied" data taking
    - » incl. Moller meas.
    - » incl. 3–4 shifts of overhead
  - → Leaves 2 shifts for remaining instrumentation/calibration runs below

SHMS Production		
Setting	P_0	Angle
A	7.5	11.0°
B	7.0	13.3°
C	6.3	15.5°
D	5.6	18.0°

HMS Production		
Setting	P_0	Angle
A'	4.3	13.5°
B'	5.1	16.4°
C'	4.0	20.0°
D'	2.5	25.0°

- Instrumentation / Calibration runs
  - » BPM calibration (2 hour)
  - » BCM calibration (2 hour)
  - » Beam energy (2 hour)
  - → ie. Roughly 1 shift of time to get a "set"
  - → Plan to take 2 sets during 5-pass running (2 shifts)

- NOT explicitly included:
  - → Target spin flips
    - » Once every 3 days?
    - » 1/week can probably be opportunistic (beam studies, RF recovery, etc.)
    - » 2nd will be on us (part of overhead)
  - → λ/2 plate flips (negl. overhead)
  - → Do we have sufficient coverage for Rad. Corrections, or can we make our lives easier with some additional kin points?

1-pass Running

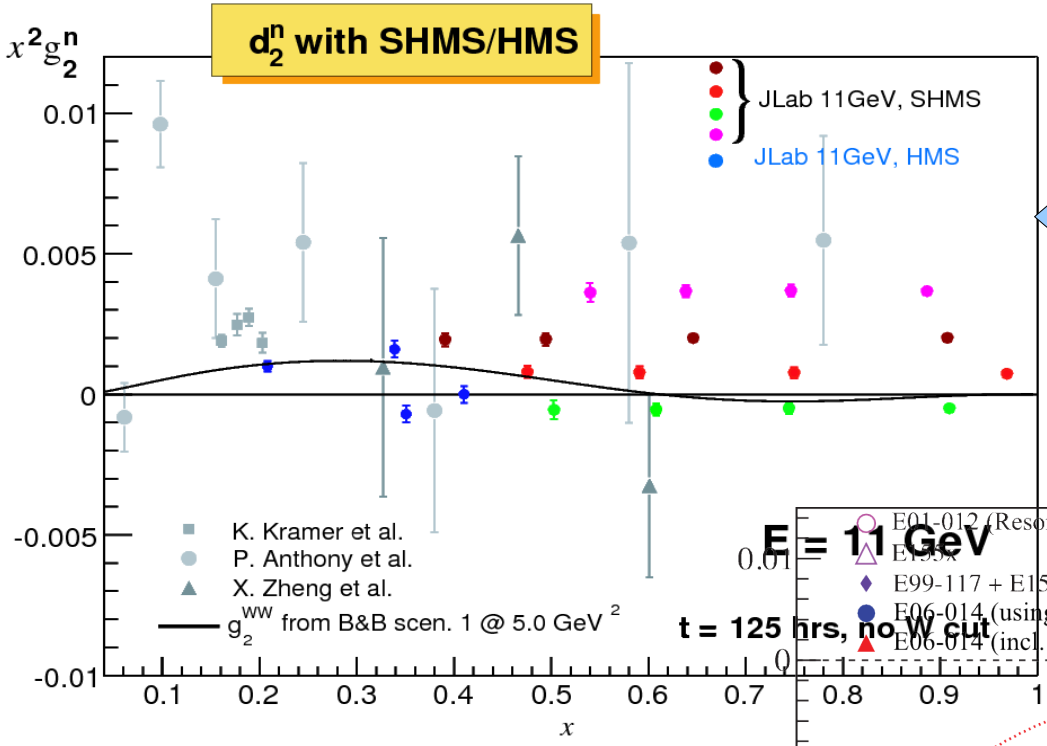
- **1-pass beam allocation**
  - → 3 calendar days (*TBD)
- **Nominal todo list**
  - → 8 hr Moller run
  - → 4 hr Optics at p0 = 2.2 GeV/c
    - » C foils, Sieve
    - » Done already? Cross-check, or augment data from Fall as needed?
  - → 2 hrs Hydrogen elastics
  - → 3 hours delta QE meas.
    - » λ/2 flip in middle
  - → **3He elastic data**
    - » *See Table on Right*
      - – Details in next talk
    - » Pos. pol running?

Spectrometer	E_{beam} [GeV]	Label	θ [°]	Q^2 [fm^{-2}]	Estimated Cross Section [mb/sr]	Rate [Events/hr]	Time PAC hrs
SHMS	2.216	k1	11	4.57	4.39×10^{-4}	2,605,270	1
		k2	13	6.34	5.14×10^{-5}	305,609	1
		k3	15	8.38	4.37×10^{-6}	25,946	1
		k4	17	10.66	2.22×10^{-7}	1,319	10
		k5	19	13.18	5.97×10^{-8}	355	11
HMS	2.216	k6	21	15.93	3.99×10^{-8}	427	24

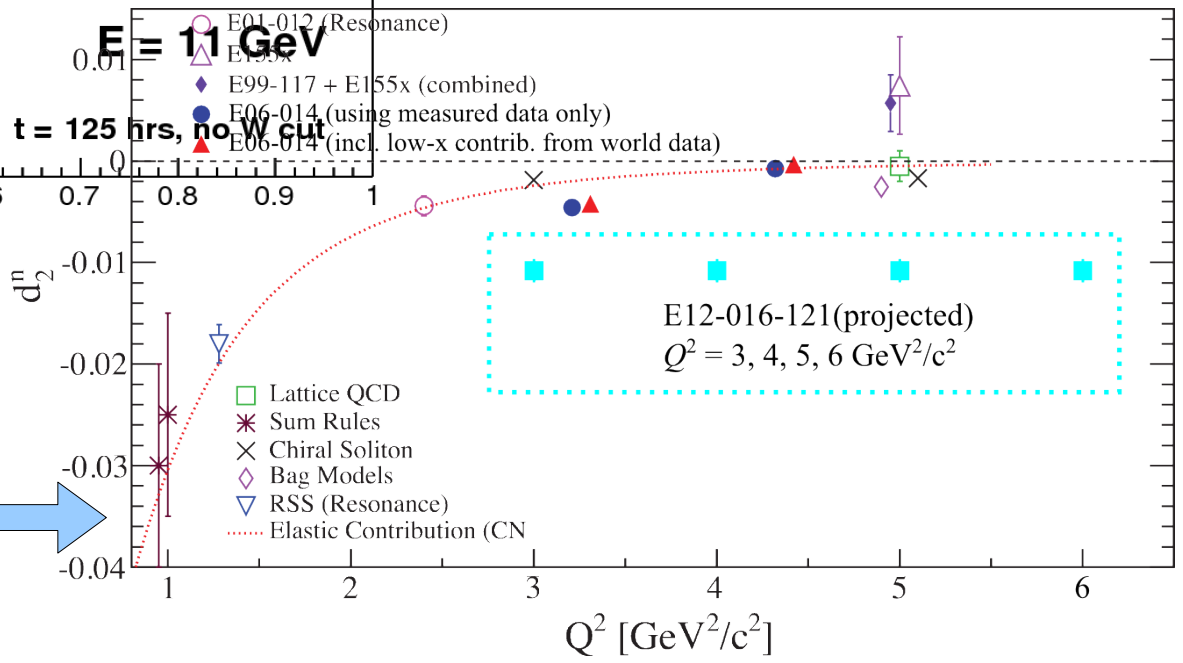
- Optional / Float between 1-pass and 5-pass as desired
  - → BCM, BPM measurements
- Details still TBD to make a run plan:
  - → Split run time in table before/after target pol. flip?
    - » Flip target polarization takes ~1 hr
  - → Integrate λ/2 plate flips
  - → ...

Backup Slides

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.



Q^2 evolution of d_2^n in a region where models are thought to be accurate.

Direct overlap with 6 GeV Hall A measurements.

Standard Hall C Detector Packages

- SHMS ('default' detector package)
  - → Hodoscopes, Wire chambers, NGC, Calorimeter
  - → HGC tank remains installed: may pump to vacuum, or fill with Argon for auxiliary PID
- HMS ('default' detector package)
  - → Hodoscopes, Wire chambers, Calorimeter
  - → HGC fill with Argon, or C4F10 (sub-atmosphere)
- DAQs
  - → Standard DAQ and triggers
- See also: Spectrometer and Detector Systems talk

Nominal Beam Requirements

- Beam Characteristics
  - » See 'Performance Requirements' slide in A1n overview and running conditions for general shared requirements.

→ 1-pass, 5-pass requested (see upcoming slide for more details)

→ Beam polarization: 80%

→ < 50 ppm charge asym (average over ~ 1–2 hr run)

→ 30 uA (max) on glass cell targets

→ 60 uA (max) on solid targets

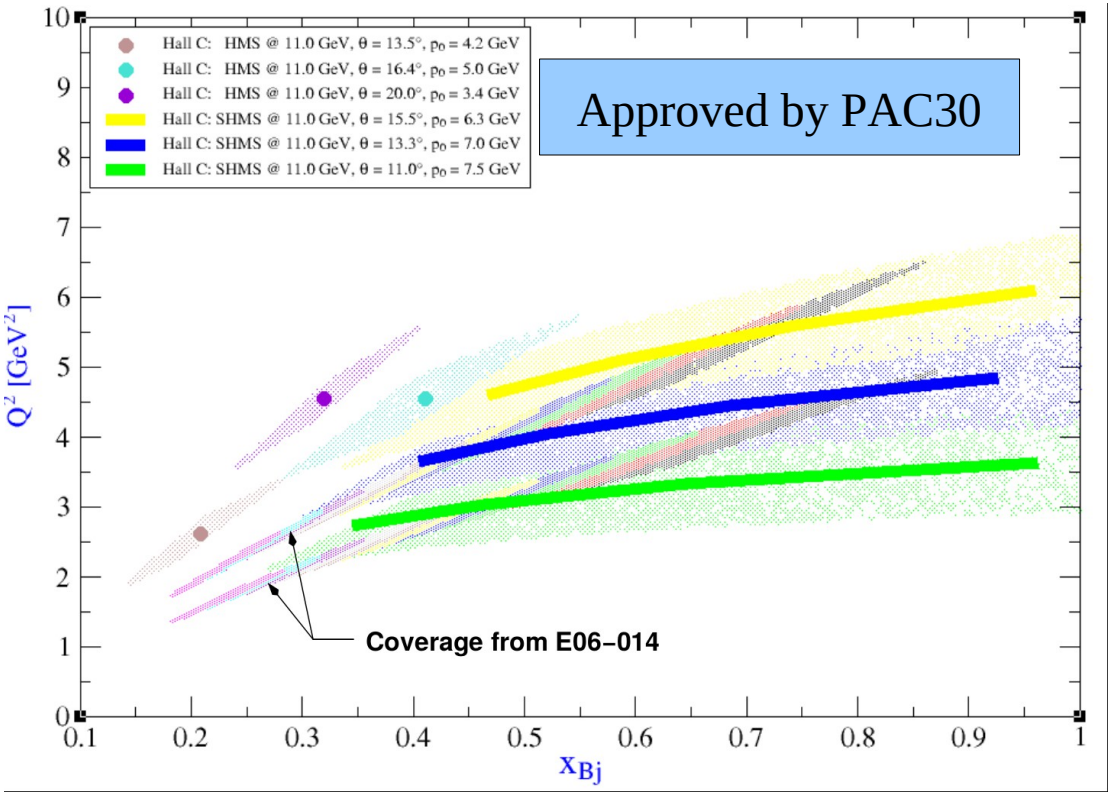
Nominal Target Requirements

- Polarized ^{3}He Target Requirements
  - » See 'Performance Requirements' slide in A1n overview and running conditions for general shared target requirements.
  - → 55% polarization
  - → 30 uA beam current capability
  - → ~0.1 spin angle measurement (2 mrad)
    - » Challenging, but achievable

- Target Ladder components
  - → Polarized ^{3}He production cell (40cm)
  - → Reference cell:
    - » vacuum, H_2, ^{3}He, Nitrogen
  - → Optics foils (7)
  - → Single-carbon foil
  - → Carbon-hole (alignment, raster checks)

Fallback / Contingency Plans

- Original proposal approved by PAC30 was more conservative:
  - → Beam
    - » 10 uA
    - » 80% polarized
  - → Target: 2008 params
    - » 40 cm long
    - » 50% polarization
  - → 3 'paired' kinematic groups (instead of 4)
    - » ~200 hours for each pair

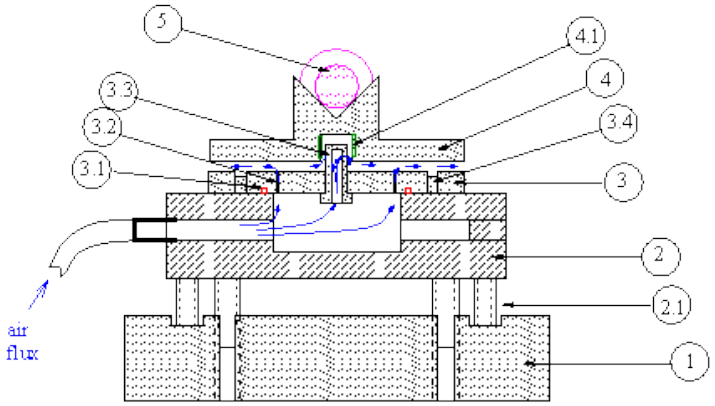


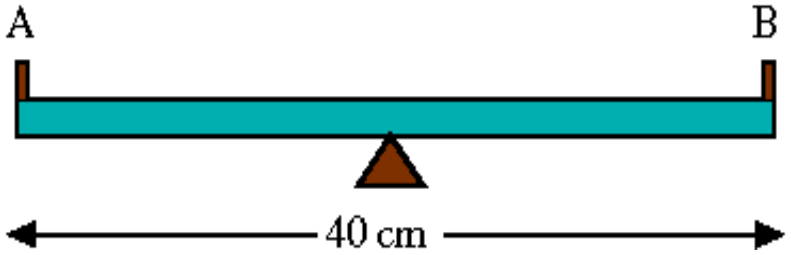
- Worst case:
  - → Fall back to these params and we still have a viable measurement.
- See also:
  - → Section 5 of PAC36 Update (last few paragraphs)

Supporting Documentation

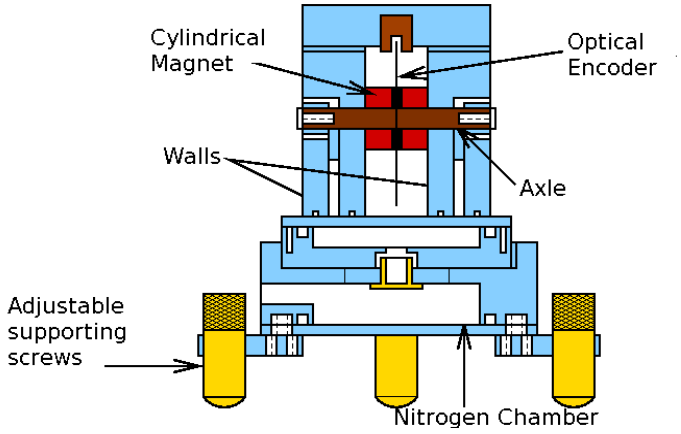
- Supporting Documentation
  - → PAC30 Proposal
  - → PAC36 Update
- Polarized ^{3}He ERR Page
  Supporting Documentation
- E06-014 (2009 d2n Exp.) Wiki

Magnetic Field Direction





Longitudinal Field: - air floating compass (left)
- needle compass (above)
$\Delta\Theta < 2$ mrad (< 0.1 degree)



Transverse Field: - air floating compass (left)
$\Delta\theta \sim 1$ mrad (~0.05 degree)

A. Kolarkar, Ph.D. Thesis, UKy, 2008
C. Dutta, Ph. D. Thesis, UKy, 2010

Production Kinematics for HMS

Table 4: Expected rates for the three HMS settings. The uncertainties for $A_{\parallel}$ 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]	$t_{\parallel}$ [hrs]	$t_{\perp}$ [hrs]	$\Delta A_{\parallel}$ [$\cdot 10^{-4}$]	$\Delta A_{\perp}$ [$\cdot 10^{-4}$]
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

- Rate table from PAC36
  - → 30 uA beam
  - → 55% polarization
  - → Assumed 60 cm long cell
- Current target
  - → 40 cm long cell
- As discussed in the PAC36 update, we have been conservative on our statistical run times and are not statistics limited, even with the shorter production cell.

Production Kinematics for SHMS

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

SHMS Setting	E'_{bin} [GeV]	Q^2 [GeV^2]	x	W [GeV]	e^- rate [Hz]	π^- rate [Hz]	$t_{\parallel}$ [hrs]	$t_{\perp}$ [hrs]	$\Delta A_{\parallel}$ [$\cdot 10^{-4}$]	$\Delta A_{\perp}$ [$\cdot 10^{-4}$]
$\theta_0 = 11^\circ$	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 from PAC36 update

  → Same considerations as noted on prior slide apply.

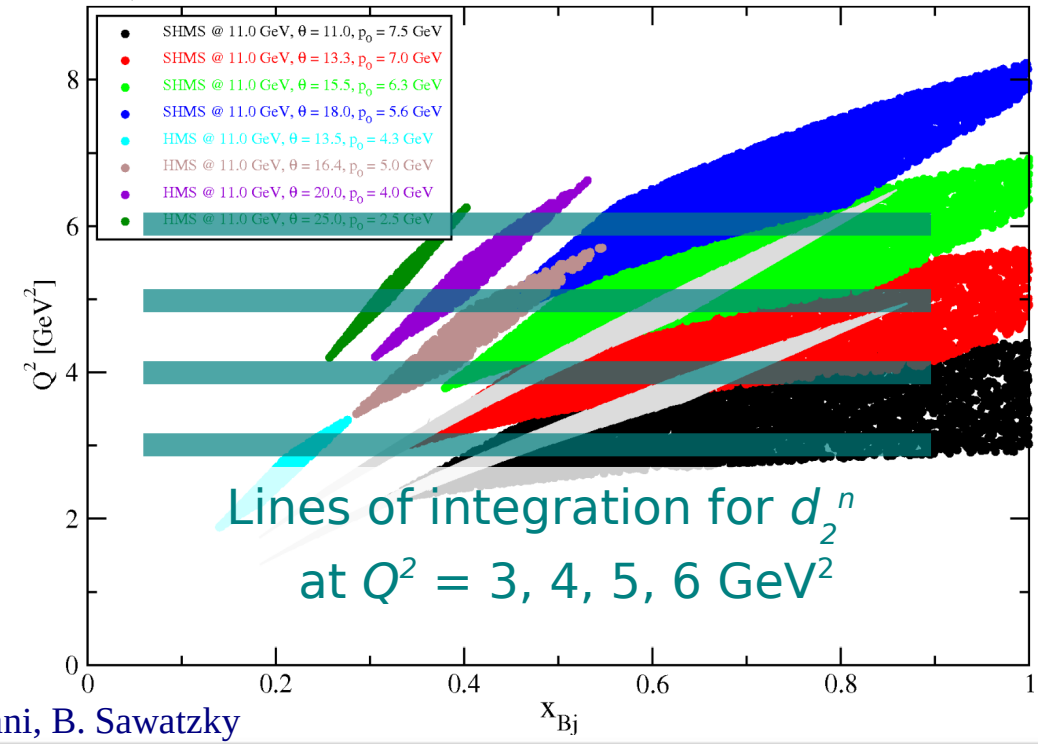
Systematic Error Table

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	≈ 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		≤ 5 %
From ^{3}He to Neutron correction		5 %
Total systematic uncertainty (for both $g_2^n(x, Q^2)$ and $d_2(Q^2)$)		≤ 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* $d_2 = 5 \times 10^{-3}$)		$\Delta d_2 \approx 5 \times 10^{-4}$

- PREx-II, CREx ERR accepted < 0.1 ppm Charge Asym requirement as achievable
- Target spin direction precision achievable (see backup slide)

E12-06-121: d_2^n, g_2^n

- 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.
  - → The new Hall C 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 $(0.23 < x < 0.85)$
- d_2 is a clean probe of quark-gluon correlations / higher twist effects
- 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.



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