Probing the Spin Structure of the Neutron:

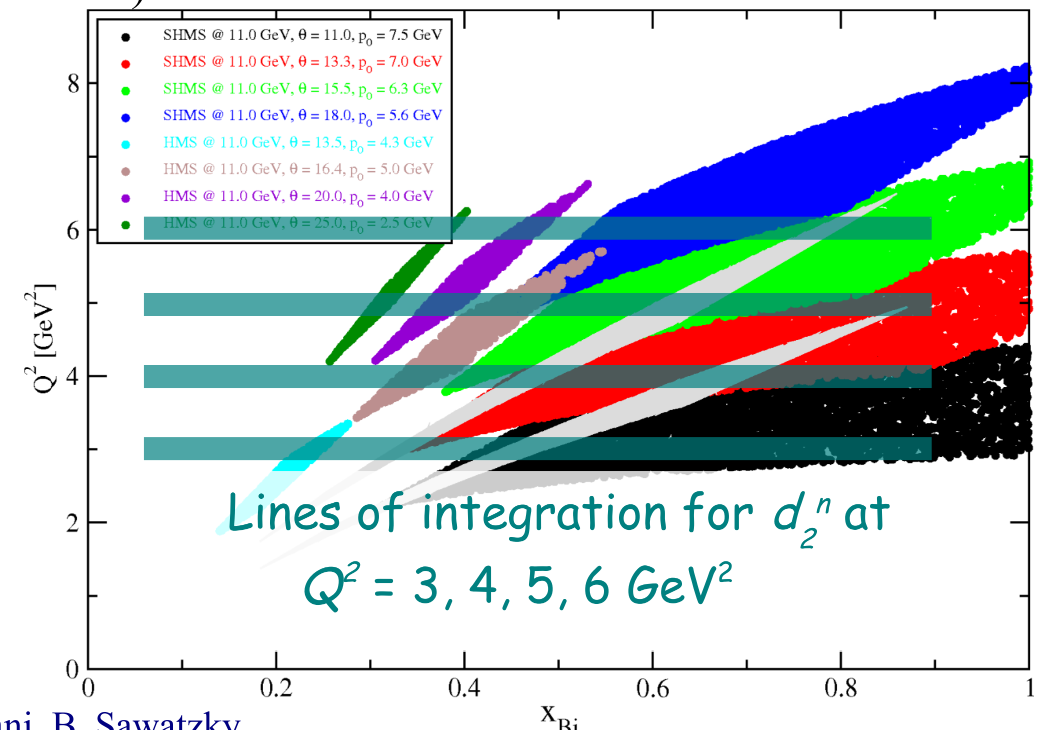
E12-06-121: d_2 and g_2 for the Neutron

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

Brad Sawatzky
Jefferson Lab

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

- Directly measure the Q² dependence of the neutron $d_2^n(Q^2)$ at $Q^2 \approx 3, 4, 5, 6$ GeV² with the new polarized ³He 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.



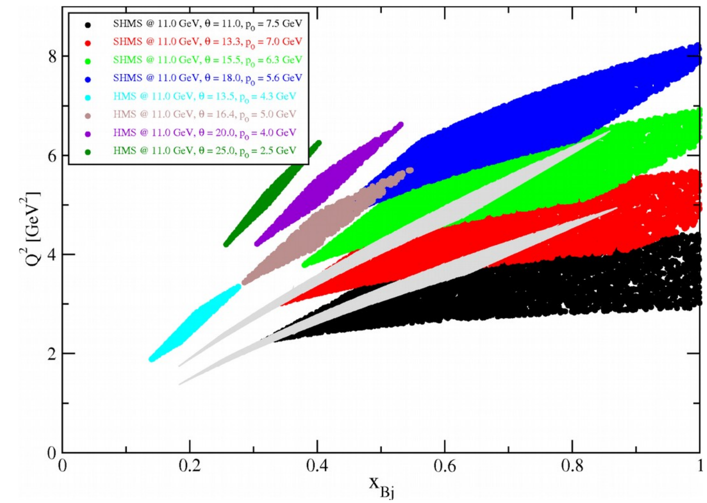
- Spokespeople: T. Averett, W. Korsch, Z.E. Meziani, B. Sawatzky

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

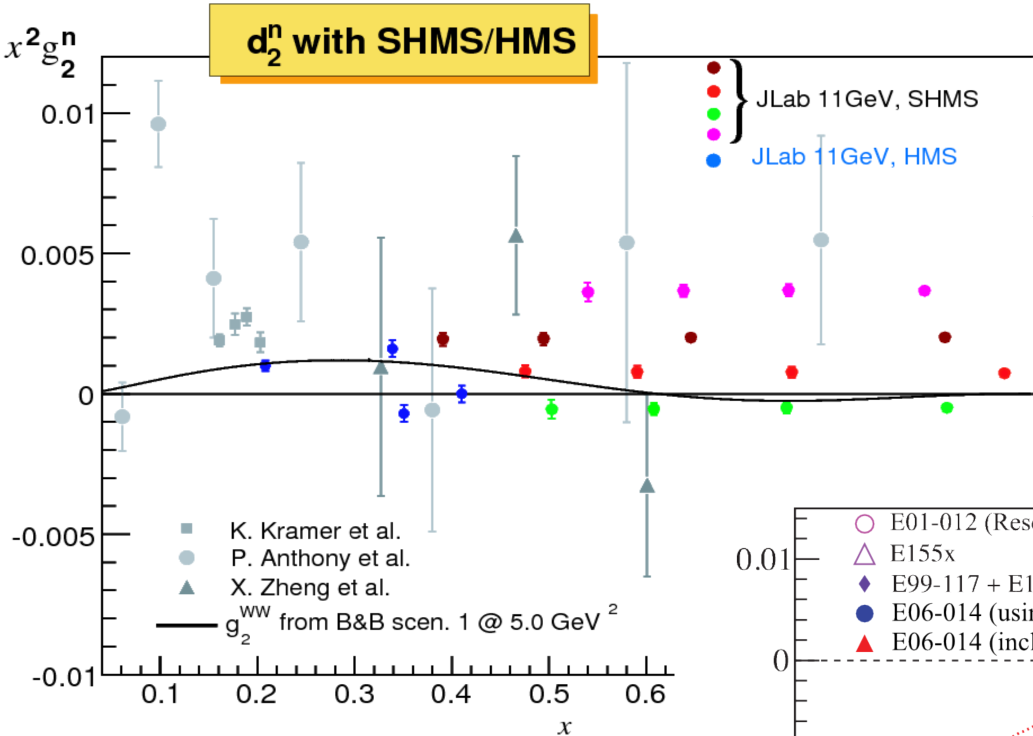
- <u>Hall C: SHMS + HMS</u>
- Two beam energies:
  → 11 GeV/c (production)
  → 2.2 GeV/c (calib.)
- Beam Current
  → 30 uA (production)
  → 45 uA (max, I calib.)
- Target: 40 cm Polarized ^{3}He
- Each arm measures an <u>absolute polarized cross section</u> independent of the other arm (g_1, g_2)
  → $d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$
- 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°

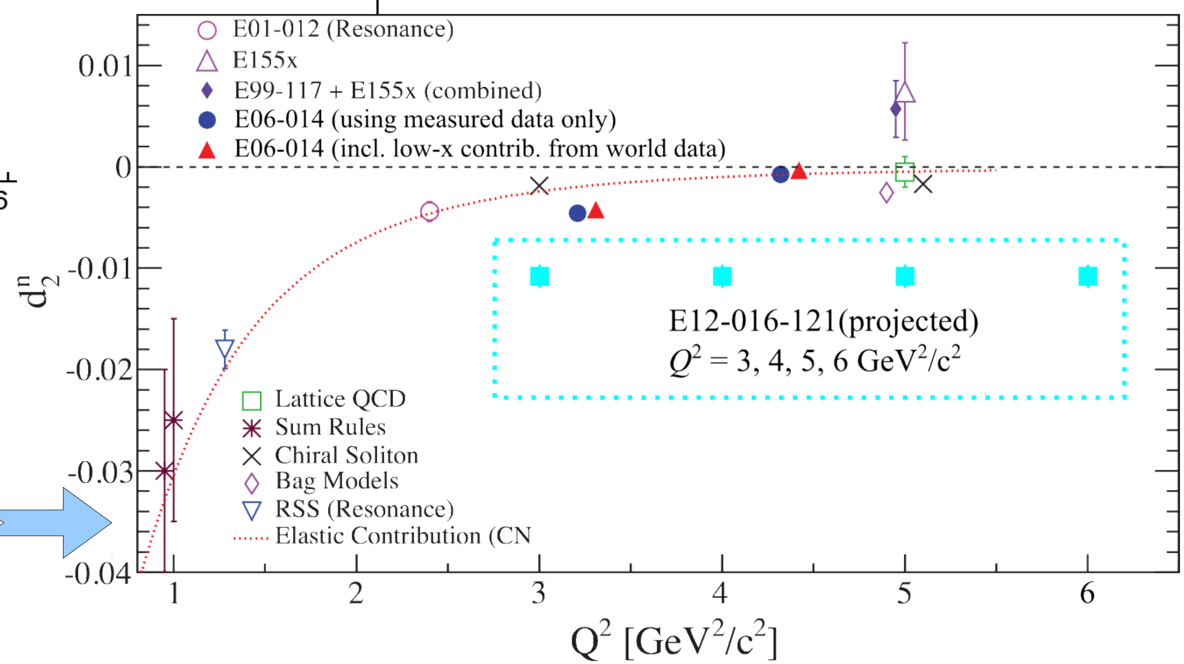
HMS Production		
Setting	P_0	Angle
A'	4.3	13.5°
B'	5.1	16.4°
C'	4.0	20.0°
D'	2.5	25.0°



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 C_4F_{10} (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

→ 30 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)

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
    - » [*] ~ 20 calibration hours include data to be shared w/ A1n (elastics, optics, etc.)

- 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]

Analysis Readiness

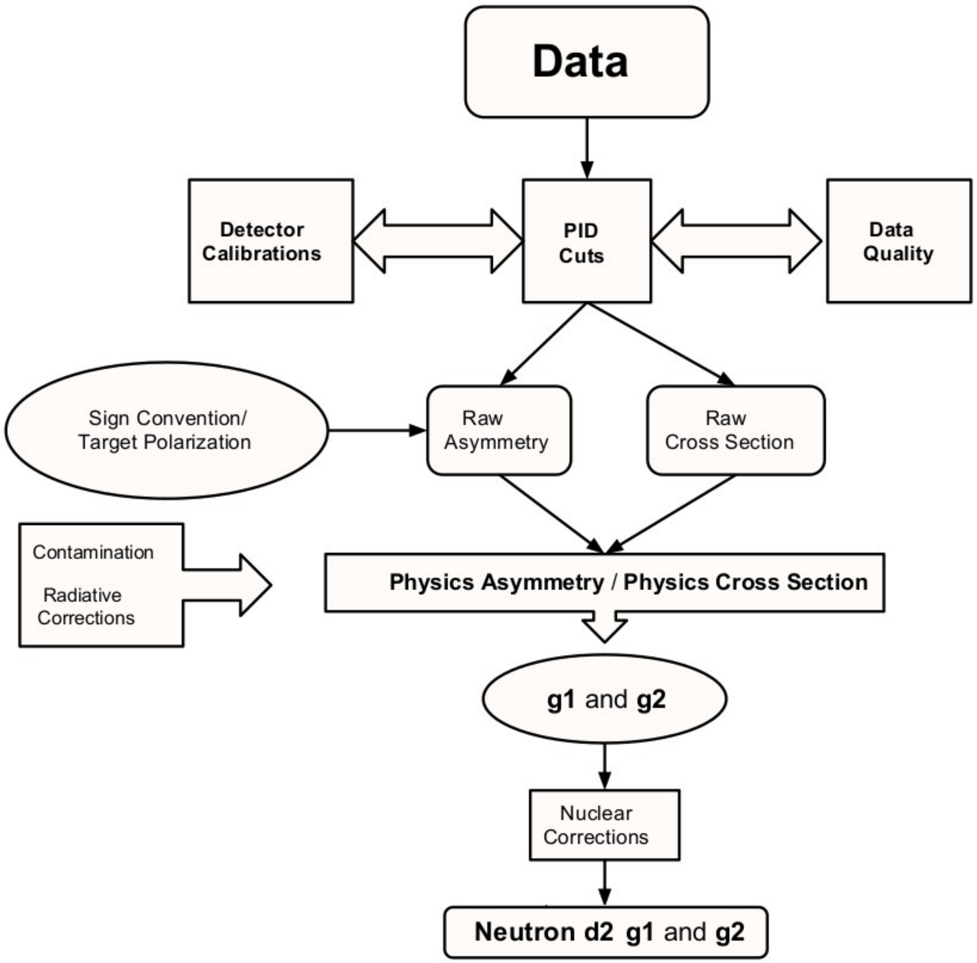
- Software needed for analysis is already in place
  - → HCANA
    - » ROOT based online and offline analysis package
    - » New analyzer cross-checked against old ENGINE analyzer using old HMS data
    - » Same analysis engine used for experiments on the floor now
  - → Get thy students to the Analysis Workshop!
- Simulations / Acceptance codes available
  - → SIMC, SAMC
- Radiative Corrections
  - → Same process as used for E06-014, updated for new kinematics
  - → Toolkit already in place
- Target analysis procedure
  - → Basically same process as used in 2008/9.
- 3He → neutron corrections
  - → In place for lower-x data, need additional support for high-x data
  - → Methodology is available, will to work with Wally Melnitchouk et al. to finalize.
- General Analysis templates available from E06-014 (and others)
  - → Provides a clear analysis path from data w/ lessons learned for similar measurement.

Items to Develop in Advance

- Resurrect rate / yield codes
  - → Needed to tune / cross check earlier rate estimates, and optimize for final beam energy
    - » Wolfgang?
- Radiative Corrections
  - → Same process as used for E06-014
  - → Resurrect that code and have it ready to go (could be good coding/analysis exercise for student!)
    - » Zein-Eddine?
- Air compass development
    - » Wolfgang?
- ^{3}He → neutron corrections
  - → Contact Wally Melnitchouk et al. and develop the extraction method for our conditions
    - » ______________
- Update Theory motivations/ predictions
  - → New LQCD calculation?
  - → ???
    - » ______________

Analysis Flow Chart / Timeline

(promises made at ERR...)



(Above) Figure 8.1(modified) from
M. PosikE06-014 (d2n 2009) dissertation

Rough Milestones

- 2 months
  - → Screen run list
  - → Establish analysis framework
  - → Detector calibrations
- 4 months
  - → Final optics, good PID
  - → Target polarimetry analysis
- 6 months
  - → Acceptance calculations
  - → Finalize target polarimetery
  - → Begin 'applied' work on necessary nuclear corrections (w/ Theory support)
- 12 months
  - → Begin Rad. Correction analysis
  - → Initial 3He cross section extractions
- 18 months
  - → Finalize Rad. Corrections
  - → Finalize Nuclear corrections
  - → Finalize Systematics
- Target first short paper: 18 months
- Long paper: 30 months

Analysis Personnel for E12-121 (Preliminary)

- Z.E. Meziani (Temple U.)
  → PostDoc
  → Grad Student (Shuo Gia)
- W. Korsch (U. of Kentucky)
  → Grad Student (TBD)
- T. Averett (William & Mary)
  → Grad Student (Junhao Chen)

- B. Sawatzky (JLab)

Backup Slides

Analysis Timeline

- E06-014 analysis allowed us to establish procedures and software tools that will significantly accelerate analysis of E12-06-121
  - → Three excellent dissertations that provide a roadmap with lessons-learned for future analyses.
  - → Radiative corrections were time consuming for E06-014. This framework now exists and can be extended for new measurement.
- E06-014 involved understanding a new, open-geometry detector package (BigBite). This was a big job and consumed a lot of time.
  - → E12-06-121 involves two high-precision 'standard' spectrometers that should be well understood by the time the Pol. 3He group runs.
  - → Both SHMS & HMS are standard equipment with a solid analysis toolkit already developed.

Supporting Documentation

- Supporting Documentation
  → PAC30 Proposal
  → PAC36 Update

- Polarized ^3He ERR Page
  Supporting Documentation

- E06-014 (2009 d2n Exp.) Wiki

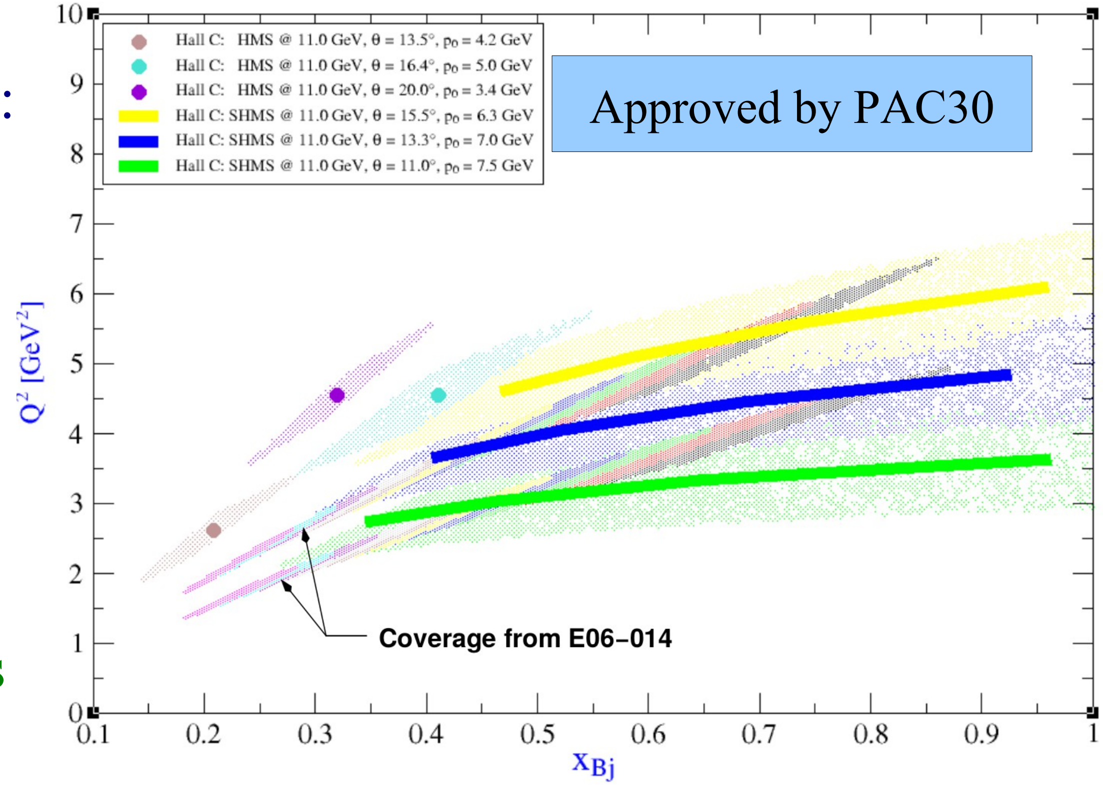
Excellent Analysis 'Templates' from E06-014

- E06-014 ran in Hall A 2009
  - → Extracted d2n, g1n, g2n using very similar equipment and analysis methodology
  - → Experience and documented procedures will be invaluable

- PhD Dissertations / Analysis 'road-maps':
  - →D. Flay dissertation (Temple U.)
  - →D. Parno dissertation (CMU)
  - →M. Posik dissertation (Temple U.)

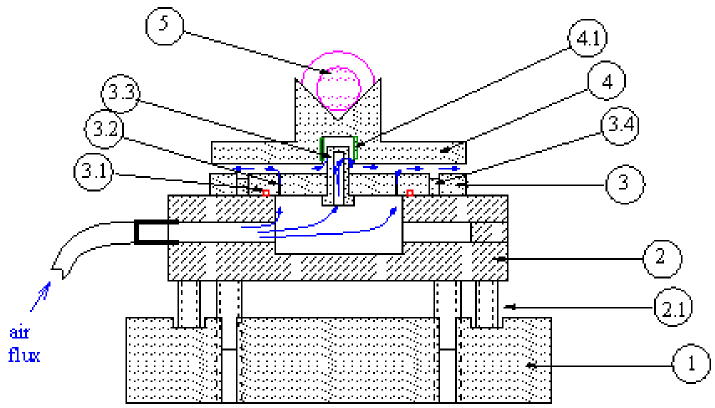
Fallback / Contingency Plans

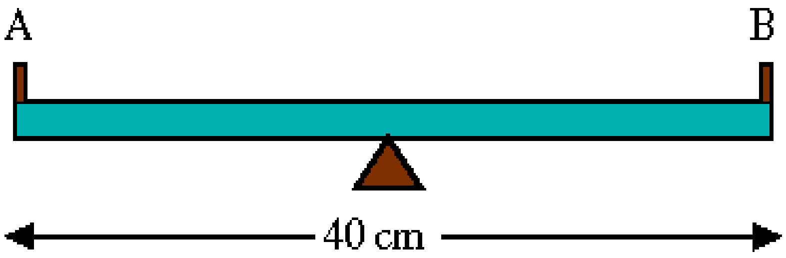
- Original proposal approved by PAC30 was more conservative:
  - →Beam
    - » 10 uA
    - » 80% polarized
  - →Target: 2008 params
    - » 40 cm long
    - » 50% polarization
  - → 3 'paired' kinematic groups (instead of 4)
    - » ~200 hours for each pair

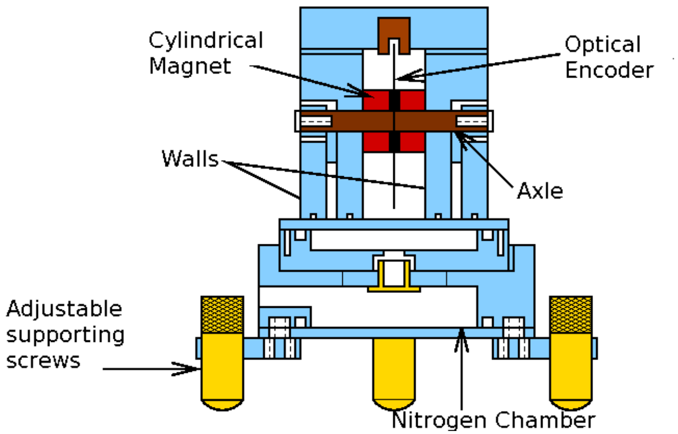


- Worst case:
  - →Fall back to these params and we still have a viable measurement.
- See also:
  - → Section 5 of PAC36 Update (last few paragraphs)

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 $A_{||}$ 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

- 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]	$\Delta A_{\parallel}$ [$\cdot 10^{-4}$]	$\Delta A_{\perp}$ [$\cdot 10^{-4}$]
$\theta_0 = 11°$	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
$\theta_0 = 13.3°$	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
$\theta_0 = 15.5°$	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
$\theta_0 = 18.0°$	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	$\approx$ 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 $d_2 = 5 \times 10^{-3}$*)		$\Delta d_2 \approx 5 \times 10^{-4}$

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