12 GeV Hall C A_1^n Measurement (E12-10-101/E12-06-110) 2018 Update

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In this document we summarize the latest calculations for the Hall C 12 GeV A_1^n experiment (E12-10-101/PR12-06-110). The conditions are the stage-I upgraded polarized ^{3}He target [30μA, 40 cm, (55-60)% polarization and a 60% polarization is used in all calculations here], using both HMS and SHMS, and keep the total beam time at the approved 36 PAC days.

1 Running and Simulation Conditions

Conditions used in the calculation include:

1. The latest simulation package for both HMS and SHMS for rate estimation. The cross section used were the radiated x-section code from Hall C;

2. Beam polarization: 85%, measured to 2%;

3. 684 PAC hours for both DIS and resonance production time (total beam time 36 PAC days as approved in 2010).

4. A N_2 dilution factor of 0.92 was used.

5. Bosted's fit on the proton and the neutron $F_{1,2}$ and R structure functions for nuclear correction.

6. When the values of $A_1^{p,n}$ are needed for nuclear corrections, the fits in Zheng's thesis were used.

7. The statistical errors were enlarged by 15% based on comparison of our calculation for the 6 GeV kinematics and running time (28 calendar days) and the actual 6 GeV results (our code gives 15% too small error). This can be due to the level of accuracy of the simulation/calculation, beam current ramping (effectively less beam on target), and the event loss in the analysis (fiducial cuts, etc).

2 Kinematics and Rates for DIS, Resonance, Elastic and $\Delta(1232)$ Measurements

The kinematic settings for both DIS and resonance measurements are shown in Table 1 below along with the latest rates from simulations. The resonance measurement will provide data needed for radiative corrrections. The pion to electron ratios are shown for each kinematics. The SHMS is designed to achieve a pion rejection factor of $500 - 1000$ with the electron efficiency at or above 99% by using a gas cherenkov detector and lead-glass counters, and the HMS has routinely provided similar PID performance, both will be sufficient to limit the systematic uncertainty from the pion background to a negligible level compared to the expected statistical uncertainty. Details of the systematic uncertainties from the pion and pair production (positron) background were discussed in sections 2.5 and 2.6 of the original proposal (year 2006) and will not be repeated here.

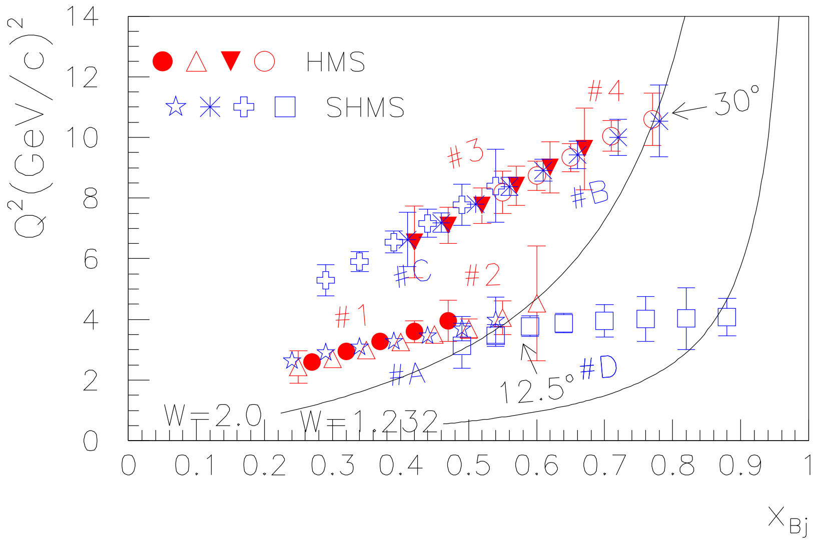
Figure 1 shows the updated projected uncertainties on A_1^n for the four settings each on the HMS and the SHMS, plotted at the corresponding x and Q^2 values. The resonance data will be taken only on the SHMS due to limitations in the HMS momentum settings.

Table 1: Kinematics for large x measurements of the A_1^n asymmetries at JLab 12 GeV Upgrade in Hall C. Both HMS and SHMS will be used at similar settings for DIS kinematics, with the π and e^+ background rates estimated using Wiser's fit. Kinematics #D for SHMS is located in the nucleon resonance region and provide data needed for radiative corrections.

	Kine	E_b GeV	E_p GeV	θ (°)	(e,e') rate (Hz)	π^-/e	e^+/e^-	x (Q^2, in GeV^2) (W, in GeV) coverages
					DIS			
1	HMS	11.0	5.70	12.5	575.42	< 0.4	$< 0.1\%$	0.25-0.55 (2.59- 4.40) (2.1- 2.9)
2	HMS	11.0	6.80	12.5	426.14	< 0.2	$< 0.1\%$	0.25-0.60 (2.43- 4.53) (2.0- 2.9)
3	HMS	11.0	2.82	30.0	2.69	< 10.7	$< 0.1\%$	0.40-0.71 (6.55-10.19) (2.2- 3.3)
4	HMS	11.0	3.50	30.0	0.74	< 2.4	$< 0.1\%$	0.50-0.77 (7.72-10.60) (2.0- 2.9)
A	SHMS	11.0	5.80	12.5	701.73	< 0.5	$< 0.1\%$	0.25-0.60 (2.64- 4.42) (2.0- 3.0)
B	SHMS	11.0	3.00	30.0	2.70	< 12.2	$< 0.1\%$	0.40-0.77 (6.63-10.54) (2.0- 3.3)
C	SHMS	11.0	2.25	30.0	6.96	< 91.0	$< 0.1\%$	0.25-0.65 (4.71- 9.49) (2.4- 3.9)
					Resonances			
D	SHMS	11.0	7.50	12.5	104.79	–	–	0.50-1.00 (3.12- 4.45) (0.9- 2.0)

Table 2 shows the kinematic settings and the updated rate estimation for the elastic and the $\Delta(1232)$ measurements. These measurements will be used to check the product

Figure 1: Kinematic coverage of A_1^n measurement using HMS and SHMS with a 11 GeV beam. The higher (lower) Q^2 settings correspond to a scattering angle of 30° (12.5°). Kinematic points with overlapping x and Q^2 bins are shifted horizontally for clarity. The error bars are proportional to the expected statistical uncertainties on A_1^n. Here we try to match ΔA_1^n (stat.) at the two different Q^2 values. At highest x settings (30° angle), the smaller angle acceptance of the SHMS is compensated by its large y_{targ} acceptance, hence error bars from the SHMS is about the same as those from the HMS. The two solid curves show the separation between DIS and resonance kinematics ($W = 2.0$ GeV) and the location of the $\Delta(1232)$ resonance, respectively. Statistical uncertainties combining the two spectrometers and different kinematics are given in section 3.



of beam and target polarizations $P_b P_t$ to a 0.5% (statistical) level and to check the sign of transverse asymmetries. The kinematics stay the same as the original proposal, only rates and the beam time are different.

Table 2: Kinematics for elastic longitudinal and $\Delta(1232)$ transverse asymmetries. The HMS and SHMS will be set at the same momentum and angle settings. The beam times shown are the expected single-spectrometer time.

Kine	E_b GeV	E_p GeV	θ (°)	elastic x-sec (nb/sr)	elastic rate (Hz)	Asymmetry	Time (hours)
Elastic	2.200	2.160	12.5	106.986	1293.9	$A_\parallel = 0.0589$	11.2
$\Delta(1232)$	2.200	1.815	12.5	-	-	$A_\perp \sim$ a few %	6

3 Expected Results

3.1 Expected Results for A_1^n and Uncertainties

Table 3 and Fig. 2 show the projected uncertainties on A_1^n. See 2016 proposal for explanation of theoretical predictions. All systematic uncertainties are calculated in

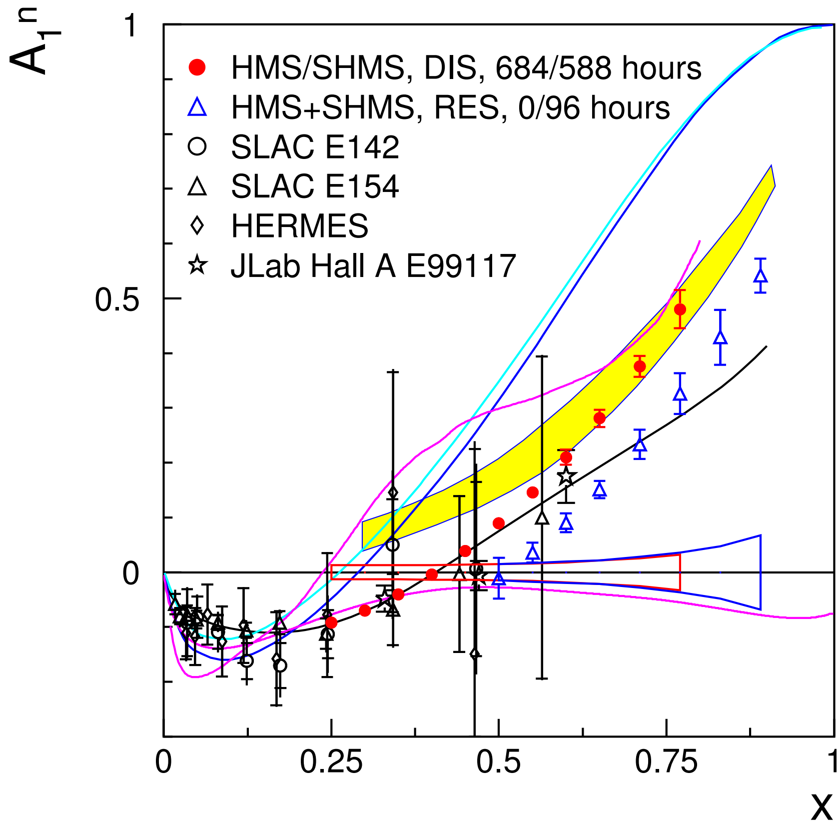
Table 3: Projected statistical and systematic uncertainties for DIS data at different x and Q^2. As a comparison, the 6 GeV result at $x = 0.61$ was $A_1^n = +0.175 \pm 0.048(\text{stat.})^{+0.026}_{-0.028}(\text{syst.})$. And the 2010 proposed values are ΔA_1^n(stat.)= 0.0288 and ΔA_1^n(total)= 0.0446.

x	ΔA_1^n(stat.) low Q^2	ΔA_1^n(stat.) high Q^2	ΔA_1^n(stat.) two Q^2 combined	ΔA_1^n(syst.)	ΔA_1^n(total)
0.25	0.0034	–	0.0034	0.0131	0.0135
0.30	0.0037	–	0.0037	0.0130	0.0135
0.35	0.0048	0.0157	0.0046	0.0129	0.0137
0.40	0.0062	0.0159	0.0058	0.0134	0.0146
0.45	0.0085	0.0123	0.0070	0.0138	0.0154
0.50	0.0124	0.0112	0.0083	0.0146	0.0168
0.55	–	0.0122	0.0107	0.0159	0.0192
0.60	–	0.0135	0.0134	0.0180	0.0224
0.65	–	0.0157	0.0157	0.0217	0.0268
0.71	–	0.0189	0.0189	0.0254	0.0316
0.77	–	0.0346	0.0346	0.0325	0.0475

Table 4: Projected statistical and systematic uncertainties for resonance data at different x and Q^2. Resonance data will be taken at a scattering angle of 12.5° (same as the low Q^2 DIS data). The DIS fit for A_1 was used in the systematic uncertainty study.

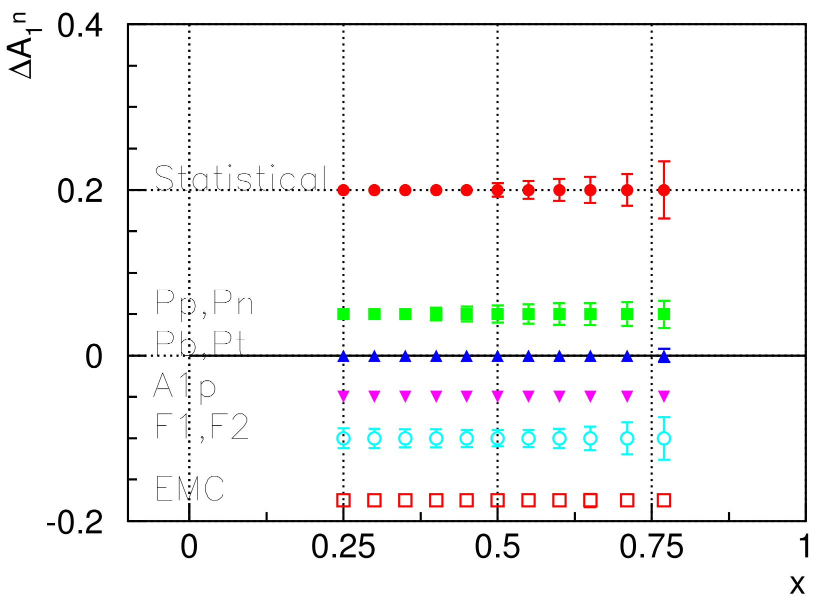
x	ΔA_1^n(stat.)	ΔA_1^n(syst.)	ΔA_1^n(total)
0.55	0.0180	0.0171	0.0249
0.60	0.0171	0.0198	0.0261
0.65	0.0158	0.0215	0.0266
0.71	0.0269	0.0279	0.0388
0.77	0.0371	0.0362	0.0518
0.83	0.0505	0.0476	0.0694
0.89	0.0310	0.0678	0.0746

Figure 2: Projected data (red solid circles) for measurements of asymmetries A_1^n in the large-x region using a 11 GeV beam and HMS and SHMS in Hall C. Both DIS and resonance data are shown. The error bars show the expected statistical error and the error bands around the horizontal axis illustrate the expected systematic uncertainties.



the same way as the original proposal, and are illustrated in Fig. 3. The dominating systematics comes from the uncertainty in the proton polarization inside ^{3}He (P_p) and the $F_{1,2}$ used in the nuclear correction. For the uncertainty from A_1^p in the nuclear correction, we used the projected A_1^p results of the approved CLAS12 experiment (PR12-06-109).

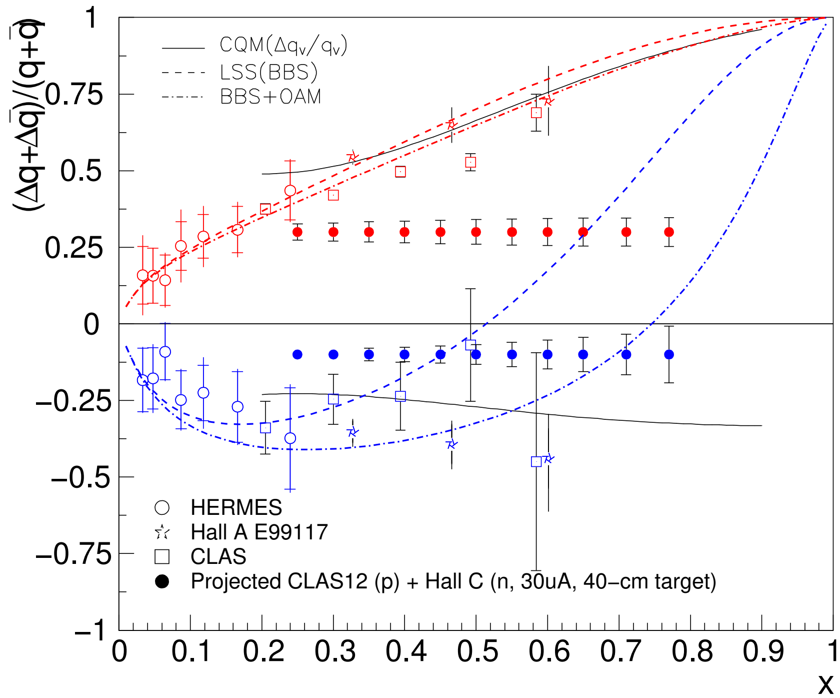
Figure 3: Statistical and systematic uncertainties for the proposed A_1^n measurement. Only DIS data are shown here. Systematic uncertainties shown here are mostly due to nuclear corrections in the data analysis. Uncertainties due to instrumentation and backgrounds (such as the detector's PID performance which determines the uncertainties from pion and pair production background) are not shown because they are expected to be negligible compared to the statistical error for the proposed measurements.



3.2 Expected Results for $\Delta q/q$ if Combined with CLAS12

Neglecting sea quark contributions, the polarized to unpolarized PDF ratio $\Delta q/q$ can be extracted by combining data on A_1^p and A_1^n, or g_1^p/F_1^p and g_1^n/F_1^n. Although the approved CLAS12 experiment (PR12-06-109) will measure both the proton and the neutron spin structure functions, the best results on $\Delta d/d$ are expected from combining the CLAS proton results with the neutron results from this experiment (up to $x = 0.77$). Figure 4 shows the expected results if the A_1^n DIS measurements proposed here are combined with the CLAS12 projected proton results. The error bars include both statistical and systematic errors.

Figure 4: Expected results on $\Delta u/u$ (red) and $\Delta d/d$ (blue) extracted from the neutron results of the A_1^n measurement and the proton results of CLAS12. Also shown are predictions from RCQM (solid curves), the leading-order pQCD-based LSS(BBS) parameterization of pre-JLab data (dahsed curves), and the latest pQCD-based parameterization which incorporates the effects of quark OAM in the fit (dash-dotted curves).



4 Beam Time Allocation

The beam time allocation for production runs at each kinematics is shown in Table 5.

Table 5: Beam time for DIS and resonance production measurements (total 684 hours).

Kine	E_b (GeV)		θ ($^\circ$)	E_p (GeV)	e^- production (hours)	e^+ prod. (hours)	Tot. Time (hours)
				DIS			
1	11.0	HMS	12.5	5.70	12	0	12
2	11.0	HMS	12.5	6.80	24	0	24
3	11.0	HMS	30.0	2.82	96	0	96
4	11.0	HMS	30.0	3.50	551	1	552
A	11.0	SHMS	12.5	5.80	36	0	36
B	11.0	SHMS	30.0	3.00	464	0	464
C	11.0	SHMS	30.0	2.25	88	0	88
				Resonances			
D	11.0	SHMS	12.5	7.50	96	0	96

Additional beam time (all in PAC units unless otherwise specified) include:

- Commissioning of the spectrometers, the beamline and the Compton polarimeter. Assuming this is not the first experiment in Hall C to use the newly-installed polarized ^{3}He target, the commissioning will likely take 3 PAC days.
- To check the dilution factor due to unpolarized material in the target, and for inputs to the nuclear corrections, we need data on the reference cell filled with N_2, ^{3}He, and H_2: 2 hours each at the HMS kinematics 1 and 2 and the SHMS kinematics A, and 4 hours each at the HMS kinematics 3 and 4 and the SHMS kinematics C and D. This requires a total of 12 PAC hours.
- To check the product of beam and target polarizations $P_b P_t$ and to check the sign of transverse asymmetries, we need 8 PAC hours to measure the longitudinal asymmetry of $\vec{e} - {}^3\vec{\mathrm{He}}$ elastic scattering (including PAC 2 hours of reference cell runs) and 6 PAC hours to measure the transverse asymmetry of $\Delta(1232)$ production. The beam energy for these two measurements will be 2.2 GeV and both SHMS and HMS will be set at 12.5°;
- optics runs: data will be taken on a multi-foil carbon target with the 2.2 GeV beam to study the optics of the HMS and the SHMS. This will take 8 PAC hours total.
- beam pass change from 2.2 to 11 GeV, 8 PAC hours;

- beam polarization measurements: For each energy, it takes about one (calendar) shift to setup the Moller and an additional 4 calendar hours to perform one measurement. We plan to perform one Moller measurement at 2.2 GeV and six at 11 GeV (approximately once every 10 calendar days). Total time required is $(8 + 4 * 6) + (8 + 4)$ calendar hours, or 22 PAC hours.

- configuration changes: 12 (angle or momentum or target spin direction) $\times$ 0.5 hours + + 8 (polarity) = 14 PAC hours;

- target polarization measurements, about 4% of production time (that's about 1 hour per day), or 28 hours.

The total beam time request is 862 hours, or 36 PAC days.