Precision Measurement of the Neutron d_2: Towards the Electric χ_E and Magnetic χ_B Color Polarizabilities

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March 10, 2007

1 Introduction

E06-014 will measure the unpolarized cross section $\sigma_0^{^3He}$, the parallel asymmetry $A_{\parallel}^{^3He}$ and the perpendicular asymmetry $A_{\perp}^{^3He}$ to extract the g_2 structure function. This measurement will cover excitation energies in the deep inelastic valence quark region where x and Q^2 are large ($0.2 \leq x \leq 0.7$ and $2 \leq Q^2 \leq 6$ GeV^2). We will extract the higher twist piece of the spin structure function $\overline{g}_2$ and evaluate the quantity $d_2^n = \int_0^1 \overline{g}_2 \, dx = \int_0^1 x^2 (2g_1 + 3g_2) \, dx$ which is related to a twist three matrix element.

In inclusive polarized lepton-nucleon deep-inelastic scattering, one can access two spin-dependent structure functions of the nucleon, g_1 and g_2. In the last twenty five years, measurements of g_1 have been used to test Quantum Chromodynamics (QCD) through the Björken sum rule and investigate the spin content of the nucleon in term of its constituents. While g_1 can be understood in terms of the Feynman parton model which describes the scattering in terms of *incoherent* parton scattering, g_2 cannot. Rather, one has to consider parton correlations initially present in the target nucleon, and the associated process is given a *coherent* parton scattering in the sense that more than one parton takes part in the interaction. Indeed, using the operator product expansion (OPE), it is possible to interpret the g_2 spin structure function beyond the simple quark-parton model as a higher twist structure function. As such, it is exceedingly interesting because it provides a unique opportunity to study the quark-gluon correlations in the nucleon which cannot otherwise be accessed.

Within the OPE framework d_2^n is connected to a twist-three matrix-element directly measuring quark-gluon correlations within the nucleon. Ji and Filippone have shown that this quantity reflects the response of the *color* electric and magnetic fields to the polarization of the nucleon (alignment of its spin along one direction). d_2^n has seen considerable study in Lattice QCD and is one of the cleanest observables with which to test the theory.

We will use the longitudinally polarized ($P_b \geq 0.75$) CEBAF electron beam and a 40 cm-long high-pressure polarized ^{3}He target. The measurement will be performed at two beam energies: 4.6, and 5.7 GeV (corresponding to 4-pass and 5-pass at a nominal fixed per-pass energy of 1.15 GeV). At each beam energy the BigBite spectrometer will be used to acquire the asymmetry data (perpendicular and parallel) while the left arm HRS spectrometer will be used to measure the absolute cross section. The spectrometers will be positioned at a scattering angle of 45° on opposite sides of the beam line.

This measurement has been granted 13 PAC days (312 hours). We have requested 180 hours at 5.7 GeV and 80 hours at 4.6 GeV. Of the remaining 52 hours, 28 are allocated to cover overhead and target polarization measurements and 24 hours will be contributed to the joint commissioning of BigBite and the LHRS in cooperation with the Transversity collaboration.

2 Experimental Configuration

2.1 Kinematics

BigBite's mode of operation is such that a single magnetic field setting will cover the entire kinematic range at each beam energy. The Left HRS central momentum will be stepped across the same kinematic range to measure the absolute cross section as a function of x. Tables 1 and 2 present the kinematic bins and anticipated signal rates. Figure 1 plots the kinematic coverage over x and Q^2.

2.2 The Polarized Beam

Our rate calculations assume that the achievable beam polarization at CEBAF is 75% with a current of 15μA although 80% electron beam polarization has been delivered on a regular basis in Hall A. The polarization of the beam will be measured with the Hall A Möller and Compton polarimeters.

2.3 The Polarized ^{3}He Target

The target preparations will be covered in their own section and will not be repeated here. *Reference?*

2.4 Spectrometer Configuration

We plan to use the BigBite spectrometer in Hall A to take the bulk of the data, and one HRS spectrometer, the left arm, to perform cross section measurements and calibrations. Both will be located at 45° symmetrically with respect to the incident beam line.

Table 1: Parameters per bin in (Q^2,x) plane for the 5.7 GeV runs. Note that it is a single spectrometer setting for BigBite but different central momentum settings for the HRS_L.

E_i (GeV)	bin central p (GeV)	x	Δx	Q^2 (GeV^2)	W (GeV)	Rate (Hz)		
5.700	1.603	0.696	0.097	5.35	1.79	3.0		
5.700	1.450	0.607	0.081	4.84	2.00	5.0		
5.700	1.312	0.532	0.069	4.38	2.18	7.0		
5.700	1.187	0.468	0.059	3.96	2.32	8.9	Single	
5.700	1.074	0.413	0.051	3.59	2.44	10.4	BigBite	
5.700	0.971	0.365	0.044	3.24	2.55	11.6	Spectrometer	
5.700	0.878	0.324	0.038	2.93	2.65	12.5	Setting	
5.700	0.794	0.288	0.034	2.65	2.73	13.1		
5.700	0.718	0.256	0.029	2.40	2.80	13.5		
5.700	0.650	0.229	0.026	2.17	2.86	13.8		
							$Time_\perp$ hours	$Time_\parallel$ hours
Total (5.7 GeV data set)							172	8

Table 2: Parameters per bin in (Q^2,x) plane for the 4.6 GeV runs. Note that it is a single spectrometer setting for BigBite but different central momentum settings for the HRS_L.

E_i (GeV)	bin central p (GeV)	x	Δx	Q^2 (GeV^2)	W (GeV)	Rate (Hz)		
4.600	1.502	0.696	0.118	4.05	1.63	4.22		
4.600	1.366	0.607	0.097	3.68	1.81	7.95		
4.600	1.243	0.532	0.080	3.35	1.96	10.8		
4.600	1.131	0.468	0.067	3.05	2.08	14.1	Single	
4.600	1.028	0.413	0.057	2.77	2.19	16.8	BigBite	
4.600	0.933	0.365	0.049	2.51	2.29	18.9	Spectrometer	
4.600	0.847	0.324	0.042	2.28	2.38	20.3	Setting	
4.600	0.768	0.288	0.036	2.07	2.45	21.3		
4.600	0.696	0.256	0.032	1.88	2.52	21.8		
4.600	0.633	0.229	0.028	1.71	2.57	22.0		
							$Time_\perp$ hours	$Time_\parallel$ hours
Total (4.6 GeV data set)							72	8

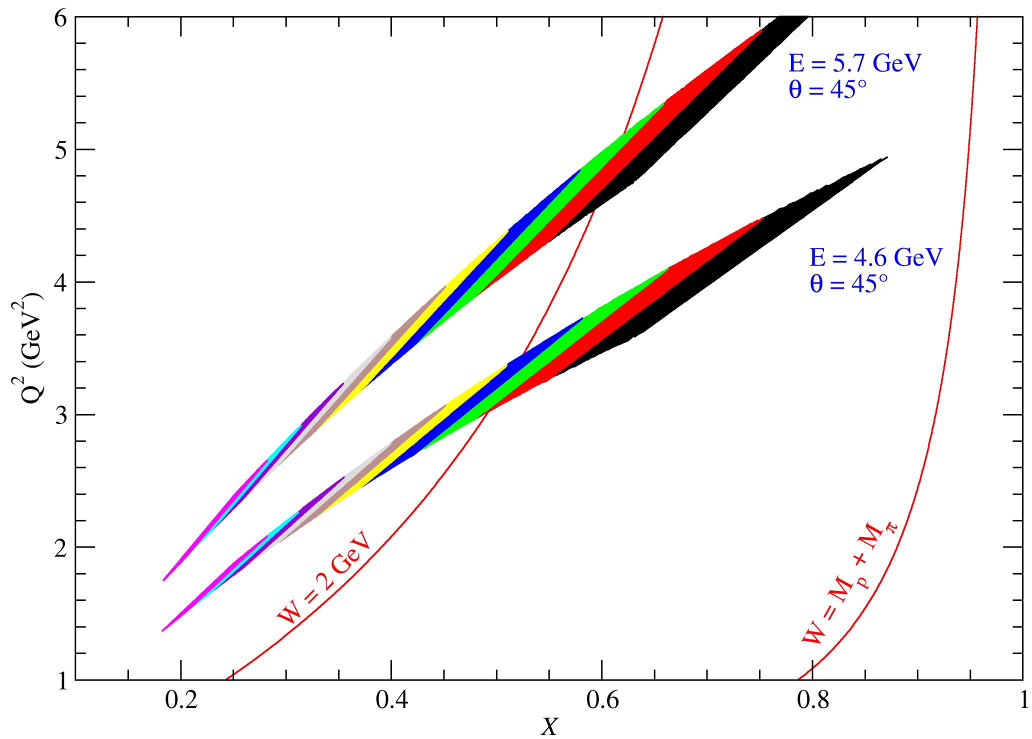

Figure 1: Kinematic range for the measurement at a constant energy and angle. The bands represents the horizontal angular acceptance of the BigBite spectrometer. Each band is split into bins associated with the 10 L-HRS spectrometer momentum settings used at each beam energy.

2.4.1 The BigBite spectrometer

We will share the same BigBite detector configuration as Transversity. The only difference will be that BigBite will be located at $\theta = 45^\circ$ (whereas Transversity has BigBite at $\theta = 30^\circ$). Figure 2 shows a top and side view of the detector stack showing the new Cerenkov detector.

The BigBite spectrometer will be positioned at a distance of 1.5 m from the target and its dipole magnet set at full current providing a central field of $B = 1.2$ T The BigBite detector package will consist of

- Three Multi-wire Drift Chambers (MWDC) for tracking information (2 are back-to-back and located at the front of the detector stack, the third chamber is just downstream of the Cerenkov),

- a Gas Cerenkov counter between the front MWDC assembly and the rear MWDC, used for trigger-level pion rejection,
- a scintillator plane for timing information, and
- a double-layer lead-glass calorimeter for energy determination and improved pion rejection.

The detector package configuration for BigBite similar to that of E02-013 (G_E^n) except that we plan to move the middle MWDC to the front of the detector stack and install a threshold gas Cerenkov counter in the resulting gap. Since this experiment is inclusive the addition of the Cerenkov counter for pion and proton rejection is critical.

The new Cerenkov detector design and development milestones are covered in detail in a dedicated section of the review document.

Reference?

2.4.2 Left High Resolution Spectrometer

The Hall A Left High Resolution Spectrometer (LHRS) will be positioned at 45° to measure absolute cross sections over the same x range as the the BigBite spectrometer. The LHRS detector configuration will match that of the Transversity experiment and is described in detail elsewhere in this document.

Reference?

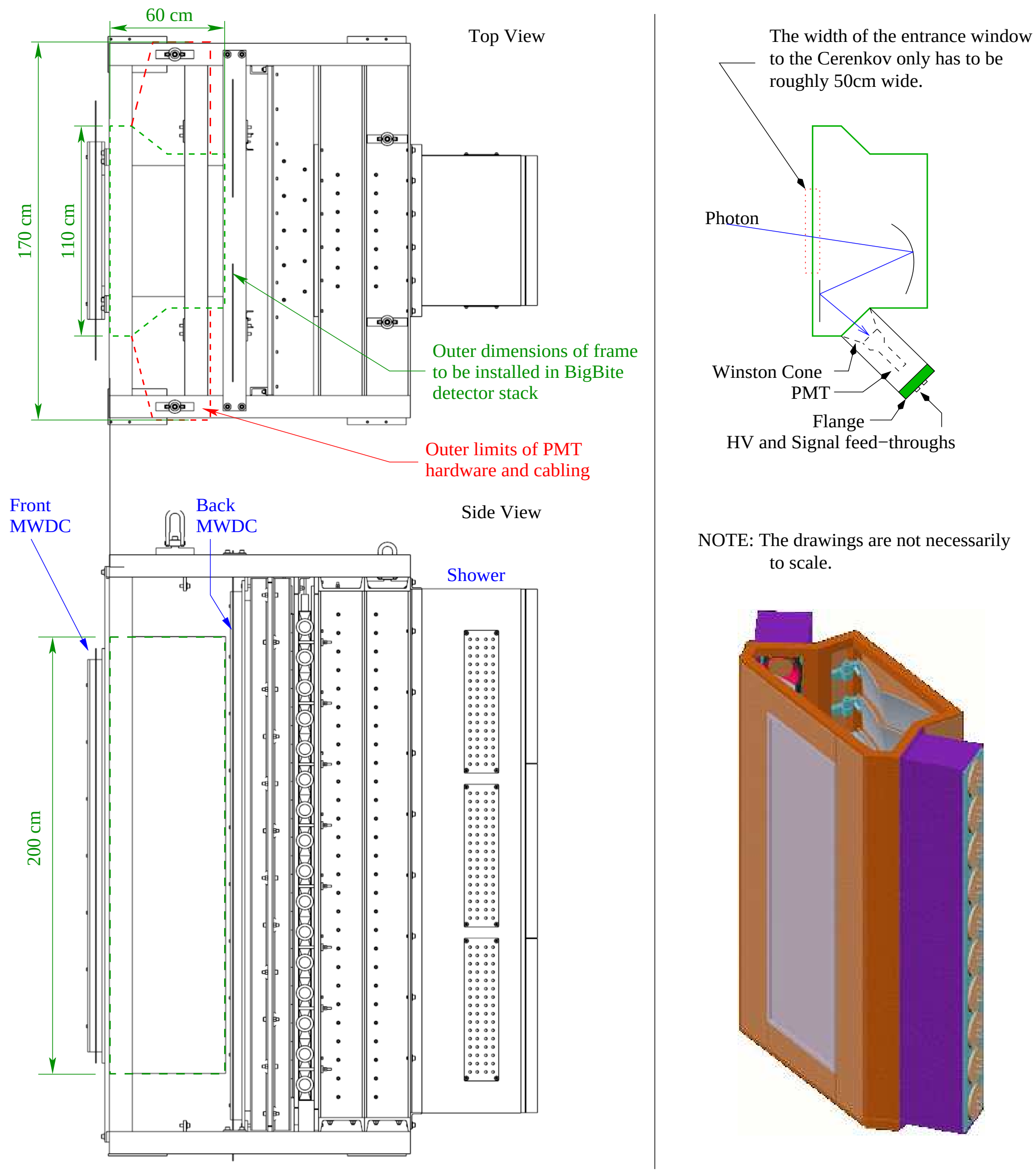

Figure 2: Conceptual diagram of the BigBite detector stack with an overlay of the Cerenkov detector's outer dimensions. The sketch on the upper right illustrates how the PMTs will be mounted to the tank. The rendering on the lower right is from a recent CAD model.