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THE GLUON SPIN STRUCTURE FUNCTION FROM SLAC E161

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Abstract. We will determine the gluon spin density $\Delta g(x)$ in the nucleon by measuring the asymmetry for polarized photo-production of charmed quarks from polarized targets in End Station A at SLAC. The quasi-mono-chromatic circularly polarized photon beam will be produced from an oriented diamond crystal. The target will be longitudinally polarized LiD at a temperature of 0.3 K, centered in a 6.5 T magnetic field to obtain high polarization. Photo-production of open charm will be tagged by decays of D mesons into high transverse momentum muons. The asymmetry for single muons will be measured as a function of muon momentum, muon transverse momentum, and photon beam energies with sufficient precision to discriminate among models of $\Delta g(x)$ that differ from each other by as little as 10% in the range $0.1 < x < 0.2$.

MOTIVATION

The spin degree of freedom has, in recent years, opened up a new window into our understanding of nucleon structure. Much of this improvement is due to measurements of the structure functions g_1 using the SLAC high energy, high current, and high polarization electron beam combined with recent major advances in polarized target technology. One of the goals of these experiments has been the determination of the spin distributions of the quarks and gluons using the evolution equations We will continue this program by directly measuring the gluon spin distribution function.

A major goal of the g_1 experiments has been the determination of spin distributions of quarks and gluons in the nucleon (“what carries the spin?"). A “spin crisis", resulting in numerous theoretical papers, arose when early determinations [1] of $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ were found to be much smaller than expected [where $\Delta f = \int_0^1 \Delta f(x,Q^2)dx$, and $\Delta f(x,Q^2)$ are the individual polarized quark spin distribution functions]. At present, the world average for $\Delta\Sigma$ is approximately 0.23 ± 0.07 [2], much smaller than the relativistic quark model prediction of 0.58. One explanation for at least part of this discrepancy is that the strange sea may be highly polarized, but this depends rather strongly on assumptions of SU(3) symmetry between the beta decays in the baryon octet. In any case, the low value of $\Delta\Sigma$ implies strong gluon contributions via loop and radiative corrections in QCD, expected to be stronger in the polarized case than in the unpolarized case due to the triangle diagram axial anomaly.

Many authors have made fits to the existing data on g_1 to parameterize the spin distribution function (SDF’s) $\Delta u(x)$, $\Delta d(x)$, $\Delta s(x)$, and $\Delta g(x)$ using the GLAP evolution equations. Due to the imprecision of present data, different theoretical constraints and parameterizations of the x-dependence are used. The result is that the gluon distributions

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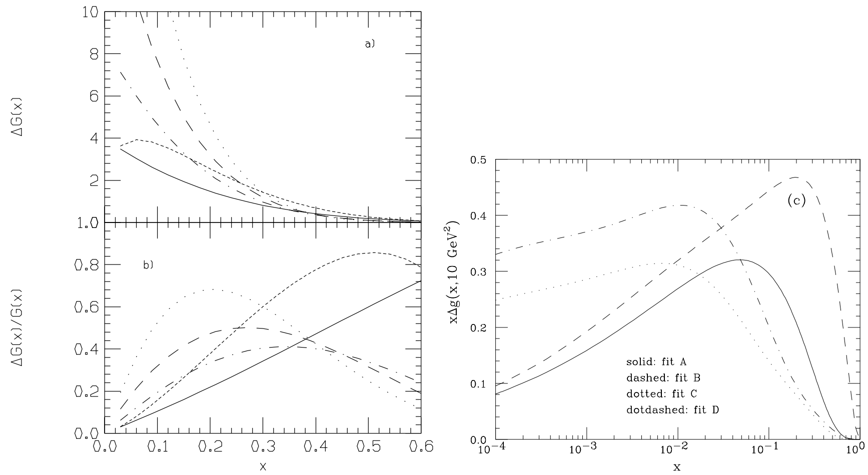

FIGURE 1. Various predictions for the gluon spin density from References [3](Left) and [4](Right).

differ quite significantly, as can be seen in Fig. 1. Some of the fits have maximum values of $\Delta g(x)/g(x)$ close to unity. There are corresponding large range in values in the total spin from the gluon, ΔG, from near zero to over 2. According to GRSV [3], inevitably the large uncertainty in $\Delta g(x)$ implies that the small x behavior of g_1 is completely uncertain and not reliably predictable, with values ranging from less than 5 to greater than 10 at $x = 0.0001$.

METHOD

Our approach for studying polarized gluons in the nucleon is photo- or electro-production of either open charm or inelastic J/ψ's through the hard process of photon-gluon fusion $\gamma + g \rightarrow c\bar{c}$. Higher order diagrams have been calculated for both the polarized and unpolarized cases. The relatively large charm quark mass ensures that the relevant momentum transfer scale μ^2 is of order $\mu^2 = 4m_c^2 \approx 9$ GeV^2. where perturbative QCD is expected to work well. Other mechanisms for producing charm are suppressed because of the large (~ 1.5 GeV) mass of the charm quark. To leading oder for polarized photons and longitudinally polarized nucleons, the polarized experimental cross section difference, $\Delta\sigma_{\gamma p}(k)$, is a convolution of Δg and hard scattering $\Delta\sigma$ [5]

$$\Delta\sigma_{\gamma p}(k) = \int_{x_{min}}^{1} \Delta g(x, Q^2) dx \int_{-1}^{1} \Delta\sigma(\hat{s}, \cos(\theta^*))\ \varepsilon(\hat{s}, \cos(\theta^*))\ \beta\ d\cos(\theta^*) \quad (1)$$

where k is the photon energy, $x_{min} = 4m_c^2/2Mk$, m_c is the charmed quark mass of about 1.5 GeV, M is the nucleon mass, $s = 2Mk + M^2$ is the square of the c.m. energy in the photon-nucleon system, $\beta = \sqrt{1 - 4m_c^2/\hat{s}}$ is the c.m. velocity of the charmed quark, $\hat{s} = xs$ is the square of the c.m. energy in the photon-gluon system (or the $c\bar{c}$ system), Q^2 is the squared momentum transfer to the gluon (taken in our calculations to be $Q^2 = \hat{s}$),

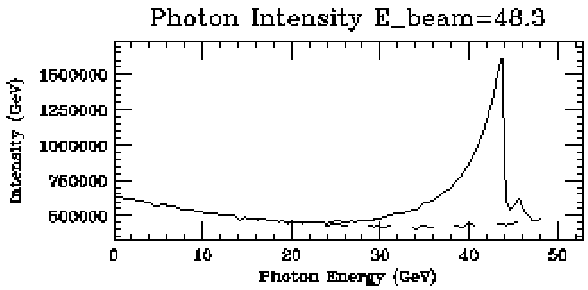

FIGURE 2. Calculated intensity (flux times energy) for collimated coherent bremsstrahlung at the highest energy for this experiment. The dashed lines are incoherent radiation only, while the solid lines include coherent contributions.

θ^* is the c.m. angle of the charmed quarks,

$$\Delta\sigma(\hat{s},\cos(\theta^*)) = \frac{4}{9}\frac{2\pi\alpha\alpha_s(\hat{s})}{\hat{s}}\left[\frac{4m_c^4(\hat{t}^3+\hat{u}^3)}{\hat{t}^2\hat{u}^2} + 2\frac{\hat{t}^2+\hat{u}^2-2m_c^2\hat{s}}{\hat{t}\hat{u}}\right], \qquad (2)$$

$\hat{t} = \frac{\hat{s}}{2}[1+\beta\cos(\theta^*)]$, and $\hat{u} = \frac{\hat{s}}{2}[1-\beta\cos(\theta^*)]$. The produced $c\bar{c}$ pair will be detected by their fragmentation into B and $\bar{B}$ mesons and subsequent decay into high p_T muons. The method requires a high energy longitudinally polarized photon beam, a polarized target and a spectrometer to detect the muons.

The Photon Beam

The beam will be produced using collimated coherent bremsstrahlung of a polarized electron beam hitting an oriented diamond crystal. The electron beams will have energies from 9.9 to 48.5 GeV; an intensity of up to 5×10^{10} electrons per pulse; repetition rate of 120 Hz; pulse length of 500 nsec; and polarization of about 83%. A typical photon beam energy spectrum is shown in Fig. 2. The coherent peak is produced by constructive interference of the photons produced at different planes of the diamond crystal.

The Target

The target will be a 5 cm long, 1 cm diameter cylinder filled with ^{6}LiD , which is polarized using the technique of Dynamic Nuclear Polarization (DNP). Using a dilution refrigerator at 300mK, in conjunction with a magnetic field of up to 6.5 T, we expect 70% polarization [6] for the deuteron and ^{6}Li. The setup will be similar to that used in SLAC experiments E143 and E155.

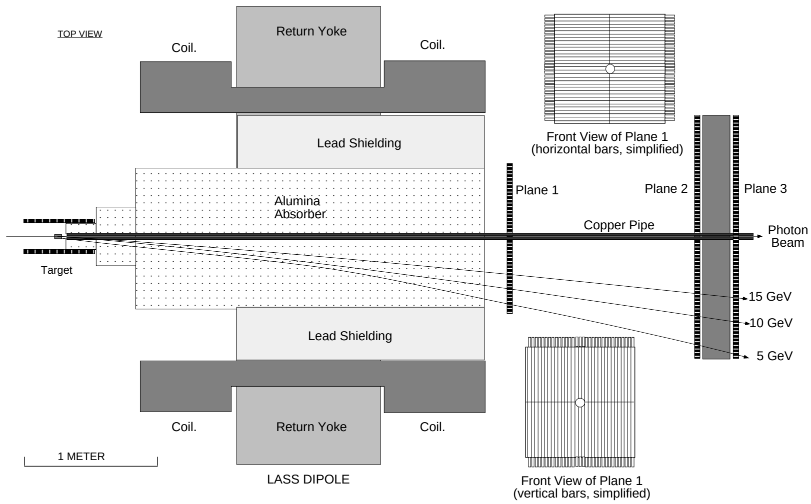

FIGURE 3. Overall plan view of the main components of the spectrometer. The absorber fills most of the gap of the LASS dipole, and also extends into the warm bore of the target magnet. A thick evacuated copper beam pipe contains the photon beam. The three detector planes are made from scintillator hodoscopes. Two simplified front views of the front plane are shown. The dashed curves are typical trajectories for muons with $p_t = 0.7$ and $P = 5$, 10, and 15 GeV.

The Spectrometer

We will identifying the high p_t prompt muons from open charm decay amongst the approximately 1000 times higher rate of long lifetime pions and kaons. The detector shown in Fig. 3 has absorbers are placed very close to the target with enough interaction lengths and radiation lengths to almost completely contain all hadronic and electromagnetic showers. The amount of absorber needed is reduced somewhat by placing the material in a magnetic field, which is also used to determine the momentum of the muons. Tracking of the muons will be done using planes of scintillator hodoscopes. The fine granularity and good timing of this type of system are needed to match hits from muon tracks that will occur on average every 15 to 25 nsec. We plan to use three planes of hodoscopes as seen in Fig. 3. The first two planes have fine resolution for measuring momentum and angles, while the last plane, shielded behind additional lead, has less granularity and will be used to establish a point in space and time on the muon track at a location where the singles rates are much lower. The planes are segmented into top and bottom halves for the horizontal measuring readout (vertical fingers), and left and right halves for the vertical measuring readout (horizontal fingers). This is done to reduce the random hit rate per finger, and to reduce the spread in signal height from attenuation of the light in the scintillator.

RESULTS

The anticipated statistical precision of the experiment is shown in Fig. 4 for the three peak energies of the beam and two different muon momentum ranges. The data points

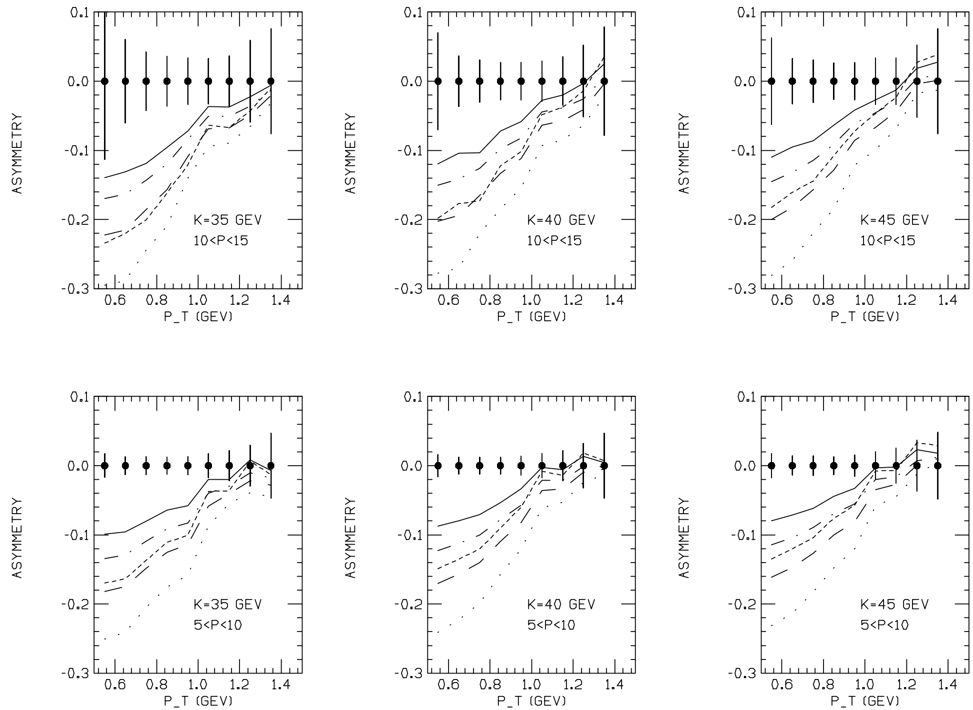

FIGURE 4. Asymmetries for five fits to the gluon polarization as a function of p_T^{μ} of the detected muon for six kinematic conditions. The points indicate the projected statistical errors. Experimental systematic errors will be highly correlated from point-to-point, and will be approximately 0.10 of the measured asymmetries.

are shown at the arbitrary value of zero, with the errors expected from the experiment. The error estimates include the corrections due to pion and kaon decay and those due to associated production. The errors are as small as 0.012 on the asymmetry over many data points at different energies and p_T^{μ}. Predicted asymmetry using representative fits are shown here. Our experiment can easily distinguish between them. Averaging over the points will give an error of about 0.006 at each of the energies.

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