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GLUON SPIN DISTRIBUTION AND GDH SUM RULE MEASUREMENTS AT THE STANFORD LINEAR ACCELERATOR CENTER

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A quasi-monochromatic circularly-polarized photon beam with energies up to 45 GeV will be developed at the Stanford Linear Accelerator Center. Using this beam, measurements will be made of the gluon spin density by photo-production of open-charm from a polarized target, and of the spin-dependent cross section on longitudinally polarized protons and neutrons to test the Gerasimov-Drell-Hearn sum rule.

1 Introduction

A cohesive program of three fixed-target real-photon experiments has been approved for running several months during each of the years 2003 through 2005 at the Stanford Linear Accelerator Center (SLAC). There is a significant overlap in required beams, targets, and detectors for these three experiments. This has led to the formation of a Real Photon Collaboration that currently includes over 50 physicists from 15 institutions in both Europe and the United States. Two of these experiments are of direct relevance to this workshop. The first, E161, is the measurement of the gluon-spin density Δg within the nucleon by measuring the asymmetry of polarized photo-production of charmed quarks from a polarized lithium-deuteride target. The second, E159, is the measurement of the difference in the spin-dependent total hadronic cross sections for right-handed and left-handed circularly polarized photons absorbed on longitudinally polarized protons and neutrons as it pertains to the fundamental Gerasimov-Drell-Hearn (GDH) sum rule. A third experiment, that will be run first, utilizes much of the same equipment as the other two experiments, but it should be less demanding because it does not need a polarized beam or target. It will undertake the measurement of the atomic number dependence of several nuclei, and hence the dependence on nuclear radius, of the J/ψ and ψ' photo-production cross sections. Four nuclear targets ranging from Be to Pb will be used. Among its aims, this measurement, using a relatively simple photon probe, may constrain the possible causes of J/ψ suppression in ultra-relativistic heavy-ion collisions which will serve as a signature of the formation of a quark-gluon plasma. No further discussion of this third experiment will be undertaken, as it is less relevant to this workshop than the other two experiments.

In the sections to follow, we will first discuss the method of producing the photon beam to be used in all three experiments, to be followed by the specifics of the Δg and GDH measurements.

2 Photon Beams

Because the SLAC electron beam has a low-duty factor of the order of 10^{-4}, the most advantageous way to produce the required circularly polarized photon beams for the Δg and GDH experiments, is to direct high-energy longitudinally polarized electron beams onto a thin diamond crystal. The electrons radiate in the crystal, and through constructive interference, a coherent quasi-monochromatic photon beam results. In order to reduce systematic errors, the electrons will have their helicity reversed on a pseudo-random pulse to pulse basis. The diamond crystal will have a thickness of about 80 μm, and an area as large as 10 x 10 mm^2. It will have its crystal planes precisely oriented at an angle with respect to the electron beam by means of a goniometer so as to give the primary photon energy peak for the reciprocal lattice basis (0, 2, 2) crystal orientation. Photon circular polarizations of over 75% will be obtained at the peak for this crystal orientation. Furthermore, if the photon beam is collimated, the energy spread in the photon beam is greatly narrowed. For these experiments, electrons with longitudinal polarization of over 83% having energies from 9.9 to 51.3 GeV will be used to produce photon beams from 4.5 to 45 GeV. The photon beam line, which extends 110 m from the diamond radiator to the polarized targets, will include magnets for dumping the electron beam after it passes through the diamond radiator, and other magnets beyond the photon collimator that will act as sweeping magnets. To center the photon beam on the collimator, a four-quadrant tungsten pin-cushion shower–emission detector will be used. A Compton polarimeter will be placed beyond the targets followed by other beam monitors. Average electron beam currents will be kept below about 0.6 μA to prevent overheating the diamond radiator. For currents of this order, over 10^7 photons per second in the peak will be obtained. This method of using a diamond crystal to produce a photon beam is based upon a proven past program at SLAC [4].

3 Measurement of the Gluon Spin Density

The measurement of spin degrees of freedom in the past decade has markedly improved our understanding of nucleon structure and electroweak interactions within the Standard Model. A "spin crisis" was found when the sum of the quark spin distribution functions $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ was found to be much smaller than expected, where Δf are the individual polarized quark spin distribution functions $\Delta f(x,Q^2)$ integrated over Bjorken x from 0 to 1. The current world average is approximately 0.23 ± 0.07 [2], instead of 0.58 as predicted by the relativistic quark model [3]. This low value of $\Delta\Sigma$ implies strong gluon contributions to the spin 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 [1]. Fits to the existing data on the longitudinal spin structure function g_1, which include several constraints on the x-dependence based upon constituent quark counting rules and on the magnitudes based upon the Bjorken Sum Rule, differ widely. Clearly a direct measurement of the polarized gluon density is called for.

It is proposed to study polarized gluons in the nucleon by photo-production of open charm through the hard process of photon-gluon fusion shown in Fig. 1. Other mechanisms for producing charm are suppressed because of the large (~1.5 GeV) mass of the charm quark. The gluon spin density will be determined by measuring the asymmetry of polarized photo-production of charmed quarks from a polarized target in the range $0.1 < x < 0.5$. The experiment will be carried out in End Station A at SLAC, using a large solid-angle muon-spectrometer, as shown in Fig. 2. Photo-production of open charm will be tagged by decays of D mesons into high transverse momentum muons. The parallel/anti-parallel asymmetry for producing open charm is closely related to the fundamental polarized gluon spin density. 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 that differ from each other by as little as 10%. Significant constraints will be placed on both the shape and magnitude of this x region. The projected errors are significantly smaller than for other experiments that plan to make direct measurements of Δg as shown in Fig. 3. The target will be longitudinally polarized LiD at a temperature of 300 mK, centered in a 6.5 T magnetic field to obtain a polarization of about 60%.

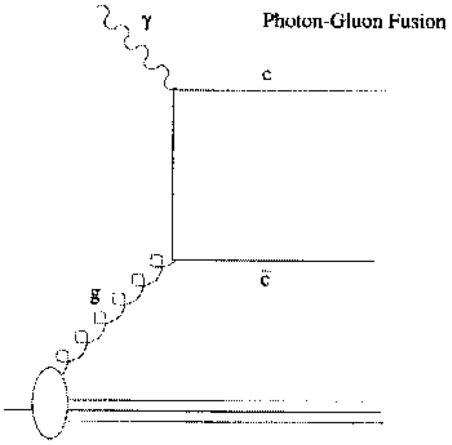

Figure 1. Photon-gluon fusion to produce an open charm/anti-charm pair.

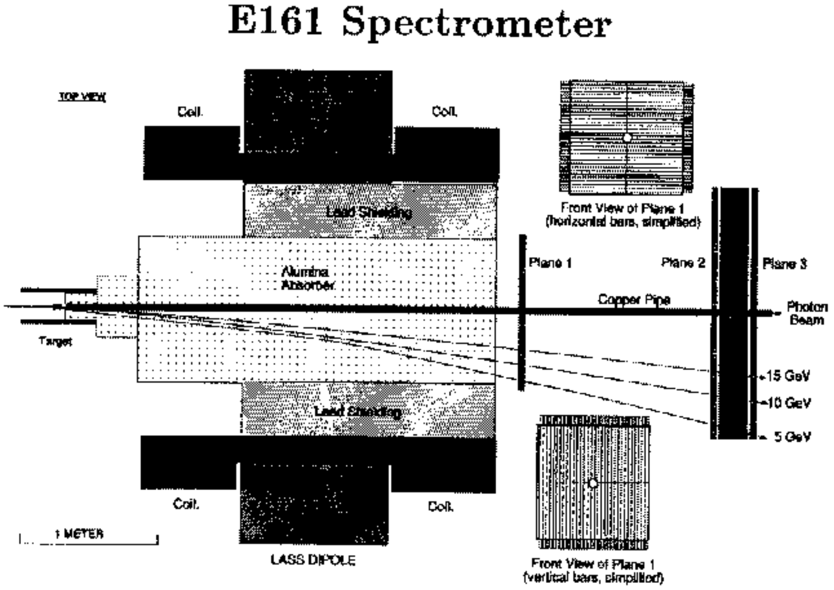

Figure 2. Muon spectrometer. The absorber extends into the warm bore of the target magnet. The three detector planes are scintillator hodoscopes. A copper absorber, filling only the downstream half of the magnet will be used instead of the alumina so as to enhance the rate of background muons from pion and kaon decays.

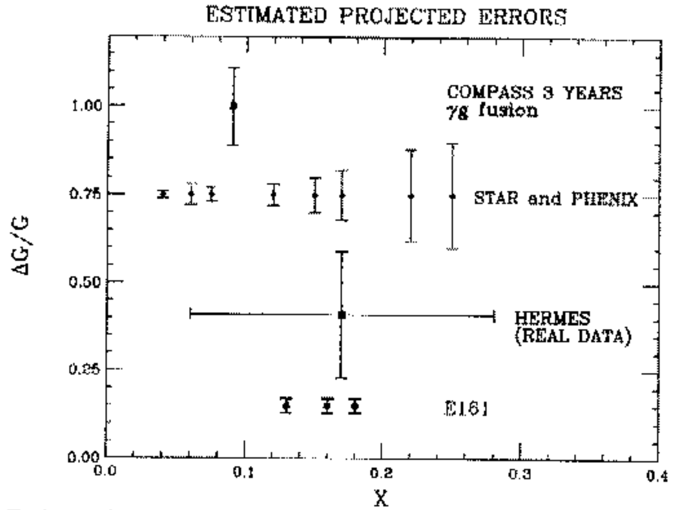

Figure 3. Estimated errors for E161 and some other projected experiments.

4 Measurement of $\Delta\sigma^{\gamma N}(k)$ and the Gerasimov-Drell-Hearn Sum Rule

The Gerasimov-Drell-Hearn (GDH) sum rule relates the difference in total hadronic photo-absorption cross sections between left-handed and right-handed cross sections $\Delta\sigma^{\gamma N}(k)$ for circularly polarized photons interacting with longitudinally polarized nucleons to the square of the nucleon's anomalous magnetic moment κ. These spin-dependent total hadronic cross sections will be measured in the in the photon energy range $5 < k < 40$ GeV. This experiment will test the convergence of the sum rule at high energies, and will give insights into the reaction mechanisms that govern $\Delta\sigma^{\gamma N}(k)$, which in turn will help to understand the low-x behavior of the spin structure function g_1. The polarized target system will use NH_3 and ND_3 to provide polarized protons and deuterons, and possibly ^3He as an alternate way to probe the neutron spin. Calorimetric detectors will be used to identify hadronic interactions and reject electromagnetic backgrounds. The front 27 radiation length (r.l.) segment of each detector will contain the electromagnetic shower, and the remaining 54 r.l. will measure the hadronic energy. The detectors will be used in both a counting and a flux integration mode as shown in Fig. 5. Beam energies between 10 and 48 GeV will be used, with approximately one-third of the running time above 30 GeV.

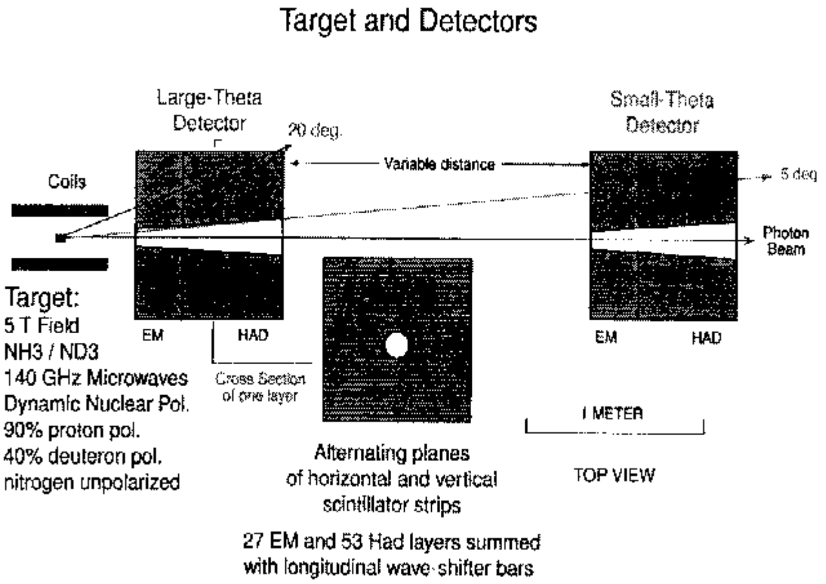

Figure 4. Lead-scintillator detectors for GDH Sum Rule measurement: left, detector for angles up to 20°; right, movable similar detector is for angles up to 5°.

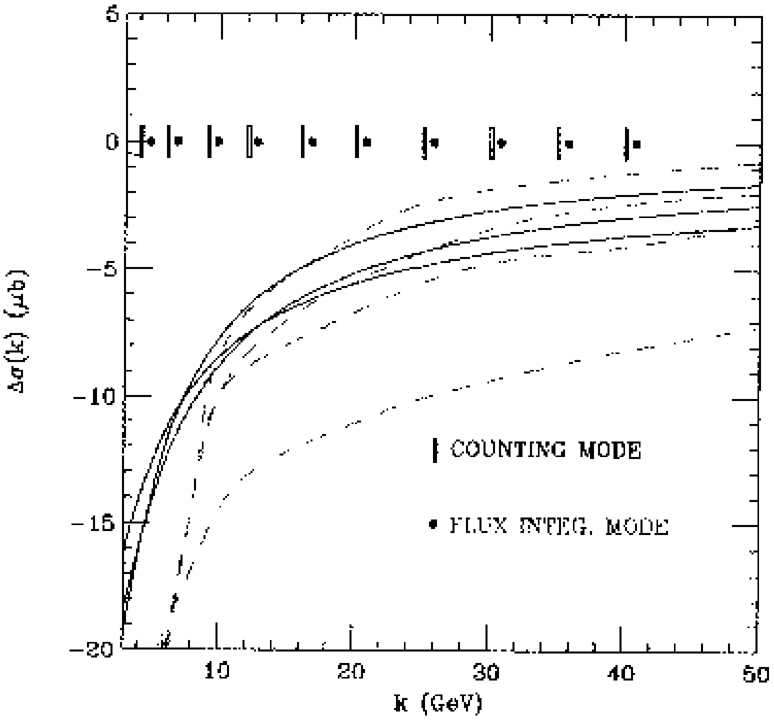

Figure 5. Estimated errors for the GDH sum rule measurements of the differences of cross section for the proton measured in the counting and flux integration modes. The curves are from various representative models given in reference [5] and [6].

More information about these experiments may be found at the web addresses http://www.slac.stanford.edu/exp/e159/ & http://www.slac.stanford.edu/exp/e161/.

5 Acknowledgements

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