Polarimetry Options for E160

As evidenced, for example, by the workshop held at JLab in 1998 on "Polarized Photon Polarimetry", (http://www.jlab.org/ccc/hypermail_archives/collaborations/cuga/0050.html) our objective of measuring the linear polarization of a high-energy photon beam is one shared researchers at several laboratories. Despite investigations extending over three decades, a definitive solution has yet to emerge to this experimental challenge. It is apparent that the polarimetry requirements for E160 and the other experiments of the SLAC real-photon program need ongoing study. At this time we are familiarizing ourselves with the literature and issues, and preparing the simulation tools necessary to develop a successful methodology for our range of photon energies. While our current concepts should be considered as only rudimentary, they are nevertheless backed up by the impressive cumulative effort of other researchers .

Figure 1 defines the most promising candidate processes for determining photon polarization by means of the high-cross-section atomic interactions. For the 5 – 40 GeV energies of interest to us, the Compton cross section is much too small. In this range the interaction cross section is strongly dominated by pair production, both from the nucleus, and from atomic electrons (triplet production.) In the GeV range these cross sections are independent of photon energy. The nuclear pair cross section is proportional to Z^2, whereas the triplet cross section is proportional to Z. Hence the pair-to-triplet conversion ratio varies as Z.

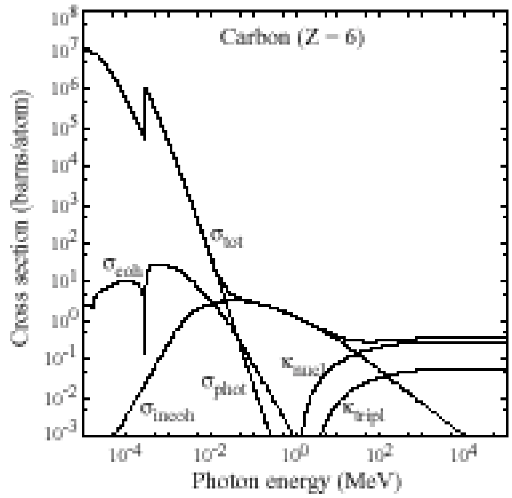

Fig. 1: Photon cross section for ^{12}C.

The general concept for determining linear polarization is to measure the azimuthal asymmetry of a reaction product around the plane of linear polarization of the incident beam. The generic equation has the form

$$\sigma = \sigma_{unp}\left(1 + P\Lambda\cos(2\phi)\right) ,$$

where σ_{unp} is the unpolarized cross section, P measures the polarization of the incident beam, and Λ is the analyzing power of the technique. While it is clearly favorable to have Λ as large as possible in order to precisely determine P, bear in mind that the figure-of-merit, given by $F = \Lambda^2 \sigma_{unp}$, also depends on the cross section.

Pair Production

As a result of work published by Maximon and Olsen (Phys. Rev. **120** (1962) 310), it has generally been considered that the best analyzing power is obtained not from co-linearly produced pairs, but by measuring pairs where the nucleus recoils with non-negligible momentum. Tedeschi and collaborators at JLab (http://solomon.physics.sc.edu/~tedeschi/

research/strips/se-aps99) use this approach to obtain an analyzing power $\Lambda \approx 0.25$, with only a weak dependence on photon energy, for photon energies up to a couple of GeV.

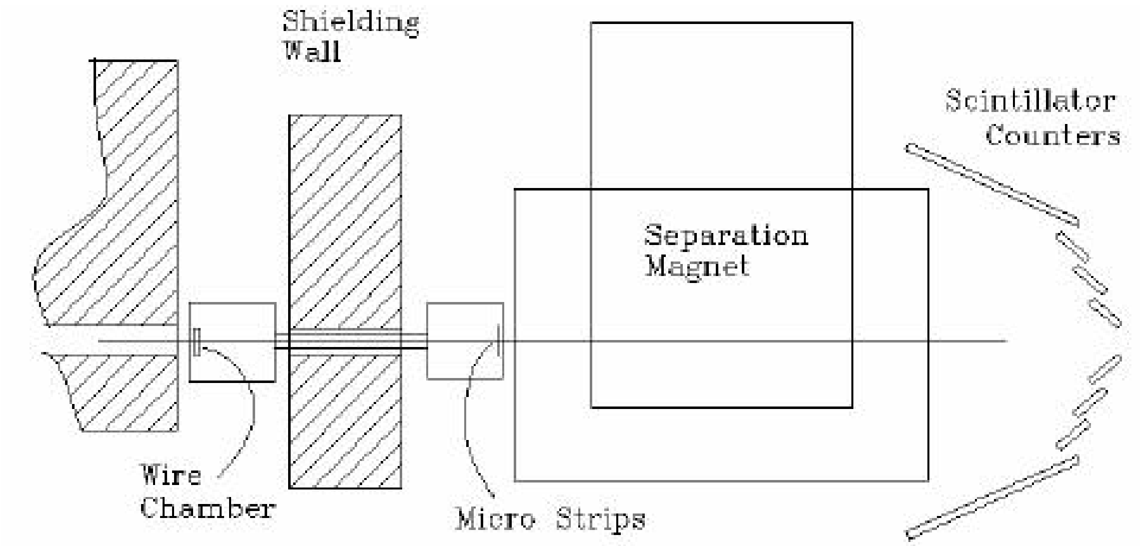

Fig. 2: Concept for using pair production for polarimetry in Hall B, Jefferson Lab.

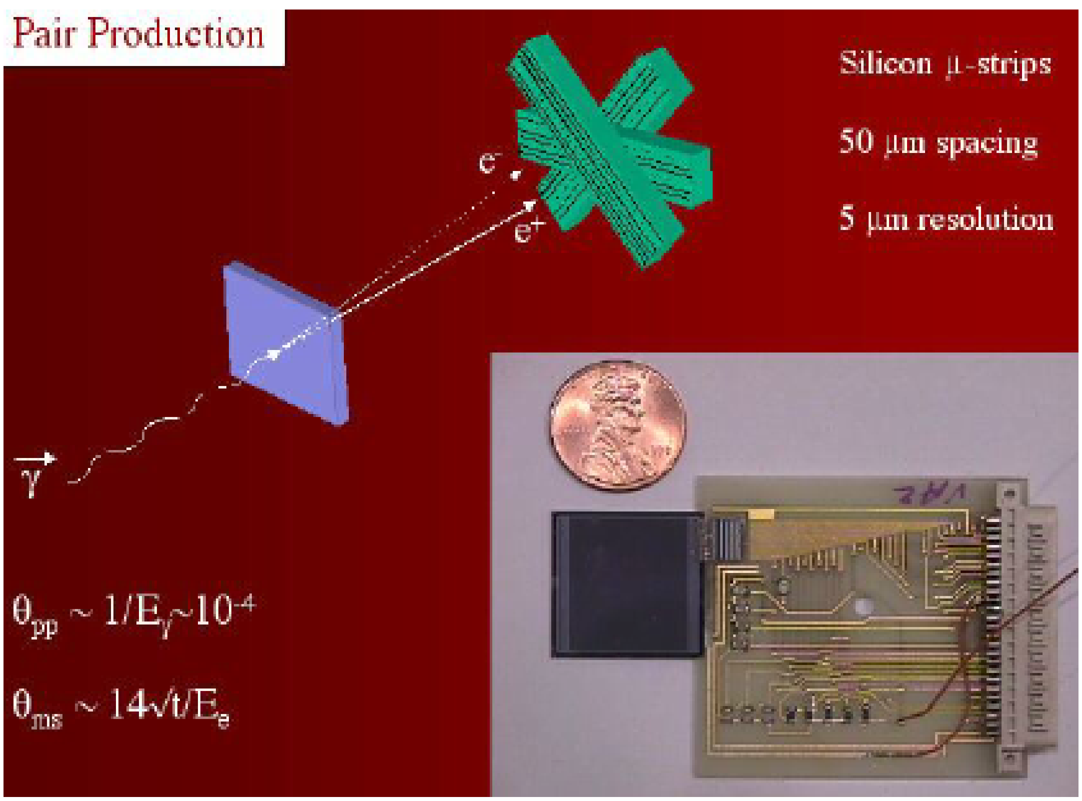

Fig. 3: Silicon microstrip detector.

The design concept for Tedeschi's method is indicated in Figs. 2 and 3. Pairs are produced in the thin walls of a small wire chamber that not only serves as an active converter but also determines the conversion point. Trajectory angles are measured using a silicon microstrip array shown in Fig. 3, for which the spatial resolution is 5 μm. The pair is then separated by means of a dipole magnet and simultaneous detection in a symmetric set of scintillator counters serves as one element of the polarimeter's trigger.

Potylitsin has proposed a means of realizing an analyzing power as large as 0.3 by measuring *colinear* pairs, albeit in a restricted phase space. Whatever the analysis method, the big disadvantage of pair conversion, particularly for the high photon energies of interest to us, is the very small opening angle between the pair fragments. This angle is given approximately by m/ω, where m is the electron mass and ω is the photon energy, The $<$ 0.1 mr opening angles expected at SLAC energies would make it extremely difficult to measure the azimuthal dependence with the precision needed to make a meaningful determination of the photon polarization. At first sight, two ultra-high resolution microstrip detectors placed several meters apart would permit angular measurements down to the 0.01 mr level, but this idea is defeated by multiple scattering in the first detector.

Triplet Production

More promising is the method that relies on measuring the azimuthal asymmetry of recoil electrons from triplet conversion. Irrespective of beam energy, many of these electrons recoil at large angles with detectable momenta in the range 1 – 10 MeV/c, making them readily measurable. Peresun'ko *et al*. (Fizika B **8** (1999) 101) have shown that the analyzing power varies strongly over the phase space, but that by taking advantage of the integrating properties of sizable recoil detectors, workable average analyzing powers can be achieved. Integrated cross sections and analyzing powers are shown in Fig. 4 for different photon energies. These are plotted as a function of q_0,, the low recoil momentum limit for the integration given in units of the electron mass m.

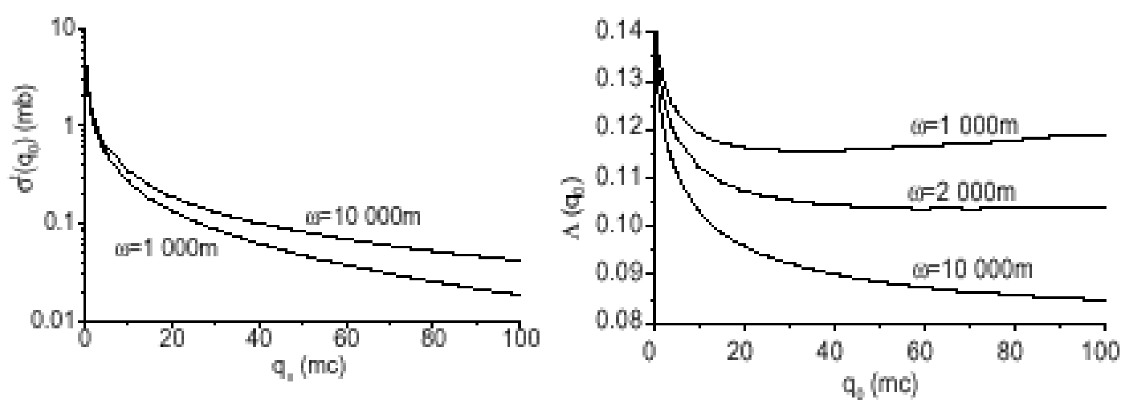

Fig. 5: Left: Integrated triplet production cross section, plotted as a function of the lower integration limit for the recoil electron momentum, for two incident photon energies. Momentum and energy are both expressed in units of the electron mass m. Right: Corresponding plot for the analyzing power. Note offset zero.

Although the integrated analyzing power decreases somewhat for high photon energies, this is counterbalanced by higher integrated cross sections such that the figure-of-merit is almost independent of energy. While several proposals have been made to increase the analyzing power from the value of about 0.1 indicated in the figure, this always entails a restriction in the final-state kinematics which offsets the gains in analyzing power.

Polarimeters based on triplet conversion have been developed at Kharkov, Mainz, Tokyo, and Saskatoon. The overall features of these devices are similar, with the main differences found in the types of counters used to detect the pair and recoil electron and pair detection. Figure 6 shows the variant used at Tokyo (Nucl. Ins. and Meths., **A280** (1989) 144), and this serves a starting point for our design concept. A similar polarimeter is being developed at George Washington University by Grant O'Reilly and Jerry Feldman for use in Hall B of JLab.

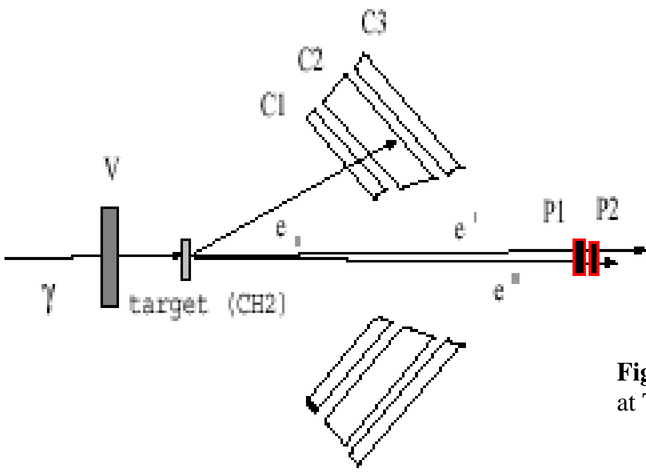

Fig. 6. Arrangement of triplet polarimeter tested at Tokyo. See text for details.

The figure depicts triplet production by an incident tagged photon beam in a CH_2 converter, with the electron-positron pair being detected in two forward scintillation counters P1 and P2. The threshold for both P1 and P2 is set at the level corresponding to the passage of two minimum-ionizing particles. Recoil electrons are detected in sets of scintillator telescopes, each containing a 1 mm-thick *dE/dx* counter (C1), a 45 mm-thick *E*-counter (C2), and a 6 mm-thick veto counter (C3) to reject penetrating high-energy particles. In this arrangement the scintillator telescopes spanned a polar angle range of 10° to 45°, and had a width of 30° in the azimuthal angle. Five telescopes were constructed. The V counter upstream of the converter is a 1 mm thick scintillator which serves to reject any charged particles which might accompany the beam. The article in Nuclear Instruments details the performance of this device.

O'Reilly and Feldman have tested a similar device in the Compton back-scattered beam at LEGS, measuring the asymmetry with good precision, as indicated in Fig. 7. Unfortunately, 2.7% asymmetry result compares poorly with the 12% value expected on the basis of the 95% linearly-polarized LEGS photon beam and the calculated analyzing

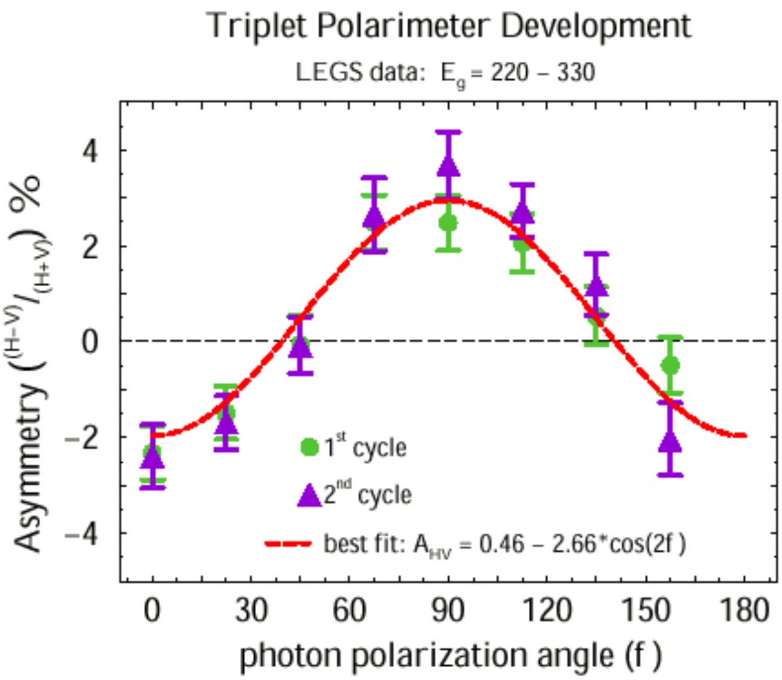

Fig. 7. Triplet assymetry measured by George Washington group at Brookhaven LEGS facility using prototype polarimeter.

power! This discrepancy is now understood to be due to two effects, multiple scattering, and the production of low-energy secondary electrons in the converter.

Due to difficulties experienced in observing the expected asymmetry, the GWU group replaced their thin converter with an active target consisting of a 2 mm thick spare scintillator wrapped with 0.25 mm polyethylene sheet and 25 µm thick aluminum foil. Multiple scattering in such a thick converter is appreciable, especially in the 1 – 10 MeV/c momentum range of the recoil electrons, and this accounts for half the discrepancy. The secondary electrons that account for the remainder of the discrepancy are most likely due to the Moller scattering of photoproduced pairs in the thick converter. These electrons can be produced at large angles with energies in the same range as the triplet recoils, thus making the process *indistinguishable* from triplet conversion.

Although the LEGS tests were made with 220 – 330 MeV photons, it is not expected that the nature of these problems will change very much at SLAC energies since the relevant cross sections, for pair and triplet photoproduction, and Moller scattering are all effectively independent of energy. Moreover, the energy and angular distributions of the triplet recoil electrons have negligible change with energy.

Concept design for triplet polarimeter

Notwithstanding the failure of the LEGS test run to give a plausible value of the longitudinal polarization without large corrections, some encouraging aspects emerge from this study. For example, the small asymmetry that was observed was measured precisely and reproducibly in an acceptable interval lasting about 1.5 hours. The detailed simulations of the George Washington group quantitatively prove that the discrepancy is due to multiple scattering and Moller scattering, two products of the excessively thick conversion target. The polarized photon flux in SLAC experiment E160 will be 1–2 orders of magnitude larger than the LEGS photon flux, permitting the use of a much thinner target. Both the multiple scattering and the Moller background should decrease with target thickness, and this is presently being investigated using our simulation tools. During the commissioning phase of the E160 experiment we would seek to calibrate the polarimeter using a range of converter thicknesses in order to test the simulation results.

Even with the quite clean photon beam at LEGS, it was found essential to use an active converter. For this reason we could use a thin-walled gas chamber with conversion taking place in the upstream chamber wall. Better still would be to separate the functions of the converter and gas chamber by having the converter separately mounted on a target ladder just upstream of the chamber. In this way we would have the flexibility of using converters having different thicknesses and atomic compositions. During production running both the converter and the gas chamber should be removed from the beam path.

Other than this modification, our initial concept is very similar to the arrangement depicted in Fig. 6. In order to speed the polarimetry runs we would seek to construct 12 identical recoil telescopes, each spanning an azimuthal angle of 30^o.

Of course, the polarimetry runs would necessarily be dedicated runs, lasting perhaps and hour and repeated daily until we were assured of the stability of the beam polarization and the reproducibility of the polarization measurement.

In constructing a crude budget it is assumed that we can re-use phototubes already in hand from previous End Station A experiments. Similarly, most of our electronics requirements can be satisfied using existing instrumentation. Much of the machining can be done in our UMass mechanical workshops where we pay only for materials, not for labor.

The largest expenses will likely be incurred in the fabrication of the vacuum chambers and the motion systems required for the radiator and small wire chamber. Since we seek to measure electrons with energies as low as 1–2 MeV the flight path to the first dE/dx elements of the scintillator telescopes should be in vacuum in order to reduce multiple scattering.

VERY **Crude cost estimates**

Plastic scintillator	\$3k
Materials for wire chamber	\$1k
Motion systems	\$7k
Vacuum chamber- materials and fabrication	\$6k
CAD design work	\$7k
Misc. materials, supplies	\$4k
Total	\$28k

Summary

Within the above discussion we have briefly reviewed the work of other groups to develop polarimeters for high-energy photon beams based on the production of electron pairs and triplets. Note, however, that all published reports on this topic are devoted to the design and testing of the polarimeters, not to their application in a physics measurement!

One approach, represented by investigations made at Bonn that also used a coherent bremsstrahlung source is to simply calculate the photon polarization, and not attempt any experimental verification. In Hall B at JLab two parallel efforts are being made to determine photon polarization, one by pair and triplet photoproduction. The E160 collaboration could take the same approach, one based on triplet electron production, and the other based on the photoproduction of high-mass pairs.