A Review of High Energy Polarimetry, With a view toward RHIC

David G. Underwood
High Energy Physics
Argonne National Laboratory
Argonne II 60439

ABSTRACT

We present four physics processes that have measured asymmetries at high energy. Some problems and some advantages of utilizing each in a polarimeter are discussed. For each we give references to examples of experimental setup and data.

INTRODUCTION

The energy dependence of the analyzing power for the processes we discuss here is shown in a general way in reference 1. The analyzing power from interference of strong amplitudes in elastic or quasi-elastic scattering falls as roughly the inverse of the beam momentum. The others, Inverse-Primakoff, Coulomb-Nuclear, and large-x pion inclusive appear to be energy independent in the relevant ranges.

The possibilities can be evaluated with the following parameters in mind:

- + Analyzing power vs Energy,
- + Usable Luminosity,
- + Quality factor, $A^2 N$,
- + The continuum from Online Scaler readout to Difficult analysis,
- + Absolute vs Relative Analyzing power,
- + Internal to an Accelerator vs in External Beamline.

These parameters are discussed in terms of the advantages and difficulties for each polarimeter.

P P Elastic and P N elastic

There are a number of problems which make elastic scattering a more difficult process to utilize at increasingly high energy. The analyzing power typically peaks near a t , momentum transfer squared, of $0.15 (\text{GeV}/c)^2$, and falls off at higher t . The analyzing power falls roughly as $1/p_{\text{lab}}$, so that at $100 \text{ GeV}/c$, the analyzing power is down to about 1 %. The next problem is that the increasing number of pions produced at high

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energy is a serious background to both the forward and the recoil detection. The angular separation between the forward scatter and the beam becomes small so that, for example, at 300 GeV in Fermilab experiment 61, a septum was required in a Cherenkov counter at 100 meters from the target.² One way around these difficulties which was used in an AGS external beamline up to 22 GeV was to utilize magnetic spectrometers for the forward and recoil arms, and to accept somewhat larger angle forward scatters and higher t at the highest energies.³

Elastic scattering has been used effectively for internal polarimeters in accelerators even in the face of difficulties like limited space and a quasi-elastic background from CH targets. One example is at KEK for energies up to 12 GeV.⁴

Another recent example is the polarimeter in the AGS for the partial Siberian snake tests.⁵ In this case, the forward scatter was inaccessible, both because the small forward angle put it inside the beam pipe at some energies, and because of high background rates. The recoil arms were designed to use an angle-energy correlation to separate elastics from quasi-elastics, with the protons stopping in a plastic scintillator for the energy measurement. A veto counter was used to eliminate penetrating pions. A previous version of the polarimeter utilized range information in a limited way. This version has a very great improvement, almost an order of magnitude, in eliminating the quasi elastics from carbon in the fishline target, but it is not perfect. A carbon fiber was added to the target flipping mechanism so that measurements were made with C and CH₂ targets, and a carbon subtraction could be made from the data.

There were some interesting technical aspects to this polarimeter. The energy-angle correlation in the recoil proton measurement was done with memory lookup units which could handle several tens of millions of events per second peak rate. The new target flipping mechanism could place the target in the beam in 50 milliseconds while the fishline was spooling at a meter per second to reduce heat and radiation damage. A baler for spooling the fishline contributed to the overall reliability during the two week run.

COULOMB-NUCLEAR INTERFERENCE

The Coulomb-nuclear interference polarimeter utilizes the interference between the spin flip part of the Coulomb elastic amplitude, and the large imaginary part of the strong amplitude. From the known amplitudes in the $p p$ case, one can calculate the analyzing power and the t value in elastic scattering where the maximum occurs. The maximum is

about 4%, almost independent of energy, at $-t$ of 0.005 (GeV/c)^2 . Calculations, and to some extent data, indicate similar parameters for p-Carbon elastic.⁶

One needs good kinematic constraints to separate the elastic scattering from diffraction dissociation, which has a similar low energy recoil and fast forward particles. A precise t measurement is needed, for example ± 0.001 at t of -0.003 (GeV/c)^2 . In the fixed target experiments done to date, primarily Fermilab experiment E704,⁷ the main experimental problem was to isolate and measure the recoil. For this reason, a momentum and angle measurement on the forward scattered particle was also done to help in the kinematic constraint. The forward particle is at an angle of about 1.5×10^{-4} radian at 200 GeV/c, so that it was within the beam phase space for the measurements done. A particular problem with a solid sensitive target is that the beam particles deposit energy in the target with magnitude comparable to that deposited by the recoil. For some of the Fermilab data, a Stilbene target was used, which has a different scintillation pulse time dependence for fast minimum ionizing particles, such as the beam, than for slow stopping protons, such as the recoil.

There is some interest in using this process inside an accelerator with a gas jet target. for example at RHIC. The kinematics of the forward particle are then the same as in the unpolarized experiments to measure the real part of the elastic amplitude. These experiments use Roman pot detectors in the accelerator lattice. The recoil particle detection would be free of carbon background and energy deposition by the beam. However, precise measurements of the 30 to 100 MeV/c momentum recoil may be difficult in an environment with many pions. Many pions are produced each 110 ns when a beam bunch crosses the target. There are also beam-gas backgrounds from the accelerator.

It should also be possible to use the Coulomb-nuclear method with elastic scattering of the two proton beams in a collider, with Roman pots on either side of the interaction region. One has to consider the reduced luminosity possible at the high beta parameter needed to detect the scatters, in light of the number of events needed at the low analyzing power. High beta means the beam is almost parallel trajectories and not tightly focused.

INVERSE PRIMAKOFF

Primakoff originally proposed using the connection between S-channel and T-channel scattering as a way to measure the electromagnetic coupling, radiative width, of

short lived particles. This is of interest to us because we can relate a body of low energy data on polarized photoproduction of baryon resonances to the high energy process of producing these resonances in the Coulomb field of a nucleus. For example, the asymmetry in the Coulomb dissociation of high energy protons into a proton plus pi-zero with invariant mass near $1350 \text{ MeV}/c^2$ is directly related to the asymmetry in photoproduction on a polarized proton target with photons of 400 to 500 MeV. This has been done at 200 GeV in Fermilab Experiment E704, and it works, albeit with some experimental difficulties.^{7, 8}

The primary experimental difficulty in this type of polarimeter is the separation of Coulomb dissociation from diffraction dissociation. The parameter which is used for this separation is the slope of the t distribution. For Coulomb events the distribution has a slope determined primarily by experimental resolution, which has to be about $e^{-2000 t}$ in order to do the separation. The slope for strong diffraction is approximately $e^{-10 A^{2/3} t}$, which is $e^{-400 t}$ for diffraction off a lead nucleus. The direction of the proton-pi-zero effective mass must be determined to about $\pm 3 \times 10^{-5}$ radian at 200 GeV/c. This requires a rather good spectrometer for the proton and a photon detector with good position and energy resolution for the pi-zero.

In principle, an analyzing power of 90% is possible independent of energy. In practice the analyzing power is dominated by the fraction of background, which can be determined well, but not eliminated. Thus, in E704, the measured analyzing power was about 30%, and substantial analysis effort was required, at the level of a PhD thesis. This may be practical for a one-time absolute polarization measurement, but not for a beam tuning polarimeter where information is required quickly and repeatedly.

PION INCLUSIVE

Large asymmetries in the production of very forward pions from polarized proton beams have been observed over a large range of energy. There are data at 6 and 12 GeV from the ZGS, and at 200 GeV in E704.⁹ There are also pion production asymmetries with polarized targets at Cern at 30 GeV and at Serpukhov at 70 GeV. The 200 GeV data are well characterized in terms of x_f and p_t , and will be useful at similar energies. One can speculate that the effects are largely energy independent, however there is insufficient data to connect all the energies in a useful parameterization to show this. As shown in reference 9, the π^+ and π^- asymmetries are large, almost linear in x_f , and approximately mirror images of each other. The pi-zero asymmetry is smaller.

The RHIC Spin Collaboration is considering this process for an internal polarimeter in the RHIC machine. Measurements are desired on a repetitive basis several times per hour. π^- production appears to have several advantages. π^+ would require the separation of protons at forward angle and high momentum whereas the anti proton flux in this region is negligible. The Kaon flux could either be considered a dilution factor or could possibly be eliminated with a Cherenkov. π^0 s would require something like a lead glass array very close to the beam pipe and considerable event reconstruction effort.

The optimum pion momentum has been determined by finding the derivative of a parameterization for A^2N , the quality factor which minimizes error bars. The cross section was parameterized as a function of x_f above p_t of 0.7 GeV/c and the asymmetry was also so parameterized. The result is that x_f of about 1/2 is optimum. The apparatus must select pions of 1/2 the proton momentum and p_t of greater than 0.7 GeV/c. This may be done with magnetic spectrometers using either limited aperture or very fast electronics to correlate hodoscopes, so that primarily events of interest are scaled.

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