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**A METHOD OF MEASURING THE POLARIZATION
OF HIGH MOMENTUM PROTON BEAMS**

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ABSTRACT

A method of measuring the polarization of high momentum proton beams is proposed. This method utilizes the Primakoff effect and relates asymmetries at high energy to large asymmetries already measured at low energy. Such a new method is essential for the success of future experiments at energies where present methods are no longer feasible.

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INTRODUCTION

Experiments are now being proposed^{1,2} which will use high momentum (< 300 GeV/c) polarized proton beams derived from lambda decay. For these experiments it is essential to know the polarization of the beam accurately and the proposed methods of calculating polarization are probably not adequate due to backgrounds and uncertainties in geometry. Also, experiments now in progress³ are somewhat dependent on knowing the polarization in ordinary high momentum beams ($.2 < x < .8$). We discuss some methods of measuring beam polarization at high energy and describe one particularly attractive method in detail.

DISCUSSION

Some methods used to measure beam polarization at lower momentum (≤ 12 GeV/c) are known not to work well at higher momentum, e.g., elastic scattering from carbon or hydrogen. The effects are very small at low t ($\sim .2(\text{GeV}^2/c)^2$) and the cross sections are too small at higher t ($\sim 1.4(\text{GeV}^2/c)^2$) as measured in Fermilab Exp. #61.³

One proposed method involves looking at Λ^0 decay for Λ^0 produced in the forward direction from protons. In the exact forward direction the Λ^0 must carry the spin direction of the proton due to angular momentum conservation.

This method may not be applicable if flip amplitudes exist

at smaller values of t than can be resolved experimentally. In diffractive production of n^* at $|t|$ of about $.02 \text{ GeV}/c^2$, angular distributions implying the existence of large helicity amplitudes and some flip amplitudes have been observed.⁵ While these amplitudes may not be fundamental in the diffractive interaction, they do exist in the observable final state. Such amplitudes could be present for lambdas produced diffractively or multi-peripherally.

There are a number of low momentum transfer high energy processes which are related to low energy processes by crossing or time reversal. For example, the deck effect diffractive process $PA \rightarrow A P \pi^+ \pi^-$ (Fig. 1) looks like $500 \text{ MeV}/c$ πp elastic scattering with the complication that the pion is off the mass shell part of the time and there may be final state interactions.

In principle one could relate the asymmetry parameter in $\pi p_\perp$ scattering measured at various energies and angles to asymmetries expected in the $p \pi^+ \pi^-$ system for polarized incident $300 \text{ GeV}/c$ protons. Such a calculation may be possible in limited kinematic regions, but one would probably want to calibrate by using protons of known polarization from Λ^0 decay in a spectrometer such as that in Fermilab Experiment #8.⁴ They have already proposed to do diffraction dissociation of neutrons in their Λ^0 spectrometer as a measurement of backgrounds for a proposed K beam.

There is, however, a much more appealing channel for which calculations can be done, for which there are essentially no final state interactions not already present in the low energy data, and for which time reversal symmetry (and the calculations) have been experimentally verified to about $\pm 3\%$.

The processes of radiative decay of meson and baryon resonances, production of such resonances in the coulomb field of nuclei, and photoproduction of resonances can be related as discussed by Primakoff,⁶ Good and Walker,⁷ and many others. More specifically for our purposes, one can calculate $p + A \rightarrow A + p\pi^0$ in the coulomb production region from measurements of $\sigma p + \pi^0 p$ at low energy. Such calculations apply to the general process and not just to resonance production.

For $P\pi^0$ masses above the Δ mass the total cross section, differential cross section, and many spin combinations have been measured⁸ or will soon be measured⁹ for $\gamma p \rightarrow P\pi^0$. Typical results are shown in Fig. 2.

The $P\pi^0$ final state was chosen because very precise measurements of both position and momentum of final state particles are needed. It is difficult to measure the neutron momentum from $n\pi^+$ with a resolution of 1% of the beam momentum. The $P\pi + \pi^-$ final state was not considered because photoproduction data in appropriate spin states are not yet adequate.

To measure the polarization of the proton beam, one would look at the angular distributions in the Gottfried-Jackson or t - helicity frame for appropriate $p\pi^0$ masses. These can probably be translated into a combination of hits of MWPC wires before and after an analysis magnet in conjunction with scintillator hits in a lead-scintillator π^0 detector. Polarization could then be measured in real time with the on-line computer for an experiment.

The system could be self-calibrated by carefully analyzing recorded events and doing background subtractions. The analyzing power for a clean sample of events would be known from the

photoproduction data.

Since the virtual photon direction is nearly anti-parallel to the beam direction in the proton rest frame, and t helicity frame, this system will analyze any polarization component perpendicular to the beam. The beam spin can be rotated using the anomalous moment in order to measure any polarization component.

An argument¹⁰ based on electromagnetic current conservation shows that only helicity ± 1 states of the virtual protons in the coulomb field contribute to coulomb dissociation. Since there is momentum transfer between the nucleus and the proton but almost no energy transfer to the nucleus, the proton is off the mass shell or has invariant mass squared of t (negative). At $2 \times t_{\min}$ where most of the production occurs this is $\sim 10^{-5} \text{ (GeV)}^2$.

SOME PRACTICAL CONSIDERATIONS

The direct measurement of coulomb production at Fermi-Lab energies requires that the transverse momentum error on individual track measurements be less than 20 MeV/c and preferably less than 10 MeV/c. The beam direction must then be measured to about .03 mR or .3 mm in 10. m. This resolution has been achieved in several experiments such as diffraction dissociation experiments 27 and 305, and measurements of coulomb interference in elastic scattering. Given this resolution, the angles of the pion or proton in the t helicity frame (which corresponds to the S helicity frame in photo production) are known to about $\pm 5^\circ$. This resolution is adequate for cutting the data for comparison

with photoproduction data or in order to use an angular region with high analyzing power.

It also becomes simple to measure polarization as a function of position or angle within the beam. The capability could be quite useful with low momentum high divergence beams where polarization is expected to vary with position or angle because of the effects of quadrupoles.

Differential cross sections and some polarization asymmetry data exist for $\gamma n \rightarrow \pi^- p$ at low energy (500 MeV to 1. GeV) and total cross sections and angular distributions exist for $n + P_b \rightarrow P_b + p\pi^-$ at 300 GeV for $p\pi^-$ masses from threshold up. This process will not have the same polarization effects as $\gamma p \rightarrow p\pi^0$ because of the charged current coupling of π^- but the effective mass distribution, t distribution, and cross section in the coulomb dissociation process can serve to illustrate what would have to be measured and to what accuracy as shown in Fig. 3.

The $p\pi^0$ mass spectrum produced by coulomb dissociation dies out quickly above the Δ mass for two reasons: 1) the cross sections are small even in photoproduction. 2) there is a kinematic factor ($t_{\min}$) in coulomb production which suppresses higher masses for these reasons we would like to work near the Δ mass. At the central mass of the Δ the ratio of Δ production to non-resonant production may be too large to produce significant polarization effects by interference. On the low mass side of the Δ it may be experimentally difficult to obtain the required resolution and acceptance: This leaves the high mass side of the Δ .

The proton asymmetry data $T(\theta)$ for π^0 photoproduction with a polarized target are only available at present for masses above 1480 GeV. Asymmetries calculated from the 1969 walker amplitude fits¹¹ (Fig.2) agree qualitatively, but not well enough to be used for detailed polarization measurements using lower mass $P\pi^0$ systems.

A Japanese collaboration, reporting on π^+n photoproduction at the 1976 conference on high energy physics with polarized beams and targets,⁹ expects to publish new data on $P\pi^0$ photoproduction and a comparison with new amplitude analyses soon.

The cross section for $p\pi^0$ coulomb production on P_b is about 10.mb at 25 GeV/c and about 20.mB at 250 GeV/c for the relevant t' range ($|t| < .005$). The total cross section for protons on P_b is about 3000 mb. The target must be thin ($< \frac{1}{2}$ rad length) to obtain adequate directional resolution. Half a radiation length is about 3% of an interaction length. Thus, 2×10^{-4} of the beam gives coulomb events, and perhaps 5% of this, or 1×10^{-5} of the beam is useful for polarization analysis. At 1×10^7 beam per spill we could get a 3% polarization measurement in 10 spills. Since the polarization is controlled primarily by geometry and beamline settings, this seems like a reasonable time period (~ 2 minutes at Fermilab).

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FIGURE 1:

FIGURE 2: Energy dependence of the polarized target asymmetry $T(\theta)$ for pion cm angles of 40° , 50° , 70° , 110° , 130° and 145° . The curves show fits by Walker, M.O.R. and Devenish, Lyth and Rankin.

b) $M(p\pi^-) \text{ GeV/c}^2$

c)

FIGURE 3: