PROTON-PROTON POLARIZATION EXPERIMENTS AT NAL: POLARIZED TARGETS VS POLARIZATION ANALYZERS

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ABSTRACT

Two possible schemes to measure the polarization in elastic proton-proton scattering at 200 GeV/c have been considered. One involves a polarized target and the other a double scattering technique. It is concluded that, due to the limitation of the maximum allowable proton flux on the polarized target, the two techniques are indeed competitive for large $|t|$ measurements.

The object of this note is to make a brief comparison of the relative usefulness of polarized targets and polarization analyzers in proton-proton polarization experiments at energies which will be attainable at NAL. Polarized lanthanum and alcohol targets have been used successfully in a wide class of experiments in recent years. This success has resulted in the minimal use of the double-scattering technique in high-energy polarization measurements. We will argue here, however, that the double-scattering scheme, which proved so successful in low-energy measurements, will have some distinct advantages over polarized targets in the very high energy region (> 50 BeV).

Some of the common objections to the double-scattering technique are:

1. The need for a second scatter reduces the counting rate by some substantial factor (> 25).
2. Except at low energies, the analyzing powers of all elements are fairly small.
3. Extreme care must be taken to insure that all possible instrumental biases are cancelled.

In medium and large $|t|$ proton-proton polarization measurements at NAL, however, polarized targets will suffer the disadvantage that because of the concomitant target radiation damage and heating (resulting in a loss of target polarization) the main proton beam ($\sim 3 \times 10^{13}$ protons/pulse) cannot be used. Even with schemes of sweeping the incident beam across the face of the polarized target, it is not expected that an integrated flux of more 4×10^{15} incident protons per target could be tolerated. This figure is based on current data on alcohol targets (radiation damage would render lanthanum targets useless at only $\sim 10^{13}$ incident protons). This would mean, for example, in an experiment fully utilizing the external proton beam a new target would have to be inserted and cooled to $\sim 1\,°K$ on the order of every eight minutes! This, of course, is not practical. In the double-scattering scheme, however, a single conventional liquid hydrogen target would be required.

In order to establish that the above statements do point out a real relative disadvantage of polarized targets, we must show that there are polarization experiments of significant interest which indeed require the main external proton beam, and that the disadvantages of the double-scattering scheme enumerated above are not prohibitive at high energies.

Let us consider an experiment to measure the polarization in elastic proton-proton scattering in the region $0.2\ (\mathrm{GeV/c})^2 \le |t| \le 4.0\ (\mathrm{GeV/c})^2$ at 200 GeV/c. All present data indicate the existence of a minimum in the polarization at $t \sim -1\ (\mathrm{GeV/c})^2$, and there are theoretical reasons to expect that the minimum will become more pronounced at higher energies and that an additional minimum will develop at $-t \ge 3.0\ (\mathrm{GeV/c})^2$.[1] It is true also, however, that the maximum value of the polarization (over all t) is expected to be very small at 200 GeV/c. Nevertheless, a survey experiment here is of great interest and is certainly warranted. Below we will investigate the yield for the case when the experiment is done using a polarized target and for the case when a double-scattering scheme is employed, assuming the same target hydrogen content in each case.

For purposes of calculation let us employ the experimental beam layout proposed in NAL Summer Study Report C. 2-68-90 for p-p angular distribution measurements, and also Krisch's parametrization[2] of $d\sigma/dt$ in terms of $(\beta p_\perp)^2$ to estimate the cross section at 200 GeV/c. We have, for

1. a liquid hydrogen target length of 10 cm,
2. a c.m. solid angle of 5×10^{-4} sr,
3. an incident proton intensity of 3×10^{13} protons per pulse,
4. a repetition rate of 1000 pulses/hr and
5. $(d\sigma/d\Omega)_{min} = 2 \times 10^{-31}\ \mathrm{cm}^2$ [200 GeV/c, $t = -4\ (\mathrm{GeV/c})^2$], an event rate

(for single scatters) of $\sim 12 \times 10^5$/hr.

Now, if we assume that in order to configure a polarized target experiment with a reasonable duty cycle we should allow target changes on the average of only every forty hours, the maximum tolerable beam intensity on the target would be $\sim 10^{14}$/hr or $\sim 10^{11}$/pulse. We are now in a position to compare the rates for the polarized target case and the double-scattering case, once we state the parameters of our polarization analyzer. Let us assume an analyzer with an efficiency of ~ 4%, with an analyzing power of ≥ 0.25, and which is capable of analyzing recoil protons from 100 MeV to 2 GeV [corresponding roughly to the range between -0.2 and -4.0 $(\mathrm{GeV/c})^2$ at 200 GeV/c].

Thus, for a polarized alcohol target of 40% polarization 58 hours would be required to measure the polarization at one large $|t|$ point to ± 0.005, i.e., $\Delta p \sim \Delta E/p_T \sim [1/(\sqrt{N}\, p_T)]$, where E is the asymmetry in the number of counts with target polarization "down" and target polarization "up," p_T is the target polarization and N is the total number of events. No factor has been applied to account for the downtime required to change targets.

The corresponding time to measure one point to an accuracy of $\Delta p = \pm 0.005$ in the double-scattering scheme is about 12 hours. In principle, therefore, the double-scattering experiment could be completed in ~ 1/5 of the time required for the polarized target experiment, assuming that systematic errors are appropriately controlled.

A carbon analyzer system with approximately the parameters listed above presently exists. It has been used sucessfully in a p-p polarization experiment in the region of 1-3 GeV.[3] Techniques have been developed to retain the systematic errors to the order of 0.01 in p, and this number can be reduced with an improved design. That part of the proposed 200 GeV/c double-scattering experiment associated with the second scatter should hold no problems which have not been encountered and solved previously. The incident recoil proton energies would be in the same range as before, as well as the recoil proton intensities. Except for the addition of the double-scattering element, the experimental layout could be the same as proposed by Krisch for the $d\sigma/d\Omega$ measurements.[4] Indeed, the two experiments could be performed simultaneously.

Another advantage of the double-scattering technique is that there is no background associated with scatters from bound protons as in the polarized target case.

In conclusion, we have argued on the basis of a specific p-p polarization experiment that there is a class of high-energy polarization experiments for which the double-scattering technique is quite competitive with the polarized target. This result is based primarily on the limitation imposed by the maximum allowable radiation exposure of present polarized targets. Of course, the discovery of a new radiation resistant target material capable of being highly polarized could change the conclusion. However, some target experts doubt that such a breakthrough will be forthcoming in the next decade. Polarized targets, even without significant advances in the technology, will certainly continue to be the dominant tool in the majority of polarization measurements and should be given high priority by NAL. However, for those polarization experiments that can benefit from the use of the external proton beam, serious consideration should be given to the use of a simple polarization analyzer.

REFERENCES

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