A POLARIZED PROTON BEAM FROM Λ^o DECAY

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ABSTRACT

We show how beams of high-energy protons with intensities $\sim 10^5$ protons per pulse and with transverse and longitudinal polarization each as high as 50% can be produced from Λ^o decay. The transverse and longitudinal component are variable, and can be calculated from the kinematics of Λ^o. Beams of similarly polarized anti-protons should also be available with intensities $\sim 10^3$ per pulse.

It will be very important to study spin dependence of proton interactions at the higher energies that become available at the 200-GeV accelerator. Prevailing theoretical opinions expect the spin dependence to vanish at sufficiently high energies. In order to investigate these questions, it would be very desirable to have a relatively intense beam of protons polarized both transversely and longitudinally. Since anticipated spin-dependence effects may be small, it would be particularly valuable if the proton polarization were known. Otherwise the polarization of the beam must be determined by a second scatter or interaction sensitive to the spin dependence. A null effect at the second scatter leaves undetermined whether the beam was unpolarized or if there is a lack of spin dependence (i.e., no analyzing power) at the second scatterer. A positive effect, e.g., a left-right scattering asymmetry, indicates beam polarization, but separate experiments must be performed to calibrate the analyzing power of the scattering material.

It is the intent of this note to show how beams of high-energy protons, with intensities $\sim 10^5$ protons per pulse, with transverse and longitudinal polarization components each as high as 50%, can be produced from Λ^o decay. Moreover, the transverse and longitudinal components are variable, and can be calculated from the kinematics of Λ^o decay. Beams of similarily polarized anti-protons should also be available by reversing magnet polarities. Crude estimates give polarized antiproton intensities of $\sim 10^3$ per pulse

I. POLARIZED DECAY PROTONS

A treatment of the polarization resulting from hyperon decay has been given in a separate paper[1] which reviews various possibilities for producing polarized protons at the 200-GeV accelerator. If the hyperons are not produced polarized, selection of the decay protons for limited intervals of decay angles and momenta will result in both transverse and longitudinally polarized protons. These polarization components will be proportional to the hyperon decay parameter α, the proportionality coefficient depending on the angular interval selected; Λ^o decay is an excellent choice since the α decay parameter is large ($\alpha_\Lambda = 0.65$), it is convenient to work in a neutral beam, and neutral beams at the 200-GeV accelerator should provide prolific sources of Λ^o hyperons. Protons selected from one hemisphere, for example from the left of the hyperon beam line, will have a transverse polarization in that direction equal to $\alpha/2$. This transverse polarization can be increased by selecting from limited regions of azimuthal angle and center-of-mass angle. Longitudinal polarization results from discriminating between protons that decay forward versus backward in the hyperon center-of-mass, i.e., selecting the fast decay protons from the slow.

As examples, consider two cases. In the first, if we select protons corresponding to center-of-mass decay interval of 20 - 50°, and a quadrant of azimuth (for example 45° above and below the horizontal to left of hyperon beam), the protons will have a 34% horizontal transverse component of polarization and a 50% longitudinal component. The decay solid angle in hyperon center-of-mass selected is 0.15π sterad. For the second case, consider the same quadrant of azimuth but a center-of-mass interval 60° to 120°. This results in 55% transverse polarization and no longitudinal polarization. The solid angle for this case is 0.5π sterad. By appropriate choices of angle intervals in principle one can select protons with a large range of polarization components.

II. POLARIZED PROTONS FROM Λ-DECAY

To realize such polarized beams we propose selecting protons from Λ^o decay with a magnetic lens system which deflects and focuses the decay protons into a usable beam. The capability of the system to select polarization components is based on two important considerations. First of all, in a region where the momentum spectrum is rapidly decreasing (or increasing) a given interval of proton momenta has a strong correspondence to a center-of-mass decay angle interval and also to laboratory decay angle interval. This effect is enhanced by the center-of-mass to laboratory transformation which concentrates (in lab angle) the forward decay hemisphere much more than the backward hemisphere. Thus a magnetic system that focuses protons of some Δp about a central p will be selecting a decay center-of-mass interval.

The second important feature of such a lens system is that angles into the system become transformed to points on the focal plane of the system. Thus a slit on the focal plane selects protons from a certain laboratory decay angular interval and hence with given components of transverse and longitudinal polarization. We will elaborate further on each of these two features.

To illustrate how a combination of momentum and angle selection sets the center-of-mass interval, consider that we wish to have a beam of 160 GeV/c polarized protons and that our magnet system selects this momentum with a $\Delta p/p = \pm 5\%$. The momentum spectrum of Λ^o produced at 0° by 200-GeV protons can be expected from Hagedorn-Ranft calculations to peak at about 120 GeV/c and falls off rapidly beyond 160 GeV/c. To produce protons in our desired momentum interval requires Λ^o's of greater than 160 GeV/c. From 160 GeV/c to 180 GeV/c Λ^o hyperons all protons in the momentum interval specified are produced from 0° to 90° in the center-of-mass. Because of the rapid falloff of the Λ^o momentum less than 10% of the Λ^o's with momentum exceeding 160 GeV/c are in the 180 - 200 GeV/c interval. If now we select a laboratory decay angle interval of 0.020° ± 0.008° (by position and width of slit at focal point of magnetic lens system), we will further limit the decays in the center-of-mass to be between 20 - 50°. This results in polarizations calculated above in the example. Or if we select those protons in the ±5% momentum interval about 160 GeV/c with laboratory decay angles exceeding 0.03° (maximum is ~ 0.04°) we cover the center-of-mass interval 60° - 120° of the second example for which polarization was calculated above. In this way a combination of momentum and angle selection can result in protons from decays in a given center-of-mass interval.

This polarized proton scheme is conveniently realized in a neutral beam such as discussed in another 1969 Summer Study Report.[2] The basic scheme of the magnetic system is illustrated in Fig. 1, which is self-explanatory. The requirements on the quadrupole lens have not been worked out in detail but appear to be well within current practice. It is perhaps worth noting that this technique of selecting angles by collimation in the focal plane has been successfully carried out in several other existing beams. In particular the rf separated beam at the AGS uses a similar arrangement in its "stopper section" which is capable of selecting angles to ~ 0.1 mrad.[3]

III. ANTICIPATED RATES

We consider briefly again the question of rates. Our basic assumptions for Λ^o production are discussed in Ref. 2. We recall that the solid angle accepted from the production target is limited to 10^{-8} steradians in order for the initial direction of the

Λ^o to be sufficiently well defined for the above technique. We give the optimisitc estimate first. The number of protons is:

$$N_p = N_{\Lambda^o} \times \text{(fraction decaying in 10 m)} \times \text{(fraction of protons accepted)}$$

$$N_p = 1.6 \times 10^8 \times \underset{\uparrow}{2/3} \times \underset{\uparrow}{\frac{0.1\pi}{4\pi}}$$

(approximate value for 160 GeV/c) (typical rather pessimistic fraction, see text)

Therefore

$N_p = 2.7 \times 10^6$ protons of ~160 GeV/c per 3×10^{12} interacting protons.

The pessimistic number is down by a factor of 30:

$N_p \simeq 10^5$ protons of 160 GeV/c per 3×10^{12} interacting protons.

We anticipate $\overline{\Lambda^o}$ to be ~1% of Λ^o production, so corresponding $\bar{p}$ (polarized) fluxes range from 10^3 to 3×10^4 $\bar{p}$'s per pulse. Momenta from ~100 GeV/c to ~160 GeV/c will have comparable fluxes.

We comment that the "purity" of the proton beam can be determined experimentally by adding sufficient apparatus to detect and measure the direction of the π^- from the Λ^o decay. One can then see what fraction of the protons in the beam indeed originate from Λ^o decay. With careful collimation and beam design, it seems possible to essentially eliminate non-Λ^o protons.

We conclude that the system provides intensities of uniquely determined polarized protons sufficient for many of the possible scattering experiments. Particularly when used with polarized targets, a large range of polarization phenomena at these high energies can be investigated.*

REFERENCES

[1]O. E. Overseth, Polarized Protons at the 200-GeV Accelerator, National Accelerator Laboratory 1969 Summer Study Report SS-118, Vol. 1.

[2]J. Sandweiss and O. E. Overseth, A High Intensity Y^-, Y^o Beam, National Accelerator Laboratory 1969 Summer Study Report (unpublished).

[3]Foelsche et al., Rev. Sci. Instr. 38, 879 (1967).

*An experiment to measure the degree of polarization of a proton beam from Λ-decay has been run at Argonne by M. L. Good, Y. Y. Lee, and D. Reeder. The results are not yet available.

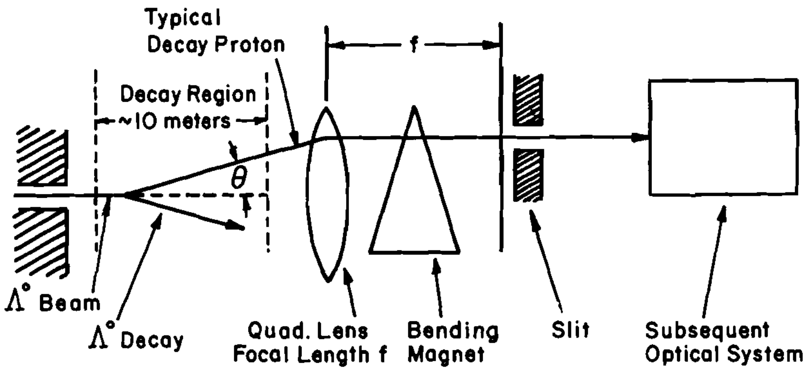

Fig. 1. Production of a polarized proton beam from the decay of lambdas.