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# A Proposal to Study $\Xi^0$ and $\bar{\Lambda}^0$ Production and Polarization


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ABSTRACT

We propose to measure the production spectrum and polarization of the $\Xi^0$ and $\overline{\Lambda^0}$ hyperons in the M2 beam line using the E-8 spectrometer. The discovery by E-8 that 300 GeV protons produce lambdas which are strongly polarized, $\langle P_\Lambda \rangle = .15 \pm .01$ for lambdas with $p_T > .8$ GeV/c, motivates us to investigate the polarization of other accessible neutral hyperons. If polarization is found, the magnetic moment of the $\Xi^0$ and $\overline{\Lambda^0}$ , previously unmeasured, will be determined.

We request 400 hours in the M2 diffracted proton beam with $4 \times 10^8$ protons/pulse at 400 GeV/c steered at up to 10 mrad onto the production target. There are no major changes necessary in the E-8 spectrometer or M2 beam line for this experiment.

## Introduction

The discovery that 300 GeV unpolarized protons interacting with an unpolarized target produce strongly polarized $\Lambda^{0}$'s[1] was not anticipated by current theoretical models and the mechanism responsible for this polarization is not known. Such polarization has not been observed at Brookhaven energies.[2]

E-441[3] will investigate the kinematic behavior and target dependence of the $\Lambda^{0}$ polarization. Further insight can be gained by determining if other particles are produced polarized in high energy inclusive reactions. Hyperons are uniquely suited for this study because they reveal their spin via the weak decay and two candidates which are experimentally accessible, the $\Xi^{0}$ and $\overline{\Lambda^{0}}$, are considered in this proposal. Knowledge of their production spectra and polarization will impose severe constraints on models of high energy interactions.

The technique employed to measure polarization involves spin precession in the neutral beam sweeping channel[1] and will also yield the first measurement of the $\Xi^{0}$ and $\overline{\Lambda^{0}}$ magnetic moment, providing that the polarizations are non-zero. It is expected that $\mu_{\overline{\Lambda^{0}}} = -\mu_{\Lambda^{0}}$ as a consequence of the TCP theorem, but knowledge of $\mu_{\Xi^{0}}$ would contribute valuable information regarding symmetry breaking in the baryon octet. An observed polarization of 0.1 would give the $\Xi^{0}$ magnetic moment with a precision equal to the precision to which the $\Lambda^{0}$ magnetic moment is now known.

## Inclusive Polarization

Inclusive lambda polarization has been studied at Argonne, Brookhaven, CERN, and FNAL. A net lambda polarization was observed at Argonne[4] at 6 GeV/c. However, the relationship between production at this low energy and Fermilab is not clear since at 6 GeV the lambda production cross section is a factor of two lower than that from 20 to 300 GeV.[5] Furthermore, the kinematic behavior of the Argonne polarization is quite different than that at FNAL. A bubble chamber measurement at 6.6, 13, and 28 GeV/c[2] observed no polarization.

Analysis of the reaction $K^- + p \rightarrow \Lambda^\circ + X$ for $K^-$ at 3.9, 7.3, and 14.3 GeV/c found polarized lambdas in the fragmentation region of the $K^-$ which were attributed to nucleon exchange.[6,7,8] A 30% polarization in the proton fragmentation region was observed at 3.93 GeV/c, but was measured to be zero at 7.3 and 14.3 GeV/c. These low energy data confirmed expectations that polarization effects decrease with increasing energy,[8] in contrast to the higher energy FNAL results.

E-8 found the $\Lambda^\circ$ polarization ($P_\Lambda$) is a function of $p_T$ and independent of $x = p_{\parallel}^{cm}/p_{max}^{cm}$ from $.3 \leq x \lesssim .8$. $P_\Lambda(p_T)$ is consistent with a monotonic rise from $P_\Lambda(0) = 0$ to $P_\Lambda(1.5\ \text{GeV/c}) = 28\%$.[1] This measured polarization is extremely large when one considers that the sample includes $\Lambda^\circ$'s from $\Sigma^\circ$ decay which have -1/3 the polarization of the parent $\Sigma^\circ$.[9] The $\Sigma^\circ/\Lambda^\circ$ ratio for proton production has never been measured, but it can be estimated to be between 1/2 and 1 from the average of $\Sigma^+$ and $\Sigma^-$ data at 24 GeV/c, $p_T > .8$ GeV/c.[10] Thus the directly produced lambdas may have a polarization from 36% (if $P_{\Sigma^\circ} = -P_\Lambda$, $\Sigma^\circ/\Lambda^\circ = 1/2$) to as high as 84% (if $P_{\Sigma^\circ} = +P_\Lambda$, $\Sigma^\circ/\Lambda = 1$) at $p_T = 1.5$ GeV/c.

$\Lambda^0$ hyperons from $p + p \rightarrow \Lambda^0 + X$ can be produced from the incident proton by $K^*$ exchange. If exchange mechanisms of this type are responsible for $\Lambda^0$ polarization, then any $\Xi^0$ and $\bar{\Lambda}^0$ polarization would be expected to have a different kinematic behavior since their production would involve an exotic single exchange process. Because the $\Xi^0$, like the $\Lambda^0$, preserves the baryon number of the incident proton, $\Xi^0$ behavior in the projectile fragmentation region might be expected to resemble that of the $\Lambda^0$. In contrast the $\bar{\Lambda}^0$ would behave differently. On the other hand, the $\Lambda^0$ polarization might arise from the central region in pp collisions. In that case, $P_{\Lambda^0}$, $P_{\Xi^0}$, and $P_{\bar{\Lambda}^0}$ might have similar kinematic behavior.

## Apparatus and Trigger

The proposed experiment uses the neutral hyperon beam spectrometer of E-8 as shown in Figure 1 with the location of the elements optimized for the longer $\Xi^0$ decay sequence. The spectrometer consists of 7 MWPC's, an analyzing magnet (AVIS), and an array of 72 lead glass blocks. The spectrometer reconstructs lambdas (antilambdas) with a $\pm$ 3 MeV mass resolution. A lead-MWPC sandwich just upstream of the lead glass converts gammas to obtain a precise position. The energy resolution of a gamma converting in the lead glass array is $\pm$ 8.5%, giving a $\Xi^0$ mass resolution of $\pm$ 16 MeV. Figure 2 shows the reconstructed mass for a sample of $\Xi^0$ candidates collected during E-8 at 0 mrad production angle using a $\Xi^0$ trigger.

The special $\Xi^0$ trigger required a "lambda"; i.e., a high momentum positive particle and a low momentum negative particle, in coincidence with a minimum amount of energy deposited in the lead glass array

(1.5 GeV). The 3% trigger efficiency ( $\Xi^0$/total triggers) gives a data accumulation rate well below the on-line computer capacity of 300 events/pulse for the incident proton flux requested. A $\overline{\Lambda^0}$ trigger, requiring a high momentum negative particle and a low momentum positive particle, was 7% efficient in a 0 mrad test during E-8. Since this trigger rate would saturate the data acquisition capacity at the small production angles, the $\overline{\Lambda^0}$ trigger will be prescaled before ORing with the $\Xi^0$ trigger. The $\overline{\Lambda^0}$ rate is a factor of 40 greater than the reconstructed $\Xi^0$ rate, so the prescaled $\overline{\Lambda^0}$ trigger will still collect a large sample of $\overline{\Lambda^0}$ 's.

## Polarization Measurement

The $\overline{\Lambda^0}$ 's and $\Xi^0$ 's will have a vertical production plane so that the parity conserving polarization would be perpendicular to the magnetic field of the sweeping magnet. Any polarization would be precessed by the magnetic field allowing the removal of apparatus bias and the measurement of the magnetic moment of the particle.[1]

## Anti Lambdas

The polarization of the $\overline{\Lambda^0}$ is analyzed by the asymmetry of the anti-proton from the $\overline{\Lambda^0} \rightarrow \overline{p}\,\pi^+$ decay. This asymmetry was measured by E-8 for the $\overline{\Lambda^0}$ 's acquired while running with the general vee trigger. The 226 $\overline{\Lambda^0}$ 's collected at $p_T > .8$ GeV/c were insufficient to determine whether there is a polarization of the same magnitude as that found for the $\Lambda^0$ (Figure 3). The proposed experiment will collect about 100,000 $\overline{\Lambda^0}$ 's with $p_T > .8$ GeV/c giving a polarization measurement precision of $\pm$ .01.

## Cascades

The $\Xi^\circ$ is observed from the decay chain $\Xi^\circ \rightarrow \Lambda^\circ + \pi^\circ$, $\Lambda^\circ \rightarrow p + \pi^-$, $\pi^\circ \rightarrow \gamma + \gamma$ where the momenta of the p and $\pi^-$ and the energy and position of both $\gamma$'s are measured. The spectrometer is strongly biased against backward $\pi^\circ$'s. Because of this bias, the determination of $\Xi^\circ$ polarization from the asymmetry of lambda emission in the $\Xi^\circ$ rest frame is less precise than the analogous determination for $\Lambda^\circ$ or $\overline{\Lambda^\circ}$ polarization.

Another method of determining the $\Xi^\circ$ polarization ( $P_{\Xi^\circ}$ ) relies on the spin of the lambda to analyze the spin of the $\Xi^\circ$. The spectrometer acceptance for measuring the $\Lambda^\circ$ polarization is relatively unbiased and well understood from E-8 polarization results.

The $\Lambda^\circ$ polarization resulting from the weak $\Xi^\circ$ decay is[12]

$$\vec{P}_\Lambda = (1+\alpha_\Xi \vec{P}_\Xi \cdot \hat{\Lambda})^{-1}\left[(\alpha_\Xi + \vec{P}_\Xi \cdot \hat{\Lambda})\hat{\Lambda} + \beta_\Xi (\vec{P}_\Xi \times \hat{\Lambda}) - \gamma_\Xi \hat{\Lambda} \times (\hat{\Lambda} \times \vec{P}_\Xi)\right]$$

in the $\Xi^\circ$ rest frame. This analysis has been applied to $\Xi^\circ$ decays obtained at 0 mrad production angle in E-8 where $P_\Xi = 0$. The raw proton distribution relative to the $\Lambda^\circ$ direction in the $\Xi^\circ$ rest frame is shown in Figure 4. The asymmetry in this distribution indicates $\Lambda^\circ$ polarization from the decay of the unpolarized $\Xi^\circ$. A preliminary analysis of these data gives $\alpha_{\Xi^\circ} = -0.46 \pm 0.03$.[13] Assuming $\beta_\Xi = 0$, then $|\gamma_\Xi| = .89$ so that the sensitivity to $P_\Xi$ via $P_\Lambda$, is not much different than the sensitivity in measurements of $P_\Lambda$. A sample of $10^4$ $\Xi^\circ$'s would give $\Delta P_{\Xi^\circ} = \pm .03$.

## Run Plan

Because the software to analyze polarization of both $\Xi^{\circ}$ and $\overline{\Lambda}^{\circ}$ is already in existence and has been thoroughly tested, we plan to begin running at 8 mrad and analyze each data tape as soon as it is written. If a significant polarization is observed, more running time at a larger production angle may be needed to follow the polarization to higher transverse momentum. If initial studies at the 8 mrad production angle show that $\Xi^{\circ}$ and $\overline{\Lambda}^{\circ}$ polarizations are unobservably small ($< .05$), the experiment will concentrate on mapping the $\Xi^{\circ}$ single particle inclusive production spectrum at smaller production angles. The following estimates are based on the measured $\overline{\Lambda}^{\circ}$, $\Xi^{\circ}$, and background rates from E-8 using a 1/2 interaction length target. It was assumed that the $\Xi^{\circ}$ production cross section has the same $p_T$ dependence as $\Lambda^{\circ}$ and $\overline{\Lambda}^{\circ}$.

| Production Angle in millirad | Hours | N( $\overline{\Lambda}^{\circ}$ ) | N( $\Xi^{\circ}$ ) | Protons/Pulse |
|---|---|---|---|---|
| 8 | 200 | $10^5$ | $2 \times 10^4$ | $4 \times 8^8$ |
| 6 | 50 | $10^5$ | $10^4$ | $4 \times 10^8$ |
| 5 | 35 | $10^5$ | $10^4$ | $4 \times 10^8$ |
| 4 | 25 | $10^5$ | $10^4$ | $4 \times 10^8$ |
| 3 | 15 | $10^5$ | $10^4$ | $4 \times 10^8$ |
| 2 | 10 | $10^5$ | $10^4$ | $4 \times 10^8$ |
| 0 | 10 | $10^5$ | $10^4$ | $2 \times 10^8$ |
| Target out and calibration | 55 | | | |
| TOTAL | 400 | $7 \times 10^5$ | $8 \times 10^4$ | |

## Footnotes

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2. B. Y. Oh and G. A. Smith, Nuc. Phys. B49, 13 (1972).
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4. A. Lesnik et al., PRL 35, 770 (1975).
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6. H. Abramowicz et al., Nuc. Phys., B105, 222 (1976).
7. A. Borg et al., Nuovo Cimento, 22A, 559 (1974).
8. S. U. Chung et al., Phys. Rev., D11, 1010 (1975).
9. R. Gatto, Phys. Rev., 109, 610 (1958).
10. V. Blobel et al., Nuclear Physics B69, 454 (1974). The ratio $\left(\frac{\Sigma^+ + \Sigma^-}{2}\right)/\Lambda^\circ$ is consistant with being an increasing function of $p_T$. However, for the observed polarization to be due only to the decay of polarized $\Sigma^\circ_s$, the $\Sigma^\circ_s$ would have to be 100% polarized.
11. R. D. Field, ANL/HEP 75-02, or CALT-68-459. A naive triple-Regge model using $K^*$ exchange predicts zero $\Lambda^\circ$ polarization for $p+p \to \Lambda + X$.
12. P. M. Dauber et al., Phys. Rev., 179, 1262 (1969).
13. Particle Data Group, Phys. Lett. 50B. (1974) gives $\alpha_{\Xi^\circ} = -.44 \pm .08$.

PLAN VIEW OF EXPERIMENT 8

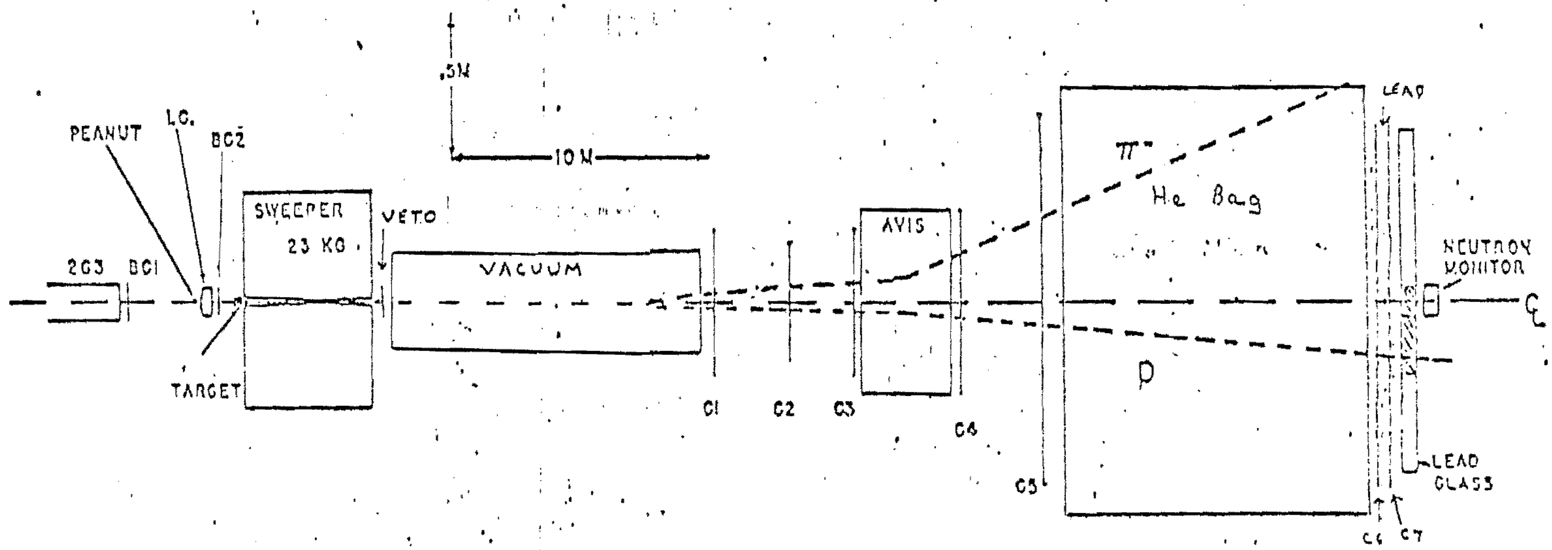


Figure 1. E-8 spectrometer in the M-2 beam line.

| Mass in GeV | |
|---|---|
| 1.258 | 8 |
| 1.262 | 17 |
| 1.266 | 25 |
| 1.270 | 21 |
| 1.274 | 32 |
| 1.278 | 39 |
| 1.282 | 85 |
| 1.286 | 126 |
| 1.290 | 195 |
| 1.294 | 292 |
| 1.298 | 444 |
| 1.302 | 625 |
| 1.306 | 807 |
| 1.310 | 869 |
| 1.314 | 863 |
| 1.318 | 832 |
| 1.322 | 664 |
| 1.326 | 508 |
| 1.330 | 313 |
| 1.334 | 222 |
| 1.338 | 160 |
| 1.342 | 84 |
| 1.346 | 56 |
| 1.350 | 43 |
| 1.354 | 29 |
| 1.358 | 24 |
| 1.362 | 13 |
| 1.366 | 7 |
| 1.370 | 9 |
| 1.374 | 7 |
| 1.378 | 3 |
| 1.382 | 2 |
| 1.386 | 2 |
| 1.390 | 0 |
| 1.394 | 5 |
| 1.398 | 2 |
| 1.402 | 1 |
| 1.406 | 0 |
| 1.410 | 0 |
| 1.414 | 0 |
| 1.418 | 2 |
| 1.422 | 0 |
| 1.426 | 1 |
| 1.430 | 1 |
| 1.434 | 1 |
| 1.438 | 2 |
| 1.442 | 0 |

Figure 2. Reconstructed mass of $\Xi^{\circ}$ candidates after fit of $\gamma$'s to $\pi^{\circ}$ mass. Data from E-8.

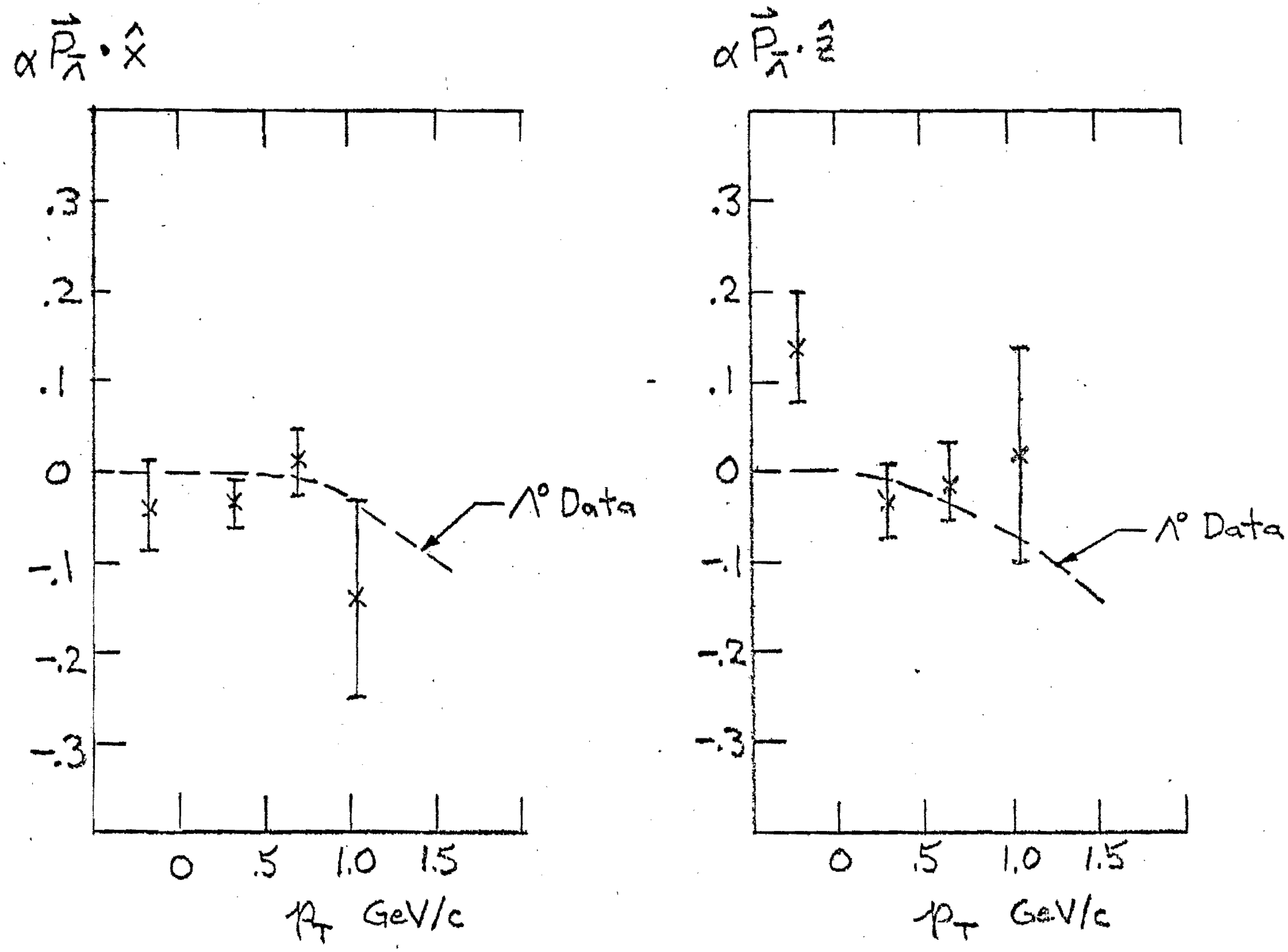


Figure 3. Antilambda polarization components in horizontal plane (after precession), plotted as function of $p_T$, from E-8 data. Curves represent polarization expected if the $\bar{\Lambda}^{\circ}$ polarization were equal to the $\Lambda^{\circ}$ polarization.

HISTOGRAMME 34 ARG(401)

1=VRAI, // 16=VRAI,XI(RH) //

COS(PROTON,L) IN LAMBDA REST FRAME PAS DE 9

| | | |
|---|---|---|
| 1 | -1.000 | 707 |
| 2 | -.9000 | 705 |
| 3 | -.8000 | 663 |
| 4 | -.7000 | 700 |
| 5 | -.6000 | 663 |
| 6 | -.5000 | 638 |
| 7 | -.4000 | 587 |
| 8 | -.3000 | 556 |
| 9 | -.2000 | 543 |
| 10 | -.1000 | 553 |
| 11 | 0. | 481 |
| 12 | .1000E+00 | 493 |
| 13 | .2000 | 479 |
| 14 | .3000 | 444 |
| 15 | .4000 | 445 |
| 16 | .5000 | 426 |
| 17 | .6000 | 403 |
| 18 | .7000 | 370 |
| 19 | .8000 | 354 |
| 20 | .9000 | 338 |

10549 ENTREES NON COMPRIS LES DEPASSEMENTS INFERIEURS 0 ET SUPERIEURS 0

10549 ENTREES EN TOUT MOYENNE -.1288 DEVIATION STANDART .5637

Figure 4. Distribution of proton from $\Lambda^\circ \rightarrow p\pi^-$ in the $\Lambda^\circ$ rest frame relative to the $\Lambda^\circ$ direction in the $\Xi^\circ \rightarrow \Lambda^\circ + \pi^\circ$ rest frame $(\hat{p} \cdot \hat{\Lambda})$ for $\Xi^\circ$ candidates.