Polarization Studies of Hyperons

C.J. Solano

EFEI, Itajubá and CBPF, Rio de Janeiro, Brazil

Abstract. Using data from Fermilab fixed-target experiment E791, we have measured polarization for \( \Xi^- \) and \( \Xi^+ \) hyperons in \( \pi^- \) – nucleon interactions at 500 GeV/c. The polarization is measured as function of the angular distribution, transversal to the production plane, and over the ranges of Feynman-x \((x_F)\) and \(p_T > 0.12 \leq x_F \leq 0.12 \) and \(0 \leq p_T^2 < 4(\text{GeV}/c)^2\). We didn’t find a convincing evidence for polarization non-zero. Our results only have statistical errors and are very preliminary.

INTRODUCTION

Since the unexpected measurement of substantial polarization for inclusively produced Lambdas by 300 GeV/c protons on Beryllium [1], it has been determined that hyperons produced at high energy have non-zero polarization. The measurements all [2] seem to be consistent with a polarization given by:

\[
\bar{P}_{A \rightarrow a+b+X} = f_{a,b}(x_F, p_T^2, A) \hat{n}
\]

where \( A \) is the atomic weight of the target nucleus and \( \hat{n} \) the normal to the production plane.

Several theoretical ideas have been proposed to explain this phenomena. Anderson [3] proposed that polarization from the soft, semiclassical process of quark-antiquark pair production by tunneling in a confined color field. De Gran and Miettinen [4] use the parton recombination model to relate the polarization to a Thomas precession like term in the recombination process.

There are a few results of hyperon polarization in \( \pi^- \)-nucleus interactions. For \( \Lambda^0 \) in \( \pi^- - Cu \) interactions at 230 GeV/c, Barlag [5] found, for \( x_F > 0 \) and \( p_T^2 > 1(\text{GeV}/c)^2 \), a polarization of \(-0.28 \pm 0.09 \pm 0.02\). For \( \Xi^- \) and \( \Xi^+ \) there are no studies with a \( \pi^- \) beam, but just a few results with a proton and \( \Sigma^- \) beam found a polarization of 10%.

1 javier@cbpf.br
THE EXPERIMENT AND THE SAMPLE

As a byproduct of our charm program in Fermilab experiment E791, we collected a large sample of $\Lambda^0/\bar{\Lambda}^0$, $\Xi^-/\Xi^+$, and $\Omega^-/\Omega^+$ hyperons. Initially, we used the $\Xi^-$ and $\Xi^+$ samples to measure the polarization production reported here, but we expect to continue the studies with the other hyperons.

Experiment E791 recorded data from 500 GeV/c $\pi^-$ interactions in five thin foils (one platinum and four diamond) separated by gaps of 1.38 to 1.39 cm. Each foil had a thickness of approximately 0.4% of a pion interaction length (0.5 mm for the upstream platinum target, and 1.6 mm for each of the carbon targets). The E791 spectrometer [6] in the Fermilab Tagged Photon Laboratory was a large-acceptance, two-magnet spectrometer augmented by eight planes of multiwire proportional chambers (MWPC) and six planes of silicon microstrip detectors (SMD) for beam tracking. The magnets provided a total transverse momentum kick of 512 MeV/c. Downstream of the target there were 17 planes of SMD’s for track and vertex reconstruction, 35 drift chamber planes, two MWPC’s, two multicell threshold Čerenkov counters, electromagnetic and hadronic calorimeters (with apertures about 70 by 140 mm), and a muon detector. An important element of the experiment was its extremely fast data acquisition system [7] which was combined with a very open transverse-energy trigger to record a data sample of $2 \times 10^{10}$ events. The trigger required that the total “transverse energy” (i.e., sum of the products of energy observed times the tangent of the angle from the target to each calorimeter segment) be at least 3 GeV.

The $\Lambda^0/\bar{\Lambda}^0$ sample was from approximately 7% of the overall sample recorded for the experiment. The total signal, taken as the sum of background subtracted signal in each bin, was $2.587 \pm 1.780$ $\Lambda^0$'s and $1.690 \pm 1.500$ $\bar{\Lambda}^0$'s. $\Xi^-$ were selected via the decay mode $\Xi^- \rightarrow \Lambda^0 \pi^-$ and $\Omega^-$ via the decay mode $\Omega^- \rightarrow \Lambda^0 K^-$. Beginning with a $\Lambda^0$ candidate, we added a third, distinct track as a possible pion or kaon daughter. All three tracks were required to have hits in the drift chamber region only. For these samples, we removed the requirement on the $\Lambda^0$ impact parameter. The invariant mass of the candidate hyperon (calculated from the known mass and measured momentum of the $\Lambda^0$, as determined by its two decay tracks, together with the third track) was required to be between 1.290 and 1.350 GeV/c$^2$ for the $\Xi^-$ and between 1.642 and 1.702 GeV/c$^2$ for the $\Omega^-$. As with the $\Lambda^0$ sample, the $\Xi^-/\Xi^+$ and $\Omega^-/\Omega^+$ invariant mass plots were fit to a Gaussian signal plus linear background for each interval of $x_F$ and $p_T^2$. With the final selection criteria and the full E791 data set, we found $996 \pm 1200$ $\Xi^-$, $706 \pm 1020$ $\Xi^+$, $8750 \pm 110$ $\Omega^-$, and $7460 \pm 100$ $\Omega^+$ after background subtraction. Again, these numbers and their errors come from the sum of signals in all bins. We checked that the $\Xi^-$ contamination for the $\Omega^-$'s, after all cuts, was negligible.

Selection criteria for the particle and antiparticle samples were identical. However, geometrical acceptances and reconstruction efficiencies were not necessarily the same, mostly due to an inefficient region in the drift chambers produced by the negative pion beam. To evaluate this effect, a large sample of Monte Carlo (MC) events was created using the PYTHIA/JETSET event generators [8]. These were projected through a detailed
simulation of the E791 spectrometer to simulate “data” in digitized format which was then processed through the same computer reconstruction code as that used for data from the detector. Candidate events were then subjected to the same selection criteria as that used for data. To account for correlations between $x_F$ and $p_T^2$, efficiencies were determined in bins of the two parameters.

**PROCEDURE**

To study the polarization of the $\Xi$ one looks at the angular distribution of the lambda in the decay $\Xi^- \rightarrow \Lambda^0\pi^-$ with $\Lambda^0 \rightarrow p^+\pi^-$ (and the corresponding conjugate decay), with respect to the normal to the production plane. This plane is defined as the one formed by the beam direction and the momentum of the $\Xi$.

The angular distribution of $\Lambda$’s produced is not isotropic but it depends on the cosine of angle between the momentum of the $\Lambda$ (in the $\Xi$ rest frame) and the quantization direction of the spin ($\alpha_{\Xi^-} = -\alpha_{\Xi^+} = -0.456$)

$$\frac{1}{N_o} \frac{dN_\Xi}{d\cos\theta_{\Lambda R}} = \frac{1}{2} (1 + \alpha_{\Xi}p_{\Xi}\cos\theta_{\Lambda R})$$ (2)

with

$$\cos\theta_{\Lambda R} = \frac{\hat{p}_{\Lambda\text{CMS}} \cdot \hat{p}}{|p_{\Lambda\text{CMS}}|}$$ (3)

For the actual state of our analysis, in hyperon polarization, we corrected the data by the efficiency of MC. After that, we fitted the angular distributions of polarization for $\Xi^-$ and $\Xi^+$ and the results you can see in the tables.

**Polarization of $\Xi^-$**

<table>
<thead>
<tr>
<th>$p_{\Xi^-}$</th>
<th>$0 \leq p_T^2 \leq 1$</th>
<th>$1 \leq p_T^2 \leq 2$</th>
<th>$2 \leq p_T^2 \leq 3$</th>
<th>$3 \leq p_T^2 \leq 4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-0.12 \leq x_F \leq -0.06$</td>
<td>0.058 ± 0.048</td>
<td>0.008 ± 0.136</td>
<td>0.472 ± 0.206</td>
<td>0.382 ± 0.284</td>
</tr>
<tr>
<td>$-0.06 \leq x_F \leq 0.00$</td>
<td>0.120 ± 0.032</td>
<td>0.026 ± 0.090</td>
<td>0.350 ± 0.150</td>
<td>0.176 ± 0.198</td>
</tr>
<tr>
<td>$0.00 \leq x_F \leq 0.06$</td>
<td>0.008 ± 0.048</td>
<td>0.180 ± 0.126</td>
<td>0.248 ± 0.204</td>
<td>0.144 ± 0.282</td>
</tr>
<tr>
<td>$0.06 \leq x_F \leq 0.12$</td>
<td>0.068 ± 0.156</td>
<td>0.174 ± 0.312</td>
<td>0.436 ± 0.518</td>
<td>0.598 ± 0.606</td>
</tr>
</tbody>
</table>

**Polarization of $\Xi^+$**

<table>
<thead>
<tr>
<th>$p_{\Xi^+}$</th>
<th>$0 \leq p_T^2 \leq 1$</th>
<th>$1 \leq p_T^2 \leq 2$</th>
<th>$2 \leq p_T^2 \leq 3$</th>
<th>$3 \leq p_T^2 \leq 4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-0.12 \leq x_F \leq -0.06$</td>
<td>-0.106 ± 0.056</td>
<td>-0.236 ± 0.138</td>
<td>-0.148 ± 0.222</td>
<td>-0.170 ± 0.310</td>
</tr>
<tr>
<td>$-0.06 \leq x_F \leq 0.00$</td>
<td>-0.096 ± 0.034</td>
<td>-0.128 ± 0.092</td>
<td>-0.294 ± 0.158</td>
<td>-0.224 ± 0.238</td>
</tr>
<tr>
<td>$0.00 \leq x_F \leq 0.06$</td>
<td>-0.082 ± 0.048</td>
<td>-0.148 ± 0.122</td>
<td>-0.198 ± 0.218</td>
<td>0.168 ± 0.290</td>
</tr>
<tr>
<td>$0.06 \leq x_F \leq 0.12$</td>
<td>0.058 ± 0.160</td>
<td>-0.524 ± 0.326</td>
<td>0.062 ± 0.360</td>
<td>-0.786 ± 0.784</td>
</tr>
</tbody>
</table>

367
RESULTS AND CONCLUSIONS

Most of the intervals we checked (see tables) are compatible with no polarization. In few intervals we have non zero polarization but just with statistical errors. We need to continue the study to look for systematic effects. Another future step of our analysis is to extend the study to the other two hyperons, $\Lambda^0/\bar{\Lambda}^0$ and $\Xi^-/\bar{\Xi}^+$.

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of the staffs of Fermilab and of all the participating institutions. This research was supported by the FAPEMIG (Brazil).

REFERENCES