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TEST OF CP INVARIANCE IN Λ^0 DECAY

(R608 Collaboration)

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Abstract

In an experiment at the CERN Intersecting Storage Rings with $\sqrt{s} = 31$ GeV, we have measured αP , the product of asymmetry parameter and polarization, for $\bar{\Lambda}^0$'s and Λ^0 's produced in $\bar{p}p$ and pp interactions, respectively. The ratio, $(\alpha P)_{\bar{\Lambda}}/(\alpha P)_{\Lambda} = -1.04 \pm 0.29$, is consistent with the value -1 , and constitutes the first test of CP invariance in Λ decay.

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We report measurements of αP , the asymmetry parameter times polarization, for inclusive $\bar{\Lambda}^0$'s and Λ^0 's produced in the forward direction in the reactions:

at the CERN Intersecting Storage Rings (ISR) with center-of-mass energy $\sqrt{s} = 30.8$ GeV (The $\bar{\Lambda}^0$ in Reaction (1) is detected in the direction of the incoming $\bar{p}$). An absence of polarization for $\bar{\Lambda}^0$'s (centrally) produced in pp interactions^[1] has thus far prevented any determination of $\alpha_{\bar{\Lambda}}$. In the experiment reported here, however, the $\bar{\Lambda}^0$'s in Reaction (1) are fragmentation products of the beam $\bar{p}$ and are thus expected to be polarized in essentially the same way as the Λ^0 's in Reaction (2). This gives us the opportunity to make the first comparison of $\alpha_{\bar{\Lambda}}$ and α_{Λ} . CP invariance in Λ^0 decay requires that these two parameters have equal magnitude but opposite sign ($\alpha_{\bar{\Lambda}} = -\alpha_{\Lambda}$). Thus, we expect to find the measured αP in the two reactions also equal in magnitude and opposite in sign. That is, $(\alpha_{\bar{\Lambda}} P_{\bar{\Lambda}}) = -(\alpha_{\Lambda} P_{\Lambda})$.

An earlier measurement of Λ^0 polarization^[2] in Reaction 2 at the ISR found similar polarization as had been observed in an experiment by Bunce et al.^[3] using a Beryllium target at FNAL. This result showed that the Λ^0 polarization was a consequence of the beam proton fragmentation^[4] and had little, if anything, to do with the nature of the target particle.

C-invariance in the strong $\bar{p}p$ interaction requires that particles produced with a production angle θ have properties identical to those of the anti-particles produced with an angle $(\pi - \theta)$ in the same reaction. In other words, the fragmentations and hence the polarizations of $\bar{p} \rightarrow \bar{\Lambda}^0$ and $p \rightarrow \Lambda^0$, in $\bar{p}p$ interactions should be identical. Thus, the question of whether the hyperons in Reactions 1 and 2 have the same polarization can be rephrased as: is the polarization of $p \rightarrow \Lambda^0$ in $\bar{p}p$ interactions the same as $p \rightarrow \Lambda^0$ in pp interactions? We discuss this question of factorization below.

The measurements reported here were made with the forward spectrometer of experiment R608^[5] installed at the ISR. There were two independent spectrometers positioned, respectively, above and below the same outgoing beam pipe, "sandwiching" the pipe between them. Fig. 1 shows a sketch of the two magnet apertures, looking downstream from the ISR interaction region. The magnetic field B is in the same direction in both upper and lower magnets. Thus, the left-right acceptance asymmetry introduced by the magnetic bend of the slow $\pi^+(\pi^-)$ from the $\bar{\Lambda}^0(\Lambda^0)$ is the same in both spectrometers. On the other hand, the vector $\hat{n}$, which is normal to the production plane ($\hat{n} \approx \vec{p}_{\text{beam}} \times \vec{\Lambda}^0$), tends to be opposite. This results in different geometrical acceptances, with respect to $\hat{n}$, in the two spectrometers. Since the polarization measurements in the two spectrometers should agree, this situation provides us with a verification of our acceptance correction methods. As an additional test of our procedures, we measure the polarization of "non- Λ^0 " $\bar{p}\pi^+(p\pi^-)$ pairs (i.e., those whose invariant mass lies to either side of the $\bar{\Lambda}^0(\Lambda^0)$ peak and whose vertices fall in the beam-beam crossing region). The polarization of these events should be zero.

In order to minimize any possible systematic uncertainties, the data for Reactions (1) and (2) were recorded with opposite magnetic field. Thus, the π^+ 's from $\bar{\Lambda}^0$ decay bend in the same direction as the π^- 's from Λ^0 decay. This ensures that the geometric acceptance and efficiency corrections are not significantly different for the $\bar{p}p$ and pp data, respectively.

To obtain pure inclusive samples of $\bar{\Lambda}^0$ and Λ^0 , the data were recorded with a minimum-bias trigger, which required only that two or more tracks traversed the spectrometer (signaled by appropriate wire-chamber multiplicity requirements). Off-line reconstruction yields background-free vertex distributions in the beam-beam crossing region. For events with $\bar{\Lambda}^0$ or Λ^0 , a primary vertex is not required, but the reconstructed momentum vector of the $\bar{\Lambda}^0(\Lambda^0)$ is found to intersect the beam-beam plane with a background-free distribution similar to that of the primary vertices in "non- Λ^0 " events. Typical $\bar{p}\pi^+$ and $p\pi^-$ invariant mass spectra were shown in reference [6]. $\bar{\Lambda}^0$'s and Λ^0 's were selected for the final data sample if their invariant mass was in the 12 MeV wide interval centered at the Λ^0

TABLE I: $\bar{\Lambda}^0$ And Λ^0 Measurements

p_t Range (GeV)	$\bar{\Lambda}^0$ (a)	Λ^0 (a)	$\alpha_{\bar{\Lambda}}/\alpha_{\Lambda}$ (b)
0.4-0.6	4.2 ± 4.0	-3.1 ± 3.1	
0.6-0.8	11.7 ± 4.7	-9.9 ± 3.5	-1.18 ± 0.45
0.8-1.0	19.2 ± 6.7	-17.9 ± 4.9	-1.07 ± 0.47
1.0-1.4	30.7 ± 10.5	-35.3 ± 7.5	-0.87 ± 0.56
0.6-1.4 (UP)	13.5 ± 5.2	-15.8 ± 3.9	-0.85 ± 0.39
0.6-1.4 (DOWN)	15.4 ± 5.1	-15.3 ± 3.8	-1.01 ± 0.42
0.6-1.4 (all)	16.1 ± 3.6	-15.5 ± 2.7	-1.04 ± 0.29
0.6-1.4 ("non- Λ^0 ")	2.1 ± 4.6	3.0 ± 3.8	

(a) measured values of αP (in percent) divided by the absolute value of α_{Λ} .

(b) ratio of columns 2 and 3 (assuming $P_{\Lambda} = P_{\bar{\Lambda}}$).

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Figure Captions

1. Schematic drawing of the magnet as viewed from interaction region. Shaded area is a septum plate which shields the circulating ISR beam. The magnetic field $\vec{B}$ is down in both magnets for proton-proton runs. The normal to the production plane, $\hat{n} \approx \vec{p} \times \vec{\Lambda}^0$, is typically opposite for Λ^0 's entering the up and down magnets, respectively.
2. Comparison of inclusive longitudinal momentum distributions of charged particles and $\bar{\Lambda}^0$'s and Λ^0 's in pp and $\bar{p}p$ interactions; (a) Numbers of charged particles per event per GeV, p_{ℓ} ; (b) Numbers of $\bar{\Lambda}^0(\Lambda^0)$ per event per GeV, p_{ℓ} .
3. Polarization ($\alpha P/|\alpha_{\Lambda}|$) of $\bar{\Lambda}^0$ and Λ^0 vs. transverse momentum, p_t .

mass. There is a 3% background in the final $\bar{\Lambda}^0$ and Λ^0 samples. The data sample used for the results reported here consists of 9,553 $\bar{\Lambda}^0$'s and 17,028 Λ^0 's, all in the range of longitudinal momentum $6.0 < p_\ell < 13.7$ GeV (corresponding to the Feynman-x range: $0.4 < x_F < 0.9$) and transverse momentum $p_t < 1.4$ GeV.

Fig. 2 shows the comparison between the p_ℓ spectra of inclusive single particles in pp and $\bar{p}p$ interactions at $\sqrt{s} = 31$ GeV. Fig. 2(a) compares ($\bar{p} \rightarrow$ negative tracks) with ($p \rightarrow$ positive tracks), and also ($\bar{p} \rightarrow$ positive tracks) with ($p \rightarrow$ negative tracks), as a function of p_ℓ . To avoid biases, Cerenkov information is not used in making these plots. Thus the upper data set contains a large proton (antiproton) component which is not in the lower data set. The normalizations are not arbitrary; the points plotted are numbers of particles per event per GeV of p_ℓ . There is a remarkable agreement between the secondary particle distributions in $\bar{p}$ and p fragmentation in $\bar{p}p$ and pp collisions, respectively. From the C-invariance argument given above for $\bar{p}p$ interactions, this comparison is equivalent to comparing proton fragmentation in $\bar{p}p$ and pp interactions, respectively, and tests factorization in these interactions. The small excess of positive tracks (and deficiency of negative tracks) in the pp data compared with the $\bar{p}p$ data is due to the annihilation effects at large x_F described in ref. [6].

Similar agreement is seen in Fig. 2(b) between the p_ℓ distributions of $\bar{\Lambda}^0$ and Λ^0 , respectively, although the small violations of factorization^[6] are seen at the upper end of these spectra as well. In the p_ℓ range of our polarization measurements, however, it appears likely that the $\bar{\Lambda}^0$ and Λ^0 polarizations are the same in Reactions (1) and (2), respectively, at least to a level much better than the statistical uncertainty in the measurements of αP reported here.

The Λ^0 decay angular distribution is described by:

$$dN/d(\cos \theta_p) \approx (1 + \alpha_\Lambda P_\Lambda \cos \theta_p) \quad (3)$$

where $\alpha_\Lambda = 0.642$ is the Λ^0 asymmetry parameter^[7] and P_Λ is the polarization of the Λ^0 along $\hat{n}$. θ_p is the polar angle of the proton in the Λ^0 rest frame with the z-axis chosen as $\hat{n}$. The decay angular distribution of the $\bar{\Lambda}^0$'s produced in Reaction (1) is described by the same distribution, but with the $\bar{\Lambda}^0$ polarization, $P_{\bar{\Lambda}}$, and asymmetry parameter, $\alpha_{\bar{\Lambda}}$. αP is evaluated in the following way: For chosen bins in p_ℓ - p_t , the distribution in Eq. (3) is multiplied by the calculated acceptance, $A(\theta_p)$, and fit to the data using a χ^2 -minimization program.

Due to the limited statistics in the data sample used for this analysis, we take a weighted average over p_ℓ and present the polarization only as a function of p_t . Table I and Fig. 3 show the results for four p_t bins between 0.4 and 1.4 GeV. In Table I and Fig. 3, the fitted values of αP are divided by the absolute magnitude of α_Λ . Thus, if $|\alpha_{\bar{\Lambda}}| = |\alpha_\Lambda|$, the resulting numbers have the magnitude of $P_{\bar{\Lambda}}(P_\Lambda)$, but carry the joint sign of $\alpha_{\bar{\Lambda}}P_{\bar{\Lambda}}(\alpha_\Lambda P_\Lambda)$. There is a remarkable similarity observed between the $\bar{\Lambda}^0$ and Λ^0 results, consistent with the polarization being the same in Reactions (1) and (2) and with $\alpha_{\bar{\Lambda}} = -\alpha_\Lambda$. The agreement between the results from the "UP" and "DOWN" spectrometers, as well as the polarization compatible with zero observed for the "non- Λ^0 " events, provides the necessary verification mentioned above.

The last column in Table I contains the ratios of the entries in columns 2 and 3 and may be interpreted as the ratio $\alpha_{\bar{\Lambda}}/\alpha_\Lambda$ (assuming that $P_{\bar{\Lambda}} = P_\Lambda$). The weighted average over the entire observed p_t range is -1.04 ± 0.29 . This result is consistent with the expected value of -1 and constitutes a test of dominant CP-invariance in Λ^0 decay.

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Fig. 2

Fig. 1

Fig. 3