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Determination of the α Parameter for the Decay $\Xi^- \rightarrow \Lambda \pi^- *$

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The standard description of non-leptonic hyperon decays is characterised by asymmetry parameters α , β , and γ , defined in terms of isospin-changing s-wave and p-wave amplitudes S and P:

$$\alpha = \frac{2\text{Re}(S^*P)}{|S|^2 + |P|^2}, \quad \beta = \frac{2\text{Im}(S^*P)}{|S|^2 + |P|^2}, \quad \text{and} \quad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}. \quad (1)$$

For a given isospin multiplet, it is possible to derive these amplitudes from the decay probabilities and the asymmetry parameters, and thereby test the empirical $\Delta I = 1/2$ rule. The Ξ decay is particularly interesting in this respect since $\Delta I = 5/2$ amplitudes cannot contribute, in contrast to the case of Λ decays. Furthermore corrections due to final-state interaction phase shifts cancel in the ratio $\Gamma(\Xi^0 \rightarrow \Lambda\pi^0)/\Gamma(\Xi^- \rightarrow \Lambda\pi^-)$ since both final states are pure $I = 1$ states (unlike the $p\pi^-$ and $n\pi^0$ final states in Λ decay which have different mixtures of $I = 1/2$ and $I = 3/2$ components). The angular distribution for the sequential decay $\Xi^- \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\pi^-$, can then be expressed as

$$N(\theta) = 1 + \alpha_{\Lambda} \alpha_{\Xi}^- \cos \theta \quad (2)$$

where α_{Ξ}^- refers to the decay $\Xi^- \rightarrow \Lambda\pi^-$, α_{Λ} to the decay $\Lambda \rightarrow p\pi^-$, and θ is the angle between the proton direction and the direction antiparallel to the parent Ξ^- direction in the Λ rest frame.

The data presented here were obtained from an experiment in the CERN SPS charged hyperon beam, to measure the total cross sections of Ξ^- and Ξ^0 on nucleons. The apparatus, shown schematically in figure 1, and the hyperon beam have been described in detail elsewhere [1]. A magnetic channel with a momentum acceptance of $\pm 4\%$ (rms) selects particles produced by 250 GeV/c protons striking a beryllium oxide target. The Ξ^- are identified in a DISC cerenkov counter which has a momentum acceptance of between $\pm 0.5\%$ and $\pm 2.1\%$ (rms) depending on the diaphragm setting. The counting rate is typically 300 Ξ^- per burst for 10⁶ beam particles and the Ξ^- contamination of the Ξ^0 signal is 3%. The Λ chambers, which are two clusters of multiwire proportional chambers (MWPC), measure the trajectories of beam particles as they pass through the DISC. The beam then enters one of three 2 m long

DETERMINATION OF THE α PARAMETER FOR THE DECAY $\Xi^- \rightarrow \Lambda\pi^-$ *

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ABSTRACT

The α parameter for $\Xi^- \rightarrow \Lambda\pi^-$ decay has been determined to be $\alpha_{\Xi}^- = -0.462 \pm 0.015$, from a sample of 1.5×10^5 events recorded in the CERN SPS hyperon beam. This value is 2.5 standard deviations higher than the current world average.

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targets, which contain H_2 , D_2 , or vacuum and which are alternated about every 10 bursts. Only the data sample recorded with the vacuum target is used in this analysis since it contains the highest proportion of non-interacting Ξ^- .

The decay products are analysed by a set of MWPC (B, C and D) arranged in 6 clusters of 6 planes each, a spectrometer magnet (aperture $60 \times 60 \text{ cm}^2$) located 15 m downstream of the target centre, and an array of drift chambers.

The overall acceptance of the apparatus is limited mainly by the length available for the sequential decays $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$ which have decay lengths of approximately 5.0 m and 8.2 m respectively at a beam momentum of 135 GeV/c, and 3.8 m and 6.1 m respectively at 102 GeV/c. The decay zone considered in the first stage of analysis extends from the exit of the DISC to a region approximately 8 m downstream, located between the C and D chambers. The geometrical acceptance of the spectrometer is complete for the three charged particles from $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$ decays occurring in the last 5 m of this zone, however it falls to 90% for $\Xi^- \rightarrow \Lambda \pi^-$ decays occurring at the exit of the DISC, due to loss of π^- emitted at large angles. (Decays in this 3 m region of incomplete acceptance are later rejected, as described below).

The reconstruction of charged particle tracks follows the method described in [2]. At this stage of the analysis there is a small loss of events in which the $\Lambda \rightarrow p \pi^-$ decay occurs close to the end of the decay zone, caused by the inability of the D chambers to resolve tracks separated by a distance comparable to the wire spacing.

The trigger for the total cross section measurement consists of a Ξ^- signal from the DISC in coincidence with signals from the beam scintillation counters. A total of 4.7×10^6 Ξ^- triggers were recorded with the vacuum target, resulting in 6.0×10^5 reconstructed sequential decays $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$ (branching ratio 64%) occurring in the 8 m long decay zone.

In the kinematic reconstruction the positive track is assumed to be a proton and the two negative tracks are assumed to be pions, since there is no secondary particle identification. The pion yielding a $(p \pi^-)$ effective mass closest to the Λ mass is taken to be the decay pion of the Λ . A first set of relatively loose cuts is applied to these fully reconstructed events: i) the reconstructed Ξ^- momentum is required to be within 20 GeV/c of the mean beam momentum (fwhm is 5 GeV/c); ii) the angle between the incident Ξ^- trajectory measured by the beam chambers and the Ξ^- direction determined from the decay products must be less than 1.0 mrad; iii) the $(p \pi^-)$ effective mass must be within 20 MeV/ c^2 of the Λ mass. These cuts accept 95% of the events.

A further set of more restrictive cuts is applied in order to eliminate possible biases due to acceptance and double track resolution: iv) the decay kink angle in the (Ξ^-, π^-) trajectory must be greater than 3 mrad (this cut ensures a precise location of the decay vertex along the beam direction and its acceptance is 95%); v) the decay kink is required to occur in a restricted decay zone, approximately 5 m long extending from the end of the target, where the spectrometer acceptance is 100% (cut acceptance 40%); vi) at the magnet centre, the three extrapolated trajectories must be separated from each other by at least 1 cm both horizontally and vertically (cut acceptance 75%). This eliminates uncertainties caused by the finite two-track resolution of the D chambers mentioned above.

The $(\Lambda \pi^-)$ effective mass distribution for the remaining Ξ^- candidates shows a clear peak with a width of 7 MeV/ c^2 (fwhm), small non Gaussian tails and a negligible background. The peak is about 1 MeV/ c^2 higher than the Ξ^- mass and this could indicate a normalisation error of 0.5% in the magnetic field parameterisation. Events with an effective mass within 15 MeV/ c^2 of the central value (cut (vii)), acceptance 95% are retained, yielding a final event sample of $148810 \Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$ decays (45740 at 135 GeV/c and 103070 at 102 GeV/c).

investigated and found to be negligible. The double track resolution of the proportional chambers (about 2.5 mm for the C and D chambers), is simulated in the Monte Carlo program and controlled by cut (vi). An increase of this cut from 1 to 2 cm slightly reduces the value of $\alpha_{\Lambda^0 \Xi^-}$ (see Table 1). The other strong cuts are (iv) and (v). If they are not applied, the value of $\alpha_{\Lambda^0 \Xi^-}$ remains unchanged (see Table 1). The discrepancy of about 1 MeV/c² between the average ($\Lambda \pi^-$) effective mass and the Ξ^- mass has no effect. Relaxing cut (vii) on the ($\Lambda \pi^-$) mass by a factor of two increases $\alpha_{\Lambda^0 \Xi^-}$ by 0.003, whereas relaxing cuts (i) to (iii) by a factor of two reduces this quantity by 0.003. Changing the value assumed for the mean beam momentum by 1 GeV/c (the estimated error on this quantity) changes $\alpha_{\Lambda^0 \Xi^-}$ by 0.001. Confusion between the two π^- from the sequential decay $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$ occurs for less than 0.5% of the events and accidental hits in the chambers have no significant effect.

Figures 3a to 3f show the Monte Carlo corrected distributions of the Λ direction cosines in the Ξ^- centre of mass for the final event samples. (A right-handed coordinate system is used with the z axis along the beam direction and the y axis in the upward vertical direction.) A polarisation of the Ξ^- beam would require these distributions to have non-zero slopes. It has been observed that hyperons produced with a transverse momentum greater than 0.5 GeV/c in high-energy pN collisions have a significant polarisation [3]. However, the Ξ^- collected in our hyperon channel are produced with transverse momenta of less than 0.1 GeV/c and are not expected to be polarised. The observed slopes of the Λ direction cosines (see Table 2) correspond to Ξ^- polarisations of $(3.7 \pm 3.8)\%$ and $(3.5 \pm 2.4)\%$ for the 135 and 102 GeV/c data, respectively. Thus the measured polarisations are small and consistent with zero. It may be noted that a finite polarisation will have no effect on the measurement of $\alpha_{\Lambda^0 \Xi^-}$ provided that the entire phase space of the Ξ^- cascade decay is measured with uniform efficiency. Although there are small departures from full acceptance in our final data sample (see discussion of cuts (iv) and (vi)), we can deduce an upper limit on the Ξ^- polarisation which is sufficiently small to ensure that its effect on the estimated value of α_{Ξ^-} is negligible. Subdividing the space in the

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In order to correct the data for the cuts imposed in the event selection, a Monte Carlo program is used to simulate the experiment. The program first generates a beam of Ξ^- which decay exponentially into $\Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$. The three particles from the decays are traced through the apparatus, and the track coordinates are calculated in the appropriate projection at each chamber plane. Measurement errors are simulated by giving each coordinate a random displacement, consistent with the resolution function of the chamber, to produce "hits". Tracks are then reconstructed from these hits. Uncertainties in the magnetic field parameterisation are taken into account by assigning to each track a normally distributed momentum error of 0.5% (rms). Similarly, every track is given an angular error which corresponds to the multiple scattering in 4% of a radiation length of material. Finally, the effects of nuclear interactions of the decay products in the apparatus and of non-Gaussian measurement errors are simulated in a somewhat arbitrary way by causing one of the decay products to scatter at its origin according to an $\exp(-8p_T^2)$ distribution, for approximately 5% of the tracks. In this way the tails observed in the $\Lambda \pi^-$ mass distribution are accurately reproduced by the Monte Carlo program.

The $\cos \theta$ distributions (see equation (2)) are shown in Figs 2a and 2b for the 135 GeV/c and 102 GeV/c data, after correction for the efficiencies of the selection criteria. Least squares fits to the data result in the straight lines in the figures which correspond to $\alpha_{\Lambda^0 \Xi^-} = -0.303 \pm 0.010$ for the 135 GeV/c data and $\alpha_{\Lambda^0 \Xi^-} = -0.297 \pm 0.007$ for the 102 GeV/c data. The χ^2 values per degree of freedom are 21.2/20 and 17.8/20, respectively.

A careful search has been made for possible sources of bias. The MWPC efficiencies and their stability with respect to intensity variations have been studied for the total cross section analysis [1]. The efficiency of each chamber plane in the beam spot is always greater than 97% (typically 99%) and furthermore two independent measurements of the X and Y coordinates are made in each MWPC cluster. Therefore the efficiency of each cluster is close to 100% over the whole fiducial area. The drift chamber efficiencies are 97% per plane and for track reconstruction only 3 hits out of 4 are required. The effect of a possible beam spot inefficiency on α_{Ξ^-} has been

Ξ^- cms into four regions defined to be: 1) $\cos x > 1/2$;

2) $\cos y > 1/2$; 3) $\cos z > 1/2$; 4) $\cos x, \cos y, \cos z < 1/2$,
we obtain the results shown in Table 1, which are all compatible amongst themselves.

A comparison of the values obtained above for the product of the Λ and Ξ^- decay asymmetries:

$$\alpha_{\Lambda} \alpha_{\Xi^-} = -0.297 \pm 0.007 \text{ at } 102 \text{ GeV/c}$$

$$\text{and } \alpha_{\Lambda} \alpha_{\Xi^-} = -0.303 \pm 0.010 \text{ at } 135 \text{ GeV/c}$$

shows they are consistent within their quoted errors, which at this stage are purely statistical. We therefore take the weighted mean and obtain the result:

$$\alpha_{\Lambda} \alpha_{\Xi^-} = -0.299 \pm 0.006$$

From our stability and consistency checks, we estimate that the total systematic bias is less than ± 0.004 . Taking this limit as our systematic error and combining it in quadrature with the statistical error, we obtain the final result

$$\alpha_{\Lambda} \alpha_{\Xi^-} = -0.299 \pm 0.007$$

Using $\alpha_{\Lambda} = 0.647 \pm 0.014$ [4] we find:

$$\alpha_{\Xi^-} = -0.462 \pm 0.015$$

This value of α_{Ξ^-} is more than 2.5 standard deviations higher than the average of 7 previous experiments, -0.397 ± 0.017 [5,6]. (It may be noted that the smallest error quoted for a single experiment is ± 0.032).

The $\Delta I = 1/2$ rule with phase-space corrections [7] predicts that $\alpha_{\Xi^-}/\alpha_{\Xi^0} = 0.977$ and $\Gamma_{\Xi^0}/\Gamma_{\Xi^-} = 0.484$. Radiative corrections are smaller than the effects of phase space [7] and are neglected here. Defining

$\Delta\alpha = (\alpha_{\Xi^0}/\alpha_{\Xi^-}) - 0.977$ and $\Delta\Gamma = (\Gamma_{\Xi^0}/\Gamma_{\Xi^-}) - 0.484$, and using the most recent experimental values: $\alpha_{\Xi^0} = -0.490 \pm 0.042$ [8],

$$\Gamma_{\Xi^-} = (1.623 \pm 0.018) \times 10^{-10} \text{ s} [6,9],$$

$$\Gamma_{\Xi^0} = (2.89 \pm 0.10) \times 10^{-10} \text{ s} [6,10],$$

we obtain $\Delta\alpha = 0.084 \pm 0.096$ and $\Delta\Gamma = 0.078 \pm 0.020$. To test the $\Delta I = 1/2$ rule, $\Delta\alpha$ and $\Delta\Gamma$ are written as linear expressions [11] of the ratios of $\Delta I = 3/2$ and $\Delta I = 1/2$ amplitudes:

$$\Delta\alpha = 1.37(S_3/S_1) - 1.37(P_3/P_1),$$

$$\Delta\Gamma = -1.44(S_3/S_1) - 0.06(P_3/P_1)$$

$S_3(P_3)$ and $S_1(P_1)$ are the s-wave (p-wave) amplitudes with $\Delta I = 3/2$ and $\Delta I = 1/2$, respectively. Solving for S_3/S_1 and P_3/P_1 , we find:

$$S_3/S_1 = -0.050 \pm 0.014,$$

$$P_3/P_1 = -0.111 \pm 0.068.$$

There is a clear indication of a violation of the $\Delta I = 1/2$ rule in the s-wave amplitude ratio which is determined mainly from the decay rates. The asymmetry measurements combined with the rates allow a test of the rule in the p-wave amplitudes and a 1.6 standard deviation effect is observed here. However, there is a relatively large error on the value obtained for P_3/P_1 which comes mainly from the experimental error on α_{Ξ^0} . Thus a better measurement of this quantity is needed to establish if there is a violation of the $\Delta I = 1/2$ rule in the p-wave amplitude.

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Table 1

Measurements of $\alpha_{A_{\pi^-}}$ at 102 GeV/c and 135 GeV/c for various data cuts.
Only statistical errors are quoted in this table. The text should be
consulted for the definitions of these samples and to understand the extent
to which they are independent.

	135 GeV/c	102 GeV/c
Standard cuts	-0.303 ± 0.010	-0.297 ± 0.007
Cut (vi) at 2 cm	-0.294 ± 0.015	-0.295 ± 0.009
Without cuts (iv) and (v)	-0.304 ± 0.008	-0.295 ± 0.006
In $\bar{\pi}^-$ cm Region 1	-0.345 ± 0.025	-0.305 ± 0.016
Region 2	-0.282 ± 0.018	-0.294 ± 0.014
Region 3	-0.287 ± 0.018	-0.295 ± 0.014
Region 4	-0.320 ± 0.026	-0.306 ± 0.018

Figure captions

Fig 1: The experimental arrangement.

Fig 2: The $\cos \theta$ distribution for a) the 135 GeV/c data and b) the 102 GeV/c data. The data have been corrected for the efficiencies of the selection criteria. The errors are statistical errors only, and the vertical scale is arbitrary. The straight lines are the result of least squares fits.

Fig 3: The Λ direction cosines in the Ξ^- centre of mass. The data have been corrected for the efficiencies of the selection criteria. (a)-(c) 135 GeV/c data; (d)-(f) 102 GeV/c data. The errors are statistical errors only, and the vertical scale is arbitrary. The straight lines are least squares fits to the data.

Table 2

Fitted slopes of the Λ direction cosine distributions in Fig 3. Only statistical errors are quoted in this table.

	135 GeV/c	102 GeV/c
Slope ($\cos x$) (χ^2/DF)	-0.011 ± 0.010 (12.9/10)	-0.003 ± 0.006 (29.4/10)
Slope ($\cos y$) (χ^2/DF)	-0.003 ± 0.009 (7.0/10)	-0.005 ± 0.006 (2.3/10)
Slope ($\cos z$) (χ^2/DF)	-0.013 ± 0.011 (4.7/10)	-0.014 ± 0.007 (8.2/10)

Figure 1

Figure 2a

Figure 2b

Figure 3