STRANGE PARTICLE PRODUCTION AT THE CERN SPS COLLIDER

UA5 Collaboration

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ABSTRACT

First results are presented on kaon and lambda yields in $p\bar{p}$ collisions at $\sqrt{s} = 540$ GeV. Our data show an increase in the K/π ratio and especially in kaon mean transverse momentum relative to results at lower energies.

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INTRODUCTION

In this paper we present results on the production of strange particles, $K^\pm$, K_S , K_L , Λ , and $\bar{\Lambda}$, in $p\bar{p}$ interactions at a c.m. energy of 540 GeV. The results were obtained using the UA5 streamer chamber detector [1] at the CERN Super Proton Synchrotron (SPS) Collider. The data which we present here are based on the observation of strange-particle decays within the visible volume of the streamer chamber. The excellent spatial resolution allows a very clear identification of such decay vertices, even in events of high multiplicity.

These data constitute the first evidence for the production of strangeness at collider energies. A recent result from the CERN Intersecting Storage Rings (ISR) [2] has suggested a rapid increase in the production of kaons and hyperons over the ISR energy region, although an earlier survey [3] found a more nearly constant kaon fraction in charged-particle production. There is clearly a sharp rise in charm production at the ISR [4] which should be associated with increasing kaon yields. There are also indications from cosmic-ray experiments above ISR energies that the production of baryons and kaons [5] and charm [6] could be increasing rapidly with energy.

EXPERIMENTAL PROCEDURE

The UA5 detector has been described in refs. [1], [7] and [8]. Charged-particle tracks were observed in two $6\text{ m} \times 1.25\text{ m} \times 0.5\text{ m}$ streamer chambers, placed 4.5 cm above and below the SPS beam axis. This small distance between the sensitive volumes of the chambers and the collision point meant that there was a significant ($\sim 10\%$) probability of observing K_S , Λ , and $\bar{\Lambda}$ decays in the chamber.

All tracks seen on the photographs were digitized and reconstructed, and then associated with primary or secondary vertices. Software cuts were applied to the measurements in order to find strange-particle decay candidates in the chamber volume. We searched for V's (i.e. $K_S \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$, $\bar{\Lambda} \rightarrow \bar{p}\pi^+$, or $K_L \rightarrow 2\text{ charged} + \text{neutrals}$) and for one- or three-pronged decays of charged particles ($K^\pm$ or $\pi^\pm$ decays). A pair of tracks starting close together and forming a

vertex within the chamber constituted a V, whilst a track ending in the chamber volume and having one or more other tracks starting nearby was regarded as a charged decay candidate. All candidate decays were checked visually.

An independent visual scan was also carried out on a subsample of ~ 1100 events, searching for V's and for one- and three-prong charged decays. Candidate decays from scanning were compared with the candidates from the measurements, and a definitive sample of good decays was thereby produced. Since the scan was performed independently of the measuring, the efficiency for finding decays by each method could be determined, and the efficiency for a decay appearing in the final sample calculated. This over-all efficiency was investigated as a function of decay angle and position in the chamber, and was found to be typically $\sim 90\%$ for charged decays and $\sim 80\%$ for neutral decays.

The results presented below on K_S and $\Lambda/\bar{\Lambda}$ are based on the full sample of ~ 2100 measured minimum bias events, whilst the results on K_L and $K^\pm$ decays use only the sample of events on which the independent scan was performed.

ANALYSIS OF THE NEUTRAL DECAYS

Although the acceptance of the UA5 detector extends to ± 5 units of pseudo-rapidity ($\eta = -\ln \tan \theta/2$), the probability for strange particles with $|\eta| > 3$ to decay in the chamber becomes small. We have therefore excluded those few decays, and all our results will refer to the range $|\eta| < 3$.

The sample of V's includes decays of K_L , K_S , Λ , and $\bar{\Lambda}$, and photon conversions in the chamber gas. Photon conversions were eliminated by demanding the opening angle of the V be greater than 3° . To separate K_L decays, we used the fact that K_S , Λ , and $\bar{\Lambda}$ all decay into two particles, and that therefore the primary and the two secondaries should be coplanar, whereas an unseen neutral particle is produced in K_L decays, usually yielding a V not coplanar with the primary vertex. As a check on this separation we found that the "photon" and " K_L " V's were distributed uniformly throughout the chamber, as expected, because their decay or conversion lengths are much greater than the dimensions of the chamber, whilst the

K_S and $\Lambda/\bar{\Lambda}$ sample was concentrated near the base of the chamber because their decay lengths are much shorter.

In the absence of momentum measurements on the secondary tracks, each coplanar V could be either K_S or $\Lambda/\bar{\Lambda}$ *). Once one assumes a hypothesis for the masses of the particles, it is a straightforward matter to calculate the momentum of the decaying particle and the decay angle in its rest frame, θ_K^* , from the observed laboratory angles of the parent and secondary tracks**). We can obtain an almost clean unbiased sample of K_S decays in the following way. In a $\Lambda/\bar{\Lambda}$ decay the $p/\bar{p}$ tends to carry off most of the laboratory momentum of the parent, and is therefore likely to be emitted at a smaller angle relative to the parent direction than is the accompanying pion. If such an asymmetric decay were interpreted as a K_S it would yield a large value of $|\cos \theta_K^*|$. Conversely, a K_S decay with $|\cos \theta_K^*|$ near zero would produce a symmetric decay in the laboratory, and such a decay could be interpreted as a $\Lambda/\bar{\Lambda}$ only by giving the $\Lambda/\bar{\Lambda}$ a small laboratory momentum.

We therefore reconstruct each coplanar V with both the K_S and $\Lambda/\bar{\Lambda}$ hypotheses. There are in fact two $\Lambda/\bar{\Lambda}$ solutions, but the one in which the $p/\bar{p}$ is emitted at the wider angle always leads to a very small $\Lambda/\bar{\Lambda}$ momentum corresponding to a negligible probability of reaching the chamber, and so can always be neglected. We can then calculate for each hypothesis the probability P_i that the decaying particle could have survived to the observed point of decay. In fig. 1a, we plot P_{Λ}/P_K versus $|\cos \theta_K^*|$. It is clear that for $|\cos \theta_K^*| < 0.5$ the lifetime probability strongly favours the K_S hypothesis. Figure 1c shows the acceptance-corrected lifetime distribution for K_S with $|\cos \theta_K^*| < 0.5$. This distribution is consistent with an exponential behaviour with the expected slope.

*) We cannot distinguish Λ from $\bar{\Lambda}$ since we cannot measure the sign of charge in our non-magnetic detector. However, we know their production cross-sections must be equal in $p\bar{p}$ interactions from CP invariance. Henceforward we denote either Λ or $\bar{\Lambda}$ by writing $\Lambda/\bar{\Lambda}$.

**) There is no significant difference between the directly computed p , θ_K^* values and the values obtained from a one-constraint (i.e. coplanarity) fit.

We therefore take the 46 V's, which under interpretation as K_S give $|\cos \theta_K^*| < 0.5$, as a clean sample of K_S . The $|\cos \theta_K^*|$ distribution for K_S (fig. 1b) should be uniformly populated, and hence there should be 46 K_S with $|\cos \theta_K^*| > 0.5$, whilst there are 92 V's observed in that region. We can then interpret the remaining 46 V's with $|\cos \theta_K^*| > 0.5$ as $\Lambda/\bar{\Lambda}$.

ANALYSIS OF THE CHARGED DECAYS

The three-prong decays may be unambiguously interpreted as $K\pi_3$ decays. The one-prong decays could be either kaon or pion decays. To separate these, we exploit the fact that $K^\pm$ have a much larger c.m. decay momentum than $\pi^\pm$ and therefore will produce much larger decay angles. By rejecting decays of angle $\leq 15^\circ$ (depending on rapidity) we reject essentially all pion decays whilst removing only a modest and readily calculable fraction of kaon decays. After making the corrections outlined below, the $K^\pm \rightarrow 3$ -prong branching ratio obtained was $6.7 \pm 2.5\%$, in agreement with the accepted value [9], showing that the K/π separation was reasonable.

RESULTS

The numbers of observed decays of each type are given in Table 1a. A Monte Carlo program was used to correct the data for the probability of decay within the chamber volume and the various cuts described above. Further corrections were made for trigger losses, scanning, and measuring losses, and for unseen neutral decay modes using branching ratios from ref. [9]. In fig. 2a we show the p_T distribution for the "clean K_S " sample. The distribution is consistent with an exponential form, e^{-bp_T} , over the range of p_T observed, with $b = 2.8 \pm 0.5 \text{ GeV/c}^{-1}$. Assuming this slope applies to all p_T would imply an average transverse momentum $\langle p_T \rangle = 0.70 \pm 0.12 \text{ GeV/c}$. With this information we can then subtract the K_S contribution (obtained by adding 0.5 to the $|\cos \theta_K^*|$ of those V's with $|\cos \theta_K^*| < 0.5$, and reanalysing them as Λ) from the V's with $|\cos \theta_K^*| > 0.5$ and thus derive the $\Lambda/\bar{\Lambda}$ p_T distribution, shown in fig. 2a. An estimate of $\langle p_T \rangle = 0.67 \pm 0.20 \text{ GeV/c}$ is indicated for $\Lambda/\bar{\Lambda}$ production.

As a check on the analysis procedure, we compare the overall form of the $|\cos \theta_K^*|$ distribution with a Monte Carlo calculation adjusted to give K_S and $\Lambda/\bar{\Lambda}$ in the indicated 2 to 1 ratio, using $\langle p_T \rangle$ values as derived above. As fig. 1b shows, the data are entirely consistent with this interpretation, and, in particular, the Monte Carlo implies that less than 2% of the $\Lambda/\bar{\Lambda}$ would satisfy the "clean K_S " cut.

The average numbers of K_S and $\Lambda/\bar{\Lambda}$ produced per inelastic event (table 1a) may be obtained by integrating the fits, again assuming an exponential distribution at all p_T . Since we cannot measure the momenta of the K_L and $K^\pm$, we assume, in correcting for acceptance, that they have the same distribution in p_T as we observe for K_S . The corrected number of K_L and $K^\pm$ found are given in table 1a.

The cross-sections for K_S and K_L production should be equal, and one would conventionally expect that $(K^+ + K^-) \approx (K_S + K_L)$. Our results are seen to be consistent with these relations. This is a valuable check on the value of $\langle p_T \rangle$ for kaons; increasing $\langle p_T \rangle$ would increase the number of K_S decays seen, since their decay length is short and most of them decay before reaching the streamer chamber, and would reduce the numbers of K_L and $K^\pm$ since their decay lengths are much larger than the size of the chamber. In fact, if we assume equality in charged and neutral kaon production, the observed yields imply a 90% confidence lower limit of 0.58 GeV/c in the "mean p_T " defined by exponential fit.

Our estimate of the average transverse momentum of kaons (as inferred by extrapolating the slope of fig. 2a) is compared with lower energy data [10] in fig. 3a. In making this comparison we have restricted ourselves to experiments covering a similar range of p_T and rapidity. We see from fig. 3a that $\langle p_T \rangle$ rises by only $\sim 10\%$ as $\sqrt{s}$ increases from 4 to 63 GeV, reaching a value of ~ 0.43 GeV/c at $\sqrt{s} = 63$ GeV, with little dependence on the kaon charge. The rather high value of the estimated $\langle p_T \rangle$ of 0.70 ± 0.12 GeV/c seen in the present experiment at $\sqrt{s} = 540$ GeV suggests that we may possibly have crossed an effective threshold for some process giving kaons of a higher average transverse momentum, such as charm.

To pursue the comparison of our K_S results with lower-energy pp and $p\bar{p}$ data, we express the yield in terms of the ratio of neutral kaons (K^0 and $\bar{K}^0$) to charged pions, in the range $|\eta| < 3$. The pion multiplicity was obtained by integrating our published charged-particle data [7] over $|\eta| < 3$ and subtracting our measured $K^\pm$ multiplicity (table 1a)*). The resulting $(K^0, \bar{K}^0)/\pi^\pm$ ratio, $11 \pm 2\%$, is compared with lower energy data [10,11] in fig. 3b. It is clear that the ratio is higher at the SPS Collider than at FNAL energies, but the situation at ISR energies is unclear. Fortunately the UA5 detector is in the unique position of having taken data at both the ISR [12,13] and the SPS Collider. In our ISR set-up the chambers were further away from the beams, and as expected we see almost no K_S decays. We have therefore taken $\langle p_T \rangle$ to equal 0.42 GeV/c [3] in calculating the $K^\pm$ and K_L yields. The K/π ratios obtained in our streamer chamber experiment (table 1b and fig. 3b) imply an increase of at least a factor of two in going from $\sqrt{s} = 53$ to 540 GeV.

The charged and neutral kaon pseudorapidity distributions (fig. 2b) are consistent with each other and flat within errors. The yields of charged and neutral kaons in three regions of observed total charged multiplicity (table 1c) show an increase in kaons per event proportional to the charged multiplicity.

SUMMARY

The following aspects of strange-particle production in $p\bar{p}$ collisions at $\sqrt{s} = 540$ GeV/c have been measured in the pseudorapidity interval -3 to 3, using the UA5 detector.

- i) The multiplicity of neutral kaons (K^0 and $\bar{K}^0$) per inelastic event is 2.0 ± 0.4 . This corresponds to a ratio of neutral kaons to charged pions of $11 \pm 2\%$.
- ii) The production rates of charged and neutral kaons are consistent with being equal.

*) It seems reasonable to ignore central $p/\bar{p}$ production in view of the fairly low $\Lambda/\bar{\Lambda}$ yield (table 1a).

- iii) The transverse momentum distribution of neutral kaons $(1/\sigma)(d\sigma/dp_T^2)$ is proportional to $\exp(-2.8 p_T)$ for p_T between 0.3 and 1.6 GeV/c. This form would imply a mean p_T of 0.70 ± 0.12 GeV/c if extended to all p_T .
- iv) The multiplicity of $\Lambda/\bar{\Lambda}$ is 0.35 ± 0.10 per inelastic event, with an estimated mean p_T of 0.67 ± 0.20 GeV/c.

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Table 1

a) Strange particle yields at $\sqrt{s} = 540$ GeV		
Decay type	Uncorrected No. of decays used	Mean No. per event in $ \eta < 3$
K_S	92	1.0 ± 0.2
K_L	17	1.0 ± 0.3
$K^\pm \rightarrow \begin{array}{l} \nearrow \text{1-prong} \\ \searrow \text{3-prong} \end{array}$	$\begin{array}{l} 123 \\ 7 \end{array}$	$\left. \begin{array}{l} \\ \end{array} \right\} 1.8 \pm 0.2$
$\Lambda/\bar{\Lambda}$	46	0.35 ± 0.10
b) Strange particle yields at $\sqrt{s} = 53$ GeV (refs. 12,13)		
Decay type	No. of decays	Mean No. per event in $ \eta < 3$
K_S	2	0.4 ± 0.4
K_L	9	0.23 ± 0.09
$K^\pm \rightarrow \begin{array}{l} \nearrow \text{1-prong} \\ \searrow \text{3-prong} \end{array}$	$\begin{array}{l} 68 \\ 4 \end{array}$	$\left. \begin{array}{l} \\ \end{array} \right\} 0.42 \pm 0.09$
$\Lambda/\bar{\Lambda}$	3	0.15 ± 0.09
c) Multiplicity dependence of kaon production (in $ \eta < 3$) at $\sqrt{s} = 540$ GeV		
Observed multiplicity (n_{ch}^{obs})	$\frac{\langle n(K_S/K_L) \rangle}{\langle n_{ch}^{obs} \rangle}$	$\frac{\langle n(K^\pm) \rangle}{\langle n_{ch}^{obs} \rangle}$
≤ 20	0.08 ± 0.02	0.07 ± 0.01
21-39	0.08 ± 0.02	0.08 ± 0.01
≥ 40	0.11 ± 0.03	0.07 ± 0.01
all	0.09 ± 0.02	0.08 ± 0.01

Figure captions

- Fig. 1 : a) P_{Λ}/P_K for each coplanar V^0 , where P_i is the probability for the assumed particle to have a lifetime at least as long as that observed, plotted against $|\cos \theta_K^*|$, where θ_K^* is the centre-of-mass decay angle of the V^0 interpreted as a K_S .
b) Distribution of observed coplanar V^0 in $|\cos \theta_K^*|$, the projection of (a) on the horizontal axis. The curve shows the prediction of a Monte Carlo calculation with observed K_S and $\Lambda/\bar{\Lambda}$ in the ratio 2 to 1, normalized to the number of V^0 observed.
c) The proper lifetime distribution of the coplanar V^0 observed with $|\cos \theta_K^*| < 0.5$, corrected for acceptance. The line shows the expected distribution for K_S .
- Fig. 2 : a) Inclusive transverse momentum distributions for K_S production and $\Lambda/\bar{\Lambda}$ production.
b) Inclusive pseudorapidity distributions for charged and neutral kaon production.
- Fig. 3 : a) Dependence on centre-of-mass energy of inclusive kaon mean transverse momentum, estimated from fits to data from typically $0.2 < p_T < 2$ GeV/c. Data, other than UA5, are from ref. 10.
b) Energy dependence of the K/π ratio, estimated from fits as in (a). Data, other than UA5, are from refs. 10 and 11. The UA5 data apply only to the range $|\eta| < 3$.

Fig. 1

Fig. 2

Fig. 3