

# Measurement of the $\bar{p}p \rightarrow K_S K_S \eta$ cross section at beam momenta in the regions of 1.45 and 1.7 GeV/c

P.D. Barnes<sup>a</sup>, B. Bunker<sup>e</sup>, H. Dennert<sup>b</sup>, R.A. Eisenstein<sup>e</sup>,  
W. Eyrich<sup>b</sup>, H. Fischer<sup>c</sup>, G. Franklin<sup>a</sup>, J. Franz<sup>c</sup>, R. Geyer<sup>d</sup>,  
P. Harris<sup>e</sup>, J. Hauffe<sup>b</sup>, D. Hertzog<sup>e</sup>, T. Johansson<sup>f</sup>, T. Jones<sup>e</sup>,  
K. Kilian<sup>d</sup>, W. Oelert<sup>d</sup>, S. Pomp<sup>f,\*</sup>, B. Quinn<sup>a</sup>, K. Röhrich<sup>d</sup>,  
E. Rössle<sup>c</sup>, K. Sachs<sup>d</sup>, H. Schmitt<sup>c</sup>, T. Sefzick<sup>d</sup>, J. Seydoux<sup>a</sup>,  
F. Stinzing<sup>b</sup>, R. Tayloe<sup>e</sup>, R. Todenhagen<sup>c</sup>, E. Traneus<sup>f</sup>,  
S. Wirth<sup>b</sup>

<sup>a</sup> *Carnegie Mellon University, Pittsburgh, PA 15213, USA*

<sup>b</sup> *Universität Erlangen-Nürnberg, 91058 Erlangen, Germany*

<sup>c</sup> *Universität Freiburg, 79104 Freiburg, Germany*

<sup>d</sup> *IKP, Forschungszentrum Jülich, 52428 Jülich, Germany*

<sup>e</sup> *University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA*

<sup>f</sup> *Uppsala University, 75121 Uppsala, Sweden*

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## Abstract

The PS185 experiment at LEAR/CERN has investigated strangeness production in  $\bar{p}p$  collisions with final states such as  $\bar{\Lambda}\Lambda$ ,  $\bar{\Sigma}^0\Lambda+c.c.$ ,  $\bar{\Sigma}^+\Sigma^+$ ,  $\bar{\Sigma}^-\Sigma^-$  and  $K_S K_S$ . Results are presented from a study of about 32,000  $K_S K_S X$  events obtained at several  $\bar{p}$  momenta in the regions of 1.45 and 1.7 GeV/c. The  $\bar{p}p \rightarrow K_S K_S \eta$  cross sections extracted at these momenta constitute the first measurement of this reaction in flight and are broadly consistent with expectations of a phase-space extrapolation of branching ratios from annihilation at rest.

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\* Corresponding author.

*Email address:* pomp@tsl.uu.se (S. Pomp).

## 1 INTRODUCTION

The PS185 experiment at the Low Energy Antiproton Ring, LEAR, at CERN was designed to study strangeness production in  $\bar{p}p$  collisions. Most attention has been drawn to the two-body  $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$  reaction [1]. Several observables, such as total and differential cross sections, polarisations and spin correlations, have been measured over the momentum region from threshold to 2 GeV/c. PS185 has also investigated other two-body final states in the  $\bar{p}p \rightarrow \bar{\Sigma}^0\Lambda + c.c.$  [2],  $\bar{p}p \rightarrow \bar{\Sigma}^+\Sigma^+$  and  $\bar{p}p \rightarrow \bar{\Sigma}^-\Sigma^-$  [3] and  $\bar{p}p \rightarrow K_S K_S$  [4] reactions.

These studies are now extended to many-body final-states with two neutral strange particles. We present in this paper a measurement of the  $\bar{p}p \rightarrow K_S K_S \eta$  cross section from  $\bar{p}p$  annihilation in flight. This constitutes the first cross section measurement of the reaction since the only other available data on this final state is the branching ratio from  $\bar{p}p$  annihilation at rest, obtained in a bubble chamber experiment [5].

A study of the  $\bar{p}p \rightarrow K_S K_S \eta$  reaction is interesting because all three final-state particles contain strangeness and this may provide additional information on strangeness production. In a constituent quark model, the process can be viewed as the annihilation of quark-antiquark pairs with the subsequent creation of strange-antistrange quark pairs. Such models are depicted in Fig. 1a. The process could also proceed via the dissociation of a strangeness component in the (anti-)proton, as shown in Fig. 1b, an idea which has already been applied to the  $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$  reaction [6]. More conventionally, the reaction can be described in a one-baryon-exchange model via charged  $\Sigma$  exchange. The final state can then either be directly produced (Fig. 1c) or proceed via the excitation of a resonance (Fig. 1d). In the latter case one would expect the  $K_3^*(1780)$  resonance to be important in flight since it is the only known  $K^*$  resonance in this mass region with a substantial decay branching ratio into the  $K_S \eta$  channel ( $30 \pm 13$ )% [7]. However, to the best of our knowledge, no theoretical calculation has been made for this reaction.

## 2 EXPERIMENT AND ANALYSIS

In this study, we used data from two PS185 runs. The first involved six beam momentum settings between 1.440 and 1.477 GeV/c, whereas the second was performed at beam momenta of 1.657, 1.662 and 1.774 GeV/c. We will use  $1.455 \pm 0.020$  GeV/c and  $1.715 \pm 0.060$  GeV/c as momenta for the data sets.

The PS185 experimental set-up is shown in Fig. 2. It employs a segmented

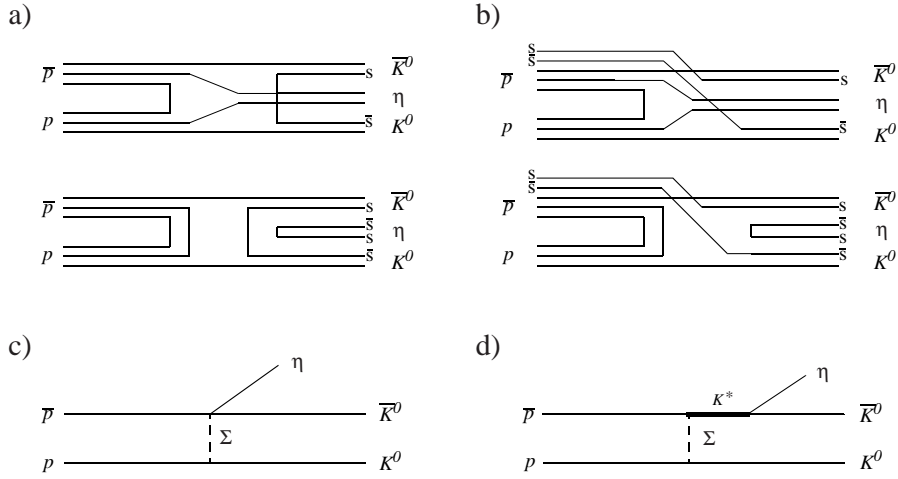


Fig. 1. Examples of diagrams for  $K_S K_S \eta$  production. The upper row shows quark-line diagrams without (a) and with (b) strangeness from the (anti-)proton; the lower row shows diagrams for one-baryon-exchange models (see text).

target consisting of five cylindrical cells each with a length and diameter of 2.5 mm. The first cell is made from pure carbon whereas the others consist of polyethylene ( $\text{CH}_2$ ). The 5 cells are embedded and separated by scintillators which are used as vetoes to allow for triggering on events with neutral final particles. A two-layer scintillator hodoscope detects the charged decay products. The sequence of charged  $\rightarrow$  neutral  $\rightarrow$  charged states forms the signature of the desired events and is the basis for the triggering.

A chamber stack, consisting of multiwire proportional chambers (MWPC) and drift chambers (DC), is located between the target and the hodoscope. A set of three drift chamber planes, contained inside a magnetic field and placed downstream of the hodoscope, allows a charge determination. The backward region is covered by an arrangement of limited streamer tubes.

Charged particle tracks are reconstructed in the chamber stack and combined pairwise to form neutral decay  $V^0$ 's. A kinematical fit is then performed on the  $V^0$ 's assuming that they correspond to  $K_S \rightarrow \pi^+ \pi^-$  decays. It is based on a procedure described in Ref. [8], which has been extended to handle the case where only angles and no momenta are measured (cf. Ref. [9]). Monte Carlo simulations show that the resulting uncertainty in the reconstructed momenta is about 10%.

Both the  $K_S K_S X$  and the  $\Lambda \bar{\Lambda} X$  reaction channels lead to events with two  $V^0$ 's in the final state and it is not possible to separate these channels using the kinematical fit alone since no momenta are measured. However, the information from the energy loss in the hodoscope can be used to differentiate between them. Fig. 3a shows a scatter plot of the energy losses of particles

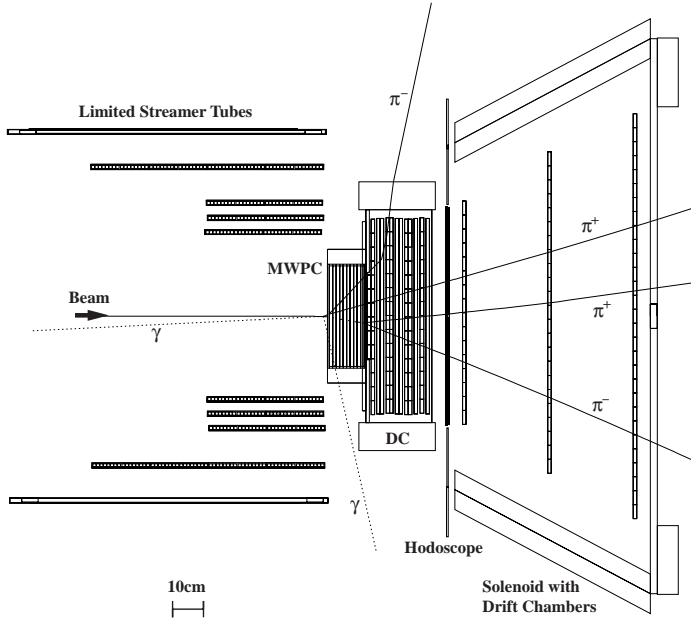


Fig. 2. The PS185 detector with a superimposed  $\bar{p}p \rightarrow K_S K_S \eta$  event from the Monte Carlo simulation. The target is located just in front of the MWPC. The two  $\gamma$ 's originating from the  $\eta$  decay are not detected.

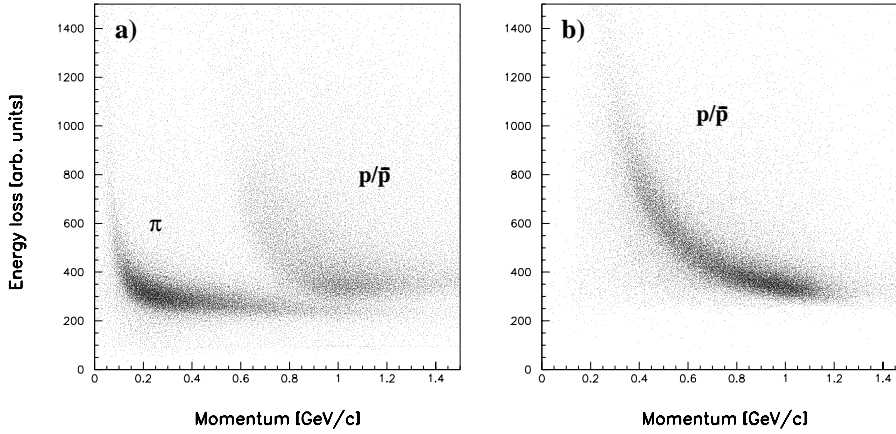


Fig. 3. (a) Energy losses from particle tracks in the hodoscope plotted versus their momenta for assumed  $K_S$  decays. (b) Energy losses of assigned (anti-)proton tracks in the hodoscope plotted versus their momenta for assumed  $\Lambda(\bar{\Lambda})$  decays.

in the hodoscope versus their momenta obtained from the kinematical fit assuming a  $K_S$  decay. Bands belonging to pions and (anti-)protons are clearly visible. The protons originate from  $\Lambda(\bar{\Lambda})$  decays and constitute background events. As a consistency check, these background events are refitted assuming  $\Lambda(\bar{\Lambda})$  decays. The results given in Fig. 3b confirm the (anti-)proton assignment for these events.

We obtained a total sample of 31,732  $K_S K_S X$  events originating from either  $\bar{p}p$  or  $\bar{p}C$  interactions from the two data-sets. Due to the relatively sharp lower edge of the Landau distribution, the contamination in the event sample arising from the hyperon background is estimated to be less than 2%. As a check of the final event sample, we determined the lifetime for the assigned kaons. Based on the measured decay length and the fitted momentum, we derived a value of  $(93 \pm 4)$  ps, which is in good agreement with the PDG value of 89.35 ps [7].

Fig. 4 illustrates the missing mass distributions for the extracted  $\bar{p}A \rightarrow K_S K_S X$  events. They show a broad distribution stretching from 0 to 1.2 and 1.4 GeV/c<sup>2</sup>, respectively, which is due to  $K_S K_S X$  production on <sup>12</sup>C, involving the production of  $K^*$ 's and  $\pi^0$ 's, as well as combinatorial background. In addition, three peaks are visible in the spectra from the CH<sub>2</sub> cells at the masses of the  $\pi^0$ ,  $\eta$  and  $\omega$  mesons (lower row) which are not found in the spectra from the carbon cell (upper row). These peaks are attributed to the  $\bar{p}p \rightarrow K_S K_S \pi^0$ ,  $\bar{p}p \rightarrow K_S K_S \eta$  and  $\bar{p}p \rightarrow K_S K_S \omega$  reactions.

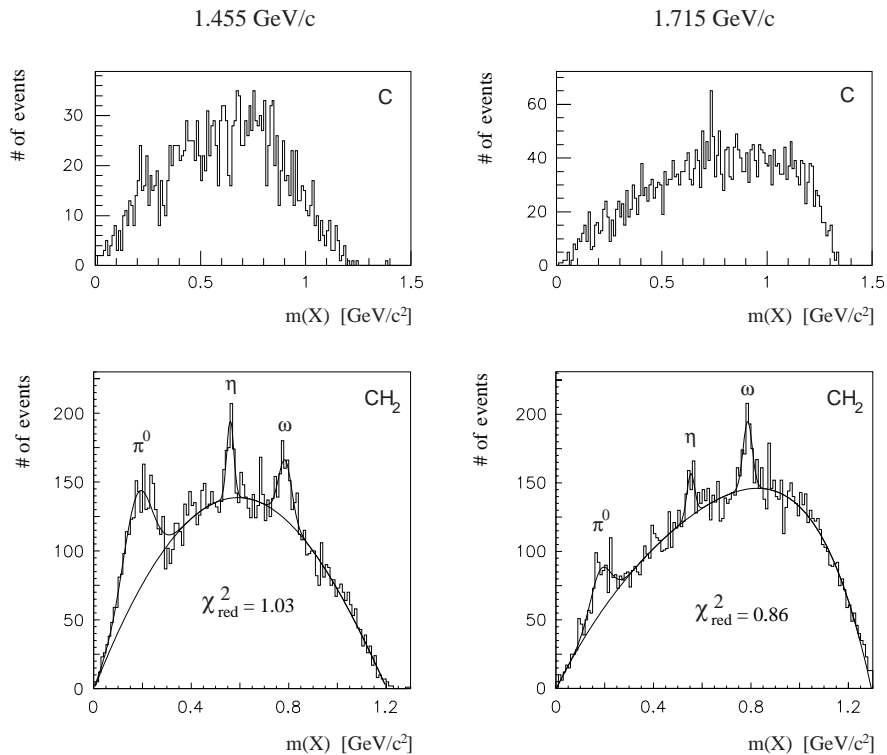


Fig. 4. Missing mass distributions for  $\bar{p}A \rightarrow K_S K_S X$  events for the 1.455 GeV/c (left) and 1.715 GeV/c (right) data-set. The upper row contains events from the carbon cell and the lower row events from the CH<sub>2</sub> cells. Peaks at the masses of the  $\pi^0$ ,  $\eta$  and  $\omega$  mesons are visible in the spectra from the CH<sub>2</sub> cells. The solid lines represent fits assuming a 5th order polynomial and three gaussians.

### 3 RESULTS AND CONCLUSIONS

We have made fits to the missing mass distributions from the CH<sub>2</sub> cells to obtain the number of events with  $\pi^0$ 's,  $\eta$ 's and  $\omega$ 's in the final states arising from  $\bar{p}p$  interactions. These involve a 5th order polynomial for the background and three gaussians; the results for the two data-sets are shown in Fig. 4.

The central values of the  $\eta$  and  $\omega$  peak are found to be  $(560 \pm 14)$  MeV/c<sup>2</sup> and  $(786 \pm 27)$  MeV/c<sup>2</sup> for the 1.455 GeV/c data and  $(553 \pm 17)$  MeV/c<sup>2</sup> and  $(786 \pm 19)$  MeV/c<sup>2</sup> for the 1.715 GeV/c data. The ratios of the number of  $\eta$  to  $\omega$  events are  $0.691 \pm 0.139 \pm 0.069$  (1.455 GeV/c) and  $0.560 \pm 0.160 \pm 0.056$  (1.715 GeV/c), where the first error is statistical and the second systematical. The latter, which is due to the uncertainty in the background subtraction, is estimated to be about 10%. The  $\pi^0$  case requires a slightly different treatment which will be described later.

The detector has the highest efficiency for forward-going (charged) particles. Due to the influence of the  $\eta/\omega$  mass difference on the kinematics, we expect a larger acceptance for  $\bar{p}p \rightarrow K_S K_S \eta$  than for  $\bar{p}p \rightarrow K_S K_S \omega$  events. This difference is less important at higher energies.

The acceptances have been estimated by generating events with phase space distributions and applying cuts representing the geometrical acceptance and reconstruction efficiency. From these considerations we obtain relative efficiencies  $\epsilon(\omega)/\epsilon(\eta) = 0.791 \pm 0.040$  at 1.455 GeV/c and  $0.882 \pm 0.044$  at 1.715 GeV/c. These results are consistent with the expectations mentioned above.

Different sets of cuts were tried and it was found that the relative efficiencies are not very sensitive to the specific set. This is not unexpected since the topologies for the two types of events are very similar provided that the differential distributions of the two reactions are rather alike. We investigated this by looking at the distribution of the c.m. scattering angles. We defined six regions in the missing mass spectrum: one covering each of the  $\eta$  and  $\omega$  peaks and one on either side of them. The c.m. scattering angle distributions for these regions are not significantly different from each other. Furthermore, the experimental momentum and scattering angle distributions and those obtained from Monte Carlo simulations based on phase space distributions are quite similar.

We rely on the known  $\bar{p}p \rightarrow K_S K_S \omega$  cross section to obtain the absolute normalisation of the  $\bar{p}p \rightarrow K_S K_S \eta$  cross section. Data on the  $\bar{p}p \rightarrow K_S K_S \omega$  cross section are found in Refs. [10–15] and summarised in Ref. [16]. It is worth noting that all the data, except those of Ganguli *et al.* [15], have to be corrected for unseen decay modes before the total cross section can be obtained. For this

analysis, we confined ourselves to the data in the  $\bar{p}$  momentum range from 1.0 to 2.2 GeV/c. The cross sections given in Ref. [14] have not been included since they are averages of values already given in Ref. [13]. The remaining 18 data points shown in Fig. 5 have been corrected for the unseen  $\omega$  decay modes using the branching ratio  $\text{BR}(\omega \rightarrow \pi^+\pi^-\pi^0) = 0.89$  [7]. A linear fit is sufficient to describe the data in this region ( $\chi^2_{red} = 0.65$ ). From the fit we obtain  $\sigma(\bar{p}p \rightarrow K_S K_S \omega) = (50.0 \pm 2.5) \mu\text{b}$  at  $p_{\bar{p}} = 1.455$  GeV/c and  $(39.7 \pm 2.0) \mu\text{b}$  at  $p_{\bar{p}} = 1.715$  GeV/c.

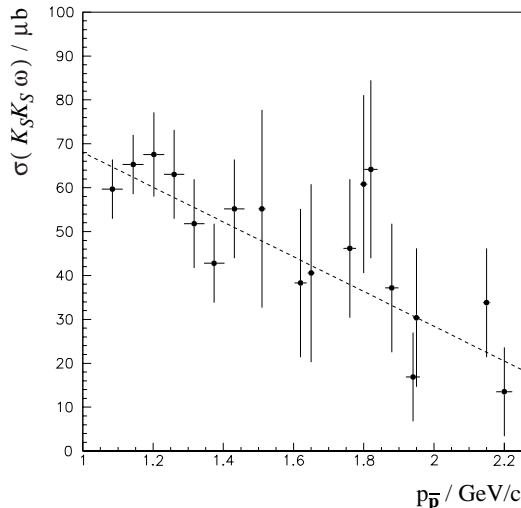


Fig. 5. Linear fit to the cross section data for  $\bar{p}p \rightarrow K_S K_S \omega$  from Refs. [11–13].

The cross section for the  $\bar{p}p \rightarrow K_S K_S \eta$  reaction is finally deduced using the relation

$$\sigma(\bar{p}p \rightarrow K_S K_S \eta) = \frac{\text{number of } \eta \text{ events}}{\text{number of } \omega \text{ events}} \times \frac{\epsilon(\omega)}{\epsilon(\eta)} \times f_{neut} \times \sigma(\bar{p}p \rightarrow K_S K_S \omega), (1)$$

where  $\epsilon(\omega)$  and  $\epsilon(\eta)$  denote the acceptances of the corresponding reactions and  $f_{neut}$  is the relative suppression of  $\omega$  events compared to  $\eta$  events due to the different neutral branching ratios. The branching ratio for neutral decays is  $(9.0 \pm 0.7)\%$  for the  $\omega$  and  $(71.6 \pm 0.4)\%$  for the  $\eta$  [7] leading to  $f_{neut} = 0.126 \pm 0.010$ .

Inserting the numbers quoted above into Eq. 1 leads to cross sections for  $\bar{p}p \rightarrow K_S K_S \eta$  of  $(3.44 \pm 0.69 \pm 0.50) \mu\text{b}$  at  $1.455 \pm 0.020$  GeV/c and  $(2.47 \pm 0.71 \pm 0.36) \mu\text{b}$  at  $1.715 \pm 0.060$  GeV/c, where the first uncertainty is statistical and the second systematical.

Many systematic uncertainties cancel when forming ratios as in Eq. 1. As a cross check of the method, we derived also the  $\bar{p}p \rightarrow K_S K_S \pi^0$  cross section in a similar way. We obtained the number of  $K_S K_S \pi^0$  events from the missing

mass plot. The sample also contains some  $\bar{p}p \rightarrow K_S K_S$  events lying under the  $\pi^0$  peak. The cross section for this reaction is small, about  $2 \mu\text{b}$  [4,16], and this, together with the lower acceptance, allows us to neglect its contribution within the precision of the present experiment.

The ratios of the number of  $\pi^0$  to  $\omega$  events are  $6.23 \pm 0.86 \pm 0.62$  (1.455 GeV/c) and  $3.85 \pm 0.61 \pm 0.38$  (1.715 GeV/c). The relative efficiency for measuring the  $\bar{p}p \rightarrow K_S K_S \omega$  and  $\bar{p}p \rightarrow K_S K_S \pi^0$  reactions becomes  $0.80 \pm 0.04$  and  $0.93 \pm 0.05$  at the two momenta and  $f_{neut} = 0.091 \pm 0.007$ . With these values, we find  $(22.7 \pm 3.1 \pm 3.3) \mu\text{b}$  at  $1.455 \pm 0.020$  GeV/c and  $(12.9 \pm 2.0 \pm 1.9) \mu\text{b}$  at  $1.715 \pm 0.060$  GeV/c for the  $\bar{p}p \rightarrow K_S K_S \pi^0$  cross section. The good agreement between these results and the published data [16] shown in Fig. 6 gives us further confidence in the analysis.

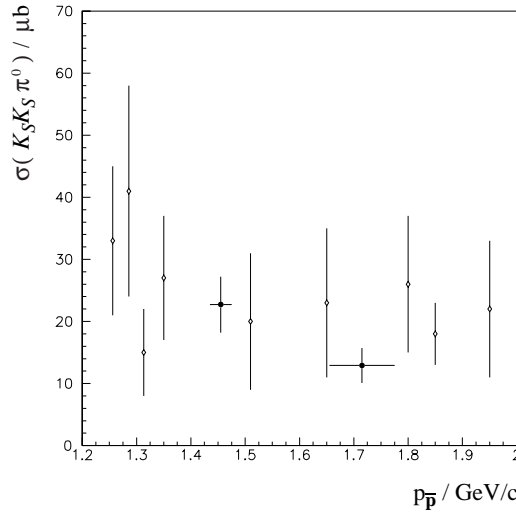


Fig. 6. Comparison of our results for the  $\bar{p}p \rightarrow K_S K_S \pi^0$  cross section (solid points) with values given in Ref. [16]. For the latter values, the uncertainties in the momenta are not shown.

The only published data on  $\bar{p}p \rightarrow K_S K_S \eta$  is the branching ratio for annihilation at rest,  $\text{BR}(\bar{p}p \rightarrow K_S K_S \eta) = (0.25 \pm 0.04) \times 10^{-3}$  [5]. The corresponding value for the  $K_S K_S \omega$  annihilation channel is  $\text{BR}(\bar{p}p \rightarrow K_S K_S \omega) = (1.16 \pm 0.06) \times 10^{-3}$  [5,17]. In order to compare these data with the results of our measurement, we extrapolated the ratio of the  $K_S K_S \eta$  and  $K_S K_S \omega$  cross sections from the threshold value to the momentum range between 1.2 and 2.0 GeV/c. To do this, we retained only phase space factors, assuming that the ratio of the matrix elements for both transitions is constant. Such considerations predict cross section ratios of  $0.043 \pm 0.007$  at 1.455 GeV/c and  $0.039 \pm 0.006$  at 1.715 GeV/c. Our data points lie within one standard deviation above this estimate.

In conclusion, we have made the first measurement of the cross section for



the  $\bar{p}p \rightarrow K_S K_S \eta$  reaction in flight in two regions of  $\bar{p}$  momenta, around 1.455 and 1.715 GeV/c. The magnitude of the cross section is in reasonable agreement with an extrapolation from the known  $\bar{p}p \rightarrow K_S K_S \eta$  and  $\bar{p}p \rightarrow K_S K_S \omega$  branching ratios at rest using phase space arguments.

We hope that these results will stimulate further theoretical efforts to shed light on the process of strangeness production.

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