

 $\bar{p}p$ ANNIHILATION INTO NEUTRAL KAONS

ASTERIX Collaboration

CERN¹-Mainz²-München³-Orsay (LAL)⁴-
TRIUMF-Vancouver-Victoria⁵-Wien⁶-Zürich⁷

S. Ahmad⁴, C. Amsler⁷, R. Armenteros¹, E.G. Auld⁵, D. Axen⁵, D. Bailey¹,
S. Barlag¹, G. Beer⁵, J.C. Bizot⁴, M. Botlo⁶, M. Comyn⁵, W. Dahme³,
B. Delcourt⁴, M. Doser⁷, K.D. Duch², K. Erdmann⁵, F. Feld-Dahme³,
U. Gastaldi¹, M. Heel², B. Howard⁵, R. Howard⁵, J. Jeanjean⁴,
H. Kalinowsky², F. Kayser², E. Klempt², C. Laa⁶, R. Landua¹,
G. Marshall⁵, H. Nguyen⁴, N. Prevot⁴, J. Riedlberger⁷, L. Robertson⁵,
C. Sabev, U. Schaefer³, O. Schreiber², U. Straumann², P. Truöl⁷,
H. Vonach⁶, B.L. White⁵, W.R. Wodrich³, M. Ziegler².

Presented by C. Amsler

Abstract

We have observed $\bar{p}p$ annihilation at rest into $K_S K_S$ using a hydrogen gas target at normal temperature and pressure. This channel is forbidden from atomic $\bar{p}p$ S states. A preliminary analysis gives a branching ratio of $(2.2 \pm 0.5 \pm 0.5) \times 10^{-5}$. We have also observed the channel $K_S X$ where X is a K_S or K_L escaping detection in our apparatus. The $K_S K_L$ mode is allowed from atomic S but forbidden from atomic P orbitals. Using the known branching ratio of $(7.8 \pm 0.4) \times 10^{-4}$ for $\bar{p}p \rightarrow K_S K_L$ and our preliminary figure of $(3.8 \pm 0.4 \pm 0.8) \times 10^{-4}$ for $K_S X$ we deduce that the fraction of S state annihilation in hydrogen gas at NTP is $(46 \pm 10) \%$. This in turn yields an absolute branching ratio of $(4.1 \pm 0.9 \pm 1.0) \times 10^{-5}$ for $\bar{p}p \rightarrow K_S K_S$ from P orbitals, showing that the $(K_S K_S + K_L K_L)$ mode is suppressed by an order of magnitude compared to the $K_S K_L$ mode.

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Introduction

Antiproton-proton annihilation at rest into $K_S K_S$ has not been observed in liquid hydrogen. Only four candidate events have been reported [1]. On the other hand annihilation at rest into $K_S K_L$ occurs at a rate of $(0.78 \pm 0.04) \times 10^{-3}$ in liquid hydrogen [2]. Parity and charge conjugation conservations forbid the $K_S K_S + K_L K_L$ mode from $\bar{p}p$ atomic S states, but allows the $K_S K_L$ mode from the 3S_1 state. The situation is reversed for $\bar{p}p$ annihilation from atomic P states: $K_S K_S + K_L K_L$ is allowed from the 3P_2 and 3P_0 orbitals while $K_S K_L$ is strictly forbidden.

The non-observation of $K_S K_S$ was used to derive a 95 % confidence level upper limit of 6 % for P wave annihilation in liquid hydrogen [3]. The high collision rate in liquid, inducing Stark mixing (Day-Snow-Sucher mechanism [4]), populates the high S orbitals of the antiprotonic atom from which the $\bar{p}p$ system annihilates (large overlap of the wave functions due to the absence of angular momentum barrier). In gaseous hydrogen, on the other hand, the reduced collision rate enables a substantial fraction of annihilation from atomic P levels. Our recent data [5] show indeed that a large fraction of $\bar{p}p$ annihilation in gaseous hydrogen at normal temperature and pressure proceeds through P state annihilation. We have searched for the channels $K_S K_S$ and $K_S K_L$ in gaseous hydrogen to establish the relative contribution of S and P wave in gas and the absolute branching ratio for $\bar{p}p \rightarrow K_S K_S$ for P wave annihilation.

$\bar{p}p \rightarrow K_S K_S$

Antiprotons from LEAR enter a solenoidal magnetic detector (0.8T). After passing through a moderator they stop in a 76 cm long, 16 cm diameter hydrogen target (NTP). Stopping \bar{p} are defined by a scintillation counter telescope followed by a veto counter. Typically 10^4 \bar{p} /s enter the telescope. An argon/ethane drift chamber surrounds the hydrogen target. The momenta of the outgoing particles are measured by the drift chamber and seven cylindrical multi-wire proportional chambers with anode (ϕ) and cathode (z) readout. The solid angle acceptance is 2π . The vertex from which a pair of tracks emerge is determined by computing the distance of closest approach. A more detailed description of the apparatus can be found elsewhere [6].

A total of 1.5×10^6 annihilations into 4 prongs were examined. Events were required to have two pairs of tracks each consistent with the invariant mass condition

$$445 < m(\pi^+ \pi^-) < 545 \text{ MeV}$$

assuming pions in the final state. The total measured momentum was required to be less than 200 MeV/c. The events were then submitted to a 4C kinematics fit to $\bar{p}p \rightarrow 2\pi^+ 2\pi^-$. The 2π invariant mass of the fitted 1730 events is shown in fig.1a. The corresponding scatterplot $m(\pi^+_1 \pi^-_2)$ versus $m(\pi^+_3 \pi^-_4)$ is shown in fig.1b. No obvious enhancement is observed at the K^0 mass (497 MeV). Fig.1c shows the distribution of the distance between the two vertices. For $\bar{p}p \rightarrow K_S K_S$ this distance d is expected to follow the probability distribution

$$f(d) = (d/\Lambda^2)\exp(-d/\Lambda)$$

where Λ is the K_S mean free path (4.3 cm). The average distance is 2Λ . Fig.2 shows the 2π invariant mass distribution for events with a vertex separation of at least 3 cm. A clear $K_S K_S$ signal of 22 events is observed in the mass range 488 to 508 MeV. The background contribution is estimated from side bins to be less than 2 events. The mass resolution is 8 MeV.

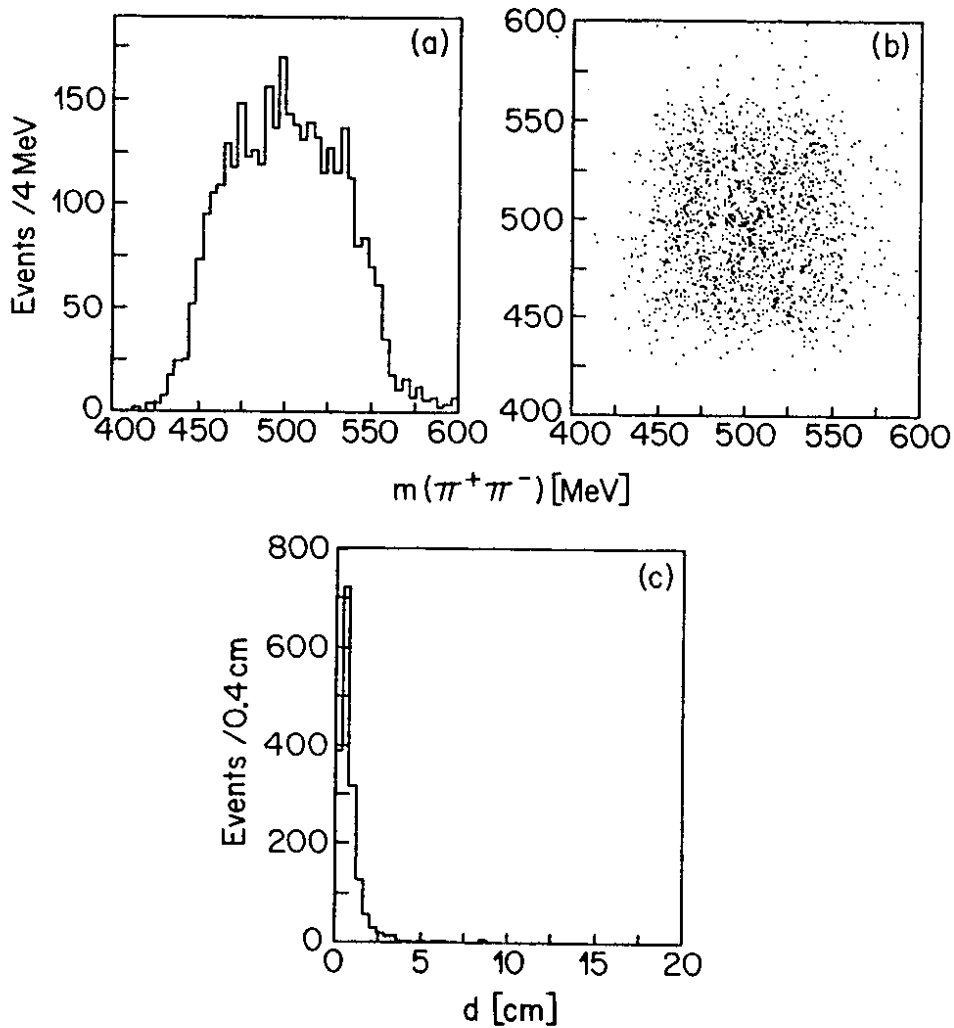


Figure 1a: 2π invariant mass (2 combinations per event).
 b: $m(\pi^+_1\pi^-_2)$ versus $m(\pi^+_3\pi^-_4)$.
 c: Distribution of vertex separation.

The angular distribution of the π^+ in the K_S rest frame, shown in fig. 3, is consistent with isotropy ($\chi^2 = 7.5$ for 9 degrees of freedom). A maximum likelihood fit to the vertex separation ($d > 3$ cm) yields a mean K_S lifetime of $(0.85 \pm 0.12) \times 10^{-10}$ s in agreement with the table value $(0.892 \pm 0.002) \times 10^{-10}$ s.

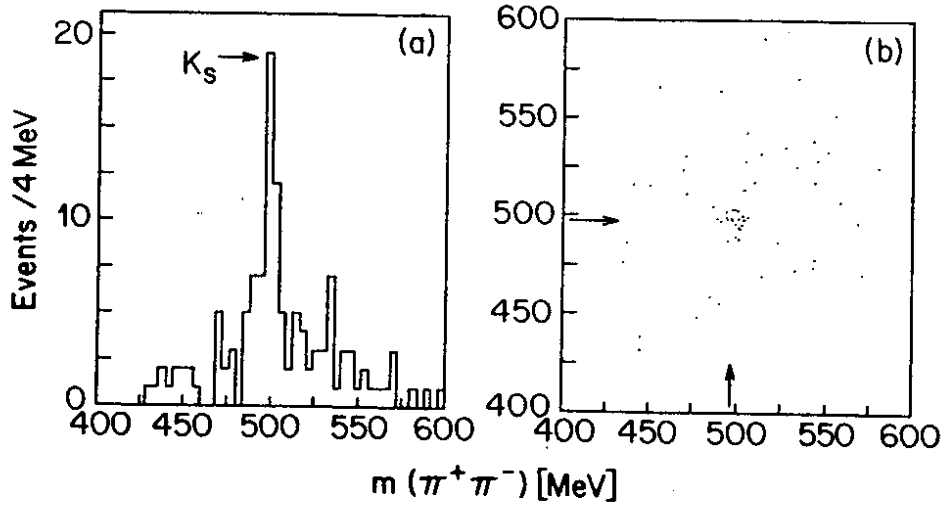


Figure 2a: 2π invariant mass for events with vertices separated by more than 3 cm.
 b: $m(\pi^+_1\pi^-_2)$ versus $m(\pi^+_3\pi^-_4)$.

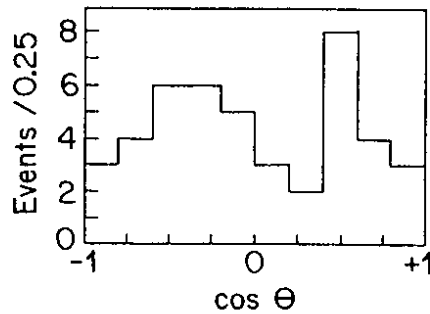


Figure 3: $\cos\Theta$ distribution of the π^+ in the c.m.s. frame of the $\pi^+\pi^-$ pair.

We conclude therefore that we have observed the annihilation channel $\bar{p}p \rightarrow K_S K_S$. Fig. 4 shows a typical $K_S K_S$ event in the ASTERIX detector.

The branching ratio was calculated by Monte Carlo simulation of the detector acceptance and the \bar{p} stop distribution in the target. We assumed that the branching ratio for annihilation into four prongs + missing mass is 48 %, in accordance with bubble chamber experiments [2]. Our data show indeed that the charged multiplicity distribution is not significantly different in gaseous hydrogen. Correcting for the unseen $K_S \rightarrow \pi^0\pi^0$ decay mode ($K_S \rightarrow \pi^0\pi^0 / K_S \rightarrow \pi^+\pi^- = 1/2$), we arrive at a branching ratio of $(2.2 \pm 0.5) \times 10^{-5}$. The systematical normalization uncertainty is estimated to be 25 %.

$$\bar{p}p \rightarrow K_S K_L$$

Since K_L escape detection in our apparatus, we have searched for this channel in $\bar{p}p \rightarrow \pi^+\pi^- + \text{missing mass (MM)}$. Fig. 5 shows the missing mass recoiling against $\pi^+\pi^-$ from a sample of 1.6×10^5 annihilations into two prongs.

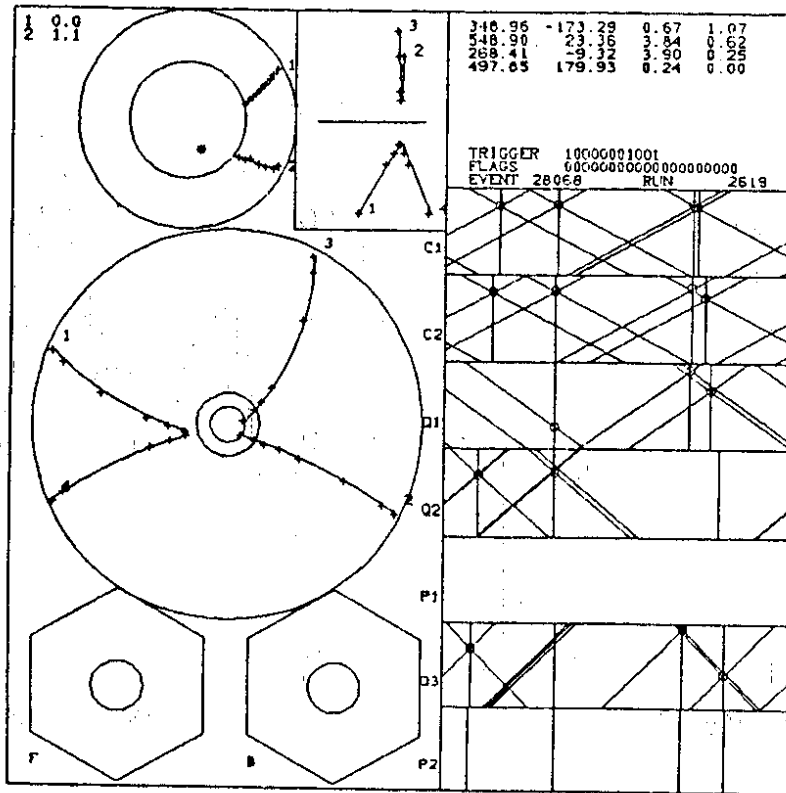


Figure 4: A typical $K_S K_S$ event in the ASTERIX detector. The pattern on the right shows the MWPC wire hits.

For optimum resolution both pions were required to reach the outermost wire chamber. Signals from $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\eta$ and $\pi^+\pi^-\rho^0$ (or ω) are clearly visible above the background from $\bar{p}p \rightarrow \pi^+\pi^-MM$ with more than one neutral pion. Events with a detected $K_S \rightarrow \pi^+\pi^-$ and a missing K^0 have been looked for within the missing mass window $0.125 < MM^2 < 0.375 \text{ GeV}^2$. The upper boundary coincides with the $K_S K^0 \pi^0$ threshold. In addition the total $\pi^+\pi^-$ momentum was required to be more than 650 MeV/c. Fig. 6 shows the corresponding $\pi^+\pi^-$ invariant mass. A clear signal of 80 events appears at the K^0 mass. The events in the peak correspond to $\bar{p}p \rightarrow K_S X$ where X is a K_S or a K_L that has escaped detection.

The branching ratio for $K_S X$ was again estimated by Monte Carlo simulation assuming a branching ratio of 42% [2] for $\bar{p}p$ annihilation into two prongs and correcting for the unseen $\bar{p}p \rightarrow K_S X$ ($K_S \rightarrow \pi^0 \pi^0$). We find $(3.8 \pm 0.4) \times 10^{-4}$ with a systematical normalization uncertainty of 20%.

P / S Ratio

The fraction R of S wave annihilation in gas can now be derived:

$$R = [\Gamma_1(K_S X) - \Gamma_1(K_S K_S)] / \Gamma_2(K_S K_L)$$

where $\Gamma_1(K_S X) = 3.8 \times 10^{-4}$, $\Gamma_1(K_S K_S) = 2.2 \times 10^{-5}$ and Γ_2 is the $K_S K_L$ branching ratio in liquid hydrogen (7.8×10^{-4}). We assume that annihilation in liquid is dominantly ($\approx 100\%$) S state. The relative contribution of annihilation from S orbitals in gaseous hydrogen (NTP) is therefore $R = (46 \pm 10)\%$.

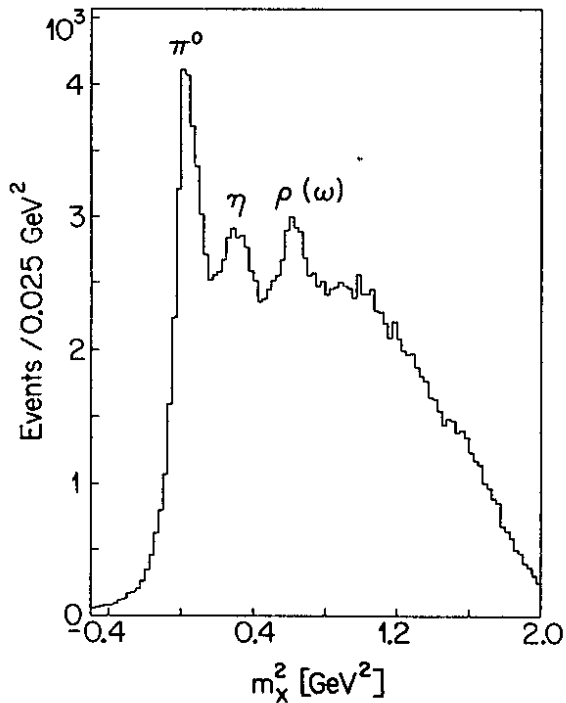


Figure 5: Missing mass² recoiling against $\pi^+\pi^-$.

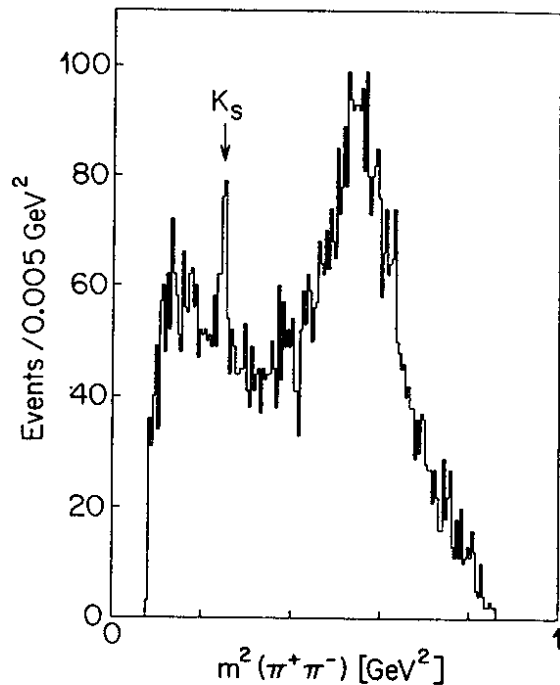


Figure 6 : Invariant $m^2(\pi^+\pi^-)$ for events with a missing mass² in the range 0.125 to 0.375 GeV² and a total $\pi^+\pi^-$ momentum larger than 650 MeV/c.

Our earlier data showed significantly less S wave annihilation in gas [5]. We wish to emphasize at this point that - as explained in [5] - these data were taken with an on-line trigger on X-ray transitions to the 2p state of protonium (L X-rays) thus enhancing P state annihilation.

The absolute branching ratio for $pp \rightarrow K_S K_S$ for $\bar{p}p$ annihilation from atomic P states can now be derived. Since this channel is forbidden from S orbitals, we find a preliminary branching ratio of $(4.1 \pm 0.9) \times 10^{-5}$ with a 25 % normalization uncertainty. Under the assumption of equal contributions from $K_S K_S$ and $K_L K_L$, this result shows that the $C = +1$ ($K_S K_S + K_L K_L$) mode is suppressed by an order of magnitude compared to the $C = -1$ $K_S K_L$ mode.

References

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