P- versus S-wave $\bar{p}p$ -annihilation at rest in LH_2

C. Amsler¹³, I. Augustin⁷, C.A. Baker⁴, B.M. Barnett¹⁰, C.J. Batty⁴, K. Beuchert²,
P. Birien¹, J. Bistirlich¹, P. Blüm⁷, R. Bossingham¹, H. Bossy¹, K. Braune¹¹, J. Brose¹⁰,
D.V. Bugg⁸, M. Burchell⁵, T. Case¹, A. Cooper⁸, K.M. Crowe¹, H.P. Dietz¹¹,
S. v. Dombrowski¹³, M. Doser⁵, W. Dünnweber¹¹, D. Engelhardt⁷, M. Englert¹¹,
M.A. Faessler¹¹, C. Felix¹¹, G. Folger¹¹, R. Hackmann¹⁰, R.P. Haddock⁹, F.H. Heinsius⁶,
N.P. Hessey⁵, P. Hidas³, P. Illinger¹¹, D. Jamnik^{11,a}, H. Kalinowsky¹⁰, B. Kämmele⁶,
T. Kiel⁶, J. Kisiel¹¹, E. Klempt¹⁰, M. Kobel⁵, H. Koch², C. Kolo¹¹, K. Königsmann¹¹,
M. Kunze², R. Landua⁵, J. Lüdemann², H. Matthae², M. Merkel^{10,b}, J.P. Merlo¹⁰,
C.A. Meyer¹³, U. Meyer-Berkhout¹¹, L. Montanet⁵, A. Noble¹³, K. Peters², G. Pinter³,
S. Ravndal², A.H. Sanjari⁸, E. Schäfer¹⁰, B. Schmid¹³, P. Schmidt⁶, S. Spanier¹⁰,
C. Straßburger¹⁰, U. Strohmusch⁶, M. Suffert¹², D. Urner¹³, C. Völcker¹¹, F. Walter¹⁰,
D. Walther², U. Wiedner⁶, N. Winter⁷, J. Zoll⁵, Č. Zupančič¹¹

*The Crystal Barrel Collaboration***Abstract**

The annihilation $\bar{p}p \rightarrow \pi^0\pi^0$ was measured for antiprotons stopped in liquid hydrogen (LH_2). This reaction is only allowed from odd angular momentum states of the $\bar{p}p$ -atom. The resulting branching ratio $\text{BR}(\bar{p}p \rightarrow \pi^0\pi^0)_{\text{LH}_2} = (6.93 \pm 0.22_{\text{stat}} \pm 0.37_{\text{syst}}) \times 10^{-4}$, combined with a previous measurement of the branching ratio $\text{BR}(\bar{p}p \rightarrow \pi^+\pi^-)_{2\text{P}}$ in gas from the 2P-state of $\bar{p}p$ suggests a fraction of P-wave annihilation in LH_2 of $(28.8 \pm 3.5)\%$, much larger than the values obtained from other annihilation channels. A method of reconciling the contradictory results is discussed.

Submitted to Physics Letters B

-
- 1) University of California, LBL, Berkeley, CA 94720, USA
 - 2) Universität Bochum, D-4630 Bochum, Germany
 - 3) Academy of Science, H-1525 Budapest, Hungary
 - 4) Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, UK
 - 5) CERN, CH-1211 Genève, Switzerland
 - 6) Universität Hamburg, D-2000 Hamburg, Germany
 - 7) Universität Karlsruhe, D-7500 Karlsruhe, Germany
 - 8) Queen Mary and Westfield College, London E1 4NS, UK
 - 9) University of California, Los Angeles, CA 90024, USA
 - 10) Universität Mainz, D-6500 Mainz, Germany
 - 11) Universität München, D-8000 München, Germany
 - 12) Centre de Recherches Nucléaires, F-67037 Strasbourg, France
 - 13) Universität Zürich, CH-8001 Zürich, Switzerland
 - a) On leave of absence from the University of Ljubljana, Ljubljana, Slovenia
 - b) This work comprises part of the PhD thesis of M. Merkel

The fraction of antiproton-proton annihilations at rest from states with odd angular momenta has been a point of controversy since the first observation of the annihilation process

$$\bar{p}p \rightarrow \pi^0\pi^0 \quad (1)$$

for antiprotons stopping in liquid hydrogen (LH₂) [1]. Antiproton-proton annihilation into two neutral pseudoscalar mesons is forbidden from states with even orbital angular momentum because of parity and C-parity conservation in strong interactions. The presence of the annihilation mode (1) therefore signals contributions from odd angular momenta (i.e. from P-states of the $\bar{p}p$ -atom). For reaction (1) a branching ratio of $(4.8 \pm 1.0) \times 10^{-4}$ was observed in reference [1], and from the frequency of $\bar{p}p \rightarrow \pi^+\pi^-$ which is allowed from both even and odd angular momentum states, it was concluded that in LH₂ $(39 \pm 8)\%$ of annihilations into $\pi^+\pi^-$ proceed via P-states. This indicated that at least for some specific channels the usual assumption was wrong that S-wave capture predominates in $\bar{p}p$ annihilations at rest [2, 3]. Antiprotons are captured by protons in highly excited orbits. In collisions with neighbouring H₂ molecules they experience intense electric fields which lead to Stark mixing of states with different angular momenta. Hence S-wave annihilation may (and will) occur already from high- n states. The S-wave dominance hypothesis was supported by the small rate of $\bar{p}p \rightarrow K_S^0 K_S^0$ (allowed from P- and not from S-states) compared to $K_S^0 K_L^0$ (allowed from S- and not from P-states), and by the ρ decay angular distribution in the $\pi^+\pi^-\pi^0$ final state [4] which indicated an upper limit of 5% for the P-wave contribution [5] to that final state. Later experiments observed reaction (1) with a much smaller rate [6, 7, 8] giving reduced P-wave contributions to the $\pi^+\pi^-$ channel, in better agreement with the general prejudice. Recently the frequency of $\bar{p}p$ annihilations into $\pi^+\pi^-$ from P-states was measured directly [9]. A comparison with the frequency of $\bar{p}p$ annihilations into $\pi^0\pi^0$ in LH₂ permitted a determination of the probability f_P that the stopped antiproton annihilates in LH₂ from a protonium P-state into any final state. With the average $\pi^0\pi^0$ branching ratio from the different experiments [1,6-8] an f_P of $(8.5 \pm 1.5)\%$ was obtained [10], in good agreement with cascade calculations [11].

In this letter we report on a new precision measurement of reaction (1) using the Crystal Barrel detector at the Low Energy Antiproton Ring (LEAR) at CERN, and discuss the implications for the fraction of P-wave annihilations.

The distinctive component of the Crystal Barrel detector is a calorimeter consisting of 1380 CsI crystals all pointing at the LH₂ target in the centre of the detector. The liquid hydrogen target is surrounded by two Multi-Wire Proportional Chambers (MWPC) and a Jet Drift Chamber (JDC). The assembly of LH₂ target, MWPC's, JDC and CsI crystals is surrounded by a solenoidal magnet providing a field of 1.5 Tesla. Beam antiprotons are detected by a segmented silicon diode. A detailed description of the detector can be found elsewhere [12].

The 4.0×10^6 events used for this analysis [13] were taken with an *open-trigger* asking for an antiproton to enter the target. From the data we cut empty events, pile-up events in which a second antiproton entered the target within $\pm 10\mu\text{s}$, and events in which one particular crystal showed a rather high noise level. This reduces the number of useful events by 9.9%.

Events with tracks from charged particles were used to determine the vertex distribution. We found that $(3.9 \pm 0.7)\%$ of all annihilations did not originate from the target. These arise predominantly from annihilations in the entrance beam counters and their casing.