CERN/EP 84-167
11 December 1984

SEARCH FOR MONOCHROMATIC PION EMISSION IN $\bar{p}p$ ANNIHILATION
FROM ATOMIC p STATES

ASTERIX Collaboration

S. Ahmad^{1(*)}, C. Amsler², R. Armenteros³, E. Auld⁴, D. Axen⁴, D. Bailey³,
S. Barlag³, G. Beer⁵, J.C. Bizot¹, M. Caria^{2(**)}, M. Comyn⁶, W. Dahme⁷,
B. Delcourt¹, M. Doser², K.D. Duch⁸, K. Erdman⁴, F. Feld¹,
U. Gastaldi^{8(***)}, M. Heel⁸, B. Howard⁴, R. Howard⁴, J. Jeanjean¹,
H. Kalinowsky⁸, F. Kayser⁸, E. Klempt⁸, R. Landua³, G. Marshall⁵,
H. Nguyen¹, N. Prevot¹, L. Robertson⁵, C. Sabev⁽⁺⁾, U. Schaefer⁷,
R. Schneider⁸, O. Schreiber⁸, U. Straumann²⁽⁺⁺⁾, P. Truöl²,
B. White⁴, W. Wodrich⁷ and M. Ziegler⁸

- 1 Laboratoire de l'Accélérateur Linéaire, Orsay, France
- 2 Universität Zürich, Zürich, Switzerland
- 3 CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 4 University of British Columbia, Vancouver, Canada
- 5 University of Victoria, Victoria, Canada
- 6 TRIUMF, Vancouver, Canada
- 7 Universität München, München, Germany (FRG)
- 8 Universität Mainz, Mainz, Germany (FRG)

Submitted to Physics Letters B

-
- (*) Now at TRIUMF, Vancouver, Canada.
(**) Now at University of Cagliari, Italy.
(***) Now at CERN, Geneva, Switzerland.
(+) CERN Visitor.
(++) Now at Universität Mainz, Mainz, Germany (FRG).

ABSTRACT

Narrow states observable through the emission of monoenergetic charged pions have been searched for in $\bar{p}p$ annihilation at rest in a gaseous hydrogen target where annihilation from atomic angular momentum $L = 1$ states dominates. No structure is observed. The 5σ upper limit for the production of narrow states in the mass range 1100 to 1670 MeV is 2×10^{-3} of all annihilations.

In this letter we report the results of a study of the inclusive charged pion momentum spectrum observed in $\bar{p}p$ annihilation at rest in a hydrogen gas target. The main aim of the experiment is a high statistics investigation of classical ($q\bar{q}$) mesons and a search for exotic resonances like glueballs, hybrids and baryonia in exclusive annihilation channels [1]. We have nevertheless undertaken first a study of the inclusive charged pion spectrum to establish as early as possible the frequencies with which quasi-two-body phenomena of the general type $\bar{p}p \rightarrow \pi^\pm + \text{narrow resonance}$ occur.

Directly connected with the study of the charged pion momentum spectrum is the question of the possible existence of $\bar{N}N$ bound states. Potential models for the $\bar{N}N$ interaction predict many states with masses between 1000 and 2500 MeV and widths between 1 and 100 MeV [2]. Exotic states of 4 quarks ($qq\bar{q}\bar{q}$) have also been predicted by quark models [3]. States below $\bar{N}N$ threshold can be produced in $\bar{p}$ deuterium annihilation at rest with the emission of a monoenergetic neutron or proton. The experimental upper limit for the production of narrow states associated with monochromatic neutrons is 3×10^{-3} [4]. Quasinuclear $\bar{p}p$ states could also be produced by monochromatic γ , π^0 or $\pi^\pm$ transitions from the anti-protonic atom with (very model dependent) predicted branching ratios of 10^{-2} to 10^{-3} [5]. Candidates for $\bar{p}p$ bound states at 1684, 1646 and 1345 MeV with yields of 3×10^{-3} and widths < 20 MeV have been observed in radiative transitions from the $\bar{p}p$ atom [6].

Previous experiments - mostly bubble chamber experiments - have used liquid hydrogen. Due to Stark mixing the electromagnetic cascade is highly suppressed: the $\bar{p}p$ system annihilates from a high atomic level with relative angular momentum $L = 0$. On the other hand we have shown [7] that $\bar{p}p$ annihilation in hydrogen gas at NTP is dominated by annihilation from $L = 1$ atomic orbitals. The dominance of p state annihilation was deduced from an analysis of the angular distribution of the pion in the rest frame of the ρ in the reaction $\bar{p}p \rightarrow \rho\pi$ ($\rho \rightarrow \pi\pi$). As indicated by the strong production of f in $\bar{p}p \rightarrow f\pi^0$ ($f \rightarrow \pi^+\pi^-$) in hydrogen gas [7], conservation laws will yield different branching ratios for the production of resonances and may enhance higher spin states. In particular, $\bar{p}p$ bound states with higher angular momentum are more likely to be narrow and should therefore be more easily observable. This is due to the centrifugal barrier which

reduces the overlap of the p and $\bar{p}$ wave functions and hence inhibits annihilation. So far no data exist for $\bar{p}p$ annihilation from p states.

The apparatus is shown in fig. 1. Antiprotons from LEAR enter a solenoidal magnetic detector (0.8 T) with a momentum of 308 MeV/c. After passing through a moderator they stop in a 76 cm long 16 cm diameter gaseous hydrogen target (NTP). Stopping antiprotons are defined by a scintillation counter telescope followed by a veto counter. Typically 10^4 $\bar{p}$ /s enter the telescope. The fraction of stopping antiprotons in hydrogen is typically 10% at 308 MeV/c. An argon/ethane cylindrical drift chamber (XDC) surrounds the hydrogen target. The separation is provided by a thin 6 μ aluminized mylar membrane at high voltage transparent to X-rays with energies larger than 1 keV. X-rays are converted in the drift chamber and their energies measured by pulse height analysis on 90 signal wires at ground voltage running parallel to the beam axis at a radius of 15 cm. The pulse height on every wire is sampled every 32 ns by flash ADC's. The drifttime determines the conversion point. The coordinate along the wire is determined by charge division of signals from both ends of the wires. Charged annihilation products usually fire several wires and can be distinguished from X-rays by their characteristic long pulse shape while X-ray conversions are well localized in space. The data presented here were taken with a trigger that enhances annihilation events with associated atomic transition to the 2p state of protonium (L X-rays).

The momentum of the charged outgoing particles is measured by seven cylindrical multiwire proportional chambers (C1, C2, Q1, Q2, P1, Q3, P2) with a wire pitch of 2 mm. The anode signal wires run parallel to the beam. The inner and outer cathode surfaces are made of helicoidal wires providing the longitudinal coordinates of the hits with an accuracy of ± 2 mm. Two chambers (P1, P2) have no cathodic readout. The solid angle subtended by P2 is 2π .

The momentum resolution of the spectrometer for long tracks (i.e. those reaching Q3 with an average length of 80 cm) is $\Delta p/p[\text{FWHM}] = 0.13 p[\text{GeV}/c] + 0.005/p[\text{GeV}/c]$. The resolution was calculated by Monte-Carlo simulation and checked experimentally by three different methods:

- (a) With cosmic rays traversing all chambers, by comparing the momenta of the incoming and outgoing tracks.
- (b) With the resolution obtained for 928 MeV/c pions in the reaction $\bar{p}p \rightarrow \pi^+\pi^-$.
- (c) By performing a 4-constraints kinematics fit to $\bar{p}p \rightarrow 2\pi^+2\pi^-$ in 4-prong events with a total energy of more than 1760 MeV and comparing the fitted and the measured momenta.

We have analyzed 3.5×10^6 $\bar{p}p$ events requiring a unique vertex in hydrogen within a fiducial volume of 7 cm in radius and 72 cm in length. Only events with at least one track reaching Q_s were considered: the corresponding minimum transverse momentum is 100 MeV/c. The momentum distribution of the 6.6×10^5 tracks satisfying these requirements is shown in fig. 2(a). The momentum resolution is indicated by horizontal bars. Tracks are grouped in 2 MeV/c bins below 300 MeV/c and in 10 MeV/c bins above 300 MeV/c. The first half of the spectrum has been fitted with a 6th order polynomial (full curve). The χ^2 is 77 for 88 degrees of freedom. The second half of the spectrum shows an enhancement at 460 MeV/c. A fifth-order polynomial and a Breit-Wigner distribution were fitted to the data. Here the χ^2 is 58 for 41 degrees of freedom. The momentum at the peak corresponds to a resonance with a mass of 1320 ± 2 MeV and width 99 ± 4 MeV which we identify as the A_2 produced in $\bar{p}p \rightarrow A_2^+\pi^-$. The fitted curves were then subtracted from the data (fig. 2(b)). We do not observe any narrow structure.

Upper limits for the existence of monochromatic charged pion of any origin e.g. transitions from the $\bar{p}p$ atomic state to deeply bound quasi-nuclear states can be computed from the inclusive distribution of fig. 2(a). The charged multiplicity distribution was determined by two different methods:

- (a) By Monte-Carlo simulation of 2, 4 and 6-prong events assuming phase space distribution and by comparison with the observed multiplicity distribution.
- (b) By counting the number of charged tracks detected for individual events in the XDC.

Both methods agree and show that the charged multiplicity distribution is not significantly different from the known multiplicity distribution in bubble chamber experiments. The average number of charged pions is $\int \rho(p) dp = 3$ where $\rho(p)$ is the momentum distribution. We have computed the detection efficiency $\eta(p)$ by Monte-Carlo simulation assuming phase space distribution and the branching ratios $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ (7%), $\pi^+\pi^-\pi^0$ (9%), $\pi^+\pi^-\pi^0$ (23%), $\pi^+\pi^-\pi^0$ (3%), $2\pi^+2\pi^-$ (6%), $2\pi^+2\pi^-\pi^0$ (19%), $2\pi^+2\pi^-\pi^0$ (17%), $2\pi^+2\pi^-\pi^0$ (4%), $3\pi^+3\pi^-$ (2%), $3\pi^+3\pi^-\pi^0$ (2%) from bubble chamber experiments. The branching ratios for channels with more than one π^0 were taken from ref. [8]. Above 300 MeV/c the shape of the simulated spectrum agrees very well with our data of fig. 2(a). The detection efficiency $\eta(p)$ was then obtained by normalizing the simulated spectrum to the observed spectrum above 300 MeV/c ($\eta(p) = 1$ for $p \geq 300$ MeV/c). Below 300 MeV/c $\eta(p)$ decreases smoothly with momentum (Table 1, column (b)).

The branching ratio for the reaction $\bar{p}p \rightarrow X^\pm \pi^\mp$ leading to a state $X^\pm$ with width smaller than our experimental resolution and producing an n standard deviation peak above background is $R(p) = nN^{1/2} [\int \eta(p)\rho(p)dp] / N_T \eta(p)$ where N_T is the number of measured tracks (6.6×10^5) and N the number of tracks in a bin of size consistent with our resolution.

The sensitivity of the results can be improved by considering all tracks emerging from the hydrogen target within a fiducial length of 72 cm and reaching Q3. Since in this case no vertex and hence no second track are required, the statistics is increased by a factor of 2 due to solid angle acceptance. Annihilation in argon is suppressed by rejecting events with a large energy deposit of stopping $\bar{p}$ in the XDC gas. (A residual contamination of 8% argon events was measured by studying events with a reconstructed vertex in argon). The shape of the momentum spectrum is consistent with the distribution of fig. 2(a). No narrow state is observed either. This procedure reduces $R(p)$ by a factor $\sqrt{2}$. The resulting upper limits are given in table 1, column (c) for a $n = 5$ standard deviation effect.

Clearly broad or overlapping resonances are very difficult to observe in an inclusive spectrum. Our data do not show an enhancement around 770 MeV/c corresponding to ρ production in $\bar{p}p \rightarrow \rho^\pm \pi^\mp$. In this region while the $\pi^+\pi^-\pi^0$ contribution increases with pion momentum, the other annihilation channels lead to a rapid decrease of the inclusive spectrum.

We are indebted to the LEAR staff for the commissioning of the machine and for their strong technical support. We are grateful to L. Cerrito and J. Martoff for their contributions in the early stage of the experiment. This work was supported by the Deutsches Bundesministerium für Forschung und Technologie, by the Institut National de Physique Nucléaire et de Physique des Particules, in part by the Schweizer Nationalfond and by the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

- [1] S. Ahmad et al., Physics at LEAR with Low Energy Cooled Antiprotons, Edited by U. Gastaldi and R. Klapisch, Plenum (1984) 253.
- [2] I.S. Shapiro, Phys. Rep. C35 (1978) 129;
W.E. Buck, C.B. Dover and J.M. Richard, Ann. Phys. 121 (1979) 47.
- [3] Chang Hong-Mo and H. Hogaasen, Nucl. Phys. B136 (1978) 401;
R.J. Jaffe, Phys. Rev. D15 (1977) 267.
- [4] C. Amsler et al., Phys. Rev. Lett. 44 (1980) 853.
- [5] C.B. Dover, J.M. Richard and M.C. Zabek, Ann. Phys. 130 (1980) 70.
- [6] P. Pavlopoulos et al., Phys. Lett. 72B (1978) 115.
- [7] S. Ahmad et al., VII European Symposium on Antiproton Interactions, Durham, UK (1984).
- [8] C. Ghesquière, Symposium on Antinucleon Interactions, Liblice, Yellow Report CERN 74-18 (1974) 436.

FIGURE CAPTIONS

Fig. 1 Side and front views of the detector.

Fig. 2 (a) Momentum spectrum of charged pions in $\bar{p}p$ annihilation. The experimental resolution is indicated by horizontal bars. The curves are fits through the data (see text).
(b) Residual data after subtraction of the fitted curves.

Fig. 2