Frascati Physics Series Vol. XXX (1999), pp. 000-000
Workshop on Hadron Spectroscopy 99 - Frascati, March 8-12, 1999

SEARCH FOR QUASINUCLEAR BOUND STATES CLOSE TO THE N$\bar{\text{N}}$ THRESHOLD

Volker Credé (representing the Crystal Barrel Collaboration)
ISKP-Universität Bonn, Nussallee 14-16, D-53115 Bonn, Germany

ABSTRACT

About 4 million $\bar{\text{p}}$d annihilation events with neutral final states have been recorded with the Crystal Barrel Detector at CERN. Our analysis was dedicated to the search for quasinuclear bound states close to the N$\bar{\text{N}}$ threshold which are predicted by N$\bar{\text{N}}$ potential models. We have selected channels with different pion multiplicities (k π^0 + n) as well as (k π^0 + η + n) and compare the neutron momentum distributions. This method is particularly sensitive to the existence of such states. The result is negative; no evidence for narrow states is seen.

1 Introduction

Apart from the loosely bound deuteron consisting of a proton and a neutron there is no evidence for the existence of a bound nucleon-nucleon system. This situation changes completely if we regard a system of a nucleon and an antinucleon. As the same mesons that are responsible for the nucleon-nucleon interaction are also responsible for the nucleon-antinucleon interaction, we can simply derive the N$\bar{\text{N}}$ potential via G-parity transformation:

$$\mathrm{V(NN)(r)} = \sum_M V_M(\mathrm{r}) \quad \rightarrow \quad \mathrm{V(N\bar{N})(r)} = \sum_M G_M \; V_M(\mathrm{r}),$$

where M denotes the exchanged meson and G_M its corresponding G-parity.
The resulting $N\bar{N}$ interaction is strongly attractive at short distances ($r < 0.5$ fm) due to coherent contributions of different attractive meson exchange forces which leads to the existence of a variety of $N\bar{N}$ bound states and $N\bar{N}$ resonances [1, 2].
However, little is known about extremely short distances where the hadron wave functions overlap. While the NN force is repulsive due to the Pauli principle the $N\bar{N}$ force is dominated by annihilation.
A very sensitive method to search for quasinuclear bound states is the investigation of the reaction:

$$\bar{p} \;+\; d \rightarrow n_r + X, \quad X = N\bar{N} \text{ bound state.}$$

Here, the recoil nucleon removes the excess energy to build X. The momentum spectrum of the recoil nucleons shows a characteristic shape which reflects the Fermi motion of nucleons in deuterons, even though high-momenta also occur due to final-state interaction or due to production of resonances. A narrow X is then observed as peak in the neutron momentum distribution.

2 The Crystal Barrel Experiment

We have investigated the reactions:

- $\bar{p}d \rightarrow k\pi^0 + n$, k=2,3,4,5
- $\bar{p}d \rightarrow \eta(k\pi^0) + n$, k=1,2,3,4

The data were recorded with the Crystal Barrel detector at the Low Energy Antiproton Ring (LEAR) at CERN. The *zero prong* data sample was used for this analysis requiring an antiproton stopping in the target and no signal in the Jet Drift Chamber (JDC) surrounding the target. Events with 4, 6, 8 and 10 γ's underwent a kinematical fit to the $(n\gamma)$n hypothesis imposing energy and momentum conservation. If the neutron is fitted as an unmeasured quantity, energy and momentum conservation provides one constraint (1C). About 433000 events passing this fit with 1% confidence level were exposed to further kinematical fits using the masses of the π^0 and η as additional constraints. Events are selected with a confidence level $> 10\%$, respectively, whereas background due to competitive channels is suppressed based on the corresponding confidence level of the kinematic fit.

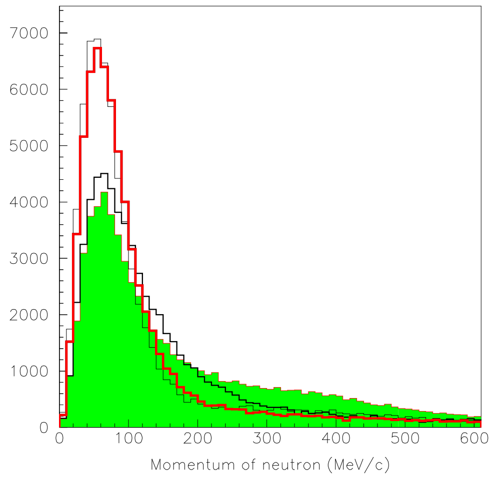

Fig. 1. *Momentum distribution of the spectator neutron for $\bar{p}d \rightarrow k\pi^0 + n$, for k=2 (middle), k=3 (thick), k=4 (grey shaded), k=5 (thin).*

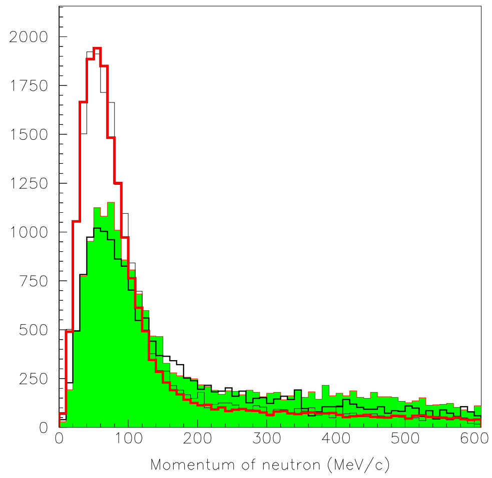

Fig. 2. *Momentum distribution of the spectator neutron for $\bar{p}d \rightarrow (k\pi^0)\eta + n$, for k=1 (middle), k=2 (thick), k=3 (grey shaded), k=4 (thin).*

2.1 Results

Figures 1 and 2 show the momentum distributions of the recoiling neutron for the different reactions. In order to facilitate the comparison the distributions are normalised to 70000 for the kπ^0 and to 20000 for the $\eta(k\pi^0)$ events. If the annihilation process proceeds via formation of intermediate mesons recoiling against the residual nucleon, the momentum distribution should show a peak; in case of quasinuclear bound states close to the N$\bar{\text{N}}$ threshold, this peak falls into the region of the Fermi momentum and a deviation from the expected distribution should reflect the new state. Such states very close to the N$\bar{\text{N}}$ threshold have been claimed by different authors [3, 4, 5, 6].

We notice that the 2π and the 4π momentum distributions have higher intensities at large momenta than the 3π and the 5π have. The distributions with one η meson show a similar behaviour. Again channels with an even number of particles have higher intensities at large momenta.

3 Conclusion

We believe that the different shapes of the distributions for even and odd numbers of neutral particles are likely due to differences in the S- and P-capture probabilities. Annihilation into $2\pi^0$ is strictly forbidden from $p\bar{p}$ in S-state, annihilation into $4\pi^0$ is not absolutely forbidden from S-states but requires a complex cascade like, e.g.:

$$\begin{array}{lll} p\bar{p} \rightarrow \pi^0 a_2(1650) & & \\ & a_2(1650) \rightarrow \pi^0 f_2(1270) & \\ & & f_2(1270) \rightarrow 2\pi^0 \end{array}$$

P-state annihilation of the $p\bar{p}$ system is allowed from S-wave orbits of the $\bar{p}d$ atom; in this case the neutron and the annihilating $p\bar{p}$ system have then one unit of angular momentum, which implies a preference for large momenta of the surviving neutron. In order to confirm this conjecture as well as to check for an isospin dependence of the distributions we changed one π^0 meson to an η meson. Again, the distributions with large intensities at high neutron momenta are forbidden ($\bar{p}d \rightarrow \pi^0\eta$) or rare ($\bar{p}d \rightarrow 3\pi^0\eta$) in annihilation from the $p\bar{p}$ system in S-state. No dependence on isospin can be observed.
The different shapes of the distributions for even and odd numbers of neutral particles are likely due to differences in the S- and P-capture probabilities. We conclude that there is no evidence for contributions from bound quasinuclear states in any of these reactions, at least not with a yield exceeding $5 \cdot 10^{-4}$. This is in conflict with predictions of $N\bar{N}$ potential models including one boson exchange.

References

1. I.S. Shapiro, *Phys. Rep.* **C35** (1978) 129
2. W.W. Buck, C.B. Dover and J.-M. Richard, *Ann. Phys. (N.Y.)* **121** (1979) 71
3. D. Bridges et al., *Phys. Lett.* **B180** (1986) 313
4. T. Kalogeropoulos et al., *Phys. Rev. Lett.* **34** (1975) 1047
5. O.D. Dalkarov, *contribution to LEAP 1996*, Dinkelsbühl, Germany
6. L.N.Bogdanova, O.D.Dalkarov, I.S.Shapiro *Annals of Physics* **84**, (1974) 261