MESON SPECTROSCOPY WITH THE CRISTAL BARREL

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Abstract

We summarize the preliminary results obtained with the Crystal Barrel detector from last year's runs and describe the physics programme for the next years.

1 Introduction

The experiment PS197 is studying $\bar{p}p$ annihilation at rest and up to 2 GeV/c into channels involving $\eta$'s and/or several neutrals which have not been studied so far. The main motivations are a search for glueballs and other exotic mesons and a determination of branching ratios for annihilation into various final states which are relevant to low energy QCD inspired phenomenology.

2 Status of the apparatus

Following last year's set-up the Crystal Barrel is now operational. The initial difficulties with beam size and beam alignment on the target have been alleviated by inserting four thin silicon counters in the target cryostat to define the incident beam. The preliminary $\gamma$ energy resolution of the CsI barrel is $\sigma/E = 0.025/E[GeV]^{1/4}$, comparable to the energy resolution obtained by Crystal Ball. The crystals have been calibrated by using minimum ionizing pions from $\bar{p}p$ annihilation at rest (which deposit 170 MeV when traversing the crystals) and, in a second step, from $\pi^0$ decay. The photodiode/preamplifier noise which strongly influences the resolution below 100 MeV is typically 250 keV rms. For the jet drift chamber (JDC) a positional resolution of $\sigma_{\phi} = 125\mu$ in the plane transverse to the magnetic field has now been obtained. The resolution along the magnetic axis (charge division) is $\sigma = 8$mm.

The typical data acquisition rate is 10 Hz (limited by the tape writing speed) and the reaction rate (equal to the incident flux for annihilation at rest) a few $10^4$ s$^{-1}$, limited by pile-up in the CsI crystals. Hence final state triggers are required. The various stages of the final state multiplicity trigger (fast charged multiplicity, barrel cluster multiplicity, total energy, $\pi^0$ and $\eta$ triggers) are also operational and currently being tested for efficiency, but have not yet been used to collect statistically significant data samples.
The event reconstruction program requires 300 ms (CERN units) for a minimum bias event or about 50 hours (CERN units) for each day of data taking. So far the data have been processed on the CERN central computers and on the computing facilities of the participating institutions.

3 Preliminary results

The first physics data were taken in November and December 1989 during which we collected some $10^6$ minimum bias events at rest in liquid hydrogen and some $10^6$ all neutral events by requiring online no hits in the first layers of the JDC. A further sample of $1.3 \times 10^6$ neutral events and $10^6$ minimum bias events was collected during our first 1990 run in June. These data show that the detector is able to reconstruct at least up to ten $\gamma$'s (channel $\pi^0\pi^0\eta, \eta \to 3\pi^0$). A selection of 6$\gamma$ events leads to the following reconstructed final states:

- The channel $\pi^0\pi^0\pi^0$ (50k events) shows the production of the $f_2(1270)$ and the production of a state with mass 1520 MeV and width 105 MeV, decaying into $\pi^0\pi^0$. The Dalitz plot and its projection are shown in fig.1. A preliminary spin-parity analysis gives for the state at 1520 MeV $J^{PC}=2^{++}$. This state is likely to be the AX discovered earlier by the ASTERIX collaboration at LEAR [1] in the final state $\pi^+\pi^-\pi^0$ in hydrogen gas. It is either a two-quarks two-antiquarks state or one of the long sought baryonium bound states [2]. AX is mainly produced from $I=1$ atomic P states [1] and is not observed from S states. This is not necessarily in contradiction with its present observation in liquid since $3\pi^0$ is a pure $I=1$ and annihilation into $\pi^+\pi^-\pi^0$ from S states is dominantly $I=0$.

- The channel $\pi^0\eta\eta$ (3k events) shows the production of a state around 1550 MeV decaying into $\eta\eta$ (fig.2). No spin-parity analysis is available yet. It could be the AX or the $0^{++}$ glueball candidate observed by the GAMS collaboration [3].

- The channel $\omega\omega$ ($\omega \to \pi^0\gamma$) is observed for the first time. Figure 3 shows the $\pi^0\gamma$ vs $\pi^0\gamma$ mass distribution. Events around the $\omega\omega$ peak are due to combinatorial background. This shows the capability of the detector to search for the states decaying into $\omega\omega$, recently reported by GAMS [4].

In addition we have 12k events for $\pi^0\pi^0\eta$ and 230 events for $\eta\eta\eta$. The former channel is being analyzed to search for the exotic $1^{++}$ state at 1400 MeV, decaying into $\pi^0\eta$, reported by GAMS [5]. Clearly more statistics will be required for these channels which are observed for the first time.

The 4-$\gamma$ events show the channels $\pi^0\pi^0$, $\pi^0\eta$ and $\eta\eta$ with very little background (fig. 4). Most branching ratios for two-neutral mesons are unknown and some of the rates, determined earlier from the inclusive $\pi^0$ or $\eta$ momentum spectra, are not consistent within experiments [6,7]. These and other branching ratios, like $\pi^0\eta'$, $\eta\eta'$, $\phi\pi^0$ and $\eta\phi$, are essential as input to quark models of $\bar{p}p$ annihilation [8]. The production of $\phi$ mesons seems to exceed the prediction of the OZI rule by large factors when assuming no strange quark in the nucleon. This is an important point to clarify by comparing $\phi\pi^0$ to $\omega\pi^0$. 
From $\pi^+\pi^0\pi^0\pi^0$ we obtain the channel $\pi^0\omega$ and from $\pi^+\pi^-\pi^0\eta$ the channel $\eta\omega$ (fig. 5). These channels are also observed in the $5\gamma$ final state with $\omega \rightarrow \pi^0\gamma$. A determination of the branching ratios for the signals shown in fig. 3-5 is in progress.

4 Programme for the next years

4.1 Minimum bias data in liquid hydrogen

Final state triggers will eventually be used to enhance channels with small branching ratios ($\sim 10^{-4}$). However, branching ratios are hard to determine with triggered data and furthermore the appropriate online cuts have to be studied first with a minimum bias data sample large enough to already show the relevant signal. For example, the signal for $\bar{p}p \rightarrow E\pi^+\pi^- (E \rightarrow \eta\pi^0\pi^0)$ is expected at the level of $10^{-4}$ [9]. Hence we reckon that we need some $10^7$ annihilations to detect this or other signals with branching ratios of the same order of magnitude. In addition we will determine the branching ratios for rare channels like $\pi^0\eta'$, $\eta\eta'$, $\phi\pi^0$ and $\eta\phi$.

4.2 Neutral events in liquid hydrogen

As already indicated, we need a larger statistical sample to study the channels $\pi^0\pi^0\eta$ and $\pi^0\eta\eta$. We will collect another $1.5 \times 10^7$ neutral events by requiring zero prong in the multiwire proportional chambers (PWC) and inner JDC layers.

4.3 Online triggers

We now list some of the high priority physics topics to be covered with the online triggers once their efficiencies have been determined with minimum bias events:

- In the final state $\pi^+\pi^0\pi^0\pi^0\eta$ we will search for the decay mode $E \rightarrow \pi\pi\eta$ (and for other pseudoscalars like $\eta(1275)$). The $E$ was first observed in $\bar{p}p$ annihilation at rest (decaying to $K\bar{K}\pi$) [10] and recently confirmed to be $0^+$ [11]. $E$ is probably identical to $\iota$ observed in radiative $J/\psi$ decay. However $\iota(1430)$ does not decay into $\eta\pi\pi$ (although MarkIII and DM2 observe a signal at 1385 MeV), while a signal is seen in $\pi^-p$ interaction [12]. This will help clarify whether $E$ and $\iota$ are indeed the same object.

- In the same final state we will search for the missing isoscalar $1^{++}$ partner of the $b_1(1235)$ decaying presumably to $\eta\omega$ ($\bar{p}p \rightarrow \eta\omega\pi^0$). A state decaying into $K\bar{K}\pi$ has recently been reported [13].

- Again in the same final state we will search for the decay mode $a_2(1320) \rightarrow \eta'\pi^-, (\eta' \rightarrow \eta\pi\pi)$ in $\bar{p}p \rightarrow a_2\pi$ and determine the pseudoscalar mixing angle by comparison with $\bar{p}p \rightarrow \eta\pi, \eta \rightarrow 3\pi$ in the final state $\pi^+\pi^-3\pi^0$. The trigger requires 2 prong in the PWC/JDC, 8 clusters in the barrel and the online reconstruction of 2 $\pi^0$ and 1 $\eta$.

- The trigger 2 prong, 6 clusters in the barrel and 2 $\pi^0$'s recoiling against at least 1 GeV can be used to enrich the channel $\phi\pi^0\pi^0$ ($\phi \rightarrow K^+K^-$) and search for the decay $b_1(1235) \rightarrow \phi\pi$ as well as other exotics decaying to $\phi\pi$. 

• The trigger 2 prong and 1 γ will be used to search for states decaying into \(\pi^+\pi^-\) and \(K^+K^-\) and the trigger 0 prong, 5γ, 2η, or 1η and 1π⁰, for states decaying into ηη or ηπ⁰ with monochromatic γ emission.

• Radiative annihilations viz. \(\bar{p}p \rightarrow \gamma\pi^0, \gamma\eta, \gamma\omega, \gamma\eta', \gamma\gamma\) are rare (\(\sim 10^{-5}\) or less) and require a trigger. Apart from \(\gamma\pi^0\) (B.R. \(1.7 \times 10^{-5}\) [6]) for which we have preliminary evidence, none of the other channels have been seen so far.

• By requiring 2 prong and an odd number of γ’s we can search for radiative decays of the ω in the final states \(\pi^+\pi^-\omega\) or \(\pi^0\omega\): \(\omega \rightarrow \eta\gamma\) (B.R. \(=3.5\pm2.9 \times 10^{-4}\)), \(\omega \rightarrow 3\gamma\) (no upper limit so far), \(\omega \rightarrow \pi^0\pi^0\eta\) (B.R. \(\leq 4 \times 10^{-4}\)), \(\omega \rightarrow \pi^+\pi^-\gamma\) (B.R. \(\leq 4 \times 10^{-3}\)).

4.4 Annihilation in hydrogen gas

Based on results from the former ASTERIX experiment, one finds that meson production strongly depends on the angular momentum of the initial \(\bar{p}p\) state. A typical example is the AX(1565), first observed in the \(\pi^+\pi^-\pi^0\) channel in hydrogen gas [1] where P wave annihilation contributes about 50%, while only about 9% in liquid hydrogen [14]. New states can be uncovered by switching from liquid to gas:

• The production of two pseudoscalars is strongly suppressed in liquid due to the dominance of annihilation from atomic S states (\(^3S_1\) and \(^1S_0\)). With hydrogen gas we will search for pseudoscalars with the reaction \(\bar{p}p \rightarrow X\pi\) \((X \rightarrow \pi\pi\eta, K\bar{K}\pi)\) which is allowed from atomic P states.

• The production of \(0^{++}\) and \(2^{++}\) states is strongly suppressed by phase space in \(\bar{p}p \rightarrow \pi^+\pi^-X\) in liquid hydrogen. since annihilation from S states can only occur with at least one unit of angular momentum, which is unlikely at rest for states in the 1.4 to 1.7 GeV mass range. These states can however be produced from P states in gaseous hydrogen.

The liquid hydrogen target will be replaced by a gas target at NTP and the incident momentum decreased from 200 MeV/c to 100 MeV/c where range straggling is about 12 cm (FWHM). Monte Carlo simulations do not show any degradation of the energy resolution of the CsI detector with such a relatively long stopping distribution. Again, a reasonable sample of minimum bias data is required before special triggers are used.

4.5 Annihilation at rest in liquid deuterium

Annihilation on the neutron is a pure isospin 1 process and the angular momentum of the annihilating \(\bar{p}n\) system can be controlled by varying the momentum of the spectator proton [15]. As the spectator nucleon removes the excess energy one can study the formation of \(\bar{p}p\) and \(\bar{p}n\) states below threshold as a function of mass viz

\[
\bar{p}n(p) \rightarrow X^-(p), X^- \rightarrow \pi^0\pi^-, \eta\pi^-, \eta\pi^0\pi^- ...
\]

\[
\bar{p}p(n) \rightarrow X^0(n), X^0 \rightarrow \pi\pi, \eta\pi, \eta\pi\pi, \eta\eta...
\]

For the first reaction all particles will be detected, whilst for the second, one has enough constraints to reconstruct the undetected neutron.
Through the reaction $\bar{p}n \rightarrow X\pi$ one can also study the production of states $X$ from initial $I=1$ states. Recently a $2^{++}$ state at 1500 MeV associated with a spectator momentum $\lesssim 200$ MeV/c and decaying into $\rho^0\rho^0$ has been reported [16] and confirmed by the ASTERIX collaboration [17]. Enhancements in $\rho\rho$ are also observed in $\gamma\gamma$ collisions. The enhanced $\rho^0\rho^0$ production over $\rho^+\rho^-$ is possibly due to the existence of mass degenerated $I=0$ and $I=2$ states [18]. We will search for the $\rho^+\rho^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ decay mode of the state observed in deuterium. Annihilation studies in deuterium do not require any modification of the apparatus.

4.6 Annihilation in flight at 700 MeV/c

At 700 MeV/c two states are observed in $\bar{p}p$ annihilation into $X\pi^+\pi^-$, $X \rightarrow K\bar{K}\pi$ and $X \rightarrow \pi\pi\eta$ [19,20], the one around 1280 MeV being the $f_1(1285)$. There is no definitive spin-parity analysis of the second state around 1420 MeV (E meson) although $0^{-+}$ is preferred. However a $1^{++}$ state (also called E) is observed at this mass in $\pi\rho$ experiments. We hope to settle the E meson controversy with a large statistical sample at 700 MeV/c.

4.7 Annihilation in flight at 2000 MeV/c

In the flux tube model hybrid mesons are predicted with a mass of 1.9 GeV [21]. These states decay into an $L=0$ and an $L=1$ meson, for instance $f_1(1285)\pi$, and are quite broad. Some of these hybrids carry exotic quantum numbers ($1^{-+}$). Since the center of mass energy is 2.4 GeV with LEAR running at its maximum momentum of 1.9 GeV/c, there is little hope to see the broad ones but the relatively narrow ones ($\sim 100$ MeV) could be observed with the reactions

$$\bar{p}p \rightarrow X\pi, X \rightarrow f_1(1285)\pi, f_1 \rightarrow \eta\pi\pi \quad (3)$$

$$\bar{p}p \rightarrow X\pi, X \rightarrow b_1(1235)\pi, b_1 \rightarrow \omega\pi \quad (4)$$

Since there are several neutrals in the final state, the Crystal Barrel should be a suitable detector to study these reactions.

We will also search for the $AX(1565)$ and the $2^{++}$ states recently reported by GAMS at 1640 and 1960 MeV [4], decaying into $\omega\omega$, with the reaction $\bar{p}p \rightarrow \omega\omega\pi^0$.

Annihilation in flight can be studied with the Crystal Barrel with minor modifications of the incident beam telescope. We will need a $\bar{p}$ flux of $\sim 10^6$ s$^{-1}$.

5 Summary

In summary the Crystal Barrel is working well and according to expectation. Table 1 summarizes the physics programme for the next years. Note that the priorities will finally be set depending on physics results. Also the Collaboration might decide to perform this programme in a different order. Finally, we wish to express our interest in measuring the excitation functions for $\bar{p}p$ annihilation into two neutral mesons as a function of $\bar{p}$ momentum [24].

References


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TABLE 1: Proposed physics programme with the Crystal Barrel
FIGURE 1: Dalitz plot of $\bar{p}p \rightarrow 3\pi^0$ (a) and its projection (b) [22]
FIGURE 2: $\eta \eta$ invariant mass in $\bar{p}p \rightarrow \eta \eta \pi^0$ [22]

FIGURE 3: Lego-plot of $m(\pi^0\gamma)$ vs. $m(\pi^0\gamma)$ in $\bar{p}p \rightarrow \pi^0\pi^02\gamma$. The peak is due to $\omega \omega$ [22]
FIGURE 4: $\gamma \gamma$-invariant masses for $\bar{p}p \rightarrow 4\gamma$ (3 entries per event). The accumulation of events in the bottom left corner is due to $\pi^0\pi^0$, around 500 MeV to $\pi^0\eta$ and in the center to $\eta\eta$. The dark band is due to combinatorial background.

FIGURE 5: (a): $\pi^+\pi^-\pi^0$ mass for $\bar{p}p$ annihilation into $\pi^+\pi^-$ and 4 $\gamma$'s; (b): invariant mass recoiling against $\omega$ after subtraction of control regions around the $\omega$ peak of (a) [23] (preliminary data).