SEARCH FOR EXOTICS IN PROTON ANTIPROTON ANNIHILATION IN FLIGHT WITH THE CRYSTAL BARREL EXPERIMENT

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ABSTRACT

An overview over the ongoing analyses of in flight data at PS197 is given. Most emphasis is put on the final states $3\pi^o$, $2\pi^o\eta$, $2\eta\pi^o$ and 3η at an incident $\bar{\text{p}}$ momentum of 1.94 GeV/c.

1. Introduction

Light meson spectroscopy nowadays aims to clarify the behaviour of quarks and gluons in the low energetic regime of non-perturbative QCD. Especially the finding of some predicted but still not experimentally confirmed states is of major interest in this field of physics. These are states which are not built up from a quark-antiquark pair like ordinary mesons but consist out of several $q\bar{q}$ pairs (di-mesons, di-baryons,...) or contain so called constituent gluons (glueballs, hybrids).

Always $p\bar{p}$ annhilation has been considered as a source rich of glue. To overcome the limitations in the phasespace accessible in at rest experiments, Crystal Barrel has also measured with incident $\bar{\text{p}}$ momenta of 600, 1200 and 1940 MeV/c corresponding to values of $\sqrt{s}$ =1962, 2149 and 2409 MeV/c^2 respectively. Many promising final states are now under investigation. To start with two-body final states containing π^o, η, η' and ω mesons which are analyzed to determine the contributing partial waves in the annihilation process in flight. A dominant partial wave in one or more channels

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Zürich[1] - William and Mary[2] - Karlsruhe[3] - RAL[4] - Mainz[5] - Bochum[6] - LBL[7] - München[8] - QMC[9] - CERN[10] - UCLA[11] - Budapest[12] - Hamburg[13] - Bonn[14] - Carnegie Mellon[15] - Strasbourg[16]

may indicate the formation of a resonance. The outcome of these analyses will be valueable input for spin parity analyses involving more than two particles in the final state.

Common to all multi-meson final state analyses is the search for final state interactions. These as interpreted in the commonly used isobar model are due to intermediate states decaying into two or three mesons. The five-body final states $4\pi\eta$ might be produced by the decay chain of a hybrid state with exotic quantum numbers $J^{PC} = 1^{-+}$ predicted by Isgur[1]: $\mathrm{p\bar{p}} \to \hat{\rho}_1\pi \to (f_1(1285)\pi)\pi \to (a_0(980)\pi)\pi\pi \to (\eta\pi)\pi\pi\pi$.

Similarily the analysis of $\pi^+\pi^-\pi^o\omega$ is intended to find the reaction $\mathrm{p\bar{p}} \to \hat{f}_1\pi \to (b_1(1235)\pi)\pi \to (\omega\pi)\pi\pi$. The $\hat{f}_1$ is the isoscalar partner of the $\hat{\rho}_1$.

The ongoing analysis of the $3\pi\eta$ final state indicates promissing signals in the $\pi\pi\eta$ invariant mass spectrum which are likely new states decaying to $f_2\eta$ and/or $a_0\pi$. The analysis of $\pi\omega\omega$ is intended to confirm the $\omega\omega$ resonance at 1640 MeV/c^2 claimed by other experiments[2,3]. Fixing the relative branching ratios to $\omega\omega$ and $\omega\rho$ is expected to reveal insights to the nature of this object. Another interesting peak has been found in the $\eta\omega$ invariant mass spectrum at 1680 MeV/c^2 in the $\pi^o\eta\omega$ final state. In all analyses involving vector mesons the analysis of the decay of these mesons will be very helpfull for detecting spin and parity of resonances. The 3-body final states made out of $\pi^o$and η mesons are described in more detail in the following sections of this article.

2. Detector and Data Reconstruction

The Crystal Barrel detector at CERN is a multi-purpose detector with almost hermetic coverage of the solid angle ($98\% \times 4\pi$) for $\mathrm{p\bar{p}}$ annihilations at rest. It is designed to measure tracks of charged particles and photons simultanuously. The charged tracks are seen by a jet drift chamber (JDC) and two cylindrical multi-wire proportional chambers (PWCs) surrounding a liquid hydrogen target where the $\mathrm{p\bar{p}}$ annihilations take place. Photons are detected by 1380 CsI(Tl)-crystals adjacent to the JDC. The whole apparatus is inside a magnet yoke providing a magnetic field upto 1.5 T. The antiproton beam is extracted from LEAR. A detailed description can be found elsewhere[4].

For the data presented in this talk no hits in the PWCs was required by the trigger and a rough energy window was set around the nominal value. For the preparation of the $3\pi^o$, $2\pi^o\eta$, $2\eta\pi^o$ and 3η final states offline cuts requiring no charged tracks in the JDC and six photons each above 20 MeV energy deposit in the calorimeter as indentified by the CB reconstruction software. Thus the final states were selected as observed in pure 2-photon decays of π^o and η mesons. The quality of the data is shown in figure 1 where the $\gamma\gamma$ invariant mass is plotted after the data has passed a kinematical fit to the hypothesis $\pi^o\pi^o\gamma\gamma$. The spectrum shows in the region displayed an enhancement due to the decay $\mathrm{p\bar{p}} \to \pi^o\pi^o\eta, \eta \to \gamma\gamma$ with an excellent resolution and signal to background ratio.

The quality has been further improved by applying kinematic fits testing the

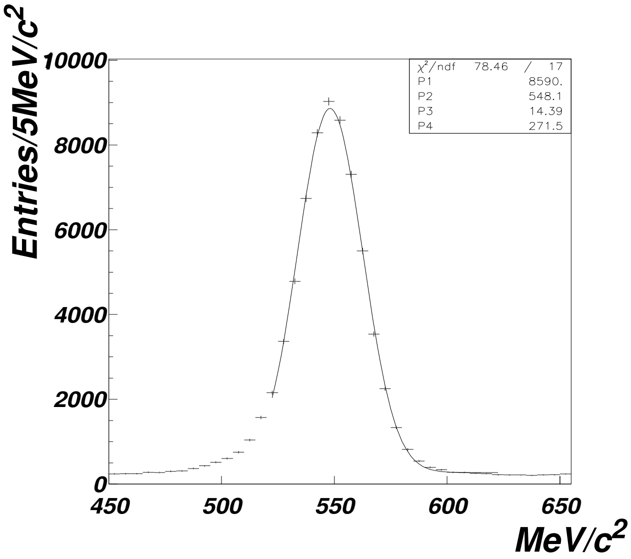

Fig. 1. $\gamma\gamma$ invariant mass spectrum for the fitted hypothesis $\pi^o\pi^o\gamma\gamma$.

hypotheses $3\pi^o$, $2\pi^o\eta$, $2\eta\pi^o$ and 3η. As shown by Monte Carlo studies the channels

	$3\pi^o$	$2\pi^o\eta$	$\pi^o\eta\eta$	3η
$3\pi^o$	26%	2×10^{-4}	1×10^{-4}	2×10^{-5}
$2\pi^o\eta$	5×10^{-4}	28%	1×10^{-3}	6×10^{-4}
$\pi^o\eta\eta$	8×10^{-5}	2×10^{-5}	24%	6×10^{-4}
3η	0	8×10^{-5}	1×10^{-3}	27%

Table 1. Efficiencies and cross talk for the reconstruction and separation of the channels $3\pi^o$, $2\pi^o\eta$, $\pi^o\eta\eta$ and 3η. On x-axis are listed the generated final states (each more than 100000 events), on y-axis the final states as identified by the analysis.

can be separated by imposing rigorous cuts on the χ^2-values resulting from the fits. The fits considered the z-coordinate of the $p\bar{p}$ annihilation vertex as unmeasured and free respecting the homogenous distribution of reactions along the 4.4 cm long target. The resulting acceptances vary not more than 20% over the kinematically allowed region of the Dalitz plots and show no structures.

3. The Data

So far only data from annihilations with $\bar{p}$ momentum of 1.94 GeV/c have been studied in detail. We are going to present here the selected final states from events that have been measured during the beam periods in July 1992 and July/August 1994. The pictures shown are still preliminary as the calibration method of the crystals has undergone a slight improvement since then. However final plots available after recalibration are expected to differ not significantly.

3.1. $3\pi^o$

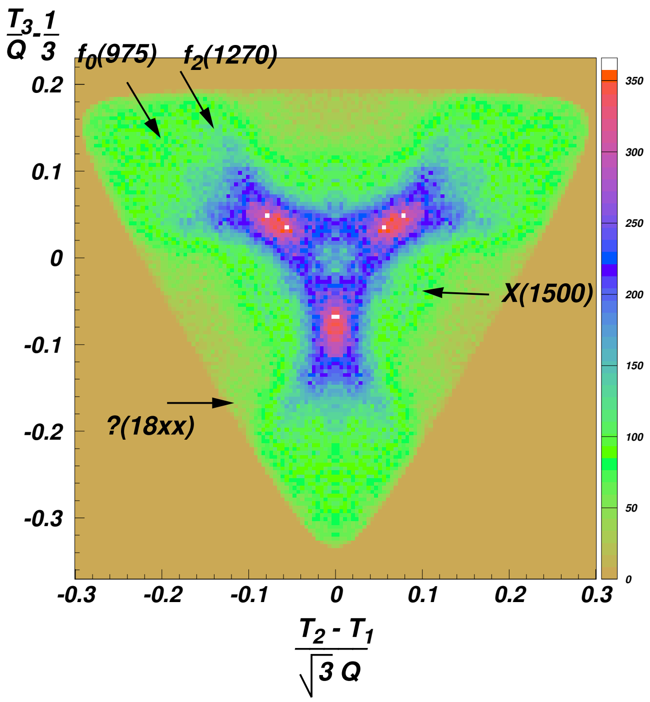

Fig. 2. Dalitz plot of the $3\pi^o$ final state.

Figure 2 shows the $3\pi^o$ Dalitz plot making use of the sixfold symmetry originating from the six possible permutations of three identical mesons. It contains 161888 events with six entries per event. Clearly this final state is dominated by $f_2(1270)$ production. Also a sharp triangular line corresponding to the $f_0(975)$ is visible. Besides this well established $\pi^o\pi^o$ resonances there can be also seen a triangular structure in the center of the Dalitz plot. This corresponds to an enhancement in the $\pi^o\pi^o$ invariant mass at around 1500 MeV$/c^2$. Unfortunately it cannot be descerned in the invariant mass spectrum (see fig.3). The analysis of this final state is intended to show wether this is the same object as seen at $p\bar{p}$ annihilations at rest or not[5]. The very recent analysis of the full statistics available on data at rest from the Crystal Barrel experiment assigns dominantly spin zero to this mass region, whereas a tensor contribution cannot be excluded. Having more observables in in flight reactions, it is an important check to do this analysis. The educated eye may find an additional enhancement at around 1850 MeV$/c^2$ but it is likely to be a too small signal for an analysis to be sensitive to it.

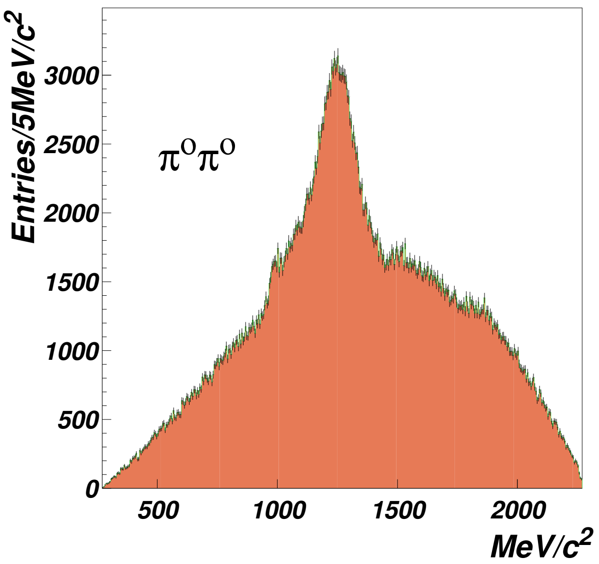

Fig. 3. $\pi^o\pi^o$ invariant mass spectrum of the $3\pi^o$ final state.

3.2. $2\pi^o\eta$

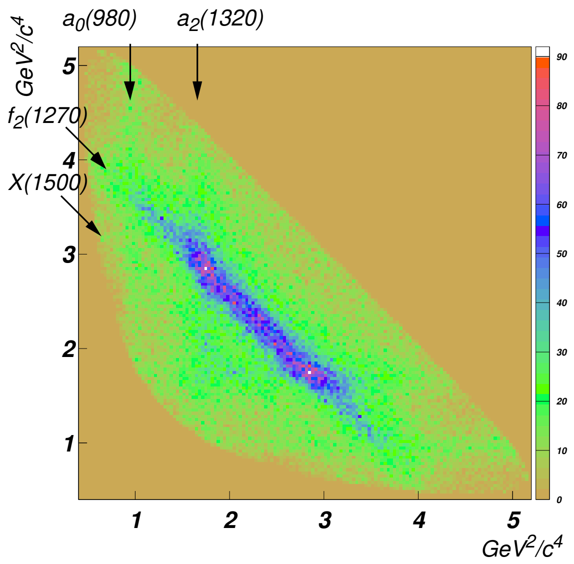

Fig. 4. Dalitz plot of the $2\pi^o\eta$ final state.

The final state $2\pi^o\eta$ allows also for isovector intremediate states. The Dalitz plot in figure 4 shows 79810 events, two entries per event. Besides $f_2(1270) \rightarrow \pi^o\pi^o$ we find $a_0(980)$ and $a_2(1320) \rightarrow \pi^o\eta$. Here the structure at 1500 MeV/c^2 in the $\pi^o\pi^o$ invariant mass is a striking signal.

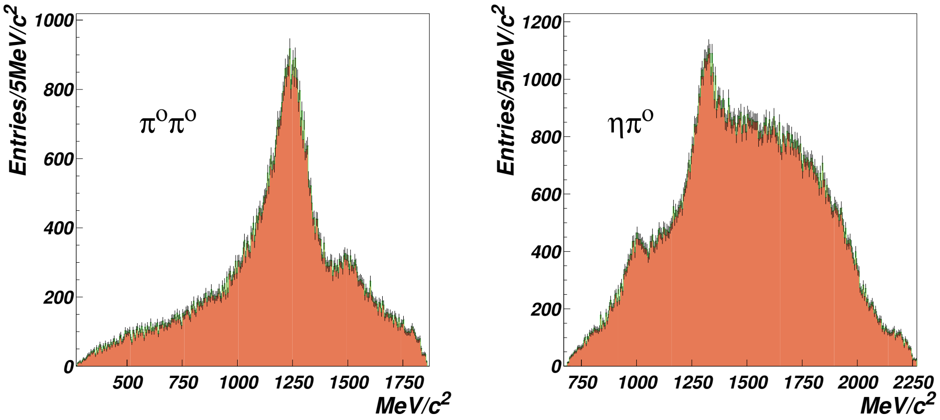

Fig. 5. Invariant $\pi^o\pi^o$and $\pi^o\eta$ mass in the $2\pi^o\eta$ final state.

3.3. $2\eta\pi^o$

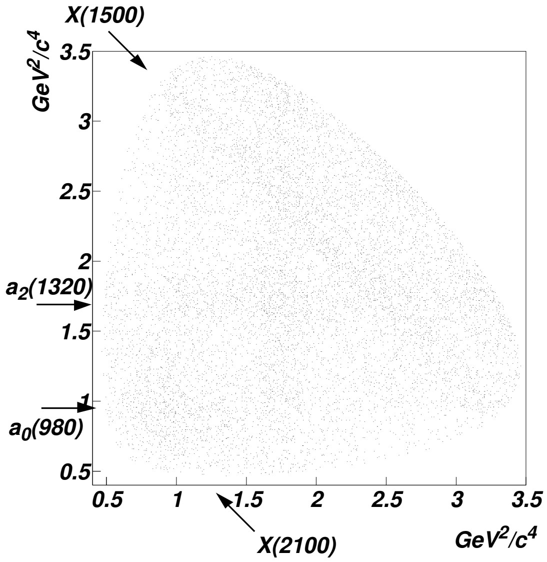

Fig. 6. Dalitz plot of the $\pi^o\eta\eta$ final state.

Although lacking statistics (5454 events) in the $2\eta\pi^o$ final state, the absence of the $f_2(1270)$ allows us to see the 1500 MeV/csqr signal more clearly. The $\eta\eta$ invariant mass spectrum (fig.7) shows a well defined peak. Its width as estimated by eye is below 100 MeV/c^2. The bump at the crossing of the $a_0(980)$ bands might be due to constructive interference, but an interpretation as an object with mass around 2100 MeV/c^2 decaying into $\eta\eta$ is more attractive as evidence for such an intermediate state comes from other experiments[6].

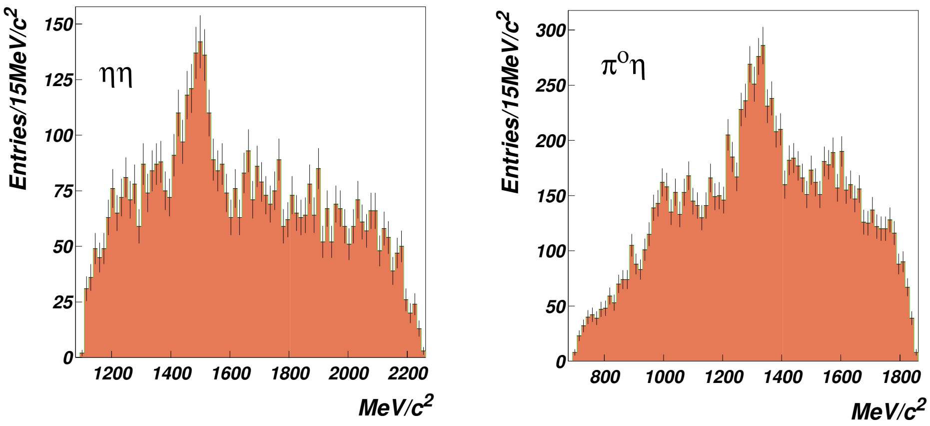

Fig. 7. Invariant $\pi^o\pi^o$and $\pi^o\eta$ mass in the $\pi^o\eta\eta$ final state.

3.4. 3η

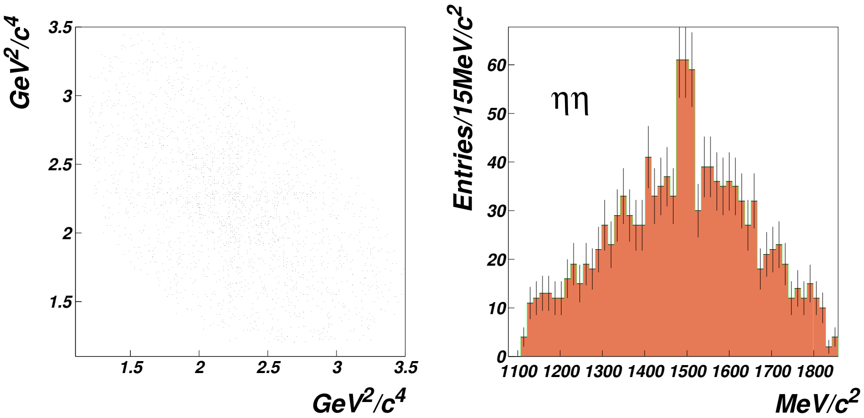

Fig. 8. Dalitz plot and invariant $\eta\eta$ mass in the 3η final state.

In the 3η final state we have only gathered 432 events. However the only structure visible in the Dalitz plot as well as in the $\eta\eta$ invariant mass spectrum is a narrow structure around 1500 MeV/c^2. Assuming the object being the low lying 0^{++} glueball as predicted by Jaffee[7] and that η couples strongly to glue[8], this channel can be used to find the predicted 1^{++} glueball at 2.41 GeV/c^2 in the direct formation $p\bar{p} \rightarrow g_1(2410) \rightarrow f_0(1500)\eta \rightarrow (\eta\eta)\eta$.

4. Spin Parity Analysis

The spin parity analysis of the discussed final states interprets the data using the isobar model. The formula used is derived within the helicity formalism[9] using Breit-Wigner functions and Blatt-Weisskopf barrier factors[10] to describe the energy dependent part. We are also working on introducing K-matrix formalism to this analysis as it has been already successfully applied to previous analyses[5]. This will enable us to analyze more than one final state simultanuously. The full formula inhibits a huge number of free parameters which increases with the number of $p\bar{p}$ scattering waves taken into account. At 1940 MeV/c incident $\bar{p}$ momentum where partial waves upto $l = 6$ are expected to contribute[11], it seems advisable to reduce the number of free parameters by introducing a simplified formula which can be motivated by averaging over all production mechanisms and thus skipping one dimension of phase space.

$$I = | \sum_{c,\lambda,k} F_\lambda^c \times D_{\lambda 0}^{J_c\star}(\varphi, \vartheta, 0) \times \Delta^c(m)|^2 \tag{1}$$

where Δ is the energy dependent term and the summation extends over all resonances c, all helicity states λ of the resonances and all combinations (k) of choosing a meson pair out of three mesons. An even simpler approach ignores another observable and yields

$$I = \sum_\lambda | \sum_{c,k} F_\lambda^c \times d_{\lambda 0}^{J_c}(\vartheta) \times \Delta^c(m)|^2 \tag{2}$$

5. Summary, Conclusion and Outlook

It is well known that light meson spectroscopy is a privilleged field to learn about non-perturbative QCD. The variety of new states seen by various experiments demonstrate the need of future research. One hot glueball candidate has been found in $p\bar{p}$ annihilations at rest while experiments usings annihilations in flight promiss to discover a large scope of the glueball and hybrid spectrum due to the mass range accessible.

The Crystal Barrel detector has proven to operate extremely well also for incident $\bar{p}$ momenta upto the present LEAR limit. The data obtained and analyzed so far let us hope to establish the 1500 MeV/c^2 object as a glueball and explore also higher non $q\bar{q}$ states.

As an outlook we want to draw your attention to the prospects of an upgrade of the LEAR machine outlined by M. Fässler's[12] talk at this conference.

6. Acknowledgements

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7. References

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