Memorandum to the PSCC regarding the Future of LEAR (Cogne Meeting).

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MESON FORMATION IN PROTON-ANTIPROTON ANNIHILATION AT LEAR

C. AMSLER
Physik-Institut der Universität Zürich, Schönberggasse 9,
CH-8001 Zürich, Switzerland
and
The CRYSTAL BARREL Collaboration
CERN-Hamburg-Karlsruhe-LBL-Mainz-Munich-Queen Mary-
RAL-Strasbourg-UCLA-Zurich

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Abstract

This is a letter of interest to study the formation of two mesons in $\bar{p}p$ annihilation, especially two neutrals like $\pi^0\pi^0$, $\pi^0\eta$, $\eta\eta$, $\pi^0\omega$, $\eta\omega$, $\omega\omega$, K_SK_S and K_SK_L as a function of $\bar{p}$ momentum at LEAR with the Crystal Barrel detector.

Bound states of the $\overline{N}N$ system are predicted by potential models of the $\overline{N}N$ interaction. A search for these states was one of the main motivations for the construction of LEAR. Narrow bound states have not been seen when looking for the emission of monochromatic γ, π^0 or $\pi^\pm$ in $\bar{p}p$ annihilation at rest [1]. These states are presumably broad due to strong annihilation. In fact, a candidate at 1565 MeV with a width of 170 MeV has been found at LEAR by the ASTERIX collaboration [2], decaying into two pions in the three pion annihilation channel. This state is now also observed by the Crystal Barrel collaboration [3].

$\overline{N}N$ resonances ($M \geq 1.88$ GeV) are also predicted by potential models. Also, many missing $q\bar{q}$ states ($L\geq2$ and radial excitations) are expected in the 2 GeV mass region. These states could be formed e.g. by the reaction $\bar{p}p \to X \to$ mesons. No structure has however been observed at LEAR in the total and integral annihilation cross sections as a function of $\bar{p}$ momentum with an upper limit of a few mb×MeV [4,5].

This is perhaps not surprising since weak or broad structures cannot easily be observed in total cross section experiments due to the high background from non-resonating amplitudes. Indeed, four S waves, eight P and eight D waves are expected to contribute at low energy. On the other hand, only very few partial waves contribute to $\bar{p}p$ annihilation into two mesons, especially two neutral mesons. A few examples are shown in Table 1 (see also ref.[6]). Note that exotic quantum numbers (0^{--}, 0^{+-}, 1^{-+}) cannot be formed in $\bar{p}p$. Such states (e.g. hybrids) must be sought in production. A measurement of the cross section, angular distribution (possibly with a polarized target) of final states with two neutral mesons as a function of momentum in the LEAR range (1.88 to 2.4 GeV) allows the study of meson formation with the help of partial wave analyses.

Annihilation into broad mesons (for example $f_2\pi^0$) can in principle also be studied. These channels however require a complete Dalitz plot analysis due to interference with channels leading to the same final state. Such a study would require large statistics samples for every beam momentum setting.

Apart from statistically very poor data on K_SK_S and K_SK_L [7] there are no data on any of these channels below 1 GeV/c and nearly no data below 2 GeV/c.

A resonance activity has actually been found for the few channels studied in the past:

- The channels $\pi^0\pi^0$ and $\eta\pi^0$ have been investigated between 1.1 and 2.0 GeV/c [8] and a $2^{++}(0^+)$ $\pi^0\pi^0$ resonance discovered at 2.15 GeV with a width of 250 MeV [9].
- The channel $\rho\omega$ (five pions in the final state) shows an 80 MeV broad enhancement at 1.96 GeV. A spin density analysis of the ρ and the ω favors the quantum numbers $2^{++}(1^+)$ [10].
- The channel $\pi^+\pi^-$ resonates in the partial waves 1^{--}, 2^{++}, 3^{--}, 4^{++} and 5^{--} [11] in the region of the T(2200) and U(2350) resonances. Incidentally, there is still no satisfactory explanation to the origin of the T and U enhancements observed in the total, total annihilation, elastic and charge exchange cross sections.
- The differential cross section for the channel K^+K^- shows a backward peak [12] which would correspond to the exchange of an exotic S=+1 baryon. More likely, this peak signals the presence of an s-channel resonance. A partial wave analysis is however difficult here, since both isospins 0 and 1 contribute to all partial waves due to the absence of G-parity constraint.

Angular distribution data for the channel $\pi^0\pi^0$ would constrain the partial wave analysis of $\pi^+\pi^-$ from the forthcoming data of PS172. The channel $\pi^0\pi^0$ proceeds only through $\bar{p}p$ P states and is therefore suppressed in liquid hydrogen at rest since annihilation mainly occurs from atomic S states following $\bar{p}$ capture. On the other hand, PS173 found a very strong P wave in flight, even at low momentum (200 MeV/c) [13]. Thus the $\pi^0\pi^0$ cross section should rise above threshold. Hence this channel (and other two neutral speudoscalars) can be used to study the onset of the P wave which plays a central role in $\bar{p}p$ interaction at low energy, in contrast to pp where the P wave contribution is negligible.

The channel $K^0\overline{K^0}$ would constrain the K^+K^- data as the amplitude for $K^0\overline{K^0}$ (K^+K^-) is the sum (difference) of the isospin 0 and 1 amplitudes. $K^0\overline{K^0}$ appears as K_SK_S for even parity and as K_SK_L for odd parity. Figure 1 shows recent measurements of the cross sections below 1.2 GeV/c [7].

We wish at this point to comment on the channel $\phi\phi$ for which a good kaon identification is required. This channel, sensitive to the formation of glueballs, will be studied by JETSET. The accessible mass range at LEAR is 2.02 GeV ($\phi\phi$ threshold) to 2.4 GeV (maximum available LEAR momentum of 1.9 GeV/c). Broad states are unlikely to be discovered in this range due to this very narrow mass window and therefore one will need higher center of mass energies. A $\bar{p}p$ minicollider is suggested in another letter of interest.

The Crystal Barrel is a suitable detector to measure the excitation function (cross section and angular distribution) for the channels shown in Table 1. The γ angular resolution is 1^0 and photons are detected over the angular range $|\cos(\theta)| \leq 0.98$. Figure 2a shows preliminary data collected at rest, requiring four photons and no charged particle in the final state. The peak around 1000 MeV is due to $K_S K_L$ with $K_S \rightarrow \pi^0 \pi^0$ and K_L escaping detection. Figure 2b shows a scatterplot of two-gamma invariant masses for events with total energy above 1500 MeV. The peak at the bottom left is due to $\pi^0\pi^0$, around 500 MeV to $\eta\pi^0$ and the one at the center from $\eta\eta$. The channels $\eta\omega$ and $\pi^0\omega$ are also observed by the Crystal Barrel in the seven γ final state. All these channels, seen cleanly for the first time, could also be reconstructed in flight.

The present liquid hydrogen target (4 cm) would have to be shortened to access the momentum range below 500 MeV/c. The magnetic field is not required (except possibly for $K_S K_S$) since neutral final states will be selected ($\omega \rightarrow \pi^0\gamma$). A trigger is available to reconstruct η's and π^0's and thus select online the channels with small branching ratios. The experiment could be run in its present location at various $\bar{p}$ momenta between 0.2 and 1.9 GeV/c.

Recent data from PS172 show a very large analyzing power in the reaction $\bar{p}p \rightarrow \pi^+\pi^-$ and K^+K^- [14] reaching the value of one for large angular ranges (which means that π^+ and K^+ are scattered only to one side of the beam for 100% target polarization). This phenomenon, which cannot be accomodated by baryon exchange models, is not understood. Conceivably, and in a second step, one could measure the excitation function for the channels shown in Table 1 with a frozen spin polarized target inserted into the cavity of the Crystal Barrel after removal of the jet driftchamber. Two small supraconductive coils would supply the holding field and the magnet, which is not required for a measurement of neutral final states, would be removed.

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Channel	$J^{PC}(I^G)$
$\pi^0\pi^0$, $\eta\eta$, $\eta\eta$'	0^{++}, 2^{++} (0^+)
$\pi^0\eta$, $\pi^0\eta$'	0^{++}, 2^{++}, (1^-)
$\pi^0\omega$, $\pi^0\phi$	1^{+-}, 1^{--}, 2^{--} (1^+)
$\eta\omega$, $\eta\phi$	1^{+-}, 1^{--}, 2^{--} (0^-)
$\omega\omega$, $\omega\phi$, $\phi\phi$	0^{++}, 0^{-+}, 1^{++}, 2^{++}, 2^{-+} (0^+)
K_SK_L	1^{--}, 3^{--}
K_SK_S	0^{++}, 2^{++}

TABLE 1: Contributing $\bar{p}p$ waves up to D waves for $\bar{p}p$ annihilation into two neutral mesons

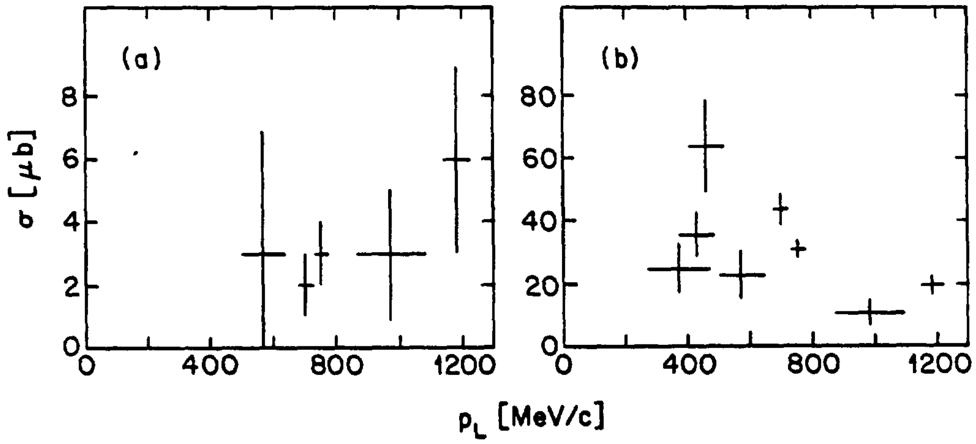

FIGURE 1: Cross sections for K_SK_S (left) and K_SK_L (right) from ref.[7]

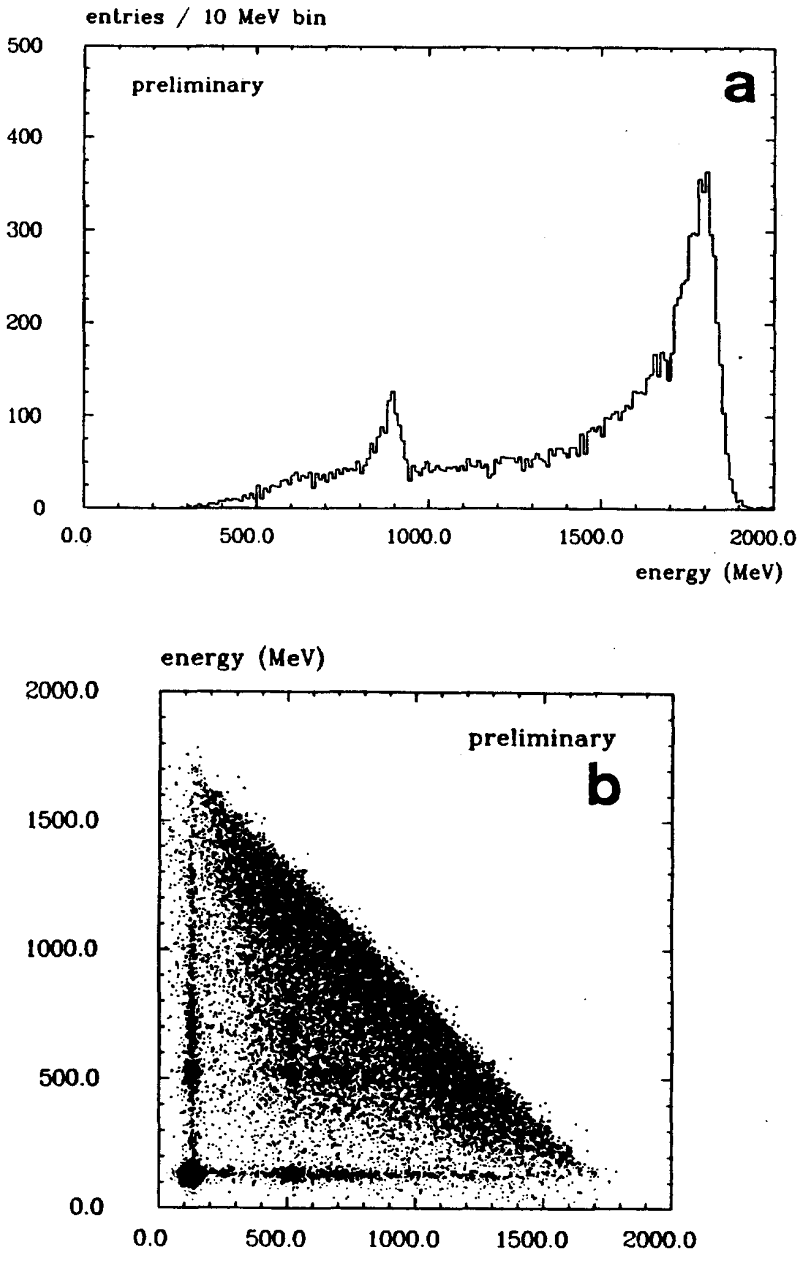

FIGURE 2: Total energy for $\bar{p}p$ annihilation at rest into 4γ (a) and two-γ invariant masses for a total energy of more than 1500 MeV (b) (3 entries per event). Data from the Crystal Barrel