EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/82-66
28 May 1982

SEARCH FOR NARROW BARYONIUM STATES NEAR THE $\bar{N}N$ THRESHOLD

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ABSTRACT

The reactions $\bar{p}p \rightarrow \pi^-X$ and $\bar{p}d \rightarrow pX$ have been used as a search for narrow baryonium states in the mass region between 1.6 and 2.0 GeV/c². No such state has been observed. In the first reaction the upper limit for the production of narrow baryonium states is 8 $\mu\text{b/sr}$ for a 3 standard deviation signal with 4 MeV/c² width. In the second reaction this limit is 10 $\mu\text{b/sr}$. The second reaction is rather insensitive for observation of baryonium states as it is dominated by quasi-free contributions.

(Submitted to Nuclear Physics B)

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 - *) Supported by the Bundesministerium für Forschung und Technologie, Germany.

1. INTRODUCTION

Following the observation in 1974 of a narrow resonance in the $\bar{p}p$ system with a mass of $1932 \text{ MeV}/c^2$ [1], many other narrow resonances were observed in the baryon-antibaryon channel. (For recent reviews see, for example, ref. [2].) These resonances were usually associated with the name "baryonium", implying that the observed states should be coupled strongly to the nucleon-antinucleon ($N\bar{N}$) system rather than being mesons of normal type.

In the conception of nuclear physics, baryonium represents a quasi-nuclear state made out of $N\bar{N}$ [3]. Here stability would require high angular momentum states for which annihilation should be hindered by the centrifugal barrier. In the quark model, baryonium is an exotic meson composed of a diquark and an antidiquark [4]. It may be stable owing to some selection rule, analogous to the Okubo-Izuka-Zweig rule or, as in the nuclear model, because of the centrifugal force between the diquark and antidiquark. According to this model one expects narrow states below and close above the threshold. At higher masses the decay into the $N\bar{N}$ channel would broaden the states. This type of baryonium state called T baryonium has diquark and antidiquark in the $3 \times \bar{3}$ colour symmetry -- this means in the same colour symmetry as the diquark and antidiquark in proton and antiproton. Furthermore, the existence of M baryonium states was suggested. Their stability is ascribed to the internal colour coupling $6 \times \bar{6}$. However, their masses are predicted above the mass range studied in this paper.

In the fall of 1977 the possible existence of about 10 narrow baryonium states was reported in the literature [2]. Motivated by these findings, we started a further search for narrow baryonium states in the $N\bar{N}$ system. Since bound states and resonances close to the $N\bar{N}$ threshold should be the most narrow and consequently the easiest to identify, we concentrated our search in this mass region. The best established resonance was the so-called S meson at a mass of about $1936 \text{ MeV}/c^2$ corresponding to $60 \text{ MeV}/c^2$ above the $N\bar{N}$ threshold. The experiments, however, differ in their results for the mass and the width of this resonance [5]. Less well

established were three bound states at 1684, 1646, and 1395 MeV/c² in the inclusive gamma transition spectrum from antiprotons stopped in liquid hydrogen [6]. Further resonances have been reported above 2 GeV/c² (see, for example, Ref. [2]).

2. MOTIVATION OF THE EXPERIMENT

Two reactions were selected for the search presented in this paper. The first one, $\bar{p}p \rightarrow \pi^- X$, covered the mass spectrum between 1.4 and 2 GeV/c² of the baryonium here denoted as X. In this reaction the antiproton momentum was 1.3 GeV/c and the pion momentum was measured from 0.29 to 0.87 GeV/c. In the second reaction, $\bar{p}d \rightarrow pX$, baryonium states were searched for, in the mass region between 1.75 and 2 GeV/c², by using antiprotons of 650 and 810 MeV/c and measuring proton momenta from approximately 0.6 to 0.85 GeV/c.

The idea of the reaction $\bar{p}p \rightarrow \pi^- X$ can be perceived by analysing fig. 1. On one hand baryonium states can be produced by a baryon exchange in the t-channel (figs. 1a and b).*) Comparing fig. 1a with fig. 1b, it is seen that the reaction with a pion is favoured over that with a gamma, since the strong interaction coupling constant is greater than the electromagnetic one. This means that this reaction is complementary to the measurement of inclusive γ -spectra which have been studied already experimentally and theoretically [6]. On the other hand, this reaction can be interpreted in terms of s-channel formation. In this way, a pion transition from a higher to a lower mass baryonium state is generated (fig. 1c). Another stimulation to use this reaction for baryonium search was its analogy to the reaction $pp \rightarrow \pi^+ d$ shown schematically in fig. 1f. This reaction is known to have the highest yield of 1.4 mb/sr in the forward direction at a proton momentum of 1.3 GeV/c [8]. The energy dependence of the production cross-section is thought to be due to the Δ resonance in the pion-nucleon vertex as shown in fig. 1g. It is however difficult to predict whether any similar mechanism would also enhance baryonium production. But the choice of the 1.3 GeV/c antiprotons was also motivated by the strong intensity at this momentum being the highest possible with this

) It should be noted that a baryon exchange can also be generated by using an incoming pion and an outgoing proton (fig. 1d). This mechanism has been used to explain two resonances which were observed in the Omega spectrometer at CERN with masses of 2020 and 2200 MeV/c² [7]. In the Omega experiment, incoming pions had momenta of 9 and 12 GeV/c and outgoing baryons were N^ and Δ (fig. 1e).

beam line. The cross-sections for the γ and π emission to baryonium states have been calculated by Dosch and Povh in a non-relativistic approximation [9]. The result indicates an enhancement of a factor of about 10 for the pionic transitions over the γ transitions.

The second reaction $\bar{p}d \rightarrow pX$, was measured in the kinematical region that is characteristic for a knock-out reaction. The proton momentum is close to that of the antiproton; the antiproton replaces the proton in the deuteron and has small momentum relative to that of the neutron. Therefore one should have an increased probability of observing possible baryonium resonances in the antiproton-neutron system. In addition, by varying the outgoing angle of the proton, one has a control over the angular momentum transfer in the reaction. In this way, production of resonances with different angular momenta can be selected. A more detailed discussion of this reaction will be given in section 6.

There are, however, two major restrictions to these reactions. First of all, only baryonium states with isospin equal to one can be observed. Secondly, only T baryonium states are produced. This is due to the fact that the baryonium state is produced in a "soft" process, in contrast to production experiments performed at higher energies, such as, for example, experiments with the Omega spectrometer at CERN [7].

3. EXPERIMENTAL SET-UP

The experiment was performed at the Proton Synchrotron of CERN. Figure 2 shows the experimental apparatus. The antiproton momentum was measured in the last part of the beam with an accuracy of about 3 MeV/c. The relative momentum acceptance of the beam was $\Delta p/p = 1.1\%$ (r.m.s.). Both the pion and proton momenta were measured in the SPES II spectrometer from Saclay. The angular and momentum acceptances of this spectrometer are 20 msr and $\pm 18\%$ respectively. The momentum was measured with a precision of 600 keV/c. The identification of the incoming $\bar{p}$ was done basically by measuring the time of flight between the scintillators H_{ent} and T. For the highest $\bar{p}$ momenta (1.3 GeV/c) additional identification was required

at the entrance of the antiproton spectrometer. This was accomplished by means of a Čerenkov hodoscope filled with the liquid FC88 (Dow Chemical Corporation; refractive index $n = 1.24$). The particle identification of the reaction products was achieved by the measurement of the time of flight between T and H_{ext} . Furthermore, the knowledge of coordinates at the exit of the SPES II spectrometer, and its known transfer matrix allowed the calculation of particle coordinates at the target. Comparison of the reconstructed coordinates at the target with those measured by means of the wire chambers W_3 and W_4 , was a powerful cut against background from antiproton annihilation inside the SPES II spectrometer.

The experimental apparatus was completed by 9 scintillator slabs which formed a hodoscope around the target and covered a solid angle of about 8 sr.

4. EXPERIMENTAL RESULTS: REACTION $\bar{p}p \rightarrow \pi^- X$

In order to measure this reaction the antiproton spectrometer was set at its maximal nominal momentum of 1.3 GeV/c. About 6 different settings of the SPES II spectrometer were necessary to cover the mass range of baryonium m_X between 1.55 and 1.95 GeV/c². For this purpose the nominal momentum of the SPES II spectrometer was varied between 320 and 720 MeV/c. This allowed the measurement of pion momenta between 290 and 870 MeV/c. In all the settings the pion spectrometer was set at 15° in order to facilitate the reconstruction of the coordinates of the wanted reaction, and in this way to reject background.

For a further background reduction, two off-line cuts were very effective. Firstly, the interaction angle could be measured with the four chambers (W_1 - W_4) in front of and behind the target. Since the wanted pion from the reaction had to leave the target at an angle of 15°, one could reject unwanted non-interacting beam particles which did not change their angle. Secondly, knowing the coordinates of the particles at the exit of the SPES II spectrometer one could reconstruct their corresponding coordinates at the target with good accuracy. Comparing the reconstructed coordinates with those measured at the target, one could reject particles coming from the beam interactions in the walls of the pion spectrometer. Finally, additional cleaning was performed by demanding at least one hit in the target hodoscope -- selecting events with annihilation in the target -- and by

restricting the limits of the pion time of flight after a correction of the variations in its path length in the spectrometer.

The mass spectra were then corrected for the acceptance for every setting of the spectrometer separately, summed up for every mass bin. The sum of these spectra is presented in fig. 3. The background contamination has been measured with empty target and is less than 10%.

The mass spectrum presented in fig. 3 does not show any evidence for the presence of resonances. The upper limit extracted from this measurement for baryonium production is 8 $\mu\text{b/sr}$ for a 4 MeV/c^2 wide, 3 standard deviation signal. The spectra for the different multiplicities in the target hodoscope were also investigated, but no baryonium production can be reported either.

5. EXPERIMENTAL RESULTS: REACTION $\bar{p}d \rightarrow pX$

As was mentioned above, this reaction was measured in the energy range that is characteristic for the knock-out reaction. Therefore the incoming momentum of the antiproton was close to that of the outgoing proton. The antiproton momenta chosen were 650 and 817 MeV/c . The central momentum of the proton was taken at 723, 683, and 676 MeV/c and the measured momentum range as defined by the spectrometer SPES II was $\pm 15\%$. The outgoing angle of the proton was varied between 0° and 30° . In this way one had control over the angular momentum transfer in the reaction, allowing a selection of quantum numbers of baryonium.

It is worth while to note that it was much easier to identify this reaction than the reaction $\bar{p}p \rightarrow \pi^- X$ presented in the previous section. The incoming momentum of the antiproton was smaller, and the substantial energy-loss difference of the antiproton and pion in the counter T (fig. 2) allowed easier identification of the antiproton. Since the polarity of the magnetic field in the SPES II spectrometer is opposite to that of the antiproton beam, the passing particles from the beam line could not reach the exit chambers of the proton spectrometer. Therefore the "standard" selection criteria, like selection of the time of flight and the reconstructed coordinates at the target, allowed identification of the reaction

$\bar{p}d \rightarrow pX$ practically without background. In addition, the information from the target hodoscope H_{tar} allowed the collection of a signal of reaction products.

The missing-mass spectra, obtained after these selection criteria have been applied, are presented in fig. 4 for different spectrometer settings. The experimental energy resolution of $3 \text{ MeV}/c^2$ corresponds to one and a half bins in each spectrum. The background contamination is estimated to be smaller than 1%. This estimate is based on empty target measurements.

The most characteristic feature of the spectra presented in fig. 4 is the prominent peak right above the two-nucleon threshold. Its width increases with the reaction angle from $10 \text{ MeV}/c^2$ at 0° to $32 \text{ MeV}/c^2$ at 25° . This peak together with the smooth background can easily be interpreted with the diagrams shown in fig. 5, as will be discussed in section 6. They represent the simplest and most significant reaction mechanisms which lead to a proton recorded in SPES II. The graph in fig. 5a represents the usual quasi-free scattering in which the antiproton, after a head-on collision with the proton, does not interact with the spectator neutron. The graphs in figs. 5b and c are similar except that the antiproton elastically scatters on the neutron (b) or annihilates with it (c). In the graph in fig. 5d the antiproton annihilates with the neutron and the spectator proton is knocked out by a pion of annihilation. The contribution of the graph in fig. 5a can be estimated via standard calculations; it produces the peak just above threshold. The shape of this peak is determined by the Fermi momentum of the proton in the deuteron. Obviously such a reaction mechanism cannot induce any baryonium production. On the other hand the graphs in figs. 5b and c may contain baryonium production. In both cases the final-state interaction can be non-resonant or resonant, i.e. corresponding to baryonium production. Therefore, one should search for narrow baryonium peaks on top of the smooth non-resonant contribution which can be well described theoretically.

Fortunately, it is possible to distinguish experimentally the different reaction channels since in the direct annihilation (figs. 5c and d) there are besides the proton only pions in the final state, while in the two other channels (figs. 5a

and b) the antiproton leaves the interaction region, travels for some time, and then annihilates in the target or outside the target. Since the kinematics determine a low antiproton velocity the time of flight is long enough to be measured. Therefore one may observe a difference in the timing of the target hodoscope H2 for these two different cases.

An example of a typical time-mass scatter plot is presented in fig. 6a. It shows the quasi-elastic events delayed by about 1 ns compared to the annihilation events. The disentangled spectra are presented in figs. 6b, c, and d. Despite the fact that this cut does not allow an absolutely clean separation between different channels, it is very useful for two reasons. First of all it shows that the interpretation of the spectra presented above was correct, and secondly it allows a search for baryonium production in different channels separately.

An inspection of the spectra with the best statistics (figs. 7a and 9a) does not reveal any statistically significant signal for baryonium. The cross-section for a 3 standard deviation signal and a width of $4 \text{ MeV}/c^2$ is $10 \text{ } \mu\text{b}/\text{sr}$, which can be considered as an upper limit.

6. THEORETICAL ANALYSIS OF THE REACTION $\bar{p}d \rightarrow pX$

In order to understand the deuteron spectra quantitatively one has to calculate the contributions to the cross-section represented by the graphs in fig. 5. For this purpose we have used an adaptation of the calculations of Dosch and Hepp [10] for the $K^-d \rightarrow \pi^- \Lambda p$ reaction. Corresponding to their arguments the following approximations and assumptions have been introduced:

- i) The Fermion propagators as well as the antiproton-proton scattering amplitude $\mathcal{T}$ were replaced by their mass-shell values. This is justified because only invariant masses close to the two-nucleon threshold are considered. Since the deuteron is a loosely bound system the internal momenta allow a sizeable cross-section in this region only. The amplitude $\mathcal{T}$ has been interpolated from the measurements of Eisenhandler et al. [11] at 690, 790, and 860 MeV/c.

ii) The antiproton neutron elastic amplitude $\mathcal{L}_{el}$ as well as the annihilation amplitude $\mathcal{L}_{inel}$ were taken at the mass shell at a momentum for the neutron $\vec{n} = \vec{d}/2$, where $\vec{d}$ is the deuteron momentum. These amplitudes have to be calculated close to the two-nucleon threshold ($p \lesssim 800$ MeV/c), where data are scarce and not very accurate. Since the $\bar{p}n$ and $\bar{p}p$ total cross-sections are the same above 1 GeV/c it was assumed that they are equal below 800 MeV/c too. Their values have been extrapolated from the compilation in ref. [12].

With these simplifications, the cross-section for the quasi-elastic channel (figs. 6a and b) can be written as

$$\begin{aligned} d\sigma_{el} = & \frac{1}{(2\pi)^{15}} \frac{(2\pi)^2}{\sqrt{s^2 - 4sm^2}} (2m)^6 |\mathcal{J}|^2 \times \\ & \times \left| -\frac{F(t)}{t - m^2} + \frac{2m^2}{(2\pi)^8} \mathcal{L}_{el} \mathcal{F}(v, w, s) \right|^2 \times \\ & \times \frac{d^3 \bar{p}'}{2\bar{p}'_0} \frac{d^3 n'}{2n'_0} \frac{d^3 p'}{2p'_0}, \end{aligned} \quad (1)$$

where $\bar{p}'$, p' , and n' are the momenta of the antiproton, the proton, and the neutron in the final state, respectively. The kinematic variables are defined by

$$s = (\bar{p} + d)^2, \quad t = (d - n)^2, \quad w = \bar{p} - p', \quad v = M_X^2 = (d + \bar{p} - p')^2. \quad (2)$$

The function $\mathcal{F}(v, w, s)$ and the deuteron form factor $F(t)$ which has been calculated with a relativistic generalization of the Hulthén wave function are the same as in ref. [10].

For the inelastic cross-section of fig. 6c the following expression can be derived:

$$\begin{aligned} d\sigma_{inel} = & \frac{1}{(2\pi)^{25}} \frac{(2\pi)^2}{\sqrt{s^2 - 4sm^2}} (2m)^7 |\mathcal{J}|^2 |\mathcal{F}|^2 \times \\ & \times \frac{1}{2} \sum_K \left| \mathcal{L}_K^{inel} \right|^2 R_{n-1}(p + d - p') \frac{d^3 p'}{2p'_0}, \end{aligned} \quad (3)$$

where R_{n-1} is the phase space of the annihilating $\bar{p}n$ system.

Since it cannot contribute to any baryonium production, the pion back-scattering of fig. 5 has not been calculated. However, as will be seen later, this contribution constitutes an important background to the annihilation channel [13].

In order to compare our calculations with our data we have separated the quasi-elastic and annihilation contributions. Figure 7 shows this for the mass spectrum at the scattering angle of 25° . The upper part depicts the complete spectrum. From this the annihilation contribution as determined according to fig. 6 has been subtracted, yielding the quasi-elastic contribution shown in fig. 7b. The full curve represents our calculation of the contributions of figs. 5a and b, whereas the dashed line neglects the final-state interaction (fig. 5b) and shows the contribution of fig. 5a alone. Considering the accuracy of our cross-section calibration of about 10% the agreement is good. It is important to note that the small contribution of the final-state interaction is the amplitude into which possible baryonium states would enter. For illustration we consider the elastic signal for the S meson seen in ref. [14]. On the basis of our model, it would be equivalent to a signal of $0.6 \mu\text{b/sr}$ with a width of $4 \text{ MeV}/c^2$. The annihilation part of the cross-section is depicted separately in fig. 8. After subtraction of a smooth curve we obtain a bump which agrees quantitatively with the result of our calculation of the annihilation channel [fig. 5c and eq. (3)]. By far the most important contribution stems, however, from the non-resonant amplitude of fig. 5d. Any resonance would give an evanescent signal on top of the little contribution from the final-state annihilation. For the S meson [14] one would get a signal of $0.1 \mu\text{b/sr}$.

This finding is the quantitative corroboration of the qualitative result in ref. [15], who investigated the $\bar{p}d$ annihilation channels in a bubble-chamber experiment. However, the initial-state interaction in ref. [15] would account for a very small part of the annihilation only.

In a similar counter experiment [16] in which the $\bar{p}d \rightarrow nX$ knock-out reaction was investigated no signal for baryonium states has been observed with a limit of $180 \mu\text{b/sr}$ for a 4 standard deviation signal. Unfortunately, it is not possible to

apply our considerations to the results of ref. [16], since this experiment has been performed in a different kinematical region, i.e. at reaction angles larger than 45° . In this region the validity of our model is limited. However, qualitatively one might interpret the broad bump in the annihilation as being largely due to the annihilation of the slow recoil $\bar{p}$ in a second interaction in the target. This means it is caused by the quasi-elastic scattering and not by the small contribution from the direct final-state annihilation. It is not evident that the observation of baryonium in this kinematical region is possible.

A further comparison of measurement and calculation is given in fig. 9 for a scattering angle of 0° . For this angle we can no longer disentangle the two contributions, since the recoil antiproton is so slow that it annihilates quickly in the target and cannot be separated in time from the direct annihilation. In order to compare, nevertheless, we have drawn the smooth line indicated in fig. 9a as the non-resonant annihilation. Figure 9b again shows almost perfect agreement. The subtraction does not take into account the final-state annihilation contributing only 4% in the maximum.

7. CONCLUSIONS

The limits on the production cross-section of the narrow baryonium states in the reaction $\bar{p}p \rightarrow \pi^- X$ with the incoming antiproton momentum of 1.3 GeV/c were presented above. These limits exclude the existence of baryonium of the "nuclear type", where the baryonium is a large object composed of a nucleon and an anti-nucleon, similarly to the deuteron composed of a proton and a neutron. The production cross-section for such states was calculated by Dosch and Povh [9], and the limits on the production cross-section presented here are lower by a factor of about 10 than those calculated.

In view of the failure of our search, the positive result of the gamma-ray experiment is puzzling. Since the pion transition to the baryonium state should be more probable than the gamma transition as shown in ref. [8], one can rule out the possibility that the states with masses of 1684, 1646, and 1395 MeV/c², reported in ref. [6], have isospin 1.

Of course, the limits on the baryonium production obtained here cannot exclude the existence of the "quark-type baryonium" composed of the diquark and the antidiquark with the structure very different from that of the deuterium, because the production cross-section for such states cannot be calculated since a detailed model does not exist. In addition, the existence of many broad and overlapping baryonium resonances which sum up to form a continuum cannot be excluded.

The results of the $\bar{p}d$ reaction are not more decisive. The non-observation of the S meson is theoretically understandable. However, the estimate of a possible contribution of the S meson may be too pessimistic because we did not consider the enhancement due to the finite momentum transfer in our model calculations. On the other hand, the angular momentum of this resonance is not known and all statements would be speculative. It is, however, suitable to note that the two amplitudes in which the expected baryonium resonances would manifest themselves are small contributions to the quasi-elastic and the pion back-scattering, respectively. The statistical accuracy is consequently governed by these backgrounds. Statistics orders of magnitude higher are therefore required in order to make this reaction meaningful as a search for baryonium.

The discussion of both experiments depends on theoretical concepts, the predicting power of which cannot be estimated very well. One should not take our negative results as a general proof against baryonium.

Acknowledgement

It is a pleasure to thank H.G. Dosch for clarifying discussions and his adaption of the theoretical formulae to our reaction.

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Fig. 5

Fig. 6

Figure captions

- Fig. 1 Graphs for the reactions discussed in Section 2.
- Fig. 2 Experimental set-up: P = production target, M_i = magnetic dipoles, ES = electrostatic separator, S = collimator, H_{ent} = entrance hodoscope, $H_{x,y}$ = X- and Y- hodoscopes, W_i = multiwire proportional chambers, T = target scintillator, H_{tar} = target hodoscope, H_{ext} = exit hodoscope, E_1, E_2 = exit scintillators.
- Fig. 3 Missing mass spectrum for the reaction $\bar{p}p \rightarrow \pi^- X$ at a momentum of 1300 MeV/c and a scattering angle of 15° . This spectrum represents the sum of 6 different settings of the π spectrometer, which have individually been corrected for the spectrometer acceptance.
- Fig. 4 Missing mass spectra for the reaction $\bar{p}d \rightarrow pX$ for the following settings of spectrometer angle beam momentum $p_{\bar{p}}$ and central spectrometer momentum p_p : a) 0° , $p_{\bar{p}} = 650$ MeV/c, $p_p = 723$ MeV/c; b) 0° , $p_{\bar{p}} = 817$ MeV/c, $p_p = 700$ MeV/c; c) 15° , $p_{\bar{p}} = 650$ MeV/c, $p_p = 723$ MeV/c; d) 15° , $p_{\bar{p}} = 817$ MeV/c, $p_p = 723$ MeV/c; e) 25° , $p_{\bar{p}} = 817$ MeV/c, $p_p = 680$ MeV/c.
- Fig. 5 Graphs representing the discussed model of the reaction $\bar{p}d \rightarrow pX$: a) quasi-free scattering, b) final-state elastic scattering, c) final-state annihilation, d) direct annihilation with backscattering of a pion.
- Fig. 6 Separation of the quasi-elastic and annihilation contributions to the cross-section of $\bar{p}d \rightarrow pX$ at a scattering angle of 25° : a) scatter-plot of missing mass versus target hodoscope time of flight (TOF); the arrows indicate the position of the cut in TOF, b) complete spectrum, c) events with short TOF: 'annihilation', d) events with long TOF: 'quasi-elastic scattering'.
- Fig. 7 a) Cross-section for the measurement of $\bar{p}d \rightarrow pX$ at 25° , b) Comparison of the quasi-elastic cross-section with the result of the calculation. The quasi-elastic contribution has been obtained by the TOF separation. The results of the calculation including final-state interaction are shown as a full line; the dashed line indicates the results without final-state interaction.

Fig. 8 a) The annihilation part of the cross-section depicted in fig.7a; the full line indicates the smooth background which has been subtracted for the comparison shown in (b) with the calculated contribution corresponding to the graph in fig. 5c. The kink in the theoretical curve originates from a too large real part of the amplitude function $\tilde{F}(v,w,s)$. The real part is calculated [10] from the imaginary part by approximating the amplitude in the final-state vertex by a constant rather than introducing a realistic mass dependence.

Fig. 9 a) Cross-section for the measurement of $\bar{p}d \rightarrow pX$ at 0° and $p_{\bar{p}} = 817$ MeV/c. The full line indicates the background subtracted to obtain the shape of the quasi-elastic peak. b) Comparison of the quasi-elastic cross-section with the model calculation. The full line represents the results of the calculation including the final-state interaction, the dashed line indicates the results without final-state interaction.

Fig. 1

Fig. 3

Fig. 4

Fig. 7

Fig. 8

Fig. 9