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Can four-quark states be easily detected in baryon-antibaryon scattering?

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We attempt to explain the experimental sparsity of diquonia candidates given the theoretical abundance of such states. We do this by investigating the lowest-order contributions of such states as intermediates in $p\bar{p}$ scattering into exclusive baryon-antibaryon final states. We find that the contributions depend on the partial widths for the meson-meson decays of the diquonia, and that resonant effects can be easily made to disappear. We conclude that if the meson-meson widths of diquonia are larger than about 50 MeV, most of these states will be extremely difficult to observe in $p\bar{p}$ scattering, for instance. We note that diquonia may offer a convenient means of describing some aspects of the dynamics of baryon-antibaryon scattering.

I. INTRODUCTION

In a recent paper,[1] we listed the SU(3) multiplets of T diquonia, and evaluated the partial and total widths into exclusive baryon-antibaryon channels. For the baryons, we also used the SU(3) multiplets. We found that while some of the total widths were very large (>500 MeV), many were quite small and could be detectable experimentally (<10 MeV).

The number of SU(3) multiplets we studied was quite large, but this number was consistent with the number of states investigated by other authors, who assumed that SU(2) was valid.[2–8] A few authors have also studied diquonia with strangeness,[9–11] while Ono[12] has presented the mass spectrum for diquonia with strangeness as well as charm. It is somewhat puzzling, therefore, that of the very large number of states predicted by theorists, very few candidates have been seen experimentally,[13] and of these, none are firmly established.

In this paper, we address this puzzle by looking at the baryon-antibaryon ($B\bar{B}$) decays of diquonia. In particular, we evaluate the partial and total widths for decay into $B\bar{B}$ channels, and use these to estimate the lowest-order contributions of these states to the cross sections of a few $B\bar{B}$ scattering processes. In doing this, we are assuming that the scattering process takes place via the mechanism illustrated in Fig. 1. We limit the discussion to $p\bar{p}$ scattering between 2 and 3 GeV, since this should be sufficient to illustrate why many more diquonia candidates have not been observed experimentally.

Let us emphasize that we are not undertaking a complete calculation of $p\bar{p}$ scattering cross sections, as this would require the inclusion of many contributions that have no bearing on the point we are investigating. We comment further on this later.

The paper is organized as follows. Sec. II lists the diquonia states that we study, as well as their partial and total $B\bar{B}$ widths. We also comment briefly on these widths in this section. The cross sections for $p\bar{p}\to B\bar{B}$ are calculated and discussed in Sec. III, while conclusions are presented in Sec. IV.

II. STATES AND WIDTHS

The diquonia that we study are assumed to consist of an S-wave diquark and an S-wave antiquark, with some relative orbital angular momentum L between them. The diquark may belong to a sextet ($\mathbf{6}$) or antitriplet ($\bar{\mathbf{3}}$) of color, while the antidiquark may be a member of an antisextet ($\bar{\mathbf{6}}$) or triplet ($\mathbf{3}$). For a color-singlet hadron, the color content of the diquonium state must be ($\bar{\mathbf{3}}\mathbf{3}$) or ($\mathbf{6}\bar{\mathbf{6}}$), where the color multiplet of the diquark is mentioned first. For decays into baryon pairs in the $^3P_0$ model, only the ($\bar{\mathbf{3}}\mathbf{3}$) or true diquonia are of interest.

Since we are interested in processes such as $p\bar{p}\to B\bar{B}$, we need consider only diquonia that can couple to $p\bar{p}$ pairs. These diquonia will therefore not possess any strange quarks, although decays into baryons with strangeness are allowed, through vacuum creation of a strange-quark pair. We can therefore classify the states using the notation of SU(2). Note, however, that when we calculate the masses of the diquonia, we explicitly break this symmetry by choosing the d quark to be 6 MeV heavier than the u quark. This allows us to look at the effects due to nearly degenerate states. For this reason, we classify the states by their quark content. The

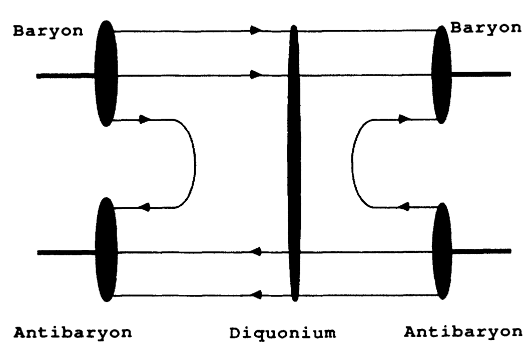

FIG. 1. Baryon-antibaryon scattering via diquonium intermediate.

nine types of diquonia states that may decay into $p\bar{p}$ pairs are shown in Table I.

Let us note here that our states are flavor eigenstates, not isospin eigenstates. The effects of isospin mixing do not modify the results and conclusions that we present significantly. Such mixing appears only for the C states of Table I, and would change the magnitude of the cross sections (by factors of the order of unity) but would not modify the effects that we wish to demonstrate.

To evaluate the masses of these states, we use an additive potential consisting of a linear confining term, together with a short-range spin-spin term and a Coulomb term. The form used is the same as in Ref. 1. The procedure we use to evaluate the masses is also described in some detail in that reference, so we refer the interested reader to that work.

The masses obtained are shown as Regge-type trajectories in Table I. Note that, as in Ref. 1, the masses of our A states are smaller than those reported elsewhere.[2,3,5] The consequences of this will be discussed in the next section. For the purposes of this paper, we discuss only the 41 states with masses greater than the $p\bar{p}$ threshold, but less than 3.2 GeV.

To calculate the $B\bar{B}$ partial widths of these states, we use the ${}^3P_0$ vacuum pair-creation model, where we assume that u, d, and s pairs may be created with equal probability. The model is illustrated in Fig. 2, and is discussed in detail elsewhere.[14] The partial and total widths obtained are given in Table II, where only states with total widths greater than 10 MeV are shown, and we have limited the discussion to baryons from the ground-state octet and decuplet: we do not include orbitally excited baryons. Note that when we evaluate cross sections, we use all of the partial widths, even the very small ones. It would appear that this is not the case in the work of Barbour and Gilchrist,[5] who also estimate the contributions of diquonia to the cross sections for some $N\bar{N}$ scattering processes.

Let us mention here that not all states are shown in Table II. As mentioned in the previous paragraph, we have omitted states with total baryon-antibaryon widths less than 10 MeV. We also show only a half of the B states: the omitted ones are the charge-conjugate partners of those shown. In addition, for the C states, we do not show all of the decay channels. A C state that can decay into a channel such as $n\bar{\Delta}^0$ will also decay into the charge-conjugate channel $\Delta^0\bar{n}$, with the same partial width. In the table, only one of each pair of such channels is shown.

TABLE I. Diquonia states, quark content and masses. S (column 3) is the total spin of the state.

State	Quark content	S	M^2 (GeV^2)
A	$(ud-du)(\bar{u}\,\bar{d}-\bar{d}\,\bar{u})/2$	0	$1.26L+1.08$
B	$(ud+du)(\bar{u}\,\bar{d}-\bar{d}\,\bar{u})/2$	1	$1.46L+2.23$
B	$(ud-du)(\bar{u}\,\bar{d}+\bar{d}\,\bar{u})/2$	1	$1.46L+2.23$
C	$(ud+du)(\bar{u}\,\bar{d}+\bar{d}\,\bar{u})/2$	0	$1.742L+2.270$
C	$uu\bar{u}\,\bar{u}$	0	$1.736L+2.292$
C	$(ud+du)(\bar{u}\,\bar{d}+\bar{d}\,\bar{u})/2$	1	$1.692L+2.627$
C	$uu\bar{u}\,\bar{u}$	1	$1.686L+2.645$
C	$(ud+du)(\bar{u}\,\bar{d}+\bar{d}\,\bar{u})/2$	2	$1.470L+3.957$
C	$uu\bar{u}\,\bar{u}$	2	$1.467L+3.959$

Before going on to discuss cross sections, a few brief comments on these partial and total widths are in order. First, we point out that many of the partial widths are similar to those obtained for the corresponding multiplets presented in Ref. 1. For instance, the partial widths of the C states into $p\bar{p}$ are small, while the widths into $\Delta^{++}\bar{\Delta}^{++}$ are very large, and are by far the dominant contribution to the total widths of these states. In general, decays of C states into pairs of baryons from the decuplet dominate over decays into pairs from the octet. The A states have the largest partial widths into $p\bar{p}$ and $n\bar{n}$, while the B states are intermediate between the A and C states, as is the case in Ref. 1. In addition, as in Ref. 1, we find that there are states of T diquonia that have very small baryon-antibaryon total widths, with no admixture of M diquonia.

III. CROSS SECTIONS

To evaluate the cross section for the process $p\bar{p}\to B\bar{B}$ via diquonia intermediates, we use the prescription of Ref. 5: for scattering from a pair of baryons with total spin j to a pair with spin j', the cross section is

$$\sigma_{jj'}=\frac{\pi}{k^2}\sum_{J,l,l'}(2J+1)\left|\sum_{L,S}\frac{M\mathcal{M}(l,j,k)\mathcal{M}(l',j',k')}{E^2-M^2-iM\Gamma}\right|^2,$$

where Γ is the total width of the intermediate diquonium state, M is its mass, and $\mathcal{M}(l,j,k)$ are the amplitudes calculated in the ${}^3P_0$ model, with phase-space factors included (the $\mathcal{M}$ are the $\Gamma^{1/2}$ of Ref. 5). J is the total angular momentum of the intermediate diquonium, L is its orbital angular momentum and S is its total spin. k is the three-momentum of the initial pair of baryons, k' is that of the final pair, E is the total center-of-momentum energy of either pair, and $l,l'=L\pm1$. Note that k and k' are evaluated off shell. The second summation includes summation over all the internal (magnetic) quantum numbers of each diquonium, as well as summation over all the diquonia states with a given J. Note that for most of the

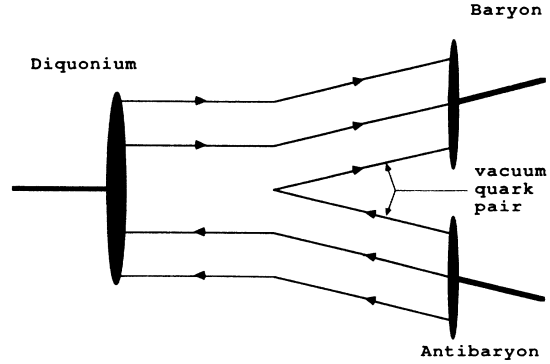

FIG. 2. Diquonium decay into a baryon-antibaryon pair in the vacuum pair-creation model.

TABLE II. Baryon-antibaryon partial and total decay widths of diquonia.

State (mass)	Widths (MeV)							
	Partial							Total
	$p\bar{p}$	$n\bar{n}$	$p\bar{\Delta}^+$	$n\bar{\Delta}^0$	$\Delta^+\bar{\Delta}^+$	$\Delta^0\bar{\Delta}^0$	$\Delta^{++}\bar{\Delta}^{++}$	
B(1.9144)	18	18	0	0	0	0	0	36
C(2.0936)	28	0	0	0	0	0	0	28
C(2.0945)	28	28	0	0	0	0	0	56
A(2.1515)	53	52	0	0	0	0	0	105
B(2.2417)	30	30	0	0	0	0	0	60
C(2.2960)	19	19	26	26	0	0	0	142
C(2.2963)	19	0	6	0	0	0	0	32
C(2.3935)	2	2	20	20	0	0	0	84
C(2.3956)	2	0	5	0	0	0	0	12
A(2.4315)	79	78	0	0	0	0	0	159
C(2.4584)	7	7	28	27	0	0	0	124
C(2.4597)	7	0	7	0	0	0	0	21
B(2.5383)	49	48	0	0	0	0	0	100
C(2.5617)	20	20	39	39	122	118	0	438
C(2.5618)	20	0	10	0	8	0	621	671
A(2.6928)	99	99	0	0	0	0	0	201
C(2.7450)	4	4	53	52	81	79	0	384
C(2.7457)	4	0	13	0	5	0	412	452
C(2.7759)	9	9	55	54	109	108	0	460
C(2.7761)	9	0	14	0	7	0	556	606
B(2.8134)	57	57	0	0	0	0	0	119
C(2.8296)	19	0	12	0	11	0	901	969
C(2.8299)	19	19	50	50	177	175	0	602
A(2.9422)	107	106	0	0	0	0	0	218
C(3.0423)	4	0	18	0	9	0	699	763
C(3.0429)	4	4	73	73	138	136	0	589
C(3.0587)	8	0	17	0	10	0	834	904
C(3.0594)	8	8	67	66	164	162	0	627
B(3.0721)	54	54	0	0	0	0	0	116
C(3.0891)	16	0	13	0	14	0	1130	1209
C(3.0901)	16	16	51	50	223	220	0	700
A(3.1793)	99	99	0	0	0	0	0	203

State (mass)	Widths (MeV)				
	Partial				
	$\Lambda\bar{\Lambda}$	$\Sigma^0\bar{\Lambda}$	$\Sigma\bar{\Sigma}$	$\Sigma\bar{\Sigma}^*$	$\Sigma^*\bar{\Sigma}^*$
A(2.4315)	1	0	0	0	0
C(2.4584)	0	0	1	0	0
C(2.4597)	0	0	1	0	0
B(2.5383)	0	3	0	0	0
C(2.5617)	0	0	3	0	0
C(2.5618)	0	0	4	0	0
A(2.6928)	3	0	0	0	0
C(2.7450)	0	0	1	2	0
C(2.7457)	0	0	1	2	0
C(2.7759)	0	0	2	3	0
C(2.7761)	0	0	2	3	0
B(2.8134)	0	6	0	0	0
C(2.8296)	0	0	7	3	1
C(2.8299)	0	0	7	3	1
A(2.9422)	5	0	0	0	0
C(3.0423)	0	0	2	6	2
C(3.0429)	0	0	2	6	2
C(3.0587)	0	0	4	6	3
C(3.0594)	0	0	4	5	3

TABLE II. (*Continued*).

State (mass)	Widths (MeV)				
	Partial				
	$\Lambda\bar{\Lambda}$	$\Sigma^0\bar{\Lambda}$	$\Sigma\bar{\Sigma}$	$\Sigma\bar{\Sigma}^*$	$\Sigma^*\bar{\Sigma}^*$
$B(3.0721)$	0	9	0	0	0
$C(3.0891)$	0	0	9	5	4
$C(3.0901)$	0	0	9	5	4
$A(3.1793)$	6	0	0	0	0

channels, symmetry considerations require $j=j'$.

The cross sections we obtain for $p\bar{p}\to p\bar{p}$, $n\bar{n}, \Sigma^+\bar{\Sigma}^+$, $\Lambda\bar{\Lambda}$, $\Sigma^0\bar{\Lambda}$, $\Delta^{++}\bar{\Delta}^{++}$, $\Delta^0\bar{\Delta}^0$, and $\Delta^0\bar{n}$ are shown in Figs. 3–10, respectively. Other channels show effects that are similar to those seen in one of the above channels. In these figures, the squares are the experimental data (where available) and the solid curves show the contribution to the cross section via diquonia intermediates with total widths exactly as calculated in the previous section. The long-dashed curve shows the contribution when the meson-meson decay widths of diquonia with $L=0$ is assumed to be 100 MeV, and those with $L=1$ is assumed to be 10 MeV. States with higher L may have negligible meson-meson decay widths, as the centrifugal barrier involved may be too large to be overcome. The dotted curves show the contribution when the meson-meson widths (and/or widths for decay into channels containing excited baryons) of all the diquonia are 50 MeV. Note that the solid curve and the long-dashed curve are indistinguishable for most of the cases shown.

Before discussing each of these figures individually, let us make a few general comments. First of all, we note that in all cases where experimental data[15] exist, the contribution to the cross section calculated herein is of the same order of magnitude as the data. In the case of $p\bar{p}$ final states, the theoretical contribution is always less than the experimental data, while for the other channels, it is much closer to the data and sometimes exceeds it. This may be understood in terms of the mechanism required for producing the specific final state. For $p\bar{p}$, the four-quark intermediate states does not give the leading contribution, which may come from a six-quark state. For other channels, on the other hand, the four-quark state is necessarily present in some form, since one pair of quarks must be annihilated and another pair of different flavor created.

The fact that the diquonia contribution exceeds the data for $n\bar{n}$ and $\Lambda\bar{\Lambda}$ may be traced to two related factors. The first is that the decay amplitudes grow like $k^l e^{-a^2k^2}$, where a is some constant, and k is the three-momentum magnitude of the baryon pair in the center-of-momentum frame. For large l, this form continues to grow for relatively large k, and k increases with energy since it is calculated off shell. For $n\bar{n}$ and $\Lambda\bar{\Lambda}$, the main resonant contributions come from the A states with $L=3$, 4, 5, 6, and 7, corresponding to $l=2-8$, and hence the cross sections continue to grow in the energy range shown. Note that this effect is present to a lesser extent in the $p\bar{p}$ channel as well.

The second and related factor is that our A states are too light. Thus, the states of a given mass correspond to

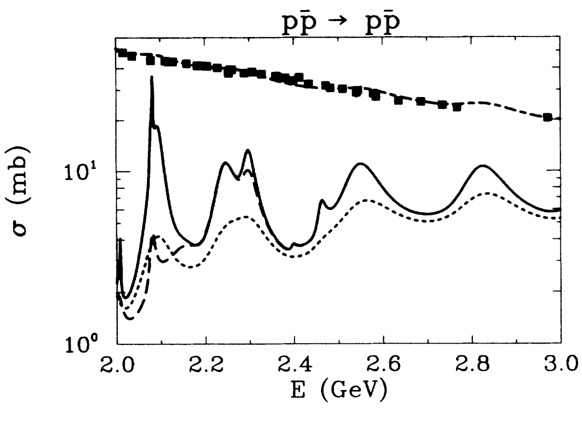

FIG. 3. Contribution of diquonia states to $p\bar{p}$ elastic scattering. The solid curves show the contribution to the cross section via diquonia intermediates with total widths exactly as calculated in Sec. II. The long-dashed curve shows the contribution when the meson-meson decay widths of diquonia with $L=0$ are assumed to be 100 MeV, and those with $L=1$ are assumed to be 10 MeV. All other states have zero meson-meson widths. The dotted curves show the contribution when the meson-meson widths (and/or widths for decay into channels containing excited baryons) of all the diquonia are 50 MeV. Note that the solid curve and the long-dashed curve are indistinguishable for most of the cases shown.

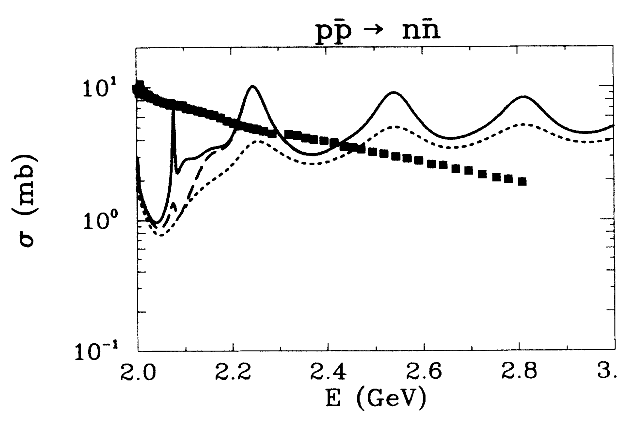

FIG. 4. Contribution of diquonia states to $p\bar{p}\to n\bar{n}$. Notation same as in Fig. 3.

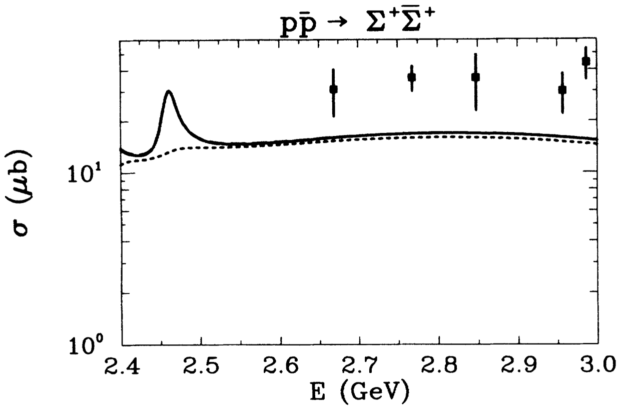

FIG. 5. Contribution of diquonia states to $p\bar{p}\to\Sigma^+\bar{\Sigma}^+$. Notation same as in Fig. 3.

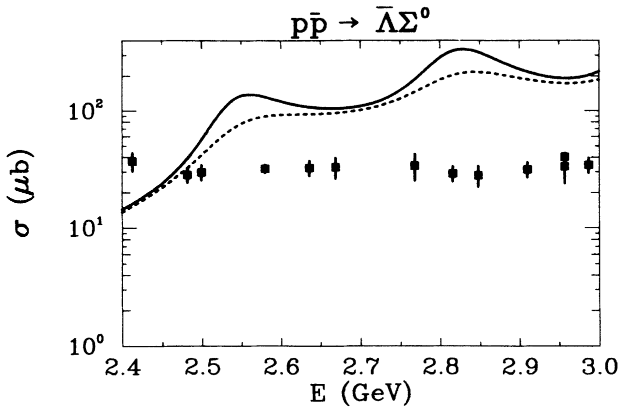

FIG. 7. Contribution of diquonia states to $p\bar{p}\to\Sigma^0\bar{\Lambda}$. Notation same as in Fig. 3.

an L that is too large. This means that more realistic values of L corresponding to the masses we have obtained (or equivalently, more realistic masses for a given L) would be smaller (larger). In addition, and perhaps more importantly, the larger phase volume available for heavier states makes these states broader, so that resonant effects become more difficult to observe. These effects are illustrated in Fig. 6, and are discussed in more detail later.

Perhaps the most striking feature of all these figures is the number of resonant features that are seen. For instance, in the elastic scattering channel, there are 27 diquonia states with masses between 2 and 3 GeV, but only eight structures are present in the cross section. The main reason for this is that many of the states are very broad, so that resonant effects in the cross sections due to such states are not easily discernible. This is especially so in the case of the C states, and a little less so in the case of the B states. In keeping with this, note that most of the resonant features seen in the figures correspond to A states. Let us look at each channel in some more detail.

$p\bar{p}\to p\bar{p}$ (Fig. 3): As mentioned before, it is clear that diquonia intermediate states do not provide the major contribution to $p\bar{p}$ elastic scattering. This, in fact, may be expected to come from processes in which one or more pairs of quarks simply scatter off each other. Alternatively, this intermediate may be described as "protonium" as shown in Fig. 11.

The noticeable features here are the remarkable disappearance or diminishing of resonant effects as the meson-meson widths of some or all of the diquonia are made nonzero. The scenario that corresponds closest to physical reality is that with all meson-meson widths set to 50 MeV. To see how this case looks when compared with the data, we add an incoherent "background" of the form $400/E^3$, where E is the total center-of-momentum energy of the baryon pair. This is shown as the dotted-dashed curve of Fig. 3. Note that this form may correspond to no real physics.

Because the resonant features in the cross section are made to disappear so easily, it is not surprising that not many diquonia candidates have been identified in $p\bar{p}$ elas-

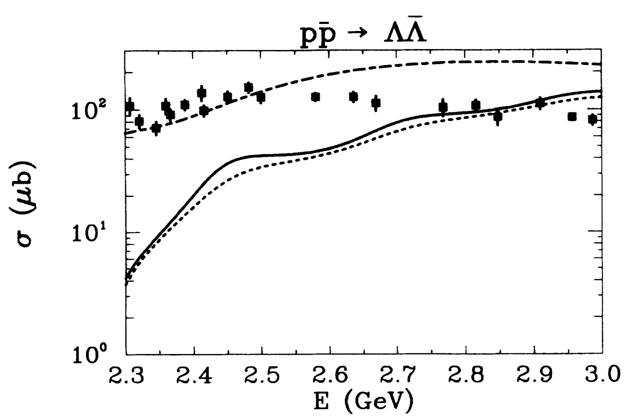

FIG. 6. Contribution of diquonia states to $p\bar{p}\to\Lambda\bar{\Lambda}$. Notation same as in Fig. 3.

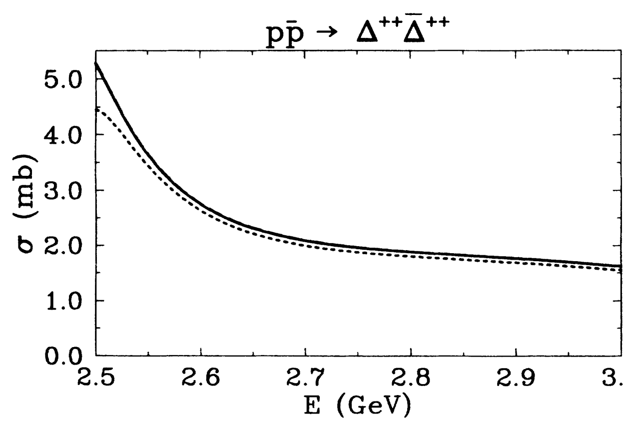

FIG. 8. Contribution of diquonia states to $p\bar{p}\to\Delta^{++}\bar{\Delta}^{++}$. Notation same as in Fig. 3.

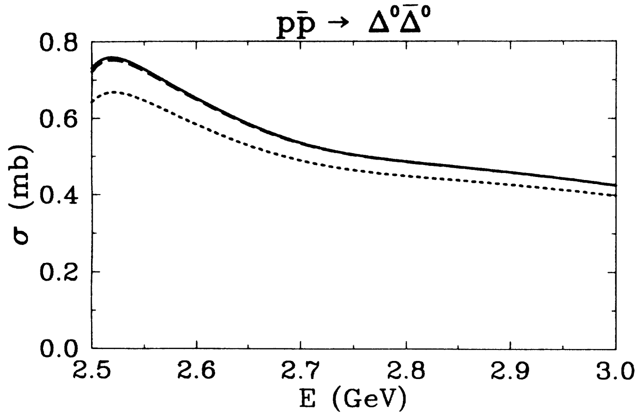

FIG. 9. Contribution of diquonia states to $p\bar{p}\rightarrow\Delta^0\bar{\Delta}^0$. Notation same as in Fig. 3.

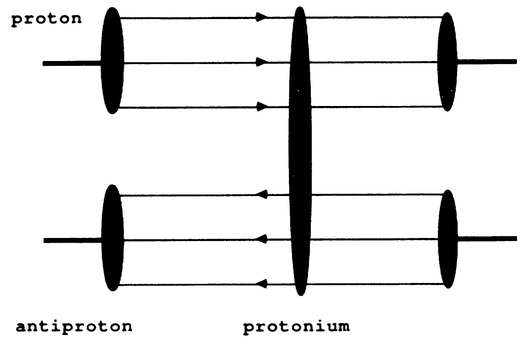

FIG. 11. Possible dominant contribution to $p\bar{p}$ elastic scattering, via "protonium" intermediate.

tic scattering. Indeed, the above scenario suggests that they may be impossible to find, unless techniques such as phase-shift analyses are employed. Even then, the number of nearly degenerate states will complicate matters somewhat.

$p\bar{p}\rightarrow n\bar{n}$ (Fig. 4): Much of what has been said for the $p\bar{p}$ channel is also applicable here, but with a few differences. The first difference is that the few resonant effects that remain when all the meson-meson widths are set to 50 MeV are a little more clearly visible. This is largely because no background is needed in this channel so that on the scale used, resonant effects are more easily discernible. However, these can be made to disappear by increasing the meson-meson widths a little further.

The second difference between this channel and the $p\bar{p}$ channel is that the contribution from diquonia intermediates is comparable to the data without addition of any "background." This is because a four-quark intermediate state of some sort must play the leading role in $p\bar{p}\rightarrow n\bar{n}$. In fact, the theory exceeds the data above 2.5 GeV, but this is understood as a consequence of the light A states that we use. The rising cross section is also attributable

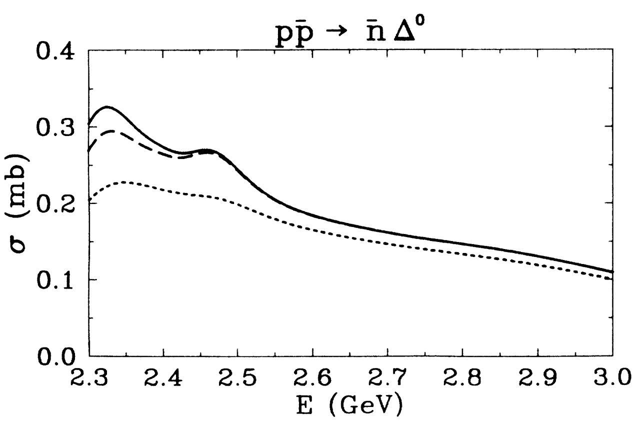

FIG. 10. Contribution of diquonia states to $p\bar{p}\rightarrow\Delta^0\bar{n}$. Notation same as in Fig. 3.

to the light A states, as discussed earlier. Like the elastic scattering channel, this channel shows few resonant effects, and the effects that are seen can be made to vanish.

$p\bar{p}\rightarrow\Sigma^+\bar{\Sigma}^+$ (Fig. 5): In this channel, there is only one "observable" resonant feature in the energy range explored, which persists when the meson-meson widths of diquonia with $L=0,1$ are nonzero, but which disappears entirely when all meson-meson widths are nonzero. As in the previous channel, the theory is "consistent" with the data, but is consistently less than the data. This can be remedied by increasing the partial widths for decay into this channel by a factor of 2. This is not as drastic as it sounds: the largest partial width for this channel is less than 10 MeV, and most of the partial widths are less than 4 MeV.

$p\bar{p}\rightarrow\Lambda\bar{\Lambda}$ (Fig. 6): This channel shows very weak resonant effects even with all meson-meson widths set to zero, and these effects essentially vanish when these widths are all set to 50 MeV. Again, the theory has the right order of magnitude, but is wrong in details. This is another effect of our light A states, which are the only ones that contribute to this channel. If we make these states heavier (more precisely, we keep the same masses but decrease L for each of these states) and recalculate the total and partial widths, as well as the cross section, the result is the dashed-dotted curve in Fig. 6. The form of this curve is more consistent with the trend of the data, although it exceeds the data beyond 2.5 GeV. Similar to the previous channel, this can be remedied by decreasing the partial widths into the $\Lambda\bar{\Lambda}$ channel by a factor slightly different from unity. Again, this is not a drastic condition, since the partial widths here are already small.

$p\bar{p}\rightarrow\Sigma^0\bar{\Lambda}$ (Fig. 7): Resonant effects in this channel remain visible even when all meson-meson widths are 50 MeV. As usual, larger meson-meson widths will diminish these effects further. The cross section obtained for the theory in this channel is larger than the experimental data, but, as in Figs. 5 and 6, this can be remedied by changing the partial width for decay into this channel. Note, however, that the change required is larger than in the $\Lambda\bar{\Lambda}$ and $\Sigma^+\bar{\Sigma}^+$ channels, and may be somewhat more difficult to accommodate in the model, even though the partial widths are already quite small.

$p\bar{p}\to\Delta^{++}\bar{\Delta}^{++}$ (Fig. 8): This is one of the less interesting cases as no resonant effects are seen, even with meson-meson widths set to zero. The absence of observable resonance features here is easily understood, since all the states that contribute to this channel are extremely broad, with total widths covering most, if not all or more, of the energy range shown. The very large partial widths, and subsequently, the dominant branching ratios into this channel, lead to a large cross section for production of $\Delta^{++}\bar{\Delta}^{++}$ pairs: it is comparable to the cross section for production of $n\bar{n}$ pairs at the same energy. This appears a little surprising, but has not yet been tested experimentally.

$p\bar{p}\to\Delta^{0}\bar{\Delta}^{0}$ (Fig. 9): This is similar to the previous channel in that no resonant features are seen. This is also due to the large total widths of the states that contribute to this channel. The predicted cross sections in this channel are somewhat smaller than in the $\Delta^{++}\bar{\Delta}^{++}$ channel.

$p\bar{p}\to\Delta^{0}\bar{n}$ (Fig. 10): This channel shows two structures below 2.5 GeV. Note, however, that the structure between 2.3 and 2.35 GeV is a combination of resonant and threshold effects, as the nearest lying states are at 2.29 and 2.39 GeV. As in most of the channels discussed, these structures disappear when all meson-meson widths are made nonzero. These last three channels together could constitute an interesting test of the mechanism described herein.

IV. CONCLUSION

The figures and discussion of the previous section have illustrated that diquonia states can be difficult to observe experimentally, even though the theoretical spectrum is quite rich. Relatively "small" widths for decays of such states into meson-meson pairs, or baryon-antibaryon channels with excited baryons, can lead to the disappearance of detectable resonant effects in most baryon-antibaryon channels.

In addition, let us emphasize that we have considered only the lowest-order effects due to diquonia. Since we are dealing with the strong force, higher-order terms should be included for a complete treatment of the scattering process. Inclusion of such terms, some of which would be equivalent to "rescattering" terms, will smear any resonant effects that are still visible. This has the effect of making such resonant signals even more difficult to observe. The overall result is that *most diquonia may be extremely difficult to detect experimentally.*

One very attractive by-product of this analysis is the reasonably good agreement between the cross sections obtained here, and the experimental data, where such data exist. Whether this agreement is merely coincidental is yet to be determined, but is perhaps not too surprising, since a four-quark state of some sort must play a role in baryon-antibaryon production from proton-antiproton scattering. In addition, we note that duality arguments,[16] as well as the P-matrix formalism of Jaffe and Low,[17] suggest that an approach such as this is useful in attempting to understand the dynamics of hadron scattering.

An important test of the mechanism described is the measurement of the cross sections for channels including Δ's: $\Delta^{++}\bar{\Delta}^{++}$, $\Delta^{0}\bar{\Delta}^{0}$, and $\Delta^{0}\bar{n}$, for example. Confirmation or contradiction of the predictions of the model for channels such as these will be useful in determining whether the agreement obtained so far is merely fortituous.

Other tests would include comparison for experiment with the model for other baryon-antibaryon scattering processes into baryon-antibaryon final states. Note, for instance, that in this model, creation of baryons with more than a single strange quark (Ω^- or Ξ, for example) from $p\bar{p}$ is suppressed, so that cross sections for such processes should be smaller. This is borne out by the little data available in channels containing such baryons. More stringent tests of the model would be the comparison of predicted angular distributions with experimental data.

If we take our results at face value, then the mechanism involving diquonia intermediates offers a viable alternative description of baryon-antibaryon scattering processes. This could be compared with other approaches where the scattering process has been characterized in terms of meson exchange or potential scattering, for example,[18] and there is certainly some overlap between the treatment described herein and that of meson exchange. However, a detailed discussion of such a comparison is beyond the scope of this paper.

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