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Observation of Excessive and Direct γ Production in $\bar{p}d$ Annihilations at Rest*†

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The charge-independence-violating effects observed in the previous paper are caused by the production of 0.73 ± 0.08 γ per annihilation above what is expected, 3.04 ± 0.02, from charge independence. The γ-energy spectrum extends over the γ spectrum generated from π^0. The spectra associated with specific topologies show peaks which are indicative of electromagnetic transitions between $\bar{p}N$ bound states or states of the cosmion (C).

Following our observations[1,2] of charge-independence-violating effects in $\bar{p}d$ annihilations at rest we have undertaken a study of the γ-energy spectra. Our objectives were twofold: (1) to identify the source of the excess in the energy of the neutrals, and (2) to look for the electromagnetic transitions

$$\bar{p} + d \to (N\bar{N})^* + N \qquad (1a)$$

$$\hookrightarrow (N\bar{N})^{**} + \gamma \qquad (1b)$$

which would produce peaks in the γ-energy spectra. Several direct and indirect observations[3] have strongly suggested the existence of narrow bound and resonance $N\bar{N}$ states and have been the motivating force for these searches for electromagnetic effects.

To this end we have double scanned the same[2] $\bar{p}d$ bubble chamber film, searching for e^+e^- pairs from γ conversions anywhere in the chamber. We found that ~95% of all such pairs point to an annihilation vertex. Comparison of the two scans yields an overall scanning efficiency of ~93% and 2317 events were found in 12 500 frames representing 5% of the available film. After geometrical reconstruction, in order to improve the resolution, only those γ's whose vertices are ~10 cm away from the chamber walls and have a dip angle <45° have been accepted. After two measurements 96% of all events were reconstructed. The momentum of the pairs was found pointing (all with <3° and 50% of them <1°) to an annihilation vertex. The average energy resolution ($\Delta E/E$) for the γ energy, as determined from the e^+e^- energies, is ~±5% with $|\Delta E/E| < 10\%$ for 90% of the γ's. (Higher percentage errors are frequently associated with low-energy γ's.)

The observed γ average energy is found to be 210 ± 4 MeV. The scanning efficiency was found to be independent of energy. After taking into account the energy dependence for pair production in deuterium,[4] we find that the average γ energy is

$$\langle \omega_\gamma \rangle = 184 \pm 3 \text{ MeV}, \qquad (2)$$

the error being statistical. Using the energy[2] which goes into neutrals for pionic annihilations, we obtain

$$\langle N_\gamma \rangle = (693 \pm 10 \text{ MeV})/(184 \pm 3 \text{ MeV}) = 3.77 \pm 0.08. \qquad (3)$$

(A similar result,[5] 3.92 ± 0.46, was obtained for $\bar{p}p$ annihilations at rest by using the results of kinematical fits.) Charge independence[6,2] implies that $\langle N_{\pi^\pm} \rangle = 2\langle N_{\pi^0} \rangle = \langle N_\gamma \rangle$, where[7] $\langle N_{\pi^\pm} \rangle = 3.04 \pm 0.02$. Therefore, *the excess in neutral energy is due to an excess of 0.73 ± 0.08 γ per $\bar{p}d$ annihilation. This is a surprisingly large number since it implies that in almost every event there is an extra γ which does not relate to π^0 assumed to correlate to the $\pi^\pm$ by charge independence.*

This result leads to two alternatives: Either more π^0 are produced than allowed by charge independence (a fundamental breaking of the isospin symmetry in "strong" interactions) or there is direct γ production, which we assume in what follows and which is indicated by the presence of narrow $\bar{N}N$ s-channel phenomena observed around threshold.[3] Figure 1(a) presents the spectrum for $\bar{p}d$ annihilations. The curve is the expected "background" from π^0 assumed[8] to have the same energy spectrum as $\pi^\pm$ and normalized to 3.04/3.77 of the total number of γ's. The direct γ's are distributed over the entire observed energy region and suggestive of structure. If the structure is not due to statistical fluctuations but to transitions represented by Reactions (1a) and (1b), then one might expect association with specific "annihilation" channels. Figures 1(b) and 1(c) show the spectra for γ's associated with annihilations on the neutron and proton, respectively. Clearly, the significant "fluctuations" correlate well with the annihilations on the proton of the deuteron. Moreover, they correlate impressively with the most common topologies [Figs. 1(d) and 1(e)]. *On the basis of these correlations of the fluctuations we are encouraged with our limited sample to claim that we are observing the radiative transitions represented by Reactions (1a) and (1b).* In studying our structures one should keep in mind our measuring resolution ($\sim \pm 5\%$), the Doppler effects due to the "spectator" momentum ($\sim \pm P_s/2M_N$), and the inclusion in the sample of about 20% in-flight, ~200–400-MeV/c, contamination.

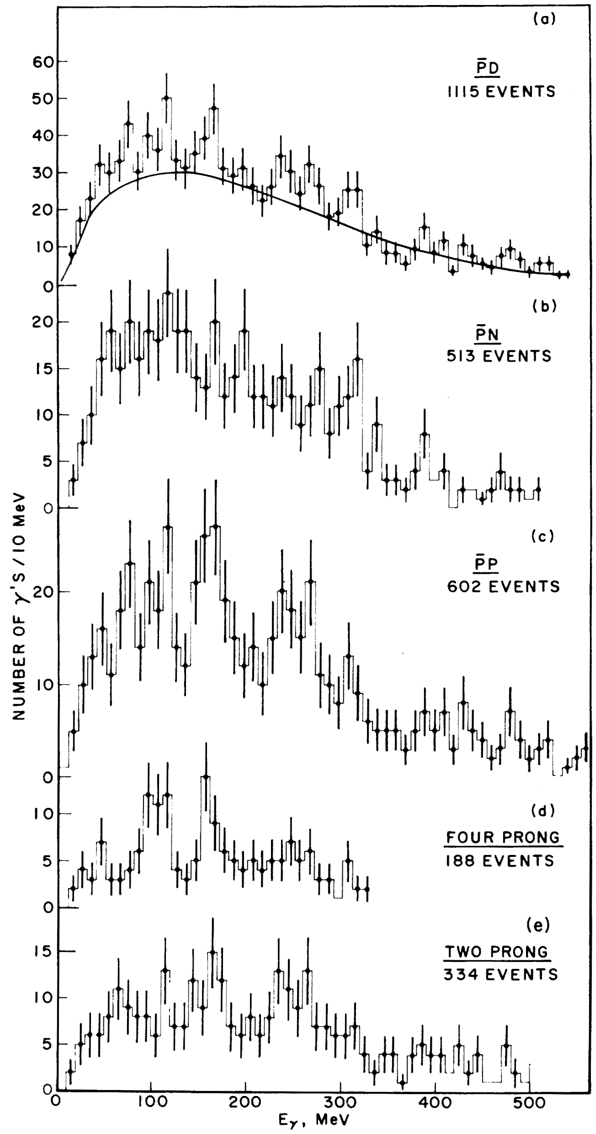

FIG. 1. Energy spectra of γ's. (a) All γ's. Curve, see text. (b), (c) γ's from $\bar{p}n$ and $\bar{p}p$ annihilations. (d), (e) γ's from $\bar{p}p$ annihilations with four and two charged pions, respectively.

This result reveals dramatically the long-suspected metastable bound $\bar{N}N$ states. It is, of course, a great mystery at the present time why the strong forces, presumably responsible for the ultimate destruction of the baryon numbers, do not "act" with expected typical, $\gtrsim 10^2$ MeV, strong-interaction widths. The truth must be hidden in the nature of the cores of the baryons which seem to act as the analogs of the nucleus in the hydrogen atom. This $\bar{N}N$ system with its world of metastable states deserves a name of its own. We propose to name it the *cosmion* (from the Greek for jewel, beautiful, and cosmos). The cosmion gives the opportunity for the first time to search for antimatter in the Universe and thus settle the speculations regarding its existence at large.

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Color-Symmetry Breaking and the Baryon Spectrum*

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In the colored-quark model, if the three vector gluons that correspond to an SU(2) subgroup of SU(3) are heavier than the other gluons, a quark-diquark structure for baryons results. Furthermore, the predicted baryon SU(6) representations are the 56 for even parity and the 70 for odd parity, in agreement with recent experimental indications.

Recent analyses of the baryon spectrum suggest that the even- and odd-parity baryons correspond exclusively to the SU(6) representations 56 and 70, respectively.[1] This contradicts the harmonic-oscillator quark model for all but the lowest two levels; for example, the model predicts even-parity resonances corresponding to the 56, 70, and 20 at the second excited level.[2]

Several years ago Lichtenberg, and later Ono, proposed that a baryon is a composite of a quark and a diquark.[3,4] The diquarks are assumed to correspond to the symmetric SU(6) representation 21, so that the unobserved twentyfold baryon representation is forbidden. There are three serious difficulties with this model. First, if there are just three fundamental quarks that do not satisfy Fermi statistics, it is hard to imagine a simple force that will bind two closely, and leave the third at larger distances. Second, quark-quark statistics are neglected, a proper procedure only if the diquark is pointlike. Third, 56 and 70 representations are predicted at every energy level. Lichtenberg showed that this last difficulty may be overcome by the introduction of a quark-exchange force, but this force is clearly of a different nature from that which binds the diquark.[3]

In this paper it is assumed that the quarks have color SU(3) indices as well as regular SU(3) and spin indices, and that the quark binding forces