ghost admixture.

In a general vein, we remark that coupling several matter fields in the conventional way is unlikely to lead to miraculous cancelations, since all $R_{\mu\nu}^2$ terms obtained so far have the same sign. Also, if one starts with an original gravitational Lagrangian with $R_{\mu\nu}^2$ terms to absorb the unrenormalizable ΔL, these terms will in turn generate higher powers of R at the one-loop level (in addition to implying a very unpleasant higher-order equation for the quantum fields $h_{\mu\nu}$), so that a Lagrangian which is a finite polynomial in the curvature is unlikely to help.[8]

As for two-loop calculations, they present enormous technical complications. It would be most important if one could at least discover whether pure gravity involves terms $\Delta L \sim \mathrm{Tr}[(R_{\nu\alpha\beta}{}^{\mu})^3]$ there, since these are presumably a sign of nonrenormalizability.

Detailed results will be published elsewhere.

Note added.—The coupling of fermions to gravitation has now been analyzed; the one-loop divergences include a term proportional to $(\bar{\psi}\gamma_5\gamma_\alpha\psi)^4$. Hence this system is also nonrenormalizable.

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[5]The one-loop renormalizability of pure gravitation is an immediate consequence of this identity, the generic form $\Delta L = [(-g)^{1/2}/\epsilon](\alpha_1 R_{\mu\nu}^2 + \alpha_2 R^2 + \alpha_3 R_{\alpha\beta\mu\nu}^2)$, and the field equations $R_{\mu\nu} = 0$.

[6]This idea has also been proposed by S. Weinberg, private communication.

[7]Scale invariance of massless fields of spin $\frac{1}{2}$, 1 necessarily leads to this combination of curvatures, which is just the square of the (scale-invariant) Weyl tensor $C_{\nu\alpha\beta}{}^{\mu}$. Indeed, the pure photon contribution to Eq. (4) is just 4 times ΔL of Eq. (8), which result was also found by D. M. Capper, M. J. Duff, and L. Halpern, International Centre for Theoretical Physics Report No. IC/73/130, 1973 (unpublished).

[8]An initial photon-graviton Lagrangian of the Weyl type (purely quadratic in R) does not involve dimensional constants and so is reproduced by ΔL; however, the graviton propagator behaves as p^{-4}.

Observation of Structure in $\bar{p}p$ and $\bar{p}d$ Total Cross Sections below 1.1 GeV/c*

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Total cross sections of $\bar{p}p$ and $\bar{p}d$ have been measured between 360 and 1050 MeV/c, with high statistical precision. Structures are observed in both cross sections at about the same momenta. For $\bar{p}p$, the central mass is 1932 ± 2 MeV/c^2, and a fit to the data with a simple Breit-Wigner resonance plus background gives $\Gamma = 9_{-3}^{+4}$ MeV/c^2. The data suggest that the structures are in the isospin-1 state.

There have been many claims[1-11] of narrow meson resonances with masses in the range 1900 to 2000 MeV/c^2; the observed widths varied from ~10 to 200 MeV/c^2. However, many other similar experiments have not observed such resonances and others have directly challenged the basis of such claims.[12-16] Searches for meson resonances in this mass region have been made in missing-mass experiments, multipion mass spectra, and $\bar{p}p$-formation experiments. A review of the subject is given by Diebold,[17] where the conclusion is that no narrow resonances in this mass region have been confirmed.

Total-cross-section measurements have in the past been very successful in searching for new resonances, because even though they are not intrinsically sensitive, they can be carried out to a very high statistical accuracy and with small point-to-point systematic errors. In an attempt to clarify the problem of the possible existence of meson resonances in the mass region around 1950 MeV/c^2, we have measured $\bar{p}p$ and $\bar{p}d$ total cross sections using antiprotons of momenta 360 to 1050 MeV/c (center-of-mass total energies between 1910 and 2100 MeV/c^2).

The experiment was carried out in a partially separated beam[18] produced from a target in the slow external beam of the Brookhaven National Laboratory alternating gradient synchrotron. It was a standard transmission measurement, but with special precautions taken to avoid the problems inherent in such a technique at low energies; details have been given previously.[19] In this experiment the incident antiprotons were identified both by time of flight and with the Cherenkov counter which counted pions in anticoincidence; contamination of the $\bar{p}$ signal was always negligible. The hydrogen, deuterium, and vacuum targets were 3 ft long for measurements above 680 MeV/c, but because of the large momentum loss of the antiprotons in passing through the targets, they were shortened to a length of 1 ft for measurements below this momentum. Some measurements with the longer targets were made below 680 MeV/c, and the results were in good agreement with those of the shorter targets. Because of the antiproton momentum loss in passing through the targets, which ranged from 160 MeV/c at the lowest $\bar{p}d$ point to 50 MeV/c at the highest $\bar{p}p$ point, we used as the momentum for each measurement the mean momentum of the particles traversing the target. The $\Delta p/p$ of $\pm 1\%$ of the incident beam was negligible compared to the momentum loss.

In the data analysis, a quadratic extrapolation to zero solid angle was made using the five largest counters; these covered a range of maximum $|t|$ (for elastic scattering) of 0.0023 to 0.0094 $(\text{GeV}/c)^2$. The statistical accuracy of the total cross sections obtained for the 3-ft targets was always better than $\pm 0.25\%$, and for the 1-ft targets was generally $\sim\pm 1\%$ except for the three lowest points where it rose to $\pm 3\%$. Four cycles of hydrogen, deuterium, and evacuated target were made for each momentum, and many momenta were checked by repeating measurements at intermediate points in order to ensure the stability of the apparatus to within the statistical error.

There were a number of small corrections that had to be applied to the cross sections (a full description of how these are derived is given by Cool *et al.*[20]): (i) HD in the deuterium. This was measured, and a correction of $\sim + 0.4\%$ applied to the deuterium results. (ii) Single Coulomb scattering. The correction was $\sim - 0.1\%$. (iii) Coulomb-nuclear interference. A knowledge of the real part of the forward-scattering amplitude is needed, and we have used those obtained by a reasonable extrapolation of the values given by Söding,[21] with the assumption that the real parts for protons and neutrons are equal. The correction varied between + 2.3% at the lowest momentum and + 1.2% at the highest.

Considering the possible uncertainties on the corrections, and in other quantities such as the mass of hydrogen and deuterium in the targets, the overall systematic error is estimated to be about 1%. Relative point-to-point systematic errors are estimated to be always less than the statistical errors.

Our results are shown in Fig. 1; in Fig. 2 they are compared with previous data,[22-29] where the agreement is seen to be good. In Fig. 1 we see that the $\bar{p}p$ and $\bar{p}d$ cross sections are smooth except for structure at ~475 MeV/c. The smooth curve shown in Fig. 1 is of the form $A + BP_{\text{lab}}^{-1}$; other forms such as $C + DP_{\text{c.m.}}^{-1}$ and $E + F\beta_{\text{lab}}^{-1}$ fit the data above and below the structure regions almost as well, and such behavior of antiproton

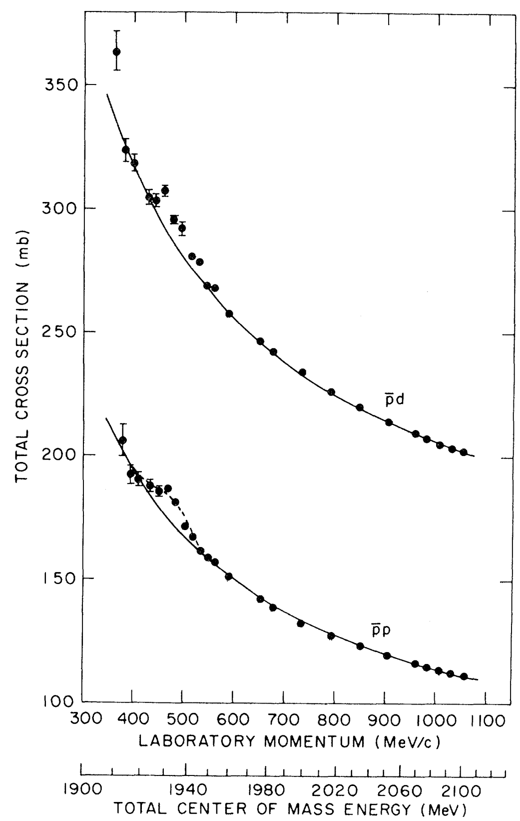

FIG. 1. Results of this experiment for $\bar{p}p$ and $\bar{p}d$ total cross sections. The solid curves are of the form $A + BP_{\text{lab}}^{-1}$. The dashed curve on the $\bar{p}p$ data is the result of the best fit as described in the text.

cross sections has been observed previously.[26,28,16] By subtracting this background from the $\bar{p}p$ data, the structure is found to be centered at 475 ± 10 MeV/c, or 1932 ± 2 MeV/c^2 total energy.

Since the width of the observed structure is narrow, we have folded in the known momentum resolution from ionization losses in the target in determining the resonance parameters for the structure. We have fitted the $\bar{p}p$ data from 379 to 1054 MeV/c with a background of the form $A + BP_{\rm lab}^{-1}$ and a simple Breit-Wigner resonance of width of Γ and height of σ. For a width of 9 MeV/c^2 we obtain $\chi^2 = 17$ for 21 degrees of freedom whereas for a zero-width resonance, $\chi^2 = 30$. If the data are fitted only with the background parameters, the χ^2 is 97 for 22 degrees of freedom, clearly indicating the significance of the structure. With this background parametrization the parameters of the fit are $\Gamma = 9_{-3}^{+4}$ MeV/c^2, $\sigma = 18_{+6}^{-3}$ mb for a mass of 1932 MeV/c^2. This gives $\sigma/4\pi\lambda\!\!\!^{-2}$ [which is equal to $\frac{1}{2}(J+\frac{1}{2}) \times$elasticity] of $0.19_{+0.06}^{-0.04}$.

From the $\bar{p}p$ and $\bar{p}d$ cross sections (σ_p and σ_d) it is possible to derive the $\bar{p}n$ cross section (σ_n) and thus the $\bar{p}$-nucleon cross sections in the isospin-0 and -1 states (σ_0 and σ_1). We have

$$\sigma_p = \tfrac{1}{2}\sigma_0 + \tfrac{1}{2}\sigma_1, \qquad (1)$$

$$\sigma_n = \sigma_1 \qquad (2)$$

$$\sigma_d = \sigma_p + \sigma_n - \delta\sigma, \qquad (3)$$

where $\delta\sigma$ is the Glauber[30,31] shielding correction given by

$$\delta\sigma = \langle r^{-2}\rangle\, \sigma_p\sigma_n/4\pi, \qquad (4)$$

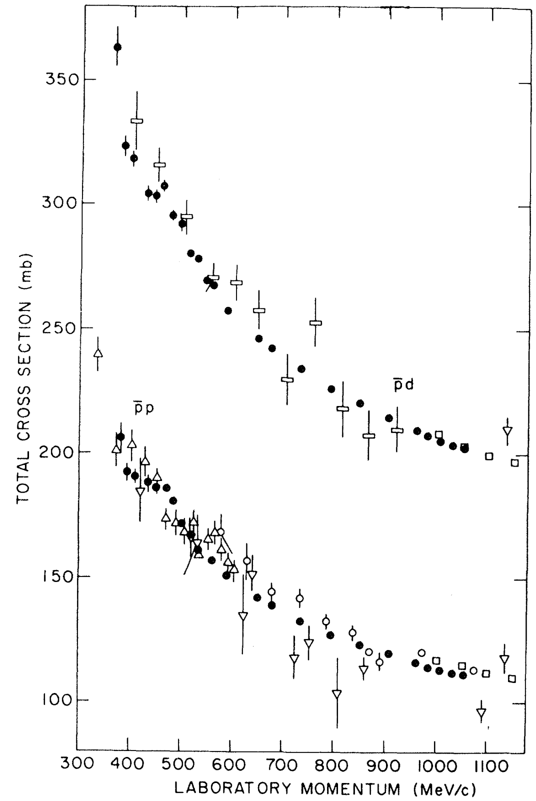

FIG. 2. Results of this experiment compared with previous data. Open circles, Amaldi *et al.* (Ref. 26); triangles, Amaldi *et al.* (Ref. 22); squares, Abrams *et al.* (Ref. 27); rectangles, Burrows *et al.* (Ref. 28); inverted triangles, miscellaneous (Refs. 23–25 and 29); closed circles, this experiment.

where $\langle r^{-2}\rangle$ is the average inverse square separation of the nucleons in the deuteron. Equation (4) has been modified by Wilkin[32] to the form

$$\delta\sigma = (\langle r^{-2}\rangle/4\pi)\{2\sigma_p\sigma_n(1-\rho_p\rho_n) - \tfrac{1}{2}[\sigma_p^2(1-\rho_p^2) + \sigma_n^2(1-\rho_n^2)]\}, \qquad (5)$$

where ρ_p and ρ_n are the ratios of the real to imaginary parts of the forward-scattering amplitudes for $\bar{p}p$ and $\bar{p}n$, respectively.

The procedure for obtaining σ_1 and σ_0 has been described before.[20] The σ_p data are "smeared" by the Fermi momentum; using this and σ_d (which naturally contains Fermi motion) and the expression for $\delta\sigma$, we can solve for σ_0 and σ_1. The effect of the Fermi momentum is then unfolded to derive the final values of σ_0 and σ_1.

In applying the above analysis in the present case, there are two problems:

(i) The "smeared" proton cross sections requires knowledge of σ_p below our measured values; using our best estimate of $A + BP_{\rm lab}^{-1}$ causes the smeared cross section to rise sharply below ~400 MeV/c, and at low enough momenta it becomes larger than the extrapolated deuteron cross section.

(ii) Substituting Eq. (4) into Eq. (3) and solving for σ_n, we find that σ_n approaches infinity as σ_p approaches $4\pi/\langle r^{-2}\rangle$ [using $\langle r^{-2}\rangle = 0.033$ mb^{-1}, this occurs at $\sigma_p = 380$ mb]; a similar problem occurs using Eq. (5).

We have nevertheless carried out the analysis, since although the above problems will cause large uncertainties in the absolute values of σ_1 and σ_0, they should not introduce or remove any structures. We have tried all combinations of the following assumptions for $\delta\sigma$: (a) Eq. (5), with $\rho_p = \rho_n = 0$; (b) Eq. (5) with $\rho_p = \rho_n$ = values used earlier; (c) Eq. (5) with σ_n set equal to σ_p, to avoid difficulty (ii); (d) Eq. (4); (e) $\langle r^{-2}\rangle = 0.033$ mb^{-1}; (f) $\langle r^{-2}\rangle = 0.027$ mb^{-1} (see Ref. 27).

In all cases structure is observed in σ_1 at ~475 MeV/c, and in some cases structure in σ_0 also. Until there is more information on the form of $\delta\sigma$ applicable to our case, more knowledge of ρ_p and ρ_n, and more knowledge of σ_p below 350 MeV/c, is is not possible to proceed further in the isospin analysis.

In summary, we have observed structures in $\bar{p}p$ and $\bar{p}d$ total cross sections at the same mass. For $\bar{p}p$ the mass is 1932 (± 2) MeV/c^2, width 9^{+4}_{-3} MeV/c^2, and cross section 18^{-3}_{+6} mb. These structures could be one or more meson resonances. In determining their isospin, there are so many assumptions that it is unclear how meaningful the results are. Nevertheless, it seems probable that the structure is in the isospin-1 state, but it is not possible at present to rule out structure in the $I = 0$ state at the same mass.

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