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New comparisons of the coupled-channel model with elastic deuteron form factors

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The coupled-channel model is compared to new, accurate measurements of the deuteron elastic electric structure function. The fit to previous elastic form-factor data is also shown because of small modifications arising from correcting the sign of a tensor term in the NN to $\Delta\Delta$ coupling potential. The improved fits give preference to the Gari-Krümpelmann nucleon electromagnetic form factors and also to the radius of asymptotic freedom of quarks corresponding to the cloudy bag model. The sensitivity of the choice of radius of asymptotic freedom to the result of the analysis of recent T_{20} data remains high.

In a recent paper[1] elastic electron-deuteron form-factor data were compared with the predictions of a model coupling nucleon-nucleon and $\Delta\Delta$ channels by realistic meson-exchange potentials, at long range, and a meromorphic boundary condition, at a radius of quantum chromodynamics (QCD) asymptotic freedom, r_0. The model, which couples the $NN(^3S_1,{}^3D_1)$ states to the $\Delta\Delta(^3S_1,{}^3D_1,{}^7D_1)$ channels, is fitted (by the free, energy-independent constants of the boundary condition) to the NN scattering data for $T_{\mathrm{lab}} < 1$ GeV. This data is only sensitive to the total coupling strength to the $\Delta\Delta$ D states leaving the ratio of the $^7D_1$ to $^3D_1$ states variable. The elastic magnetic-deuteron form-factor $B(q^2)$ is very sensitive to this ratio. The ratio can be determined by either the lower-momentum transfer $q < 5.4\ \mathrm{fm}^{-1}$ or the higher-q $B(q^2)$ data in the region of the first diffraction minimum. Since it is determined in one region, the result in the other region is a prediction. The diffraction minimum later observed in the data[2] was correctly predicted by this model. There are two successful models differing in r_0, called C and D in Ref. 1. Model C corresponds to the minimum radius of asymptotic freedom $r_0 = 0.74\ \mathrm{fm}^{-1}$ and model D to the radius required by the cloudy bag model $r_0 = 1.05\ \mathrm{fm}^{-1}$.

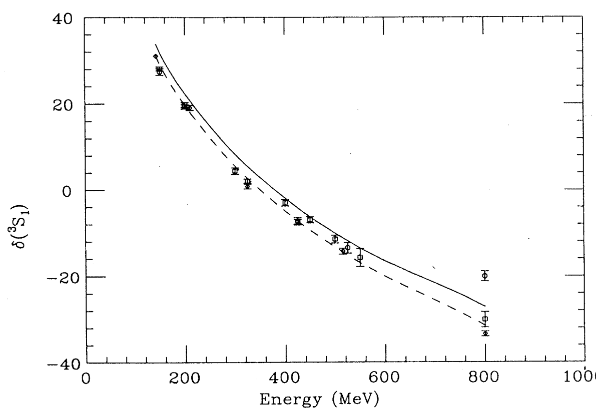

FIG. 1. The phase shift $\delta(^3S_1)$. The solid curve is the prediction of model C', and the dashed curve is of model D'. The phase-shift-analysis points are from R. A. Arndt *et al.*, Phys. Rev. D **35**, 128 (1987) (squares), D. V. Bugg (private communication) (diamonds), and J. Bystricky *et al.*, J. Phys. (Paris) **48**, 199 (1987) (circles).

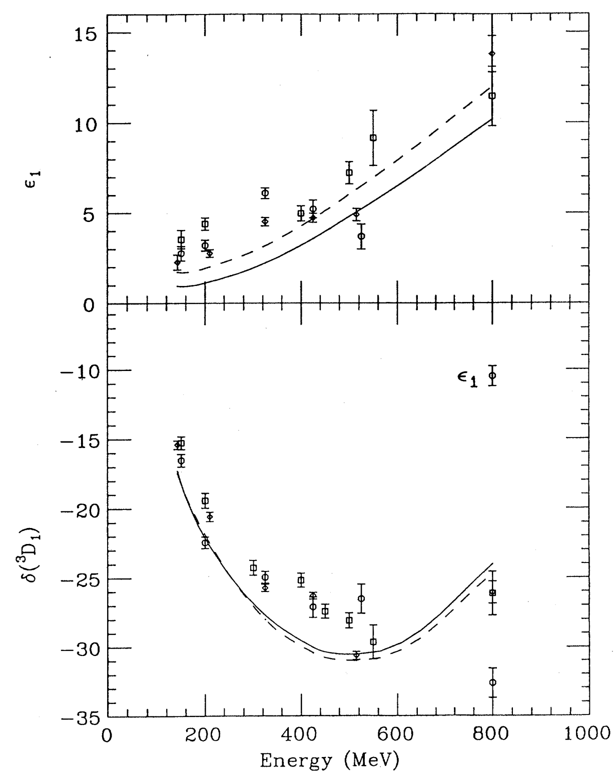

FIG. 2. The phase parameters $\delta(^3D_1)$ and ϵ_1. The curves and data are denoted as in Fig. 1.

TABLE I. The constant f-matrix components f_{ij}^0. The first enetry is model C' and the second is model D'.

	$NN(^3S_2)$	$NN(^3D_1)$	$\Delta\Delta(^3S_1)$	$\Delta\Delta(^3D_1)$	$\Delta\Delta(^7D_1)$
$NN(^3S_1)$	16.6737	−0.17	0.0	−10.0	0.0
	15.8237	2.835	0.0	−6.365	2.645
$NN(^3D_1)$		0.45	0.0	0.0	0.0
		1.80	0.0	−1.805	0.45
$\Delta\Delta(^3S_1)$			3.0	0.0	0.0
			1.0	0.0	0.0
$\Delta\Delta(^3D_1)$				4.0	0.0
				−0.8	0.0
$\Delta\Delta(^7D_1)$					2.0
					−0.8

This Brief Report is prompted by the availability of the fully analyzed data from a precision measurement[3] of the electric structure function $A(q^2)$ for $q<4.5\ \text{fm}^{-1}$, and by the rectification of an error in the coupling potential. It was pointed out[4] that our reference for the NN to $\Delta\Delta$ transition potential[5] had a sign error in the tensor part of the potential (corrected in subsequent literature[6]). The sign is of no consequence for those elements of the transition matrix which consist of only the tensor term, as only the squares of the off-diagonal transition terms enter the Schrödinger equation. However, the element that couples the $NN(^3D_1)$ to the $\Delta\Delta(^3D_1)$ has both a spin-spin and a tensor contribution. It is possible to compensate for the change in relative sign of these two terms at any one energy by altering the boundary condition parameter. Because the tensor term is dominant this results in only a small difference in the energy dependence of the fit to the NN scattering data. This change actually improves the fit of Ref. 1 as is shown in Figs. 1 and 2. The refitted models C and D, labeled C' and D', respectively, fit all three phase parameters very well in the whole energy range. The values of $g_{\pi NN}^2/4\pi$ are 14.8 and 15.0, and the triplet scattering length a_t is 5.44 and 5.45 fm in models C' and

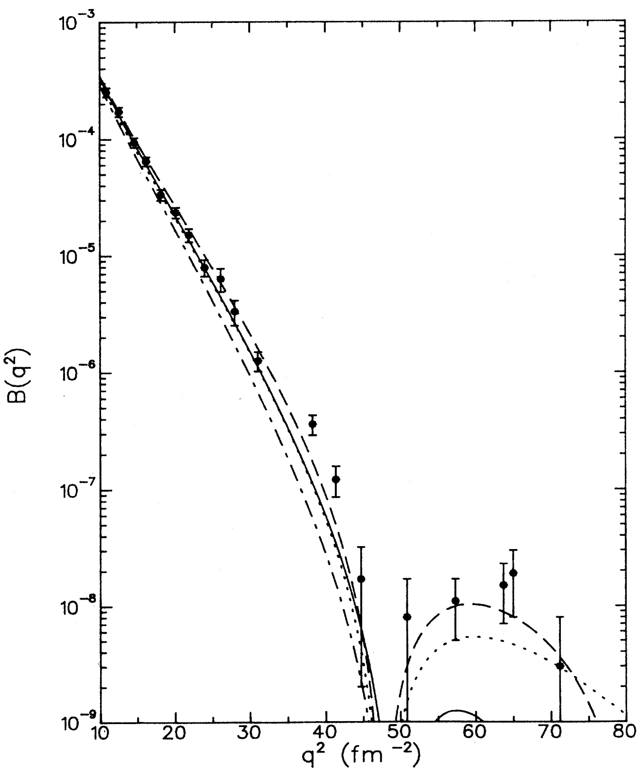

FIG. 3. The magnetic structure function $B(q^2)$ for model C' with the HPS (solid curve) and GK (dashed curve) nucleon EMFF, and for model D' with the HPS (dash-dotted curve) and GK (dotted curve) nucleon EMFF. The experimental points are as given in Ref. 1.

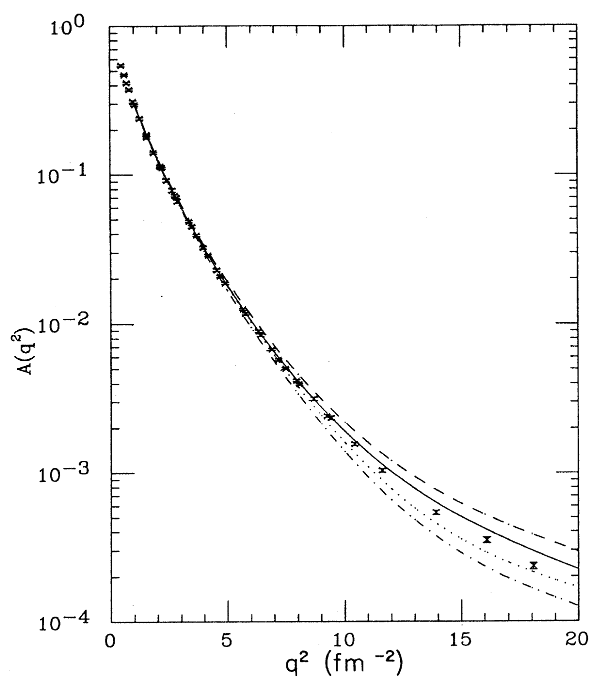

FIG. 4. The electric structure function $A(q^2)$ in the momentum-transfer range of the recent experiment of Ref. 3 (shown by crosses). The curves are as denoted in Fig. 3.

TABLE II. Deuteron properties of the models and experimental values.

	BE (MeV)	P_D (%)	$P_{\Delta S}$ (%)	$P_{\Delta 3}$ (%)	$P_{\Delta 7}$ (%)	(A_S fm$^{-1/2}$)	A_D/A_s	Q (fm^2)	$\mu_d(\mu_N)$
Model C'	2.2247	5.69	0.00	1.12	0.64	0.889	0.0254	0.285	0.869[a]
Model D'	2.2247	5.34	0.00	5.13	2.07	0.891	0.0258	0.285	0.869[a]
Expt.	2.2246					0.880 ±0.006	0.0256 ±0.0004	0.2860 ±0.0015	0.857 35

[a]Not including the negative relativistic and spin-orbit corrections.

D', respectively. The $V_{2\pi}$ coefficients of models C' and D' are not changed from those of models C and D, vanishing in D and D'. We note, however, a typographical error in Ref. 1. In Table I of that reference the coefficient for $NN(^3S_1)-\Delta\Delta(^3S_1)$ should read -0.2, not 0.2, for model C. Table I displays the fitted constant f-matrix parameters of the models. Model D' has the same f-matrix pole as model D. The static deuteron properties are listed in Table II. The standard MEC (meson-exchange-current) corrections[1] are included in these and the following deuteron predictions.

Figure 3 shows the results of models C' and D' for $B(q^2)$, using both the meson-exchange-pole type [Höhler, Pietarinen, and Sabba-Stefanescu[7] (HPS] and the pole-plus-quark-asymptotic-freedom type [Gari and Krumpelmann[8] (GK)] of nucleon electromagnetic form factors (EMFF). The fits are much as before, except that model C' with the GK EMFF fits better at low q than model C. Therefore, the GK nucleon EMFF are best with both models C' and D', leading to good fits over the whole range of q.

The new $A(q^2)$ data[3] impose more constraint on the models than was possible in Ref. 1. These data are compared with the new models in Fig. 4 showing that model D' with the GK nucleon EMFF is the best fit. However, model C' with the HPS nucleon EMFF is nearly as good. The values of $A(q^2)$ for $q > 4.5$ fm^{-1} are, as in models C and D, too large when the GK nucleon EMFF are used (Fig. 5). This may indicate that the GK neutron electric form factor is too large at high q, while the GK prediction for the neutron magnetic form factor is correct as indicated by $B(q^2)$. On the other hand, the discrepancy at large q may be due to the neglect of relativistic corrections, which are expected to reduce $A(q^2)$ significantly in

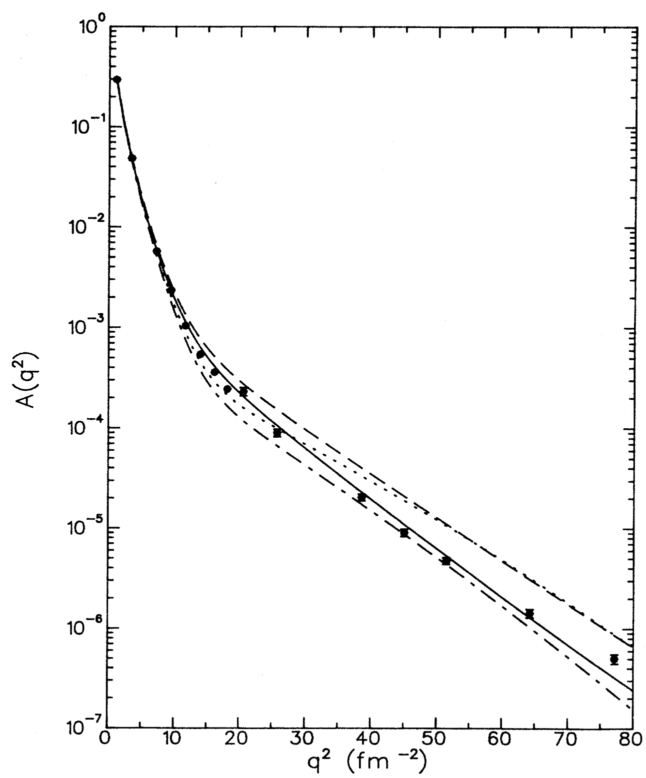

FIG. 5. The electric structure function $A(q^2)$ for the full momentum-transfer range. The data set is the same as in Ref. 1. The curves and data are as denoted in Fig. 3.

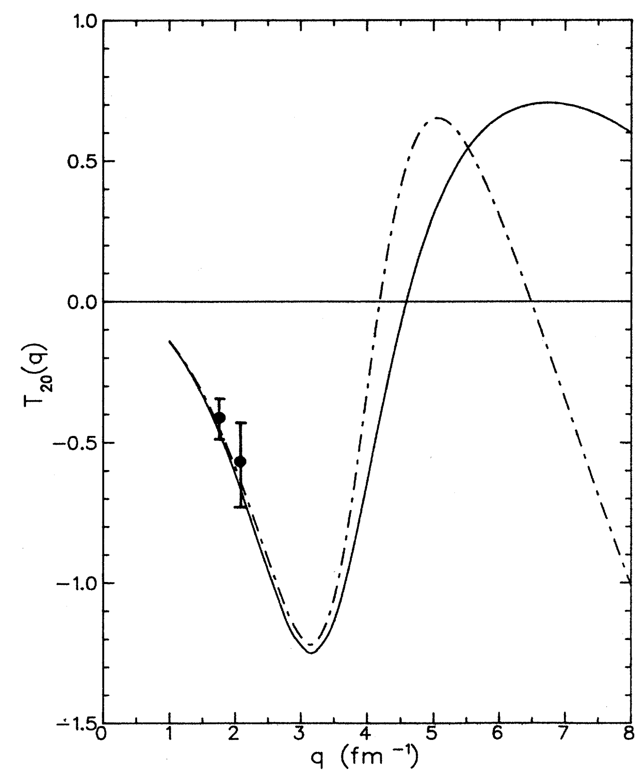

FIG. 6. The tensor polarization $T_{20}(q)$ at $\theta_e = 70°$. The data set is the same as in Ref. 1. Models C' (solid curve) and D' (dash-dotted curve) are shown only with the HPS nucleon EMFF. The GK case differs negligibly.

this range.[9]

The tensor polarization is very similar to that of Ref. 1 as is shown in Fig. 6. As before, it is insensitive to the choice of nucleon EMFF. It follows that the analysis of the recent experiment[10] for T_{20} at $q = 4-5\ \text{fm}^{-1}$ can, when complete, distinguish between solutions C' and D'.

We conclude that the data now available for comparison from both elastic *NN* scattering and the deuteron elastic electromagnetic form factors are compatible with either model C', using the minimum radius of asymptotic freedom (0.74 fm), or with model D', using the larger value of r_0 (1.05 fm) implied by cloudy bag model dynamics. We note that model D', which includes a pole in the f matrix determined by the cloudy bag model, predicts exotic resonances near 2.7 GeV/c^2 mass which have some confirmation in experiment.[11] The new $A(q^2)$ results[3] require that the HPS nucleon EMFF be used with model C' and that the GK nucleon EMFF be used with model D'. At high q, where more uncertainties due to relativistic and MEC contributions arise, $A(q^2)$ favors the HPS electric while $B(q^2)$ favors the GK magnetic nucleon EMFF. The T_{20} results at $q = 4-5\ \text{fm}^{-1}$, which are insensitive to the nucleon EMFF and do not have significant relativistic corrections, are needed to determine the appropriate radius of asymptotic freedom r_0.

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