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ON THE DETERMINATION OF THE PROTON-PROTON $^1S_0$ SHAPE PARAMETER

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In a recent letter[1] a determination of the $^1S_0$ shape parameter P for proton-proton scattering was produced through fits to very accurate phase shifts, as obtained from experimental data at five energies between 0.3825 MeV and 3.037 MeV in the laboratory system.[2,3] The main conclusion was that best agreement with the data was achieved by the Coulomb-corrected-partial-wave dispersion relation (PWDR). The boundary condition model (BC) was ruled out because it gave the wrong sign for the shape parameter.[1]

G. Breit has expressed some doubts about such determination of the shape parameter,[4] and it is the purpose of this note to present some evidence against the certainty of our knowledge of P, based on shape dependent (SD) fits to the five experimental points today available with high accuracy, without and with the vacuum polarization correction[5] (from now on called VPC), and also fits to the experimental points, excluding the points at 1.397 and 0.3825 MeV, again with and without the VPC. The reason for doing this may be found in the paper by Foldy and Eriksen[5] concerning the VPC, where they discuss at length the implications of their choice of the parameter C, as calculated by Jackson and Blatt[6] for the Yukawa well, in the expression

$$K = A + BE + CE^2 \qquad 1$$

where E is the laboratory energy in MeV. They mention that, had they chosen $C = 0$ (shape independent fit, SI) the improvement of the agreement that they found between the parameters of the so-called low energy region (0.2 to 0.5 MeV lab) and the parameters of the high energy region (0.5 to 4.203 MeV lab) would vanish, leaving totally indetermined the point of the experimental confirmation of the vacuum polarization effects. They state that the uncertainty cannot be removed until sufficiently more accurate data are available to determine the coefficient C from the data themselves. It will be shown that it is not yet possible to comply with this requirement and that more experimental data are necessary.

The function K is related to the function F defined below through the equality $K = RF$ (F is currently used nowadays in the representation of low energy p-p scattering)

$$F = C^2 k \cot \delta_o + \frac{1}{R} h(\eta) = -\frac{1}{a_p} + \frac{1}{2} r_e k^2 - P r_e^3 k^4 \qquad 2$$

where

$$C^2 = \frac{2\pi\eta}{e^{2\pi\eta}-1} \quad , \quad k^2 = \frac{M_p E}{2\hbar^2} \quad , \quad R = \frac{\hbar^2}{M_p e^2}$$

$$h(\eta) = \mathrm{Re}\frac{\Gamma'(-i\eta)}{\Gamma(i\eta)} - \lg\eta \quad ,$$

E is the laboratory energy, M_p is the proton mass, $\eta = \frac{e^2}{\hbar v_{LAB}}$ (e is the proton charge, $\hbar$ is Planck's constant divided by 2π, v_{LAB} is the relative velocity) η is usually called Coulomb parameter, r_e is the effective range and P is the shape parameter.

Table I summarizes the results of the least squares fit to the data as described previously. One learns from the table that, excluding the points at 0.3825 and at 1.397 MeV lab the effect of the VPC is simply to turn the SD fit more SI, whereas the sign of P remains negative. Including the point at 1.397 MeV the effect of the VPC is to reverse the sign of the shape parameter P although with or without VPC, P can be considered consistent with zero because of the experimental error of ±0.014 (see Ref. 1 and table I). Finally, including the point at 0.3825 MeV there is again a reversal of sign when one includes the VPC and P becomes much larger. This certainly means that the VPC is apparently dominating the parameter. There is in this fact a basic contradiction with the meaning of the shape parameter P due to the algebraic structure of equation 2 or its equivalent C in equation 1. C is the coefficient of the quadratic term of expansion 1, and therefore it should be determined by the higher energy points. The function 1 should be very well approximated by a straight line at low energies if C is small, and deviate at higher energies. A large scale plot of the function K easily reveals that the vacuum polarization corrected point at 0.3825 MeV lab is too low with respect to the almost straight line defined by the remaining four points, and this forces the increase in the parameter.

The conclusions seem simple: the existing very accurate data do not seem to confirm yet the validity of the VPC. In the author's opinion a reiteration of the old measurements at 0.3 MeV and 0.2 MeV lab with high accuracy is necessary to settle the question of the VPC as it stands now, lower energy measurements, if possible, would also be desirable. Additional measurements between 0.3825 MeV and 1.397 MeV should help to confirm the measurement at 0.3825 MeV. Finally, the algebraic structure of (2) implies that the shape parameter P should be determined preferably by the context of the higher energy points. If the context of the very low energy points forces a shape

parameter in disagreement with the higher energy points (the latter being more sensitive to it) the result should be viewed with suspicion. Lastly, and this refers to the remaining scattering parameters also, a re-examination of the electromagnetic corrections to the p-p scattering parameters is desirable on a different basis than the approach of Schneider and Thaler,[7] in view of the accuracy of present data and experimental possibilities. The present author has explored the effect of the extended charge of the proton with positive results[8] to be published elsewhere.

If all the above mentioned questions and problems are favorably solved, more meaningful and accurate scattering parameters will be obtained, and the sign and value of the shape parameter will perhaps be definitely settled, permitting thereby a choice between existing models for the nuclear interaction, and/or a readjustment of their parameters.

Table I. Comparison of the SD fit to the experimental data without and with VPC, at 5, 4, and 3 energies, excluding successively the lower energy points, SD: shape dependent fit, SI: shape independent fit.

	A	B MeV^{-1}	C MeV^{-2}	$-a_p$ f	r_e f	P
SD[a]				7.8284±0.0080	2.794±0.026	0.026±0.014
SI[a]				7.8163±0.0048	2.746±0.014	0
Five experimental points[b]						
SD (no VPC)	3.73380	0.45644	0.003367	7.7189	2.6306	-0.0443
SD (with VPC)[c]	3.67934	0.48690	-0.002767	7.8332	2.8062	0.0277
Four experimental points[d]						
SD (no VPC)	3.71969	0.46967	0.0005888	7.7482	2.7069	-0.00711
SD (with VPC)	3.68698	0.479713	-0.001189	7.8170	2.7648	0.0133
Three experimental points[e]						
SD (no VPC)	3.74955	0.44521	0.005330	7.6865	2.5659	-0.0755
SD (with VPC)	3.72181	0.46042	0.001039	7.7438	2.6536	-0.0133

[a]Values taken from reference number 1.

[b]At 0.3825, 1.397, 1.855, 2.425, and 3.037 MeV LAB.

[c]The slight discrepancy with the values of Ref. 1 is well within experimental errors and has no effect on the arguments presented in this paper.

[d]At 1.397, 1.855, 2.425, and 3.037 MeV LAB.

[e]At 1.855, 2.425 and 3.037 MeV LAB.

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