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WHAT NP ELASTIC SCATTERING DATA ARE NEEDED

FROM 200 TO 520 MeV?

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1. Introduction

Present np elastic scattering data in this energy range are rather sparse. They consist[1] of several measurements of $d\sigma/d\Omega$ (which frequently differ systematically by several times their quoted errors), polarisation data (mostly from quasi-elastic pn scattering in deuterium), and isolated measurements of triple scattering parameters (again frequently from deuterium). Attempts at phase shift analyses have been made.[2] However, without the strait jacket imposed by energy-dependent analysis, there are ambiguities and large errors in the solutions. In several cases it is clear that some existing data must be in error, but it is hard to say which.

The BASQUE experiment is intended to rectify this sorry state of affairs. The following measurements are planned in free np scattering:

D, R, A, D_T, R_T, A_T	(55-125 deg, 10 deg steps, ± 0.03)
P	(55-125 deg, 10 deg steps, ± 0.02)
$d\sigma/d\Omega$	(5-180 deg, 5 deg steps, ± 1%).

Below 520 MeV, measurements of D_T, R_T, and A_T will not extend fully to 55 deg, because of a 110 MeV requirement on the energy of the recoil proton for good analysing power in carbon. However, it is possible to extend the D_T, R_T, and A_T measurements towards 180 deg if this is necessary.

The objective of this report is to assess quantitatively what the impact will be of each measurement, so as to select the most economical and definitive set, and to assess whether further measurements might be necessary. Present uncertainties are such that the conclusions can only be tentative.

2. Present Data

Present pp and np data are used in single-energy phase shift analyses at 210, 320, 425 and 520 MeV. At all energies, I=0 phases are varied up to and including $^3G_5$, and I=1 phases up to $^3H_6$. The value of g^2 is fixed at 14.4. The reasons for releasing all I=0 G-waves are that (i) at 210 and 425 MeV, where the phase shift solutions are reasonably stable, $^3G_3$ is significantly different from OPE, (ii) the OPE value of $^3G_4$ is large (9.2 deg at 425 MeV), and (iii) in pp scattering, $^1G_4$ is known to deviate significantly from OPE. Table I shows χ^2 as successive G-waves are fixed at OPE values.

Data from pd scattering have not been corrected for rescattering effects; these are expected to be at the 1 to 10% level, depending on the geometry of the measurement. So the errors quoted for some present data may be optimistic. Data at 210 MeV from pd scattering above 160 deg have not been used, because of the large systematic effect of the pp final state interaction.[3]

At 210 MeV, the phase shift solution is stable enough that one has some confidence in predictions from it. At 320 MeV, the solution is very poorly defined, and the vicinity of the χ^2 minimum is shallow and wrinkled. At 425 MeV, the solution is just stable, but imprecise. At 520 MeV, no stable solution is found unless one of the low I=0 partial waves is fixed; arbitrarily, $^3S_1$ has been fixed at -12 deg in order to force a solution.

The $d\sigma/d\Omega$ data from Princeton[4] pose a serious problem at 320 MeV and above. Apparently of high accuracy they differ systematically in shape from Liverpool[5] (350 MeV) and Carnegie[6] (400 MeV) data by many times the quoted errors. If the latter two sets are discarded, one still cannot get a fit with a reasonable χ^2. At 320 MeV, for example, χ^2 is 604 for 111 deg of freedom, while if the Liverpool data are used instead $\chi^2 = 76$ for 69 deg of freedom. The effects of the Princeton data are (i) to force the fitted values of $d\sigma/d\Omega$ to very high values near 0 deg and 180 deg, (ii) to force an unreasonably high value of σ_T, and (iii) to require a normalization constant of 0.6 to 0.7. For these reasons the Princeton data have been omitted at all energies.

3. The Effect of New Data

We assume that existing data will be supplemented by measurements of D, R, and R′ in pp scattering in the range 10 to 50 deg; measurements are planned both at TRIUMF and SIN. These data will act as an important constraint on high partial waves in the I=1 state and on g^2. When hypothetical new np data are added, one finds a remarkably consistent picture at all energies: two direct and transfer Wolfenstein parameters (e.g. D, R, D_T, R_T) are required from 55 deg to 125 deg, 1% measurements of $d\sigma/d\Omega$ over the full angular range in both pp and np, and little else. Instead of one of the Wolfenstein parameters one could substitute C_{NN}, but one can do without C_{NN} if enough Wolfenstein parameters are measured. In the angular range 125 deg to 180 deg, measurement of one of the transfer parameters (usually D_T) is useful in pinning down residual uncertainties, but does not have the same dramatic effect as measurements near 90 deg.

Tables II, III and IV illustrate this argument in detail at four energies. At present, C_{NN} measurements are not planned in np scattering in this energy range, so the tables concentrate on a set of measurements omitting C_{NN}. It would, however, be a useful parameter, and Table III(a) illustrates in the last four rows just how useful at 210 MeV. The tables are simplified by the assumption that direct and transfer parameters (e.g. D and D_T) will be measured simultaneously where this is kinematically possible.

3.1 210 MeV

If $d\sigma/d\Omega$ cannot be measured to 1% accuracy, all the Wolfenstein parameters D, D_T, R, R_T, A and A_T play a valuable role. Table II(c) shows that sizable errors persist in predictions close to 0 and 180 deg, many of them in parameters experimentally inaccessible, namely direct parameters near 180 deg (slow recoil neutron) and transfer parameters near 0 deg (slow proton). The most decisive way of eliminating these uncertainties is by 1% measurements of $d\sigma/d\Omega$ over the full angular range; this is a particularly difficult measurement near 0 deg. If it is feasible, A and A_T (60-120 deg) become rather redundant; however, in view of the difficulty of np measurements, one should perhaps regard A and A_T as a valuable cross-check against systematic errors. From Tables II(d) and III(a) one sees that D_T (130-170 deg) is also a useful though not crucial measurement. Finally A' (13 deg) is desirable; the need for it originates from inadequacies in present pp data (i.e. uncertainties in I=1 phases), and could be removed by 1% measurements of $d\sigma/d\Omega$ (5-20 deg) or 2.5% measurements of A' in the range 10 to 50 deg in pp scattering.

If C_{NN} could be measured in np scattering, it would be a powerful measurement. In every one of Tables II(a)-(d) the error in this quantity stays persistently high compared with other observables. It is the parameter most sensitive to $^3S_1$. However, as one sees from line 13 of Table III(a), C_{NN} is not essential if $d\sigma/d\Omega$ and enough Wolfenstein parameters are measured to the required accuracy.

A subsidiary benefit of the np measurements is a noticeable improvement in the errors of I=1 phases [Table V(a)], roughly a factor 2 in $(\text{error})^2$. It originates largely from D and R (symmetric about 90 deg). They are as effective as direct measurements on the pp system in the same angular range, and eliminate the need[7] for pp measurements of D and R near 90 deg.

3.2 320 MeV

Again, measurements of $PDRAD_TR_TA_T$(55-125 deg) plus 1% measurements of $d\sigma/d\Omega_{np}$ (5-180 deg) almost complete the task of reducing errors on all observables to the arbitrary limits specified in the Introduction. At this energy A and A_T appear more useful than R and R_T. A few residual errors survive near 0 deg and 180 deg on observables which are experimentally inaccessible. However, unlike the situation at 210 and 425 MeV, D_T, R_T and A_T in the region 130 to 170 deg do not appear favourable for resolving these errors unless an accuracy of ±0.015 is achieved. C_{NN} (130-170 deg) does a much better job. To eliminate uncertainties in I=1 amplitudes near 0 deg, one would like 1% measurements of $d\sigma/d\Omega$ (5-20 deg) and 2.5% measurements of A and A′ in the range 10-50 deg in pp scattering.

3.3 425 MeV

Here the only pp measurement required is $d\sigma/d\Omega$ to 0.8% accuracy. At this energy A_T, R_T'(140-170 deg) and to a lesser extent D_T and R_T (140 to 170 deg) play a useful role in whittling down the final uncertainties, more so than at 325 MeV. Again C_{NN} would be a valuable measurement in np scattering from 30 to 170 deg, but one can manage without it.

3.4 520 MeV

Existing data are so limited that it is hard to tell just what will be required. However, good $d\sigma/d\Omega$ measurements in both pp and np scattering, plus D, D_T, R, R_T, A and A_T from 55-125 deg and D_T (135-170 deg), seem to do a good enough job that one can manage without C_{NN} in np scattering.

A general comment applicable at all energies is that some Wolfenstein parameters (both direct and transfer) vary very rapidly with angle, and that if an accuracy of ±0.03 is to be achieved on every parameter, systematic errors on the scattering angle need to be kept down to ±1 deg in the centre of mass system, or ±0.5 deg lab.

4. Transfer Parameters Near 180 deg

The BASQUE experiment is planned on the assumption that a nearly monoenergetic neutron beam of high polarisation can be made by scattering polarised protons from deuterium through an angle of about 9 deg lab (18 deg centre of mass). This technique, suggested by Folkmann and Measday,[8] was based on an early phase shift analysis, which can now be updated. The predictions for D_T and R_T from the latest data sets are shown in Table V. Predictions for R_T remain encouragingly high and stable. Predictions for other transfer parameters have changed quite significantly from those given by Folkmann and Measday, and there are signs that D_T could be a useful mechanism for making a polarised neutron beam at the higher energies.

5. Conclusions

The most urgent requirement is for comprehensive measurements of D, D_T, R, R_T, A and A_T from 55-125 deg in np scattering, plus 1% measurements of $d\sigma/d\Omega$ in both np and pp scattering over the full angular range. Measurements of D_T, R_T and A_T from 125-180 deg are less crucial, but fulfill a useful mopping-up operation in constraining the final errors. Measurements of C_{NN} over the full angular range would be a powerful addition to these measurements, but one can manage without it, with slightly worsened errors if necessary. In pp scattering, measurements of D, R and A′ are very powerful in the angular range 10-50 deg.

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Table I. Values of χ^2 with various I=0 G-waves fixed at OPE values.

Variables	g^2	Energy (MeV)			
		210	320	425	520
All G-waves free	free	88.45	-	64.15	-
All G-waves free	14.4	88.66	76.1	64.4	82.5
$^3G_5$ fixed at OPE	14.4	89.21	77.4	65.6	85.5
$^3G_4$ and $^3G_5$ fixed at OPE	14.4	90.31	91.9	76.4	no solution
All G-waves fixed at OPE	14.4	102.3	153.8	86.9	136.7

Table II(a). Predicted errors on common np observables at 210 MeV from the phase shift analysis of existing data. (g^2 fixed at 14.4; phases varied up to $^3G_5$)

Angle (c.m. deg)	$\delta\sigma/\sigma$	δP	δD	δR	δA	$\delta R'$	$\delta A'$	δC_{KP}	δC_{NN}	δD_T	δR_T	δA_T	$\delta R_T'$
10	0.051	0.012	0.029	0.030	0.018	0.026	0.116	0.010	0.036	0.036	0.015	0.036	0.032
20	0.043	0.019	0.033	0.028	0.032	0.043	0.077	0.016	0.047	0.033	0.024	0.035	0.025
30	0.040	0.016	0.031	0.022	0.035	0.042	0.032	0.016	0.058	0.036	0.039	0.025	0.026
40	0.046	0.015	0.024	0.024	0.044	0.048	0.045	0.024	0.060	0.046	0.068	0.032	0.030
50	0.043	0.017	0.024	0.027	0.059	0.065	0.056	0.047	0.080	0.064	0.092	0.031	0.035
60	0.036	0.016	0.031	0.027	0.056	0.055	0.037	0.064	0.102	0.084	0.094	0.024	0.041
70	0.027	0.015	0.050	0.040	0.040	0.038	0.031	0.057	0.098	0.091	0.084	0.029	0.045
80	0.017	0.013	0.061	0.049	0.031	0.041	0.054	0.029	0.101	0.080	0.059	0.029	0.038
90	0.015	0.009	0.051	0.044	0.026	0.033	0.057	0.012	0.117	0.070	0.027	0.041	0.028
100	0.017	0.010	0.047	0.037	0.021	0.037	0.042	0.018	0.107	0.075	0.062	0.047	0.036
110	0.015	0.009	0.050	0.029	0.032	0.056	0.032	0.023	0.094	0.081	0.083	0.050	0.042
120	0.014	0.006	0.045	0.017	0.048	0.065	0.028	0.025	0.091	0.076	0.075	0.055	0.036
130	0.012	0.006	0.039	0.011	0.056	0.057	0.020	0.029	0.079	0.059	0.057	0.055	0.022
140	0.010	0.005	0.041	0.012	0.050	0.038	0.015	0.039	0.066	0.042	0.039	0.044	0.018
150	0.010	0.006	0.038	0.022	0.037	0.016	0.023	0.039	0.083	0.045	0.017	0.033	0.026
160	0.009	0.007	0.044	0.029	0.045	0.020	0.030	0.022	0.092	0.053	0.015	0.023	0.024
170	0.012	0.004	0.065	0.019	0.047	0.058	0.019	0.005	0.065	0.043	0.034	0.011	0.012

Table II(b). As Table II(a) after the addition to existing data of P and D measurements from 60 to 120 deg at 10 deg steps and D_T measurements from 90 to 120 deg at 10 deg steps.

Angle (c.m. deg)	$\delta\sigma/\sigma$	δP	δD	δR	δA	$\delta R'$	$\delta A'$	δC_{KP}	δC_{NN}	δD_T	δR_T	δA_T	$\delta R_T'$
10	0.041	0.009	0.016	0.019	0.013	0.018	0.072	0.007	0.033	0.030	0.011	0.016	0.026
20	0.035	0.014	0.019	0.018	0.024	0.030	0.052	0.011	0.037	0.029	0.017	0.017	0.015
30	0.033	0.012	0.021	0.013	0.026	0.030	0.028	0.013	0.039	0.029	0.026	0.014	0.012
40	0.037	0.012	0.017	0.013	0.024	0.026	0.027	0.014	0.033	0.030	0.042	0.022	0.014
50	0.033	0.012	0.013	0.015	0.025	0.029	0.027	0.016	0.034	0.033	0.053	0.021	0.014
60	0.027	0.010	0.013	0.020	0.022	0.023	0.021	0.021	0.042	0.037	0.046	0.012	0.014
70	0.023	0.009	0.016	0.030	0.017	0.019	0.025	0.022	0.039	0.039	0.034	0.013	0.019
80	0.016	0.007	0.017	0.031	0.017	0.018	0.025	0.016	0.038	0.032	0.030	0.011	0.021
90	0.014	0.006	0.016	0.021	0.016	0.014	0.022	0.010	0.042	0.022	0.020	0.014	0.016
100	0.016	0.006	0.016	0.017	0.013	0.018	0.018	0.014	0.039	0.017	0.019	0.016	0.017
110	0.015	0.005	0.016	0.015	0.016	0.025	0.016	0.022	0.039	0.019	0.025	0.021	0.022
120	0.013	0.005	0.017	0.009	0.027	0.028	0.015	0.021	0.040	0.019	0.029	0.028	0.021
130	0.011	0.005	0.022	0.005	0.034	0.026	0.010	0.018	0.032	0.023	0.031	0.030	0.016
140	0.010	0.005	0.025	0.008	0.032	0.020	0.007	0.025	0.033	0.031	0.026	0.027	0.017
150	0.010	0.006	0.027	0.016	0.025	0.010	0.015	0.026	0.057	0.039	0.012	0.023	0.021
160	0.009	0.006	0.028	0.021	0.037	0.014	0.021	0.015	0.066	0.038	0.010	0.017	0.018
170	0.011	0.003	0.049	0.014	0.039	0.042	0.014	0.003	0.051	0.027	0.021	0.008	0.008

Table II(c). As Table II(a) after the addition to existing data of D, R and A measurements from 60 to 120 deg at 10 deg steps and D_T, R_T and A_T measurements from 90 to 120 deg at 10 deg steps.

Angle (c.m. deg)	$\delta\sigma/\sigma$	δP	δD	δR	δA	$\delta R'$	$\delta A'$	δC_{KP}	δC_{NN}	δD_T	δR_T	δA_T	$\delta R_T'$
10	0.033	0.007	0.013	0.016	0.009	0.012	0.053	0.005	0.027	0.022	0.008	0.010	0.018
20	0.030	0.012	0.016	0.015	0.018	0.022	0.039	0.009	0.028	0.023	0.012	0.012	0.011
30	0.029	0.011	0.017	0.011	0.020	0.023	0.024	0.012	0.028	0.025	0.018	0.013	0.009
40	0.030	0.010	0.014	0.010	0.018	0.021	0.022	0.012	0.024	0.024	0.027	0.016	0.011
50	0.027	0.009	0.010	0.012	0.017	0.020	0.019	0.013	0.024	0.024	0.032	0.013	0.011
60	0.024	0.009	0.008	0.013	0.014	0.015	0.013	0.016	0.027	0.025	0.029	0.010	0.011
70	0.021	0.007	0.011	0.016	0.011	0.012	0.015	0.017	0.027	0.026	0.025	0.011	0.012
80	0.015	0.006	0.015	0.016	0.010	0.013	0.015	0.013	0.028	0.023	0.022	0.009	0.012
90	0.014	0.006	0.015	0.012	0.011	0.013	0.015	0.009	0.029	0.017	0.015	0.010	0.010
100	0.015	0.006	0.014	0.011	0.010	0.014	0.013	0.010	0.026	0.013	0.012	0.011	0.012
110	0.015	0.005	0.015	0.009	0.011	0.017	0.011	0.014	0.025	0.014	0.014	0.012	0.014
120	0.013	0.004	0.016	0.006	0.015	0.018	0.010	0.014	0.025	0.016	0.015	0.014	0.014
130	0.011	0.004	0.018	0.004	0.019	0.016	0.007	0.014	0.022	0.020	0.016	0.017	0.013
140	0.010	0.004	0.020	0.006	0.019	0.013	0.005	0.020	0.024	0.028	0.015	0.019	0.016
150	0.009	0.006	0.023	0.014	0.020	0.008	0.012	0.021	0.039	0.034	0.008	0.019	0.018
160	0.009	0.005	0.030	0.018	0.029	0.010	0.017	0.012	0.046	0.033	0.008	0.014	0.015
170	0.011	0.003	0.035	0.012	0.031	0.029	0.012	0.002	0.037	0.022	0.017	0.007	0.007

Table II(d). As Table II(a) after the addition to existing data of D, R, A measurements from 60 to 120 deg in 10 deg steps, D_T, R_T, A_T from 90 to 120 deg in 10 deg steps, and 1% $d\sigma/d\Omega$ measurements from 5 to 180 deg in 5 deg steps.

Angle (c.m. deg)	$\delta\sigma/\sigma$	δP	δD	δR	δA	$\delta R'$	$\delta A'$	δC_{KP}	δC_{NN}	δD_T	δR_T	δA_T	$\delta R_T'$
10	0.005	0.005	0.008	0.009	0.005	0.008	0.041	0.004	0.010	0.009	0.005	0.008	0.009
20	0.004	0.009	0.010	0.009	0.010	0.013	0.029	0.007	0.011	0.008	0.008	0.007	0.008
30	0.004	0.009	0.012	0.007	0.012	0.014	0.016	0.009	0.015	0.010	0.012	0.008	0.008
40	0.005	0.007	0.010	0.008	0.013	0.015	0.015	0.010	0.015	0.012	0.020	0.012	0.009
50	0.004	0.007	0.007	0.010	0.014	0.016	0.016	0.012	0.018	0.017	0.024	0.010	0.010
60	0.005	0.007	0.007	0.012	0.013	0.014	01012	0.015	0.024	0.022	0.024	0.008	0.010
70	0.005	0.007	0.010	0.015	0.010	0.012	0.013	0.015	0.024	0.023	0.022	0.009	0.011
80	0.004	0.006	0.014	0.015	0.009	0.013	0.014	0.011	0.022	0.020	0.020	0.008	0.011
90	0.005	0.006	0.015	0.011	0.008	0.012	0.012	0.006	0.023	0.016	0.013	0.008	0.009
100	0.004	0.005	0.014	0.009	0.008	0.013	0.011	0.008	0.023	0.013	0.012	0.009	0.010
110	0.004	0.004	0.014	0.008	0.010	0.016	0.010	0.011	0.022	0.013	0.013	0.010	0.012
120	0.004	0.003	0.015	0.005	0.011	0.017	0.009	0.010	0.020	0.015	0.013	0.011	0.012
130	0.004	0.003	0.017	0.003	0.013	0.014	0.006	0.010	0.018	0.018	0.013	0.011	0.010
140	0.004	0.003	0.018	0.004	0.014	0.009	0.005	0.014	0.018	0.023	0.011	0.011	0.011
150	0.004	0.004	0.015	0.008	0.013	0.003	0.009	0.014	0.021	0.027	0.005	0.011	0.012
160	0.004	0.003	0.013	0.011	0.014	0.006	0.011	0.008	0.022	0.026	0.005	0.009	0.010
170	0.004	0.002	0.017	0.007	0.014	0.016	0.007	0.002	0.016	0.017	0.012	0.004	0.005

Table II(e). Predicted errors on common np observables at 320 MeV from the phase shift analysis of existing data. (g^2 fixed at 14.4; phases varied up to $^3G_5$)

Angle (c.m. deg)	$\delta\sigma/\sigma$	δP	δD	δR	δA	$\delta R'$	$\delta A'$	δC_{KP}	δC_{NN}	δD_T	δR_T	δA_T	$\delta R_T'$
10	0.051	0.015	0.026	0.031	0.019	0.019	0.055	0.017	0.071	0.118	0.014	0.075	0.115
20	0.047	0.025	0.023	0.041	0.029	0.030	0.056	0.030	0.064	0.081	0.021	0.084	0.086
30	0.054	0.022	0.035	0.038	0.032	0.035	0.065	0.047	0.056	0.056	0.037	0.082	0.070
40	0.045	0.014	0.052	0.036	0.038	0.053	0.065	0.067	0.056	0.056	0.059	0.072	0.059
50	0.037	0.012	0.059	0.048	0.044	0.073	0.053	0.082	0.067	0.060	0.071	0.055	0.047
60	0.043	0.010	0.047	0.053	0.046	0.081	0.036	0,083	0.091	0.084	0.074	0.041	0.038
70	0.050	0.009	0.016	0.054	0.046	0.070	0.027	0.064	0.130	0.131	0.083	0.034	0.032
80	0.053	0.010	0.027	0.056	0.049	0.039	0.066	0.034	0.177	0.173	0.088	0.034	0.029
90	0.053	0.009	0.048	0.049	0.068	0.025	0.110	0.036	0.205	0.163	0.080	0.048	0.023
100	0.042	0.009	0.061	0.035	0.099	0.035	0.116	0.037	0.196	0.103	0.066	0.067	0.015
110	0.023	0.009	0.072	0.026	0.111	0.041	0.083	0.040	0.158	0.077	0.061	0.078	0.022
120	0.012	0.008	0.072	0.020	0.092	0.042	0.044	0.040	0.120	0.100	0.065	0.073	0.024
130	0.008	0.008	0.067	0.014	0.066	0.037	0.019	0.032	0.093	0.111	0.059	0.058	0.024
140	0.007	0.007	0.053	0.015	0.051	0.035	0.014	0.038	0.077	0.104	0.040	0.047	0.039
150	0.006	0.007	0.041	0.022	0.054	0.036	0.017	0.038	0.083	0.091	0.018	0.048	0.053
160	0.004	0.008	0.069	0.031	0.067	0.063	0.024	0.021	0.085	0.076	0.040	0.043	0.049
170	0.005	0.004	0.105	0.023	0.066	0.101	0.019	0.006	0.054	0.055	0.051	0.020	0.023

Table II(f). Predicted errors on common np observables at 425 MeV from the phase shift analysis of existing data. (g^2 fixed at 14.4; phases varied up to $^3G_5$)

Angle (c.m. deg)	$\delta\sigma/\sigma$	δP	δD	δR	δA	$\delta R'$	$\delta A'$	δC_{KP}	δC_{NN}	δD_T	δR_T	δA_T	$\delta R_T'$
10	0.042	0.014	0.031	0.032	0.012	0.012	0.036	0.010	0.076	0.089	0.014	0.031	0.084
20	0.033	0.023	0.028	0.035	0.018	0.020	0.032	0.019	0.064	0.069	0.017	0.035	0.052
30	0.031	0.022	0.026	0.032	0.018	0.023	0.032	0.019	0.051	0.052	0.017	0.037	0.032
40	0.027	0.014	0.024	0.026	0.016	0.024	0.034	0.014	0.036	0.037	0.027	0.031	0.027
50	0.023	0.008	0.022	0.021	0.014	0.022	0.036	0.021	0.026	0.030	0.037	0.025	0.040
60	0.022	0.006	0.025	0.019	0.016	0.024	0.034	0.031	0.028	0.040	0.042	0.034	0.050
70	0.021	0.006	0.025	0.019	0.017	0.025	0.027	0.035	0.031	0.046	0.041	0.038	0.047
80	0.022	0.008	0.020	0.023	0.023	0.028	0.024	0.027	0.025	0.037	0.030	0.025	0.029
90	0.023	0.009	0.018	0.024	0.027	0.030	0.025	0.008	0.022	0.022	0.011	0.013	0.016
100	0.026	0.009	0.033	0.029	0.021	0.027	0.021	0.032	0.034	0.042	0.034	0.023	0.033
110	0.029	0.009	0.052	0.043	0.020	0.038	0.022	0.050	0.044	0.066	0.060	0.022	0.044
120	0.025	0.011	0.049	0.041	0.028	0.045	0.025	0.041	0.053	0.072	0.069	0.028	0.035
130	0.022	0.010	0.032	0.021	0.032	0.034	0.020	0.024	0.044	0.061	0.064	0.027	0.022
140	0.018	0.007	0.039	0.016	0.033	0.040	0.014	0.021	0.029	0.050	0.050	0.035	0.031
150	0.016	0.005	0.053	0.019	0.039	0.070	0.012	0.021	0.056	0.060	0.041	0.048	0.044
160	0.017	0.006	0.080	0.019	0.067	0.109	0.019	0.017	0.075	0.074	0.051	0.048	0.043
170	0.020	0.003	0.117	0.013	0.077	0.130	0.017	0.010	0.071	0.058	0.051	0.022	0.020

Table III(a). Diagonal I=0 elements of the error matrix (degrees^2) at 210 MeV from existing data, W, and hypothetical additions. In the additions, $\delta P = \pm 0.02$, $\delta\sigma/\sigma = \pm 0.01$, and the other errors = ±0.03; g^2 is fixed at 14.4; $d\sigma/d\Omega$ is assumed at 5 deg steps, other data at 10 deg steps. Ref = W + PDR(13,33,53 deg)$_{pp}$.

W	P D R A 60-120 deg	D_T R_T A_T 90-120 deg	D_T 130-170 deg	$d\sigma/d\Omega$ 5-180 deg	C_{NN} 60-120 deg	$^3S_1$	$\overline{\varepsilon}_1$	$^3D_1$	$^1P_1$	$^3D_2$	$^3D_3$	$\overline{\varepsilon}_3$	$^3G_3$	$^1F_3$	$^3G_4$	$^3G_5$
✓						2.58	0.58	2.05	6.23	3.17	0.74	0.51	0.34	0.90	1.27	0.49
Ref						2.49	0.58	1.92	6.31	2.94	0.74	0.50	0.33	0.89	1.27	0.48
Ref		✓ ✓ ✓				0.58	0.38	0.34	1.39	0.67	0.38	0.094	0.15	0.22	0.33	0.13
Ref	✓ ✓ ✓ ✓					0.36	0.28	0.28	1.02	0.38	0.24	0.11	0.12	0.24	0.24	0.12
Ref	✓ ✓	✓				0.49	0.33	0.35	1.87	0.65	0.37	0.094	0.16	0.21	0.49	0.14
Ref	✓ ✓ ✓	✓ ✓				0.42	0.29	0.28	1.10	0.46	0.23	0.080	0.12	0.15	0.36	0.11
Ref	✓ ✓ ✓ ✓	✓ ✓ ✓				0.29	0.25	0.21	0.67	0.30	0.21	0.065	0.093	0.12	0.17	0.084
Ref	✓ ✓ ✓ ✓	✓ ✓ ✓	✓			0.29	0.099	0.21	0.65	0.25	0.21	0.036	0.093	0.10	0.16	0.080
Ref	✓ ✓	✓		✓		0.27	0.18	0.25	0.76	0.24	0.077	0.046	0.055	0.098	0.11	0.075
Ref	✓ ✓ ✓	✓ ✓		✓		0.22	0.17	0.20	0.46	0.18	0.045	0.041	0.036	0.063	0.089	0.046
Ref	✓ ✓ ✓ ✓	✓ ✓ ✓		✓		0.16	0.15	0.17	0.34	0.14	0.041	0.036	0.031	0.054	0.068	0.036
Ref	✓ ✓ ✓ ✓	✓ ✓ ✓	✓	✓		0.16	0.071	0.16	0.32	0.11	0.040	0.024	0.028	0.047	0.058	0.036
	Ditto + A′(13 deg)$_{np}$					0.15	0.070	0.15	0.27	0.06	0.039	0.012	0.026	0.040	0.040	0.036
Ref					✓	0.51	0.45	0.27	3.24	0.62	0.43	0.11	0.16	0.36	0.36	0.11
Ref	✓ ✓	✓			✓	0.27	0.32	0.18	1.32	0.34	0.27	0.064	0.11	0.14	0.19	0.086
Ref	✓ ✓ ✓ ✓	✓ ✓ ✓			✓	0.22	0.25	0.16	0.61	0.21	0.20	0.055	0.078	0.090	0.10	0.070
Ref	✓ ✓ ✓ ✓	✓ ✓ ✓		✓	✓	0.08	0.14	0.12	0.31	0.11	0.036	0.029	0.028	0.044	0.053	0.028

Table III(b). As III(a) at 320 MeV.

Ref	P D A R 55-125 deg	D_T A_T R_T 75-125 deg	$d\sigma/d\Omega$ 5-180 deg	$^3S_1$	$\overline{\varepsilon}_1$	$^3D_1$	$^1P_1$	$^3D_2$	$^3D_3$	$\overline{\varepsilon}_3$	$^3G_3$	$^1F_3$	$^3G_4$	$^3G_5$
✓				8.8	6.4	5.8	4.1	9.8	1.5	0.40	2.3	0.32	1.5	0.35
✓	✓ ✓	✓		0.86	0.47	0.51	2.0	1.6	0.47	0.14	0.65	0.17	0.62	0.21
✓	✓ ✓ ✓	✓ ✓		0.50	0.39	0.38	0.93	0.65	0.42	0.098	0.43	0.14	0.16	0.16
✓	✓ ✓ ✓ ✓	✓ ✓ ✓		0.38	0.33	0.33	0.59	0.38	0.33	0.067	0.24	0.089	0.12	0.13
✓	✓ ✓ ✓ ✓	✓ ✓ ✓	✓	0.29	0.16	0.22	0.51	0.23	0.16	0.020	0.043	0.047	0.11	0.059
Ditto + $d\sigma/d\Omega$ (5-20 deg)$_{pp}$				0.28	0.15	0.20	0.50	0.22	0.15	0.019	0.042	0.038	0.11	0.055
Ditto + AA′ (33,53 deg)$_{pp}$				0.23	0.15	0.17	0.48	0.22	0.13	0.018	0.041	0.029	0.097	0.051
Ditto + C_{NN} (135,150,160,170 deg)$_{np}$				0.19	0.12	0.16	0.26	0.12	0.081	0.017	0.039	0.023	0.069	0.038

Table III(c). As III(a) at 425 MeV.

Ref	P D R A 55-125 deg	D_T R_T A_T 65-125 deg	$\left(\frac{d\sigma}{d\Omega}\right)_{np}$ 5-180	$\left(\frac{d\sigma}{d\Omega}\right)_{pp}$ 5-90	$^3S_1$	$\overline{\varepsilon}_1$	$^3D_1$	$^1P_1$	$^3D_2$	$^3D_3$	$\overline{\varepsilon}_3$	$^3G_3$	$^1F_3$	$^3G_4$	$^3G_5$
✓					5.50	2.73	2.60	5.51	3.38	1.10	1.53	0.67	1.11	1.05	0.46
✓	✓ ✓	✓			2.38	0.98	1.15	2.04	0.89	0.80	0.37	0.39	0.19	0.35	0.24
✓	✓ ✓ ✓	✓ ✓			1.72	0.83	1.04	1.60	0.69	0.67	0.22	0.25	0.16	0.26	0.20
✓	✓ ✓ ✓ ✓	✓ ✓ ✓			1.37	0.70	0.88	1.26	0.52	0.55	0.16	0.18	0.13	0.22	0.16
✓	✓ ✓ ✓ ✓	✓ ✓ ✓	✓	✓	0.86	0.26	0.31	0.56	0.29	0.24	0.06	0.06	0.05	0.05	0.05
Ditto + A_T R_T' D_T R_T (140-170 deg)$_{np}$					0.54	0.18	0.22	0.48	0.17	0.07	0.04	0.03	0.03	0.04	0.025

Table III(d). As III(a) at 520 MeV.

Data	$^3S_1$	$\overline{\varepsilon}_1$	$^3D_1$	$^1P_1$	$^3D_2$	$^3D_3$	$\overline{\varepsilon}_3$	$^3G_3$	$^1F_3$	$^3G_4$	$^3G_5$
W	74.2	100.8	27.9	283.7	94.1	74.2	43.4	69.3	95.9	26.6	30.4
W + PDR(13,33,53 deg)$_{pp}$ + R′(33,53)$_{np}$ = Ref	59.9	94.5	25.2	266.9	88.1	67.9	41.5	61.5	93.9	26.5	29.1
Ref + PDRAD$_T$R$_T$A$_T$(55-125 deg)$_{np}$	2.7	2.5	1.5	9.4	1.0	1.7	0.50	0.45	0.86	0.50	0.52
Ditto + $d\sigma/d\Omega$(5-180 deg)$_{np}$ + $d\sigma/d\Omega$(5-90 deg)$_{pp}$	0.48	0.31	0.32	0.22	0.22	0.16	0.10	0.09	0.06	0.06	0.04
Ditto + D_T(140-170 deg)$_{np}$ = X	0.46	0.13	0.23	0.22	0.18	0.16	0.05	0.08	0.06	0.04	0.04
X + C_{KP}(90 deg)$_{pp}$	0.46	0.13	0.22	0.21	0.18	0.16	0.05	0.08	0.06	0.04	0.04
X + C_{NN}(30-90 deg)$_{pp}$	0.46	0.13	0.23	0.22	0.18	0.16	0.05	0.08	0.06	0.04	0.04

Table IV(a). Diagonal I=1 elements of the error matrix at 210 MeV from existing data, W, and hypothetical additions. Ref ≡ W + PDR(13,33,53 deg)$_{pp}$.

Data	$^3P_0$	$^1S_0$	$^3P_1$	$^3P_2$	$\overline{\varepsilon}_2$	$^3F_2$	$^1D_2$	$^3F_3$	$^3F_4$	$\overline{\varepsilon}_4$	$^3H_4$	$^1G_4$	$^3H_5$	$^3H_6$
W	0.28	0.28	0.045	0.029	0.017	0.059	0.079	0.031	0.025	0.0073	0.041	0.010	0.028	0.018
Ref	0.26	0.25	0.039	0.026	0.015	0.057	0.067	0.028	0.022	0.0048	0.033	0.009	0.022	0.016
Ref + PD(60-120 deg)$_{np}$ + D_T(90-120 deg)$_{np}$	0.22	0.15	0.034	0.025	0.013	0.051	0.033	0.026	0.021	0.0044	0.028	0.006	0.018	0.013
Ref + PDR(60-120 deg)$_{np}$ + D_TR_T(90-120 deg)$_{np}$	0.13	0.13	0.030	0.021	0.010	0.025	0.026	0.025	0.013	0.0034	0.018	0.005	0.015	0.009
Ref + PDRA(60-120 deg)$_{np}$ + $D_TR_TA_T$(90-120 deg)$_{np}$	0.13	0.12	0.027	0.019	0.010	0.023	0.025	0.023	0.012	0.0033	0.016	0.005	0.014	0.009
Ditto + $d\sigma/d\Omega$(5-180 deg)$_{np}$ + D_T(130-170 deg)$_{np}$	0.11	0.11	0.026	0.018	0.009	0.019	0.021	0.018	0.011	0.0027	0.011	0.005	0.010	0.005

Table IV(b). As Table IV(a) at 320 MeV

Data	$^3P_0$	$^1S_0$	$^3P_1$	$^3P_2$	$\overline{\varepsilon}_2$	$^3F_2$	$^1D_2$	$^3F_3$	$^3F_4$	$\overline{\varepsilon}_4$	$^3H_4$	$^1G_4$	$^3H_5$	$^3H_6$
W	2.64	1.36	0.80	0.28	0.14	0.29	0.15	0.36	0.044	0.065	0.090	0.065	0.26	0.026
W + PDR(13,33,53 deg)$_{pp}$ = Ref	1.85	0.48	0.46	0.12	0.083	0.25	0.081	0.31	0.029	0.023	0.050	0.032	0.14	0.018
Ref + PDD_T(55-125 deg)$_{np}$	0.55	0.40	0.28	0.10	0.043	0.076	0.064	0.13	0.025	0.013	0.029	0.028	0.085	0.015
Ref + $PDAD_TA_T$(55-125 deg)$_{np}$	0.43	0.36	0.22	0.090	0.036	0.064	0.062	0.068	0.023	0.010	0.027	0.026	0.063	0.013
Ref + $PDARD_TA_TR_T$(55-125 deg)$_{np}$	0.33	0.24	0.18	0.078	0.033	0.051	0.052	0.054	0.020	0.009	0.022	0.023	0.047	0.012
Ditto + $d\sigma/d\Omega$(5-180 deg)$_{np}$	0.30	0.18	0.16	0.070	0.029	0.044	0.039	0.050	0.018	0.005	0.016	0.017	0.037	0.011
Ditto + $d\sigma/d\Omega$(5-20 deg)$_{pp}$	0.29	0.18	0.15	0.062	0.027	0.038	0.029	0.042	0.014	0.005	0.013	0.012	0.031	0.007
Ditto + AA′(33,53 deg)$_{pp}$	0.28	0.17	0.056	0.035	0.018	0.032	0.028	0.030	0.013	0.005	0.012	0.010	0.016	0.007
Ditto + C_{NN}(135,150-170 deg)$_{np}$	0.27	0.16	0.055	0.033	0.017	0.030	0.028	0.030	0.013	0.005	0.012	0.010	0.016	0.007

Table IV(c). As Table IV(a) at 425 MeV.

Data	$^3P_0$	$^1S_0$	$^3P_1$	$^3P_2$	$\overline{\varepsilon}_2$	$^3F_2$	$^1D_2$	$^3F_3$	$^3F_4$	$\overline{\varepsilon}_4$	$^3H_4$	$^1G_4$	$^3H_5$	$^3H_6$
Ref = W + PDR(13,33,53 deg)$_{pp}$ + R′(33 deg)$_{pp}$	0.65	0.36	0.26	0.13	0.10	0.091	0.092	0.052	0.033	0.033	0.048	0.032	0.073	0.027
Ref + PDD_T(55-125 deg)$_{np}$	0.44	0.32	0.24	0.12	0.086	0.071	0.086	0.048	0.030	0.023	0.043	0.028	0.061	0.026
Ref + $PDRD_TR_T$(55-125 deg)$_{np}$	0.38	0.28	0.23	0.11	0.068	0.068	0.084	0.047	0.028	0.017	0.037	0.026	0.054	0.024
Ref + $PDRAD_TR_TA_T$(55-125 deg)$_{np}$	0.36	0.26	0.22	0.11	0.058	0.065	0.071	0.045	0.027	0.016	0.032	0.024	0.052	0.021
Ditto + $d\sigma/d\Omega$(5-180 deg)$_{np}$ + $d\sigma/d\Omega$(5-90 deg)$_{pp}$ = X	0.26	0.17	0.11	0.064	0.040	0.026	0.036	0.016	0.008	0.009	0.014	0.011	0.016	0.008
Ditto + $A_TR_T{}'D_TR_T$(140-170 deg)$_{np}$	0.23	0.16	0.096	0.056	0.031	0.021	0.035	0.016	0.008	0.008	0.011	0.011	0.010	0.007
X + C_{NN}(30-170 deg)$_{np}$	0.24	0.15	0.082	0.050	0.032	0.023	0.029	0.014	0.008	0.008	0.014	0.010	0.010	0.007

Table IV(d). As Table IV(a) at 520 MeV

Data	$^3P_0$	$^1S_0$	$^3P_1$	$^3P_2$	$\overline{\epsilon}_2$	$^3F_2$	$^1D_2$	$^3F_3$	$^3F_4$	$\overline{\epsilon}_4$	$^3H_4$	$^1G_4$	$^3H_5$	$^3H_6$
W	16.5	29.2	8.6	1.25	3.45	1.71	12.7	2.9	0.50	2.0	1.03	3.85	1.19	0.36
W + PDR(13,33,53 deg)$_{pp}$ + R′(33,53 deg)$_{pp}$ = Ref	6.6	6.8	1.8	0.50	0.70	0.43	1.55	0.42	0.15	0.63	0.25	1.14	0.27	0.16
Ref + PDRAD$_T$R$_T$A$_T$(55-125 deg)$_{np}$	0.68	1.23	0.45	0.14	0.17	0.13	0.57	0.26	0.094	0.048	0.063	0.11	0.12	0.062
Ditto + $d\sigma/d\Omega$(5-180 deg)$_{np}$ + $d\sigma/d\Omega$(5-90 deg)$_{pp}$	0.35	0.53	0.17	0.049	0.056	0.029	0.074	0.036	0.010	0.017	0.022	0.015	0.015	0.013
Ditto + D$_T$(140-170 deg)$_{np}$ = X	0.33	0.53	0.17	0.048	0.051	0.027	0.071	0.035	0.010	0.015	0.022	0.013	0.015	0.013
X + C$_{KP}$(90 deg)$_{pp}$	0.32	0.53	0.16	0.048	0.039	0.025	0.070	0.035	0.010	0.013	0.021	0.013	0.015	0.012
X + C$_{NN}$(30-90 deg)$_{pp}$	0.33	0.37	0.16	0.040	0.047	0.026	0.046	0.032	0.008	0.014	0.020	0.009	0.013	0.012

Table V. Predictions for D_T and R_T in np scattering from the present energy-independent phase shift analyses

Energy (MeV)	210	320	425	520
R_T(140 deg)	-0.631 ± 0.039	-0.555 ± 0.027	-0.477 ± 0.050	-0.046 ± 0.110
R_T(150 deg)	-0.844 ± 0.017	-0.702 ± 0.014	-0.649 ± 0.041	-0.528 ± 0.073
R_T(160 deg)	-0.849 ± 0.015	-0.750 ± 0.037	-0.792 ± 0.051	-0.841 ± 0.042
R_T(170 deg)	-0.504 ± 0.034	-0.394 ± 0.045	-0.417 ± 0.051	-0.535 ± 0.047
D_T(140 deg)	0.040 ± 0.042	0.063 ± 0.093	0.522 ± 0.050	0.163 ± 0.107
D_T(150 deg)	0.110 ± 0.045	0.275 ± 0.081	0.685 ± 0.060	0.480 ± 0.107
D_T(160 deg)	0.073 ± 0.053	0.405 ± 0.068	0.821 ± 0.074	0.579 ± 0.086
D_T(170 deg)	-0.144 ± 0.043	0.164 ± 0.049	0.434 ± 0.058	0.234 ± 0.053