A Survey of Experimental Results on Nucleon–Nucleon Scattering Work Done by the Orsay Group

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This report presents experimental results obtained by the Orsay group in France. Firstly, experiments of differential cross-section polarization and depolarization in pp scattering at 150 MeV. Secondly, polarization and correlation measurements in pp scattering at 600 MeV.

INTRODUCTION

This survey paper about experimental results on nucleon–nucleon scattering work performed by the Orsay group will be relatively brief.

I will present: (1) Our results in p–p scattering at about 150 MeV; (2) Our P and C_{nn} measurements at 600-MeV p–p scattering, using a polarized target. These measurements were performed at CERN (Geneva).

PROTON–PROTON SCATTERING NEAR 150 MeV

150 MeV is probably the energy region most explored. There were at least three groups (Harvard, Harwell, and Orsay) working at this energy. In spite of a great deal of data, the situation was at first not satisfactory; differential cross-section curves were different in general shape; absolute values diverged by more than 15% with claims of 2% or 3% accuracy: and the same problems existed in double and triple scattering parameters. What is important, and due to the competition between the three groups, is the fact that now results converge in absolute scale, and the precision is improved. I have to add that all measurements mentioned here were made by classical methods, using liquid hydrogen or polythen targets, scintillator telescopes, and electronic devices.

Table I gives our values of differential cross-section measurements[1] at 156 MeV. In Fig. 1, these values are compared with Harvard[2] renormalized values at 147 MeV and Harwell[2] precise new values at 144 MeV. Errors indicated in our values are absolute, including statistics, absolute monitoring, and target thickness (atoms/cm^2); all values are mean values of 2 or 3 series of independent measurements. The curve on Fig. 1 results from analysis of data by Perring[2] starting from Harwell values at 144 MeV. Our old values need a 1.02 renormalization factor to fit this curve well.

Table II and Fig. 2 give our results concerning polarization in p–p scattering at 138 MeV. Values given here are renormalized by a factor of 0.85 with regard to previous[3] published values. This renormalization was necessary because we made a systematic error on our beam polarization, having used for its calibration incorrect values[4] of the analyzing power of carbon at 135 MeV. The renormalized factor is probably very good, determined by a precise measurement by Jarvis and Rose[5] and rechecked by us.[6] These renormalized values are in very good agreement with the new precise Harwell values[7] at 140 MeV.

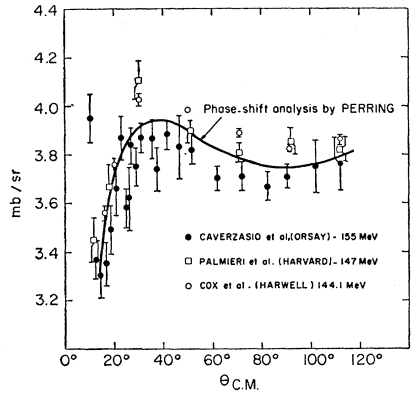

FIG. 1. Differential cross section in p–p scattering at 155 MeV, comparing results from three laboratories.

Figure 3 represents D parameter values given by the three 150-MeV groups. Our values[3] (renormalized with the new P value) is in good agreement with the Harvard measurements. I think there is no new Harwell data, and so, a difference remains here. In any case, the D measurement is probably the most difficult amongst triple scattering parameters and most liable to systematic errors.

[1] C. Caverzasio, K. Kuroda, and A. Michalowicz, J. Phys. Radium **T22,** 628 (1967).
[2] B. Rose, Harwell Publication HL 66/1362.
[3] C. Caverzasio, A. Michalowicz, K. Kuroda, M. Poulet, and N. Poutcherov, J. Phys. Radium **T24,** 1048 (1963).
[4] J. M. Dickson and Salter, Nuovo Cimento **6,** 235 (1957).
[5] O. N. Jarvis and B. Rose, Phys. Letters **15,** 271 (1965).
[6] M. Poulet, A. Michalowicz, Y. le Guen, K. Kuroda, D. Croneberger, and G. Coignet, J. Phys. Radium **T26,** 399 (1965).
[7] O. N. Jarvis, B. Rose, and J. P. Scanlon, *Proceedings of the 2nd International Symposium on Polarization* (Karlshrue, Germany, 6 Sept. 1965).

TABLE I. Differential cross section at 156 MeV.

$\theta_{c.m.}$	$\sigma(\theta)$
8°.3	8.48±0.22
10°.4	3.95±0.10
12°.5	3.37±0.08
14°.5	3.30±0.09
16°.8	3.35±0.09
18°.7	3.49±0.10
20°.8	3.66±0.11
22°.9	3.87±0.09
25°	3.58±0.08
26°	3.62±0.13
27°	3.84±0.08
29°	3.75±0.08
31°.1	3.87±0.06
35°.5	3.865±0.08
37°.3	3.74±0.09
41°.5	3.88±0.06
46°.6	3.83±0.03
51°.7	3.82±0.06
62°	3.70±0.08
72°	3.71±0.06
82°.2	3.67±0.06
90°.2	3.71±0.05
102°.2	3.75±0.11
112°	3.76±0.11

POLARIZATION AND SPIN CORRELATION PARAMETERS AT 600 MeV

I shall go now from 150 MeV to 600 MeV and present results of experiments we performed at the CERN[8] synchrocyclotron, using a polarized target for measurement of P and a polarized target and a polarized beam with both spin orientations[9] for C_{nn} measurements, but a classical electronic method for detection, monitoring, and data taking. The target polarization was about 70%.

TABLE II. Polarization in p–p scattering at 138 MeV.

$\theta_{c.m.}$	P
20°.7	0.177±0.008
24°.8	0.191±0.005
29°	0.194±0.005
33°.1	0.210±0.006
37°.2	0.208±0.006
41°.3	0.208±0.006
45°.4	0.199±0.005
49°.5	0.189±0.005
53°.6	0.186±0.005
57°.7	0.164±0.006
61°.8	0.161±0.006
65°.8	0.125±0.007
69°.9	0.121±0.005
74°	0.105±0.004
82°.0	0.085±0.003
86°.0	0.060±0.005
88°.0	0.004±0.006

[8] C. Coignet, D. Cronenberger, K. Kuroda, A. Michalowicz, J. Olivier, M. Poulet, J. Teillac, M. Borghini, and C. Ryter, Nuovo Cimento **43**, 708 (1966).

[9] C. Coignet, D. Cronenberger, K. Kuroda, Y. le Guen, A. Michalowicz, C. Olivier, L. Dick, and L. di Lella, Nuovo Cimento **43**, 701 (1966).

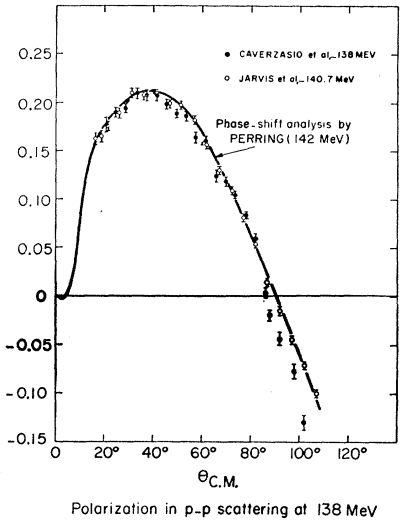

FIG. 2. Polarization in p–p scattering at 138 MeV, comparing results from two laboratories.

When we performed these experiments, the situation at 600 MeV was rather confused. There were P and C_{nn} measurements at Dubna[10] by conventional methods, and at Berkeley using polarized target and ordinary techniques for detection and data taking. Results on C_{nn} were about similar in the two laboratories, but the P data at Dubna were systematically about 30% lower than Berkeley's.

Table III shows our results on P measurements at 595 MeV. These results are discussed and compared with the values obtained by other groups, in the paper presented by Ducros. Note however that our results are in good agreement with those obtained at the same energy at Saclay[11] using similar experimental methods and compatible with measurements of Cheng[12] performed by conventional techniques. Cheng's values are systematically higher by about 10%; this discrepancy may be explained by an overvaluation of our target polarization, or an undervaluation of the beam used by

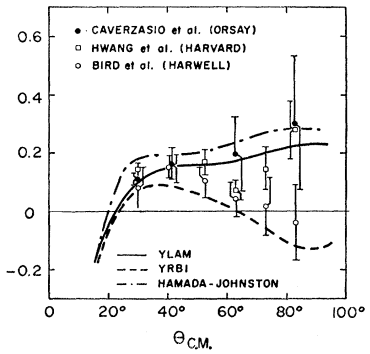

FIG. 3. The triple scattering parameter D in p–p scattering at 138 MeV showing results from three laboratories.

[10] Complete list of references will be found in Refs. 8 and 9.

[11] Y. Ducros, Rev. Mod. Phys. **39**, 531 (1967), this conference.

[12] D. Cheng, UCRL 1192υ (unpublished).

Cheng. Cheng obtained his polarized beam by scattering at 605-MeV proton beam on a carbon target at 6°, and found 32% polarization. At a similar energy, we found 39.5% polarization scattering the beam on carbon at −7°.5; our measurement is made both by reversing the spin orientation of first scattered beam, and by measuring asymmetry in two symmetric telescopes placed after the second carbon scatterer. Both measurements give the same result in the limit of statistical errors.

Our values of C_{nn} at 575 MeV are given in Table IV. In a later paper, Catillon will analyze the dependence of C_{nn} against energy. We first remark that our value at 90° c.m. lies 40% lower than those obtained by Dost[13] at 680 MeV using a similar method. However Golovin[14] recently found at 605 MeV and 90° c.m., $C_{nn}=0.56\pm 0.16$ in very good agreement with our value at 575 MeV; his old values at 640 MeV being in agreement with those of Dost at 680 MeV; Golovin used a classical method with an ordinary hydrogen target.

TABLE III. Polarization measurements at 596 MeV.

$\theta_{\text{c.m.}}$ (degrees)	$-t$(GeV/c)^2	$P(\theta)$ (%)	$\Delta P(\theta)$ (%)
23°.00	0.044	44.46	±7.40
32°.00	0.086	47.35	±11.70
36°.50	0.111	52.60	±2.70
41°.00	0.138	48.78	±2.65
45°.40	0.168	48.75	±2.50
49°.80	0.200	45.85	±2.05
54°.20	0.234	42.55	±2.20
62°.90	0.308	38.05	±2.00
67°.00	0.345	29.70	±1.45
75°.60	0.425	23.05	±1.30
79°.70	0.464	16.05	±1.30
83°.90	0.505	10.55	±1.10
87°.90	0.544	04.05	±1.10
91°.20	0.577	−01.83	±0.95
96°.00	0.624	−08.40	±1.05
103°.90	0.700	−23.50	±1.40

[13] H. E. Dost, J. F. Arens, F. W. Betz, O. Chamberlain, M. J. Hausroul, L. G. Holloway, C. H. Schulz, and G. Shapiro, Phys. Rev. **148**, 1289 (1966).
[14] Preprint, Dubna, 1966, p. 2776.

TABLE IV. Correlation parameter measurements at 575 MeV.

$\theta_{\text{c.m.}}$ (degrees)	$-t$(GeV/c)^2	$C_{nn}(\theta)$ (%)	$\Delta C_{nn}(\theta)$ (%)
36°.30	0.105	56.15	±7.60
40°.80	0.132	32.46	±7.15
45°.20	0.160	43.50	±7.65
49°.60	0.191	35.90	±7.45
54°.00	0.223	43.90	±5.50
62°.60	0.293	56.45	±5.65
66°.90	0.329	38.40	±5.85
75°.30	0.405	47.60	±6.10
79°.40	0.443	51.95	±5.20
83°.60	0.481	53.40	±7.55
87°.60	0.520	54.80	±5.20
90°.90	0.551	51.15	±5.85
95°.70	0.596	54.95	±5.75
103°.60	0.670	56.20	±5.05

The 40% disagreement between C_{nn} values at 575–605 MeV on one side and 640–680 MeV on the other could be a real effect with a rapid variation of C_{nn} and hence triplet contribution, with energy in this region; this will be interesting to analyze theoretically. But it could also come entirely or partially from systematic errors.

In the 600 MeV and higher-energy region, we find ourselves in the same situation that we were in a few years ago in the 150-MeV region: accumulation of experimental data, amelioration of relative accuracy, but not enough certainty in the absolute scale. To obtain reliable values by classical methods, the next step would be to devote one's energies to measure systematically the polarization in scattering protons by C and other targets as a function of energy and angles. In the other hand, after the conference on polarized targets, at Saclay in 1966, perhaps a common philosophy concerning precise calibration of the target polarization will arise.