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Complete Sets of pp Elastic Scattering Experiments in the Energy Range from 0.8 to 2.8 GeV

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The experimental possibilities of the Saclay polarized beam and target facility determine the choice of a particular set of observables for the complete reconstruction of the nucleon-nucleon scattering amplitudes. The status of the pp part of the program and a summary of new results is presented. The influence of the new data points on the determination of the imaginary parts of the phase shifts is shown for several partial waves.

§1. Introduction

The aim of the nucleon-nucleon program at SATURNE II is to determine the amplitudes of pp and np elastic scattering in the energy range of the Saclay accelerator. The pp part of this program includes the measurement of spin-dependent total cross section differences $\Delta\sigma_T$ and $\Delta\sigma_L$ between 0.5 and 2.8 GeV [1] and the measurement of complete sets of observables requiring polarized beam and/or polarized target, and/or rescattering of one of the outgoing particles.

§2. Experimental Facility

The polarization of the extracted proton beam is vertical and is flipped every burst. The beam polarization is typically $\sim$90% below 1 GeV and $\sim$75% at the highest energy. It is measured by a polarimeter in the first focus of the extracted beam. The beam polarization at the final focus can be oriented in the normal ($\vec{n}$) and longitudinal ($\vec{k}$) directions by a movable magnet system [1]. In conjunction with the polarized target magnet the system also allows to produce a transverse beam polarization with substantial $\vec{s}$ component. The transverse components $\vec{n}$ and $\vec{s}$ before entering the target field are measured by a second polarimeter.

The polarized proton beam is scattered on the frozen spin polarized proton target 4.2 cm long and 2 cm in diameter. This target is made of doped pentanol placed in a ^{3}He-^{4}He dilution refrigerator cooled down to $\sim$38 mK. The target polarization can be oriented in the $\pm\vec{n}$, $\pm\vec{k}$ or $\pm\vec{s}$ directions with a holding field of 3.3 KGauss. The relaxation time is $\sim$45 days for the intensities below 10^8 particles/sec, it decreases to $\sim$14 days at 2.10^8 particles/sec.

Scattered and recoil particles are detected in the experimental set-up shown in Fig. 1. The fourfold coincidence of the scintillation counters TD.ΣH3.TG.ΣH12 triggers the read-out of seven MWPC's C1 to C14 . Each MWPC comprises three planes with 2 mm wire spacing. The momentum of the scattered particle is analyzed by a large apperture magnet, the time-of-flight of both of the outgoing particles is measured .

The spectrometer and the polarimeter arms have an acceptance of $\pm 11°$ lab horizontally and $\pm 5°$ lab vertically. The polarimeter accepts rescattering up to 12° at any point of the carbon analyzer.

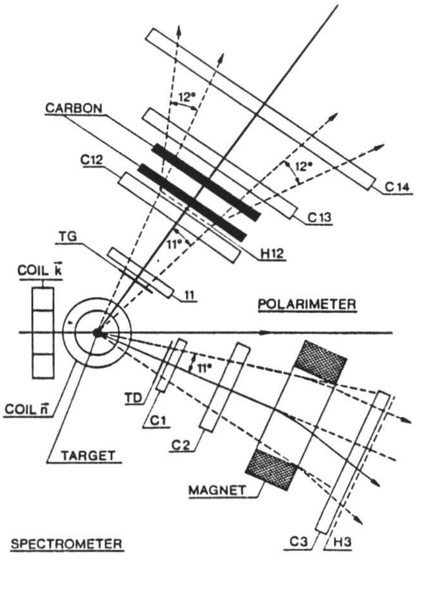


Fig. 1. Experimental set-up.

§3. Choice of Observables

For the beam, target and detector lay-out described above we have determined the optimal complete set of observables for the reconstruction of the scattering amplitudes. This set, given in Table 1, optimizes the statistical precision for a given running time.

Table 1.

N° of configuration		I	II		III	IV
Orientation of Polarization	Beam	$\pm\vec{k}$	$\pm\vec{n}(.87P_B)$	$\pm\vec{s}(.5P_B)$	$\pm\vec{n}$	$\pm\vec{k}$
	Target	$\pm\vec{k}$	$\pm\vec{k}$	$\pm\vec{k}$	$\pm\vec{n}$	$\pm\vec{n}$
Re-scattering (A)	three-index	N_{onkk} 1	$N_{os''nk}$ 2	N_{onsk} 3		$N_{os''kn}$ 12
	two-index	$D_{os''ok}$ 4	$D_{os''ok}$	$D_{os''ok}$		
		$K_{os''ko}$ 5				$K_{os''ko}$
			K_{onno} 6			
				$K_{os''so}$ 7		
						D_{onon} 13
	one-index	P_{onoo}	P_{onoo}	P_{onoo}		P_{onoo}
No Re-scattering (B)	two-index	A_{ookk} 8		A_{oosk} 9	A_{oonn} 10	
	one-index		A_{oono}		A_{oono} 11	
					A_{ooon}	A_{ooon}

Alternate sets of experiments involving also measurements with unpolarized beam or with liquid hydrogen target were not retained since the counting rate capability of detectors and data acquisition is already saturated using only fraction of the available polarized protons. This upper limit still corresponds to sufficiently long relaxation time of the target polarization. The observables 5,6,7 and 11 in Table 1 could be measured with liquid hydrogen target. This however would results in no overall gain since it would require at least two more measurements.

The same set of observables (Table 1) is measured at all energies up to $\theta_{CM} = 90°$, in two positions of the spectrometer arm. The minimum CM angles, at each energy, are imposed by the condition, that the recoil proton has a kinetic energy of more than 60 MeV for observables of type A and of more than 100 MeV for observables of type B.

The Table 1 shows the observables measured with the four different beam and target configurations I to IV. The two signs of the beam polarization correspond to alternate bursts whereas reversal of the target polarization corresponds to separate runs.

Data for observables of type A and B, respectively, are registered in separate runs with different selection criteria. For the rescattering measurement the on-line microprocessor selects events with scattering of more than 3° in the carbon analyzer. Several of the observables are measured in different configurations.

The measurements I, II and III provide 11 observables (1 to 11 in Table 1) which form a minimal complete set for reconstruction of the amplitudes. The two observables 12 and 13 measured in configuration IV provide redundancy in the analysis. All these observables are linearly independent combinations of amplitudes [2].

In special runs with unpolarized target at 0.720 GeV and with unpolarized beam at 0.644 and 0.790 GeV the beam- and target-analyzing powers were measured separately and were found to be equal within errors. For determination of the observables given in Table 1 we assume $A_{oono} = A_{ooon}$ as required by Pauli principle, and $P_{onoo} = A_{ooon}$ by time reversal invariance.

The np part of the program[x)] will cover the same angular region. The polarized

x) in collaboration with the group of Prof. R.Hess, University of Geneva, which has provided the neutron detector.

neutron beam from deuteron break-up will have a maximum energy of 1.2 GeV. The energy range can be extended by using polarized protons incident on a polarized deuteron target. The scattered neutron will be detected in a counter made of 15 scintillator bars 20 cm thick, covering an area of 3 m horizontally by 1.2 m vertically. Assuming isospin invariance, a set of np experiments as given in Table 1 will determine the I=0 amplitudes.

§4. Present Results

The present status of the pp elastic scattering measurements is given in Table 2.

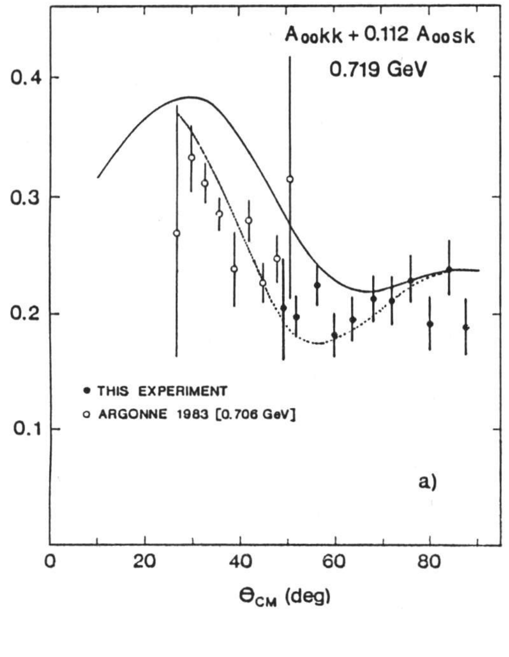
The Saclay group presents at this conference the final results for the spin correlation parameters A_{ookk} , A_{oosk} , A_{oonn} and for the analyzing power. In the following we give a summary of these results. For more details see the contributions 3,4,5,6) to this conference.

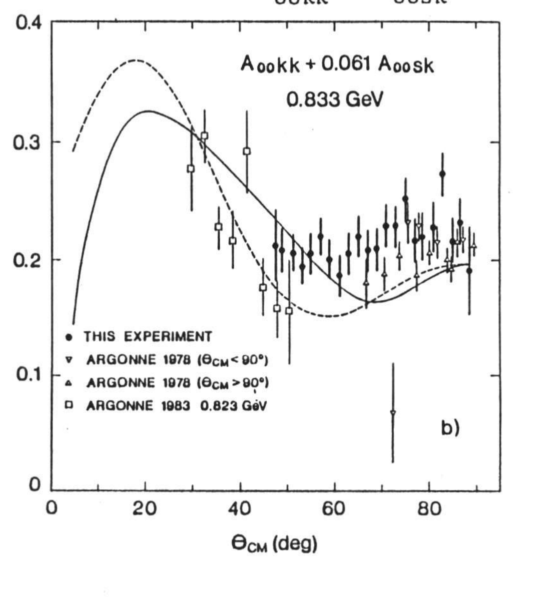
The spin correlation parameter A_{ookk} was determined at 6 energies from 0.725 to 1.1 GeV . The results of our measurements are in fact the linear combinations $(A_{ookk} + \delta A_{oosk})$ where the coefficients $|\delta|$ are small varying from 0.034 to 0.138 depending on the energy. Furthermore, the value of A_{oosk} is also small, comprises between +0.1 et -0.1. The Fig . 2 shows, as examples, the results of $(A_{ookk} + \delta A_{oosk})$ at 0.719 and 0.833 GeV

Table 2.

Incident Kinetic Energy (GeV)	$\theta_{lab} < 21°$					$\theta_{lab} > 20°$				
	I	II	III	IV	Total Obs.	I	II	III	IV	Total Obs.
0.500	-	-	-	-	-	-	-	X	-	2
0.580	-	-	-	-	-	-	-	X	-	2
0.650	-	-	-	-	-	-	-	X	-	2
0.707	-	-	-	-	-	-	-	X	-	2
0.725	-	-	-	-	-	A	-	X	-	3
0.800	-	-	-	-	-	-	-	X	-	2
0.840	-	-	-	-	-	X	X	X	X	13
0.880	X	X	X	X	13	X	X	X	X	13
0.940	-	-	-	-	-	X	X	X	X	13
1.000	-	-	-	-	-	X	X	X	X	13
1.100	X	X	X	X	13	X	X	X	X	13
1.300	X	X	X	X	13	X	X	X	X	13
1.600	X	X	X	X	13	X	X	X	X	13
1.800	X	X	X	X	13	X	X	0	0	10
2.100	X	X	X	X	13	X	X	0	0	10
2.400	X	X	X	-	11	0	0	0	0	0
2.7 or 2.8	0	0	0	0	0	A,0	A,0	A,0	A,0	4

X ... all experiments have been done.
A ... only correlation parameters and analyzing powers have been measured .
\- ... will not be measured .
0 ... all observables will be measured.





Figs. 2a and 2b.
Results for $(A_{ookk} + \delta A_{oosk})$.

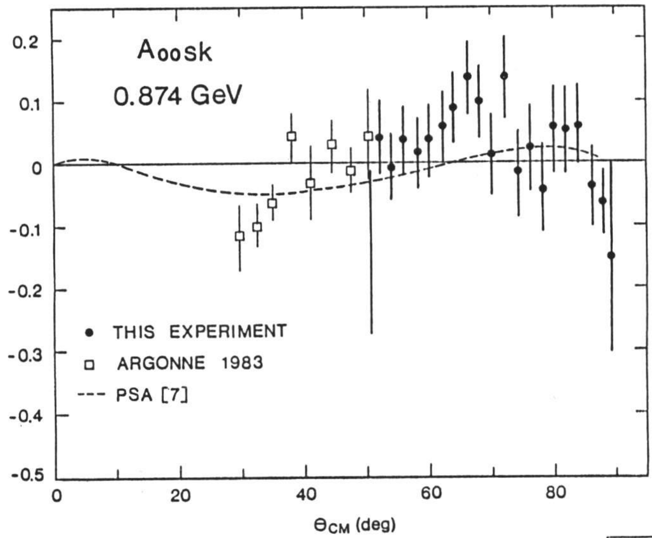


Fig.3. Results for A_{oosk}.

together with the predictions of the earlier phase shift analyses (PSA) [7,8] - full and dashed lines - and other existing data [9,10]. The new Saclay-Geneva PSA (see below) is represented by a dotted line. Above 0.9 GeV the angular distribution of A_{ookk} shows that this observable is decreasing when approaching 90° CM [11].

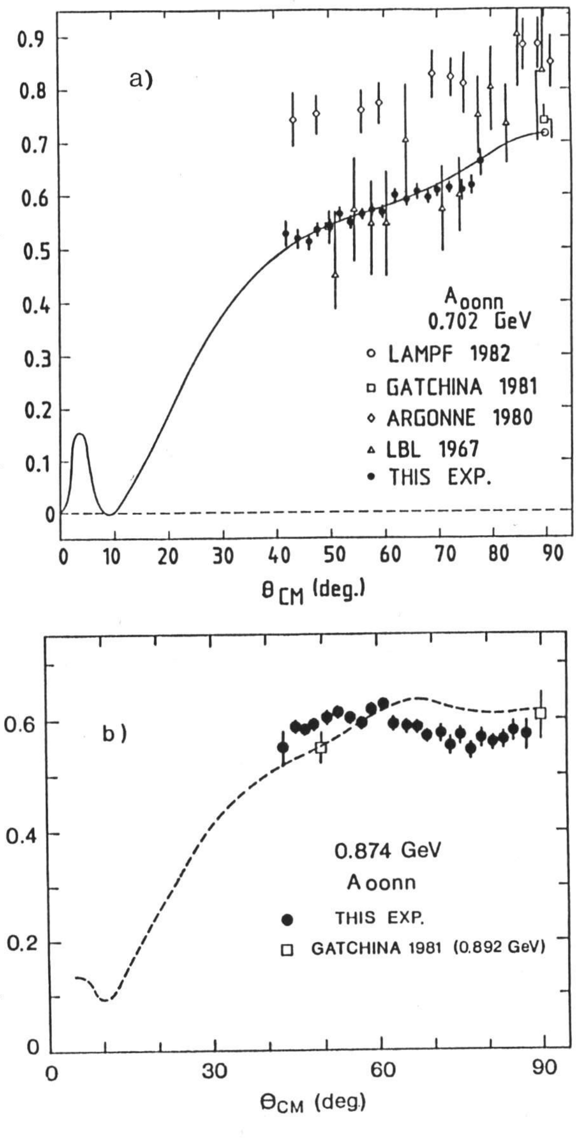
An additional measurement at 0.874 GeV with only transverse beam polarization ($\vec{n}$ and $\vec{s}$) has yielded an independent result for the parameter A_{oosk}(Fig. 3). Our data at $\theta_{CM} > 50°$ connect smoothly with the ANL data [9] at smaller angles. The curve in Fig. 3 shows the PSA prediction [7] for A_{oosk}.

The spin correlation parameter A_{oonn} and the analyzing power $A_{oono} = A_{ooon}$ were determined at 11 energies ranging from 0.5 to 1.1 GeV. In Figs. 4a,b are shown, as examples, the results for A_{oonn} at 0.702 and 0.874 GeV, compared with other existing data and with the PSA predictions [7,8]. Our data at 0.702 GeV clarify the discrepancy between some of the previous results. At higher energies the order of magnitude of A_{oonn} [4] is as predicted by the PSA [8] but not the angular distribution, except for the minimum at about 75° CM, which seems to develop with increasing energy. The values of A_{oonn} at θ_{CM} = 90° are slightly decreasing with increasing energy as it was expected from the PSA in ref. [11].

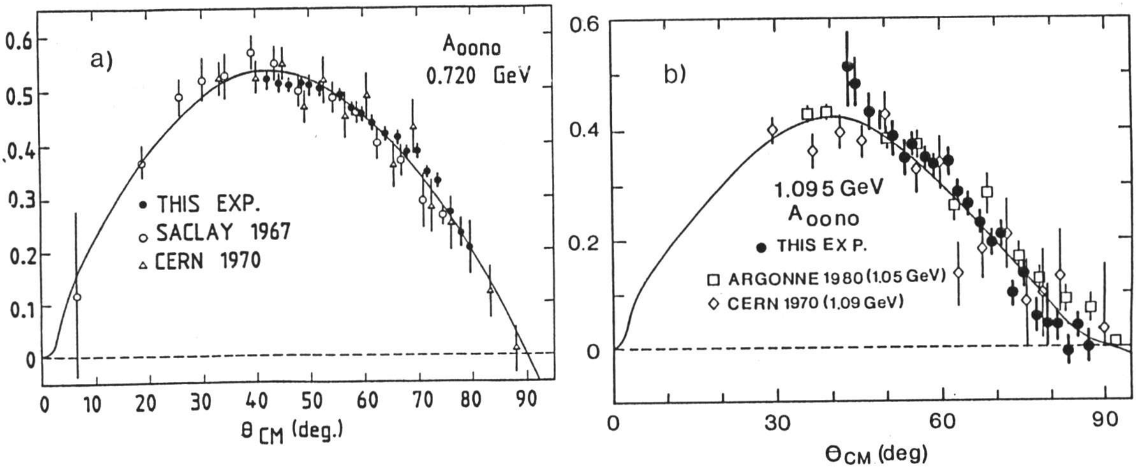
Examples of the results for A_{oono} at 0.720 and 1.095 GeV are shown in Figs. 5a,b together with most of existing data and the PSA predictions [7,8]. We observe a progressive change of the shape of the angular distribution $A_{oono} = f(\theta_{CM})$ characterized by a considerable change of the slope when approaching θ_{CM} = 90°. A possible relation to the t-dependent structure of A_{oono} in high energy pp elastic scattering is discussed in another contribution to this conference (ref. 5).

§5. Consequences for PSA

The present data allow to extend the phase shift analysis to 1.1 GeV using the 340 new data points above 0.8 GeV presented at this conference (refs. 3,4,5 and 6) .

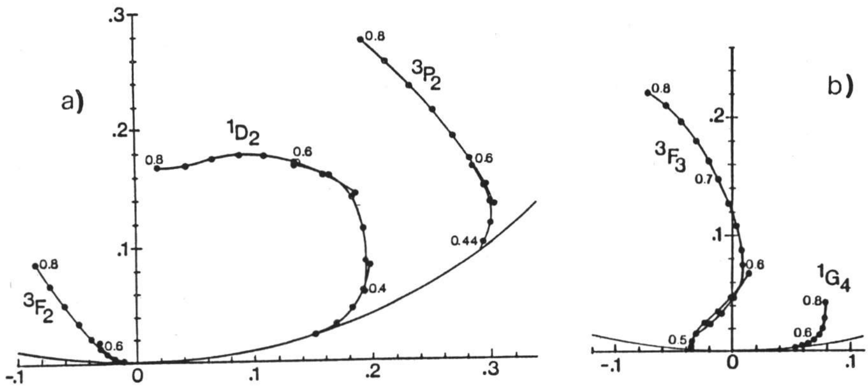


Figs. 4a and 4b. Results for A_{oonn}.



Figs. 5a and 5b. Results for A_{oono}.

The 314 new points below 0.8 GeV have already been introduced in the Saclay-Geneva phase shift analysis [7] together with other recent results from SATURNE II, SIN, LAMPF and KEK. In order to illustrate the present status of the Saclay-Geneva PSA up to 0.8 GeV we present as examples the results for the real and imaginary parts of phase shifts in the form of Argand diagrams. The imaginary parts of $^3P_0$ and $^3P_1$ vanish in the new analysis. The Argand diagrams for $^3P_2$, $^1D_2$, $^3F_2$, $^3F_3$ and $^1G_4$ phase shifts are shown in Figs. 6a and 6b.



Figs. 6a and 6b. Argand diagrams for five phase shifts.

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DISCUSSION

FICK: Can you tell us briefly the physical interpretation of your phases?

LEHAR: Including our data, as well as the other recent data from Saclay and other laboratories, the energy dependence of phase shifts connect smoothly in four energy intervals of the PSA. The imaginary parts of $^3P_0$ and $^3P_1$ phase shifts vanish up to 0.8 GeV. We observe clear structure in the real part of the $^3P_2$ phase shift around 450 MeV which may be those predicted by E. Lomon (MIT).

PLESSAS: For the development of theoretical models for the N-N interaction these new data are important in that respect that they provide means to tune existing non-relativistic models like, e.g., the Paris potential, in their extensions to include inelasticities. Finally such data allow for a check of the validity of dynamical assumptions like meson-exchange towards higher energies (up to the 1 GeV region). Corresponding attempts have already been undertaken by the Paris group, for instance.

LEHAR: The final numerical table of all presented results is available. The Saclay group will not continue the measurements of pp elastic scattering below 0.8 GeV.

UEDA: Would you have any phase shift analysis result at higher energies than 800 MeV?

LEHAR: Above 0.8 GeV we have only an energy dependent fit (using the PSA formalism) of existing differential cross section data and analysing power measurements. There exist only few other spin dependent parameters, except at 1 GeV, which are grouped at several energies. At such energies the energy fixed PSA was performed up to few GeV, e.g. by Prof. N. Hoshizaki (Kyoto). Our results will permit the extension of the energy-dependent PSA up to 1.1 GeV in the near future.

SETH: Since people have speculated time and again about evidence for dibaryons in pp phase shift analyses, I would like to ask if you would care to make any comments about lack of looping in your $^3F_3$ Argand plot.

LEHAR: I think that people have speculated about evidence for dibaryons mainly on the basis of the measured experimental data ($\Delta\sigma_L$, $\Delta\sigma_T$, A_{oonn} (90° CM) etc.). Our PSA, which will change only little since practically all new data are already introduced, show no conclusive evidence for the existence of a dibaryon in the $^3F_3$ state. I recall that the anticlockwise motion in the energy dependence of the Argand diagram is only a necessary and not sufficient condition for the existence of the resonance.