NUCLEON-NUCLEON AND PION-NUCLEON INTERACTIONS UP TO 1 GeV

Rapporteur *Yu. M. Kazarinov*

Secretaries: *N. S. Amaglobeli, I. M. Vasilevskii, Yu. P. Kumekin, and S. N. Sokolov*

Fairly extensive information is currently available on nucleon-nucleon and pion-nucleon collisions. In the limited time and number of pages alloted to the rapporteur it is hardly possible to discuss all the problems in this field in detail. It is debatable which problem should be considered the most important in this context. However, I think that many will agree that a unique determination of the scattering amplitudes is one of the most challenging problems. Accordingly, all the experimental data from the literature as well as that presented at the conference will be considered in the present paper primarily from this point of view.

1. NUCLEON-NUCLEON INTERACTIONS

a) Elastic scattering. The concept of a comprehensive experiment on the scattering of nucleons by nucleons was formulated approximately ten years ago by L.I.Puzikov, R.M.Ryndin, and Ya.A.Smorodinskii [1]. They showed in the most general form that for a unique reconstruction of the amplitude of elastic nucleon-nucleon scattering in the energy range below the meson formation threshold one must measure five quantities characterizing the scattering process. At first sight it may seem that in order to determine the scattering amplitude in practice, much less experimental data are required, so that the proposed comprehensive experiment would be of purely academic interest. However, this is not quite so. In fact, when carrying out a phase analysis in each individual case by some method it is possible to estimate the maximum orbital momentum l_{max}, for which at the given energy a noticeable interaction still takes place, and thus reduce the problem to the determination of $5l_{max} + 2$ of parameters. To set up $(5l_{max} + 2)$ independent equations we must measure three parameters characterizing the scattering process.* However, the system of equations obtained has, as shown by Klepikov [2], $2^{5l_{max}+2}$ solutions, and in order to pick out the true one more quantity must be measured. In an actual case it is most likely necessary to measure a fourth unknown parameter.

A further simplification of the problem of reconstructing the scattering amplitude from experimental data is introduced when using certain theoretical representations, or assumptions, with regard to the energy dependence of the scattering amplitude.

The greatest success in performing a comprehensive experiment has been hitherto achieved in the study of elastic *pp*-scattering at energies of 52, 140–150, 210, 310, and 630–660 MeV. When performing a comprehensive experiment for the study of *np*-collisions great experimental difficulties are encountered. Conse-

* More accurately, three comprehensive experiments give $(6l_{max} + 1)$ equations.

Table 1

Energy, MeV	*pp*-Scattering									*np*-Scattering				
	σ	p	D	R	A	A'	R'	C_{nn}	C_{cr}	σ	p	D	R	A
23.1	×	×	—	—	—	—	—	×	—	×	×	×	—	—
40	×	×	—	—	—	—	—	—	—	×	×	—	—	—
52	×	×	×	—	×	—	—	×	×	×	×	—	—	—
66	×	×	—	—	—	—	—	—	—	×	×	—	—	—
95	×	×	×	×	—	—	×	—	—	×	×	—	—	—
126	×	×	—	—	—	—	—	—	—	×	×	—	—	—
140—150	×	×	×	×	×	—	×	—	—	×	×		×	×
210	×	×	×	×	×	—	×	—	—	×	×	×	—	—
310	×	×	×	×	×	—	—	×	+	×	×	×	—	—
380—400	×	×	—	—	—	—	—	×	×	×	×	—	—	—
430	×	×	+	+	+	+	—	—	—	—	—	—	—	—
630—660	×	×	×	×	×	—	—	×	×	×	×	+	+	—
970—1000	×	×	—	—	—	—	—	—	—	× (90°)		—	—	—

Remark: × – results known earlier. A detailed bibliography is given in Wilson's monograph [11]. + – results of works presented at the conference. The energies are grouped in accordance with phase analysis studies.

quently, the *np*-scattering characteristics in the energy range under consideration are less thoroughly studied (Table 1).

Since the last conference a number of interesting studies on elastic scattering of nucleons by nucleons have been carried out. A hydrogen bubble chamber was used to measure the cross section for elastic *np*-scattering at 22.5 MeV with good accuracy in a wide range of angles (Los Alamos). The use of a polarized hydrogen target made it possible to measure C_{nn}^{pp} (90°) at 20 MeV (Saclay). Extensive investigations of triple scattering processes and spin correlations were conducted at energies of 52 MeV (Kyoto University, Rutherford Laboratory) and 140–150 MeV (Harvard, Harwell). The triple scattering parameter A at 660 MeV was found (Dubna).

The list of studies presented at this conference (in the order as they were received by the rapporteur) begins with works carried out in Dubna at a nucleon energy of 630 MeV and ends with a cycle of investigations conducted on a polarized target in Berkeley in the energy range from 3.0 to 6 GeV (Table 2).

A characteristic feature of the nucleon-nucleon scattering experiments in the last two years is the wide use of spark chambers controlled by a system of scintillation counters. A polarized target was used in two experiments in Saclay and Berkeley. However, the use of this novelty in the experimental technique should no doubt sharply increase in the near future.

b) Phase analysis of nucleon-nucleon scattering. As already said, the determination of the amplitude of nucleon-nucleon scattering at energies up to the meson formation threshold requires three–four experiments, even when we decide to consider the interaction only in states with a completely determined orbital momentum. Thus, the possibility of performing a phase analysis actually exists (remembering the table of known experimental data) at three–four energies in *pp*-scattering and at no more than one energy

Table 2

Studies on the scattering of nucleons by nucleons, presented at the conference*

Energy, MeV	Parameter	Angle	Laboratory	Author
605 **	R_{pn} P_{pn}	90° 90°	Dubna	Kazarinov, Legar, Rozanova, Pisarev Simonov
605	C^{pp}_{nn} $C^{pp}_{\text{кр}}$	90° 90°	»	Bystritskii, Golovin, Zul'korneev, Medved', Nikanorov, Pisarev
635 **	D_{np} D_{pp} (free) D_{pp} P_{np} P_{pp} P_{pp}	112° 112° 112° 45.7—145.7° 45.7—145.7° 34.5—155.7°	»	Dzhelepov, Golovin, Nadezhdin, Satarov, The same
310	C^{pp}_{cr} C^{pp}_{nn}	45° 45°	»	Kazarinov, Legar, Peter, Pisarev, Fal'brukh
430	P_{pp} D_{pp} R_{pp} A_{pp} A'_{pp} R_{pp}	30—120° 30—120° 30—120° 30—120° 30—120° 30—120°	Princeton Chicago Columbia University	Ross Rait, Kloppel, Handler Pondrom
330—6000	P_{pp}	30—120°	Berkeley	Betz, Arens, Dost, Pansrol, Holloway, Schultz, Shapiro, Troka, Steiner, Chamberlain, Dieterle, Grenness, Van Rossum, Waldon

* Here and in the following the works are listed in the order they were received by the rapporteur.

** Obtained in experiments in which the deuteron was used as a neutron target.

(147 MeV) in the case of *np*-scattering. However, already at the Geneva Conference (1962) it was shown that by using certain theoretical considerations, the experimental data then available enabled a fairly unique determination of the nucleon-nucleon scattering amplitude in the energy range from 95 to 300 MeV [3, 4].

In the period between the two conferences, along with investigations intended for the more accurate determination of earlier found solutions, a number of studies have been carried out on phase analysis of nucleon-nucleon scattering data at a fixed energy below 100 MeV as well as above the meson formation threshold. Therefore, at the present time, the energy range, in which the scattering amplitude is fairly uniquely established, has been extended toward low energies down to 20 MeV, i.e., almost to energies at which pure *S*-scattering occurs. Above the meson formation threshold the scattering amplitude was determined at three energies: 430 (Table 3), 630, and 970 MeV. For the energies 95, 147, and 210 MeV the scattering amplitude was uniquely determined, whereas in all other cases (23, 40, 52, 126, 310, 630, and 970 MeV) the situation was not so good – the number of solutions varied from two to three. If, however, it is assumed that the energy dependences of the phase shifts are monotonic, the most probable solution can be found in all the indicated cases.

The adopted phase analysis program is based on the following assumptions.

1. The interaction of nucleons in states with high orbital momenta is correctly described by Feynman's one-meson diagram [5, 6].

2. The orbital momenta, starting from which the one-meson approximation is applicable, can be estimated either from the known wavelength of the nucleon at the given energy in the center-of-mass system and from the range of the nuclear forces (the Compton wavelength of the π meson), or on the basis of the fact that in the one-meson approximation the polarization in nucleon-nucleon scattering is equal to zero [7].

3. The nuclear forces are charge-independent.

4. The formation of π mesons goes mainly in accordance with the resonance model from initial states with a total isotopic spin $T = 1$ [8, 9].

It should be noted that the first three assumptions are quite convincingly confirmed in all the energy ranges investigated. The coupling constant in cases when it is taken as a free parameter is close to the value obtained from πp-scattering. The estimate of the maximum value of the orbital momentum (after which the one-meson approximation may be used) – made on the basis of section 2 – was found to be correct. The phase shifts of $T = 1$, obtained in a combined phase analysis, agree well with the results of an analysis of pp-data alone. As regards the last assumption on meson-formation processes, it is considerably less well founded, though it very strongly affects the analysis results. This apparently should be taken into account when considering the phase analysis results for energies above the meson-formation theshold.

When using simultaneous phase analysis of np- and pp-data at relatively low energies, it

Table 3

Measurements of scattering characteristics at 430 MeV (Ross et al.)

θ_{CM}	D	R	A	A'	P
30	0.34±0.22	0.06±0.11	—	0.47±0.20	0.33±0.06
45	0.60±0.19	0.40±0.11	−0.15±0.12	0.06±0.11	0.40±0.06
60	0.47±0.13	0.43±0.08	0.36±0.09	0.06±0.09	0.25±0.04
75	0.52±0.11	0.47±0.07	0.35±0.08	0.22±0.08	0.16±0.03
90	0.67±0.10	0.47±0.05	0.27±0.07	0.36±0.07	—
105	0.65±0.15	0.35±0.11	−0.12±0.16	0.01±0.11	−0.22±0.05
120	0.59±0.25	0.34±0.18	−0.12±0.22	0.08±0.22	−0.40±0.11

is very important to correctly allow for the Coulomb effects. Calculation of the Coulomb effects in phase analysis at relatively high energies (beginning from 40 MeV and higher) can be carried out by the method used by Stapp, Ypsilantis, and Metropolis in their first investigation on phase analysis at 310 MeV [10]. The results of integrating the Schrödinger equation, obtained in Dubna by Silin and Om San Kha, show that the inaccuracy in the calculation of the Coulomb effects by the method used in [10] does not exceed in the most severe cases two errors in the determination of the nuclear part of the phase shift.

Existing methods of calculating the Coulomb contributions in the range of lower energies apparently give an appreciably lower accuracy. It is known that the scattering lengths in the $^1S_0$ -state, obtained in an analysis of the results of *np*- and *pp*-experiments, are -23.68 ± 0.03 fermi [11] and -17 ± 3 fermi [12], respectively. It should be noted that the value of 17 fermi also considerably contradicts the results of the measurements of Voitovetskii, Korsunskii, and Pazhin (Kurchatov Institute of Atomic Energy). These authors found in their experiment that the scattering length in the system of the two neutrons in the $^1S_0$ -state is 23.6 ± 2.0 fermi.

Phase analyses carried out in Dubna for several fixed energies in the interval 20 – 630 MeV have been presented at the conference (Tables 4, 5), * as well as a phase analysis of *pp*-scattering at 970 MeV, carried out in Kyoto (Hama and Hoshizaki), and new corrected *pp*- and *np*-phase parameters, obtained at Yale University by Breit, Christakis, Hull, and Simon.

The method used by the Yale group for finding the phase shifts [13] differs from the usual method of phase analysis hitherto mentioned. Assuming some form of the energy dependence of the phase shifts, the authors were in a position to simultaneously process data obtained at different energies, and thus find the phase shifts even at those energies where the experimental data are clearly insufficient for a phase analysis by the usual method.

The values found from different potential models are used as initial approximations for the phase shifts at the given energy. A noticeable shortcoming of this method is the difficulty in establishing the uniqueness of the obtained solution. At the same time, when the experimental information is insufficient, the functional minimized for finding the phase shifts has the form of a very complicated surface and the likelihood of there being a false minimum with respect to one or several parameters is fairly high.

The results presented by the Yale group were obtained by processing 780 points for 97 energies for *pp*-scattering and 762 points for 85 energies for *np*-scattering; the ratio $\chi/\bar{\chi}^2 \approx 2$. The obtained energy dependences of the phase shifts are given in Fig. 1. The phase analysis data for fixed energies are shown for comparison on the same figure by points.

The greatest discrepancy between the parameters found by the different methods lies in the values of the mixing parameter ϵ_1. It is true that the accuracy of determination of this parameter in the energy range below 100 MeV is very low, but for energies of 147 and 310 MeV the discrepancy is appreciable.

* The authors of the paper, Kiselev and Satarov, participated in the investigations.

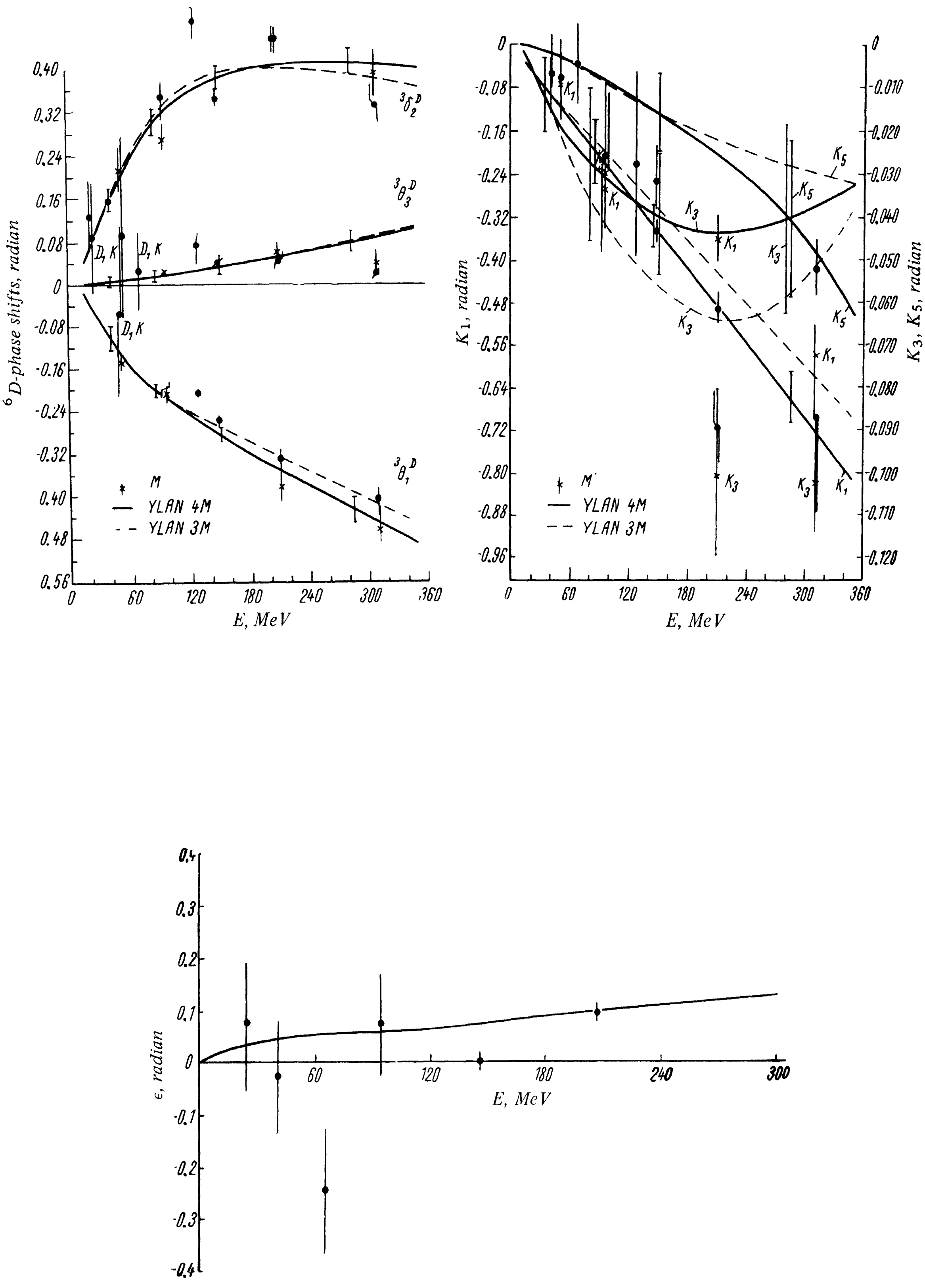
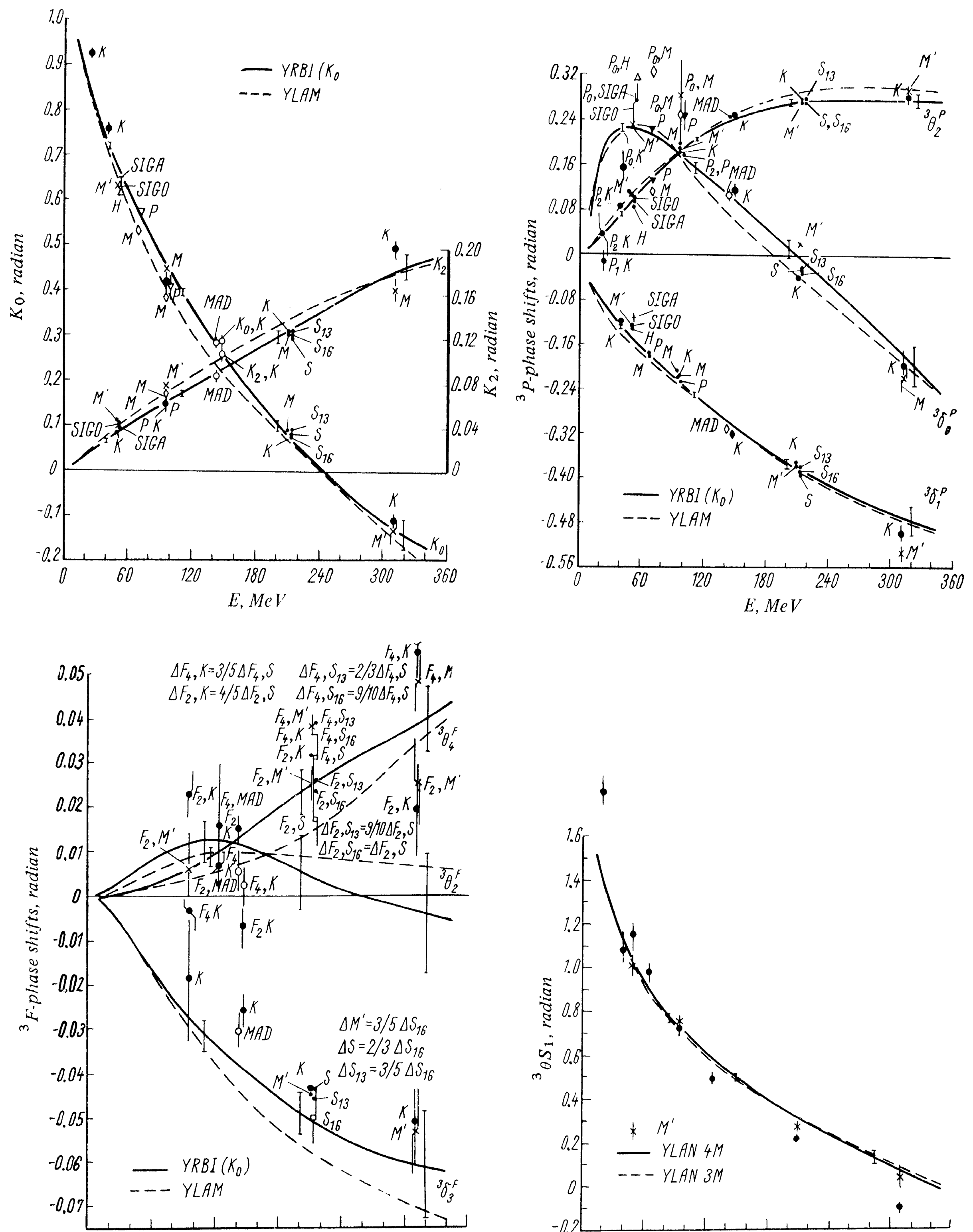


Fig. 1. Energy depenaences of the phase shifts in nucleon-nucleon scattering: the solid curves represent the results of the Yale



group; ● are the results of the work carried out in Dubna.

Table 4

Most probable values of the phase shifts

Parameter	Energy, MeV				
	23.1	40	52	66 *	95
f^2	0.19±0.5	0.12±0.01	0.12±0.04	0.06±0.04	0.068±0.012
$^1S_0$	52.71±0.40	43.11±0.73	35.52±1.53	35.88±2.11	24.14±1.86
$^3S_1$	102.39±5.81	61.80±3.69	65.11±4.08	55.58±2.24	40.25±2.67
$^3P_0$	2.18±2.46	9.02±1.76	16.43±2.39	7.65±9.23	10.76±2.67
$^1P_1$	2.30±1.06	−3.09±1.09	−4.06±4.49	−2.14±4.48	−12.12±8.40
$^3P_1$	−1.01±1.47	−6.85±0.44	−6.96±0.53	−10.68±2.00	−12.37±0.46
$^3P_2$	2.22±0.16	4.76±0.26	5.51±0.63	8.30±1.39	10.01±0.46
ε_1	4.30±7.66	−1.54±6.86	−2.44±29.4	−14.40±7.05	3.88±5.93
$^3D_1$	4.82±6.51	−5.10±4.52	−2.82±9.48	1.55±4.55	−11.23±2.35
$^1D_2$	0.76±0.19	1.67±0.10	2.46±1.59	2.20±0.96	3.57±0.37
$^3D_2$	7.34±3.94	8.65±5.02	5.61±12.5	4.43±0.01	19.82±2.42
$^3D_3$	0.21±3.30	0.77±1.92	3.74±4.62	3.93±1.59	1.78±1.69
ε_2	—	—	—	—	−2.42±0.50
$^3F_2$	—	—	—	—	−0.54±0.54
$^1F_3$	—	—	—	—	0.12±2.46
$^3F_3$	—	—	—	—	−1.07±0.86
$^3F_4$	—	—	—	—	−0.19±0.21

* The set of data was obtained by a correction of the interpolated values of the phase shifts.

Programming of the experiment [14] shows that for a reliable determination of the mixing parameter ϵ_1 for energies below 100 MeV measurements of the polarization correlation coefficients or experiments with polarized beams and polarized targets would be very useful.

In concluding this section we note the following.

1. The solutions obtained earlier in the phase analysis of nucleon-nucleon scattering data are quite consistent. As a rule, they satisfactorily predict the results of future experiments (Fig. 2) and after correction are shifted by no more than one – two errors.

2. The phase shifts of waves with an isotopic spin $T = 0$ and $T = 1$ are approximately equal in magnitude. The interactions in these states are thus equally intense.

3. Meson formation in states with $T = 1$ takes place mainly from initial $^1D_2$- and ^3F-states and in this sense has a peripheral character.

4. The coupling constant of a π meson to a nucleon is close to 0.07 everywhere, with the exception of the phase analysis for 147 MeV. The reason for this deviation is not quite clear.

c) S i n g l e f o r m a t i o n o f π m e s o n s i n n u c l e o n - n u c l e o n c o l l i s i o n s. More or less complete information on meson formation processes in the energy range under consideration is currently available only for inelastic proton-proton scattering. The situation with the investigation of inelastic *np*-collisions is much worse.

Fig. 3 gives the energy dependences of the cross sections for the formation of π^0 and π^+ mesons in *pp*-collisions in the energy range up to 1 GeV. The angular distributions of the π mesons forming in *pp*-collisions up to 660 MeV are satisfactorily described by the ex-

Table 5

Most probable values of the phase shifts

Parameter	Energy, MeV			
	147	210	310	630
f^2	0.040±0.006	0.068±0.004	0.073±0.007	0.060±0.007
$^1S_0$	15.11±0.51	4.31±0.44	−6.05±1.56	−26.18±3.90
$^3S_1$	28.83±0.71	11.70±1.42	−6.24±2.56	−3.06±5.69
$^3P_0$	5.78±0.51	−0.95±0.51	−11.29±1.48	−41.16±17.2
$^1P_1$	−19.91±1.31	−28.48±1.55	−23.67±3.54	−24.45±7.32
$^3P_1$	−17.52±0.18	−21.83±0.17	−28.62±0.76	−35.47±5.32
$^3P_2$	14.00±0.13	16.06±0.13	16.38±2.55	19.41±2.79
ε_1	−0.01±1.17	5.51±1.28	21.71±2.57	7.32±9.24
$^3D_1$	−14.40±0.60	−18.26±1.29	−22.96±1.60	−36.01±9.03
$^1D_2$	5.95±0.13	7.20±0.18	11.48±0.48	10.64±3.03
$^3D_2$	19.83±1.06	26.12±1.29	18.77±1.93	14.56±7.14
$^3D_3$	2.40±0.73	2.74±1.25	1.01±1.24	−4.64±2.48
ε_2	−2.35±0.10	−2.67±0.10	−2.08±0.38	−3.14±2.00
$^3F_2$	−0.40±0.29	1.40±0.25	1.12±0.60	−6.46±2.07
$^1F_3$	−1.84±0.52	−5.10±0.52	−5.00±1.32	−17.91±3.51
$^3F_3$	−1.45±0.22	−2.36±0.17	−2.56±0.60	−1.55±1.54
$^3F_4$	0.51±0.17	1.94±0.16	3.15±0.32	1.94±1.11
ε_3	—	—	—	4.15±3.54
$^3G_3$	—	—	—	3.36±3.48
$^1G_4$	—	—	—	6.40±0.89
$^3G_4$	—	—	—	19.00±3.89
$^3G_5$	—	—	—	2.00±1.78
ε_4	—	—	—	−5.75±0.90
$^3H_4$	—	—	—	0.69±0.74
$^1H_5$	—	—	—	2.67±2.17
$^3H_5$	—	—	—	−3.39±1.02
$^3H_6$	—	—	—	0.86±0.47
Imaginary part of the phase shifts				
$^3P_0$	—	—	—	1.75±6.11
$^3P_1$	—	—	—	−2.58±3.11
$^1P_2$	—	—	—	1.82±2.34
$^3D_3$	—	—	—	13.19±8.06
$^3F_2$	—	—	—	3.80±3.56
$^3F_3$	—	—	—	9.12±4.05

pression $a + b \cos^2 \theta$. Thus, the formation of π mesons takes place mainly in *S*- and *P*-states. A *D*-wave apparently begins to make its presence felt only above 700 MeV.

The nonmonoenergetic character of high-energy neutron beams and the three particles in the final state of most π meson formation reactions strongly complicate the study of the reactions. As a result, the greater part of the data on meson formation processes in *np*-collisions was obtained in experiments using the deuteron as a "neutron" target. Fig. 4 gives the dependence of the total cross section for π-meson formation in *np*-collisions. The angular distributions of the formed π mesons up to 600 MeV also θ do not contain terms of higher order than $\cos^2 \vartheta$.

Concerning the papers presented at the conference, I would first of all like to speak of the work of Guzhavin, Kliger, Kalganov, Lebedev, Marish, Musin, Prokoshkin, Smolyankin, Sokolov, Soroko, Chui Va Chuan (Dubna), who used a liquid hydrogen chamber to study the formation of π mesons in *pp*-

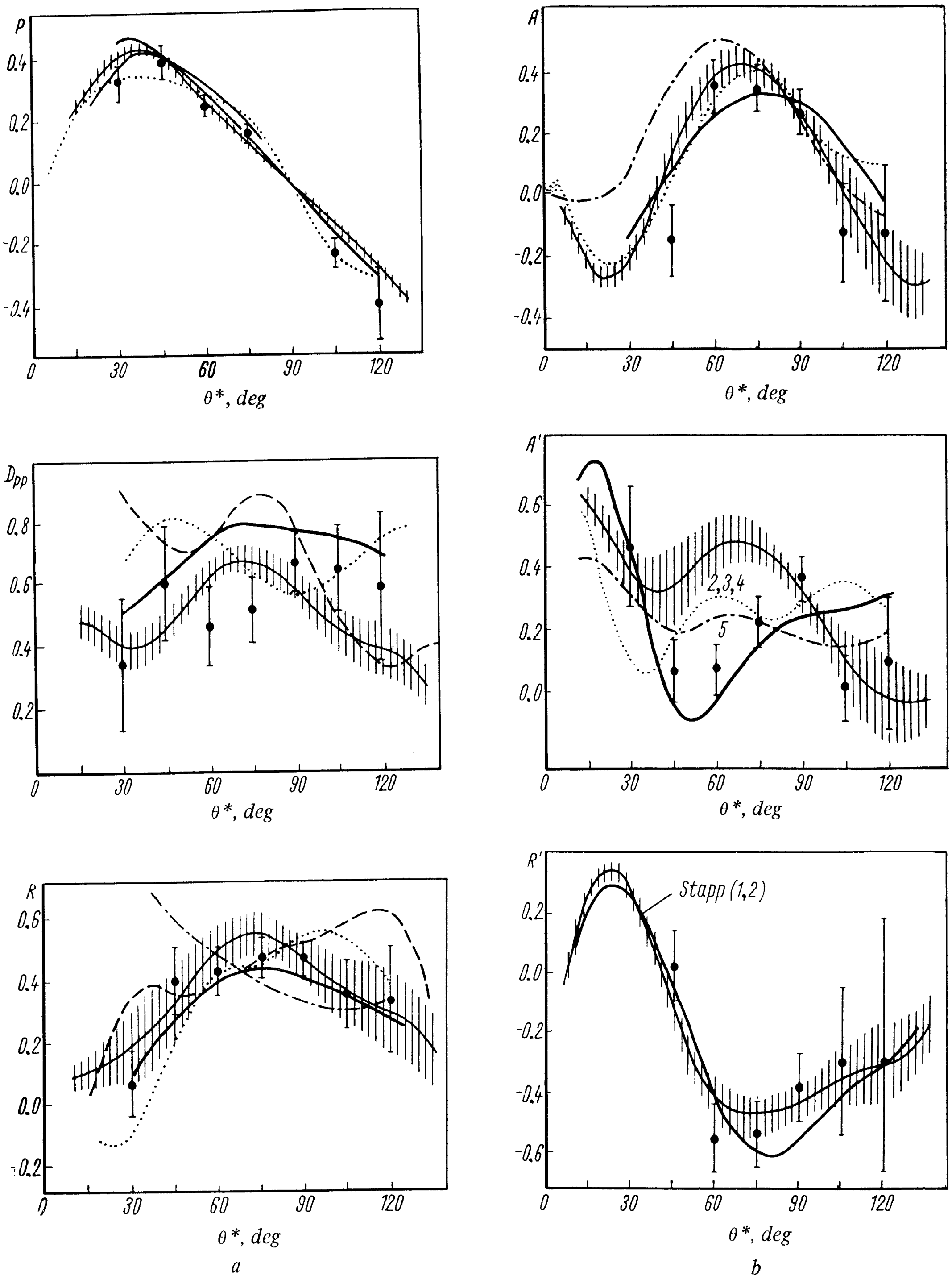


Fig. 2. Comparison of the measured parameters of *pp*-scattering at 430 MeV with the predictions of a phase analysis performed earlier by Azhgirei (Dubna):

—— — Scott and Wong, 430 MeV; — . — — Hama and Hoshizaki, 660 MeV; ..... — Stapp et al. [2 – 4], 400 MeV; — — — — Stapp et al. [1], 400 MeV; the curve with the vertical dashes — Azhgirei (JETP 45, 1988 (1963)), 400 MeV.

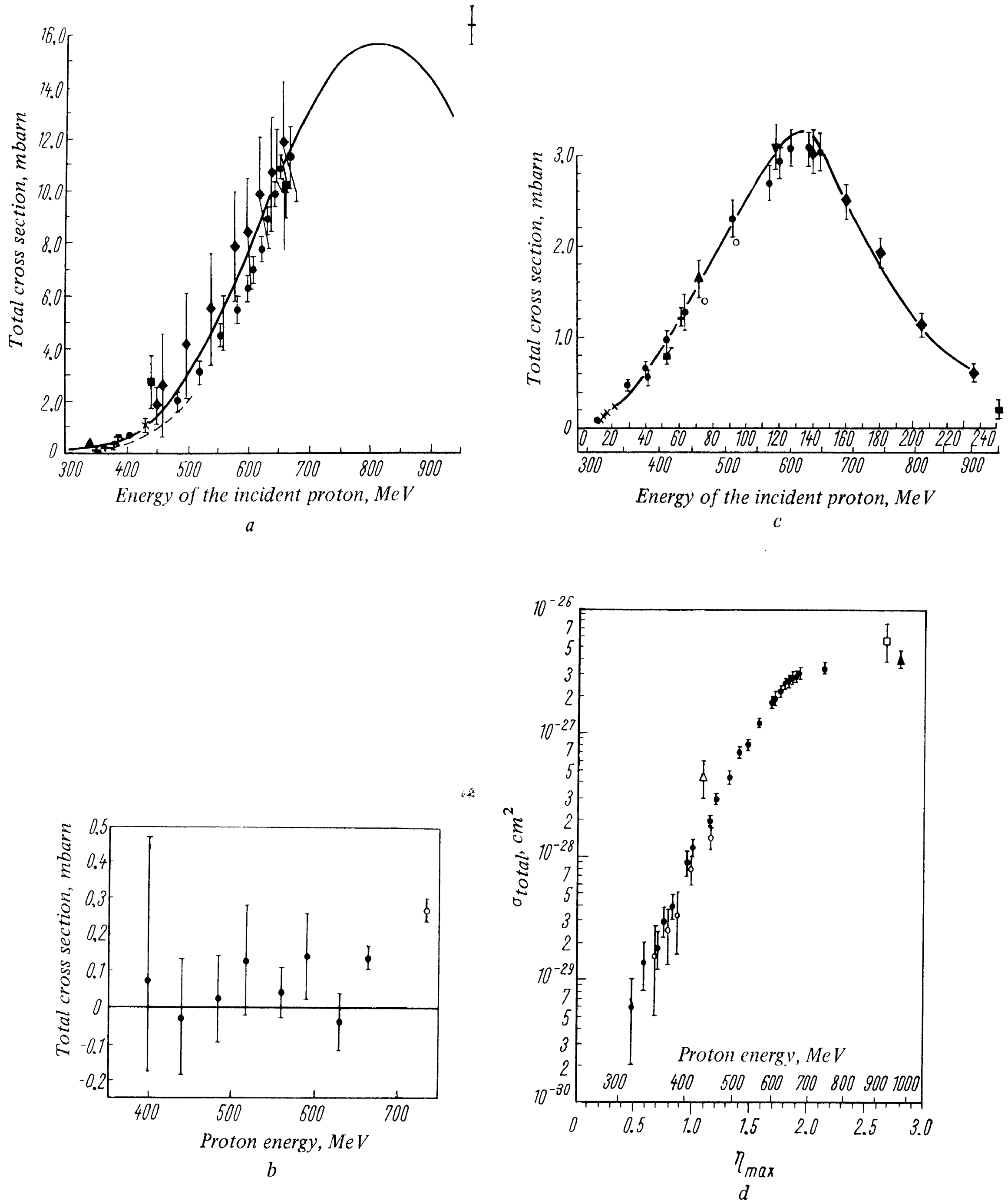


Fig. 3. Energy dependences of π meson formation cross sections in pp-collisions. Energy dependence of the coefficient b of $\cos^2\theta$ in the angular distribution of π^0 mesons:

a – total cross section for the reaction $p + p \to \pi^+ + p + n$; b – value of the coefficients in the expansion $d\sigma\pi^0 / d\Omega = a + b \cos^2\theta$; c – total cross section for the reaction $p + p \to \pi^+ + d$; d – total cross section for the reaction $p + p \to p + p + \pi^0$.

collisions at 650 MeV. The results obtained indicate that at this energy the contribution from the resonance 3/2–3/2-interaction to the cross section of the reaction $p + p \to \pi^+ + n + p$ amounts to 72 ± 3 . Thus, the contribution of nonresonant states at this energy is quite large. The measured angular distributions of the π^+ and π^0 mesons remove some disagreements which existed earlier between experimental data and the consequences of isotopic invariants.

The reaction $p + p \longrightarrow \pi^+ + d$ at 990 MeV was studied by Colley, Chapman, Johns, Ken, MacKin, Tanimura, Van der Raay and Morrey (Birmingham), its inverse reaction in the 0.65–1.95 GeV/c momentum range of the π mesons was investigated by Dekkers, Jordan, Mermond, Ting, Weber, Willis, Winter, de Boer, and Vivargent (CERN, Saclay). The results in the energy range under consideration agree with the earlier obtained data (see Fig. 3).

Rushbrooke, Bagge, Oxly, Zoll, Jobes, Kinson, Riddiford, and Tallini used the neutron beam from the Birmingham proton synchrotron in investigations of the formation of π mesons in np-collisions with the aid of a hydrogen bubble chamber (diameter of 22.5 cm) in the energy range from 290 to 970 MeV. The results obtained are shown in Table 6.

The data of Table 6 give the ratio $\sigma_{np\pi^0} / \sigma_{pp\pi^0} = 2.67 \pm 0.43$, if the formation probability of Dalitz pairs is taken equal to 0.1196 [16]. This cross section ratio indicates a very large contribution from initial states of the np system with a total isotopic spin $T = 0$ to the $pp\pi^-$ cross section. The channel $T = 0$ predominates in the formation of two π mesons. Experiment gives for $\sigma_{np\pi^+\pi^-}$ a value of $0.08 \cdot 10^{-27}$ cm^2, which is considerably larger than $\sigma_{pp\pi^+\pi^0}$.

Table 6

Type of reaction	Number of cases observed
$n+p \to p+p+\pi^-$	1721
$n+p \to n+p+\pi^0;\ \pi^0 \to e^+ + e^- + \gamma$	54
$n+p \to n+p+\pi^+ + \pi^-$	52
$n+p \to p+p+\pi^- + \pi^0$	12 (?)

The angular distributions of the protons from the reaction $pp\pi^-$ and $pp\pi^0$ and the cross section ratios are compared with the predictions of the peripheral model of Ferrari and Selleri. The cross section ratio differs somewhat, in the author's opinion, from the required value of $\sigma(pp\pi^0)/\sigma(pp\pi^-) = 2$. The angular distributions agree quite satisfactorily.

Further verification of the peripheral model was obtained by means of the Treiman-Yang criterion [15]. The Treiman-Yang angular distributions, however, appear to be appreciably nonisotropic.

Analysis of the distributions of the escape angles of the π mesons in the rest system of the assumed isobar and of the directions of motions of the isobar in the general rest systems, found on the basis of the obtained data, well confirms the predictions of the isobaric model.

The neutron beam of the Birmingham proton synchrotron was used by Doddo, Riddiford and Witekker to investigate the formation of π mesons in nd-collisions. Assuming that the deuteron may serve as a target of "free" nucleons, the authors found that $\sigma pp\pi^- / \sigma pp\pi^- = 3.15 \pm 0.26$. This value differs appreciably from that predicted by the isobaric model. According to the authors, the discrepancy lies in the effect of the Pauli principle, which suppresses the reaction $pp\pi^-$ in cases where the proton has a relatively low energy.

In concluding this section the following should be noted.

1. The contribution of nonresonant states to the formation cross section of π^+ mesons in pp-collisions at energies from 600 MeV is fairly large, amounting to approximately 30%. Accordingly, the contribution of the interaction of nucleons in states with an isotopic spin $T = 0$ to the cross section of π meson formation in np-collisions is also quite appreciable. Mandelstam's resonance model is thus not completely valid and requires some correction. This apparently should also be taken into account in phase analysis of data on nucleon scattering by nucleons in this energy range.

2. Ferrari and Selleri's peripheral model does not always correctly predict the experimental results, and, in particular, the Treiman-Yang criterion [17] is apparently not satisfied at an energy of 970 MeV.

2. π-NUCLEON INTERACTION

a) Elastic scattering of π mesons by nucleons. The scattering amplitude of π mesons by nucleons

$$M = a + b\,(\sigma \mathbf{n})$$

has two independent complex parameters. Thus, in general four experiments must be performed in order to determine it at a given fixed energy. These experiments can only be carried out when a polarized target is used [18]. In the range up to the meson-formation threshold the amount of data required reduces to one half. If we consider only the interaction in definite states, the number of independent equations which are necessary for determining the $(2l_{max} + 1)$ parameters occurring in the amplitude can be found from measurements of only one differential cross section. In this case, however, as in the analysis of nucleon-nucleon collisions, this system of $(2l_{max} + 1)$ equations has $(2^{2l_{max}+1})$ solutions [2], and to remove the indeterminacy measurement of the polarization of the recoil nucleons or the use of any other data, for example, the energy dependence of the phase shifts, is required.

From a general summary of the experimental data it follows that the large majority of the experiments on πp-scattering deals with the measurement of the scattering differential cross sections. Measurements of the polarization of recoil nucleons are considerably less numerous. The parameters R and A have hitherto not been measured at all (Fig. 5).

The papers presented at the conference are listed in Table 7 and indicated in Fig. 5 by arrows. The differential cross sections for elastic π^+p-scattering were measured in the energy range from 300 to 700 MeV at Berkeley and Saclay and in the range from 700 to 1,400 MeV at Chilton. Exchange scattering was studied in the range from 500 to 1,300 MeV at Berkeley and in the range from 500 to 1,150 MeV by the Cambridge-Padua group on the cosmotron at Brookhaven.

The polarization of the recoil protons was measured at 300 MeV in Dubna and at 523, 572, 684, 689, 981, and 1,300 MeV at Berkeley.

The measurements of the differential cross sections for elastic and exchange scattering of π mesons by protons enabled the Berkeley-Saclay group to obtain the elastic-scattering cross section in the state with total isotopic spin $T = 1/2$. The obtained cross section is approximated by the series

$$\cdot\sigma = \sum_n a_n \cos^n \vartheta$$

and the energy dependences of the first four coefficients are given. The character of the angular dependences of the coefficients points, in the author's opinion, to a strong $D_{15}F_{15}$-

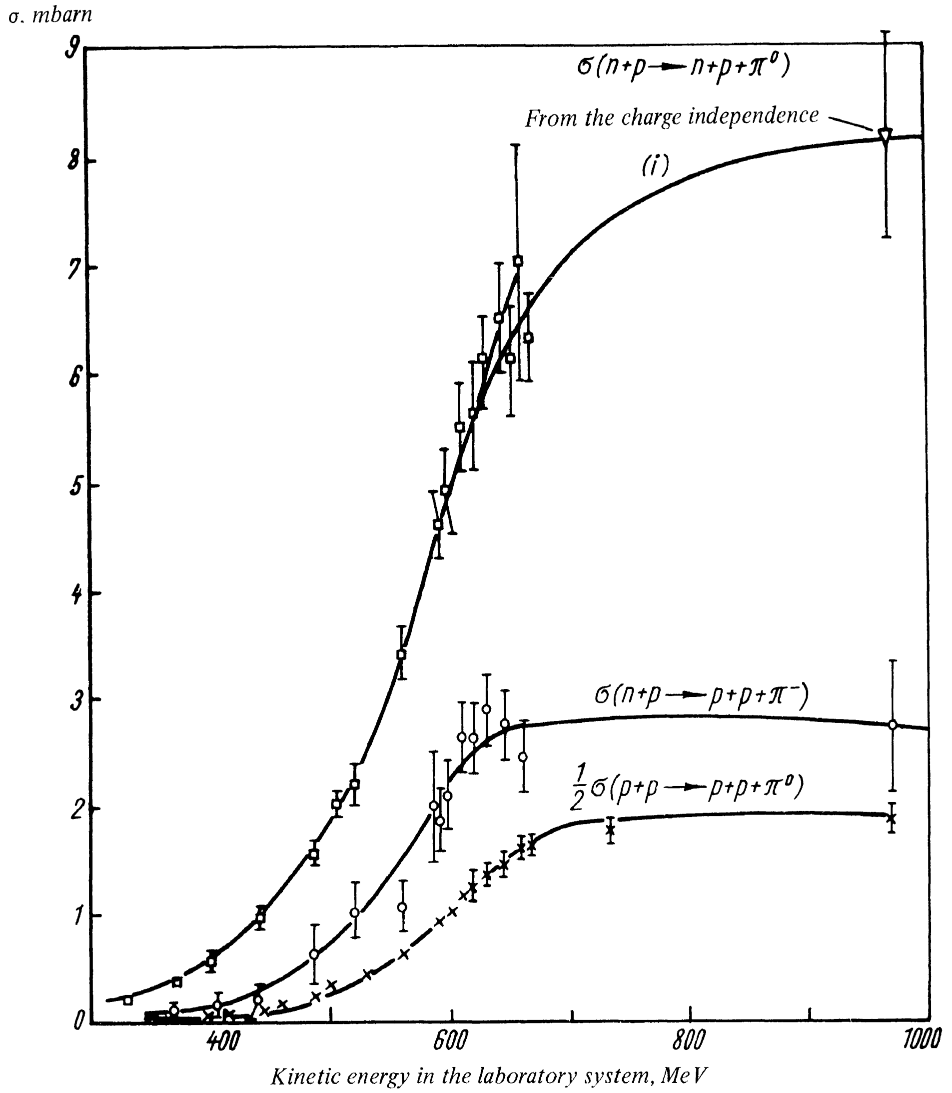


Fig. 4. Energy dependences of the cross section for π meson formation in πp collisions. The dependence of σ_{π^-} in the interval up to 650 MeV was obtained on the basis of isotopic invariance.

interference near 900 MeV and makes it possible to draw some conclusions with regard to the behavior of the partial amplitudes.

The results obtained by the Cambridge-Padua group in the study of exchange scattering also indicates strong $D_{15}F_{15}$ interference near 900 MeV and confirm the existence of two maxima in the total cross section $\sigma_T = 1/2$. The measured π^0 distributions in addition agree well with the values of the forward scattering amplitudes found from the dispersion relations on the basis of the data earlier obtained in Saclay.

The results of the measurements of the polarization of the recoil protons made at Berkeley show that polarization at an angle of 90° CM in π^-p scattering in the energy range from 600 to 1,000 MeV changes sign twice. It is negative below 700 MeV, positive at 700 MeV, and again becomes negative and

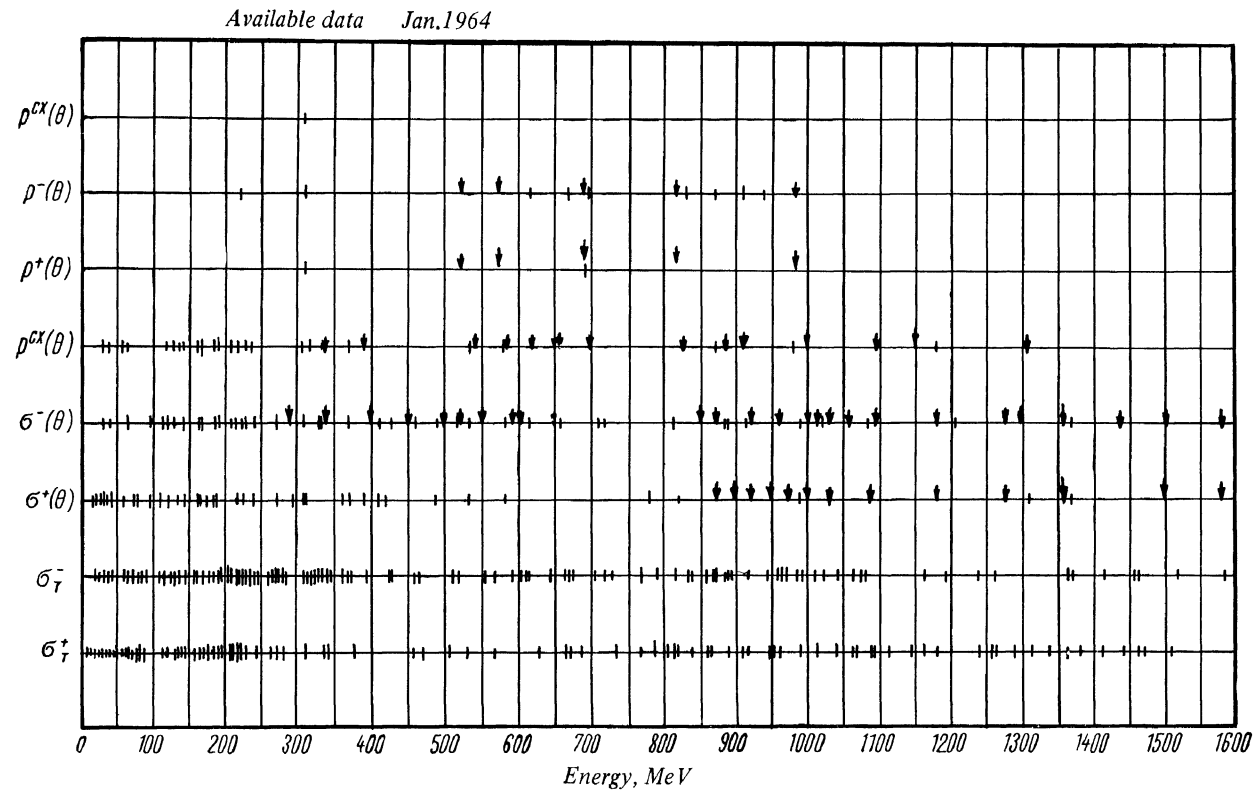


Fig. 5. Summary of experimental data on πp scattering. The arrows indicate data presented at the conference.

large above 900 MeV. In $\pi^+ p$ scattering, P (90°) is negative below 700 MeV and remains positive above 700 MeV.

When considering the experimental technique in this range it is necessary to mention first of all that at Berkeley a polarized target was used in measuring the proton polarization in πp scattering. In addition, experiments measuring the polarization of the recoil neutrons in exchange πp scattering are apparently very promising [19]. This method enables us to penetrate considerably further and, possibly, more easily than any other method into the range of small angles.

b) Phase analysis of π nucleon scattering. The first phase analysis of $\pi^+ p$ scattering was made by Anderson, Fermi, Martin, and Nagle in 1953. The total number of works on phase analysis of πp scattering carried out since then is well over twenty. However, it is possible that owing to the fact that in the first phase analyses only data on the scattering differential cross sections were used, the analysis results appeared to be nonunique. And judging from the remarks of Prof. Segre at the past conference in Geneva, the problem of the phase analysis of πp scattering in 1962 was considerably more puzzling than the problem of the phase analysis of nucleon-nucleon scattering. Since then new data on the polarization of recoil particles in π nucleon collisions have appeared, making it possible to appreciably reduce the indeterminacy in the phase analysis.

Three works on phase analysis were presented at the conference. In the first Vasilevskii, Vishnyakov, and Ivanchenko (Dubna) performed a phase analysis of π meson scattering of hydrogen using the new experimental data obtained in Dubna on the polarization

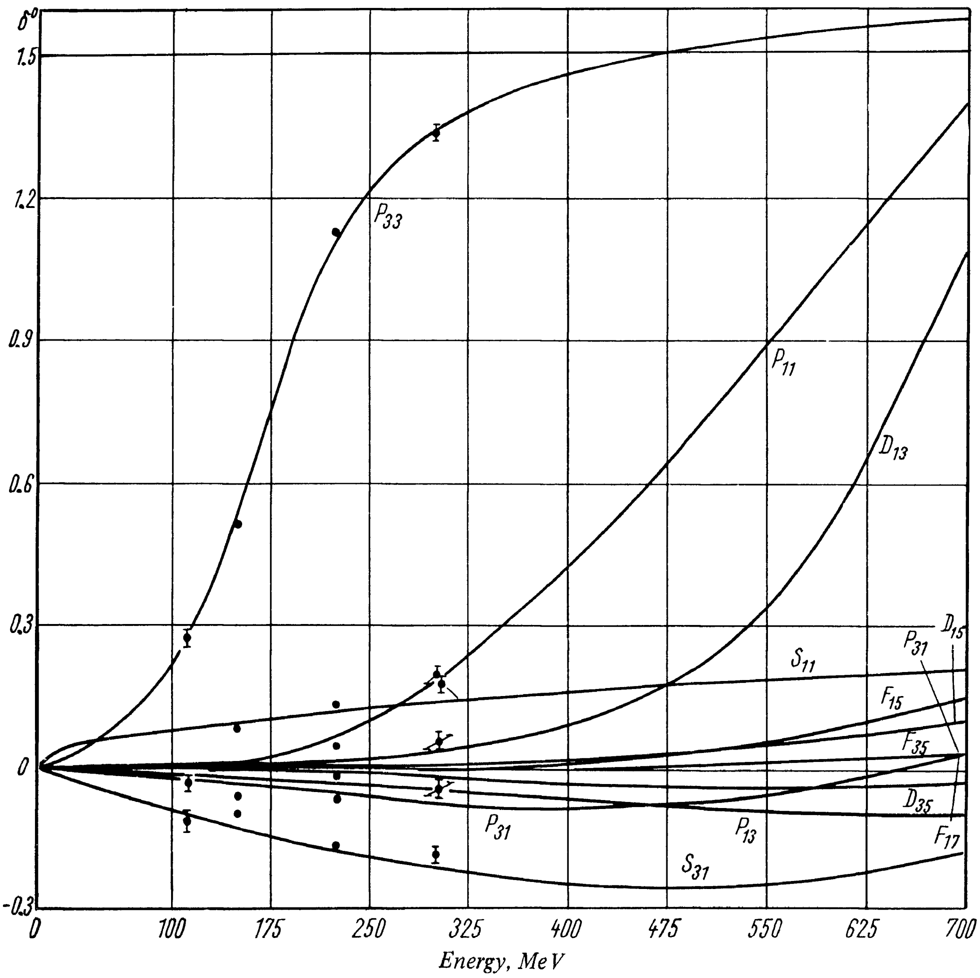


Fig. 6. Roper's phase analysis results. The points denote the results of some phase analyses performed for fixed energies.

of the recoil protons in elastic $\pi^- p$ scattering at 300 MeV and earlier known data on πp scattering at this energy.

The search for phase shift sets for $l_{max} = 2$ (SPD analysis) with random initial values for waves with an isotopic spin $T = 1/2$ was carried out using only part of the above indicated data. The phase shifts of $T = 3/2$ were taken equal to the values obtained by Chamberlain et al. [20] and assumed constant. The admixture of inelastic collisions was neglected. Three phase shift sets were found, similar to those obtained by Vik and Rugge [21]. Subsequently, the phase sets were corrected for $l_{max} = 2 - 3$ from the complete set of experimental data.

It was found that the results for $l_{max} = 2$ do not satisfy the χ^2-criterion, thus indicating the necessity to allow for the interaction in the F-state at 300 MeV. Further tests of the obtained solutions showed that one of them (solution 2) may be discarded as not satisfying the neutron polarization measured in the exchange $\pi^- p$ scattering reaction [19] for $\Delta\chi^2 = 14$. The first solution [21] and its close set are given in Table 8. It should be

Table 7

Experimental data on πp-scattering, presented at the conference

Energy, MeV	Parameter	Authors
300—700	$\sigma(\upsilon)$	D. E. Hagge, J. A. Helland and P. M. Ogden (Lawrence Radiation Laboratory), M. Banner, J. F. Detoeuf and J. Teiger (Saclay)
700—1400	$\sigma(\upsilon)$	P. J. Duke, D. P. Jones, M. A. Kemp, P. G. Murphy, J. D. Prentice and J. J. Thresher (England)
300	$P(\upsilon)$	I.M. Vasilevskii, V.V. Vishnyakov, A.A. Tyapkin (Dubna).
523—1301	$P(\upsilon)$	R. D. Eandi, T. J. Devlin, R. W. Kenney and P. G. McManigal (Lawrence Radiation Laboratory)
600—850	$\sigma_{ex}(\upsilon)$	A. Muller, E. Pauli, R. Barloutand, J. Meyer (Saclay, France) M. Beneventano, G. Glalanella, L. Paoluzi (Roma, Italy)
500—1300	$\sigma_{ex}(\upsilon)$	C. B. Chiu, R. D. Eandi, R. W. Kenney, B. J. Moyer, J. A. Poirier, W. B. Richards (Lawrence Radiation Laboratory); R. J. Cence, V. Z. Peterson, V. J. Stenger (University of Hawaii)
500—1150	$\sigma_{ex}(\upsilon)$	C. A. Bordner, A. E. Brenner, M. E. Law, E. E. Ronat, K. Strauch, J. J. Szymanski (Harvard Univ. USA) P. Bastien, B. B. Brabson, Y. Eisenberg, B. T. Feld, V. K. Fischer, J. A. Pless, L. Rosenson and R. K. Yamamoto (MIT and Laborarory for Nuclear Science USA) F. Bulos, R. E. Lanou, A. E. Pifer, A. M. Shapiro, M. Widgoff (Brown Univ. USA) R. Panvini (Brandeis Univ USA) G. Calvelli, L. Guerriero, G. A. Salandin, A. Tomasin, L. Ventura, C. Voci and F. Waldner (Padua Univ. Italy)

noted that this solution, in contrast to the remaining two, remains quite consistent under a change in the number of parameters.

The following two works on phase analysis of πp-scattering were carried out by Cence at the Hawaii University and by Roper at the Lawrence Radiation Laboratory. The works were carried out by several different methods over a wide energy range up to 700 MeV.

Roper assumed that the energy dependence of the phase shifts can be represented as a power series of the momentum in the center-of-mass system

$$\delta = \sum_n a_n k^n$$

and after this was able to simultaneously process data at different energies.

It should be noted that this method is very similar to that used earlier by the Yale group in processing nucleon-nucleon scattering data.

In the analysis with $l_{max} = 4$ Roper obtained $\chi^2 = 2400$ for 1200 processed points. The agreement cannot be regarded as good, but it should be taken into account that with the analysis method selected the number of variable parameters is always smaller than in

Table 8

Most probable phase shifts in πp-scattering at 310 MeV

Parameter	From data of	
	Vik and Rugge	Vasilevskii, Vishnyakov, Ivanchenko, Shchegel'skii
$S_{3.1}$	—21.2	—18.8±1.1
$P_{3.1}$	—12.1	—4.6±1.8
$P_{3.3}$	137.2	133.5±0.6
$D_{3.3}$	—3.3	2.2±1.3
$D_{3.5}$	1.5	—4.2±1.0
$F_{3.5}$	—1.8	0.4±0.4
$F_{3.7}$	3.3	—0.2±0.7
$S_{1.1}$	10.9	17.0±1.2
$P_{1.1}$	23.1	19.2±0.9
$P_{1.3}$	—3.5	—2.4±0.6
$D_{1.3}$	6.5	5.0±0.6
$D_{1.5}$	0.6	3.5±0.8
$F_{1.5}$	2.1	1.1±0.2
$F_{1.7}$	—1.2	1.0±0.4
χ^2	64.2	48
$\bar{\chi}^2$	52	57

phase analysis for a fixed energy, and therefore description with regard to the χ^2-criterion will always be worse.

Roper's energy dependence of the phase shifts is shown in Fig. 6 and 7. The points give for comparison the phase shifts obtained from an analysis of the data for fixed energies. The agreement may be regarded as satisfactory up to 300 MeV. Roper's set of phase shifts contains three resonances: P_{33}, P_{11}, and D_{13} at energies of 198, 570, and 650 MeV, respectively. P_{11} and D_{13} at the indicated energies have appreciable absorption coefficients.

Cence's phase analysis was performed for several fixed energies. The search for solutions started at 310 MeV from Vik and Rugge's set 2, and in passing to higher energies the result obtained for the previous energy was taken as the initial approximation for the phase shifts. It should be noted that in the case of lack of experimental data, this method of searching for solutions can hardly be regarded as the best. Encountering a false minimum at one of the energies, it is afterwards impossible to return to the correct solution.

Cence's phase shifts at 600 MeV for $T = 3/2$ are in qualitative agreement with Roper's results.

At the meeting dealing with theoretical aspects of nucleon-nucleon and π-nucleon interaction the results of the phase analysis of πp-data by Lovelace et al., performed for eleven fixed energies in the range from 310 to 700 MeV, were reported. The search at 310, 533, 581, and 698 MeV was carried out quite thoroughly, and for other energies only that solution was found which had the maximum correspondence to the interpolated data of the phase shifts. The results describe the experimental data ($\chi^2/\bar{\chi}^2 = 584/558$) considerably better and agree with Roper's curves only up to 600 MeV. The phase shift of P_{11} in this case reaches approximately 110° at 600 MeV and then sharply decreases with increasing energy (Fig. 8*a* and *b*).

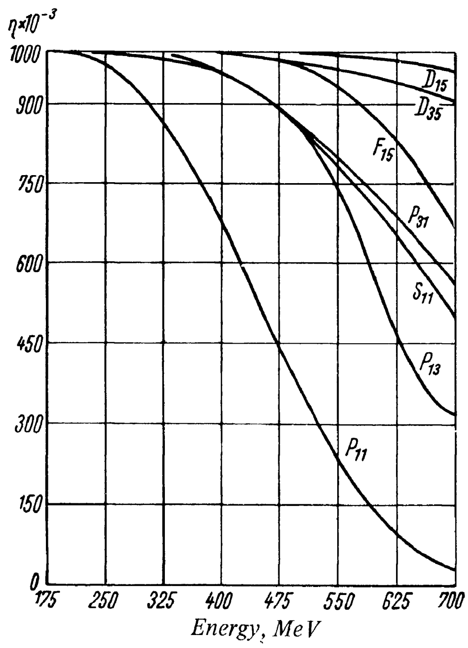


Fig. 7. Roper's phase analysis results. Absorption coefficients.

Thus, at the present time the amplitude of πp scattering is fairly uniquely determined in the energy range up to 300 MeV. In the range from 300 to 600 MeV all conclusions regarding the behavior of the phase shifts should be drawn much more carefully. Here, no doubt, some preference should be given to the results of Lovelace et al., but then it should be borne in mind that when there is a lack of experimental data the probability of encountering a false minimum is high.

c) Single π-meson formation in πp-collisions at energies below 1 GeV. Among the papers presented at the conference, only two refer to this section.

Batusov, Bunyatov, Sidorov, and Yarba (Dubna) studied the reaction

$$\pi^- + p \rightarrow \pi^+ + \pi^- + n$$

by means of a photoemulsion chamber. The dependence of the total cross section of the reaction on energy in the primary π meson energy range of 200 – 300 MeV, the angular distributions of the secondary particles, and the spectra of the effective masses of the $\pi^{\pm} n$ and $\pi^+ n^-$ systems were determined in the work. Analyzing the results, the authors concluded that the data obtained cannot be interpreted without taking into account the interaction of the particles in the final state. Allowance for the interaction in the final state is made by the method of Ansel'm and Gribov [22], which under certain assumptions makes it possible to relate the experimentally observed distribution of the particles over the relative momenta to the differences in the $\pi\pi$-scattering lengths in states with isotopic spin $T = 0$ and $T = 2$. Batusov et al. obtain for this difference the value $a_0 - a_2 = 0.25 \pm 0.05$.

Thus, the results of these authors point to the existence of an appreciable $\pi\pi$ interaction near the threshold of the reaction being studied.

Blokhintseva, Grebinnik, Zhukov, Kravtsov, Libman, Nemenov, Selivanov, Yuan' Zhun-fan (Dubna) investigated the following reactions at 344 MeV in a liquid hydrogen bubble chamber:

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n;$$

$$\pi^- - p \rightarrow \pi^- + \pi^0 + p$$

The cross sections of the reactions were found to be equal to

$$\sigma_{\pi^-\pi^+} = (1.5 \pm 0.1) \text{ mbarn}, \quad \sigma_{\pi^-\pi^0 p} = \left(0.23 \begin{array}{l} +0.04 \\ -0.07 \end{array}\right) \text{ mbarn}.$$

In the study of these authors a procedure is proposed for quantitative estimation of the contribution of the isobar (3/2, 3/2) to the cross section of inelastic π–nucleon interaction.

Analysis of the obtained experimental data by the method proposed by the authors enabled them to conclude that the investigated reactions at 344 MeV cannot be described by an isobar model taking into account only the transition $D_{3/2} \rightarrow sP_{1/2}$ in the state $T = 1/2$. The contribution of isobaric channels to the total cross section $\sigma_{\pi^-\pi^+ n}$ does not exceed one half, which also indicates the considerable role of the $\pi\pi$ interaction.

The total cross sections of meson-formation reactions in πp collisions are given in Fig. 9. The results presented at the conference are marked by arrows. They are in good agreement with the known data of other authors. The solid curves in the figures give the excitation functions of the π meson formation reactions in πp collisions, calculated from the Iodh-Olsson isobaric model [23]. The model assumes the formation of the isobar N $(33)^-$ in the S-state and decay in the p-states. It is then found that meson forma-

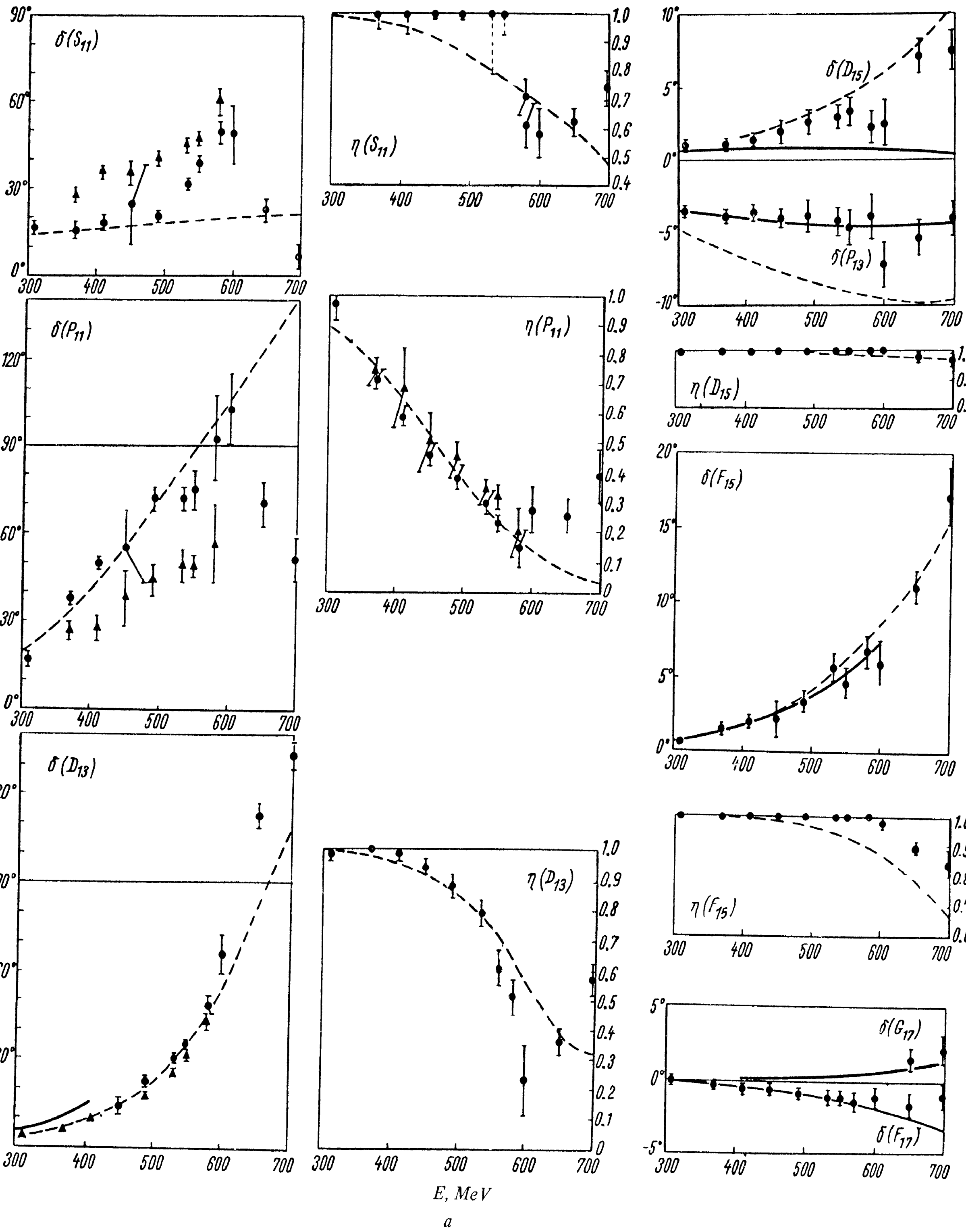
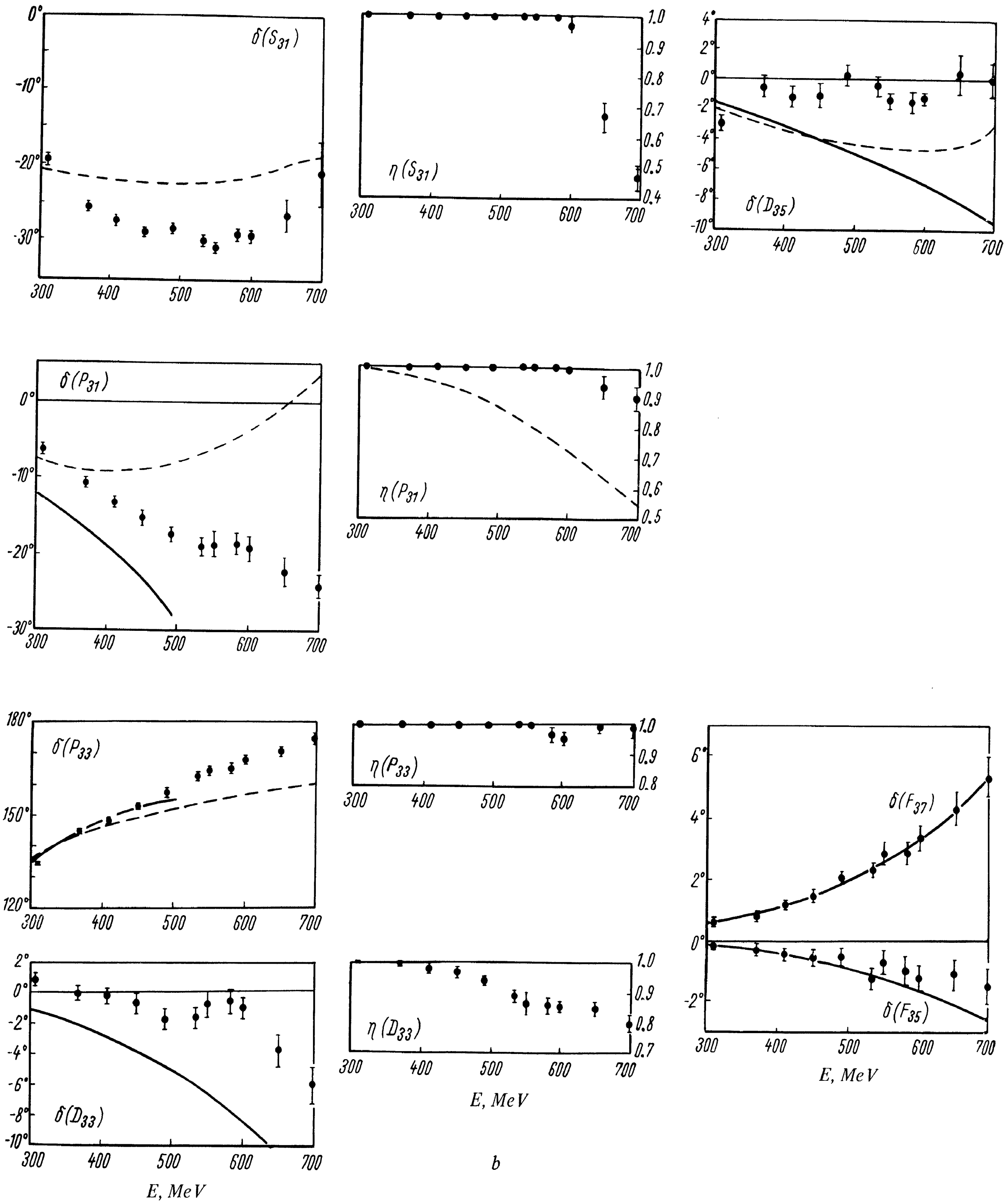


Fig. 8. Phase analysis results of Lovelace et al. and their



b

comparison with Roper's results.

tion takes place from the initial states D_{33}, D_{13}, and P_{13}, P_{33}. The model is in qualitative agreement with Roper's phase analysis results, and satisfactorily describes the dependence of the total cross sections in the energy range from the threshold to 700 MeV. The differential cross sections are poorly described, but this apparently may be due to interference effects.

It is thus clear that when describing meson formation in πp collisions, the interaction of the particles in the final state should be taken into account. However, a quantitative estimate of the role of $\pi\pi$ and π–nucleon interactions in this case still involves difficulties.

REFERENCES

1. Puzikov, L.I. et al. JETP, 32, 592 (1957).
2. Klepikov, N.P. JETP, 44, 376 (1963).
3. Kazarinov, Yu.M., Silin, I.N. Proc. Intern. Conf. on High Energy Physics, p. 25, 1962.
4. Lapidus, L. Proc. Intern. Conf. on High Energy Physics, p. 725, 1962.
5. Okun'. L.B., Pomeranchuk, I.Ya. JETP, 36, 300 (1959).
6. Cziffra, P. et al. Phys. Rev., **114**, 880 (1959).
7. Kazarinov, Yu.M. et al. JETP, 41, 197 (1961).
8. Hoshizaki, N., Machida, S. Progr. Theoret. Phys., 29, 49 (1963).
9. Zul'karneev, R., Silin, I.N. Phys. Lett., 3, 265 (1963).
10. Stapp, H.P. et al. Phys. Rev., **105**, 302 (1957).
11. Wilson, R. Nucleon-Nucleon Interaction. Int. Publ., 1963.
12. Bete, G., Morrison, F. Elementarnaya teoriya yadra.– Moskva, Izdatel'stvo inostr. lit., 1958.
13. Breit, G. et al. Phys. Rev., **120**, 2227 (1960).
14. Sokolov, S.N. Preprint OIYaI, D-573, Dubna, 1963.
15. Cence, R.J. et al. Phys. Rev., **131**, 2713 (1963).
16. Josef, D.W. Nuovo cimento, 16, 997 (1960).
17. Treiman, S.B., Yang, C.N. Phys. Rev. Lett., 8, 140 (1962).
18. Kim, Y.S. Phys. Rev., 129, 862 (1963); Bilen'kii, S. M. et al. Preprint OIYaL, P-1634, Dubna, 1964.
19. Hill, R.E. et al. Bull. Amer. Phys. Soc., 9, 410 (1964).
20. Rogers, E. et al. Rev. Mod. Phys., 33, 356 (1961).
21. Vik, O.T., Rugge, H.R. Phys. Rev., **129**, 2311 (1963);
22. Ansel'm, A.A., Gribov, V.N. JETP, 37, 501 (1959).
23. Olsson, M., Iodh, G. Phys. Rev., Lett., 10, 353 (1963), Olsson, M.T.R.-379, Maryland Univ., 1964.

ADDITIONAL REMARKS

After the conference I received a letter from Prof. R. Wilson, in which it was reported that the polarization values in *pp* scattering at 147 MeV, measured in the work of J. Palmieri, A.M. Cormack, H.F. Ramsey, and R. Wilson [Ann. Phys., 51, 299 (1958)], should be corrected by a multiplicative factor of 0.933.

The corrected values of P_{pp} were used for correcting the phase analysis for 147 MeV. It was found that the most satisfactory description of the experiment is obtained for $l_{max} = 4$ and for the following values of the phase shifts in the order used in Table 5:

0.062 ± 0.007; 16.86 ± 0.57; 31.92 ± 0.95; 5.70 ± ± 0.57; —8.23 ± 1.54; —17.13 ± 0.13; 13.99 ± 0.12; —2.13 ± 1.29; —17.12 ± 0.96; 5.35 ± 0.20; 25.36 ± ± 1.26; —2.53 ± 0.66; —2.53 ± 0.10; —0.04 ± ± 0.30; 0.48 ± 1.08; —1.64 ± 0.20; 0.53 ± 0.16; 1.23 ± 0.72; —4.40 ± 0.50; 0.76 ± 0.11; 6.14 ± ± 0.82; —0.35 ± 0.29.

The value obtained for the coupling constant is in this case close to 0.07, as for the remaining energies. It is true that the description of the experiment requires a somewhat larger number of parameters ($l_{max} = 4$).

DISCUSSION

M.G. Meshcheryakov

My question is addressed to Kazarinov. What models were referred to in your paper when you touched upon the works of the Yale group?

Yu.M. Kazarinov

In the works of the Yale group use was made of the following formula for the energy dependence of the phase shifts

$$\delta = \delta_0(E) + \sum_q a_{pq} f_{pq}(E).$$

The values of the phase shift in the first approximation, $\delta_0(E)$, were calculated from different potential models. In addition, the function $f_{pq}(E)$ was also obtained from some model representations.

P.T. Matthews

Could we have some information on the pion-nucleon phase shift of Lovelace at al? I think their results are a considerable improvement on Roper.

Yu.M. Kazarinov

Unfortunately, due to shortage of time, I could not include this study in my lecture. The paper was submitted to another reporter, and the results were reported at the meeting dealing with the theory of nucleon-nucleon and π-nucleon-collisions at energies below 1 GeV (see text of the lecture).

G. Breit

Regarding the comparison of D or chi square (χ^2) obtained in single energy with those in many energy analyses it seems necessary to remark that it is obviously not fair to compare the values directly. This is so because values obtained for phase parameters at different energies by the single energy analyses should be compared with each other. The figures shown in the first slide that we have seen indicate that the single energy determinations do not fall on the smooth all energy curves. This supports the view just stated.

I should like to make another comment which is in a way an amplification and supplement to a statement I made in one of the parallel sessions. The second slide showed in the last figure a different sign of parameter ρ_1, in the Yale notation, between the all energies and the single energy analyses. The Yale group has also had negative values of this parameters in some cases at all energies in other cases with a sign reversal. Fit YLAN 3M from which YLAN 3M was derived had in fact a sign reversal similar regarding energy analyses we have seen in the slide. Our main reason for the for the choice of sign is its agreement with simple potential models. This argument is not meant in an absolute way – only in the sense of what is probable.

C. Lovelace

The disagreement between Roper's phases and ours at the higher energies that Kaszarinov referred to, is primarily due to the fact that we included charge exchange in the fit, whereas Roper did not fit the charge exchange. However, it is by no means established in our phases that P_{11} actually goes through 90°. It could quite well reach 80° or 85° and then fall back.

Furthermore, our χ^2 is very much better than Roper's and we searched very carefully in the vicinities of Roper's solution, so if there is any false minimum, it is not we who are in it.

S.V. Nurushev

Great difficulties arise in a joint phase analysis of pp- and np-scattering data for energies above the meson formation threshold, in particular due to the small amount of information on the interaction of nucleons in states with isotopic spin $T = 0$. In this connection it is of interest to consider what additional information on NN-collisions can be obtained from experiments with elastic scattering of nucleons on light nuclei, using the formal approach proposed by Rosenfeld and Watson and developed by Bethe, Macmanus, Kromer et al. A group of experimenters from JINR consisting of Azhgirei, Kumekin, and others carried out a complete set of experiments with elastic small-angle scattering of protons with an energy of about 600 MeV on carbon nuclei. A comparison of these results with the predictions of all three sets of NN-scattering phases, obtained by Kazarinov et al., shows that none of the phase sets existing at an energy of about 600 MeV gives a satisfactory agreement with pC-scattering experiments. This discrepancy may be due to three reasons:

1) incorrectness of some initial assumptions used by Kazarinov et al. in the phase analysis of NN-scattering;

2) inherent disagreement of the experimental data on NN- and pC-scattering.

3) inaccuracy of the apparatus used for calculating the observed values in pC-scatterings from NN-scattering phases.

The first two possible reasons are under study, and as regards the third reason, we showed that the apparatus used by us, which contains as an important point the momentum approximation, gives for 315 MeV good agreement between the experimental pC-scattering data and the predictions of the first set of NN-scattering phase shifts obtained by Kazarinov et al. Since the applicability of the momentum approximation improves as the energy rises, it seems to us that the observed disagreement at 600 MeV between the predictions of the NN-scattering phases and the experimental pC-scattering data cannot be due to imperfection of the calculation method.

Accordingly, highly interesting would be experiments intended for measuring the triple-scattering parameter A at different energies, which would make it possible to reconstruct the energy dependence of the imaginary part of the spin-orbital potential $V_{SI}(r)$. From pC-scattering data at 315 and 660 MeV it follows that the potential changes sign near $\sim$400 MeV, being negative at 315 MeV and positive at 660 MeV. At the same time if follows from the results of the phase analysis of NN-scattering that V_{SI} does not change sign in the range from 100 to 660 MeV. Up to the present time, the parameter A, which is very sensitive to changes in $V_{SI}(r)$, has not been measured in pC-scattering at a single energy, with the exception of 660 MeV.

Yu.M. Kazarinov

We assume that the phase shifts at 630–660 MeV can be used for the time being only in the planning of future experiments, since the solutions found apparently depend very strongly on the assumptions made in the phase analysis of the pp-data.

I.I. Levintov

1. Are the calculations of the real part of forward *n-p-* and *p-p-*scattering (*p-p* — for the nuclear part of the scattering) sensitive to different sets of solutions for the phase analysis?

2. If the calculations of the forward real part are sensitive to different solutions, is it not possible to use the experimental data on the real part for $\theta = 0$ as an independent source of information for the phase analysis?

Yu.M. Kazarinov

No, they are not very sensitive. The errors in the determination of the real part are very large.

G. Valadas

The preliminary results of our polarisation measurements in $\pi^+ p$-scattering at 490 MeV disagree very much with Roper's phases and agree with Lovelace's results.

B.J. Moyer

Although the phase shifts are not yet clearly determined in scattering at energies above 300 MeV, certain physical effects have emerged clearly.

1) The effect of η^0 production. At this threshold the imaginary part of the S_{11} phase markedly increases, and this is reflected in the angular distribution in pure $T = 1/2$ elastic scattering. This is well-correlated with the η^0 threshold behavior presented by Lanou and by Peterson, and is exhibited also in the phase shift work of Lovelace.

2) The recent charge-exchange experiments at Brookhaven and Berkeley have made possible the exhibiting of the pure $T = 1/2$ scattering, and the predominant importance of S_{11}, P_{11}, and D_{13} amplitudes emerges clearly.

3) As energy is increased toward the third resonance (900 MeV), the predominant amplitudes in $T = 1/2$ are P_{11}, D_{15} and F_{15}.

M.G. Meshcheryakov

It seems to me that the conclusion of the rapporteur that the angular distribution of the π mesons in inelastic *NN*-collisions is isotropic is not general. One cannot speak thus about all possible reactions. It is long known for example, that in the reaction $p + p \rightarrow \pi^+ + d$ the π^+ mesons are distributed non-isotropically $(0.22 + \cos^2 \theta)$ in a wide energy range.

Yu.M. Kazarinov

I already stated in the lecture that the angular distribution of the π mesons forming in a nucleon-nucleon collision is described up to 650 MeV by the expression $A + B \cos^2 \theta$. In my opinion this is a sufficiently well-established fact.

B.M. Golovin

1. What at the present time is more useful for a more accurate phase analysis: a thorough correction of the data on cross sections and polarization or the appearance of new data on complicated scatterings (triple, correlation, polarized beam, and polarized target)?

2. Considering the present state of the theory, does Dr. Kazarinov believe it possible to use data on pion formation in *NN*-collisions (angular distribution, spectra, polarization) in the phase analysis?

3. R e m a r k . From Kazarinov's lecture it follows that the basis of our information on *np*-scattering are experiments with *pd*-collisions.

In recent years a series of works have appeared which study corrections to the momentum approximation, but nevertheless insufficient attention is paid to this. I would like to express the wish that at the next conference this problem will be brought up in a special discussion.

Yu.M Kazarinov

1. This depends on the specific case. Thus, at energies below 100 MeV it would be extremely desirable in order to noticeably correct the mixing parameter ϵ_1, for example, to measure the polarization correlation coefficient or to perform experiments with polarized beams and polarized targets. Incidentally, it should be noted that Dr. Lapidus recently proposed the use of data on photodisintegration of the deuteron for correcting the phase analysis.

2. I do not know of the existence of a detailed apparatus which would make it possible to use the enumerated characteristics in phase analysis.