BOSON RESONANCES

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BOSON RESONANCES

A. Astier

Introduction

The mission of the experimentalists is to extract from the world of their experiments all possible information and to present them to the other people in particular to the theorists, with whom they have to work. This is not a simple job because

1) the experimental techniques,
2) the formalism used for the interpretation,
3) the estimation methods for the final presentation of the results, vary from one experiment to another and, in all cases, have intrinsic biasses difficult to identify.

We shall see an example of these difficulties in a moment when discussing the A_2.

Eddington said that every knowledge is linked with a «net», or a series of nets, the first, of course, being the language itself: the kind of fishes we gather, I mean the objects which finally we are faced to, depends on the size and the shape of the meshes. It is the reason why I refused for the plan of this talk to use a particular net, as the $q\bar{q}$ mnemonic. I chose to present the results net by net, I mean firstly the results coming from a well-defined experimental technique and a well-defined formalism used for the interpretation, then to pass to another one. And so on. You will see the plan I got this way: it is not too far from giving the bosonic resonances by increasing masses.

I. $\pi\pi$, $K\bar{K}$ and $K\pi$-interactions

1. INTRODUCTION

Because we have not pion- nor kaon- target, the study of the $\pi\pi$-, the $K\bar{K}$-, and the $K\pi$-interactions have to be indirect and therefore complicated and imprecise. The only way now available to perform this study is to have $\pi\pi$ or KK or $K\pi$ system in the final state of some reaction. The results obtained are not independent, of course, of the experimental techniques used for getting these final states, because the efficiency of the detection or of the scanning, the possible mistakes or the ambiguities remaining in the identification of the events, and finally the resolution in momentum and effective mass, differ from one experiment to another. However, I made no special distinction of these methods, and took as a whole the $\pi\pi$-, $K\bar{K}$-, and $K\pi$-interaction experiments, because the results obtained in these, whatever they are, depend much more strongly on the formalisms used for the analysis, particularly for getting the phase-shifts.

2. $\pi\pi$-INTERACTION

Here, in the analysis of the data, it is easy to distinguish three conceptual nets.

The first is simply the Breit — Wigner language applied to the effective mass distributions. The second is the effective range approximation language which uses scattering lengths and effective ranges, if necessary. The third one is the phase shift language, accessible through Chew — Low extrapolation technics. I shall present the results using successively the three nets.

a) Breit — Wigner language. At this conference three groups have presented studies of $\pi\pi$ effective mass distributions. All these experiments were made in heavy-liquid bubble chambers. Strugalski et al. (ref. 1), have presented a study of the $\pi^0\pi^0$ mass distribution obtained in the JINR xenon bubble chamber by interaction of 2.34 *GeV/c* π^+ on quasi-free neutrons. The result is shown on the fig. 1. The enhancement centred at about 730 *MeV* suggests that the *S*-wave $\pi\pi$-amplitude goes through a maximum at this energy. In the experiment performed by Baldin et al. (ref. 2) in the 120 *l* propane — xenon bubble chamber ITEP at $p_{\pi^+} = 2.9$ *GeV/c*, a similar result is obtained for the $\pi^0\pi^0$ mass distribution observed in the reaction $\pi^+p \to \Delta^{++}\pi^0\pi^0$ $(t < 15\ m_\pi^2)$ (fig. 2). A similar phe-

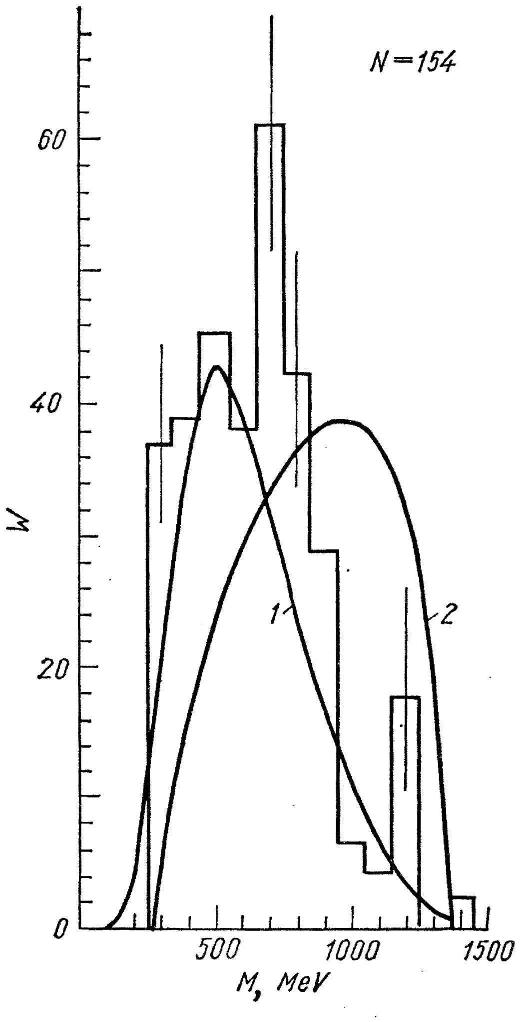


Fig. 1. Distribution of the effective mass $M_{4\gamma}^{4\gamma}(\pi^0\pi^0)$. The curve *1* represents the distribution of random π^0 — π^0 combinations normalized to the mass interval $M_{4\gamma}^{4\gamma} \leqslant 550$ *MeV*. The curve *2* shows the phase space for reactions $\pi^+ + n \to \pi^0 + \pi^0 + p$ for 2.34 *GeV/c* π^+ momentum.

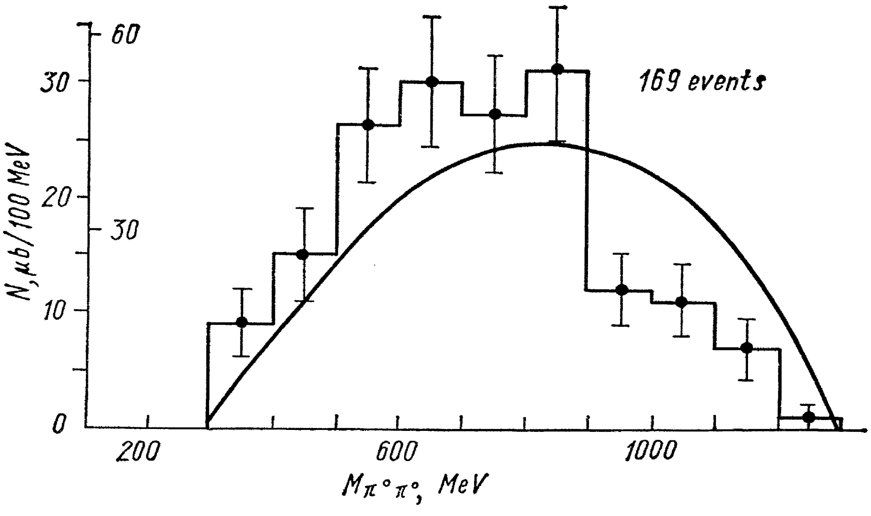


Fig. 2.

nomenon is also seen by Barmin et al. (ref. 3) in the reaction $\pi^- p \to n + m\gamma$ at 2.94 *GeV/c*.

b) Scattering length language. Four papers have been presented at this Conference using the scattering length language. They all concern electronic experiments.

In the first one (Blair et al. (ref. 4)) the $\pi^- p \to \pi^- \pi^+ n$ reaction is studied at 247 *MeV* kinetic energy of the incident pion. Because the available energy is small, the authors consider as a reasonable assumption to take into account only non-resonant $\pi\pi$ S-wave and to use scattering length parametrization. Then, using Anselm and Gribov theory for the production of three particles near threshold (ref. 5), they get

$$a_2 - a_0 = (-0.42 \pm 0.10)\, m^{-1}.$$

There a_0 and a_2 are the S-wave $\pi\pi$ scattering lengths for the $I = 0$ and $I = 2$ states respectively. This difference is compatible with the one resulting from the a_0 and a_2 values predicted by Weinberg (ref. 6) and in good agreement with the values $a_2 - a_0 = (-0.36 \pm 0.19)\, m_\pi^{-1}$ and $(-0.25 \pm 0.05)\, m_\pi^{-1}$ obtained by the emulsion group Batusov et al. (ref. 7).

The two following papers are studies by different models of the same reaction $\pi^- p \to \pi^0 \pi^0 n$ at 378 *MeV* kinetic energy of the incident pion. The analysis uses either the S-wave Chew — Mandelstam solution (ref. 8) for $\pi\pi$ phase shift or the Roberts — Wagner method (ref. 9) (Maung et al. (ref. 10)) or the Namysłowski isobar model (ref. 11) (Botke (ref. 12)). The values they obtain for a_0 are respectively (in m_π^{-1} unit)

$$a_0 = 0.28 \pm 0.21 \text{ and } a_0 = 0.2^{+0.08}_{-0.1}$$

still is good agreement with the Weinberg values (ref. 6).

Before presenting the fourth paper it is perhaps worth reminding that in a paper recently published Aref'ev et al. (ref. 13) have obtained a good fit of their Chew — Low extrapolated $\sigma_{\pi\pi}$ $I = 2$ (analysing the reaction $\pi^+ p \to \pi^+ \pi^+ n$ at 720 *MeV/c*) by an effective-range parametrization

$$a_2 = (0.19 \pm 0.02)\, m_\pi^{-1} \quad r = (4.1 \pm 2.3)\, m_\pi^{-1}.$$

The fourth paper is the one of Maglič et al. (ref. 14). Maglič has presented very recent results obtained in the analysis of the reactions

$$p + d \to \mathrm{He}^3 \pi^+ \pi^- \text{ and } p + d \to \mathrm{He}^3 \pi^0 \pi^0.$$

I recall that these reactions are the same as those studied by Abashian et al. (ref. 15) as early as in 1963.

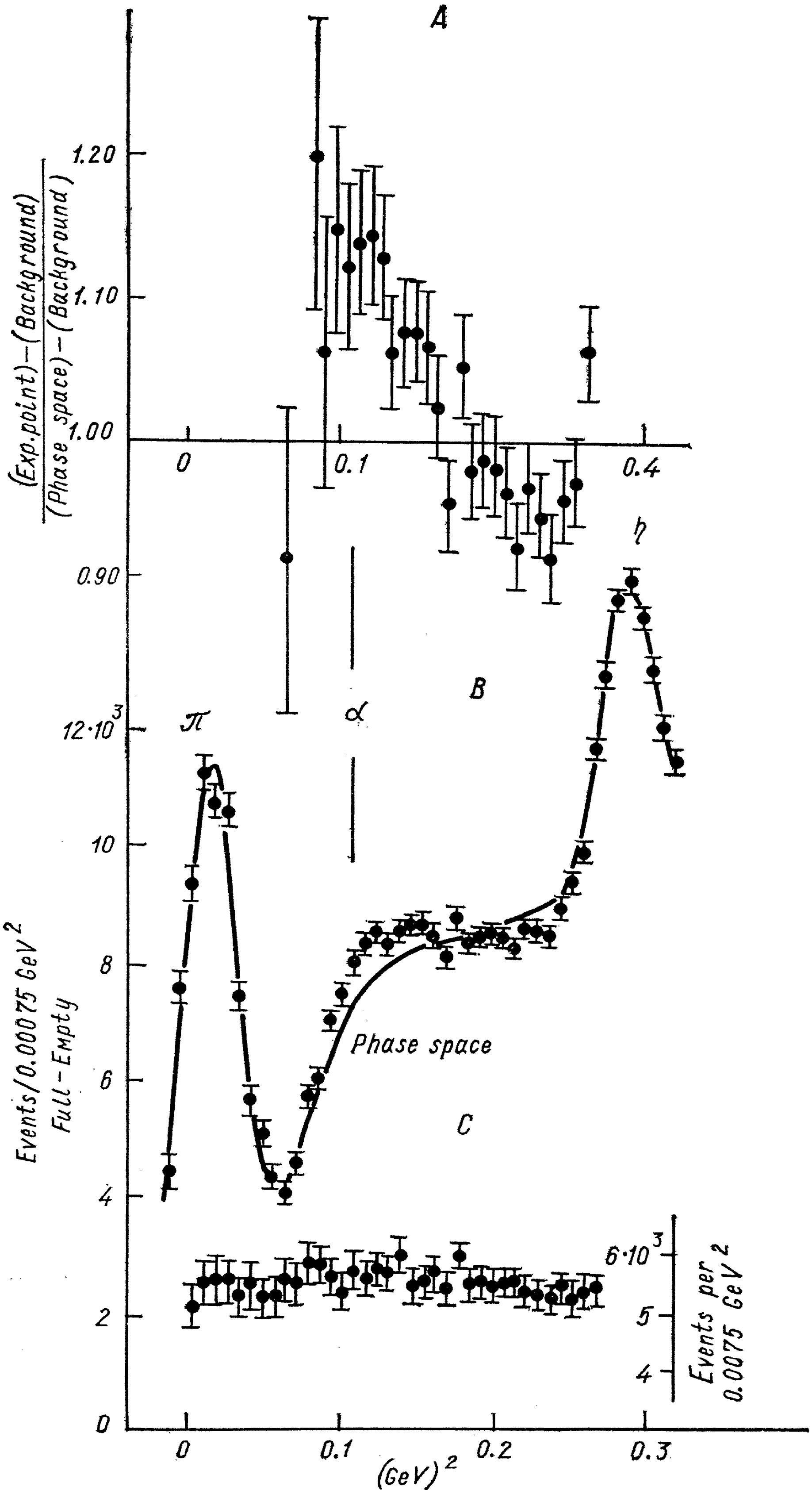


Fig. 3. *A* — «excess». *B* — combined data: $2GeV + 3GeV$ runs; full — empty; $(7.5\ MeV)^2$ bins. *C* — combined data: $2GeV + 3GeV$ runs, empty only.

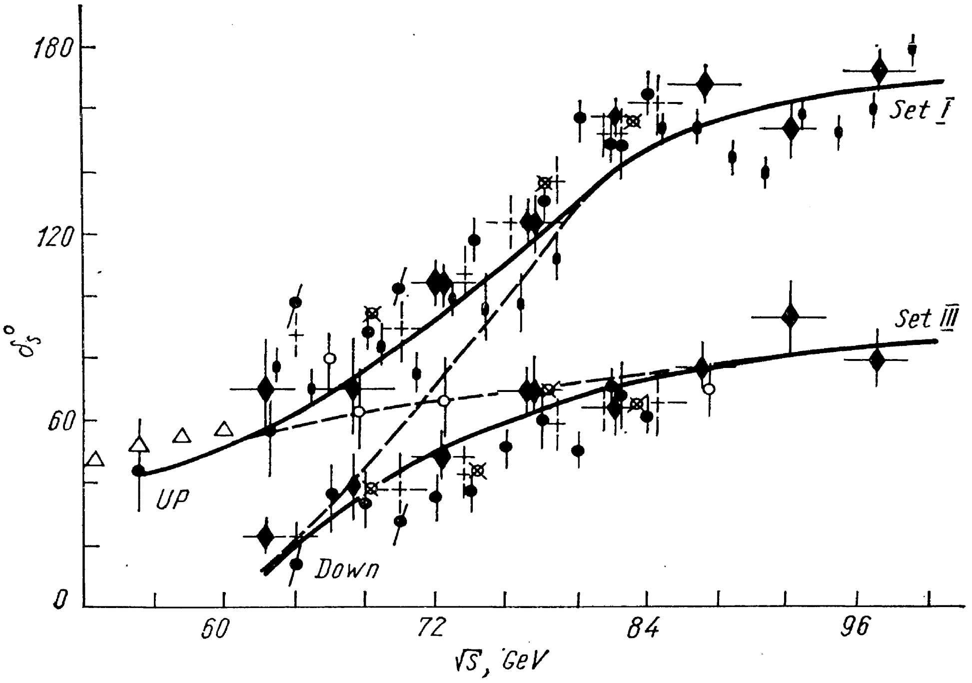


Fig. 4.

The experiment has been performed at three different incident energies using a missing mass spectrometer. The resulting missing mass spectrum (to the recoiling He^3) shows an important amount in the 300—400 *MeV* energy region (fig. 3), what the authors interpret as an «excess» above the background. This «excess» corresponds to a $\pi\pi$ scattering length

$$a_0 = (0.58 \pm 0.08)\, m_\pi^{-1}.$$

Magliĉ said that it might also be interpreted as a $\pi\pi$ resonant state

$$M = (330 \pm 15)\, MeV \quad \Gamma = (60 \pm 30)\, MeV,$$

the most likely quantum numbers of which would be $I^G = 0^+$, $J^P = 0^+$.

c) Phase-shift language. Now I will report about the papers presented at this conference in terms of $\pi\pi$ phase-shift, starting from the δ_0^0 one, I mean $I = 0$ S-wave phase shift, for which there are many controversies.

δ_0^0 — Before presenting very briefly these papers, I will recall that, one year ago at the time of the Lund conference, there was some agreement for the so-called «up-down» solution. The fig. 4 shows the summary at that time of the two δ_0^0 solutions obtained at each $\pi\pi$-energy. The two solutions are not too far from one another in the region of the ρ-mass, so that crossing is certainly acceptable. The «up-down» choice came essentially from the comparison of the results obtained with the different charge states of the dipion, $\pi^0\pi^0$ with $\pi^+\pi^-$ in particular (see, for example Deinet et al., ref. 16, and Smith and Manning, ref. 17). Now the agreement for this choice is far from being unanimous.

Four papers have been presented at this conference.

1. For Baton et al. (ref. 18) who studied the reaction $\pi^- p \rightarrow \pi^-\pi^+ n$ at 2.77 *GeV/c*, it is clear that the true solution below the ρ-mass is the down solution. Above the ρ-mass, they do not know: due to the rising of inelasticity and the appearance of D-waves, the analysis has to be pursued by taking into account more parameters (what they have not yet done). The reason for their choice below m_ρ is essentially based on the fact that among the two solutions one should be the true, of course; then if one extrapolates several things to the pion pole, namely in their case the forward-backward asymmetry of the $\pi\pi$ system, or the coefficients of the

Legendre polynomial expansion of the differential cross-section, or the total cross-section, the δ_0^0 values to be obtained should be the same for the true solution, but not necessarily for the wrong one. Indeed they observe such a stability for one solution and not for the other, as seen on the figs. 5—6. The fig. 5 shows the δ_0^0 values obtained by the extrapolation of the asymmetry parameter. The fig. 6 shows the extrapolated cross-section compared to the ones obtained by the two sets of δ_0^0 corresponding to the curves of the previous figure.

The fact that the authors succeeded in deciding between the two solutions below the ρ-mass is due to the success (the precision) of their extrapolations. And this precision is due for a large part to the fact that the authors succeeded in using a large range of t values (without introducing instabilities) by performing a conformal mapping of the t-plane onto the plane of a «better suited» variable.

2. Jacobs (ref. 19) has made a careful analysis of the same reaction $\pi^- p \rightarrow \pi^-\pi^+ n$ starting from the phase-shifts obtained by Baton et al. in this reaction, using δ_0^2 from the reaction $\pi^- p \rightarrow \pi^-\pi^0 p$, and taking account of ρ^0, f^0, $\Delta^\pm$ (1238), N^+ (1688) resonance production (note 20).

Adopting the factorization conjecture, and parametrizing the helicity amplitudes according to the Froggatt — Morgan prescription (ref. 21) with the addition of exponential t factors, he fitted the experimental differential cross-section keeping fixed the phase shifts obtained by Baton et al. (down-down and down-up solutions) and leaving free the other parameters.

The result of the fit is in favour of the «down-up» solution, but he said, that this should not be regarded in any way as a final result.

3. The results presented by Shibata et al. (ref. 22: study of the reaction $\pi^- p \rightarrow \pi^0\pi^0 n$ at 10 *GeV/c*) are in disagreement with the «standard» solutions, but in agreement with the results of Sonderegger and Bonamy (ref. 23).

4. The S-wave $\pi\pi$ interaction has also been studied by the Aachen — Berlin — CERN collaboration (ref. 24) in the reaction $\pi^+ p \rightarrow \pi^+\pi^-\Delta^{++}$ at 8 *GeV/c*. They have submitted successively two versions of their analysis. The first one deals with the $\pi\pi$-phase shifts below and in the region of m_ρ: the results are compatible with the standard solutions given in the fig. 1. In the second version the phase-shift analysis has been performed in the mass region 1.0—1.5 *GeV* taking account of D-wave contribution and inelasticities in all channels. The values obtained for δ_0^0 are shown in the fig. 7.

The connection of these values with those of the lower energy region is not

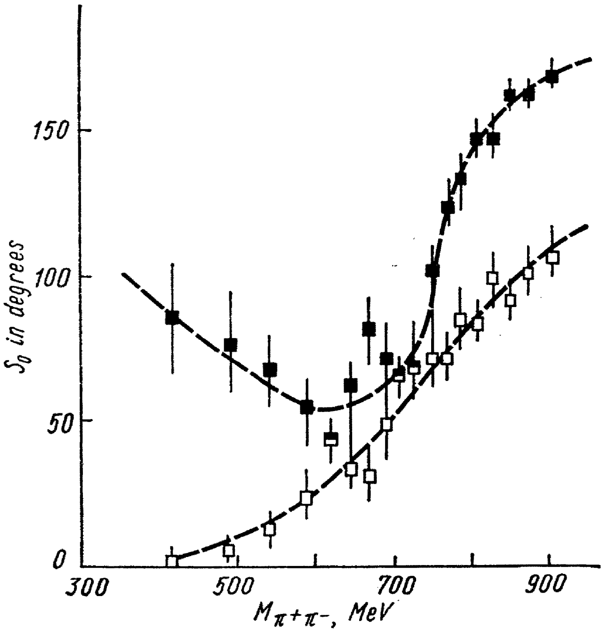


Fig. 5.

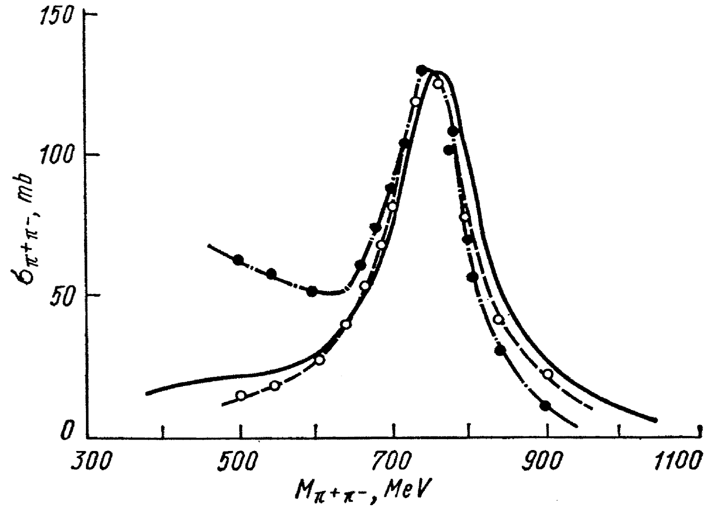


Fig. 6.

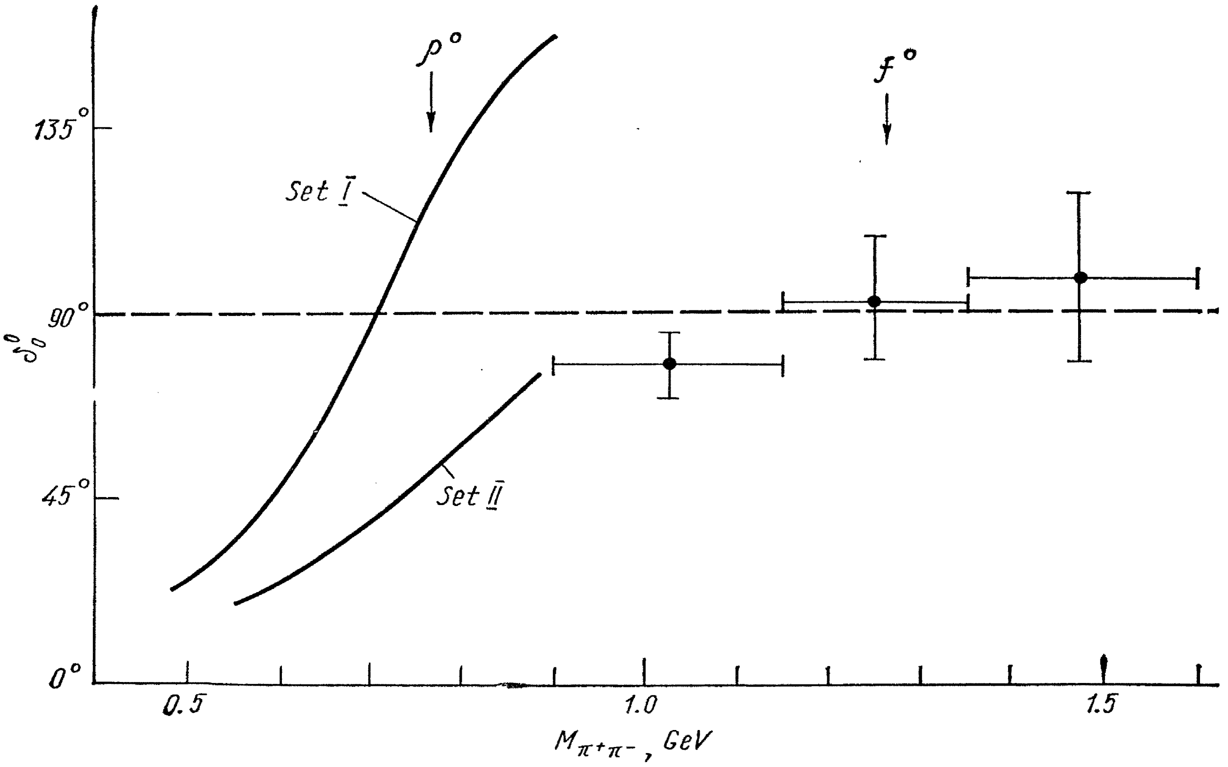


Fig. 7. $\pi^+ p \to \Delta^{++}\pi^+\pi^-$ at 8 GeV/c.

simple. Of course they can be connected with the «down» solution, because they are of the order of 80°, the same as the down solution above the ρ-mass. But that means S-wave resonant behaviour only at the f^0 mass: we are not accustomed to such a fact. Now, if one makes the other choice, one gets a situation in which δ_0^0 goes through 90° at about 750 *MeV*, perhaps through 180° at about 950 *MeV* and again through 90° at 1.1 or 1.2 *GeV*, while the elasticity parameter δ_0^0 goes down from 1 at ~ 750 *MeV* to 0.7 at ~ 950 *MeV* and to 0.3 at 1.1 *GeV*.

This last solution yields for the modulus squared of the amplitude a behaviour which has to be compared to the so-called CDD parametrization (ref. 25) used by the CERN — Collège de France collaboration (ref. 26) just for fitting the background in their $\bar{p}p$-annihilations at rest into four and five pions (dip at ~ 950 *MeV*).

Now before I present the δ_0^2 results, I have still to mention some very recent values obtained for δ_0^0 at low ππ mass by Makarov et al. (ref. 27). These results, which have been given during the conference, run from about 40° at the K^0 mass to 20° at 380 *MeV*. As the authors remark, these values are a good continuation toward the low energy region of the well-known «up-up» and «up-down» solutions. The difference $\delta_0^0 - \delta_0^2$ obtained at the K^0 mass is about 55°.

δ_0^2 — Now for the δ_0^2 determination, we had two contributions to this conference, both using the reaction $\pi^- p \to \pi^-\pi^-\Delta^{++}$ at different energies.

The first one (Beketov et al. ref. 28) simply off-shell corrections, but takes into account the possible D-wave contribution for the high-energy region. The results they have obtained using different form factors give a $I = 2$ ππ cross-section of the order of 10 *mb* at the ρ-mass.

The second one (ref. 29) performs linear extrapolations after having divided the cross-section by Dürr — Pilkuhn form factors as normalization functions. In a second attempt care has been taken of the background yielded by the $\pi^- p \to (\pi^-\pi^+)\,\pi^- p$ reaction. The results are shown on the fig. 8, together with the old results of Baton et al. (ref. 30) and Vetlitskii et al. (ref. 31).

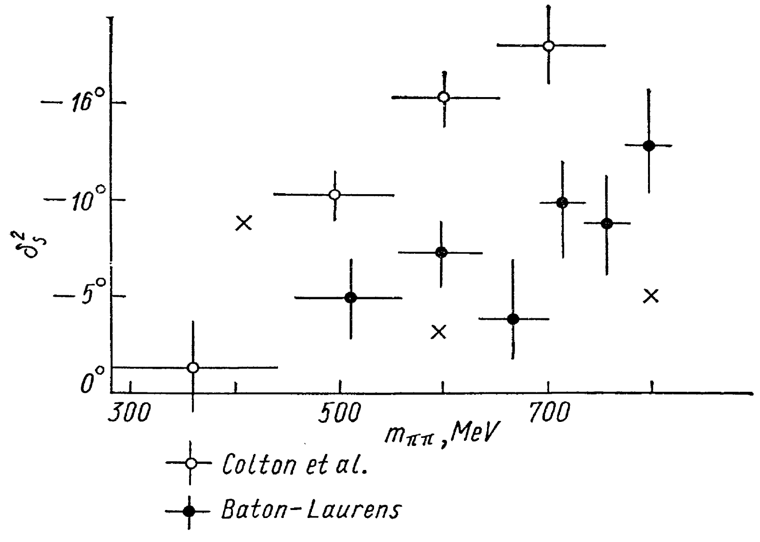


Fig. 8.

d) Conclusions? Is it possible to draw some general conclusions from these results? I think it is still too early.

Of course there is no problem for the δ_1^1 phase shift. Apart from the sign, there is also no problem for the δ_0^2 one, which remains small. But for the δ_0^0 phase shift, the situation is still not clear. Even if we take as definitive the down choice below the ρ-mass, the question remains completely open above m_ρ. What is sure, is that the analysis has to be done taking into account the rising D-waves and also the increasing inelasticity of the $\pi\pi$ scattering amplitude: speaking about down-down or down-up solutions is certainly a too simple way to present the results. The main point is: has the modulus squared of the S-wave $I = 0$ $\pi\pi$ amplitude a profound dip at 950—1000 *MeV* or not? I recall that the careful analysis of the Wisconsin — Toronto collaboration recently published (ref. 32) does not show such a dip. We shall encounter again the same problem in the next section.

3. S^* AND $\pi\pi \to K\bar{K}$-INTERACTION

Because we have no K-target, the situation is for the $K\bar{K}$ interaction the same as for the $\pi\pi$ one. The analysis of $K\bar{K}$-interaction comes essentially from $K\bar{K}$ production by incident $\pi^\pm$, so that what one gets immediately is the phase-shift δ of the $\pi\pi \to K\bar{K}$ reaction. But models used to fit the $K\bar{K}$ mass distribution near threshold provide rough values of the $K\bar{K}$ phase shift δ_K. So, because for well-defined j^P and I values, $2\delta = \delta_\pi + \delta_K$, where is the corresponding

Table 1

Table of Mass and Width of the S^*

Authors	BEAM (*GeV/c*)	*M* (*MeV*)	Γ (*MeV*)	Observed state
Harrington et al.	$\pi^\pm 18.5$	~1070	~80	K^+K^-
Beusch et al.	$\pi^- 4.0$	1055±6	$205\ ^{+44}_{-32}$	$K_1^0K_1^0$
	$\pi^- 6.2$	1053±5	$208\ ^{+39}_{-28}$	$K_1^0K_1^0$
Duboc et al.	$\bar{p}$ 1.18	1042±8	22±7	$K_1^0K_1^0$
	$\bar{p}$ 1.18	1020±5	29±8	$K_1^0K_1^0$

$\pi\pi$ phase shift, checks can be made of the consistency of the results, using known $\pi\pi$ phase shifts. Conversely, the study of the $\pi\pi \rightarrow K\bar{K}$ interaction can yield information for $\pi\pi$ phase-shifts above the opening of the $K\bar{K}$-channel. Results of this last kind have been presented at this conference by Beusch et al. (ref. 33).

a) S^* — Let me begin by the study of the $K\bar{K}$ mass-spectrum. Three papers have been presented at this conference which confirm the results already known. The so-called S^*-enhancement can always be fitted by a Breit — Wigner curve, but the results obtained in the πp-reactions (Beusch et al., ref. 33, Harrington et al., ref. 34), namely a broad resonance centred at 1055—1070 *MeV* with a width of the order of 100—200 *MeV*, differ from the results obtained in the $\bar{p}p$-annihilations (ref. 35), — that is a narrow resonance centred at 1020—1040 *MeV* with a width of the order of 20—30 *MeV*.

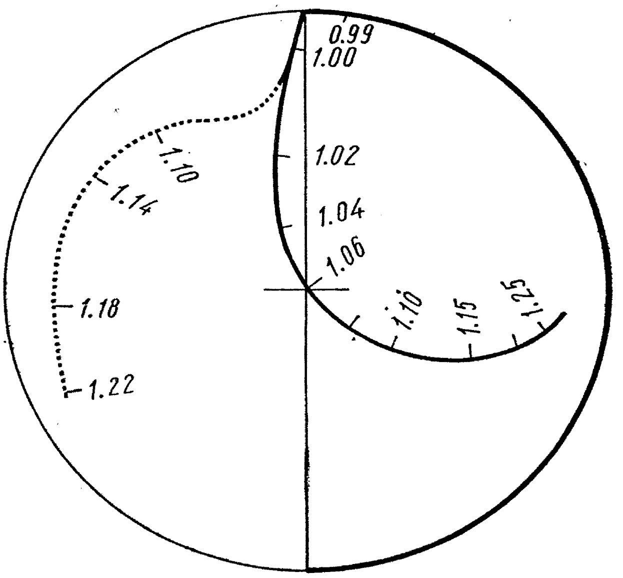


Fig. 9. An example of an Argand diagram for $I = 0$ S-wave $\pi\pi$ amplitude. Full curve: S^* resonance, dotted curve: scattering length with effective range.

As mentioned by Beusch et al., the difference may originate from the difference in production mechanism. $I = 1$ states and final state interactions may be important in the $\bar{p}p$-annihilations, while they are absent from the high energy πp-reactions, if the $K\bar{K}$ system is produced peripherally. The table 1 summarizes the values.

Now, of course the S^*-enhancement can also be fitted by an effective-range parametrization with opposite signs for the scattering length and the effective range. Both models provide δ_k values in this energy range.

b) Information obtained for the $\pi\pi$-interaction. On the other hand, the important value $\sigma = 0.7$ *mb*, obtained for the $\pi\pi \rightarrow K\bar{K}$ cross-section by extrapolation to the pion pole, is very near the unitarity limit (0.8 *mb*), and indicates that the elasticity parameter η of the $I = 0$ S-wave $\pi\pi$ amplitude suddenly almost vanishes when the $K\bar{K}$ channel is open. The results obtained this way for this amplitude is shown in the form of an Argand diagram on the fig. 9. Among the many open possibilities, one is a very important dip in the $\pi\pi$-cross-section just above the $K\bar{K}$-threshold.

4. $K\pi$-INTERACTION

As for the $\pi\pi$-interaction, several languages can be used for presenting the results concerning the $K\pi$-interaction.

a) Breit — Wigner language. The first one, the bump language, has been used by three papers submitted to this conference. Before presenting them, let me recall, as Gerson Goldhaber did in the parallel session, the ($K\pi$) enhancements which have been seen during the last years between the K^*_{890} and K^*_{1420} (table 2).

1. The CERN — Munich collaboration (ref. 36) has examined the $K^+\pi^\pm$ — effective mass distributions observed in the three body final states obtained by 4.6 *GeV/c* K^+ interacting on deuterium. They see no statistically significant peaks in ($K^+\pi^-$) and some indication of a K^*_{1080} in ($K^0\pi^+$).

2. Brody et al. (ref. 37), analysing the interaction on hydrogen of 3 to 8 *GeV/c* incident K^0_2, observe a rather narrow peak in the $(K\pi)^0$ effective mass distribution

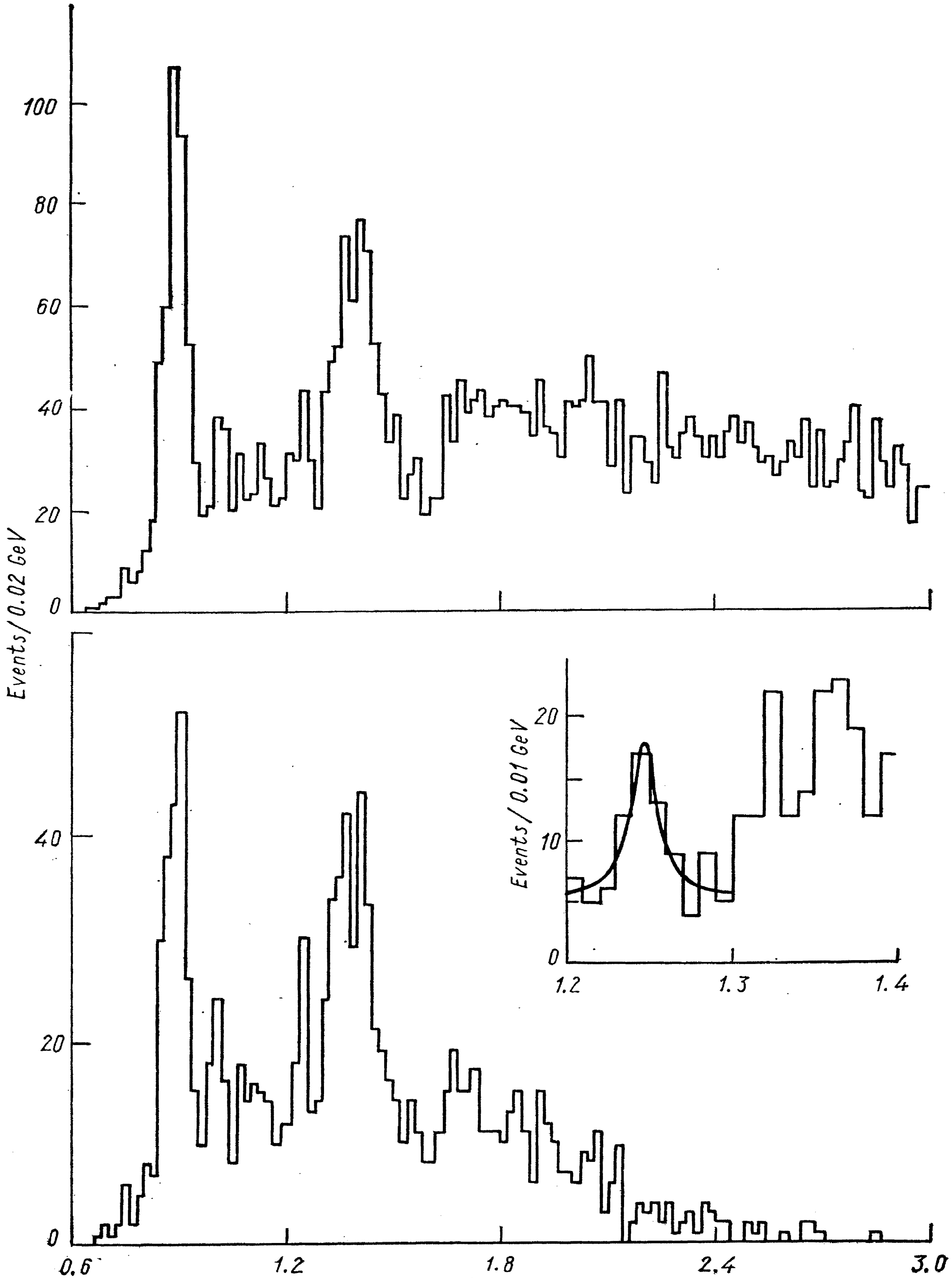

100
80
60
40
20
0
Events/0.02 GeV
40
20
0
Events/0.01 GeV
20
10
0
1.2
1.3
1.4
0.6
1.2
1.8
2.4
3.0
M(K+, π−), GeV

Fig. 10.

Table 2

Table of the ($K\pi$) Enhancements Seen During the Last Years Between the K^*_{890} and K^*_{1920}

GROUP	REACTION	M_0 (*MeV*)
C. E. R. N. — Bruxelles Nuovo Cim. **51 A**, 40 (1967)	$K^+p \to (K\pi)^+p$ 3.5 *GeV/c*	~1080
T. G. Trippe P. L. 283, 203 (1968)	$K^+p \to (K^+\pi^-)\,\Delta^{++}$	~1100
D. J. Crennel et al. P. R. L. **22**, 487 (1969)	$K^-n \to (K^0_s\pi^-)\,n$ 3.9 *GeV/c*	~1160
W. D. Dodd et al. Phys. Rev. **177**, 199 (1969)	$K^+p \to (K^0_S\pi^+)\,p$ 3—3.5 *GeV/c*	~1260
P. Antich et al. P. R. L. **21**, 842 (1968)	$K^+p \to (K^+\pi^-)\,\Delta^{++}$ 5.5 *GeV/c*	~1360

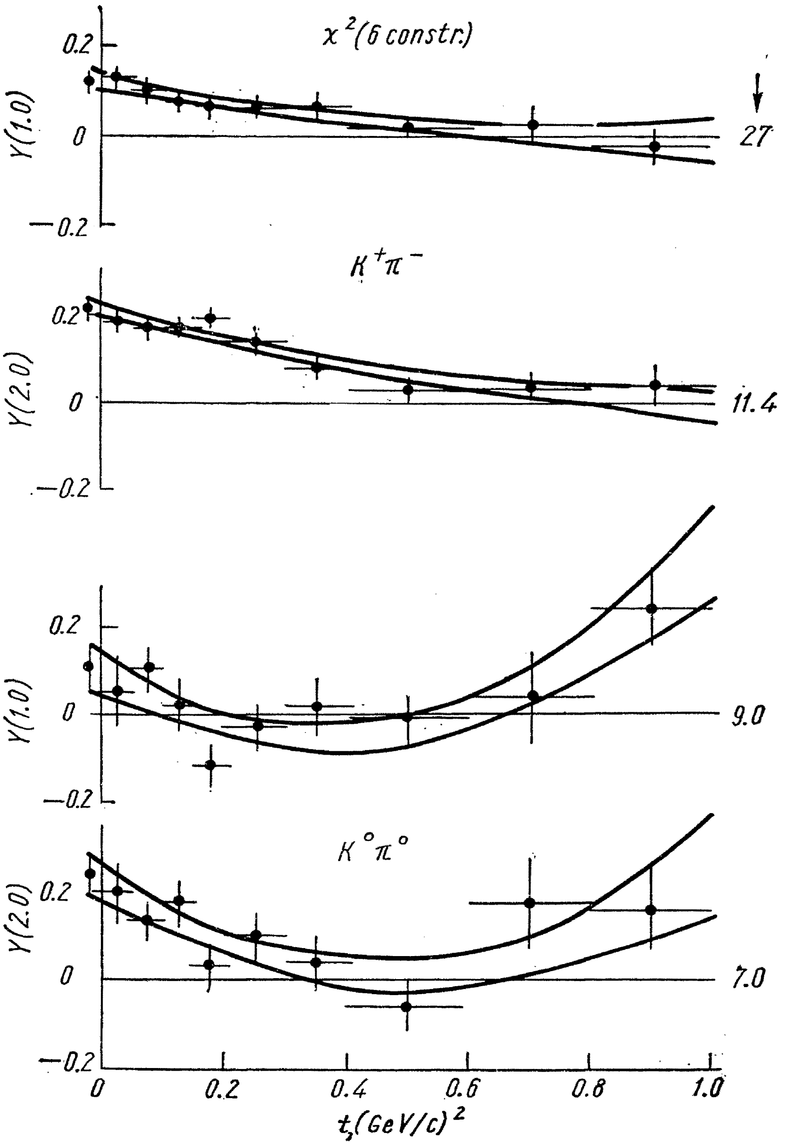


Fig. 11. $K\pi$ extrapoltion moments $0.88 < M_{K\pi} < 0.9$ *GeV*.

extracted from the three body final state. The peak is centred at ~ 1195 *MeV* with a width ~ 50 *MeV*. But the authors estimate that there is a good chance that this peak be a statistical fluctuation.

3. G. Goldhaber (ref. 38) showed preliminary results of interaction of 12 *GeV/c* K^+ on deuterium. In the reaction $K^+d \rightarrow K^+\pi^- pp_S$ they observe a sharp peak in the $(K^+\pi^-)$ effective mass distribution centred at ~ 1250 *MeV*; width: (20^{+9}_{-6}) *MeV* (fig. 10). This enhancement is centred at the same mass value as an old one (see ref. 39), but it is much narrower. Until now the authors have not found the way to explain this phenomenon as an effect other than a resonance.

The analysis of the $K\pi$ angular distribution in this region indicates that $J^P = 0^+$ and 1^- contributions are sufficient to explain the results.

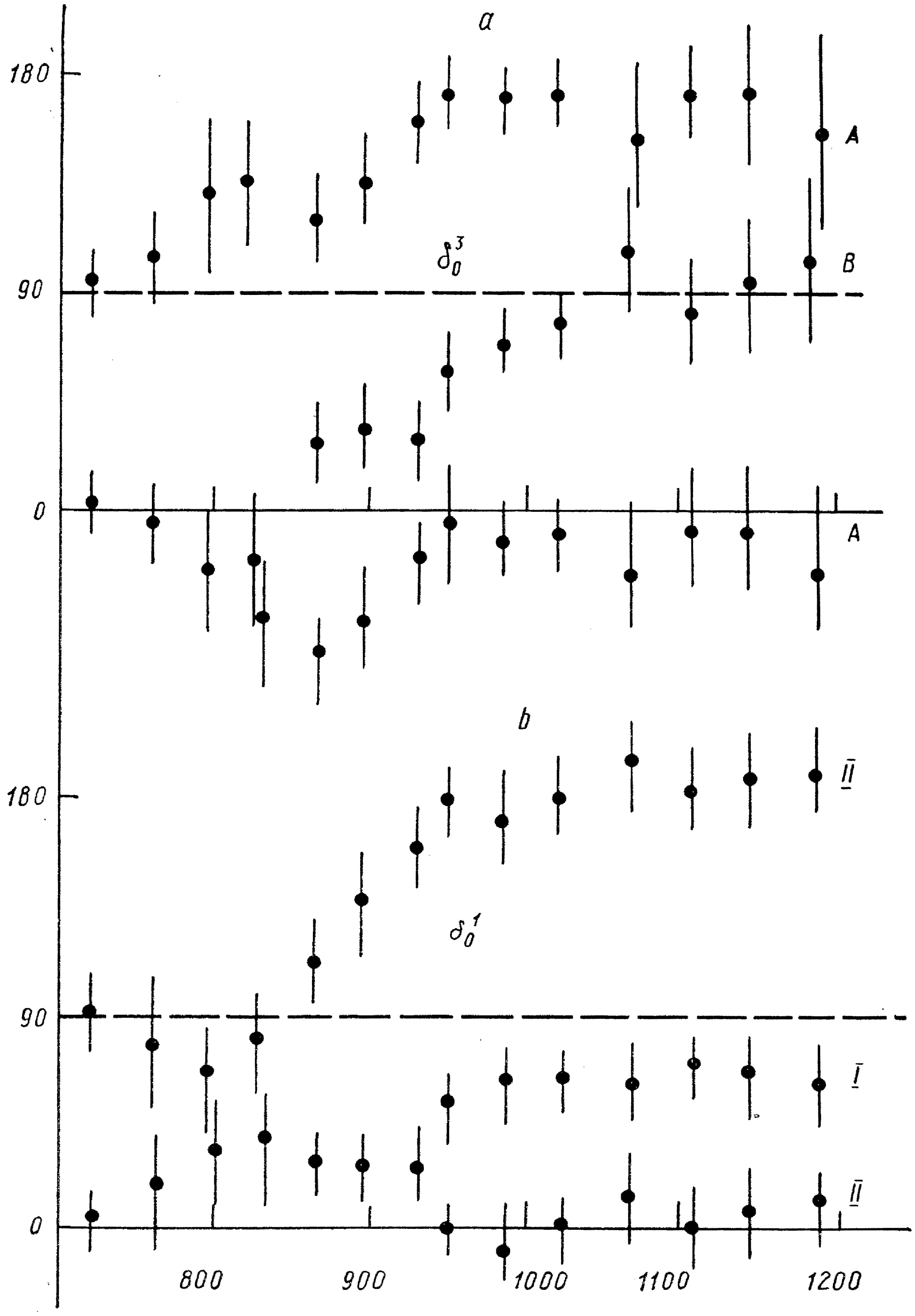


Fig. 12.

Furthermore, this J^P analysis performed on the same reaction in the $K\pi$ mass region just below the centre of the K^*_{1420} yields similar results.

So Gerson Goldhaber said that one interpretation of these data would include the presence of a $J^P = 0^+$ or 1^- signal at $\sim$1360 *MeV* with a width $\sim$ 60 *MeV* in addition to the K^*_{1420}. This assumption coincides with the observation of Antich et al. (ref. 40).

b) Phase-shift language. 1—2. Two very careful $K\pi$ phase-shift analyses, both based on the K^+p world data, have been presented at this conference, by the Johns Hopkins (ref. 41) and the CERN groups (ref. 42) respectively.

Because the world sample is sufficiently large, they can extrapolate to the pion pole not only the $K\pi$ total cross-sections, but also the differential ones, that means the coefficients of the Legendre polynomial expansion of the $K\pi$ differential cross-sections. The extrapolation of these «moments» has been made without using form factors as normalization functions. Examples of extrapolating curves are shown in the fig. 11. Then the extrapolated moments have been analysed in terms of $K\pi$ phase-shifts δ_l^{2I}.

The δ_1^1 passes through 90° near 890 *MeV*, as it should. The δ_1^3 is predicted to be small. The situation is much more complicated for δ_0^1 and δ_0^3. The authors have attempted to eliminate some of the four possible solutions for δ_0^1, δ_3^0 by reconstructing the total cross section with them and comparing it with the cross-section obtained by extrapolation. Both Johns Hopkins and CERN groups agree for favouring the non-resonant solutions (solution I for δ_0^1 and B followed by A for δ_0^3, fig. 12).

3. Another studies of $K\pi$ phase-shifts have been presented at this conference.

Malamud (ref. 43) showed very preliminary results of a high statistics 2.0 *GeV/c* K^+ experiment on deuterium. The analysis is now in progress. They can already ascertain that δ_0^1 is of the order of 60° at 950 *MeV*, in good agreement with the preceding results.

4—5. Two other papers (ref. 44—45) deal with the $I = {}^3/_2\, K\pi$ elastic scattering measured in the reaction $K^-d \rightarrow K^-\pi^-p\ (p)$ at 4.2 *GeV/c* and 5.5 *GeV/c*, respectively. In both of them an $I = {}^3/_2 K\pi$ elastic scattering cross-section is obtained by the extrapolation technique and is of the order of 2—3 *mb*.

6. I have also to mention an analysis of the S- and P-wave $K\pi$ scattering by dispersion relations presented by Isaev (ref. 46). Assuming an $I = {}^1/_2$ S-wave resonant behaviour, he found for this K-meson a mass of 1100 *MeV* and a width of about 400 *MeV*. He also predicted small δ_0^3.

c) Conclusions. As for the $\pi\pi$ interaction, the situation remains unclear for the S-wave $K\pi$ interactions, for both I-values ${}^1/_2$ and ${}^3/_2$.

However there is no contradiction between the bumps presented at this conference in the effective mass distributions and the phase-shift results, since the bumps are situated above the region explored by the phase-shift analysis.

II. Study of effective mass distributions, particularly by the matrix element technics (essentially bubble chamber work)

In this second chapter, which is the main part of my report, I will present the results obtained by the conventional ways in the bubble chamber experiments.

1. INTRODUCTION

These results constitute a whole, connected with a well defined series of nets. Indeed in this domain all experimentalists use almost the same methods for scanning the pictures, for reconstructing the events in space, for calibrating and computing the errors, for identifying the events, for «purifying» the samples by «background subtraction», for fitting the experimental results to Monte-Carlo generated events weighted by matrix elements corresponding to well defined J^P hypotheses, etc., etc. The conclusions drawn, I mean the probability of the existence of the objects detected and the probability of these objects having well-defined quantum numbers, strongly depend on the methods used, particularly on the techniques of analysis and on the concepts utilezed. Concerning the techniques of analysis, the experimentalists are completely responsible and they take this responsibility upon themselves. But concerning the concepts, they share the responsibility with the theorists.

2. THE 3π SYSTEM IN THE A REGION

In this section I shall consider the behaviour of the 3π system, neutral or singly charged in the 1 to 2 *GeV* energy region. Since a long time three (note 47) enhancements have been seen in the 3π effective mass distributions, which have been called A_1, A_2, A_3, corresponding roughly to the energy bands 1050—1100, 1250—1350 and 1600—1750 *MeV*. I will examine successively the present experimental situation concerning the A_1, the A_2 and the A_3.

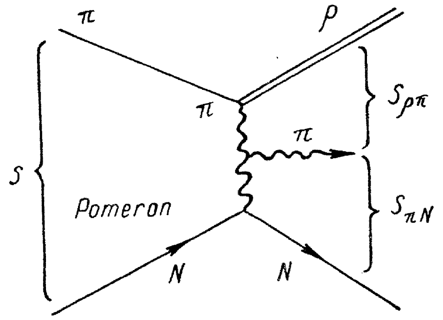
A_1

a) Existence. Almost all the experimental groups, who have studied the 3π system in this energy band, found an enhancement centred at about 1070 *MeY*. So that it seems that now nobody has strong doubt about the existence of the phenomenon. A very good analysis of the situation is presented in the last issue of the «Review of particle properties» (RPP). Therefore I will not enter into details. I will just remind the controversy, which opposed some time ago one of the three groups, who made K^+p experiments at different but close energies 9 *GeV/c* (ref. 48), 12 *GeV/c* (ref. 49) and 12.8 *GeV/c* (ref. 50), to the other two. A careful reexamination of the two last experiments, it is written in the RPP, led to the conclusion that both experiments are consistent with one another. It is an example of good results coming from the verification of the different nets the people use. In this case I think it is more likely the second net than the first one, I mean the methods used for fitting the histograms to Breit — Wigner curves after or not subtraction of background, a very delicate job.

Although there have been many discussions about the A_1 phenomenon, it seems to present two simple and essential features.

1. When it is peripherally produced with possible diffractive scattering of the exchanged pion at the baryon vertex, the Deck-type computations of the 3π effective mass give distributions, the shape of which is, with more or less success, in agreement with the experimental results, so that one often speaks about «kinematical effect explanation» of the A_1-phenomenon.
2. Whether the A_1 is kinematical effect or resonance, the spin parity assignment of the 3π system, which is favoured in the analysis of almost all experiments, is 1^+ (2^- and 1^- not excluded).

b) Kinematical effect or resonance, a false dilemma. Since the introduction of the finite energy sum rules and the concept of duality, if I will understand what the theorists say, in particular what Chew and Pignotti wrote in 1968, the dilemma kinematical effect of the Deck-type or resonance is a false one. Consider specifically the double Regge-pole exchange diagram for the $N\pi \rightarrow \rho\pi N$ reaction.



Because it is possible to keep fixed all members of a complete set of variables except the $\pi\rho$ subenergy, one can reduce the description of the reaction to a single peripheral description and apply to the $\pi\rho$ channel the duality argument. The fact that the Deck-type calculations enhance the low $\pi\rho$ effective mass can be interpreted as large low energy $\pi\rho$-cross-section, that means resonant behaviour. So, as Chew and Pignotti said, the Deck calculation might be described as prediction of the A_1.

As a consequence, I shall not report about the Deck or double Regge-pole exchange calculations made for the A_1. The table 3 (see below) will summarize the data.

Table 3

Summary of recent A_1 data

Experiment	Ref.	Enhancement seen	Spin parity determination, if any	Agreement with the experimental result of the Deck-effect calculation, if any	Observation of the enhancement in the case the Deck-effect is absent * a priori	Resonance behaviour of a well determined J^P
Kenyon et al.	[51]	Yes		Not well	Yes	No
Crennell et al.	[52]	Yes	1^+2^-			
Ballam et al.	[53]	Yes	1^+2^- ($l = 0{,}2$)			
Miyashita et al.	[54]	Yes		Not well		
Caso et al.	[55]	Yes				
Eisenstein et al.	[56]	Broad $A_1 - A_2$		Yes		
D. G. M. P. P.	[57]	Yes		Yes		
Abramovich et al.	[58]	Yes	1^+ (0^-, 1^-)			
Biswas et al.	[59]	Broad $A_1 - A_2$	1^+ (2^-)			
Beketov et al.	[60]	Yes		Yes		
Brandenburg et al.	[61]	Broad $A_1 - A_2$	1^+ (+ others)			
Berlinghieri et al.	[50]	Yes	0^+, 1^+, 2^-		Yes	
Alexander et al.	[48]	Yes			Yes	
Juhala et al.	[62]	Yes	0^-, 1^+, 2^-		Yes	
Suen et al.	[63]	Yes			Yes	
Rabin et al.	[49]	No				
ABBCCHW	[64]	No				

(*) See the discussion in the RPP August 70.

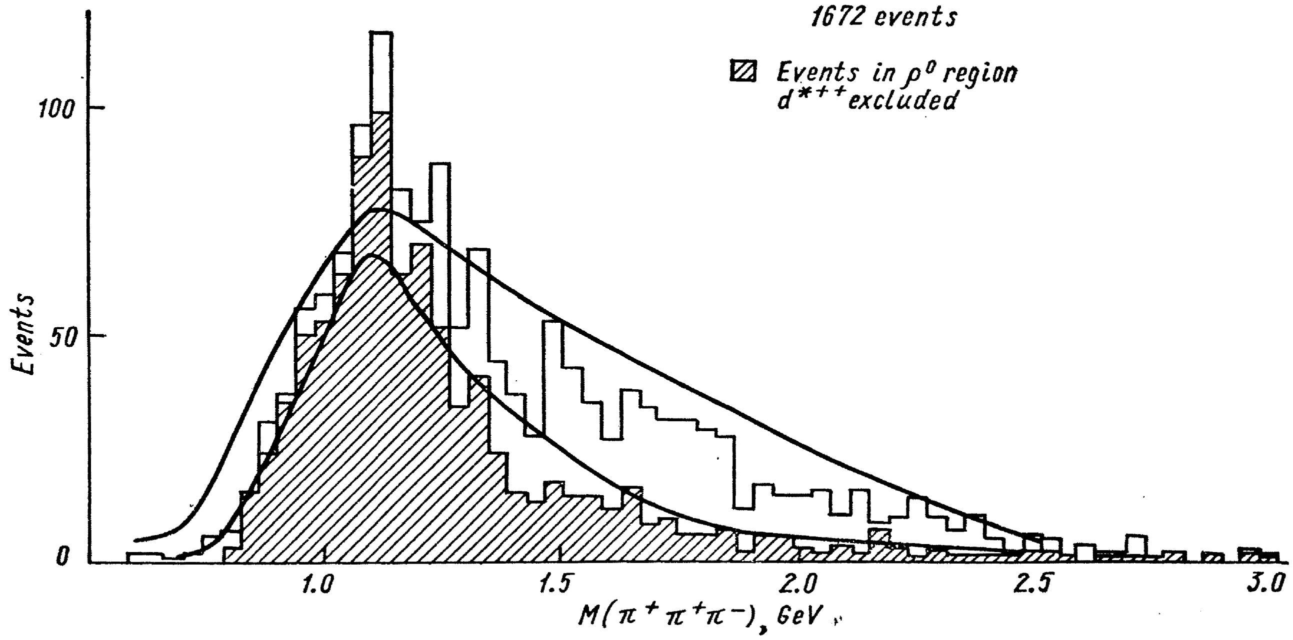


Fig. 13. $\pi^+ d \to d\pi^-\pi^+\pi^+$ at 11.7 GeV/c.

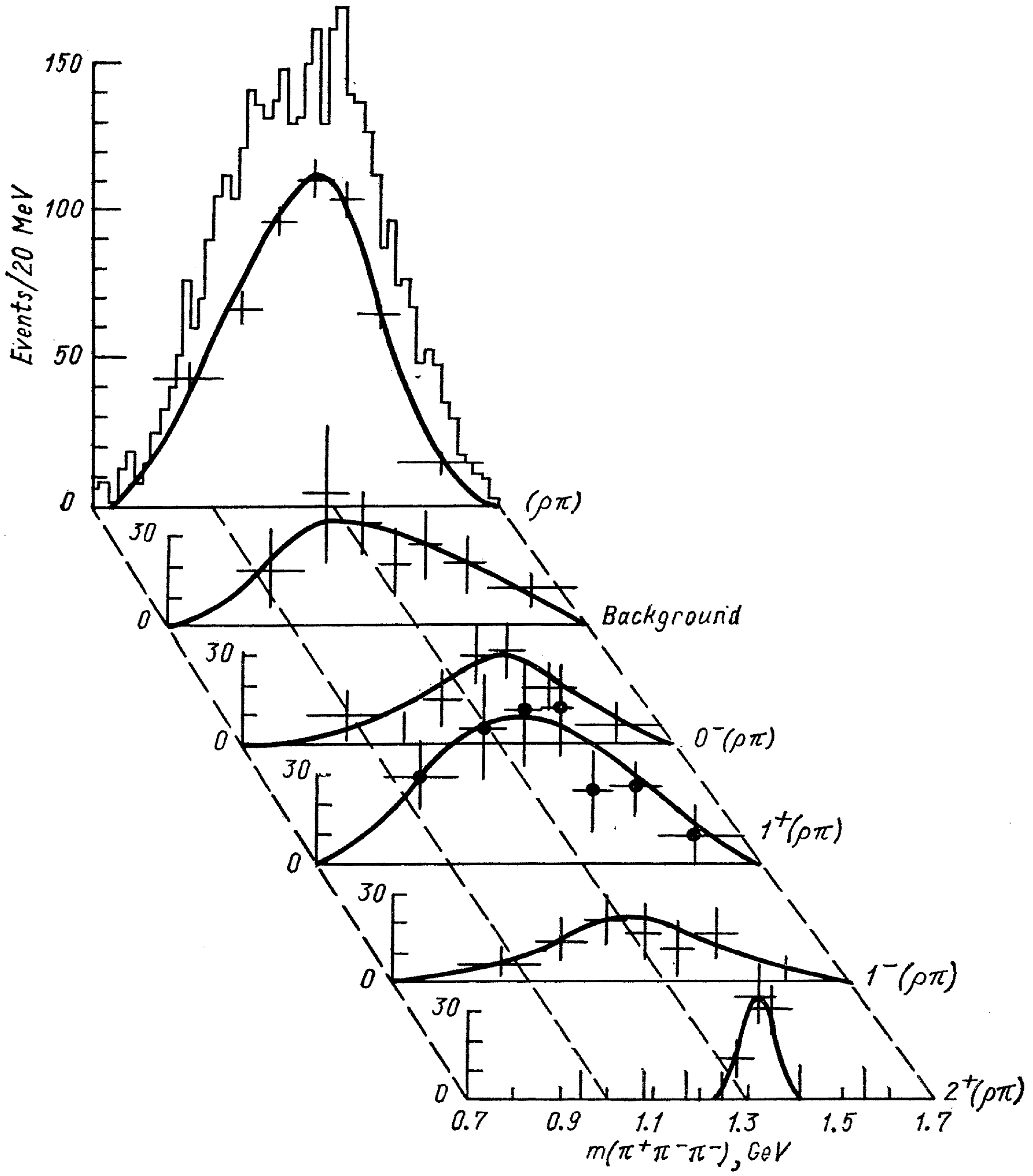


Fig. 14.

I just will show an example of the kind of agreement one gets this way. The fig. 13 represents the $\pi^+\pi^+\pi^-$ effective mass distribution obtained by the Durham — Geneva — Milano — Paris collaboration (ref. 57) in their 11.7 *GeV/c* π^+-experiment in deuterium: the dashed-dotted curve is the result of Deck calculation.

c) Is the A_1 a resonance? It remains that, even if the success of the Deck type calculations is not against but in favour of a resonance interpretation of the A_1, we have to try to establish whether or not it is a resonance.

There are few ways to do that, essentially two.

The first one is to choose reactions, in which *a priori* the Deck-effect is absent, and to look at the 3π effective mass distribution.

The second one is to study carefully (even in the case the Deck-effect is prominent, of course) the variation with the energy of the different spin parity components appearing in the 3π system.

Unfortunately, the first method has given positive results and the second one negative results, so the question is still completely open.

The table 3 summarizes the results of the papers published last year and of those presented at the conference.

I will precise that the spin — parity analysis has been made very carefully either by fitting the density of the 3π Dalitzplot to Zemach amplitudes (ref. 58—59) or by studying correlation between the decays $A \rightarrow \rho\pi$ and $\rho \rightarrow \pi\pi$ à la Berman — Jacob (ref. 59).

The fig. 14 shows the results obtained by the CERN group in function of the 3π effective mass. The Dalitz-plot density has been fitted by adding incoherently the $\rho\pi$ amplitude and the 3π background.

As the authors showed, the different J^P Zemach amplitudes do not interfere. On the figure the detail of the component of the background is not given. For the $\rho\pi$-states we see clearly the resonant behaviour of the 2^+ state. The 1^+ $\rho\pi$ state is large in all the A_1 — A_2 region with a broad maximum, which cannot explain the A_1-enhancement. More data are needed to clarify the situation.

A_2

Concerning the A_2, there is no question about its existence, I mean the existence of at least one resonance at $\sim$ 1300 *MeV*. But the so-called splitting observed in several experiments raises the problem whether we are in presence of one or two resonances or a new kind of objects usually called dipole. In front of this big problem the classical questions of decay modes and spin — parity seem to be less important. In fact they are, because the discovery of different behaviours of the lower and the higher parts of the A_2 would solve the problem of the splitting.

I was considerably helped in preparing this brief report by the summary which appears in the last RPP, which includes part of the Barbaro — Galtieri review talk at the Philadelphia conference. What I made essentially is to add to the table the new results presented at this conference (see the table 4 below).

These papers can be roughly classified into two groups. Those of the first one show splitting, but in general do no present spin — parity analysis. Those of the second group, which in general have no evidence for splitting, perform careful spin — parity analysis. I will briefly present successively these papers. The decay modes of the A_2 will appear by the way.

a) New evidences for splitting. Still consistent with himself, the CBS spectrometer group (ref. 65), working now with the collaboration of the IHEP group, has found a new evidence for the A_2 splitting in his test run at CERN. This time the decay mode is $\eta^0\pi^-$. The table gives the confidence level of the splitting.

Summary of

Group	Ref.	Reaction	p beam (GeV/c)	Decay mode	Method
Benz et al.	[71]	$\pi^- p$	2.6	$(MM)^-$	0°
	[71]	»	6.7	$(MM)^-$	Jacob. peak
Baud et al.	[72]	»	7.	$K_1^0 K^-$	CBS
Baud et al.	[65]	»	11.	$\eta\pi^-$	CIBS
Bologna—CERN—Strasbourg	[66]	»	3.2	$(MM)^0 \to \pi\pi m\gamma$	MMS
Crennell et al.	[73]	»	6.	$(MM)^0 \pi^-$	HBC
Grigoriev et al.	[82]	»	3.25	$\rho^0\pi^-$	HBC
Abramovich et al.	[58]	»	3.9	$\rho^0\pi^-$	HBC
Ascoli et al.	[80]	»	5.0, 7.5	$\rho\pi$	HBC
ABBCCHW collab.	[81]	»	16.	$\rho\pi$, $\eta\pi$, $K\overline{K}$	HBC
Barbaro — Galtieri et al.	[70]	$\pi^+ p$	7.	$\rho^0\pi^+$	HBC
	[70]	»	7.	$\eta\pi^+$	HBC
	[70]	»	7.	$K_1^0 K^+$	HBC
Böckmann et al.	[74]	»	5.	$\rho^0\pi^+$	HBC
Goldhaber et al.	[67]	»	3.7	$\rho^0\pi^+$	HBC
Ghidini et al.	[69]	$\pi^+ d$	5.1	$K_1^0 K^\pm$	DBC
Crennell et al.	[76]	$K^- n$	3.9	$\rho^0\pi^-$	DBC
Aguilar — Benitez et al.	[75]	$\bar{p}p$	0, 0.7, 1.2	$K_1^0 K^\pm$	HBC
Donald et al.	[77]	»	1.2	$\rho^0\pi^\pm$	HBC
Atherton et al.	[68]	»	3.6	$K_1^0 K^\pm$, $P_1^0 K_1^0$	HBC

Another evidence for the splitting of the A_2 in a missing mass experiment has been presented by Massam (ref. 66). This neutral A_2 is seen in the reaction $\pi^- p \to \to A_2^0 n$, with the requirement that the A_2^0 is decaying into two charged particles plus at least one γ (fig. 15). The confidence level, as seen in the table, is 67% for the dipole fit and 1% for the single Breit — Wigner fit.

Now, what is new, an evidence of splitting has been obtained in a $\pi^+ p$ reaction by Goldhaber and coworkers (ref. 67) at 3.7 GeV/c in a fairly high statistics experiment (fig. 16). The confidence level for dipole and single BW fits can be read on the table.

Another evidence of A_2 splitting has been presented (ref. 68). The A_2 is seen decaying into $K\overline{K}$ in the reactions $\bar{p}p \to K_1^0 K^\mp m\pi$ ($m = 1, \dots, 4$) and $\bar{p}p \to K_1^0 K_1^0 \pi^+ \pi^-$ and $K_1^0 K_1^0 \pi^+ \pi^- \pi^0$. However the statistical significance of the dip is not larger than 2 s. d.

b) Discussion. What conclusions may be drawn from this new information? Because Barbaro — Galtieri et al. (ref. 70) in their very high statistics $\pi^+ p$ experiment do not see any evidence of splitting, neither in $\rho\pi$, nor in $K\overline{K}$, nor in $\eta\pi$, we have tried to discuss the problem in a small informal meeting few days ago.

I never felt the troubles of the different nets used by the physicists for gathering their fishes more than during this very constructive discussion.

First of all, the people compared the general shape of their experimental nets, momentum and sign of the incident pion, angle of the recoiling nucleon, t-regions used, and so on. Unfortunately these general shapes do not coincide, although not too far from one another. But also they compared the size of the meshes of their

Table 4

A_2 Data

$-t$ $(GeV/c)^2$	$\Gamma_r/2$ (MeV)	Events in peak	Background	P (χ^2) (%)		
			Signal	Single *BW*	Dipole	Two *BW*
0.09—0.68	5.2	1100	5.3	$\ll 0.2$	$\geqslant 40$	(coherent) $\geqslant 40$
0.20—0.29	8.	1400	4.0			
0.20—0.29	10.	145	0.34	1	> 60	
0.17—0.30	14.	$\sim$ 100	$\sim$ 1.	15	80	
0.35—0.65	8.	$\sim$ 2000	$\sim$10.	1	67	(incoherent) 23
0.22—0.39	10.	100	1.5	Apparent splitting		
		$\sim$ 150	$\sim$ 3.	Non significant dip		
all 0.05—0.65		$\sim$ 140	$\sim$ 6.5			
> 0.2	6.4	833	1.4	14	0.3	
all	8.2	151	0.23	13	0.3	
all	3.6	101	0.34			
$t' > 0.1$	5	108	1.3	20	60	
$0.1 < t' < 2.0$	7.	$\sim$ 300	1.6	9	50	
		$\sim$ 25	$\sim$ 1			
		$\sim$ 45	1.8	single peak		
	5.	270	3.5	4	65	
	12.	$\sim$ 150	3.5	2		(incoherent) 40
	4	$\sim$ 110	$\sim$ 8	30	60	(incoherent) 18

respective nets. «In the A_2 region my resolution is $\pm$ 8 *MeV*», said Kienzle. «It is obtained by a simple and reliable formula, the parameters of which I checked on very well-known particles», «Exactly the same for us», said Angela Barbaro-Galtieri, «the parameters entering the error matrices have been checked on well-known reactions». So I think we have to believe in the values given by anybody for their resolution.

Now comes the second net. «Why do you use dipole fit?» At this time nobody knows if this concept is meaningful. The answer is: «because it is a very simple and economic formula and also because it encounters some success». I will not enter into the details how to put in coherence two Breit — Wigner objects. The theory would require to add coherently the K-matrix elements, not the T ones. No matter, the simple addition of BW functions with relative phase factor is still an efficient parametrization. The essential point is that we have to speak the same language and in this case it is almost completely worked out.

But it is not true for the third net, the estimation net. After discussion, we agreed to eliminate maximum likelihood ratios, and to speak only the χ^2 probability language. Unfortunately the procedures followed by each group are not the same. As a consequence, the confidence levels quoted in the table are not completely comparable. They have to be taken with *«grano salis»*.

c) Conclusion. I think you wait for a personal conclusion about the question. I will give it to you.

1) I consider that in at least one experiment the splitting is sure. By «sure» I mean that the probability the splitting does not exist is of the same order as that of me being mad (but perhaps I am biased concerning my madness). See the figure in the table.

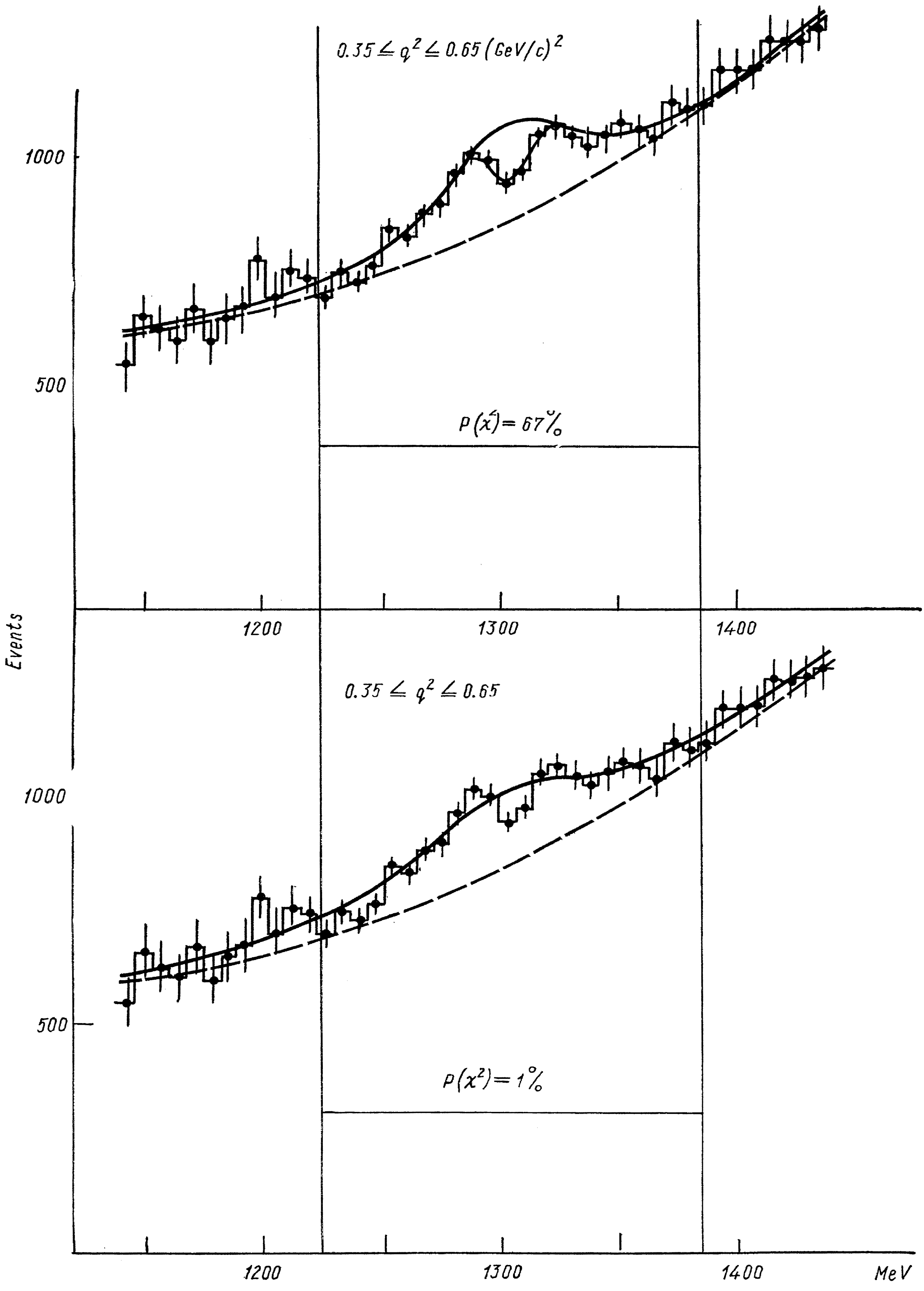


Fig. 15. Neutron missing mass spectrum, $\pi^- p \rightarrow A_2^0 n$.

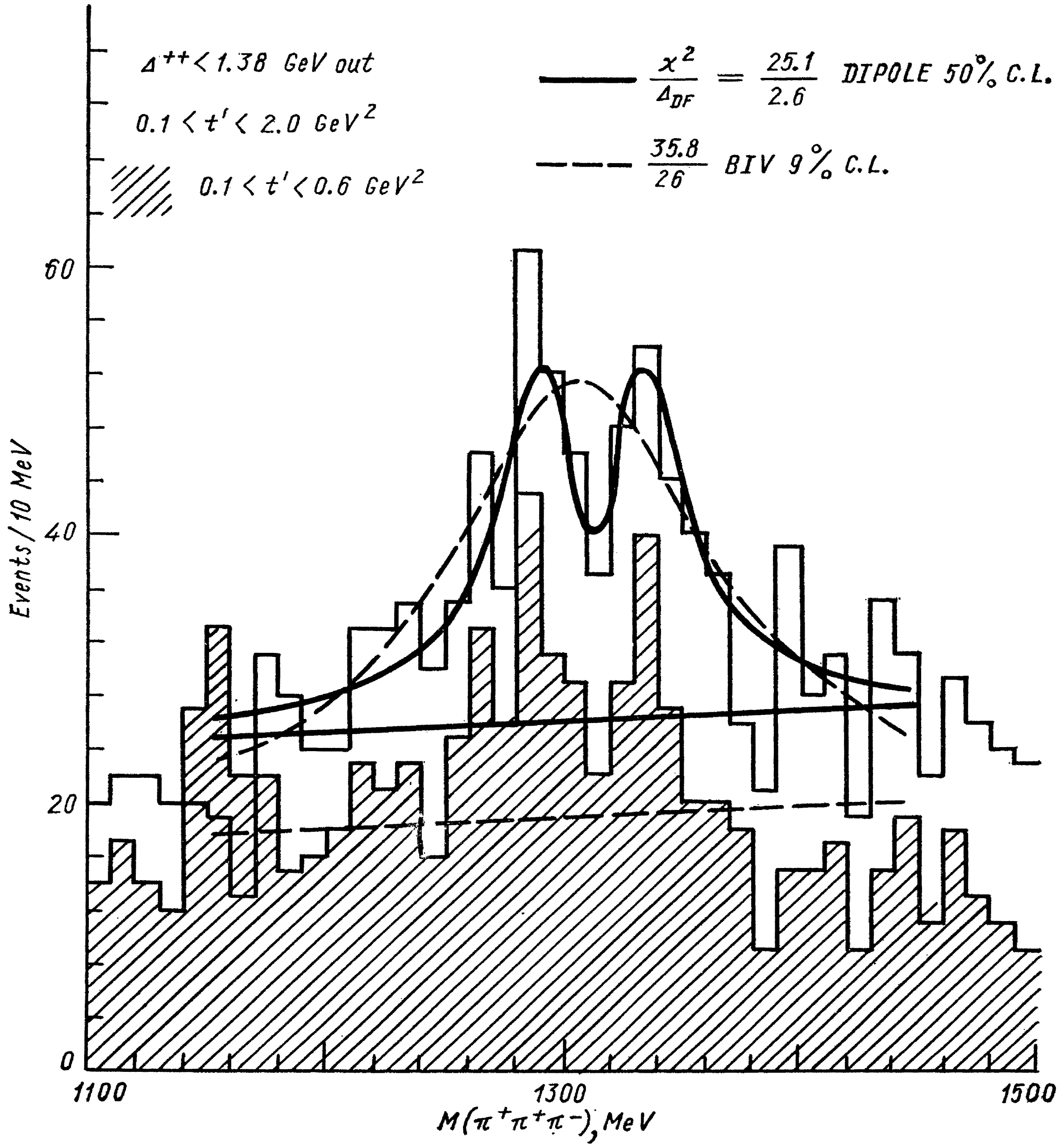


Fig. 16. $p\pi^+\pi^+\pi^-$ at 3.7 *GeV/c*.

2) All the experiments, except probably one, are comparable with a splitting. By «comparable» I mean that the probability of splitting is greater than or equal to 1%. I say «probably» in excepting the Barbaro — Galtieri et al. experiment, because I have not enough information on χ^2 probability for judging.

3) That does not mean that «the A_2 is splitted», if by these words one means an object (quasi) independent of the experimental conditions, as would be the case for the «dipole», I suppose. Indeed, if the results obtained by Barbaro — Galtieri et al. are confirmed, this universal splitting has to be eliminated. Then the fan of the possibilities would be completely open, the most attractive thing being two objects identical J^P and close masses. The resulting mass distributions in that case would vary from an experiment to another.

Two papers have been submitted to this conference presenting different models, which could account for the present experimental results. The first one (ref. 78) assumes that the A_2 production by ρ exchange would not be the same as that by f^0 exchange. So we have to look carefully at the A_2 observed in the $\bar{p}$ annihilations where this mechanism would be absent. The second one (ref. 79) presents a model of two coupled, or interfering, wide and narrow width particles. Goldhaber himself has shown in the parallel session how the simplest model of this kind gives very different mass distributions when the phase is varied.

d) Spin-parity analysis. One way to see whether or not the A_2 is a superposition of different objects is to look at the J^P components of the 3π system in the region of the A_2 mass.

Four papers have been presented at this conference. I have already shown the results obtained at CERN by Abramovich et al. (ref. 58 and figure 14). The only J^P component showing a resonant behaviour in the A_2 region is the 2^+. The same results have been obtained by Ascoli et al. (ref. 80). This is also the conclusion of the ABBCCHW Collaboration (ref. 81).

But Grigoriev et al. (ref. 82) have different results. The 2^+ is certainly favoured for the higher part of the A_2, while the fit favours 1^- for the lower part. However, due to the uncertainties in the background subtraction, the authors do not claim that this study indicates the possibility of different quantum numbers for the A_{2L} and A_{2H} mesons.

A_3

This name has been attributed long time ago to the 3π enhancements observed in different reactions at about 1650 *MeV*. Recently evidence has been presented that in fact two objects have to be distinguished among these 3π enhancements, an $I = 1$ object which is now often called π (1940) and an $I = 0$ object which is called Φ (1660).

At this conference papers have been presented showing evidence for both.

a) π (1640). The existence of this $I = 1$ 3π enhancement is now in no doubt. But its decay modes, if you allow me to use *a priori* the resonance language, are not clear.

Table 5

Summary of recent π (1640) data

M (*GeV*)	% $f\pi$	% $\rho\pi$	% 3π	j^P	Reference
1.645	~ 100	~ 0	0	—	[83]
1.65	~ 100				[84]
1.67	76^{+24}_{-38}				[85]
1.66	~ 100	3^{+37}_{-3}	6^{+47}_{-6}	0^-, 1^+, 2^-, 3^+	[86]
1.68	60 ± 15				[87]
1.63	> 51	< 17			[54]
1.66	few	~ 0	~ 100		[88]
1.69					[51]

Recently Crennell et al. (ref. 83) have shown that the enhancement they see at about 1645 *MeV* can be completely described by the $f^0\pi^-$-contribution, a fact they use for questioning whether this object is threshold enhancement of kinematical origin or resonance. As I already mentioned for the A_1, problem and as Crennell et al. mentioned themselves, from the duality point of view, threshold enhancements and resonances are linked. Nevertheless we have to examine what are the decay modes of this object.

The table 5 summarizes the situation.

Three papers have been presented at this conference, all concerning $\pi p \rightarrow$ $\rightarrow (3\pi) p$ interactions at high energy (9 to 20 *GeV/c*). The results are different.

The Bari — Bologna — Firenze collaboration (ref. 84) finds that the enhancement is completely described by the $f^0\pi^-$ contribution. In the Notre Dame group experiment (ref. 87) the $f^0\pi^-$ contribution is still dominant, but there are also $\rho\pi$ and 3π contributions. The result of the Harvard group (ref. 88) are completely different from the first ones and from those of Crennell et al. The study of the 3π Dalitz plot at different energies of the 3π system (from 1.26 to 1.98 *GeV*) shows a bump of the 3π contribution at the mass value of the A_3 enhancement (1.66 *GeV*), but no $\rho\pi$ nor $f\pi$ contributions. This is shown on the fig. 17. The $f\pi$ system has a small enhancement but at a higher energy.

So, more information is needed to clarify the situation.

b) Φ (1660). The Toronto — Wisconsin collaboration (ref. 89) has presented new evidence at this conference for the existence of an $I = 0$ 3 π object at about 1660 *MeV*. The object is seen as an enhancement of the $(\pi^+\pi^-\pi^0)$ system obtained in a π^+d interaction at 7.0 *GeV/c*, as it was the case in the previous experiments at 8 *GeV/c* (ref. 90) and 9 *GeV/c* (ref. 91).

The evidence for the isospin zero assignment to this object comes from

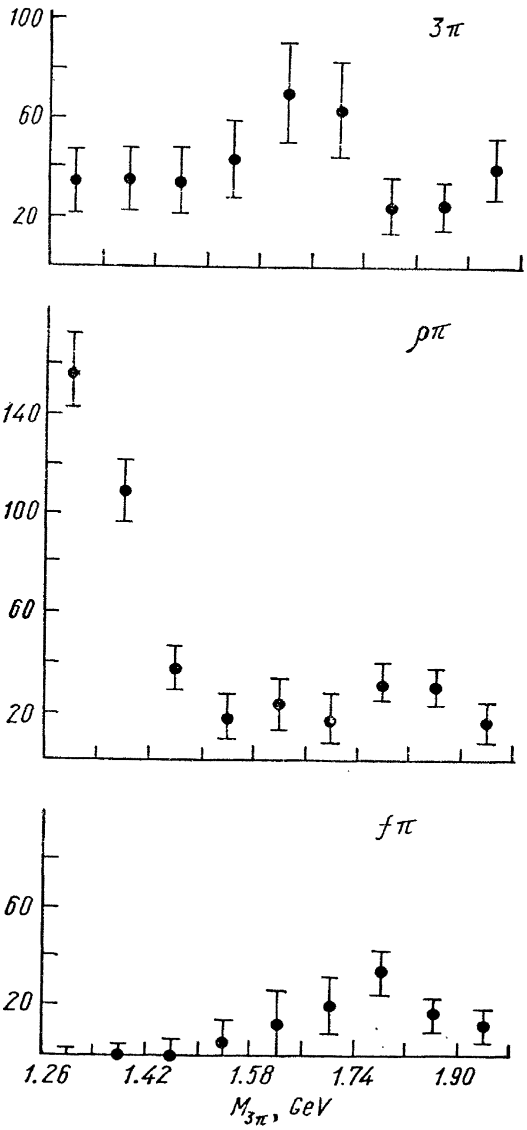


Fig. 17.

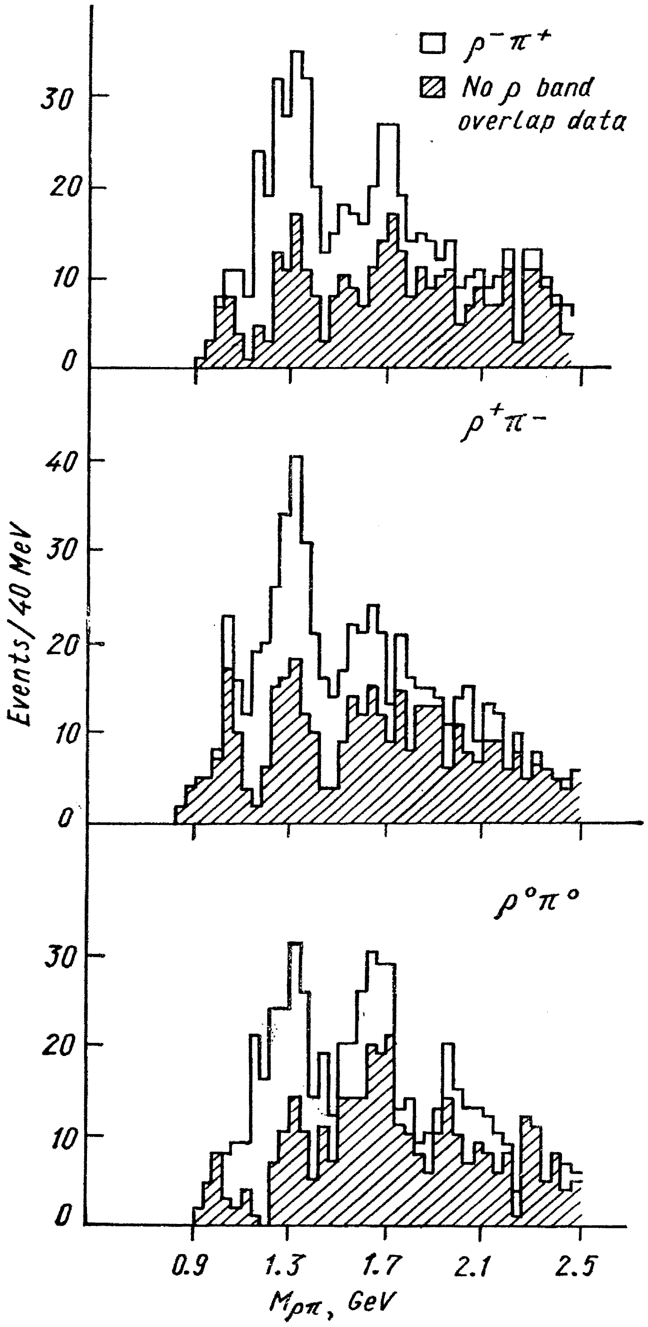


Fig. 18. $\pi^+d \to pp\pi^+\pi^-\pi^0$.

the fact that the $f^0\pi^0$-contribution is practically absent, while the $\rho^0\pi^0$ one is strong, as seen on the fig. 18. A spin-parity analysis shows that the 1^-, 2^+, 3^- J^P values are favoured, while 1^+, 2^- are not excluded.

3. 2π AND 4π SYSTEMS IN THE 1.1 to 1.9 *GEV* REGION

Now I shall present the results concerning the 2π and the 4π systems in the 1.1 to 1.9 *GeV* energy region, that means, in the old nomenclature, the f^0, the g and the B.

f^0

Concerning the f^0, there are two contributions to this conference.

The first one is a confirmation by the CERN — Zürich — London collaboration (ref. 33) of the branching ratio Γ $(f^0 \rightarrow K\bar{K})/\Gamma$ $(f^0 \rightarrow \pi\pi)$. I shall not describe this experiment, which I have already talked about (see above 1—3). The value they get (4.7 ± 1.2%) comes from the measurement of the production cross section $(\pi^-p \rightarrow nf^0$ compared to the corresponding cross section with f^0 decaying
$\;\;\;\;\;\;\;\;\;\;\;\;\;\;\;\;\hookrightarrow K_1^0K_1^0)$
into 2π. The presence of the f^0 in the reaction $\pi^-p \rightarrow K_1^0K_1^0\,n$ is required by the fit of the $K_1^0K_1^0$ effective mass, in spite of the presence of the A_2, the percentage of $f^0 \rightarrow K_1^0K_1^0$ being mainly determined from the lower half of the peak.

The second contribution to this conference comes from the Notre-Dame group (ref. 92). This group has studied the $\pi^+\pi^-$ system obtained in the reaction $\pi^-p \rightarrow \pi^-\pi^+n$ (8 *GeV/c*) and $\pi^+d \rightarrow \pi^+\pi^-pp$ (5.4 *GeV/c*). Although their data are very well fitted by a single Breit — Wigner resonance centred at 1275 *MeV*, they are also well fitted, because of a dip appearing in both reactions, by a coherent superposition of two resonances, a narrow one centred at 1230 *MeV* and a broad one centre at 1280 *MeV*. This splitting suggestion has to be remembered for further experiments.

g

As for the «A_3» it is very likely now that under the name «g», attributed long time ago to the first enhancement seen in the 2π neutral system at about 1650 *MeV*, there are at least two different objects, an $I = 1$ at ~ 1660 *MeV* and probably an $I = 0$ at ~ 1750 *MeV*, which we should call ρ^0 (1660) and η (1750), if we follow the Rosenfeld's admonition. Indeed these objects, which are seen to decay into 2π and 4π, have even isoparity.

But the situation is not as clear as in the case of the A_3. The table 6 will be used as a guide for showing the difficulties which we are faced to.

a) ρ (1660). Anyway, it is sure now that there exists an $I = 1$ broad resonance with a mass (1660 ± 10) *MeV* and a width of the order of 100—200 *MeV*. The clear evidences presented at this conference come from the Aachen — Berlin — CERN collaboration (ref. 93) and the Toronto — Wisconsin collaboration (ref. 94).

This resonance has been seen in its 2π decay in the reaction $\pi^+p \rightarrow \pi^+\pi^0\,p$ at 8 *GeV/c* and in the reactions $\pi^+d \rightarrow \pi^+\pi^-p$ (p) and $\pi^-p \rightarrow \pi^-\pi^+n$ at 7 *GeV/c*, respectively.

A 4π enhancement with about the same mass and the same width has also been seen by these two collaborations in the reaction $\pi^+p \rightarrow \pi^+\pi^0\pi^+\pi^-p$ (8 *GeV/c*) and in the reaction $\pi^-p \to \pi^-\pi^0 p$ (7 GeV/c), respectively. This fact strongly suggests that one is in presence of the 2π and 4π decay modes of an unique resonance.

Indeed each of these two collaborations have tried to prove that. And in both cases, the proof passes through a careful J^P analysis of the decay modes.

For the Toronto — Wisconsin group the evidence comes from the fact that they get $J^P = 3^-$ for the spin-parity of the 2π state and $J^P \geqslant 3^-$ for the one of the $\rho\rho$ state (which is the dominant 4π mode).

Table 6

Summary of recent *g*-meson data

Group	Ref.	M (MeV)	Γ (MeV)	Charge state	Decay modes	Spin parity
D — G — M — P collaboration	[96]	1650	?	$(2\pi)^0$	2π	
Stuntebeck et al.	[92]	1655	narrow	$(2\pi)^0$	2π	
A — B — C collaboration	[93]	1650 1670	180 160	$(2\pi)^+$ $(4\pi)^+$	2π, 4π, $K\bar{K}$, $K\bar{K}\pi$	3^-
Matthews et al.	[94]	1670 1680	190 110	$(2\pi)^0$ $(\rho\rho)^-$	2π $\rho\rho$, $\omega\pi$	3^-
Barnham et al.	[95]	1630	110	$(4\pi)^+$	$\rho\pi\pi$, $\omega\pi$, ~~2π~~, ~~$K\bar{K}$~~	unnatural J^P 0^-, 1^+, 2^-
D — G — M — P collaboration	[57]	1550—1800		$(4\pi)^+$	essentially $\rho\pi\pi$	unnatural 0^-, 1^+, 2^- (coherent prod.)
Vetlitskii et al.	[98]	1650—1850		$(4\pi)^0$	$\rho^0\rho^0$, $\rho^0\pi^+\pi^-$, 4π	
Armenise et al.	[99]	1740	170	$(2\pi)^0$	$\pi^+\pi^-$, ~~$\pi^0\pi^0$~~	
Stuntebeck et al.	[92]	1765	40	$(2\pi)^0$	$\pi^+\pi^-$	
Ballam et al.	[100]	~1710	?	$(4\pi)^\pm$	$\rho\pi\pi$, $\omega\pi$, $A_1\pi$?, $A_2\pi$?	

For the Aachen — Berlin — CERN collaboration the evidence comes from the fact that

1) the J^P analysis of the 2π state leads to the conclusion that the *g*-meson is not an elastic resonance decaying only into 2π,

2) the introduction of a reasonable inelasticity (the authors claim that $\eta \sim 0.4$) favours the $J^P = 3^-$ assignment.

I shall not enter into the details of the spin-parity analyses which are different from one experiment to another.

Finally I have to add that other decay modes of this $I^GJ^P = 1^+3^-$ resonance have been seen:

$\omega\pi$ (ref. 93) and also $K\bar{K}$ and $K\bar{K}\pi$ (ref. 94).

Untill now, the situation is therefore clear. But recently the Birmingham — Glasgow collaboration (ref. 95) has published results concerning a ρ (1630) resonance, the properties of which are incompatible with what I just said. It has been observed in $\rho\pi\pi$ and $\omega\pi$ effective mass distributions coming from the reaction $K^+p \to K^0\rho^+$ (1630) p at 10 GeV/c, but not in the $(\pi^+\pi^0)$ nor in the $(K^+\bar{K}^0)$ effective mass distributions. The authors conclude that this resonance cannot be identified with the well-defined *g*-meson, I have just talked about.

Moreover, the Durham — Geneva — Milano — Paris (EP, IPN) collaboration ref. 57) presents at this conference a clear 4 π-enhancement seen in the reaction $\pi^+ d \rightarrow \pi^+\pi^0\pi^-\pi^+ d$ at 11.7 GeV/c. The enhancement lies in the mass region 1.55 — 1.80 GeV/c^2. But, as the authors mention, due to the presence of an unbroken deuteron and the steep t' distribution, this inelastic interaction is of the coherent type; therefore, if this enhancement is a resonance, it has probably an unnatural spin-parity, and cannot be identified to the g-meson.

We still need many new informations in order to disentangle the situation.

Before presenting the η (1750) evidences, I have to add that three other papers have been submitted to this conference showing evidence for 2π decays of the ρ (1660) meson (ref. 96, 92, 97).

b) η (1750). Let me recall that the first evidence for this possible resonance has been published last year by Vetlitskii et al. (ref. 98). Studying the reaction $\pi^- p \rightarrow \pi^-\pi^+\pi^-\pi^+ n$ at 4.7 and 5.74 GeV/c they have observed an enhancement in the 4π effective mass distribution (1.65 — 1,85 GeV region). Selecting the $\rho^0\rho^0$ events, they still observe a peak, but the significance is poor. Anyway if this peak was a resonance, it should be an $I = 0$ one.

Another broad enhancement centred at 1740 MeV has been published recently by Armenise et al. (ref. 99). It appears in a $(2\pi)^0$ effective mass spectrum. The significance is about 3 s. d.

Finally in the paper they submitted to this conference, Stuntebeck et al. (ref. 92) observe also an enhancement in a $(2\pi)^0$ effective mass distribution. The enhancement is centred at about 1765 MeV, but its width is only 40 MeV (?).

All these enhancements have to be found again in higher statistics, before they receive the resonance status.

Now I do not know the way to present another enhancement seen in the same mass region by Ballam et al. (ref. 100), because it is charged. The authors find this (4π) enhancement in the $\rho\pi\pi$ and $\omega\pi$ effective mass distributions. $A_1\pi$ and $A_2\pi$ decay modes are not excluded.

B

a) Existence. There is no doubt, at the present time, about the existence of an $\omega^0\pi$ resonant state with mass $\sim$ 1240 MeV and width $\sim$ 100 MeV called Buddha or B-meson.

The B-meson was first observed in πp interactions in 1963 (ref. 101), but, since, it has also been observed in $\bar{p}p$ annihilations at rest (ref. 102, 103) and, at this conference, it has been reported that it is also produced in K-nucleon interactions, in the reaction $K^- n \rightarrow \Lambda B^-$ $(B^- \rightarrow \omega^0\pi^-)$ (ref. 104) at 3 GeV/c.

b) Spin-parity. The question of the spin-parity assignment is not so clear; 3 spin-parity analyses were proposed at this conference for the B-meson.

In the annihilation at rest $\bar{p}p \rightarrow B^\pm\pi^\mp$ $(B^\pm \rightarrow \omega^0\pi^\pm)$ Diaz et al. (ref. 105) with a statistics twice as high as in their first publication (ref. 103), cannot obtain a good fit to the $\omega^0\pi^+\pi^-$ Dalitz plot, if they suppose that the $\omega^0\pi$ system is in a pure angular momentum state in the B-mass region. Rather, they propose two resonances, one with $J^P = 1^+$ and another with either 1^- or 0^-.

Abramovich et al. (ref. 106) in the reaction $\pi^- p \rightarrow \pi^-\pi^+\pi^-\pi^0 p$ at 3.9 GeV/c favors uniquely $J^P = 1^+$, when Ascoli et al. (ref. 107) in the same reaction at 5.0 and 7.5 GeV/c give 90% and 23% of confidence level for 1^+ and 2^- respectively. Both use the same technique of moment analysis in the decay chain $B \rightarrow \omega^0\pi$, $\omega^0 \rightarrow \pi^+\pi^-\pi^0$.

4. HIGH ENERGY ENHANCEMENTS (*STUX* REGION)

The well-known enhancements, called $STUX_i$, seen at high energy, from 1.9 to 3.2 *GeV*, by the CERN — CBS group will be recalled in the chapter III, where the most recently discovered ones will also be presented (see note 108).

The salient feature of the bosons observed in the missing mass spectrometer experiments is their narrow width. This is true, in particular, for the high energy enhancements. An important point is to examine whether or not such narrow bumps are also observed in the bubble chamber results.

Table 7

High energy enhancements observed in bubble chamber experiments

Region	Mass (MeV/c^2)	Width (MeV)	Decay mode	Reaction	Group	Ref.
S	~1930	100—150	$(4\pi)^+$ and $(\rho\pi\pi)^+$	$\pi^+d \to 2\pi^+\pi^-\pi^0 d$ at 11.7 GeV/c	D — G — M — P (EP, IPN) collab.	[57]
	1975±12	45±20	$\pi^+\pi^0$	$\pi^+p \to \pi^+\pi^0 p$ at 13.1 GeV/c	Miller et al. Kramer et al.	[109] [110]
T	2157±10	78±18	$\pi^+\pi^0$ and $(4\pi)^+$	$\pi^+p \to \pi^+\pi^0 p$ and $2\pi^+\pi^-\pi^0 p$ at 13.1 GeV/c	Miller et al. Kramer et al.	[109] [110]
U	2380±10	<40	$(K\bar{K}\pi)^0$ and $(KK2\pi)^0$	$\bar{p}p \to K\bar{K}m\pi$ at 5.7 GeV/c	Atherton et al.	[111]
	~2420	~40	$(KK\,3\pi)^\pm$	$\bar{p}p \to K\bar{K}m\pi$ at 3.6 GeV/c	Atherton et al.	[111]
	2420±25	⩽80	$\rho^0\rho^0\pi^-$	$\pi^-p \to (5\pi)^-\pi^0 p$ at 12 GeV/c	Johnson et al.	[112]
?	~2470	~40	$(K\bar{K}k\pi)^\pm$ $k > 1$	$\bar{p}p \to K\bar{K}m\pi$ at 3.6 GeV/c	Atherton et al.	[111]
X_i	~2620	~40	$(K\bar{K}2\pi)^{\pm}_{0}$	$\bar{p}p \to K\bar{K}m\pi$ at 3.6 and 5.7 GeV/c	Atherton et al.	[111]
	~2620	~40	$(4\pi)^+$	$\pi^+p \to 2\pi^+\pi^-\pi^0 p$ at 13.1 GeV/c	Miller et al.	[109]
	3035±25	200±60	$3\pi^+3\pi^-$	$\bar{p}p \to 3\pi^+3\pi^-\pi^0$ at. 6.94 GeV/c	Alexander et al.	[113]

Until now, only few of the heavy enhancements ($STUX_i$ region) have been seen in the effective mass distributions obtained in the bubble chamber experiments.

The table 7 summarizes the new evidences presented at this conference. Many of them are rather narrow, with widths of the order of (60 ± 20) *MeV*, not incompatible at first sight with the widths observed in the CBS experiments.

Concerning the masses, as it can be seen in the table, some are compatible with those observed in the CBS experiments. Their distribution is the following: 2 in the S-region, 1 in the T-region, 3 in the U-region, 1 between U- and X_i-region, and 3 in the X_i-region.

For the time being, the authors do not claim to present resonances: they just show the enhancements seen in their mass distributions.

5. $KKm\pi$ AND $\eta k\pi$ SYSTEMS

In this section I will present the results, concerning the so-called D^0, E^0, and F_1-mesons, which have been seen at the origin as $K\bar{K}\pi$ enhancements. Now there are evidences for the D decaying into $\rho\pi\pi$.

In the same section I will also present the results concerning the $\eta\pi$ and the $\eta\pi\pi$ systems, I mean the evidences for the so-called $\delta \to \eta\pi$ and the hypothetical decay $D \to \delta\pi$.

δ (962)

Since the discovery by the CBS group in 1965 of a very sharp peak at 962 *MeV* with $\Gamma < 5$ *MeV* (ref. 114) a lot of experimental works have been done to try to confirm the existence and analyse the properties of the δ (962) meson.

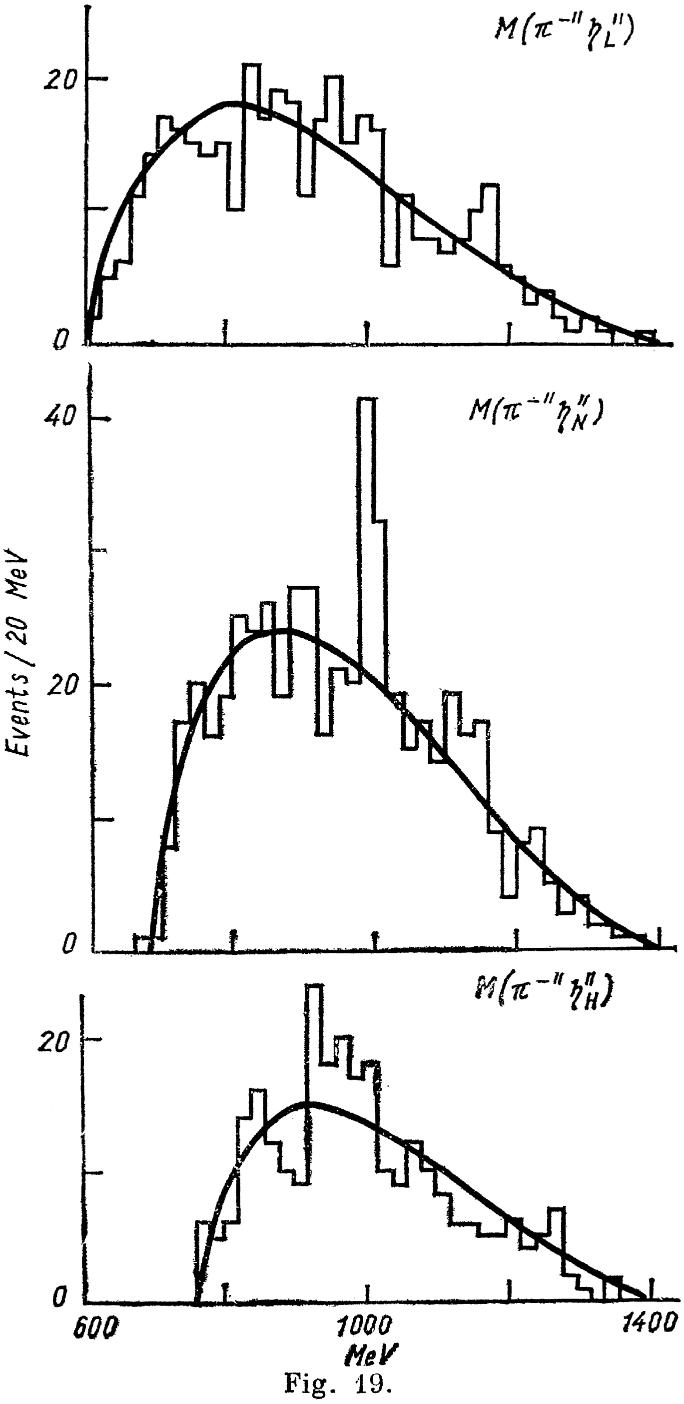


Fig. 19.

a) Missing mass experiments. First there is the controversy whether or not the δ-meson is produced in the missing mass experiments of the type $pp \to dX^+$ where the deuteron is produced near at 0° in the laboratory.

Three experiments agree now that the cross-section for the production of a narrow δ (962) in such a reaction (ref. 115, 116, 117) is very small or compatible with zero, in contradiction with Oostens at al. (ref. 118).

However the data of Abolins et al. (ref. 116) suggest the existence of a wide δ with mass and width

$$M = (952 \pm 12)\, MeV,$$

$$\Gamma = (60^{+16}_{-10})\, MeV,$$

but, as remarked by Anderson et al. (ref. 117), a wide δ would be hard to distinguish from a $d\pi\rho$ threshold effect.

b) Bubble chamber experiments. Several bubble chamber experiments give now convincing evidence for a narrow resonance in the $\eta^0\pi$ system at a mass close to the one of the δ (962). One of them (ref. 119) was reported at this conference by the Oxford UCLA group.

The «δ»-meson is produced in the reaction:

$$K^- p \to (MM)^0\, \pi^-\pi^+\Lambda \text{ at } 3.3\ Gev/c.$$

A sharp peak of mass $M = (995 \pm \pm 15)$ *MeV* and width $\Gamma < 40$ *MeV* is observed in the $(MM)^0\pi^-$ system when the missing mass $(MM)^0$ is chosen in the η-region. The peak is absent when control side bands are taken near the η-position (fig. 19). On the other hand no significant signal is observed in the $\eta^0\pi^+$ system; but this is explained by the fact that the δ^- is mainly produced in the peripheral process $K^-p \rightarrow \delta^-\Sigma^+$ (1385).

A strong decay of the δ into $\eta^0\pi$ requires $I^G = 1^-$ and $J^P = 0^+, 1^-, 2^+, \ldots$ ..., $J^P = 0^+$ being favoured because it forbids a 3π decay mode which is not observed. Now these quantum numbers are the most likely ones of the π_N (1016), which could be just the $K\bar{K}$ enhancement produced by the δ virtual bound state (ref. 120).

$D \rightarrow \delta\pi$

This interpretation would be reinforced by the observation of the decay chain $D^0 \rightarrow \delta^\pm\pi^\mp$, $\delta^\pm \rightarrow \eta^0\pi^\pm$, as the $K\bar{K}$ decay mode of the D^0 (1280) is likely dominated by the process $D^0 \rightarrow \pi_N^\pm$ (1016) $\pi^\mp$ (ref. 121). Unfortunately the situation concerning the δπ decay mode of the D^0 is rather confuse. The difficulties come from the reflection of the ω^0, which is abundantly produced in the multipion final states where the decay $D^0 \rightarrow \delta^\pm\pi^\mp$ can be observed. The point is that a $\pi^\pm\pi^+\pi^-\pi^0$ system with one $\pi^+\pi^-\pi^0$ combination in the η^0 region and the other one in the ω^0 mass region has a mass spectrum which is maximum at the δ mass.

In the reaction $\bar{p}p \rightarrow 3\pi^+3\pi^-\pi^0$ at 1.1 *GeV/c* for example, Donald et al. (ref. 122) do not observe any production of δ, when they remove the ω^0 events, in contradiction with the observation of Defoix et al. (ref. 123). But Otwinowski (ref. 124) has some indication for the presence of the decay chain $D^0 \rightarrow \delta^\pm\pi^\mp$, $\delta^\pm \rightarrow \eta^0\pi^\pm$ in the reaction $\pi^+p \rightarrow p\, 3\pi^+\, 2\pi^-\pi^0$ at 8 *GeV/c* independently from ω^0 production.

Miller et al. (ref. 125) see two signals in the $\eta^0\pi^+\pi^-$ system at the D^0 and E^0 masses, which are not due to the ω^0 production in the reaction: $\pi^+d \rightarrow \pi^+\pi^-\eta^0 pp_S$ at 2.7 and 3.1 *GeV/c*. But their evidence for a δπ decay mode of the D^0 is very poor.

Finally the CBS group in the test run of the CERN — IHEP boson spectrometer (CIBS) has also some evidence for a δπ decay of the D^0 meson (ref. 126). The

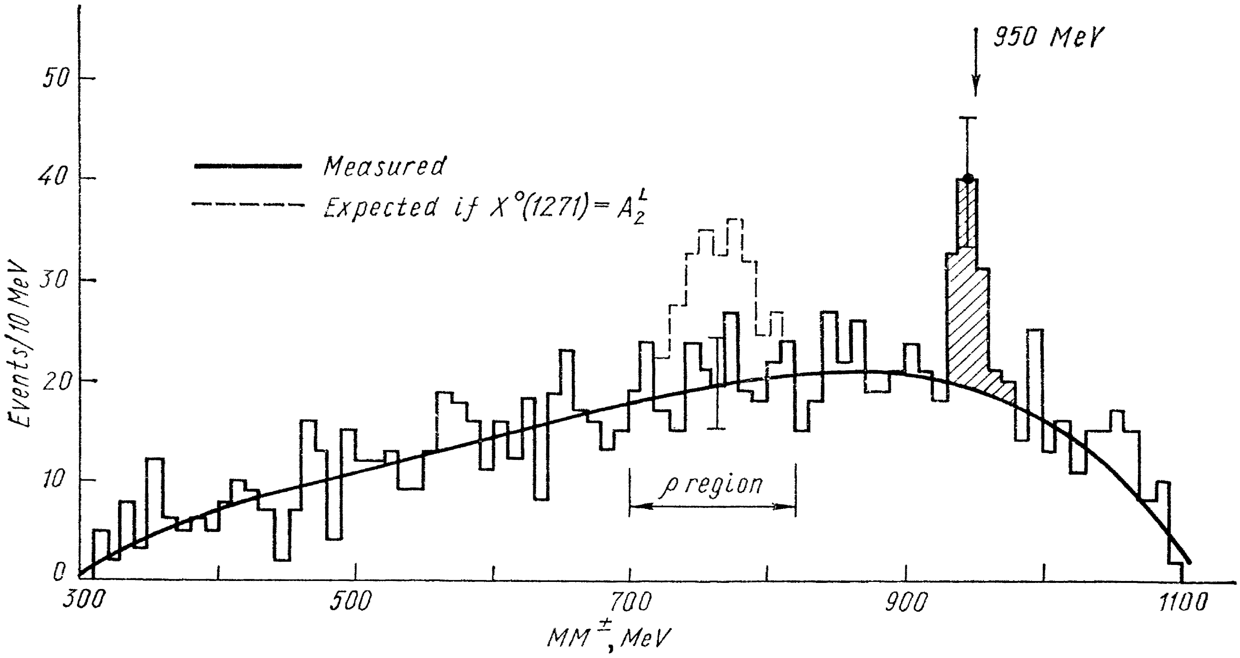


Fig. 20. CERN — IHEP boson spectrometer test runs at CERN, 1970. $\pi^-p \rightarrow pX^-$; $X^- \rightarrow \pi^-X^0$; $X^0 \rightarrow \pi^\mp + MM^\pm$ with $1240 < M\,(X^0) < 1300$ *MeV*; $p_1 = 10.5$ and 11 *GeV/c*.

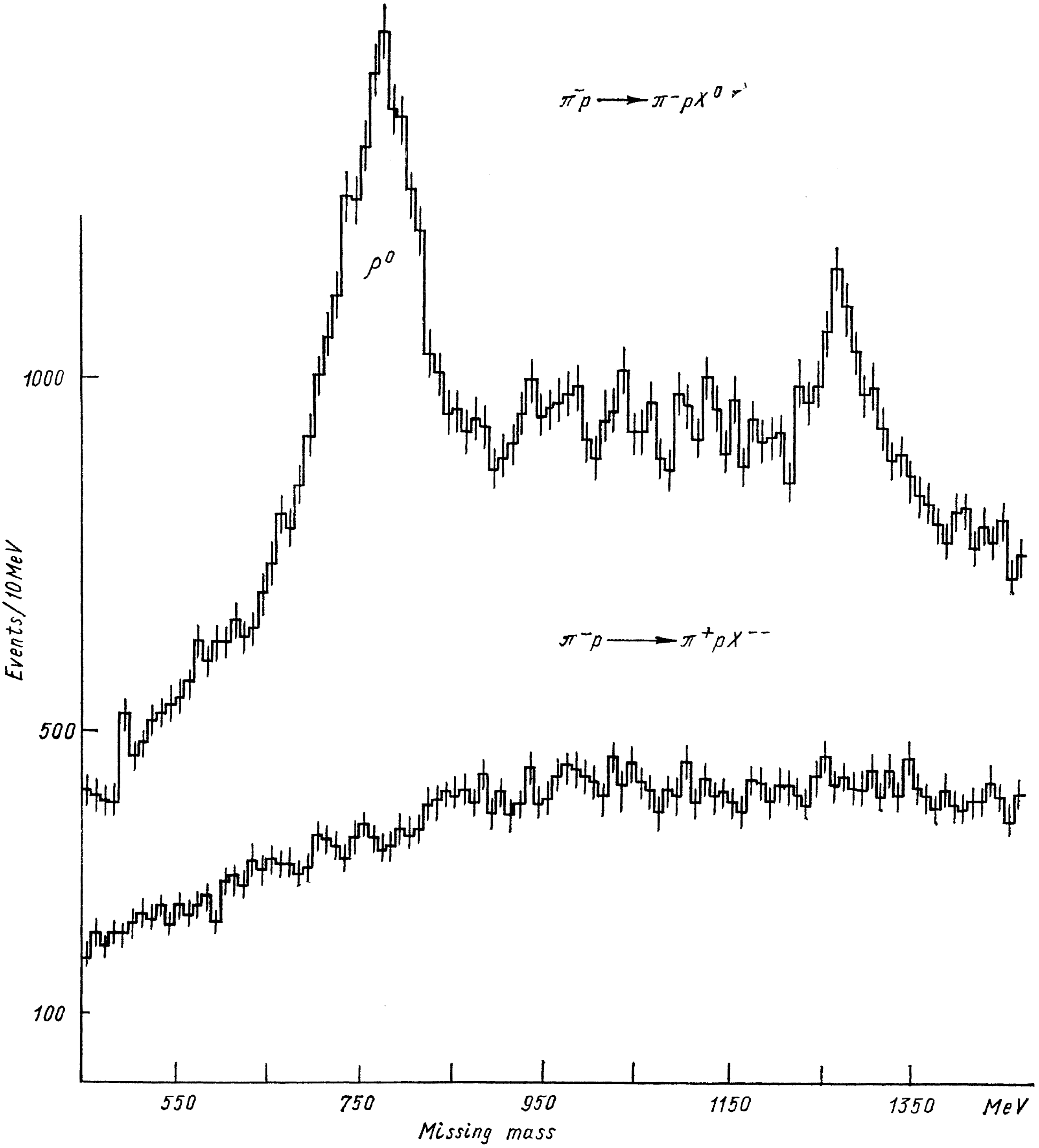


Fig. 21. CERN — IHEP boson spectrometer test runs at CERN, winter 1970.

fig. 21 shows the X^0 spectrum they obtained in the reaction $\pi^- p \to \pi^- X^0 p$
$\llcorner\!\!\to \pi^{\pm}(MM)^{\mp}$.
Beside the ρ^0, a clear signal is seen at ~1271 *MeV* with a $\Gamma \to 34$ *MeV*. An analysis of the decay products of the X^0 (1271) is made to look for possible decays X^0 (1271) $\to \pi^{\pm}(MM)^{\mp}$. The interpretation X^0 (1271) $= f^0 \to \pi^+\pi^-$ is rejected as there is no X^0 (1271) signal in the $\pi^{\pm}(MM)^{\mp}$ system for $(MM)^{\mp} = 1$ pion.

The fig. 20 shows the $(MM)^{\pm}$ distribution for the X^0 (1271) events. No $\rho^{\pm}$ enhancement is seen, excluding the second possible interpretation X^0 (1271) $=$ $= A^0_{2L}$. On the other hand, a significant narrow peak (~ 5 standard deviations) compatible in mass with the δ is present. Therefore the most likely interpretation is X^0 (1271) $= D^0 \to \delta\pi$ or $D^0 \to$ other modes. Nevertheless, as the authors mention, the situation is not satisfactory because: why are the f^0 and the A_2^0 not produced?

D-meson

a) Decay modes. Apart from the possible $\eta\pi\pi$ decay mode I just discussed, what about the other pionic decay modes of the D-meson? Two evidences for a $\rho^0\pi^+\pi^-$ decay mode of the D have been presented at this conference.

Defoix et al. (ref. 127) observe a peak in the $\rho^0\pi^+\pi^-$ system at 1285 *MeV* with width $\Gamma \sim 50$ *MeV* produced in the reaction $\bar{p}p \to \omega^0\rho^0\pi^+\pi^-$ at 1.2 *GeV/c*. As the D was already observed at this energy in the process $\bar{p}p \to \omega^0 D^0$, $D^0 \to K_1^0 K^\pm \pi^\mp$ (ref. 128), it is natural to associate the $\rho^0\pi\pi$ enhancement with the D meson.

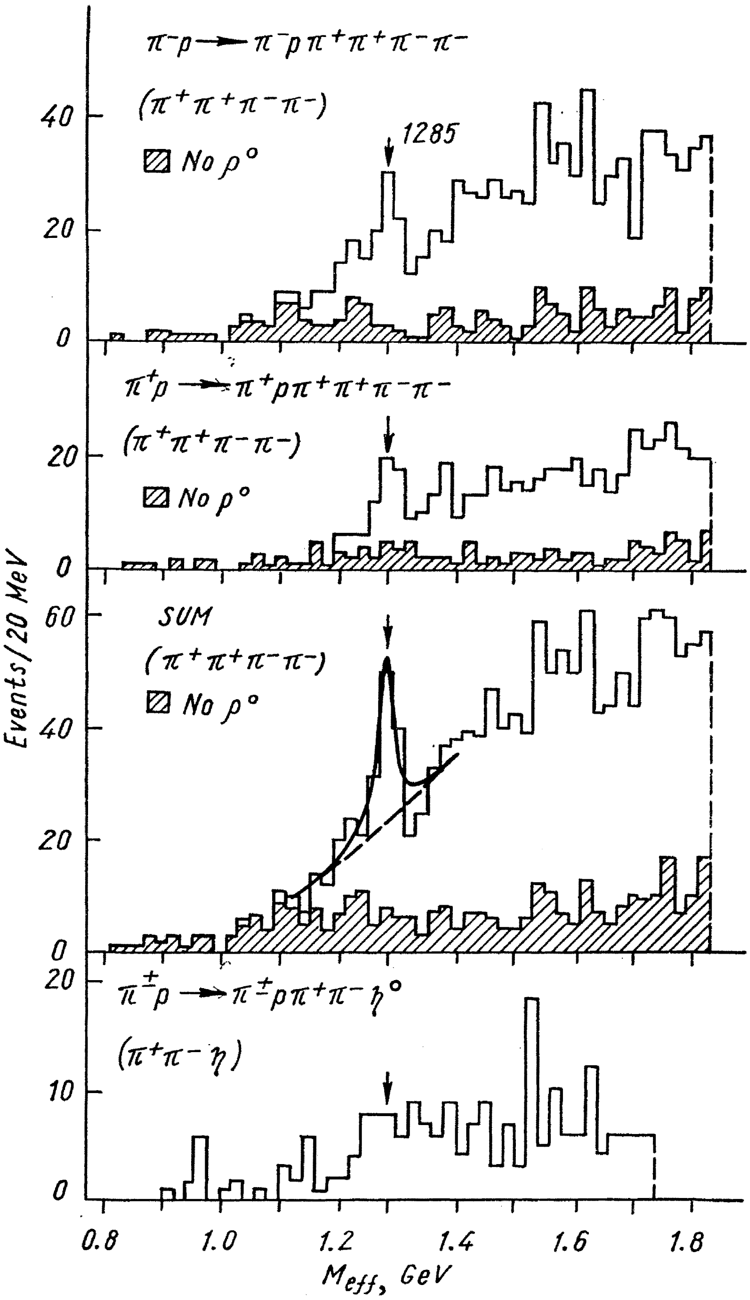


Fig. 22. $\pi^\pm p$ interactions at 16 *GeV/c*.

The ABBCCHW collaboration (ref. 129) observes also a peak at (1279 ± 5) *MeV* with a width (24 ± 11) *MeV* in the $\rho^0\pi^+\pi^-$ system produced in the reaction $\pi^\pm p \to \pi^\pm p$ $(\rho^0\pi^+\pi^-)$ at 16 *GeV/c* (fig. 22). On the other hand they do not find any D^0 signal in the $\eta^0\pi^+\pi^-$ system, giving $R = \frac{D \to \eta\pi\pi}{D \to \rho\pi\pi}\ 1.5$ (90% CL).

b) Quantum numbers. Previous analyses (ref. 121, 130) have established $I^G = 0^+$ and $J^P = 0^-, 1^+, 2^-, \ldots$, $G = +1$ is confirmed by the observation $D \to 4\pi$. A new spin-parity analysis was presented at this conference by M. Goldberg et al. (ref. 131). They study the angular correlations between the normals to the decay planes of the D^0 and ω^0 in the process near threshold $\bar{p}p \to D^0\omega^0$, $D^0 \to K_1^0 K^\pm \pi^\mp$, $\omega^0 \to \pi^+\pi^-\pi^0$ at 1.1 *GeV/c*. At this energy, the relative momentum $D - \omega$ in the total centre of mass is around 200 *MeV/c*, so that they suppose $L_{D\omega} \leqslant 1$.

They conclude that $J^P = 0^-$ is excluded and, if $L_{D\omega} = 0$ dominates, $J^{PC} = 1^{++}$ is favoured.

Remark. In this analysis of the D and the δ results, we have assumed implicitly that the different enhancements observed are manifestations of an unique D-meson and an unique narrow object called δ. However, due to the divergence of the mass values, the question has to be raised, whether we are for the δ in presence of an unique object or not, and also for the D.

All the δ masses are compatible with 975 MeV within 2 s. d., but the difference of the extreme values (995 ± 15) MeV (ref. 119) and (955 ± 10?) MeV (ref. 126) is so big that it suggests the possible existence of two different objects.

The same situation holds for the enhancements called D meson in all these papers. The mass value obtained in the reference 123 is (1310 ± 10?) MeV while the one obtained in the reference 126 is (1271 ± 10?) MeV. This fact has to be compared to the apparent splitting ($\sim$ 2 s. d., effect) of the D meson observed in the reaction $\bar{p}p$ $(K_1^0K^{\mp}\pi^{\mp})\ \pi^+\pi^-$ at 1.1 GeV/c (ref. 132): $M_1 = (1274 \pm 3)\ MeV$, $M_2 = (1323 \pm 4)\ MeV$.

The E(1420) and F_1 (1540)-mesons

No new significant results were reported on the E-meson. An indication for the $\eta^0\pi^+\pi^-$ decay mode of the E is given by Miller et al. (ref. 125) (see above). New data on $\bar{p}p$ annihilations at 1.1 GeV/c, is also produced at this energy in the processes:

$$\begin{array}{ll} \bar{p}p \to E\pi^0 & E \to K_1^0K^{\pm}\pi^{\mp}; \\ \bar{p}p \to E\pi^+\pi^- & E \to K_1^0K^{\pm}\pi^{\mp}. \end{array}$$

The same data give a good evidence for the reaction $\bar{p}p \to F_1^0\eta$, $F_1^0 \to K_1^0K^{\pm}\pi^{\mp}$, $\eta \to$ neutrals. As the reaction occurs very near threshold, one can make the hypothesis $L_{F_1^0\eta} = 0$. This hypothesis allows a spin, parity and charge conjugation analysis, leading to J^{PC}: 1^{+-} or 2^{-+}.

η' or X^0-meson

There was no contribution concerning the spin-parity of the η' at this conference. I would like, however, to recall that $J^P = 2^-$ is still not excluded by the present data, as mentioned in the review of particle properties (ref. 133).

6. NEW THINGS

At this conference some new enhancements have been reported which I have not yet mentioned, because they could not take place in my previous sections. These are

1) An ($\omega\pi$) 1040 *MeV*. This enhancement has been seen by the Collège de France group (ref. 127) in the $(\omega^0\pi^{\pm})$ effective mass distribution obtained in the 7 pion final states of $\bar{p}p$-annihilations at 0.7 and 1.2 GeV/c, after subtraction of the background. It is a narrow 4 SD effect.

$$M \sim 1040\ MeV \quad \Gamma \sim 60\ MeV.$$

2) A narrow (3π) 1010 *MeV* («h(1000)»?). This enhancement has been seen by the Durham — Geneva — Hamburg — Milano — Saclay collaboration (ref. 134) in the $(\pi^+\pi^-\pi^0)$ effective mass distribution obtained in the reaction $\pi^+p \to$

$\rightarrow (\pi^+\pi^-\pi^0)\, p\pi^+$ at 11.7 GeV/c, after cleaning the sample from possible contaminations. It is a narrow 6 SD effect.

$$M \sim 1010\ MeV \quad \Gamma \sim 60\ MeV.$$

By cross-section comparison the authors show that it is not due to misidentified $\eta' \rightarrow \rho\gamma$ events. On the other hand, the decay Dalitz-plot shows that it is not the Φ meson decaying into $\pi^+\pi^-\pi^0$. Finally the most likely J^P assignment is 1^+.

These results strongly support the evidence for an «h (1000)» meson given by Goldhaber et al. at the Lund Conference.

3) A broad (3π) 975 *MeV*? Another (3π) enhancement has been seen in the same mass region by the S.A.B.R.E. collaboration (ref. 135) in the reaction $K^-d \rightarrow p_S\Lambda\pi^-\pi^+\pi^-\pi^0$, $K^-d \rightarrow p_S\Sigma^-\pi^+\pi^-\pi^0$ at 3 GeV/c. This time, the enhancement is broad, and it is mainly due to the production of η' and Φ. In their paper, the authors said that, after subtraction of this production, a small residual effect of $\sim 2\,SD$ remains. But J. Goldberg, in his presentation of the results at the parallel session added that, due to the uncertainties of the computations, the effect might be completely explained by η' and Φ production.

Remark. These results remember the so-called H^0 object, which has been killed during the last years. At this conference, Chaudhary and Marquit (ref. 136) have reported the results of a remeasuring of their original events, which showed the H^0. Now the peak broadens out, and they have shown that the previous enhancement was primarily due to the distorsion of the phase-space by the ρ-band cut.

4) A ($K_1^0K_1^0$) 1420 *MeV*. In their study of the $K_1^0K_1^0$ system in the reaction $\pi^-p \rightarrow K_1^0K_1^0\, n$ at 6.2 GeV/c, Beusch et al. (ref. 33) had troubles because of a shoulder around 1400 MeV. They could not fit correctly their $K_1^0K_1^0$ effective mass distribution without introducing a Breit — Wigner enhancement centred at (1421^{+10}_{-11}) MeV with a width (91^{+24}_{-32}) MeV.

5) A ($\pi^-\gamma$) 275 *MeV*. Finally, in the study of the reaction $\pi^-p \rightarrow \pi^-p + 2$ or 3γ using the one meter propane bubble chamber of the JINR, Budagov et al. (ref. 137) have observed a $4\,SD$ enhancement in the $\pi^-\gamma$ effective mass distribution. This enhancement is centred at (275 ± 3) MeV.

7. SYSTEMS WITH NON ZERO STRANGENESS

I will close the presentation of the effective mass distributions observed in the bubble chamber experiments by reporting the analyses of the $S \neq 0$ enhancements submitted to this conference. I have already talked about the $K\pi$ systems with mass lower than 1400 MeV/c^2 (section 1—4). This section will be mainly devoted to the $K\pi\pi$ systems, namely the «Q enhancement» and the «L-meson». Some new results will also be presented about the branching ratio $K^+_{1420} \rightarrow K\pi\pi/K^*_{1420} \rightarrow K\pi$. Finally about the heavy K^*, I shall just say that there is no new evidence of $\bar{Y}^*N$ enhancements.

Q-Enhancement

Concerning the so-called Q-enhancement, I think nothing essentially new has been presented at this conference. The situation is still not clear.

As I already said, when I talked about the A_1 and the A_3, the opposition kinematical effect — resonance is now not meaningful. So I will not talk about «explanation» by Deck-effect. The results of this type of calculation, when it is done, is given in the table 8 (see below) which summarizes the situation.

I will just recall what is sure and what differs from one experiment to another.

Table 8

Summary of recent Q-enhancement data

Group	Ref.	Incident particle (GeV/c)	Reaction	Decay modes	Mass(es) and width(s) (MeV)	Spin-parity	«Explanation by Deck-effect»
Werner et al.	[138]	$K^{\pm}$ 4.6—12.7	all charge exchange reactions available $K^{\pm}p \to$ $\to (K_1^0\pi^{\pm}\pi^{+})\, n$		no signal		
Abrams et al.	[139]	K^{+} 2.53, 2.76, 3.20	$K^{+}p \to$ $\to (K^{+}\pi^{-}\pi^{+})\, p$	$K^*\pi$, $K\rho$	no substructure $M \sim 1300$	1^{+} (2^{-}, 3^{+})	
Antich et al.	[140]	5.5	$K^{+}p \to$ $\to (K^{+}\pi^{-}\pi^{+})\, p$	$K^*\pi$	no substructure	1^{+} ($2^{\pm}$)	
Charrière et al.	[141]	8.25	$K^{+}p \to$ $\to (K^{+}\pi^{-}\pi^{+})\, p$ $(K^0\pi^{+}\pi^0)\, p$	$K^*\pi$, $K\rho$	no substructure $M = 1260$ $M = 1240$		
Alexander et al.	[142]	9.	$K^{+}p \to$ $\to (K^{+}\pi^{-}\pi^{+})\, p$ $(K^0\pi^{+}\pi^0)\, p$	$K^*\pi$, $K\rho$, $K\varepsilon^0$	splitting $M_1 = 1260 \pm 10$, $\Gamma_1 = 40 \pm 10$ $M_2 = 1380 \pm 20$, $\Gamma_2 = 120 \pm 20$		
Holland et al.	[143]	9.	$K^{+}d \to$ $\to (K^{+}\pi^{-}\pi^{+})\, d$	$K^*\pi$	apparent splitting $M_2 \sim 1340$, $\Gamma_2 \sim 40$		
B — G — O collab.	[144]	10	$K^{+}p \to$ $\to (K^{+}\pi^{-}\pi^{+})\, p$ $(K^0\pi^{+}\pi^0)\, p$	$K^*\pi$, $K\rho$, $K\varepsilon^0$	splitting $M_1 = 1250 \pm 15$, $\Gamma_1 = 100 \pm 15$ $M_2 = 1405 \pm 15$, $\Gamma_2 = 130 \pm 15$	1^{+} 1^{+}	
Farber et al.	[145]	12.7	$K^{+}p \to$ $\to (K^{+}\pi^{-}\pi^{+})\, p$ $(K^0\pi^{+}\pi^0)\, p$	$K^*\pi$, $K\rho$	no substructure $M \sim 1260$, $\Gamma \sim 180$	1^{+} (2^{+})	not well
Carney et al.	[146]	16.	$K^{+}p \to$ $\to (K^{+}\pi^{-}\pi^{+})\, p$	$K^*\pi$, $K\rho$	no substructure		
SABRE Collab.	[147]	K^{-} 3.	$K^{-}d \to$ $\to (K^{-}\pi^{+}\pi^{-})\, d$ $(\bar{K}^0\pi^{-}\pi^0)\, d$	$K^*\pi$	non-significant structure		yes
Werner et al.	[148]	5.5	$K^{-}d \to$ $\to (K^{-}\pi^{+}\pi^{-})\, d$	$K^*\pi$	non-significant structure	1^{+}	partial
Jen — Shu Hsieh et al.	[149]	7. π^{-}	$\pi^{-}p \to \Lambda K 4\pi$ $N K \bar{K} 3\pi$		single peak $M = 1256 \pm 8$, $\Gamma \sim 45$		a priori Deck effect not present

Contin. tabl. 8

Group	Ref.	Incident particle (*GeV/c*)	Reaction	Decay modes	Mass(es) and width(s) (*MeV*)	Spin-parity	«Explanation by Deck-effect»
Haguenauer et al.	[150]	10 K^+	coherent production $K^*\pi$ on nuclei		no structure $M\sim1275$, $\Gamma\sim300$		
Cnops et al.	[151]	10 and 12.7 K^-	coherent production $K^*\pi$ on nuclei		determination of σ_{tot} $(Q-N)$ assuming Q is a single resonance $M=1300$, $\Gamma=290$		

a) What is sure.

1) *Diffractive production.* The Q enhancement has been observed in $K^{\mp}N$ interactions only in the same charge state as the incident particle. Hence the so-called diffractive nature of Q-production.

At this conference a paper has been presented by the Rochester group (ref. 138) which is an unfruitful search of Q-production in charge exchange reactions (world data; using a double Regge model, they expected about 50 events for the Q-signal).

2) *Spin-parity.* The $J^P=1^+$ assignment to the Q-bump is favoured by all the spin-parity analyses which have been done. This result does not depend on the assumptions concerning the single or double resonance status of the Q. I have to add that 2^- and 2^+ are sometimes not excluded.

b) What differs from one experiment to another.

1) *Decay modes.* The decay $Q\to K^*\pi$ is evident in all the experiments. The decay $Q\to K\rho$ is not evident in some experiments, but it is particularly clear in the experiments of the Birmingham — Glasgow — Oxford (BGO) collaboration (ref. 144) and the CERN — Bruxelles collaboration (ref. 141). Moreover the careful analysis of the Q-bump Dalitz plot, made by the BGO collaboration, suggests that, beside the ρ, some ε^0 production is possibly present, as Alexander et al. already mentioned one year ago (ref. 142).

2) *Effective mass distributions.* Here also the divergences remain unchanged. In some experiments, there is only one enhancement, more or less broad. The BGO collaboration, on the contrary, sees a splitting, I mean two well separated enhancements; however I have to add that the higher one is not separated from the K^*_{1420}.

One important thing has to be precised. While in the case of splitting the lower peak is centred at about 1240—1260 *MeV*, when the experimental results show only one big peak, this one is centred around 1270 *MeV*, that means not too far from the lower peak of the splitting case. Now it may be questioned how the BGO collaboration succeeds in separating the higher peak from the K^*_{1420}. This is performed in two ways. The first one is just the subtraction of the K^*_{1420} contribution, estimated from the K^*_{1420} production in the reaction $K^+p\to(K^0\pi^+p)$ and the known branching ratio $R=\dfrac{K^*_{1420}\to K\pi\pi}{K^*_{1420}\to K\pi}$ taking into account the t-distribution in this reaction. The second one is the careful spin-parity analysis they have done of the $K\pi\pi$ system in the region of the Q-bump. The contribution of 2^+ is small, even in the K^*_{1420} region.

Finally the BGO collaboration gives the following values for the mass and the width of the two peaks

$$M_1 = (1250 \pm 15)\,MeV, \qquad M_2 = (1405 \pm 15)\,MeV;$$
$$\Gamma_1 = (\ 100 \pm 15)\,MeV, \qquad \Gamma_2 = (\ 130 \pm 15)\,MeV.$$

The end of their conclusion is the following: «The most natural qualitative interpretation of our results is the hypothesis of two 1^+ resonant amplitudes, as already put forward by Goldhaber (ref. 152). This hypothesis is supported by the observation of a $1^+K\pi\pi$ resonance with a mass of 1.240 *MeV* and a width of 127 *MeV* in antiproton annihilations (ref. 153)».

However I have to mention that in the more recent results shown during the conference by the BGO collaboration, the dip at $\sim$ 1300 *MeV* does not seem, with the higher statistics, as significant as before.

Remark. Special attention has to be paid to the coherent Q-production on nuclei (see table 8, above).

K^*_{1420}

Two studies of the K^*_{1420} branching ratio have been submitted to this conference.

The first one comes from the study of the reaction $K^-p \to (K^-\pi^+)\,n$ and $K^-p \to (K^0_1\pi^-\pi^+)\,n$ and of the reactions $K^-p \to (K^-\pi^+)\,\Delta^0$ and $K^-p \to (K^-\pi^+\pi^0)\,\Delta^0$ at 10 *GeV/c* by Aachen — Berlin — CERN — London collaboration (ref. 154). The authors chose these charge exchange reactions (at the baryon

Table 9

Branching ratios of the K^*_{1420}

Reaction	σ (μb)	Branching ratio
	Reference 154—10 *GeV/c* K^-	
$K^-p \to K^{*0}_{1420}n$ $\hookrightarrow K^0_1\pi^-\pi^+$	4.3 ± 1.5	$\dfrac{K^*_{1420} \to (K\pi\pi)}{K^*_{1420} \to K\pi} = 0.55 \pm 0.2$
$K^-p \to K^{*0}_{1420}n$ $\hookrightarrow K^-\pi^+$	36.1 ± 3.4	
$K^-p \to K^{*0}_{1420}\Delta^0$ $\hookrightarrow K^-\pi^+\pi^0$	3.7 ± 1.4	$\dfrac{K^*_{1420} \to (K\pi\pi)}{K^*_{1420} \to K\pi} = 0.45 \pm 0{,}2$
$K^-p \to K^{*0}_{1420}\Delta^0$ $\hookrightarrow K^-\pi^+$	11.2 ± 1.4	
	Reference 155—5 *GeV/c* K^+	
$K^+p \to K^{*0}_{1420}\Delta^{++}$ $\hookrightarrow (K^0_1\pi^+)\pi^-$	75 ± 20	$\dfrac{K^*_{1420} \to K^*_{890}\pi}{K^*_{1420} \to K\pi} = 0.8 \pm 0.3$
$K^+p \to K^{*0}_{1420}\Delta^{++}$ $\hookrightarrow K^+\pi^-$	143 ± 11	

Contin. tabl. 9

Reaction	σ (μb)	Branching ratio
$K^+p \to K^{*+}_{1420}p$ $\lfloor\!\to (K^+\pi^-)\,\pi^+$	78 ± 13	$\dfrac{K^*_{1420} \to K^*_{890}\pi}{K^*_{1420} \to K\pi} = 1.06 \pm 0.3$
$K^+p \to K^{*+}_{1420}p$ $\lfloor\!\to K^0_1\pi^+$	111 ± 22	
Reference 156—4.2 *GeV/c* K^-		
$K^-p \to K^{*-}_{1420}p$ $\lfloor\!\to K^0_1\pi^-$		$\dfrac{K^*_{1420} \to K^*_{890}\pi}{K^*_{1420} \to K\pi} = 0.45 \pm 0.2$
$K^-p \to K^{*-}_{1420}p$ $\lfloor\!\to (K^-\pi^+)\,\pi^-$		

vertex) in order to be free of Q-contamination in the ($K2\pi$) reactions. Unfortunately the $K^*_{1420} \to K2\pi$ enhancement is not clear in the first reaction and absent in the second one, so that, as the authors said, the results depend very much upon the shape assumed for background. The results obtained are given in the table 9 where I have also quoted, as a comparison, the result obtained in 5 *GeV/c* K^+p by the CERN — Bruxelles collaboration (ref. 155), where the $K^*_{1420} \to K2\pi$ — enhancement is clear in reaction $K^+p \to (K^{*+}\pi^-)\,\Delta^{++}$.

I have also quoted in the table the results presented at this conference by Amsterdam — Nijmegen collaboration (ref. 156).

L-meson

At this conference very good evidences have been reported that the $K^*_{1420}\pi$ is not the only decay mode of the L-object, which therefore should be considered now as a resonance.

1) The first evidence comes from the study of the reaction $K^-p \to (K^-\pi^+\pi^-)\,p$ at 10 *GeV/c*. This study has been made by the Aachen — Berlin — CERN — London — Vienna collaboration (ref. 157). When they draw the ($K\pi\pi$) effective mass distribution after the events with $K^*_{1420} \to K^-\pi^+$ have been excluded, the L-signal is still clearly visible (fig. 23). The non $K^*_{1420}\pi$ L-events are estimated by the authors to amount to 166 ± 31 among the total (321 ± 60) L-events.

2) The second evidence comes from the study of a series of reactions $K^+p \to (Km\pi)\,p$ where $m = 2, 3, 4$ (π^0 included) at 10 *GeV/c*. This study has been made by the Birmingham — Glasgow collaboration (ref. 158). First, as the ABCLV collaboration, they have good evidence of non $K^*_{1420}\pi$ L-events. Moreover, when they fit the decay Dalitz-plot, taking account of $K^*\pi$, $K\rho$ and $K^*_{1420}\pi$ contributions plus an uniform background, they get the following figures

$$(120 \pm 60)\,K^*\pi, \quad (90 \pm 45)\,K\rho, \quad (100 \pm 50)\,K^*_{1420}\pi.$$

Then, examining the ($K\,3\pi$) p and ($K\,4\pi$) p reactions, they get good evidence for L-decays into $K^*\rho$ and $K^*\omega$, but no evidence for $K\omega$.

The $K^*\rho$ and $K^*\omega$ decays are shown on the figs. 24—25.

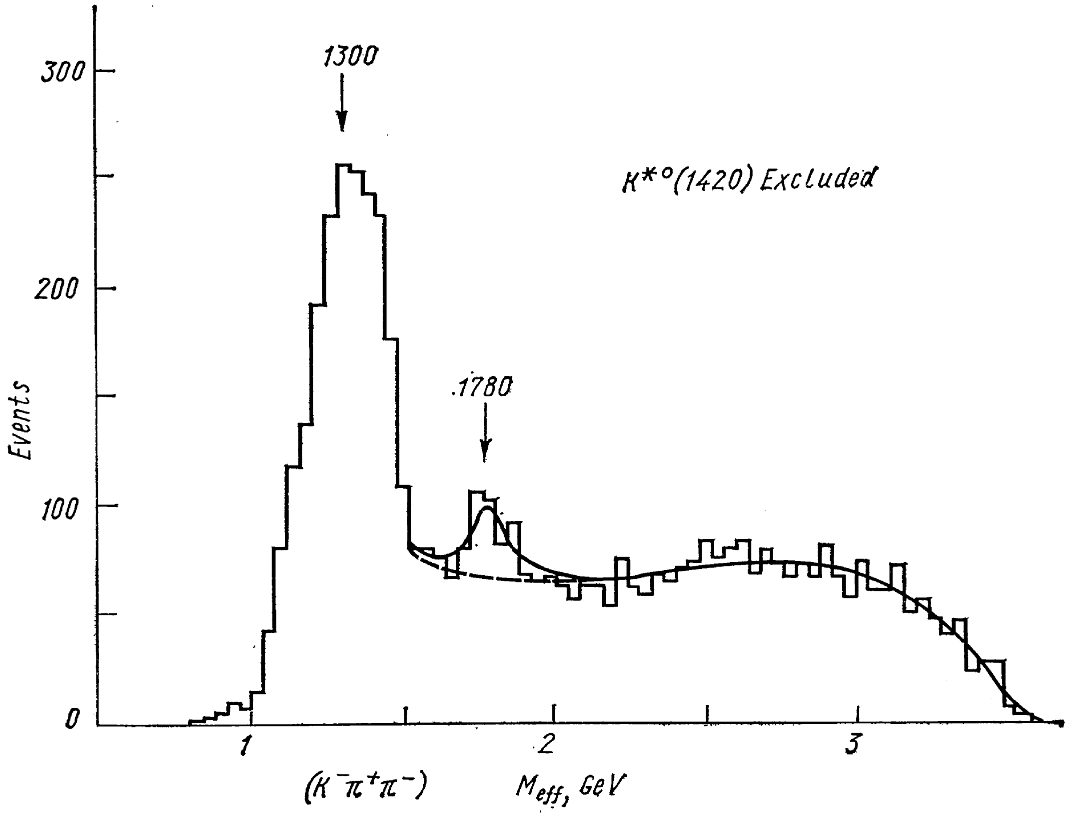


Fig. 23.

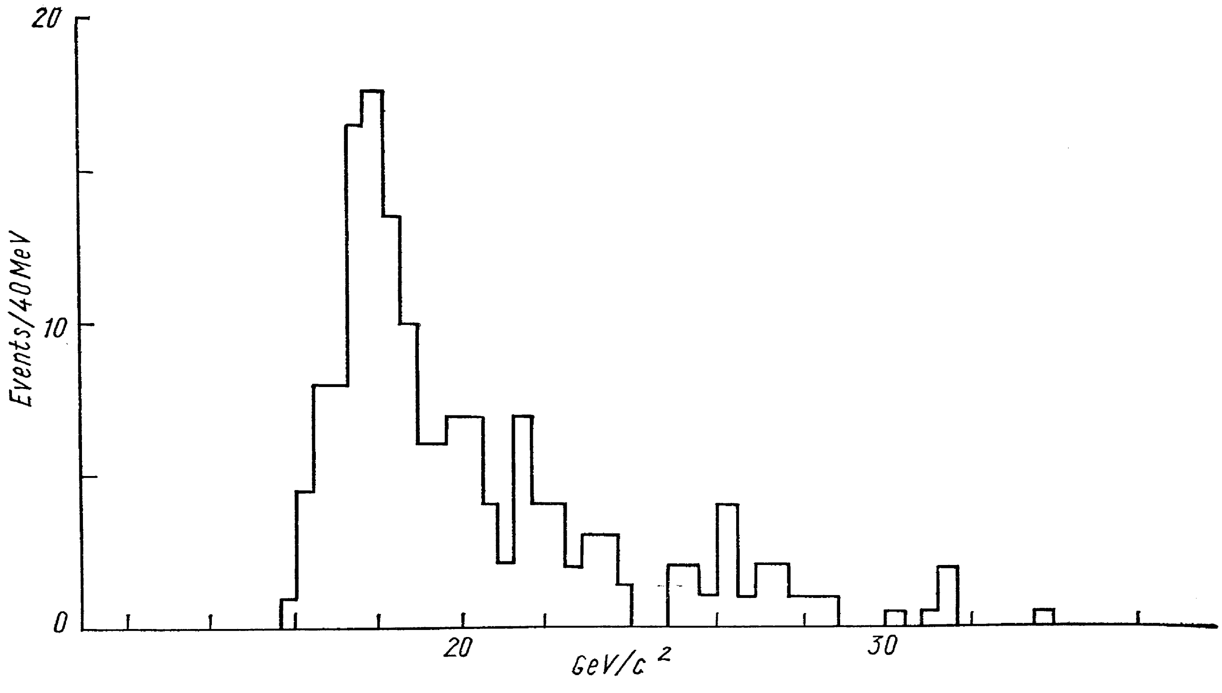


Fig. 24. Effective mass $K^0\pi^+\pi^+\pi^-$; $K^{*+}\rho^0$ selected, Δ^{++} antiselected. Number of entries 159.

However, I have to mention that the L-mass obtained for the well-known $K^*_{1420}\pi$ decay mode (1733 ± 8) *MeV* is significantly lower than the mass obtained for the $K^*\rho$ decay (1802 ± 6) *MeV* and the $K^*\omega$ decay (1788 ± 15) *MeV*.

3) Finally, I should mention that Aguilar — Benitez et al. (ref. 159) have also obtained good evidence for non $K^*_{1420}\pi$ L-events in a paper published recently.

Heavy K^*

There is only one contribution in this domain. The CERN — Bruxelles collaboration (ref. 160) does not find significant enhancement in the $\overline{Y}^*N$ mass distributions obtained at 8.25 *GeV/c* in the reactions

$$K^+p \to \overline{\Lambda}pp,\ \overline{\Sigma}^0pp,\ \overline{\Lambda}pp\pi^0,\ \overline{\Lambda}pn\pi^+.$$

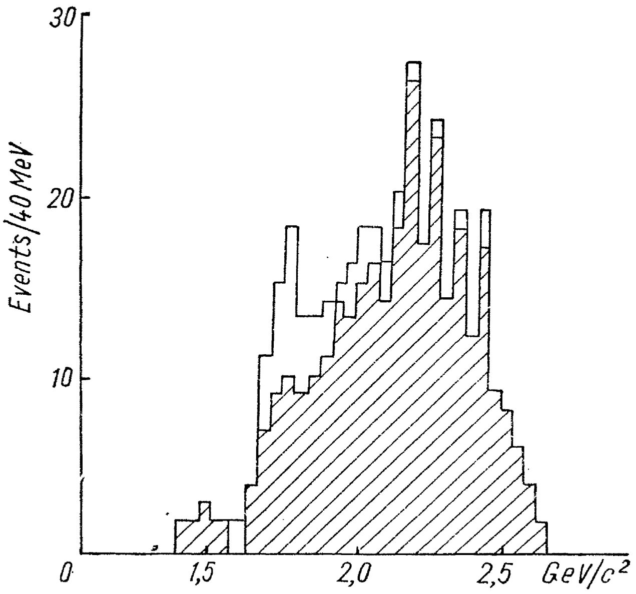


Fig. 25. Effective mass $K4\pi$ (Δ^2 (p/p) < <0.2 *GeV/c*²) from $K^+p \to K^0\pi^+\pi^+\pi^-\pi^0p$; K^*_{890} ω antiselected shown hatched.

These results have to be compared to the results obtained recently by Lissauer et al. (ref. 161) in the same reactions at 9 *GeV/c*. They got fairly good evidence for $(\overline{\Lambda}p)$ and $(\overline{\Sigma}^{\pm}N)$ enhancements at ~ 2240 *MeV* with a width of ~ 80 *MeV*.

8. SEARCH FOR EXOTIC STATES
(of the first kind)

At this conference three searches for bosonic exotic states have been presented. By exotic states I mean exotic states of the first kind in the Lipkin nomenclature (ref. 162): I and Y values not found in the quark antiquark model.

1) *Search for $\rho^-\pi^-$ resonant states.* The Rochester group (ref. 163) has carried out a search out for possible $\pi^-\rho^-$ resonances in the reaction $\pi^-d \to \pi^-\rho^-pp$ not only in their events (7 *GeV/c*) but in the world data (3.2, 3.7, and 5 *GeV/c*). In the total sample the enhancement seen in the 1250—1350 *MeV* region (ref. 164) is now not significant.

2) *Search for X^{--} in missing mass spectrometer experiments.* In their test runs of the CERN — IHEP boson spectrometer (ref. 126) the CBS group does not see any structure in the X^{--} mass spectrum obtained in the reaction $\pi^-p \to X^{--}\pi^+p$ at 10—16 *GeV/c* (see fig. 20).

3) *Search for $S = +2$ mesons.* The Rochester group (ref. 165) has carried out a search for $S = +2$ mesons in the reactions

$$\begin{aligned} K^+p &\to \Sigma^+X^+ \\ &\to \Lambda^0X^{++} \\ &\to \Sigma^-X^{+++} \end{aligned}$$

at 12.7 *GeV/c*.

Of special interest was the search for X^+ having a mass $< 2m_K$ (quasi-stable mesons). The X^+ mass spectrum does not show any structure below 1000 *MeV*.

On the other hand, the total spectrum ($X^{+} + X^{++} + X^{+++}$) shows a small enhancement at ~ 2900 *MeV* but the significance is very poor.

* * *

Therefore, we have still no evidence for bosonic exotic states of the first kind.

III. Results of the missing-mass spectrometer experiments

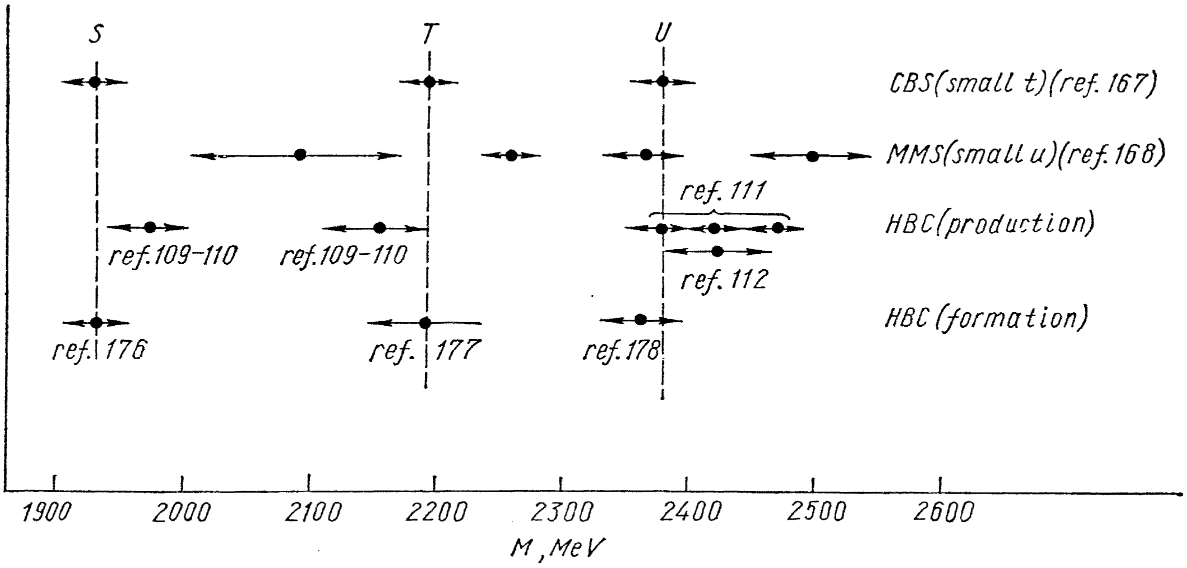
Apart from the very recent results obtained by the CERN boson spectrometer group in their test runs of the CIBS, which I have already talked about (see sections II — 2 and II — 5), all the results obtained by this group are known because they have been presented at the Philadelphia conference on Meson Spectroscopy (ref. 166). On the other hand, I have already presented the results obtained by other groups in the δ (section II — 5) and A_2 (section II — 2) mass region. Therefore I will confine myself to recall briefly the present situation.

1. METHODS

Restricting myself to the $\pi^{-}p \rightarrow (MM)^{-}p$ reaction let me recall that the missing mass spectrometers can be operated in different ways, yielding different results. There are essentially two classes of operation methods: at small t and at small u, I mean for examining forward and backward boson production. Furthermore in the case of small t operation, the methods can be subdivided into the 0^{0} production method and the so-called jacobian peak method depending whether the measured parameter is essentially the momentum or the angle of the recoil proton.

Table 10

Summary of the *STU* region



All the methods are reliable because they all yield the well-known ρ^{-} or A_2^{-} mesons. However, while the two small t methods give the same results, the peaks obtained at small u do not all coincide with those obtained at small t. The table 10

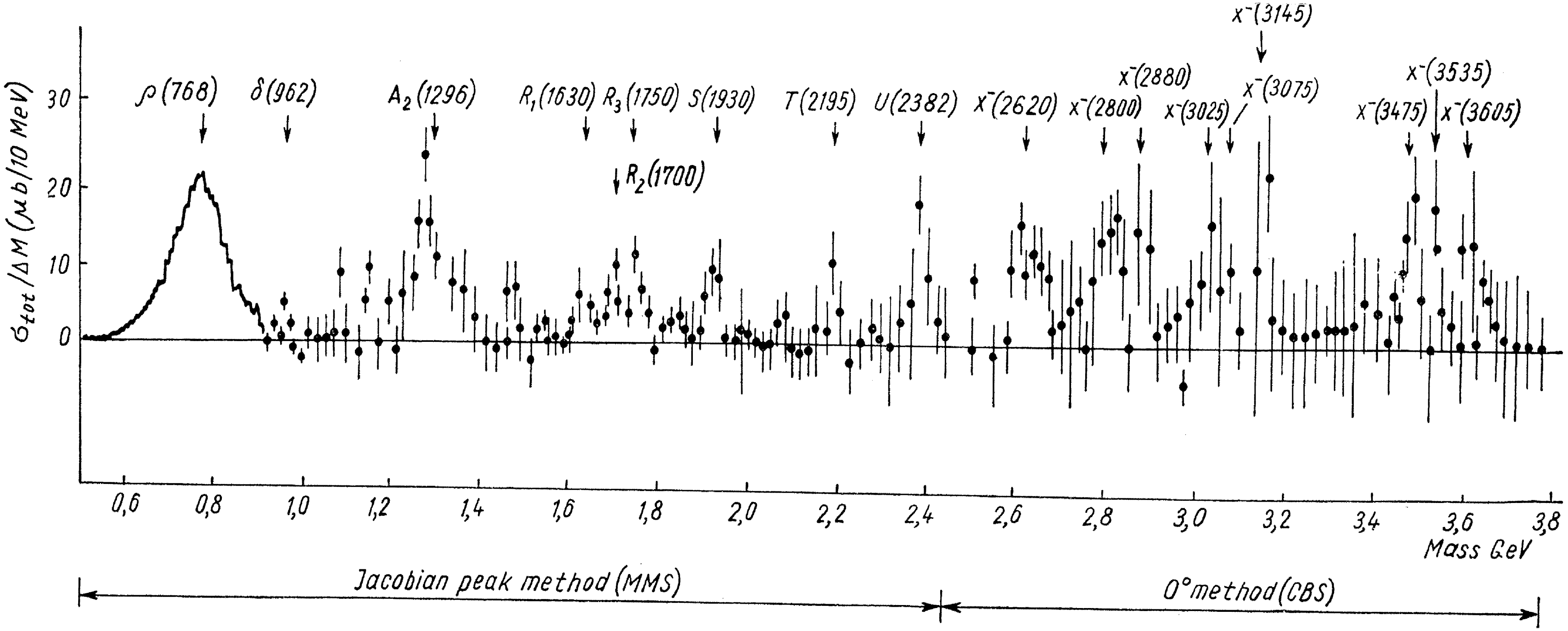


Fig. 26. Boson mass — spectrum in ($\pi^- p \to p + (\text{boson})^-$, CERN 1965—70.

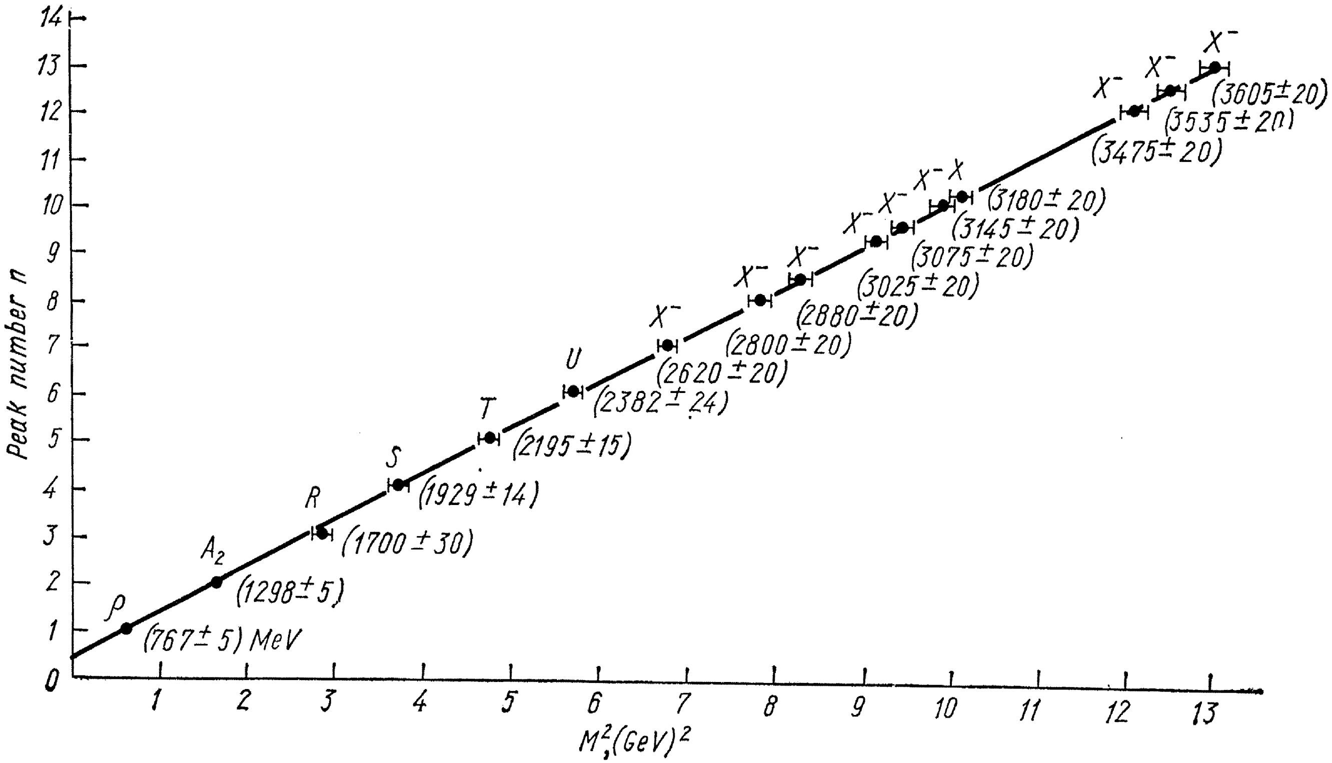


Fig. 27.

summarizes the results obtained by the different methods in the so-called *STU* region, together with the bubble chamber results obtained either in the production experiments (section II — 4) or in the formation experiments (see below chapter IV), which also do not all coincide.

Still examples of different things gathered by different nets.

2. RESULTS

Since the results concerning the δ (ref. 115, 116, 117, 118), the *D* (ref. 126) and the A_2 (ref. 65, 66) have already been presented, and since I just talked about the *STU* region, I will just recall the peaks observed at higher energy (note 169). The fig. 26 extracted from the reference 166 summarizes the situation. The three highest peaks have been obtained recently (ref. 170) by the small t (0^0) method of operation with incident pion momenta running from 10.5 to 15.5 *GeV/c*.

It has to be noticed that the remarkable regularity (fig. 27) observed between «peak number» and mass-squared in the 0 to 8 $(GeV/c^2)^2$ region does not seem continue to show up at higher mass values. Moreover, as mentioned above, the fact that mass values obtained for the peaks in the different missing mass and bubble chamber experiments do not all coincide even in the *STU* region brings some suspicion into the regularity itself.

IV. ($\bar{N}N$) cross-section bumps

(formation experiments)

Finally, I have to present the results obtained by a completely different method, namely the anomalies observed in the cross-sections of well-defined $\bar{N}N$ reactions.

1. METHODS

The study of the heavy bosons ($M \gg 2\ m_N$) in the formation experiments can be performed in different ways.

A first information can be obtained just by looking at the total $\bar{N}N$ cross-section, as the BNL group did a few years ago (ref. 171).

But it is certainly by studying well-defined $\bar{N}N$ reactions that precise information might be obtained on mass, width and quantum numbers of the possible resonances, namely $\bar{p}p$ elastic scattering, charge exchange reaction $\bar{p}p \rightarrow \bar{n}n$, 2 body annihilation channels as $\pi^+\pi^-$ or K^+K^-, and finally all well defined annihilation channels, so long as they are not too complicated.

Results have already been obtained in $\bar{p}p$ backward elastic scattering (ref. 172, 173), $\pi^+\pi^-$ and K^+K^- annihilation channels (ref. 174). But no anomaly has been seen (ref. 175) in the charge exchange reaction.

2. RESULTS

At this conference, new results have been presented in the *STU* region coming from the study of the background $\bar{p}p$ elastic scattering, and th $\rho^0\rho^0\pi^0$ and $K\bar{K}\ 3\pi$ annihilation channels.

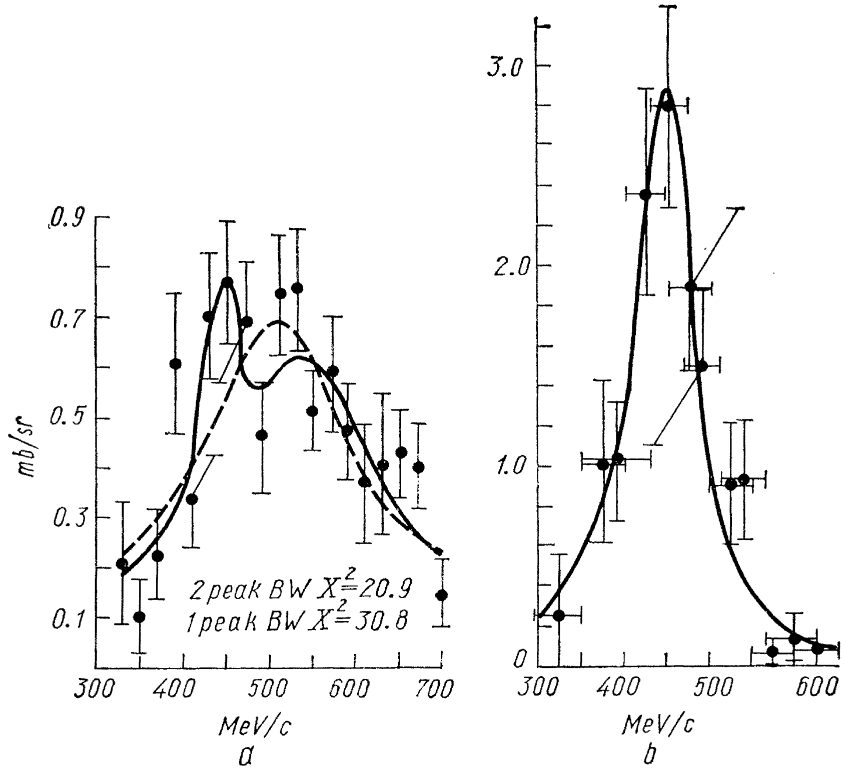


Fig. 28. (*a*) $\bar{p}p$ elastic scattering; $\cos\theta^*_{\bar{p}p} = 0.9$ to -1.0. (*b*) $\bar{p}p$ elastic scattering extrapolated to 180°. $\Gamma \simeq 17.6$ *MeV*, $M \simeq 1926$ *MeV*.

a) *S* region: enhancement in backward σ ($\bar{p}p \to \bar{p}p$). The study of the $\bar{p}p$ backward elastic scattering in the momentum range 0.250—0.740 *GeV/c* by Cline et al. (ref. 176) shows that the variation of the cross-section with energy (in the $\cos\theta^*$ region —0.9 to —1.) is accounted for by two Breit — Wigner curves, the masses and widths of which are:

$$M_1 = (1.925 \pm 2.3)\,MeV, \qquad \Gamma_1 = (7.6 \pm 3.5)\,MeV;$$

$$M_2 = (1.947 \pm 16)\,MeV, \qquad \Gamma_2 = (52. \pm 10.)\,MeV.$$

But the extrapolation to 180° exhibits only the first peak, with a mass ~ 1926 *MeV* and a width ~ 18 *MeV* (fig. 28). The Legendre polynomial analysis of the data gives an apparent structure up to $\sim a_6$ implying $L = 3$ at least.

b) *T* region: enhancement in σ ($\bar{p}p \to \rho^0\rho^0\pi^0$). As presented at the Philadelphia conference by Kalbfleisch (ref. 177), there is rather agreement between the ANL and the BNL data concerning the reaction $\bar{p}p \to \rho^0\rho^0\pi^0$ at 1.1 — 1.5 *GeV/c*. The combined data are shown in the fig. 29. The cross-section for resonating effect is (0.4 ± 0.1) *mb*. The position and the width are

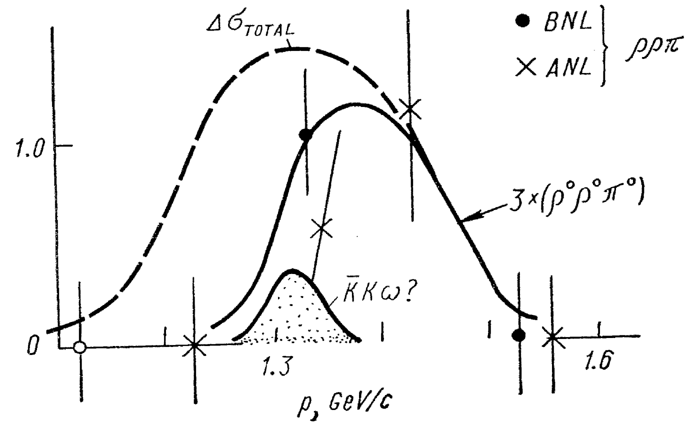


Fig. 29. Possible situation, regarding states in the $\bar{p}p \to$ «*T*» region. *M*, Γ, σ are schematic.

approximately

$$M \sim 2190\ MeV,$$
$$20 < \Gamma < 80\ MeV.$$

c) U region: enhancement in σ ($\bar{N}N \rightarrow K^*\bar{K}\ 2\pi$). Oh et al. (ref. 178) have studied the $\bar{p}p$ annihilations into kaons in the momentum range (1.51 — 1.95) GeV/c and the $\bar{p}n$ annihilations in the range (1.60—2) GeV/c. They found that in the $K\bar{K}\ 3\pi$ channels the percentage of K^* reaches a maximum around 1.8 GeV/c. The variation of the cross-section of the reaction $\bar{p}N \rightarrow K^*\bar{K}\pi\pi$ ($\bar{K}^*K\pi\pi$) is shown in fig. 30.

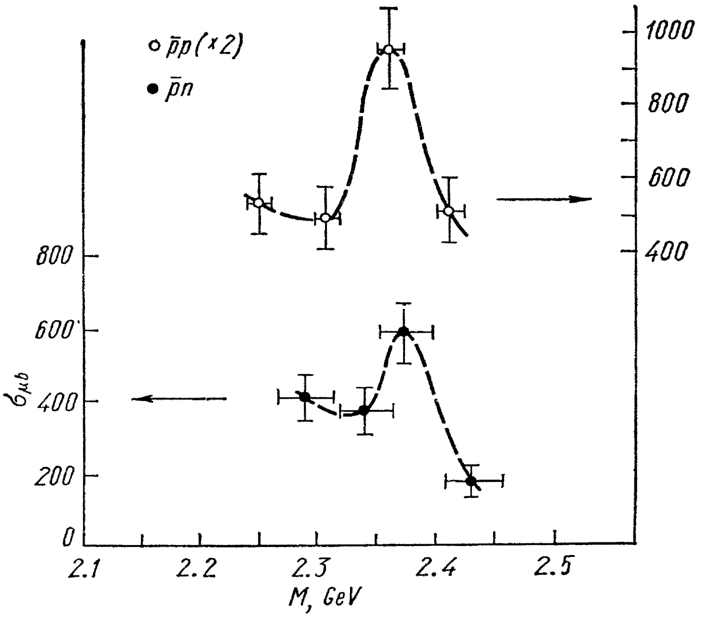


Fig. 30. K^* (890) cross section.

The best estimate of the position is $M = (2360 \pm 25)\ MeV$ with $\Gamma < 60\ MeV$.

d) The other works on boson formation presented at this conference do not reach definite conclusion regarding the existence of s-channel effects (ref. 179, 180).

V. Electromagnetic decays

Two kinds of papers have been submitted to the conference:

1) direct measurements of electromagnetic decays into π^0's and γ's of the η, the ω, the η' and the Φ;

2) electromagnetic decay of the ω into $\pi^+\pi^-$ and $\omega - \rho^0$ interference.

1. ELECTROMAGNETIC DECAYS OF η, ω, η' AND Φ INTO π^0'S AND γ'S

η

The most difficult problem is to give a correct evaluation of the $\pi^0\gamma\gamma$ decay mode which is certainly much less frequent than the other modes.

Regarding this decay mode, the situation before the conference is summarized in the august 1970 review of particle properties (RPP) (ref. 181). The results are contradictory. Among the eight values of the branching ratio $\frac{\eta \rightarrow \pi^0\gamma\gamma}{\eta \rightarrow \gamma\gamma}$ quoted in the RPP, five are compatible with zero within 2 s. d., the three others are not. In particular a recent experiment made by Cox et al. (ref. 182) yielded the following result

$$R_2 = \frac{\eta \rightarrow \pi^0\gamma\gamma}{\eta \rightarrow \text{neutrals}} = (12.2^{+5.2}_{-4.4})\ \%.$$

But the three papers presented at this conference have not disentangled the situation.

Buttram et al. (ref. 183) have made a careful analysis of a sample (after background subtraction) of 7200 events $\pi^-p \rightarrow \eta n$. The eta production was detected by the neutron time of flight, and the energy of the gamma rays was measured in an optical spark chamber. The fit of the single gamma energy spectrum in the η c. m. to Monte-Carlo generated events allowed the authors to give the following branching ratios

$$R_1 = \frac{\eta \to \gamma\gamma}{\eta \to \text{neutrals}} = (53.5 \pm 1.8)\%,$$

$$R_2 = \frac{\eta \to \pi^0\gamma\gamma}{\eta \to \text{neutrals}} = (2.6 \pm 1.9)\%,$$

$$R_3 = \frac{\eta \to 3\pi_0}{\eta \to \text{neutrals}} = (43.9 \pm 2.4)\%.$$

Schmitt et al. (ref. 184) have also made a careful analysis of the same reaction (6170 $\pi^- p \to \eta n$ events selected by neutron missing mass spectrometer and iron-plate spark chamber set up). The parameter used by the authors is essentially for each event the probability of being a true ($\pi^0\gamma\gamma$) η-decay. The fit of the experimental distribution to Monte-Carlo generated events yielded the following result:

$$R_2 = (1.6 \pm 4.7)\%.$$

But Strugalski et al. (ref. 1) have obtained in their xenon bubble chamber experiment I have already talked about (see section 1—2) a R_2 value which is not compatible to zero within 2 s. d. ($R_2 = (11 \pm 3)\%$).

Therefore the situation after the conference is as controversial as before.

ω

Results concerning the neutral decay modes of the ω have been obtained in the two heavy liquid bubble chamber experiments I have just talked about at the beginning of my talk (Strugalski et al., ref. 1; Baldin et al., ref. 2).

Table 11

Electromagnetic ω decays into π^0' s and γ's

Group	Ref.	$\frac{\omega \to \eta\gamma}{\omega \to \pi^0\gamma}$	$\frac{\omega \to \pi^0\pi^0\gamma}{\omega \to \pi^0\gamma}$
Strugalski et al.	[1]	0.22 ± 0.08	0.16 ± 0.13
Baldin et al.	[2]	<0.40 (95% c. l)	<0.14 (95% c. l)
Deinet et al.	[185]	<0.26 (90% c. l)	<0.21 (90% c. l)

The results are summarized in the table 11, where I also quoted the recent results of Deinet et al. (ref. 185).

η'

A new measurement of the branching ratio $R = \frac{\eta' \to \gamma\gamma}{\eta' \to \text{all}}$ has been presented at this conference by Harvey et al. (ref. 186).

The value obtained is $R = (1.7 \pm 0.6)\%$ (to be compared with the earlier value of Bollini et al., ref 187; $(5.5^{+3.6}_{-3.0})\%$).

Φ

The e^+e^- storage ring group of Orsay has now in operation an apparatus which detects simultaneously γ rays and charged particles. Studying the 3γ decays of the Φ, they have obtained the following results (ref. 188)

$$R_{\Phi 1} = \frac{\Phi \to \eta\gamma}{\Phi \to \text{all modes}} = (2.0 \pm 0.75)\%,$$

$$R_{\Phi 2} = \frac{\Phi \to \pi^0\gamma}{\Phi \to \text{all modes}} < 0.24\%.$$

This last result has to be compared to the result of Bemporad et al. (ref. 189) $R_{\Phi 2} < 0.35\%$.

2. ELECTROMAGNETIC $\omega \to \pi^+\pi^-$ DECAY AND $\omega - \rho$ INTERFERENCE

a) Electromagnetic $\omega \to \pi^+\pi^-$ decay. Due to the *G*-violating electromagnetic interaction the physical $|\omega\rangle$, I mean the state having a well defined life time, is a mixture of the two *G*-eigenstates $|\omega_0\rangle$ and $|\rho_0\rangle$: $|\omega\rangle = |\omega_0\rangle + \varepsilon|\rho_0\rangle$ (see for example ref. 190). Then the $\omega \to \pi^+\pi^-$ decay could come either from the directtransition $\omega_0 \to 2\pi$ or from the $\rho_0 \to 2\pi$ decay present with amplitude ε in the physical ω. Nevertheless, it has been shown that, even if the $\omega_0 \to 2\pi$ transition is important, it can be neglected, because the effect of the direct transition is cancelled by the effect of the same transition as intermediate state contributing to ε. Now, if the other real intermediate states can be neglected, the analysis can be performed assuming that only virtual intermediate states contribute to ε (the off diagonal mass matrix elements are real).

As far as I know, all the analyses of experimental results presented until now make this assumption.

b) $\omega - \rho^0$ interference. Now, in these experiments ρ^0 and ω are produced simultaneously. And the experimental results have shown that in most cases an interference occurs between the two productions. A phenomenological way to take into account this possible interference, which can be partial or complete, is to introduce a (real) «coherence factor» α ($0 \leqslant \alpha \leqslant 1$) factorizing the interference term. Then, if A_ω is the amplitude of 2π production with a given 2π mass through the intermediate ω state and A_ρ the corresponding production through the intermediate ρ^0 state, the interference term is written $2\alpha\,|A_\omega|\,|A_\rho|\,\mathrm{Re}\,(BW_\omega \times BW_\rho^* \times e^{i\varphi})$. If $\alpha = 1$ (complete coherence), φ is just the relative phase of A_ω and A_ρ, i. e. the sum $\varphi = \beta + \beta'$ of the relative production phase β between ω and ρ^0, which differs from a production process to another, and the relative phase β′ of the *G*-violating $\omega \to \pi^+\pi^-$ decay, which is a definite number independent of the production process (it can be shown that $\beta' \sim \pi/2$ at m_ω).

c) Experimental results. In order to obtain the branching ratio $R = \frac{\omega \to \pi^+\pi^-}{\omega \to 3\pi}$, α has to be known, otherwise only lower limit can be obtained for *R*.

Four papers have been submitted to this conference regarding this branching ratio. The results are summarized in the table 12 where are also quoted recent published results.

Hagopian et al. (ref. 195) observe a constructive interference in the reaction $\pi^- p \to (\pi^+\pi^-)\, n$ at 2.3 *GeV/c* and give the lower limit $R = (0.36 \pm 0.1)\%$, assuming $\alpha = 1$.

Burns et al. (ref. 196) have just observed a constructive interference in the reaction $\bar{p}p \to 4\pi$ at 0.94 *GeV/c*. The analysis is in progress.

Now, to determine an upper limit to *R*, Bizzarri et al. (ref. 197) have studied the $\bar{p}n$ annihilations at rest. Assuming that the annihilation proceeds mainly from

$L = 0$ states, and because $I = 1$, the G-eigenstates coincide with the S states (S = total spin): $G = (-1)^{S+1}$. Then the ω and the ρ productions, which take place from states of opposite G, consequently from different spin states, are incoherent.

Table 12

Summary of $\omega - \rho^0$ interference results

Reaction	p_{in} (GeV)	R (%)	Φ	α	Interference	Group	Ref.
$\pi^+p \to \omega\Delta^{++}$ $\quad \lfloor_{\to \pi\pi\Delta^{++}}$	3.7 — 4.0	> 0.25 (95% cl)	1.5±0.3 *rad*		destr.	Goldhaber et al.	[191]
$K^-p \to \Lambda\omega$ $\Lambda\pi\pi$ $\omega \to 3\pi$	1.5 1.7—2.6	> 0.2 (90% cl) no effect		no assumption	constr.	Flatté	[192]
$\pi^-p \to \pi^-p\pi^+\pi^-$ $\pi^-p\pi^+\pi^-\pi^0$	3.9	> 1.1 (95% cl) (select Δ^2) >0.1 (95% cl) (all data)			constr.	Abramovich et al.	[193]
$p\bar{p} \to \pi^+\pi^-\pi^+\pi^-$	1.26—1.65	$\Gamma(\omega \to 2\pi) =$ $= (0.18-$ $-5.3)$ *MeV*	60°—90°	~0.9	constr.	Alison et al.	[194]
$\pi^-p \to \pi^-\pi^+n$	2.3	>(0.36±0.1) if α =0 R = 3.2±0.8	—15°±30°	~1	constr.	Hagopian et al.	[195]
$p\bar{p} \to 4\pi$	.940				constr.	Burns et al.	[196]
$\bar{p}n \to N\pi$	at rest	<4. 3 (95% cl)		0		Bizzarri et al.	[197]
$e^+e^- \to \omega$ coll. beam		$(3.3^{+2.8}_{-2.0})$	—164°±28°	1		Augustin et al.	[198]
$\gamma + c \to \pi^+\pi^-C$	~4.2	$(0.8^{+.28}_{-.22})$	$15^\circ\ ^{+38^\circ}_{-30^\circ}$	1		Biggs et al.	[199]

The fact that the authors do not observe ω decay into $\pi^+\pi^-$ allows them to put an upper limit to $R : R < 4.3\%$ (95% confidence limit).

Finally Biggs et al. (ref. 199) have obtained a value of R in their study of $\omega - \rho$ photoproduction on carbon at 4.2 *GeV/c*.

$$R = (0.80^{+0.28}_{-0.22})\%.$$

This result has to be compared to that obtained last year by Augustin et al. (ref. 198) in their e^+e^- storage ring experiment $R = (3.3^{+2.8}_{-2.0})\%$.

It is worth mentioning that in these two cases of complete coherence, the phases Φ obtained from the experimental results are respectively $15^\circ{}^{+38^\circ}_{-30^\circ}$ and $164^\circ \pm 28^\circ$, while the theory gives on pure phenomenological grounds a value close to $\beta' = \pi/2$, namely $\sim 100^\circ$. This is a difficult problem.

Conclusion

I will just say, as a conclusion, that even if sometimes this is not clear, we, experimentalists, are not presenting psychological but scientific results. I know that often people are saying «it **seems** to me that... strongly supports»... or «my **feeling** is that...» or «do you **believe** in the δ?». Do you believe? We are not dealing with beliefs, we are not theologians, but science men. I think the way to eliminate this bad situation is to be always aware that our results depend on the techniques and the formalisms we use, I mean the nets, in the Eddington language.

DISCUSION

Ting:

Could you please comment on the spin-parity assignments of the π (1600) and φ (1600) mesons? Can they be vector mesons?

Astier:

For the π (1640) the only J^P study I know is that of Geneva — Milano — Saclay group (Caso et al.), published during the last year.

The $J^P = 0^-, 1^+, 2^-$... are favored. For the φ (1660) the J^P analysis made by the Toronto—Wisconsin group (Mathews et al.) shows that the 1^-, 2^+, 3^- are favored, while 1^+, 2^- are not excluded.

Bingham:

I want to remark that something new was presented here on the $A1$ and Q. The Q interaction cross-section in nuclear matter has been estimated by comparing Q production rates in heavy liquid bubble chambers (CERN 1.2m HLBC, BNL 80″ H_2 — NEON BC) with $H_2 + O_2$ production rates. The result for the Q^- (obtained by the BNL — Berkeley — Milan — Orsay — Saclay collaboration at 10.1 and 12.7 GeV/c) is: $R = 0.98^{+0,24}_{-0,37}$ times the K^- total cross-section (~ 21 mb) in good agreement with higher symmetry model predictions assuming the Q is a resonance, and 3 to 4σ away from simple Deck model predictions. The Bergen — Ecole — Polytechnique — Strasbourg — Madrid K^+ 10 GeV/c HLBC data similarly compared with Birmingham — Oxford — Glasgow H_2 BC data gives a compatible $R = 1.2 \mp 0.6$ (preliminary). For the $A1$, Beusch reported that the $A1$ absorption cross-section is between 20 and 25 mb, i. e. $R \sim 1$ based on a CERN — ETH — IPL — Milan spark chamber experiment, and convincing confirmation of the result $R < 1$ obtained by a previous HLBC (Orsay — Milan — Berkeley collaboration, analysed by A. S. Goldhaber et al., PRL, 1969) experiment.

Lynch:

I want to make a comment in an attempt to clarify the situation concerning the structure of the A_2 meson. I have a transparency that I wish to show. This is intended as a joint statement of the two groups that have the most significant evidence concerning the A_2 structure: the CERN Boson Spectrometer group, which observes splitting, and group A from LRL in Berkeley which does not observe splitting. These two experiments differ in a number of respects. The CERN group observes the negative A_2 in the t region from 0.2 to 0.3, whereas the LRL group observes the positive A_2 over a much larger t region.

The CERN group observes a mass distribution that is consistent with a dipole shape in both the 3π and $K\bar{K}$ decay modes. For the 3π decay mode they observe a splitting of more than 8 standard deviations. For the LRL experiment all three decay modes — 3π, $K\bar{K}$ and $\eta\pi^-$ fi well to the same Breit — Wigner. When these three decay modes are combined a dipole shap is rejected relative to a Breit — Wigner by more than 5 standard deviations. When a t cut i made to the LRL data corresponding to the t interval studied by the CERN group, the rema ning data do not have enough statistical significance to observe any disagreement with th CERN data.

We believe that these two experiments observe different structure and this difference is not explainable in terms of a statistical fluctuation. We must conclude that either one of these two experiments is wrong or the mechanism that produces splitting is either charge dependent or t dependent.

Finally, let me add that both of our experiments find that for both halves of the A_2 its spin is 2^+.

JOINT STATEMENT ON THE A_2 BY CBS GROUP (CERN) AND GROUP A (LRL)

CERN	LRL
$\pi^- p \rightarrow pA_2^-$ (7 and 2.6 GeV/c)	$\pi^+ p \rightarrow pA_2$ (7 GeV/c)
$\Downarrow$	$\Downarrow$
decays: 3π and $K\bar{K}$ $(\eta\pi)$	3π, $\underbrace{K\bar{K},\ \eta\pi}$
	$\nearrow$
$0.2 < \lvert t\rvert < 0.3$ $(GeV/c)^2$	$\lvert t\rvert < 0.2$ all t
Splitting of $>$ 8 st. dev.	Dipole rejected by $>$ 5 st. dev. (for combined decay modes)

Derrick:

If there is a difference between the A_2^+ and A_2^- one possibility is interference between $f^0 + \rho$ exchange. If the exchange is dominant then the A_2 neutral to A_2 charged ratio is simply given. What is the data about this point?

W. Walker:

Concerning the energy dependence of A_2^-, A_2^0 production. If ρ exchange were the dominant process for A_2 production one would expect a ratio A_2^0 of ${}^2/_1$ whereas we find a ratio of $\sim {}^1/_2$. There is also evidence that the energy dependence is quite different for $A_2^\pm$ and A_2^0. Thus there are probably at least 2 different amplitudes contributing.

Dubovik:

We with our collaborators B. Markovsky, L. Soroko, T. Striž proposed some method of analysis of experimental hystograms, containing a multiplet structure. The method consists of the Fourier transformation of experimental plot and subsequent comparison of the Fourier transformation with the one of the idealysed curve of the spectrometer resolution. The method makes it possible to observe doublet structure even when it is not visible on the real experimental hystogram. I hope we can solve a number of resonance splitting problems discussed at the conference by this method. The method is described in our report contributed to the 14-th section at this conference.

Khalfin:

I would like to comment the problem of the A_2-meson. From the mathematical view-point using only the distribution of masses to prove the existence of resonances (unstable particles) i. e. to prove the existence of complex singularities in the mass plane is, in principle, impossible due to incorrectness of the problem of analytical continuation into the complex plane. To solve the similar problem it is necessary «to strengthen» the fact of resonance existence by investigating the effects which are infinitely sensitive to the peculiarities of the mass distribution in the complex plane. Such a «strengthening» is possible in studying the decay law (at large values of times) or the cross-section of the reaction in the crossing-channel (at large energies). To solve the problem of A_2-meson one must use the investigation of asymptotics (at large energies) of the reactions in the crossing-channel of which the exchange of the states with the quantum numbers of A_2 ($I^G = 1^-, J^P = 2^+$) is possible. In my paper (JETP Lett. 2, 454, 1970) the utilization of the reaction $\pi^- p \rightarrow n\eta$ was suggested, where in the cross-channel only the exchange of the states with quantum numbers of A_2 is possible. The method suggested by me can give the complete solution of the A_2 problem: what are the quantum numbers of the A_2 mesons, do they have the same quantum numbers if there are more than one A_2 meson, and also to clarify whether A_2 is a dipole. In the last case the factor ln$s$ must appear in the asymptotics. Certainly investigating the asymptotics is not an easy problem but the importance of the A_2 problem in connection with the SU scheme justifies that the experimental set-up used nowadays can't solve the problem of the A meson structure.

Maglič:

I have two comments of more general nature and I have asked Prof. Jentschke to let me make them at the end of this discussion:

1. I propose that the **Rapporteurs talks be abolished.** The quantity of material in each field (or sub-field) has increased to the point that nobody can hope to present the status of one whole field of research in one hour. This remark has no personal projection on this rapporteurs' talk — I have had a similar experience as — rapporteur in Lund last year — I failed to present the whole review.

I propose that the Rapporteur's talks be replaced by «Highlights» of the developments (in each field) at the conference or within the last two years. The choice of the most important and/or most interesting developments («Highlights») is to be left to the discretion of the reviewer. **Without this change, I feel our High Energy Conferences will become boring events.**

2. To the experimentalists in this session I would like to make the following parting remarks: Our job is **not** to test theories or to make experimental examinations on some specific points of some specific theory. To quote Prof. Hofstadter: «We are doing experimental Physics **for the fun of it».** Our role is to **explore.** Our job is to be invertive. Our pleasure is derived from the process of research.

I feel that unless this attitude is taken by our younger fellow-experimentalists, the whole field of High Energy Physics will become (and already is becoming) monotonous and boring to the point of losing the best people to other fields. Let's not allow anyone to turn our exciting field of particle research into ordinary industrial production.

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