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Novosibirsk
1970

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A B S T R A C T

Using the colliding beam machine, VEPP-2, the excitation curve of ϕ-meson resonance was investigated in the three main decay modes. The resonance parameters obtained are the width, the total cross-section and the branching ratios. Namely:

$\Gamma = (4,67 \pm 0,42)$ Mev, $B(K^+K^-) = (54,0 \pm 3,4)$ %

$\sigma_0 = (3,96 \pm 0,35)\,\mu b$, $B(K_S^0K_L^0) = (25,7 \pm 3,0)$ %

$B(e^+e^-) = (2,81 \pm 0,25)\cdot 10^{-4}$ $B(\pi^+\pi^-\pi^0) = (20,3 \pm 4,2)$ %

In addition, the pion form factor at 2E=1020Mev is obtained together with an upper limit for branching ratio of ϕ-meson decay into pion pair.

$|F_\pi|^2 = 2,3 \pm 1,1$ $B(\pi^+\pi^-) < 0,8$ %

Using two colliding-beam installations (Novosibirsk and Orsay) a number of experiments on neutral vector meson investigation has been performed /I-8/. The present work on ϕ -meson resonance is an extension of these researches. Its difference from the similar work /6,7/ by the Orsay group consists in the simultaneous detection of three main ϕ-meson decay modes: K^+K^- , $K_S^o K_L^o$ (through $K_S^o \to \pi^+\pi^-$) and $\pi^+\pi^-\pi^o$, as well as the $\pi^+\pi^-$ pairs. The preliminary results of the work are already published /8/.

The experiments have been made using the electron-positron storage ring VEPP-2. The working conditions of the storage ring during the experiments (in the summer of 1969) are specified by the following parameters, namely: the average luminosity $10^{28} cm^{-2} sec^{-1}$ the initial currents 60 ma and 40 ma, for electrons and positrons,respectively, and the effective lifetime of the beams 5 hours.

The spark chamber system used in the experiment consists of two identical parts(upper and lower) covering the solid angle 2x0.9 steradians near the vertical axis. The layout of the spark chamber system is shown in Fig.I. Thin-plate chambers are used to determine the angles of outcoming particles as well as the coordinates

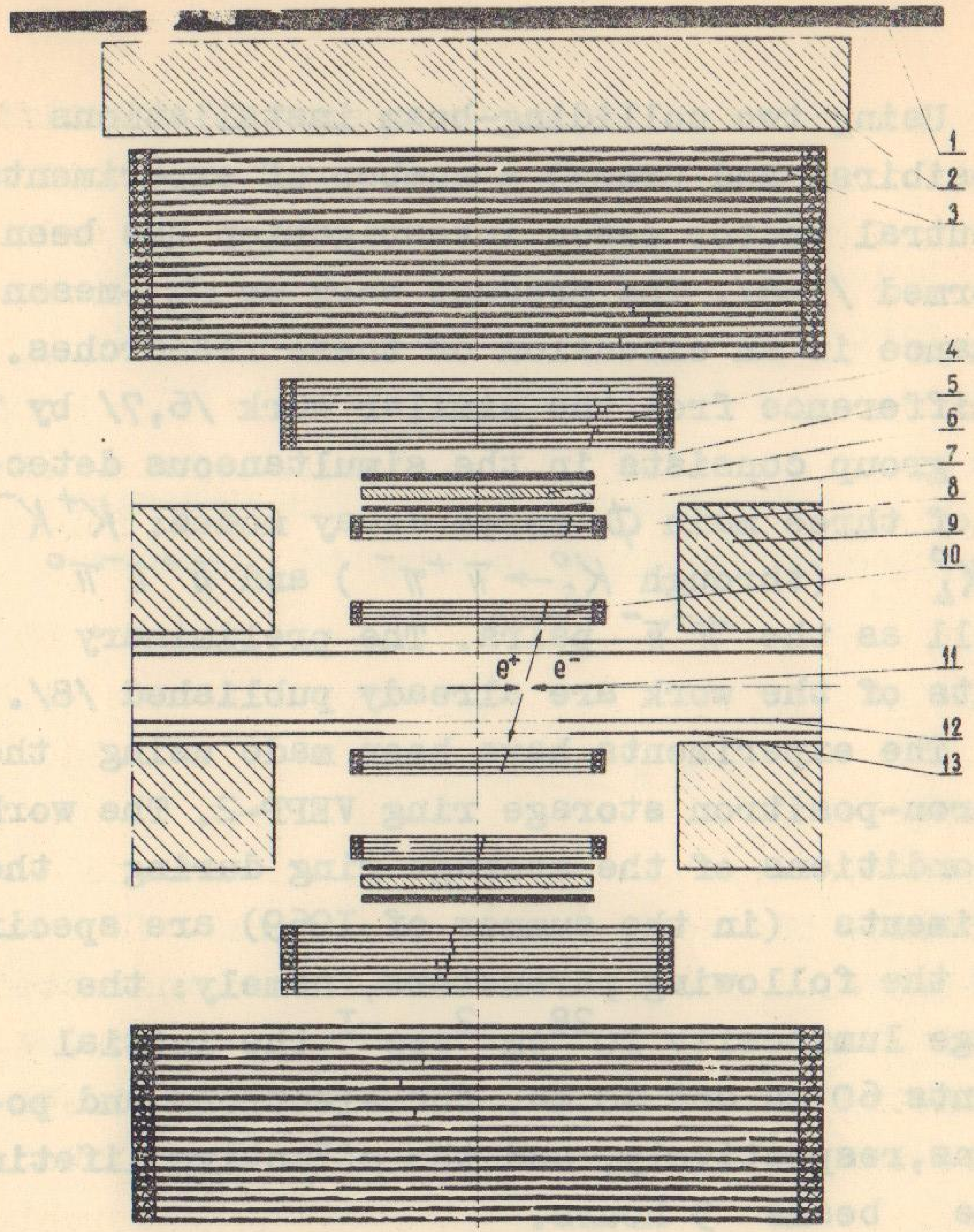

Fig.I. Spark Chamber system:

I-anticoincidence scintillation counter, 2-lead absorber, 200 mm thick, 3-range spark chamber, 4-shower spark chamber, 5,7-scintillation counters, 6-duraluminium absorber, 20 mm thick, 8, I0-thin-plate spark chamber, 9-storage ring magnet, II-interaction region, I2, I3-inner and outer vacuum chambers.

of the interaction point. The particle identification is achieved by observing their interaction with the material plates in the "shower"- and the "range"- spark chambers. The "shower" chamber consists of II lead plates of 2 mm thick each. The "range" chamber consists of 2I plates each of 8mm thick stainless steel. An elaborate system of mirrors allowed the use of single camera for recording.

The spark chamber system is triggered by four scintillation counters in coincidence with the resolving time of 20 nsec. The four-fold coincidence detected the minimum ionizing particles with the efficiency of 97 %. The two-fold coincidence between the inner scintillation counters, close to the vacuum chamber, detected charged K-mesons with the efficiency of I00 %. The kinetic energy of K-mesons at the φ-resonance maximum is only I6 Mev, and hence the light yield in the scintillator is considerably greater than that of relativistic particles. To fascilitate the later analysis the magnitude of these pulses for each event was recorded on the film of spark chamber pictures.

An anticoincidence counter of dimensions I60xI60x5 cm^3 was viewed by a single photomultiplier FEU-65 and is used for vetoing the cosmic ray. Between the veto-counter and the chambers a 20 cm thick lead absorber is placed to prevent the particles under investigation from reaching this counter. The anticoincidence counter reduced the cosmic-ray triggering rate by more than a factor of 50. An additional reduction of factor 4 was obtained when the counters were gated by the RF signal. Under these conditions the triggering rate due to cosmic-rays is 40 counts per hour while the triggering rate due to the particles from the colliding beams was much higher.

The accuracy of the absolute energy determination by means of magnetic field measurements is about I %. The stability in energy and its reproducibility for various runs was checked up by the nuclear resonance mehtod with an accuracy of 0.0I %. The absolute energy calibration was made by the tabulated energy value, I0I9,5 Mev, ϕ -meson resonance /9/.

Checking the conditions of the beam collision and luminosity monitoring (integration) were performed by recording the double bremsstralung events /I6/. This process was recorded by the two NaI scintillation counters in coincidence (2 γ -monitor). The energy threshold of these counters was set at 5 Mev.

The main bulk of event recording took I.5 months of 24 hours per day operation of the storage ring. The experiments were performed at nine energy values, from 508 Mev up to 5I4 Mev, of the colliding beams. One-fourth of the whole period was spent on "background" measurements with the beams vertically displaced from each other at a distance of 2 mm. In addition the background of cosmic-rays was measured.

Table I summarises the results of measurements.

Table I

	effect	background	cosmic
Measurement time (hour)	222	67	68
2 γ -monitor ($I0^3$)	I292	2,3	-
Number of pictures($I0^3$)	86.I	25.6	I0.2
Luminosity integral ($I0^{33}cm^{-2}$)	8.5	-	-

Through the analysis of the photographed events the following six types of the reaction were selected:

I) $e^+e^- \to e^+e^-$. The collinearity and the presence of characteristic showers in both upper and lower chamber systems allow to select this type of process clearly without background contamination. The deviation, $\Delta\omega$, from the collinearity was required to satisfy $\Delta\omega < 10^o$.

2) $e^+e^- \to K^+K^-$. The main criteria for selection were collinearity ($\Delta\omega < 10^o$) and pulses of high amplitude in a pair of triggering scintillation counters. In "shower" and "range" chambers about one-third of registered events of this process showed a characteristic picture of decay of K-meson stopped in the first scintillation counter. The latter events have no background.

3) $e^+e^- \to K^o_S K^o_L$. The decay $K^o_S \to \pi^+\pi^-$ was recorded. The branching ratio of this mode is 68.7 ± 0.6 % /9/. The angle of non-collinearity, $\Delta\omega$, was required to be from 10^o to 34^o. The upper limit is set by the K^o_S-meson momentum. The range of the π -mesons from this process does not allow them to penetrate beyond the fourth gap of "range" chamber. This condition was used as an additional criterion for selection. The events with azimuthal component, $\Delta\varphi$, of $\Delta\omega$ smaller that 5^o were not accepted, since they are contimated by the $e^+e^- \to \pi^+\pi^-\gamma$ process.

4) $e^+e^- \to \pi^+\pi^-\pi^o$. To this process were assigned those events in which the angle of non-collinearity or the range of one of the pions

exceeded the values expected for the preceding process. The criterion $\Delta\varphi < 5^o$ is also retained here. An additional condition of $\Delta\omega < 65^o$ is further imposed in order to decrease the background contamination.

5) $e^+e^- \to \pi^+\pi^-$. To this process were assigned those events in which both ends of the collinear track, ($\Delta\omega < 2,5^o$) were either in the "shower" - or in the "range" chamber.

6) $e^+e^- \to \mu^+\mu^-$. To this process were assigned those events in which the collinear track ($\Delta\omega < 2,5^o$) extended in both directions beyond the "range" chambers. The results of this process are given elsewhere /10/ where the domain of applicability of QED is investigated.

The results of the experiment are summarized in Table 2.

Table 2

Channel	Number of Events Detected			Pure Effect (background subtracted)	Efficiency of Detection
	effect	background	cosmics		
e^+e^-	530	0	0	530± 23	(0.0625 μb)
K^+K^-	633	20	2	565±29	7.1±0.1
$K^o_S K^o_L$	95	0	0	95±10	3.4±0.2
$\pi^+\pi^-\pi^o$	21	0	0	21±4.6	0.71±0.08
$\pi^+\pi^-$	40	3	15	28.6±7	6.0±0.7
Normalisation factor	1	0.298	1.32		

The number of background events in the above accepted events was normalized to that in the "background" run by using the total numbers of pictures taken in the respective runs. In estimating the background for the process $\pi^+\pi^-$ we used the "cosmic" run instead of "background" run because of the better statistical accuracy.

During the course of experimental runs the relative integral luminosity was checked by 2γ - monitor. The absolute value of the luminosity was determined from the large angle electron-positron elastic scattering.

The geometrical detection efficiency of the spark chamber system was calculated by Monte Carlo method. The detection probabilities given in Table 2 include corrections for the efficiency of the coincidence circuit, and for the probability of π -mesons to satisfy the range requirement, etc. The elastic scattering cross-section given in Table 2 for the present detector geometry already includes the radiative correction /II/. In calculating the $K^0_S K^0_L$ mode cross-section it was taken into account that a part of the events $\pi^+\pi^-\pi^0$ would satisfy the selection requirements for $K^0_S K^0_L$. The probability for an $\pi^+\pi^-\pi^0$ - event to be mistaken as a $K^0_S K^0_L$ -event is equal to (0,I4 ± 0,02) %.

The radiative corrections are rather important for the analysis of the resonance process under investigation /I2/. The measured cross-section, σ_m , is related by the following formula to the "ideal" cross-section, σ , which we are looking for, $\sigma_m = \sigma(1+\delta_R)$. At the peak of φ - resonance, $\delta_R = -0,24$.

The duration of runs is from 2 to 5 hours. Since the time of radiative polarization for the beams at the energy of 5I0 Mev in storage ring VEPP-2 is three hours /I3/, in the absence of depolarization effects the polarization of the beam will influence the results of cross-section measurements in the K^+K^- channel. In this case the correction for the cross-section will be δ_p = 0.06. In other words, if there are no depolarization effects, our results for the total cross-section of this mode should be reduced by 6 %. It is possible to estimate this correction from the observation of the rate of occurence of K^+K^- -events as a function of time after the beams were injected into the storage ring. This method gave $\delta_p = 0,02 \pm 0,03$ and we took the value $\delta_p = 0$ in the present analysis.

Figs.2-4 show the results of experimental data analysis of three main decay modes of φ - meson. The fit of the experimental results to

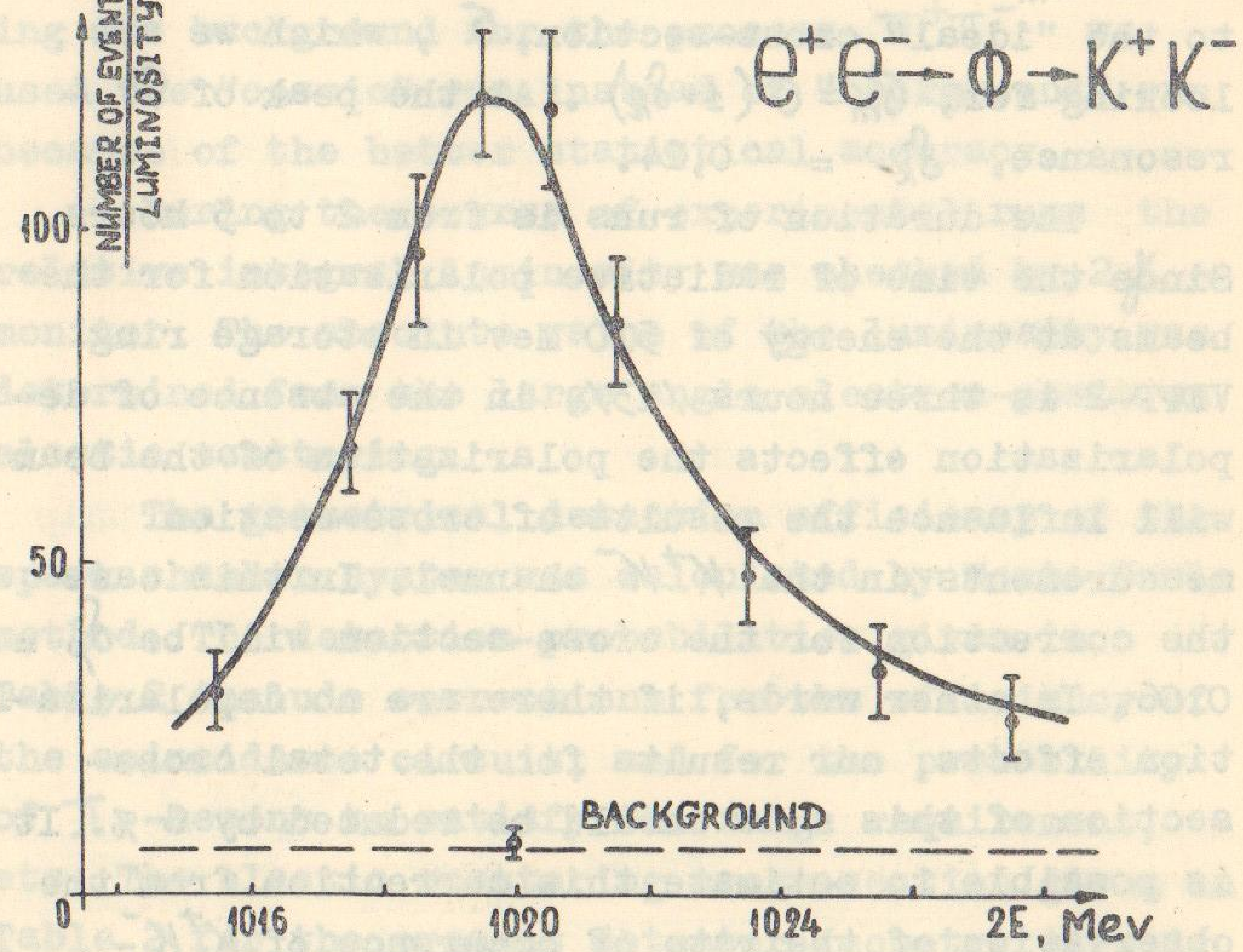

Fig.2. $e^+e^- \rightarrow \varphi \rightarrow K^+K^-$-reaction. At the chosen normalization the ordinates of the points correspond to the number of detected events.

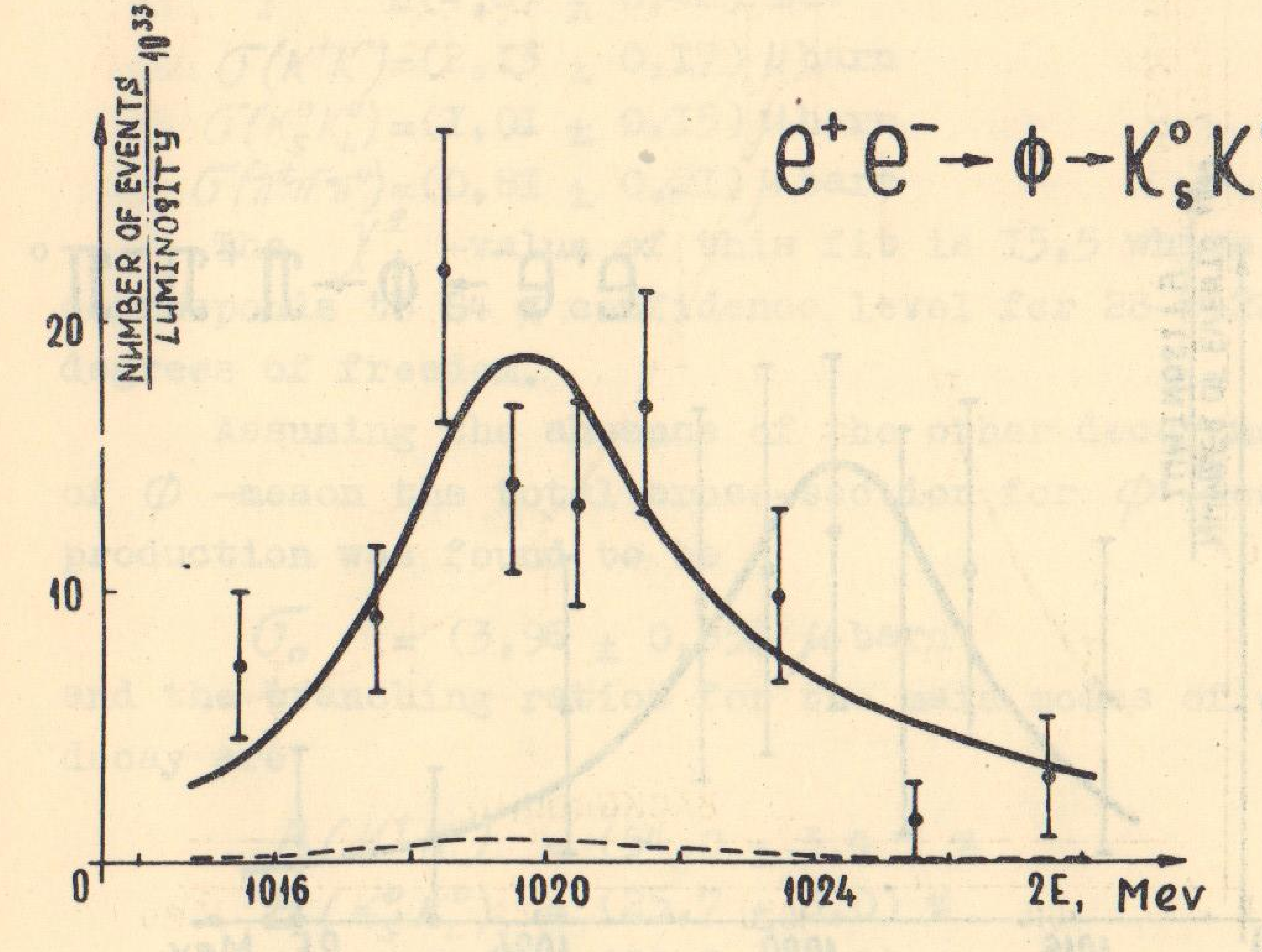

Fig.3. $e^+e^- \rightarrow \varphi \rightarrow K^0_S K^0_L$. The admixture of the $\pi^+\pi^-\pi^0$ channel is shown by the dotted line.

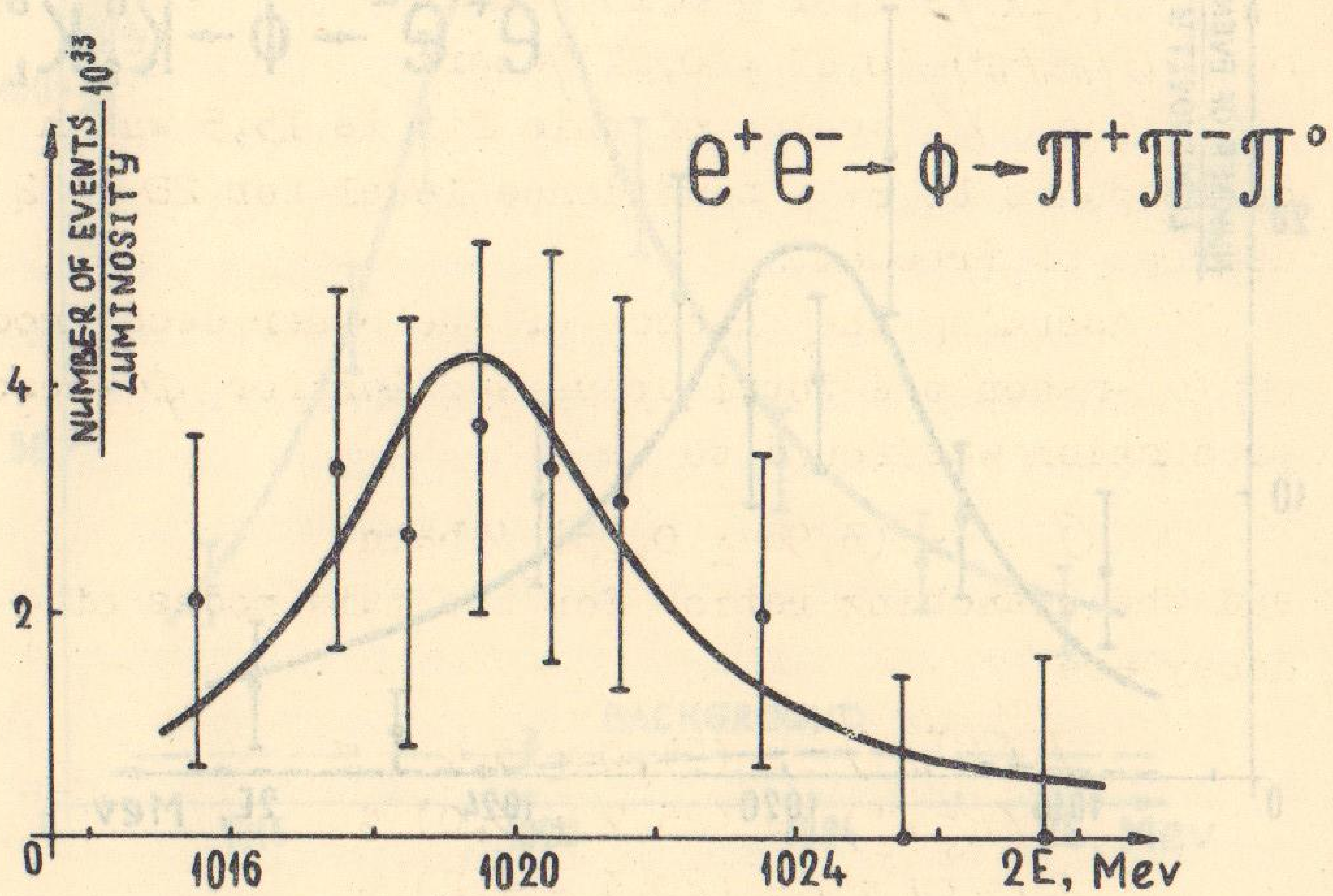

Fig.4. $e^+e^- \to \varphi \to \pi^+\pi^-\pi^o$-reaction.

the Breit-Wigner formula using the maximum likelyhood method gave the following values for the resonance width and for the partial resonance cross-section of three reaction modes:

$$\Gamma = (4,67 \pm 0,42) \text{ Mev}$$
$$\sigma(K^+K^-) = (2,I3 \pm 0,I7)\ \mu\text{barn}$$
$$\sigma(K_S^oK_L^o) = (I,0I \pm 0,I5)\ \mu\text{barn}$$
$$\sigma(\pi^+\pi^-\pi^o) = (0,8I \pm 0,2I)\ \mu\text{barn}$$

The χ^2 -value of this fit is I5,5 which corresponds to 84 % confidence level for 28-6=22 degrees of freedom.

Assuming the absence of the other decay modes of φ -meson the total cross-section for φ -meson production was found to be

$$\sigma_o = (3,96 \pm 0,35)\ \mu\text{barn}$$

and the branching ratios for the main modes of decay are

$$B(K^+K^-) = (54,0 \pm 3,4)\ \%$$
$$B(K_S^oK_L^o) = (25,7 \pm 3,0)\ \%$$
$$B(\pi^+\pi^-\pi^o) = (20,3 \pm 4,2)\ \%$$

Using these results we can obtain the branching ratio as well as the width of e^+e^--decay of φ - meson. Namely:

$$B(e^+e^-) = (2,8I \pm 0,25)\cdot I0^{-4}$$
$$\Gamma(e^+e^-) = (I,3I \pm 0,I2) \text{ kev}$$

The coupling constant of φ -meson is

$$\frac{g^2}{4\pi} = \frac{\alpha^2 m_\varphi a_\varphi}{3\Gamma(e^+e^-)} = II,7 \pm I,I$$

where $a_\varphi = 0{,}85$ takes care of the effect of finite width /I4/.

The results obtained here are in satisfactory agreement with those of Orsay group in France.

The analysis of $\pi^+\pi^-$ process allowed the presence of a noticeable amount of non-resonant production in the energy range investigated. The form factor of π -meson is then estimated to be at I020 Mev

$$|F_\pi|^2 = 2{,}7 \pm 0{,}7$$

This value is higher than the value I,6 ± 0,3 estimated from the extrapolation of the Breigt-Wigner for ρ -meson resonance /2,4/.

Our attempt to observe the interference between this non-resonant tail and the resonant $\varphi \to \pi^+\pi^-$ decay was unsuccessful. We obtained an upper limit for the branching ratio of the $\pi^+\pi^-$ decay mode of φ -meson. That is

$$B(\pi^+\pi^-) < 0{,}[illegible]\ \%$$

with the confidence level of 95 %. Including the possible interference effect the maximum likelyhood estimate gives

$$|F_\pi|^2 = 2{,}3 \pm 1{,}1$$

During the analysis about I00 non-collinear events were selected which didn't belong to either of 6 reaction channels considered. These events have zero ranges in shower chambers.

The detection threshold for the 4-fold coincidence circuit was I3 Mev for electrons and 35 Mev for pions. The r.m.s. angle of multiple scattering in foil is $\sim 5^\circ$ for these events. Therefore we may assume that in this process the electrons of $\sim$I5 Mev are detected. The distribution of these events as a function of beam energy shows that they are not connected with the φ -resonance.

The possible source of these events is the process of e^+e^- pair-production.

$$e^+e^- \to e^+e^- + e^+e^-$$

The total cross-section of this process is very large. Unfortunately today we have no calculations of its energy and angular distribution.

The authors are grateful to V.N.Bayer, A.I.Vainshtein and I.B.Khriplovich for useful discussions and to the large group of co-workers taking part in data processing.

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