hep-ex/9906032 22 Jun 1999

Measurement of the ϕ meson parameters with CMD-2 detector at VEPP-2M collider *

R.R.Akhmetshin, E.V.Anashkin, M.Arpagaus, V.M.Aulchenko, V.Sh.Banzarov, L.M.Barkov, S.E.Baru, N.S.Bashtovoy, A.E.Bondar, D.V.Chernyak, A.G.Chertovskikh, A.S.Dvoretsky, S.I.Eidelman, G.V.Fedotovich, N.I.Gabyshev, A.A.Grebeniuk, D.N.Grigoriev, B.I.Khazin, I.A.Koop, P.P.Krokovny, L.M.Kurdadze, A.S.Kuzmin, I.B.Logashenko, P.A.Lukin†, A.P.Lysenko, K.Yu.Mikhailov, I.N.Nesterenko, V.S.Okhapkin, E.A.Perevedentsev, A.A.Polunin, E.G.Pozdeev, V.I.Ptitzyn, T.A.Purlatz, N.I.Root, A.A.Ruban, N.M.Ryskulov, A.G.Shamov, Yu.M.Shatunov, A.I.Shekhtman, B.A.Shwartz, V.A.Sidorov, A.N.Skrinsky, V.P.Smakhtin, I.G.Snopkov, E.P.Solodov, P.Yu.Stepanov, A.I.Sukhanov, Yu.V.Yudin, S.G.Zverev

Budker Institute of Nuclear Physics, Novosibirsk, 630090, Russia

J.A.Thompson

University of Pittsburgh, Pittsburgh, PA, 15260, USA

Abstract

About 300 000 $e^+e^- \to \phi \to K^0_L K^0_S$ events in the center of mass energy range from 984 to 1040 MeV were used for the measurement of the ϕ meson parameters. The following results have been obtained: $\sigma_0 = (1367 \pm 15 \pm 21)$ nb, $m_\phi = (1019.504 \pm 0.011 \pm 0.033)$ MeV/c^2, $\Gamma_\phi = (4.477 \pm 0.036 \pm 0.022)$ MeV, $\Gamma_{e^+e^-} \cdot \mathrm{B}(\phi \to K^0_L K^0_S) = (4.364 \pm 0.048 \pm 0.065) \cdot 10^{-4}$ MeV.

*Work is supported in part by grants RFBR-98-02-17851, RFBR-99-02-17053, RFBR-99-02-17119

†contact person. e-mail: P.A.Lukin@inp.nsk.su

1 Introduction

This paper presents a precise determination of the mass, and total and leptonic widths of the ϕ, based on one of its dominant decay modes, $\phi \to K^0_L K^0_S$. High precision measurements of the ϕ meson parameters provide valuable information for various theoretical models describing interactions of light quarks.

The results of this work are based on data collected with the CMD-2 detector [1, 2] which has been running at the high luminosity collider VEPP-2M [3] since 1992. The data come from four scans of the center of mass energy range $2E_{beam}$ from 984 to 1040 MeV. In the first scan, performed in 1994 with integrated luminosity of 0.18 pb^{-1}, the resonance depolarization method [4] was used for precise beam energy calibration at each point. Three other scans, performed in 1996, corresponding to integrated luminosity of 2.19 pb^{-1}, do not have resonance depolarization information. The collected integrated luminosity of 2.37 pb^{-1} corresponds to 3.4×10^6 ϕ meson decays.

2 CMD-2 detector

The CMD-2 detector has been described in detail elsewhere [1, 2]. It is a general purpose detector consisting of a drift chamber (DC) with about 250 μ resolution in the plane transverse to the beam and proportional Z-chamber (ZC) used for the trigger, both inside a thin (0.38 X_0) superconducting solenoid with a field of 1 T.

The barrel calorimeter placed outside the solenoid consists of 892 CsI crystals of $6\times6\times15$ cm^3 size. It covers polar angles from 0.8 to 2.3 radian. The energy resolution for the photons in the CsI calorimeter is about 8 % in the energy range from 100 to 700 MeV.

The trigger signal is generated either by the charged trigger based on DC and Z-chamber hits [5] or by the neutral trigger [6] which takes into account the number of clusters detected in the CsI calorimeter as well as the total energy deposition. Two independent triggers of CMD-2 can be used to study the trigger efficiency.

3 Analysis

The process $\phi \to K^0_L K^0_S$ was detected using the K^0_S decay into two charged pions. Events were selected according to the following conditions:

- Two oppositely charged tracks were found coming from the vertex closest to the beam.

- Both tracks had polar angles $0.95 < \theta_{1,2} < \pi - 0.95$. The distance between the beam and the vertex in the $R - \varphi$ plane is: $R_{vert} < 1.5$ cm.

- The invariant mass of the two vertex tracks, taken as pions, was $450 < M_{inv} < 550$ MeV/c^2 (see Fig. 1a) and the missing momentum satisfied the conditions $60 < P_{mis} < (\sqrt{E^2_{beam} - m^2_{K^0}} + 40)$ MeV/c, where $m_{K^0} = 497.672$ MeV/c^2 is the neutral kaon mass [7].

- Track momenta were $140 < P_{1,2} < 300$ MeV/c and the average momentum was $180 < (P_1 + P_2)/2 < 250$ MeV/c as shown in Fig. 1b.

At each energy the cross section of $K^0_L K^0_S$ production was calculated according to the formula:

$$\sigma(e^+e^- \to K^0_L K^0_S) = \frac{N}{\varepsilon \cdot L \cdot (1+\delta_{rad}) \cdot (1+\delta_{loss}) \cdot B(K^0_S \to \pi^+\pi^-)},$$

where N is the number of events; L is the integrated luminosity determined from large angle Bhabha events with the help of the procedure described in [8]; δ_{rad} is the radiative correction calculated according to [9]; δ_{loss} is a correction for event losses due to decays in flight and nuclear interactions of the charged pions; $\mathrm{B}(K^0_S \to \pi^+\pi^-) = 0.6861 \pm 0.0028$ is the branching ratio of the decay $K^0_S \to \pi^+\pi^-$ from [7]; and ε is a product of the reconstruction efficiency and geometrical efficiency (acceptance), $\varepsilon = \varepsilon_{rec}\varepsilon_{geom}$. The acceptance is the probability to detect two pions from the K^0_S decay within a solid angle determined by the cuts above.

To obtain the number of $K^0_L K^0_S$ events, cosmic ray events were removed by subtracting a smooth background in the distribution over the Z-coordinate of the vertex as demonstrated in Fig. 1c. A sum of two gaussian functions was used as a fitting curve, one gaussian describing $K^0_L K^0_S$ events and the other describing the shape of background. To estimate a systematic uncertainty because of the background subtraction, we used an alternative assumption that the background was described by a straight line with a slope. The difference in the number of events obtained by two methods was 0.3%. The distribution over the K^0_S meson decay length after all selections and background subtraction is shown in Fig. 1d. The exponential curve in the Figure was calculated using the generally accepted value of the K^0_S lifetime [7] and agrees well with the data.

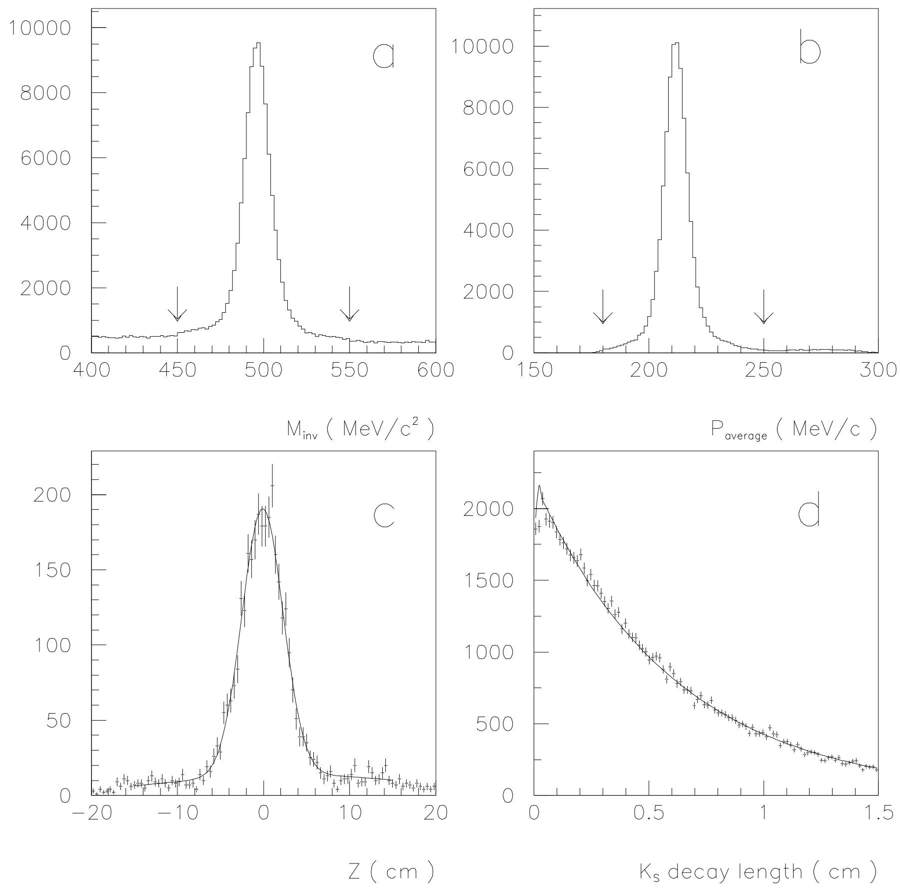

Figure 1: Distributions used for the selection of $e^+e^- \to \phi \to K_L^0 K_S^0$ events. a - Invariant mass of two tracks; b - Average momentum of two tracks; c - Z-coordinate of the vertex; d - Decay length of K_S^0 meson.

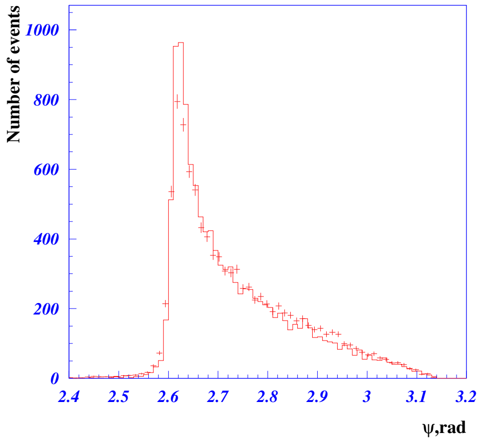

Figure 2: Distribution of the space angle between two tracks. The histogram is simulation, points with errors are data.

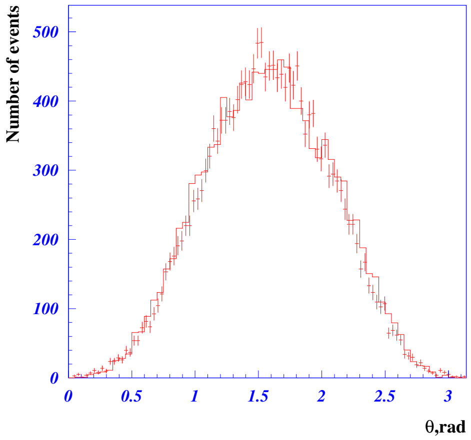

Figure 3: Distribution of the K_L^0 polar angle. The histogram is simulation, points with errors are data.

The background from the $\phi \to K^+K^-$ and $\phi \to \pi^+\pi^-\pi^0$ decays was estimated from Monte Carlo simulation to be less than 0.04%.

With the above cuts 2.97×10^5 $K_L^0 K_S^0$ events have been selected. The distribution of the space angle between the tracks presented in Fig. 2 shows a minimal angle typical for pions from the K_S^0 decay. Figure 3 shows the distribution for the K_L^0 polar angle calculated from the momenta of the tracks as well as their angles. The shape of the distribution is consistent with that expected for the $K\bar{K}$.

About 50 % of the K_L^0 events have a cluster in the CsI calorimeter resulting from a nuclear interaction. Using the polar and azimuthal angles of this cluster as well as the angles of the clusters produced by pions from the decay $K_S^0 \to \pi^+\pi^-$, one can reconstruct the $\phi \to K_L^0 K_S^0$ event without DC information. Such "test" events were used to determine the charged trigger efficiency.

To study the reconstruction efficiency, the same events have been used with an additional requirement of ZC hits and at least one track in DC to reduce background from the $\phi \to \pi^+\pi^-\pi^0$ decays.

About 9 000 "test" events were selected. The detailed description of the efficiency determination procedures can be found in [10].

The acceptance as well as the correction for decays in flight was calculated by Monte Carlo simulation.

Table 1: Efficiencies, corrections and their errors at $2E_{beam} = 1020.0$ MeV

Efficiency	Value,%	Stat. error,%	Syst. error, %
ε_{rec}	90.30	1.51	0.70
ε_{trig}	98.32	0.93	0.50
ε_{geom}	46.87	0.35	0.90
$1+\delta_{loss}$	95.53	0.17	0.10
$1+\delta_{rad}$	77.67	0.26	0.50

Table 2: Energy, number of events, integrated luminosity and measured cross section for the 1994 data.

№	$E_{c.m.}$, MeV	$N_{K_L K_S}$	L, nb^{-1}	σ, nb
1	1010.272 ± 0.030	135 ± 13	16.98 ± 0.25	43.07 ± 2.84
2	1017.086 ± 0.020	8487 ± 95	80.50 ± 0.80	626.73 ± 27.92
3	1018.136 ± 0.018	4697 ± 78	27.68 ± 0.36	921.22 ± 81.49
4	1018.956 ± 0.018	5347 ± 74	25.59 ± 0.34	1327.92 ± 58.83
5	1019.214 ± 0.020	7610 ± 89	27.23 ± 1.23	1325.12 ± 92.42
6	1019.986 ± 0.020	9372 ± 103	35.44 ± 0.39	1341.46 ± 52.03
7	1020.128 ± 0.020	3725 ± 62	16.00 ± 0.20	1164.35 ± 91.97
8	1021.850 ± 0.022	1900 ± 46	17.34 ± 0.27	615.33 ± 55.78
9	1023.972 ± 0.020	2645 ± 90	48.16 ± 0.45	277.42 ± 48.23

Typical values of the efficiencies and corrections are presented in Table 1 for $2E_{beam} = 1020.0$ MeV (the ϕ meson peak).

For the 1994 data the beam energy at each point was measured by the resonance depolarization method [4]. For the 1996 data the beam energy was determined from the momenta of charged kaons and the analysis of the magnetic field of the collider [8].

Tables 2,3 show the number of selected events, integrated luminosity and measured cross section at each energy.

4 Data fits and ϕ meson parameters

The experimental points were fit with a function which includes the contributions of the ρ, ω, ϕ as well as higher resonances $\omega(1420)$, $\rho(1450)$, $\omega(1600)$, $\phi(1680)$, $\rho(1700)$ (below referred to as $\omega', \rho', \omega'', \phi', \rho''$ respectively) and the

Table 3: Energy, number of events, integrated luminosity and measured cross section for the 1996 data.

№	$E_{c.m.}$, MeV	$N_{K_L K_S}$	L, nb^{-1}	σ, nb
Scan-2				
1	1004.25±0.36	77± 37	31.23±0.30	11.83± 4.26
2	1010.53±0.11	216± 19	21.62±0.27	49.24±3.84
3	1016.36±0.04	2265± 50	29.13±0.33	398.06±12.26
4	1017.19±0.03	6552± 86	55.72±0.40	603.50±12.11
5	1018.06±0.03	8214± 94	47.04±0.36	903.80±22.06
6	1018.99±0.02	15755±127	63.79±0.42	1295.37±22.60
7	1020.00±0.02	18403±137	71.46±0.45	1228.57±18.92
8	1020.96±0.02	10855±108	52.13±0.38	926.26±19.72
9	1021.88±0.05	2800± 55	19.71±0.24	617.27±26.36
10	1027.69±0.09	862± 70	21.33±0.29	136.53±14.05
11	1033.63±0.36	492± 84	28.76±0.29	52.61±14.17
12	1039.48±0.36	285± 19	22.89±0.26	34.86±4.98
Scan-3				
1	1004.64±0.36	39± 28	42.60±0.45	4.55± 2.55
2	1011.30±0.06	640± 45	55.15±0.90	62.60± 3.62
3	1015.99±0.03	4570± 86	61.59±0.41	378.37± 7.97
4	1016.93±0.02	7541±106	67.59±0.43	573.30±10.29
5	1017.91±0.02	17836±164	100.02±0.52	924.53±11.52
6	1019.04±0.02	27070±190	103.52±0.53	1345.42±12.95
7	1019.95±0.02	25681±183	98.95±0.52	1296.68±14.12
8	1020.86±0.02	18433±158	91.79±0.51	950.55±12.52
9	1021.74±0.03	8685±110	58.36±0.41	664.54±12.07
10	1022.67±0.05	3326± 69	39.55±0.35	458.51±20.41
11	1028.36±0.09	845± 44	25.13±0.27	110.09± 8.24
12	1034.06±0.36	487± 41	28.44±0.28	50.00± 8.38
Scan-4				
1	1004.19±0.36	46± 10	25.08±0.26	11.25± 2.36
2	1011.30±0.07	382± 37	32.12±0.30	66.11± 9.68
3	1015.91±0.03	2478± 61	33.16±0.30	391.00±18.90
4	1016.94±0.02	6735± 95	61.84±0.41	600.76±18.22
5	1017.92±0.02	14703±140	79.37±0.47	989.72±18.87
6	1018.76±0.02	21322±163	84.61±0.48	1287.46±19.00
7	1019.68±0.02	22823±167	86.89±0.49	1356.42±20.34
8	1020.68±0.03	8800±105	40.75±0.34	1058.66±29.39
9	1021.60±0.03	6237± 91	41.57±0.34	699.48±24.72
10	1022.59±0.04	4072± 74	38.15±0.32	465.68±19.25
11	1028.41±0.07	961± 45	30.77±0.31	104.97±12.18

nonresonant background:

$$\sigma_K(s) = \frac{\pi\alpha^2}{12} \cdot \frac{\Phi_{2K^0}(s)}{s^{5/2}} \cdot |A_{bkg} + A_\rho + A_\omega + A_\phi + A_{\omega'} + A_{\rho'} + A_{\omega''} + A_{\phi'} + A_{\rho''}|^2,$$

where s is the center of mass energy squared, $\Phi_{2K^0}(s) = (s/4 - m_{K^0}^2)^{3/2}$ is a phase space factor for two kaons, A_{bkg} is a constant amplitude of nonresonant background. $A_V = (g_{V\gamma} g_{VK\bar{K}}) \cdot \Delta_V$ are vector meson amplitudes and $\Delta_V = (s - m_V^2 + \imath\sqrt{s}\Gamma_V(s))^{-1}$ are vector meson propagators with the energy dependence of the width as in [11]:

$$\begin{aligned}
\Gamma_\rho(s) &= \Gamma_\rho \cdot \frac{m_\rho^2 \Phi_{2\pi}(s)}{s\Phi_{2\pi}(m_\rho^2)}, \\
\Gamma_\omega(s) &= \Gamma_\omega \left(B_{2\pi} \frac{m_\omega^2 \Phi_{2\pi}(s)}{s\Phi_{2\pi}(m_\omega^2)} + B_{\pi^0\gamma} \frac{\Phi_{\pi^0\gamma}(s)}{\Phi_{\pi^0\gamma}(m_\omega^2)} + B_{3\pi} \frac{\sqrt{s}\Phi_{3\pi}(s)}{m_\omega \Phi_{3\pi}(m_\omega^2)} \right), \\
\Gamma_\phi(s) &= \Gamma_\phi \left(B_{K^+K^-} \frac{m_\phi^2 \Phi_{K^+K^-}(s)}{s\Phi_{K^+K^-}(m_\phi^2)} + B_{K_L K_S} \frac{m_\phi^2 \Phi_{K_S K_L}(s)}{s\Phi_{K_L K_S}(m_\phi^2)} + \right. \\
&\left. + B_{\eta\gamma} \frac{\Phi_{\eta\gamma}(s)}{\Phi_{\eta\gamma}(m_\phi^2)} + B_{3\pi} \frac{\sqrt{s}\Phi_{3\pi}(s)}{m_\phi \Phi_{3\pi}(m_\phi^2)} \right),
\end{aligned}$$

where B_f are the branching ratios of the major decay modes of ω and ϕ, and Φ_f(s) are corresponding phase space factors. For the radiative decay into $P\gamma$ where $P = \eta(\pi^0)$, $\Phi_{P\gamma}(s) = (\sqrt{s}(1 - m_P^2/s)/2)^3$. For the $\Phi_{3\pi}(s)$ calculation the model assuming the decay $V \to \rho\pi \to 3\pi$ was used [12]. The masses and widths of the higher resonances were taken from [7].

The constants $g_{V\gamma} g_{VK\bar{K}}$ were calculated using the experimental values of the electronic widths [7] and assuming SU(3) relations with ideal mixing. The coupling constants of the higher resonances were parameters of the fit. Relative phases between ρ and $\rho'(\rho'')$, ω and $\omega'(\omega'')$ as well as between ϕ and ϕ' were taken equal to π according to [13].

The cross section can be rewritten in terms of σ_0 - the cross section in the resonance peak for the $\phi \to K_S^0 K_L^0$ decay mode:

$$\begin{aligned}
\sigma_K(s) = \sigma_0 \cdot & \frac{\Phi_{2K}(s)}{\Phi_{2K}(m_\phi^2)} \cdot \frac{m_\phi^7 \Gamma_\phi^2}{s^{5/2}} | - \Delta\rho + \frac{1}{3}\Delta\omega + \Delta\phi + \\
& \frac{g_{\rho'\gamma} g_{\rho' K\bar{K}}}{g_{\phi\gamma} g_{\phi K\bar{K}}} \Delta\rho' + \frac{g_{\rho''\gamma} g_{\rho'' K\bar{K}}}{g_{\phi\gamma} g_{\phi K\bar{K}}} \Delta\rho'' \\
& - \frac{g_{\omega'\gamma} g_{\omega' K\bar{K}}}{g_{\phi\gamma} g_{\phi K\bar{K}}} \Delta\omega' - \frac{g_{\omega''\gamma} g_{\omega'' K\bar{K}}}{g_{\phi\gamma} g_{\phi K\bar{K}}} \Delta\omega'' \\
& - \frac{g_{\phi'\gamma} g_{\phi' K\bar{K}}}{g_{\phi\gamma} g_{\phi K\bar{K}}} \Delta\phi' + \frac{A_{bkg}}{g_{\phi\gamma} g_{\phi K\bar{K}}} |^2.
\end{aligned}$$

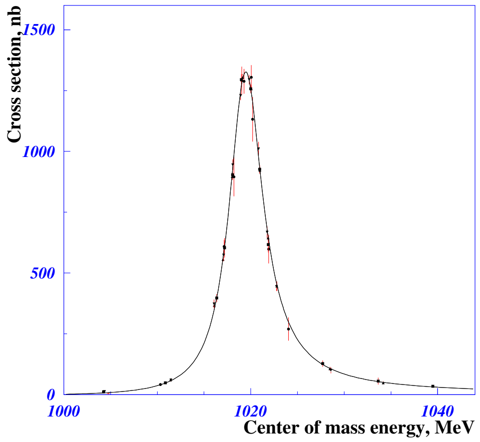

Figure 4: Experimental cross section and ϕ meson excitation curve in the channel $e^+e^- \to \phi \to K_L^0 K_S^0$ (all data).

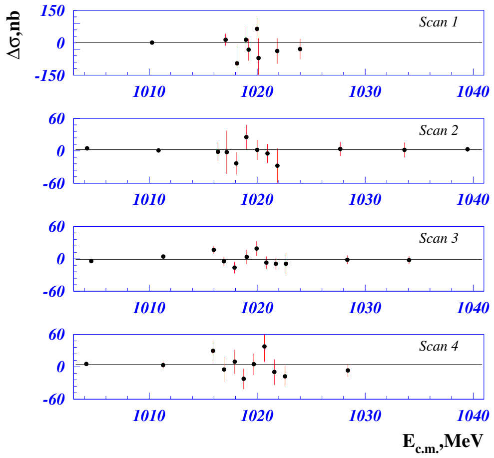

Figure 5: Residuals between the measured and fitted cross sections versus center of mass energy in each scan

The non-resonant background amplitude can be written as:

$$A_{bkg} = \sqrt{\frac{\sigma_{bkg}}{\sigma_0}} \frac{1}{m_\phi \Gamma_\phi} \cdot g_{\phi\gamma} g_{\phi K\bar{K}},$$

where σ_{bkg} is the cross section of the non-resonant background.

The values of σ_{bkg} as well as coupling constants of the higher resonances obtained from the fit are consistent with zero and were fixed at zero to determine the ϕ meson parameters. The determination of the beam energy [8] showed that the energy scale of VEPP-2M had a slope of about

$$\frac{\partial E_{scale}}{\partial E_{beam}} \sim 0.005,$$

where E_{scale} is the beam energy determined and E_{beam} is the real beam energy of the collider measured by the depolarization method. This slope results in a systematic uncertainty of the ϕ meson width $\frac{\partial E_{scale}}{\partial E_{beam}} \cdot \Gamma_\phi \sim 0.022$ MeV which is smaller than the statistical error of the width value. It allows to consider the width as a common parameter for all data fits, while the masses and peak cross sections were different for each scan. As it was found from the fit:

$$\Gamma_\phi = 4.477 \pm 0.036 \pm 0.022 \text{ MeV},$$

Table 4: ϕ meson parameters obtained in the experiment.

Scan	σ_0, nb	m_ϕ, MeV/c^2	$\Gamma_{e^+e^-}B\times10^4$, MeV
1	$1370 \pm 26 \pm 33$	$1019.487 \pm 0.064 \pm 0.020$	$4.374 \pm 0.086 \pm 0.105$
2	$1332 \pm 12 \pm 32$	$1019.558 \pm 0.027 \pm 0.045$	$4.253 \pm 0.041 \pm 0.102$
3	$1374 \pm 9 \pm 33$	$1019.444 \pm 0.014 \pm 0.080$	$4.386 \pm 0.027 \pm 0.105$
4	$1396 \pm 12 \pm 34$	$1019.399 \pm 0.027 \pm 0.122$	$4.454 \pm 0.043 \pm 0.107$
Average	$1367 \pm 15 \pm 21$	$1019.504 \pm 0.011 \pm 0.033$	$4.364 \pm 0.048 \pm 0.065$

where the first error is statistical and the second is systematic. The values of the ϕ meson mass and peak cross section obtained from the fit are presented in Table 4. The experimental data together with the fitting curve are presented in Fig. 4 where the experimental points of individual scans were shifted in accordance with the difference between the average values of the mass and cross section in the peak and their values in individual scans. The residuals between the measured and fitted cross section versus center of mass energy are shown in Fig. 5 for each scan.

The systematic error of the mass from scan 1 in which the beam energy was measured by the resonance depolarization method is determined by the precision of this technique. Systematic errors for the mass for scans 2 – 4 were estimated from the difference between energy values obtained by two methods of the beam energy determination mentioned above. For the second scan it was 0.045 MeV and increased to 0.080 MeV and 0.122 MeV for scans 3 and 4 respectively. The systematic error of σ_0 consists of two parts. The first one is common for all four scans and comes from the uncertainty of the radiative corrections to the cross section of Bhabha events used for the luminosity determination ($\sim 1.5\%$). The second part is about 1.9% and comes from various factors:

background subtraction	– 0.3% ;
reconstruction efficiency	– 0.7% ;
trigger efficiency	– 0.5% ;
radiative corrections for the $e^+e^- \to K_L^0 K_S^0$ process	– 0.5% ;
correction for decays in flight and nuclear interactions	– 0.1% ;
solid angle uncertainty	– 0.9% ;
uncertainty in beam energy spread	– 0.2% ;
selection criteria and efficiencies for Bhabha events	– 1.3% .

This part of the systematic error of σ_0 is numerically the same (1.9%) for all scans, although it was independently estimated for each scan. Results for

Table 5: Results of σ_0 measurements by various groups.

Group	$\sigma_0(e^+e^- \to \phi \to K_L^0 K_S^0)$, nb	Reference
OLYA,1978	1400 ± 90	[15]
OLYA,1984	1440 ± 60	[16]
ND, 1991	1430 ± 143	[17]
SND, 1997	1360 ± 46	[18]
CMD-2,1994,1996	1367 ± 26	This work

the ϕ meson mass from different scans are also independent. Therefore we can average results from different scans both for the cross section in the peak and mass. To average data, we used a standard weighted least-squares procedure. For calculations of the weights statistical and systematic errors were added in quadrature. In case of σ_0 only the variable part of the systematic error equal to 1.9% was added and the resulting error was combined with the common error of 1.5%. The average values of the ϕ meson parameters are shown in the last line of Table 4.

The value of the ϕ meson mass obtained in this work is the most precise measurement of this parameter among e^+e^- experiments and is consistent with all previous results. There is only one fixed target experiment which gave a more precise value of the ϕ mass [14], differing from ours by 2.6 standard deviations.

The value of the ϕ meson width obtained in our work is consistent with all previous results and is the most precise. Note that its precision surpasses the world average quoted by [7], which is based on the results of nine previous measurements.

The measurement of $\sigma_0(\phi \to K_S^0 K_L^0)$ has been performed by a number of groups with the results presented in Table 5.

One can see that our value $\sigma_0(\phi \to K_L^0 K_S^0) = (1367 \pm 26)$ nb does not contradict these measurements and is the most precise.

The cross section in the peak obtained in our experiment is related to the product $\Gamma_{e^+e^-} \cdot \mathrm{B}(\phi \to K_L^0 K_S^0)$. To obtain this value, special fits with this product as a free parameter have been performed separately for each scan (see the last column of Table 4). The averaging procedure similar to that for σ_0 gives the following result:

$$\Gamma_{e^+e^-} \cdot \ \mathrm{B}(\phi \to K_L^0 K_S^0) = (4.364 \pm 0.048 \pm 0.065) \cdot 10^{-4} \ \mathrm{MeV}.$$

The obtained value of $\Gamma_{e^+e^-} \cdot B(\phi \to K_L^0 K_S^0)$ is the most precise direct measurement of this product.

Using $\Gamma_{e^+e^-}$ from other experiments, one can obtain $B(\phi \to K_L^0 K_S^0)$. For example, for $\Gamma_{e^+e^-} = (1.32 \pm 0.04)$ keV from [7], $B(\phi \to K_L^0 K_S^0) = 0.329 \pm 0.006 \pm 0.010$ has been obtained.

Alternatively, taking $B(\phi \to K_L^0 K_S^0)$ from other works, $\Gamma_{e^+e^-}$ can be calculated. For $B(\phi \to K_L^0 K_S^0) = 0.331 \pm 0.009$ from [7], we obtain for the leptonic width $\Gamma_{\phi \to ee} = (1.32 \pm 0.02 \pm 0.04)$ keV. The first number is our experimental error (both statistical and systematic), while the second one describes the uncertainty of the values from [7].

5 Conclusion

Using the CMD-2 data sample of 2.97×10^5 $\phi \to K_L^0 K_S^0$ events with reconstructed $K_S^0 \to \pi^+\pi^-$ decay, the following values of the ϕ meson parameters have been obtained:

$$\begin{aligned}
\sigma_0 &= (1367 \pm 15 \pm 21) \text{ nb}, \\
m_\phi &= (1019.504 \pm 0.011 \pm 0.033) \text{ MeV/c}^2, \\
\Gamma_\phi &= (4.477 \pm 0.036 \pm 0.022) \text{ MeV }, \\
\Gamma_{e^+e^-} \cdot B(\phi \to K_L^0 K_S^0) &= (4.364 \pm 0.048 \pm 0.065) \cdot 10^{-4} \text{ MeV}.
\end{aligned}$$

These results are more precise than the corresponding measurements from any other e^+e^- experiment, and the value of the width is more precise than all previous measurements.

6 Acknowledgements

The authors are grateful to the staff of VEPP-2M for excellent performance of the collider, to all engineers and technicians who participated in the design, commissioning and operation of CMD-2.

Special thanks are due to V.N. Ivanchenko for numerous useful discussions.

References

[1] G.A. Aksenov *et al.,* Preprint Budker INP 85-118, Novosibirsk, 1985.

[2] E.V. Anashkin *et al.,* ICFA Instr. Bulletin **5** (1988) 18.

[3] V.V. Anashin *et al.,* Preprint Budker INP 84-114, Novosibirsk, 1984.

[4] A.D. Bukin *et al.,* Proceedings of 5 International Workshop on High Energy Physics, Warsaw, 1975, p. 138.

[5] E.V. Anashkin *et al.,* Nucl. Instr. Meth. **A323** (1992) 178.

[6] V.M. Aulchenko *et al.,* Preprint Budker INP 92-28, Novosibirsk, 1992.

[7] C. Caso *et al.,* Eur. Phys. J. **C3** (1998) 1 (Review of Particle Physics).

[8] R.R. Akhmetshin *et al.,* Preprint Budker INP 99-11, Novosibirsk, 1999.

[9] E.A. Kuraev and V.S. Fadin, Sov J. Nucl. Phys. **41** (1985) 466.

[10] R.R. Akhmetshin *et al.,* Preprint Budker INP 99-14, Novosibirsk, 1999.

[11] R.R. Akhmetshin *et al.,* Phys. Lett. **B434** (1998) 426.

[12] E.A.Kuraev and Z.K.Silagadze, Phys. Atom. Nucl. **58** (1995) 1589.

[13] F.Manè *et al.,* Phys. Lett. **99B** (1981) 261.

[14] H.Dijkstra *et al.,* Z. Phys. **C31** (1986) 375.

[15] A.D. Bukin *et al.,* Sov. J. Nucl. Phys. **27** (1978) 516.

[16] L.M. Kurdadze *et al.,* Preprint INP 84-7, Novosibirsk, 1984.

[17] S.I. Dolinsky *et al.,* Phys. Rep. **202** (1991) 99.

[18] M.N. Achasov *et al.,* Preprint Budker INP 97-78, Novosibirsk, 1997.