Measurement of $\phi(1020)$ meson leptonic width with CMD-2 detector at VEPP-2M collider

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Introduction

Why is it interesting ?

- Determine coupling constant of a photon with vector meson in VDM
- Provide information about wave function of quark interaction in vector meson at r = 0

Current experimental status:

$\Gamma_{ee} = (1.27 \pm 0.05)\, keV\ (CMD\text{-}2, 1995)$ Simultaneous analysis of 4 decay modes

$\Gamma_{ee} = (1.29 \pm 0.03)\, keV\ (SND, 2001)$ Study of the interference in $e^+e^- \to \mu^+\mu^-$

$\Gamma_{ee} = (1.32 \pm 0.06)\, keV\ (KLOE, 2004)$ Study of forward-backward asymmetry

$\Gamma_{ee} = (1.27 \pm 0.04)\, keV\ (PDG 2010)$

Present work is new measurement of ϕ meson Γ_{ee} in combined analysis of 4 major decay modes, studied with CMD-2 detector in 1994-1998

Systematic error of Γ_{ee}

Maximum likelihood function:

$$L = -\sum \frac{\left[f_i^{EXP}(1+\delta_j)(1+\Delta_k) - f_i^{THEOR} \right]^2}{2\sigma_{EXP}^2} + \frac{\delta_j^2}{2\delta_{EST}^2} + \frac{\Delta_k^2}{2\Delta_{EST}^2}$$

- **Taking into account correlations due to common sources of the systematic errors**

- **Split the systematic error of the channel in "Common" (Δ) and "Individual" (δ) parts:**

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Experiment

Combined analysis of 4 separate measurements of the partial cross sections.

Mode	$\int Ldt,\ pb^{-1}$	Reference
K^+K^-	1.0	Phys.Lett.B669(2008) 217.
K_LK_S	1.77	Phys.Lett. B508(2001) 217.
3π	12.0	Phys. Lett. B642(2006) 203.
$\eta\gamma$	12.0	Phys.Lett. B605(2005) 26.

Cross section energy dependence

The cross section energy dependence is approximated with sum of the Breit-Wigner functions, including contributions of ρ, ω, ϕ mesons, the same like in dedicated studies:

$$f(s) = BW_{K^+K^-}(s, \Gamma_{ee}, m_\phi, \Gamma_\phi, B_{K^+K^-})$$
$$+ BW_{K_L K_S}(s, \Gamma_{ee}, m_\phi, \Gamma_\phi, B_{K_L K_S})$$
$$+ BW_{3\pi}(s, \Gamma_{ee}, m_\phi, \Gamma_\phi, B_{3\pi})$$
$$+ BW_{\eta\gamma}(s, \Gamma_{ee}, m_\phi, \Gamma_\phi, B_{\eta\gamma})$$

$$\sum_{X = K_L K_S, 3\pi, \eta\gamma} B(\phi \to X) = \left(1.0 - \sum_{X \neq K^+K^-, K_L K_S, 3\pi, \eta\gamma} B(\phi \to X)\right)$$

Mass, total and leptonic widths as well as branching fractions of the ϕ(1020) meson decays and phase of ϕ-ω interference in $\phi \to 3\pi$ were parameters of the fit

Systematic error of Γ_{ee} (Cont.d)

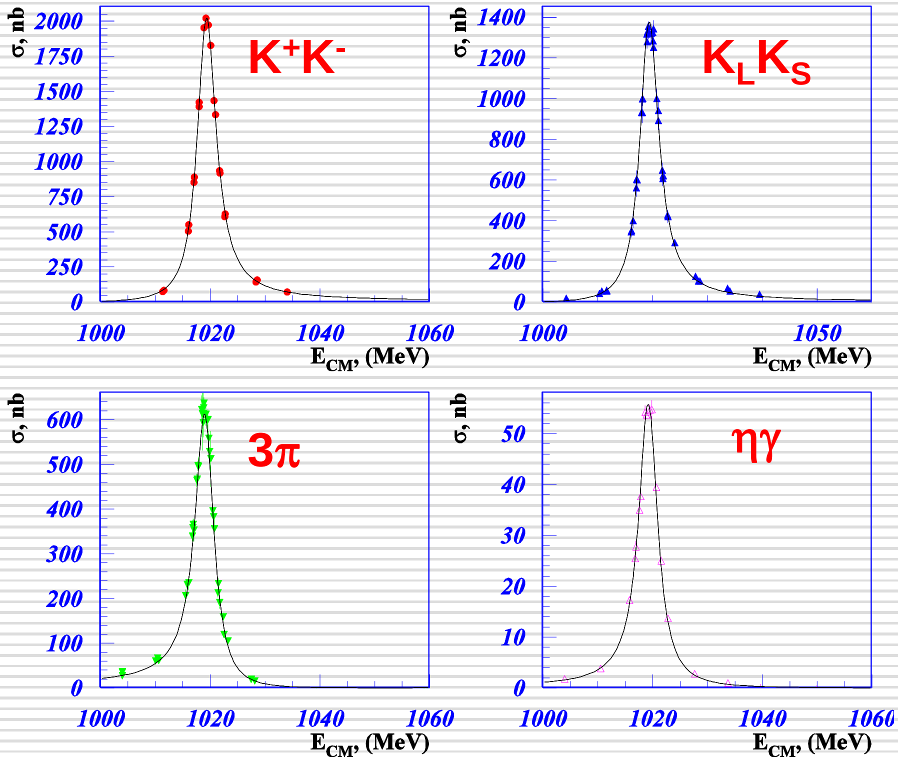
Source	K^+K^-	$K_L K_S$
Luminosity*	1.0	1.0
Radiative correction*	0.5	0.5
Selection criteria	1.6	1.2
Trigger efficiency	1.0	0.5
Background shape	0.4	0.3
Uncertainty in energy spread	0.2	0.2
Total	2.2	1.7

Source	$\pi^+\pi^-\pi^0$	$\eta\gamma$
Luminosity*	2	2
Radiative correction*	1	1
Selection criteria	-	4
Trigger efficiency	1	2
Simulation statistic	0.4	-
Background subtraction	0.3	3
π^0 reconstruction efficiency	0.4	-
Model uncertainty	-	0.1
Total	2.5	5.6

Common sources of the systematic errors denoted using *

The result of the fit

$$\Gamma_{ee} = (1.206 \pm 0.022)\, keV$$



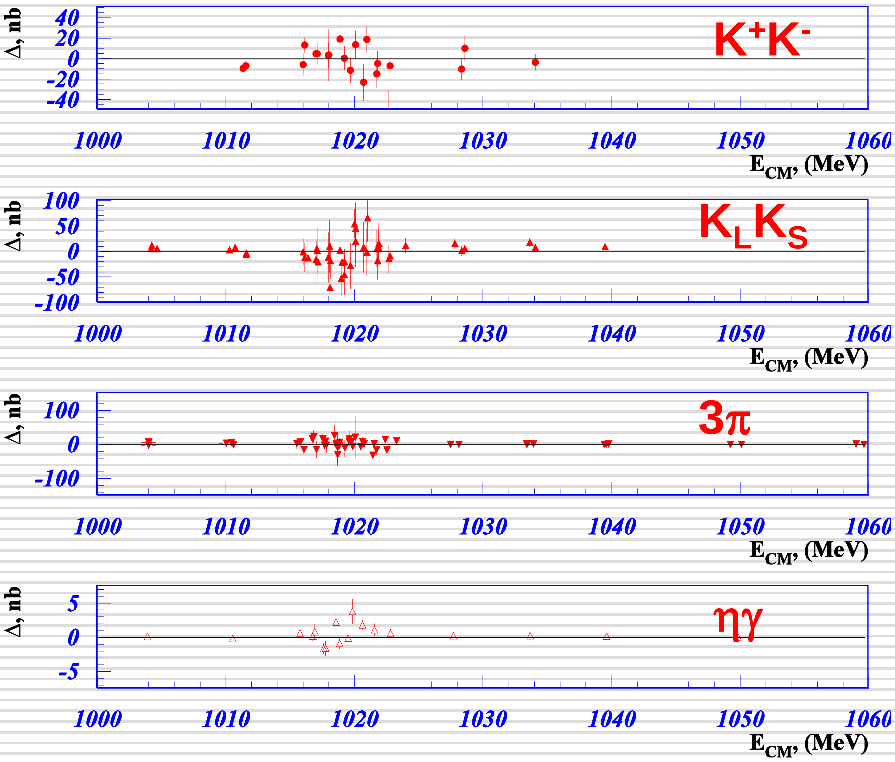
$$B_{K^+K^-} = (49.25 \pm 0.80)\%,$$

$$B_{K_L K_S} = (33.58 \pm 0.64)\%,$$

$$B_{3\pi} = (15.53 \pm 0.50)\%,$$

$$B_{\eta\gamma} = (1.38 \pm 0.03)\%$$

The result of the fit (Contd.)



$$\chi^2 / n.d.f. = 116.50 / 130$$

Statistical errors

We do not take into account terms describing correlations due to common sources of the systematic errors

Maximum likelihood function:

$$L = -\sum \frac{\left[f_i^{EXP}(1+\delta_j)(1+\Delta_k) - f_i^{THEOR}\right]^2}{2\sigma_{EXP}^2} + \frac{\delta_j^2}{2\delta_{EST}^2} + \frac{\Delta_k^2}{2\Delta_{EST}^2}$$

0 0 0 0

Errors summary

Parameter	Statistical error	Experimental error
Γ_{ee}, keV	1.219 ± 0.006	1.206 ± 0.022
$B_{K^+K^-}, \%$	49.34 ± 0.31	49.25 ± 0.80
$B_{K_L K_S}, \%$	33.55 ± 0.22	33.58 ± 0.64
$B_{3\pi}, \%$	15.45 ± 0.22	15.53 ± 0.50
$B_{\eta\gamma}, \%$	1.40 ± 0.02	1.38 ± 0.03

Do we get unbiased values of the parameters ?

Toy Monte Carlo: At each experimental energy point we calculate cross sections of the corresponding decay channels according to Breit-Wigner with KNOWN input parameters (mass, branching fractions, total and leptonic widths), normally distributed with the experimental cross section errors.

From the analysis of 1000 ToyMC samples:

- ✓ **Shape of the likelihood function** $\Delta\Gamma_{ee} = -(0.0051 \pm 0.0001)\, keV$
- ✓ **Taking into account correlations between the systematic errors** $\Delta\Gamma_{ee} = -(0.0287 \pm 0.0002)\, keV$

$$\Gamma_{ee} = 1.219 + 0.005 = 1.224 \pm 0.006$$

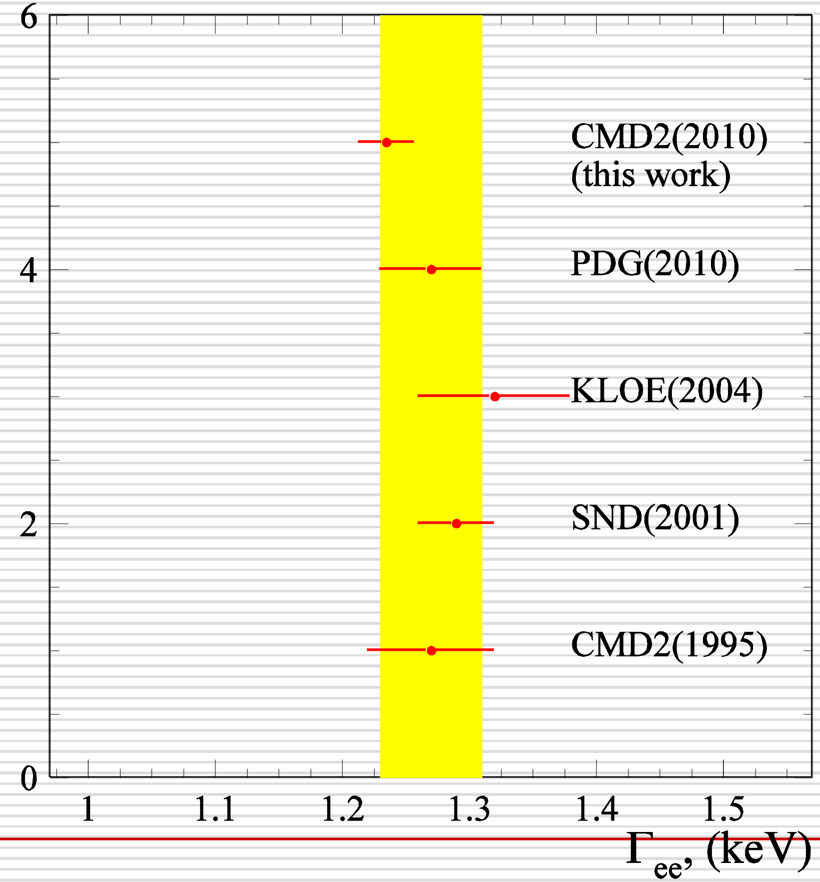
$$\Gamma_{ee} = 1.206 + 0.029 = 1.235 \pm 0.022$$

Our final Γ_{ee} value is:

$$\Gamma_{ee} = 1.235 \pm 0.022\,(keV)$$

Discussion

$$\Gamma_{ee} = (1.235 \pm 0.022)\, keV \quad (CMD2, 2010)$$



Conclusion

✓ φ(1020) meson leptonic width and φ meson branching fractions have been measured in combined analysis of 4 major φ decay modes.

This work	PDG(2010)
$\Gamma_{ee} = (1.235 \pm 0.006 \pm 0.022)\, keV$	$(1.27 \pm 0.04)\, keV$
$B_{K^+K^-} = (49.25 \pm 0.31 \pm 0.74)\%$	$(48.9 \pm 0.5)\%$
$B_{K_L K_S} = (33.58 \pm 0.22 \pm 0.60)\%$	$(34.2 \pm 0.4)\%$
$B_{3\pi} = (15.53 \pm 0.22 \pm 0.44)\%$	$(15.32 \pm 0.32)\%$
$B_{\eta\gamma} = (1.38 \pm 0.02 \pm 0.02)\%$	$(1.309 \pm 0.024)\%$

✓ Obtained values are in agreement with the results of previous measurement.

✓ Error of the leptonic width is estimated to be 2.2%, dominated by the systematic one improving world average accuracy

Addition:

BACKUP SLIDES

Theoretical cross section formulas

$$\sigma_{K^+K^-}(s) = \frac{1}{s^{5/2}} \cdot \frac{q^3(s)}{q^3(m_\phi^2)} \cdot \left| -\frac{m_\phi^3 \sqrt{12\pi \cdot \Gamma_\phi \Gamma(\phi \to e^+e^-) B(\phi \to K^+K^-)/m_\phi}}{D_\phi(s)} - \right.$$

$$- \frac{\sqrt{\Gamma_\phi \Gamma_\omega m_\phi^2 m_\omega^3 6\pi B(\omega \to e^+e^-) B(\phi \to K^+K^-)}}{D_\omega(s)} -$$

$$\left. - \frac{\sqrt{\Gamma_\phi \Gamma_\rho m_\phi^2 m_\rho^3 6\pi B(\rho \to e^+e^-) B(\phi \to K^+K^-)}}{D_\rho(s)} \right|^2 \frac{Z(s)}{Z(m_\phi^2)},$$

$$\sigma_{K_L^0 K_S^0}(s) = \frac{1}{s^{5/2}} \cdot \frac{q^3(s)}{q^3(m_\phi^2)} \cdot \left| -\frac{m_\phi^3 \sqrt{12\pi \cdot \Gamma_\phi \Gamma(\phi \to e^+e^-) B(\phi \to K_L^0 K_S^0)/m_\phi}}{D_\phi(s)} - \right.$$

$$- \frac{\sqrt{\Gamma_\phi \Gamma_\omega m_\phi^2 m_\omega^3 6\pi B(\omega \to e^+e^-) B(\phi \to K_L^0 K_S^0)}}{D_\omega(s)} -$$

$$\left. + \frac{\sqrt{\Gamma_\phi \Gamma_\rho m_\phi^2 m_\rho^3 6\pi B(\rho \to e^+e^-) B(\phi \to K_L^0 K_S^0)}}{D_\rho(s)} \right|^2,$$

Theoretical cross section formulas (Cnt.d)

$$\sigma_{\pi^+\pi^-\pi^0}(s) = \frac{1}{s^{3/2}} \cdot \frac{W(s)}{W(m_\phi^2)} \cdot \left| \frac{\sqrt{m_\phi^3 12\pi \cdot \Gamma_\phi \Gamma(\phi \to e^+e^-) B(\phi \to \pi^+\pi^-\pi^0)}}{D_\phi(s)} e^{i\psi_\phi} + \right.$$

$$\left. + \frac{W(m_\phi^2)}{W(m_\omega^2)} \frac{\sqrt{m_\omega^3 12\pi \cdot \Gamma_\omega \Gamma(\omega \to e^+e^-) B(\omega \to \pi^+\pi^-\pi^0)}}{D_\omega(s)} \right|^2$$

$$\sigma_{\eta\gamma}(s) = \frac{F_{\eta\gamma}(s)}{s^{3/2}} \cdot \left| - \frac{\sqrt{m_\phi^3 12\pi \cdot \Gamma_\phi \Gamma(\phi \to e^+e^-) B(\phi \to \eta\gamma)/F_{\eta\gamma}(m_\phi^2)}}{D_\phi(s)} + \right.$$

$$+ \frac{\sqrt{\Gamma_\omega^2 m_\omega^3 12\pi B(\omega \to e^+e^-) B(\omega \to \eta\gamma)/F_{\eta\gamma}(m_\omega^2)}}{D_\omega(s)} +$$

$$\left. + \frac{\sqrt{\Gamma_\rho^2 m_\rho^3 12\pi B(\rho \to e^+e^-) B(\rho \to \eta\gamma)/F_{\eta\gamma}(m_\rho^2)}}{D_\rho(s)} \right|^2,$$