6. E.J. Eichten, C.T. Hill and C. Quigg, Phys. Rev. Lett. **71** (1993) 4116; Fermilab-Conf-94/118-T (1994).

7. S.N. Gupta and J.M. Johnson, Phys. Rev. **D 51** (1995) 168.

8. A.F. Falk and T. Mehen, Phys. Rev. **D 53** (1996) 231.

9. N. Isgur, Phys. Rev. **D 57** (1998) 4041.

10. D. Ebert, V.O. Galkin and R.N. Faustov, Phys. Rev. **D 57** (1998) 5663.

11. M. Feindt and O. Podobrin, DELPHI Collaboration, Submitted to the ICHEP Conference, Warsaw, July 1996, ICHEP96 Ref pa01-021.

12. Private Communication with C. Quigg, July, 1998. In addition to effects of phase space in the HQET predictions, an effective increase of the decay width may occur if the Q value is large enough to include the tail of the decay $B^{**} \to B\rho$. Both of these effects would cause higher-mass states to have larger decay widths.

Frascati Physics Series Vol. XV (1999), pp. 321-326
WORKSHOP ON HADRON SPECTROSCOPY - Frascati, March 8-12, 1999

SPECTROSCOPY AT B-FACTORIES USING HARD PHOTON EMISSION

M. Benayoun[a], S.I. Eidelman[a,b], V.N. Ivanchenko[a,b], and Z.K. Silagadze[b]
[a]*LPNHE des Universités Paris VI et VII-IN2P3, Paris, France*
[b]*Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia*

presented by V.N. Ivanchenko

ABSTRACT

The process of hard photon emission by initial electrons (positrons) at future B-factories is discussed. It is shown that studies of the bottomonium spectroscopy will be feasible for the planned integrated luminosity of the B-factory experiments.

1 Introduction

Heavy-quark physics is one of the frontier areas in studies of the fundamental properties of matter. This is why a new generation of e^+e^- colliders (B-factories) has been designed. The CLEO-III [1)], BELLE [2)], and BABAR [3)] experiments are expected to begin in 1999. Their main goal is the precise investigation of the Cabibbo-Kobayashi-Maskawa matrix and, first of all, CP-violation in the b-quark sector. To achieve this goal, most of the time of future experiments will be spent on runs at the energy of the $\Upsilon(4S)$ resonance. At the same time there are physical tasks related to the spectroscopy of quarkonium systems which require scanning the energy region of $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ [4)]. The main part of the bottomonium family has been observed, their masses and main decay modes have been measured [5)]. The list of experiments with the largest integrated luminosity is shown in Table 1.

Table 1: *The list of selected experiments with the largest integrated luminosity in which the transitions between different $b\bar{b}$ states have been studied. The integrated luminosity (L) and corresponding number of produced initial $\Upsilon(2S)$ or $\Upsilon(3S)$ mesons (N) are shown.*

Process	detector	L, pb^{-1}	$N, 10^6$
$\Upsilon(3S) \to \chi_b\gamma$	CLEO-II [6]	116	0.40
$\Upsilon(3S) \to \chi_b\gamma$ $\Upsilon(3S) \to \Upsilon(2S)\pi^0\pi^0$ $\Upsilon(3S) \to \Upsilon(1S)\pi^0\pi^0$	CUSB-II [7]	288	0.99
$\Upsilon(3S) \to \Upsilon(2S)\pi^+\pi^-$ $\Upsilon(3S) \to \Upsilon(2S)\pi^0\pi^0$ $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$ $\Upsilon(3S) \to \Upsilon(1S)\pi^0\pi^0$	CLEO-II [8]	130	0.47
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$ $\Upsilon(2S) \to \Upsilon(1S)\pi^0\pi^0$	CLEO-II [9]	79	0.49

On the other hand, the accuracy of the measured parameters of the bottomonium family is not very high which prevents precise comparison between the data and different model predictions for the mass spectrum, decay rates, and dynamics of transitions. Moreover, some predicted states ($\eta_b(2S)$, $\eta_b(1S)$, $h_b(1P)$) have not yet been observed. So, new experiments are necessary which will provide complete information about all states below the open flavor threshold. Unfortunately, scanning of the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ is not foreseen at asymmetric B-factory experiments. Of course, it can be done in a traditional way by CLEO-III but that will decrease the total integrated luminosity which is expected to be collected by CLEO-III at $\Upsilon(4S)$. That is why we consider a possibility to perform Υ-spectroscopy studies at the $\Upsilon(4S)$ energy.

The process $e^+e^- \to \gamma h$, where h is a hadronic system and γ is a photon emitted by the electron or the positron, is well known. Different possibilities of using radiative photons are now under intensive discussions [10, 11, 12, 13]. Moreover the experiment has been performed by H1 [14] to measure the longitudinal structure function $F_L(x,Q^2)$ at HERA using radiative events with the emission of a hard photon collinear to the incident lepton beam.

In the present work the following reaction is studied:

$$e^+e^- \to \gamma V \to \gamma f, \tag{1}$$

where V is one of the vector resonances $\Upsilon(3S)$, $\Upsilon(2S)$, $\Upsilon(1S)$ etc. decaying to a final

state f. Our main task is to show the practical feasibility of using such processes for spectroscopy studies at B-factories in near future.

2 Calculation of the production cross sections

The differential cross section of the process (1) can be obtained in the first Born approximation using the quasireal electron method [15, 16]

$$\frac{d\sigma(s,x)}{dx\,d\cos\theta} = \frac{2\alpha}{\pi x} \cdot \frac{(1 - x + \frac{x^2}{2})\sin^2\theta}{(\sin^2\theta + \frac{m_e^2}{E^2}\cos^2\theta)^2} \cdot \sigma_0(s(1-x)), \tag{2}$$

where $s = 4E^2$, E is the beam energy in the center of mass system of the electron and the positron, m_e is the mass of the electron, α is the fine structure constant, $x = E_\gamma/E$ is the fraction of the beam energy taken by the radiative photon with the energy E_γ, θ is the photon angle with respect to the beam ($0 < \theta < \pi$), $\sigma_0(s)$ is the cross section of hadronic production. Note that more complicated expressions, which take into account the leading α^2 contributions, are well known [17, 18, 19].

The cross section of the narrow resonance production is given by the standard Breit-Wigner formula. So, if one performs integration over θ and over x in (2), the following cross section is obtained:

$$\sigma_V(s) = \frac{12\pi\alpha B_{ee}\Gamma_V}{m_V \cdot s} \cdot \frac{1 + \frac{m_V^4}{s^2}}{1 - \frac{m_V^2}{s}} \cdot (2\ln\frac{\sqrt{s}}{m_e} - 1). \tag{3}$$

where m_V, Γ_V, B_{ee} are the mass, the width, and the branching fraction of the $V \to e^+e^-$ decay respectively.

Assuming that the experiment is carried out at the $\Upsilon(4S)$ energy, the production cross sections of vector mesons with quantum numbers $J^{PC} = 1^{--}$ can be calculated using (3) and PDG values [5]. The results are shown in Table 2. Additionally, the numbers of produced events are presented which correspond to the collected integrated luminosity of 10 fb^{-1}.

3 Prospects for spectroscopy of bottomonium

Two types of events to study spectroscopy of bottomonium can be considered in which background will be small. The first one can be called "tagged photon" events. In these events a hard photon is emitted at a large angle with respect to the beam axis and is recorded by the main calorimeter of the detector. Using high energy and position resolution of the calorimeter for photons, the recoil energy for the hadronic

Table 2: *Cross sections of radiative production of $J^{PC} = 1^{--}$ mesons at the $\Upsilon(4S)$ energy (leading second order estimation is also indicated in the parentheses), the total number of mesons produced in the experiment with the integrated luminosity of* 10 fb^{-1}, *and the number of lepton decays of these mesons.*

Meson	σ_V (nb)	N_{total}, 10^6	$N_{\gamma e^+e^-}$, 10^3	$N_{\gamma\tau^+\tau^-}$, 10^3
$\Upsilon(3S)$	0.038 (0.031)	0.38	6.85	6.81
$\Upsilon(2S)$	0.016 (0.015)	0.16	1.95	1.93
$\Upsilon(1S)$	0.021 (0.019)	0.21	5.21	5.16
$\psi(2S)$	0.013 (0.014)	0.13	1.13	0.44
$J/\psi(1S)$	0.034 (0.036)	0.34	20.3	0
ϕ	0.024 (0.027)	0.24	0.07	0
ω	0.014 (0.016)	0.14	0.01	0
ρ	0.160 (0.182)	1.56	0.07	0

system in the reaction (1) can be reconstructed. This will provide precise identification of the produced $b\bar{b}$ state and a possibility to study all its decay modes. Using the angular distribution of the emitted photon (2) one can obtain the probability for the hard photon to be emitted with the polar angle $\theta_{mim} < \theta < \theta_{max}$. The results are shown in Table 3.

Table 3: *The detection efficiency for the hard photon in calorimeters of the B-factory detectors in case of* $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$ *production.*

Detector	θ_{min}, *degrees*	θ_{max}, *degrees*	ϵ, %
CLEO-III	30.0	150.0	13.9
BELLE	18.3	163.7	19.9
BABAR	26.5	156.3	15.9

The main part of hard photons is emitted along the beam axis. Thus, this photon will not fire the detector calorimeter. In this case complete reconstruction of the hadronic system in the reaction (1) is necessary. It was recently shown by CLEO-II [9] that studying events with lepton and pion pairs in the final state allows to have a practically clean sample of pion transitions between $\Upsilon(2S)$ and $\Upsilon(1S)$ resonances. The estimated numbers of events of such type in radiative production at $\Upsilon(4S)$ are shown in Table 4. One of the important tasks for the bottomonium spectroscopy is to study radiative transitions. If the final $\Upsilon(2S)$ and $\Upsilon(1S)$ decay into a lepton pair, the signature of these reactions "two photons and lepton pair" will allow background rejection. The estimated number of produced events with gamma transition is shown in Table 5.

Table 4: *The estimated number of events of hadron transitions with two pions and lepton pair in the final state for an experiment with the integrated luminosity of* 10 fb^{-1}.

Reaction	N events
$\Upsilon(3S) \to \Upsilon(2S)\pi\pi \to l^+l^-\pi\pi$	428
$\Upsilon(3S) \to \Upsilon(1S)\pi\pi \to l^+l^-\pi\pi$	1248
$\Upsilon(2S) \to \Upsilon(1S)\pi\pi \to l^+l^-\pi\pi$	2268

Table 5: *The estimated number events of radiative decays with two photons and lepton pair for experiment with the integrated luminosity of* 10 fb^{-1}.

Reaction	N events
$\Upsilon(3S) \to \chi_{b2}(2P)\gamma \to \Upsilon(2S)\gamma\gamma$	164
$\Upsilon(3S) \to \chi_{b1}(2P)\gamma \to \Upsilon(2S)\gamma\gamma$	212
$\Upsilon(3S) \to \chi_{b0}(2P)\gamma \to \Upsilon(2S)\gamma\gamma$	22
$\Upsilon(3S) \to \chi_{b2}(2P)\gamma \to \Upsilon(1S)\gamma\gamma$	183
$\Upsilon(3S) \to \chi_{b1}(2P)\gamma \to \Upsilon(1S)\gamma\gamma$	22
$\Upsilon(3S) \to \chi_{b0}(2P)\gamma \to \Upsilon(1S)\gamma\gamma$	9
$\Upsilon(2S) \to \chi_{b2}(1P)\gamma \to \Upsilon(1S)\gamma\gamma$	122
$\Upsilon(2S) \to \chi_{b1}(1P)\gamma \to \Upsilon(1S)\gamma\gamma$	192
$\Upsilon(2S) \to \chi_{b0}(1P)\gamma \to \Upsilon(1S)\gamma\gamma$	10

4 Conclusion

Estimations performed in this work have demonstrated feasibility of using a radiative photon for studies of the bottomonium spectroscopy at B-factories. These processes have to be taken into account as a possible background to different reactions which will be studied in these experiments at the $\Upsilon(4S)$ energy. The number of estimated events of $\Upsilon(2S), \Upsilon(3S)$ shown in Table 2 is smaller than one collected by a standard method in CLEO-II experiments [6, 8, 9]. If the integrated luminosity of about 100 fb^{-1} will be collected, the number of events for spectroscopy studies with clean signature will be higher than that collected now.

The same method can be considered to study decay modes of ρ and ω mesons at the DAΦNE ϕ-factory. If the integrated luminosity of about 300 pb^{-1} will be collected, the number of $\omega\gamma$ events will be 10^6 and $\rho\gamma$ — 10^7.

References

1. CLEO Collaboration, The CLEO III Detector: Design and Physics Goals, http://www.lns.cornell.edu/public/CLEO/CLEO3/CLEO3.html (1994).
2. Belle Collaboration, A Study of CP Violation in B Meson Decays: Technical Design Report, KEK report 95-1 (1995).
3. BaBar Collaboration, BaBar Technical Design Report, SLAC-R-95-457 (1995).
4. M.B. Voloshin and Yu.M. Zaitsev, Sov. Phys. Usp. **30** 553 (1987).
5. C. Caso *et al.* (Particle Data Group) Europ. Phys. Jour. **C3** 1 (1998).
6. R. Morrison *et al.*, Phys. Rev. Lett. **67** 1696 (1991).
7. U. Heintz *et al.*, Phys. Rev. **D46** 1928 (1992).
8. F. Butler *et al.*, Phys. Rev. **D49** 40 (1994).
9. J.P. Alexander *et al.*, Phys. Rev. **D58** 052004-1 (1998).
10. M.W. Krasny, W. Placzek, H. Spiesberger, Z.Phys. **C53** 687 (1992).
11. L. Favart *et al.*, Z.Phys. **C72** 425 (1996).
12. A.B. Arbuzov, E.A. Kuraev, N.P. Merenkov, L. Trentadue, JHEP 9812:009,1998 (hep-ph/9804430).
13. S. Binner, J.H. Kuehn, K. Melnikov, hep-ph/9902399.
14. S. Aid *et al.*, Nucl. Phys. **B470** 3 (1996).
15. V.N. Baier, V.S. Fadin, V.A. Khoze, Nucl. Phys. **B65** 381 (1973).
16. G. Bonneau, F. Martin, Nucl. Phys. **B27** 381 (1971).
17. D.R. Yennie, S.C. Frautschi, H. Suura, Ann. Phys. (NY) **13** 379 (1961).
18. E.A. Kuraev and V.S. Fadin, Sov. J. Nucl. Phys. **41** 466 (1985).
19. O. Nicrosini, L. Trentadue, Phys. Lett. **B196** 551 (1987).

Frascati Physics Series Vol. XV (1999), pp. 327-336
WORKSHOP ON HADRON SPECTROSCOPY - Frascati, March 8-12, 1999

REVIEW OF RECENT DATA ON CHARMONIUM

Nadia Pastrone for the E835 Collaboration *
Istituto Nazionale di Fisica Nucleare - Torino,
Via P. Giuria 1, I-10125 Torino, Italy

ABSTRACT

Recent results on charmonium resonances from experiments studying $\bar{p}p$, e^+e^- and $\gamma\gamma$ collisions are reviewed.
FNAL-E835 reports new measurements of parameters of the ground state $\eta_c(1^1S_0)$, $\gamma\gamma$ partial width of η_c and $\chi_{c2}(1^3P_2)$ and the first evidence of $\chi_{c0}(1^3P_0)$ direct formation in $\bar{p}p$ annihilations.
New measurements of η_c and χ_{c2} $\gamma\gamma$ partial widths obtained in two-photon collisions at high energy e^+e^- colliders are reported by CESR and more recently LEP.
A new measurement of the χ_{c0} parameters studied in $\psi(2S)$ decays by the Beijing Spectrometer (BES) at BEPC is presented.
The results of these and older experiments are compared.

* G. Garzoglio, A. Hahn, W. Marsh, J. Peoples Jr., S. Pordes, J. Streets, S. Werkema (*Fermi National Accelerator Laborutory*), M. Ambrogiani, W. Baldini, D. Bettoni, R. Calabrese, P. Dalpiaz, E. Luppi, R. Mussa, M. Savriè, G. Stancari (*INFN and University of Ferrara*), A. Buzzo, M. Lo Vetere, M. Macrì, M. Marinelli, M. Pallavicini, C. Patrignani, E. Robutti, A. Santroni (*INFN and University of Genova*), K. E. Gollwitzer, G. Lasio, M. Mandelkern, J. Schultz, M. Stancari, G. Zioulas (*University of California at Irvine*), X. Fan, S. Jin, J. Kasper, P. Maas, T. Pedlar, J. Rosen, K. K. Seth, A. Tomaradze (*Northwestern University*), S. Argirò, S. Bagnasco, G. Borreani, R. Cester, F. Marchetto, E. Menichetti, M.M. Obertino, N. Pastrone, P. Rumerio (*INFN and University of Torino*)

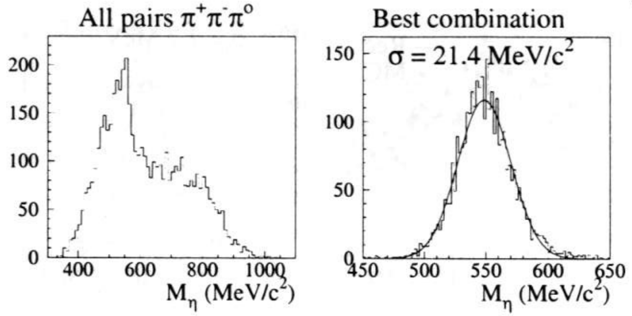

Figure 3: *Invariant masses for all $\pi^+\pi^-\pi^o$ combinations and for the best combination giving the η mass.*

signal with a signal/noise ratio greater than 70 is obtained. The expected 10,000 events of this kind translate to a BR determination with 2.1% statistical error.

4 Conclusions

KLOE is expected to collect 100 pb^{-1} during its first 1999 run. One of the first analysis items will be the study of $\Phi \to f_o\gamma$, $\Phi \to a_o\gamma$ radiative decays. The analysis of montecarlo events obtained with a realistic detector simulation and a full event reconstruction indicates a sensitivity of $\sim 1 \div 2\,\%$ on the branching ratios.

References

1. N.N.Achasov V.N.Ivanchenko, Nucl. Phys. **B315**, 465 (1989).
2. M.N.Achasov *et al*, Phys. Lett. **B440**, 442 (1998).
3. M.N.Achasov *et al*, Phys. Lett. **B438**, 441 (1998).
4. R.R.Akhmetshin *et al*, "Recent Results from CMD-2 Detector at VEPP-2M", Preprint **Budker INP 99-11** (1999).
5. The KLOE Collaboration, "KLOE, A General Pourpose Detector for DAΦNE", **LNF-92/019** (1992).
6. G.Vignola, "DAΦNE Design Criteria and Project Overview", Workshop on Physics and Detectors for DAΦNE, Frascati, April 1991, **LNF-91/037**, 11 (1991).
7. A.Bramon *et al*, Phys. Lett. **B283**, 416 (1992).

Frascati Physics Series Vol. XV (1999), pp. 479-488
WORKSHOP ON HADRON SPECTROSCOPY - Frascati, March 8-12, 1999

RECENT RESULTS FROM CMD-2 DETECTOR AT VEPP-2M

Evgeny P. Solodov (CMD-2 collaboration)
Budker Institute of Nuclear Physics, Novosibirsk, Russia

ABSTRACT

Abstract

Recent results of the study of e^+e^- annihilation into hadrons by the CMD-2 collaboration at VEPP-2M are presented for the c.m. energy range from 0.61 to 1.39 GeV. New measurements of ρ, ω and ϕ-mesons parameters are reported. Also discussed are the cross sections and production mechanisms for the multipion production in the non-resonant energy ranges.

Introduction

Investigation of e^+e^- annihilation into hadrons at low energies has a long history, but despite thirty years of experimental studies, we are still rather far from the complete understanding of the field. One needs more precise measurements of the ρ-, ω- and ϕ-meson parameters as well as of the properties of the continuum which will provide unique information about interactions of light quarks and spectroscopy of their bound states.

These physical tasks became the goal of the general-purpose detector CMD-2 [1)] which has been running at the VEPP-2M e^+e^- collider [2)] in Novosibirsk from

1993 studying the c.m. energy range from threshold of hadron production to 1.4 GeV. In Table 1 all runs performed till 1999 are listed. The results of the analysis,

Table 1: CMD-2 data taking information. Arrows show the direction of the beam energy variation during scanning

Legend	Date	C.m. energy, GeV	Run numbers	Wiggler	$\int Ldt$ pb^{-1}
PHI-93	16/02/93÷16/07/93	0.994↔1.040	2100 - 2750	Yes	1.43
PHI-94/1	24/01/94÷01/02/94	1.019→0.980	3001 - 3040	No	0.05
RHOM-94	01/02/94÷26/02/94	0.970→0.810	3041 - 3165	No	0.15
PHI-94/2	13/11/94÷26/11/94	1.018↔1.024	4038 - 4106	No	0.16
RHOM-95	30/11/94÷06/06/95	0.810→0.600	4107 - 4541	No	0.16
PHI-96	12/04/96÷14/07/96	0.984↔1.034	4545 - 5150	No	2.18
LOW-96	20/09/96÷26/10/96	0.512→0.370	5749 - 5961	No	0.10
HIGH-97	29/01/97÷16/06/97	1.040↔1.370	6115 - 7030	No	5.93
PHI-98	10/10/97÷23/03/98	0.984↔1.060	7097 - 8427	Yes	11.93
RHOM-98	24/03/98÷30/06/98	0.970→0.360	8428 - 9345	Yes	3.50
HIGH-99	09/01/99÷	1.080→	9402 -	Yes	

based on the part of avalable data are published in papers [3, 4, 5, 6, 7].

In total, in experiments with CMD-2 the integrated luminosity of 25 pb^{-1} has been collected so far. Several dedicated runs around the ϕ-meson have been performed with the total integrated luminosity of 15.8 pb^{-1} or about 2.1×10^7 ϕ-meson decays. The bulk of data includes also $3\cdot10^5$ multihadron events and $2.1\cdot10^6$ $\pi^+\pi^-$ events. More details can be found in recently published papers [8, 9, 10]. A short description of most interesting results is presented in this paper.

Measurements of ρ,ω and ϕ-meson parameters

The analysis of the $e^+e^-\to\pi^+\pi^-$ reaction from the **RHOM-95** run (10% of data) is completed while other data is still under analysis. The data sample was collected at 43 energy points with the center-of-mass energies from 610 till 960 MeV. The beam energy was measured with the help of the resonance depolarization technique at almost all energy points. The pion form factor, obtained in **RHOM-95** data analysis, is presented in Fig. 1. The systematic error for these data is about 1.4%, coming mainly from the uncertainty of the theoretical calculations for the radiative corrections. The obtained ρ-meson parameters based on the Gounaris-Sakurai parametrization are presented in Table 3. Details about the **RHOM-95** data analysis can be found in [9].

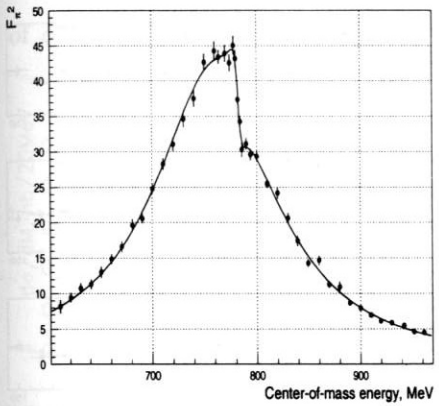

Figure 1: Pion form factor, obtained in **RHOM-95** data analysis.

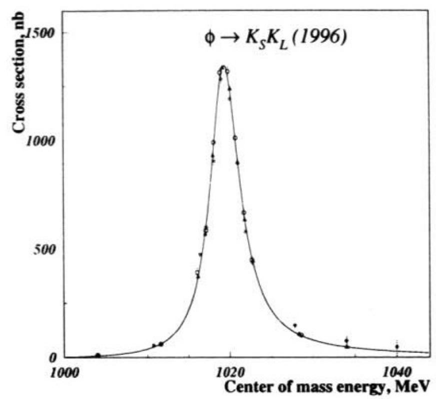

Figure 2: ϕ-meson excitation curve

During **RHOM-95** run the ω-meson excitation curve has been measured with a total integrated luminosity of 150 nb^{-1}. The ω-meson parameters were measured by $\omega\to\pi^+\pi^-\pi^0$ decay mode. The obtained ω-meson parameters are listed in Table 3.

The process $e^+e^-\to\phi\to K_L^0K_S^0$, $K_S^0\to\pi^+\pi^-$ was used to measure the ϕ-meson parameters. The data sample collected during the **PHI-94/1**, **PHI-94/2** and **PHI-96** runs in the c.m. energy range 984 – 1040 MeV (3.4×10^6 ϕ-mesons) corresponds to the integrated luminosity of 2.37 pb^{-1}. 2.97×10^5 of $K_L^0K_S^0$ events have been selected. For 1994 data the beam energy at each point was measured by the resonance depolarization method [12]. For data collected in 1996 the beam energy was determined with the help of charged kaon momenta and by the collider magnetic field analysis [10].

The obtained cross section for the process $e^+e^-\to K_L^0K_S^0$ is presented in Figs. 2. The obtained ϕ-meson parameters are listed in Table 2. The ϕ resonance was also studied in $\pi^+\pi^-\pi^0$ and $\eta\gamma$ modes with η decay into $\pi^+\pi^-\pi^0$ and $\pi^0\pi^0\pi^0$.

Study of $\phi\to\pi^+\pi^-$ and $\phi\to\mu^+\mu^-$ decays

The ϕ signal is seen as interference pattern in the $e^+e^-\to\pi^+\pi^-$ and $e^+e^-\to\mu^+\mu^-$ cross sections and is described by the complex amplitude Z [10]. The data with the integrated luminosity 1.8 pb^{-1} collected in 1996 were analysed. The visible cross sections vs energy for pions and muons are presented in Fig. 3.

The direct amplitude of ϕ decay into two pions can be extracted from the

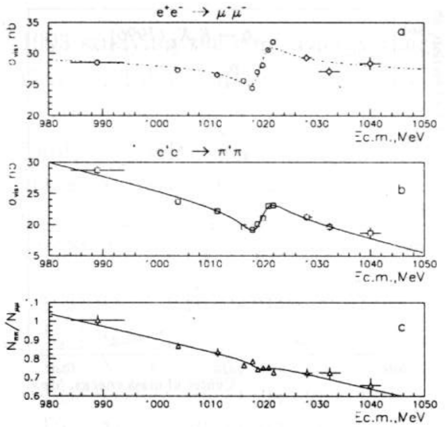

Figure 3: a,b. Visible cross sections. c. Ratio of number of pions to number of muons vs energy.

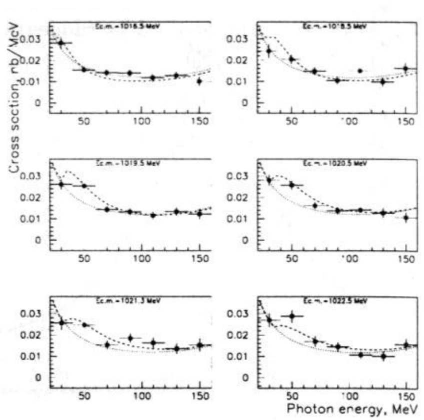

Figure 4: The photon spectra for $\pi^+\pi^-\gamma$ events in the "ϕ" region.

ratio of the number of pions to that of muons. This ratio is shown in Fig. 3c. The signal is seen at the 2σ level in the imaginary part of Z: $Re(Z) = 0.002 \pm 0.010 \pm 0.003$, $Im(Z) = 0.0224 \pm 0.0107 \pm 0.0030$. The last result can be presented as upper limit at 90% C.L.(see Table 2).

$\phi \to \pi^+\pi^-\gamma$ channel

The data with the integrated luminosity 14.8 pb^{-1} corresponding to about 20 millions of ϕ decays were used for this analysis. The events with two charged particles and one photon were selected.

The observed events are dominated by bremsstrahlung processes and the signal from $\phi \to \pi^+\pi^-\gamma$ decay was searched for as an interference pattern in the energy dependence cross section as well as in the photon spectra of the selected events (Fig. 4) around the ϕ peak. The photon spectra analysis indicates the increasing of events over bremsstrahlung spectra in (40-50) MeV region. The "visible" branching ratios and relative phase have been obtained and are presented in Table 2.

$\phi \to \pi^0\pi^0\gamma$ channel

The decay $\phi \to f_0\gamma$ with $f_0 \to \pi^0\pi^0$ has no bremsstrahlung background and can help to determine the f_0 structure.

Events with 5 photons detected both in the CsI and BGO calorimeter with no charged particles were selected and were subject of a constrained fit. 268 ± 27

of $\phi \to \pi^0\pi^0\gamma$ events have been found. Figure 5a presents the differential cross

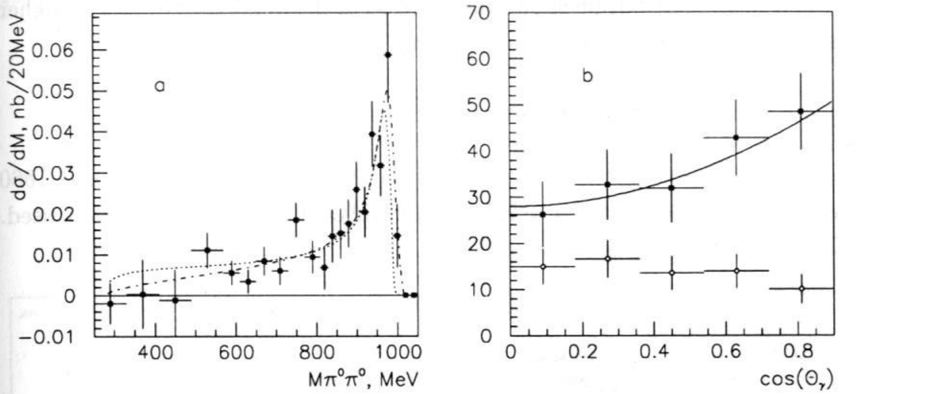

Figure 5: a. Differential cross section vs invariant mass. The line is the theoretical prediction for f_0 production for the 3.1×10^{-4} branching ratio; b. Angular distribution for signal events and background. Line is $dN/d\theta_\gamma \approx (1 + cos^2(\theta_\gamma))$

section vs invariant mass. The angular distribution conforms the presence of scalar resonance (Fig.5b)

The experimental ratio of "visible" branching with charged pions to that with neutrals was found to be 0.26 ± 0.08 instead of two. The model suggested in [13] describes these two channels assuming the strong destructive interference in the charged mode. The combined fit for both channels gives the following f_0 parameters, coupling constants and branching ratio:
$m_{f_0} = 975 \pm 4$ MeV/c^2, $g^2_{KK}/4\pi = (1.64 \pm 0.37)$ GeV^2, $g^2_{\pi\pi}/4\pi = (0.44 \pm 0.06)$ GeV^2, $Br(\phi \to f_0\gamma) = (3.11 \pm 0.23) \cdot 10^{-4}$ and relative phase (1.42 ± 0.18) radians.

The obtained coupling constants support hypothetis about four quark f_0 structure. In this interpretation the f_0 final state dominates. The admixture of other resonances can reduce the f_0 component, but it cannot be lower than about $1.5 \cdot 10^{-4}$.

Observation of $\phi \to \eta\pi^0\gamma$ decay

This channel was searched for in the 5 photon mode with η decays into two photons. The constrained fit finding one best combination of photon pairs with π^0 mass and pion momentum less than 350 MeV/c was performed. The invariant masses of coupled combinations of the two remaining most energetic two photons were studied.

At the broad background distribution from three pion η decays the peak with 80 ± 22 events and $m_\eta = (545 \pm 4)$ MeV was seen. The branching ratio is shown in Table 2. The invariant mass distribution shows the increase of the number of events to higher masses supporting the hypothesis about the $a_0(980)$ intermediate state.

$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ below ϕ-meson

For analysis of the process $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ in the c.m. energy range 600–1060 MeV the data samples collected in **PHI-98** and **RHOM-98** experiments were used. The obtained cross section is shown in Fig. 6.

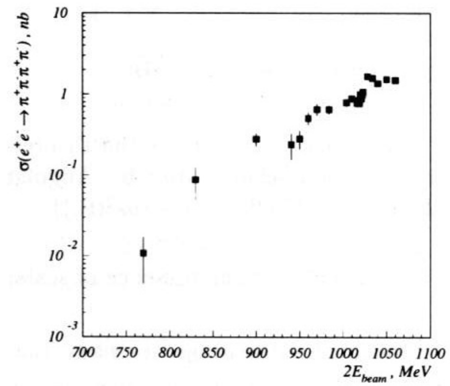

Figure 6: Cross section of the process $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ below ϕ-meson

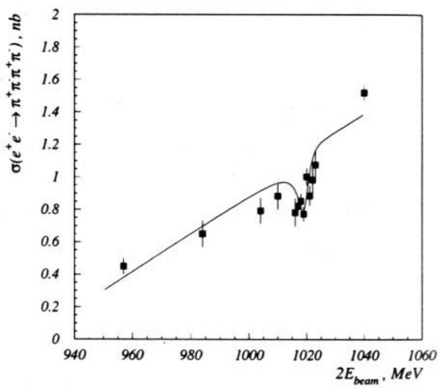

Figure 7: Cross section of the process $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ near ϕ-meson

In the energy range $E_{beam} = 365$–405 MeV (around the maximum of ρ-meson) $N_{4\pi} = 3$ events were selected. The number of expected background events was estimated to be ~ 1.

The behaviour of the cross section near the ϕ-meson is shown in more detail in Fig. 7. The ϕ contribution is seen. The obtained branching ratios can be found in Tables 3,2.

$e^+e^- \to 4\pi$ above ϕ-meson

The process of 4π production is one of the dominant in the total cross section of e^+e^- annihilation into hadrons in the energy range above ϕ. Our analysis is based on the data sample corresponding to the integrated luminosity of 5.8 pb^{-1} collected

in **HIGH-97**. To describe four pion production we used a simple model assuming quasitwoparticle intermediate states taking into account identical final pions (see [15])) and the interference of all possible amplitudes.

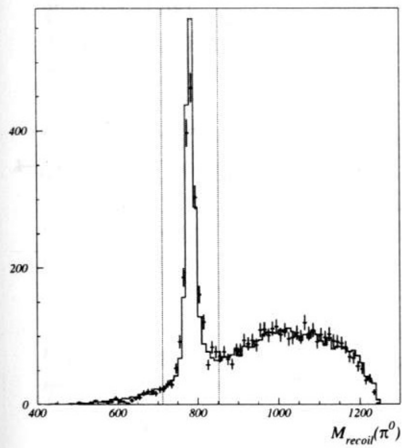

Figure 8: Distribution over π^0 recoil mass for $\pi^+\pi^-2\pi^0$

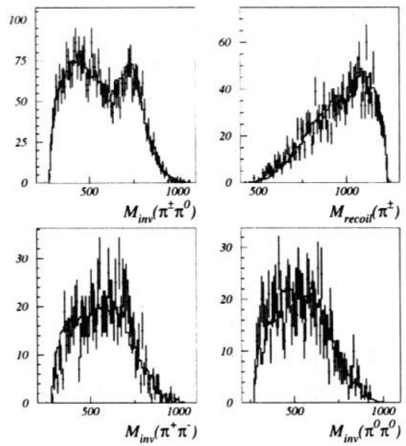

Figure 9: Distributions over $M_{\pi^\pm\pi^0}$, $M_{recoil}(\pi^\pm)$, $M_{\pi^+\pi^-}$ and $M_{\pi^0\pi^0}$ for $\pi^+\pi^-2\pi^0$ in class 2.

Figure. 8 shows the distribution over $M_{recoil}(\pi^0)$ at the energy $E_{beam} =$ 690 MeV with signal from the process $\omega\pi^0$.. The histogram shows MC simulation.

Fot the next analysis all $\omega\pi^0$ events were subtracted. The distributions for the remaining events are shown in Figs. 9. A clear signal of $\rho^\pm$ is observed while there is no signal of the ρ^0. Thus, one can assume that these events originate from a heavy isospin 1 resonance. The best candidate for this intermediate state was found to be $a_1(1260)$. Details including cross section vs. energy measurement can be found in paper [8]).

Conclusions

The two tables below summarize our results. Table 2 gives the results on the ϕ-meson study.. Of special importance is the confirmation by two independent methods of our first measurement of the rare decay mode $\phi \to \eta'\gamma$ which makes complete a list of the magnetic dipole transitions between vector and pseudoscalar mesons and is a milestone for the theory of radiative decays. Our results on the electric dipole transitions confirm earlier observations by SND of the decay modes $\phi \to \pi^0\pi^0\gamma$ and $\phi \to \eta\pi^0\gamma$ and add information about $\phi \to \pi^+\pi^-\gamma$ decay.

Table 2:

	CMD-2 Data	PDG'98
m_ϕ, MeV	$1019.470 \pm 0.013 \pm 0.018$	1019.413 ± 0.008
Γ_ϕ, MeV	$4.51 \pm 0.04 \pm 0.02$	4.43 ± 0.05
$Br(\phi \to K^+K^-)$	$(49.1 \pm 1.2)\%$	$(49.1 \pm 0.8)\%$
$Br(\phi \to K_LK_S)$	$(33.5 \pm 1.0)\%$	$(34.1 \pm 0.6)\%$
$Br(\phi \to 3\pi)$	$(14.5 \pm 0.9 \pm 0.3)\%$	$(15.5 \pm 0.7)\%$
$Br(\phi \to \eta\gamma, \eta \to \pi^0\pi^0\pi^0)$	$(1.24 \pm 0.02 \pm 0.06)\%$	$(1.26 \pm 0.06)\%$
$Br(\phi \to \eta\gamma, \eta \to \pi^+\pi^-\pi^0)$	$(1.18 \pm 0.03 \pm 0.06)\%$	$(1.26 \pm 0.06)\%$
$Br(\phi \to e^+e^-)$	$(2.87 \pm 0.09) \cdot 10^{-4}$	$(2.99 \pm 0.08) \cdot 10^{-4}$
$\delta_{\phi-\omega}$	$(162 \pm 17)^\circ$	
$Br(\phi \to \eta'\gamma, \eta' \to \pi^+\pi^-\gamma\gamma)$	$(1.35^{+0.55}_{-0.45} \pm 0.2) \cdot 10^{-4}$	$(1.2^{+0.7}_{-0.5}) \cdot 10^{-4}$
$Br(\phi \to \eta'\gamma)$	$(0.58 \pm 0.18 \pm 0.15) \cdot 10^{-4}$	$(1.2^{+0.7}_{-0.5}) \cdot 10^{-4}$
$\eta' \to \pi^+\pi^-\pi^+\pi^-\pi^0$		
$\eta' \to \pi^+\pi^-\pi^+\pi^-\gamma$		
$Br(\phi \to \eta e^+e^-, \eta \to \gamma\gamma)$	$(1.12 \pm 0.17 \pm 0.17) \cdot 10^{-4}$	$(1.3^{+0.8}_{-0.6}) \cdot 10^{-4}$
$Br(\phi \to \eta e^+e^-, \eta \to \pi^+\pi^-\pi^0)$	$(1.00 \pm 0.18) \cdot 10^{-4}$	$(1.3^{+0.8}_{-0.6}) \cdot 10^{-4}$
$Br(\phi \to \pi^+\pi^-\gamma)$	$(0.28 \pm 0.08 \pm 0.03) \cdot 10^{-4}$	$< 3 \cdot 10^{-5}$
$Br(\phi \to \pi^0\pi^0\gamma)$	$(1.08 \pm 0.17 \pm 0.09) \cdot 10^{-4}$	$< 1 \cdot 10^{-3}$
$Br(\phi \to \eta\pi^0\gamma)$	$(0.90 \pm 0.24 \pm 0.10) \cdot 10^{-4}$	$< 2.5 \cdot 10^{-3}$
$Br(\phi \to \pi^0e^+e^-)$	$(1.29 \pm 0.29 \pm 0.19) \cdot 10^{-5}$	$< 1.2 \cdot 10^{-4}$
$Br(\phi \to \mu^+\mu^-\gamma)$	$(1.15 \pm 0.36 \pm 0.11) \cdot 10^{-5}$	$(2.3 \pm 1.0) \cdot 10^{-5}$
$Br(\phi \to \rho\gamma)$	$< 3 \cdot 10^{-4}$	$< 7 \cdot 10^{-4}$
$Br(\phi \to \rho\gamma\gamma)$	$< 5 \cdot 10^{-4}$	no data
$Br(\phi \to \eta\pi^+\pi^-)$	$< 3 \cdot 10^{-4}$	no data
$Br(\phi \to \mu^+\mu^-)$	$(3.54 \pm 0.32 \pm 0.37) \cdot 10^{-4}$	$(2.5 \pm 0.4) \cdot 10^{-4}$
$Br(\phi \to \pi^+\pi^-)$	$(2.20 \pm 0.25 \pm 0.20) \cdot 10^{-4}$	$(0.8^{+0.5}_{-0.4}) \cdot 10^{-4}$
$Br(\phi \to \pi^+\pi^-)_{direct}$	$< 0.13 \cdot 10^{-4}$	no data
$Br(\phi \to \pi^+\pi^-\pi^+\pi^-)$	$(0.77 \pm 0.21 \pm 0.20) \cdot 10^{-5}$	$< 8.7 \cdot 10^{-4}$

Table 3 presents our results on the ρ- and ω-meson study. Also listed in Table 3 are results obtained in the ϕ-meson energy range using the tagged kaons and η-mesons. This is a good demonstration of the high potential of ϕ-factories for high precision studies of the kaon and η-meson properties. Finally, we present the cross section of the kaon regeneration and total inelastic cross section obtained for the first time at a very small momentum of 110 MeV/c, also relevant to CP studies at the ϕ-factories.

This work is supported in part by the grants: RFBR-98-02-1785, INTAS 96-0624.

Table 3:

	CMD-2 Data	PDG'98
m_ω, MeV	$782.65 \pm 0.09 \pm 0.10$	781.94 ± 0.12
Γ_ω, MeV	$8.82 \pm 0.18 \pm 0.20$	8.41 ± 0.09
Γ_{ee}, keV	$0.63 \pm 0.01 \pm 0.02$	0.60 ± 0.02
$Br(\omega \to \pi^+\pi^-)$	$(1.3 \pm 0.3)\%$	$(2.21 \pm 0.30)\%$
m_ρ, MeV	$775.28 \pm 0.61 \pm 0.20$	776.0 ± 0.9
Γ_ρ, MeV	$147.7 \pm 1.29 \pm 0.40$	150.5 ± 1.1
Γ_{ee}, keV	$6.93 \pm 0.11 \pm 0.10$	6.77 ± 0.32
$Br(\rho \to e^+e^-)$	$(4.67 \pm 0.15) \cdot 10^{-5}$	$(4.49 \pm 0.22) \cdot 10^{-5}$
$Br(\rho \to \pi^+\pi^-\pi^+\pi^-)$	$< 2 \cdot 10^{-5}$	$< 2 \cdot 10^{-4}$
$Br(K_S \to \pi e\nu)$	$(7.19 \pm 1.35) \cdot 10^{-4}$	$(6.70 \pm 0.07) \cdot 10^{-4}$, recalculation from K_L
$Br(K^+ \to \pi^+\pi^0)$	$(21.69 \pm 0.48 \pm 1.03)\%$	$(21.16 \pm 0.14)\%$
$Br(K^+ \to \pi^0e^+\nu)$	$(4.89 \pm 0.17 \pm .17)\%$	$(4.82 \pm 0.06)\%$
$Br(\eta \to e^+e^-\gamma)$	$(7.56 \pm 0.92 \pm 1.13) \cdot 10^{-3}$	$(4.9 \pm 1.1) \cdot 10^{-3}$
$Br(\eta \to \pi^+\pi^-e^+e^-)$	$(3.5 \pm 2.0) \cdot 10^{-4}$	$(13^{+12}_{-8}) \cdot 10^{-4}$
$Br(\eta \to \pi^+\pi^-)$	$< 3 \cdot 10^{-4}$	$< 9 \cdot 10^{-4}$
$Br(\eta \to \pi^0\pi^0)$	$< 5 \cdot 10^{-4}$	no data
σ_{reg}(Be, 110 MeV/c)	(55.1 ± 5.9 ± 5.0) mb	no data
σ_{tot}(Be, 110 MeV/c)	(580 ± 72 ± 174) mb	no data

References

1. G.A.Aksenov *et al.*, Preprint Budker INP 85-118, Novosibirsk, 1985.
   E.V. Anashkin *et al.*, ICFA Inst. Bull. **5** (1988) 18.
2. V.V.Anashin *et al.*, Preprint Budker INP 84-114, Novosibirsk, 1984.
3. R.R.Akhmetshin *et al.*, Phys. Lett. **B364** (1995) 199.
4. R.R.Akhmetshin *et al.*, Phys. Lett. **B398** (1997) 423.
5. R.R.Akhmetshin *et al.*, Phys. Lett. **B415** (1997) 445.
6. R.R.Akhmetshin *et al.*, Phys. Lett. **B415** (1997) 452.
7. R.R.Akhmetshin *et al.*, Phys. Lett. **B434** (1998) 426.
8. R.R.Akhmetshin *et al.*, Preprint Budker INP 98-83, Novosibirsk, 1999.
9. R.R.Akhmetshin *et al.*, Preprint Budker INP 99-10, Novosibirsk, 1999.
10. R.R.Akhmetshin *et al.*, Preprint Budker INP 99-11, Novosibirsk, 1999.
11. C.Caso *et al.*, Eur. Phys. J. **C3** (1998) 1, Review of Particle Physics.
12. A. Lysenko *et al.*, Nucl. Instr. Meth. **A359** (1995) 419.
13. N.N.Achasov and V.N.Ivanchenko, Nucl. Phys. **B315**(1989) 465.
    N.N.Achasov, V.Gubin and E.P.Solodov, Phys. Rev. **D55** (1997) 2672.
    N.N.Achasov and V.Gubin, Phys. Rev. **D57** (1998) 1987.
14. M.Hashimoto, Phys. Rev. **D54** (1996) 5611.
15. S.I.Eidelman, JETP Lett. **26** (1977) 417.

Frascati Physics Series Vol. XV (1999), pp. 489-498
WORKSHOP ON HADRON SPECTROSCOPY - Frascati, March 8-12, 1999

RECENT RESULTS FROM SND EXPERIMENT AT THE VEPP-2M e^+e^- COLLIDER

M.N. Achasov, V.M. Aulchenko, K.I. Beloborodov, A.V. Berdyugin, A.V. Bozhenok, A.D. Bukin, D.A. Bukin, S.V. Burdin, T.V. Dimova, S.I. Dolinsky, A.A. Drozdetsky, V.P. Druzhinin, M.S. Dubrovin, I.A. Gaponenko, V.B. Golubev, V.N. Ivanchenko, I.A. Koop, A.A. Korol, M.S. Korostelev, S.V. Koshuba, G.A. Kukartsev, E.V. Pakhtusova, V.M. Popov, A.A. Salnikov, S.I. Serednyakov, V.V. Shary, Yu.M. Shatunov, V.A. Sidorov, Z.K. Silagadze, A.N. Skrinsky, Yu.S. Velikzhanin, A.V. Vasiljev, A.S. Zakharov
Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia
Novosibirsk State University, Novosibirsk 630090, Russia

presented by V.N. Ivanchenko

ABSTRACT

The results of experiments with Spherical Neutral Detector (SND) at VEPP-2M e^+e^- collider in the energy range $2E_0 = (0.98 - 1.38)$ GeV are presented. The results are based on analysis of the data with the integrated luminosity 18.6 pb^{-1}.

1 Detector and Experiments

The SND detector [1, 2] was designed for experiments at the VEPP-2M e^+e^- collider in Novosibirsk. The main part of SND is an electromagnetic calorimeter built of 1632 NaI(Tl) crystals. The calorimeter energy resolution for photons can be approximated as $\sigma_E(E)/E = 4.2\%/E(GeV)^{1/4}$, an angular resolution is approximately equal to $\sigma_{\theta,\varphi} = 1.5°$. The calorimeter and the event reconstruction program allow to detect photons with the energies above 20 MeV with a solid angle coverage 90% of 4π. In this work we present the results of the following SND experiments:

- **PHI96** [3]: 7 scans of the energy region 985–1040 MeV were performed, integrated luminosity is 4.3 pb^{-1}, corresponding to $8.2 \cdot 10^6$ ϕ decays.
- **MHAD97** [4]: the data collected in the energy region 1040-1380 MeV with the integrated luminosity 6.3 pb^{-1}.

- **PHI98** [5]: 2 scans of the energy region 985–1050 MeV were performed with the integrated luminosity 8.0 pb^{-1}, corresponding to $12.2 \cdot 10^6$ ϕ decays.

2 Decays $\phi \to \eta\gamma, \pi^0\gamma$

In the analysis of the PHI96 experiment two radiative decays $\phi \to \eta\gamma$ and $\phi \to \pi^0\gamma$ were studied in 3-gamma final state in the processes $e^+e^- \to \eta\gamma, \pi^0\gamma \to \gamma\gamma\gamma$. The main background comes from QED processes $e^+e^- \to \gamma\gamma, \gamma\gamma\gamma$. The analysis of the data is based on the kinematic fit of the events employing the 4-momentum conservation. The obtained cross sections of processes $e^+e^- \to \eta\gamma, \pi^0\gamma$ (Fig.1) were fitted in the framework of the vector dominance model (VDM). Phases of vector mesons were $\varphi_\rho = \varphi_\omega = 0$, $\varphi_\phi = \pi$ for $\eta\gamma$ decay, $\varphi_\phi = (158 \pm 11)^\circ$ for the $\pi^0\gamma$ decay. As the results of the fit the following values were obtained:

$$B(\phi \to \eta\gamma) = (1.338 \pm 0.012 \pm 0.052)\%, \quad (1)$$

$$B(\phi \to \pi^0\gamma) = (1.226 \pm 0.036^{+0.096}_{-0.089}) \cdot 10^{-3}, \quad (2)$$

where systematic errors include uncertainties in the integrated luminosity (2.5%), in the detection efficiency (2%), and in the values $B(\phi \to e^+e^-)$ (3%) and $B(\eta \to \gamma\gamma)$ (1%). The decay $\phi \to \eta\gamma$ was studied [7] also in the final state $\eta \to 3\pi^0$. The standard SND cuts [3] for the energy-momentum balance were applied to the events with 6 to 8 photons. The spectra of the recoil mass of the most energetic photon (Fig.2) demonstrates that the background from the process $\phi \to K_S K_L$ is small. So, event sample is clean and the following result was obtained:

$$B(\phi \to \eta\gamma) = (1.296 \pm 0.024 \pm 0.057)\%. \quad (3)$$

3 Decay $\phi \to \eta'\gamma$

The first observation of the $\phi \to \eta'\gamma$ decay was done at VEPP-2M in the CMD-2 experiment [8]. The measurement of this decay by SND was performed using the decay mode $\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^-\gamma\gamma$. The main problem of this measurement is large cross sections of the background processes $e^+e^- \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$, $e^+e^- \to \pi^+\pi^-\pi^0$, and $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$. For the analysis the events with two charged tracks and three photons were studied. To suppress the background a complex selection algorithm was developed [9]. That allowed to obtain the decay rate

$$B(\phi \to \eta'\gamma) = (6.7^{+3.4}_{-2.9}) \cdot 10^{-5}. \quad (4)$$

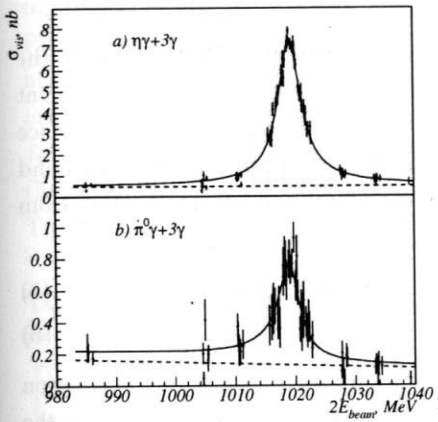

Figure 1: *Visible cross section for $\eta\gamma$ and $\pi^0\gamma$ events. Points – data, solid lines – result of the fit, dashed lines – QED background.*

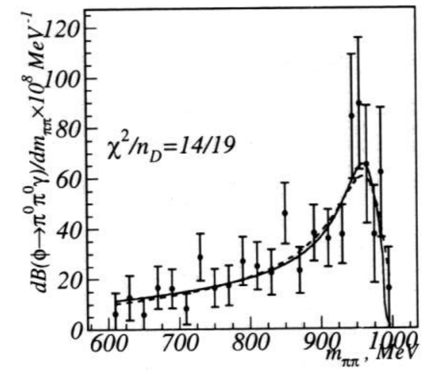

Figure 3: *The measured $\pi^0\pi^0$ invariant mass spectrum in the $\phi \to \pi^0\pi^0\gamma$ decay. Points – data, solid line – the result of the "broad resonance" fit, dashed line – the result of the "narrow resonance" fit.*

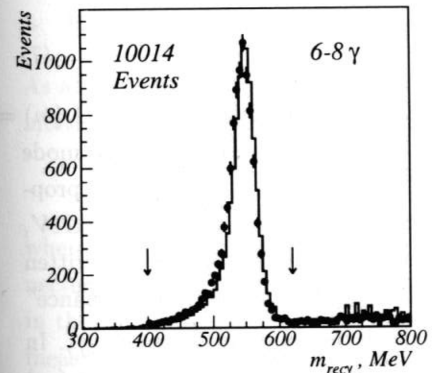

Figure 2: *The recoil mass of the most energetic photon in an event in study of the $\phi \to \eta\gamma \to 3\pi^0\gamma$ decay. Points – data, histogram – simulation.*

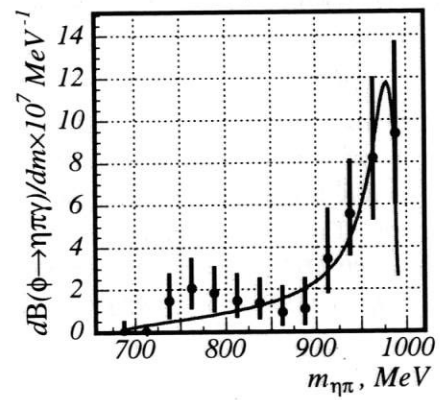

Figure 4: *The measured $\eta\pi^0$ invariant mass spectrum for the $\phi \to \eta\pi^0\gamma$ decay. Points – data, solid line – the result of the fit.*

4 Decay $\phi \to \pi^0\pi^0\gamma, \eta\pi^0\gamma$

First indications [10] of the decay $\phi \to \pi^0\pi^0\gamma, \eta\pi^0\gamma$ were seen by SND in 1997 on the base of half statistic of PHI96. After completing the analysis of PHI96 experiment the results were published in [11, 12]. In 1998 CMD-2 [13] confirmed the existence of both decays. These rare decays are seen after strong suppression of background processes $\phi \to \eta\gamma \to 3\pi^0\gamma$ and $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ using full information from the SND calorimeter. As a result the branching ratios were obtained

$$B(\phi \to \pi^0\pi^0\gamma) = (1.14 \pm 0.10 \pm 0.12) \cdot 10^{-4}, \quad (5)$$

$$B(\phi \to \eta\pi^0\gamma) = (0.83 \pm 0.23 \pm 0.12) \cdot 10^{-4}, \quad (6)$$

where the systematic errors are determined mainly by the background subtraction (5%) and the detection efficiency estimation (8%). For the decay $\phi \to \pi^0\pi^0\gamma$ the enhancement at large $m_{\pi\pi}$ (Fig.3) is compatible only with the large $f_0\gamma$ contribution. The result (5) is not based on model assumptions about a f_0 structure. Assuming that the process is fully determined by $f_0\gamma$ one can obtain from (5) $B(\phi \to f_0(980)\gamma) = (3.42 \pm 0.30 \pm 0.36) \cdot 10^{-4}$. But it is well known [14] that the intermediate state $\sigma\gamma$ may also give a contribution. In that case the mass spectrum can be described by the following expression:

$$\frac{dBr(\phi \to \pi^o\pi^o\gamma)}{dm_{\pi\pi}} = \frac{2m_{\pi\pi}^2\Gamma(\phi \to f_0\gamma)\Gamma(f_0 \to \pi^0\pi^0)}{\pi\Gamma_\phi}\left|\frac{1}{D_f(m_{\pi\pi})} + \frac{A_\sigma \cdot e^{i\varphi_\sigma}}{D_\sigma(m_{\pi\pi})}\right|^2 \quad (7)$$

where $A_\sigma = g_{\sigma\pi\pi}g_{\phi\sigma\gamma}/g_{f\pi\pi}g_{\phi f\gamma}$ takes into account contribution from σ-meson, $D_x(m) = m_x^2 - m^2 - i \cdot m\Gamma_x(m)$ is a scalar meson propagator. Because the decay mode $f_0 \to KK$ is negligible, the relation $\Gamma_f(m) = 3\Gamma(f_0 \to \pi^0\pi^0)$ is used in the f_0 propagator. The σ-meson parameters were fixed according to Ref. [14] $m_\sigma = 1\ GeV$, $\Gamma_\sigma = 800\ MeV$, $\varphi_\sigma = 0$. The width of decay of the scalar meson can be written as $\Gamma(f_0 \to \pi^0\pi^0) = g_{f\pi^+\pi^-}^2/32\pi m_{\pi\pi} \cdot \sqrt{1 - 4m_{\pi^0}^2/m_{\pi\pi}^2}$. In the "narrow resonance" approximation [15] the width $\Gamma(\phi \to f_0\gamma)$ depends on the coupling constant $g_{\phi f\gamma}$. In the "broad resonance" fit the model [16] was used. In this case the width $\Gamma(\phi \to f_0\gamma)$ depends on the product $g_{\phi KK} \cdot g_{fKK}$. The results of the fit are presented in Table 1. Comparison of the results of the fits shows strong model dependence of f_0-meson parameters. Of course, the "broad resonance" parameterization looks more realistic. In this case the value of the coupling constants obtained from the fit agrees with the predictions of 4-quark MIT-bag model [16, 17].

More complicated situation is in the analysis of the $\phi \to \eta\pi^0\gamma$ decay, because the statistics here is lower and background is larger. In the PHI96 experiment [12] the effect is seen on level of 3σ only and the spectrum of invariant masses

$m_{\eta\pi}$ does not give evidence for any intermediate state in the decay. The analysis of PHI98 was improved in such a way that detection efficiency does not vanish for the highest part of the $m_{\eta\pi}$ spectrum (Fig.4). It is the first evidence for the $a_0(980)\gamma$ intermediate state, that gives new argument for 4-quark nature of the light scalars f_0 and a_0. Fit of this spectrum was performed using the model [16] and as a result the parameters were obtained $m_{a_0} = (985 \pm 7)MeV$ and $g_{a_0K^+K^-}^2/4\pi = (0.67_{-0.14}^{+0.18})$. The preliminary value $B(\phi \to \eta\pi^0\gamma) = (0.89 \pm 0.18) \cdot 10^{-4}$ coincides with (6).

Table 1: *The results of the fit of two pion mass spectrum for the $\phi \to \pi^o\pi^o\gamma$ decay for different models.*

Model	$m_{f,\mathrm{MeV}}$	$\Gamma_{f,\mathrm{MeV}}$	$\frac{g_{fKK}^2}{4\pi}$, GeV^2	$\frac{g_{f\pi\pi}^2}{4\pi}$, GeV^2	$\frac{g_{fKK}^2}{g_{f\pi\pi}^2}$	A
Narrow	984 ± 12	74 ± 12	-	0.20 ± 0.03	-	0
Narrow	968_{-7}^{+12}	61_{-19}^{+26}	-	$0.16_{-0.05}^{+0.07}$	-	$1.8_{-1.1}^{+1.4}$
Narrow/Wide	987_{-9}^{+7}	98_{-22}^{+29}	-	$0.27_{-0.06}^{+0.08}$	-	$0.6_{-0.6}^{+0.7}$
Wide	970 ± 6	188_{-33}^{+48}	$2.13_{-0.56}^{+0.89}$	$0.51_{-0.09}^{+0.13}$	4.1 ± 0.9	0
PDG98 [6]	980 ± 10	40-100				

5 Rare Decays of $\phi(1020)$

As a rule, rare ϕ decay reveals itself not as resonance in the cross section but as an interference pattern in the energy dependence of the Born cross section

$$\sigma(s) = \sigma_B(s) \cdot |1 - Z \cdot m_\phi\Gamma_\phi/D_\phi(s)|^2, \quad (8)$$

where $\sigma_B(s)$ is the nonresonance cross section, Z is the interference amplitude connected with ϕ decay. In SND experiments two reactions of such type were studied in the energy region around ϕ-meson peak: $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \omega\pi^0$. The measurement of the decay $\phi \to \mu^+\mu^-$ rate is the direct measurement of the leptonic width of ϕ, based on $\mu - e$ universality. Alternative measurements of the branching ratio $B(\phi \to .e^+e^-)$ at e^+e^- colliders are performed through summation of cross sections over all ϕ decay channels [18]. The main sources of background to $\mu^+\mu^-$ events are the cosmic muons, Bhabha scattering, and $\pi^+\pi^-$ events. To suppress the background a procedure of $e/\pi(\mu)$ separation was developed. Time of flight information as well as a track position with respect to the beam are used for rejection of cosmic muons. After background subtraction and applying radiative corrections [19] the cross section of the process $e^+e^- \to \mu^+\mu^-$ was found (Fig.5). It was fitted and, as a result, the following value was obtained:

$$\sqrt{B(\phi \to e^+e^-)B(\phi \to \mu^+\mu^-)} = (3.14 \pm 0.22 \pm 0.14) \cdot 10^{-4}. \quad (9)$$

The $\phi \to \omega\pi^0$ decay was discovered in the PHI96 experiment [20]. This decay is OZI and G-parity violating, so the predicted branching fraction of this decay is about $5 \cdot 10^{-5}$. It varies [21] within the wide limits depending on the nature of ρ, ω and ϕ-meson mixing and decays. The search was performed in the reaction $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$. Event selection is based on various kinematic fits, taking into account intermediate state of the process and probability of observation of fake photons in the calorimeter. In the analysis the dE/dx information from the SND drift chambers was used also. The obtained cross section (Fig.6) demonstrates a significant signal of the ϕ decay. The nonresonance cross section is in agreement with ND data [22]. In studying the interference pattern in the cross section energy dependence both real and imaginary parts of the decay amplitude were obtained (Tabl.2). In the Table the preliminary results of the analysis of PHI98 are shown which are in agreement with PHI96 data. The obtained values of $Re(Z)$ in both experiments support the "weak" $\phi - \omega$ mixing model [21].

Table 2: *The results of the fit of the cross section of the process $e^+e^- \to \omega\pi^o$.*

Experiment	Re(Z)	Im(Z)	$Br(\phi \to \omega\pi^o) \cdot 10^5$
PHI96	$0.104 \pm 0.028 \pm 0.006$	$-0.118 \pm 0.030 \pm 0.009$	$4.8^{+1.9}_{-1.7} \pm 0.8$
PHI98	$0.125 \pm 0.015 \pm 0.006$	$-0.108 \pm 0.019 \pm 0.009$	-

6 Search for CP-violation in K_S Decays

The new search for the CP-violating decay mode $K_S \to 3\pi^0$ has been performed in both PHI96 and PHI98 data. For that only neutral events with six or seven detected photons were studied. As a result the new upper limit was established $B(K_S \to 3\pi^0) < 1.4 \cdot 10^{-5}$, (90% CL), which is the best at the moment [6].

7 Cross Sections of Hadron Production

The main goal of the MHAD97 experiment [4] was a thorough measurement of different hadronic production cross sections, which can facilitate more precise tests of theoretical models, studying dynamics of hadron production, check if there are sizeable contribution from radial excitations ρ', ω', ϕ', and determine the contribution

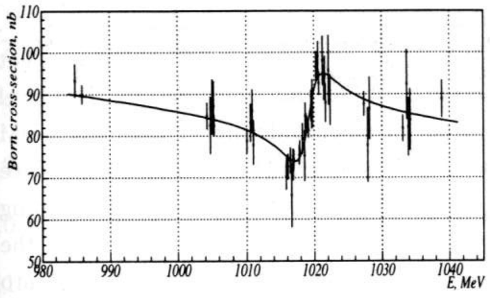

Figure 5: *The Born cross section of the process $e^+e^- \to \mu^+\mu^-$. Points - data, line - the result of the fit.*

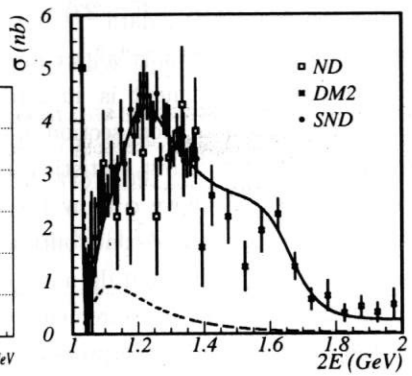

Figure 7: *The Born cross section of the process $e^+e^- \to \pi^+\pi^-\pi^0$. Points - data, solid line - the result of the fit with four resonances, dashed line - the contribution of ω and ϕ.*

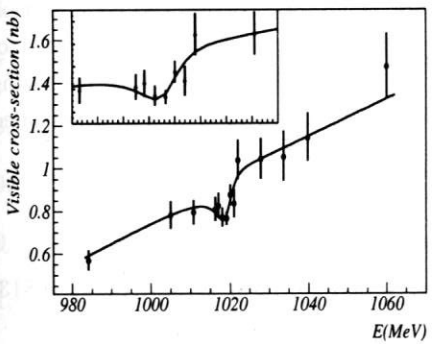

Figure 6: *The Born cross section of the process $e^+e^- \to \omega\pi^0$. Points - data, line - the result of the fit.*

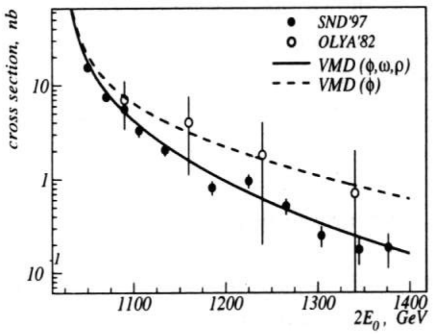

Figure 8: *The Born cross section of the process $e^+e^- \to K_SK_L$. Points - data, solid line - the result of the fit with three resonances ρ, ω, and ϕ, dashed line - only ϕ contribution.*

of this energy region into the QCD sum rule integrals. Measured cross sections of the process $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ are in agreement with all previous experiments [22] and with the new CMD-2 data [23]. On the contrary, preliminary SND data for the cross section $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ are lower than the results of ND [22]. On the other hand, this new measurement is in agreement with the data at higher energies [24].

The measured cross section of the process $e^+e^- \to \pi^+\pi^-\pi^0$ is in agreement with the ND data [22], but statistical accuracy is several times better. The level of this cross section above ϕ is by the order of magnitude higher than the VDM prediction based on ω and ϕ contributions only. These data (Fig.7) indicate existence of the resonance $\omega(1200)$ and do not confirm any signal of $\omega(1420)$ [6]. Combining the SND data with the measurements of ND [22], CMD-2 [25], and DM2 [26], the fit on the cross section of the process $e^+e^- \to \pi^+\pi^-\pi^0$ was performed taking into account contributions of ω, ϕ, $\omega(1200)$, and $\omega(1600)$. The mass and the width of the $\omega(1600)$ were fixed from the DM2 data [26] on the reaction $e^+e^- \to \omega\pi^+\pi^-$. The relative phases of resonances was fixed to be 0, π, π, 0, respectively. As a result of the fit the following parameters of $\omega(1200)$ were obtained: $m_{\omega'} = (1170 \pm 8)\ MeV$, $\Gamma_{\omega'} = (187 \pm 14)\ MeV$ with the $\chi^2/n_D = 154/154$, and with the systematic errors estimated to be 50 MeV.

The cross section of the process $e^+e^- \to K_S K_L$ was measured also (Fig.8). It was shown that the contributions of ρ, ω, and ϕ mesons describe this cross section well. Possible signal of higher states is not seen. The search was performed of the direct tensor meson production $e^+e^- \to f_2(1270) \to \pi^0\pi^0$. After applying standard SND cuts no events were found and a new upper limit was established $B(f_2 \to e^+e^-) < 6 \cdot 10^{-10}$, $(90\%\ CL)$.

8 Acknowledgment

The work is partially supported by RFBR (Grants No 96-15-96327, 99-02-16813, 99-02-16815, 99-02-17155) and STP "Integration" (Grant No 274).

References

1. V.M. Aulchenko *et al.*, Proc. of Second Workshop on physics and detectors for DAΦNE, Frascati, Italy, April 4–7, 1995, pp.605-613.
2. V.M. Aulchenko *et al.*, Preprint IYF 99-16, Novosibirsk, 1999.
3. M.N. Achasov *et al.*, Proc. of HADRON'97, p.26.

4. M.N. Achasov *et al.*, Budker INP 97-78, Oct 1997; hep-ex/9710017.
5. M.N. Achasov *et al.*, Budker INP 98-65, Sep 1998; hep-ex/9809013.
6. C. Caso *et al.* (Particle Data Group), Europ. Phys. Jour. **C3** 1 (1998).
7. M. Achasov *et al.*, JETP Lett **68**, 573 (1998).
8. R.R. Akhmetshin *et al.*, Phys. Lett. B **415**, 445 (1997).
9. V.M. Aulchenko *et al.*, Pis'ma v ZhETF, **69**, 87 (1999).
10. M.N. Achasov *et al.*, Proc. of HADRON'97, p.783; hep-ex/9711023.
11. M.N. Achasov *et al.*, Phys. Lett. **B 440**, 442 (1998).
12. M.N. Achasov *et al.*, Phys. Lett. **B 438**, 441 (1998).
13. R.R. Akhmetshin et al., Budker INP 99-11, Feb 1999; Novosibirsk, 1999.
14. N.N. Achasov, V.V. Gubin, Phys. Rev. **D 56**, 4084 (1997).
15. N.N. Achasov, V.V. Gubin, Phys. Lett. **B 363**, 106 (1995).
16. N.N. Achasov, V.N. Ivanchenko, Nucl. Phys. **B 315**, 465 (1989).
17. R.L. Jaffe, Phys. Rev. **D 15**, 267, 281 (1977).
18. R.R. Akhmetshin et al., Phys. Lett. **B 364** 199 (1995).
19. A.B. Arbuzov *et al.*, hep-ph/9702262.
20. M.N. Achasov *et al.*, Phys. Lett. **B 449**, 122 (1999).
21. N.N.Achasov,A.A.Kozhevnikov, Int. J. Mod. Phys. **A 7** 4825 (1992).
22. S.I.Dolinsky *et al.*, Phys. Reports **202** 99 (1991).
23. R.R. Akhmetshin *et al.*, Budker INP 98-83.
24. S.I. Eidelman, V.N. Ivanchenko, Nucl. Phys. Proc. Suppl. **55C** 181 (1997).
25. R.R. Akhmetshin *et al.*, Phys. Lett. **B 434** 426 (1998).
26. A. Antonelli et al., Z.Phys. C **56** 15 (1992).

16. F. Iazzi, Total $\bar{n}-p$ cross section from 50 to 400 MeV/c and hint for a narrow $\bar{n}-p$ state, in: Proc. International Nuclear Physics Conference INPC98, August, 24-28, 1998, Nucl. Phys.**A** (special issue), in press

17. S. Tessaro *et al*, $\bar{p}$ annihilation cross sections, in: Proc. LEAP98 (ed. S. Serci, Villasimius, September 1998), in press

18. P. Gauzzi, these proc.

19. V. Perepelitsa, these proc.

20. J.M. Richard, these proc.

21. J. Carbonell, these proc.

22. K. Protasov, these proc.

23. D. Hertzog, LEAR Highlights Symposium, CERN, May 1998

24. A. Feliciello, *et al*, Total and annihilation $\bar{n}-p$ cross section from 50 to 400 MeV/c, in: Proc. LEAP98 (ed. S. Serci, Villasimius, September 1998), in press

25. A. Feliciello, these proc.

26. A. Zenoni, these proc.

27. V. Crede', these proc.

28. J. Riedlberger *et al*, Phys. Rev. **C40**, 2717 (1989)

29. M. Gaspero, these proc.

Frascati Physics Series Vol. XV (1999), pp. 667-676
WORKSHOP ON HADRON SPECTROSCOPY - Frascati, March 8-12, 1999

VECTOR MESONS

V.N. Ivanchenko
Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia
Novosibirsk State University, Novosibirsk 630090, Russia

ABSTRACT

The summary of the Vector Mesons Session of the Workshop is presented. The radiative decays of light vector mesons and the spectrum of vector mesons are discussed.

1 Introduction

The physics of vector mesons has many years of history and so many aspects that it is not possible to represent all topics not only in one session but in the whole workshop. It is why we are trying to limit the subject of the discussion and concentrate our attention mainly on new results obtained in the energy region below 1.8 *GeV*. In this energy area several methods are intensively used, which provide effective vector mesons production and studying: e^+e^- collisions, photoproduction, diffractive production, and τ-lepton decays.

The progress in the experiment to study low energy meson spectroscopy in last years was great. It is why experimental talks dominate in the session: S. Giovannella (Frascati, KLOE) [1], E. Solodov (Novosibirsk, CMD-2) [2], V. Ivanchenko (Novosibirsk, SND) [3], T. Handler (Tennessee, E687 and FOCUS) [4], A. Bruni (Bologna, H1 and ZEUS) [5], R. McNulty (Liverpool, DELPHI) [6], and I. Kravchenko

(Cornell, CLEO) [7]. Progress in theory of vector mesons is much slower, and the only one theoretical presentation of M. Napsuciale (Guanajuato) [8] has been done.

2 Experimental Facilities

For more than 25 years the experiments are carried out at the e^+e^- collider VEPP-2M in Novosibirsk [9, 10]. The energy region of VEPP-2M is $2E_0 = (0.4-1.4)\ GeV$. At the moment two detectors are in operation: CMD-2 [11, 12] and SND [13, 14, 15]. The total integrated luminosity collected by each detector is about 28 pb^{-1}, which corresponds to $2 \cdot 10^7$ ϕ-mesons produced, 10^6 ω-mesons, and $2 \cdot 10^6$ ρ-mesons. The main goals of these experiments are precise measurement of the hadron production cross sections and the spectroscopy of light mesons.

From the 1999 ϕ-factory DAΦNE [16] is in operation in Frascati. The KLOE detector [17] is designed for studying CP-violation in the K_SK_L system. At the same time, KLOE provides outstanding possibility for studies of spectroscopy of light mesons. Planned integrated luminosity for the first experimental run 200 pb^{-1} is higher by the order of magnitude than that collected by SND and CMD-2.

The alternative method of studying the spectroscopy in the 1 GeV energy region is photoproduction. In FNAL the FOCUS detector [18] is in operation on the 200 GeV photon beam derived from bremmstrahlung of secondary electrons of the Tevatron proton beam. The experiment is designed for photoproduction of the charm but, at the same time, the facility provides production of vector states below the charm threshold, including ρ-meson. In the previous E687 experiment $\sim 3 \cdot 10^6$ $\pi^+\pi^-$ events were collected [4], in the FOCUS experiment the collected statistics is by the order of magnitude higher. In the Jefferson Laboratory the detector RADPHI [19] is designed for ϕ-meson photoproduction by 4 GeV tagged photon beam to study rare radiative $\phi(1020)$ decay modes. The strong competition between the photoproduction experiments and the e^+e^- experiments is foreseen in near future.

Vector mesons can be produced by the week charged current in hadronic decays of τ-lepton. The greatest sample of reconstructed τ events ($\sim 4 \cdot 10^6$) is available for analysis in the CLEO-II experiment [20], which is carried out at the b-factory CESR in Cornell University. Experiments at LEP were performed for several years in the peak of Z-boson and high statistics of hadronic decays of the τ-lepton is studied by all LEP detectors [21].

The problems of diffractive photoproduction of vector mesons have been investigated at HERA in positron/electron collisions with protons in the reactions

$ep \to epV$ and $ep \to eVX$. The wide scales of kinematic variables of virtual photons (γ^*) are available, the center of mass energy of γ^*p system varies in the range $(20-240)\ GeV$. Two great detectors H1 [22] and ZEUS [23] are in operation.

3 Radiative Decays of $\phi(1020)$

The studies of the radiative decays of light vector mesons (ρ, ω, ϕ) play an important role in understanding the electromagnetic structure of $q\bar{q}$-states and low-energy behavior of the strong interaction [24, 25, 26, 27]. Until now the e^+e^- experiments provide the best accuracy of the measurements of the radiative decays of neutral vector mesons. In the recent SND and CMD-2 experiments the new radiative decays of $\phi(1020)$ are observed (Table 1).

New measurements [12, 28, 29] of the most probable radiative decays $\phi \to \eta\gamma, \pi^0\gamma$ have been performed using the neutral decay modes of η and π^0. The results are in agreement with PDG tables [30] and with previous measurements [31]. In the SND experiment the statistical accuracy about $(1-2)$ % is achieved but systematic uncertainty is estimated at level of $(5-8)$ %. Partly the systematic is connected with the detector imperfectness, for example, with the luminosity measurement (2.5 % for SND). Such type of systematics may be decreased by improving the performance of the analysis procedure. But there are two sources of the systematics which are common for all e^+e^- experiments: the uncertainty in the branching ratio $B(\phi \to e^+e^-)$ (3 %) and uncertainty in the interference amplitude in the ϕ-meson energy region $(2-6$ %). The last systematic error will be decreased if the accuracy of the cross sections measurements in the energy region outside ϕ will be higher. The leptonic width of ϕ is determined by the two methods:

- direct measurement of the decay $\phi \to \mu^+\mu^-$ and using the μ/e universality;
- the measurement of the total cross section in the ϕ-meson maximum via the sum of cross sections of the main ϕ-meson decay modes.

Increasing the accuracy for both the value of $B(\phi \to e^+e^-)$ and the nonresonant cross sections measurements is very necessary to achieve 1 % uncertainty in the measurement of ϕ-meson decays.

The decay $\phi \to \eta'\gamma$ is a long-searched process expected by many authors to clarify the question about the gluonium (or $c\bar{c}$) content of η'. The first measurement of CMD-2 [32], is confirmed now by SND [33]. Recent CMD-2 results [12] were obtained with the use of two η' decay modes. The new values of the branching ratio are two times lower than the result of the first observation and are in agreement with the expectations based on quark model [24, 34] or on SU(3) symmetry [27]. Possible gluonium content in η' is small. KLOE experiment has a good perspective to improve the accuracy.

In the SND experiment [35, 36] the decay modes $\phi \to \pi^0\pi^0\gamma$ and $\phi \to \pi^0\eta\gamma$ were discovered and later the results were confirmed by CMD-2 [12]. In the invariant mass of $\pi^0\pi^0$ the signal of $f_0(980)$ meson dominates. The first evidence of the $a_0(980)$ signal in the spectrum of $\pi^0\eta$ was reported at this workshop [3]. Note, that statistics is poor in this first observation and there is an evidence of other contributions to the spectrum. KLOE [1] will have higher precision both decay modes and has a possibility to study in details the decay $\phi \to \pi^+\pi^-\gamma$. The CMD-2 [2] data for the last decay are in agreement with the results on the decay $\phi \to \pi^0\pi^0\gamma$ only under assumption of the destructive interference between two main amplitudes, which contribute to the process $\phi \to \pi^+\pi^-\gamma$.

Table 1: *The data on radiative decays of $\phi(1020)$.*

Decay	SND [3]	CMD-2 [2]	PDG'98
$\phi \to \pi^0\gamma$	$(1.23 \pm 0.10) \cdot 10^{-3}$	-	$(1.31 \pm 0.13)10^{-3}$
$\phi \to \eta\gamma, \eta \to 3\pi^0$	(1.296 ± 0.062) %	(1.240 ± 0.063) %	(1.26 ± 0.06) %
$\eta \to 2\gamma$	(1.338 ± 0.053) %	-	
$\eta \to \pi^+\pi^-\pi^0$	-	(1.18 ± 0.07) %	
$\phi \to \eta'\gamma$	$(6.7^{+3.4}_{-2.9}) \cdot 10^{-5}$	$(13.5^{+5.9}_{-4.9}) \cdot 10^{-5}$	$(12^{+7}_{-5}) \cdot 10^{-5}$
	-	$(5.8 \pm 2.3) \cdot 10^{-5}$	-
$\phi \to \pi^+\pi^-\gamma$	-	$(0.28 \pm 0.09) \cdot 10^{-4}$	$< 3 \cdot 10^{-5}$
$\phi \to \pi^0\pi^0\gamma$	$(1.14 \pm 0.16) \cdot 10^{-4}$	$(1.08 \pm 0.19) \cdot 10^{-4}$	$< 10^{-3}$
$\phi \to \eta\pi^0\gamma$	$(0.83 \pm 0.26) \cdot 10^{-4}$	$(0.90 \pm 0.26) \cdot 10^{-4}$	$< 2.5 \cdot 10^-3$
	$(0.89 \pm 0.22) \cdot 10^{-4}$		

4 The Nature of Light Scalars $f_0(980)$ and $a_0(980)$

After the first search of the rare ϕ decays by the ND detector [31] N. Achasov suggested [26] that study of decays $\phi \to \pi^0\pi^0\gamma$ and $\phi \to \pi^0\eta\gamma$ can provide a unique information on the structure of the lightest scalars $f_0(980)$ and $a_0(980)$. Subsequent studies [37, 38, 39, 40, 41, 42] proved this idea. In these works different models of the structure of these mesons were considered. The most popular were 2-quark model [43], 4-quark MIT-bag model [44], and $K\overline{K}$ molecular model [39].

SND demonstrates the first evidence [3] of $a_0(980)$ signal in the $\pi^0\eta$ mass spectrum. If this observation will be confirmed, it will be a very strong support for

4-quark MIT bag model [44] of $a_0(980)$ meson. This statement is based on the following arguments, which were formulated for the first time by N. Achasov [45,46]:

- the $a_0(980)$ meson has isotopic spin 1, so it includes $(u\overline{u} - d\overline{d})/\sqrt{2}$ quark state;
- the branching ratio of the decay $\phi \to a_0\gamma \to \eta\pi^0\gamma$ is practically the same as the branching ratio $\phi \to \eta'\gamma$, the recoil photon energy is the same for both decay modes, so there is no significant OZI rule suppression in both processes and there is $s\overline{s}$ pair in both a_0 and η' mesons.

So, a_0 has to include significant contribution of the $s\overline{s}(u\overline{u} - d\overline{d})/\sqrt{2}$ state. At the level of first experiments it is not possible to determine the detailed structure of a_0. Both configuration, the 4-quark bag and the $K\overline{K}$ molecule, may give some contributions. We cannot exclude some contribution of the 2-quark state $(u\overline{u} - d\overline{d})/\sqrt{2}$ too.

The same conclusion can be done for the structure of $f_0(980)$. The value of the coupling constant $g^2_{fKK}/4\pi = 2.13$, obtained from the fit of the $\pi^0\pi^0$ spectrum [35], agrees with the predictions of 4-quark MIT-bag model (2.3 GeV^2 [26, 44]) as well as the value of the branching ratio $B(\phi \to \pi^0\pi^0\gamma)$. In this model $f_0 = s\overline{s}(u\overline{u} + d\overline{d})/\sqrt{2}$. The corresponding predictions of the $K\overline{K}$ molecular model (0.6 GeV^2 [39, 47]), the $s\overline{s}$ model [26], and the $(u\overline{u} + d\overline{d})/\sqrt{2}$ model (0.3 GeV^2 [26]) are lower. On the contrary, another $s\overline{s}$ model [48] describe the data [35] well. Of course, there are open questions: what is the precision of the predictions [26, 48] and what is the contribution of σ-state [47]? Comparison of the results of the fits [3] shows a strong model dependence of f_0-meson parameters.

Note, that the analysis of all statistics collected by SND and CMD-2 will improve the accuracy by factor two, not more. KLOE [1] has a very good perspective to achieve much better precision.

5 The Spectrum of Vector Mesons

Increasing the statistical accuracy of experiments we come to a situation, when systematic uncertainty of main parameters of vector mesons are higher than corresponding statistical uncertainty. This systematic is connected with detector imperfectness and with model dependence of vector meson parameters. To illustrate this fact the masses and the widths of ρ-meson family are presented in the Table 2. The fits of the data for the reaction $e^+e^- \to \pi^+\pi^-$ and on the $\pi^+\pi^-$ photoproduction data differ systematically [30]. Moreover, the same data can be successfully described in different models [49].

Table 2: *The parameters of ρ, $\rho\prime$, and $\rho\prime\prime$, obtained in different experiments.*

Experiment	CMD-2 [2)]	CLEO-II [7)]	E687 [4)]	PDG'98
m_ρ, MeV	775.28 ± 0.64	774.3 ± 1.1	-	768.1 ± 1.3
Γ_ρ, MeV	147.70 ± 1.35	149.1 ± 1.6	-	151.0 ± 2.0
$m_{\rho\prime}$, MeV	$\equiv 1465$	1370 ± 12	$\equiv 1465$	1465 ± 25
$\Gamma_{\rho\prime}$, MeV	$\equiv 310$	386 ± 43	210 ± 77	310 ± 60
$m_{\rho\prime\prime}$, MeV	-	-	$\equiv 1700$	1700 ± 20
$\Gamma_{\rho\prime\prime}$, MeV	-	-	277 ± 50	235 ± 50

The problems of the family of ω-meson were discussed at the workshop too. First of all, new preliminary data of CMD-2 on the mass and width of $\omega(783)$ significantly differ from PDG values (Table 3). The value of the width is principal for the analysis of radiative decays of light mesons [24,27)] and for the understanding of the nature of the decay $\omega \to \pi^+\pi^-\pi^0$. The mechanism of the decay is mainly $\omega \to \rho\pi$, but significant contribution can be provided by the direct transition $\omega \to \pi^+\pi^-\pi^0$ via box diagrams. This contact amplitude is small, but it is shown [8)] that the interference of the boxes with the ρ-mediated amplitude leads to a sizeable effect in the width of the ω meson.

In the SND experiment the reaction $e^+e^- \to \pi^+\pi^-\pi^0$ in the energy range above $\phi(1020)$ was studied. The evidence of the $\omega(1200)$ resonance has been obtained and no signal of $\omega(1400)$ is observed. The resonance $\omega(1250)$ is required for the corresponding Regge trajectory [50)], 50 MeV mass difference is inside the model uncertainty. At the same time, it is difficult to accept this $\omega(1200)$ without confirmation in other processes. Isotopic invariance requires the existence of $\rho(1200)$ partner, which can be seen in the e^+e^- and photoproduction $\pi^+\pi^-$ data. At the moment old $\rho(1250)$ is excluded from the PDG tables, so additional study of the $\pi^+\pi^-$ data is necessary, which can show if there is any room for this resonance. Of course, the experimental confirmation of $\omega(1200)$ is required too.

According to CMD-2 study [52)], the $a_1(1260)\pi$ intermediate state dominates in the process $e^+e^- \to 4\pi$. Preliminary SND data [3)] do not yet confirm that additional work is necessary. The most clean samples of a_1 are observed in the τ decay modes $\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$, $\pi^+\pi^-\pi^-\nu_\tau$. The statistics of CLEO-II [7)] is great. That allows to analyze the hadronic current in details and to extract the contributions of $s-$, $p-$, and $d-$ waves into produced 3π system. Some indication of $a_1\prime(1700)$ is obtained. The process $\tau^- \to \pi^+\pi^-\pi^-\nu_\tau$ is studied by DELPHI [6)] also. The parameters of $a_1(1260)$ are obtained fitting the spectral function of the

Table 3: *The parameters of ω, $\omega\prime$, and $\omega\prime\prime$, obtained in different experiments.*

Experiment	CMD-2 [2)]	SND [3)]	DM2 [51)]	PDG'98
m_ω, MeV	782.65 ± 0.13	-	-	781.94 ± 0.12
Γ_ω, MeV	8.82 ± 0.27	-	-	8.43 ± 0.10
$m_{\omega\prime}$, MeV	-	1170 ± 50	1419 ± 31	1419 ± 31
$\Gamma_{\omega\prime}$, MeV	-	187 ± 50	174 ± 59	174 ± 59
$m_{\omega\prime\prime}$, MeV	-	-	1662 ± 13	1649 ± 24
$\Gamma_{\omega\prime\prime}$, MeV	-	-	280 ± 24	220 ± 35

decay $m_{a_1} = (1196 - 1264)\ MeV$, $\Gamma_{a_1} = (425 - 547)\ MeV$. The statistical errors are much smaller than the model uncertainty of these values. The evidence of $a_1\prime(1700)$ state is found out but mass and width of $a_1\prime$ cannot be determined from the data, so theoretical predictions for its values were used: $m_{a_1\prime} = 1700\ MeV$, $\Gamma_{a_1\prime} = 300\ MeV$. The signal of a_1 is seen in photoproduction data [4)] as well.

6 Diffractive Vector Mesons Production

Electron/positron collisions with protons at HERA provide the wide energy and momentum transfer ranges of the diffractive vector meson production [5)] from ρ-meson to Υ-mesons. The results on diffractive production of ρ, ω, and ϕ mesons can be described with a good accuracy by non-pertrubative approach based on Regge theory and Vector Dominance Model (VDM). It is connected with the soft scale of energy and momentum transfer and with the relatively large interaction radius. On the contrary, for the description of the J/ψ and Υ production the pertrubative QCD have to be applied. In this case the transverse size of the interaction is significantly smaller and VDM cannot describe the differential cross section slopes.

The analog QCD processes, so called "anomaly", are predicted for e^+e^- production. Of course, the anomaly contribution is estimated [49, 53)] to be small in comparison with the main VDM processes for the energy of e^+e^- interaction about 1 GeV, but as statistical precision of new experiments increases, the contributions of anomalies have to be taken into account or estimated to be negligible.

7 Conclusion

Few remarks can be done in the summary of the vector meson session.

- Great progress in all types of experiments was demonstrated during the session.

- SND experiment at Novosibirsk achieves statistical accuracy of (1 – 2) % for the main radiative decays but systematic uncertainty is still not better than 5 %. Limiting factors are uncertainty in the $B(\phi \to e^+e^-)$ and in the values of interfering nonresonant amplitudes.

- The existence of the decays $\phi \to \pi^0\pi^0\gamma$, $\pi^0\eta\gamma$, $\eta\prime\gamma$ at the level of 10^{-4} is confirmed by both Novosibirsk experiments. The results support 4-quark MIT bag model of f_0 and a_0 structure, but do not exclude other contributions. The gluonium content in the $\eta\prime$ is not seen.

- To use the full potential of KLOE for hadron spectroscopy the precise measurements of cross sections outside ϕ-meson are very necessary.

- Reexamination of $\rho(770)$, $\omega(783)$, and $a_1(1320)$ families seems to be unavoidable. For that it is necessary to perform not only phenomelogical analysis of the data but also to perform theoretical reexamination of the used models.

- New precise models for description of vector meson spectroscopy are welcome. It is real challenge for the theory to make predictions adequate to the precision of the experiment.

8 Acknowledgment

The author would like to thanks A. Bruni, S. Giovannella, T. Handler, V. Ivanchenko, I. Kravchenko, R. McNulty, M. Napsuciale, and E. Solodov, for presentations in the Vector Mesons Session of the Workshop and for frutful discussions. He is grateful to T. Bressani for opportunity to attend WHS99, to F. Fabbri and A. Filippi for the help in organization of the session, to INFN, Italy, and Russian Ministry of Science and Technology for financial support.

References

1. S. Giovannella, These proceedings.
2. E. Solodov, These proceedings.
3. V. Ivanchenko, These proceedings.
4. T. Handler, These proceedings.
5. A. Bruni, These proceedings.

6. R. McNulty, These proceedings.
7. I. Kravchenko, These proceedings.
8. M. Napsuciale, These proceedings.
9. A.N. Skrinsky, Proc. Workshop DAΦNE'95, (Frascati, 1995), p.3.
10. V.A. Sidorov, Proc. Workshop on Physics from ϕ to J/ψ, (Novosibirsk, 1999).
11. E.V. Anashkin *et al.*, ICFA Instr. Bull. **5**, 18 (1988).
12. R.R. Akhmetshin *et al.*, Budker INP 99-11, Novosibirsk, 1999.
13. V.M. Aulchenko *et al.*, Proc. Workshop DAΦNE'91, (Frascati, 1991), p.605.
14. M.N. Achasov *et al.*, Budker INP 98-65; e-Print Archive: hep-ex/9809013.
15. V.M. Aulchenko *et al.*, Preprint IYF 99-16, Novosibirsk, 1999.
16. The DAΦNE Project Team, Proc. of PAC93, p.1993.
17. The KLOE Collaboration, LNF-93/002(IR), January 1993.
18. W.K. Cheung *(E687 collaboration)*, Nucl. Phys. Proc. Suppl. **50**, 154 (1996).
19. J.J. Napolitano, Proc. Workshop on Physics from ϕ to J/ψ, (Novosibirsk, 1999).
20. The CLEO Collaboration, http://w4.lns.cornell.edu/.
21. Proc. Workshop TAU'98, (Santander, 1998).
22. The H1 Collaboration, http://www-h1.desy.de/.
23. The ZEUS Collaboration, http://www-zeus.desy.de/.
24. P.J. O'Donnell, Rev. Mod. Phys. **53**, 673 (1981).
25. L. Landsberg, Phys. Rep. **128**, 301 (1985).
26. N.N. Achasov, V.N. Ivanchenko, Nucl. Phys. **B 315**, 465 (1989).
27. M. Benayoun *et al.* Phys. Rev. D**59**, 114027 (1999).
28. M.N. Achasov *et al.*, JETP Lett. **68**, 573 (1998).
29. A.A. Salnikov, Proc. Workshop on Physics from ϕ to J/ψ, (Novosibirsk, 1999).

30. C. Caso *et al.* (Particle Data Group), Europ. Phys. Jour. **C3** 1 (1998).

31. S.I. Dolinsky *et al.*, Phys. Rep. **202**, 99 (1991).

32. R.R. Akhmetshin *et al.*, Phys. Lett. B **415**, 445 (1997).

33. V.M. Aulchenko *et al.*, Pis'ma v ZhETF (JETP Lett.), **69**, 87 (1999).

34. V.N. Ivanchenko, Proc. of the Workshop DAΦNE'95, (Frascati, 1995), p.559.

35. M.N. Achasov et al., Phys. Lett. **B 440**, 442 (1998).

36. M.N. Achasov *et al.*, Phys. Lett. **B 438**, 441 (1998).

37. J. Weinstein, N. Isgur, Phys. Rev. **D 41**, 2236 (1990).

38. A. Bramon, A. Grau, G. Panchieri, Phys. Lett. **B 283**, 416 (1992).

39. F.E. Close, N. Isgur, S. Kumano, Nucl.Phys. **B 389**, 513 (1993).

40. N. Broun, F.E. Close, The second DAΦNE Physics Handbook, Vol.2, Frascati: INFN Frascati, 1995, p.649.

41. A. Bramon, M. Greco, ibid, p.663.

42. J.L. Lucio, M. Napsuciale, Phys. Lett. **B 331**, 418 (1994).

43. N.A. Törnvist, Phys. Rev. Lett. **49**, 624 (1982).

44. R.L. Jaffe, Phys. Rev. **D 15**, 267, 281 (1977).

45. N.N. Achasov, Pis'ma v ZhETF (JETP Lett.) **68**, 549 (1998).

46. N.N. Achasov, Phys. Usp. **41** 1149 (1998); Usp. Fiz. Nauk **168** 1257 (1998).

47. N.N. Achasov, V.V. Gubin, Phys. Rev. **D 56**, 4084 (1997).

48. R. Delbourgo, Dongsheng Liu, M.D. Scadron, Phys. Lett. B**446**, 332 (1999).

49. M. Benayoun *et al.* Eur. Phys. J. C **2**, 269 (1998).

50. D.C. Peaslee, These proceedings.

51. A. Antonelli *et al.* Z. Phys. C **56**, 15 (1992).

52. R.R. Akhmetshin *et al.*, Budker INP 98-83.

53. M. Benayoun *et al.* Z. Phys. C **72**, 221 (1996).

Frascati Physics Series Vol. XV (1999), pp. 677-680
WORKSHOP ON HADRON SPECTROSCOPY - Frascati, March 8-12, 1999

PSEUDOSCALAR MESONS

Alberto Rotondi
Dipartimento di Fisica Nucleare e Teorica and
INFN Sezione di Pavia, Via Bassi, 6 27100 Pavia Italy

ABSTRACT

Some of the results on pseudoscalar mesons presented at the workshop are briefly discussed.

1 Is there any glue in the first 0^{-+} nonet?

The remarkable peculiarity of the first pseudoscalar nonet is the largest deviation from ideal mixing. One of the reasons could be the existence of a sizeable glue component in the η and η' mesons, due to pseudoscalar gluonium states mixed with $\bar{q}q$ states. However, the analysis of the J/Ψ decays [1] and the recent data on $\Phi \to \eta'\gamma$ coming from the CMD-2 experiment [2] seem to exclude this hypothesis. On the theoretical side, we recall also that relativistic quark models with instanton induced forces [3] can explain the $\eta - \eta'$ puzzle without any gluonium state.

In this workshop, Ambrosino has shown that the next $\Phi \to \eta'\gamma$ data from KLOE will achieve a relative accuracy of 2% and will permit a more accurate estimation of the standard SU(3) parameters of this nonet and the test of the strength of the gluonic terms [4]. KLOE has also the possibility to study the $\eta' \to \pi^+\pi^-\gamma$ decay, which is believed to proceed mainly through the $\rho(770)\gamma$ intermediate state with a small component of direct $\pi\pi\gamma$ decay due to the so-called box anomaly [5, 7]. Using this model and the known two-photon decay widths of η and η', the analysis of