LNF-91/020(R)
3 Maggio 1991

LNF-90/041 (R)
29 Maggio 1990

R. Barbieri, L. Maiani, G. Martinelli, L. Paoluzi, N. Paver, R. Petronzio, E. Remiddi:

REPORT FROM THE Φ FACTORY WORKING GROUP

INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-91/020 (R)
3 Maggio 1991

LNF-90/041 (R)
29 Maggio 1990

REPORT FROM THE Φ FACTORY WORKING GROUP

R. Barbieri
Dip. di Fisica, Universita' di Pisa;

L. Maiani, G. Martinelli
Dip. di Fisica, Universita' di Roma, La Sapienza;

L. Paoluzi
Dip. di Fisica, Universita' di Roma, Tor Vergata;

N. Paver
Dip. di Fisica, Universita' di Trieste;

R. Petronzio
Dip. di Fisica, Universita' di Roma, Tor Vergata;

E. Remiddi
Dip. di Fisica, Universita' di Bologna.

Forward

In 1990, a study group was formed, to provide the INFN Executive Board with an independent evaluation of the physics potential of DAFNE, a high luminosity Φ-factory, besides that of measuring the direct CP-violation parameter, ϵ'/ϵ. The study group conclusions appeared, in italian, as an internal report of the Frascati National Laboratories, LNF-90/041(R).

Now that the Φ-factory in Frascati has been approved, experiments are being conceived and detectors designed, we thought it appropriate to make the report available to a larger community, by providing an english translation of LNF-90/041(R).

The translation is due to Giuseppe Di Carlo, whom we gladly thank.

We thank, in addition, Enzo Iarocci, Giulia Pancheri and Rinaldo Baldini for their encouragement and interest.

1 Introduction

The project of a high luminosity e^+e^- machine, to be built in Frascati in the Adone building, has been considered. The machine characteristics are:

- C.M. energy: between the $\pi\pi$ threshold and 1.4 Gev, extendable to about 2 Gev.
- Luminosity between $10^{30}\ cm^{-2}sec^{-1}$ (at the $\pi\pi$ threshold) and $10^{32}\ cm^{-2}sec^{-1}$ (at 1.4 Gev) with a possible increase of one order of magnitude

This Φ-factory has been proposed mainly to determine the ϵ'/ϵ parameter, related to CP violation through the study of K_L decays . This possibility is now under specific feasibility study, not yet completed. It is clear to all the components of the group that the determination of ϵ'/ϵ is a scientific motivation more than sufficient to the construction of the machine itself.

The aim of this report, however, is to give an evaluation of the physics that can be done with this machine *apart* from the problem of ϵ'/ϵ . In the following we shall therefore completely ignore the question of ϵ'/ϵ .

2 General considerations and conclusions

The proposed machine is an excellent Φ-factory. In corrispondence with the decays

$$\phi \rightarrow K\bar{K}$$

$$\phi \rightarrow \gamma\eta$$

$$\phi \rightarrow \gamma\eta'$$

it is also a quite good K-factory, a fairly good η-factory and could be a good source of η'. With the cross section at the ϕ peak:

$$\sigma_{peak} = \frac{12\pi}{M^2}\frac{\Gamma_e}{\Gamma} = 4.4\ 10^{-30} cm^2$$

the luminosity of $2.5\text{x}10^{32} cm^{-2}sec^{-1}$ and a running time of 10^7 sec/year one can produce approximately

$$1.1\ 10^{10}\quad \phi/year$$

$$5.3\ 10^9\quad charged\ K's/year$$

$$3.8\ 10^9\quad K_{L,S}/year$$

$$1.7\ 10^8 \eta/year$$

In many cases it is necessary to tag the K-meson under study. If we assume to use the $K \to \mu\nu$ decay for tagging charged kaons, $K_S \to \pi^+\pi^-$ to tag K_L and $K_L \to \pi\mu\nu$ for the K_S, with the hypothesis that 65% of charged kaons , 100% of K_S and 25% of K_L decay inside the detector, the rates become:

$$2.8\ 10^9 \quad charged\ K's/year$$
$$2.6\ 10^8 \quad K_S/year$$
$$6.5\ 10^8 \quad K_L/year$$

These numbers refer to an ideal situation and do not include detector efficiencies.

It appears to us that the areas to which this machine can give a significant contribution are those related to high precision physics of hadronic interactions at low energy. In particular, we are referring to:

i) precise determinations of the characteristics of rare, but not very rare, K decays (with branching ratioes down to 10^{-6}),

ii) an improvement of some limits on decay ratioes down to 10^{-9},

iii) precision measurements of the hadronic production cross section from the $\pi\pi$ threshold to the ϕ peak and, eventually, up to 2 Gev ,

iv) vector meson spectroscopy between 1.4 and 2.0 Gev ,

v) ϕ radiative decays into $\gamma + \eta$, $\gamma + \eta'$, γ + scalar mesons.

In our opinion, the fulfillment of the scientific program of points i) and ii) can represent a significant advance in the understanding of low energy strong and weak interaction physics, and, as such, will constitute, by itself, a worthwhile undertaking.

The theoretical scheme in which this program can be discussed is that of Chiral Lagrangians, which describe low energy interactions of pseudoscalar mesons, π's and Kaons. This description takes into account in a rigorous way, the approximate chiral symmetry of strong interactions, in the Nambu-Jona Lasinio realization in which π and K are quasi-Goldstone bosons.

An experimental survey of all the K decay amplitudes should allow a more accurate verification of the relations that this symmetry implies and an extension of the predictive power of the effective Lagrangians.

In addition, the progress in lattice QCD calculations, forseeable in the next few years, should lead to the calculation of , at least, some of the coupling constants appearing in the effective Lagrangian. These values can then be compared with the experimental ones obtainable at the Φ-factory , and allow for a verification of QCD from first principles.

An isolated, self contained issue in K physics, is the study of CP asimmetry in charged K decays in three pions. An improvement of one order of magnitude in current limits appears possible and significant. Present theoretical estimates, up to now uncertain and based on the measurement of ϵ'/ϵ reported by the NA31 collaboration, predict an effect which at best is comparable with the statistical error corrisponding to the above cited production rates.

With respect to point (iii), the main goal is the reduction of the present error in the hadronic vacuum polarization contribution to the muon g-2, to put in evidence the electroweak contribution to this quantity. With present design luminosity, this reduction seems quite possible to attain. We have however to bear in mind the theoretical uncertainity which arises from the hadronic contribution to the light-by-light scattering diagrams, and which, in our opinion, has been quite understimed in the literature and could be comparable to the electroweak contribution.

The items of points (iv) and (v) are an interesting integration to the physics program, to be considered within the more general framework of hadronic spectroscopy, which cannot, however, be completed by the Φ-factory alone. In fact, systematical searches of exotic states, i.e. $qq\bar{q}\bar{q}$ states (excluding $\phi \rightarrow \gamma S$ decay), and "glueballs", do not seem realistic aims , due to the limitation in energy and cross section (relative to the possibilities of a J/ψ or charm factory).

The above referred K production rates rule out the possibility of getting informations on extremely rare K decays (branching ratioes below 10^{-10}) that could signal new physics beyond the Standard Model. Finally an aspect, which is no more relevant, is constituted by searches for a very light Higgs boson, since this has been ruled out by the recent LEP results.

In conclusion, K decays seem to offer a significant physics window for a Φ-factory. The possibility to determine the type and energy of the decaying particle (in particular for the K_S) should give an appreciable advantage over other types of K-factory under examination , which carry much higher statistics but with single K beams. It is clear that the detectors needed to achieve the necessary precision level will require a very advanced technology.

The actual feasibility of the above designed program, and the competitivity of Φ-factory experiments against the ones possible at other existing or planned K-factories, has to be checked with more detailed investigations.

3 Kaon physics and chiral Lagrangians

High energy experiments show in a convincent way that strong interaction are described by an exact gauge theory based on color symmetry (QCD), whose degrees of freedom are quarks and gluons. However, at low energy, the non perturbative regime of QCD has not allowed, up to now, to get quantitative and detailed predictions on hadronic dynamics, starting from the fundamental Lagrangian. Numerical simulations on the lattice, which are the most promising theoretical approach in this area, are still at a semi-quantitative level.

An approach, developed in the sixties to perform stringent tests on the properties of low energy strong interactions, is based on the approximate invariance of QCD under chiral transformations belonging to the group $SU(3)_L \text{x} SU(3)_R$[1].

$SU(3)_L$x$SU(3)_R$ is a symmetry spontaneously broken by strong interactions and in a soft way, by light quark masses. In this situation it is possible to get a rigorous description of the interaction of the quasi-Goldstone bosons, π, Kaons and η, in terms of the so-called chiral Lagrangian. As Goldstone bosons have a vanishing interaction in the zero quark mass and zero energy limit, it is possible to expand the amplitudes in increasing powers of momenta and masses. The $SU(3)_L$x$SU(3)_R$ symmetry implies strong restrictions on the coefficients of such an expansion, at any given order.

This situation is similar to that of an exact symmetry, for example rotational symmetry, in which the amplitudes have one part fixed by the symmetry itself, the Clebsch-Gordan coefficients, and one part dependent on the dynamics, the reduced amplitudes. Indeed, chiral Lagrangians are nothing else than the extension of the Wigner-Eckart theorem to a spontaneously broken symmetry.

At the lowest order, i.e. at m^2 or p^2 order, the amplitudes are specified through f_π and the quark masses. In terms of these parameters one can get several predictions, like the Weinberg formula for the $\pi\pi$ scattering lenght, or the Callan and Treiman relation for K_{l3} decay.

Recently several authors, Gasser and Leuthwyler[2], Donoghue and collaborators[3], etc., have provided an extension of the theoretical analysis to the first next order terms in the chiral Lagrangian (m^4, p^4, m^2p^2). This extension requires the introduction of many new parameters, to be fixed using experimental data. However, several amplitudes can still be predicted uniquely in terms of these parameters.

At the present level, many of the theoretical predictions have not been checked experimentally. In particular several of the K-meson decay amplitudes are theoretically fixed from parameters derived from pion physics, but have not yet been measured . An experimental verification of such predictions can thus be a precise test of non-perturbative QCD.

The effective Lagrangians are not able to fix a priori the parameter values. Once determined from experimental data, the parameters should then be compared with the values obtained from numerical simulations on the lattice, or from others non-perturbative methods eventually available. In such a way one can expect to give a crucial test of QCD as the theory of strong interactions, starting from the fundamental Lagrangian.

In the following we discuss briefly those kaon decays in which the contribution of a Φ-factory to the above described program can be significant.

3.1 Leptonic and semi-leptonic decays and related processes [3]

a) K_{l3}. At the lowest order of chiral theory the Callan and Treiman relation (CT) allows to predict the value of the radius of the scalar form factor. Existing data show a discrepancy between the radius as it is obtained from K^+, and which is not in agreement with the CT prediction, and the one obtained from K_L. Moreover recent experimental data on K_L are not compatible with each other, and some of them show a significant deviation from the CT relation.

b) K_{l4}. A precise measurement of the relative form factors should allow to fix some of the chiral Lagrangian parameters which are ill-determined from pion physics.

c) $K_{l2+\gamma}$, $K_{l2e^+e^-}$, $K_{l3+\gamma}$. Apart from the bremsstrahlung term, the structure dependent amplitudes of the first two processes are described by the charge radius of kaons, which is well known, and by three other parameters (h_V, h_A, r_A). The ratioes r_A/h_V and h_A/h_V are fixed from pion physics. Present data on $K_{l2+\gamma}$ give a $|h_V + h_A|$ determination in agreement with the theory, while $|h_V - h_A|$ practically has not been measured. The process $K_{l2e^+e^-}$ is very poorly determined and so there is no information on r_A. Also the process $K_{l3+\gamma}$ for what concerns the structure dependent (not bremsstrahlung) part has not been observed, so that it is impossible up to now to check the theoretical prediction, which depends on the same parameters as the others and on the f_K/f_π ratio.

An experimental clarification of point a) is of paramount importance, as well as the determination of the parameters correlated to the processes in paragraphs b) and c).

3.2 Decays involving the non-leptonic Hamiltonian, with photons or lepton pair emission[4]

a) $K^\pm \to \pi^\pm\gamma\gamma$. Chiral Lagrangians give an unique prediction on the rate and the invariant mass distribution of the two photons. Moreover the experimental observation should clarify the role of vector mesons in chiral Lagrangians. At the Φ-factory , with approximately one thousand events, it should be possible to reconstruct such a distribution.

b) $K_L \to \pi^0\gamma\gamma$. The same consideration stated above for the rate and invariant mass distribution can be applied here. Moreover from this process one can estimate the contribution of the (CP conserving) two photon exchange to the decay $K_L \to \pi^0 e^+ e^-$. When this process will be measured (the decay $K_L \to \pi^0 e^+ e^-$ can not be observed at the Φ-factory, due to luminosity limitations), it will thus be possible to identify the CP non-conserving part (one photon exchange) of this process.

c) $K \to \pi\pi\gamma$. The study of the non-bremsstrahlung contribution allows to check the validity of $\Delta I = 1/2$ rule, outside the area of the purely hadronic weak processes.

d) $K_L \to \gamma e^+ e^-$ $(\mu^+\mu^-)$. The high statistics obtainable (see Tab. 1) permits the study of the Dalitz plot of this process. This has some interest, since it allows to distinguish between various theoretical predictions which differ in the role played by the exchanged pseudoscalar mesons (π, η). Also, an experimental limit on the analogous process $K_S \to \gamma e^+ e^-$ (generated by chiral loops), although marginal because of machine luminosity, could be interesting.

In Tab. 1 we report, for processes a)-d) and other related ones, the theoretical predictions for the decay rates, the number of expected events per year, calculated from the theoretical predictions and from the production rates of tagged mesons (see Sect.2), and the present experimental values or limits.

TABLE I

	Theory (expected)	Events/year	Experiment
$K_S \to \gamma\gamma$	$2\ 10^{-6}$	(520)	$(2.4\pm1.2)\ 10^{-6}$
$K_S \to \gamma e^+e^-$	$3.2\ 10^{-8}$	(8)	--
$K_S \to \gamma\mu^+\mu^-$	$7.5\ 10^{-10}$	-	--
$K_L \to \gamma\gamma$	$[10^{-4}]$	$(6\ 10^4)$	$(4.9\pm0.4)\ 10^{-4}$
$K_L \to \gamma e^+e^-$	$9.1\ 10^{-6}$	$(6\ 10^3)$	$(1.7\pm0.9)\ 10^{-5}$
$K_L \to \gamma\mu^+\mu^-$	$2.3\ 10^{-7}$	(150)	$(2.8\pm2.8)\ 10^{-7}$
$K_L \to \pi^o\gamma\gamma$	$6.8\ 10^{-7}$	(440)	$< 2.7\ 10^{-6}$
$K^\pm \to \pi^\pm\gamma\gamma$	$5.8\ 10^{-7}$	$(1.6\ 10^3)$	$<1.0\ 10^{-6}$
$K_S \to \pi^o\gamma\gamma$	$3.3\ 10^{-8}$	(8)	--
$K^\pm \to \pi^\pm e^+e^-$	10^{-7} (theoretical input)	(700, no tag)	$(2.7\pm0.5)\ 10^{-7}$
$K^\pm \to \pi^\pm\mu^+\mu^-$	$6.1\ 10^{-8}$	(170)	$<2.3\ 10^{-7}$
$K_S \to \pi^o e^+e^-$	$5\ 10^{-9}$ - $5\ 10^{-10}$	(≤ 1)	$<4.5\ 10^{-5}$
$K_S \to \pi^o\mu^+\mu^-$	10^{-9} - 10^{-10}	(≤ 0.2)	--
$K^\pm \to \pi^\pm\pi^o\gamma \mid_{IB}$	$2.9\ 10^{-4}$	$(8\ 10^5)$	$(2.75\pm0.16)\ 10^{-4}$
$K^\pm \to \pi^\pm\pi^o\gamma \mid_{DE}$	$1.05\ 10^{-5}$	$(1.4\ 10^4)$	$(1.56\pm0.35)\ 10^{-5}$ $(2.05\pm0.46)\ 10^{-5}$ $(2.3\pm3.2)\ 10^{-5}$
$K_L \to \pi^+\pi^-\gamma \mid_{IB}$	$1.4\ 10^{-5}$	$(9\ 10^3)$	$(1.52\pm0.16)10^{-5}$
$K_L \to \pi^+\pi^-\gamma \mid_{DE}$	(1-8) 10^{-5}	$(2\ 10^4)$	$(2.89\pm0.28)10^{-5}$
$K_S \to \pi^+\pi^-\gamma \mid_{IB}$	$2.4\ 10^{-3}$	$(6\ 10^5)$	$(1.82\pm0.10)\ 10^{-3}$
$K_S \to \pi^+\pi^-\gamma \mid_{DE}$	(2-20) 10^{-8}	(5)	$< 6\ 10^{-5}$

3.3 CP violation in charged kaons

The evidence for charge asymmetry in $K^\pm$ decays is a direct proof of CP violation in the $\Delta S = 1$ weak Hamiltonian. The three pion decays:

$$K^\pm \to \pi^\pm\pi^\pm\pi^{+,-} \quad (\tau\ mode)$$

$$K^\pm \to \pi^\pm\pi^0\pi^0 \quad (\tau'\ mode)$$

are of particular interest. The asymmetries (differential or integrated) in the relative decay lenghts represent a CP violation proportional to ϵ' and are absent in a "superweak" theory.

In order to estimate the ϵ'-like effects in $K^0 \to 2\pi$, one has to bear in mind that only two final states, with isospin $I = 0, 2$, are allowed. On the contrary, in $K^\pm \to 3\pi$, in addition to the $I = 2$ amplitude, two amplitudes with $I = 1$, with different symmetries, can contribute. The suppression of the $I = 2$ amplitude , due to the $\Delta I = 1/2$ rule, depresses the CP violation effect in $K^0 \to 2\pi$, whereas an interference between the two $I = 1$ would allow for an effect in $K^\pm \to 3\pi$ not suppressed by the $\Delta I = 1/2$ rule.

In the literature, two diffent estimates of the asymmetry in $K^\pm \to 3\pi$ can be found.

The earlier ones [5,6] connect the $K \to 3\pi$ amplitude to the $K \to 2\pi$ amplitude through PCAC , i.e. through the use of chiral Lagrangians in lowest order. With this approximation, the contribution of one of the $I = 1$ amplitudes is lost, and the suppression due to the $\Delta I = 1/2$ rule holds also for $K \to 3\pi$. For the asymmetry in the widths in the τ channel [6] one thus obtains:

$$\Delta\Gamma(\tau) = \frac{\Gamma(\tau^+) - \Gamma(\tau^-)}{\Gamma(\tau^+) + \Gamma(\tau^-)} \leq 0.1 \;\; \epsilon' \quad (\textit{lowest order})$$

However it is conceivable that interference effects between the $I = 1$ amplitudes may increase the asymmetry estimates of as much as an order of magnitude[7]. A quantitative study of such effects requires the introduction of terms up to p^4 in the chiral Lagrangian. These terms depend on many unknown parameters. Following this line, but reducing rather arbitrarily the number of a priori relevant terms, Belkov et al.[8] have obtained the following predictions for the width asymmetries, $\Delta\Gamma$, and Dalitz-plot slopes,Δg:

$$\Delta\Gamma(\tau) = 5\ \epsilon' \simeq 3.9\ 10^{-5}$$
$$\Delta\Gamma(\tau') \simeq 1.1\ 10^{-4}$$
$$\Delta g(\tau) \simeq 1.4\ 10^{-3}$$
$$\Delta g(\tau') \simeq 1.4\ 10^{-3}$$

based on the ϵ'/ϵ measure reported by NA31.

These estimates are clearly uncertain, due to above cited reduction in the number of relevant parameters which are used. Moreover, they are probably optimistic: the absence of the $\Delta I = 3/2$ suppression, compensated in part by the chiral expansion parameter $(m_K/4\pi f_\pi)^2$, does not seem enough to justify the claimed increase of two orders of magnitude, with respect to the lowest order estimate of ref.[6].

The effects predicted in ref. [8] are at the limit of the statistical error corrisponding to the production rates given in sect.2. It does not appear that a CP violation in charged kaon decays can be easily evidentiated. However, the importance of any eventually detected effect and the possibility of significantly improve the present limits, make the study of $K \to 3\pi$ worth of careful consideration.

References

[1] S. Weinberg, Physica 96A (1979), 327; S. Coleman in Aspects of Symmetry, Cambridge University Press, 1985.

[2] J. Gasser, H. Leutwyler, Ann. Phys. (NY) 158 (1984), 142; Nucl. Phys. B250 (1985), 465.

[3] J.F. Donoghue, B.R.Holstein, Phys. Rev. D40 (1989) 3700.

[4] For a detailed review see: R. Battiston, D. Cocolicchio, G.L. Fogli, N. Paver CERN-TH 5664/90, 1990 published in "Proposal for a Φ-Factory", LNF-90/031(R), edited by M. Giorgi, M. Greco and M. Piccolo.

[5] C. Avilez, Phys. Rev. D30 (1981), 587.

[6] B. Grinstein, S. Rey and M. Wise, Pyhs. Rev D34 (1986), 1495.

[7] J. Donogue, B. Holstein and G. Valencia, Int. Jour. Mod. Phys. 2A (1987), 319.

[8] A. Belkov, G. Bohm, D. Ebert and A. Lanjov, Phys. Lett. 232B (1989), 118.

4 Total cross section and hadronic contribution to the muon g-2

The present experimental values for the μ anomaly are (Bayley et al.,ref.[1]):

$$a(\mu^-, exp) = (116593700 \pm 1200)10^{-11}, \quad (4.1a)$$

$$a(\mu^+, exp) = (116591100 \pm 1100)10^{-11}, \quad (4.1b)$$

The weak contribution from intermediate and Higgs boson loops is

$$a(\mu, weak) = (195 \pm 1)10^{-11}, \quad (4.2)$$

To check this prediction of electroweak theory we need, obviously, to reduce both the error in the experimental measurement as well as the error in the theoretical prediction of $a(\mu)$, to a level below that of the weak contribution.

The theoretical contributions are: a) of purely electromagnetic origin with virtually zero error[2] and b) of hadronic origin. The most complete estimate of the hadronic contributions is given in ref [3]:

$$a(\mu, hadr) = (7030 \pm 190)10^{-11}, \quad (4.3)$$

The largest part of the hadronic contribution and of the relative error in eq.(4.3) comes from:

$$a(\mu, h\ vac.pol.) = \frac{1}{4\pi^3} \int ds K(s) \sigma(e^+e^- \to hadrons; s)$$

where $\sigma(e^+e^- \rightarrow hadrons; s)$ is the total cross section for $e^+e^- \rightarrow hadrons$ annihilation at the energy $\sqrt{s}$, characterizing the immaginary part of the hadronic vacuum polarization. Given the functional form of K(s), the contribution in the low energy region is predominant. It is also the most important source of error, due to the fact that, as well known, there are no good low energy data in this region.

A theoretical estimate [4], which uses basically the same experimental data, but with a different theoretical model for the pion and kaon form factors, confirms the previous result.

The error 190 in eq.(4.3), table III of reference [3], corresponds to the combination in quadrature of a statistical error of 59 and a systematic error of 164. 59 can be considered to be the quadratic sum of 21.5, 47.5, 18 and 21, which correspond to the statistical errors in the ρ, ω, ϕ region and from everywhere else, respectively . If the errors due to the first three of the above contributions could be made negligible, the overall statistical error could be reduced from 59 to 21.

Similarly, the systematic error 164 comes from 150, 14.9, 12.9 and 63 : if the first three of these systematic errors could become negligible, the total systematic error would come down to 63, and the total error to 67 (mostly from channels in which the total energy is larger than 1.4 GeV), a value much smaller than the weak contribution (4.2).

A good measurement of the total hadronic cross-section in the Φ-factory energy region can therefore reduce the error in eq.(4.4), quite below the electroweak contribution.

Another hadronic contribution to $a(\mu)$ comes from the diagrams from light-by-light scattering in which one photon is absorbed by the external field and the other three are emitted by a μ-line. The contribution from light-by-light scattering diagrams via hadronic states is estimated to be (49±5) 10^{-11} in ref.[3]. Unlike the case of the vacuum polarization contribution, which is based on experimental data, the calculation of hadronic light-by-light contribution is based upon purely theoretical considerations.

According to ref.[3], :

i) approximating the intermediate hadronic states with quark loops of masses $m_u = m_d = 0.3\ GeV, m_s = 0.5\ GeV, m_c = 1.5\ GeV$, one obtains

$$a(\mu, h\ \gamma\gamma)_{quarks} = (60 \pm 4)10^{-11} \tag{4.5}$$

ii) saturating the hadronic states with mesons, one obtains :

$$a(\mu, h\ \gamma\gamma)_{mesons} = (49 \pm 5)10^{-11} \tag{4.6}$$

consistent with the previous result and considered to be the better one.

To estimate the effect of a given choice of the quark masses, one can consider again the vacuum polarization contribution to lowest order in α. The contribution to $a(\mu)$ from vacuum polarization due to a quark of charge Q and mass m much larger than the μ mass, is

$$a(\mu, vac.pol.)_{quark} = (3Q^2)\frac{1}{45}\frac{m_\mu^2}{m^2}(\frac{\alpha}{\pi})^2 = 11990(3Q^2)\frac{m_\mu^2}{m^2}10^{-11}$$

If we want to reproduce the experimental hadronic contribution using the previous formula for u and d quark loops, the mass m must be such that

$$a(\mu, u+d) \approx 12.000\frac{m_\mu^2}{m^2}\frac{5}{3}10^{-11}$$

and thus $m \approx 0.18\ GeV$.

This is a rather disquieting result, since a value of $m = 0.18\ GeV$ in the light-by-light scattering term, which decreases like m^{-2}, would give a result which is about a factor 3 larger than the one in (4.5) and comparable with the electroweak contribution. This argument clearly indicates that the theoretical error on the light-by-light contributions has been underestimated in ref.[3], where the theoretical uncertainty associated to the quark mass m has not been taken into proper account.

A more detailed analysis of this issue is necessary. At the present time, it is not clear to us that a more precise determination of hadronic vacuum polarization can really lead to a prediction of $a(\mu)$ with an error smaller than the predicted weak contribution.

References

[1] Bailey et al., Nucl. Phys. B150(1979) 1.

[2] T.Kinoshita, B.Nizic and Y. Okamoto, Phys. Rev. D41 (1990), 593.

[3] T.Kinoshita, B.Nizic and Y. Okamoto, Phys. Rev. D31 (1985), 2108.

[4] L.Martinovic and S.Dubnicka, preprint DUBNA E2-89-144, 1989.

5 Spectroscopy

Interesting contributions to meson spectroscopy for masses below 2 Gev can be achieved in the following channels:

1) Direct production and study of 1^{--} states in the 1.0 - 2.0 Gev range (the first vector-meson recurrences).

2) Study of states obtained through ϕ decay.

3) Direct producion and study of states produced in $\gamma\gamma$ interactions.

Direct production of 1^{--} states in the 1.0 - 2.0 Gev range, has been studied mainly at ADONE (in the seventies) and at DCI, with a luminosity at 2 Gev of $3\text{x}10^{29} cm^{-2}sec^{-1}$ and $2\text{x}10^{30} cm^{-2}sec^{-1}$ respectively[1].

The available data on exclusive cross sections come principally from DCI and refer to cross sections of the order of 30 - 40 nb ($\sigma_{4\pi}$) and 1 - 5 nb (all the others). As an example we report $\sigma_{4\pi}$ and $\sigma_{\pi\pi\eta}$ in fig.1 and fig.2 .

There are still some problems in the interpretation of the data: in particular the interpretation of the bump in the 1500-1600 Mev zone in the 4π cross section (one or two resonances) as well as of the data concerning channels with an odd number of π's, where the statistics is very poor, is still in doubt .

The possibility of having a luminosity around $10^{32}\ cm^{-2}sec^{-1}$, with a production rate larger than 100 ev/hour , for a cross section of 1 nb, would allow to sensibly improve the quality of the data in the 1.0 - 2.0 Gev range, in one month of data taking. An accurate measurement of the π and K form factors could be achieved at the same time.

Of particular interest is the search of I=0 $J^{PC} = 0^{++}$ states, which can be obtained via radiative ϕ decay. The interpretation of these states as quarkonium, glueball or $K\bar{K}$ molecule could be clarified, as suggested recently in ref. [2], by measuring the branching ratioes, predicted in the 10^{-4} - 10^{-6} range, and comparing it with various theoretical expectations which differ from one another by roughly one order of magnitude (depending on different hypotheses).

The availability of a Φ-factory would also permit to increase significantly the limits on the so-called rare ϕ decays, presently measured at VKPP-2M[3] at a level of 10^{-3} - 10^{-4}, and to obtain significant results on $\eta\eta'$ mixing.

Scalar and tensorial states can be investigated by direct study of the $\gamma\gamma$ channel in $e^+e^- \rightarrow e^+e^-\gamma\gamma$ annihilation.

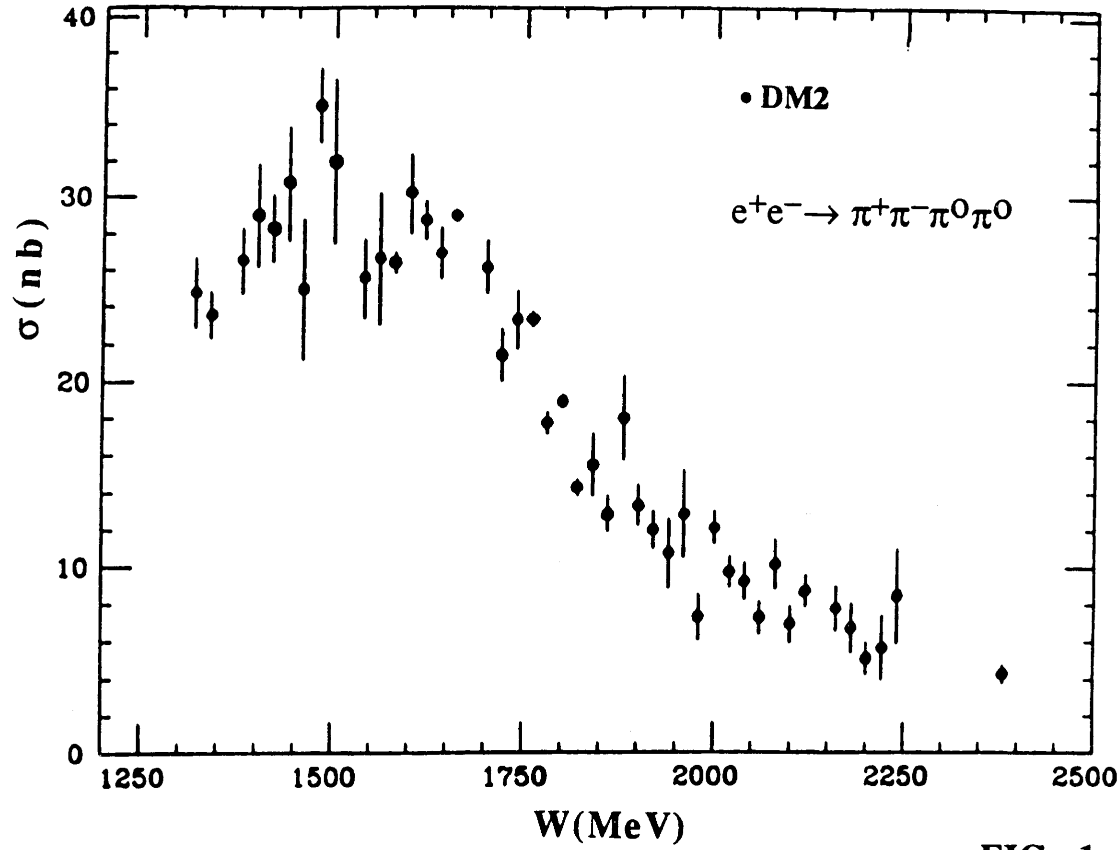
The energy range between 0.5 and 1.5 Gev has been studied at PEP and at DORIS, but in the coming years no machines with a c.m. energy below 5-6 Gev will be available and the possibility of an e^+e^- machine with a luminosity around $10^{32}\ cm^{-2}sec^{-1}$ at a C.M. energy of 2 Gev can make this an interesting research direction.

References

[1] See for instance R.Baldini in Fenice Workshop, October 1988.

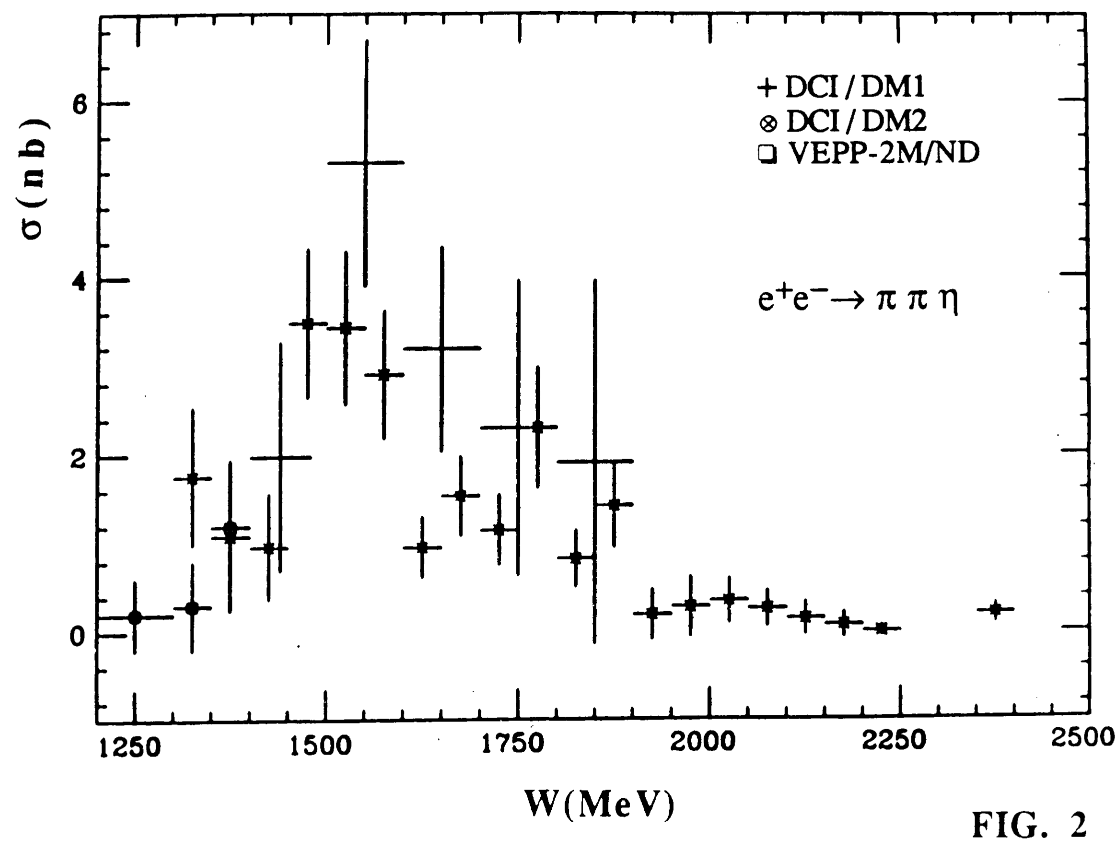
[2] F.Close and N.Isgur, Nov. 1989, unpublished; N.N.Achasov, V.I.Ivanchenko, Nucl. Physics B315 (1989) 465 ; J. Weinstein and N.Isgur , Phys. Rev. D41 (1990) 2336.

[3] Druzhinin et al., Zeit Phys. C37 (1987) 1.



• DM2
$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$
σ (n b)
W(MeV)
0
10
20
30
40
1250
1500
1750
2000
2250
2500

FIG. 1



+ DCI / DM1
⊗ DCI / DM2
❑ VEPP-2M/ND
$e^+e^- \to \pi\pi\eta$
σ (n b)
W(MeV)
0
2
4
6
1250
1500
1750
2000
2250
2500

FIG. 2