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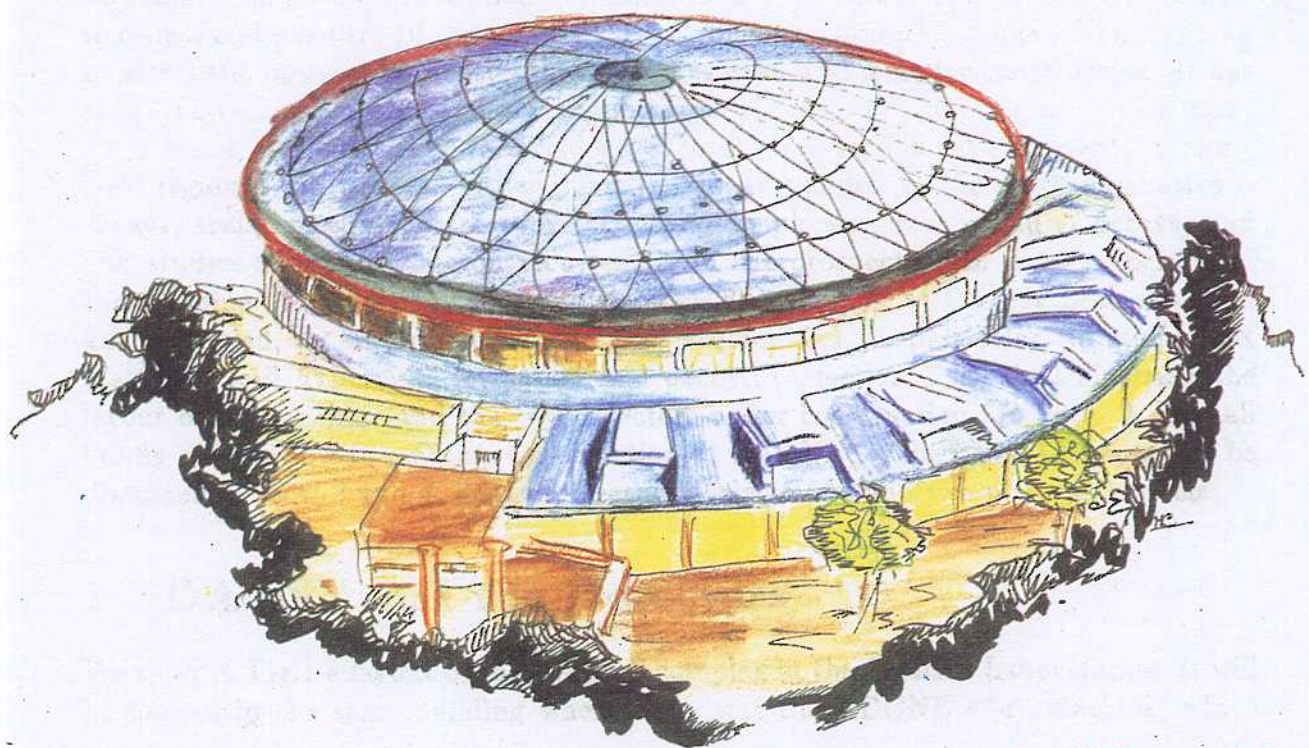
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HADRONS at DAΦNE

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Abstract

The Frascati ϕ -factory and its two planned detectors are introduced. Physics items of interest in hadron physics like chiral perturbation theory tests, vector meson dominance, two photon physics, radiative ϕ decays and the nature of scalar particles are discussed.

Introduction

In this lecture, I shall discuss some of the physics items of interest at DAΦNE [1], the symmetric ϕ -factory under construction in Frascati at INFN National Laboratories, to study CP-violation in the Kaon system [2]. The physics project aims to a precise determination of the CP-violating parameters ϵ and ϵ' , in particular of the ratio ϵ'/ϵ , recently measured with a 10^{-3} precision at CERN [3] and FermiLab[4]. For such a program, a large, high resolution, minimum bias type detector, called KLOE[5], able to collect and measure all the $10^9 \div 10^{10}$ K-meson pairs produced in one year of running at a realistic optimal luminosity, has been designed and is under construction. It has also been realized [6] that the physics potential of such a ϕ -factory encompasses many other items of physics, like rare K-decays, total cross-section measurements in the 1 GeV region, form factors. Other items [7] recently added to the list are radiative ϕ decays, scalar meson spectroscopy, two photon physics, rare ρ and ω decays, and also studies of ρ and ω -meson recurrences in the prospect of an energy upgrade of the machine. In addition, a second detector[8], called FINUDA has been designed and approved, to perform nuclear physics studies and, in particular, to study K-N scattering and hypernuclei formation and decay. In section 1 we shall illustrate the layout of the machine and the two detectors under construction. In Sect. 2 we shall briefly discuss how to measure CP-violation at DAΦNE, while hadron physics will be discussed in sect. 3 and 4, dedicated respectively to one and two photon channels.

1 DAΦNE and the Detectors

We show in Fig.1 a layout of the DAΦNE complex in the Frascati Laboratories. It will be housed in the same building where there was the ADONE e^+e^- machine, which

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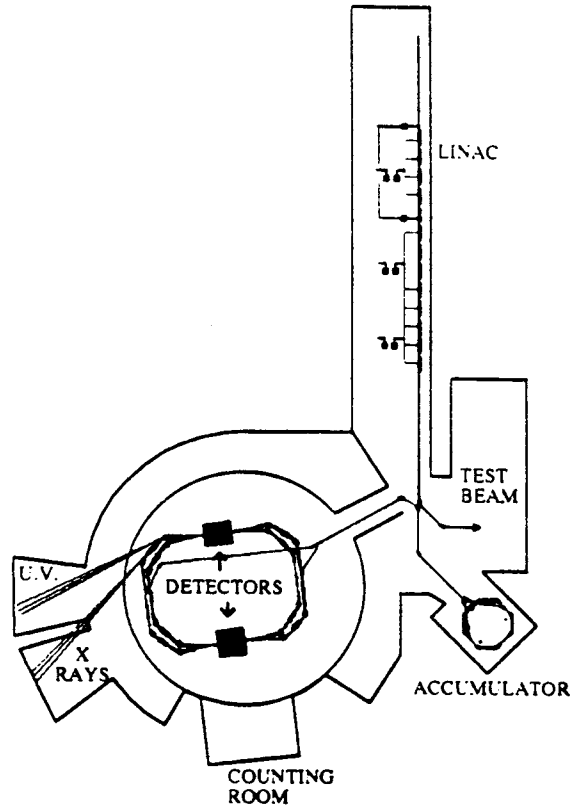


Figure 1: Layout of the DAΦNE complex at INFN National Laboratories in Frascati

has been recently dismantled. It is expected that DAΦNE will be available for physics experimentation in 1996.

DAΦNE, Double Accelerator for Nice Experiments, will be made of two storage rings in which electrons and positrons are made to circulate separately and collide at a horizontal half angle $\theta_x = 10 \div 15 \text{ mrad}$ so as to have a high collision frequency without parasitic crossings. DAΦNE will be a multibunch machine, and the project effort will be concentrated in guaranteeing the accumulation of at least 30 bunches for a total luminosity $1.3 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$. To reach the design luminosity, the number of bunches will then be raised up to 120. Already at such luminosity, DAΦNE appears as a unique opportunity for high statistics - high precision experiments in Kaon and hadron physics. We give in the following the expected yields for some processes of interest. We assume a luminosity

$$L = 5 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$$

and use the total cross-section formula at the resonance peak

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

which gives a production of $\approx 2.2 \times 10^{10}$ ϕ mesons per year (1 year = 10^7 sec). Then

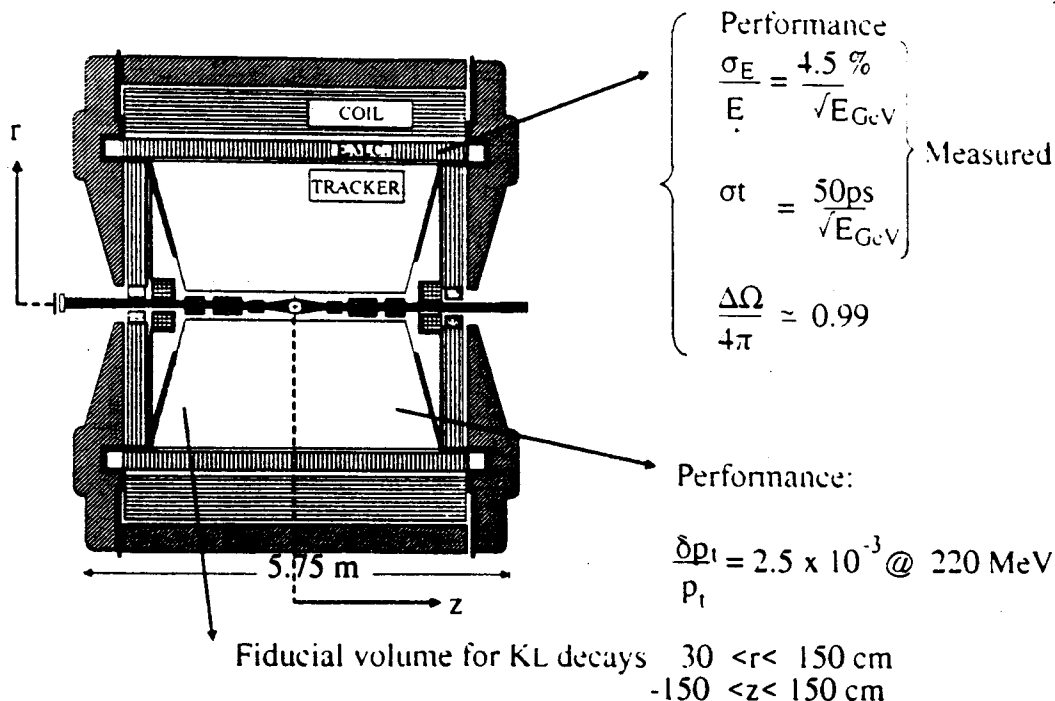


Figure 2: Schematic view of the KLOE detector and expected or measured performance of its components

for the indicated processes and branching ratios, we obtain the following table :

Table 1

Process	Branching Ratio	Number of events in 1 year
$\phi \rightarrow K^+ K^-$	0.495	1.1×10^{10}
$\phi \rightarrow K_L + K_s$	0.344	7.6×10^9
$\phi \rightarrow \eta\gamma$	0.012	2.8×10^8
$\phi \rightarrow \eta'\gamma$	$< 10^{-4}$	-

and we see that in addition of being a Kaon factory, DAΦNE will also be a good η factory.

There will be two interaction regions and two detectors have been approved for construction. Of these KLOE (K-Long Observation Experiment) will be dedicated to studying K-decays and hadron physics. The present design of the KLOE Detector is shown in Fig.2. It is a typical 4π detector, with a central tracking chamber, a calorimeter, a solenoid and muon chambers. There is a large fiducial volume for K_L decays, in which one expects about 35 per cent of all the K_L to decay and their decay products to be measured. In the figure we indicate the presently measured performance of the electromagnetic calorimeter [5] and the expected performance of the tracking chamber. The solenoid is planned to produce a 0.6 Tesla field. To avoid the adverse effect of the magnetic field on the beam, which would reduce the attainable luminosity, a system of compensating quadrupoles and solenoid has been envisaged. KLOE will also comprise a two photon tagging system, for wide angle detection.

The other detector FINUDA (FISica NUcleare at DAΦne) is a nuclear physics detector, which will use different nuclear targets both for K-N scattering as well as for

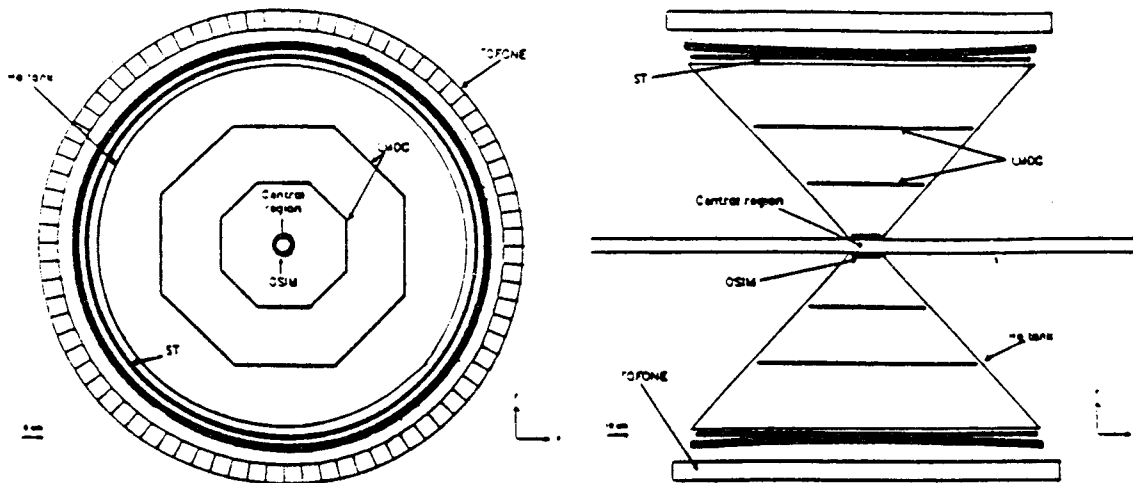


Figure 3: The proposed target/interaction region in the FINUDA detector

production of hypernuclei. Since the produced Kaons are very slow, with an energy of only ≈ 16 MeV, they can be stopped in a thickness of less than 100 mg/cm², thus avoiding straggling and uncertainties in the particle momenta. At DAΦNE, the uncertainty of the interaction point gives a momentum resolution well matched with the best magnetic spectrometer which can be designed. This is one of reasons for which the FINUDA Collaboration believes that experiments with stopped Kaons will be favoured at DAΦNE relative to other Kaon-factories. The physics program includes formation of new hypernuclei (as many as 25 new Λ -hypernuclei can be produced), Λ -hypernuclei spectroscopy and K-N scattering. We show in Fig.3 the two views of the proposed target/interaction region in the FINUDA detector.

2 CP-Violation measurements

As mentioned, the main goal of the KLOE Collaboration will be to measure CP-violation[2] in the Kaon system. At a ϕ -factory, the final state for ϕ decays into neutral Kaons is a C-odd state, allowing a "tagging" of the neutral Kaons, through observation of the process

$$e^+e^- \rightarrow \phi \rightarrow \bar{K}^0 K^0 \rightarrow \frac{K_S K_L - K_L K_S}{\sqrt{2}} \rightarrow \pi^+ \pi^-, \pi^0 \pi^0$$

through which one can study

- (i) time evolution of $K^0 \bar{K}^0$
- (ii) time asymmetries in the decays $\pi^+ \pi^-$ and $\pi^0 \pi^0$

- (iii) magnitude of the double ratio

$$\frac{\Gamma(K_L \rightarrow \pi^+\pi^-)}{\Gamma(K_S \rightarrow \pi^+\pi^-)} / \frac{\Gamma(K_L \rightarrow \pi^0\pi^0)}{\Gamma(K_S \rightarrow \pi^0\pi^0)} = 1 + 6\Re\frac{\epsilon'}{\epsilon}$$

- (iv) Branching ratios for different charge configurations

where the complex CP-violating parameters ϵ and ϵ' are defined from the amplitude ratios

$$\eta_{+-} = \frac{A(K_L \rightarrow \pi^+\pi^-)}{A(K_S \rightarrow \pi^+\pi^-)} = \epsilon + \epsilon'$$

and

$$\eta_{00} = \frac{A(K_L \rightarrow \pi^0\pi^0)}{A(K_S \rightarrow \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

In order to determine these parameters, one measures the distance travelled by the two K-mesons before decaying into a charged and neutral pion pair[9, 10, 11], respectively x_{ch} and x_0 . The number of events corresponding to a given $\{x_{ch}, x_0\}$ pair will be a function of $|\eta_{+-}|^2$, $|\eta_{00}|^2$, and of the interference between the amplitudes, i.e. $\Re\frac{\epsilon'}{\epsilon}$ and $\Im\frac{\epsilon'}{\epsilon}$. Then, if $x = x_{ch} - x_0$, integration over the symmetric variable $x_+ = x_{ch} + x_0$ defines the quantity

$$N(x) = \int N(x_{ch}, x_0) dx_+$$

from whence one can obtain the time asymmetry

$$A(x) = \frac{N(|x|) - N(-|x|)}{N(|x|) + N(-|x|)} = A_R(x)\Re\frac{\epsilon'}{\epsilon} - A_I(x)\Im\frac{\epsilon'}{\epsilon}$$

with the functions $A_R(x)$ and $A_I(x)$ such that at large x/x_s values, with x_s the distance covered by the decaying K_S during one life time, only the first terms of the above right hand side survives, allowing for a determination of $\Re\frac{\epsilon'}{\epsilon}$. Both the real and the imaginary parts of $\frac{\epsilon'}{\epsilon}$ can in principle be measured through a precise determination of the function $N(x)$ for a set of values of the distance x . If the space resolution is good enough, one can measure the expected dip in this function at $x=0$ and the asymmetrical behaviour at large positive x -values relative to the negative ones. The study in [10] indicates that an estimated accuracy $\sigma = 5mm$ could allow for a determination of $\Re\frac{\epsilon'}{\epsilon}$ with a precision of $\sim 10^{-4}$ and of $\Im\frac{\epsilon'}{\epsilon}$ with a precision of $\sim 10^{-3}$.

At present, the KLOE experiment under preparation[5] is geared to measure $\frac{\epsilon'}{\epsilon}$ with the double ratio method and to obtain a 10^{-4} precision for $\Re\frac{\epsilon'}{\epsilon}$.

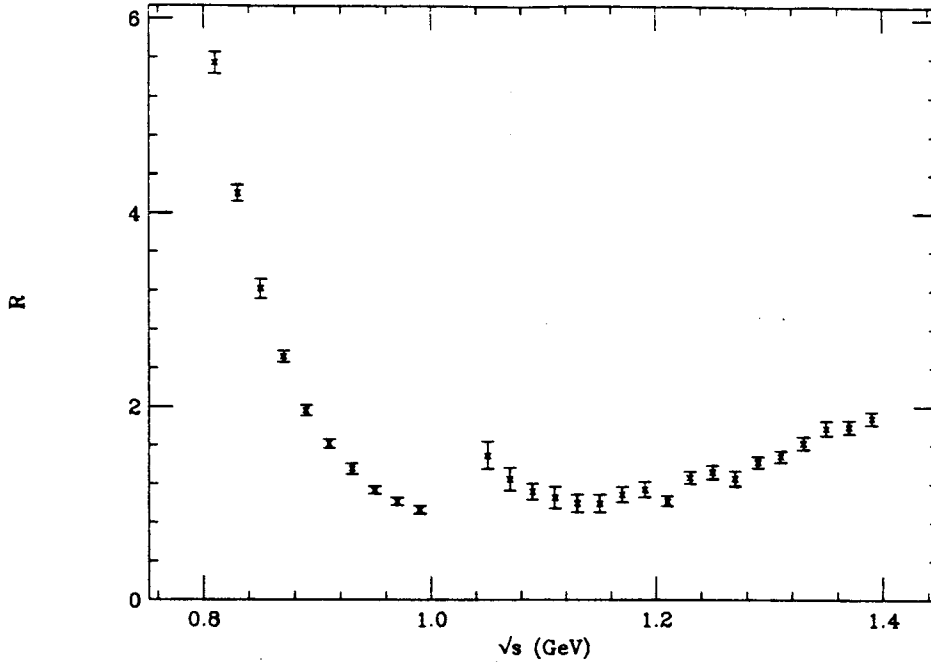


Figure 4: Ratio $R = \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$, from the Neutral Detector at VEPP2-M, data from ref. [14]. Only statistical errors are shown.

3 Hadronic Final States : One Photon Physics

In this section I shall discuss physics items which are accessed through the one photon channel, i.e. through the process

$$e^+e^- \rightarrow \gamma^* \rightarrow \text{all}$$

This includes a study of the total hadronic cross-section, of rare decays of resonances (ρ and ω) below the ϕ , of rare decays at the ϕ itself, and the study of the ρ and ω recurrences above the ϕ .

3.1 The Total Hadronic Cross-section

The cross-section in the energy region below and around $s = 1 \text{ GeV}^2$ is known with a precision no better than 10% [12, 13, 14]. The best data have been taken at VEPP-2M [14] and they are shown in Fig.4, where, following ref. [14], we have not included a 10% systematic error.

The value of σ_{had} in this region is of interest for the measurement of the muon $g-2$. The measured values [15]

$$a_{\mu^-}^{exp} = (116593700 \pm 1200) \times 10^{-11}$$

$$a_{\mu^+}^{exp} = (116591100 \pm 1100) \times 10^{-11}$$

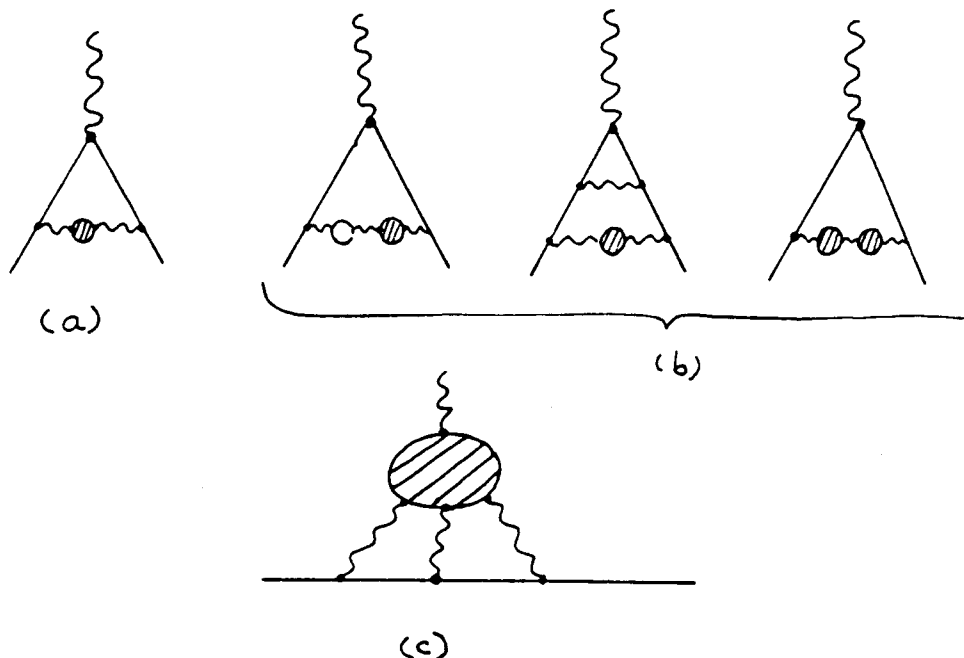


Figure 5: Examples of hadronic contributions to the muon $g-2$

can be compared with recent theoretical estimates [16, 17, 18], where the QED contribution is implemented by electroweak corrections and hadronic contributions from light by light scattering diagrams and from vacuum polarization insertion in the vertex diagram, as indicated in Fig.5. Writing

$$a_{\mu} = a_{\mu}(QED) + a_{\mu}(Electroweak) + a_{\mu}(hadrons)$$

the overall hadronic contribution from the graphs of Fig.5 was found to be [16]

$$a_{\mu}(hadron) = (7030 \pm 190) \times 10^{-11}$$

with the main part coming from Fig.5a. For this contribution one can write [19]

$$a_{\nu}^{had} = \frac{1}{4\pi^3} \int_{4m_{\pi}^2} ds \sigma_{e^+e^- \rightarrow hadrons}(s) K(s)$$

whith $K(s)$ a function coming from the triangle diagram shown in fig. 5a. The main contribution to the error comes from the poorly know region $s = 0.8 \div 2 GeV^2$, which is precisely where DAΦNE will operate. One can write

$$a_{\mu}(hadrons) = a_{\nu}(s \geq 2 GeV^2) + a_{\nu}(0.8 \geq s \geq 2 GeV^2) + \\ a_{\nu}(\leq 0.8 GeV^2) + a_{\mu}(higher had) + a_{\mu}(box)$$

where $a_{\mu}(higher had)$ and $a_{\mu}(box)$ come respectively from the graphs of Fig.5b and 5c. Using the evaluation of ref. [17] (consistent with [16] within the quoted errors), one has

type of contribution	value $\times 10^{-11}$	error $\times 10^{-11}$
$a_\mu(EW)$	195	1
$a_v(s \geq 2 \text{ GeV}^2)$	847	13
$a_v(0.8 \leq s \leq 2 \text{ GeV}^2)$	1404	100
$a_v(s \leq 0.8 \text{ GeV}^2)$	4848	31

from whence one can see that the error on the hadronic contribution from the vacuum polarization insertions is of the same order of magnitude as the entire electroweak term, so that no information about the electroweak sector can be gained from this measurement until the error on a_v is reduced.

Another interesting aspect of this measurement is that a reduced error on the contribution from Fig.5a will facilitate the study of contributions from the box diagram. For the latter, there is a theoretical uncertainty due to the choice of intermediate states[6, 7], which for the time being is completely shadowed by the error on the vacuum polarization contribution.

3.2 The Resonances below the ϕ

In [7] and subsequent work [20], it was realized that rare ρ and ω decays which can be studied at DAΦNE allow for tests of chiral perturbation theory [21] and of the possible ways in which to include vector mesons into the chiral lagrangian[21, 22, 23]. Among them, are the processes

$$e^+e^- \rightarrow \rho \text{ or } \omega \rightarrow \pi^0\gamma, \pi^0\gamma^*, \pi^0\pi^0\gamma, \rho \rightarrow \pi^+\pi^-\pi^+\pi^-$$

Chiral Perturbation Theory [21] is an effective theory of low energy Strong and Electroweak Interactions of hadrons, which incorporates the various symmetries and anomalies of Quantum Chromodynamics, with quarks and gluons as effective constituents of the meson fields. The effective lagrangian is expanded in powers of momenta and masses, and one denotes with L_2 the lowest order lagrangian. To it, one then adds a fourth order term, L_4 , which contains the QCD anomalies, so that L_2 and L_4 incorporate the basic tenets of the non-linear σ model. This lagrangian can then be used to calculate various physical quantities and loop contributions, some of which are divergent and thus cut-off dependent. To eliminate the divergences, one introduces a number of counterterms L_i which, order by order, cancel the divergent pieces from the loops, leaving at the same time finite contributions. These finite contributions can be related, through the description of specific processes, to a number of low energy constants. Thus the resulting effective low energy lagrangian can then lead to further predictions. However this procedure results in a large number of constants to be extracted from experiment : at the one loop level there are 10 constants for the non-anomalous sector and as many as 30 from the anomalous one. Experiments at

DAΦNE can help fix the value of some of these counterterms [25], through study of the above processes.

A separate question concerns the incorporation of Vector Mesons in the effective lagrangian as explicit vector fields. This possibility has been advanced by a number of authors and there exists different approaches, which can be summarized as follows :

- MYM : in the Massive Yang Mills approach [26] one starts with un gauged chiral lagrangian in which the vector mesons are successively introduced through the covariant derivatives, but with no way to give a mass to the the vector mesons;
- HS : in the Hidden Symmetry approach of Bando and collaborators [27] the vector mesons are gauge fields of a hidden local symmetry; in this way both the electroweak mesons as well as the vector mesons acquire a mass through Higgs-like mechanisms;
- VMD : conventional Vector Meson Dominance[28]

Notice that both the Massive Yang Mills as well as the Hidden Symmetry approach incorporate usual vector meson dominance. The two approaches however are not completely equivalent and it appears that there is a number of rare Vector Meson decays which can be measured at DAΦNE and which can help discriminate among the different schemes. As an example, let us consider ρ^0 -decays. The interactions among photons, ρ 's and pions are all equivalent as far as processes like

$$\gamma^* \rightarrow \pi^+ \pi^- \text{ or } \rho \rightarrow \pi \pi \gamma$$

are concerned, but they give different results when applied to the calculation of a process like

$$\rho^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-$$

In fig.6 we show the graphs which contribute to this decay in the three different schemes. The absence of multipion interactions in the VMD scheme and that of quadratic vertices in the ρ -field in the HS scheme leads to numerical results which differ by almost an order of magnitude, i.e. we have

$$\Gamma(\rho^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-)_{MYM} = 60 \pm 7 \text{ KeV}$$

$$\Gamma(\rho^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-)_{HS} = 7.5 \pm 0.8 \text{ KeV}$$

$$\Gamma(\rho^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-)_{VMD} = 25 \pm 3 \text{ KeV}$$

The present experimental limit [29, 30] is

$$\Gamma^{exp}(\rho^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-)_{VMD} \leq 30 \text{ KeV}$$

with which both the Hidden Symmetry scheme and the Vector Meson Dominance result are consistent. A sharp experimental determination, like the one possible at DAΦNE , may settle the question.

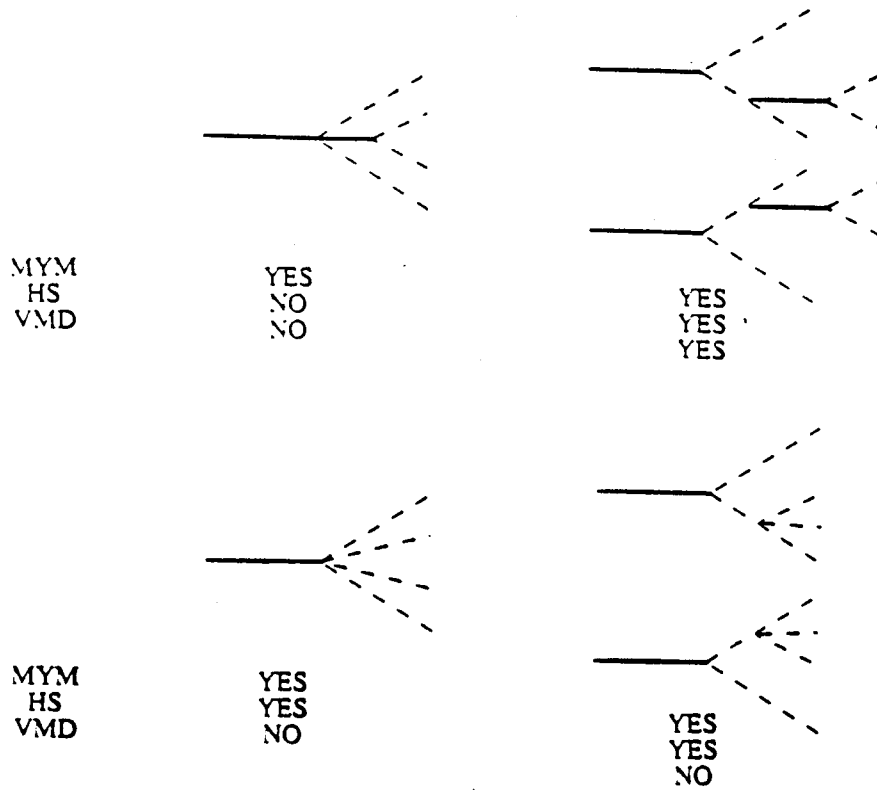


Figure 6: Diagrams for $\rho \rightarrow 4\pi$ and their contribution to the different schemes described in the text.

3.3 At the ϕ

At the ϕ -resonance there are a number of interesting radiative and non-radiative rare decays which can shed light, on the one hand, on the previous issue of vector meson contributions to chiral expansions, but also on the nature of the elusive scalar mesons. The latter issue is particularly interesting, as it appears that DAΦNE has a realistic chance to gather a large statistic for processes like

$$e^+e^- \rightarrow a_0(980 \text{ MeV})/f_0(975 \text{ MeV})\gamma$$

for which the expected branching ratios vary [31] between 10^{-3} and 10^{-6} . One can use the production rates to discriminate among the following three different models[31] for the scalar structure :

- $q\bar{q}$ states
- four quark states : $qq\bar{q}\bar{q}$ or $K\bar{K}$ "molecule"
- glueball

In the first case, the typical quarkonium scenario, the scalar mesons a_0 and f_0 can respectively be considered as

$$f_0 = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}}$$

or

$$f_0 = s\bar{s}$$

and

$$a_0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$$

Estimates for the branching ratio for $\phi \rightarrow f_0\gamma$ differ by one order of magnitude from $\leq 10^{-6}$ to 10^{-5} ($s\bar{s}$ case) and one can perhaps discriminate between the various cases by studying the ratio

$$R = \frac{\Gamma(\phi \rightarrow a_0\gamma)}{\Gamma(\phi \rightarrow f_0\gamma)}$$

which equals 1 for a $K\bar{K}$ molecule. In particular the absolute $\phi \rightarrow f_0\gamma$ decay rate can shed light on the $K\bar{K}$ molecule hypothesis, since the rate will depend upon the size of the molecule, being largest ($6 \times 10^{-4} \text{ MeV}$) for point like and smallest ($6 \times 10^{-5} \text{ MeV}$) for an extended molecule with a radius $\approx 2 \text{ fm}$ [32].

3.4 Above the ϕ

In this region there is the possibility of studying the ρ and ω recurrences [33], whose existence and properties have not been fully established. These measurements however will necessarily belong to second generation experiments, when DAΦNE will operate outside the ϕ resonance, at the higher project energies up to $\sqrt{s} = 1500 \text{ MeV}$.

4 Hadronic Final States : Two Photon Physics

Although at a machine like DAΦNE the phase space for two photon physics is rather limited, there are however a number of interesting measurements which can be done[34], provided the related background problems be overcome[35]. The possible measurements include the following :

- $\gamma\gamma \rightarrow \pi_0, \eta$ with precise determination of the pion and eta decay constant;
- $\pi\pi$ production at threshold, which can give information on the loop structure of chiral perturbation theory[36, 37], in particular for the case of neutral pion production, where there is no Born term. These processes also allow for a determination of pion polarizability [38].

We show in Fig. 7 the available data [39] for $\gamma\gamma \rightarrow \pi^0\pi^0$ together with one[36] and two loops calculation[40] from chiral perturbation theory and the unitary model by Morgan and Pennington[41]. Clearly better data can clarify some of the theoretical issues. As discussed in [35], the possibility of measuring the above decay rates and cross-sections depend crucially on the tagging of the electrons and/or positrons. Thus both a small and a wide angle tagging system are being designed, to be part of the KLOE detector.

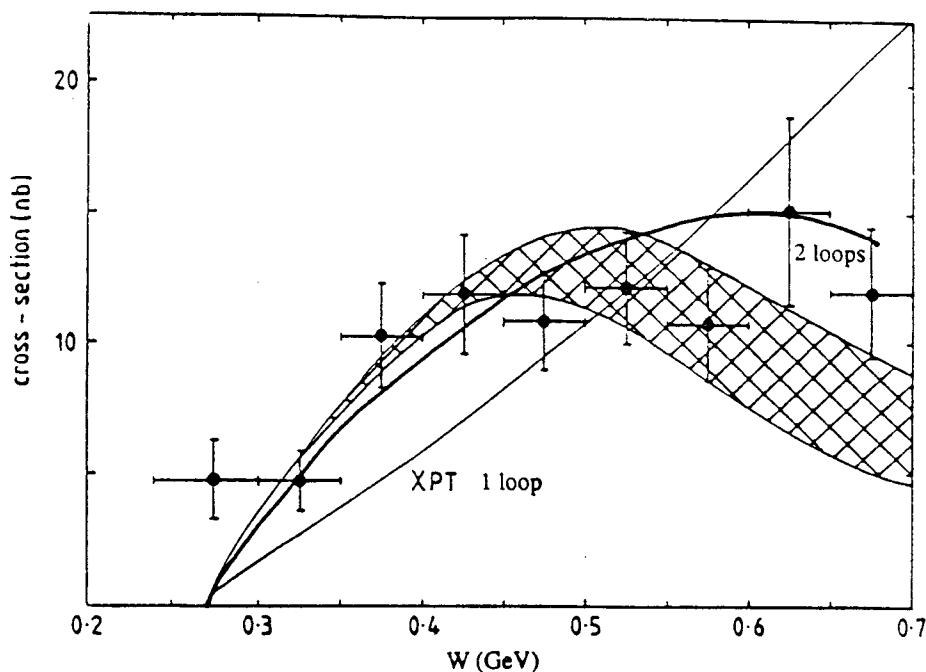


Figure 7: Data from the Crystal Ball experiment for the process $\gamma\gamma \rightarrow \pi^0\pi^0$ compared with the unitary prediction by D.Morgan and M.Pennington [41] (shaded area) and the one and two loops predictions from chiral perturbation theory

5 Conclusions

We have described the main characteristics expected for the INFN ϕ -factory under construction in Frascati and the two detectors which will be installed, KLOE, for CP-violation, Kaon and hadron physics measurements and FINUDA for nuclear and hypernuclear studies. Some of the interesting physics items in hadron physics have been discussed.

Acknowledgments

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