Photons and Other Physics @ DAΦNE

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Abstract

On overview of the main physics objectives of the Frascati ϕ-factory DAΦNE is presented. Study of CP violation in the K-meson system, Chiral Perturbation Theory tests in K-meson decays, low energy measurement of the hadronic cross-secton and the physics potential of gamma gamma interactions are discussed. A brief discussion of the hypernuclei and kaonic atom experiments is also included.

1 Introduction

In this talk I shall present on overview [1] of the main physics items to be studied at the ϕ-factory DAΦNE, presently being commissioned in Frascati. DAΦNE is made of two rings intersecting at a horizontal half angle of $\theta = 10 \div 15\ mrad$ in two interaction regions. DAΦNE is a multibunch machine, with minimum and maximum beam energy between 250 and 750 GeV, and design luminosity of $4 \times 10^{30} cm^{-2} sec^{-1}$ per single bunch. With a maximum of 120 bunches, DAΦNE aims to reach a luminosity of $5 \times 10^{32} cm^{-2} sec^{-1}$. The earliest phase of the project effort, of a minimum single bunch luminosity of $10^{30} cm^{-2} sec^{-1}$, has now been attained and the machine is expected to be very soon fully operational.

In the energy range which can be explored by DAΦNE, the physics effort is directed to obtain very precise measurements in K-meson physics and low energy hadronic behaviour, together with studies of KN scattering near threshold, hypernuclei formation and decay, kaonic atom formation. To optimize the extraction of interesting physics results, DAΦNE is being commissioned to operate at a c.m. energy equal to the mass of the ϕ-resonance, which will allow for very copious production of K-meson pairs. The three detectors which will operate at DAΦNE will be the K Long Observation Experiment (KLOE) for particle physics [2], FIsica NUcleare a DAfne (FINUDA) [3] for nuclear physics with Kaons and Dafne Exotic Atoms Research (DEAR) [4] to study the formation of Kaonic atoms.

At the design luminosity and at the ϕ resonance, Table 1 illustrates the particle yields in the final state. The full range of elementary physics items available at DAΦNE is shown in Table 2, from where one can see that, in addition to measurements related to CP-violation, there is also a rich spectrum of independent physics items in precision particle physics like:

- chiral perturbation theory (χ PT) tests in semileptonic, non-leptonic K-decays

Table 1: ϕ-decays at DAΦNE @ $\mathcal{L} = 5 \times 10^{32} cm^{-2} sec^{-1}$

decay channel	branching ratio	events in 1 y
K^+K^-	49%	1.1×10^{10}
$K^0_S K^0_L$	34%	7.5×10^9
$\rho\pi + \pi^+\pi^-\pi^0$	16%	3.4×10^9
$\eta + \gamma$	1.3 %	2.8×10^8
$\eta' + \gamma$	1.2×10^{-4}	
$f_0\gamma$	$< 1 \times 10^{-4}$	

- reduction of the error from hadronic contribution to $(g-2)_\mu$
- structure of scalar mesons from radiative ϕ decays, e.g. $\phi \to a_0, f_0\gamma$
- χ PT tests in $\gamma\gamma$ reactions : $\gamma\gamma \to \pi^0\pi^0$

Table 2: The physics spectrum that can be explored by the e^+e^-DAΦNE collider in the next 10 years and physics results which can be expected. Estimates are based on a design luminosity of $5 \times 10^{32} cm^{-2} sec^{-1}$

$\sqrt{s}$ in MeV	500÷1000	1020	1100÷ 1500
CP/CPT		ϵ'/ϵ	
K-decays precision		up to B.R. $10^{-8} \div 10^{-9}$	
η, η' physics		$\phi \to \eta, \eta'\gamma$	
$\pi\pi$ phase-shifts	$\gamma\gamma \to \pi^+\pi^-$ $\pi^0\pi^0$	$\phi \to KK$ $K \to e\nu\pi\pi$	
Scalar and Pseudoscalar meson structure	$\gamma\gamma \to \pi^0, \eta$	$\phi \to a_0/f_0\gamma$ $\to \eta'\gamma \to (\rho,\omega)\gamma\gamma$	$\rho, \omega(1450)$ $\to (\eta, \eta', \eta^*)\gamma$
Light Vector mesons	VMD and ChPT refined	the $q\bar{q}$ content of ϕ, ω	
Higher Vector Mesons			decay width mass parameters
Scalar Glueballs		$\phi \to a_0/f_0\gamma$	
$\sigma_{total} \to e^+e^-$ and hadronic contribution to $(g-2)_\mu$	presently most of the error (60%) comes from here	5% of the error	15%

In the following sections, some of these measurements and their theoretical implications will be discussed in detail.

2 CP violation in the Kaon system

DAΦNE main goal from the beginning has been the detection of direct CP-violation in K_L decays to be performed with the KLOE detector. This type of experiments is usually done at hadron accelerators, where the cross-section is of typical hadronic size, i.e. $\sigma \approx mb$, much larger than at an e^+e^- machine, where cross-sections are of electromagnetic size, but, under certain conditions, the measurement through the processes

$$\begin{aligned} e^+e^- \ \rightarrow \phi \ &\rightarrow K_S K_L \\ &\rightarrow K^0 \bar{K}^0 \end{aligned}$$

can be competitive : particular advantages in fact come from a large enough luminosity, low background at resonance, and tagged $K_S, K_L, K^0, \bar{K}^0$ due to the special quantum state.

Classification of CP-violation in the neutral K-system distinguishes between CP-violation in the mixing matrix (indirect), i.e.

$$K_{S,L} \approx \frac{(1+\epsilon)K \pm (1-\epsilon)\bar{K}}{\sqrt{2}}$$

with ϵ the amount of mixing in the mass matrix, which can be measured through the ratio

$$\frac{\Gamma(K_L \rightarrow \pi^- l^+ \nu) - \Gamma(\bar{K}_L \rightarrow \pi^+ l^- \bar{\nu})}{\Gamma(K_L \rightarrow \pi^- l^+ \nu) + \Gamma(\bar{K}_L \rightarrow \pi^+ l^- \bar{\nu})} \approx 2\Re\epsilon$$

and CP-violation in the decay amplitude (direct), which could in principle be measured through the ratio

$$\frac{\Gamma(K \rightarrow \pi^+\pi^-) - \Gamma(\bar{K} \rightarrow \pi^+\pi^-)}{\Gamma(K \rightarrow \pi^+\pi^-) + \Gamma(\bar{K} \rightarrow \pi^+\pi^-)} \approx 2\Re\epsilon'$$

Actually direct CP-violation is measured via interference between processes where it occurs both through mixing and decay. Consider the ratioes

$$\eta_{+-} = \frac{A(K_L \rightarrow \pi^+\pi^-)}{A(K_S \rightarrow \pi^+\pi^-)} = \epsilon + \epsilon'; \quad \eta_{00} = \frac{A(K_L \rightarrow \pi^0\pi^0)}{A(K_S \rightarrow \pi^0\pi^0)} = \epsilon - 2\epsilon' \tag{1}$$

Then, direct CP violation implies that $\eta_{+-} \neq \eta_{00}$ i.e.$\epsilon' \neq 0$, and direct CP violation can be measured from $|\frac{\eta_{+-}}{\eta_{00}}|^2 = 1 + 6\Re\frac{\epsilon'}{\epsilon}$.

In Table 3, we show the present theoretical [5, 6, 7, 8] and experimental [9, 10] status concerning ϵ'/ϵ . New results will soon be available from experiments NA48 [11] at CERN and E832 (KTeV) [12] at FermiLab, in addition to those from KLOE at DAΦNE. Direct CP violation at DAΦNE will be measured in two ways, the most precise being the one via the method of the Double Ratio, i.e. counting the ratio of ratios given by

$$\frac{N_L^{\pm}/N_S^{\pm}}{N_L^0/N_S^0} = |\frac{A(K_L \rightarrow \pi^+\pi^)/A(K_S \rightarrow \pi^+\pi^-)}{A(K_L \rightarrow \pi^0\pi^0)/A(K_S \rightarrow \pi^0\pi^0)}|^2 \approx 1 + 6\Re\epsilon'/\epsilon$$

which leads to a sensitivity of

$$\delta(\epsilon'/\epsilon) = 1 \times 10^{-4} \quad @L = 5 \times 10^{32} cm^{-2} sec^{-1}$$

Table 3: Present knowlegde on $\frac{\epsilon'}{\epsilon}$

Group	Theory	Experiment
	$\Re\epsilon'/\epsilon \times 10^{-4}$	$\Re\epsilon'/\epsilon \times 10^{-4}$
A.J.Buras et al.[5]	$-1.2 \div 16.0$	
M. Ciuchini et al. [6]	$4.6 \pm 3.0 \pm 0.41$	
Bertolini et al. [7]	$1.7^{+1.4}_{-1.6}$	
E. Paschos et al. [8]	9.9 ± 4.1	
NA31 [9]		23 ± 7
E731 [10]		7.4 ± 5.9

At DAΦNE, the measurement of CP-violating parameters [13] ϵ and ϵ' will also be done through interferometry experiments, which take advantage of the special quantum state of the $K\bar{K}$pair so that if one is a K_L, the other one has to be a K_S . Consider

$$\phi \to K\bar{K} \to (f_1, t_1) + (f_2, t_2)$$

where one of the K's has decayed into the final statef_1 after a time t_1 and the other one into f_2 after time t_2. Because of CP-violation, the above final state can be reached in two possible ways, and hence the possiblity of interference. Calling $I(f_1, f_2, \Delta)$ the number of events in which the ϕ has produced the final state (f_1, f_2) with a time difference $\Delta = t_1 - t_2$, one has [14]

$$I(f_1, f_2, \Delta) = \frac{1}{2\Gamma} |< f_1|K_S >< f_2|K_S > |^2 \times \quad (2)$$

$$\left[|\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-\Gamma \Delta t/2} cos\,(\Delta m \Delta t + \Delta\phi) \right] \quad (3)$$

where $\eta_i =< f_i|K_L > / < f_i|K_S >$ and the time difference $\Delta t = t_1 - t_2$ is measured through the distance crossed by the Kaons before decaying.

For $f_1 = \pi^+\pi^-$ and $f_2 = \pi^0\pi^0$ the inteference pattern for some typical values for $\Re\epsilon'/\epsilon$ and $\Im\epsilon'/\epsilon$ is shown in Fig. 1 which corresponds to $\delta(\Re\epsilon'/\epsilon) = 1.8 \times 10^{-4}$ and $\delta(\Im\epsilon'/\epsilon) = 3.4 \times 10^{-3}$

The present expectations of the KLOE experimental group are to obtain in 1999 a measurement with a precision of 10^{-3}.

3 K-decays

From Table 2, we see that one expects to measure rare and very rare K-decays up to branching ratioes of 10^{-9}, for which a comprehensive review can be found in [15]. Recently, in view of the observed $K^+ \to \pi^+\nu\bar{\nu}$ event [16] at Brookhaven, it has been suggested [17] that DAΦNE and KLOE may have a chance to improve present experimental limits for the decay $K \to \pi^0\nu\bar{\nu}$. Although there is no chance to positively observe this decay, whose B.R. in the Standard Model is a very small 3×10^{-11}, the special experimental conditions at DAΦNE and the characteristics of the detector may be able to exclude possible deviations from the Standard Model expectations.

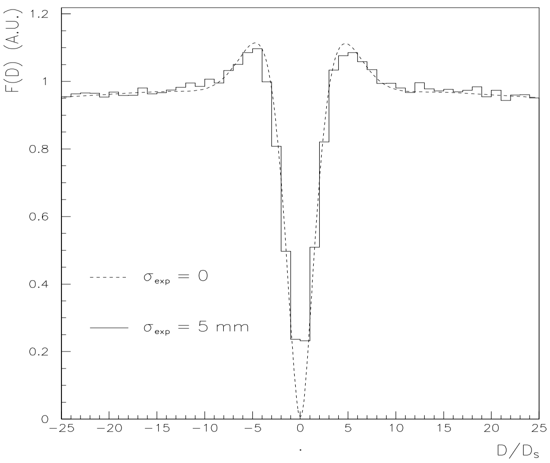

Figure 1: From [14] : theoretical expectations for the time difference distribution integrated over the pion phase space compared with the one obtained with an experimental vertex resolution $\sigma = 5mm$. The distributions are plotted as a function of the difference in the distance travelled before decay.

As indicated in Table 2, the high statistics expected at DAPHNE will allow very precise measurements of chiral dynamics in K-decays, in particular in connection with the semileptonic decays, K_{l3} and K_{l4}[18]. For the former, consider the decay channels

- $K^+(p) \to \pi^0(p')l^+(p_l)\nu_l(p_\nu) \quad [K_{l3}^+]$
- $K^0(p) \to \pi^-(p')l^+)p_l)\nu_l(p_\nu) \quad [K_{l3}^0]$

with matrix element [18]

$$T = \frac{G_F}{\sqrt{2}} V_{us}^* l^\mu F_\mu^{+,0}(p,p'), \qquad l^\mu = \bar{u}(p_\nu)\gamma^\mu(1-\gamma_5)v(p_l)$$

and

$$F_\mu^+ = \tfrac{1}{\sqrt{2}}[(p+p')_\mu f_+^{K^+\pi^0} + (p-p')_\mu f_-^{K^+\pi^0}]$$

$$F_\mu^0 = \tfrac{1}{\sqrt{2}}[(p+p')_\mu f_+^{K^0\pi^-} + (p-p')_\mu f_-^{K^0\pi^-}]$$

The four form factors $f_\pm^{K\pi}$, with $K\pi = K^+\pi^0$ or $K^0\pi^-$, contain the low energy dynamics of the decays, for which there exist predictions by Chiral Perturbation Theory (CHPT). In particular, the predictions for the so called vector form factor $f_+^{K\pi}$ are well in agreement with the experimental results whereas the situation is much confused for the scalar form factor, defined as

$$f_0^{k\pi}(t) = f_+^{K\pi}(t) + \frac{t}{M_K^2 - M_\pi^2} f_-^{K\pi}(t)$$

The experimental analysis assumes a linear $t-$dependence of the form

$$f_{+,0}^{K\pi}(t) = f_+^{k\pi}(0)\left[1 + \lambda_{+,0}\frac{t}{M_{\pi^+}^2}\right]$$

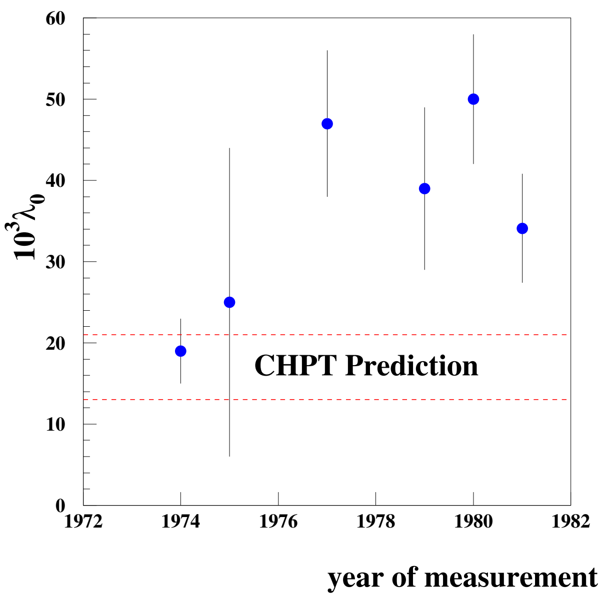

Figure 2: History of determination of the slope of the scalar form factor in K_{l3} decays[18].

Table 4: Rates of K_{l3} decays. The number of events in the third column corresponds to those data which are of relevance for the determination of the slope λ_0 of the scalar form factor.

		♯ events		
	branching ratio	Particle Data Group	DAΦNE 1 year	improve-ment
$K^+ \to \pi^0 \mu^+ \nu_\mu$	$3.18 \cdot 10^{-2}$	10^5	$3 \cdot 10^8$	$3 \cdot 10^3$
$K_L \to \pi^\pm \mu^\mp \nu$	$27 \cdot 10^{-2}$	$4 \cdot 10^6$	$3 \cdot 10^8$	70

We show in Figure 2 the status of the experimental situation compared with the theoretical predictions represented by the dashed band. The statistics of this measurement are dominated by the experiment by Donaldson [19] and can be remarbably improved by KLOE, as shown in Table 4 from [18]. The measurement of the K_{l3} form factors will be one of the first to be performed by the KLOE detector and it is expected that already in the first three months of running one should be able to improve the present statistics.

In addition to the possibility of clarifying the situation for the slope of the scalar form factor, the high statistics provided by DAΦNE should also help investigate the possibile existence of other than $V-A$ interaction in the lagrangian, notably scalar and tensor couplings. This can also be studied through the radiative K_{l2} decays, but in general higher order terms in the chiral expansion must be looked into before drawing any firm conclusions from the data.

Another interesting decay which can shed light on chiral dynamics and its loop structure is K_{l4} decays. Consider the decays[18]

$$\begin{aligned} K^+ &\to \pi^+\pi^- l^+ \nu_l \\ K^+ &\to \pi^0\pi^0 l^+ \nu_l \\ K^0 &\to \pi^0\pi^- l^+ \nu_l \end{aligned}$$

and their charge conjugate modes, with the letter l indicating either a muon or an electron. These processes will provide a measurement of $\pi\pi$ phaseshifts at threshold and hence of the pion-pion scattering length. Indeed, the only available source of clear information on $\pi\pi$ scattering at threshold are the decays $K \Rightarrow \pi\pi l\nu$ from where one can learn about $\pi\pi \rightarrow \pi\pi$ and hence a_0^0, a_0^2. There is a range of theoretical predictions for these quantity, in particular,

Current Algebra (Weinberg 1968) $a_0^0 = 0.16$

χPT : LO and NLO $a_0^0 = 0.2 \pm 0.01$[24]

$G(eneralized)\chi$PT $a_0^0 = 0.263 \pm 0.052$ [25]

to be compared with the experimental information from Rosselet et al. [20], i.e. $a_0^0 = 0.26 \pm 0.05$.

From ref.[21] we show in Fig.3 the data for $I = 0$ $S-$wave $\pi\pi$ phase shifts, δ_0^0, below

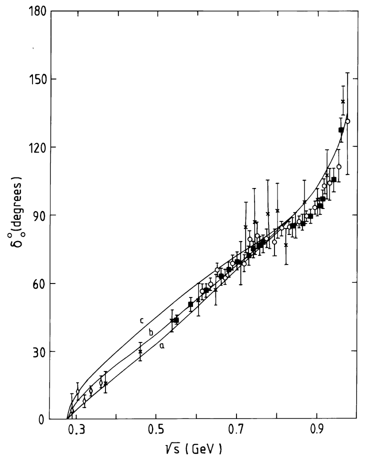

Figure 3: K_{l4} and the $\pi\pi$ system at threshold

1 GeV: experimental values are compared to BFP's fits[22] using the Roy equations [23], (fitting δ_0^0 above 500 MeV to the phases). Curves a (lowest), b and c (highest) correspond to alternative values for the $I = 0$ $S-$wave scattering length $a_0^0 = 0.17,\ 0.30$ and 0.50. The present theoretical status from Chiral Perturbation theory is summarized [24, 25] in Fig.4. Recently, new numerical solutions to the Roy equations [26] have been obtained and work is in progress to optimize the extraction of the relevant theoretical information from the forthcoming KLOE measurement.

4 Radiative ϕ-decays

Scalar, pseudoscalar and vector meson spectroscopy [27] will also be studied with great precision at DAΦNE . In particular the large statistics should allow a precise determination of radiative ϕ-decays into scalar mesons and solve some puzzling questions about their nature. In a later phase, when DAΦNE will operate at higher energies, vector meson recurrencies and higher pseudoscalars will also be investigated.

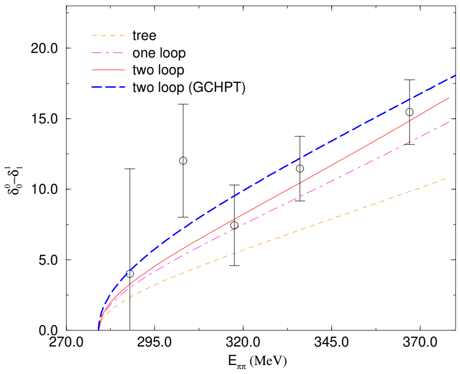

Figure 4: Results for the $\pi\pi$ phase shift difference $\delta_0^0 - \delta_1^1$ inferred from the Geneva-Saclay K_{e4} experiment and different theoretical calculations, as indicated.

5 Hadronic Contribution to $(g-2)_\mu$

It has been pointed out that the measurement of $\sigma_{hadrons}$ at DAΦNE may help reduce the error on the determination of $(g-2)_\mu$ [28]. The present status of $g-2$ experiments for the muon is shown in Table 5. It will soon be that the experimental number is more

Table 5: Status of $(g-2)_\mu$: Theory and Experiment

Laboratory	$a_\mu^{EXP} \simeq (\frac{g-2}{2})_\mu$	precision	year
CERN [29]	$(1\ 162 \pm 5) \times 10^{-6}$	4300 ppm	1960
	$(116\ 616 \pm 31) \times 10^{-8}$	270 ppm	1970
	$(1\ 165\ 924 \pm 8.5) \times 10^{-9}$	7.3 ppm	1979
BNL[30]	$(???? \pm 0.45) \times 10^{-9}$	< 1 ppm	≥ 1998

accurate than the theoretical one. Indeed, theoretically [31, 32, 33, 34] and in units of 10^{-11}

$$
\begin{aligned}
a_\mu^{th} &= \overbrace{116\ 584\ 706 \pm 2}^{a_\mu^{QED}} + \overbrace{154 \pm 4}^{a_\mu^{Weak}} + \overbrace{6882 \pm 154}^{a_\mu^{had}} \\
&= \overbrace{116\ 591\ 742 \pm 154}^{\text{total}}
\end{aligned}
$$

where

a_μ^{QED} has been calculated up to order $(\alpha/\pi)^5$

$a_\mu^{Weak} = [195(one\ loop) - 41(two\ loops)]\,10^{-11}$

$a_\mu^{had} = a_\mu^{vac-pol} + a_\mu^{light-light}$

The new BNL experiment, which is presently running, aims to have an experimental error ± 45 $(\times 10^{-11})$ to unravel $a_\mu^{weak} = 154 \pm 4$ $(\times 10^{-11})$ and test the loop structure of the electroweak theory and be senstive to physics beyond the Standard Model. Unfortunately, the error on the hadronic contribution to $(g-2)_\mu$, $\delta(a_\mu^{had}) = 154\ (\times 10^{-11})$, i.e, it is as large as the entire a_μ^{weak} and no progress can be done until a reduction of this error is achieved. The calculation of a_μ^{had} is based on graphs of the type shown in Fig.5 which are

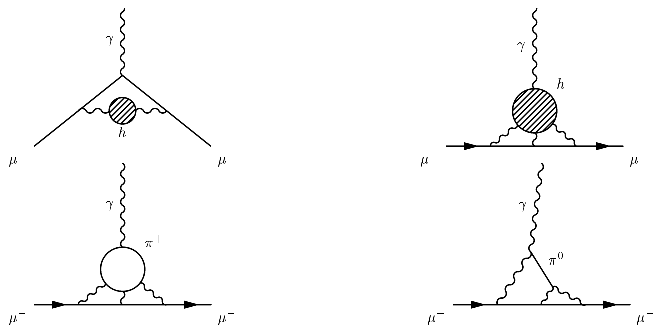

Figure 5: Graphs contributing to leading order to the hadronic contribution to $g-2_\mu$.

affected by large theoretical uncertainties due to the hadronic insertions in the loops. Of these graphs, the ones which give the largest contribution both to a_μ^{had} and to the error are those which come from vacuum polarization. To overcome these uncertaintes, it has been suggested long time ago [35, 36] to calculate this contribution from the experimental information obtained from the cross-section for $e^+e^- \to hadrons$. Theoretical calculations for leading order are based upon

$$a_\mu^{vac-pol} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^\infty \sigma_{e^+e^-\to hadrons}(s)K(s)ds$$

where $K(s)$ is function strongly peaked for small s values. Since $a_\mu^{vac-pol}$ is evaluated using the measured hadronic e^+e^- cross-sections and their error, most of the error on $a_\mu^{vac-pol}$ comes from the region $\leq 1\ GeV$, basically from the $\rho-\omega$ region where the cross-section is largest. An energy scan at DAΦNE could reduce the error, but DAΦNE is now being commissioned to operate at the ϕ peak, and running at lower energies is not envisaged in the near future. An alternative proposal [37] is to trigger on Initial State Radiation (ISR), i.e. on the process

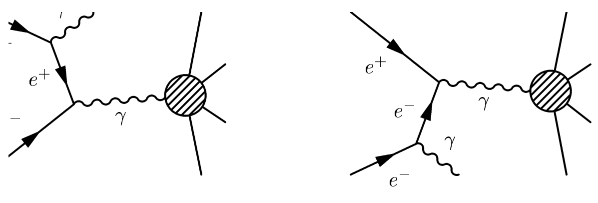

Figure 6: ISR and the Hadronic Contribution to $a_\mu^{vac-pol}$

$$\begin{aligned} e^+(p_1)e^-(p_2) &\to \gamma(k) + \quad \gamma* \to \gamma(k) \quad + hadrons \\ (p_1+p_2)^2 &= M_\phi^2 \end{aligned}$$

To leading order, the process shown in Fig.6 has cross-section

$$\frac{d\sigma(k,\theta_\gamma)}{dkdcos\theta_\gamma} \approx 2\sigma_h \frac{\alpha}{\pi}\frac{dk}{k}\frac{sin^2\theta_\gamma}{(1-\beta^2 cos^2\theta_\gamma)^2}$$

where θ_γ is the photon angle with respect to the beam. For photons emitted at an angle greater than θ_{min} the differential cross-section as a function of the photon energy is shown in Fig.7, from where one can see the reduction of the the cross-section for two different values of the angle θ_{min}

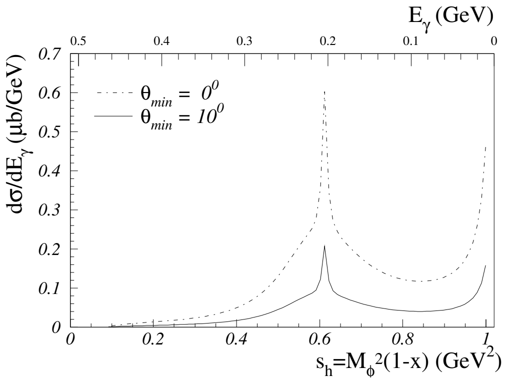

Figure 7: From [37] : differential cross-section for ISR process

With the above process, one can now write the contribution to $a_\mu^{vac-pol}$ in a region from threshold to just below ϕ as [37]

$$a_\mu^h = \frac{M_\phi^2}{\pi}\int_{k_{min}}^{k_{max}} dk \frac{K(s(k))}{H(k, M_\phi^2, \theta_{min})}\frac{d\sigma(k)}{dk} \tag{4}$$

where

$d\sigma(k)/dk$ is the cross-section for Initial State Radiation processes (ISR) integrated over θ_γ,

$K(s(k))$ as before with $s = M_\phi^2 - 2kM_\phi$

$H(k, M_\phi^2, \theta_{min})$ is the radiative factor for emission of a photon of energy k at all angles larger than θ_{min} relative to the beam direction.

Preliminary findings by S. Spagnolo[37], using the photon resolution of the KLOE detector, for 3 months running at full luminosity, indicate that the error on $a_\mu^{vac-pol}$ could be as small as 10^{-3}. This method needs calculation of radiative corrections and further detector simulations. Particular attention will be needed to estimate the contribution of hard collinear radiation from the initial state which can affect by at least 30% the determination of the available energy to the hadronic system [38]. If the proposed measurement has to include both triggering on the photon and measuring the hadronic final state, then possible final state radiation effects are also to be taken into consideration [39].

6 Photon-photon physics

Phase space is limited for $\gamma\gamma$ physics at DAΦNE but detector capabilities (KLOE) and full phase space utilization make it a possibility worth exploring [40]. The list of photon-photon physics items at DAΦNE is not short and certainly interesting :

1. Measurement of π^0, η decay constants,
2. Study of $\pi\pi$ scattering at threshold to obtain better statistics and check χPT predictions, both for
   - $\pi^+\pi^-$ and
   - $\pi^0\pi^0$
   - Study of azymuthal correlations and pion polarizability from $\gamma\gamma \to \pi\pi$

Although there is no immediate program to do $\gamma\gamma$ physics at DAΦNE , we show in the following some details about the phase space and the physics [41]. In Fig.8 the differential

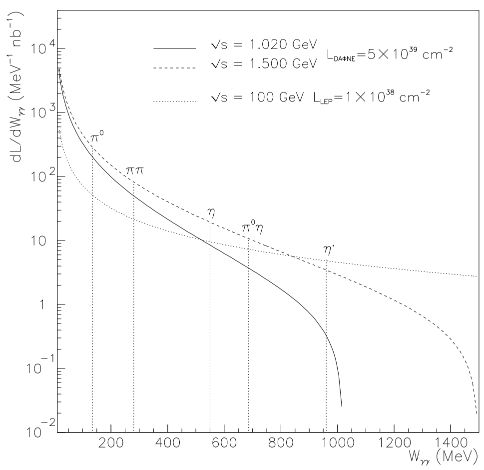

Figure 8: Photon-photon luminosity compared with LEP

luminosity in the photon-photon channel, obtained using the double equivalent photon approximation, is shown. For the sake of comparison, we also show the $\gamma\gamma$ luminosity in the same energy range as the one at DAΦNE, for the case of LEP1. Notice that at DAΦNE there are no limitations from detector acceptance only from space phase. The low hadronic activity implies also a reduced background, a notable advantage if one planned to measure the radiative width of light pseudoscalars.

As mentioned, a very interesting measurement is that of photon-photon scattering at threshold, i.e, $\gamma\gamma \to \pi\pi$, a process, which, via unitarity, is directly related to $\pi\pi$ scattering. In Fig.9 we show the experimental and theoretical status of $\gamma\gamma \to \pi^0\pi^0$. where

- the data are from the Crystal Ball Collaboration [42]
- the dashes indicate the χPT one loop result [43] $O(p^4)$
- the full line represents the χPT two loop result [44] $O(p^6)$
- and the band is the dispersive analysis [45] with $a_0^0 = 0.2$

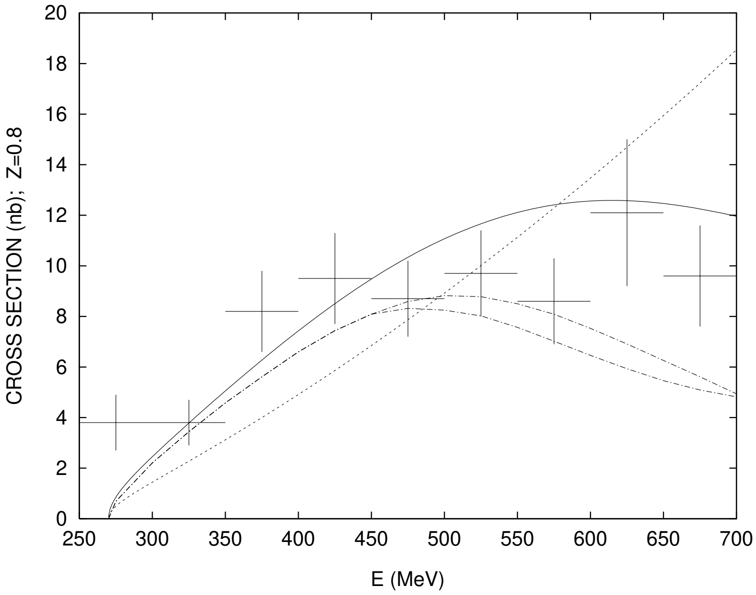

Figure 9: Status of $\gamma\gamma \to \pi^0\pi^0$

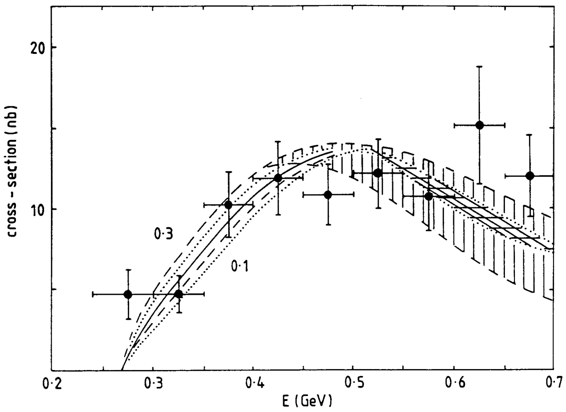

Figure 10: $\gamma\gamma \to \pi^0\pi^0$ and a_0^0 dependence

To illustrate the dependence of the theoretical models from the pion-pion scattering length, we show in Fig.10 an analysis reproduced from [46] where the dispersive calculation is plotted varying a_0^0 among a range of values. In this figure, we show the integrated cross-section for $\gamma\gamma \to \pi^0\pi^0$ as a function of the $\pi\pi$ invariant mass, $E = \sqrt{s}$. The data are from Crystal Ball scaled to the full angular range by a factor of 1.25 and the lines, labelled by the value of the $I = 0$ $\pi\pi$ S-wave scattering length in steps of 0.05 from 0.1 to 0.3, illustrate the effect of different extrapolations of the $\pi\pi$ phases above 520 MeV down to threshold on the dispersive prediction. The bands above 500 MeV on the $a_0^0 = 0.1$ and 0.3 curves mark the range generated by different asymptotics for the vector exchanges.

If the measurement of $\gamma\gamma \to \pi\pi$ could be performed, this would complement the study of the $\pi\pi$ system at threshold which will be measured at DAΦNE in K_{l4} decays.

7 Nuclear Physics with Kaons with FINUDA

Our present knowledge on hypernuclei is limited and cannot be compared with the one available on conventional nuclei (S=0), yet is has already provided and can further provide important clues on nuclear structure; most importantly [47] it has much broadened the concept of nuclear physics itself.

FINUDA, FIsica NUcleare a DAΦNE , is a nuclear physics detector which will occupy the second interaction region at DAΦNE and will perform a unique hypernuclear physics experiment in ideal conditions[48]. At DAΦNE the large flux of slow K^- produced from ϕ decay, can be stopped in a nuclear target and undergo nuclear capture, forming hypernuclei whose formation and decay can be studied with very high precision. The main advantages with respect to the conventional beams rely on the monochromaticity of the Kaon-beam, the lack of hadronic background, the reduced straggling in the target due to the low energy of the Kaons and the possiblity of tagging through the K^+. These advantages are summarized in Table 6. The detector FINUDA will study the reaction

Table 6: Hypernuclei at DAΦNE with respect to extracted Kaon beam

Low Momentum K^- (127 MeV/c)	medium-high momentum K^- (500-600 MeV/c)
Monochromatic and background free K^-	non-monochromatic K^- and not clean beam (π^- contamination)
Thin target (0.3 $g\ cm^{-2}$) Large acceptance detector (typical at a collider)	Thick target (several $g\ cm^{-2}$) small acceptance (typical of fixed target)
Tagging capability with K^+	no tagging possible with K^+
Study of hypernuclei decay feasible	study of hypernuclei decay not easy

$$K^-_{stop} +^A X_Z \rightarrow^A_\Lambda X_Z + \pi^- \quad (250\ MeV/c \leq p_\pi \leq 280\ MeV/c) \tag{5}$$

which combines the advantages of the two traditional processes of strangeness exchange and associated production reaction, i.e. $K^- + n \rightarrow \Lambda + \pi^-$ and $\pi^+ + n \rightarrow \Lambda + K^+$, with good intensity and quality of the Kaon beams coupled to a moderately, non-zero, momentum transfer to the produced Λ particle, and a moderately high hypernuclear final state production rate. The latter is estimate to be $\approx 10^{-3}$ per stopped K^-.

The topics which can be studied with FINUDA can be summarized as follows :

- High resolution Λ-hypernuclei spectroscopy ($\Delta E \leq 700 KeV$)
- Λ-hypernuclei lifetime studies
- Studies of hypernuclei decays and possible violation of the $\Delta I = 1/2$ rule
- Production of hypergragments through two-body decays
- Production of Λ-hypernuclei with a large neutron excess
- Study of $K - N$ scattering at low energies
- Measurement ofthe $K_{\mu 2}$ decay
- Search for π^+ decay mode of hypernuclei.

8 The K-N Interaction from Kaonic Hydrogen and Deuterium Transitions

According to R.H. Dalitz [49], " the most important experiment to be carried out in low energy K-meson physics today is the definitive determination of the energy level shift in the K^-p and K^-d atoms, because of their direct connection with the physics of KN interactions and their complete independence from all other kinds of measurements which bear on this interactions". The DAΦNE Exotic Atoms Research (DEAR) experiment, is an international collaboration [50] whose objective is the determination of the isospin dependent $\bar{K}N$ scattering lengths through a 1% measurement of the K_α line shifts, due to strong interactions, in kaonic hydrogen and kaonic deuterium. The strong interaction causes a shift of the lowest atomic level, whilst the absorption reduced the lifetime of the state. Precise measurements of the X-ray energy spectrum then allow to determine the energy shift ϵ and the width Γ associated with this final level. The energy shift ϵ and the width Γ in the $1s$ level in kaonic hydrogen can be related in fairly model independent way to the complex S-wave K^-p scattering length a_{K^-p} through the Deser-Trueman formula

$$\epsilon + i\frac{\Gamma}{2} = 2\alpha^3\mu^2 a_{K^-p} = 412 a_{K^-p}\ eV/fm \tag{6}$$

where μ is the reduced mass and α the fine structure constant.

It follows that both ϵ and Γ can be obtained directly from X-ray measurements, or through the scattering length measured in low energy Kaon nucleon scattering experiments. This determination should bring about

- an understanding of SU(3) chiral symmetry breaking, through the determination of the KN sigma term. As in the case of the πN sigma term, one could eventually extract this quantity from accurate threshold KN scattering data. At present th is is not possible and only estimates of the KN sigma term are available up till now.

- a measurement of the strangeness content of the nucleon since the KN sigma term is a sensitive and direct measurement of the strange-sea, unpolarized quark component in the nucleon at rest.

The principle of the DEAR experiment is very simple : kaons from the low momentum, monochromatic, high purity "Kaon beam" from the ϕ's produced in DAΦNE leave the beam pipe through a thin window, are degraded in energy down to a few MeV, enter a a pressurized, low temperature, gaseous hydrogen target placed few centimeters above the pipe and are stopped there. A fraction of kaons is captured in an outer orbit of the hydrogen atom, thus forming an exotic atom. The kaon then cascades down through its own series of bound atomic states until it reaches a level where the short-range strong interaction acts on the particle, causing its absorption.

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