LNF-10/17(P)
June 2010

Proposal for taking data with the KLOE-2 detector at the DAΦNE collider upgraded in energy

D. Babusci[a], C. Bini[b], F. Bossi[a], G. Isidori[a], D. Moricciani[c], F. Nguyen[d], P. Raimondi[a], G. Venanzoni[a], D. Alesini[a], F. Archilli[c], D. Badoni[a], R. Baldini-Ferroli[a,r], M. Bellaveglia[a], G. Bencivenni[a], M. Bertani[a], M. Biagini[a], C. Biscari[a], C. Bloise[a], V. Bocci[d], R. Boni[a], M. Boscolo[a], P. Branchini[d], A. Budano[d], S.A. Bulychjev[e], B. Buonomo[a], P. Campana[a], G. Capon[a], M. Castellano[a], F. Ceradini[d], E. Chiadroni[a], P. Ciambrone[a], L. Cultrera[a], E. Czerwinski[a], E. Dané[a], G. Delle Monache[a], E. De Lucia[a], T. Demma[a], G. De Robertis[f], A. De Santis[b], G. De Zorzi[b], A. Di Domenico[b], C. Di Donato[g], B. Di Micco[d], E. Di Pasquale[a], G. Di Pirro[a], R. Di Salvo[c], D. Domenici[a], A. Drago[a], M. Esposito[a], O. Erriquez[f], G. Felici[a], M. Ferrario[a], L. Ficcadenti[a], D. Filippetto[a], S. Fiore[b], P. Franzini[b], G. Franzini[a], A. Gallo[a], G. Gatti[a], P. Gauzzi[b], S. Giovannella[a], A. Ghigo[a], F. Gonnella[c], E. Graziani[d], S. Guiducci[a], F. Happacher[a], B. Höistad[h], E. Iarocci[a,i], M. Jacewicz[h], T. Johansson[h], W. Kluge[j], V.V. Kulikov[e], A. Kupsc[h], J. Lee Franzini[a], C. Ligi[a], F. Loddo[f], P. Lukin[k], F. Marcellini[a], C. Marchetti[a], M.A. Martemianov[e], M. Martini[a], M.A. Matsyuk[e], G. Mazzitelli[a], R. Messi[c], C. Milardi[a], M. Mirazzita[a], S. Miscetti[a], G. Morello[l], P. Moskal[m], S. Müeller[n], S. Pacetti[a,r], G. Pancheri[a], E. Pasqualucci[b], M. Passera[o], A. Passeri[d], V. Patera[a,i], A.D. Polosa[b], M. Preger[a], L. Quintieri[a], A. Ranieri[f], P. Rossi[a], C. Sanelli[a], P. Santangelo[a], I. Sarra[a], M. Schioppa[l], B. Sciascia[a], M. Serio[a], F. Sgamma[a], M. Silarski[m], B. Spataro[a], A. Stecchi[a], A. Stella[a], S. Stucci[l], C. Taccini[d], S. Tomassini[a], L. Tortora[d], C. Vaccarezza[a], R. Versaci[p],W. Wislicki[q], M. Wolke[h], J. Zdebik[m], M. Zobov[a]

[a]*Laboratori Nazionali di Frascati dell'INFN, Frascati, Italy*
[b]*Dipartimento di Fisica dell'Università "La Sapienza" e Sezione INFN, Rome, Italy*
[c]*Dipartimento di Fisica dell'Università "Tor Vergata" e Sezione INFN, Rome, Italy*
[d]*Dipartimento di Fisica dell'Università "Roma Tre" e Sezione INFN, Rome, Italy*
[e]*Institute for Theoretical and Experimental Physics, Moscow, Russia*
[f]*Dipartimento di Fisica dell'Università di Bari e Sezione INFN, Bari, Italy*

[g] *INFN, Sezione di Napoli, Napoli, Italy*
[h] *University of Uppsala, Uppsala, Sweden*
[i] *Dipartimento di Energetica, Università Sapienza, Rome, Italy*
[j] *Institut für Experimentelle Kernphysik, Universität Karlsruhe, Karlsruhe, Germany*
[k] *Budker Institute of Nuclear Physics, Novosibirsk, Russia*
[l] *Università della Calabria, Cosenza, e INFN Gruppo collegato di Cosenza, Cosenza, Italy*
[m] *Jagiellonian University, Cracow, Poland*
[n] *Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Mainz, Germany*
[o] *INFN, Sezione di Padova, Padova, Italy*
[p] *CERN, Geneve, Switzerland*
[q] *A. Soltan Institute for Nuclear Studies, Warsaw, Poland*
[r] *Museo Storico della Fisica e Centro Studi e Ricerche "E. Fermi", Rome, Italy*

Abstract

This document reviews the physics program of the KLOE-2 detector at DAΦNE upgraded in energy and provides a simple solution to run the collider above the ϕ-peak (up to 2, possibly 2.5 GeV). It is shown how a precise measurement of the multihadronic cross section in the energy region up to 2 (possibly 2.5) GeV would have a major impact on the tests of the Standard Model through a precise determination of the anomalous magnetic moment of the muon and the effective fine-structure constant at the M_Z scale. With a luminosity of about $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, DAΦNE upgraded in energy can perform a scan in the region from 1 to 2.5 GeV in one year by collecting an integrated luminosity of 20 pb^{-1} (corresponding to a few days of data taking) for single point, assuming an energy step of 25 MeV. A few years of data taking in this region would provide important tests of QCD and effective theories by $\gamma\gamma$ physics with open thresholds for pseudo-scalar (like the η'), scalar (f_0, f_0', etc...) and axial-vector (a_1, etc...) mesons; vector-mesons spectroscopy and baryon form factors; tests of CVC and searches for exotics. In the final part of the document a technical solution for the energy upgrade of DAΦNE is proposed.

Contents

1 Introduction

In this document we discuss the physics program that can be pursued by running DAΦNE at energies above the ϕ meson peak, and the upgrades to the machine required for this purpose (the so called DAΦNE-2 program).

We consider a reference luminosity of $10^{32}\text{cm}^{-2}\text{s}^{-1}$, from the ϕ up to $\sim$2.5 GeV, which seems to be feasible with a modification of the existing machine at a moderate cost, as explained in the following. With such a machine one can easily collect an integrated luminosity of about 5 fb^{-1} between 1 and 2.5 GeV in a few years of data taking. This high statistics, much larger than that collected at any previous machine in this energy range, will represent a major improvement in physics, with relevant implications for the precision tests of the Standard Model, like the $g-2$ of the muon and the effective fine-structure constant at the M_Z scale $\alpha_{em}(M_Z^2)$. The only direct competitor project is VEPP-2000 at Novosibirsk, which will cover the center-of-mass energy range between 1 and 2 GeV with two experiments. This collider has started first operations in 2009 and is expected to provide a luminosity ranging between $10^{31}\text{cm}^{-2}\text{s}^{-1}$ at 1 GeV and $10^{32}\text{cm}^{-2}\text{s}^{-1}$ at 2 GeV. Other "indirect" competitors are the higher energy e^+e^- colliders (τ-charm and B-factories) that in principle cover the DAΦNE-2 energy range by means of radiative return. However, due to the photon emission, as we will show later, the "equivalent" luminosity produced by these machines in the region between 1 and 2.5 GeV is much less than the one expected by DAΦNE-2.

The KLOE detector has succesfully taken data on DAΦNE in the last ten years [1]. It is presently starting a new period of data taking at the ϕ peak, with some hardware modification either already implemented or planned to be implemented in 2011 (so called KLOE-2 project) [2, 3]. Although a detailed Monte Carlo simulation has not been carried out yet, its measured performance, together with the improvements expected from the insertion of the new subdetectors, make us confident that KLOE-2 is the proper detector for this kind of measurements. Actually, data taking at energies higher than the ϕ mass is a relevant part of the KLOE-2 physics program.

In the following sections we first present the main physics motivations for this high-energy program [2, 3, 4]. We start with the implication for precision tests of the Standard Model from a precise measurement of the multi-hadronic cross section in the energy region below 2.5 GeV. In particular, we discuss the strategies for a precise determination of the effective fine structure constant at the scale M_Z, and of the muon $g-2$. We then concentrate on the potential of the proposed machine for the measurement of this cross section, comparing it with possible competitors. Other physics topics that can benefit from DAΦNE-2 are briefly discussed in Section 4. Finally, we discuss the main technical issues to be addressed to properly modify the machine for our purpose.

2 Precision tests of the Standard Model

The systematic comparison of Standard Model (SM) predictions with precise experimental data served in the last decades as an invaluable tool to test this theory at the quantum level. It has also provided stringent constraints on "new physics" scenarios. The (so far) remarkable agreement between the measurements of the electroweak observables and their SM predictions is a striking experimental confirmation of the theory, even if there are a few observables where the agreement is not so satisfactory. On the other hand, the Higgs boson has not yet been observed, and there are clear phenomenological facts (dark matter, matter-antimatter asymmetry in the universe) as well as strong theoretical arguments hinting at the presence of physics beyond the SM. The LHC, or a future e^+e^- International Linear Collider (ILC), will hopefully answer many questions. However, their discovery potential may be substantially improved if combined with more precise low-energy tests of the SM.

2.1 The effective fine-structure constant at the scale M_Z

Precision tests of the Standard Model require the appropriate inclusion of higher order effects and the knowledge of very precise input parameters. One of the basic input parameters is the fine-structure constant α, determined from the anomalous magnetic moment of the electron with an impressive accuracy of 0.37 parts per billion (ppb) [5] relying on the validity of perturbative QED [6]. However, physics at nonzero squared momentum transfer q^2 is actually described by an effective electromagnetic coupling $\alpha(q^2)$ rather than by the low-energy constant α itself. The shift of the fine-structure constant from the Thomson limit to high energy involves low energy non-perturbative hadronic effects which spoil this precision. In particular, the effective fine-structure constant at the scale M_Z, $\alpha(M_Z^2) = \alpha/[1-\Delta\alpha(M_Z^2)]$, plays a crucial role in basic electroweak EW radiative corrections of the SM. An important example is the EW mixing parameter $\sin^2\theta$, related to α, the Fermi coupling constant G_F and M_Z via the Sirlin relation [7, 8, 9]

$$\sin^2\theta_S \cos^2\theta_S = \frac{\pi\alpha}{\sqrt{2} G_F M_Z^2 (1 - \Delta r_S)}, \tag{2.1}$$

where the subscript S identifies the renormalisation scheme. Δr_S incorporates the universal correction $\Delta\alpha(M_Z^2)$, large contributions that depend quadratically on the top quark mass m_t [10], plus all remaining quantum effects.

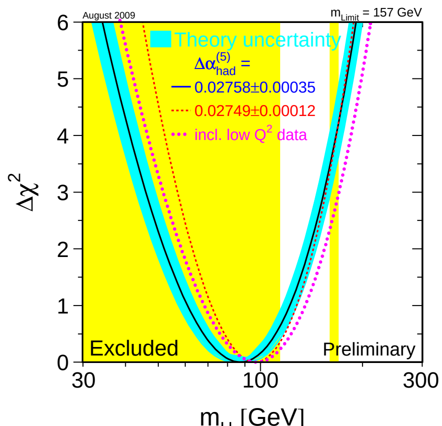

Figure 1: The line is the result of the Electroweak Working Group fit using all data (see [11] for details); the (blue) band represents an estimate of the theoretical error due to missing higher order corrections. The (yellow) vertical bands show the 95% CL exclusion limits on M_H from the direct searches.

In the SM, Δr_S depends on various physical parameters, including M_H, the mass of the Higgs boson. As this is the only relevant unknown parameter in the SM, important indirect bounds on this missing ingredient can be set by comparing the calculated quantity in Eq. (2.1) with the experimental value of $\sin^2\theta_S$ (e.g. the effective EW mixing angle $\sin^2\theta_{\rm eff}^{\rm lept}$ measured at LEP and SLC from the on-resonance asymmetries) once $\Delta\alpha(M_Z^2)$ and other experimental inputs like m_t are provided. It is important to note that the uncertainty of the effective electromagnetic coupling constant $\delta\Delta\alpha(M_Z^2)$ affects the upper bound for M_H [12, 11, 13], see Fig. 1. Moreover, as measurements of the effective EW mixing angle at a future linear collider may improve its precision by one order of magnitude, a much smaller value of $\delta\Delta\alpha(M_Z^2)$ will be required (see below). It is therefore crucial to assess all viable options to further reduce this uncertainty.

The shift $\Delta\alpha(M_Z^2)$ can be split in two parts: $\Delta\alpha(M_Z^2) = \Delta\alpha_{\rm lep}(M_Z^2) + \Delta\alpha_{\rm had}^{(5)}(M_Z^2)$. The former one, the leptonic contribution, is calculable in perturbation theory and known up to three-loop accuracy: $\Delta\alpha_{\rm lep}(M_Z^2) = 3149.7686 \times 10^{-5}$ [14]. The hadronic contribution $\Delta\alpha_{\rm had}^{(5)}(M_Z^2)$ of the five light quarks (u, d, s, c, and b) can be computed from hadronic e^+e^- annihilation data via the dispersion relation [15]

$$\Delta\alpha_{\rm had}^{(5)}(M_Z^2) = -\left(\frac{\alpha M_Z^2}{3\pi}\right) \mathrm{Re} \int_{m_\pi^2}^{\infty} \mathrm{d}s \frac{R(s)}{s(s - M_Z^2 - i\epsilon)}, \tag{2.2}$$

where $R(s) = \sigma^0_{\rm had}(s)/(4\pi\alpha^2/3s)$ and $\sigma^0_{\rm had}(s)$ is the total cross section for e^+e^- annihilation into any hadronic states, with vacuum polarisation and initial state QED corrections subtracted off. The current accuracy of this dispersion integral is of the order of 1%, dominated by the error of the hadronic cross section measurements in the energy region below a few GeV [16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27] (see Fig. 2 *up*).

Table 1 (from Ref. [20], updated in [23]) shows that an uncertainty $\delta\Delta\alpha^{(5)}_{\rm had} \sim 5\times10^{-5}$, needed for precision physics at a future linear collider, requires the measurement of the hadronic cross section with a precision of 1% from threshold up to the Υ peak.

$\delta\Delta\alpha^{(5)}_{\rm had}\times10^5$	$\delta(\sin^2\theta^{\rm lept}_{\rm eff})\times10^5$	Request on R
22	7.9	Present [23]
7	2.5	$\delta R/R \leq 1\%$ up to J/ψ
5	1.8	$\delta R/R \leq 1\%$ up to Υ

Table 1: Values of the uncertainties $\delta\Delta\alpha^{(5)}_{\rm had}$ (first column) and the errors induced by these uncertainties on the theoretical SM prediction for $\sin^2\theta^{\rm lept}_{\rm eff}$ (second column). The third column indicates the corresponding requirements for the R measurement. From Ref. [20].

As advocated in [28], the dispersion integral (2.2) can be calculated in a different and more precise way: it is sufficient to calculate $\Delta\alpha^{(5)}_{\rm had}(s)$ not directly at $s = M_Z^2$, but at some much lower scale $s_0 = -M_0^2$ in the Euclidean region, which is chosen such that the difference $\Delta\alpha^{(5)}_{\rm had}(M_Z^2) - \Delta\alpha^{(5)}_{\rm had}(-M_0^2)$ can be reliably calculated using perturbative QCD (pQCD). In (2.2) pQCD is used to compute the high energy tail, including some perturbative windows at intermediate energies. An extended use of pQCD is possible by monitoring the validity of pQCD via the Adler function, essentially the derivative of $\Delta\alpha^{(5)}_{\rm had}(s)$ evaluated in the spacelike region: $\frac{D(Q^2)}{Q^2} = -\frac{3\pi}{\alpha}\frac{d\Delta\alpha_{\rm had}}{dq^2}|_{q^2=-Q^2}$. Using a state-of-the-art pQCD prediction for the Adler function one finds that $\Delta\alpha^{(5)}_{\rm had}(-M_Z^2)-\Delta\alpha^{(5)}_{\rm had}(-M_0^2)$ can be neatly calculated from the predicted Adler function [29] for $M_0 \sim 2.5$ GeV as a conservative choice. Also the small missing $\Delta\alpha^{(5)}_{\rm had}(M_Z^2) - \Delta\alpha^{(5)}_{\rm had}(-M_Z^2)$ terms can safely be calculated in pQCD. The crucial point is that pQCD is used in a fully controlled manner, away from thresholds and resonances. There are three points to note: 1) this strategy allows a more precise determination of $\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ than the direct method based on (2.2); 2) However, it requires a very precise QCD calculation and relies on a very precise determination of the QCD parameters α_s, m_c and m_b (for the present status see [30]); 3) Most importantly, as shown in Fig. 2 *down*, the method relies mainly on a precise cross section measurement in the region below 2.5 GeV, which at the same time is most important for reducing the uncertainty of the prediction of the muon $g-2$.

Projects like KLOE-2 are therefore absolutely crucial for a better determination of the effective fine structure constant and the muon $g-2$ (for details see [23]).

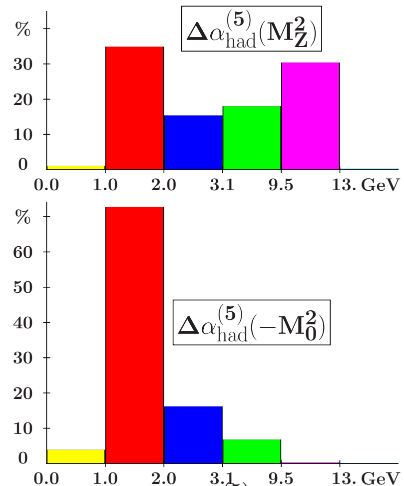

Figure 2: Present error profiles for $\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ (*standard integration, up*), and $\Delta\alpha^{(5)}_{\rm had}(-M_0^2)$ (*Adler function, down*). As it can be seen with this second method about 70% of the total error comes from the region below 2 GeV.

2.2 The muon $g-2$

Like the effective fine-structure constant at the scale M_Z, the SM determination of the anomalous magnetic moment of the muon a_μ is presently limited by the evaluation of the hadronic vacuum polarisation effects, which cannot be computed perturbatively at low energies. However, using analyticity and unitarity, it was shown long ago that the leading-order hadronic contribution to a_μ, $a_\mu^{\rm HLO}$, can be computed from hadronic e^+e^- annihilation data via the dispersion integral [31, 32]:

$$\begin{aligned} a_\mu^{\rm HLO} &= \frac{1}{4\pi^3}\int_{m_\pi^2}^\infty {\rm d}s\, K(s)\sigma^0(s) \\ &= \frac{\alpha^2}{3\pi^2}\int_{m_\pi^2}^\infty {\rm d}s\, K(s)R(s)/s\,. \end{aligned} \tag{2.3}$$

The kernel function $K(s)$ decreases monotonically with increasing s. This integral is similar to the one entering the evaluation of the hadronic contribution $\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ in Eq. (2.2). Here, however, the kernel function in the integrand gives a stronger weight to low-energy data. The contributions to $a_\mu^{\rm HLO}$ and to its uncertainty $\delta a_\mu^{\rm HLO}$ from different energy regions are shown in Fig. 3 [33]. The region below 2.0 GeV accounts for about 95% of the squared uncertainty $\delta^2 a_\mu^{\rm HLO}$, 55% of which comes from the region $1-2$ GeV.

In the last few years several papers have been published [27, 33, 34, 35, 36, 37, 38] aiming to determine the SM value $a_\mu^{\rm SM}$, including the evaluation of the $a_\mu^{\rm HLO}$ term based on the new measurements of the e^+e^- hadronic cross-sections at low energy (particularly at VEPP-2M, DAΦNE, BEPC, PEP-II and KEKB)[39]. The resulting estimates are systematically lower than the experimental result $a_\mu^{\rm exp} = 116592080(63)\times 10^{-11}$ [40] by an amount between 3.1 and 4.0 standard deviations, as for example [37]:

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = +255(80)\times 10^{-11}. \tag{2.4}$$

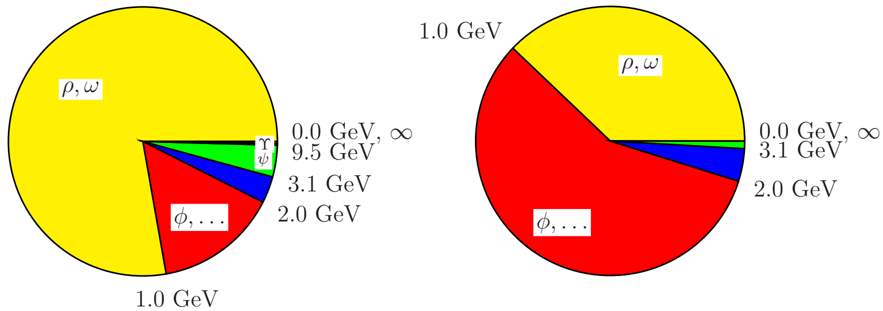

Figure 3: The distribution of contributions (left) and errors (right) in % for a_μ^{HLO} from different energy regions. The error of a contribution i shown is $\delta^2_{i\,\mathrm{tot}}/\sum_i \delta^2_{i\,\mathrm{tot}}$ in %. The total error combines statistical and systematic errors in quadrature. From Ref. [33].

As widely discussed in the literature, this result could well be the first indirect signal of physics beyond the SM [41]. Deviations of this size are indeed expected in several realistic "new-physics" scenarios, such as the minimal supersymmetric extention of the SM (for a discussion see e.g. [42, 43, 44]).

The main contributions to the error on a_μ^{SM} are shown in Table 2 for three recent estimates [33, 35, 38][1], where the two dominant contributions to the uncertainty, namely a_μ^{HLO} and the so called hadronic Light-by-Light scattering term a_μ^{LbL} [33, 45] are shown separately.

Error	[33]	[35]	[38]	prospect
$\delta a_\mu^{\mathrm{SM}}$	65	49	48	35
$\delta a_\mu^{\mathrm{HLO}}$	53	41	40	26
$\delta a_\mu^{\mathrm{LbL}}$	39	26	26	25
$\delta(a_\mu^{\mathrm{SM}} - a_\mu^{\mathrm{EXP}})$	88	80	79	40

Table 2: Estimated uncertainties δa_μ in units of 10^{-11} according to Refs. [33, 35, 38] and (last column) prospects in case of improved precision in the e^+e^- hadronic cross-section measurement (the prospect on $\delta a_\mu^{\mathrm{LbL}}$ is an *educated guess*). Last row: Uncertainty on Δa_μ assuming the present experimental error of 63 from BNL-E821 [40] (first two columns) and of 16 (last column) as planned by the future (g-2) experiments [46, 47].

In order to clarify the nature of the observed discrepancy between theory and experiment, and eventually reinforce its statistical significance, new direct measurements of the muon $g-2$ with a fourfold improvement in accuracy have been proposed at Fermilab [46] and J-PARC [47]. With these experiments the uncertainty of the difference Δa_μ between the experimental and the theoretical value of a_μ will be dominated by the uncertainty of the hadronic cross sections at low energies, unless new experimental efforts at low energy are undertaken. The last column of Table 2 shows a future scenario based on realistic

[1]Ref. [35] includes the recent BaBar 2π data; [33] uses a more conservative error analysis.

improvements in the $e^+e^- \to hadrons$ cross sections measurements. Such improvements could be obtained by reducing the uncertainties of the hadronic cross-sections from 0.7% to 0.4% in the region below 1 GeV and from 6% to 2% in the region between 1 and 2 GeV as shown in Table 3.

	$\delta(\sigma)/\sigma$ present	δa_μpresent	$\delta(\sigma)/\sigma$ prospect	δa_μprospect
$\sqrt{s} < 1$ GeV	0.7%	33	0.4%	19
$1 < \sqrt{s} < 2$ GeV	6%	39	2%	13
$\sqrt{s} > 2$ GeV		12		12
total		53		26

Table 3: Overall uncertainty of the cross-section measurement required to get the reduction of uncertainty on a_μ in units 10^{-11} for three regions of $\sqrt{s}$ (from Ref. [34]).

In this scenario the overall uncertainty on Δa_μ could be reduced by a factor 2. In case the central value would remain the same, the statistical significance would become 7-8 standard deviations, as it can be seen in Fig. 4.

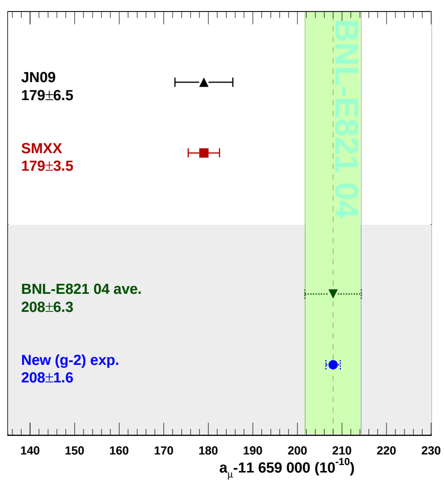

Figure 4: Comparison between $a_\mu^{\rm SM}$ and $a_\mu^{\rm EXP}$. "JN09" is the current evalution of $a_\mu^{\rm SM}$ using Ref. [33]; "SMXX" is the same central value with a reduced error as expected by the improvement on the hadronic cross section measurement at DAΦNE-2 (see text); "BNL-E821 04 ave." is the current experimental value of a_μ; "New (g-2) exp." is the same central value with a fourfold improved accuracy as planned by the future (g-2) experiments [46, 47].

The effort needed to reduce the uncertainties of the $e^+e^- \to hadrons$ cross-sections according to Table 3 is challenging but possible, and certainly well motivated by the excellent opportunity the muon $g-2$ is providing us to unveil (or constrain) "new-physics" effects. Once again, a long-term program of hadronic cross section measurements at low energies is clearly warranted.

3 Measurement of the hadronic cross sections below 2.5 GeV

In the last years the improved precision reached in the measurement of e^+e^- annihilation cross sections in the energy range below a few GeV has led to a substantial reduction in the hadronic uncertainty on $\Delta^{(5)}_{\rm had}(m_Z^2)$ and $a_\mu^{\rm HLO}$ (as discussed above). However, while below 1 GeV the error on the two-pion channel which dominates the cross section in this energy range is below 1%, the region between 1 and 2 GeV is still poorly known, with a fractional accuracy of $\sim 6\%$ (see Table 3). Since this region contributes about 40% to the total error of the hadronic contribution to the effective fine-structure constant to the scale M_Z, $\Delta^{(5)}_{\rm had}(m_Z^2)$ (and up to $\sim 70\%$ by using the Adler function as proposed in [23]), see Fig. 2, and $\sim 50\%$ to the error on the hadronic contribution of the muon anomaly $a_\mu^{\rm HLO}$ (see Fig. 3), it is evident how desiderable an improvement on this region is.

KLOE-2 can play a major role in this region, allowing to measure the hadronic cross section at the 1-2% level. With a luminosity of $10^{32}{\rm cm}^{-2}{\rm s}^{-1}$, DAΦNE upgraded in energy can perform a scan in the region from 1 to 2.5 GeV, collecting an integrated luminosity of 20 pb^{-1} (corresponding to a few days of data taking) per point. Assuming an energy step of 25 MeV, the whole region would be scanned in one year of data taking.

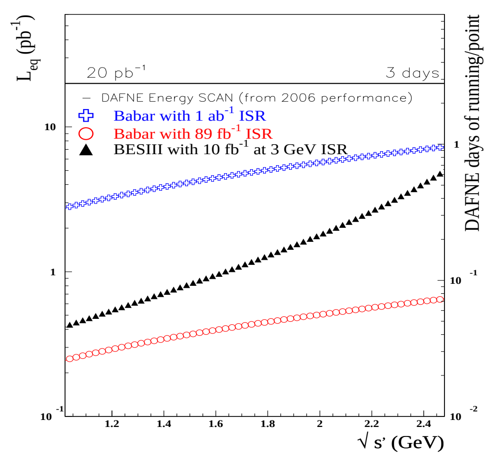

Figure 5: Equivalent luminosity for: BaBar with 1 ab^{-1} (cross); BaBar with 89 fb^{-1} (circle); BES-III with 10 fb^{-1}, using ISR at 3 GeV (triangle). A bin width of 25 MeV is assumed. A polar angle of the photon larger than 20° is assumed.

As shown in Figure 5 the statistical yield will be one order of magnitude higher than with 1 ab^{-1} at BaBar, and significantly better than BES-III. Fig. 6 shows the statistical error for the channels $\pi^+\pi^-\pi^0$, $2\pi^+2\pi^-$ and $\pi^+\pi^-K^+K^-$, which can be achieved by an energy scan at DAΦNE upgraded in energy with 20 pb^{-1} per point, compared with BaBar with published (89 fb^{-1}), and tenfold (890 fb^{-1}) statistics.

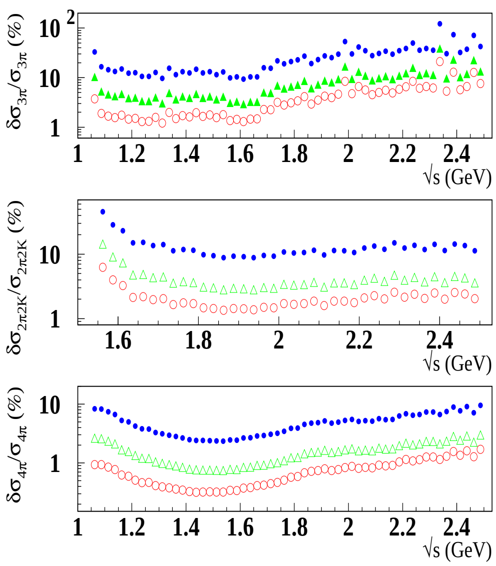

Figure 6: Comparison of the statistical accuracy in the cross-section between DAΦNE upgraded in energy with an energy scan with 20 pb^{-1} per point (∘); published BaBar results (•), BaBar with 890 pb^{-1} statistics (triangle) for $\pi^+\pi^-\pi^0$ (top), $\pi^+\pi^-K^+K^-$ (middle) and $2\pi^+2\pi^-$ (down) channels. An energy step of 25 MeV is assumed.

As can be seen, an energy scan allows to reach a statistical accuracy of the order of 1% for most of the energy points. (In addition, KLOE-2 can benefit from the high machine luminosity to use ISR as well). Comparison of exclusive vs inclusive measurements can be performed as well.

4 Other physics motivations

4.1 $\gamma\gamma$ physics

The upgrade of the KLOE detector with the installation of four smalle-angle detectors (taggers) [48] for electrons and positrons in the final state of the reaction

$$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X \, , \tag{4.1}$$

gives the opportunity to investigate $\gamma\gamma$ physics at DAΦNE. This program will benefit from the energy upgrade of DAΦNE not only for the larger $\gamma\gamma$ flux (see Fig. 7), but also from the opening of channels not avalaible at the ϕ peak, like the production of pseudo-scalar (like the η'), scalar (f_0, a_0, f'_0, a'_0, etc...), axial-vector (a_1, f_1, a'_1, f'_1, etc...), and tensor (a_2, f_2, etc...) mesons.

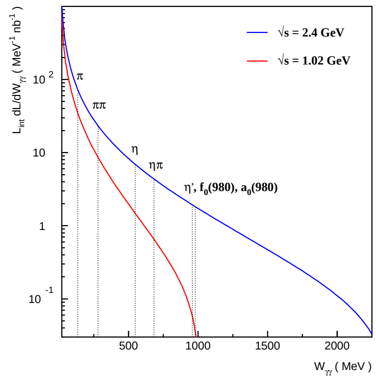

Figure 7: Effective $\gamma\gamma$ luminosity as a function of $W_{\gamma\gamma}$ corresponding to an integrated luminosity of 1 fb^{-1} at $\sqrt{s} = m_\phi$ (red curve) and at $\sqrt{s}$=2.4 GeV (blue curve)

The study of the process in the case in which $X = \pi\pi$ is a clean probe to investigate the nature of the scalar resonance. The nature of the isoscalar scalars seen in $\pi\pi$ scattering below 1.6 GeV, namely the $f_0(600)$ or σ, $f_0(980)$, $f_0(1370)$ and $f_0(1510)$ mesons, is still controversial. Various models have been proposed in which some are $\bar{q}q$, some $\bar{q}qqq$, sometimes one is a $\bar{K}K$-molecule, and one a glueball [49], but definitive statements cannot be drawn. Their two photon couplings will help unraveling the enigma.

Single pseudoscalar ($X = \pi^0$, η or η') production is also accessible and would improve the determination of the two–photon decay widths of these mesons, relevant for the measurement of the pseudoscalar mixing angle φ_P, and the measurement of the valence gluon content in the η' wavefunction. Moreover, the study of the same processes gives access to the transition form factors $F_{X\gamma^*\gamma^*}(M_X^2, q_1^2, q_2^2)$ at spacelike momentum transfers, that are relevant for the hadronic Light-by-Light scattering contribution to the $g-2$ of the muon [33, 37] [2].

By detecting one electron at large angle with respect to the beams, the transition form factor $F_{X\gamma\gamma^*}(M_X^2, Q^2, 0)$ with one quasi–real and one virtual spacelike photon ($Q^2 = -q^2$) can be measured. These form factors, as reviewed in Ref. [50], have been measured by the CELLO [51], CLEO [52] and recently BaBar [53] collaborations in the range $1 < Q^2 < 40$ GeV^2 using single–tagged samples. These data are summarized in Fig. 8. The region of very low Q^2 (less than 0.5 GeV^2, the more important for the Light-by-Light scattering contribution), is devoid of experimental data and is only accessible at DAΦNE.

By increasing the energy of the machine pseudoscalars (like the η'), scalars (like the f_0) and axial-vector (like a_1) mesons will be accessible. A measurement of all these meson transition form factors will be of fundamental importance to reduce the uncertainties that currently affect the estimates of the hadronic LbL scattering.

4.2 Spectroscopy and Baryon Form Factors

Cross sections of exclusive final states are also important for spectroscopy of vector mesons, whose properties provide fundamental information on interactions of light quarks. PDG lists the following vectors between 1 and 2 GeV [54]: $\omega(1420)$, $\rho(1450)$, $\omega(1650)$, $\phi(1680)$,

[2] Pseudoscalar form factors can be also studied in $e^+e^- \to \gamma^* \to P\gamma$ reactions.

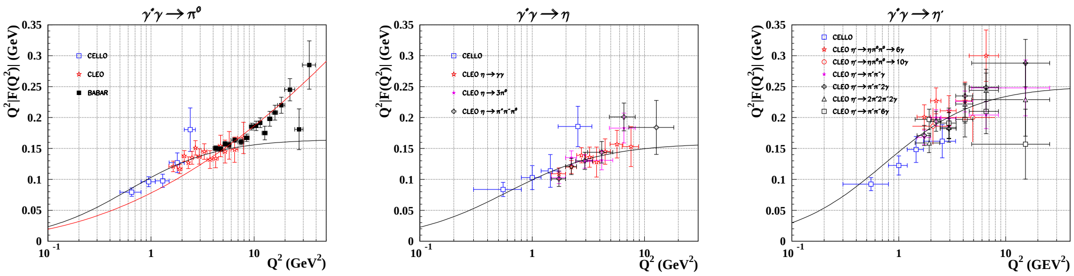

Figure 8: Left: the π^0 transition form factor as measured by the CELLO, CLEO and BaBar experiments. The curve showing an asymptotic limit at 160 MeV is from CLEO parametrization [52] while the other is from the $F_{\pi\gamma\gamma^*}(m_P^2, Q^2, 0)$ expression given in Ref. [50]. Center: the η transition form factor as measured by CELLO and by CLEO in the specified η decay channels. Right: the η' form factor as measured by CELLO and by CLEO in the specified η' decay channels. The curves in the central and left panel represent the CLEO parametrization for the form factors [52].

and $\rho(1700)$. However, even their basic parameters (M, Γ, Γ_{ee}) are badly known. In addition many states still needed a confirmed identification. As discussed in [2, 3] there are still many unsolved points; some progress can be achieved in ISR studies at BaBar and Belle, but such analyses are statistically limited, and a real breakthrough can happen at the dedicated colliders like DAΦNE-2.

Finally, above a center-of-mass energy of $\sqrt{s} = 2M_N = 1.88$ GeV, proton-antiproton and neutron anti-neutron pairs are produced and can be detected. The measurement of the cross-section for nucleon-antinucleon pairs allows to extract the nucleon time-like form factors. While the proton time-like form factors have been extensively measured in a wide q^2 region [55], the neutron time-like form factors are poorly known [56, 57]. More precise information for both time-like form factors would now have an important impact on our understanding of the nucleon structure (see e.g. Refs. [58, 59, 60, 61, 62] and references therein).

4.3 Test of CVC

The hypothesis of the conserved vector current (CVC) and isospin symmetry relate to each other e^+e^- annihilation into isovector hadronic states and corresponding hadronic decays of the τ lepton [63]. Using experimental data on $e^+e^- \to hadrons$ with I=1 one can compare the CVC predictions and τ lepton data both for decay spectra and branching ratios. A systematic check of these predictions showed that at the (5-10)% level they work rather well [64]. However new high-precision data on the 2π final state challenged this statement [65, 66, 67] and some evidence for a similar discrepancy is also observed in $e^+e^- \to \pi^+\pi^-2\pi^0$ [65, 66]. A test of CVC with very high accuracy will be feasible at DAΦNE-2 and will require detailed measurements of the energy dependence of the relevant exclusive processes, like $\pi^+\pi^-$, 4π (2 final states), 6π (3 final states), $\eta\pi^+\pi^-$, K_SK_L and K^+K^-, from threshold to tau lepton mass.

4.4 Searches

Low energy, high luminosity electron-positron colliders are an ideal tool to search for hypothetical "U" vector bosons weakly coupled with Standard Model particles. These bosons are predicted in extensions of the SM, which have recently appeared in the literature as a consequence of some intriguing and, as yet not completely explained, astrophysical observations [68, 69, 70, 71, 72]. In fact KLOE, BaBar and BES-III have already performed or are planning to perform measurements in the field [73, 74, 75, 76, 77]. There are several possible signatures to look at, such as $e^+e^- \to e^+e^- + \gamma$, $e^+e^- \to \mu^+\mu^- + \gamma$, $e^+e^- \to E_{missing} + \gamma$, $e^+e^- \to E_{missing} + e^+e^-$, or events with 4 or 6 leptons in the final state. A careful analysis of such reactions in the region of interest for this proposal would complement the above mentioned searches, particularly in the case of the channels with missing energy or multilepton jets. The cross sections for these processes are expected to be in the ballpark of 10-100 fb, thus one could expect to observe a few hundreds events at the proposed facility.

5 DAΦNE Energy Upgrade

The possibility to run the DAΦNE collider at higher energies has been extensively studied in the past [78, 79, 80]. In the following the necessary hardware modifications, mode of operation and performances estimate will be presented.

5.1 Injection

The injection energy in the DAΦNE collider is limited by several factors:

- Linac: the present maximum energy for positrons is about 530 MeV;
- Damping Ring: the present maximum energy is about 540 MeV;
- Transfer Lines: the present maximum energy is about 540 MeV;
- Injection Septa: the present maximum energy is about 540 MeV.

A significative increase of the DAΦNE injection energy requires major changes in the injection complex. In addition a solution to inject beams with energy around 1.0 GeV seems unfeasible both for the complexity of the changes in the several subsystems and for the space constraints that severely limit what can be possibly be adopted. The most reasonable solution at the moment is to inject in DAΦNE at the nominal energy of about 510 MeV and then ramp the energy up to the desired one.

5.2 Main Rings

In order to ramp-up the energy in the main rings the Final Doublet (FD) has to be replaced with a Superconducting one. In addition the permanent magnet dipole that has been added in the IR this year should also be replaced with a superconducting magnet. This solution seems technically feasible although a detailed engineering study is necessary before a final feasibility statement. In alternative the FD could be replaced by electromagnetic

Panovsky-like quadrupoles with a superconducting counter-solenoid to zero the detector field on the FD. Also this solution needs detailed studies.

The maximum beam energy in DAΦNE is presently determined by the Main Dipoles maximum magnetic field and is about 700 MeV. A preliminary study of a replacement of these Dipoles has been already made. A solution that will allow to reach a beam energy of about 1.02 GeV (2.04 CM energy) seems feasible. Again a detailed engineering study is necessary before stating the feasibility and the maximum energy that can be obtained. This ultimate value could change by +/-10% after such study.

5.3 Operations and performances

The operational scheme would be the following:

- Electrons Injection at 510 MeV, followed by the Positron one (about 10 minutes total);
- Ramp up the machine to the desired energy (5 minutes or less);
- Setting the collisions (2 minutes or less);
- Coasting in collisions for about 30 minutes;
- Dump the beams and ramp down the machine (3 minutes).

During the injection and ramping the beams will not be colliding (by changing the relative RF phase by 180 degrees) and will be enlarged (by increasing the beam coupling by means of Skew Quadrupoles) in order to increase the beam lifetimes while not making any luminosity. This kind of set-up has been already tested in several occasions in MD studies. The Wigglers will be OFF all the time since not necessary and possibly harmful at higher energy. We foresee a test of the maximum storable current without wigglers at 510 MeV sometimes in the next run. The maximum current will also be somewhat limited by the increased Synchrotron radiation power in the Dipoles at high energy. At the moment 1-1.5 Amps per beam seems a safe estimate.

Assuming a peak luminosity of about $5 \times 10^{32} cm^{-2} sec^{-1}$ at 1020 MeV and about 20 pb^{-1}/day average, we should expect about a factor 2 decrease in the peak luminosity at higher energy (because of lower beam-peak currents and possibly not optimal beam parameters) and another factor 2 decrease in the integrated luminosity because of the duty cycle introduced by the need of ramping. An average integrated luminosity of about 5 pb^{-1}/day is henceforth estimated which would be allow to scan the region up to 2 GeV in about one year (as discussed in Section 3).

5.4 Cost estimate and time schedule

A realistic cost estimate could be done during the engineering phase and probably will not exceed 10 MEur. The engineering should be performed with:

- about one year FTE of engineers expert in magnet design
- about three half years FTE of engineers expert in mechanical design, vacuum and cryogenics.

- about one year FTE of technical support

We estimate that from the date of the approval of this project about one year will be needed for the technical design. After that about one year will be needed to purchase the hardware and about 6 months for the installation in DAΦNE.

6 Summary

Precision tests of the Standard Model in future experiments require a more accurate knowledge of the hadronic cross section in the whole energy range between the $2m_\pi$ threshold and 2.5 GeV. The region between 1 and 2.5 GeV is at present the most poorly known and is crucial for the computation of the hadronic corrections to the effective fine-structure constant at the M_Z scale, $\alpha_{em}(M_Z^2)$. It rapresents also a limiting factor to the accuracy of the SM prediction of the $g-2$ of the muon. With an energy upgrade of the DAΦNE collider, KLOE-2 can reduce the accuracy of the hadronic contribution of the muon anomaly $a_\mu^{\rm HLO}$ to less than $3{\times}10^{-10}$. This would represent a twofold reduction of the present error, necessary to match the increased precision of the proposed muon $(g-2)$ experiments at FNAL and J-PARC, and to firmly establish (or constrain) "new physics" effects. A similar improvement can be expected on the determination of the hadronic contribution to $\alpha_{em}(M_Z^2)$. Additional motivations for this upgrade are provided by tests of QCD and effective theories by $\gamma\gamma$ physics with open thresholds for the production of pseudo-scalar (like the η'), scalar $(f_0, a_0, f_0', a_0',$ etc...) and axial-vector $(a_1, f_1, a_1', f_1',$ etc...) mesons; vector-meson spectroscopy and baryon form factors; tests of CVC and searches for exotics. A technical solution for the energy upgrade of DAΦNE (up to about 2 GeV) is proposed.

Acknowledgements

We would like to thank Henryk Czyż, Simon Eidelman, Fred Jegerlehner and Andreas Nyffeler for useful discussions.

References

[1] F. Bossi, E. De Lucia, J. Lee-Franzini, S. Miscetti, M. Palutan (KLOE), Riv. Nuovo Cim. **031**, 531 (2008), 0811.1929

[2] R. Beck et al. (KLOE-2) (2006), Expression of Interest for KLOE-2, http://www.lnf.infn.it/lnfadmin/direzione/roadmap/LoIKLOE.pdf

[3] G. Amelino-Camelia et al. (2010), 1003.3868

[4] F. Ambrosino et al., Eur. Phys. J. **C50**, 729 (2007), hep-ex/0603056

[5] D. Hanneke, S. Fogwell, G. Gabrielse, Phys. Rev. Lett. **100**, 120801 (2008), 0801.1134

[6] G. Gabrielse, D. Hanneke, T. Kinoshita, M. Nio, B.C. Odom, Phys. Rev. Lett. **97**, 030802 (2006)

[7] A. Sirlin, Phys. Rev. **D22**, 971 (1980)

[8] A. Sirlin, Phys. Lett. **B232**, 123 (1989)

[9] W.J. Marciano, A. Sirlin, Phys. Rev. **D22**, 2695 (1980)

[10] M.J.G. Veltman, Nucl. Phys. **B123**, 89 (1977)

[11] LEP-EW-WG (2002), electroweak Theory tests, http://lepewwg.web.cern.ch

[12] S. Schael et al. (ALEPH and others), Phys. Rept. **427**, 257 (2006), hep-ex/0509008

[13] M. Passera, W.J. Marciano, A. Sirlin, Phys. Rev. **D78**, 013009 (2008), 0804.1142; M. Passera, W.J. Marciano, A. Sirlin 1001.4528

[14] M. Steinhauser, Phys. Lett. **B429**, 158 (1998), hep-ph/9803313

[15] N. Cabibbo, R. Gatto, Phys. Rev. **124**, 1577 (1961)

[16] S. Eidelman, F. Jegerlehner, Z. Phys. **C67**, 585 (1995), hep-ph/9502298

[17] M. Davier, A. Hocker, Phys. Lett. **B419**, 419 (1998), hep-ph/9711308

[18] H. Burkhardt, B. Pietrzyk, Phys. Lett. **B513**, 46 (2001)

[19] H. Burkhardt, B. Pietrzyk, Phys. Rev. **D72**, 057501 (2005), hep-ph/0506323

[20] F. Jegerlehner, J. Phys. **G29**, 101 (2003), hep-ph/0104304

[21] F. Jegerlehner, Nucl. Phys. Proc. Suppl. **131**, 213 (2004), hep-ph/0312372

[22] F. Jegerlehner, Nucl. Phys. Proc. Suppl. **162**, 22 (2006), hep-ph/0608329

[23] F. Jegerlehner, Nucl. Phys. Proc. Suppl. **181-182**, 135 (2008), 0807.4206

[24] F. Jegerlehner, Nucl. Phys. Proc. Suppl. **126**, 325 (2004), hep-ph/0310234

[25] F. Jegerlehner (2003), hep-ph/0308117

[26] K. Hagiwara, A.D. Martin, D. Nomura, T. Teubner, Phys. Rev. **D69**, 093003 (2004), hep-ph/0312250

[27] K. Hagiwara, A.D. Martin, D. Nomura, T. Teubner, Phys. Lett. **B649**, 173 (2007), hep-ph/0611102

[28] F. Jegerlehner (1999), hep-ph/9901386

[29] S. Eidelman, F. Jegerlehner, A.L. Kataev, O. Veretin, Phys. Lett. **B454**, 369 (1999), hep-ph/9812521

[30] J.H. Kuhn, M. Steinhauser, C. Sturm, Nucl. Phys. **B778**, 192 (2007), hep-ph/0702103

[31] C. Bouchiat, , C. Michel, J. Phys. Radium **22**, 121 (1961)

[32] M. Gourdin, E. De Rafael, Nucl. Phys. **B10**, 667 (1969)

[33] F. Jegerlehner, A. Nyffeler (2009), 0902.3360

[34] F. Jegerlehner, Nucl. Phys. Proc. Suppl. **181-182**, 26 (2008)

[35] M. Davier, A. Hoecker, B. Malaescu, C.Z. Yuan, Z. Zhang (2009), 0908.4300

[36] S.I. Eidelman (2009), 0904.3275

[37] J. Prades, Acta Phys. Polon. Supp. **3**, 75 (2010), 0909.2546

[38] T. Teubner, K. Hagiwara, R. Liao, A.D. Martin, D. Nomura (2010), 1001.5401

[39] S. Actis et al., Eur. Phys. J. **C66**, 585 (2010), 0912.0749

[40] G.W. Bennett et al. (Muon G-2), Phys. Rev. **D73**, 072003 (2006), hep-ex/0602035. For a Review see J. P. Miller, E. de Rafael, B. Lee Roberts, Rept. Prog. Phys. **70** 795 (2007), hep-ph/0703049

[41] A. Czarnecki and W. J. Marciano, Phys. Rev. **D64**, 013014 (2001), hep-ph/0102122

[42] D. Stockinger, J. Phys. **G34** R45 (2007) hep-ph/0609168

[43] O. Buchmueller et al., Eur. Phys. J. **C64**, 391 (2009), 0907.5568

[44] O. Buchmueller et al., Phys. Lett. **B657**, 87 (2007), 0707.3447

[45] J. Prades, E. de Rafael, A. Vainshtein (2009), 0901.0306

[46] R.M. Carey et al. (2009), FERMILAB-PROPOSAL-0989

[47] J. Imazato, Nucl. Phys. Proc. Suppl. **129**, 81 (2004)

[48] D. Babusci et al. (2009), 0906.0875

[49] E. Klempt, A. Zaitsev, Phys. Rept. **454**, 1 (2007), 0708.4016

[50] A.E. Dorokhov, JETP Lett. **91**, 163 (2010), 0912.5278

[51] H.J. Behrend et al. (CELLO), Z. Phys. **C49**, 401 (1991)

[52] J. Gronberg et al. (CLEO), Phys. Rev. **D57**, 33 (1998), hep-ex/9707031

[53] B. Aubert et al. (BaBar) (2009), 0905.4778

[54] W.M. Yao et al. (Particle Data Group), J. Phys. **G33**, 1 (2006)

[55] B. Aubert et al. (BABAR), Phys. Rev. **D73**, 012005 (2006), hep-ex/0512023

[56] A. Antonelli et al., Nucl. Phys. **B517**, 3 (1998)

[57] V.B. Golubev, S.I. Serednyakov, K.Y. Skovpen, Y.V. Usov, Phys. Atom. Nucl. **72**, 662 (2009)

[58] R. Baldini, S. Pacetti, A. Zallo, A. Zichichi, Eur. Phys. J. **A39**, 315 (2009), 0711.1725

[59] R.B. Baldini, S. Pacetti, A. Zallo (2008), 0812.3283

[60] E.L. Lomon (2006), nucl-th/0609020

[61] A.J.R. Puckett et al., Phys. Rev. Lett. **104**, 242301 (2010), 1005.3419

[62] E. Tomasi-Gustafsson, F. Lacroix, C. Duterte, G.I. Gakh, Eur. Phys. J. **A24**, 419 (2005), nucl-th/0503001

[63] Y.S. Tsai, Phys. Rev. **D4**, 2821 (1971)

[64] S.I. Eidelman, V.N. Ivanchenko, Phys. Lett. **B257**, 437 (1991)

[65] M. Davier, S. Eidelman, A. Hocker, Z. Zhang, Eur. Phys. J. **C27**, 497 (2003), hep-ph/0208177

[66] M. Davier, S. Eidelman, A. Hocker, Z. Zhang, Eur. Phys. J. **C31**, 503 (2003), hep-ph/0308213

[67] M. Davier et al., Eur. Phys. J. **C66**, 127 (2010), 0906.5443

[68] C. Boehm, P. Fayet, Nucl. Phys. **B683**, 219 (2004), hep-ph/0305261

[69] M. Pospelov, A. Ritz, M.B. Voloshin, Phys. Lett. **B662**, 53 (2008), 0711.4866

[70] N. Arkani-Hamed, D.P. Finkbeiner, T.R. Slatyer, N. Weiner, Phys. Rev. **D79**, 015014 (2009), 0810.0713

[71] D.S.M. Alves, S.R. Behbahani, P. Schuster, J.G. Wacker (2009), 0903.3945

[72] R. Essig, P. Schuster, N. Toro (2009), 0903.3941

[73] B. Aubert et al. (BABAR), Phys. Rev. Lett. **103**, 081803 (2009), 0905.4539

[74] B. Aubert et al. (BABAR), Phys. Rev. Lett. **103**, 181801 (2009), 0906.2219

[75] P.f. Yin, J. Liu, S.h. Zhu (2009), 0904.4644

[76] M. Reece, L.T. Wang (2009), 0904.1743

[77] F. Bossi (2009), 0904.3815

[78] C. Milardi (2004), physics/0403044

[79] C. Biscari et al., DANAE Letter of Intent, http://www.lnf.infn.it/lnfadmin/direzione/roadmap/DANAE_LOI.pdf

[80] P. Raimondi (2009), talk given at the KLOE-2 Physics Workshop LNF 9-10 Apr 2009