KLOE PERSPECTIVES FOR R-MEASUREMENTS AT DAFNE2

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Abstract

As a future upgrade of the Frascati φ factory DAFNE an increase of the center-of-mass energy of the accelerator up to \( W = 2 \) GeV has been proposed (DAFNE2). In this case the hadronic cross section in the energy range between \( 1 - 2 \) GeV can be measured with the KLOE detector. The feasibility of these measurements and the impact on the hadronic contribution to the anomalous magnetic moment of the muon, \( a_{\mu}^{\text{had}} \), are discussed. The possibilities for an energy scan are compared with the radiative return technique, in which the accelerator is running at a fixed center-of-mass energy and ISR-events are taken to lower the invariant mass of the hadronic system.

THE DAFNE2 PROPOSAL

The future perspectives of the \( e^+e^- \) collider DAFNE are discussed at the Frascati laboratories (see also [1,2]). Two projects have been proposed recently: an increase of the peak luminosity to \( \approx 10^{34} \text{cm}^{-2}\text{s}^{-1} \) (DAFNE-II) and an increase of the center-of-mass energy up to 2GeV (DAFNE2, [3]), where the second option might be realized either before or within the high-luminosity-solution. While at DAFNE-II the main physics motivation is based on the investigation of the parameters of the kaon system (CP,CPT-violation), DAFNE2 provides the possibility to measure the timelike nucleon form factors at threshold and to perform hadronic cross section measurements in the \( 1 - 2 \) GeV energy range, which we will discuss in the following. Some of the components of the present machine are already designed for an energy increase. The main hardware modifications concern the dipole magnets, the splitter magnets and the low-\( \beta \) quadrupoles. No crucial issues from the accelerator physics point of view can be seen at the moment. Peak luminosities of at least \( 10^{32}\text{cm}^{-2}\text{s}^{-1} \) are expected to be in reach for this machine, which allows to collect an integrated luminosity per year of at least \( 1 \text{fb}^{-1} \).

IMPORTANCE OF THE 1-2 GEV ENERGY RANGE

Hadronic cross section data are of importance for the determination of the hadronic contribution to the anomalous magnetic moment of the muon, \( a_{\mu} \), and for the fine structure constant at the Z pole, \( \alpha(m_Z^2) \). In the following we will discuss the impact of DAFNE2 on the muon anomaly. The hadronic contribution to this fundamental quantity, \( a_{\mu}^{\text{had}} \), which is given by the hadronic vacuum polarization, cannot be calculated at low energies using perturbative QCD. A dispersion relation can however be derived, giving \( a_{\mu}^{\text{had}} \) as an integral over the hadronic cross section, multiplied by an appropriate kernel. The dominant contribution to \( a_{\mu}^{\text{had}} \) (90\%) is given by low energy cross section measurements < 2GeV [4]. This is the region where DAFNE2 will operate. An improved measurement of hadronic cross sections for the various channels of interest could therefore considerably improve the knowledge on the hadronic contribution to \( a_{\mu} \). This is needed for an interpretation of the recent new measurements [5,6] of the muon anomaly (E821 collaboration, BNL), showing a difference between the experimental and theoretical value of \( a_{\mu} \) of up to 3\( \sigma \) (see ref. [4] for details concerning the theory evaluation).

In table 1, the contributions to \( a_{\mu}^{\text{had}} \) and to the squared error \( \delta^2 a_{\mu}^{\text{had}} \) are listed for different energy ranges and for different hadronic channels [1]. It is interesting to notice that the 2\( \pi \) channel is contributing to \( a_{\mu}^{\text{had}} \) to 54\% around the \( \rho \) peak (0.6 - 1.0GeV), while the contribution to the error \( \delta^2 a_{\mu}^{\text{had}} \) in the same energy interval is only 34\%. This difference reflects the fact that the 2\( \pi \) channel around the \( \rho \) peak is well measured now by CMD-2 [7,8] with a systematic error of 0.6\%. Soon also KLOE will publish its results of this channel and of the same energy interval (see these proceedings ref. [9]). Precision measurements for this channel exist also from the analysis of hadronic \( \tau \) decays which are related via the CVC-theorem to electron-positron data and can be used for the evaluation of \( a_{\mu}^{\text{had}} \) after appropriate isospin corrections. At low energies (< 0.6GeV) and even more important at high energies (> 1GeV) a considerable improvement for the two-pion channel is required. The contribution to the error > 1GeV

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1 Ref. [3] has been used for this calculation
Figure 1: $\pi^+\pi^-\gamma$ event yield for an integrated luminosity of $1\text{fb}^{-1}$. Realistic acceptance cuts have been applied: $\Theta_\pi > 30^\circ$, $\Theta_\gamma < 20^\circ$ or $\Theta_\gamma > 160^\circ$. The yield for radiative muon pair production is also shown. The statistics is sufficient to normalize the cross section measurement to muon pairs.

Figure 2: $\pi^+\pi^-\pi^+\pi^-\gamma$ event yield for an integrated luminosity of $1\text{fb}^{-1}$. The dependence of the event rate with the polar angle cut for the pion tracks is shown. The radiated photon is selected at small angles in order to decrease the relative contribution of FSR events: $\Theta_\gamma < 20^\circ$ or $\Theta_\gamma > 160^\circ$

The design of the DAFNE2 project foresees the possibility of a systematic variation of the center-of-mass energy in the $1-2$ GeV range. An energy scan is thus possible. However, also the radiative return is an option for DAFNE2 when the center-of-mass energy of the accelerator is kept fixed at e.g. $W = 2$ GeV or close to the $N\bar{N}$ threshold region where measurements of the timelike nucleon form factor are planned. In the following we will briefly point out the advantages and possible issues of the radiative return method compared to an energy scan.

Another interesting hadronic channel is the $4\pi$ channel where measurements with a precision not better than $10 - 20\%$ exist. The $4\pi$ channel becomes important only above 1 GeV and is therefore a good candidate for DAFNE2. This will be discussed in more detail in the following. The relative contribution of the $4\pi$-channel to the error $\delta^2 a_{\mu}^{\text{hadr}}$ is 7%.

ENERGY SCAN VERSUS RADIATIVE RETURN

Up to recently an energy scan has been considered as the only way to measure hadronic cross sections $e^+e^- \rightarrow \text{hadrons}$ at electron-positron colliders. The KLOE and BABAR collaborations have shown in the meanwhile that the use of Initial State Radiation (ISR) events has to be considered as a complementary and competitive approach at particle factories, which are actually designed for fixed center-of-mass energies $W$. In this new method - called also ‘radiative return’ - hadronic events are taken, in which a photon (energy $E_\gamma$) is radiated before annihilation of the $e^+e^-$ pair. The invariant mass $M_{\text{hadr}}^2$ of the hadronic system is given by: $M_{\text{hadr}}^2 = W^2 - 2WE_\gamma$. In general the cross sections $\sigma_{\text{hadr}+\gamma} = \sigma(e^+e^- \rightarrow \text{hadrons} + \gamma)$ and $\sigma_{\text{hadr}} = \sigma(e^+e^- \rightarrow \text{hadrons})$ are related through:

$$M_{\text{hadr}}^2 \frac{d\sigma_{\text{hadr}+\gamma}}{dM_{\text{hadr}}^2} = \sigma_{\text{hadr}} \cdot H(M_{\text{hadr}}^2) \quad (1)$$

The radiator function $H$ is taken from theory. In the case of KLOE we use the PHOKHARA generator, designed specially for our purposes (see below).

One big advantage of the method is the fact that data comes as a by-product of the standard program of the machine (e.g. CP violation measurements in the case of $N\bar{N}$ and the possibility to measure the center-of-mass of the machine very precisely using the resonant depolarization technique
KLOE/BABAR) and no dedicated experimental modifications are needed. Moreover, the method allows to measure the whole energy spectrum below the center-of-mass energy of the accelerator at a time. Systematic errors from luminosity, the knowledge of the machine energy, efficiencies and acceptances have to be determined only for one single energy point (as a function of $M_{\text{hadr}}^2$ though) and not for each energy bin as it is needed in the case of an energy scan.

There are on the other side a series of issues which need to be attacked, especially if the radiative return method is used for a high precision measurement on the level of 1% or below. Clearly the method requires a precise theoretical knowledge of the ISR-process, i.e. of the radiator function $H$ in equation 1. A lot of progress has been obtained in the last years and calculations exist now up to NLO by means of the Monte Carlo generator PHOKHARA [11] [12] [13] [14] [15]. Another important issue is the suppression of FSR events, since FSR has to be considered as a background to the ISR-approach of the radiative return [16]. Unfortunately, the radiation of photons from hadrons can only be calculated within a certain model dependence. Usually the model of scalar QED is chosen for the radiation of photons from e.g. pions. The actual KLOE analysis uses events in which the radiative photon is selected at small angles, which effectively suppresses the relative amount of FSR well below 1%, such that the model dependence becomes negligible. Moreover, the validity of the model for FSR can be tested from data by measuring the charge asymmetry [11] [17] [18] and by comparing the model prediction with data.

**RADIATIVE RETURN AT DAFNE2**

The PHOKHARA Monte Carlo code has been used to study the event rates for ISR-events at DAFNE2. The machine is assumed to operate at $\sqrt{s} = 2\text{GeV}$. We have investigated the two-pion-state $\pi^+\pi^-$ and the four-pion-states $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-\pi^0\pi^0$ in the $1-2\text{GeV}$ range due to the limited resolution (see above). In figures 1 and 3 the $M_{\text{hadr}}^2$ differential event rates for the states $\pi^+\pi^-,\pi^+\pi^-\pi^+\pi^-,\pi^+\pi^-\pi^0\pi^0$ are shown, where $M_{\text{hadr}}^2$ is the invariant mass of the hadronic (muonic) system. A bin width of 0.04GeV has been chosen. The plots show the event yield for an integrated luminosity of 1fb$^{-1}$ and for realistic selection cuts (see figure caption 1). The number of $\mu^+\mu^-\gamma$ events is again shown for comparison.

In figure 1 and 3 in addition to the hadronic channels the yield of $\mu^+\mu^-\gamma$ events is shown, proving that a normalization to muon events is feasible from the statistical point of view. In the following we briefly present the main experimental issues to be studied:

- The KLOE drift chamber [19] allows a high resolution measurement of the invariant mass $M_{\text{hadr}}^2$ for the fully charged hadronic channels. In the case of the $\pi^+\pi^-\pi^0\pi^0\gamma$ channel the experimental challenge is the correct $\pi^0$ reconstruction and a possible unfolding of the mass spectrum due to the limited resolution.
of the KLOE electromagnetic calorimeter \[20\].

- The suppression of FSR is of great importance for a successful application of the radiative return (see discussion above). Fortunately at \( W = 2 \text{GeV} \) the pion form factor is very small such that the relative amount of FSR in the two-pion-channel will be reduced also.

- In contrary to the present KLOE analysis there will be no background from \( \phi \) decays (e.g. \( \phi \rightarrow \pi^+\pi^-\pi^0 \)) and therefore a much reduced background contamination can be expected at DAFNE2. Moreover, also the Bhabha cross section is considerably reduced with respect to the present DAΦNE machine.

- Above \( M^2_{\text{hadr}} = 2 \text{GeV}^2 \) the two-pion cross section is decreasing rapidly (see fig. 1) while the muonic cross section is high. An efficient separation of pions and muons might become critical in this region.

- KLOE does not have experience in the measurements of channels where four tracks are originating from the interaction point. Special reconstruction software has to be developed for the analysis of the \( \pi^+\pi^-\pi^+\pi^-\gamma \) channel.

In order to understand the final precision for these radiative return measurements, a dedicated feasibility study, including the KLOE detector simulation environment, is needed. We want to stress that no a-priori limitations for a measurement on the level of few percent can be seen at DAFNE2. Moreover, also the Bhabha cross section is considerably reduced with respect to the present DAΦNE machine.

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In order to understand the final precision for these radiative return measurements, a dedicated feasibility study, including the KLOE detector simulation environment, is needed. We want to stress that no a-priori limitations for a measurement on the level of few percent can be seen at the moment. This is sufficient for a sizeable reduction of the contribution above \( 1 \text{GeV} \) to the error on \( \alpha^\mu_{\text{hadr}} \). The experimental issues discussed above, are similar in the case of an energy scan and do not represent a drawback of the radiative return method.

**CONCLUSIONS**

DAFNE2 provides the possibility to measure the hadronic cross section in the \( 1 - 2\text{GeV} \) energy range. The radiative return seems a feasible option for these cross section measurements. Special emphasis should be put on the two-pion and four-pion-channels > 1GeV due to their importance for an improved evaluation of the hadronic contribution to the muon anomaly. The long term goal is a reduction of the error of the hadronic contribution to the muon anomaly to a value \( \delta \alpha^\mu_{\text{hadr}} = 2 \cdot 10^{-10} \). DAFNE2 can make a considerable contribution to this goal. Competition comes from the radiative return activities at BABAR and possible future activities at VEPP-2000, BELLE and CLEO-c.

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