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MEASUREMENT OF THE $e^+ e^- \to \pi^+ \pi^- \gamma$ CROSS SECTION BELOW 1 GEV WITH THE KLOE DETECTOR

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ABSTRACT

The differential cross section for the process $e^+e^- \to \pi^+\pi^-\gamma$ has been measured with the KLOE detector at the e^+e^- collider DAΦNE, as a function of the $\pi\pi$ invariant mass. From this spectrum, the total cross section $\sigma_{e^+e^-\to\pi^+\pi^-}$ for the mass range $0.35\ \mathrm{GeV}^2 < s < 0.95\ \mathrm{GeV}^2$ is extracted and the hadronic contribution to the magnetic anomaly of the muon is evaluated.

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1 Introduction

The comparison of the recent precision measurement of the muon magnetic anomaly, a_μ, at the Brookhaven National Laboratory [1] with the theoretical value is a fundamental test of the Electroweak Standard Model [2]. Because of the nonperturbative regime of QCD, the hadronic contribution is evaluated from data of $\sigma_{e^+e^-\to hadrons}$ by a dispersion integral. In particular measurements of $\sigma_{e^+e^-\to\pi^+\pi^-} \equiv \sigma_{\pi\pi}$ below 1 GeV provide the 62%. The Standard Model a_μ value disagrees by 2.7 standard deviations from the measured value.

2 Radiative return

At DAΦNE $\sigma_{\pi\pi}$ is extracted from the measurement of the differential cross section in the $\pi\pi$ invariant mass, s_π, in the reaction $e^+e^- \to \pi^+\pi^-\gamma$, using [3]:

$$s_\pi \, \frac{d\sigma_{\pi\pi\gamma}}{ds_\pi} = \sigma_{\pi\pi}(s_\pi)\; H(s_\pi) \ , \qquad (1)$$

where the initial state radiation (ISR) of a photon is parameterized by the radiator function H. This approach allows studying $\sigma_{\pi\pi}$ as a function of s_π, for $s_\pi < M_\phi^2$, M_ϕ being the mass of the Φ meson. Final state radiation (FSR) events without any ISR photon are a background for our measurement and they are suppressed at a level lower than 1% by means of the geometrical acceptance of the photon. However events with at least one ISR and a FSR photon are considered as signal in order for $\sigma_{\pi\pi}$ to be inclusive with respect to final state radiative corrections. The signal process, $e^+e^- \to \pi^+\pi^-\gamma_{ISR}(\gamma_{FSR})$, is simulated by the Monte Carlo generator `Phokhara` [4], used in this analysis for evaluating the acceptance corrections, the efficiency of the kinematic cuts and for estimating several systematic uncertainties.

3 Selection of $\pi^+\,\pi^-\,\gamma$ events

The KLOE detector consists of a high momentum and vertex resolution drift chamber, and a good energy resolution electromagnetic calorimeter providing very good time measurements. The data used for this measurement were taken from July to December 2001, yielding an integrated luminosity $\mathcal{L} = 141.4\ \text{pb}^{-1}$. In the following, the main items of the analysis of the reaction $e^+e^- \to \pi^+\pi^-\gamma$ are briefly commented, further details can be found in ref. [5].

3.1 Fiducial volume

We require the detection of two tracks with polar angles between 50° and 130°. The tracks must be connected to a vertex within a cylinder of radius $\sqrt{x^2 + y^2} < 8$ cm and $|z| < 7$ cm. Additional cuts are applied on the transverse momentum, $p_T > 160$ MeV, or on the longitudinal component, $|p_z| > 90$ MeV, for rejecting spiralling tracks and ensuring good reconstruction conditions.

3.2 Photon geometrical acceptance

For enhancing ISR with respect to FSR, events with a photon emitted at small polar angle with respect the beam line are selected. Since the KLOE electromagnetic calorimeter does not cover angles smaller than 20°, *no photon detection is required*, but cuts on the polar angle of the $\pi\pi$ system are applied: $\theta_{\pi\pi} < 15°$ (or $\theta_{\pi\pi} > 165°$). With this configuration the collinear divergence of ISR events allows high statistics and the contamination from the resonant process $e^+e^- \to \phi \to \pi^+\pi^-\pi^0$ is reduced.

3.3 Pion identification

Discrimination of pions from electrons is performed using a function based on approximate likelihood estimators. They are based on the time of flight, and on the shape and quantity of the energy released along the calorimeter of the clusters associated to the tracks. Those observables have been modeled using control samples of $\phi \to \pi^+\pi^-\pi^0$ and $e^+e^- \to e^+e^-\gamma$ events in data, in order to obtain the calorimeter response for pions and electrons. An event is selected as signal if at least one of the two tracks is identified as a pion.

3.4 Kinematic cuts

Contaminations from the processes $e^+e^- \to \mu^+\mu^-\gamma$ and $\phi \to \pi^+\pi^-\pi^0$ are rejected by cuts on the track mass variable, m_{trk}. It is defined by the four-momentum conservation from the momenta of the two tracks and the centre of mass energy under the hypothesis of a final state consisting of two particles with the same mass and one photon.

4 The differential cross section $d\sigma_{\pi\pi\gamma}/ds_\pi$

After all selection cuts we find 1.55×10^6 events. From the observed spectrum, $\Delta N_{obs}/\Delta s_\pi$, we subtract the residual background events, $\Delta N_{bkg}/\Delta s_\pi$, we divide by the total efficiency of the selection, $\varepsilon_{sel}(s_\pi)$, and by the integrated luminosity, the mass resolution allows the bin width $\Delta s_\pi = 0.01$ GeV^2:

$$\frac{d\sigma_{\pi\pi\gamma}}{ds_\pi} = \frac{\Delta N_{obs} - \Delta N_{bkg}}{\Delta s_\pi} \frac{1}{\varepsilon_{sel}(s_\pi)\ \mathcal{L}} \ . \tag{2}$$

4.1 Background estimates

Residual background from $\mu^+\mu^-\gamma$ and $e^+e^-\gamma$ events is estimated fitting the m_{trk} spectrum of the selected data sample with a superposition of three distributions describing the signal and the two background sources. The distributions for signal and $\mu^+\mu^-\gamma$ events are obtained from Monte Carlo simulation, while for $e^+e^-\gamma$ events a dedicated data sample of 152 pb^{-1} is used. The only free parameters of these fits are the relative weights of signal and backgrounds in the data. Background from $\pi^+\pi^-\pi^0$ has been estimated fitting missing mass spectra in a similar way. This latter is the invariant mass of the X state for the process $e^+e^- \to \pi^+\pi^- X$. The contribution of the whole background is less than 2% for $s_\pi > 0.5$ GeV^2 and it increases up to 10% at $s_\pi = 0.35$ GeV^2.

4.2 Efficiencies of the selection

The overall efficiency of the selection is 60%, flat in s_π. During reconstruction an offline filter identifies and rejects background events using information from the calorimeter only. This procedure is related to the different conditions of the data taken during 2001 and it yields the major systematic error, 0.6%. The other sources of systematics are 0.3% or less. From the measured spectrum, $d\sigma_{\pi\pi\gamma}/ds_\pi$ as a function of the true value of s_π is retrieved. The resolution matrix is obtained from a Monte Carlo simulation corrected to reproduce the m_{trk} data histogram and it results nearly diagonal.

4.3 Integrated luminosity

The absolute normalization of the data sample is measured using very large angle Bhabha (VLAB) events, $55° < \theta < 125°$, with a cross section $\sigma \simeq 430$ nb. The integrated luminosity is provided dividing the observed number of VLAB

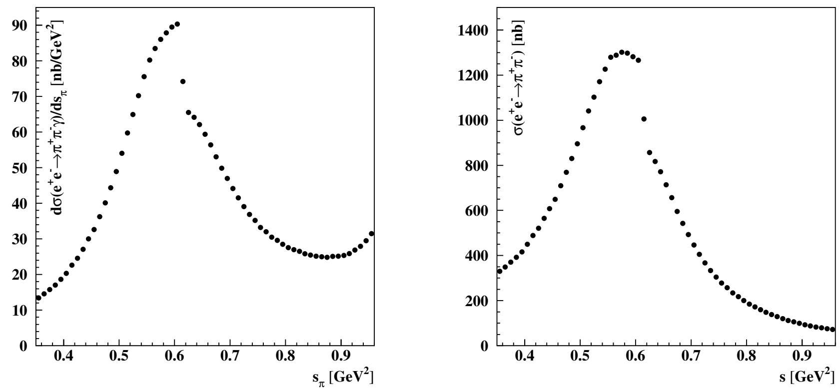

Figure 1: *Left:* $d\sigma_{\pi\pi\gamma}/ds_\pi$ *with* $\theta_{\pi\pi} < 15°$ $(\theta_{\pi\pi} > 165°)$. *Right:* $\sigma_{e^+e^-\to\pi^+\pi^-}$.

events by the effective cross section evaluated by the Monte Carlo generator of Bhabha events `Babayaga` [6], including QED radiative corrections with the parton shower algorithm, inserted in the code simulating the KLOE detector. The quoted precision of `Babayaga` is 0.5%. The background, $\pi^+\pi^-(\gamma)$ and $\mu^+\mu^-(\gamma)$ events, is well below 1% and the main systematic effect is due to the angular acceptance: the overall systematic uncertainty of the measurement is 0.3%. Then, the relative precision is $\delta\mathcal{L}/\mathcal{L} = 0.6\%$.

5 Extraction of $\sigma_{\pi\pi}$

The radiator H needed for getting $\sigma_{\pi\pi}$ as in eq.(1), is provided by the code `Phokhara` after setting the pion form factor $F_\pi(s_\pi) = 1$. The assumption of eq.(1), *i.e.* the absence of interference terms between ISR and FSR, has been tested by an alternative procedure in which only genuine ISR events are considered as signal and FSR corrections to $e^+e^- \to \pi^+\pi^-$ are finally added to $\sigma_{\pi\pi}$. This latter result is compatible with that arising from the analysis within a relative difference of 0.2%, averaged in s_π. Then, $\sigma_{\pi\pi}$ is corrected for the running of the fine structure constant, due to lepton and quark loops [7], before computing the dispersion integral for a_μ.

6 Results and conclusions: a brief outlook

Fig. 1 shows $d\sigma_{\pi\pi\gamma}/ds_\pi$ (left) with $\theta_{\pi\pi} < 15°$ $(\theta_{\pi\pi} > 165°)$ and $\sigma_{\pi\pi}$ (right), the ρ–ω interference pattern is clearly visible. The contribution to the muon magnetic anomaly due to the channel $e^+e^- \to \pi^+\pi^-$, measured in the range

$0.35 \text{ GeV}^2 < s_\pi < 0.95 \text{ GeV}^2$, is:

$$a_\mu^{\pi\pi} = (388.7 \pm 0.8_{stat} \pm 3.5_{syst} \pm 3.5_{th}) \times 10^{-10} .$$

The experimental systematic uncertainty is mainly due to the quality of the data taken in 2001, while the theoretical error takes account of the function H, the FSR corrections and the measurement of the luminosity. The presented value of $a_\mu^{\pi\pi}$, after summing all contributions, confirms the difference between theory and experiment. Future improvements are expected using data taken in 2002, where more stable data taking conditions and improved trigger logic will allow for a reduction of the experimental errors. Furthermore, improved Bhabha Monte Carlo codes are expected to be available in the near future, helping to reduce the theoretical uncertainty.

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