PION FORM FACTOR MEASUREMENT AT BESIII*

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We extract the $e^+e^- \to \pi^+\pi^-$ cross section in the energy range between 600 and 900 MeV, exploiting the method of initial state radiation. The measurement is based on an integrated luminosity of 2.93 fb^{-1}, taken at a center-of-mass energy of 3.773 GeV with the BESIII detector. The cross section is measured with a systematic uncertainty of 0.9%. We extract the pion form factor $|F_\pi|^2$ as well as the contribution to the leading order hadronic vacuum polarization contribution to $(g-2)_\mu$. We find this value to be $a_\mu^{\pi\pi,\mathrm{LO}}(600\text{–}900\ \mathrm{MeV}) = (370.0 \pm 2.5_{\mathrm{stat}} \pm 3.3_{\mathrm{sys}}) \times 10^{-10}$.

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1. Introduction

Since 1960, the anomalous magnetic momentum of the muon a_μ has been measured with ever increasing accuracy by various experiments. The latest and most precise result comes from the BNL [1], which has achieved a sub ppm precision. Also calculations of the Standard Model (SM) prediction of a_μ have been performed to a high accuracy [2]. Presently, a discrepancy of more than 3σ between the experimental results and the theoretical predictions has been observed. The QED contributions [3] and the weak contributions [4] to the SM prediction of a_μ are known to a very high accuracy. The theoretical uncertainty is entirely limited by the hadronic contributions a_μ^{QCD} [5], where the largest of these hadronic contributions stems from the leading order (LO) hadronic vacuum polarization (VP) contribution $a_\mu^{\mathrm{VP,LO}}$. Using the optical theorem, the VP contributions can be related to hadronic

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cross sections. Hence, precise measurements of these hadronic cross sections at e^+e^- colliders are an important input to the Standard Model prediction of the anomalous magnetic momentum of the muon a_μ.

The largest contribution of the hadronic cross sections stems from the process $e^+e^- \rightarrow \pi^+\pi^-$. It covers about 70% of the LO VP contribution $a_\mu^{\mathrm{VP,LO}}$. The most accurate measurements of this cross section have been performed by KLOE [6–8] and BaBar [9, 10]. Each experiment claims a precision better than 1% in the $\rho(770)$ peak. However, the results of the two experiments show a discrepancy of approximately 3% in this region and increasing towards higher energies. This deviation has a large impact on the Standard Model prediction of $a_\mu^{\mathrm{VP,LO}}$. Hence, a measurement performed by a third, independent experiment is needed to shed light on this issue.

2. New measurement at BESIII

Based on 2.93 fb^{-1} of data [12], taken at a center-of-mass energy $\sqrt{s} = 3.773$ GeV, this measurement has been performed at the BESIII experiment [11], operated at the symmetric e^+e^- collider BEPCII in Beijing, China.

The initial state radiation (ISR) method was used to access the energy region between 600–900 MeV. Therefore, events of the type $e^+e^- \rightarrow \pi^+\pi^-\gamma_{\mathrm{ISR}}$ were selected. The non-radiative cross section $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ can be determined by dividing out the radiator function [13] by the radiative $\pi^+\pi^-\gamma_{\mathrm{ISR}}$ event yield.

The dominating background contribution comes from the muon pair production $e^+e^- \rightarrow \mu^+\mu^-\gamma_{\mathrm{ISR}}$. It is suppressed successfully using an artificial neural network [14]. Monte Carlo (MC) simulations of the signal and background processes $\pi^+\pi^-\gamma_{\mathrm{ISR}}$ and $\mu^+\mu^-\gamma_{\mathrm{ISR}}$, respectively, were used to train the neural network. These MC simulations have been produced with the `PHOKHARA` event generator [15]. Possible discrepancies between data and MC simulation due to imperfections in the detector simulation, have been corrected. The systematic uncertainties are summarized in Table I. The cross section was determined with two different methods. In the first method, the efficiency corrected number of $\pi^+\pi^-\gamma_{\mathrm{ISR}}$ events is divided by the radiator function and normalized to the luminosity. The second method uses a different normalization. The event yield is rescaled to the fraction of $\mu^+\mu^-\gamma_{\mathrm{ISR}}$ in data compared to the respective theoretical number of these events. The number of $\mu^+\mu^-\gamma_{\mathrm{ISR}}$ events can be calculated analytically, since it is a pure QED process. On the other hand, selection by the artificial neural network can be inverted to select $\mu^+\mu^-\gamma_{\mathrm{ISR}}$ events as signal. Both methods agree within the errors. For the final result, only the first method is used, since the precision of the second one is statistically limited to the number of $\mu^+\mu^-\gamma_{\rm ISR}$ events. A fit of the $\pi^+\pi^-$ cross section with the Gounaris–Sakurai parametrisation [16] for the ρ–ω interference is performed. The result is shown in Fig. 1. The obtained fit parameters, shown in Table II, agree well with existing results from PDG [17].

TABLE I

Systematic uncertainties.

Source	Uncertainty [%]
Photon efficiency correction	0.2
Pion tracking efficiency correction	0.3
Pion ANN efficiency correction	0.2
Pion e-PID efficiency correction	0.2
ANN	negl.
Angular acceptance	0.1
Background subtraction	0.1
Unfolding	0.2
FSR correction $\delta_{\rm FSR}$	0.2
Vacuum polarisation correction $\delta_{\rm vac}$	0.2
Radiator function	0.5
Luminosity $\mathcal{L}$	0.5
Sum	0.9

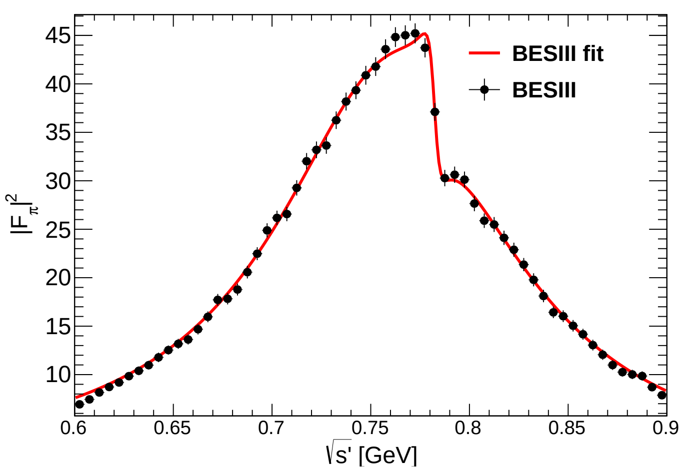

Fig. 1. Pion form factor measured by BESIII. The spectrum is fitted with the Gounaris–Sakurai parametrisation.

TABLE II

Fit parameters of the pion form factor fit.

Parameter	BESIII value	PDG 2014
m_ρ $[\mathrm{MeV}/c^2]$	776.0 ± 0.4	775.26 ± 0.25
Γ_ρ [MeV]	151.7 ± 0.7	147.8 ± 0.9
m_ω $[\mathrm{MeV}/c^2]$	782.2 ± 0.6	782.65 ± 0.12
Γ_ω [MeV]	fixed to PDG	8.49 ± 0.08
$\lvert c_\rho\rvert$ $[10^{-3}]$	1.7 ± 0.2	—
$\lvert\phi_\omega\rvert$ [rad]	0.04 ± 0.13	—

3. Results

The comparison to the published pion form factor results from BaBar and KLOE collaborations is shown in Fig. 2. It can be seen that the new BESIII measurement agrees with the result from KLOE in the mass range below the $\rho(770)$ peak. A small systematic shift w.r.t. BaBar, not exceeding 2σ, is seen. At high masses, the agreement with BaBar is very good and a clear deviation KLOE spectrum is observed. The extracted cross section can

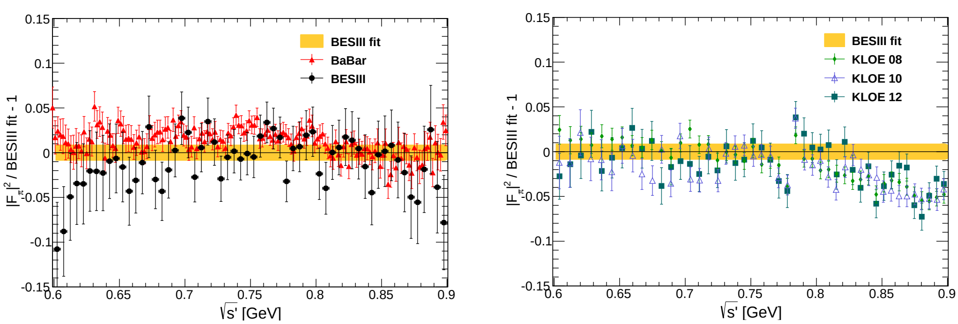

Fig. 2. Comparison of the fitted pion form factor from BESIII to BaBar (left) and KLOE (right).

be used to calculate the two-pion contribution to $a_\mu^{\pi\pi,\mathrm{LO}}$. The measured cross section is corrected for vacuum polarisation effects and final state radiation effects. The vacuum polarisation correction is taken from the PHOKHARA MC generator [15]. The result for the $\rho(770)$ peak region is found to be $a_\mu^{\pi\pi,\mathrm{LO}}(600\text{–}900~\mathrm{MeV}) = (370.0 \pm 2.5_{\mathrm{stat}} \pm 3.3_{\mathrm{sys}}) \times 10^{-10}$. The comparison of the value for $a_\mu^{\pi\pi,\mathrm{LO}}$ obtained by KLOE, BaBar and BESIII in the same energy region is illustrated in Fig. 3. This result confirms the discrepancy in a_μ between the Standard Model prediction and experiment on the level of 3 to 4 standard deviations.

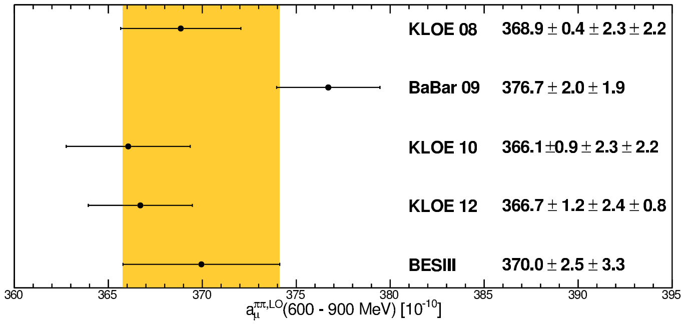

Fig. 3. Comparison of the results for $a_\mu^{\pi\pi,\mathrm{LO}}$(600–900 MeV) between KLOE, BaBar and BESIII. The errors bars include statistical and systematic errors. The band shows the 1σ range of the BESIII result.

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