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FINAL–STATE RADIATION IN ELECTRON–POSITRON ANNIHILATION INTO PION PAIR

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1 Introduction

In this article the final-state radiation (FSR) of the hard photon in $e^-(p_1) + e^+(p_2) \rightarrow \gamma^*(Q) \rightarrow \pi^+(p_+) + \pi^-(p_-) + \gamma(k)$ reaction is considered in the framework of ChPT with vector ρ and axial–vector a_1 mesons [1] (the FSR diagrams are shown in Fig.1).

Our consideration of FSR is motivated by the necessity to study model dependence of the next-to-leading order hadronic contribution $a_\mu^{had,\gamma}$ to anomalous magnetic moment (AMM) of the muon ($a_\mu^{had,\gamma}$ is the hadronic contribution, where additional photon is attached to hadrons). Also FSR is a main unre-

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stricted background to scan the hadronic cross–section at meson factories by the radiative return method [2]. In this method only ISR (initial-state radiation) events have to be chosen and the FSR processes have to be rejected. Different methods have been suggested to separate ISR and FSR contributions for the dominant hadronic channel at low energies – the pion-pair production. One of them is to choose kinematics, where photon is radiated outside the narrow cones along the momenta of the pions. In these conditions the FSR contribution is suppressed. If the FSR background can be reliably calculated in some theoretical model then it can be subtracted from experimental cross section of $e^+e^- \to \pi^+\pi^-\gamma$ or incorporated in the Monte Carlo event generator used in analysis. Finally, the theoretical predictions for FSR can be tested by studying the C–odd interference of ISR and FSR [3].

The FSR cross section has been calculated [3] in framework of the scalar QED (sQED), in which the pions are treated as point-like particles, and the resulting amplitude is multiplied by the pion electromagnetic form factor $F_\pi(s)$ evaluated in VMD model (s is the total e^+e^- energy squared) to account for the pion structure. Although sQED in some cases works well [2, 3], it is clear that sQED is a simplified model of a complicated process, which may include excitation of resonances, loop contributions, etc. In view of the high requirements for the accuracy of theoretical predictions for AMM, further studies of the FSR contribution are necessary.

2 Results of calculation

In view of the restricted space of this contribution only the results of calculations are presented (for details see Ref. [4]).

First, the charge asymmetry [3] proportional to the interference of ISR and FSR is calculated for the so-called collinear kinematics in which the hard photon is radiated inside a narrow cone with the opening angle $2\theta_0$ ($\theta_0 \ll 1$) along the direction of initial electron. In Fig.1 we show the asymmetry dependence on pion polar angle at fixed two–pion invariant mass q^2. It follows that the asymmetry changes sign at about $q^2 = 0.5$ GeV^2. At all pion angles the difference between sQED and ChPT shows up only at small values of q^2 or, equivalently, at high photon energies. Thus only at high photon energies the contribution from a_1 intermediate meson (see diagrams with a_1–meson in Fig.2) is sizable. For large values of q^2 the difference between predictions of

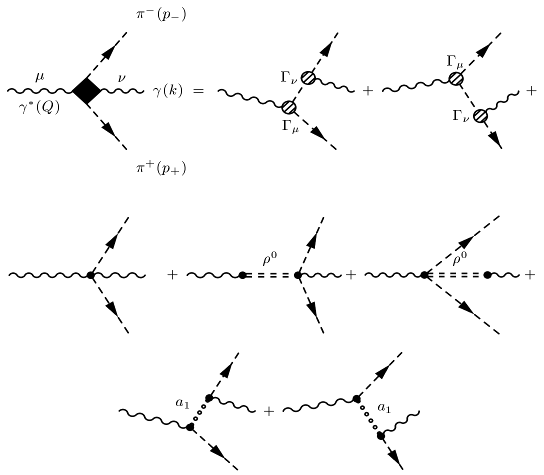

Figure 1: *Diagrams for FSR in the framework of ChPT.*

sQED and full calculation in ChPT is small: for $q^2 \geq 0.6$ GeV^2 it is less than 1% (the dashed and solid lines almost coincide in Fig.1). Taking into account that the asymmetry itself is less than 10^{-2}, the experimental observation of such deviations in the energy region $q^2 \geq 0.6$ GeV^2 is problematic.

Second, we apply the result of Ref. [4] to evaluation of $a_\mu^{\pi\pi,\gamma}$. It appears that the additional contributions to $a_\mu^{\pi\pi,\gamma}$ arising in ChPT are very small compared with sQED result (here only the radiation from hard photon ($\omega \geq E_{cut}$) is taken into account). Even for $E_{cut} = 200$ MeV the ChPT result differs from the sQED one by only 3.5%(see the solid and dashed lines in Fig.3 which almost coincide). These small deviations are not surprising. First, at fixed value of s the low–energy photon region, which is described in a similar way by both models, dominates in $a_\mu^{\pi\pi,\gamma}$. Second, the main contribution to $a_\mu^{\pi\pi,\gamma}$ comes from the region of the ρ–resonance, which is treated in the same manner in sQED and ChPT via VMD model.

At the same time, with increasing the photon energy sQED losses its predictive power. This is demonstrated in Figs.2 and 3 (right panel). In this region the contribution from a_1–meson is considerable and has to be taken into account. For example, at the photon energy about 500 MeV the deviation from sQED reaches 60%. However, this deviations (which are of the order of 10^{-12})

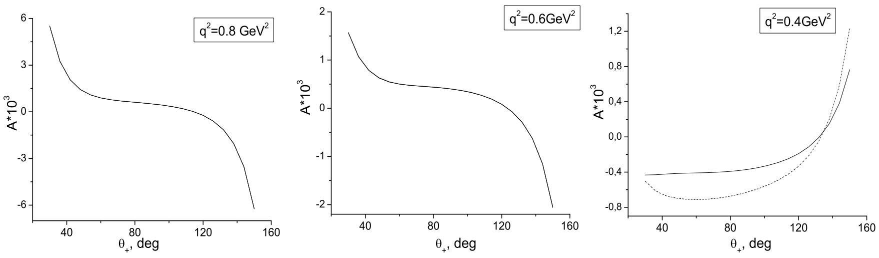

Figure 2: *Charge asymmetry as a function of pion polar angle at fixed q^2 for $s = 1\ GeV^2$. The solid line corresponds to sQED, the dashed line – the full result in ChPT.*

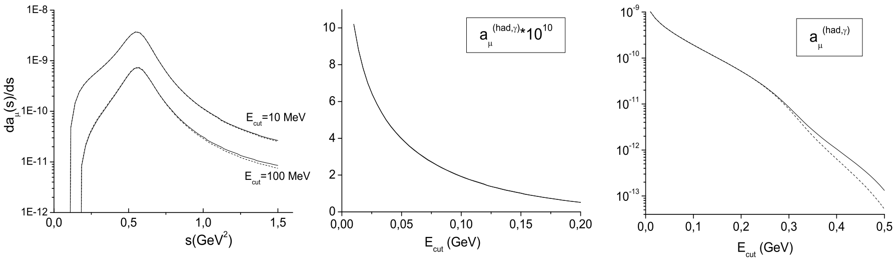

Figure 3: *Differential contribution $a_\mu^{\pi\pi,\gamma}$ (left panel). Integrated contribution to $a_\mu^{\pi\pi,\gamma}$ as a function of E_{cut} (central and right panels). Here $s_{max} = 1.5\ GeV^2$. Notations for the curves are the same as in Fig.2.*

are beyond the accuracy of the present measurements of the muon AMM.

3 Conclusions

We demonstrated that the model dependence of the two–pion contribution to $a_\mu^{had,\gamma}$ is weak, and the value of $a_\mu^{had,\gamma}$ is not sensitive to chiral dynamics beyond the ρ–meson dominance. As for the charge asymmetry, its model dependence can be observed experimentally only for q^2 near the two-pion threshold region: $4m_\pi^2 \leq q^2 < 0.4$ GeV^2.

Therefore, in the bulk of energies up to 1 GeV, sQED is sufficient to describe the FSR contribution to both $a_\mu^{had,\gamma}$ and C–odd asymmetry. To observe deviations from sQED the existing experimental error bars for $a_\mu^{had,\gamma}$ have to be reduced by at least one order of magnitude. Possibly, the more complicated many–particle channels in e^+e^- annihilation are more sensitive to the chiral dynamics.

References

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