Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Physics Letters B 611 (2005) 116–122
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Charge asymmetry and radiative ϕ decays ☆

Henryk Czyż [a], Agnieszka Grzelińska [a], Johann H. Kühn [b]

[a] *Institute of Physics, University of Silesia, PL-40007 Katowice, Poland*
[b] *Institut für Theoretische Teilchenphysik, Universität Karlsruhe, D-76128 Karlsruhe, Germany*

Received 16 December 2004; accepted 12 February 2005

Editor: P.V. Landshoff

Abstract

The study of radiative ϕ decays into scalar mesons, with subsequent decay into $\pi\pi\gamma$, constitutes an important topic at the electron–positron collider DAPHNE. The interference of the respective amplitude with the one for $\pi^+\pi^-\gamma$ production, where the photon originates from initial state radiation, will allow for unambiguous tests of models for the $\phi \to \gamma f_0(\to \pi\pi)$ amplitude. The forward–backward asymmetry of charged pions, which is a clear signal of such an interference, amounts up to 30% and is at the same time quite sensitive to the details of the various amplitudes. The results for several characteristic cases are presented and their implementation into the Monte Carlo generator PHOKHARA is described.

PACS: 13.25.Jx; 13.66.Bc; 11.30.Er; 13.40.Gp

Keywords: Radiative return; Radiative ϕ decays

1. Introduction

The method of the radiative return, i.e., the study of events with initial state radiation (ISR) at electron–positron colliders, allows to measure the hadronic cross section over a wide range of energies in a single experiment, without changing the beam energy. Originally suggested already long time ago [1], the idea has been revived in [2], after high luminosity electron–positron colliders, specifically ϕ- and B-meson factories, came into operation. Already now the method has been used to study the pion form factor at DAPHNE [3] and the production of $J/\psi(\to \mu^+\mu^-)$ [4] and of $\pi^+\pi^-\pi^0$ at BaBar [5]. It relies on the factorization into a part describing the production of the virtual photon from the initial state (including radiative corrections) and a part describing the production of hadrons from the virtual photon, which essentially corresponds to the cross section for $e^+e^- \to$ hadrons. This important feature is affected by contributions

☆ Work supported in part by EC 5th Framework EURIDICE network project HPRN-CT2002-00311, TARI project RII3-CT-2004-506078, Polish State Committee for Scientific Research (KBN) under contract 1 P03B 003 28 and BMBF/WTZ/POL01/103.

E-mail address: czyz@us.edu.pl (H. Czyż).

0370-2693/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.physletb.2005.02.027

from the emission of photons from the final state (FSR). As discussed in [2], suitable kinematic cuts can be chosen, which strongly reduce these effects in $e^+e^- \to \pi^+\pi^-\gamma$. For B-meson factories, configurations with hadrons of low invariant mass in one hemisphere and a hard photon in the opposite hemisphere are completely dominated by ISR, with a small admixture from the "two step" process $e^+e^- \to \gamma\gamma^*(\to \pi^+\pi^-\gamma)$. The situation is more involved at the ϕ-factory DAPHNE. For photons at small angles with respect to the beam direction and centrally produced pions, ISR is again dominant. This is the kinematic region studied in [3] for a measurement of the pion form factor. In general, however, FSR will be more important at these low energies. Unavoidably, the input for any FSR analysis and Monte Carlo simulation will be model dependent and a careful experimental test of the model assumptions is required. The most recent and detailed analysis of this problem [6] has been performed with the Monte Carlo event generator PHOKHARA [7], where FSR for pions is modelled by scalar QED (sQED) (a different ansatz, leading to similar conclusions is presented in [8]). This ansatz is certainly adequate for most of the kinematic regions and for cms energies away from the ϕ resonance. For $\sqrt{s} \simeq 1.02$ GeV, on top of the ϕ-resonance, an additional complication arises: the presence of the narrow ϕ-resonance leads to an enhancement of $\pi\pi\gamma$ final states through radiative ϕ-decays into (dominantly scalar) resonances. This process is important in itself and has, for many years, been the subject of theoretical investigations (see [9–15] and references therein), where the decay chain $\phi \to (f_0(980) + f_0(600))\gamma \to \pi\pi\gamma$ is generally assumed to dominate. First investigations, where this channel has been linked to the radiative return, have been published in [13]. Two distinct features allow to discriminate the radiative ϕ decay from $\pi\pi\gamma$ production through the radiative return on one hand and from FSR from charged pions on the other hand: radiative ϕ decays to γf_0 will lead to $\pi^+\pi^-\gamma$ and $\pi^0\pi^0\gamma$ states with a relative weight $2:1$; this is in contrast to FSR from pions, which, similarly to ISR, leads by construction to $\pi^+\pi^-\gamma$ only. FSR is, furthermore, strongly enhanced for photons collinear to the pions. A second important feature, which will be the main subject of this Letter, is the charge asymmetry. It arises from the interference between ISR with $\pi^+\pi^-$ in an odd charge conjugate state, and FSR and radiative ϕ decays, with $\pi^+\pi^-$ in an even charge conjugate state. With the ISR amplitude being already fairly well determined, this interference will allow to pin down size and even the relative phase of the $\phi \to \pi\pi\gamma$ amplitude in a model independent way. As a third possibility the dependence of all this distributions on the cms energy and the energy dependent relative importance of ϕ and continuum amplitude could be used. However, we will not dwell further on this last, fairly obvious, aspect.

2. Description of the model

The subsequent analysis will not attempt to study the most general amplitude for the radiative ϕ decay. Instead we will use characteristic models with different resonance admixture and variable phases and demonstrate that these will lead to marked differences in the charge asymmetry.

For definiteness, we have adopted two models describing $\phi \to \pi\pi\gamma$ decays (π stands for both neutral and charged modes), used also in [13]: the "no structure model" of [9] and the K^+K^- model of [10]. The models were extended to include both $f_0(980)$ and $f_0(600)$ (σ) intermediate states in the decay chain $\phi \to (f_0(980) + f_0(600))\gamma \to \pi\pi\gamma$, an extension required to fit experiments [16,17]. More sophisticated version of the K^+K^- model, incorporating also the complete $f_0(980) + f_0(600)$ mixing matrix, can be found in [11,12]. Contributions from the $\phi \to \pi\rho(\to \pi\gamma)$ decay chain are not taken into account. Indeed KLOE data [16] show, that they are negligible for the $\pi^0\pi^0\gamma$ final state. The branching ratios $\mathrm{BR}(\rho^\pm \to \pi^\pm\gamma)$ and $\mathrm{BR}(\rho^0 \to \pi^0\gamma)$ are comparable [18], hence the same applies to the $\pi^+\pi^-\gamma$ final state.

At present this choice of models is not based on definite experimental information, which is still quite poor, but on their simplicity. To discriminate between different models, more experimental work is needed. However, as shown in the next section, a lot can be learned from studies of charge and charge induced asymmetries.

The amplitude for FSR based on sQED, denoted $\mathcal{M}_{\mathrm{sQED}}$, is identical to the one used in PHOKHARA