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Measurement of the transition form factor in $\phi \to \eta e^+ e^-$ and $\phi \to \pi^0 e^+ e^-$ decays at KLOE

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Abstract. In this work we present a study of the Dalitz decay $\phi \to \eta e^+e^-$, with $\eta \to \pi^0\pi^0\pi^0$, performed using 1.7 fb^{-1} of e^+e^- collisions collected at KLOE in the 2004-2005 data taking period. The resulting branching fraction is: BR($\phi \to \eta e^+e^-$) = $(1.075 \pm 0.007(\text{stat.}) \pm 0.038(\text{norm.})) \times 10^{-4}$. We have also studied the invariant mass of the dilepton system, extracting the slope of the transition form factor: $b_{\phi\eta} = (1.17 \pm 0.10^{+0.07}_{-0.11})\,\text{GeV}^{-2}$. The $\phi \to \pi^0 e^+e^-$ rare decay is also being studied using the same data sample. The branching ratio will be measured, with a consistent reduction of the actual total uncertainty. The double off shell π^0 Transition Form Factor will also be measured for the first time in the time-like region, with the momentum transfer given by the e^+e^- invariant mass.

1 Introduction

Conversion decays of vector and pseudoscalar mesons (A $\to$ Bγ^*) are closely related to corresponding radiative decays (A $\to$ Bγ). The nature of the mesons and their underlying quark and gluon structure can be therefore described by the transition form factor function of A into B ($F_{AB}(q^2)$), that can be extracted from data by studying the probability of the conversion decay as a function of the squared invariant mass of the lepton pair. The decay parametrization is taken from Ref. [1]:

$$\frac{1}{\Gamma(\phi \to \eta\gamma)} \frac{d\Gamma(\phi \to \eta\, e^+e^-)}{dq^2} =$$
$$\frac{\alpha}{3\pi} \frac{|F_{\phi\eta}(q^2)|^2}{q^2} \sqrt{1 - \frac{4M^2}{q^2}} \left(1 + \frac{2M^2}{q^2}\right) \left[\left(1 + \frac{q^2}{M_\phi^2 - M_\eta^2}\right)^2 - \frac{4M_\phi^2 q^2}{(M_\phi^2 - M_\eta^2)^2}\right]^{3/2}, \tag{1}$$

with

$$F(q^2_{\phi\eta}) = \frac{1}{1 - q^2/\Lambda^2_{\phi\eta}} \tag{2}$$

in one-pole approximation. The form factor slope $b_{\phi\eta} = dF/dq^2|_{q^2=0}$ is equal to $\Lambda^{-2}_{\phi\eta}$.

The naive vector meson dominance (VMD) approach is satisfactory in the description of some conversion decays, such as, for instance, the case of $\eta \to \gamma\mu^+\mu^-$, while failing for others, such as in

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the case of $\omega \to \pi^0\mu^+\mu^-$. Recently, new models have been developed (see Ref. [2] and [3]) based on most accurate description of A $\to$ Bγ^* channels. Therefore, it is important to validate this model with the experimental results. In this note, we focus our study on the decay channel $\phi \to \eta e^+e^-$, with $\eta \to 3\pi^0$. The only existing data on $\phi \to \eta e^+e^-$ come from the SND [4] and CMD-2 [5] experiments. Their BR($\phi \to \eta e^+e^-$) measurements are $(1.19\pm0.31)\times10^{-4}$ and $(1.14\pm0.16)\times10^{-4}$ respectively. The VMD expectation is BR($\phi \to \eta e^+e^-$) = 1.1×10^{-4}. SND experiment has also measured the transition form factor from the M_{ee} invariant mass distribution on the basis of 213 events: $b_{\phi\eta}=3.8\pm1.8$ GeV^{-2}. The VMD expectation is $b_{\phi\eta}=1$ GeV^{-2}.

2 The $\phi \to \eta e^+e^-$ analysis

A detailed study of $\phi \to \eta e^+e^-$ decay is in progress, using $\eta \to \pi^0\pi^0\pi^0$ decay channel. The analyzed sample is based on 1.7 fb^{-1} data, collected at $\sqrt{s} = m_\phi$ during the 2004-2005 KLOE data taking campaign. The first step of the analysis is the rejection of splitted tracks using the broken-track algorithm [6], that retain only good track candidates coming from the interaction point.

The preselection requires:

1. one positive and one negative track in a cylinder around the interaction point (IP), with transverse radius R_{FV} = 4 cm and total height Z_{FV} = 20 cm;

2. six photon candidates, i.e. energy deposits in the calorimeter without associated tracks with energy larger than 7 MeV, in an angular acceptance $|\cos(\theta_\gamma)| < 0.92$ and in the expected time window for photon ($| T_\gamma - R_\gamma/c | <$ MIN$(3\sigma_T, 2$ ns));

3. invariant mass of the six photons inside a window around the η mass value, 400-700 MeV.

Although a large part of the backgrounds is already rejected at this level, some contamination from photon conversion events, $\phi \to \eta\gamma$, with photon conversion on BP or DC walls, is still present. This background is rejected applying a specific photon-conversion recognition algorithm. The other background components, $\phi \to K_S K_L$, with $K_S \to \pi^+\pi^-$, and $e^+e^- \to \omega\pi^0$, are rejected using the time of flight to the calorimeter. At the end of the analysis chain, the residual background contamination is at the level of 3%. After the background subtraction 29625±178 $\phi \to \eta e^+e^-$, $\eta \to 3\pi^0$, candidates remain in the analysis dataset.

2.1 Branching ratio of the $\phi \to \eta e^+e^-$ decay

The branching ratio has been calculated using bin-by-bin efficiency correction:

$$BR(\phi \to \eta e^+e^-) = \frac{\sum_i N_i/\epsilon_i}{\sigma_\phi \times \mathcal{L} \times BR(\eta \to 3\pi^0)}. \tag{3}$$

The luminosity measurement is obtained using very large angle Bhabha scattering events [7], giving an integrated luminosity of $\mathcal{L} = (1.68 \pm 0.01)$ fb^{-1}. The effective ϕ production cross section takes into account the center of mass energy variations (at 1% level) [8]: σ= (3310 ± 120) nb. The value of the BR($\eta \to 3\pi^0$)=(32.57±0.23)% is taken from [9]. Our result is:

$$BR(\phi \to \eta e^+e^-) = (1.075 \pm 0.007 \pm 0.038) \times 10^{-4}, \tag{4}$$

where the error includes the uncertainties on luminosity and ϕ production cross section. The systematic error has been evaluated moving by $\pm1\sigma$ the analysis cuts on the recoil mass and TOF, and by ±

20% those related to conversion cuts. In order to evaluate the systematic due to the variation of the analysis efficiency for low M_{ee} values, the BR has been measured for $M_{ee} > 100$ MeV, where the efficiency has a smoother behaviour. These systematics are negligible with respect to the normalization error.

2.2 Fit to the Mee spectrum and extraction of the Form Factor Slope

As result of the fit procedure, we determine a value for the form factor slope:

$$b_{\phi\eta} = (1.17 \pm 0.10^{+0.07}_{-0.11})\ \text{GeV}^{-2} \tag{5}$$

with $\chi^2/\text{NDF} = 1.17$ and Prob(χ^2)≈12.58%. In Figure 1 the fit result is shown for each invariant mass bin and compared with the data. The result is in agreement with the VDM model. The central value is smaller, although still consistent within the error, than the result obtained by the SND experiment [4].

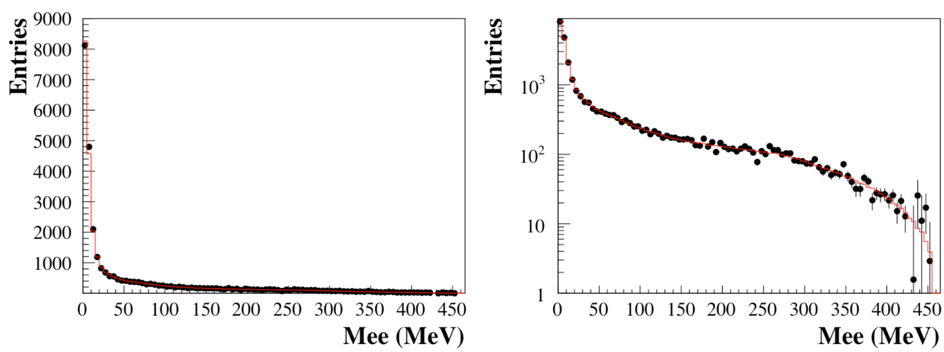

Figure 1. Fit to the M_{ee} spectrum for $\phi \to \eta e^+e^-$ candidates, both in linear (left) and logarithmic (right) scale.

Systematics for the M_{ee}(recoil), TOF and photon conversion cuts have been evaluated as for the BR measurement. Systematics related to the fit procedure have been evaluated as the RMS of the deviation from the central value obtained by varying the mass range used for the fit. The total systematic error is the quadrature of all contributions.

3 The $\phi \to \pi^0 e^+e^-$ analysis

The total absence of experimental determination of the $F_{\phi\pi^0\gamma^*}$ transition form factor and the low accuracy in the knowledge of the branching ratio (∼ 25% in the Particle Data Group world average), motivate the analysis of $\phi \to \pi^0 e^+e^-$ decay at KLOE. The signal events are selected requiring two tracks of opposite charge and two prompt neutral clusters coming from the IP. Simple kinematical cuts on the lepton energies ($E_{e^+,e^-} < 460$ MeV and $470 < E_{e^+} + E_{e^-} < 750$ MeV), photon energies ($E_{\gamma_1,\gamma_2} > 70$ MeV and $300 < E_{\gamma_1} + E_{\gamma_2} < 670$ MeV) and opening-angles of tracks and prompt clusters ($\theta^{\text{open}}_{e^+e^-} < 145°$ and $27° < \theta^{\text{open}}_{\gamma_1\gamma_2} < 57°$) allow to reject a big amount of dominant background from radiative Bhabha scattering processes (i.e. $e^+e^- \to e^+e^-\gamma\gamma$). The other main background contribution comes from the radiative decay $\phi \to \pi^0\gamma$, with the real photon converting to an e^+e^- pair on the beam-pipe and drift-chamber walls. This kind of events can be partially rejected tracking the leptons back to the conversion wall, and then cutting on the invariant-mass and distance between the tracks. At the end of the analysis path, ~ 14600 events are selected, with a background contamination of about ~ 35%. The background subtraction, the extraction of the form factor and the BR are going to be finalized soon. A preliminary result of the fit to the M_{ee} spectrum is shown in Fig. 2

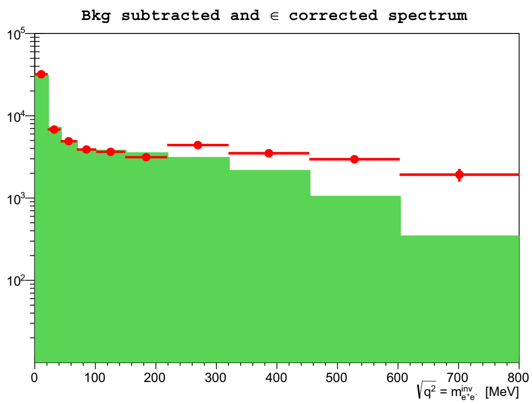

Figure 2. Fit to the M_{ee} spectrum for $\phi \to \pi^0 e^+e^-$ candidates.

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