Measurements of the Form Factor in VPγ^* Transitions and Study of the $\eta \to \pi^+\pi^-\pi^0$ Dalitz Plot at KLOE

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The Vector→Pseudoscalar γ^* decays $\phi \to \eta e^+e^-$ and $\phi \to \pi^0 e^+e^-$ have been measured based on 1.7 pb^{-1} of data collected with the KLOE experiment, for extracting the branching ratios and transistion form factors.

With 1.6 pb^{-1} of data from the same experiment, we measure the Dalitz plot distribution of the $\eta \to \pi^+\pi^-\pi^0$ decay. Preliminary values are given for the Dalitz plot parameters a, b, d, f.

1 Transition form factors of VPγ^*

The differential decay rate of Vector→Pseudoscalar γ^*, with the virtual photon decaying in a lepton pair, is described by [1]:

$$\frac{d}{dq^2}\frac{\Gamma(\mathrm{V}\to \mathrm{P}l^+l^-)}{\Gamma(\mathrm{V}\to\mathrm{P}\gamma)} = \frac{\alpha}{3\pi}\frac{|F_{\mathrm{VP}}(q^2)|^2}{q^2}\sqrt{1-\frac{4m^2}{q^2}}\left(1+\frac{2m^2}{q^2}\right)\left[\left(1+\frac{q^2}{m_\mathrm{V}^2-m_\mathrm{P}^2}\right)^2-\frac{4m_\mathrm{V}^2 q^2}{(m_\mathrm{V}^2-m_\mathrm{P}^2)^2}\right]^{\frac{3}{2}} \tag{1}$$

where q is the invariant mass of the lepton pair, F_{AB} is the transition form factor, m is the lepton mass and m_A, m_B are the masses of the mesons A and B. In the one pole approximation, the transition form factor is

$$F_{\mathrm{VP}}(q^2) = \frac{1}{1-q^2/\Lambda^2} \tag{2}$$

where Λ is the characteristic mass relevant to the process. The slope of the transition form factor is defined as

$$b_{\mathrm{VP}} = \frac{dF_{\mathrm{VP}}(q^2)}{dq^2}|_{q^2=0}$$

which for the one pole approximation gives $b_{\mathrm{VP}} = \Lambda^{-2}$.

The simple vector meson dominance model (VMD) can be used to calculate transistion form factors. This model is in general quite sucessful, but it puzzlingly fails for the decay $\omega \to \mu^+\mu^-\pi^0$, as shown by the Lepton-G [2] and NA60 [3, 4] experiments. Therefore it is important to verify other Vector→Pseudoscalar γ^* processes.

Recently, new theoretical approaches have been proposed to describe these deviations from VMD: one based on dispersion theory [5], one based on an effective field theory including light vector mesons as degrees of freedom [6] and one based on chiral effective field theory with resonances [7]. To descriminate between these models, more data on VPγ^* transition form factors, for different vector and pseudoscalar mesons, is needed.

1.1 $\phi \to \eta e^+ e^-$

The existing experimental data on the $\phi \to \eta e^+ e^-$ decay are very scarce. The branching ratio has been measured by two experiments, in units of 10^{-4} the world average is equal to 1.15 ± 0.10 (PDG [8], the result comes from SND [9] and CMD-2 [10] experiments). The slope of the transition form factor was determined only by the SND experiment with very large error, $b_{\phi\eta} = 3.8 \pm 1.8$ GeV^{-2} [9], while the value expected from VMD is $b_{\phi\eta} \simeq 1$ GeV^{-2}.

With the KLOE detector, using 1.7 pb^{-1} of data, we have measured $\phi \to \eta e^+ e^-$ with $\eta \to 3\pi^0$, with a total of 29 626 $\pm$178 events in the final sample. This results in a branching ratio of $\left(1.075 \pm 0.038_{\rm norm} \pm 0.007_{\rm stat}{}^{+0.006}_{-0.002\ \rm syst}\right) \cdot 10^{-4}$, where the normalization error comes from the uncertainty in the ϕ meson production cross-section and in the luminosity measurement. A fit of the lepton pair invariant mass spectrum to Equation 1 using Equation 2 is shown in Figure 1. This gives $b_{\phi\eta} = 1.17 \pm 0.10(\text{stat})^{+0.07}_{-0.11}(\text{syst})$.

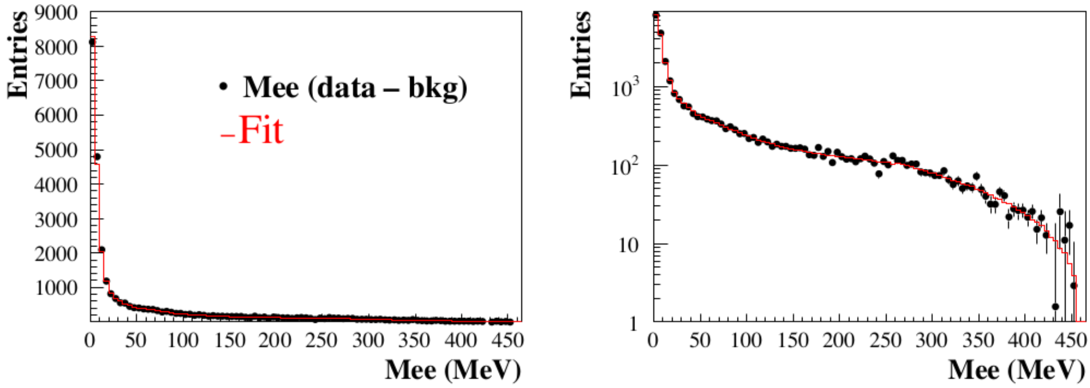

Figure 1: Observed (not corrected for acceptance) experimental distribution of invariant mass of the lepton pair for the $\phi \to \eta e^+ e^-$ signal after background subtraction. The red lines represent the best fit using Eq. 1 with single pole form factor paremetrization Eq. 2.

The modulus squared of the transition form factor as a function of the lepton pair invariant mass can be extracted by dividing, for each bin in q, the data by the number of reconstructed events simulated with $F_{\phi\eta} = 1$. This is shown in Figure 2, where the Monte Carlo data sample has been normalized to the experimental data in the first bin. A fit of this distribution to the one-pole approximation formula (Eq. 2) results in $b_{\phi\eta} = (1.25 \pm 0.10)$ GeV^{-2}, in agreement with the slope extracted directly from the acceptance uncorrected differential decay distribution.

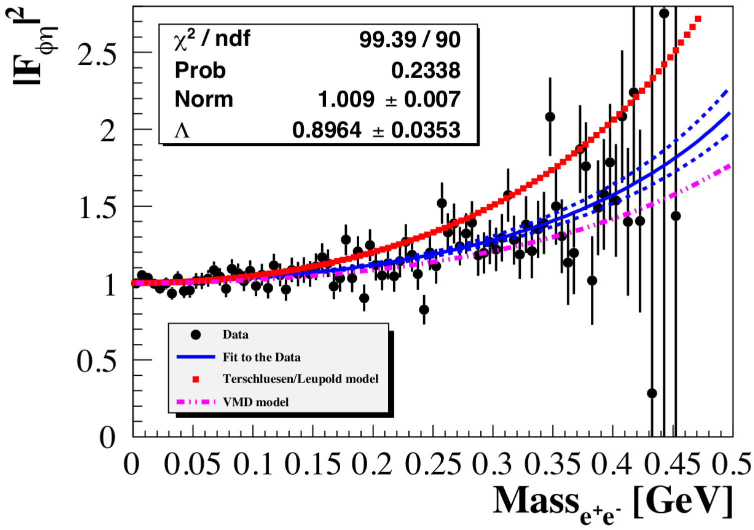

Figure 2: $|F_{\phi\eta}|^2$ as a function of the invariant mass of the lepton pair. In blue (full line with dashed error band) the result from the fit to Equation 2, in pink (dash dot line) the VMD prediction and in red (full line) the theoretical calcualtion of [6].

1.2 $\phi \to \pi^0 e^+ e^-$

For the decay $\phi \to \pi^0 e^+ e^-$ there is no data on the transition form factor slope, and the branching ratio measurements have large errors: the world average is $(1.12 \pm 0.28) \cdot 10^{-5}$ (PDG [8], the result comes from SND [11] and CMD-2 [12] experiments).

An analysis of this decay using 1.7 pb^{-1} of data collected at KLOE is underway. At the end of the analysis chain there are 14 680 events, of which Monte Carlo simulation shows about 22% are $e^+e^- \to e^+e^-\gamma\gamma$ background and 20% are $\phi \to \pi^0\gamma$ background (with conversion of the photon in the detector). The background could be subtracted bin by bin in order to extract the invariant mass distribution of the lepton pair. Results on both branching ratio and transition form factor are forthcoming.

2 Decay dynamics of $\eta \to \pi^+\pi^-\pi^0$

The isospin breaking decay $\eta \to \pi^+\pi^-\pi^0$ is sensitive to the difference of the up and down quarks, since electromagnetic effects in this decay are small [13, 14, 15, 16]. The decay width

$$\Gamma(\eta \to \pi^+\pi^-\pi^0) \propto Q^{-4} \quad \text{where } Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2} \quad \text{and } \hat{m} = \frac{1}{2}(m_d + m_u),$$

allows to determine Q, thus setting an elliptical constraint in the light quark mass plane $\frac{m_u}{m_d}$ *vs* $\frac{m_s}{m_d}$ [17]. The chiral perturbation theory calculations for the decay width show a slow converge ($\Gamma_{LO} = 66$ eV, $\Gamma_{NLO} = 160 \pm 50$ eV [18] and $\Gamma_{NNLO} = 295 \pm 17$ [19], $\Gamma_{exp} = 295 \pm 16$ eV [8]). This indicates the importance of the final state interactions between pions, which can be taken into account by the use of dispersive theory [20, 21]. Calculations have also been performed in a non-relativistic effective field theory approach [22].

A more complete comparison between theory and experiment is facilitated by the Dalitz plot, containing full information on the dynamics of the decay. For the $\eta \to \pi^+\pi^-\pi^0$ decay, the normalized variables X and Y are used

$$X = \sqrt{3}\frac{T_{\pi^+} - T_{\pi^-}}{Q_\eta} \qquad Y = \frac{3T_{\pi^0}}{Q_\eta} - 1 \qquad (Q_\eta = T_{\pi^+} + T_{\pi^-} + T_{\pi^0})$$

where T_{π^i} is the kinetic energy of the π^i in the η rest frame. The squared amplitude of the decay can be expanded around $X = Y = 0$ as

$$|A(X,Y)|^2 \simeq N(1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y)$$

and the coefficients a, b, c, d, e, f, g are called Dalitz plot parameters.

Using 1.6 pb^{-1} of data collected at KLOE we extract the Dalitz plot distribution for $\eta \to \pi^+\pi^-\pi^0$. The preliminary results for the Dalitz plot parameters are shown in Table 1, compared to earlier experimental results. Note that the present analysis includes only statistical errors as the systematic effects are under investigation.

Experiment	-a	b	d	f
Gormley[23]	1.17(2)	0.21(3)	0.06(4)	-
Layter[24]	1.080(14)	0.03(3)	0.05(3)	-
CBarrel[25]	1.22(7)	0.22(11)	0.06(fixed)	-
KLOE[26]	1.090(5)($^{+19}_{-8}$)	0.124(6)(10)	0.057(6)($^{+7}_{-16}$)	0.14(1)(2)
WASA[27]	1.144(18)	0.219(19)(47)	0.086(18)(15)	0.115(37)
This work	1.104(3)	0.144(3)	0.073(3)	0.155(6)

Table 1: Experimental results for the Dalitz plot parameters of $\eta \to \pi^+\pi^-\pi^0$.

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