Study of $e^+e^- \to e^+e^-\eta'$ in double-tag mode at BaBar and measurement of the $\gamma^\star\gamma^\star \to \eta'$ Transition Form Factor

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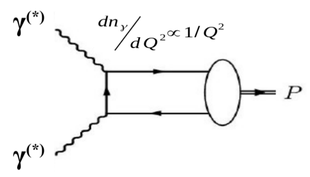
Introduction

This poster presents measurement for the first time of the transition form factor (TFF) of pseudo-scalar meson (η') with both virtual photons [1]:



P — pseudoscalar meson
$e_{1,2}$ — photon polarization
$q_{1,2}$ — 4-momentum of photon
$-\mathcal{Q}^2 = q^2$

The TFF is defined via the amplitude for the $\gamma^\star\gamma^\star \to \eta'$ transition

$$T = -i4\pi\alpha\epsilon_{\mu\nu\beta\gamma}e_1^\mu e_2^\nu q_1^\beta q_2^\gamma F_{\eta'}(Q_1^2, Q_2^2), \qquad (1)$$

where α is the fine structure constant, $\epsilon_{\mu\nu\alpha\beta}$ is the totally antisymmetric Levi-Civita tensor.

This measurement of the TFF at large Q_1^2 and Q_2^2 allows the predictions of models inspired by perturbative QCD (pQCD) to be distinguished from those of the vector dominance model (VDM).

In the case of only one off-shell photon, both classes of models predict the same asymptotic dependence $F_P(Q^2, 0) \sim 1/Q^2$ as $Q^2 \to \infty$, while for two off-shell photons the asymptotic predictions are quite different, $F(Q_1^2, Q_2^2) \sim 1/(Q_1^2 + Q_2^2)$ for **pQCD**, and $F(Q_1^2, Q_2^2) \sim 1/(Q_1^2 Q_2^2)$ for the **VDM** model.

Previous studies of $F_{\eta'}(Q^2, 0)$

- The two photon width [2]
  $\Gamma(\eta \to \gamma\gamma) = \frac{\pi\alpha^2 m_{\eta'}^3}{4} \cdot |F(0,0)|^2 = 4.36 \pm 0.14$ keV
  is equivalent to **F(0,0)** $= 0.344 \pm 0.006$ GeV^{-1}.
- **F(Q^2,0)** is measured in a list of experiments, using the reaction:
  - $\gamma\gamma^* \to \eta'$ at $Q^2 = 4 \div 40$ GeV^2 (BaBar) [3] and at $Q^2 = 1.5 \div 30$ GeV^2 (CLEO) [4]. Less precise measurements are not presented here.
  - $\eta' \to \gamma e^+e^-$ at $Q^2 = -0.75 \div -0.5$ GeV^2 (**BESIII**) [5]
  - $e^+e^- \to \eta'\gamma$ at $Q^2 = -112$ (BaBar) [6].

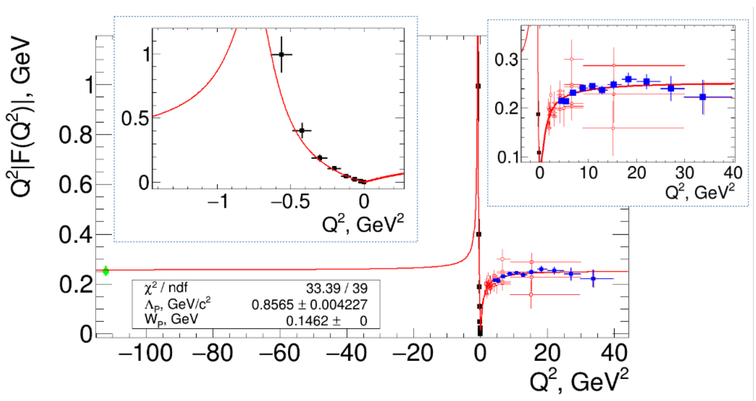
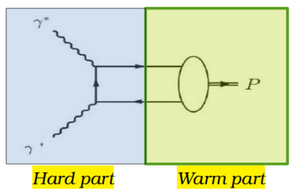


Figure 1: The line corresponds to the simplest VDM fit to data with $Q^2 > 0$ with $F_{\eta'}(Q^2, 0) = F(0,0) \cdot \frac{\sqrt{\Lambda^2(\Lambda^2+W^2)}}{((\Lambda^2+Q^2)^2+\Lambda^2W^2)}$ and fixed width $W_P = 0.1462$ GeV.

pQCD approach

In asymptotic limit $Q >> \Lambda_{QCD}$ $F_{\eta'}$ can be considered as a convolution of a perturbative hard scattering amplitude and a gauge-invariant meson distribution amplitude (DA) which incorporates the nonperturbative dynamics of the QCD bound state.



$$F(\mathcal{Q}^2_1, \mathcal{Q}^2_2) = \int T(x, \mathcal{Q}^2_1, \mathcal{Q}^2_2)\, \varphi(x, \mathcal{Q}^2_1, \mathcal{Q}^2_2)\, dx$$

x - is the fraction of the meson momentum carried by one of the quarks

$T(x, \mathcal{Q}^2_1, \mathcal{Q}^2_2)$ - hard scattering amplitude for $\gamma^*\gamma^* \to qq\text{bar}$ transition which is calculable in pQCD

$\varphi(x, \mathcal{Q}^2_1, \mathcal{Q}^2_2)$ - nonperturbative meson distribution amplitude (DA) describing transition $P \to qq\text{bar}$

$$T_H(x, Q_1^2, Q_2^2) = \frac{1}{2} \cdot \frac{1}{xQ_1^2 + (1-x)Q_2^2} \cdot \left(1 + C_F \frac{\alpha_S(Q^2)}{2\pi} \cdot t(x, Q_1^2, Q_2^2)\right) + (x \to 1-x) + O(\alpha_s^2) + O(\Lambda^4_{QCD}/Q^4)$$

NLO correction [E. Braaten, Phys. Rev. D **28**, 3 (1983)]

Taken into account the quark-flavor composition of η'-meson and asymptotic form of DA:

$$F_{\eta'}(Q_1^2, Q_2^2) = \left(\frac{5\sqrt{2}}{9} f_n \sin\phi + \frac{2}{9} f_s \cos\phi\right) \int_0^1 dx \frac{1}{2} \cdot \frac{6x(1-x)}{xQ_1^2 + (1-x)Q_2^2} \left(1 + C_F \frac{\alpha_s(\mu^2)}{2\pi} t(x, Q_1^2, Q_2^2)\right) + (x \to 1-x),$$

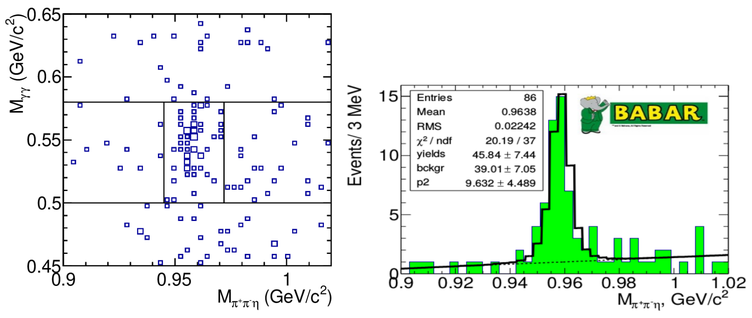
where the weak decay constants for the $|n\rangle$ and $|s\rangle$ states are $f_n = (1.08 \pm 0.04) f_\pi$ and $f_s = (1.25 \pm 0.08) f_\pi$ [7], $f_\pi = 130.4 \pm 0.2$ MeV is the pion decay constant, and Λ_{QCD} is the QCD scale parameter, $\alpha_s(\mu^2)$ is the QCD coupling strength, and $C_F = (n_c^2 - 1)/(2n_c) = 4/3$ is a color factor.

The experimental values of $F_{\eta'}(Q^2, 0)$ are in the agreement with pQCD approach as well as with VDM. **More precise data is required in order to critically test the models.**

New measurement with BaBar detector

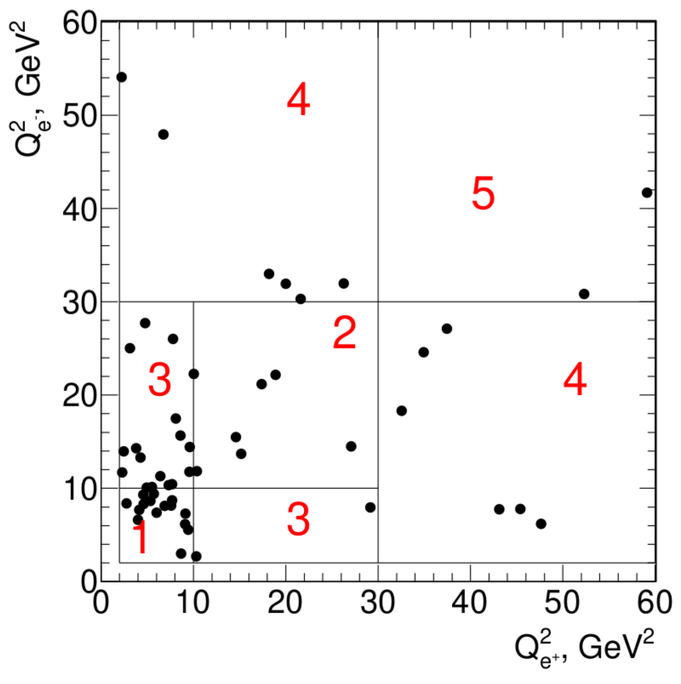
Here we present the new measurement of $F_{\eta'}(Q_1^2, Q_2^2)$ using the process $e^+e^- \to e^+e^-\eta' \to e^+e^-\pi^+\pi^-\eta \to e^+e^-\pi^+\pi^- 2\gamma$ in the double-tag mode, in which both scattered electrons are detected (tagged) and fully reconstructed η'. The tagged electrons emit highly off-shell photons with momentum transfers $q^2_{e^+} = -Q^2_{e^+} = (p_{e^+} - p'_{e^+})^2$ and $q^2_{e^-} = -Q^2_{e^-} = (p_{e^-} - p'_{e^-})^2$, where $p_{e^\pm}$ and $p'_{e^\pm}$ are the four-momenta, respectively, of the initial- and final-state electrons. We measure for the first time $F_{\eta'}(Q_1^2, Q_2^2)$ in the kinematic region with two highly off-shell photons $2 < Q_1^2, Q_2^2 < 60$ GeV^2. The bottom restriction corresponds to the limit of detector acceptance for the tagged electrons. A total integrated luminosity of 468.6 1/fb is used.

The distribution of the η candidate mass M_η versus the η' one ($M_{\eta'}$) for the selected data sample (left) and the spectrum of $M_{\eta'}$ (right) for selected data events:



A clustering of events in the central region of the distribution corresponds to the two-photon η' production.

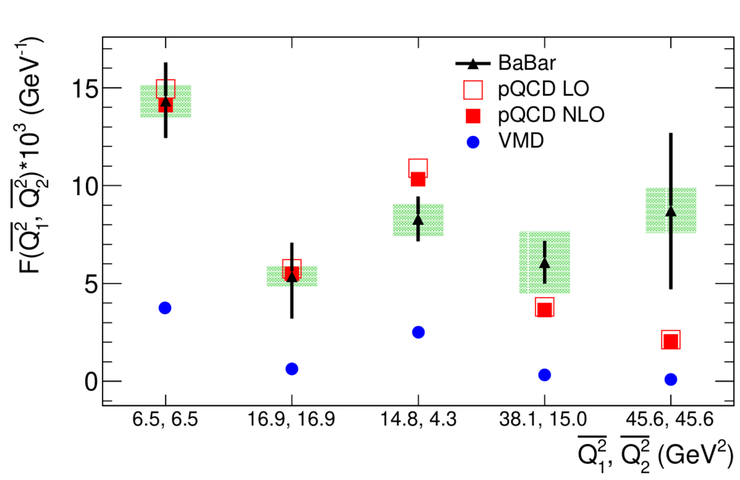
The $Q^2_{e^-}$ versus $Q^2_{e^+}$ distribution for data events:



Results

The cross section of $e^+e^- \to e^+e^-\eta'$ in the entire range of momentum transfer $2 < Q_1^2, Q_2^2 < 60$ GeV^2 is $\sigma = 11.4^{+2.8}_{-2.4\ stat}$ fb.

To extract the TFF we compare the value of the measured cross section with the calculated one in Monte-Carlo simulation. Below: comparison of the measured $\gamma^\star\gamma^\star \to \eta'$ transition form factor (triangles, with error bars representing the statistical uncertainties)



with the LO (open squares) and NLO (filled squares) pQCD predictions and the VDM predictions (circles). The NLO correction is relatively small. The measured TFF is, in general, consistent with the QCD prediction. VDM model exhibits a clear disagreement with the data. The quadratic sum of the systematic and model uncertainties is shown by the shaded rectangles.

The total systematic uncertainty of measured $F_{\eta'}(Q_1^2, Q_2^2)$ is 12% and is dominated by the selection criteria.

The model uncertainty arises from the model dependence of detection efficiency ε and cross-section $(d^2\sigma/(dQ_1^2 dQ_2^2))_{MC}$.

Conclusion

- About 46 events of $e^+e^- \to e^+e^-\eta'$ were observed in the double tagged mode for the first time with BaBar detector
- The $\gamma^\star\gamma^\star \to \eta'$ transition form factor $F(Q_1^2, Q_2^2)$ have been measured for Q^2 range from 2 to 60 GeV^2
- The form factor is in reasonable agreement with the pQCD prediction
- This is only the first step to a promising future, these data open the possibility of investigation the meson-transition form factor with both photon virtualities being large
- We propose a measurement of this quantity at BELLE II

References

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