Measurements of Form Factors with the BaBar Experiment

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Introduction

- BaBar: e^+e^- asymmetric energy collisions at $\sqrt{s} \sim 10.58 \text{ GeV}$
- Form factor measurements exploit the large data sample, other than $e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$:

- $e^+e^- \rightarrow \eta\gamma$ and $e^+e^- \rightarrow \eta'\gamma$

- $e^+e^- \rightarrow c\bar{c}$ with $\sigma=1.3 \text{ nb}$

- $D_s \rightarrow \mu\nu$

- $D_s \rightarrow \phi e\nu$

- $D \rightarrow K e\nu$

$$e^+e^- \rightarrow \eta\gamma, e^+e^- \rightarrow \eta'\gamma$$

- The cross section $e^+e^- \rightarrow \gamma^* \rightarrow P\gamma$ ($P = \eta$ or η'):

$$\sigma(e^+e^- \rightarrow P\gamma) = \frac{2}{3} \pi^2 \alpha^3 |F_P(q^2)|^2 \text{ in the asymptotic limit } q^2 \gg m_P^2$$

transition form factor

$F_P(q^2)$ can be calculated using pQCD:

$$-q^2 F_P(q^2) = \sqrt{2} f_P \left(1 - \frac{5}{3} \frac{\alpha_s(q^2)}{\pi} \right) \text{ for } q^2 \gg 1 \text{ GeV}^2$$

effective decay constant

- Measurement of form factors at high q^2 is needed to test phenomenological models.
 - Previous measurements from $\gamma^*\gamma^* \rightarrow \eta^{(\prime)}$ measure up to $q^2 \approx 20 \text{ GeV}^2$.
 - We measure the transition form factor at $q^2 = 112 \text{ GeV}^2$, i.e. approaching the asymptotic region.

$$e^+e^- \rightarrow \eta\gamma, e^+e^- \rightarrow \eta'\gamma$$

232 fb⁻¹

Very rare but clean two-body final states:

$$e^+e^- \rightarrow \eta\gamma \rightarrow 3\pi\gamma$$

$$e^+e^- \rightarrow \eta'\gamma \rightarrow 2\pi 3\gamma$$

$$e^+e^- \rightarrow \eta'\gamma \rightarrow 5\pi\gamma$$

$$\sigma(e^+e^- \rightarrow \eta\gamma) = 4.5^{+1.2}_{-1.1} \pm 0.3 \text{ fb}$$

$$\sigma(e^+e^- \rightarrow \eta'\gamma) = 5.4 \pm 0.8 \pm 0.3 \text{ fb}$$

[PRD 74:012002 (2006)]

The Transition Form Factors

$q^2=112 \text{ GeV}^2$	BaBar Data	Predictions
$q^2F(\eta')$	$0.251 \pm 0.019 \pm 0.008$	$0.25 - 0.34$
$q^2F(\eta)$	$0.229 \pm 0.030 \pm 0.008$	$0.11 - 0.22$
Ratio (η'/η)	1.10 ± 0.17	$1.56 - 2.27$

• BaBar

Δ CLEO

Theoretical predictions

[PRD 74:012002 (2006)]

$$D_s \rightarrow \mu \nu$$

- The partial width:

$$\Gamma(D_s^+ \rightarrow l^+ \nu_l) = \frac{G_F^2 |V_{cs}|^2}{8\pi} f_{D_s}^2 m_l^2 m_{D_s} \left(1 - \frac{m_l^2}{m_{D_s}^2} \right)^2$$

decay constant (form factor with $q^2 = M_{D_s}^2$)

- $D_s^+ \rightarrow \mu^+ \nu_\mu$ is most accessible experimentally.

$$\Gamma(D_s^+ \rightarrow e^+ \nu_e) : \Gamma(D_s^+ \rightarrow \mu^+ \nu_\mu) : \Gamma(D_s^+ \rightarrow \tau^+ \nu_\tau) \approx 10^{-5} : 1 : 10$$

- Precise measurement of f_{D_s} provides test of lattice QCD
- Comparison with predictions for f_D , f_B and f_{B_s} :

$$\frac{f_{D_s}}{f_D} = 1.24 \pm 0.07 \text{ and } \frac{f_{B_s}}{f_{B_d}} = 1.20 \pm 0.03$$

[PRL 95, 122002 (2005)]

[PRL 95, 212001 (2005)]

- Improve $|V_{ts}/V_{td}|$ from $\Delta m_s/\Delta m_d$

Results for $D_s \rightarrow \mu \nu$

230 fb⁻¹

- Select $D_s^{*+} \rightarrow D_s^+ \gamma \rightarrow \mu^+ \nu_\mu \gamma$ in $e^+ e^- \rightarrow c \bar{c} \rightarrow D_s^* D_{\text{tag}}$ (+ other particles)

- Look for signal in:

$$\Delta M = M_{D_s^*} - M_{D_s^+}$$

- Measure:

$$\frac{\Gamma(D_s^+ \rightarrow \mu^+ \nu_\mu)}{\Gamma(D_s^+ \rightarrow \phi \pi)} = 0.143 \pm 0.018 \pm 0.006$$

- Use the BaBar average

$$B(D_s^+ \rightarrow \phi \pi^+) = (4.71 \pm 0.46)\%$$

PRD 71, 091104 (2005)
hep-ex/0605036

to extract the decay constant

$$f_{D_s} = 283 \pm 17_{\text{stat}} \pm 7_{\text{syst}} \pm 14_{D_s \rightarrow \phi \pi} \text{ MeV}$$

$$\Rightarrow f_{D_s} / f_D = (1.27 \pm 0.14)$$

consistent with lattice QCD: $f_{D_s} / f_D = 1.24 \pm 0.07$

with CLEO - c :

$$f_D = 222.6 \pm 16.7_{\text{stat}}^{+2.8}_{-3.4} \text{ MeV}$$

[PRL 95, 251801 (2005)]

[BaBar results submitted to PRL (PUB-06/010)]

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Form Factors at BaBar

(1/3) $D_s \rightarrow \phi e \nu$

- The partial decay rate:

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_V d\cos\theta_e d\chi} \propto p_{KK} q^2 \left| (1 + \cos\theta_e) \sin\theta_V e^{i\chi} H_+ - (1 - \cos\theta_e) \sin\theta_V e^{-i\chi} H_- - 2 \sin\theta_e \cos\theta_V H_0 \right|^2$$

where $q^2 = m_{e\nu}^2$

where the helicity basis form factors are:

$$H_{\pm}(q^2) = (M_D + m_{KK}) A_1(q^2) \mp 2 \frac{M_D p_{KK}}{M_D + m_{KK}} V(q^2)$$

$$H_0(q^2) = \frac{1}{2m_{KK} \sqrt{q^2}} \left[(M_D^2 - m_{KK}^2 - q^2) (M_D + m_{KK}) A_1(q^2) - 4 \frac{M_D^2 p_{KK}^2}{M_D + m_{KK}} A_2(q^2) \right]$$

with the axial and vector form factors:

$$A_i(q^2) = \frac{A_i(0)}{1 - \frac{q^2}{m_A^2}}$$

$$V(q^2) = \frac{V(0)}{1 - \frac{q^2}{M_V^2}}$$

- We measure: $r_2 = \frac{A_2(0)}{A_1(0)}$ and $r_V = \frac{V(0)}{A_1(0)}$

$D_s \rightarrow \phi e \nu$ 78.5 fb⁻¹

[CONF-06/005]

Results for $D_s \rightarrow \phi e \nu$

- Form factor ratios at $q^2=0$:

$$\left. \begin{aligned} r_2 &= 0.705 \pm 0.056 \pm 0.029 \\ r_V &= 1.636 \pm 0.067 \pm 0.038 \end{aligned} \right\} \begin{array}{l} \text{fixing the pole masses } m_A = 2.5 \text{ GeV}/c^2 \\ \text{and } m_V = 2.1 \text{ GeV}/c^2 \end{array}$$

- If fixing only the vector pole mass m_V :

$$r_2 = 0.771 \pm 0.111 \pm 0.096$$

$$r_V = 1.633 \pm 0.081 \pm 0.068$$

$$m_A = (2.53_{-0.35}^{+0.54} \pm 0.54) \text{ GeV} / c^2$$

[CONF-06/005]

D → K_ℓ^ν

- Select $e^+e^- \rightarrow c\bar{c} \rightarrow D^{*+}X$ with $D^{*+} \rightarrow D^0\pi^+$ and $D^0 \rightarrow K^-e^+\nu_e$
- Reconstruct neutrino with constraints on D^{*+} and D^0 decay.
- Extract $f_+(q^2)$ from the decay rate:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs}|^2 p_K^3(q^2) |f_+(q^2)|^2 \quad \text{where } q^2 = m_{e\nu}^2$$

Results from $D \rightarrow K_{\text{ev}}$

75 fb⁻¹

Two Pole Ansatz' for form factors:

$$|f_+(q^2)| = \frac{f_+(0)}{1 - \frac{q^2}{m_{\text{pole}}^2}} \quad \text{or}$$

$$|f_+(q^2)| = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{D_s^*}^2}\right) \left(1 - \frac{\alpha_{\text{pole}} q^2}{m_{D_s^*}^2}\right)}$$

Experiment	$m_{\text{pole}} \text{ (GeV/c}^2\text{)}$	α_{pole}
CLEO-c	$1.98 \pm 0.03 \pm 0.02$	$0.19 \pm 0.05 \pm 0.03$
FOCUS	$1.93 \pm 0.05 \pm 0.03$	$0.28 \pm 0.08 \pm 0.07$
BELLE	$1.82 \pm 0.04 \pm 0.03$	$0.52 \pm 0.08 \pm 0.06$
BaBar	$1.854 \pm 0.016 \pm 0.020$	$0.43 \pm 0.03 \pm 0.04$

Comparison with lattice QCD
 prediction: $\alpha_{\text{pole}} = 0.50 \pm 0.04$
 [hep-ph/0408306]

[CONF-06/006]

Conclusions

- Precise form factor measurements demonstrated in various processes:
 - Transition form factor in $e^+e^- \rightarrow \eta\gamma$ and $e^+e^- \rightarrow \eta'\gamma$ at $q^2=112 \text{ GeV}^2$:
 - The ratio $\eta'/\eta = 1.10 \pm 0.17$, $\geq 3\sigma$ deviation from predictions.
 - D_s decay constant: $f_{D_s} = 283 \pm 17_{\text{stat}} \pm 7_{\text{syst}} \pm 14_{D_s \rightarrow \phi\pi} \text{ MeV}$
 - The ratio $f_{D_s}/f_D = 1.27 \pm 0.14$, consistent with lattice QCD.
 - Form factor ratios for $D_s \rightarrow \phi e \nu$
 - Details of q^2 dependence will be studied with more data.
 - Precise measurement of form factor for $D \rightarrow K e \nu$:
 - Consistent with QCD prediction
 - Study $D \rightarrow \pi l \nu$ with more data