Feasibility study of observation of $B \to K\varphi\varphi$ at SuperB

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Motivation

T-Odd correlations $\vec{p_i} \cdot (\vec{\epsilon_i} \times \vec{\epsilon_j})$ in two body decays were studied by the BaBar Colaboration[1] .

Three body decays provide more T-odd correlations, one of the simplest is: $\vec{s_i} \cdot (\vec{p_j} \times \vec{p_k})$.

An example decay which provides this kind of correlation is:

$$B^{\pm} \rightarrow K^{\pm} \phi\phi$$

[1] BABAR Collaboration, J.G. Smith, hep-ex/0406063, contribution to Moriond QCD proceedings;BELLE Collaboration, K. Abe et al., hep-ex/0408141.

Theoretical concepts 1/2

The dominating process for this decay is the loop $b \to s s \bar{s}$.

Since ϕ decays mostly into two Kaons, one can connect the T violating phase to the angular distributions of Kaons, which can be calculated.

Theoretical concepts 2/2

Branching ratio

Angle between two decaying planes

$$\frac{d\Gamma_{T-odd}(\theta_1,\theta_2,\phi,Q^2)}{dQ^2 d\cos\theta_1 d\cos\theta_2 d\phi} = \frac{9}{4}\frac{G_F^2}{2^{11}\pi^4 m_B} B^2(\phi\to KK)\left(1-\frac{Q^2}{m_B^2}\right)\sqrt{1-\frac{(2m_\phi)^2}{Q^2}}$$
$$\times\left\{-\left[\frac{1}{4}\int_{-1}^{1}\mathrm{Im}(\mathrm{H}_0(\mathrm{H}_-^* - \mathrm{H}_+^*))\mathrm{d}\cos\theta\right]\sin 2\theta_1 \sin 2\theta_2 \sin\phi\right.$$
$$\left.+\left[\frac{1}{2}\int_{-1}^{1}\mathrm{Im}(\mathrm{H}_+\mathrm{H}_-^*)\mathrm{d}\cos\theta\right]\sin^2\theta_1\sin^2\theta_2\sin 2\phi\right\},$$

Longitudinal and transverse polarizations

Halicity anglesn of kaons in phi1(2) rest frames

$$H_0 = H(0,0) = p_B\cdot(p_1-p_2)\frac{Q^2}{(2m_\phi)^2}$$
$$\times\left[2m_1\left(1-\frac{2m_\phi^2}{Q^2}\right)+m_2\left(1-\frac{(2m_\phi)^2}{Q^2}\right)\right],$$
$$H_\pm = H(\pm,\pm) = -m_1 p_B\cdot(p_1-p_2)\mp 2m_4|\vec{p}_\phi|E_B \mp m_5|\vec{p}_\phi|\sqrt{Q^2},$$

Q=p(phi1)+p(phi2)

arXiv:hep-ph/0412180

T-odd observables

Statistical significance:

Sign function

$$\bar{\varepsilon}_i = \frac{\int \mathcal{O}_i \omega_i(u_{\theta K_1}, u_{\theta K_2}) d\Gamma}{\sqrt{\int d\Gamma \cdot \int \mathcal{O}_i^2 d\Gamma}}$$

u_{θ_i} being $\cos\theta_i$

$$\mathcal{O}_{T_1} = |\vec{p}_B| \frac{\vec{p}_{K_1} \cdot (\vec{p}_B \times \vec{p}_{K_2})}{|\vec{p}_B \times \vec{p}_{K_1}||\vec{p}_B \times \vec{p}_{K_2}|} = \sin\phi,$$

$$\mathcal{O}_{T_2} = |\vec{p}_B| \frac{(\vec{p}_B \cdot \vec{p}_{K_2} \times \vec{p}_{K_1})(\vec{p}_B \times \vec{p}_{K_1}) \cdot (\vec{p}_{K_2} \times \vec{p}_B)}{|\vec{p}_B \times \vec{p}_{K_1}|^2 |\vec{p}_{K_2} \times \vec{p}_B|^2} = \frac{1}{2}\sin 2\phi,$$

Backup

$$\bar{\varepsilon}_i(B) + \bar{\varepsilon}_i(\bar{B}) \propto \sin(\theta_W + \theta_s) + \sin(-\theta_W + \theta_s) = 2\cos\theta_W \sin\theta_s,$$

$$\bar{\varepsilon}_i(B) - \bar{\varepsilon}_i(\bar{B}) \propto \sin(\theta_W + \theta_s) - \sin(-\theta_W + \theta_s) = 2\sin\theta_W \cos\theta_s.$$

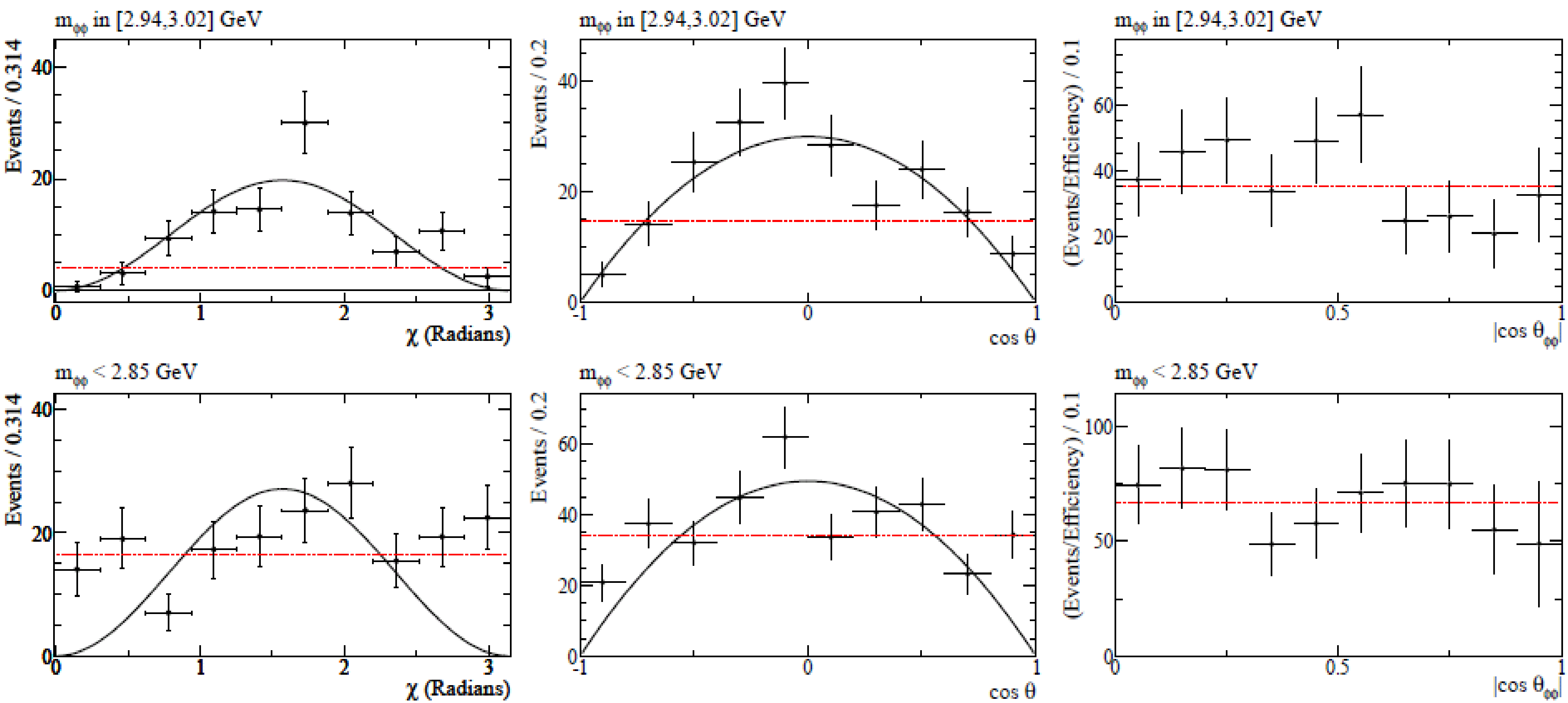
Second non vanishing eq. => T violating phase

BaBar results

BaBar Collaboration found [2]: $BR(B^{\pm} \to K^{\pm}\phi\phi) = (5.6 \pm 0.5 \pm 0.3\pm)\, 10^{-6}$

The Calculated CP violation (under η_c resonance) was:

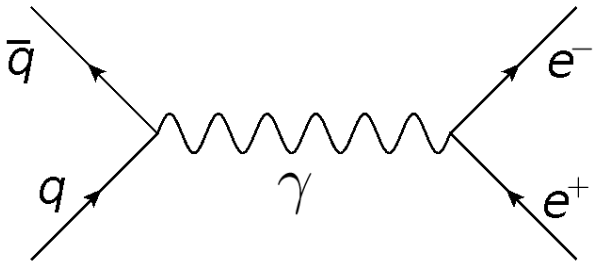
$$A_{CP} = -0.10 \pm 0.08 \pm 0.02$$



Generated Samples

Using FastSim ver. 2.7 following samples were simulated:

- 100k of $B^{\pm} \to K^{\pm}\phi\phi$
- 500k of continuum background



Predefined cut on the simulation:

for ϕ: $\Delta m = 0.02\ GeV$

for B: $m \in (5.1, 5.4) GeV$

$\Delta E \in (-0.3, 0.3) GeV$

$$\Delta E \equiv E^* - E^*_{\mathrm{beam}}$$

Background

The main SM background comes from $B^{\pm} \to \eta_c K^{\pm}$. One can eliminate this background by making a cut on $\phi\phi$ invariant mass below $2.85\ GeV$.

Other possible candidates for background are:

$$B^{\pm} \to \phi K^{\pm} K^{-} K^{+}$$
$$B^{\pm} \to K^{\pm} K^{-} K^{+} K^{-} K^{+}$$
$$B^{\pm} \to f_0 K \phi$$
$$B^{\pm} \to f_0 K^{\pm} K^{-} K^{+}$$

Can't be eliminated by using m_{ES} ΔE

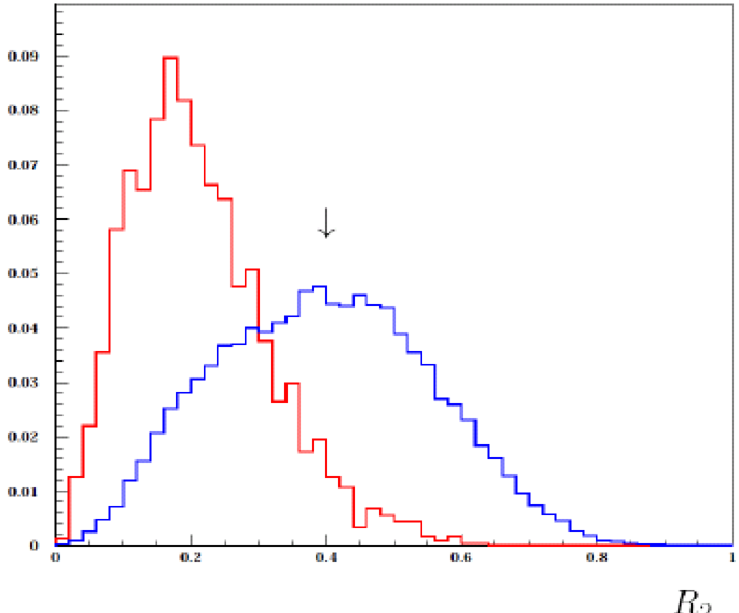
Those channel can be effectively eliminated by using cuts on ϕ mass.

Sequence cuts

- The following variables were used to perform the selection:

$$\Delta E \quad R2 \quad \chi^2{}_{Vertex} \quad m_{ES}$$

- The optimization was done by maximizing the function:



$$f(s,b) = \frac{s}{\sqrt{s+b}}$$

Gained cuts

Variable	Cut
ΔE	0.014
$R2$	0.6
$\chi^2{}_{Vertex}$	10
m_{ES}	5.27-5.30

Results

- Signal efficiency ~16%
- Continuum background fully suppressed
- After this simple selection one can expect 3,5k events a year(10 ab^-1). Much better than LHCb! =)
- Should be able to perform studies of angular
- distributions =>T Violation measurement feasible.

Thank you for your attention

Special thanks for prof. Tadeusz Lesiak

Backup

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} V_t \left[a_1 O_1 + a_2 O_2 + a_3 O_3 + a_4 O_4 \right] \ ,$$

$$O_1 = (\bar{s}b)_{V-A}(\bar{s}s)_{V-A} \ , \quad O_2 = (\bar{s}_\alpha b_\beta)_{V-A}(\bar{s}_\beta s_\alpha)_{V-A} \ ,$$
$$O_3 = (\bar{s}b)_{V-A}(\bar{s}s)_{V+A} \ , \quad O_4 = (\bar{s}_\alpha b_\beta)_{V-A}(\bar{s}_\beta s_\alpha)_{V+A} \ ,$$

$$a_1^{eff} = a_1 + \frac{a_2}{N_c}, \quad a_2^{eff} = a_2 + \frac{a_1}{N_c},$$
$$a_3^{eff} = a_3 + \frac{a_4}{N_c}, \quad a_4^{eff} = a_4 + \frac{a_3}{N_c},$$

← Wilson

Backup

$$\langle K(p_3)|\bar{b}\,\gamma_\mu(1-\gamma_5)s|B(p_B)\rangle = f_+(Q^2)P_\mu + \frac{P\cdot Q}{Q^2}Q_\mu(f_0(Q^2)-f_+(Q^2)),$$

$$\begin{aligned}
\langle\phi(\epsilon_1,p_1)\phi(\epsilon_2,p_2)|\bar{s}\,\gamma_\mu\,s|0\rangle &= \left[\epsilon_1^*\cdot\epsilon_2^*A_1 + \frac{\epsilon_1^*\cdot Q\,\epsilon_2^*\cdot Q}{Q^2}A_2\right](p_1+p_2)_\mu \\
&+\left[\epsilon_1^*\cdot\epsilon_2^*B_1 + \frac{\epsilon_1^*\cdot Q\,\epsilon_2^*\cdot Q}{Q^2}B_2\right](p_1-p_2)_\mu \\
&+C_1\epsilon_1^*\cdot Q\epsilon_{2\mu} + C_2\epsilon_2^*\cdot Q\epsilon_{1\mu},
\end{aligned}$$

$$\begin{aligned}
\langle\phi(\epsilon_1,p_1)\phi(\epsilon_2,p_2)|\bar{s}\,\gamma_\mu\gamma_5\,s|0\rangle &= i\varepsilon_{\mu\nu\rho\sigma}\epsilon_2^{\nu*}p_1^\rho p_2^\sigma(\epsilon_1^*\cdot p_2)\frac{D_1}{m_\phi^2} + i\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{\nu*}p_2^\rho p_1^\sigma(\epsilon_2^*\cdot p_1)\frac{D_2}{m_\phi^2} \\
&-i\epsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\nu}\epsilon_2^{*\rho}\Big(E(p_1+p_2)^\sigma + F(p_1-p_2)^\sigma\Big),
\end{aligned}$$

Transition matrix elements

Backup

$$\langle V_1(\epsilon_1,p_1)V_2(\epsilon_2,p_2)|\bar{s}\ \not{Q}\ s|0\rangle = (m_s - m_s)\langle V_1(\epsilon_1,p_1)V_2(\epsilon_2,p_2)|\bar{s}\ s|0\rangle = 0\ ,$$

$$\langle V_1(\epsilon_1,p_1)V_2(\epsilon_2,p_2)|\bar{s}\ (\not{p}_1 - \not{p}_2)\gamma_5\ s|0\rangle = -iE\varepsilon_{\mu\nu\rho\sigma}(p_1-p_2)^\mu\epsilon_1^{*\nu}\epsilon_2^{*\rho}(p_1+p_2)^\sigma = 0\ ,$$

$$\begin{aligned}\langle\phi(\epsilon_1,p_1)\phi(\epsilon_2,p_2)|\bar{s}\ \gamma_\mu\ s|0\rangle &= \Big[\epsilon_1^*\cdot\epsilon_2^* B_1 + \epsilon_1^*\cdot Q\,\epsilon_2^*\cdot Q\frac{B_2}{Q^2}\Big](p_1-p_2)_\mu \\ &+C\Big[\epsilon_1^*\cdot Q\epsilon_{2\mu} - \epsilon_2^*\cdot Q\epsilon_{1\mu}\Big] \\ \langle\phi(\epsilon_1,p_1)\phi(\epsilon_2,p_2)|\bar{s}\ \gamma_\mu\gamma_5\ s|0\rangle &= i\frac{D}{m_\phi^2}\Big[(\epsilon_1^*\cdot p_2)\varepsilon_{\mu\nu\rho\sigma}\epsilon_2^{\nu *}p_1^\rho p_2^\sigma + i(\epsilon_2^*\cdot p_1)\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{\nu *}p_2^\rho p_1^\sigma\Big] \\ &-iF\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\nu}\epsilon_2^{*\rho}(p_1-p_2)^\sigma .\end{aligned}$$

Backup

$$\langle K(p_3)|\bar{b}\, s|B\rangle = -\frac{P\cdot Q}{m_b - m_s} f_0(Q^2),$$

$$\langle \phi(\epsilon_1, p_1)\phi(\epsilon_2, p_2)|\bar{s}\, s|0\rangle = \frac{Q^2-(2m_\phi)^2}{2m_s}\epsilon_1^* \cdot \epsilon_2^* B_1 + \frac{\epsilon_1^*\cdot Q \epsilon_2^* \cdot Q}{2m_s}\left(\left(1-\frac{(2m_\phi)^2}{Q^2}\right)B_2 - 2C\right),$$

$$\langle \phi(\epsilon_1, p_1)\phi(\epsilon_2, p_2)|\bar{s}\gamma_5 s|0\rangle = i\frac{F}{m_s}\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\mu}\epsilon_2^{*\nu}p_1^\rho p_2^\sigma.$$

$$\mathcal{M} = \frac{G_F}{\sqrt{2}}V_{ts}V_{tb}^*\Bigg\{\left(m_1\epsilon_1^*\cdot\epsilon_2^* + \frac{m_2}{Q^2}\epsilon_1^*\cdot Q\,\epsilon_2^*\cdot Q\right)p_B\cdot(p_1-p_2) + im_3\left[\frac{\epsilon_2^*\cdot Q}{m_\phi^2}\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\mu}p_2^\nu p_1^\rho p_B^\sigma\right.$$
$$\left. +(1\leftrightarrow 2)\right] + im_4\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\mu}\epsilon_2^{*\nu}(p_1-p_2)^\rho p_B^\sigma + im_5\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\mu}\epsilon_2^{*\nu}p_1^\rho p_2^\sigma\Bigg\},$$

Backup

$$\frac{d\Gamma}{dQ^2} = \frac{|V_{tb}V_{ts}|^2 G_F^2}{2^{10}\pi^3 m_B}\left(1-\frac{Q^2}{m_B^2}\right)\sqrt{1-\frac{(2m_\phi)^2}{Q^2}}\left\{2\left[|m_{11}|^2+\frac{2}{3}|m_{12}|^2\right]e_{11}\right.$$

$$+2\left[|m_{21}|^2+\frac{2}{3}|m_{22}|^2\right]e_{22}+2\left[2Re(m_{11}m_{21}^*)+\frac{2}{3}Re(m_{12}m_{22}^*)\right]e_{12}$$

$$\left.+\left(|m_3|^2 e_{33}+|m_4|^2 e_{44}\right)+2Re(m_3 m_4^*)e_{34}+2|m_5|^2 e_{55}+4Re(m_4 m_5^*)e_{45}\right\}$$

Backup

Backup

Backup