# *B* -> *Kφφ* at SuperB

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# Why this channel?

You can measure CP and T violation in one go =)

$B^{\pm} \to K^{\pm}\phi\phi$ $\quad\quad$ $B^{\pm} \to \eta_c K^{\pm} \quad \eta_c \to \phi\phi$

$b \to s\bar{s}s$ penguin $\quad\quad$ $b \to c\bar{c}s$ transition

Both channels look similar in the detector: 5 charged kaons.

Direct measurements of CP violation:

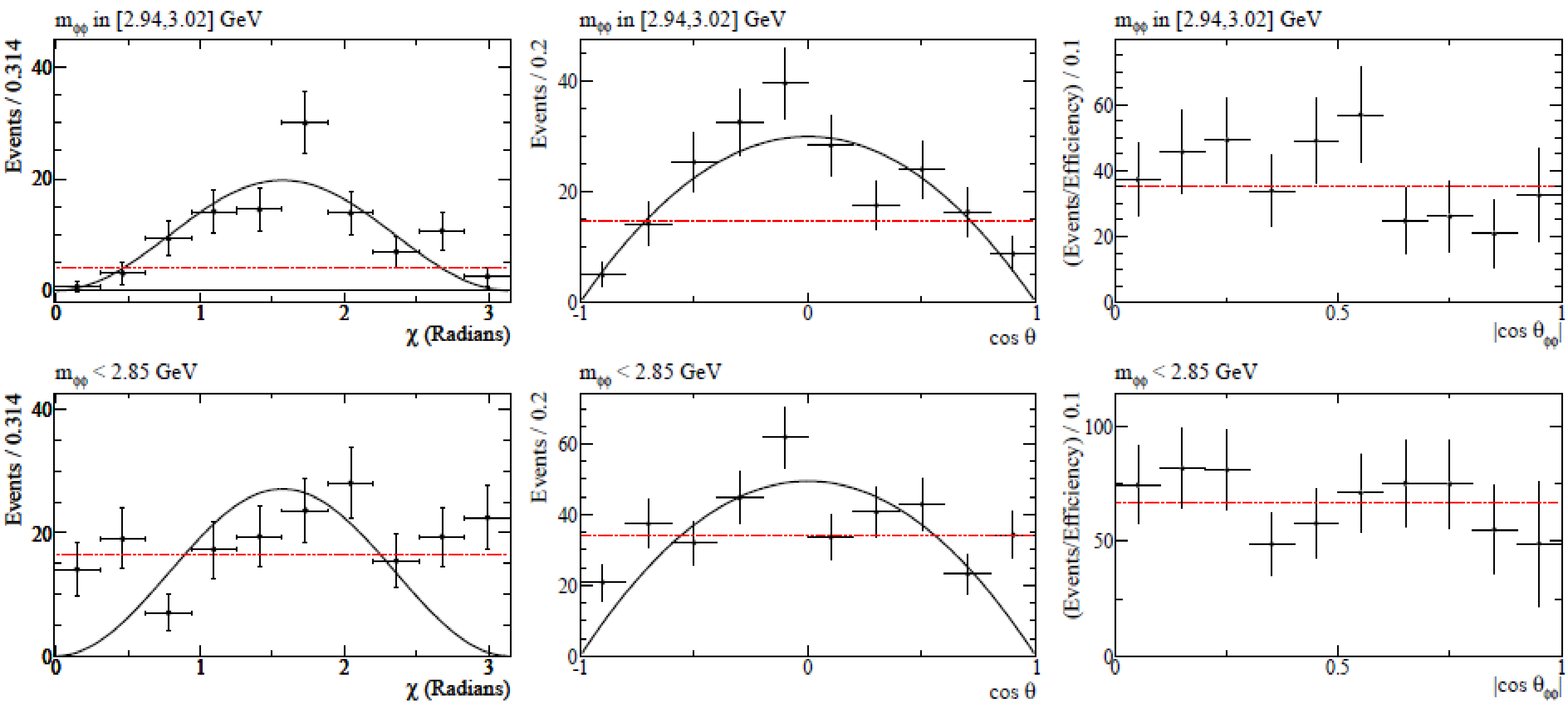
$$A_{cp} = \frac{N(B^-) - N(B^+)}{N(B^-) + N(B^+)} \qquad \arg\left(\frac{V_{tb}V_{ts}^*}{V_{cb}V_{cs}^*}\right) \approx 0$$

# BaBar results

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

The Calculated CP violation ($\eta_c$ resonance) was:

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



# Theoretical concepts 1/2

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

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

This time we run under $\eta_c$ resonanse.

# Theoretical concepts 2/2

Branching ratio

$$\frac{d\Gamma_{T-odd}(\theta_1,\theta_2,\phi,Q^2)}{dQ^2\,d\cos\theta_1\,d\cos\theta_2\,d\phi} = \frac{9}{4}\frac{G_F^2}{2^{11}\pi^4 m_B} B^2(\phi\to KK)\left(1-\frac{Q^2}{m_B^2}\right)\sqrt{1-\frac{(2m_\phi)^2}{Q^2}}$$

Angle between two decaying planes

$$\times\left\{-\left[\frac{1}{4}\int_{-1}^{1}\mathrm{Im}(\mathrm{H}_0(\mathrm{H}_-^* - \mathrm{H}_+^*))\mathrm{d}\cos\theta\right]\sin 2\theta_1 \sin 2\theta_2 \sin\phi + \left[\frac{1}{2}\int_{-1}^{1}\mathrm{Im}(\mathrm{H}_+\mathrm{H}_-^*)\mathrm{d}\cos\theta\right]\sin^2\theta_1 \sin^2\theta_2 \sin 2\phi\right\},$$

Longitudinal and transverse polarizations

$$H_0 = H(0,0) = p_B\cdot(p_1-p_2)\frac{Q^2}{(2m_\phi)^2} \times\left[2m_1\left(1-\frac{2m_\phi^2}{Q^2}\right)+m_2\left(1-\frac{(2m_\phi)^2}{Q^2}\right)\right],$$

$$H_\pm = H(\pm,\pm) = -m_1 p_B\cdot(p_1-p_2) \mp 2m_4|\vec{p}_\phi|E_B \mp m_5|\vec{p}_\phi|\sqrt{Q^2},$$

Helicity angles of kaons in phi1(2) rest frames

Q=p(phi1)+p(phi2)

**arXiv:hep-ph/0412180**

# T-odd observables

Sign function

Statistical significance:

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

$u_{\theta_i}$ being $\cos\theta_i$

$$\begin{aligned}
\mathcal{O}_{T_1} &= |\vec{p}_B| \frac{\vec{p}_{K_1} \cdot (\vec{p}_B \times \vec{p}_{K_2})}{|\vec{p}_B \times \vec{p}_{K_1}||\vec{p}_B \times \vec{p}_{K_2}|} = \sin\phi, \\
\mathcal{O}_{T_2} &= |\vec{p}_B| \frac{(\vec{p}_B \cdot \vec{p}_{K_2} \times \vec{p}_{K_1})(\vec{p}_B \times \vec{p}_{K_1}) \cdot (\vec{p}_{K_2} \times \vec{p}_B)}{|\vec{p}_B \times \vec{p}_{K_1}|^2 |\vec{p}_{K_2} \times \vec{p}_B|^2} = \frac{1}{2}\sin 2\phi,
\end{aligned}$$

# T-odd observables

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

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

Second non vanishing eq. => T violating phase

# Background

Other possible candidates for background are:

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

Those channels can also be studiet with this channel.

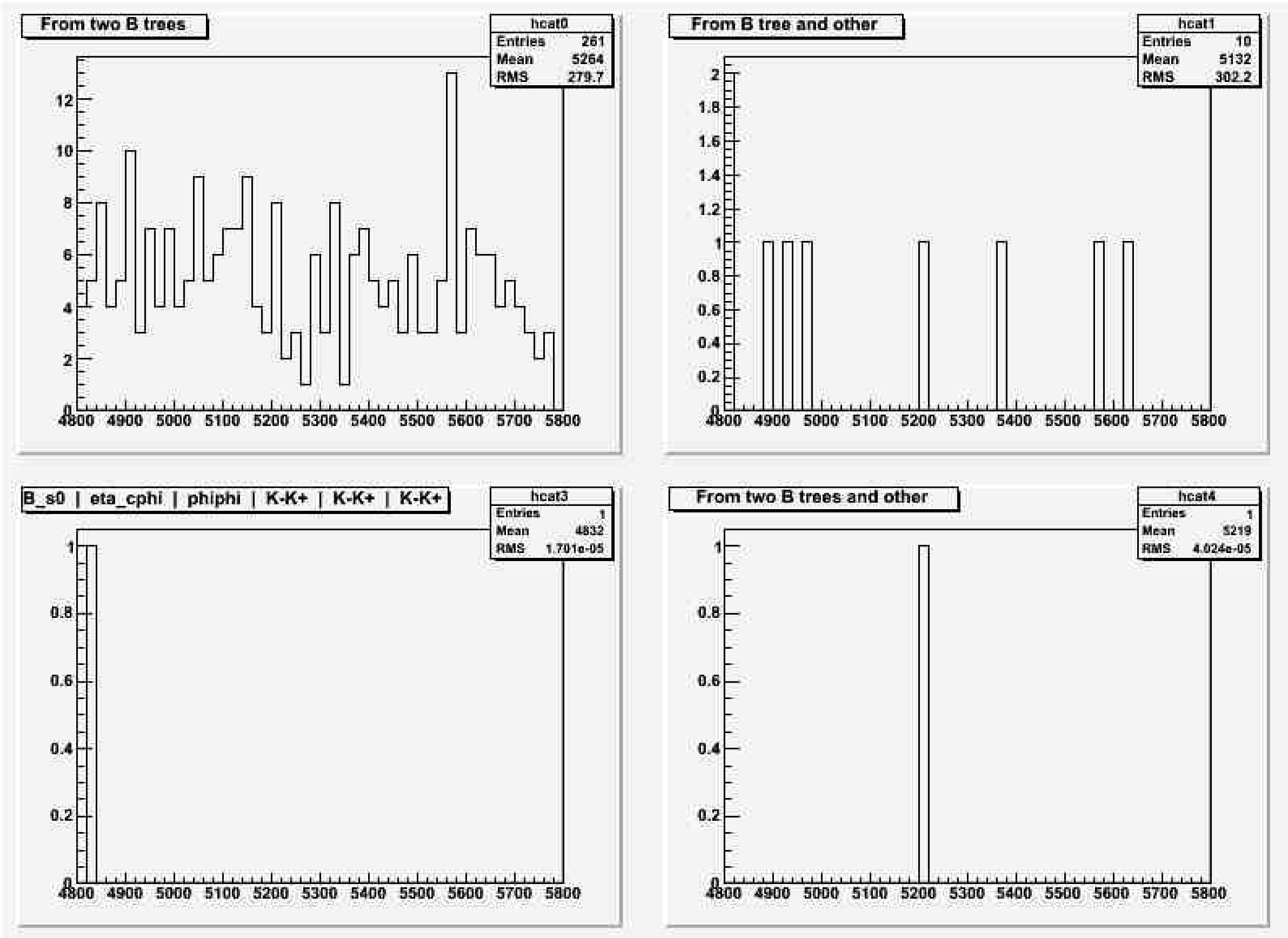
# Gained cuts

| Variable | Cut |
| --- | --- |
| $\Delta E$ | 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.

# Background from toy MC



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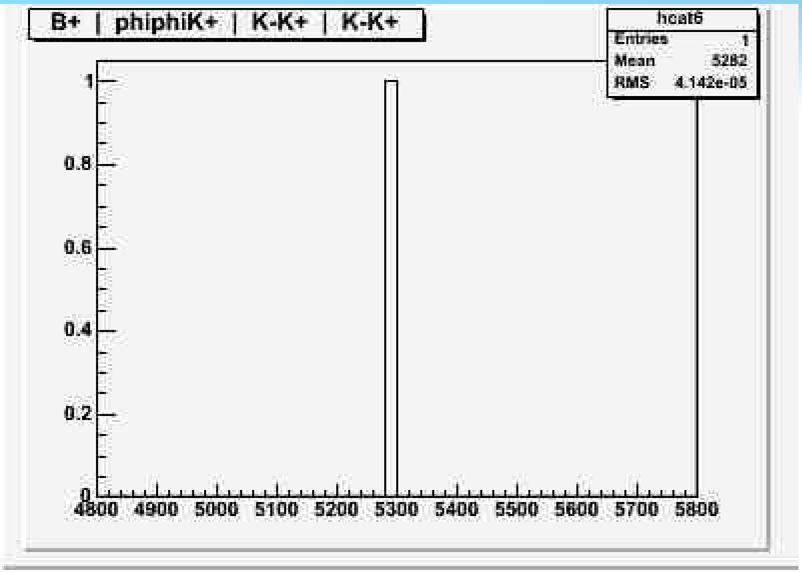


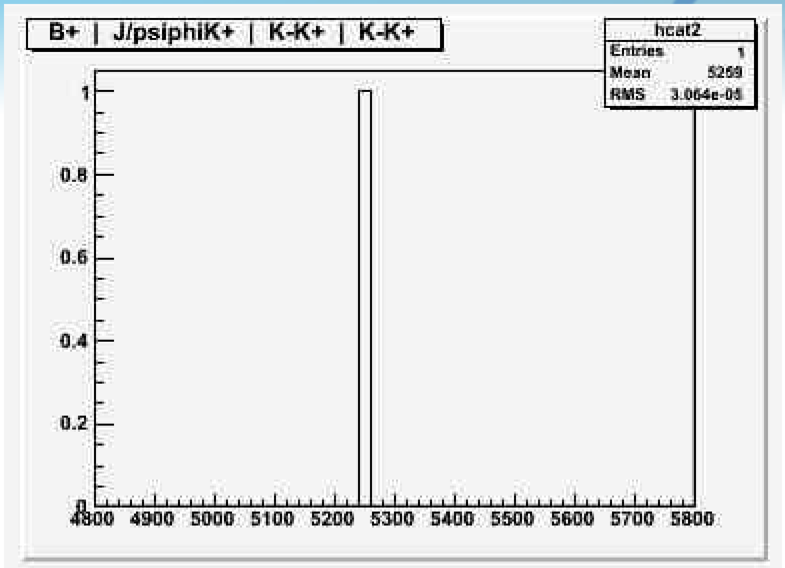


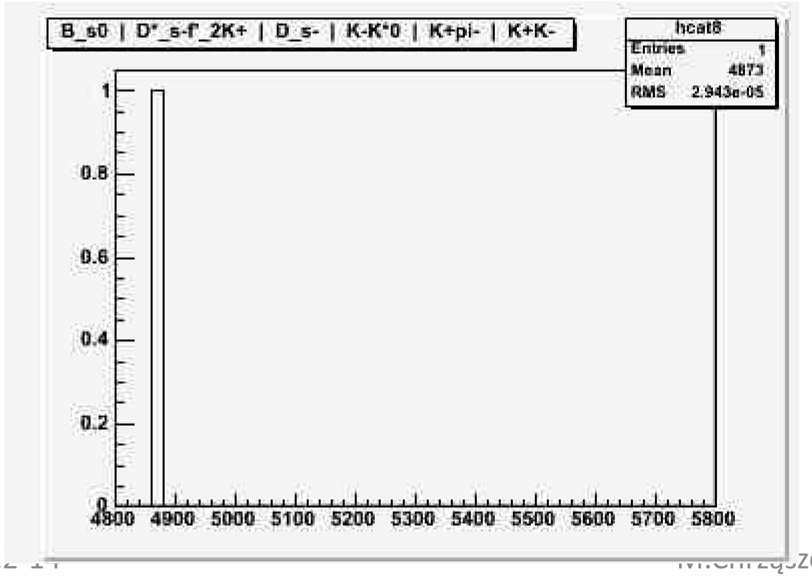


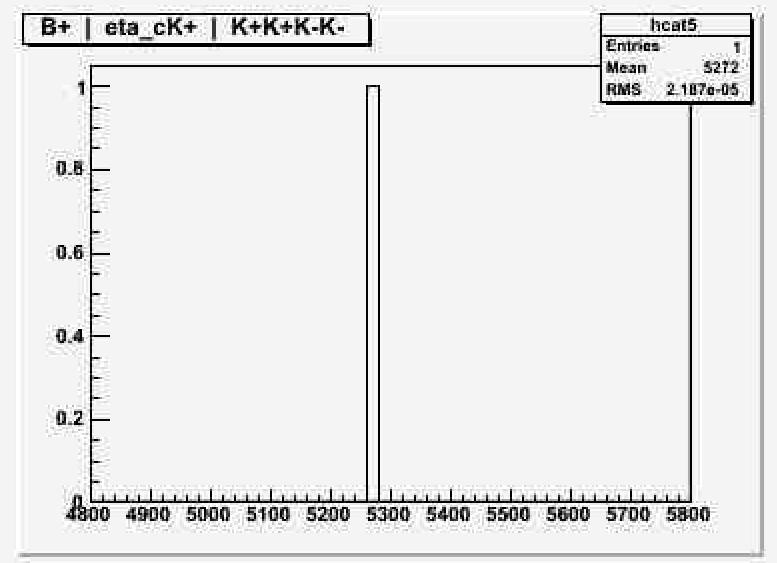

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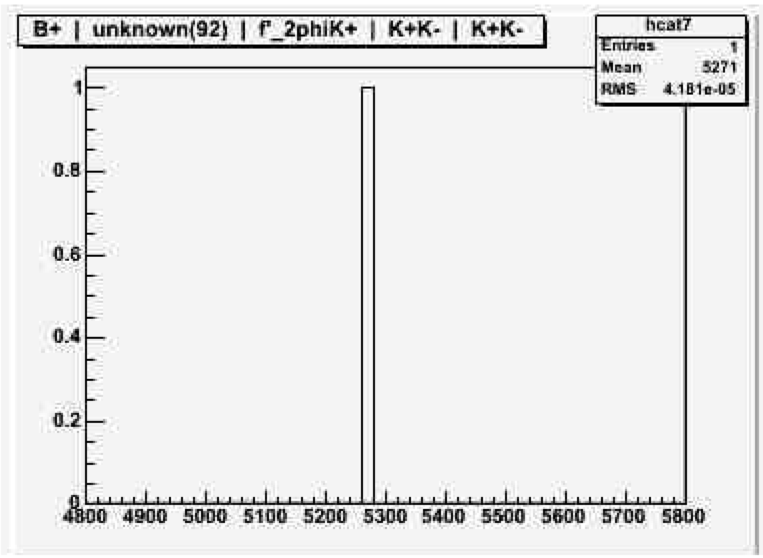


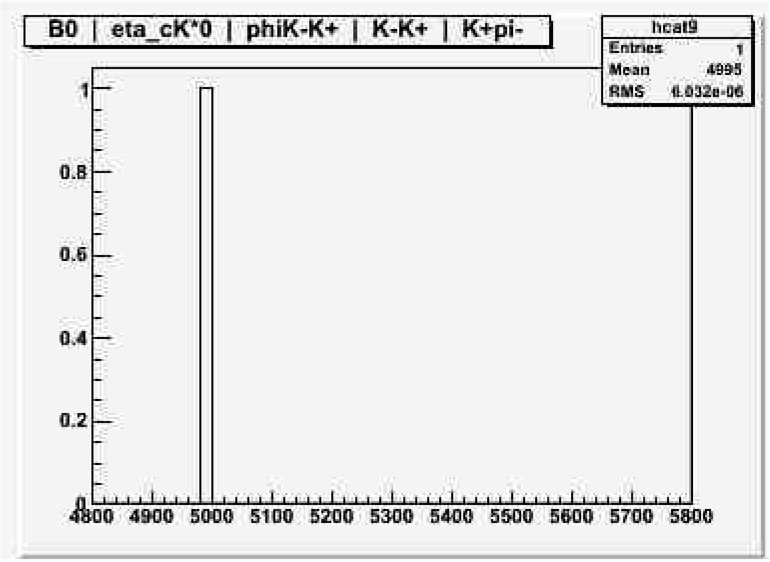

# Plans for future

Using FastSim generate:

-Signal $B^{\pm} \to K^{\pm}\phi\phi$ $B^{\pm} \to \eta_c K^{\pm}$ $\eta_c \to \phi\phi$

Add angular distribution?

-Big background samples, to estimate the efficiency.

Thank you for your attention

Special thanks for Prof. Tadeusz Lesiak

# Backup

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

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

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

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

Wilson

# Backup

$$\begin{aligned}
\langle K(p_3)|\bar{b}\,\gamma_\mu(1-\gamma_5)s|B(p_B)\rangle &= f_+(Q^2)P_\mu + \frac{P\cdot Q}{Q^2}Q_\mu(f_0(Q^2)-f_+(Q^2)),\\
\langle\phi(\epsilon_1,p_1)\phi(\epsilon_2,p_2)|\bar{s}\,\gamma_\mu\,s|0\rangle &= \left[\epsilon_1^*\cdot\epsilon_2^*A_1+\frac{\epsilon_1^*\cdot Q\,\epsilon_2^*\cdot Q}{Q^2}A_2\right](p_1+p_2)_\mu\\
&+\left[\epsilon_1^*\cdot\epsilon_2^*B_1+\frac{\epsilon_1^*\cdot Q\,\epsilon_2^*\cdot Q}{Q^2}B_2\right](p_1-p_2)_\mu\\
&+C_1\epsilon_1^*\cdot Q\epsilon_{2\mu}+C_2\epsilon_2^*\cdot Q\epsilon_{1\mu},\\
\langle\phi(\epsilon_1,p_1)\phi(\epsilon_2,p_2)|\bar{s}\,\gamma_\mu\gamma_5\,s|0\rangle &= i\varepsilon_{\mu\nu\rho\sigma}\epsilon_2^{\nu *}p_1^\rho p_2^\sigma(\epsilon_1^*\cdot p_2)\frac{D_1}{m_\phi^2}+i\varepsilon_{\mu\nu\rho\sigma}\epsilon_1^{\nu *}p_2^\rho p_1^\sigma(\epsilon_2^*\cdot p_1)\frac{D_2}{m_\phi^2}\\
&-i\epsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\nu}\epsilon_2^{*\rho}\Big(E(p_1+p_2)^\sigma+F(p_1-p_2)^\sigma\Big),
\end{aligned}$$

Transition matrix elements

# Backup

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

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

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

# Backup

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

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

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

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

# Backup

$$\frac{d\Gamma}{dQ^2} = \frac{|V_{tb}V_{ts}|^2 G_F^2}{2^{10}\pi^3 m_B}\left(1-\frac{Q^2}{m_B^2}\right)\sqrt{1-\frac{(2m_\phi)^2}{Q^2}}\left\{2\left[|m_{11}|^2+\frac{2}{3}|m_{12}|^2\right]e_{11}\right.$$
$$+2\left[|m_{21}|^2+\frac{2}{3}|m_{22}|^2\right]e_{22}+2\left[2Re(m_{11}m_{21}^*)+\frac{2}{3}Re(m_{12}m_{22}^*)\right]e_{12}$$
$$\left.+\left(|m_3|^2e_{33}+|m_4|^2e_{44}\right)+2Re(m_3m_4^*)e_{34}+2|m_5|^2e_{55}+4Re(m_4m_5^*)e_{45}\right\}$$

# Backup

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