



# CP violation and related issues

## Part 6.5: $b \rightarrow sss$ decays

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Why is  $b \rightarrow sss$  so exciting?

Measurements of CP violation in  $b \rightarrow sss$

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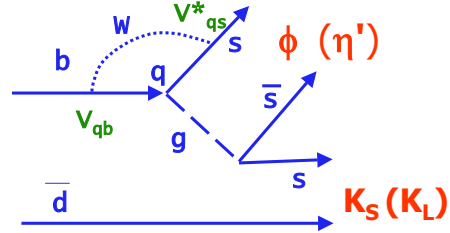
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# b->sss decays

Pure penguin diagrams



$$A(s\bar{s}s) = V_{cb}V_{cs}^*(P_s^c - P_s^t) + V_{ub}V_{us}^*(P_s^u - P_s^t).$$

$$V_{cb}V_{cs}^* = A\lambda^2$$

$$V_{ub}V_{us}^* = A\lambda^4(\rho - i\eta)$$

First term dominates ->

$\lambda$  same as for  $J/\psi K_S$

$$\lambda_{\phi K_S} = \eta_{\phi K_S} \left( \frac{V_{tb}^* V_{td}}{V_{ub} V_{ud}^*} \right) \left( \frac{V_{cd}^* V_{cb}}{V_{cd} V_{cb}^*} \right)$$

$$\text{Im}(\lambda_{\phi K_S}) = \sin 2\phi_1 = \sin 2\beta$$



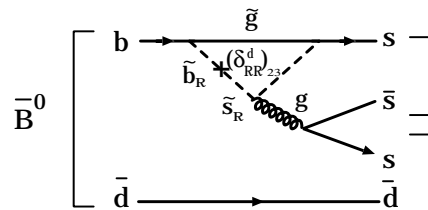
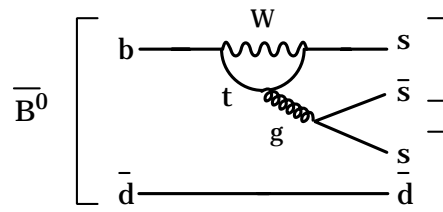
# b->sss decays

However:

$\text{BR}(B^0 \rightarrow \eta' K^0) = 5.8 \cdot 10^{-5}$  considered unexpectedly large

Contribution from new physics, i.e. in addition to the normal diagram also exotic contributions (e.g. SUSY particles in the loop)?

Could show up as a modification to the asymmetry parameters  $S_f$  and  $A_f$





# CP asymmetry

Prediction: to the leading order

$$S_f = -\eta_f \sin 2\phi_1 \quad \mathcal{A}_f = 0$$

$$a_{f_{CP}} = \underbrace{\frac{2 \operatorname{Im}(\lambda_{f_{CP}})}{1 + |\lambda_{f_{CP}}|^2}}_{S_f} \sin(\Delta mt) + \underbrace{\frac{|\lambda_{f_{CP}}|^2 - 1}{|\lambda_{f_{CP}}|^2 + 1}}_{\mathcal{A}_f} \cos(\Delta mt)$$

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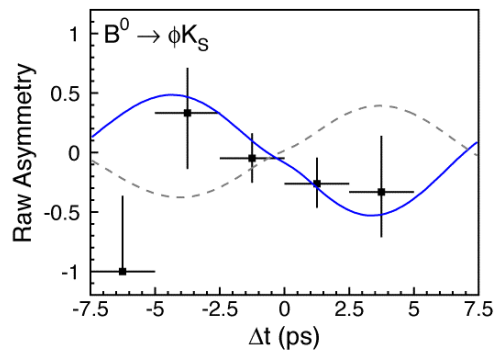


# Result of 2003 (140/fb): surprise!

Measurement: points with error bars.

Standard Model predictions: dotted

Result of the unbinned likelihood fit: blue curve



Measure:  $S = -0.96 \pm 0.50$ , expect  $S = \sin 2\phi_1 = +0.731 \pm 0.056$

not conclusive -> need more data

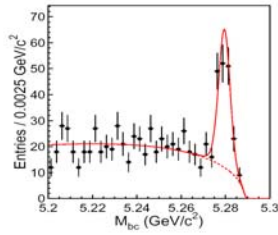
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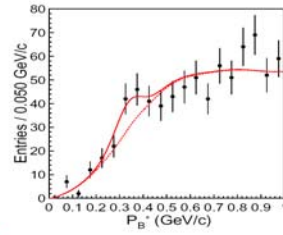
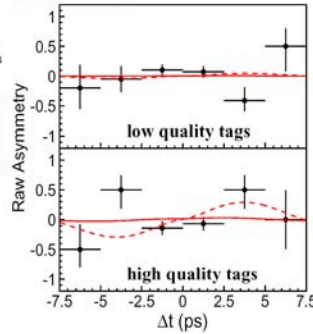


# Asymmetry in $B \rightarrow \phi K_S$ and $\phi K_L$



$B^0 \rightarrow \phi K_S$  ( $CP = -1$ )  
 $N = 139 \pm 14$ , 63% pure

$B^0 \rightarrow \phi K^0$ :



$B^0 \rightarrow \phi K_L$  ( $CP = +1$ )  
 $N = 36 \pm 15$ , 17% pure

recently published

$\sin(2\phi_1) = +0.06 \pm 0.33 \pm 0.09$ ,  $A = +0.08 \pm 0.22 \pm 0.09$

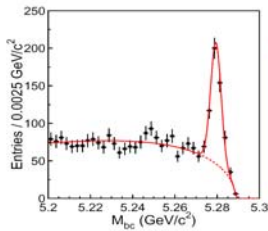
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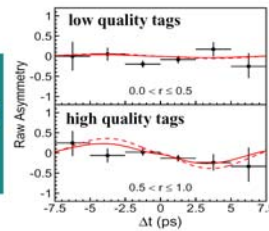
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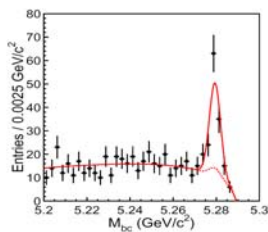
# Asymmetry in $B \rightarrow K^+ K^- K_S$ and $f^0(980) K_S$



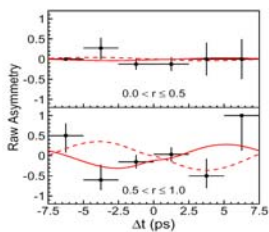
$B^0 \rightarrow K^+ K^- K_S$   
( $CP = +1$  mostly)  
 $N = 399 \pm 28$   
56% pure



$\sin(2\phi_1) = +0.49 \pm 0.18 \pm 0.04$   
 $A = -0.08 \pm 0.12 \pm 0.07$



$B^0 \rightarrow f^0(980) K_S$   
( $CP = +1$ )  
 $N = 94 \pm 14$   
53% pure



$\sin(2\phi_1) = -0.47 \pm 0.41 \pm 0.08$   
 $A = -0.39 \pm 0.27 \pm 0.08$

recently published

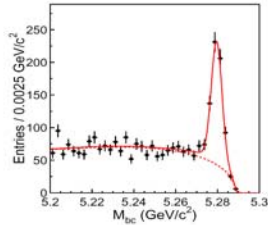
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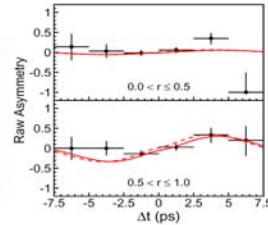
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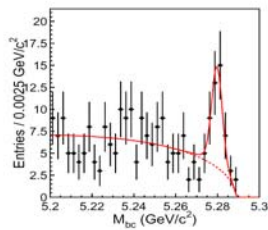
## Asymmetry in $B \rightarrow \eta' K_S$ and $\omega K_S$



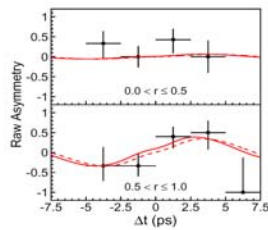
$B^0 \rightarrow \eta' K_S$   
( $CP = -1$ )  
 $N = 512 \pm 27$   
61% pure



$\sin(2\phi_1) =$   
 $+ 0.65 \pm 0.18 \pm 0.04$   
 $A =$   
 $- 0.19 \pm 0.11 \pm 0.05$



$B^0 \rightarrow \omega K_S$   
( $CP = -1$ )  
 $N = 31 \pm 7$   
56% pure



$\sin(2\phi_1) =$   
 $+ 0.75 \pm 0.64^{+0.13}_{+0.16}$   
 $A =$   
 $+ 0.26 \pm 0.48 \pm 0.15$

recently published

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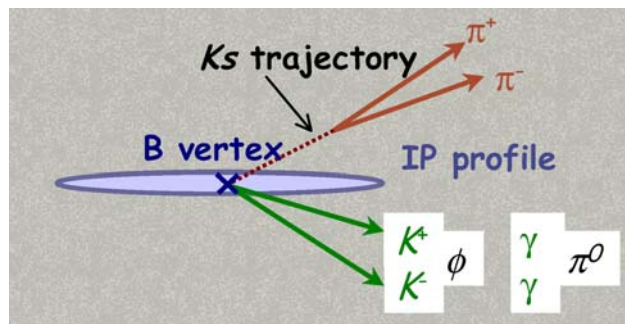
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## Vertex reconstruction in $B \rightarrow K_S K_S K_S$ and $\pi^0 K_S$

No charged track from the B decay point: extrapolate the  $K_S$  direction from the  $\pi^+\pi^-$  vertex.



Check the method by measuring the asymmetry in  $B \rightarrow J/\psi K_S$  channel, use only  $K_S$  for vertex determination (instead of two leptons from  $J/\psi$ ) -> OK!

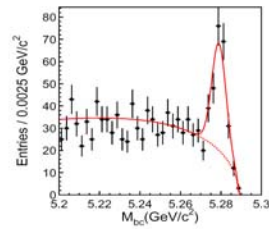
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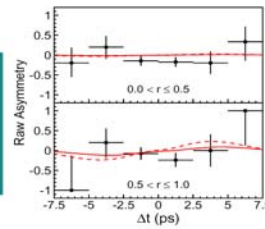
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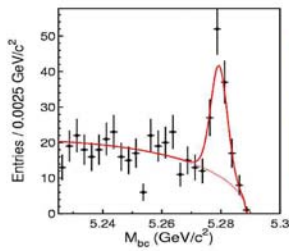
## Asymmetry in $B \rightarrow K_S K_S K_S$ and $\pi^0 K_S$



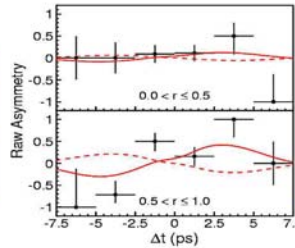
$B^0 \rightarrow \pi^0 K_S$   
( $CP = -1$ )  
 $N = 251 \pm 24$   
55/17% pure



$\sin(2\phi_1) = +0.30 \pm 0.59 \pm 0.11$   
 $A = -0.12 \pm 0.20 \pm 0.07$



$B^0 \rightarrow K_S K_S K_S$   
( $CP = +1$ )  
 $N = 88 \pm 13$   
53% pure



$\sin(2\phi_1) = -1.26 \pm 0.68 \pm 0.18$   
 $A = +0.54 \pm 0.34 \pm 0.08$

recently published

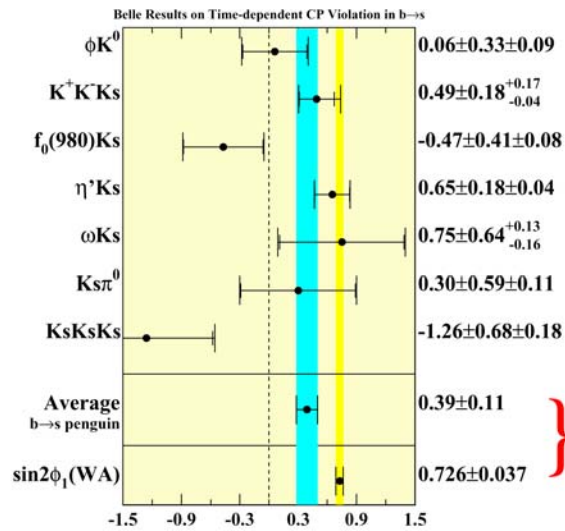
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## Summary of asymmetry measurements



}  $2.9\sigma$  difference  
 $\Rightarrow$  more statistics needed

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## Summary b->sq

Measured average in b->s penguin dominated modes:  
 $S=0.39\pm 0.11$

World average  $\sin 2\phi_1 = 0.726 \pm 0.037$

2.9  $\sigma$  difference: not conclusive

-> still need more data

-> need more accurate theoretical predictions mode by mode

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## Backup slides

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$B \rightarrow \eta' K_S$

$\eta'$ : not a pure  $ss$  state  $\rightarrow$

apart from  $P(V_{cb}V_{cs}^* \sim A\lambda^2)$  and  $P(V_{ub}V_{us}^* \sim A\lambda^4(\rho - i\eta))$

also color and Cabbibo suppressed  $b \rightarrow u$

$T(V_{ub}V_{us}^* \sim A\lambda^4(\rho - i\eta))$