Sensitivity study for $B \to \varphi K_S$ time dependent analysis

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Time dependent measurement

$\Upsilon(4S) \rightarrow B^0\overline{B}^0$ or experimentally $B_{rec}B_{tag}$

Decay rate f_+ (f_-) to final state f when B_{tag} decays as B^0 $(\overline{B}^0)$

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}[1 \pm S_f \sin(\Delta m \Delta t) \mp C_f \cos(\Delta m \Delta t)]$$

where $\Delta t = t_{B_{rec}} - t_{B_{tag}}$

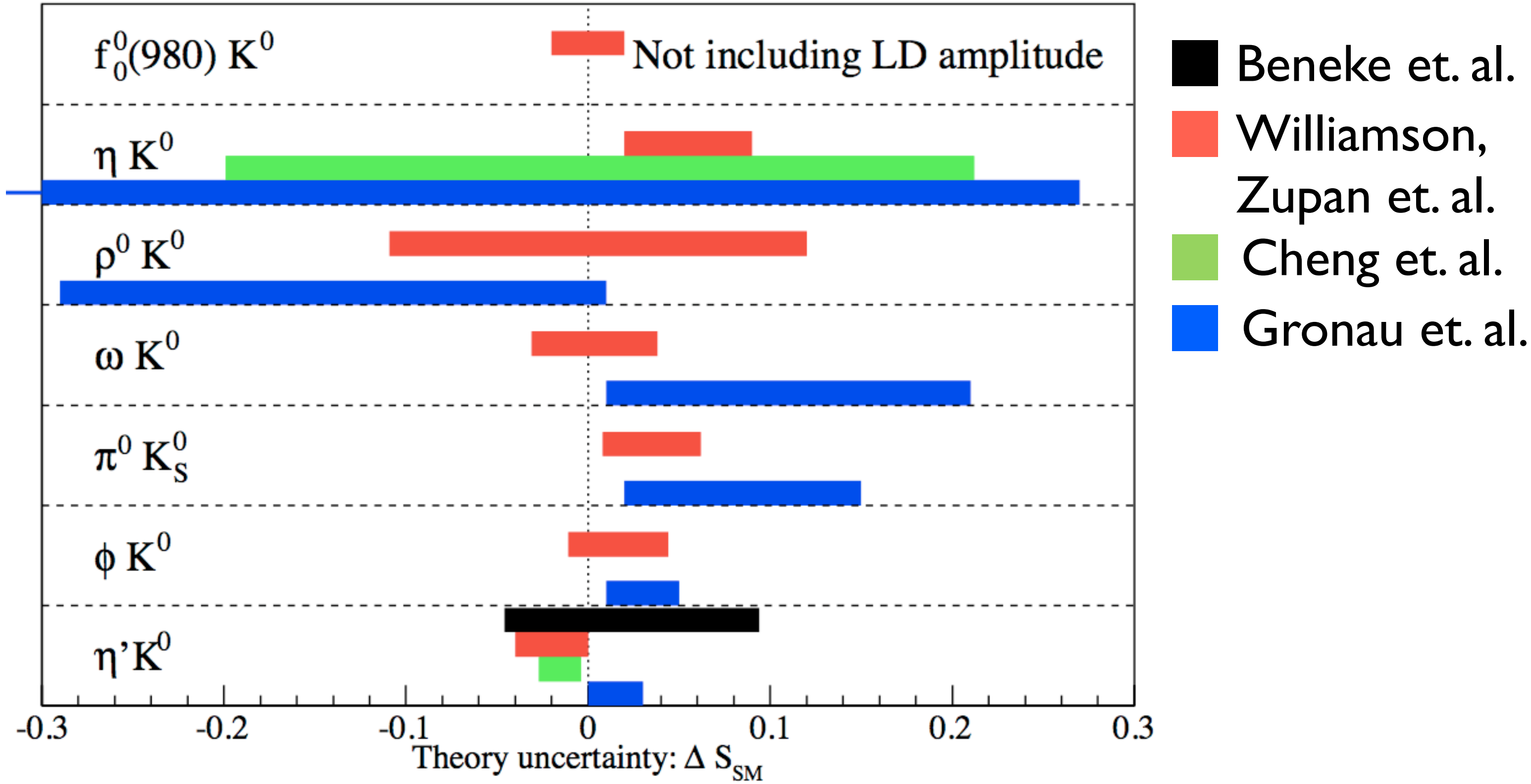
$S_f \neq 0$ CP violation in the interference between mixing and decay

$C_f \neq 0$ CP violation in the decay

$S_{\phi K^0_S} \neq S_{J/\Psi K^0_S}$ possible signature of New Physics

SM expectations for ΔS

from A. Bevan talk



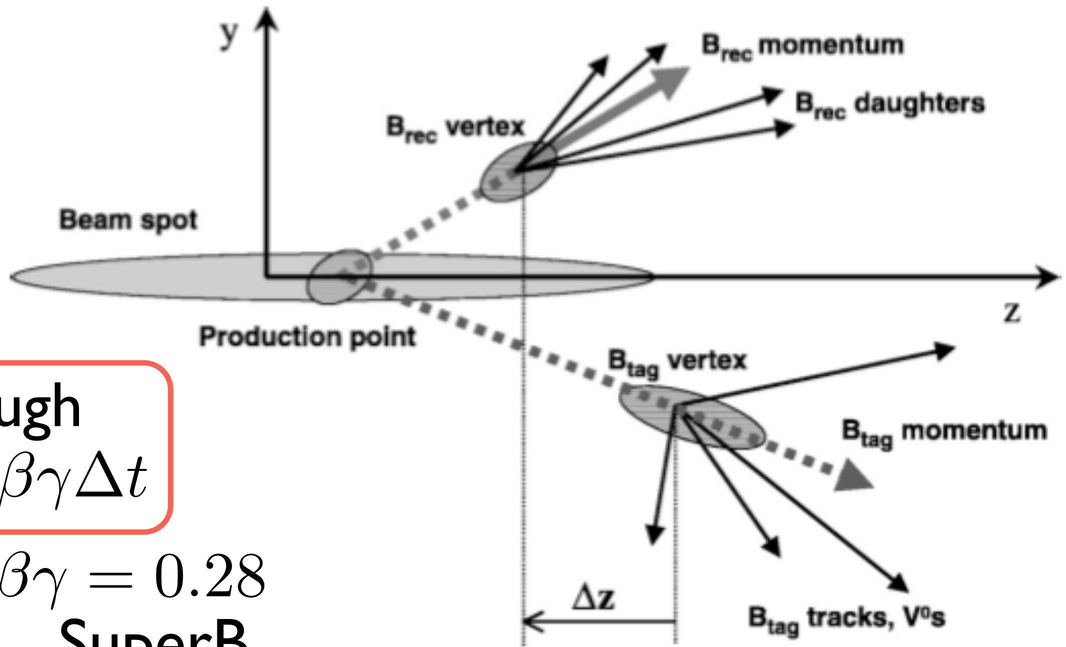
$B^0 \to \phi K_S^0$ among the cleanest mode to search for new physics. Theory uncertainty for SM predictions quite small: $-0.01 < \Delta S_{SM} < 0.05$, where $\Delta S_{SM} = S_{\phi K_S^0} - S_{J/\Psi K_S^0}$ in SM.

Experimental technique

- Reconstruct exclusively the B^0 decay and vertex position:

$B^0 \to \phi K^0_S \quad \phi \to K^+K^- \quad K^0_S \to \pi^+\pi^-$ B_{rec}

- Reconstruct inclusively the rest of event, B_{tag}, and determine the flavor and vertex position.



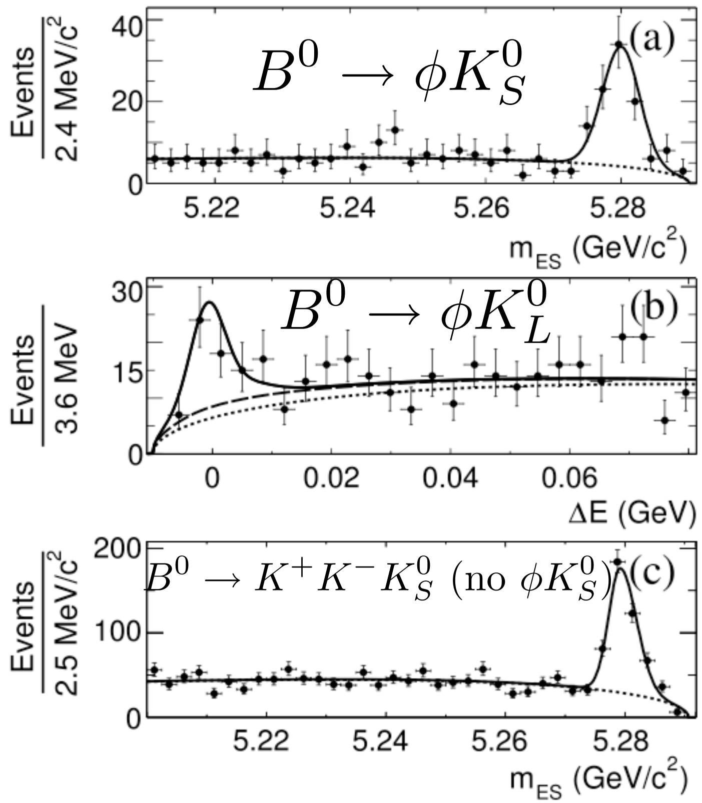
determine Δt through the relation $\Delta z \simeq \beta\gamma\Delta t$

$\beta\gamma = 0.56$ BaBar

$\beta\gamma = 0.28$ SuperB

$S_{\varphi K_S}$ results from B Factories

example plots from Phys.Rev.D71:091102,2005.



BaBar N(BB)=465M

arXiv:0808.0700

$$S = 0.26 \pm 0.26 \pm 0.03$$

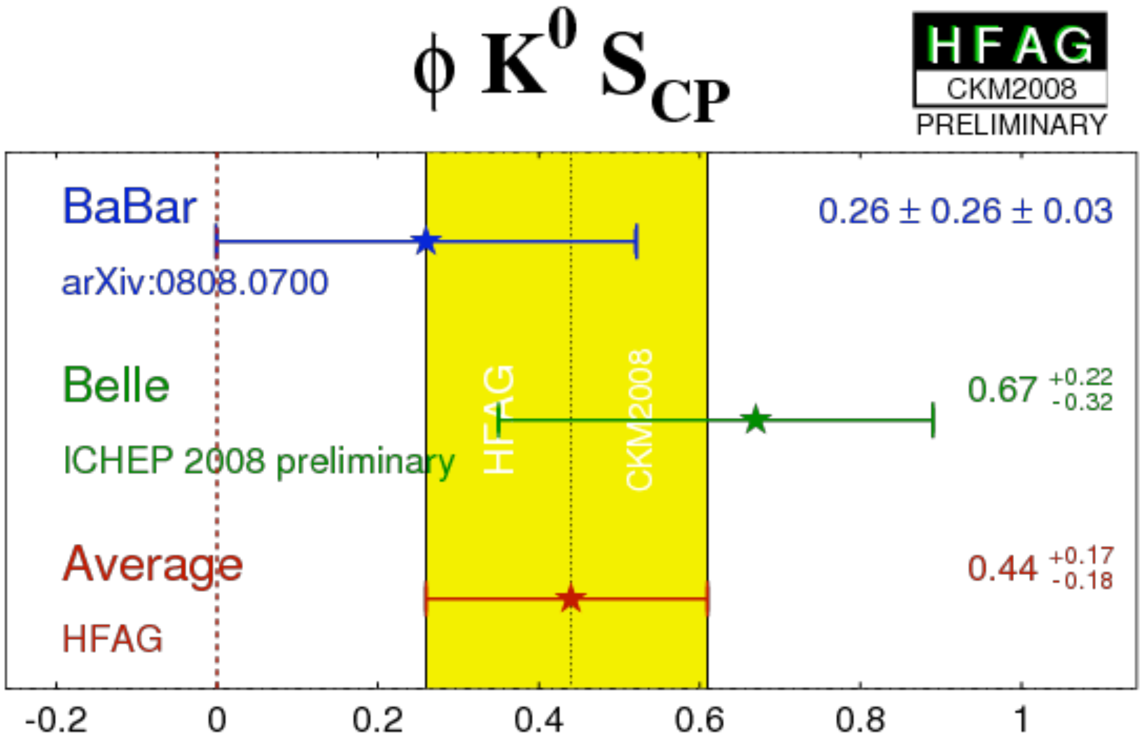
Belle N(BB)=657M

ICHEP 2008 preliminary

$$S = 0.67^{+0.22}_{-0.32}$$

High purity signal and relatively high selection efficiency. Purity ~85% (~75%), efficiency ~40% (~20%) for φK_S (φK_L)

HFAG average

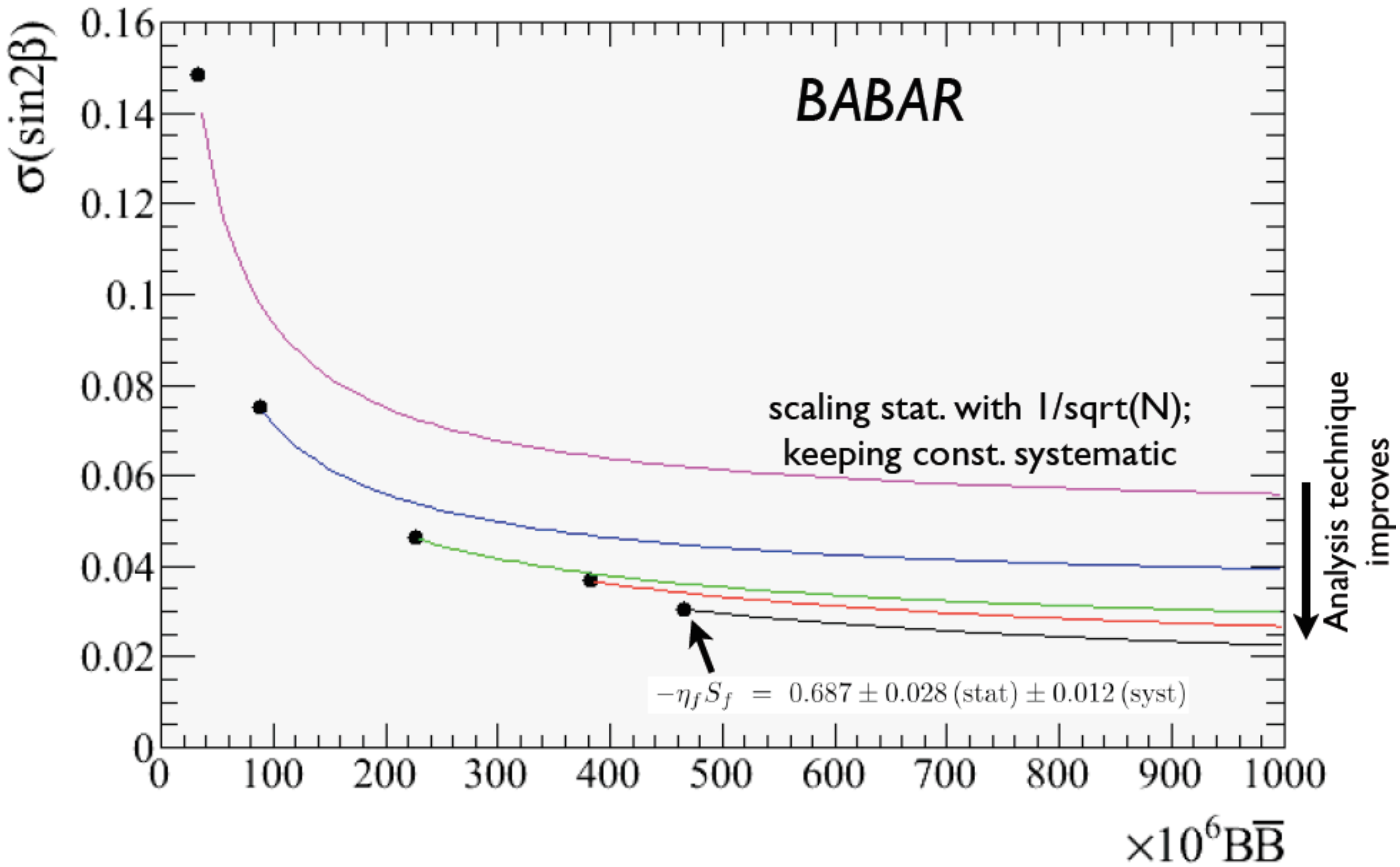


BaBar+Belle combined measurement. Statistically limited.

Sensitivity projections for SuperB

Example: sin 2β measurement evolution

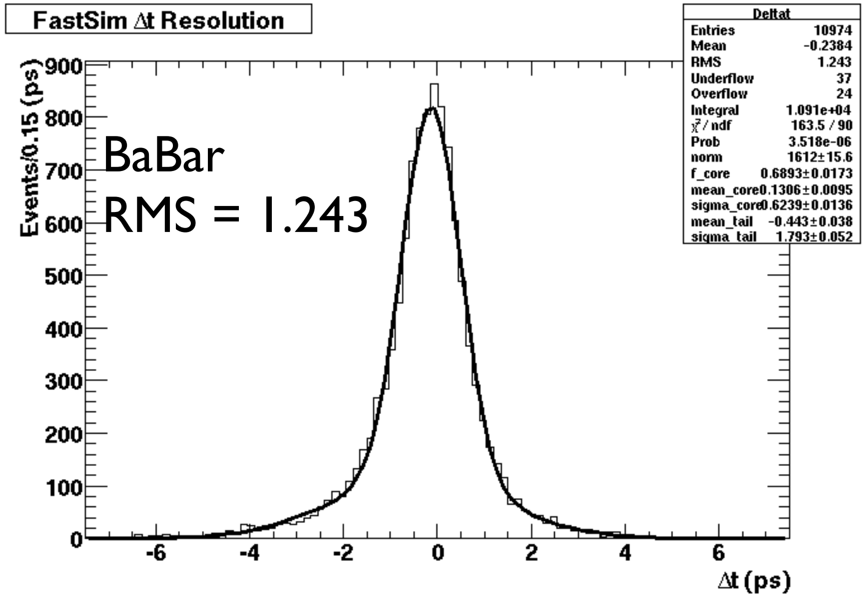
from Chih hsiang Cheng talk

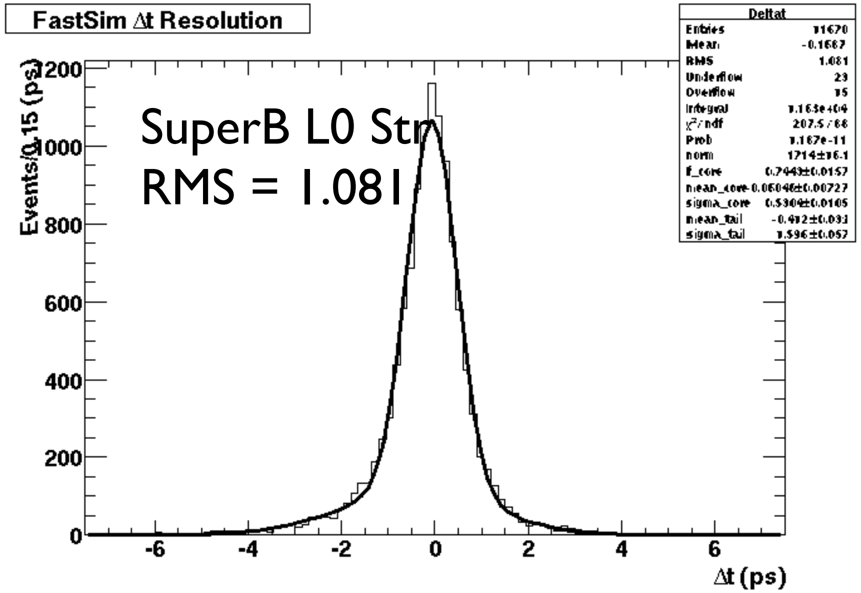


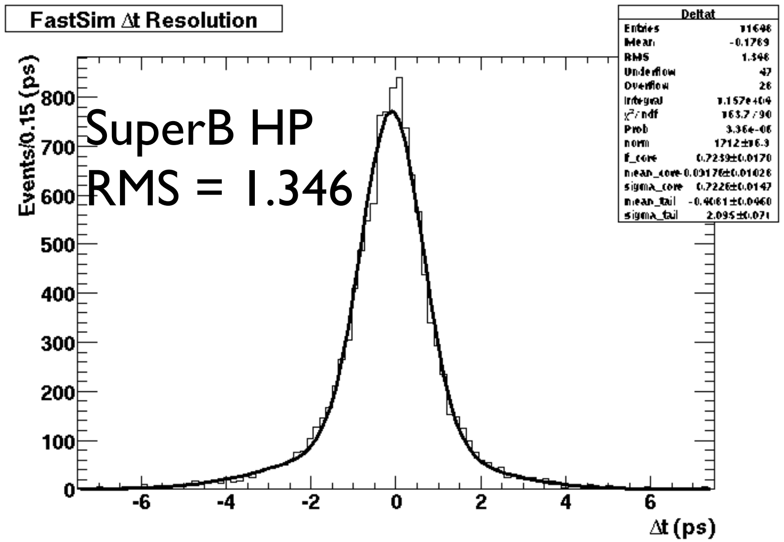
Reconstruction efficiency

- Larger tracking coverage in SuperB: i.e. SVT has 300 mrad coverage in LAB frame in BW and FW directions.
- Reco efficiency for $B^0 \rightarrow \phi K_S^0$ according to Fast Sim V0.1.1, no selection cuts and MC truth request only:
  - BaBar ε=(44.1 ± 0.3) %
  - SuperB L_0 Hybrid pixels ε=(48.8 ± 0.3) % (+10.6%)
  - SuperB L_0 Striplets ε=(49.4 ± 0.3) % (+12.0%)

Δt resolution







Δt resolution in SuperB depends on the L0 solution. Striplets (Str) configuration achieves better resolution wrt BaBar contrarily to Hybrid Pixel (HP).

B_{tag} flavor determination

- Flavor determination of B_{tag} exploits several informations such as flavor-charge correlations for primary leptons, kaons, pions, soft pions from D*, etc. Those informations are then combined in a neural network.

- Events are divided into different tagging categories in order to increase sensitivity:

Category	ε_i (%)	w_i (%)	Δw_i (%)	Q_i (%)
Lepton	8.96 ± 0.07	2.8 ± 0.3	0.3 ± 0.5	7.98 ± 0.11
Kaon I	10.82 ± 0.07	5.3 ± 0.3	-0.1 ± 0.6	8.65 ± 0.14
Kaon II	17.19 ± 0.09	14.5 ± 0.3	0.4 ± 0.6	8.68 ± 0.17
KaonPion	13.67 ± 0.08	23.3 ± 0.4	-0.7 ± 0.7	3.91 ± 0.12
Pion	14.18 ± 0.08	32.5 ± 0.4	5.1 ± 0.7	1.73 ± 0.09
Other	9.54 ± 0.07	41.5 ± 0.5	3.8 ± 0.8	0.27 ± 0.04
All	74.37 ± 0.10			31.2 ± 0.3

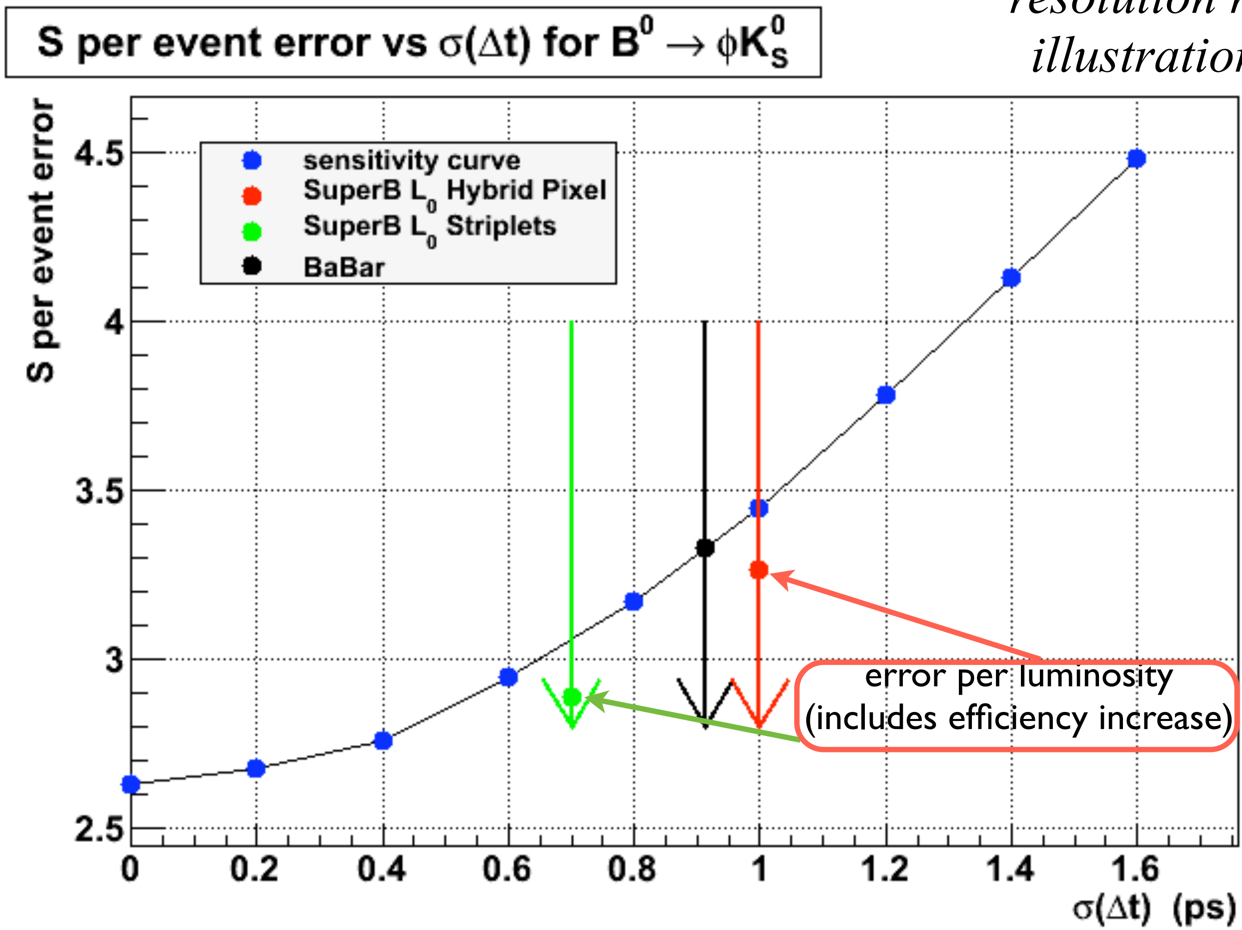
$$Q = \epsilon_{tag}(1 - 2\omega)^2$$

$$\sigma_S \propto \frac{1}{\sqrt{Q}}$$

SuperB is expecting to increase tagging performances: larger tracking coverage, improved PID, improved vertexing. No estimates so far and conservatively considering to maintain identical performances to BaBar in this study.

S per event error

note: single Gaussian resolution model for Δt for illustration purpose only



Including effects of improved B_{rec} reconstruction efficiency

Systematic errors (I)

example of systematic errors from Phys.Rev.D71:091102,2005.
Not latest BaBar analysis though.

Source	$S_{\phi K}$	$C_{\phi K}$	S_{KKK}	C_{KKK}
Detector effects	± 0.02	± 0.02	± 0.02	± 0.01
DCSD	± 0.01	± 0.03	± 0.00	± 0.03
Fit bias	± 0.01	± 0.01	± 0.02	± 0.01
B^0-$\overline{B}^0$ tagging	± 0.01	± 0.02	± 0.00	± 0.01
S-wave contamination	$+0.06$	± 0.02	-	-
Other	± 0.03	± 0.02	± 0.01	± 0.01
Total	${}^{+0.07}_{-0.04}$	± 0.05	± 0.03	± 0.04

reduced with Dalitz KKKs analysis

In 2005 analysis, the S-wave contamination represented the main contribution to the systematic error. Later BaBar Dalitz plot time-dependent analysis of $B^0 \to K^+ K^- K^0_S$ *reduced to almost negligible level this contribution. See next slide.*

Systematic errors (II)

"Measurement of CP- Violating Asymmetries in the $B^0 \to K^+K^-K^0_S$ Dalitz Plot"

$K^+K^-K_S$ Isobar model

arXiv:0808.0700v2 [hep-ex] 8 May 2009

Decay	Amplitude c_r	Phase ϕ_r	Fraction $\mathcal{F}_r$ (%)
$\phi(1020)K^0_S$	0.00897 ± 0.00096	-0.341 ± 0.232	12.6 ± 1.0
$f_0(980)K^0_S$	0.542 ± 0.044	-0.201 ± 0.157	27.8 ± 7.1
$X_0(1550)K^0_S$	0.141 ± 0.017	-0.370 ± 0.154	5.70 ± 1.70
NR (K^+K^-)	1 (fixed)	0 (fixed)	98.1 ± 18.7
$(K^+K^0_S)$	0.328 ± 0.058	1.81 ± 0.23	10.5 ± 3.4
$(K^-K^0_S)$	0.353 ± 0.066	-1.44 ± 0.27	12.1 ± 3.8
$\chi_{c0}K^0_S$	0.0298 ± 0.0046	0.732 ± 0.437	2.53 ± 0.60
D^+K^-	1.34 ± 0.19	–	3.43 ± 0.69
$D^+_sK^-$	0.826 ± 0.160	–	1.37 ± 0.46

Use Breit-Wigners and couple channel (Flatte') function for $f_0(980)$. Note the dominant contribution of KK S-wave amplitude.

	C	$-\eta S$
Whole DP	$-0.03 \pm 0.07 \pm 0.02$	$0.77 \pm 0.09 \pm 0.02$
High-mass	$-0.05 \pm 0.09 \pm 0.04$	$0.86 \pm 0.08 \pm 0.03$
$\phi(1020)K^0_S$	$-0.14 \pm 0.19 \pm 0.02$	$0.26 \pm 0.26 \pm 0.03$
$f_0(980)K^0_S$	$-0.01 \pm 0.26 \pm 0.07$	$0.29 \pm 0.25 \pm 0.06$

ϕ Γ = 4.26 ± 0.04 MeV

$f_0(980)$ Γ = 40 to 100 MeV

Systematic error on S reduced from $^{+0.07}_{-0.04}$ to 0.03!

Systematic errors (III)

example of systematic errors from latest BaBar analysis.
arXiv:0808.0700v2 [hep-ex] 8 May 2009

Parameter	Whole DP A_{CP}	Whole DP β_{eff}	ϕK_S^0 A_{CP}	ϕK_S^0 β_{eff}	$f_0 K_S^0$ A_{CP}	$f_0 K_S^0$ β_{eff}
Fixed PDF Parameters	0.010	0.010	0.014	0.010	0.025	0.015
Fit Bias	0.007	0.011	0.009	0.012	0.011	0.011
DCSD, Beam Spot, other	0.015	0.004	0.015	0.004	0.015	0.004
Dalitz Model	0.005	0.005	0.009	0.002	0.060	0.024
Total	0.020	0.016	0.024	0.016	0.068	0.031

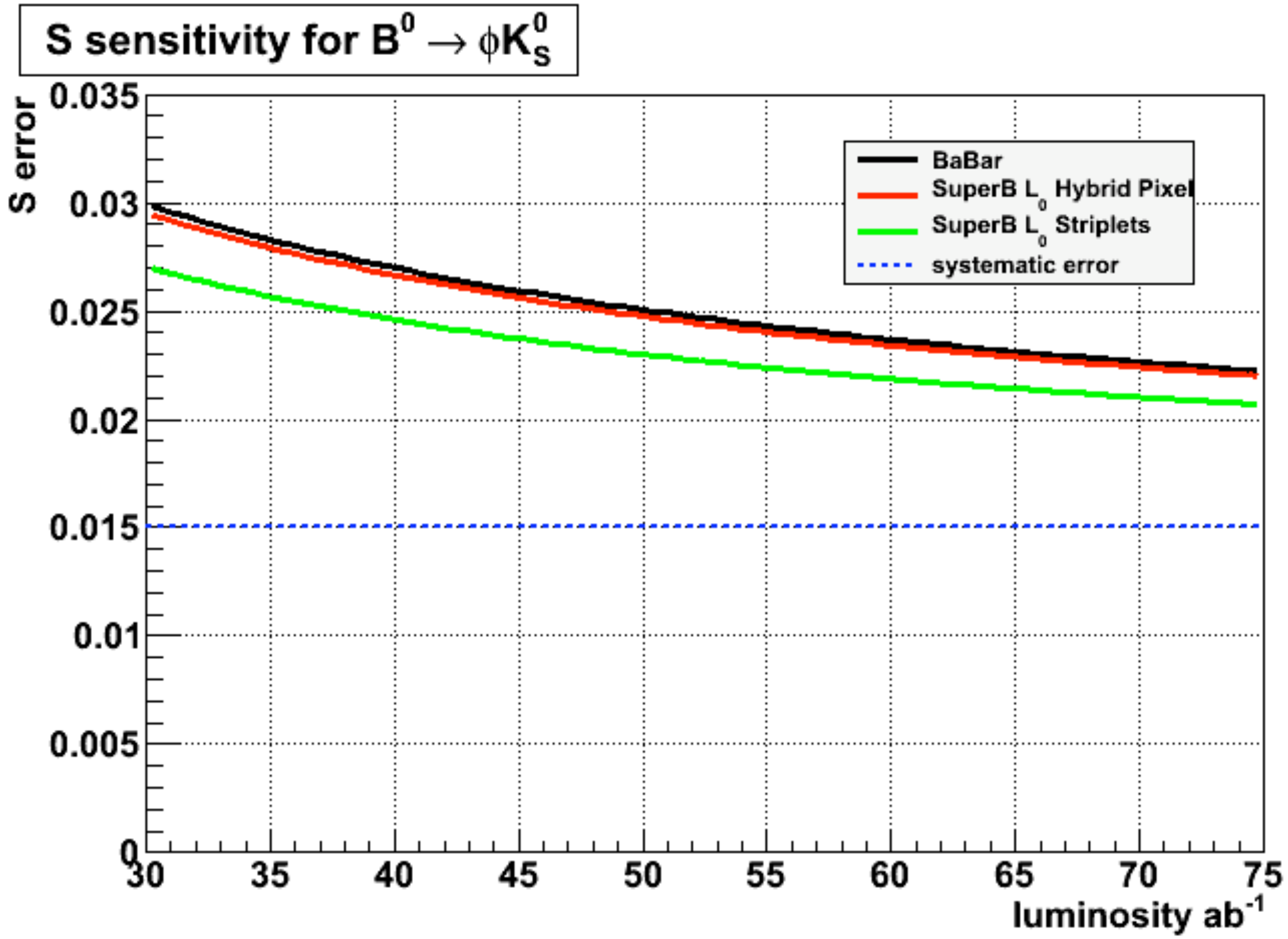
↓ high stat control sample
↓ larger Monte Carlo
↓ high stat control sample
~ same ?

$$S = \sin(2\beta_{eff}) \qquad \sigma_S \simeq \cos(2\beta_{eff})2\sigma_{\beta_{eff}} \simeq 0.03$$

Naive projection for systematic error at SuperB:
should be able to reduce it by at least a factor of 2.

$$\sigma_S(\mathrm{SuperB}) \simeq 0.010 - 0.015$$

Extrapolation to 75 ab^{-1}



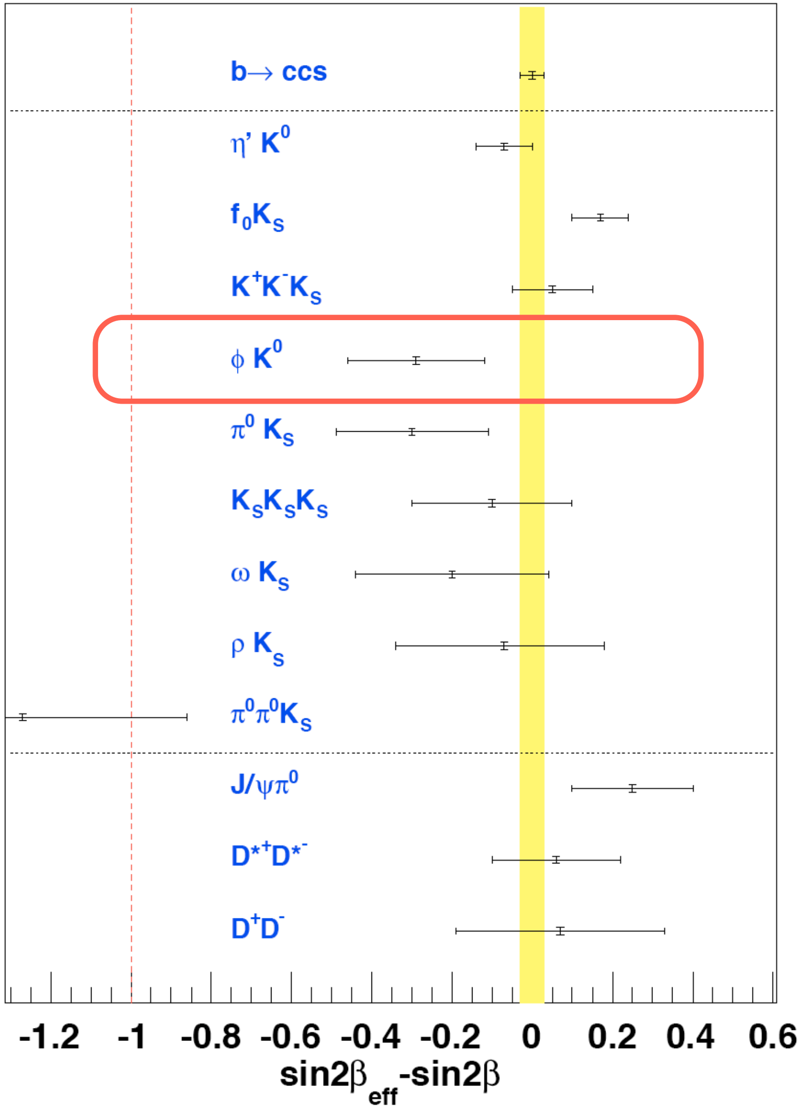
If systematic error 0.015-0.010, then statistical and systematic errors are comparable at 75 ab^{-1}. SuperB can reach a sensitivity to S close to 0.02.

Conclusions

- At B Factories $S_{\phi K^0_S}$ has been measured with a precision of 0.18 (combined measurement).
- Statistically limited and theoretically clean. Good candidate for SuperB case!
- Sensitivity projections for SuperB at 75 ab^{-1} close to 0.02 if able to reduce present systematic error by a half (quite reasonable with high stat control sample and large Monte Carlo sample).
- At SuperB, the measurement will become theoretically limited according to present SM calculations for $S_{\phi K^0_S}$. Theory uncertainty for SM predictions $-0.01<\Delta S_{SM}<0.05$.

Backup

Experimental status



from A. Bevan talk

$S_{J/\psi K_S}$ like measurements from B Factories