



Studies of penguin dominated B decays at Belle

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SUSY07

Karlsruhe, Germany
July 26 - August 1, 2007



Introduction

Time-dependent CP violation: Quantum interference
between $B^0-\bar{B}^0$ mixing and B^0 decay to CP eigenstate

$$\mathcal{A}_{CP} = \frac{\mathcal{P}(\bar{B}^0(\Delta t) \rightarrow f_{CP}) - \mathcal{P}(B^0(\Delta t) \rightarrow f_{CP})}{\mathcal{P}(\bar{B}^0(\Delta t) \rightarrow f_{CP}) + \mathcal{P}(B^0(\Delta t) \rightarrow f_{CP})}$$

$$= S \sin \Delta m \Delta t \quad + \quad A \cos \Delta m \Delta t$$

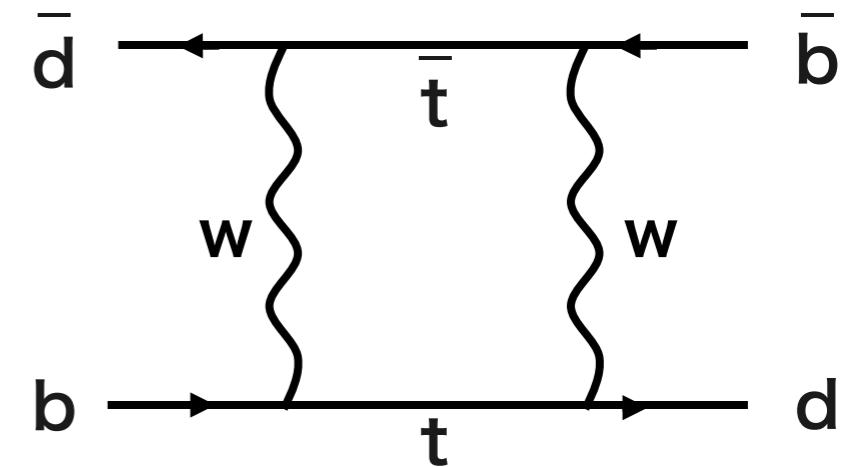
mixing induced CPV direct CPV

where $S = -\xi_f \sin 2\phi_1$

ξ_f : CP eigenvalue

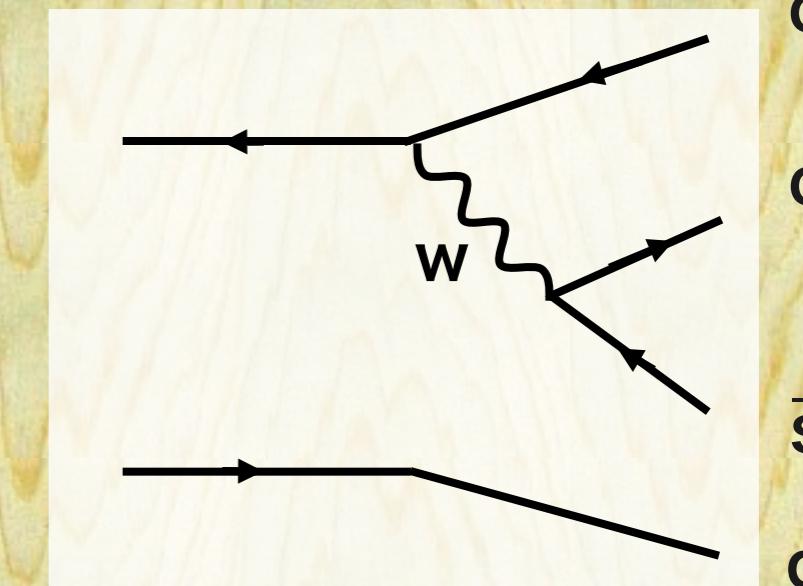
Δm : $B-\bar{B}$ mass difference

Δt : $B-\bar{B}$ decay time difference



$b \rightarrow c\bar{c}s$ tree diagram

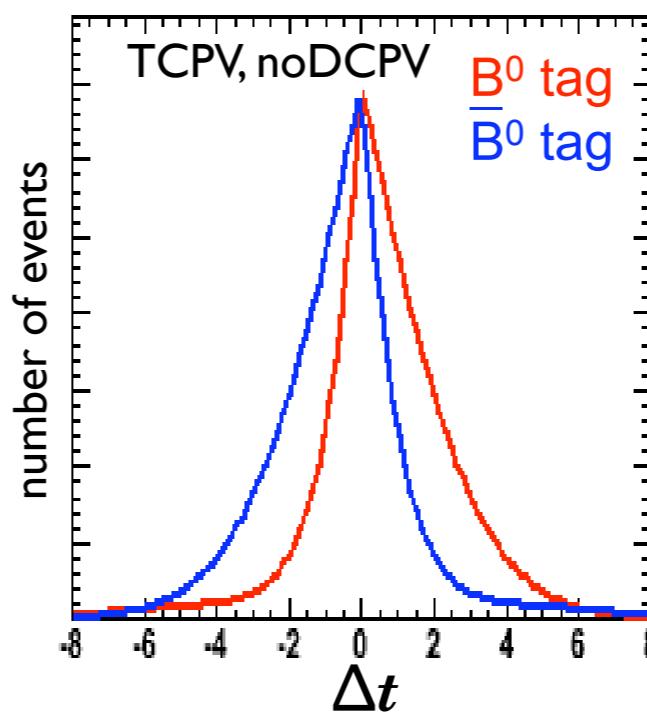
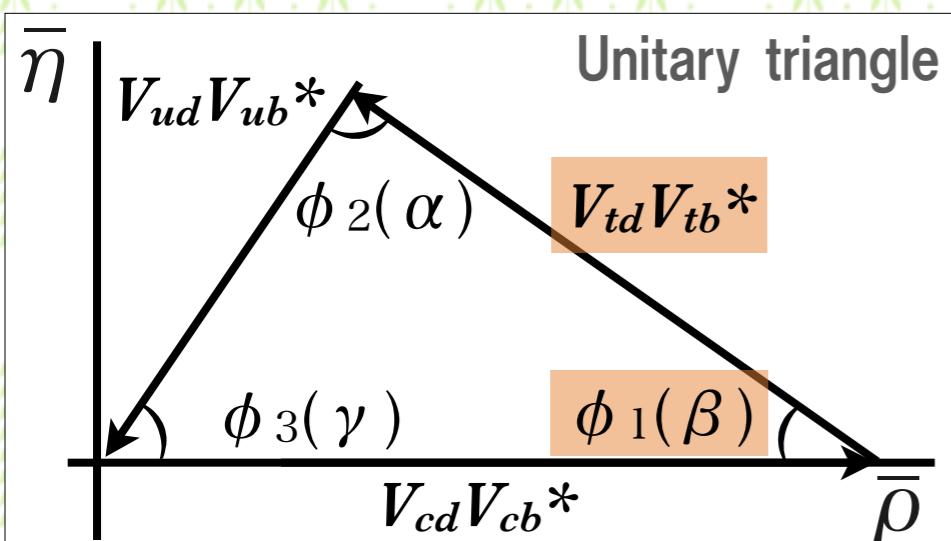
$B^0 \rightarrow J/\psi K^0$ "Golden mode"



$$S = -\xi_f \sin 2\phi_1, A \sim 0$$

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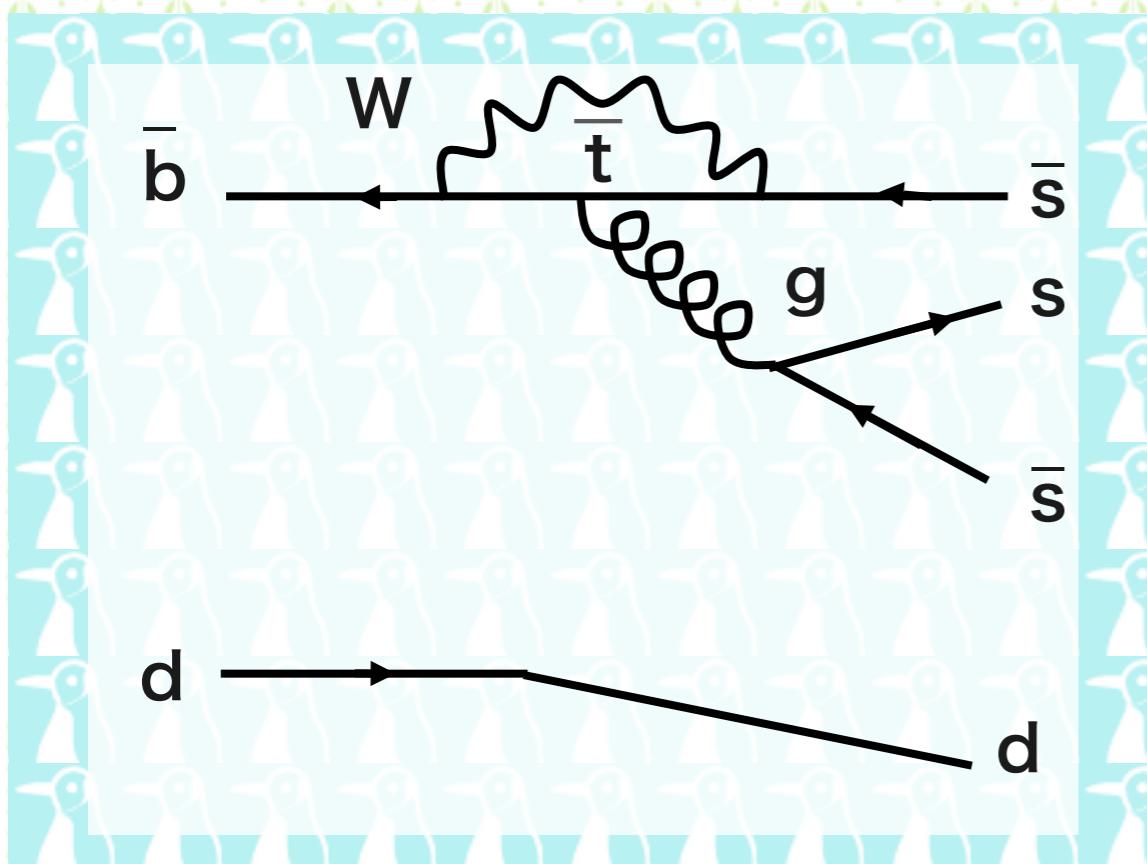
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Introduction

— $b \rightarrow sq\bar{q}$ penguin dominated modes



$$S = -\xi_f \sin 2 \phi_1$$

$A \sim 0$ (No direct CPV)

$\Delta S = \sin 2 \phi_1^{\text{eff}} - \sin 2 \phi_1^{b \rightarrow ccs}$
slightly shifts due to other
SM b -decay diagram contribution

	ΔS
$B^0 \rightarrow \eta' K^0$	0.01 ± 0.01
$B^0 \rightarrow \phi K^0$	0.02 ± 0.01
$B^0 \rightarrow \omega K^0_S$	0.13 ± 0.08
$B^0 \rightarrow \rho^0 K^0_S$	$-0.08^{+0.08}_{-0.12}$
$B^0 \rightarrow K^0_S \pi^0$	$0.07^{+0.05}_{-0.04}$

J. Zupan, hep-ph/0707.1323

	ΔS
$B^0 \rightarrow K^+ K^- K^0_S$	$0.03^{+0.02}_{-0.03}$
$B^0 \rightarrow K^0_S K^0_S K^0_S$	$0.02^{+0.02}_{-0.03}$
$B^0 \rightarrow K^0_S \pi^0 \pi^0$	$0.03^{+0.02}_{-0.03}$

Hai-Yang Cheng, hep-ph/0702252

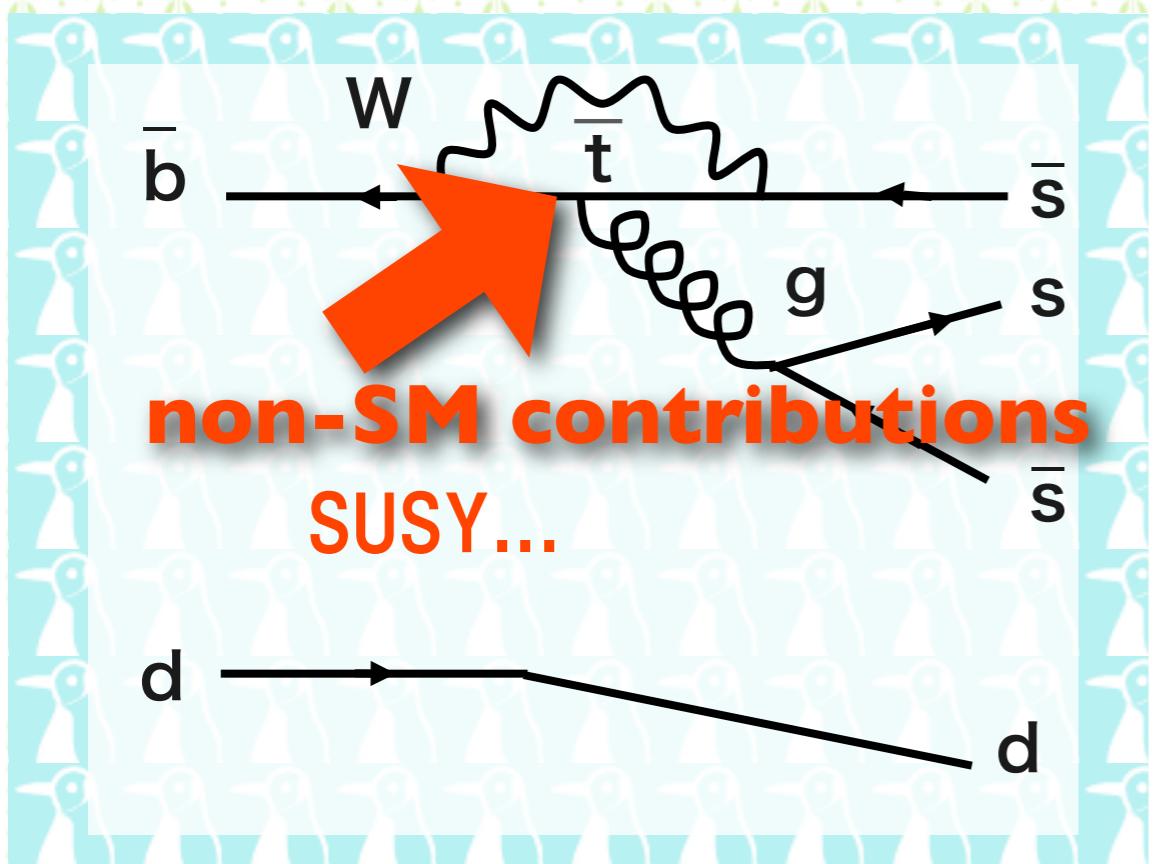
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Introduction

— $b \rightarrow sq\bar{q}$ penguin dominated modes



$$S = -\xi_f \sin 2\phi_1 \oplus \text{extra CP phase}$$

$$= -\xi_f \sin 2\phi_1^{\text{eff}}$$

$A \sim 0$ (No direct CPV)

$\Delta S = \sin 2\phi_1^{\text{eff}} - \sin 2\phi_1^{b \rightarrow ccs}$
slightly shifts due to other
SM b -decay diagram contribution

	ΔS
$B^0 \rightarrow \eta' K^0$	0.01 ± 0.01
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J. Zupan, hep-ph/0707.1323

	ΔS
$B^0 \rightarrow K^+ K^- K^0_S$	$0.03^{+0.02}_{-0.03}$
$B^0 \rightarrow K^0_S K^0_S K^0_S$	$0.02^{+0.02}_{-0.03}$
$B^0 \rightarrow K^0_S \pi^0 \pi^0$	$0.03^{+0.02}_{-0.03}$

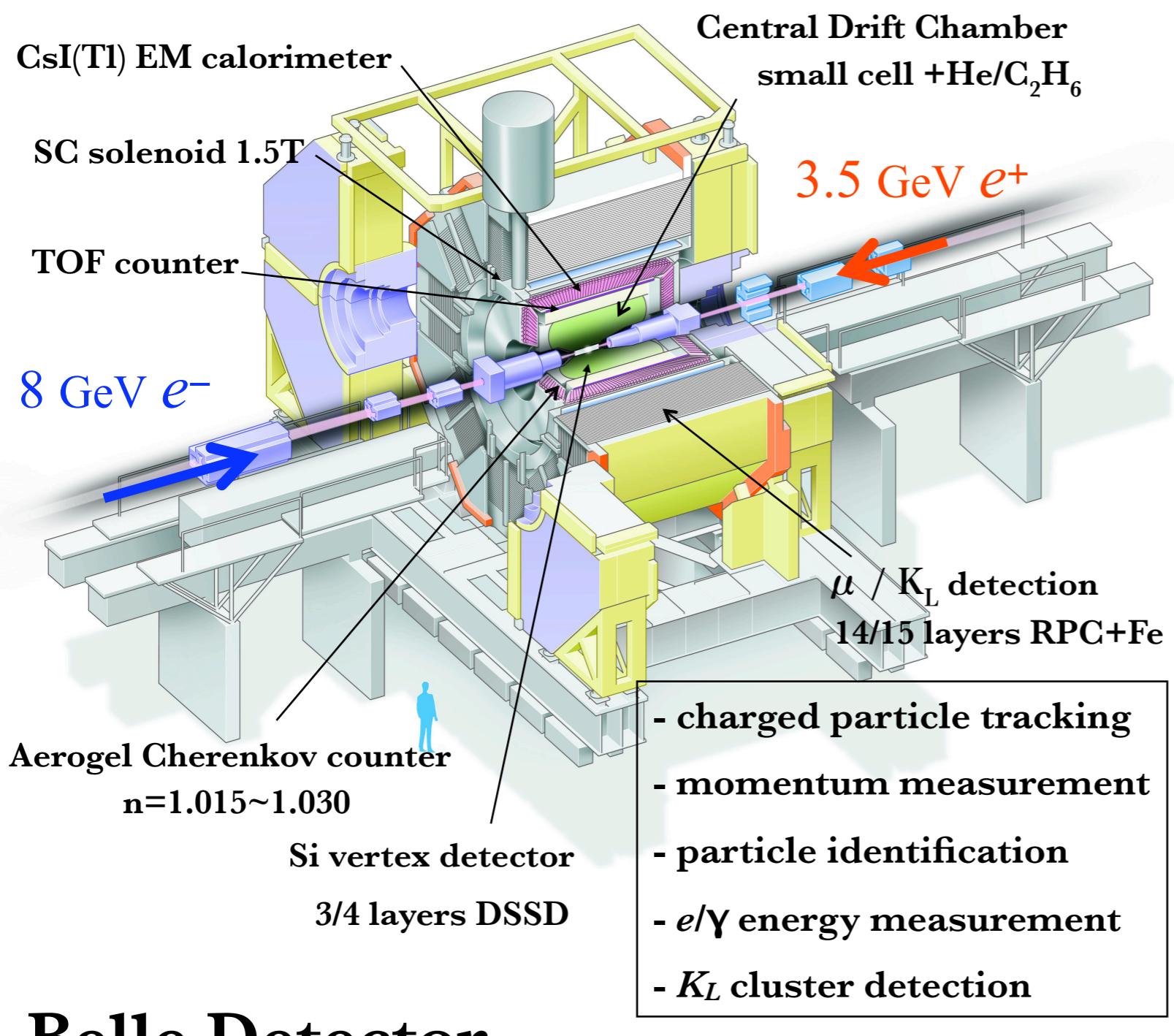
Hai-Yang Cheng, hep-ph/0702252

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Experimental apparatus

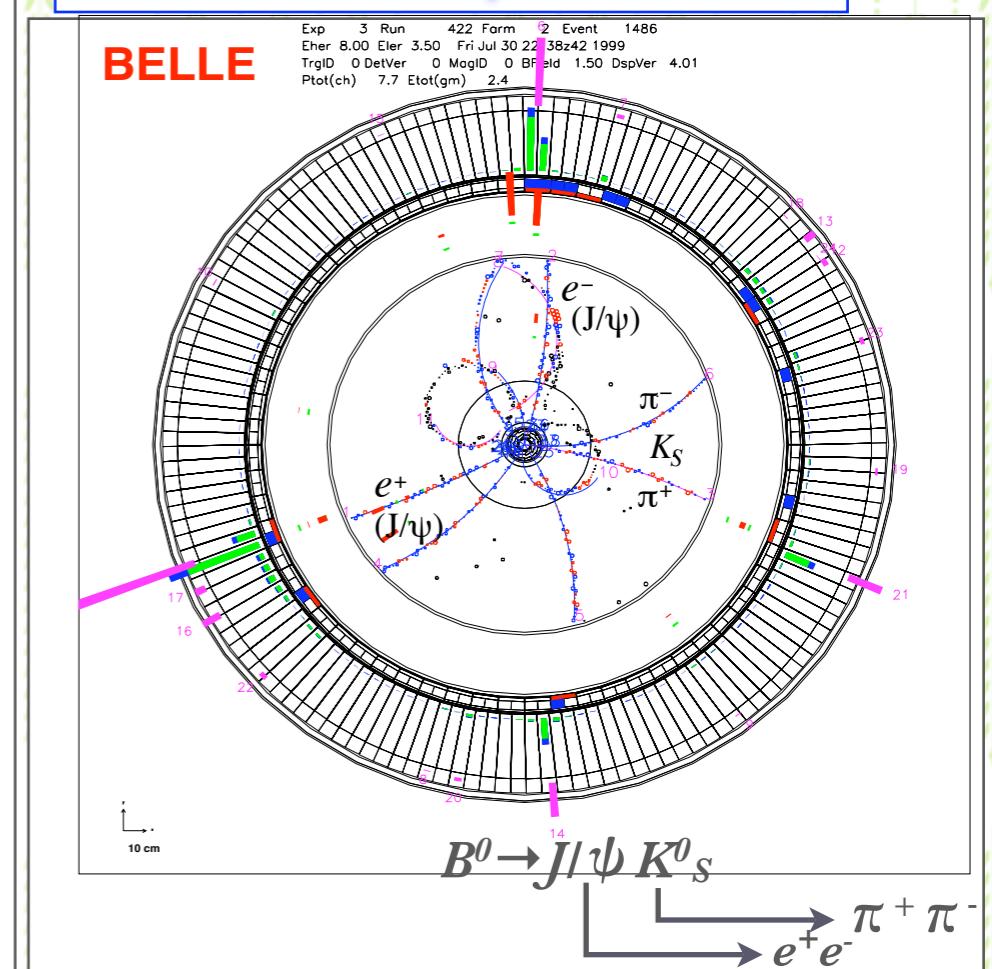


CP-side B reconstruction

- momentum
- invariant mass
- event shape variables

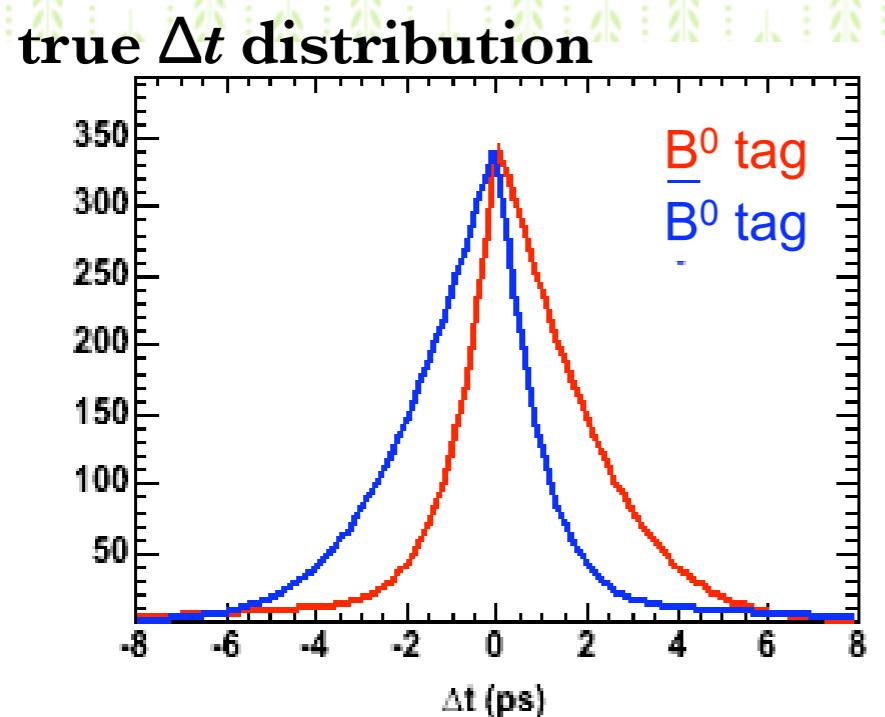
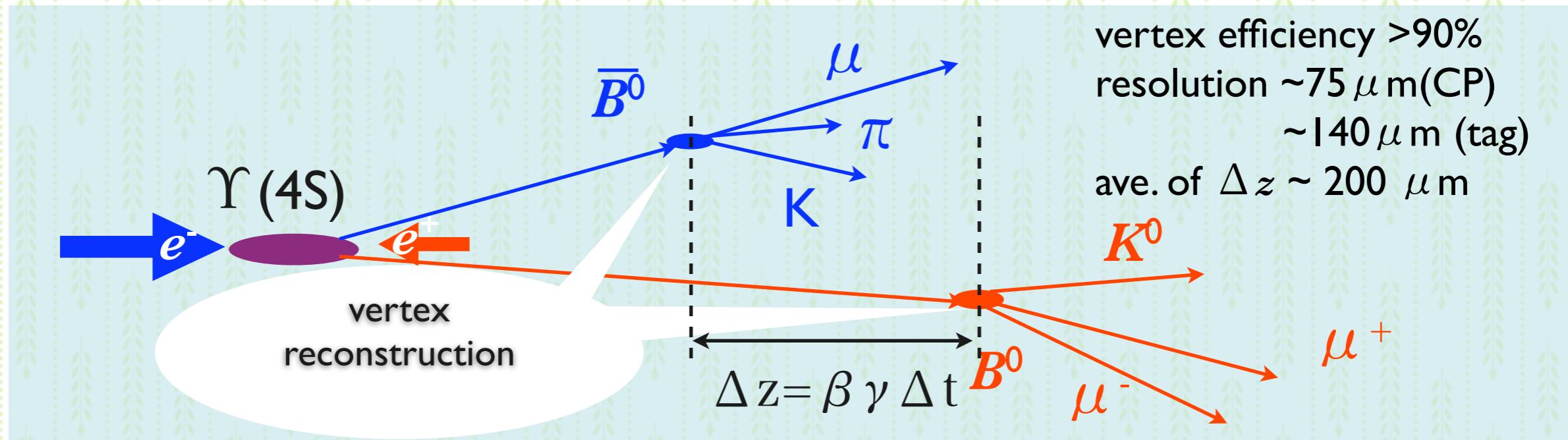
tag associate B flavor

- lepton
 - kaon
 - low momentum pion from D*
 - ...
- ~30% efficiency





CPV parameter measurement



Time dependent decay rate

$$\mathcal{P}_{sig} = \frac{1}{4\tau} e^{-\frac{|\Delta t|}{\tau}}$$

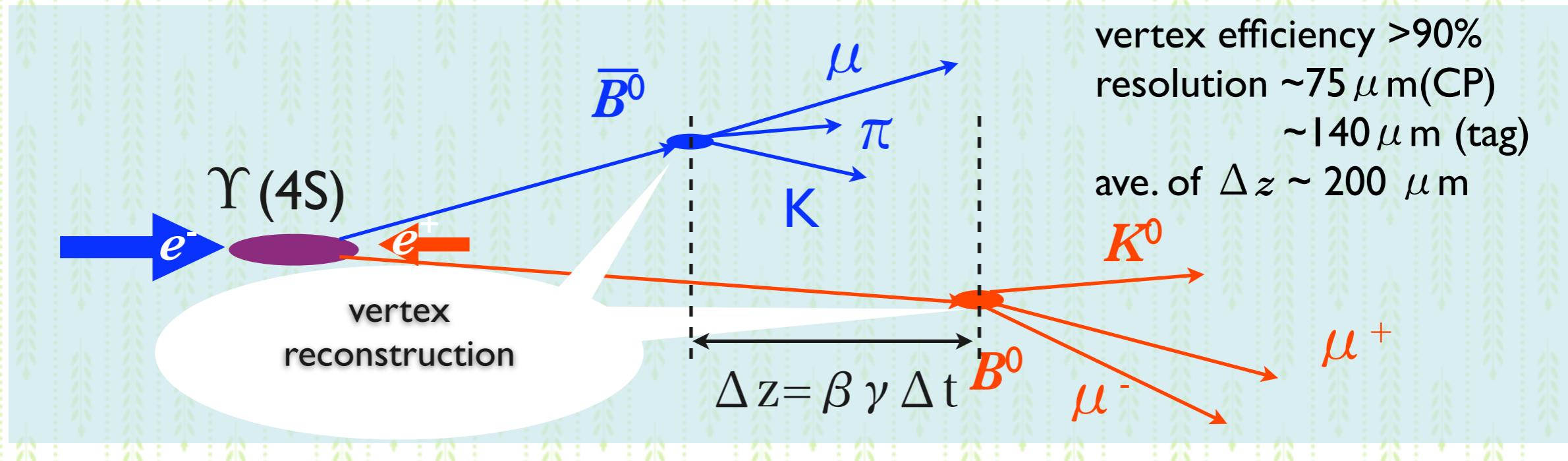
$$q(\text{Acos}\Delta m \Delta t + \text{Ssin}\Delta m \Delta t)$$

τ : B lifetime
 Δm : $B - \bar{B}$ mass difference

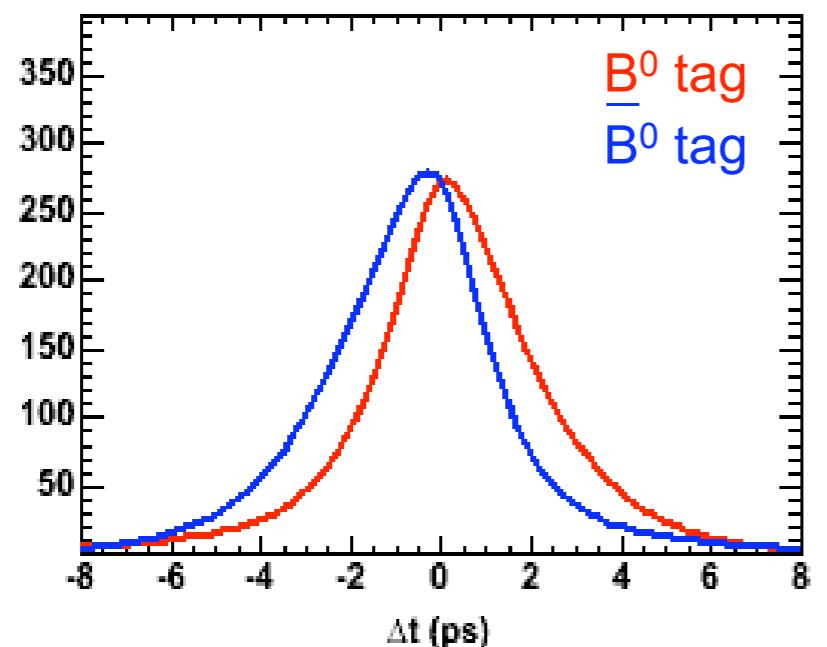
Un-binned maximum likelihood fit
 together with other observables



CPV parameter measurement



measured Δt distribution



Time dependent decay rate

$$\mathcal{P}_{sig} = \frac{1}{4\tau} e^{-\frac{|\Delta t|}{\tau}} (1-2w) q (\text{Acos}\Delta m \Delta t + \text{Ssin}\Delta m \Delta t) \otimes R(\Delta t)$$

flavor tagging quality resolution function

τ : B lifetime
 Δm : $B-\bar{B}$ mass difference

Un-binned maximum likelihood fit
 together with other observables

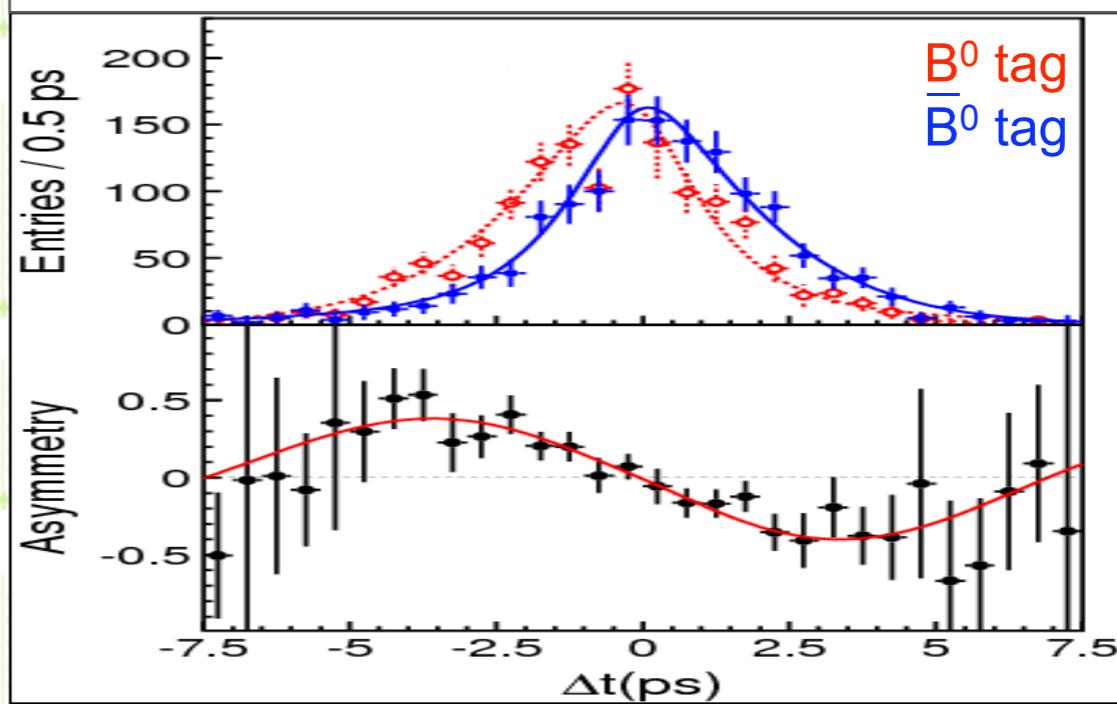
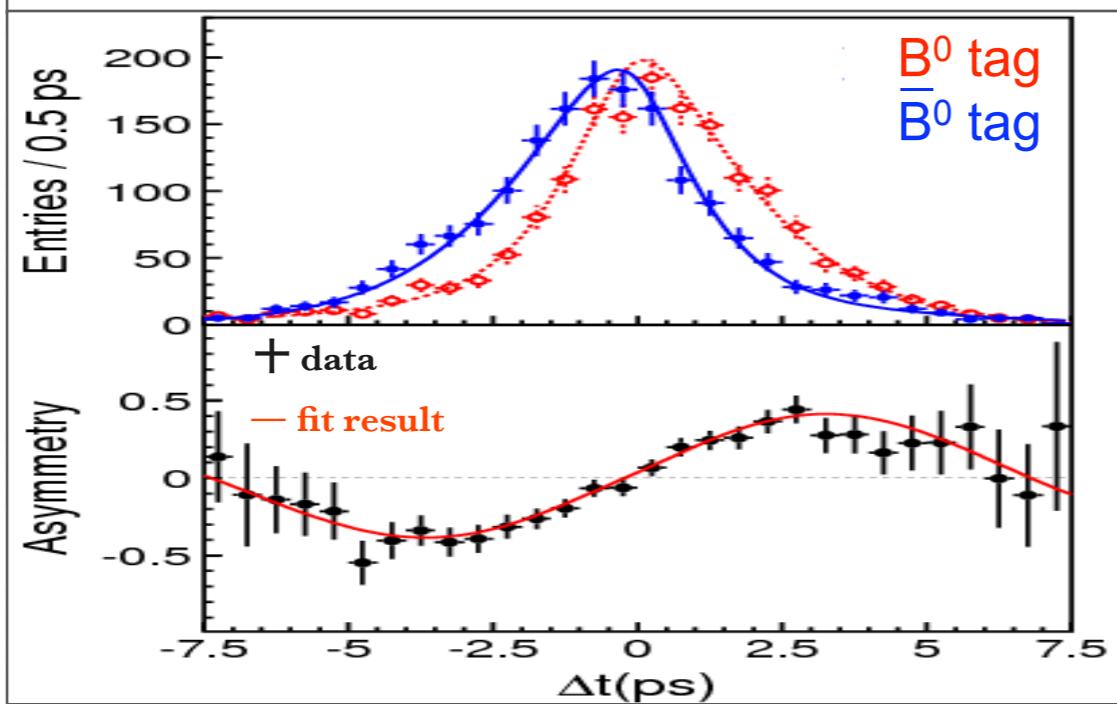
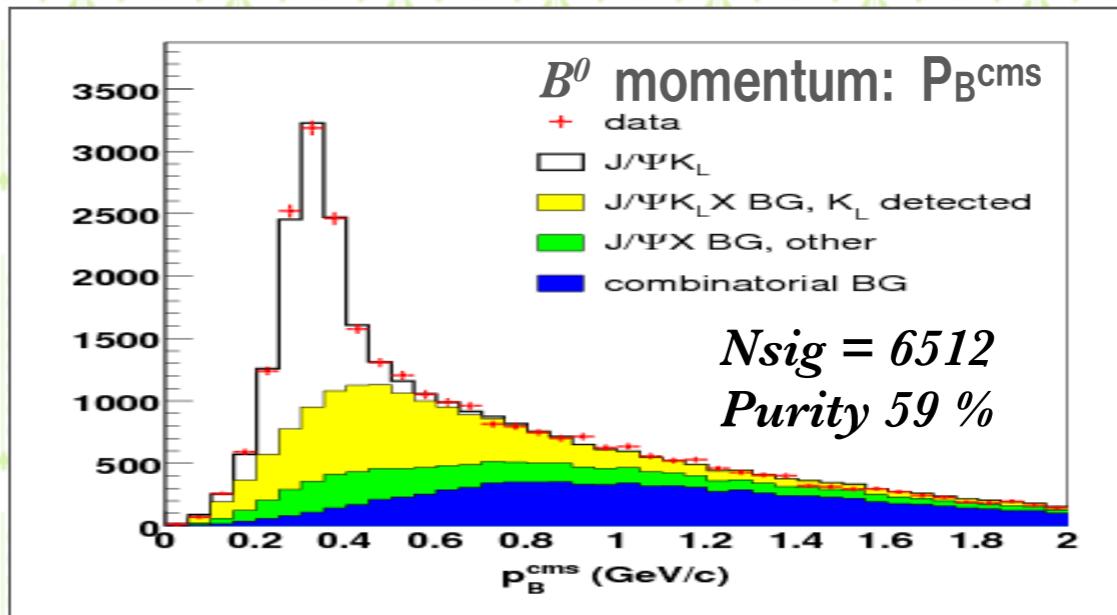
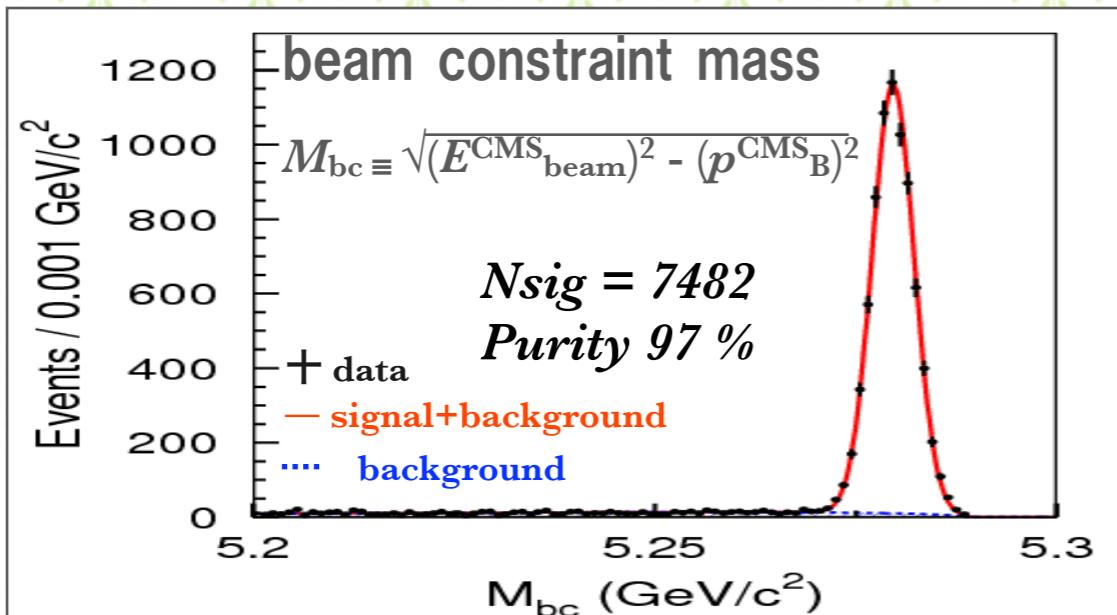


$B^0 \rightarrow J/\psi K^0$ results

535 million $\bar{B}^0 B^0$ sample

$B^0 \rightarrow J/\psi K^0_S$ CP odd ($\xi_f = -1$)

$B^0 \rightarrow J/\psi K^0_L$ CP even ($\xi_f = +1$)



$$\sin 2\phi_1 = 0.643 \pm 0.038$$

$$A = -0.001 \pm 0.028$$

$$\sin 2\phi_1 = 0.641 \pm 0.057$$

$$A = 0.045 \pm 0.033$$

Δt figures
are BG
subtracted

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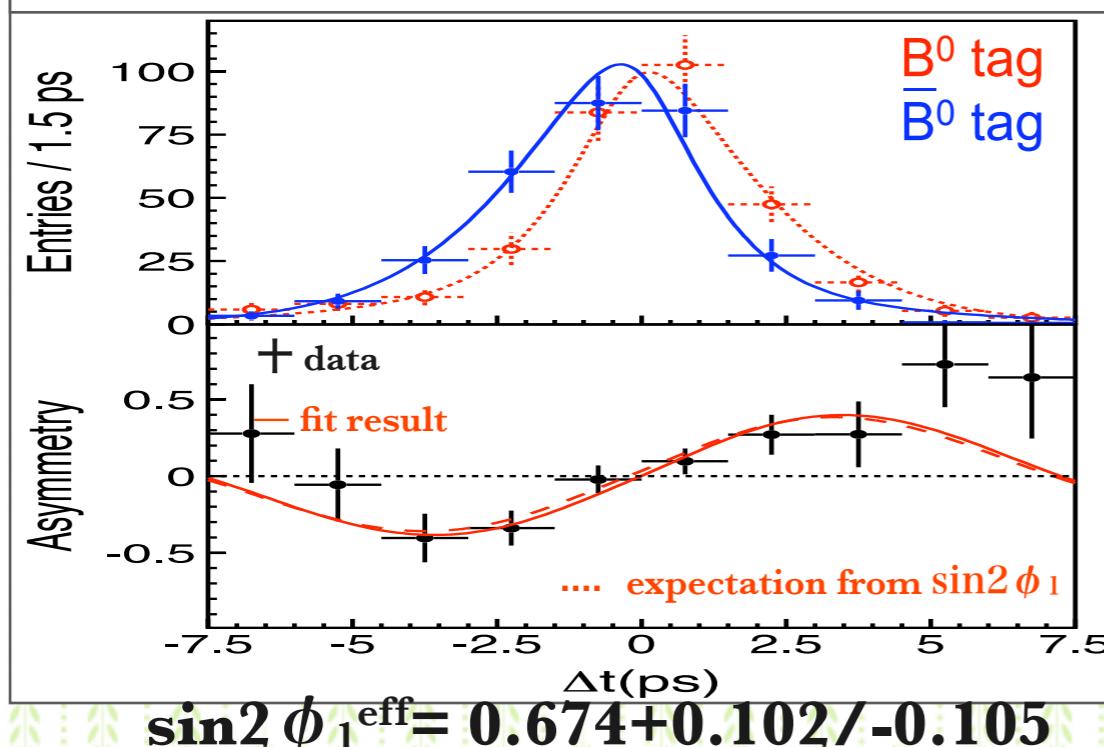
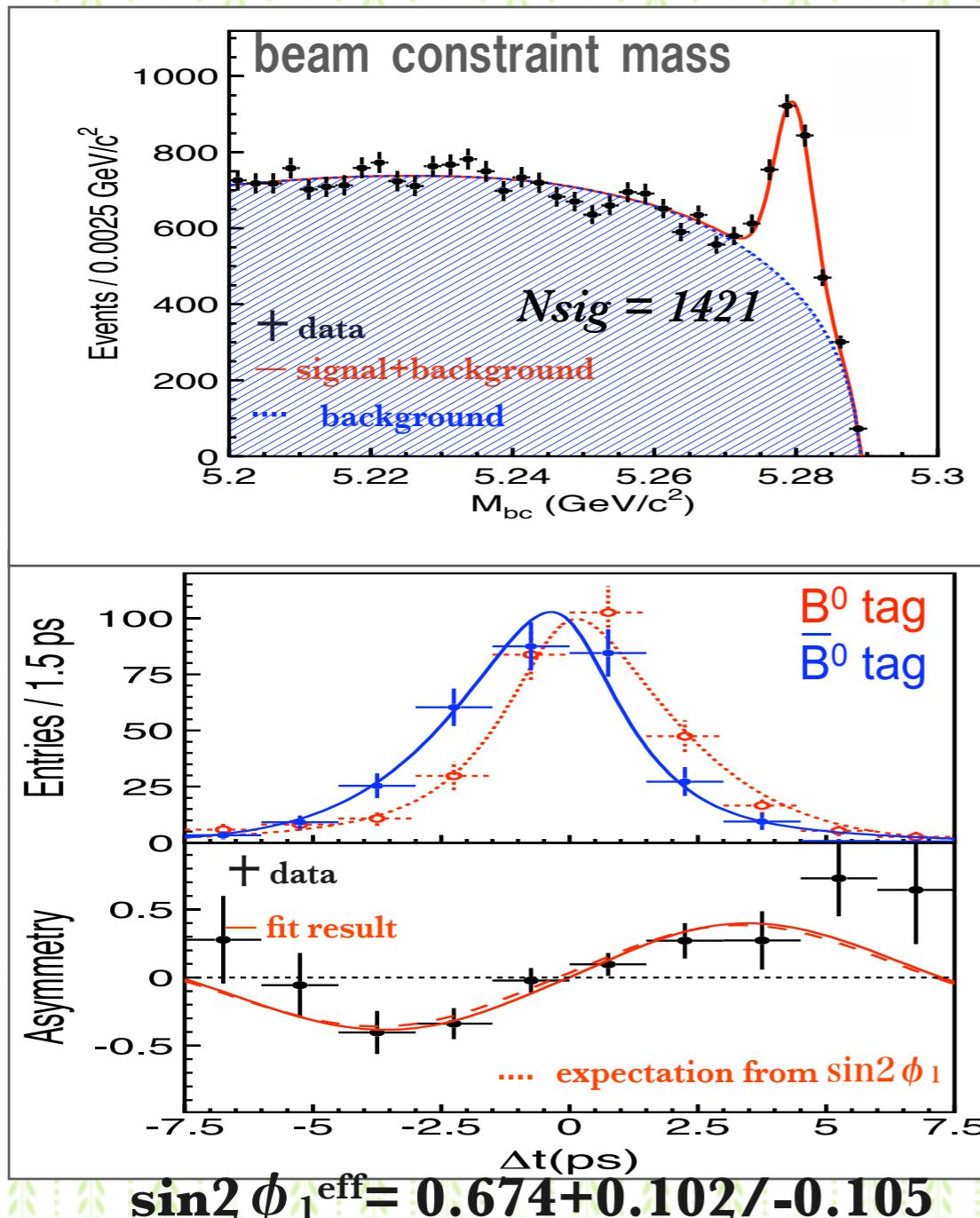


$B^0 \rightarrow \eta' K^0$ results

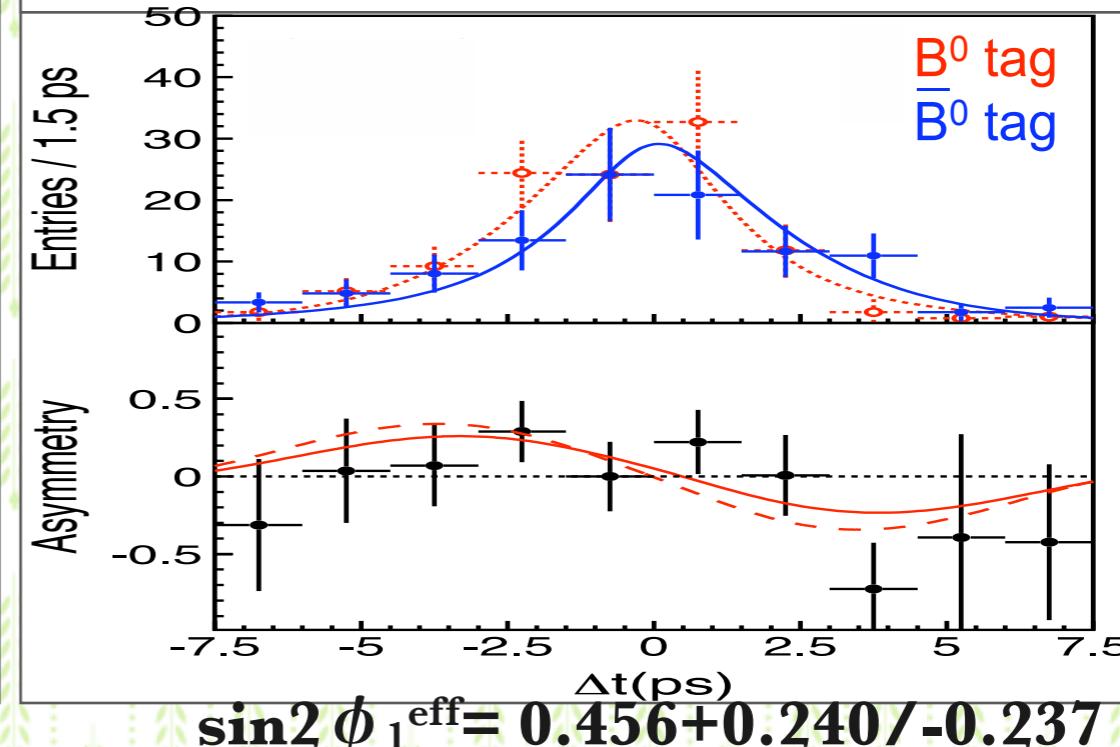
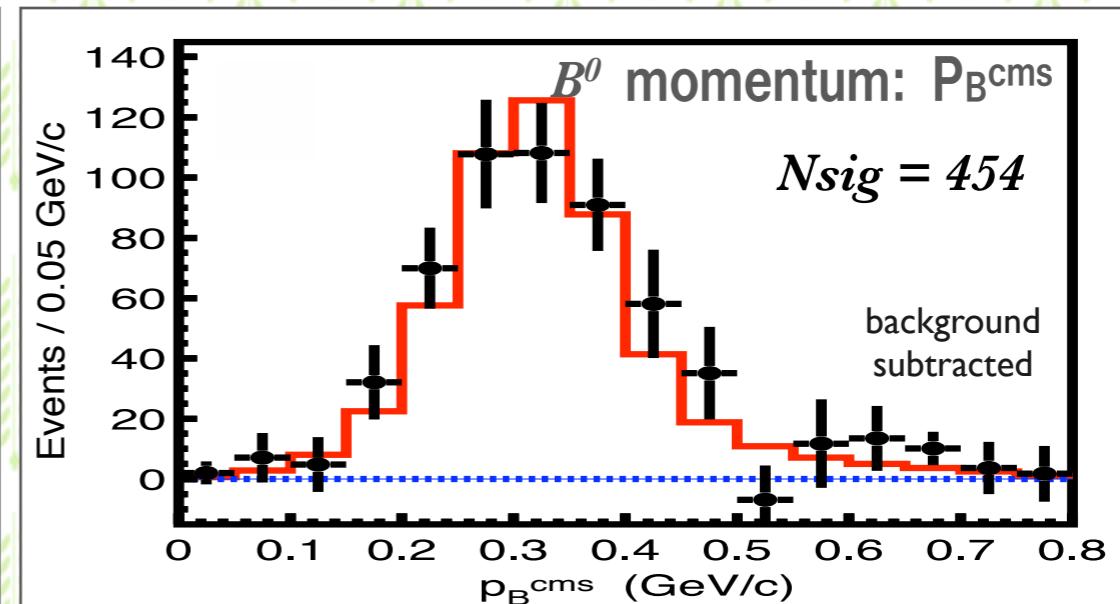
535 million $\bar{B}^0 B^0$ sample

$B^0 \rightarrow \eta' K^0_S$ CP odd ($\xi_f = -1$)

$B^0 \rightarrow \eta' K^0_L$ CP even ($\xi_f = +1$)



$$A = -0.030 \pm 0.072$$



$$A = +0.088 + 0.161 / -0.160$$

First observation of tCPV in $b \rightarrow s$ transition

Δt figures
are BG
subtracted

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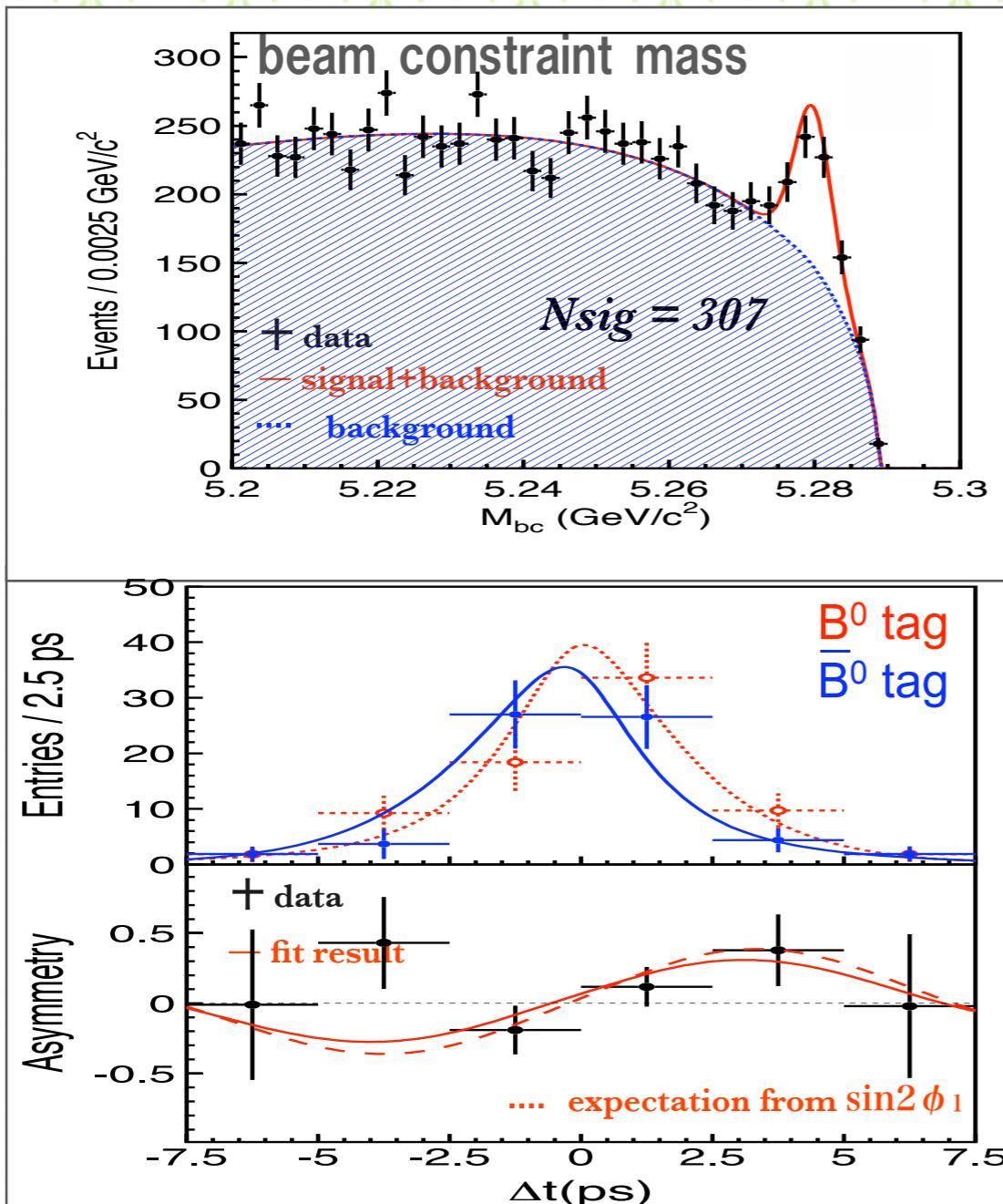


$B^0 \rightarrow \phi K^0$ results

535 million $\bar{B}^0 B^0$ sample

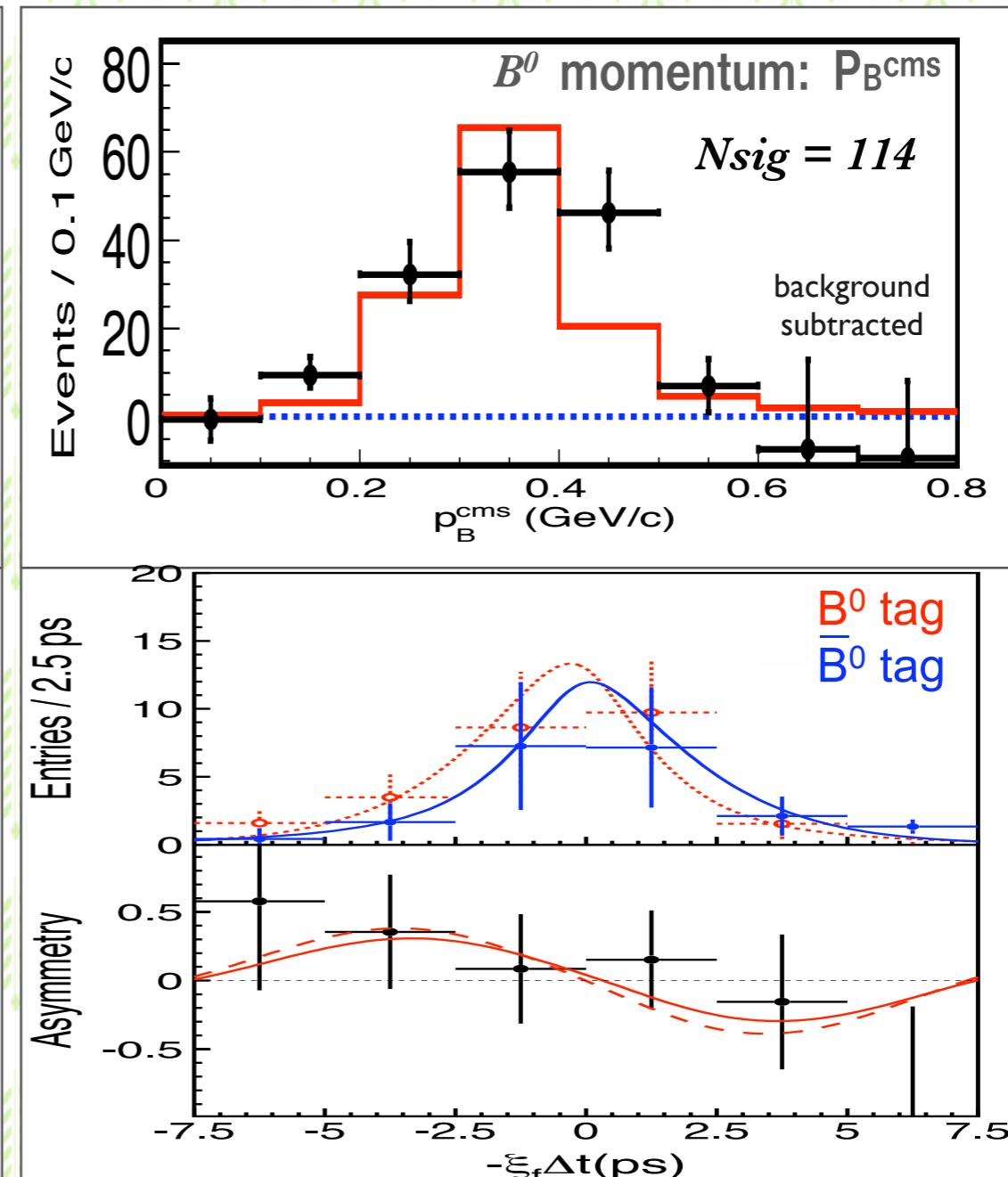
$B^0 \rightarrow \phi K^0_S$ CP odd ($\xi_f = -1$)

$B^0 \rightarrow \phi K^0_L$ CP even ($\xi_f = +1$)



$$\sin 2\phi_1^{\text{eff}} = 0.504 + 0.222 - 0.233$$

$$A = +0.110 + 0.159 - 0.160$$



$$\sin 2\phi_1^{\text{eff}} = +0.462 + 0.546 - 0.558$$

$$A = -0.145 + 0.385 - 0.373$$

Δt figures
are BG
subtracted



$B^0 \rightarrow \omega K_S^0 / K_S^0 \pi^0 / f_0 K_S^0$ results

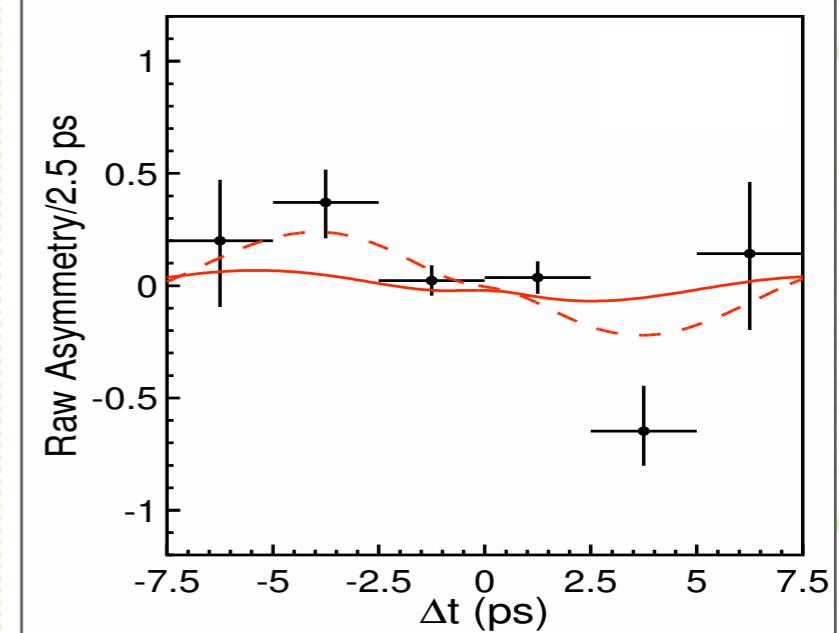
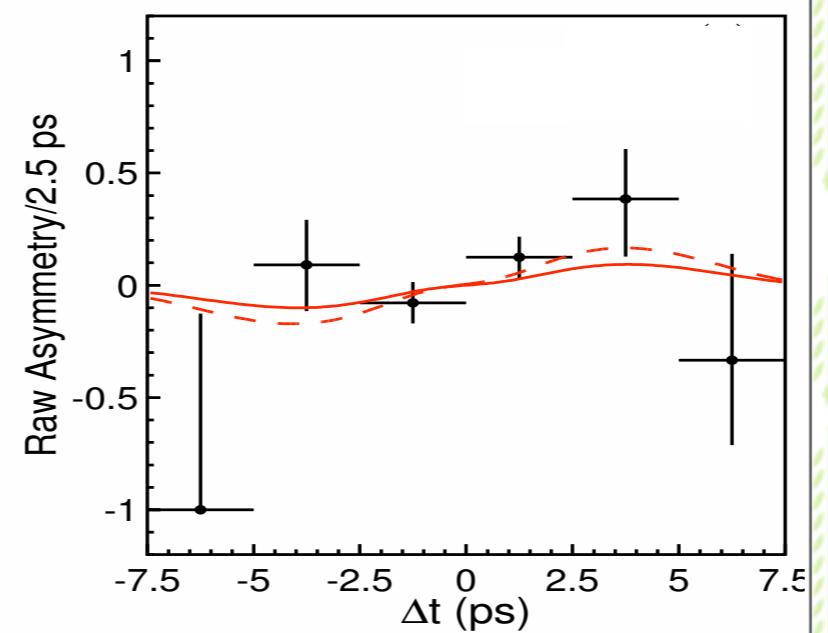
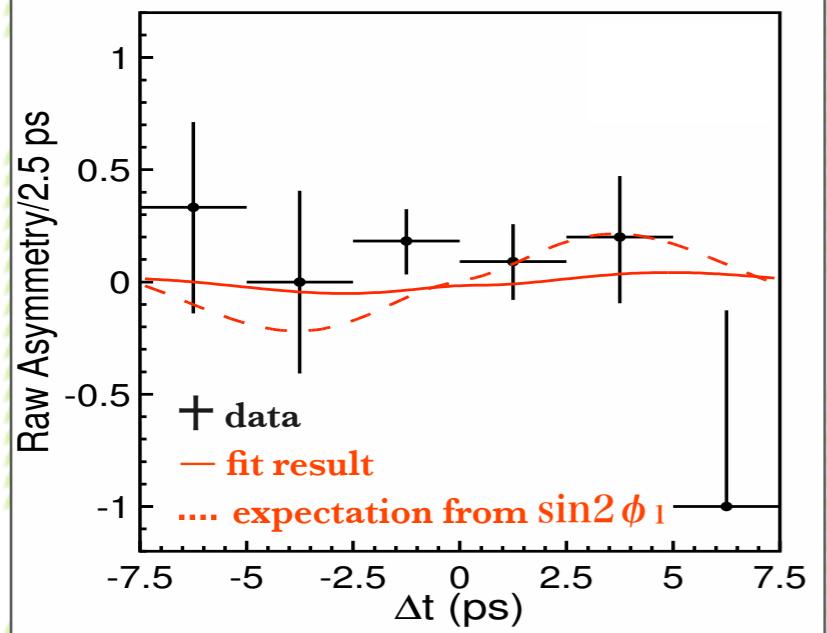
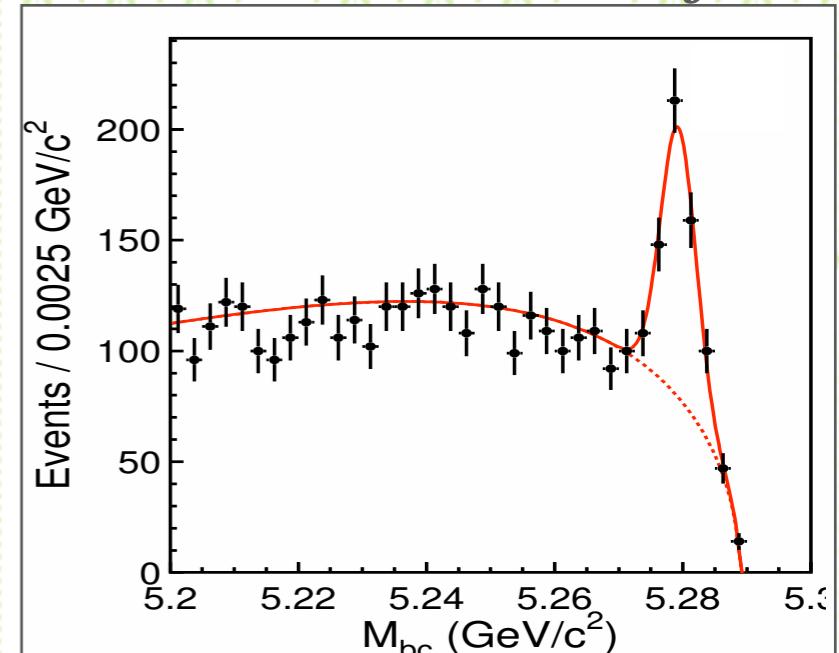
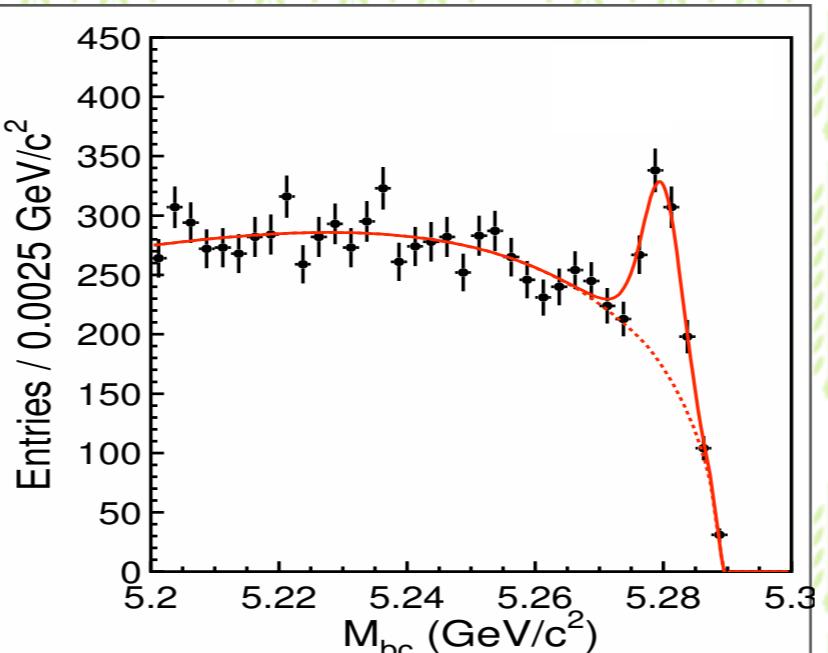
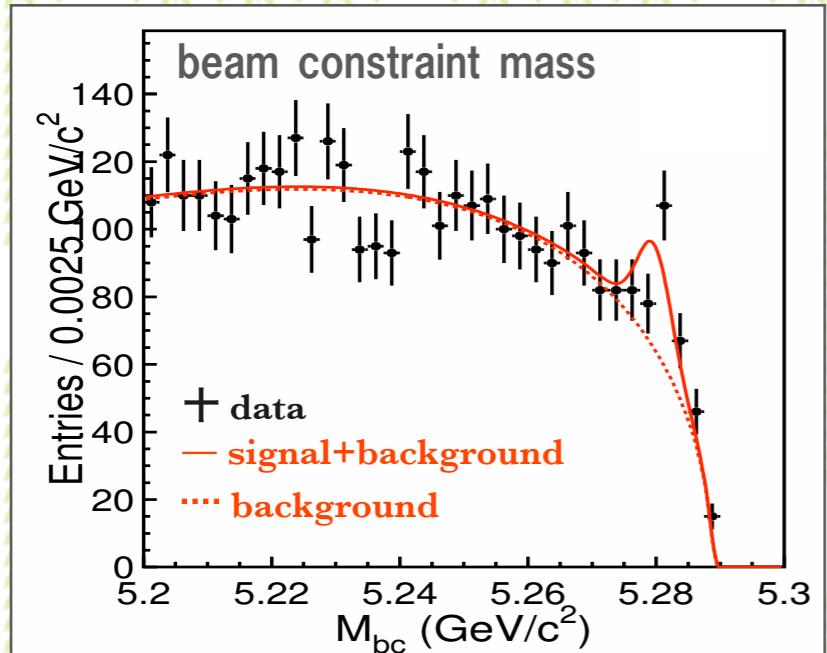
535 million $\bar{B}^0 B^0$ sample

CP even ($\xi_f = +1$)

$B^0 \rightarrow f_0 K_S^0$

CP odd ($\xi_f = -1$)

$B^0 \rightarrow \omega K_S^0$



$$\sin 2 \phi_1^{\text{eff}} = 0.11 \pm 0.46 \pm 0.06$$

$$A = -0.09 \pm 0.29 \pm 0.06$$

$$\sin 2 \phi_1^{\text{eff}} = 0.33 \pm 0.35 \pm 0.08$$

$$A = -0.05 \pm 0.14 \pm 0.05$$

$$\sin 2 \phi_1^{\text{eff}} = 0.18 \pm 0.23 \pm 0.11$$

$$A = -0.15 \pm 0.15 \pm 0.07 \text{ SUSY07}$$

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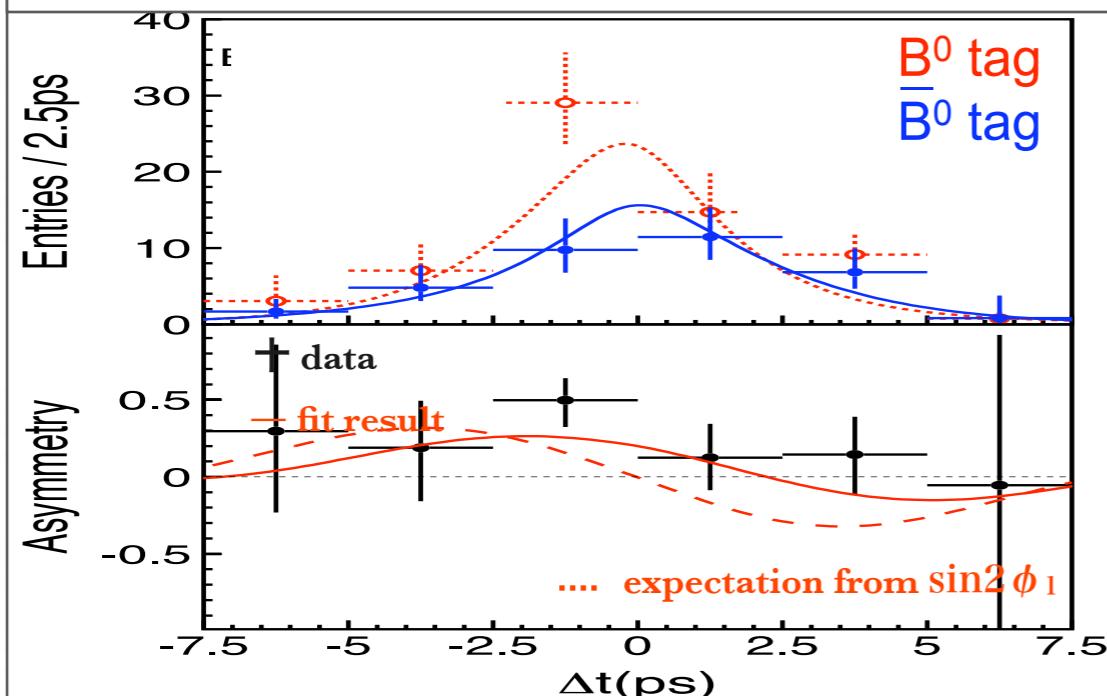
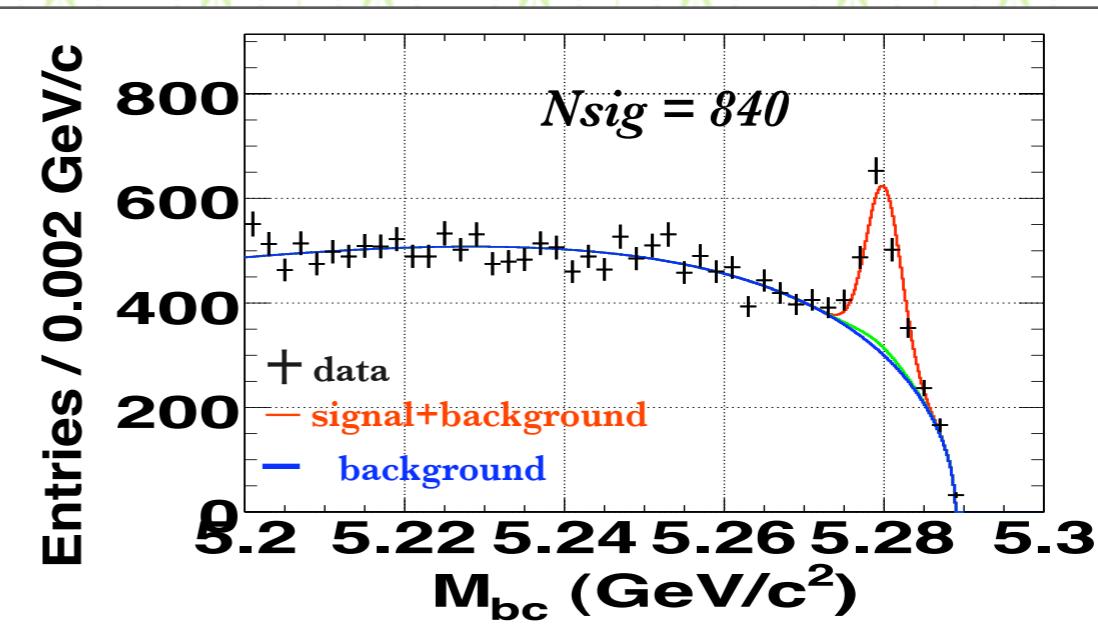
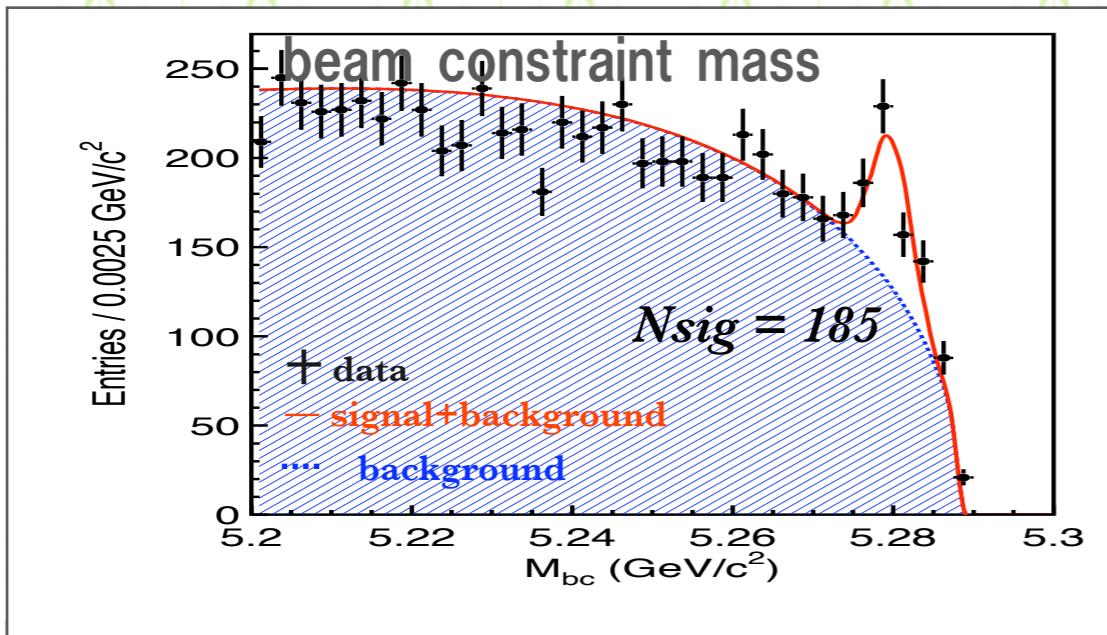
$B^0 \rightarrow KKK$ results

BG subtracted

535 million $\bar{B}^0 B^0$ sample

$B^0 \rightarrow K^0_S K^0_S K^0_S$ CP even ($\xi_f = +1$)

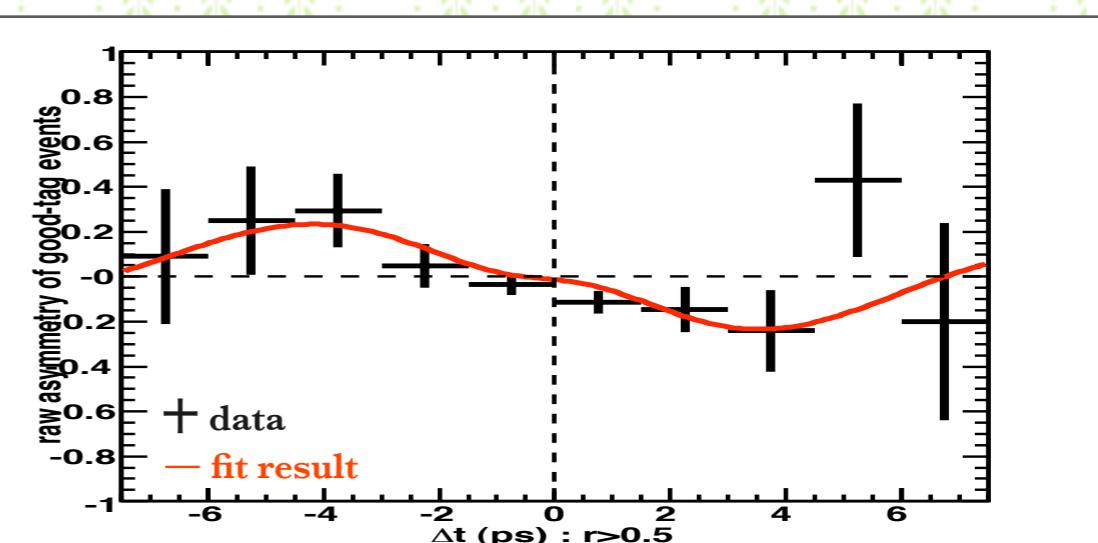
$B^0 \rightarrow K^+ K^- K^0_S$



$$\sin^2 \phi_1^{\text{eff}} = 0.30 \pm 0.32 \pm 0.08$$

$$A = 0.32 \pm 0.20 \pm 0.07$$

“mixing” of CP even and odd ($\xi_f = 2f_{+-1}$)
CP even fraction: $f_+ = 0.86 \pm 0.18 \pm 0.09$ (iso-spin relation)



$$\sin^2 \phi_1^{\text{eff}} = 0.68 \pm 0.15 \pm 0.03 + 0.21/-0.13$$

$$A = 0.09 \pm 0.10 \pm 0.05$$

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Combined results $b \rightarrow s$ penguin with 535M $B^0 \bar{B}^0$

	$\sin^2 \phi_1^{(\text{eff})}$	A
$B^0 \rightarrow J/\psi K^0$	$0.64 \pm 0.03 \pm 0.02$	$0.02 \pm 0.02 \pm 0.01$
$B^0 \rightarrow \eta' K^0$	$0.64 \pm 0.10 \pm 0.04$	$-0.01 \pm 0.07 \pm 0.05$
$B^0 \rightarrow \phi K^0$	$0.50 \pm 0.21 \pm 0.06$	$0.30 \pm 0.32 \pm 0.08$
$B^0 \rightarrow K_S^0 K_S^0 K_S^0$	$0.30 \pm 0.32 \pm 0.08$	$0.07 \pm 0.15 \pm 0.05$
Published : PRL 98, 031802 (2007)		
$B^0 \rightarrow \omega K_S^0$	$0.11 \pm 0.46 \pm 0.06$	$-0.09 \pm 0.29 \pm 0.06$
$B^0 \rightarrow f_0 K^0$	$0.18 \pm 0.23 \pm 0.11$	$-0.15 \pm 0.15 \pm 0.07$
$B^0 \rightarrow K_S^0 \pi^0$	$0.33 \pm 0.35 \pm 0.08$	$-0.05 \pm 0.14 \pm 0.05$
$B^0 \rightarrow K^+ K^- K_S^0$	$0.68 \pm 0.15 \pm 0.03$ $+0.21/-0.13$	$0.09 \pm 0.10 \pm 0.05$

$\Delta S = \sin^2 \phi_1^{\text{eff}} - \sin^2 \phi_1^{b \rightarrow ccs}$
within the SM

$B^0 \rightarrow \eta' K^0$	0.01 ± 0.01
$B^0 \rightarrow \phi K^0$	0.02 ± 0.01
$B^0 \rightarrow \omega K_S^0$	0.13 ± 0.08
$B^0 \rightarrow \rho^0 K_S^0$	$-0.08^{+0.08}_{-0.12}$
$B^0 \rightarrow K_S^0 \pi^0$	$0.07^{+0.05}_{-0.04}$
$B^0 \rightarrow K^+ K^- K_S^0$	$0.03^{+0.02}_{-0.03}$
$B^0 \rightarrow K_S^0 K_S^0 K_S^0$	$0.02^{+0.02}_{-0.03}$
$B^0 \rightarrow K_S^0 \pi^0 \pi^0$	$0.03^{+0.02}_{-0.03}$

Posted : hep-ex/0609006

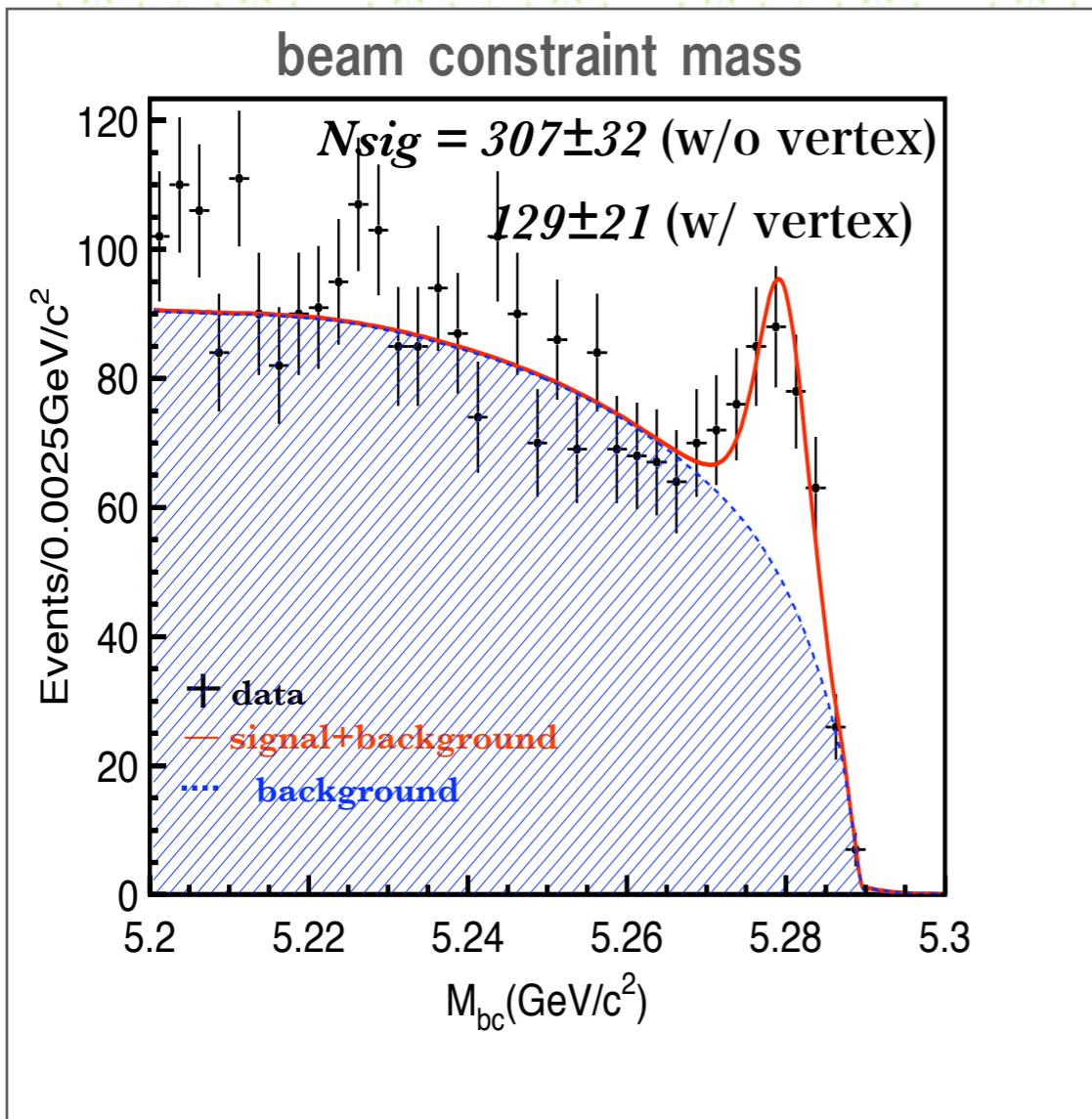


$B^0 \rightarrow K^0_S \pi^0 \pi^0$ results

Preliminary

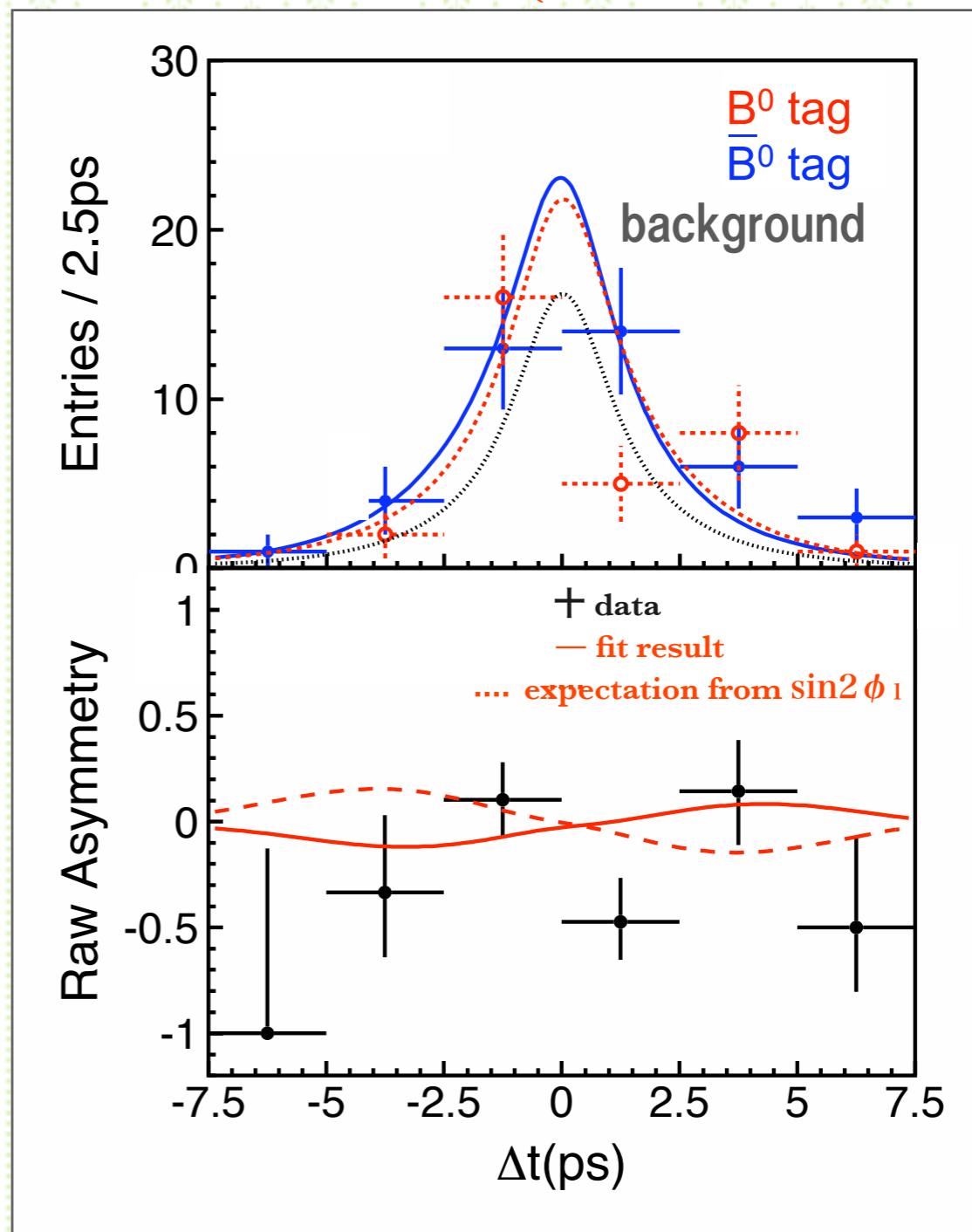
660 million $B^0 \bar{B}^0$ sample
(almost full data set)

CP even ($\xi_f = +1$)



$$\sin^2 \phi_1^{\text{eff}} = -0.43 \pm 0.49 \pm 0.09$$

$$A = -0.17 \pm 0.24 \pm 0.05$$



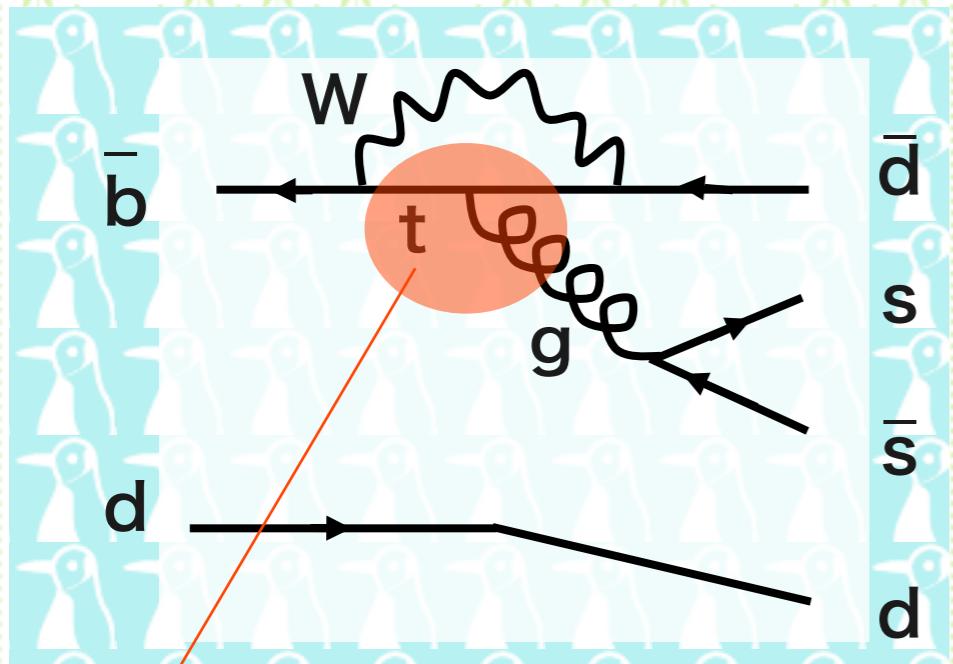


Another penguin: $B^0 \rightarrow K^0_S K^0_S$ results

Preliminary

660 million $B^0 \bar{B}^0$ sample
(almost full data set)

— $b \rightarrow d q \bar{q}$ penguin dominated mode



Weak phase cancels mixing: $S=0$
→ good probe for new physics

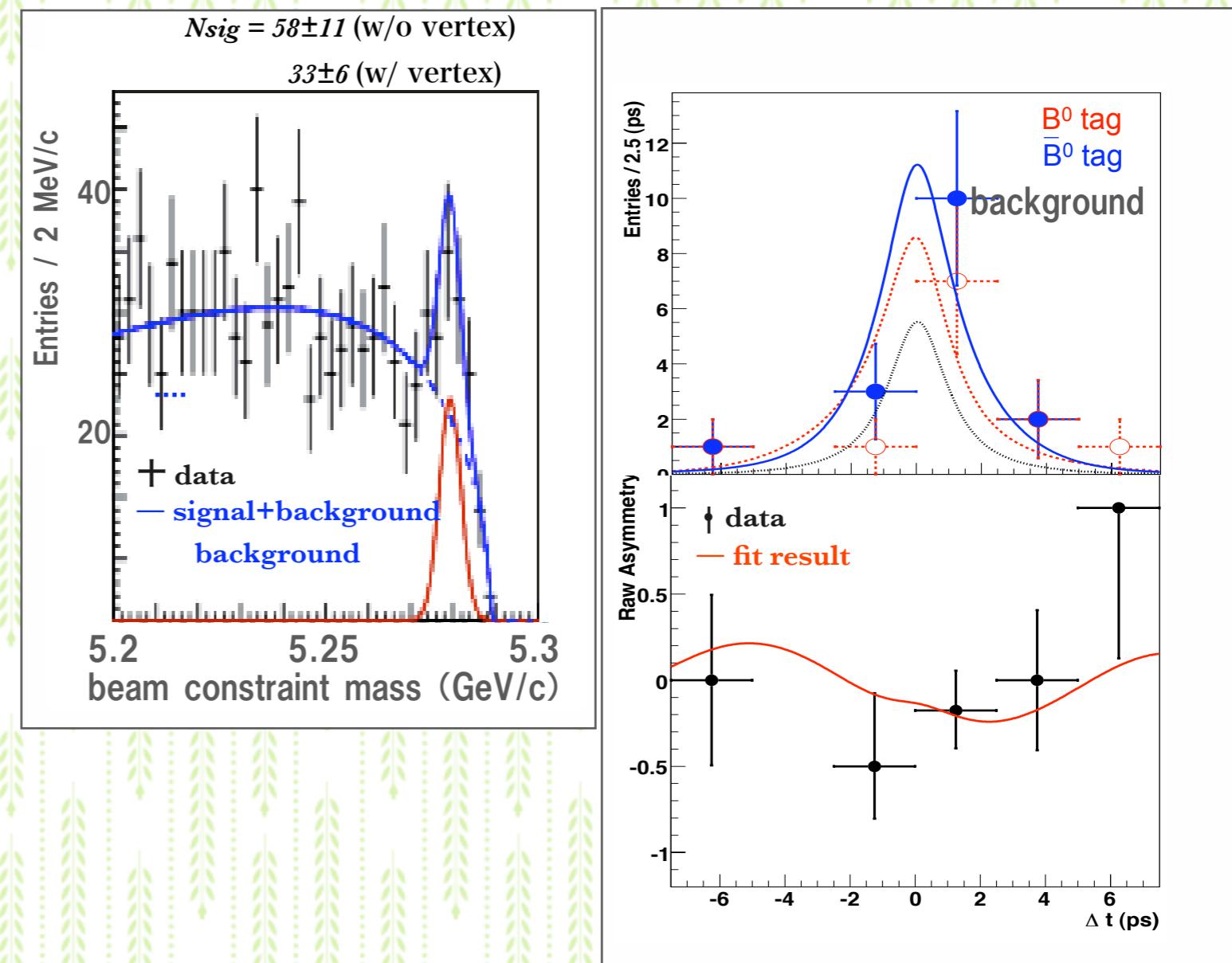
Slight shift is predicted as

$$0.02 < S < 0.13$$

$$0.15 < A < 0.17$$

(contribution from u-/c-penguin)

R.Fleischer and S.Recksiegel,
Eur. Phys. J. C38: 251-259, 2004



$$S = -0.38 \pm 0.77 \pm 0.08$$

$$A = -0.38 \pm 0.38 \pm 0.05$$

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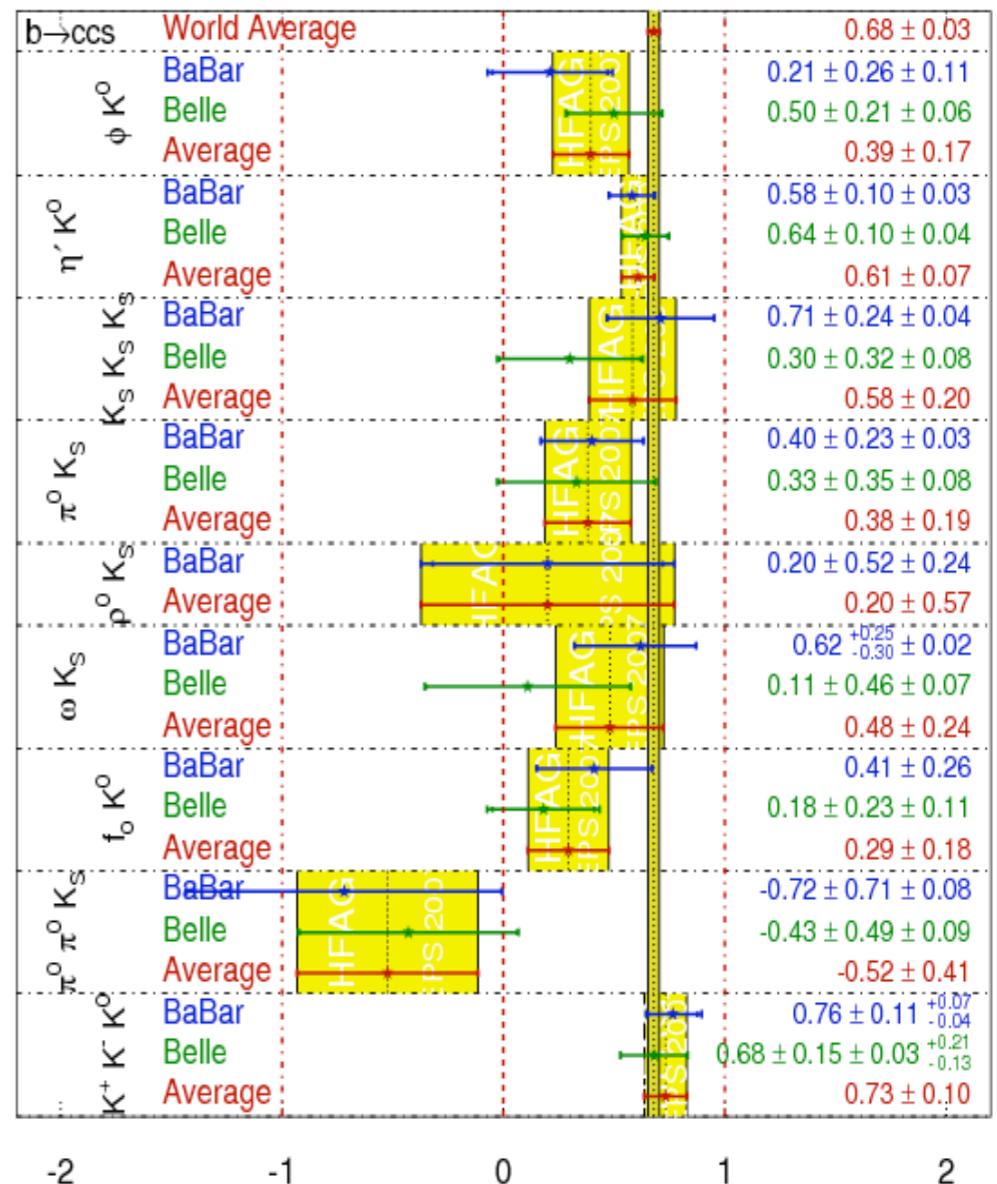
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Summary

- $\sin 2\phi_1$ from penguin-dominant b decay
 $(\sin 2\phi_1^{\text{eff}})$ is sensitive to new physics.
- $\sin 2\phi_1^{\text{eff}}$ from 8 $b \rightarrow sq\bar{q}$ and 1 $b \rightarrow dq\bar{q}$
have been measured at BELLE in past year.
- All are consistent with SM prediction
within the error.
- There are indications of negative ΔS shift.
(2.1 σ deviation between $b \rightarrow c\bar{s}s\bar{s}$ and $b \rightarrow s\bar{q}\bar{q}$)

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}}) \quad \text{HFAG} \quad \text{EPS 2007} \quad \text{PRELIMINARY}$$





Backup

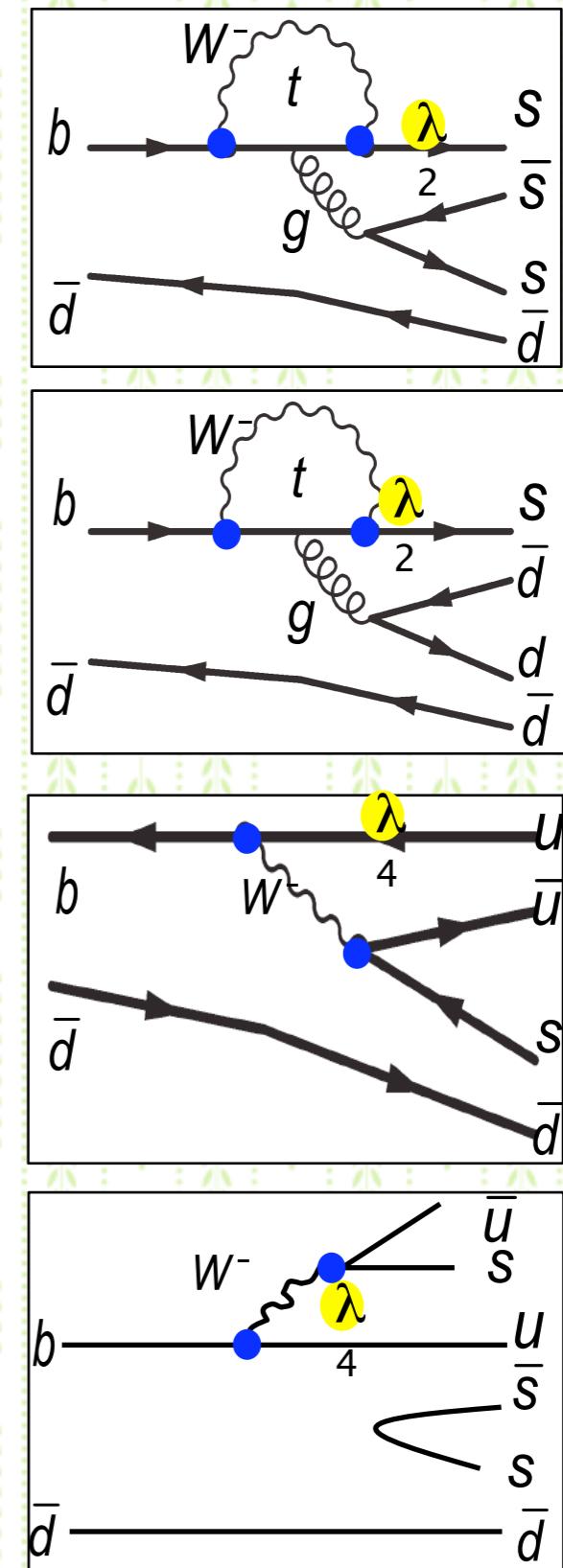
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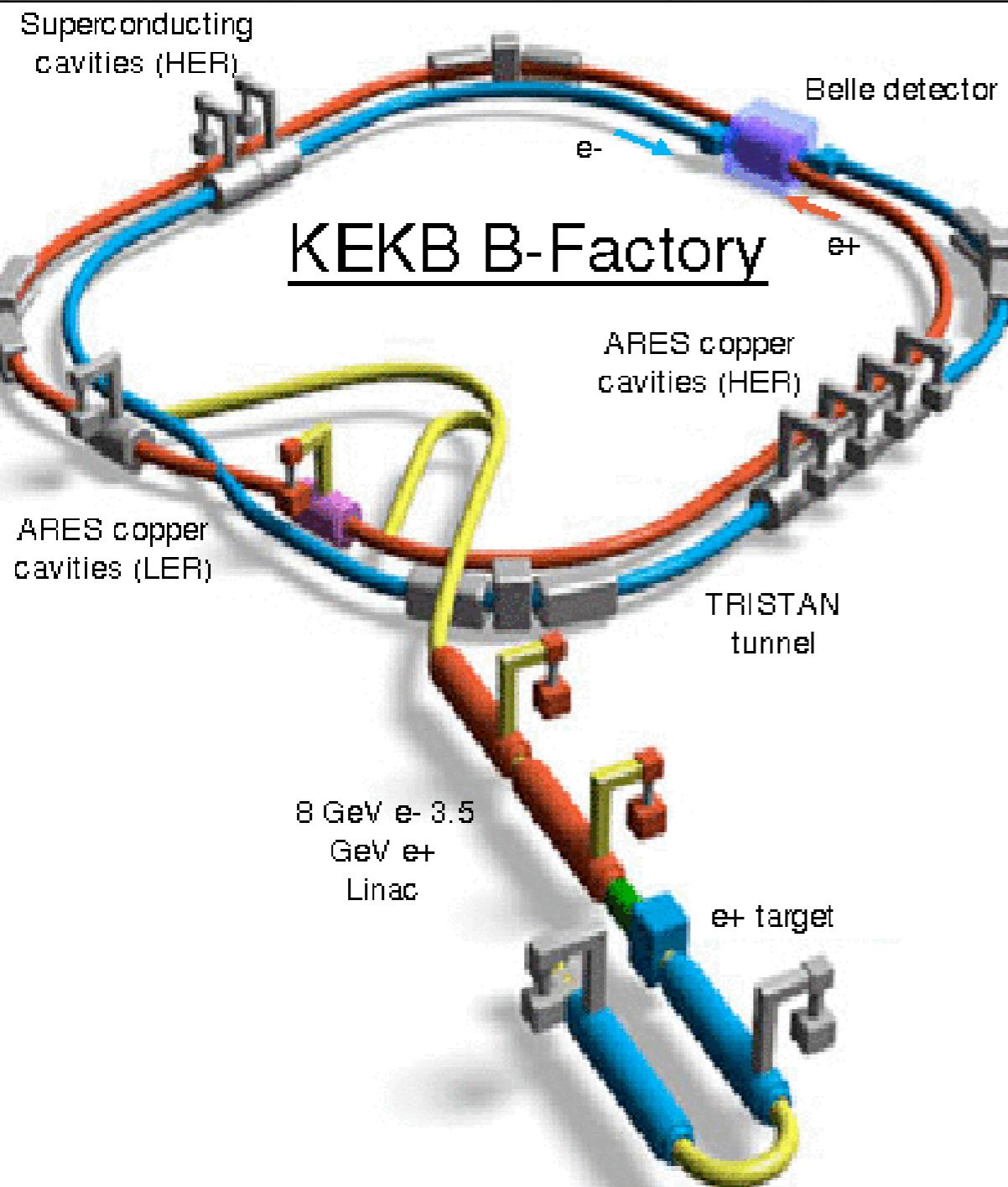


- It is essential to estimate possible deviation from $\sin^2\varphi_1$ within the SM to claim new physics.
- $b \rightarrow u$ Tree contamination

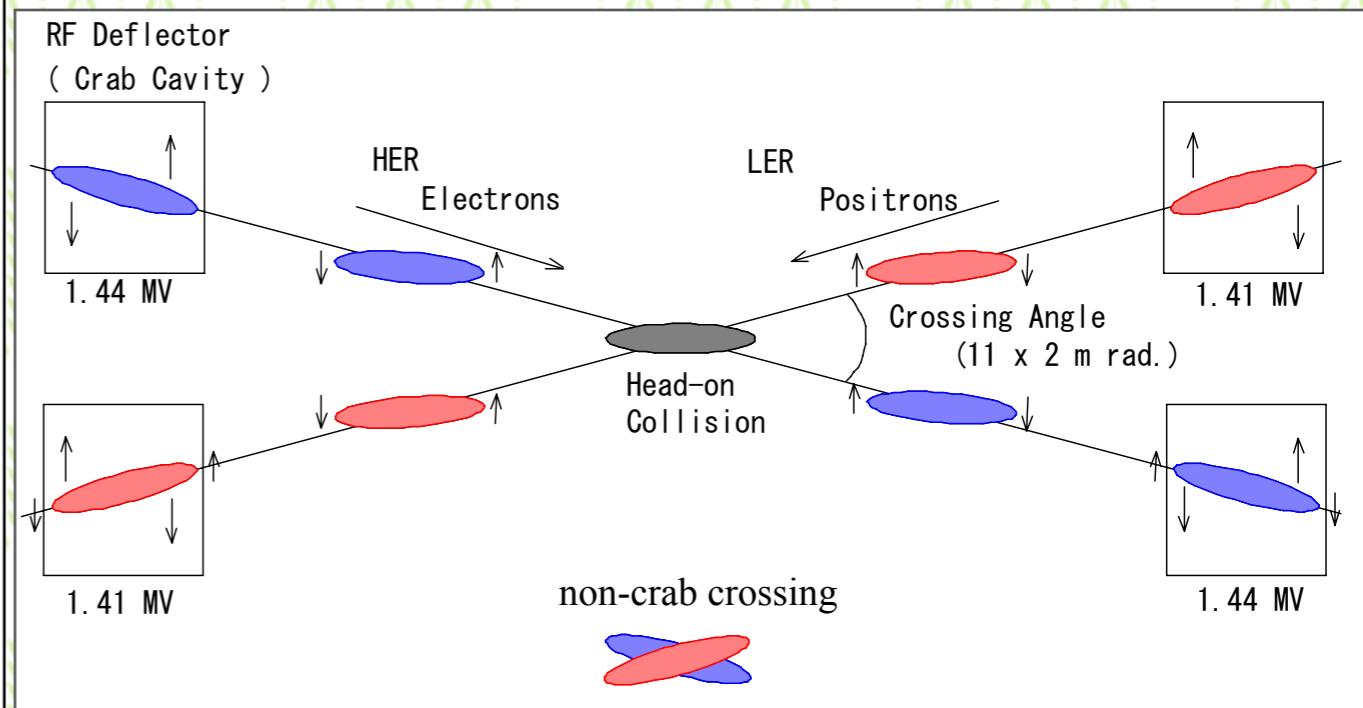
mode	ξ_{CP}	P	P'	T	T'
ϕKs	-1	O	x	x	x
$KsKsKs$	+1	O	O	x	x
K^+K^-Ks	$\sim +1$	O	O	O	O
$\eta' Ks$	-1	O	O	O	x
$f_0 Ks$	+1	O	O	O	x
ωKs	-1	x	O	O	x
$\pi^0 Ks$	-1	x	O	O	x



- Final state rescattering



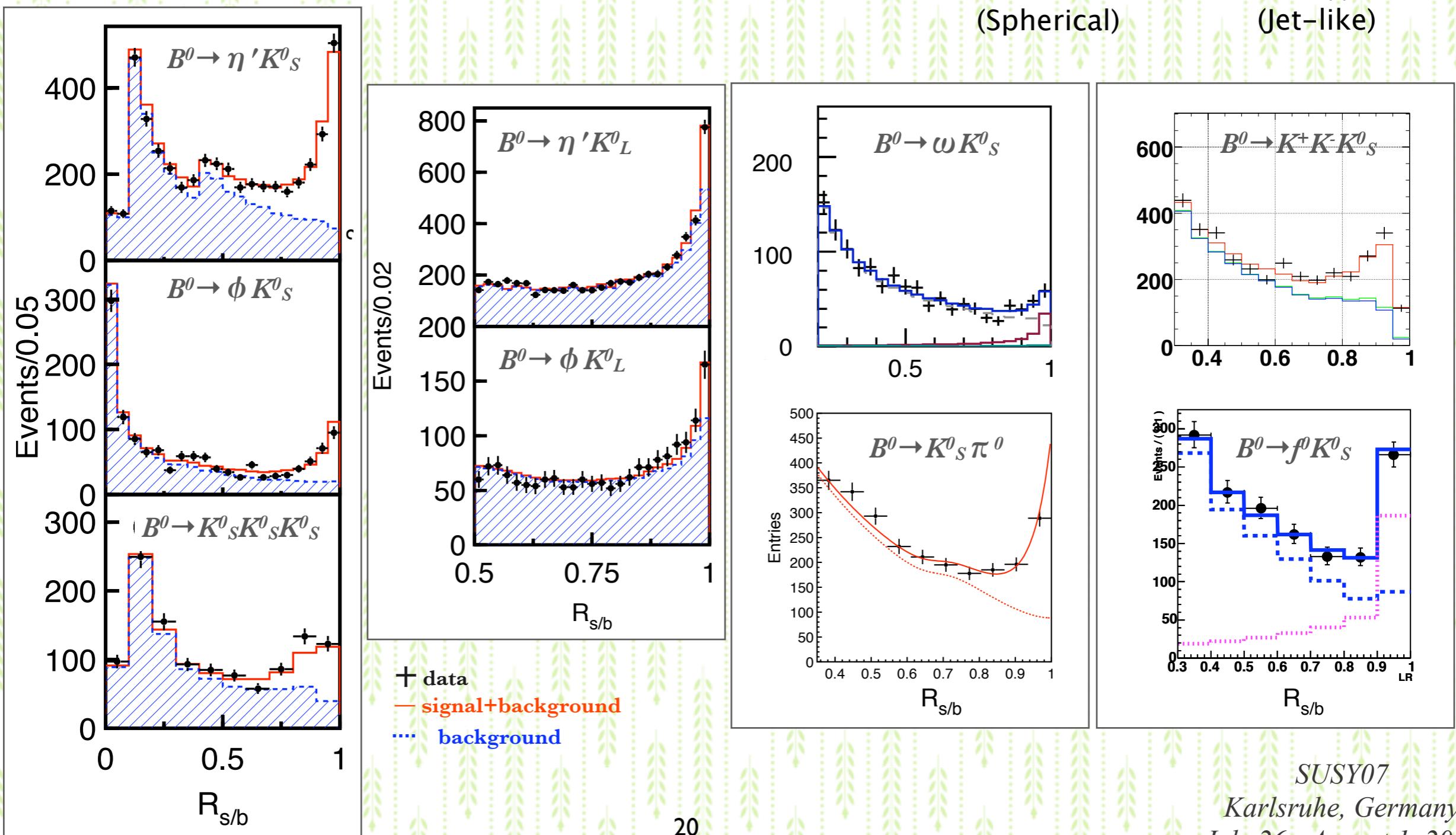
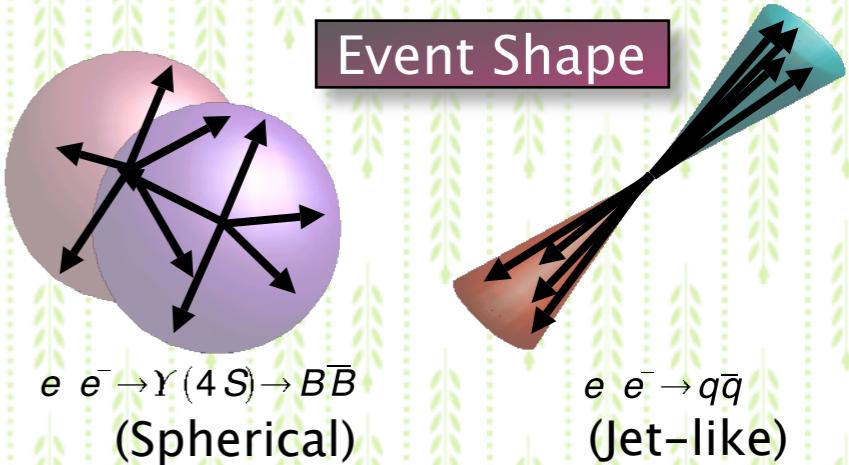
peak luminosity:
 $1.7118 \times 10^{34} /cm^2/sec$ (Nov. 15, 2006)
integrated luminosity:
710.254 /fb (- Dec. 2006)
535 million $B^0\bar{B}^0$ sample is used for this presentation





Continuum background suppression

$R_{s/b}$: likelihood ratio constructed from event topology variables





systematics

$B^0 \rightarrow J/\psi K^0$

	dS	dA
Vertexing	0.012	0.009
Flavor tagging	0.004	0.003
Resolution function	0.006	0.001
Physics parameters	0.001	0.001
Fit bias	0.007	0.004
K_S fraction	0.003	0.001
K_L fraction	0.005	0.002
Background Δt	0.001	0.001
Tag side interference	0.001	0.009
Total	0.017	0.014



systematics

	ϕK^0	$\eta' K^0$	$K_S^0 K_S^0 K_S^0$
Vertex reconstruction	0.01	0.01	0.01
Flavor tagging	0.01	< 0.01	0.01
Resolution function	0.04	0.04	0.05
Physics parameters	< 0.01	< 0.01	< 0.01
Possible fit bias	0.01	0.01	0.02
Background fraction	0.04	0.02	0.06
Background Δt shape	0.01	< 0.01	0.01
Tag-side interference	0.01	< 0.01	< 0.01
Total	0.06	0.04	0.08

	ϕK^0	$\eta' K^0$	$K_S^0 K_S^0 K_S^0$
Vertex reconstruction	0.02	0.02	0.02
Flavor tagging	0.01	0.01	0.01
Resolution function	0.01	0.02	0.02
Physics parameters	< 0.01	0.01	< 0.01
Possible fit bias	0.01	0.01	0.01
Background fraction	0.03	0.02	0.05
Background Δt shape	0.01	< 0.01	0.01
Tag-side interference	0.03	0.02	0.04
Total	0.05	0.05	0.07

dS

dA

SUSY07

Karlsruhe, Germany
July 26 - August 1, 2007



systematics

$B^0 \rightarrow \omega K^0_S$

	$\sigma^+(S)$	$\sigma^-(S)$	$\sigma^+(A)$	$\sigma^-(A)$
Vertexing	± 0.0127		± 0.0211	
- dt_cutoff_var	0.0003	0.0001	0.0001	0.0000
- $ dr $	0.0029	0.0000	0.0010	0.0030
- $ sz $	0.0017	0.0005	0.0010	0.0009
- IPprofile	0.0050	0.0072	0.0000	0.0011
- scale error	0.0033	0.0033	0.0060	0.0060
- ξ cut	0.0022	0.0064	0.0021	0.0004
- dz bias	0.0050	0.0050	0.0195	0.0195
- alignment	0.0056	0.0056	0.0040	0.0040
- Total	0.0104	0.0127	0.0209	0.0211
Flavor tagging	± 0.0154		± 0.0055	
Resol. func.	± 0.0521		± 0.0237	
Possible Fit bias	± 0.0110		± 0.0140	
Background fraction	± 0.0411		± 0.0241	
Background Δt shape	± 0.0059		± 0.0053	
Physics Parameters	± 0.0052		± 0.0032	
TSI	± 0.0010		± 0.0440	
Total	± 0.07		± 0.06	

$B^0 \rightarrow K^0_S \pi^0$

	$\sigma^+(S)$	$\sigma^-(S)$	$\sigma^+(A)$	$\sigma^-(A)$
Vertexing	± 0.010		± 0.020	
- dt_cutoff_var	0.0002	0.0000	0.0002	0.0000
- $ dr $	0.0029	0.0000	0.0010	0.0030
- $ sz $	0.0017	0.0005	0.0010	0.0009
- IPprofile	0.0032	0.0026	0.0018	0.0000
- scale error	0.0021	0.0021	0.0008	0.0008
- ξ cut	0.0022	0.0064	0.0021	0.0000
- dz bias	0.0050	0.0050	0.0195	0.0195
- alignment	0.0056	0.0056	0.0040	0.0040
- Total	0.0093	0.0104	0.0202	0.0202
Flavor tagging	± 0.0067		± 0.0047	
Resol. func.	± 0.0656		± 0.0099	
Fit bias(MC stat error)	± 0.0085		± 0.0038	
Background fraction	± 0.0091		± 0.0011	
Background Δt shape	± 0.0455		± 0.0193	
Physics Parameters	± 0.0069		± 0.0010	
TSI	± 0.0010		± 0.0430	
Total	± 0.08		± 0.05	



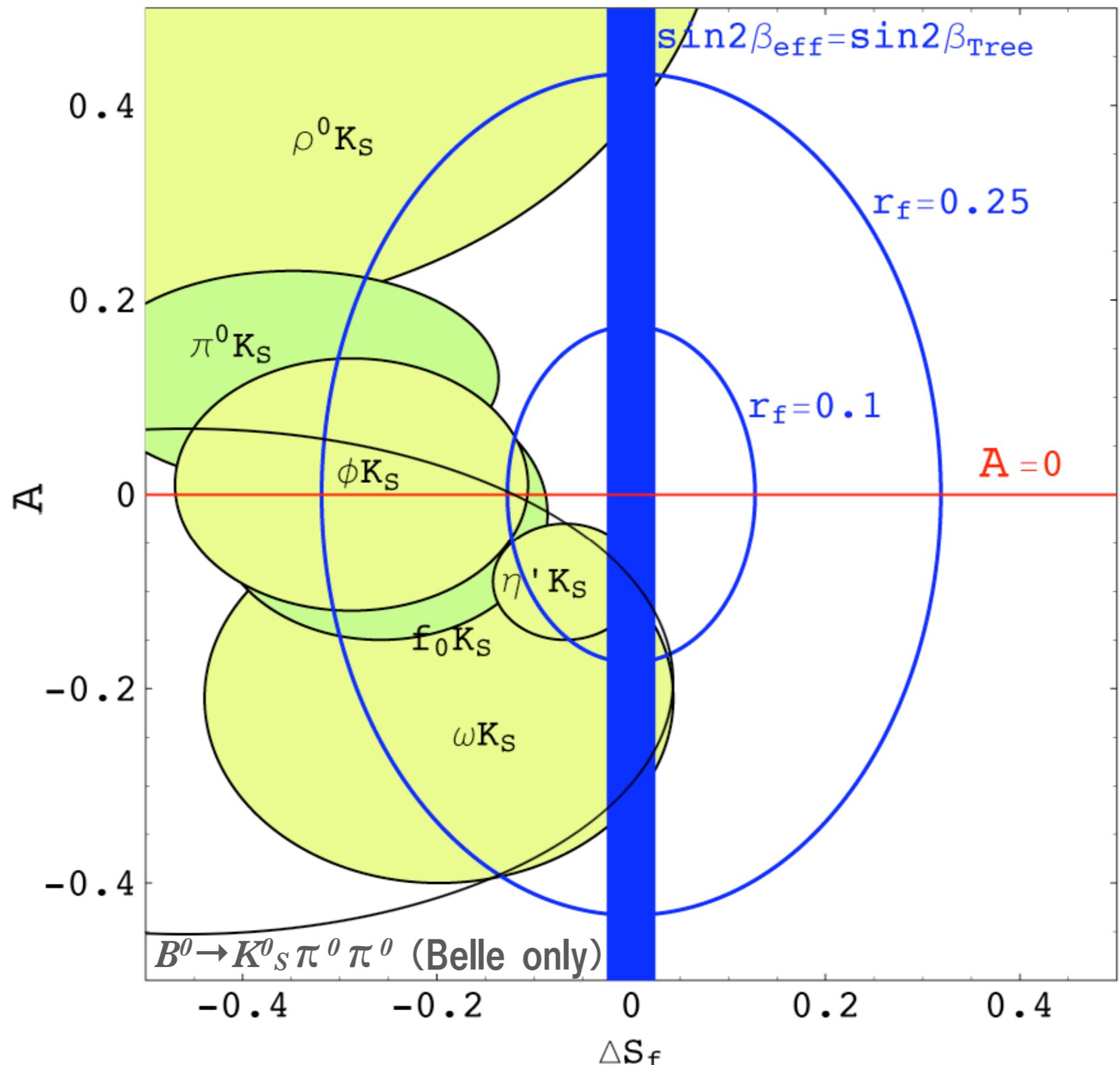
systematics

$B^0 \rightarrow K^+ K^- K^0_S$

	$\sigma^+(S)$	$\sigma^-(S)$	$\sigma^+(A)$	$\sigma^-(A)$
Vertexing	± 0.0127		± 0.0211	
Flavor tagging	± 0.0040		± 0.0040	
Resol. func.	± 0.080		± 0.050	
Fit bias(MC stat error)	± 0.0110		± 0.0010	
Background fraction	± 0.0130		± 0.0070	
Background Δt shape	± 0.0040		± 0.0010	
Physics Parameters	± 0.0020		± 0.0010	
TSI	± 0.0010		± 0.0320	
Total	± 0.03		± 0.05	

$B^0 \rightarrow f_0 K^0_S$

	$\sigma^+(S)$	$\sigma^-(S)$	$\sigma^+(A)$	$\sigma^-(A)$
Vertexing	± 0.0127		± 0.0211	
Flavor tagging	± 0.0054		± 0.0062	
Resolution function	± 0.0224		± 0.0083	
Fit bias (interference)	± 0.0620		± 0.0212	
Background fraction	± 0.0366		± 0.0292	
Background Δt shape	± 0.0851		± 0.0396	
Physics Parameters	± 0.0022		± 0.0021	
TSI	± 0.0010		± 0.0430	
Total	± 0.1145		± 0.0726	

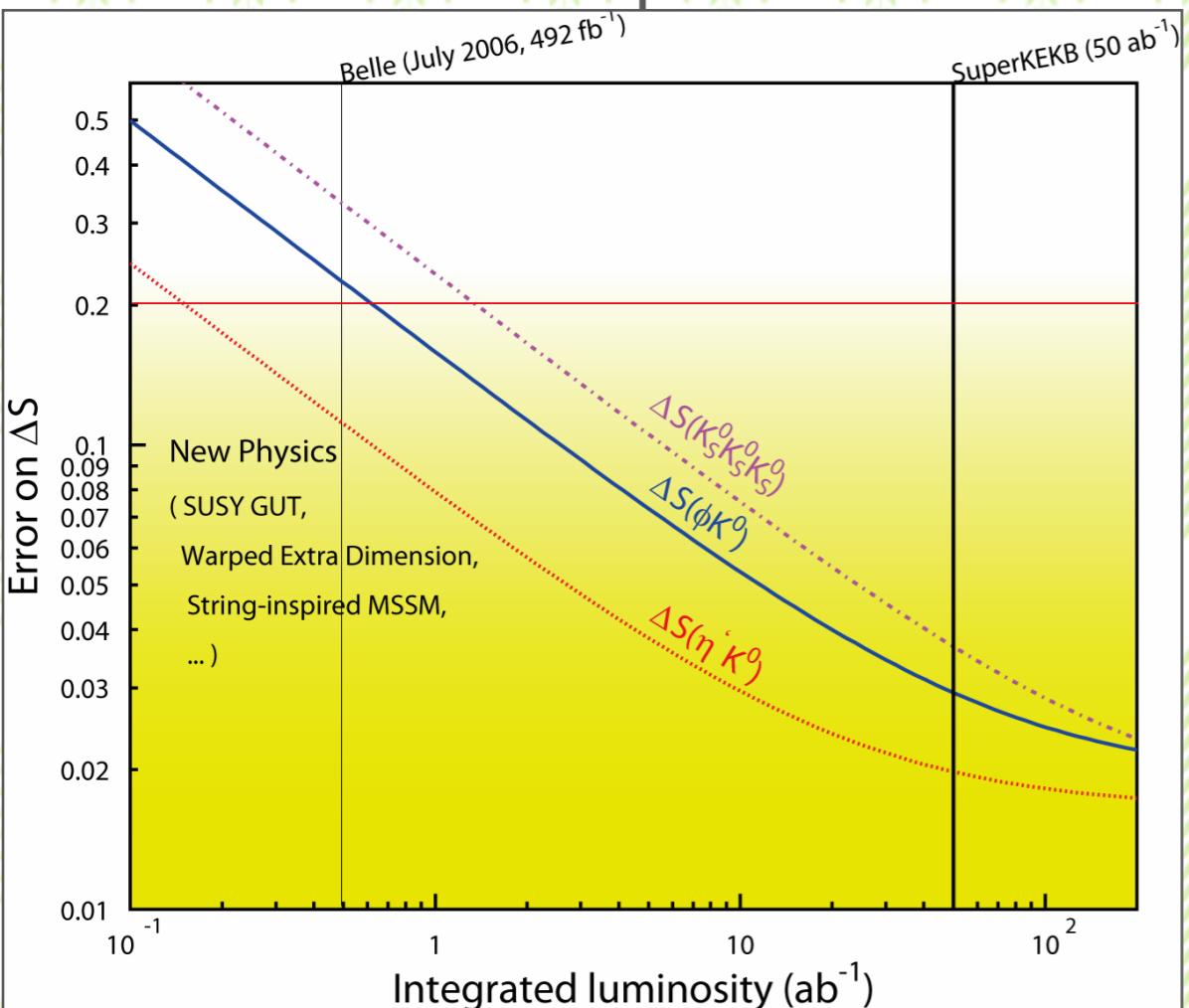




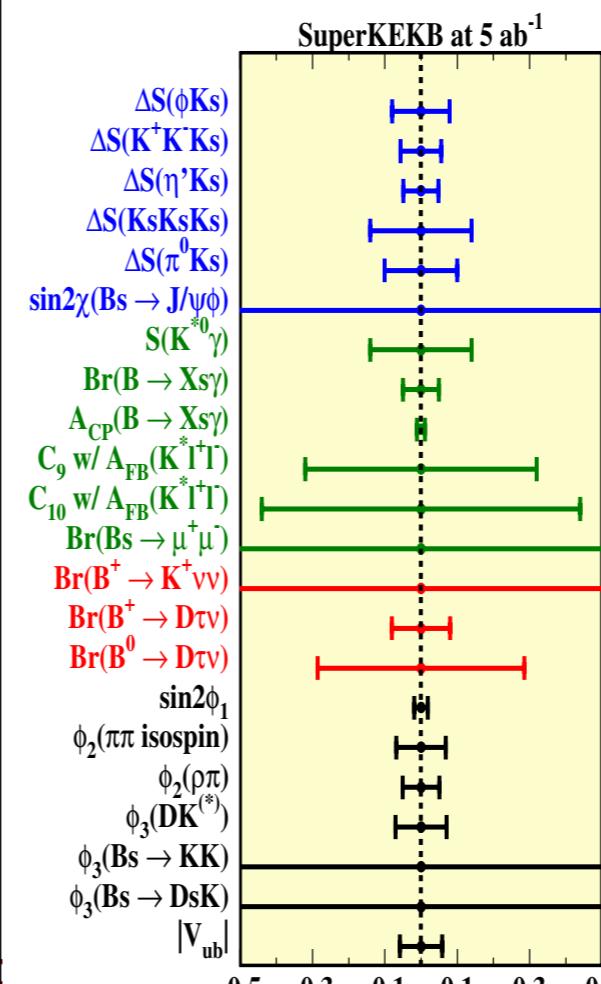
year	Number of BB (Belle+BABAR)	$\sin^2 \phi_1^{\text{eff}}$	$\sin^2 \phi_1$
2004	(275+227)M	0.41 ± 0.07	0.73 ± 0.04
2005	(386+230)M	0.50 ± 0.06	0.69 ± 0.03
2006	(535+347)M	0.53 ± 0.05	0.67 ± 0.03
2007	(660+383)M	0.56 ± 0.05	0.68 ± 0.03

hep-ex/0406071

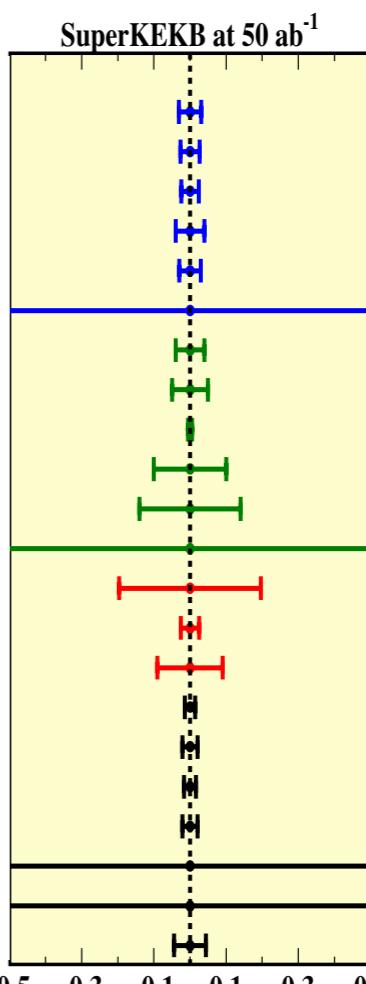
M.Hazumi presentation at WIN07



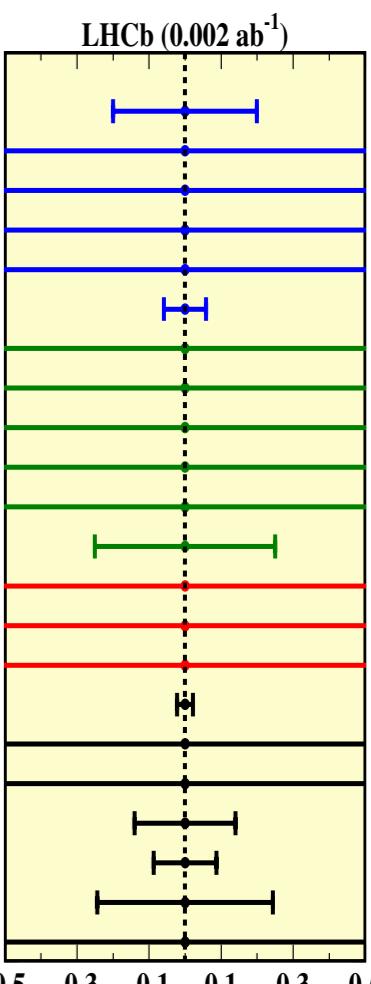
SuperKEKB 5ab⁻¹



50ab⁻¹



LHCb 2fb⁻¹



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