Review of sin2ϕ_1 and TCPV in b $\rightarrow$ s Penguins

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Outline

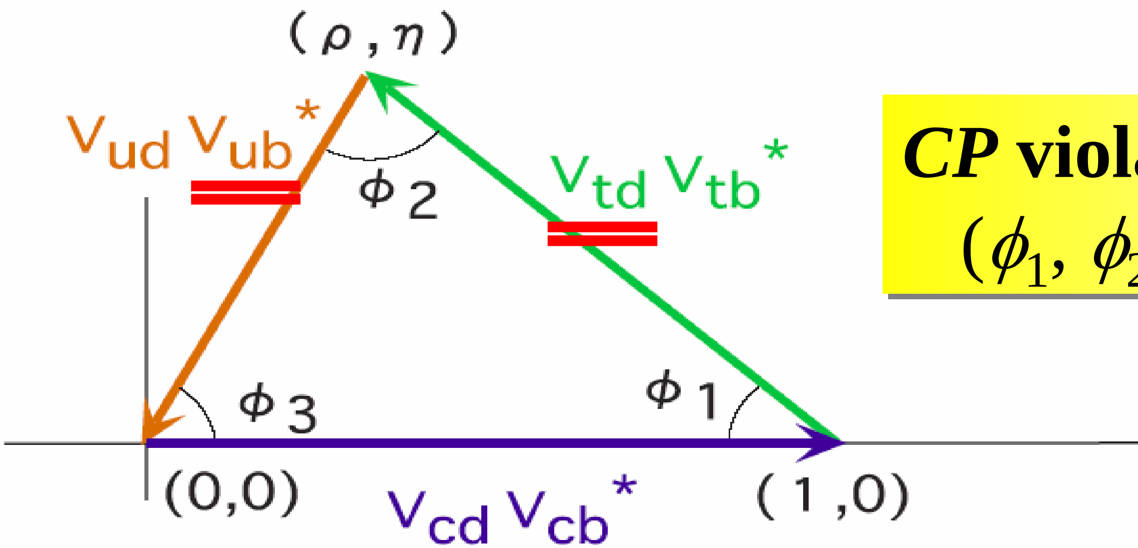
- Introduction
  - Principle of TCPV measurement
- Precise measurement of sin2ϕ_1
  - TCPV in b → $c\bar{c}s$ ($B^0 \rightarrow J/\Psi K^0$ etc.)
- TCPV in b → s penguins (Search for New Phys.)
  - b → $sq\bar{q}$
    - Deviation from sin2ϕ_1 ➔ New Physics
  - b → sγ
    - Large TCPV ➔ New Physics
- Future Prospects

Kobayashi-Maskawa Phase

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$\lambda \sim 0.22$

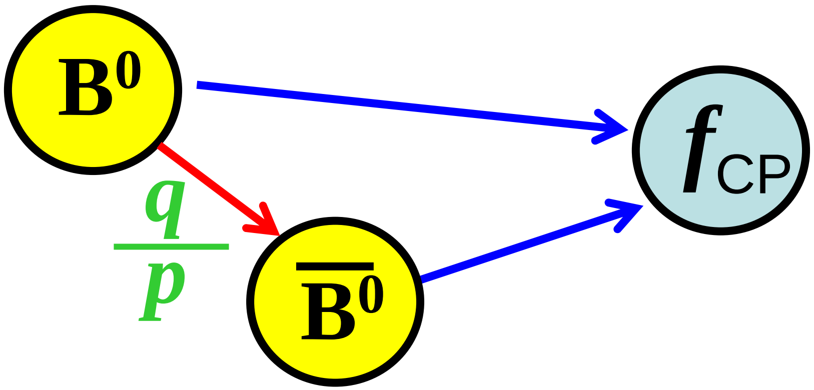
CP violation is due to a complex phase in quark mixing matrix



***CP* violation parameters**

$(\phi_1, \phi_2, \phi_3) = (\beta, \alpha, \gamma)$

Observables for TCPV



***CP* Violation** **manifests itself in** **proper-time difference (Δt) distributions** **of two *B* meson decays.**

$$A_{CP} \equiv \frac{\Gamma\left(\overline{B}_d^0(\Delta t) \to f_{CP}\right) - \Gamma\left(B_d^0(\Delta t) \to f_{CP}\right)}{\Gamma\left(\overline{B}_d^0(\Delta t) \to f_{CP}\right) + \Gamma\left(B_d^0(\Delta t) \to f_{CP}\right)}$$

$$= \mathbf{S}\,\sin(\Delta m \Delta t) + \mathbf{A}\,\cos(\Delta m \Delta t)$$

Mixing induced CPV   Direct CPV

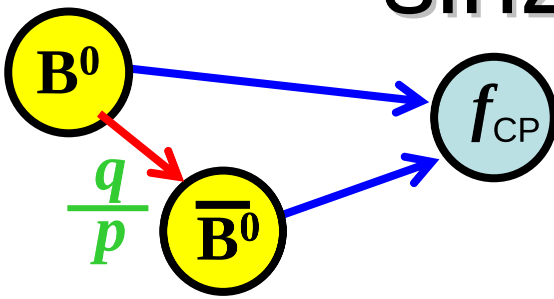
(BaBar: A = -C)

$$\mathbf{S} = \frac{2\,Im\,\lambda_{CP}}{1+|\lambda_{CP}|^2}$$

$$\mathbf{A} = \frac{|\lambda_{CP}|^2 - 1}{|\lambda_{CP}|^2 + 1}$$

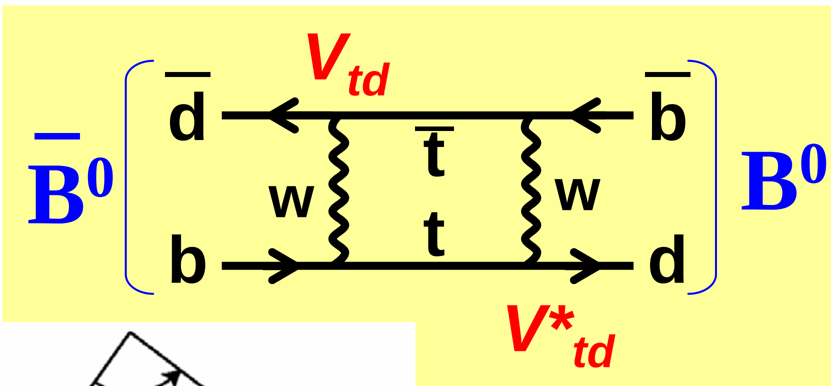
$$\lambda_{CP} = \frac{q}{p}\,\frac{\mathbf{A}(\overline{B}^0 \to f_{cp})}{\mathbf{A}(B^0 \to f_{cp})}$$

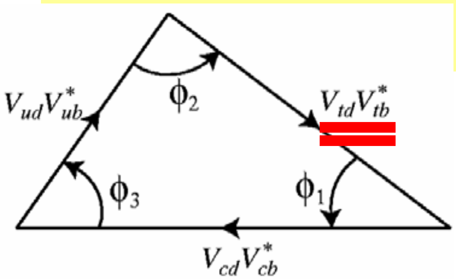
sin2ϕ_1 measurement

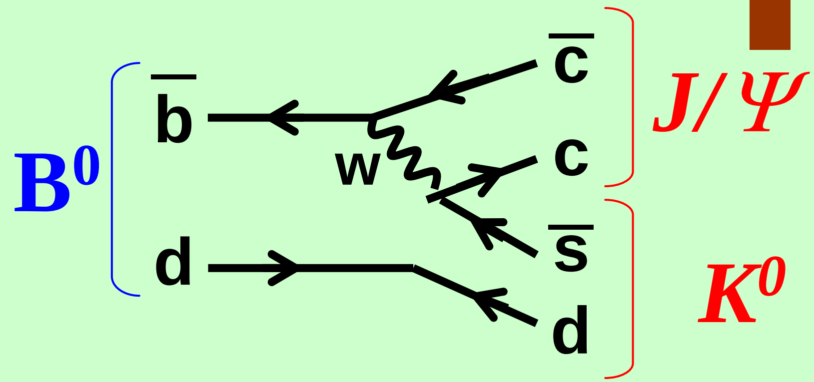


$$A_{CP} = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$$

Mixing induced CPV **Direct CPV**







$$S = -\xi_{CP} \sin 2\phi_1 , \quad A = 0$$

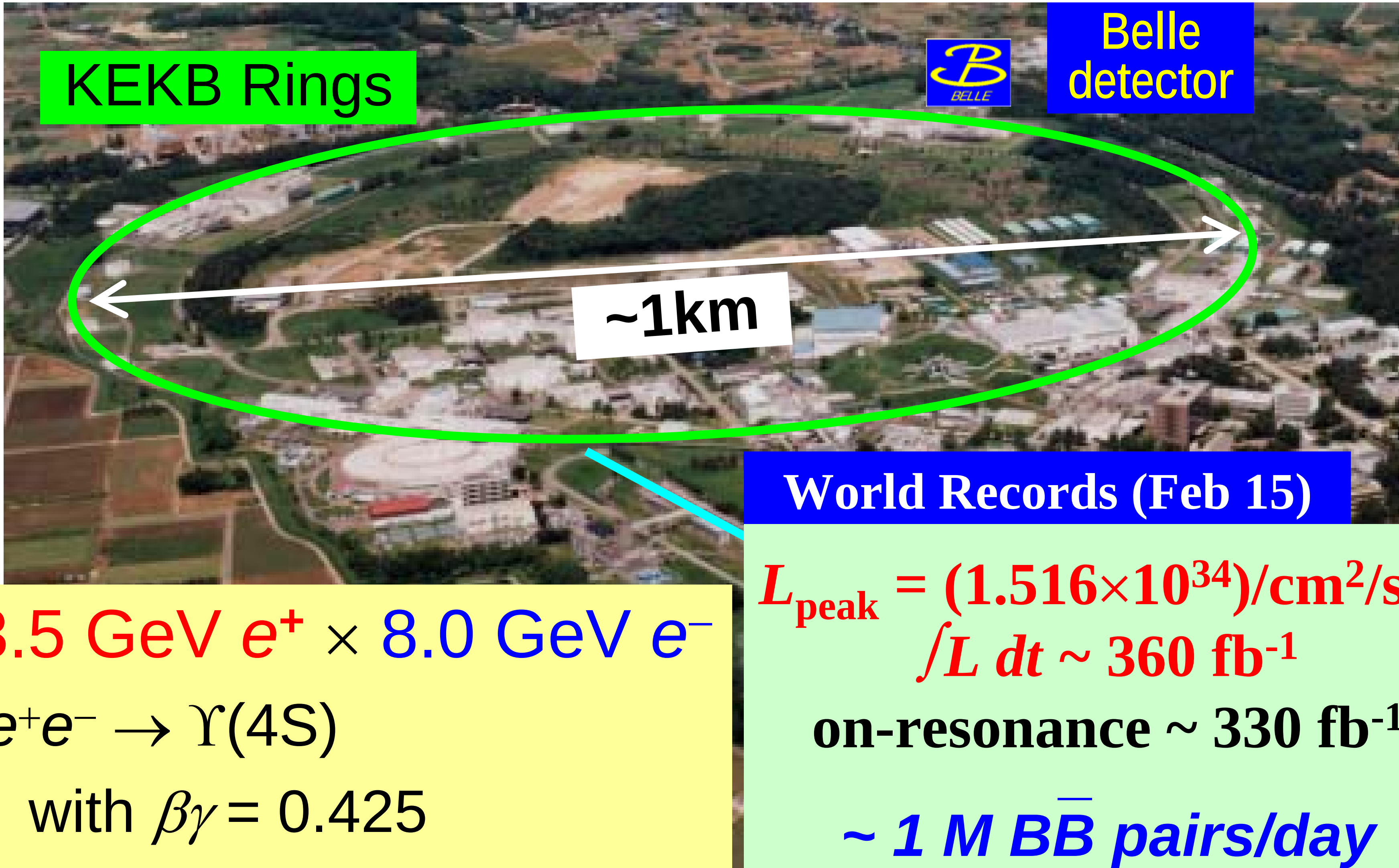
ξ_{CP} : *CP eigenvalue*

+1 (-1) for CP even (odd)

- Br(b→c$\bar{c}$s) ~ 10^{-3} → Many B-mesons are required
- Δt measurement → B-mesons should be boosted

→ **Asymmetric B-factory Acc. is the best way**

KEKB (located at Tsukuba, Japan)



World Records (Feb 15)

$L_{peak} = (1.516 \times 10^{34})/\mathrm{cm}^2/\mathrm{sec}$

$\int L\,dt \sim 360\ \mathrm{fb}^{-1}$

on-resonance ~ 330 fb^{-1}

~ 1 M $B\bar{B}$ pairs/day

~ 350 M $B\bar{B}$ pairs

3.5 GeV e^+ × 8.0 GeV e^-

$e^+e^- \rightarrow \Upsilon(4S)$

with $\beta\gamma = 0.425$

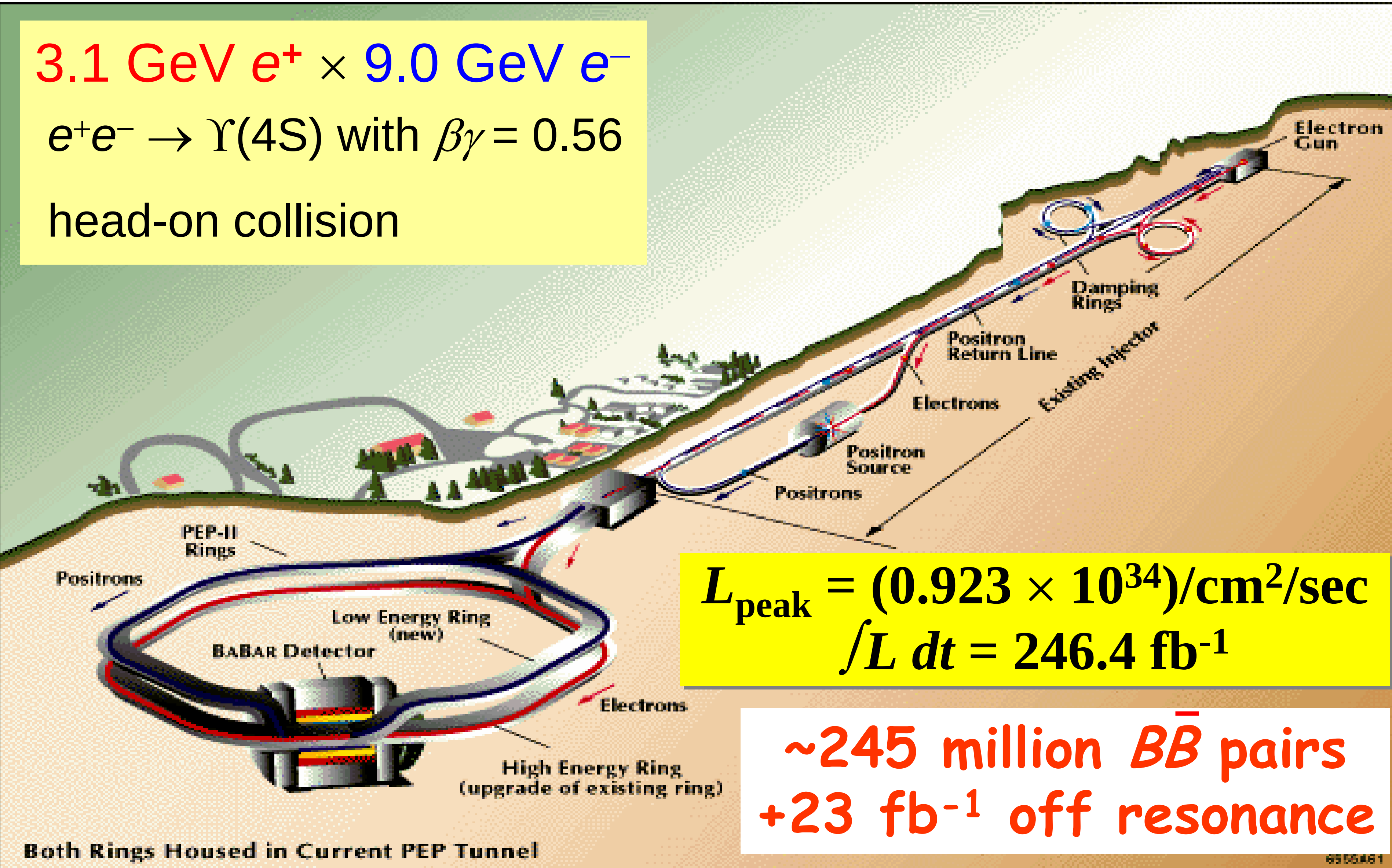
22 mrad crossing angle

PEP-II (located at SLAC, USA)

3.1 GeV e^+ × 9.0 GeV e^-

$e^+e^- \to \Upsilon(4S)$ with $\beta\gamma = 0.56$

head-on collision



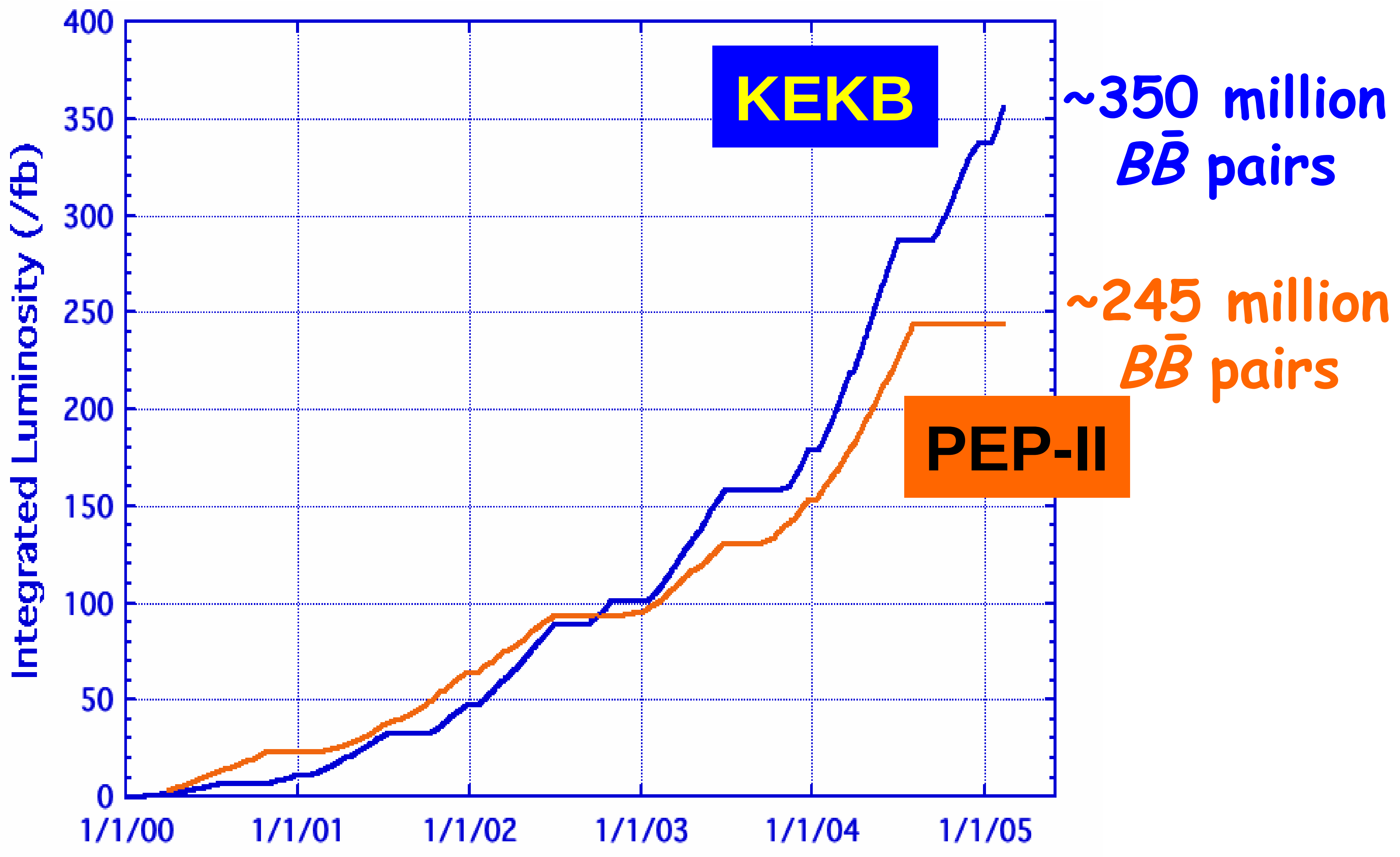
$$L_{\text{peak}} = (0.923 \times 10^{34})/\text{cm}^2/\text{sec}$$

$$\int L\,dt = 246.4\ \text{fb}^{-1}$$

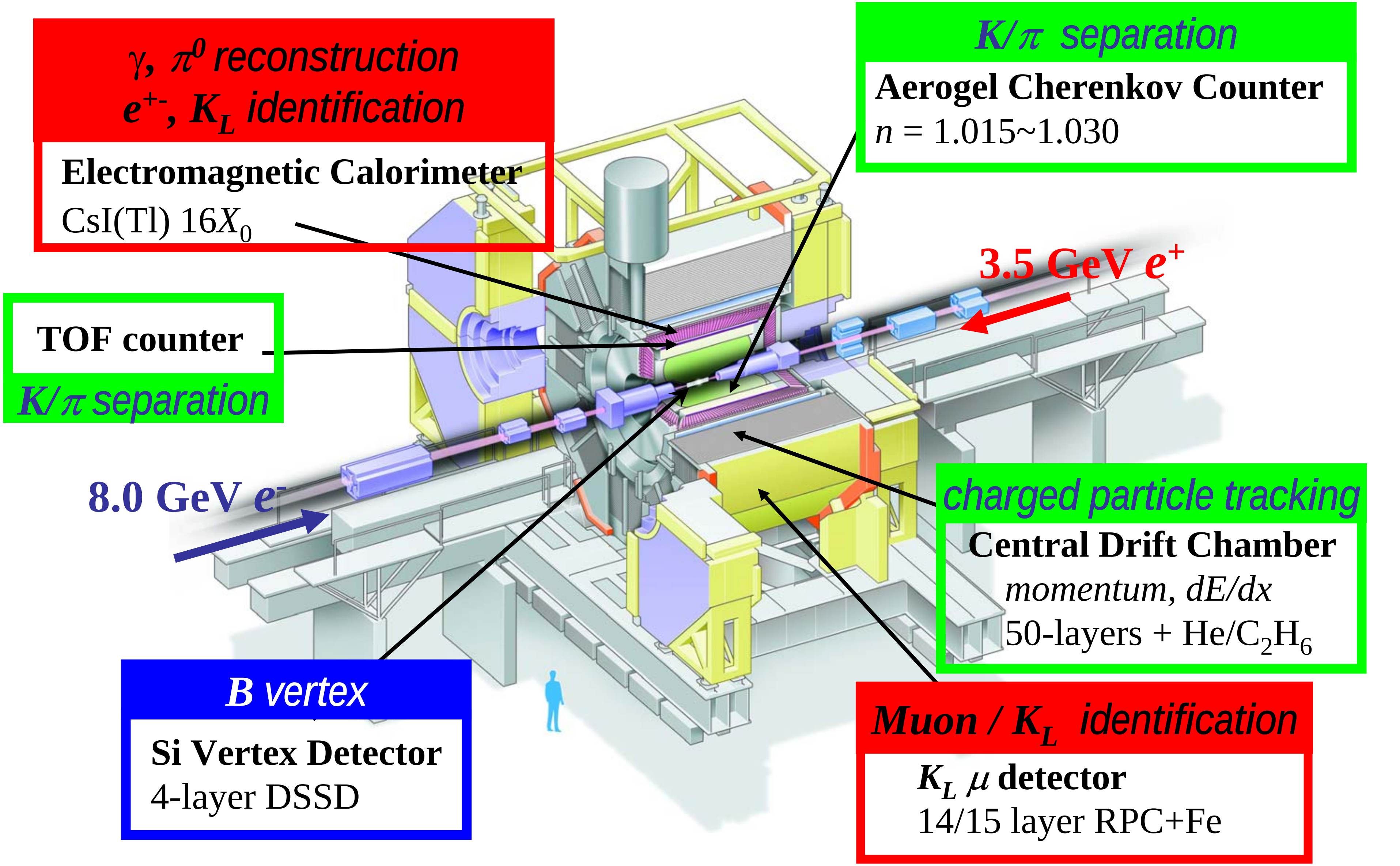
~245 million $B\bar{B}$ pairs

+23 fb^{-1} off resonance

History of Asymmetric B Factories



Belle Detector

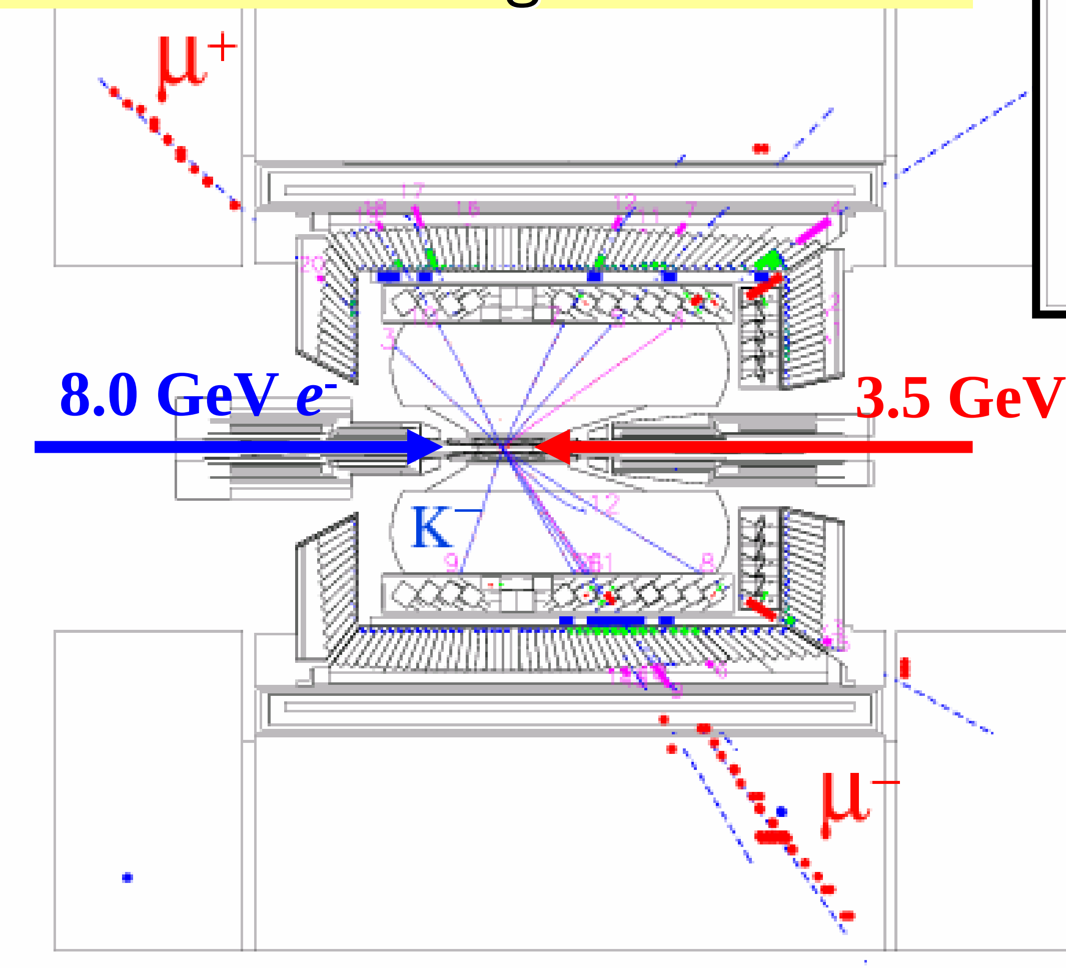


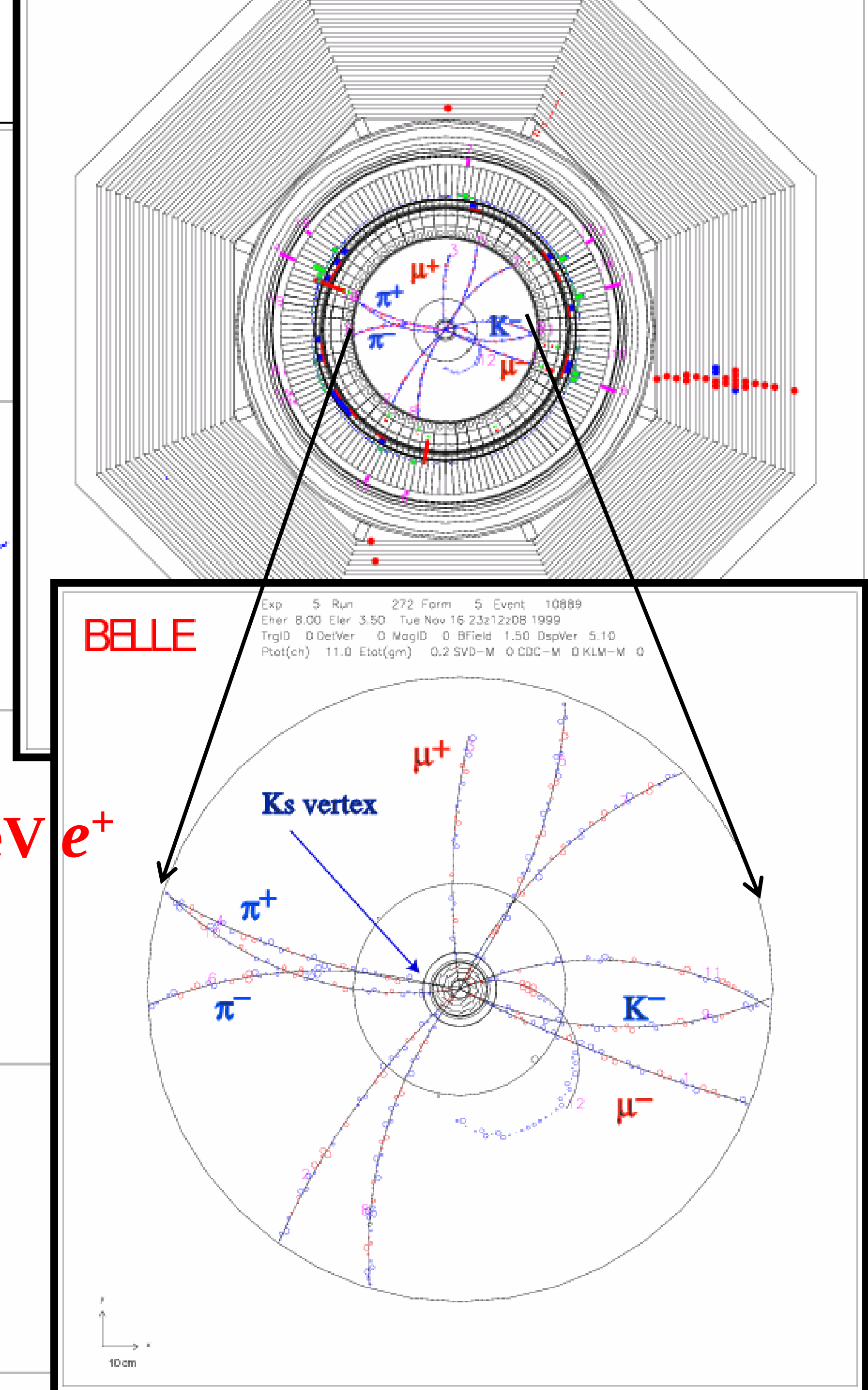
Event Display

$B^0 \rightarrow J/\Psi K_S$

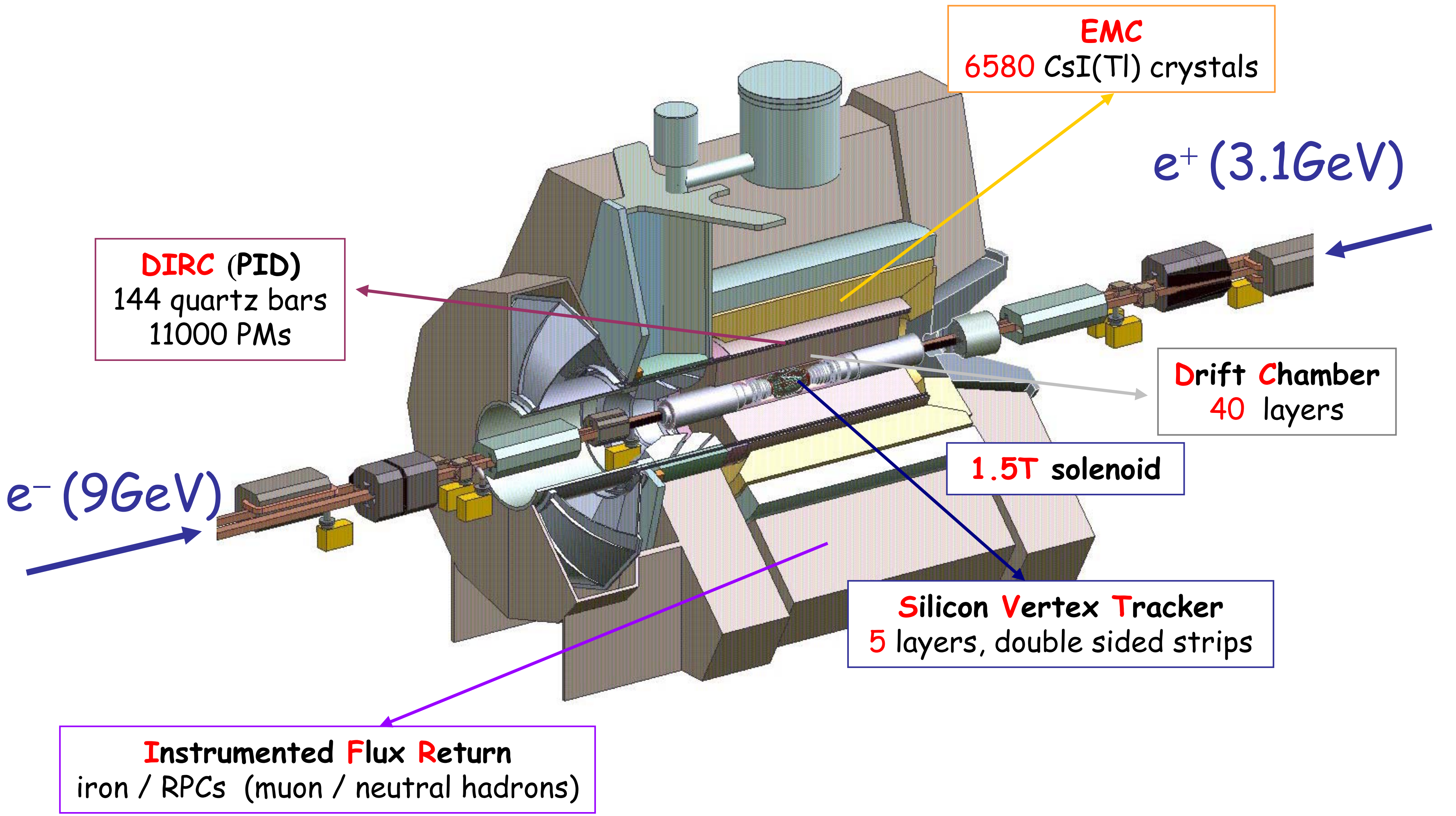
$J/\Psi \rightarrow \mu^+\mu^-$

$K_S \rightarrow \pi^+\pi^-$

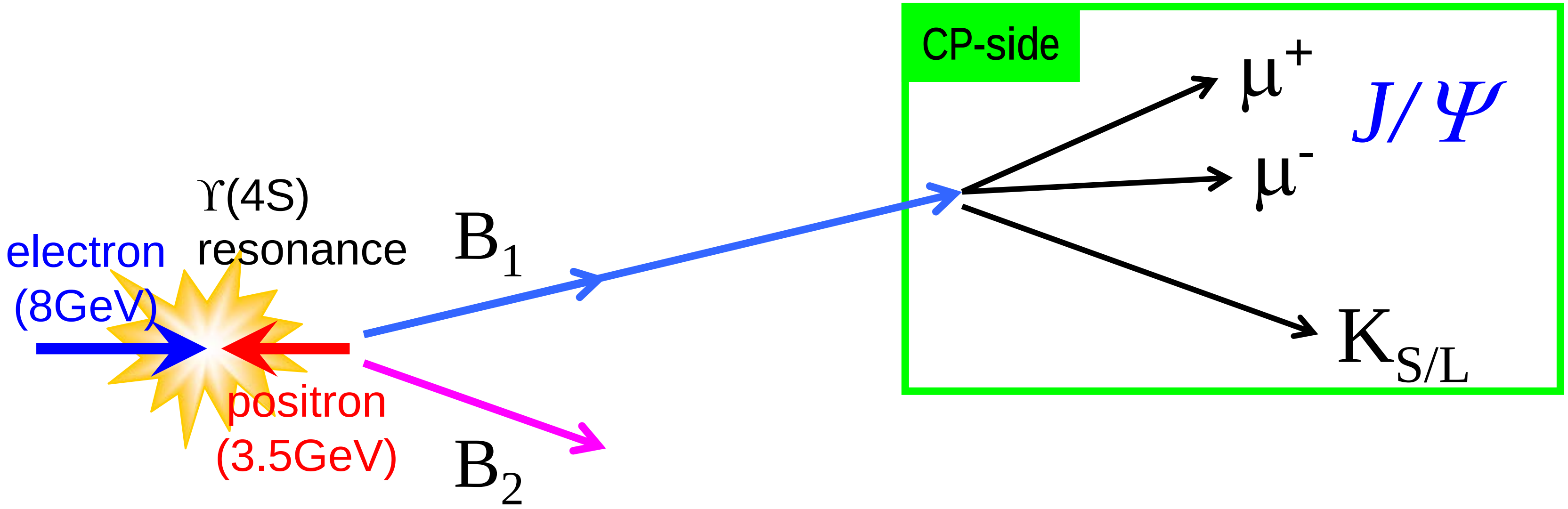




BABAR Detector



Principle of TCPV measurement



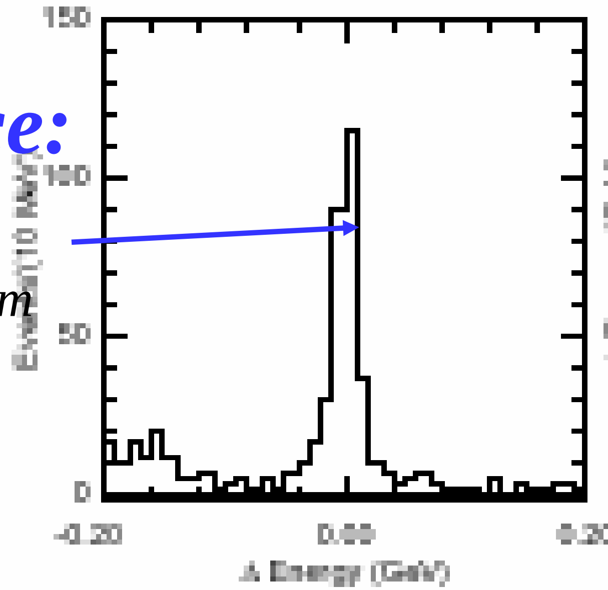
$\beta\gamma$ = 0.425 (Belle)
0.56 (BaBar)

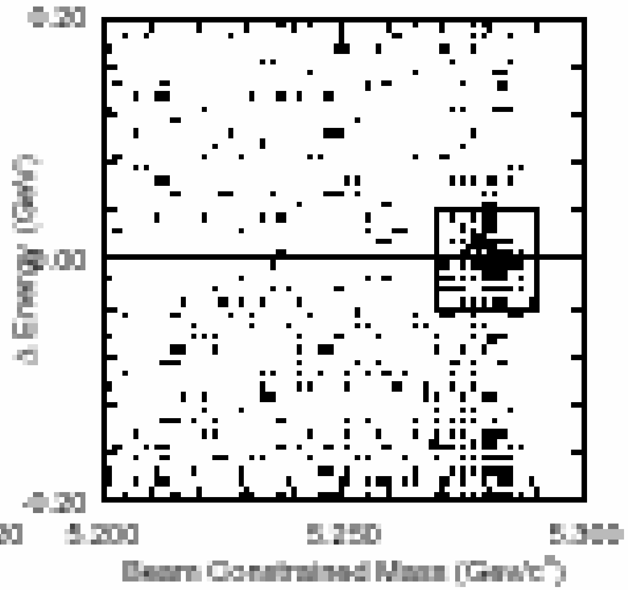
1. Fully reconstruct one B-meson which decays to CP eigenstate

B-meson Reconstruction Variables

Energy difference:

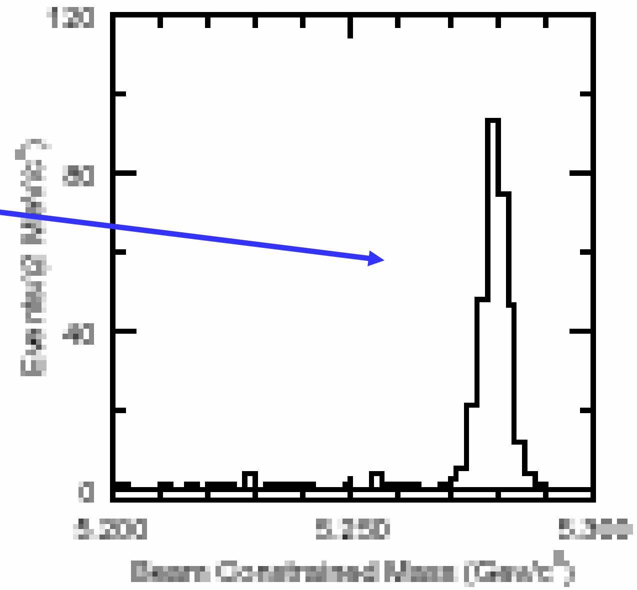
$$\Delta E \equiv E_B^* - E_{beam}^*$$





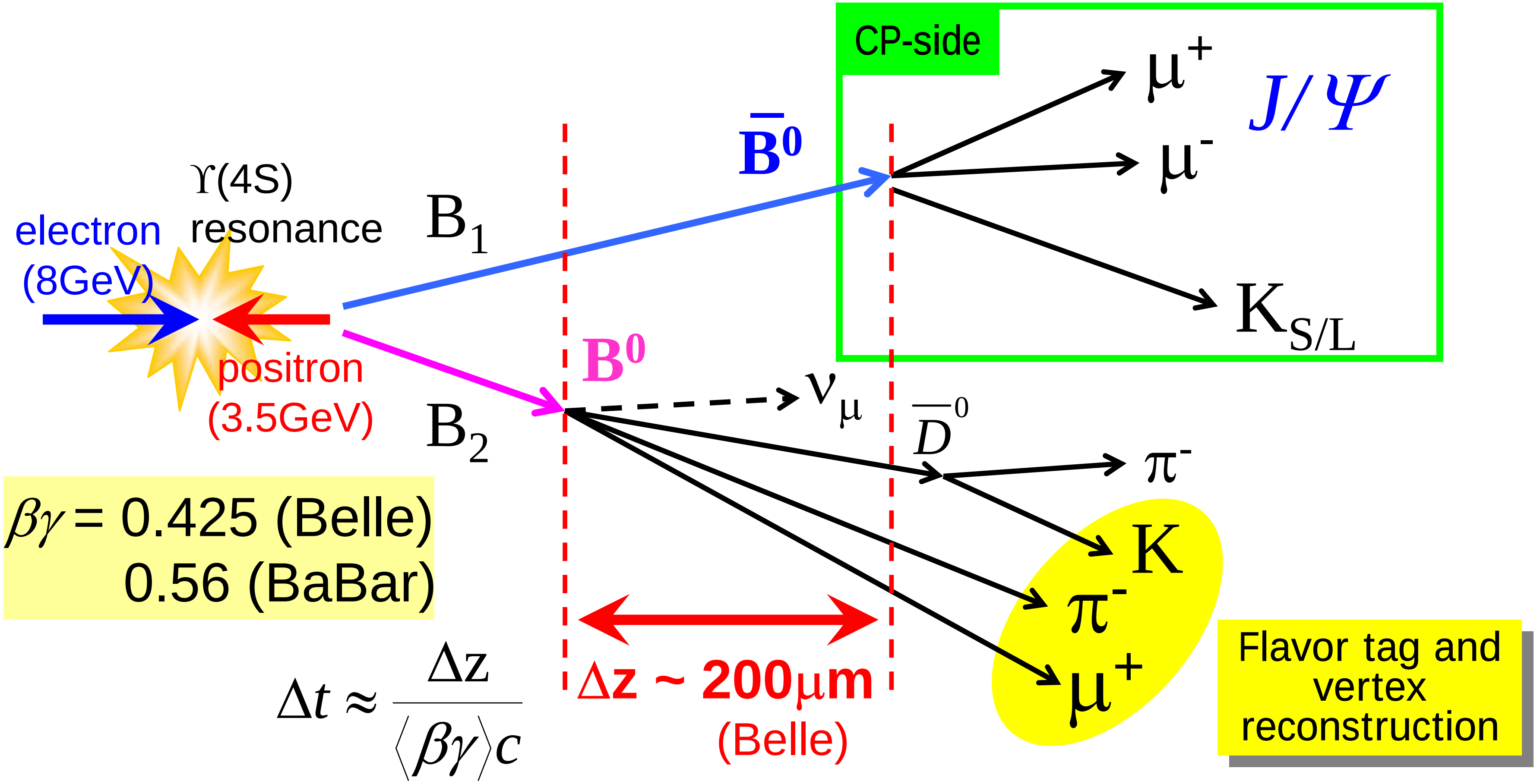
$$M_{\underset{(es)}{bc}} = \sqrt{E_{beam}^{*2} - P_B^{*2}}$$

Beam-constrained mass:



Utilize Special Kinematics at Y(4S)

Principle of TCPV measurement



1. Fully reconstruct one B-meson which decays to CP eigenstate
2. Tag-side determines its flavor
3. Proper time (Δt) is measured from decay-vertex difference (Δz)

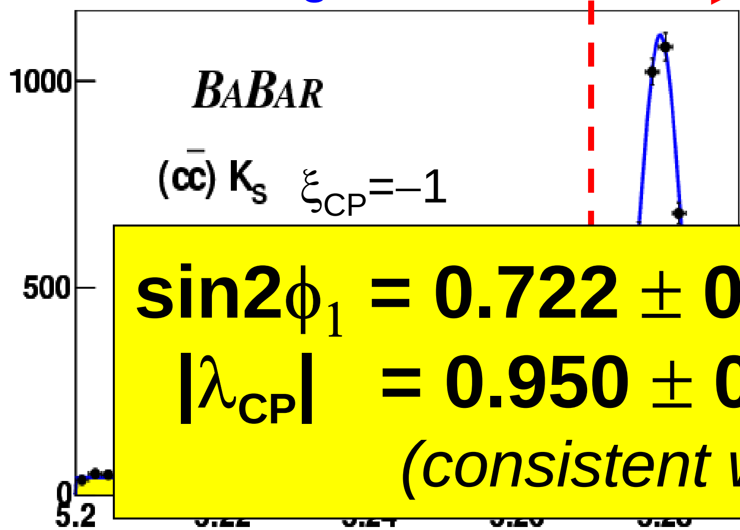
$\sin 2\phi_1$ measurement results

TCPV of $b \rightarrow c\bar{c}s$ modes

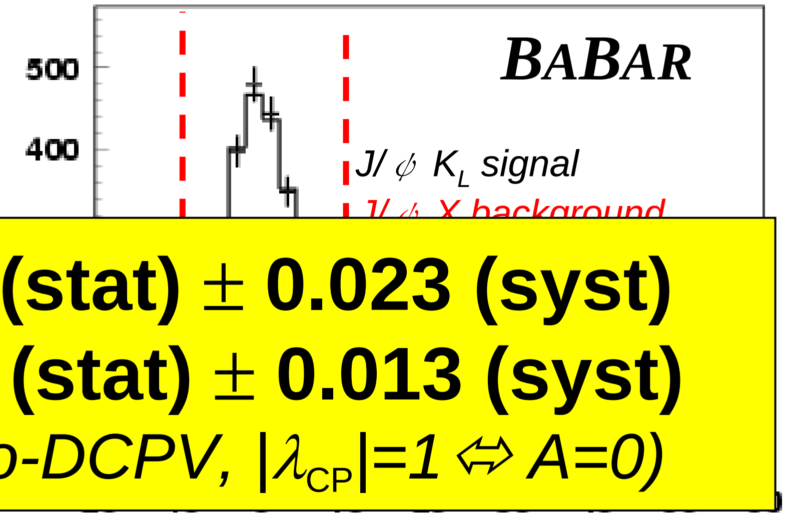
(tree-diagram)

$\sin 2\phi_1$ Results: 227 $\times 10^6$ $B\bar{B}$ pairs

3900 signal events — signal region



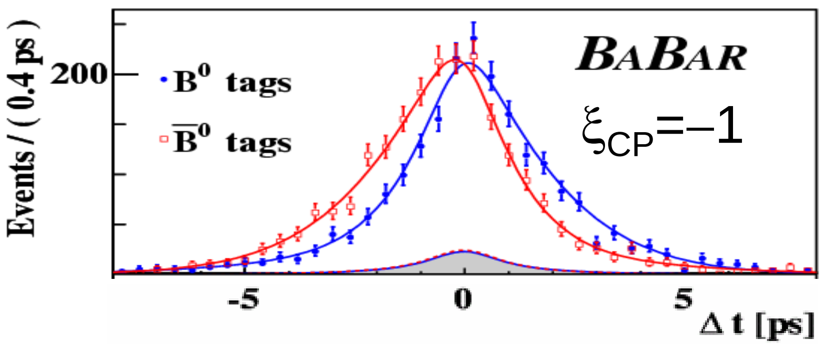
signal region — 1600 signal events

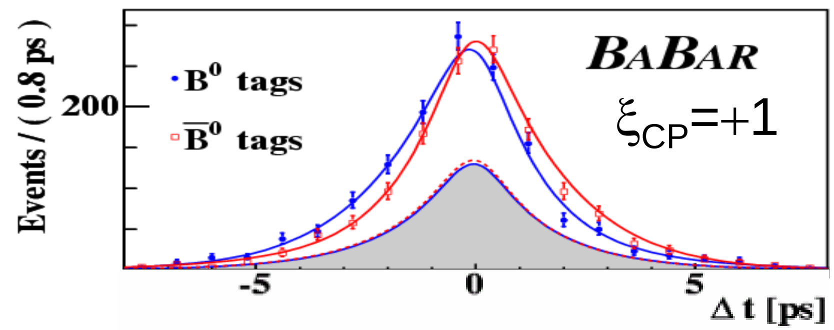


$\sin 2\phi_1$ = 0.722 ± 0.040 (stat) ± 0.023 (syst)

$|\lambda_{CP}|$ = 0.950 ± 0.031 (stat) ± 0.013 (syst)

(consistent with no-DCPV, $|\lambda_{CP}|=1 \Leftrightarrow A=0$)

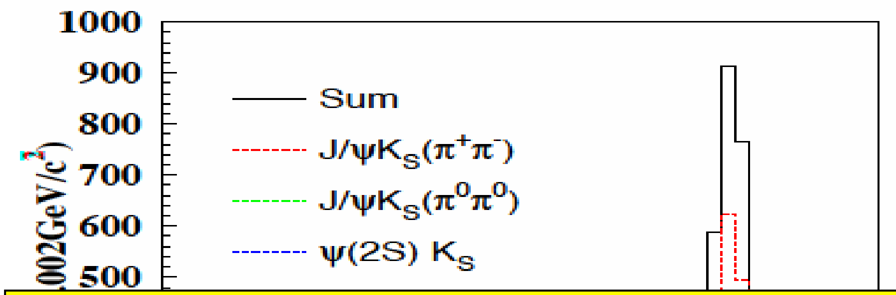




$$A_{CP}(\Delta t) = -\xi_{CP}\sin 2\phi_1 \sin(\Delta m \Delta t)$$

$\sin 2\phi_1$ Result : 152×10^6 $B\bar{B}$ Pairs

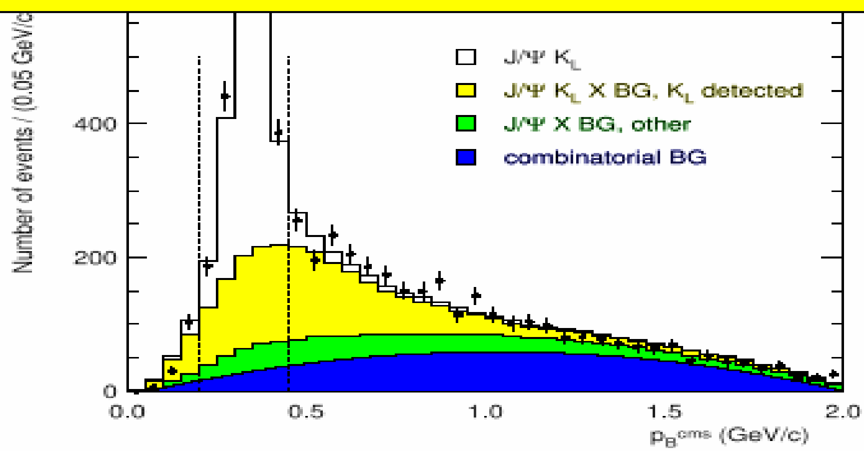
4347 signals hep-ex/0408111

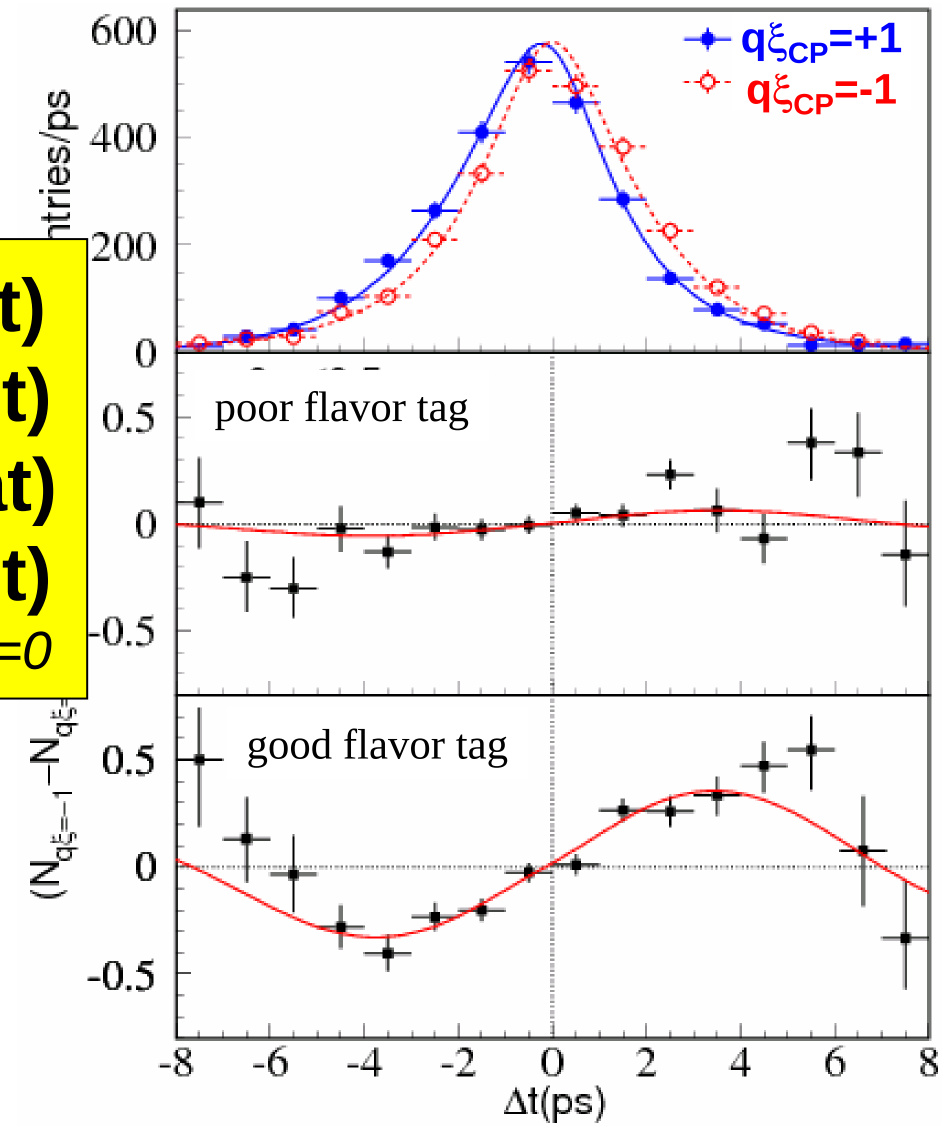


$\sin 2\phi_1 = 0.728 \pm 0.056$ (stat) $\pm\, 0.023$ (syst)

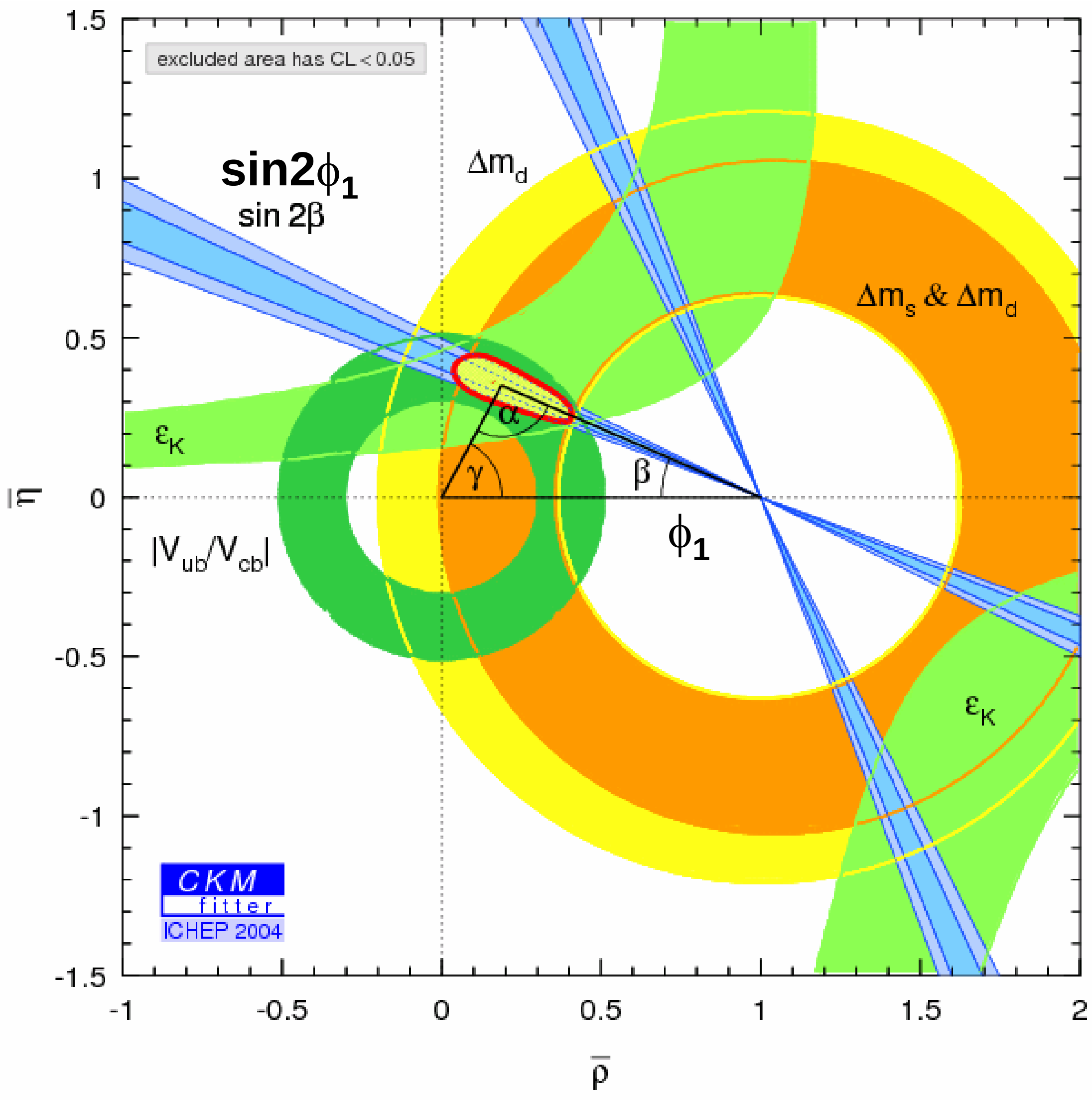
$|\lambda_{CP}| = 1.007 \pm 0.041$ (stat) $\pm\, 0.023$ (syst)

consistent with no-DCPV $|\lambda_{CP}|=1 \Leftrightarrow A=0$

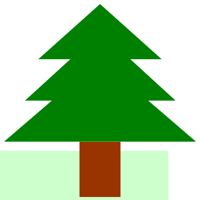




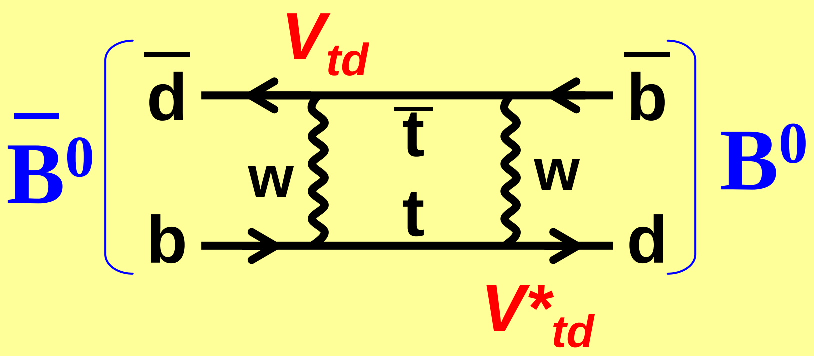
Consistency of TCPV results with indirect constraints

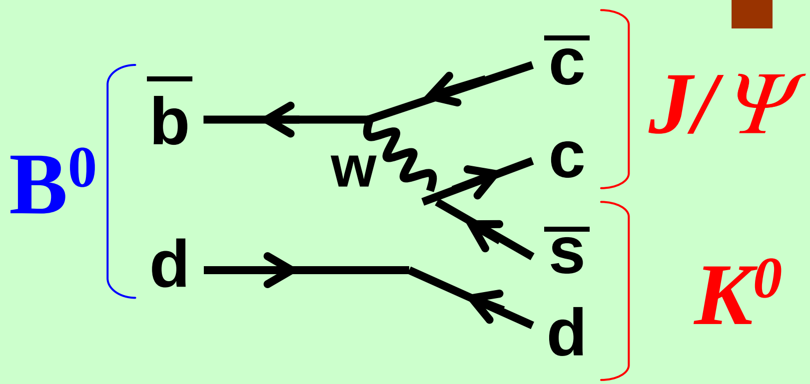


$\sin 2\phi_1$ measurement



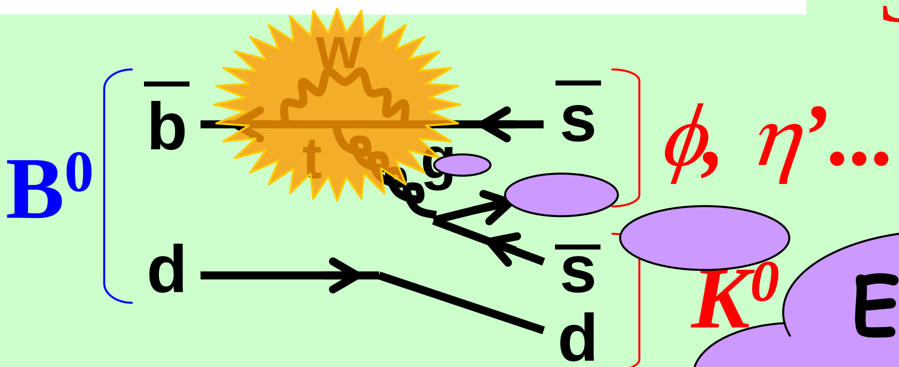
Standard Model : $\sin 2\phi_1 = 0.726 \pm 0.037$





Standard Model

$S = -\xi_{CP} \sin 2\phi_1$, $A = 0$



Standard Model

$S \neq -\xi_{CP} \sin 2\phi_1$, $A \sim 0$

Extra CPV phase

→ $S_{b\to s} \neq S_{SM}$

→ New Physics

TCPV in Hadronic $b \rightarrow s$ Penguins

New Physics Search

in "$\sin 2\phi_1$" ($= -\xi_{CP} S$) measurement

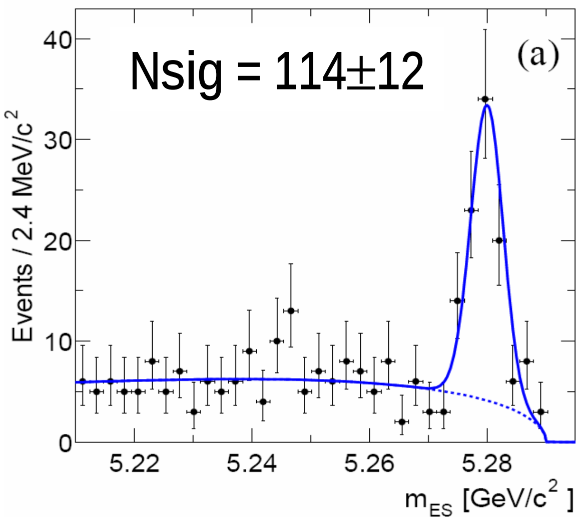
$B^0 \to \phi K^0$ signals

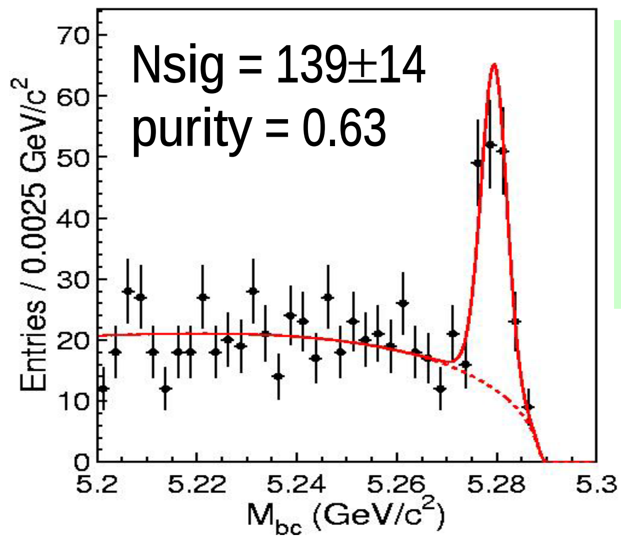
preliminary

$227M\ B\bar{B}$ [hep-ex/0502019]

$275M\ B\bar{B}$ [hep-ex/0409049]

ϕK_S:
$\phi \to K^+K^-$
$K_S \to \pi^+\pi^-$





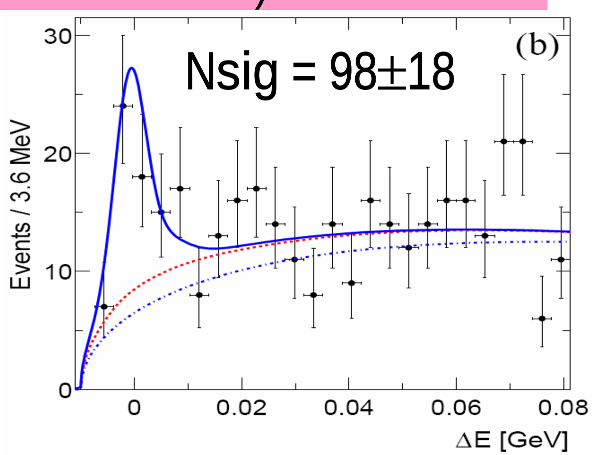
ϕK_S:
$\phi \to K^+K^-$
$K_S \to \pi^+\pi^-$,
$\pi^0\pi^0$

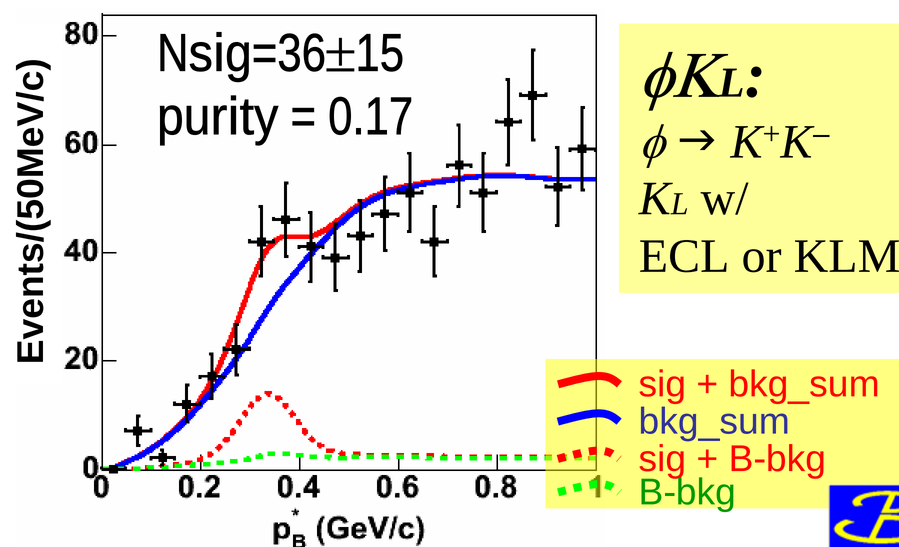
Nsig ⇔ #events for *TCPV* fit

plots for all signal events

plots for signal-enhanced regions
signals seen in the plots < Nsig
(Δt used for selection)

ϕK_L:
$\phi \to K^+K^-$
K_L w/
EMC or IFR





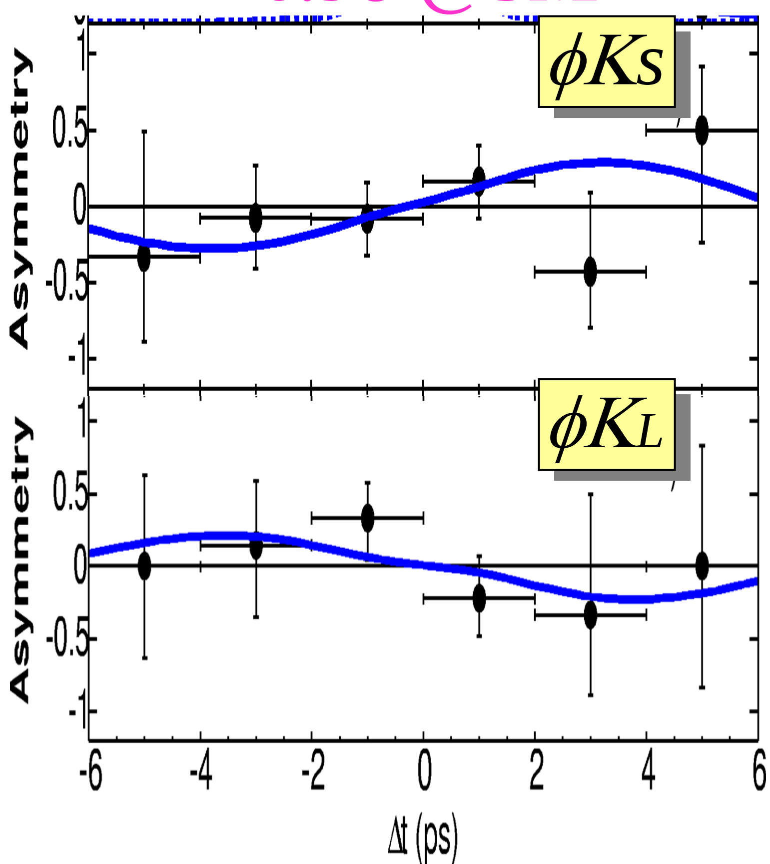
ϕK_L:
$\phi \to K^+K^-$
K_L w/
ECL or KLM

TCPV results for $B^0 \to \phi K^0$

227M $B\bar{B}$ [hep-ex/0502019]

"$\sin 2\phi_1$" $= +0.50 \pm 0.25 \,^{+0.07}_{-0.04}$
$\mathcal{A} = 0.00 \pm 0.23 \pm 0.05$

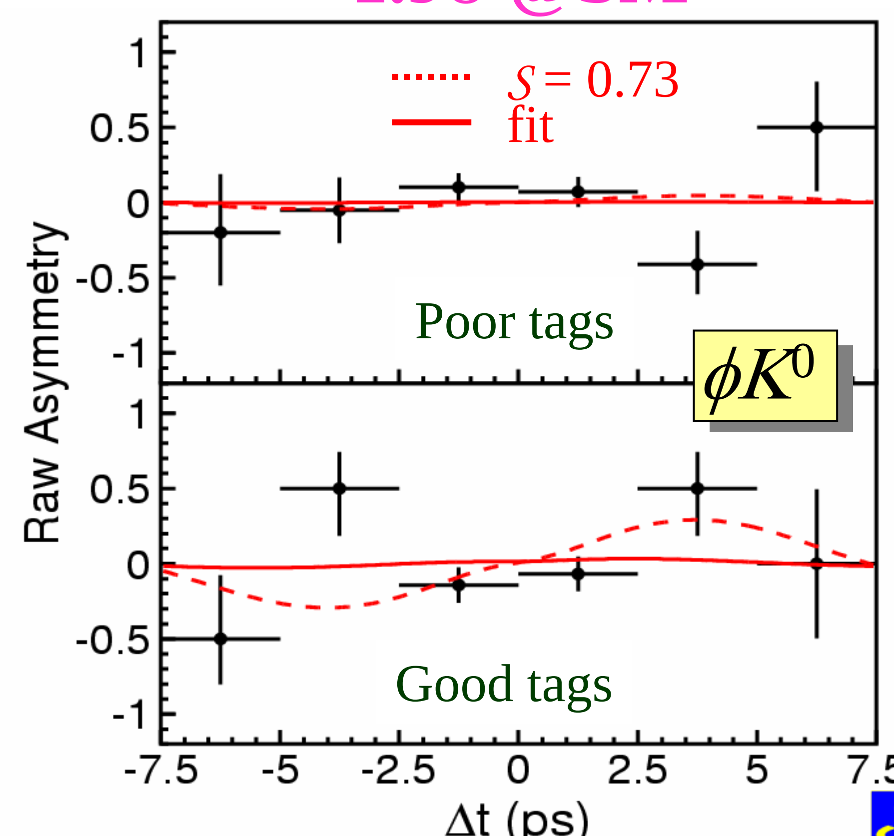
~0.9σ @SM



275M $B\bar{B}$ [hep-ex/0409049]

"$\sin 2\phi_1$" $= +0.06 \pm 0.33 \pm 0.09$
$\mathcal{A} = +0.08 \pm 0.22 \pm 0.09$

~1.9σ @SM *preliminary*

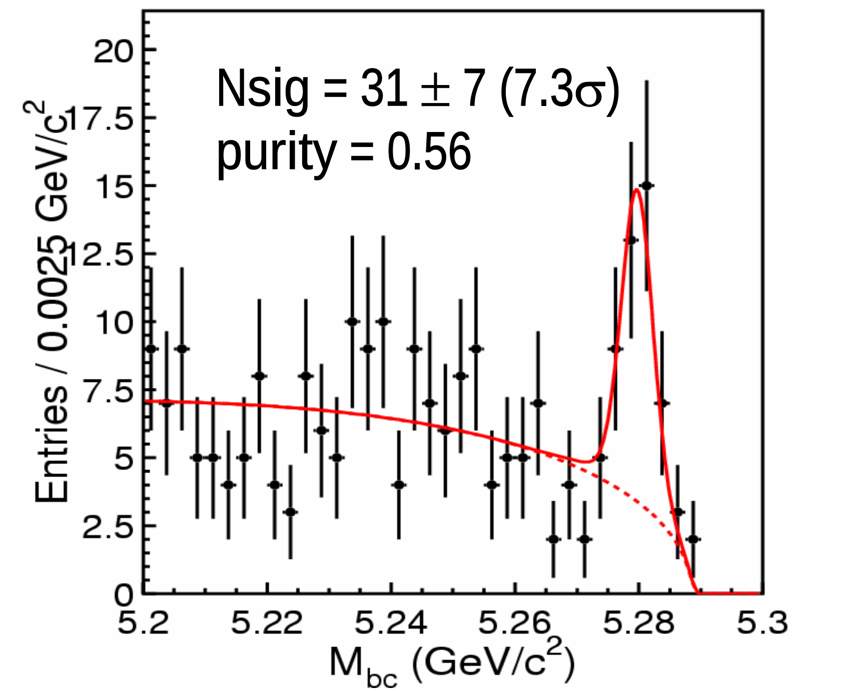


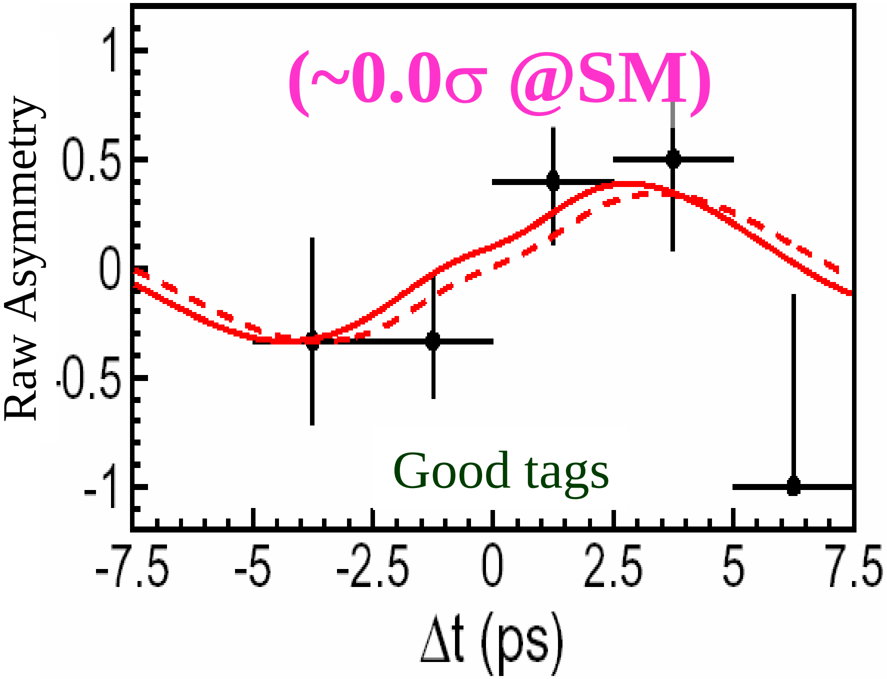
preliminary

TCPV results for $B^0 \to \omega K_S$

275M $B\bar{B}$ [hep-ex/0409049]

$$\text{“}\sin 2\phi_1\text{”} = +0.75 \pm 0.64\,^{+0.13}_{-0.16}$$
$$\mathcal{A} = +0.26 \pm 0.48 \pm 0.15$$





TCPV in $B^0 \to KsKsKs$

[hep-ex/0411056]

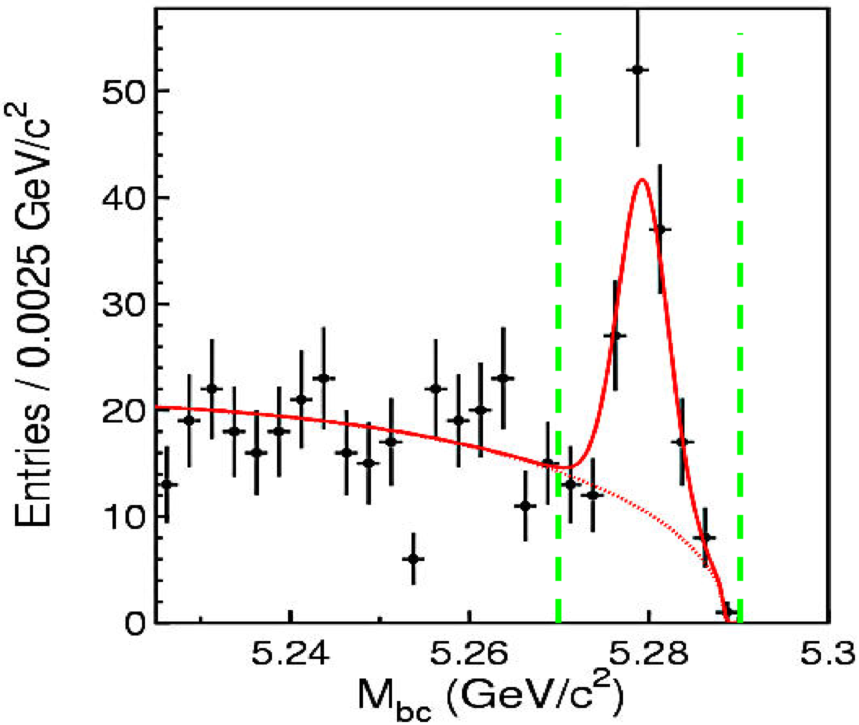
preliminary

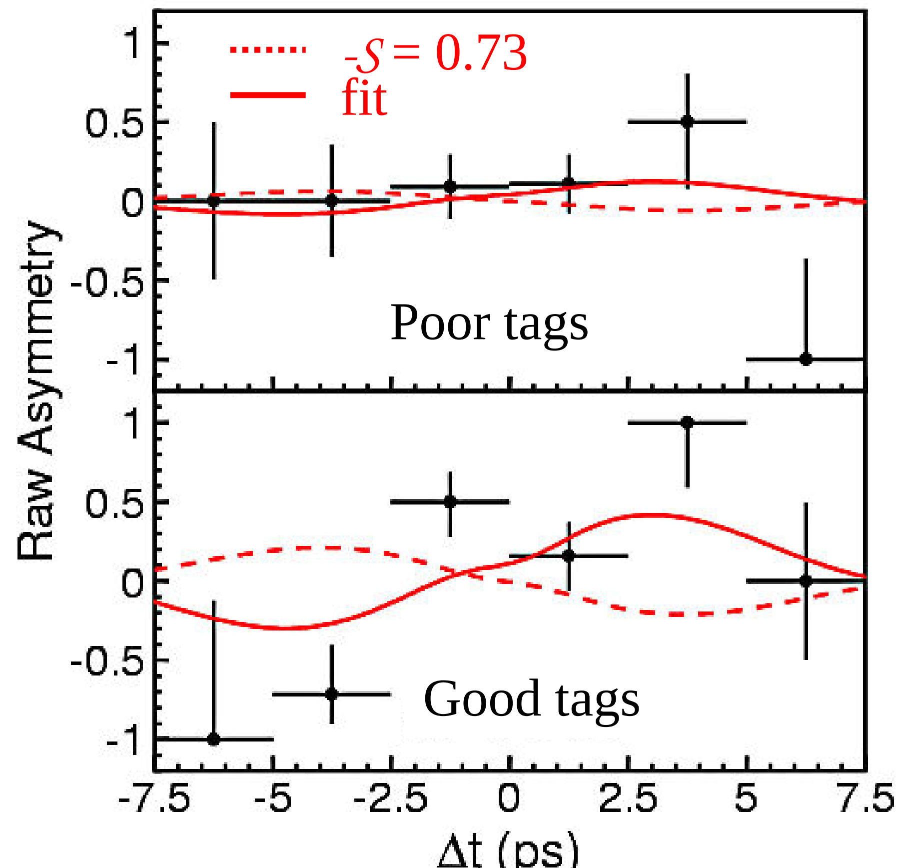
275M $B\bar{B}$

"$\sin 2\phi_1$" $= -1.26 \pm 0.68 \pm 0.18$

$\mathcal{A} = +0.54 \pm 0.34 \pm 0.08$

~2.8σ @SM

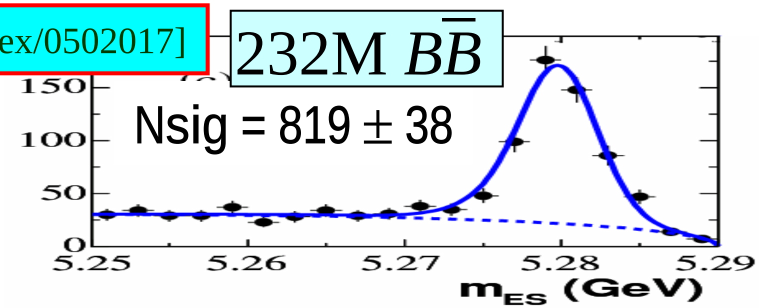




	w/ VTX	w/o VTX	total	N_{sig}
3 $(\pi^+\pi^-)$	96	32	128	72
2 $(\pi^+\pi^-)$ & $(\pi^0\pi^0)$	21	18	39	16
total	117	50	167	88

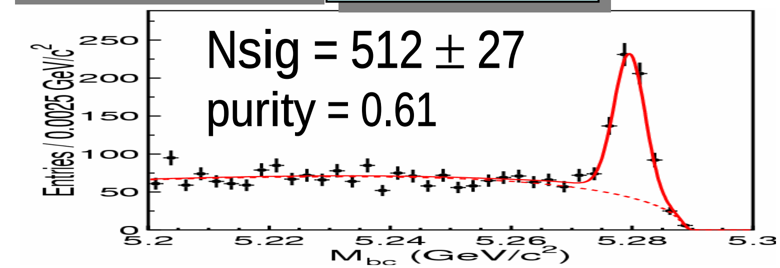
Signals for other $b \to s q\bar{q}$ modes

[hep-ex/0502017] 232M $B\bar{B}$

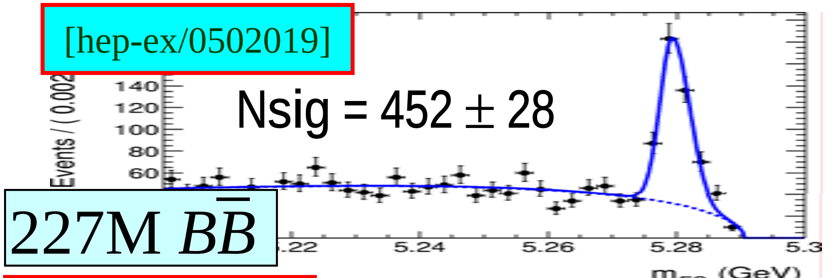


$\eta' K_S$

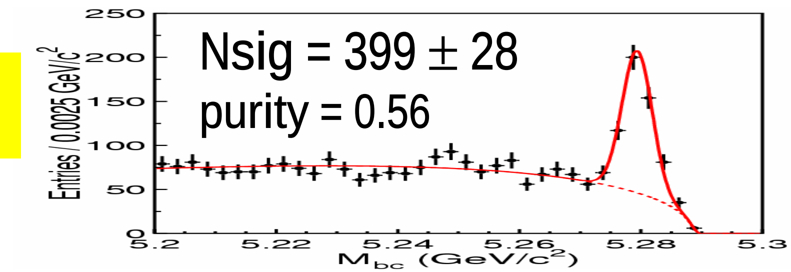
[hep-ex/0409049] 275M $B\bar{B}$ *preliminary*



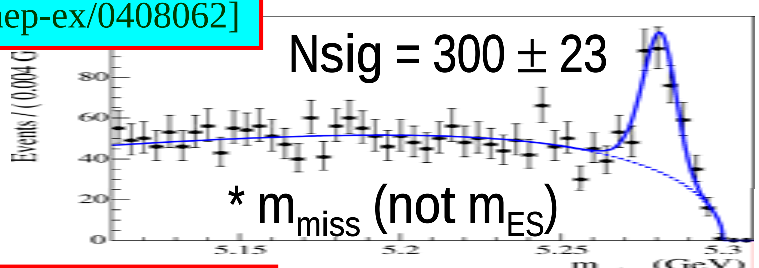
[hep-ex/0502019] 227M $B\bar{B}$



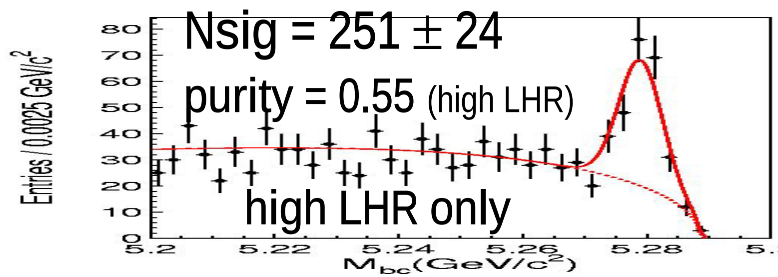
$K^+K^-K_S$



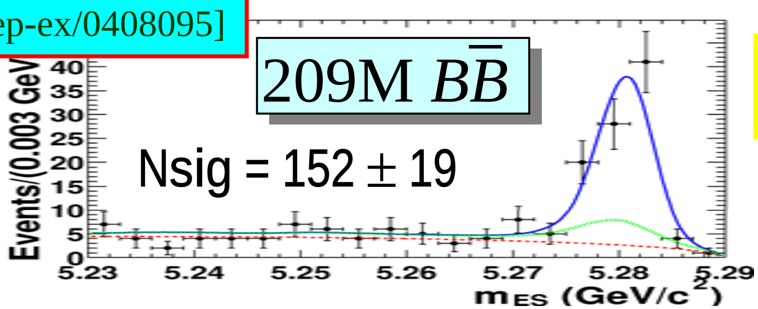
[hep-ex/0408062]



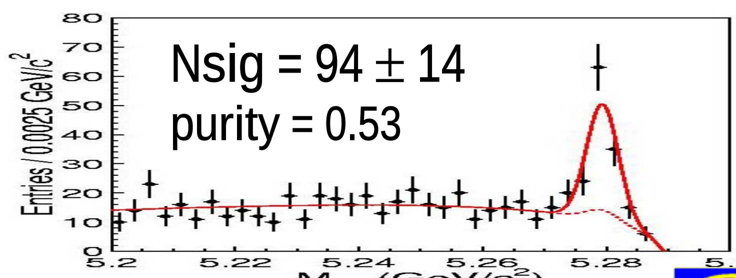
$K_S\pi^0$



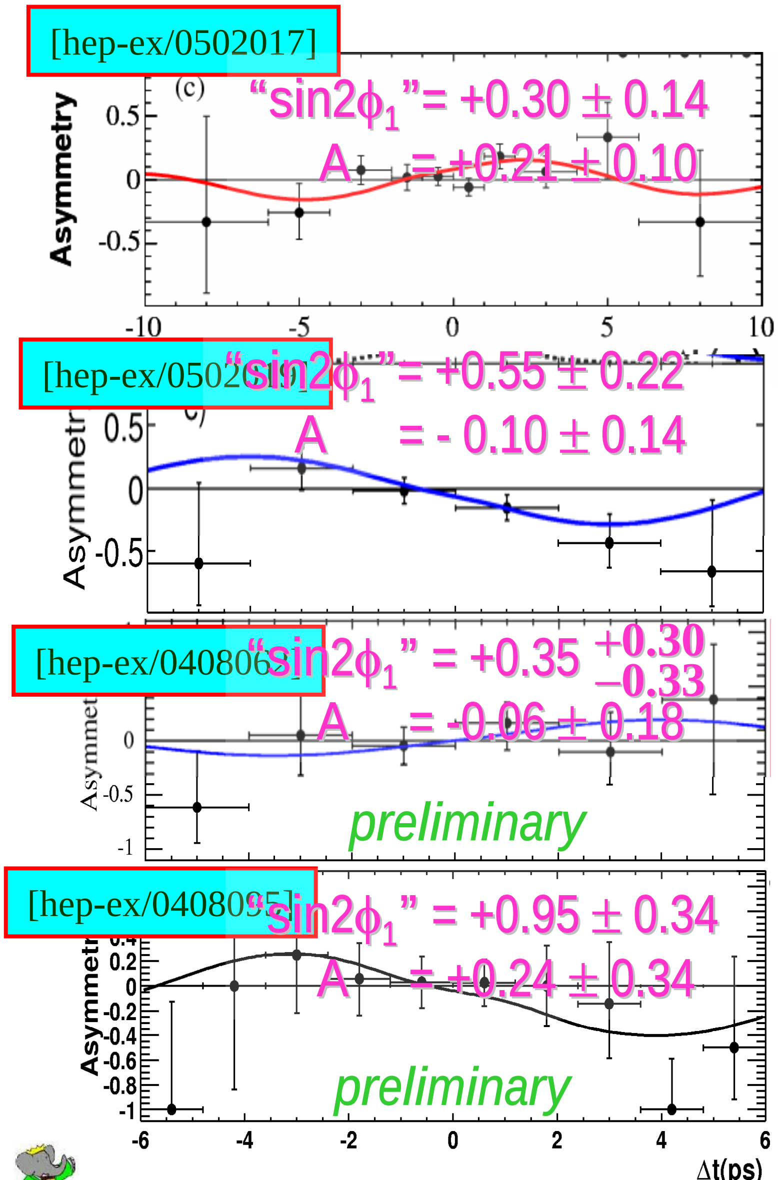
[hep-ex/0408095] 209M $B\bar{B}$



$f_0(980)K_S$



TCPV for other $b \to s q \bar{q}$ modes

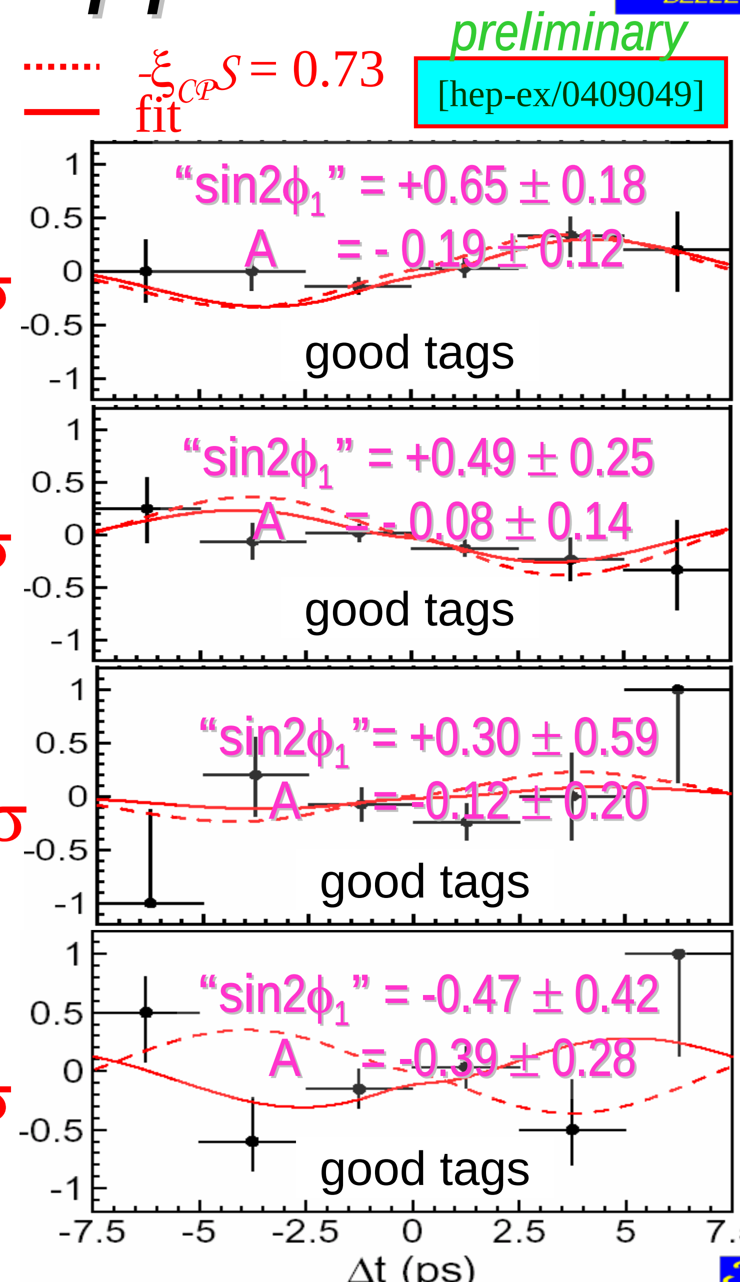


$\eta' K_S$
$3.0\sigma \Leftrightarrow 0.4\sigma$
@ SM

$K^+K^-K_S$
$0.7\sigma \Leftrightarrow 0.9\sigma$
@ SM

$K_S\pi^0$
$1.2\sigma \Leftrightarrow 0.7\sigma$
@ SM

$f_0(980)K_S$
$0.7\sigma \Leftrightarrow 2.9\sigma$
@ SM



"sin2ϕ_1" from hadronic $b \to s$ penguins

$$\sin 2\phi_1(b \to sq\bar{q}) = \begin{cases} 0.39 \pm 0.11 & \text{(Belle)} \\ 0.42 \pm 0.10 & \text{(BABAR)} \end{cases}$$

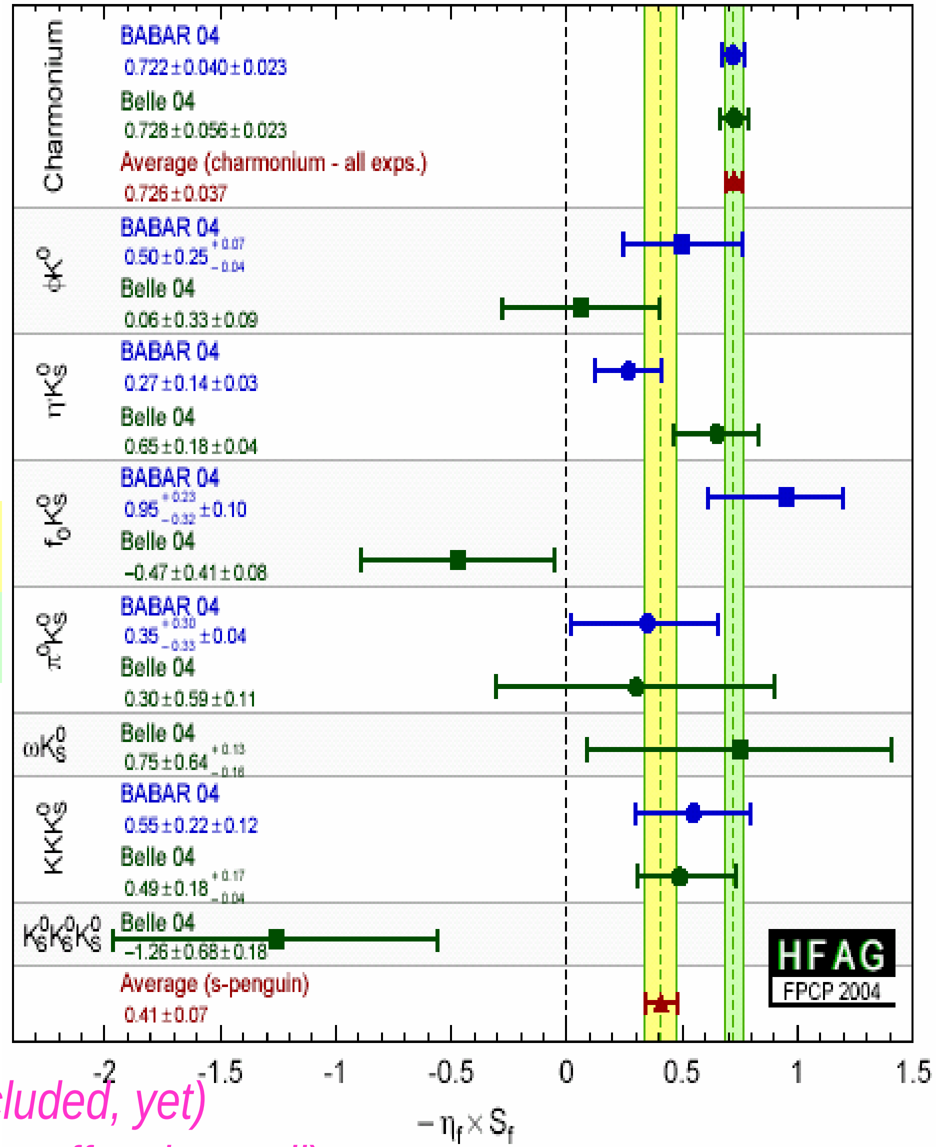
World Average (WA)

$$\sin 2\phi_1(b \to sq\bar{q}) = 0.41 \quad \pm 0.07$$

$$\sin 2\phi_1(b \to c\bar{c}s) = 0.726 \pm 0.037$$

CL ~ 10^{-4} (3.8σ)

Deviation from SM expectation !?



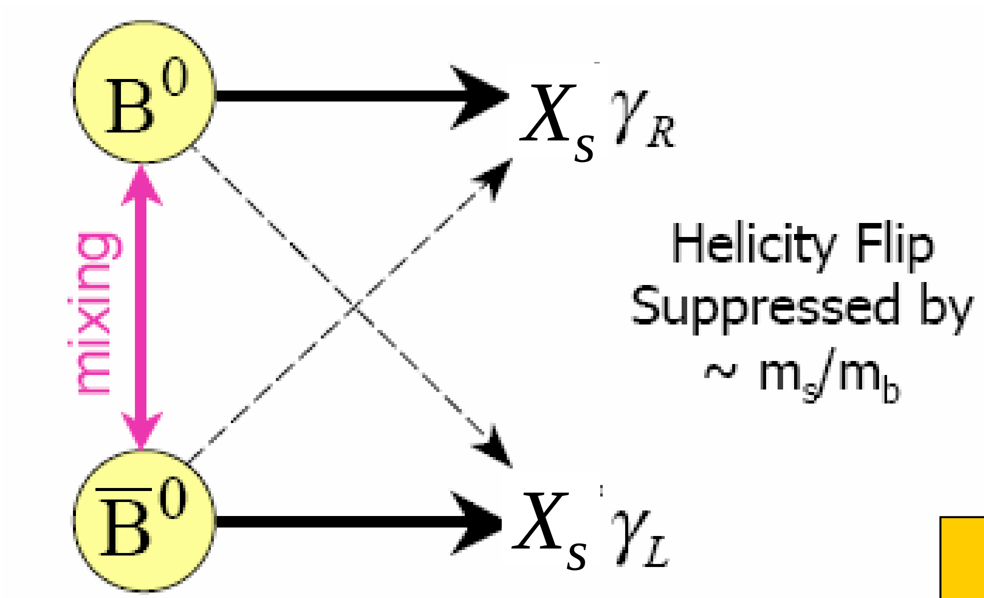
(BaBar's new results for $B^0 \to K_SK_SK_S$ are not included, yet)

(Updated $\eta' K_S$, ϕK^0, $K^+K^-K_S$ are not used, while its effect is small)

TCPV in Radiative $b \rightarrow s$ Penguins

New Physics Search

TCPV in radiative $b \to s$ penguins



$|\mathcal{S}| \approx 2(m_s/m_b)\sin 2\phi_1$

$\sim$ **3% (SM)**

$\mathcal{A} \sim$ **0.4%**

B⁰ $\boldsymbol{B^0 \to K_S \pi^0 \gamma}$

(inc. $K^* \to K_S\pi^0$)

Large TCPV implies New Physics

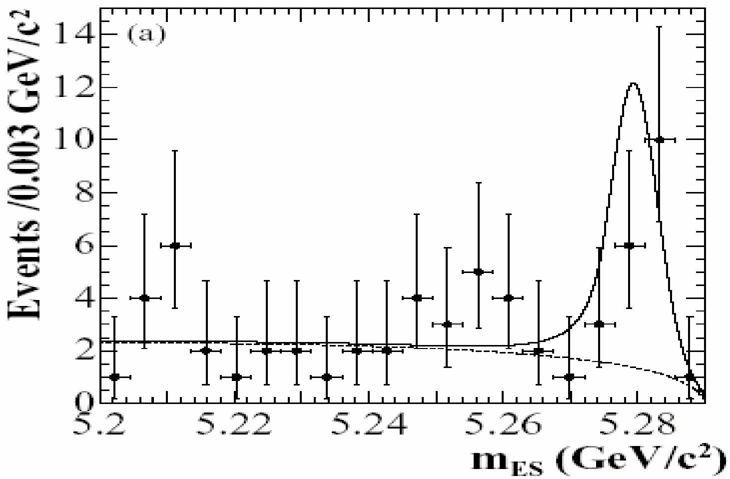
D. Atwood, M. Gronau, A. Soni Phys. Rev. Lett. 79, 185 (1997)

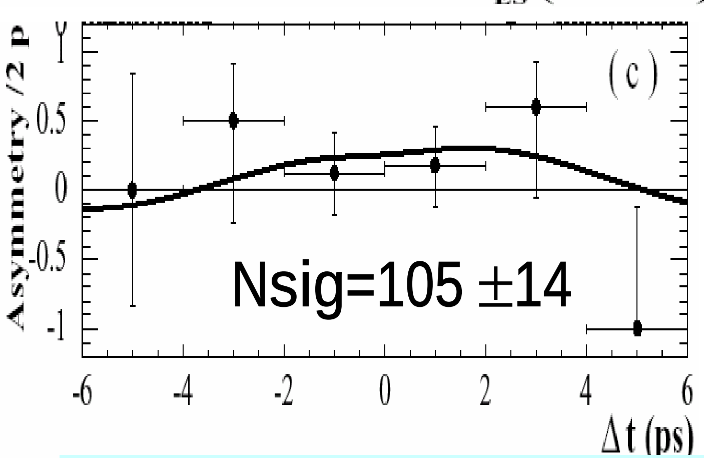
D. Atwood, T. Gershon, M. Hazumi, A. Soni hep-ph/0410036

$B^0 \to K^*[Ks\pi^0]\gamma$ TCPV

Phys.Rev.Lett. 93 (2004) 201801

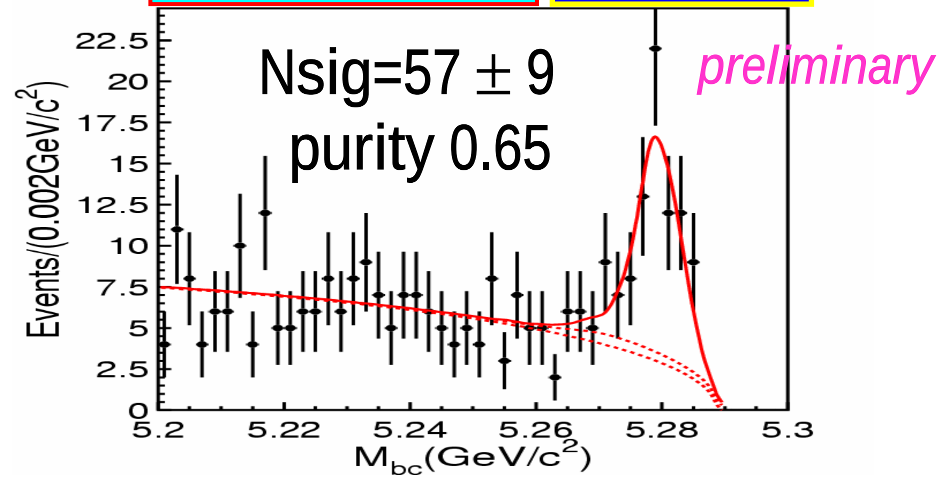
124M $B\bar{B}$

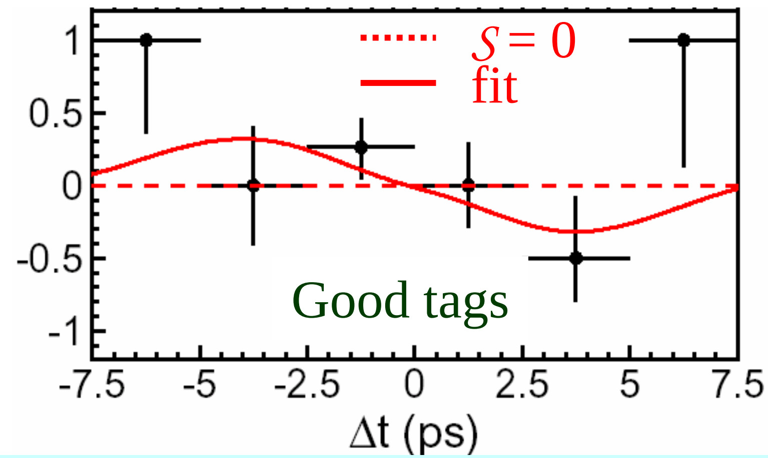




[hep-ex/0409049]

275M $B\bar{B}$





$\mathcal{S} = +0.25 \pm 0.63 \pm 0.14$

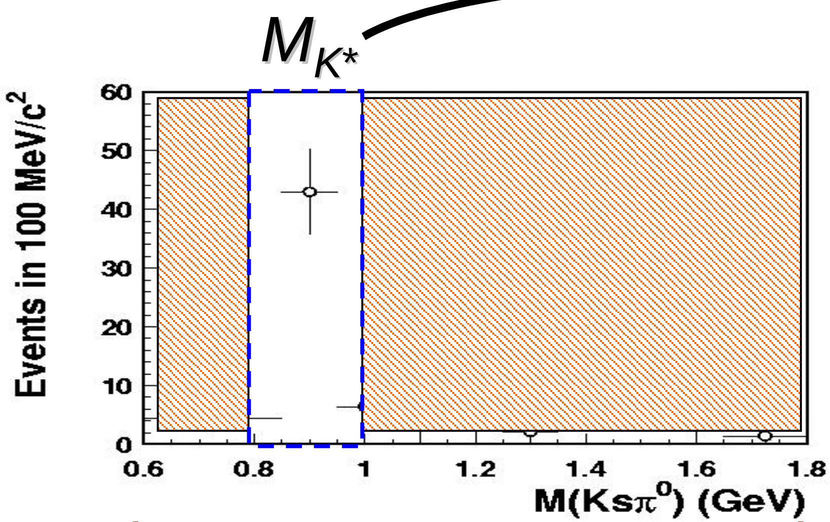
$\mathcal{A} = +0.57 \pm 0.32 \pm 0.09$

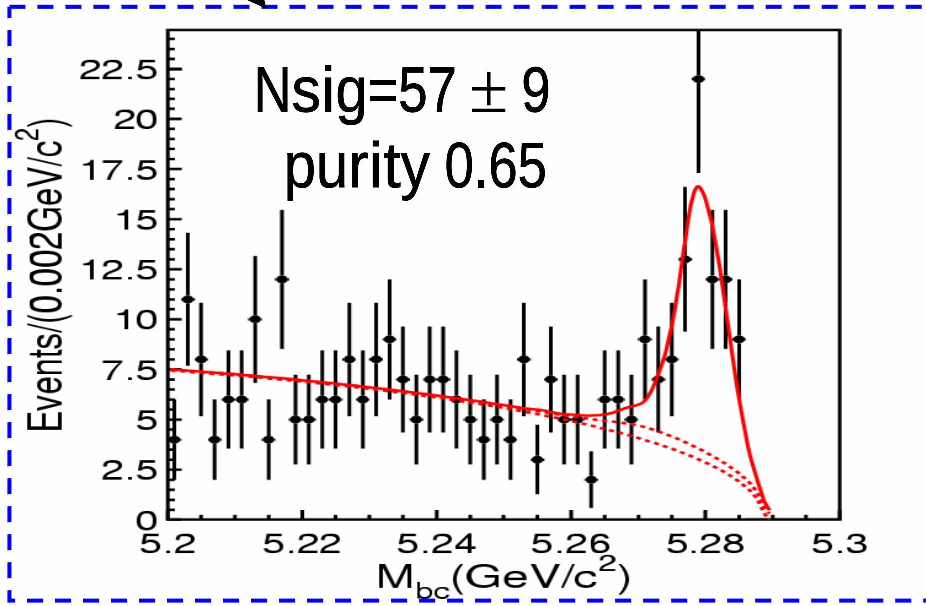
$\mathcal{S} = -0.79 \pm^{0.63}_{0.50} \pm 0.09$

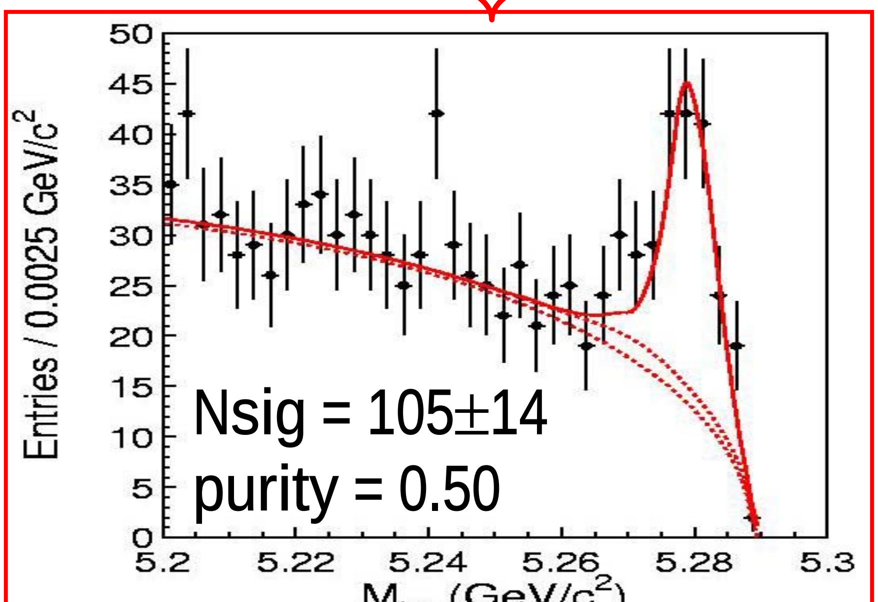
$\mathcal{A}$ fixed at zero

TCPV in $B^0 \to K_S\pi^0\gamma$ (incl. $K^*[K_S\pi^0]$)

hep-ph/04111056







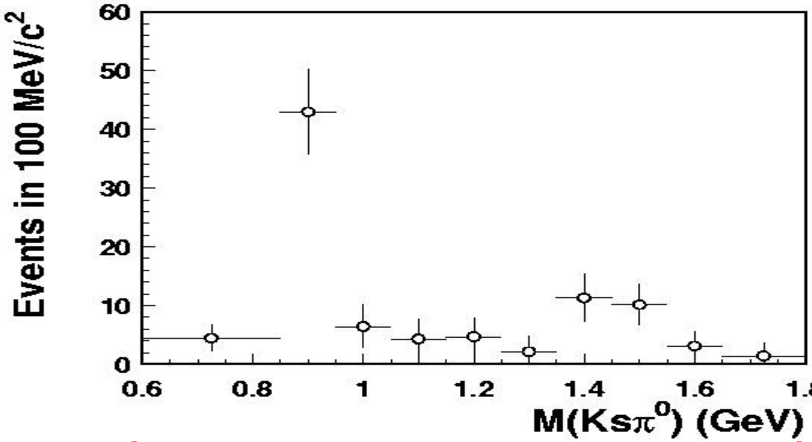
$0.6 < M(K_S\pi^0) < 1.8\,\mathrm{GeV}/c^2$

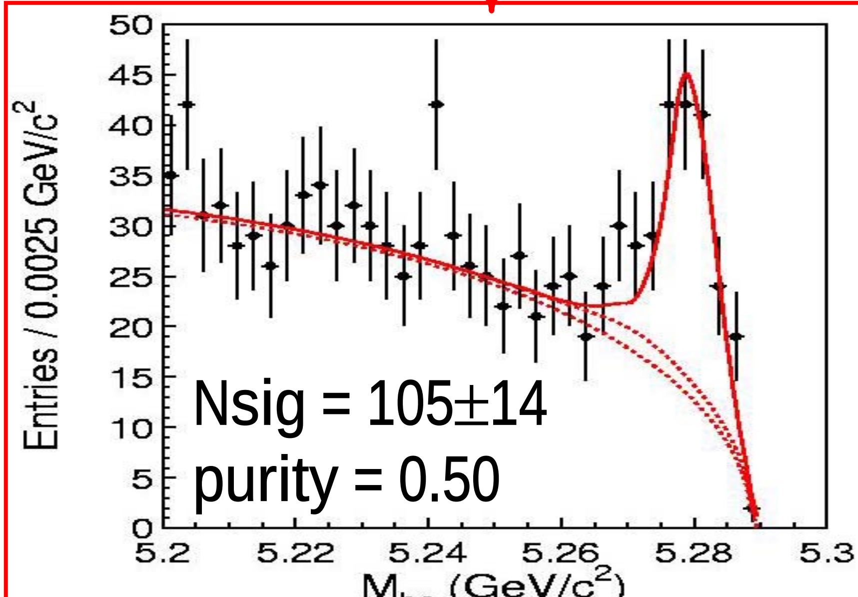
use all including K* region

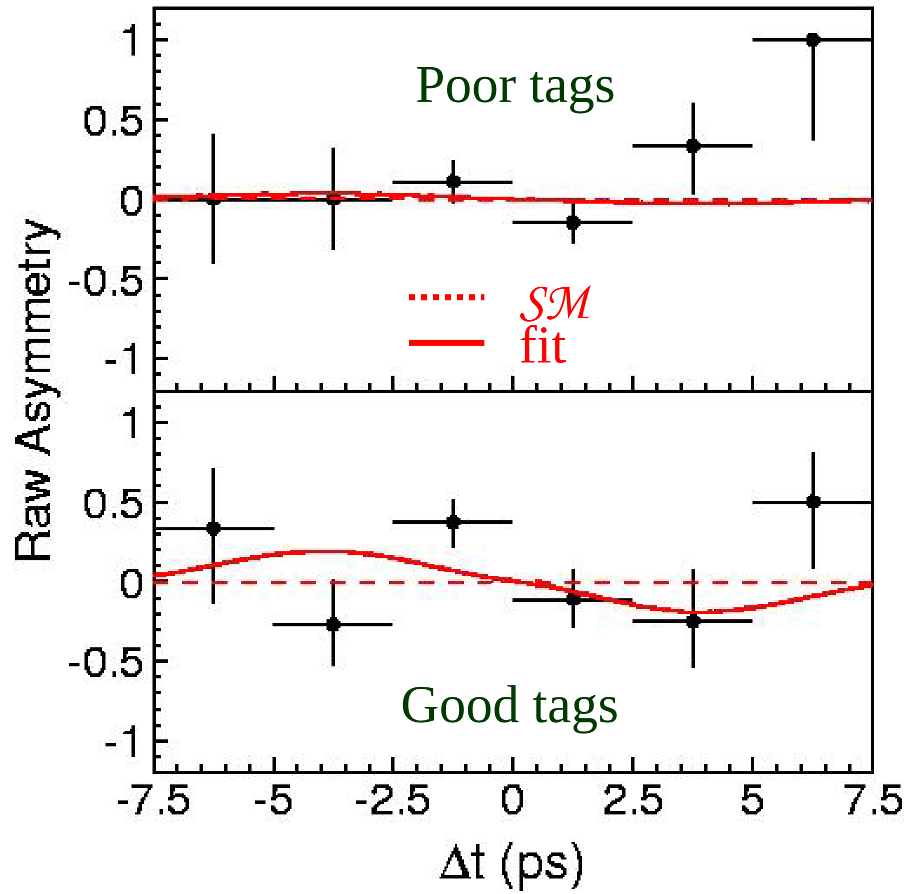
TCPV in $B^0 \to Ks\pi^0\gamma$ (incl. $K^*[Ks\pi^0]$)

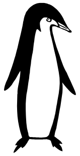
preliminary hep-ph/0411056

$$\mathcal{S} = -0.58 \; ^{+0.46}_{-0.38} \; \pm 0.11$$
$$\mathcal{A} = +0.03 \; \pm 0.34 \; \pm 0.11$$

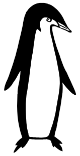








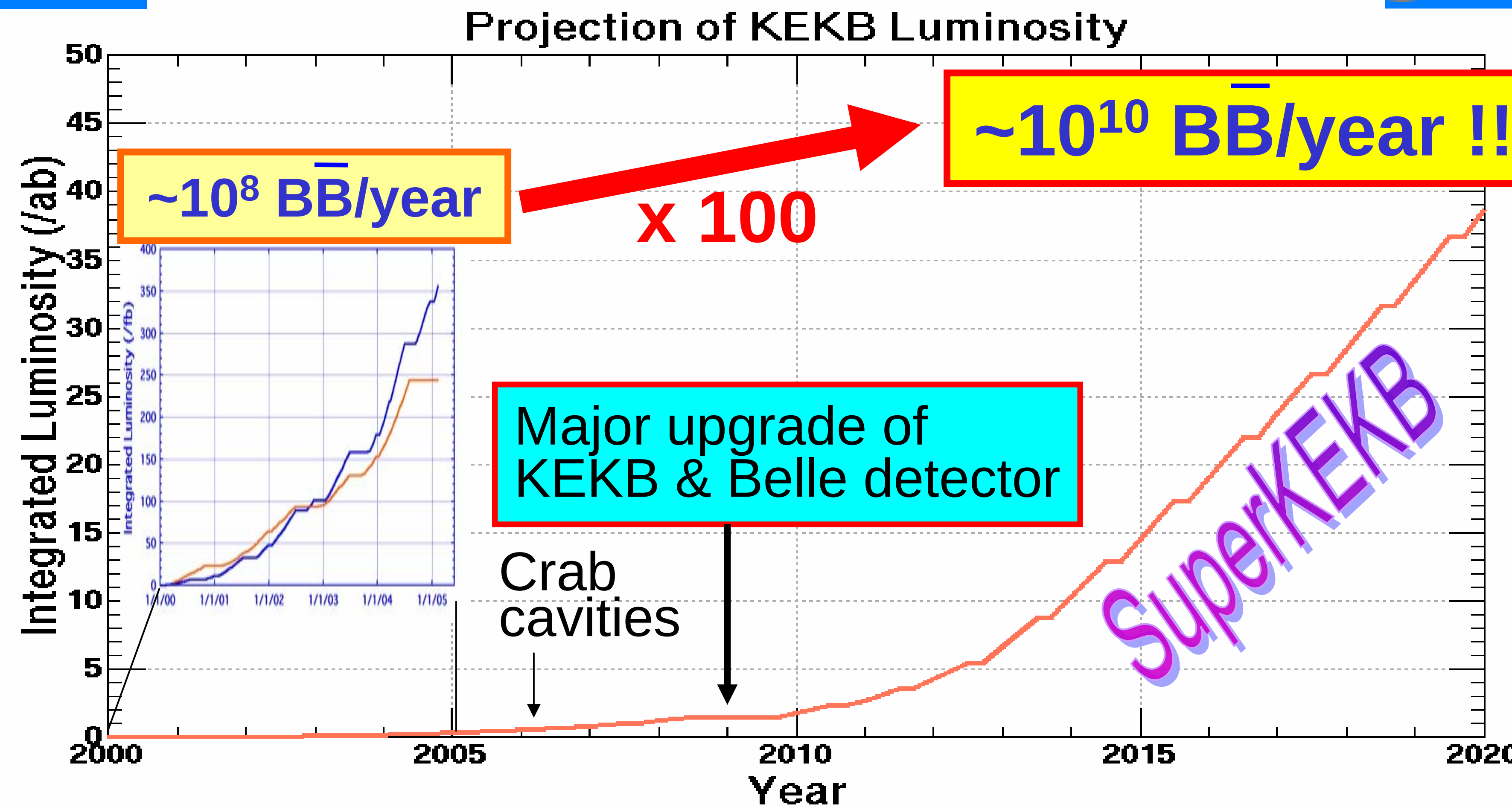
Summary of Current Status $\sin 2\phi_1$ & b→s TCPV



- Accuracy of $\sin 2\phi_1$ is ~5%
  - precise test of SM ($\sin 2\phi_1 = +0.726 \pm 0.037$)
- *TCPV* in hadronic $b \rightarrow s$ penguins
  - $\boxed{3.8\sigma}$ away from SM expectation with all results combined ("$\sin 2\phi_1$" $= +0.41 \pm 0.07$)
- *TCPV* in radiative $b \rightarrow s$ penguins
  - Reference point of SM is S~A~0
  - $B^0 \rightarrow K_S \pi^0 \gamma$ (incl. $K^*\gamma$) consistent with SM (~1σ)

Improved impressive results will come as data increases

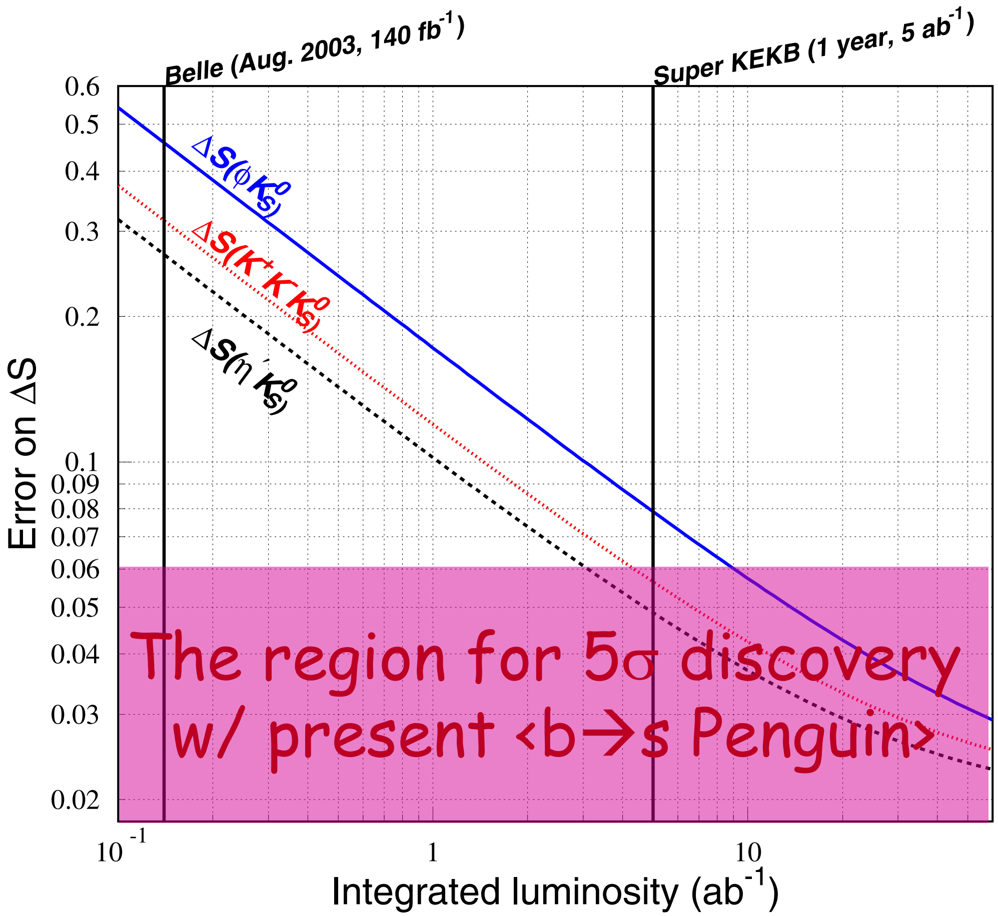
Super-KEKB

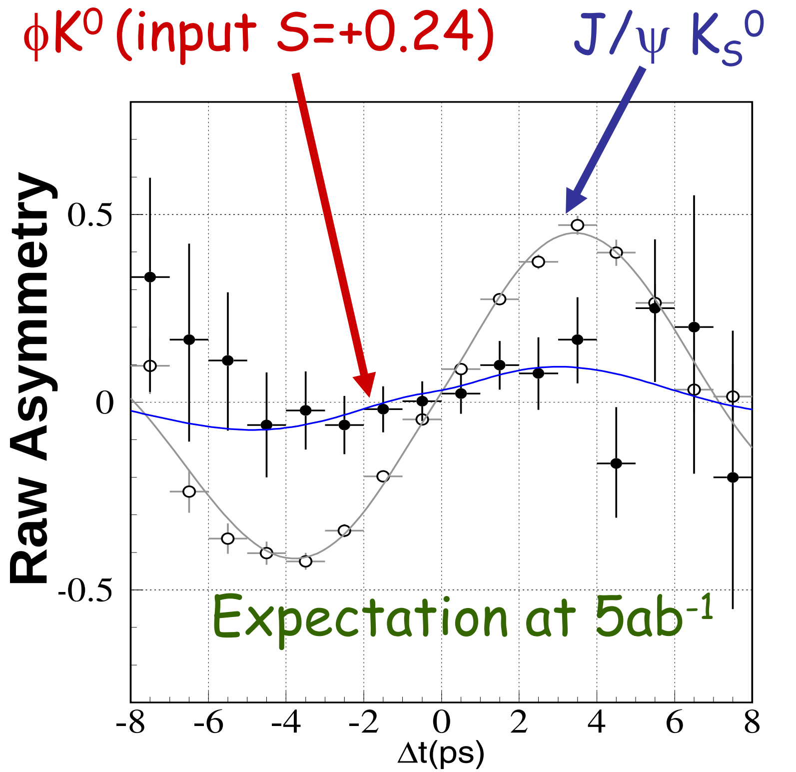


L_{peak} ($cm^{-2}s^{-1}$)	1.4×10^{34}	5×10^{34}	2.5×10^{35}
L_{int}	330 fb^{-1}	~1 ab^{-1}	~10 ab^{-1}

Hadronic b→s TCPV

Deviation of "sin2ϕ_1" can be tested with 5σ accuracy using few years of data





Summary of sin2ϕ_1 & b→s TCPV

- Accuracy of sin2ϕ_1 is ~5%
  - precise test of SM (sin2ϕ_1 = +0.726 ± 0.037)
- *TCPV* in hadronic $b \rightarrow s$ penguins
  - 3.8σ away from SM expectation with all results combined ("sin2ϕ_1" = +0.41 ± 0.07)
- *TCPV* in radiative $b \rightarrow s$ penguins
  - Reference point of SM is S~A~0
  - $B^0 \rightarrow K_S\pi^0\gamma$ (incl. $K^*\gamma$) consistent with SM (~1σ)

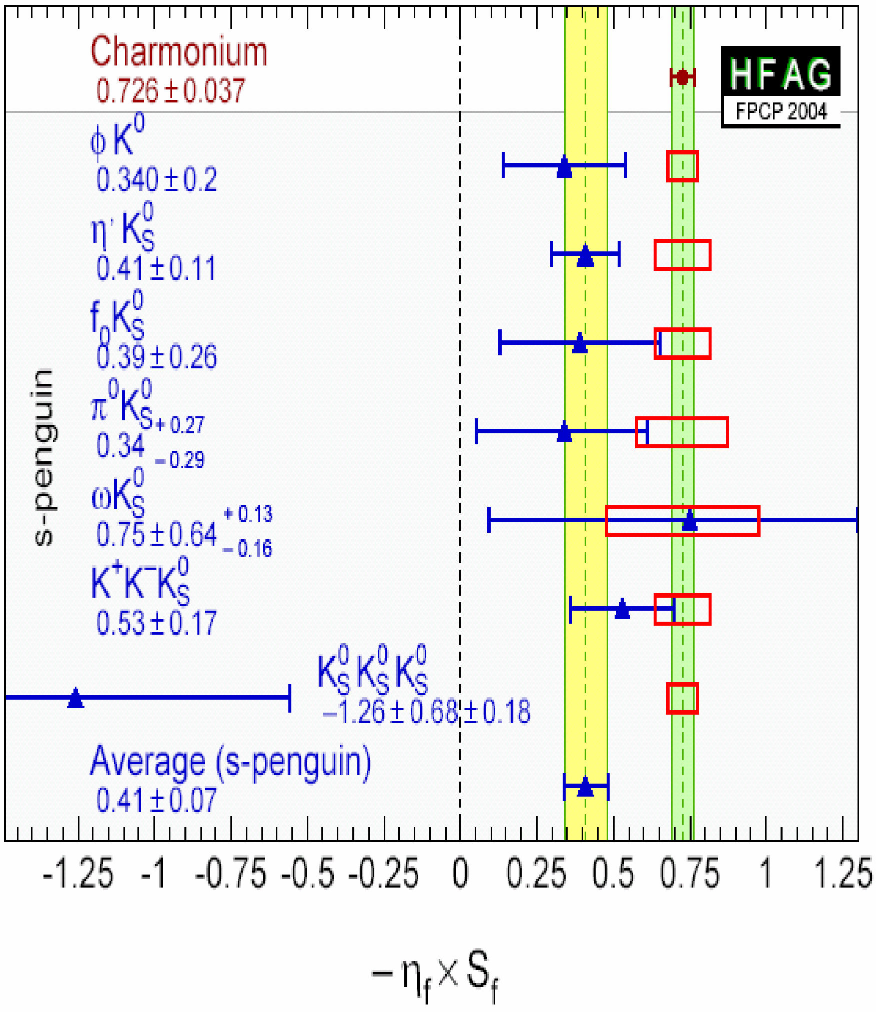
Future Prospects

Very impressive results will come with Super-B factory

Backup slides

Theoretical uncertainties of "sin2ϕ_1"

Theoretical uncertainties



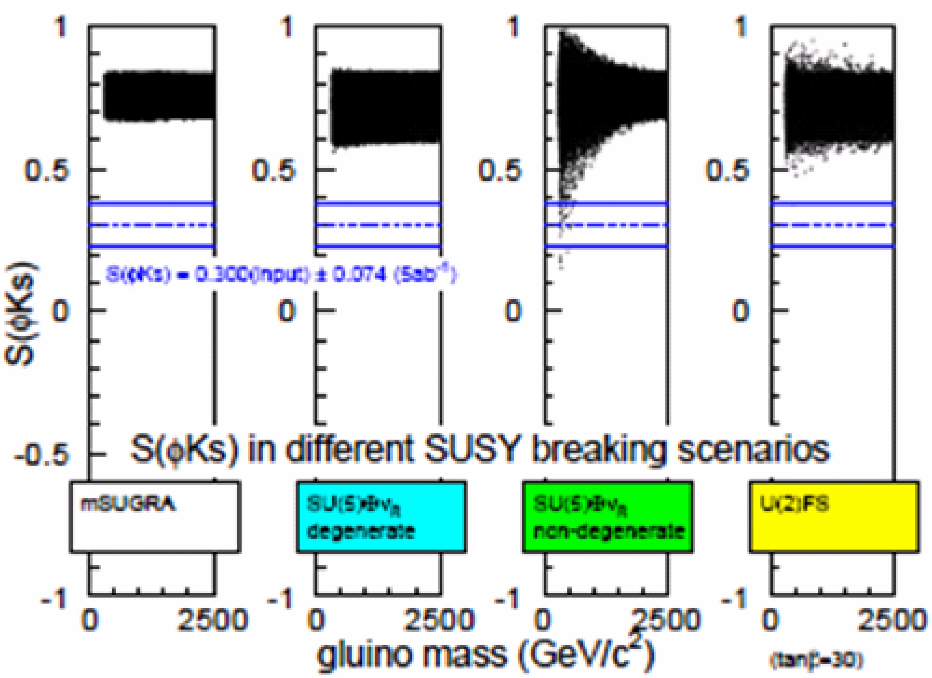
sin2ϕ_1($J/\Psi K_S$)-"sin2ϕ_1(ϕK_S, $\eta' K_S$)"
= 0.33 +- 0.11 (w/ theor. errors)
3.1σ (SM)

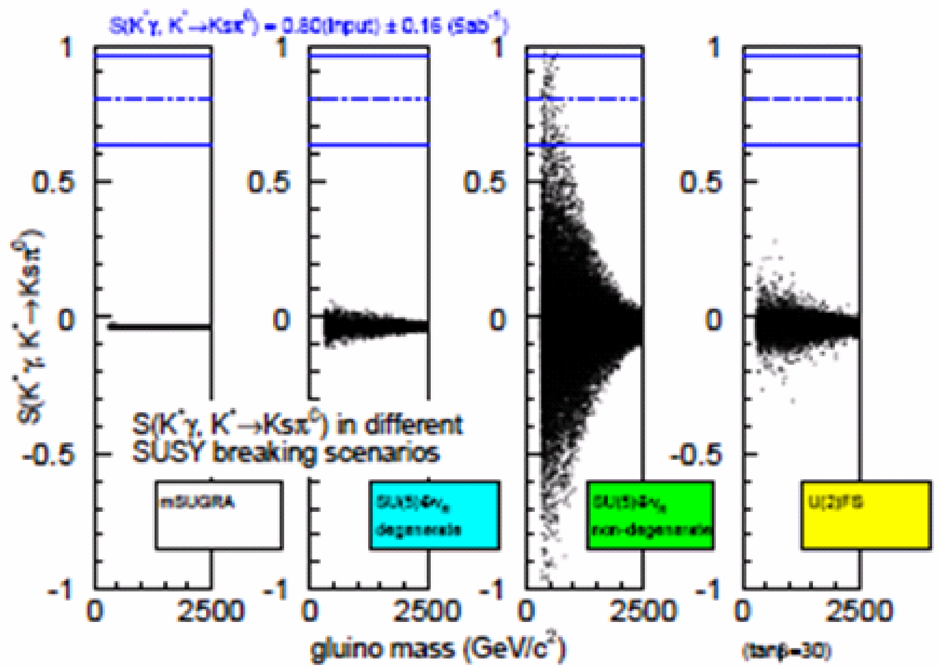
Zoltan Ligeti(LBL) in ICHEP04

Impacts for SUSY models

CP asymmetry in B $\rightarrow \phi$ Ks

CP asymmetry in B $\rightarrow$ K*γ

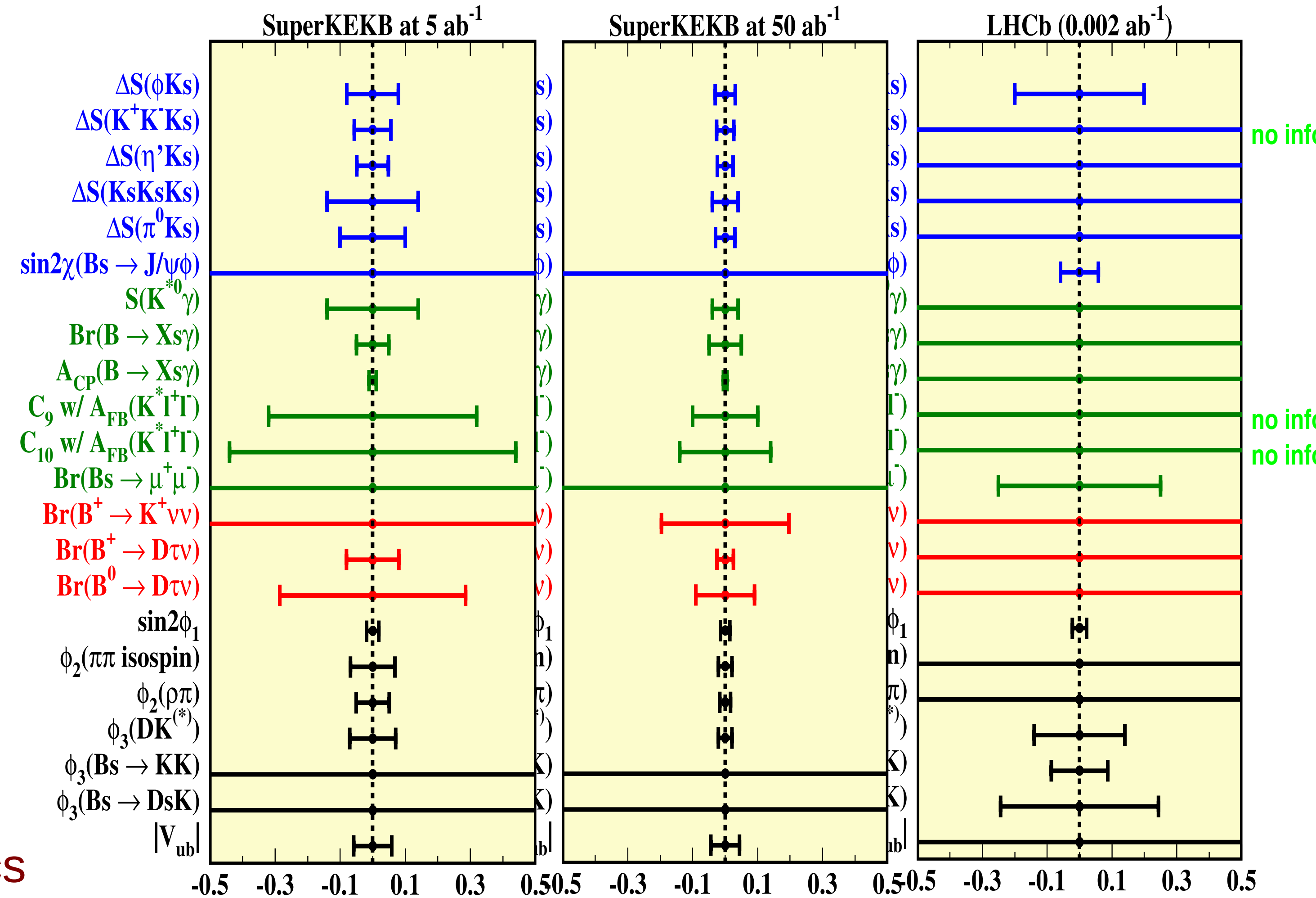




Physics Reach at Super-KEKB

	SuperKEKB ($5\ ab^{-1}$)	($50\ ab^{-1}$)
CPV ($b \to s$)	0.079	0.031
	0.056	0.026
	0.049	0.024
	0.14	0.04
	0.10	0.03
	×	×
FCNC	0.14	0.04
	5%	5%
	0.011	5×10^{-3}
	32%	10%
	44%	14%
	×	×
w/ ν		5.1σ
	8%	2.5%
	3.5σ	9%
CKM	0.019	0.014
	3.9°	1.2°
	2.9°	0.9°
	4°	1.2°
	×	×
	×	×
	5.8%	4.4%

SuperKEKB $5ab^{-1}$ $50ab^{-1}$ LHCb $2fb^{-1}$

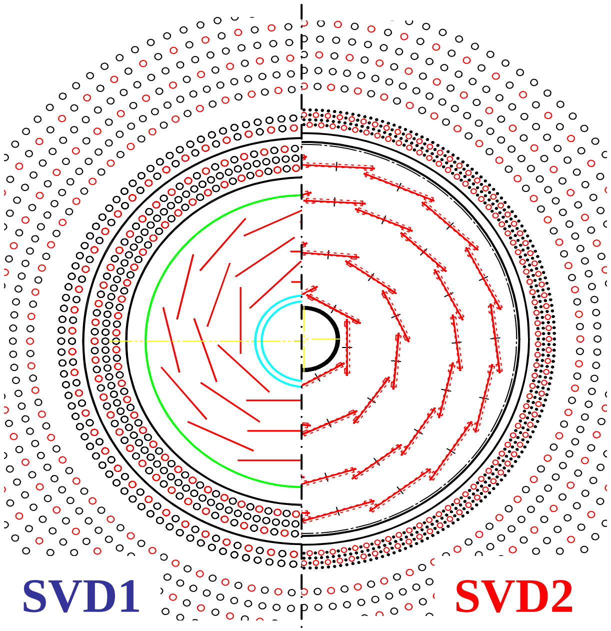


and rich τ physics

Physics at Super B Factory (hep-ex/0406071)

SVD Upgrade (Oct. 2003)

Better I.P. resolutions
Higher efficiency for Ks vertexing



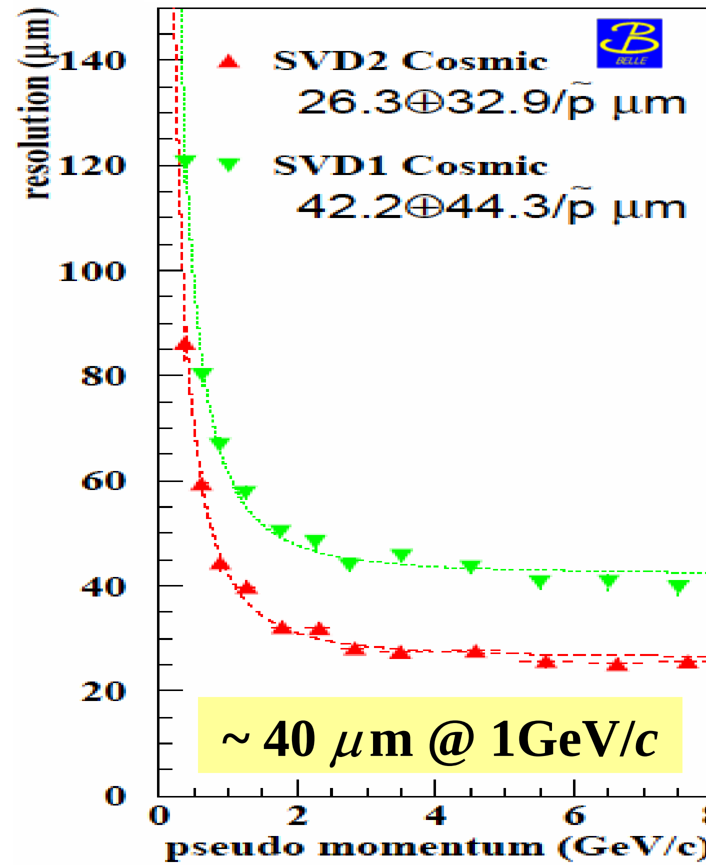
1MRad → > 20MRad

3layers → 4 layers

23°<θ<139° → 17°<θ<150°

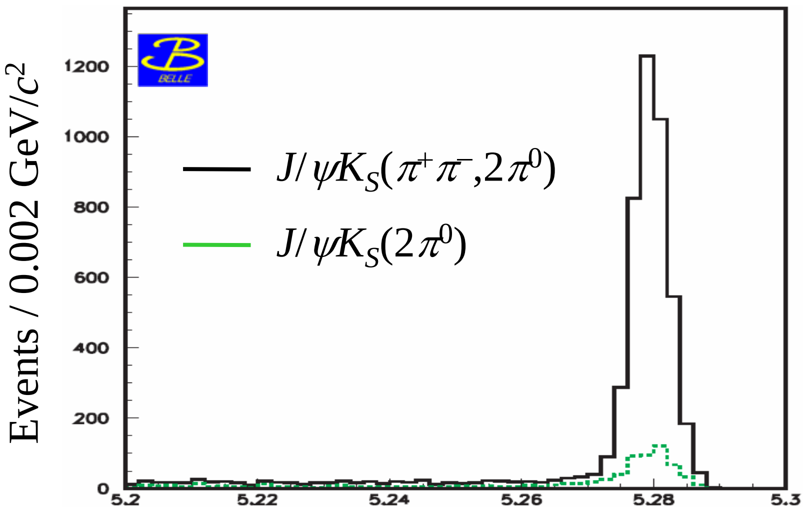
R_{bp} = 2 cm → 1.5 cm

impact parameter resolution in z

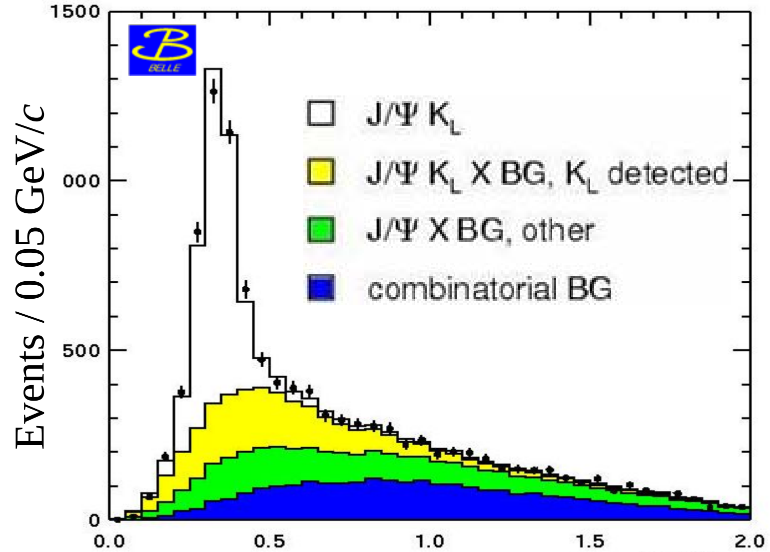


152M $B\bar{B}$ pairs with SVD1
+ 122M $B\bar{B}$ pairs with SVD2

$B^0 \to J/\psi K^0$: 274×10^6 $B\bar{B}$ Pairs



$B^0 \to J/\psi K_S$: Reconstructed mass [GeV/c^2]

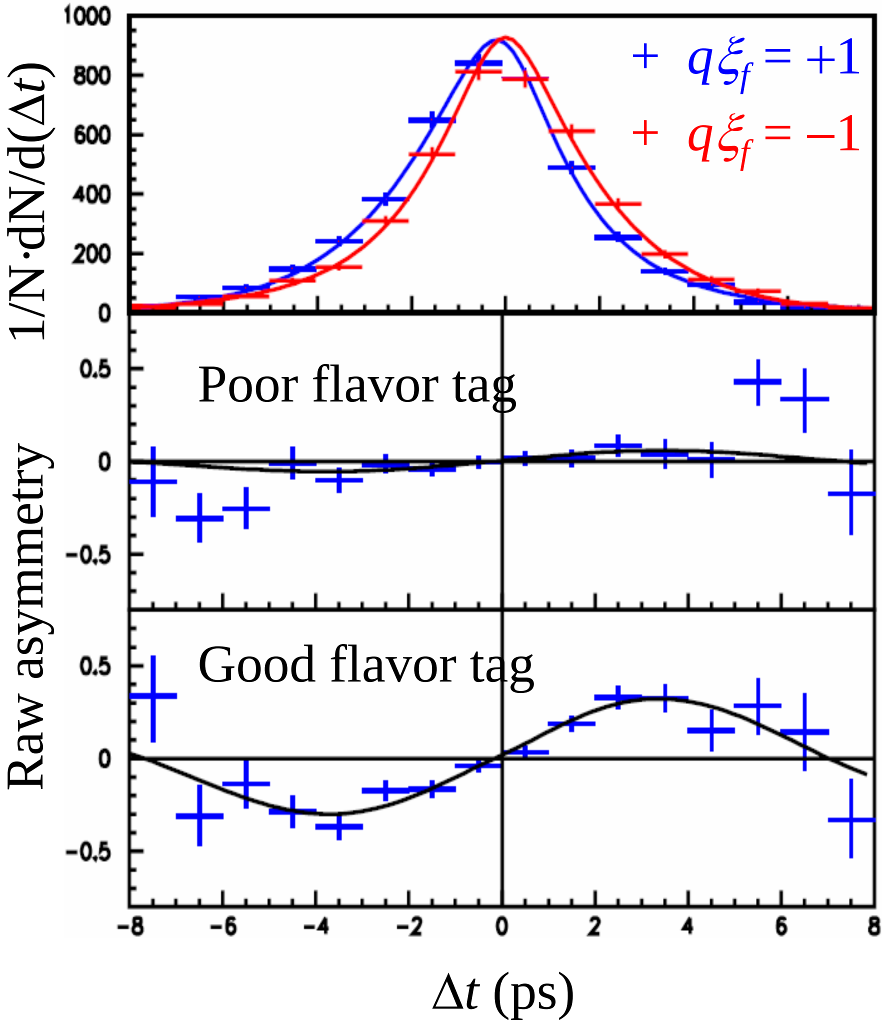


$B^0 \to J/\psi K_L$: Reconstructed P_B* [GeV/c]

Mode	*CP*	N_{sig} (N_{ev} × pur)	Purity [%]
$J/\psi K_S(\pi^+\pi^-, 2\pi^0)$	–1	4150.	96.2
$J/\psi K_L$	+1	2722.	63.1
Total		6872.	

6872 signal events are used in the *CP* asymmetry fit.

$\sin 2\phi_1$ result : 274×10^6 $B\bar{B}$ Pairs



J/ψ K^0 only *preliminary*

$\sin 2\phi_1$ = 0.666 ± 0.046
A = 0.023 ± 0.031

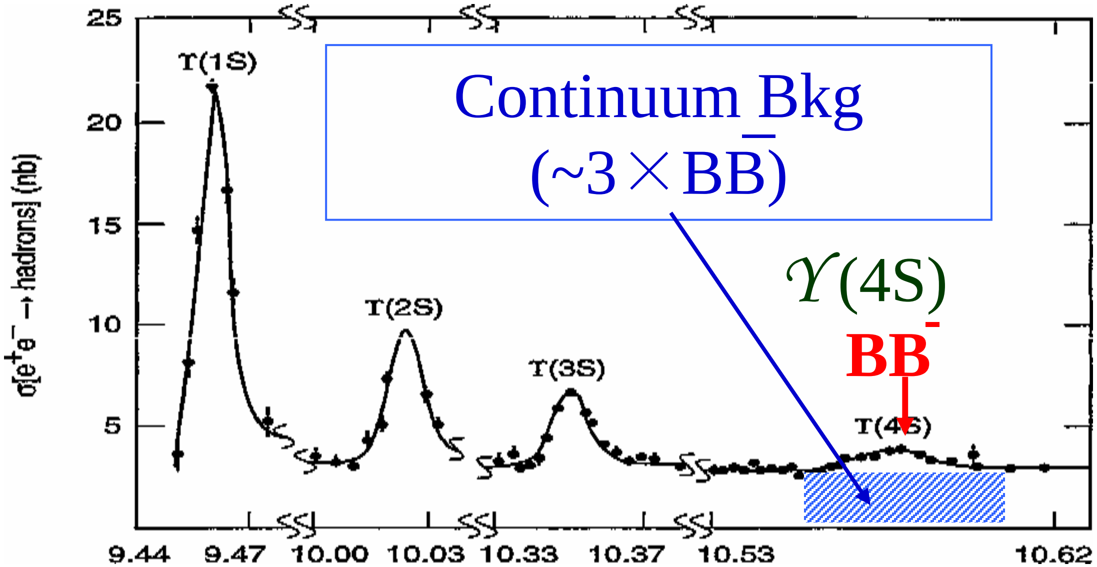
Before upgrade (152×10^6 $B\bar{B}$)

$\sin 2\phi_1$ = 0.696 ± 0.061
A = 0.011 ± 0.043

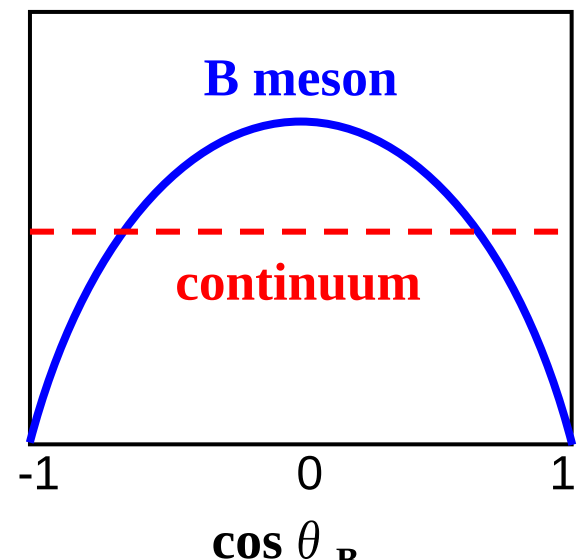
After upgrade (122×10^6 $B\bar{B}$)

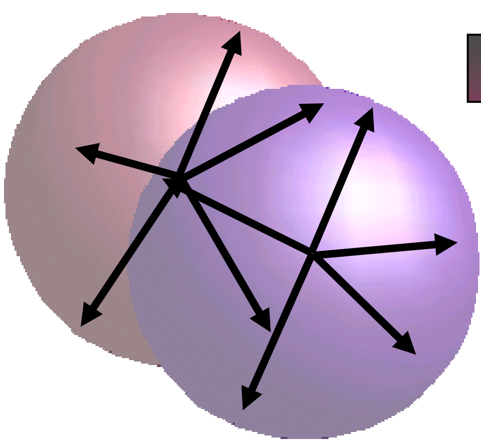
$\sin 2\phi_1$ = 0.629 ± 0.069
A = 0.035 ± 0.044

Continuum Background Suppression



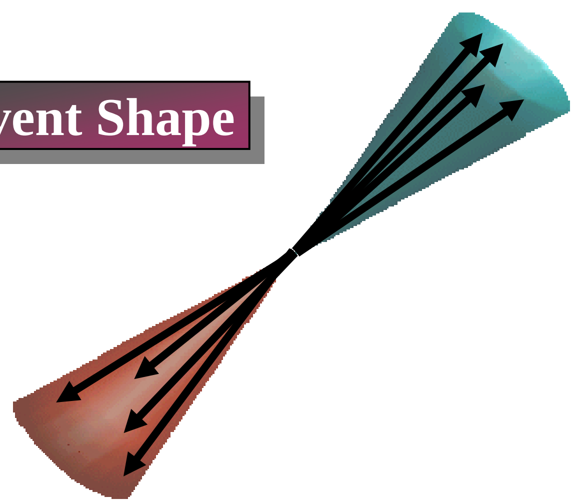
Br(b→s) = 10^{-5} ~10^{-6}
for each modes



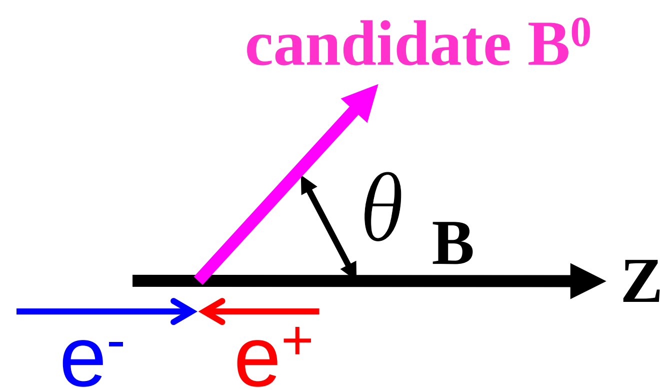


Event Shape

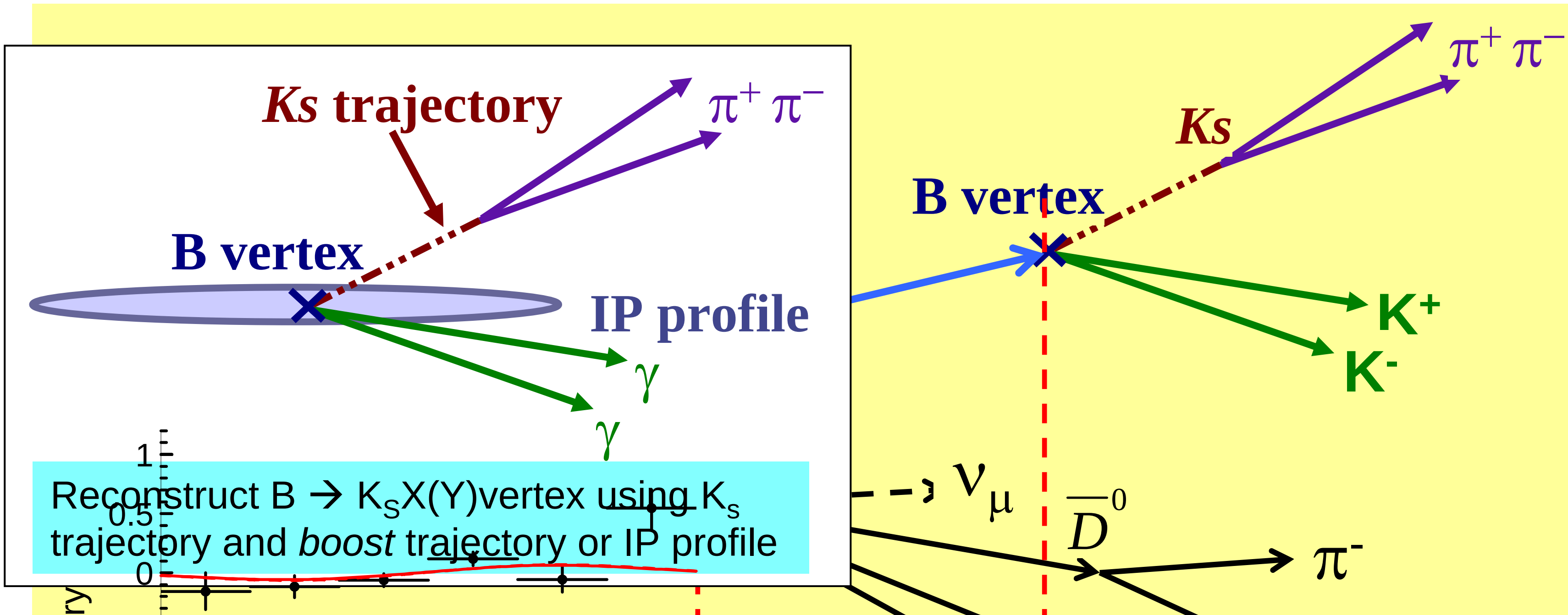
$e^+e^- \to \Upsilon(4S) \to B\bar{B}$
(Spherical)



$e^+e^- \to q\bar{q}$
(Jet-like)

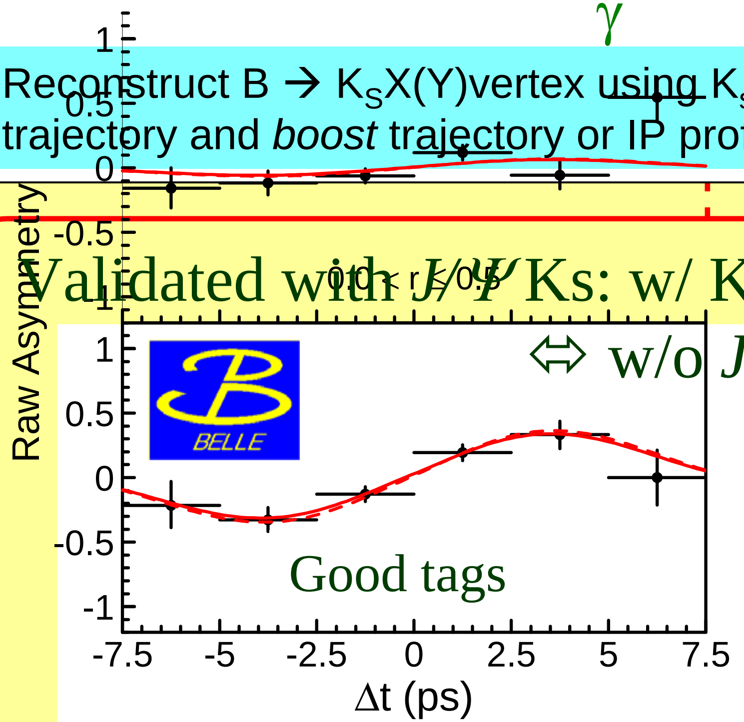


Vertex reconstruction w/ K_S trajectory



Reconstruct B → K_SX(Y)vertex using K_s trajectory and *boost* trajectory or IP profile

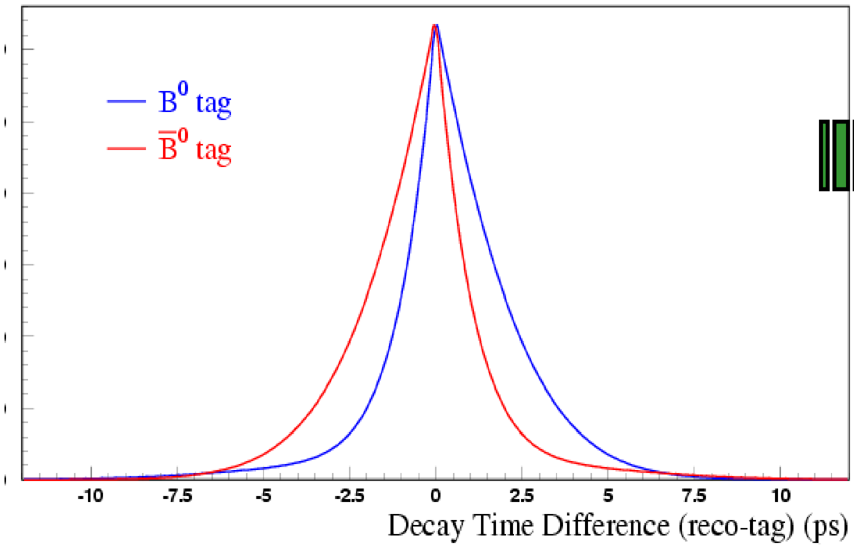
Validated with J/Ψ Ks: w/ K_S vtx ⇔ w/o J/Ψ vtx



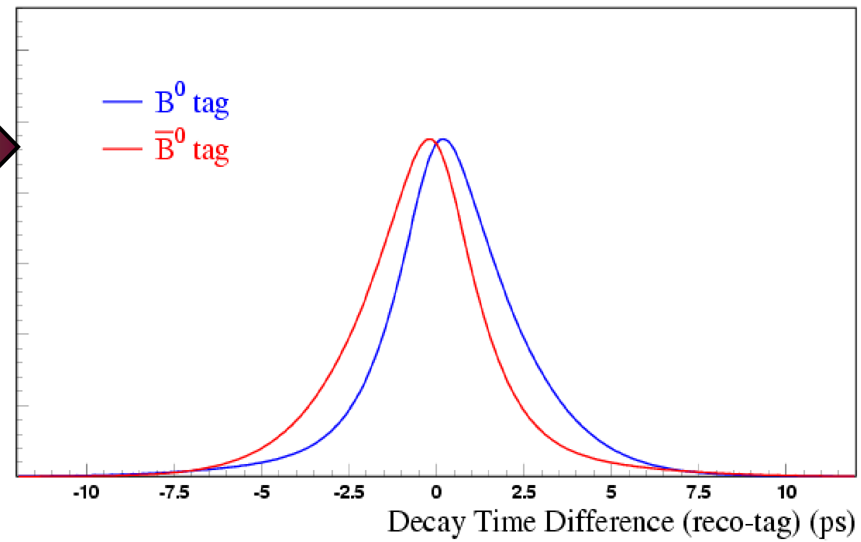
	w/ J/Ψ	w/ K_S
S	+0.65 ±0.05	+0.68 ±0.10
A	+0.01 ±0.04	+0.02 ±0.04

Tagging and Δt resolution parameters

perfect
tagging & time resolution



typical
mistagging & finite time resolution



$$f(\Delta t) = \left[\frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \left\{ 1 \mp (1-2w) S_{f_{cp}} \sin(\Delta m \Delta t) \right\} \right] \otimes R$$

R and w are determined from data with the flavor eigenstates
$B \rightarrow D^{(*)-} \pi^+, \rho^+, a_1^+$ and $J/\Psi K^{*0}$ …

CP asymmetry parameter extraction

Multi-dimensional unbinned maximum likelihood fit

Minimize $-2\sum_i \ln L_i$

Likelihood for the *i*-th event

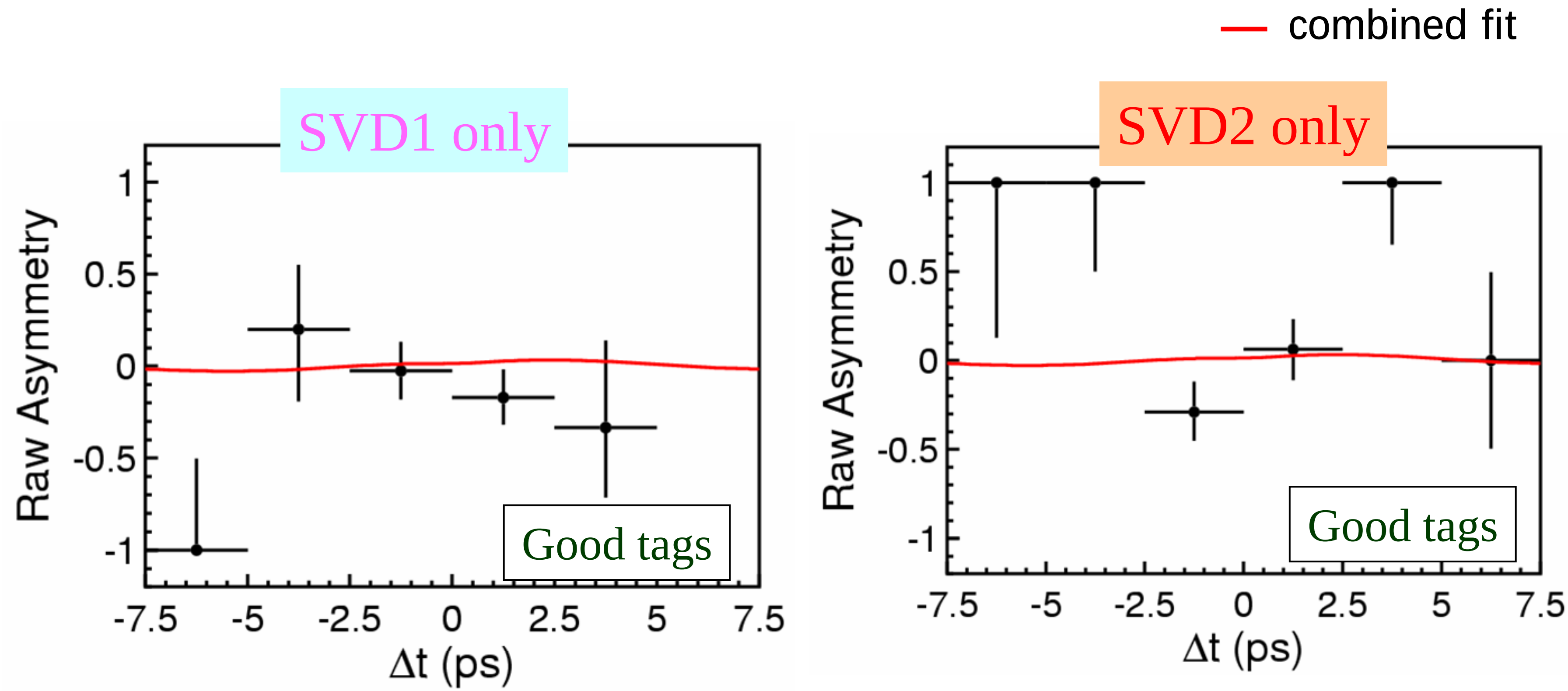
$$L_i = (1 - f_{ol})\left[f_{sig} \cdot P_{sig} \otimes R_{sig} + (1 - f_{sig}) \cdot P_{bkg} \otimes R_{bkg} \right] + f_{ol} \cdot P_{ol}$$

$$P_{sig}(\Delta t; S, A, q, w, \Delta w) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 - q \cdot \Delta w + q(1 - 2w)\left\{\boxed{S}\sin(\Delta m \Delta t) + \boxed{A}\cos(\Delta m \Delta t)\right\}\right]$$

Free parameters

Raw asymmetry plot is just a projection onto Δt axis.
Fitting is not in 1-dimension (Δt)

SVD1/2 Data Checks



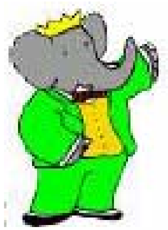
SVD1:
$\mathcal{S} = -0.68 \pm 0.46$
$\mathcal{A} = -0.02 \pm 0.28$

4.5%
$\leftrightarrow$

SVD2:
$\mathcal{S} = +0.78 \pm 0.45$
$\mathcal{A} = +0.17 \pm 0.33$

many systematic checks, all ok

$\phi K_S/K_L$ Results

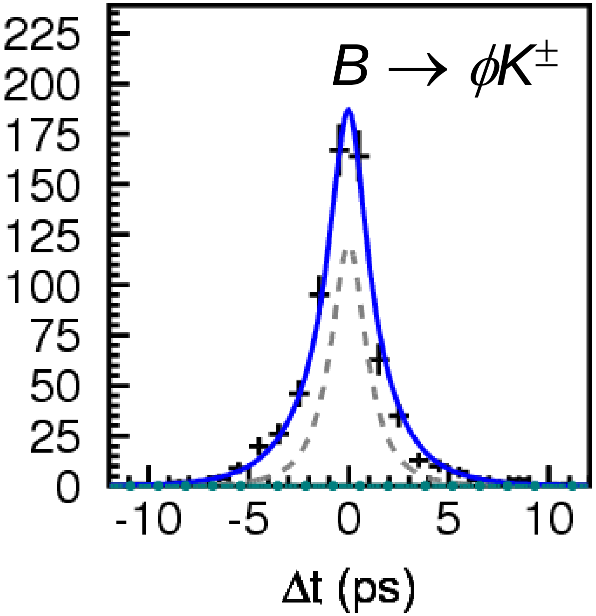
ϕK_S only		ϕK_L only
$\mathcal{S} = 0.00 \pm 0.33$ $\mathcal{A} = 0.06 \pm 0.22$	BELLE	$-\mathcal{S} = 2.3 \pm 2.0$ $\mathcal{A} = 0.6 \pm 1.2$
$\mathcal{S} = 0.29 \pm 0.31$ $\mathcal{A} = 0.07 \pm 0.27$		$-\mathcal{S} = 1.05 \pm 0.51$ $\mathcal{A} = -0.31 \pm 0.49$

$B^0 \to \phi K$: Validations

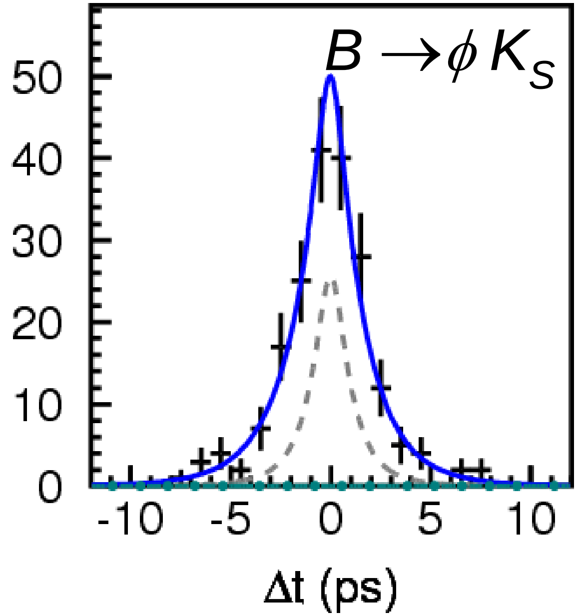
Control sample

Lifetime fit w/ $B \to \phi K^{\pm} / K_S$

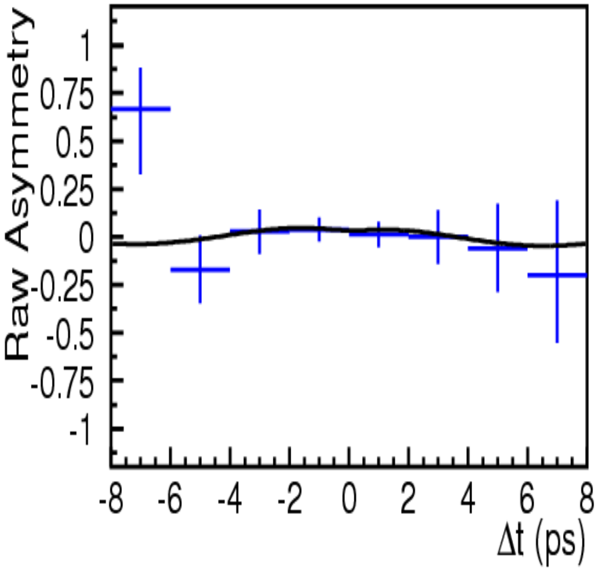
Asymmetry fit w/ $\phi K^{\pm}$



$\tau_{B^+} = 1.67\,^{+0.12}_{-0.11}$



$\tau_{B^0} = 1.59\,^{+0.20}_{-0.19}$



$S(\phi K^{\pm}) = -0.03 \pm 0.20$

$A(\phi K^{\pm}) = +0.22 \pm 0.15$

CP component in B→$K^+K^-K^0_S$ decay

λ-even fraction in $|K^0\overline{K}^0>$ can be determined by $|K_SK_S>$ system

$$|K^0\overline{K}^0\rangle = \frac{\alpha}{\sqrt{2}}(|K_SK_S\rangle + |K_LK_L\rangle) + \beta|K_SK_L\rangle$$

$CP = +1$ λ = even λ = odd

$$|K^+K^0\overline{K}^0\rangle = \frac{\alpha}{\sqrt{2}}\left(|K^+K_SK_S\rangle + |K^+K_LK_L\rangle\right) + \beta|K^+K_SK_L\rangle$$

Using isospin symmetry,

$$\mathcal{B}(B^+ \to K^+K^0\overline{K}^0) = \mathcal{B}(B^0 \to K^0K^+K^-)\times\frac{\tau_{B+}}{\tau_{B^0}}$$

$$\alpha^2 = 2\frac{\mathcal{B}(B^+ \to K^+K_SK_S)}{\mathcal{B}(B^0 \to K^0K^+K^-)}\times\frac{\tau_{B^0}}{\tau_{B+}} = \frac{\mathcal{B}(B^+ \to K^+K_SK_S)}{\mathcal{B}(B^0 \to K_SK^+K^-)}\times\frac{\tau_{B^0}}{\tau_{B+}} = \underline{1.03 \pm 0.15(\mathrm{stat}) \pm 0.05(\mathrm{syst})}$$

Available decay modes ($P^0 = Q^0$ only)

	P^0							
X^0	π^0	η	η'	f_0	a_0	K_S^0	K_L^0	D_{CP}
π^0	$\underline{\pi^0\pi^0\pi^0}$	$\eta\eta\pi^0$	$\eta'\eta'\pi^0$	$f_0 f_0\pi^0$	$a_0 a_0\pi^0$	$\underline{K_S^0 K_S^0\pi^0}$	$K_L^0 K_L^0\pi^0$	$D_{CP}D_{CP}\pi^0$
η	$\pi^0\pi^0\eta$	$\eta\eta\eta$	$\eta'\eta'\eta$	$f_0 f_0\eta$	$a_0 a_0\eta$	$K_S^0 K_S^0\eta$	$K_L^0 K_L^0\eta$	$D_{CP}D_{CP}\eta$
η'	$\pi^0\pi^0\eta'$	$\eta\eta\eta'$	$\eta'\eta'\eta'$	$f_0 f_0\eta'$	$a_0 a_0\eta'$	$K_S^0 K_S^0\eta'$	$K_L^0 K_L^0\eta'$	$D_{CP}D_{CP}\eta'$
f_0	$\pi^0\pi^0 f_0$	$\eta\eta f_0$	$\eta'\eta' f_0$	$f_0 f_0 f_0$	$a_0 a_0 f_0$	$K_S^0 K_S^0 f_0$	$K_L^0 K_L^0 f_0$	$D_{CP}D_{CP} f_0$
a_0	$\pi^0\pi^0 a_0$	$\eta\eta a_0$	$\eta'\eta' a_0$	$f_0 f_0 a_0$	$a_0 a_0 a_0$	$K_S^0 K_S^0 a_0$	$K_L^0 K_L^0 a_0$	$D_{CP}D_{CP} a_0$
K_S^0	$\underline{\pi^0\pi^0 K_S^0}$	$\underline{\eta\eta K_S^0}$	$\underline{\eta'\eta' K_S^0}$	$f_0 f_0 K_S^0$	$a_0 a_0 K_S^0$	$\underline{\underline{K_S^0 K_S^0 K_S^0}}$	$K_L^0 K_L^0 K_S^0$	$D_{CP}D_{CP} K_S^0$
K_L^0	$\pi^0\pi^0 K_L^0$	$\eta\eta K_L^0$	$\eta'\eta' K_L^0$	$f_0 f_0 K_L^0$	$a_0 a_0 K_L^0$	$\underline{K_S^0 K_S^0 K_L^0}$	$K_L^0 K_L^0 K_L^0$	$D_{CP}D_{CP} K_L^0$
D_{CP}	$\pi^0\pi^0 D_{CP}$	$\eta\eta D_{CP}$	$\eta'\eta' D_{CP}$	$f_0 f_0 D_{CP}$	$a_0 a_0 D_{CP}$	$\underline{K_S^0 K_S^0 D_{CP}}$	$K_L^0 K_L^0 D_{CP}$	
η_c	$\pi^0\pi^0\eta_c$	$\eta\eta\eta_c$	$\eta'\eta'\eta_c$	$f_0 f_0\eta_c$	$a_0 a_0\eta_c$	$K_S^0 K_S^0\eta_c$	$K_L^0 K_L^0\eta_c$	
χ_{c0}	$\pi^0\pi^0\chi_{c0}$	$\eta\eta\chi_{c0}$	$\eta'\eta'\chi_{c0}$	$f_0 f_0\chi_{c0}$	$a_0 a_0\chi_{c0}$	$K_S^0 K_S^0\chi_{c0}$	$K_L^0 K_L^0\chi_{c0}$	

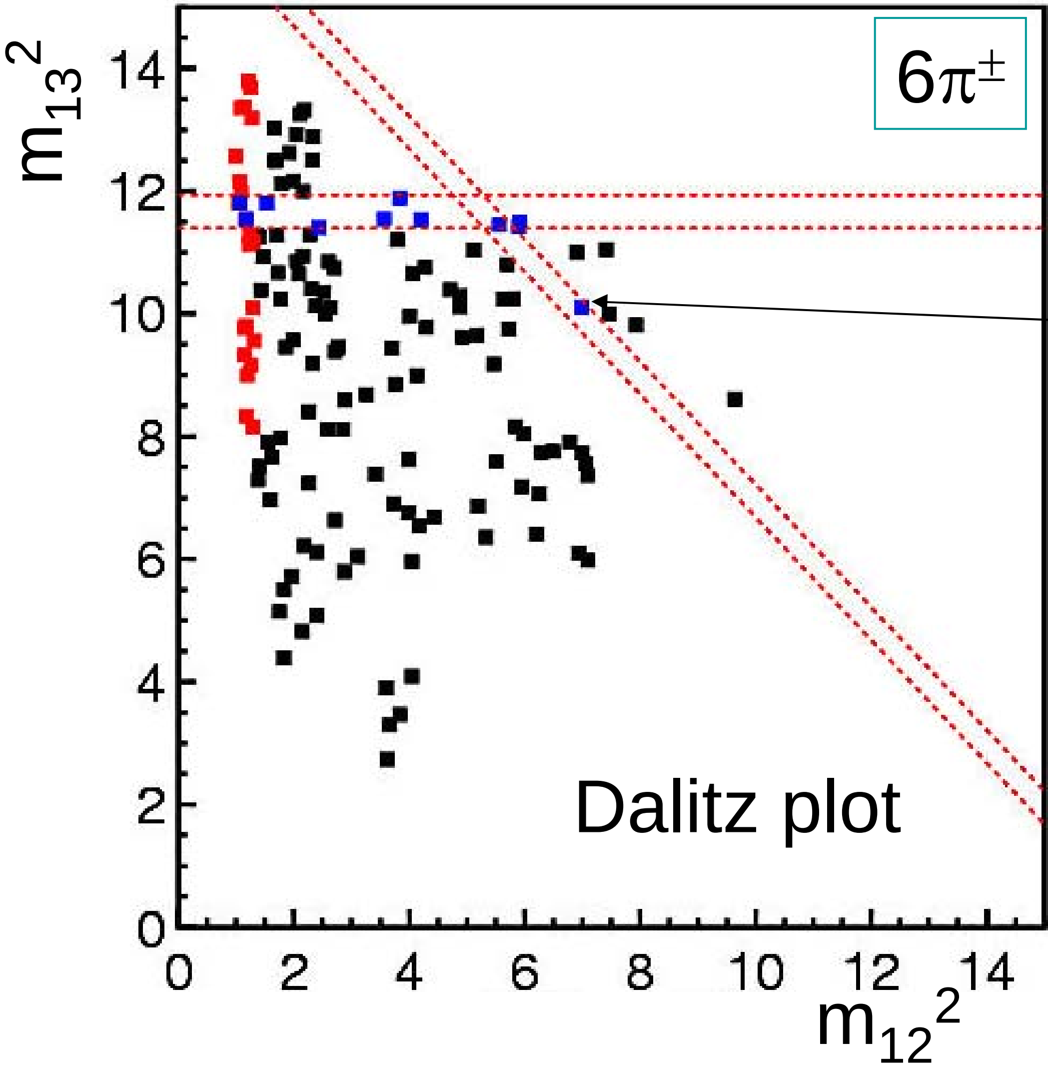
Table 1: Possible $B^0 \to P^0 P^0 X^0$ final states. Underlined modes are discussed in detail in the text. The doubly underlined mode $B^0 \to K_S^0 K_S^0 K_S^0$ has already been observed.

Systematic errors on $\mathcal{S}$

	Ks π^0	$K^*\gamma$	ω Ks	η' Ks	f_0 Ks	ϕ K^0	K^+K^-Ks
VTX	0.02	0.06	0.01	0.01	0.02	0.01	0.01
flavor tag	0.01	0.02	0.04	0.01	0.01	0.01	<0.01
resolution	0.05	0.05	0.07	0.03	0.03	0.04	0.03
fit bias	0.03	0.03	+0.01 –0.10	0.01	0.03	0.01	0.01
signal fraction	0.07	0.02	0.10	0.02	0.05	+0.08 –0.06	0.02
physics parameters	0.02	0.01	0.01	<0.01	0.01	<0.01	<0.01
background Δt shape	0.04	0.03	0.02	<0.01	0.04	0.01	<0.01
tag side interference	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
TOTAL	0.11	0.10	+0.13 –0.16	0.04	0.08	0.09	0.04

KKKS: effective $\sin 2\phi_1 \rightarrow$ 0.17 for CP-even fraction

$B^0 \to KsKsKs$ peaking background rejection



$B^0 \to \chi_{c0} Ks \to KsKsKs$

$b \to ccs$

VETOed

$B^0 \to D^0_{CP} Ks \to KsKsKs$

$B^0 \to f_0(980) Ks \to KsKsKs$

$b \to s$

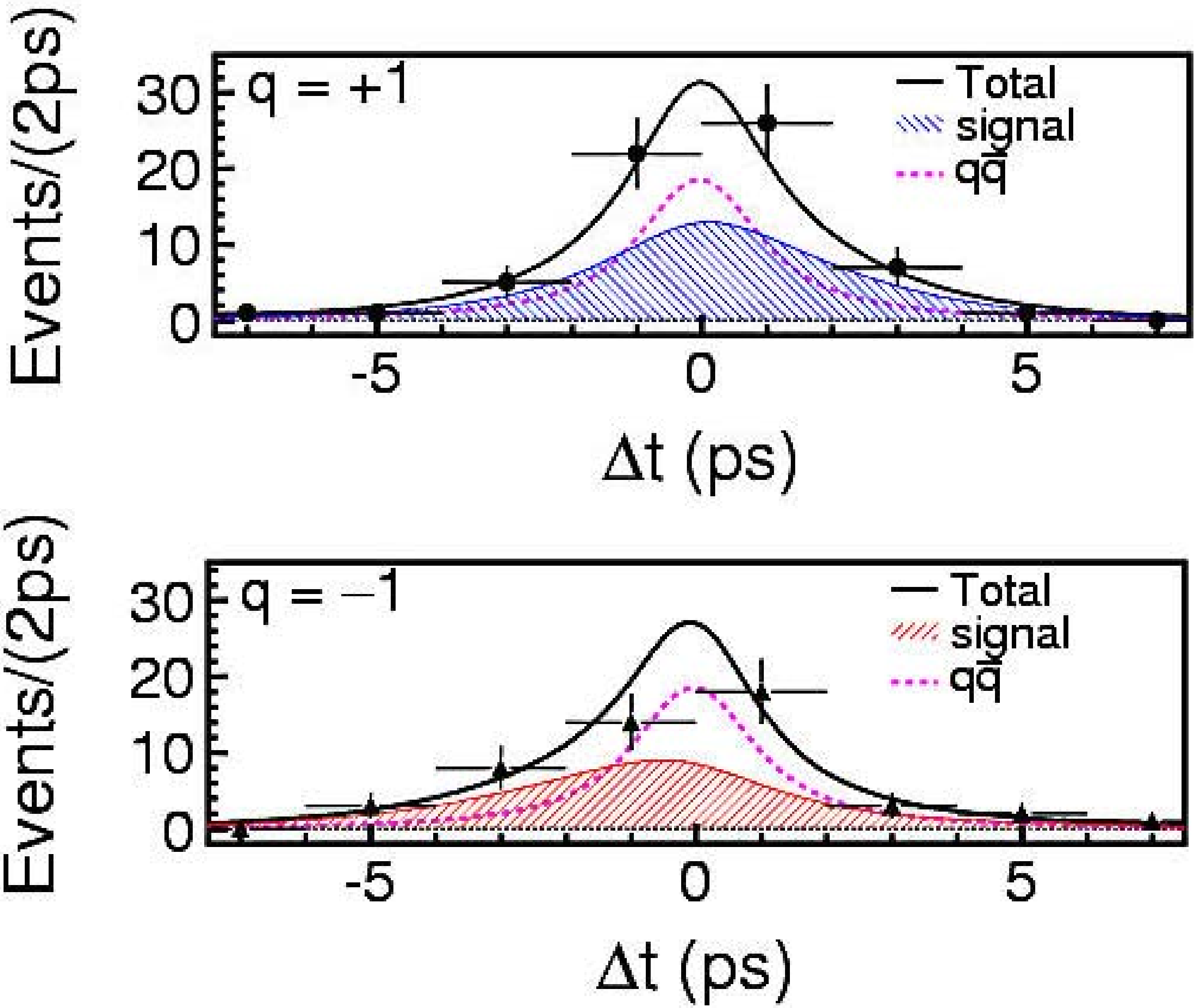
kept

$(P^*(Ks_1) < P^*(Ks_2) < P^*(Ks_3))$

$B^0 \to KsKsKs$ vertex reconstruction

	vertex eff. (SVD1)	vertex eff. (SVD2)
$3(\pi+\pi-)$ [3 tight]	77%	86%
$3(\pi+\pi-)$ [2 tight,1 loose]	83%	87%
$2(\pi+\pi-)$ $1(\pi 0 \pi 0)$	62%	74%

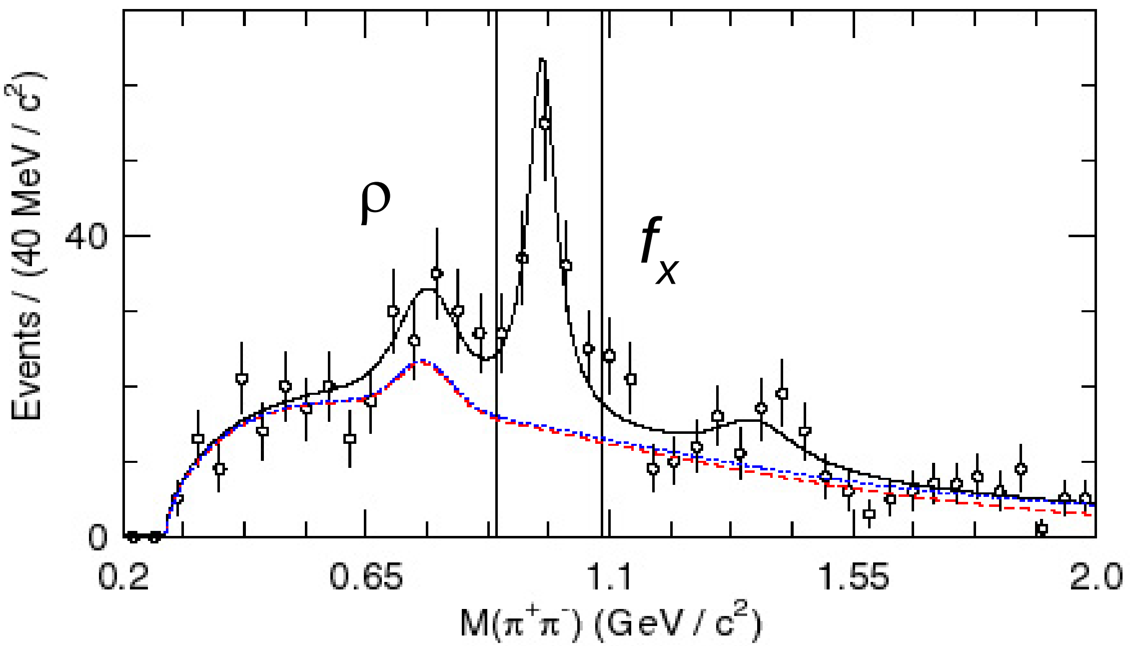
$B^0 \to KsKsKs$ proper time distribution



$B^0 \to KsKsKs$ systematic error

	$\mathcal{S}$	$\mathcal{A}$
Signal fraction	0.103	0.033
Possible fit bias	0.030	0.018
Vertexing	0.021	0.047
Background Δt shape	0.078	0.011
Δt resolution function	0.119	0.041
Tag-side interference	0.019	0017
Flavor tagging	0.040	0.008
Physics parameters	0.006	0.005
Total	0.18	0.08

$f_0(980)K_S$:$\pi^+\pi^-$ Mass didtribution



Non-f_0 components are determined from the M($\pi^+\pi^-$) distribution

- f(f_0K_S) = 91%
- f($\pi^+\pi^-K_S$) = 2.3%
- f(ρ^0K_S) = 4.8%
- f(f_xK_S) = 1.6%