CKM Phases: φ_1/β

Tom Browder (University of Hawaii)

Belle and BaBar results

Measurements of large CPV in $b \rightarrow c\,\bar{c}\,s$ modes

Studies in $b \rightarrow c\,\bar{c}\,d$ modes

Search for New Physics: CPV in $b \rightarrow s$ penguin modes

KM ansatz: CPV is due to a complex phase in the quark mixing matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\begin{pmatrix} Vud & Vus & Vub \\ Vcd & Vcs & Vcb \\ Vtd & Vts & Vtb \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

The B Physics Program

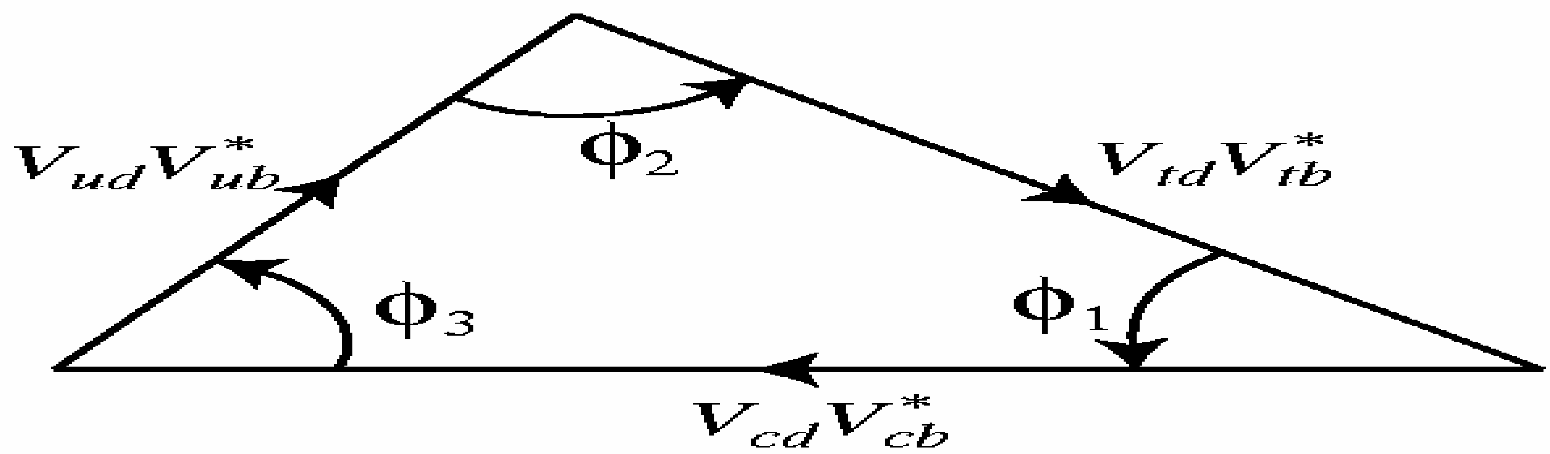
Quark couplings are complex and lead to CP violation. *Is CP violation a result of a single weak phase in the KM matrix ?*

Or is it a signal of new interactions beyond the Standard Model ?

Is there new physics in loop decays ?

Notational Conventions

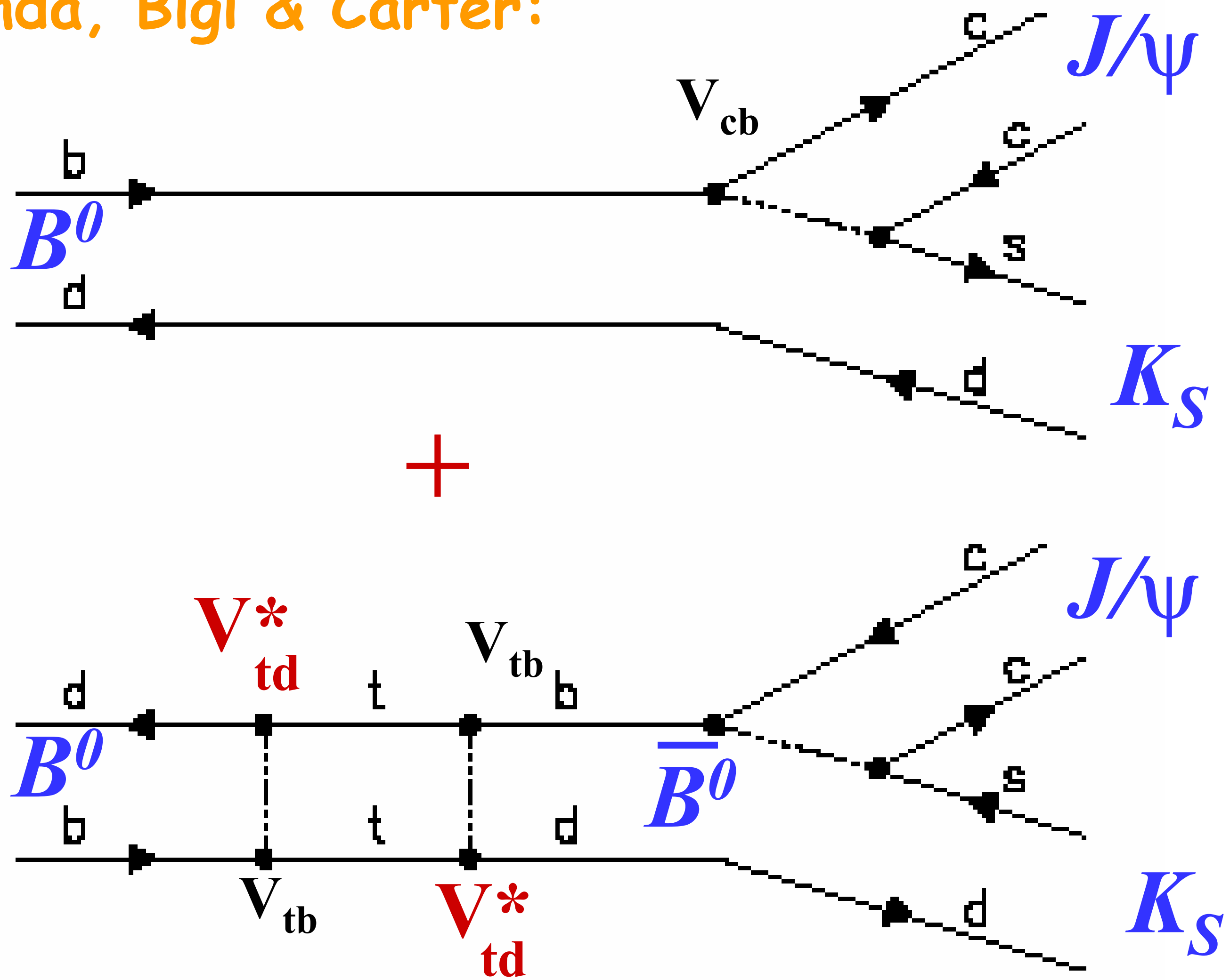
Three Angles: $(\varphi_1, \varphi_2, \varphi_3)$ *or* (β, α, γ)



Birthname: Matsui	Nickname: Godzilla
ϕ_1	β
ϕ_2	α
ϕ_3	γ

$\sin 2\phi_1$ from $B \to f_{CP} + B \leftrightarrow \bar{B} \to f_{CP}$ interf.

Sanda, Bigi & Carter:



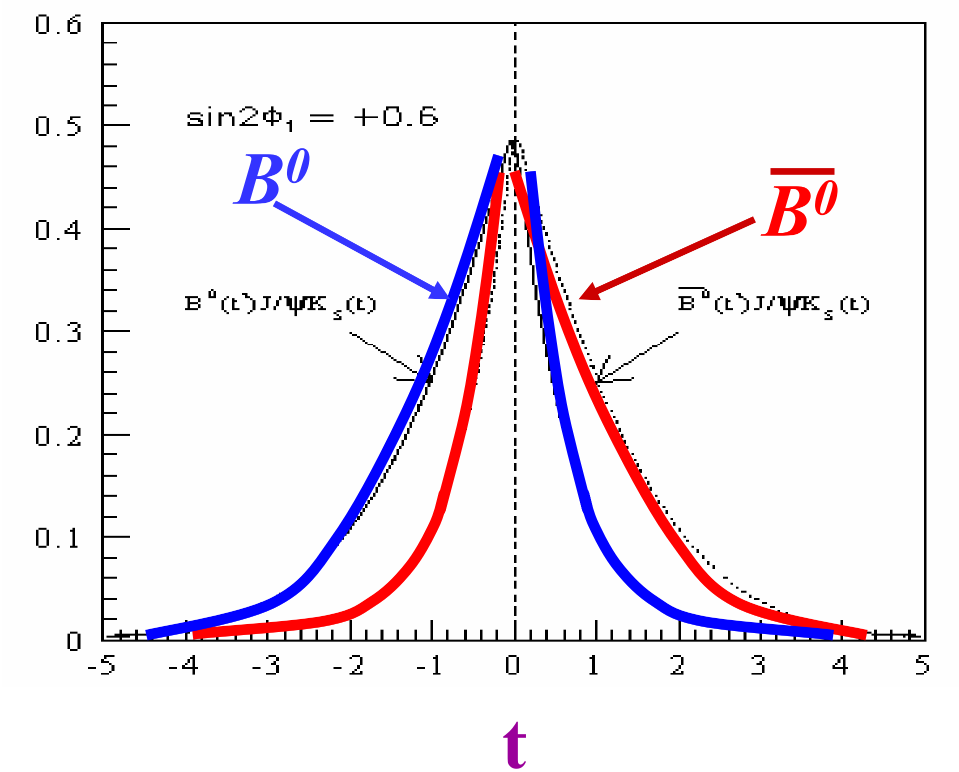
$\propto V_{td}^{*2}$

Mixing-induced CPV asymmetry

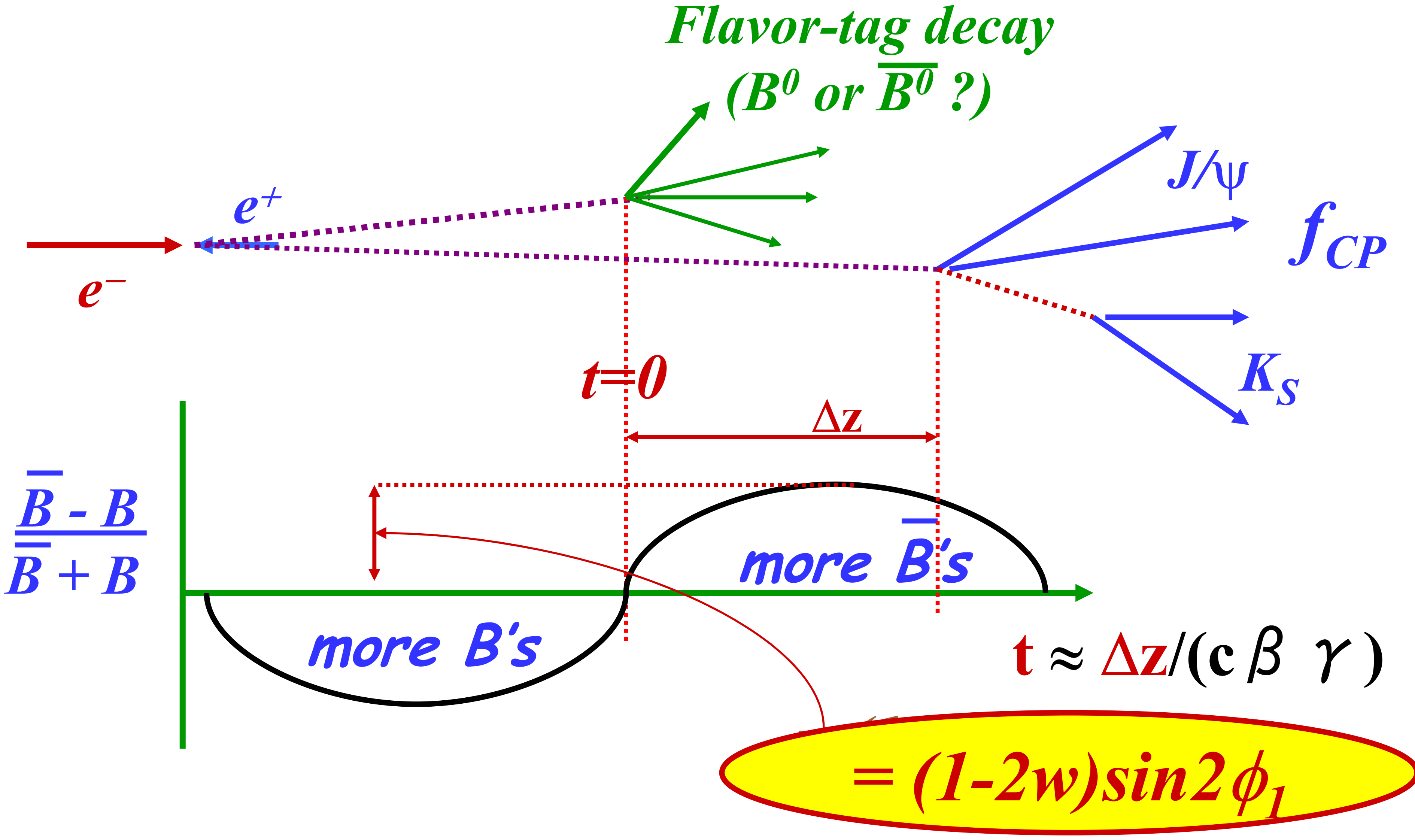
$\xi_f = \pm 1$ *for* $CP = \pm 1$

$$A(t) \equiv \frac{\Gamma(\overline{B_d}^0 \to f_{CP}) - \Gamma(B_d^0 \to f_{CP})}{\Gamma(\overline{B_d}^0 \to f_{CP}) + \Gamma(B_d^0 \to f_{CP})} = -\xi_f \sin 2\phi_1 \sin \Delta m t$$

a.k.a 2β



Principle of the Measurement



If there is more than one diagram and additional weak phases, there is the possibility of direct CPV and a new term with a cos(ΔmΔt) time dependence.

$$P(B \to f_{CP};\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}[1 + q \cdot \{A\ \cos(\Delta m \Delta t) + S\ \sin(\Delta m \Delta t)\}]$$

with q=±1

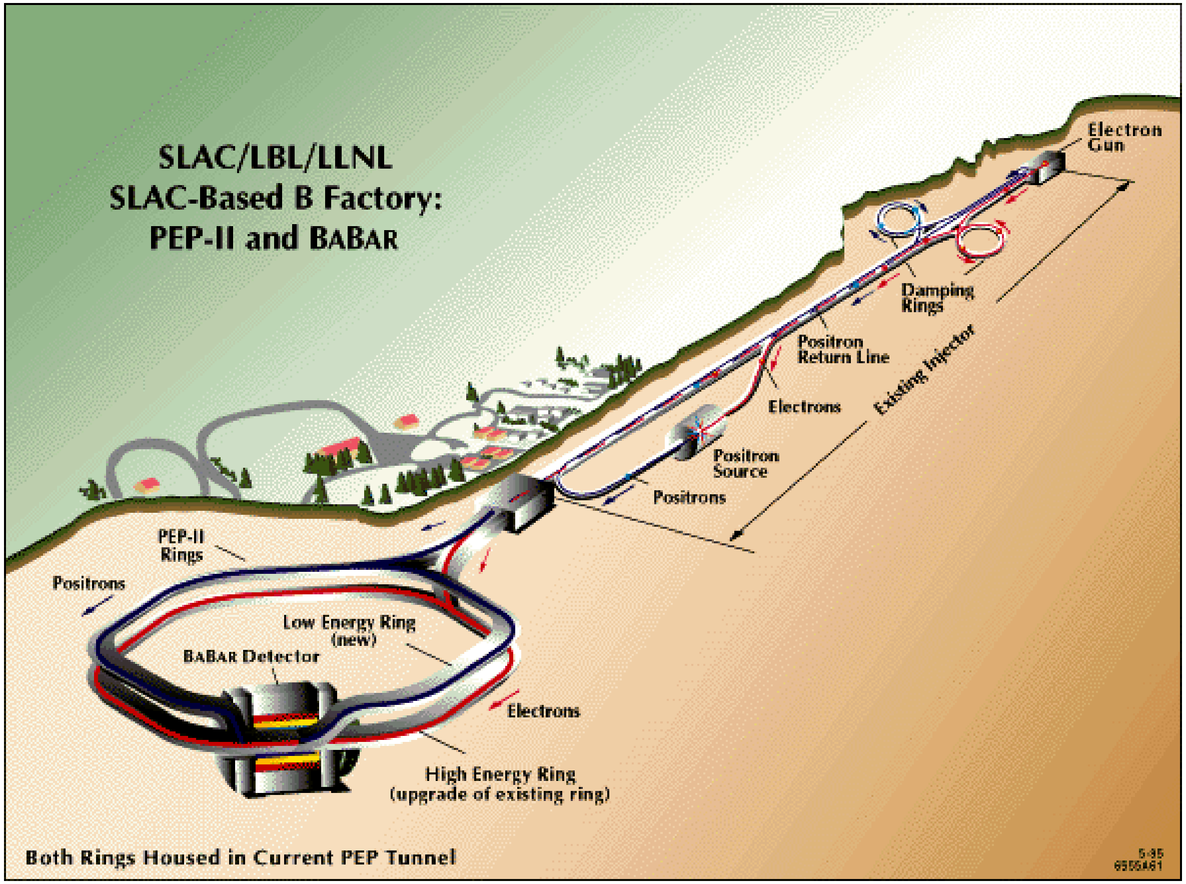
$$S = \frac{2\,\mathrm{Im}\,\lambda}{|\lambda|^2 + 1} \qquad A = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}$$

C(Babar)=-A(Belle)

Requirements for CPV measmts.

- **Many B mesons** [*Br* (B→f_{CP}) ~ O(10^{-3})]
  - 2003: **PEP-II→ 131 fb^{-1} ; KEKB → 158 fb^{-1} , 10% taken below resonance.**
- **Reconstruct+isolate CP eigenstate decays**
  - **Kinematic variables for signal +(*cont. bkg suppr+PID*).**
- **Tag flavor of the other B**
  - **Hierachial NN (Babar) or Likelihood (Belle) based flavor tagging**
- **Measure decay-time difference**
  - **Asymmetric beam energies, high precision vertexing(Δz)**
  - Likelihood fit to the Δt distributions

The PEPII Collider (magnetic separation)

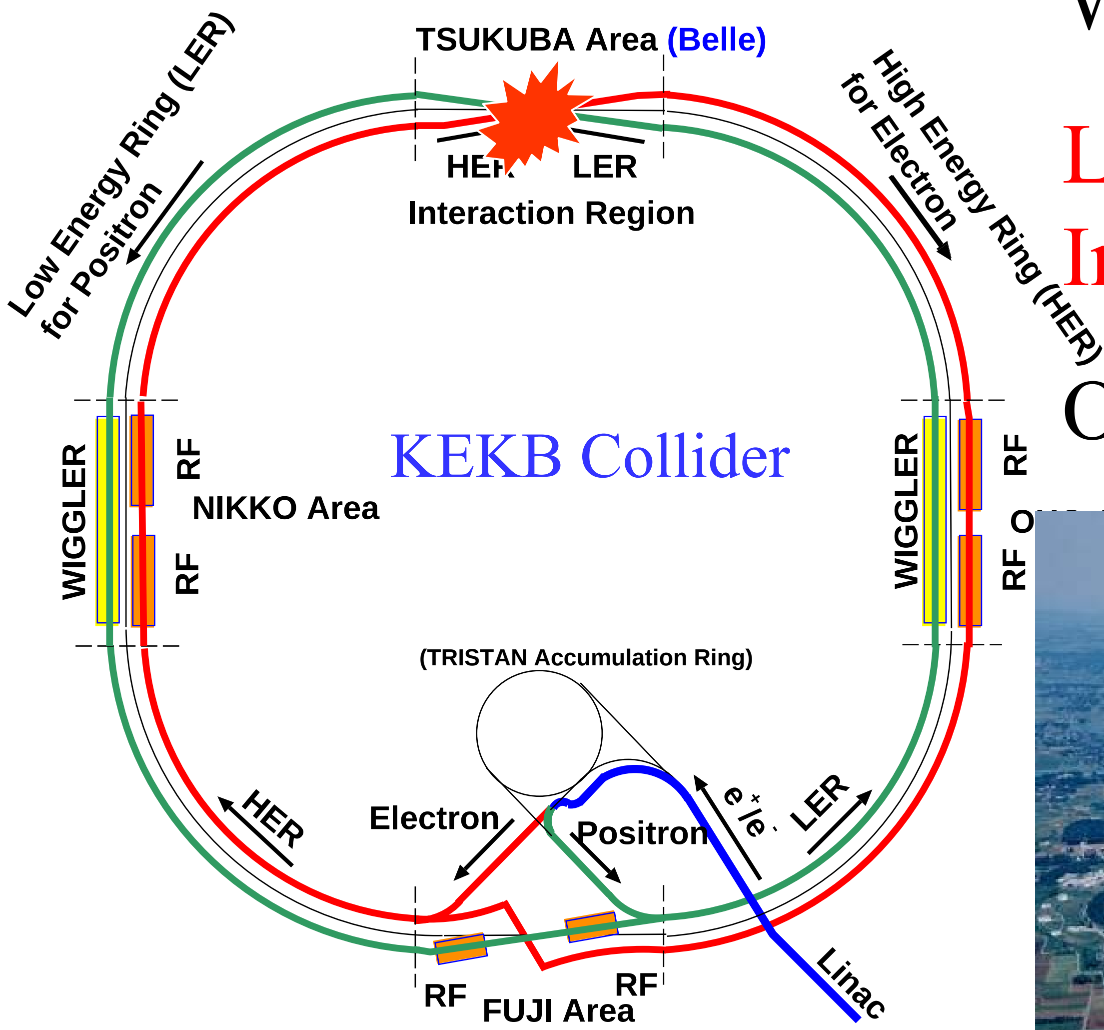


$\mathrm{Int}(L\,dt) = 131\ \mathrm{fb}^{-1}$

On resonance: $113\ \mathrm{fb}^{-1}$

9×3.0 GeV; $L = (6.5 \times 10^{33})/\mathrm{cm}^2/\mathrm{sec}$

The KEKB Collider (8 x 3.5 GeV, X angle)



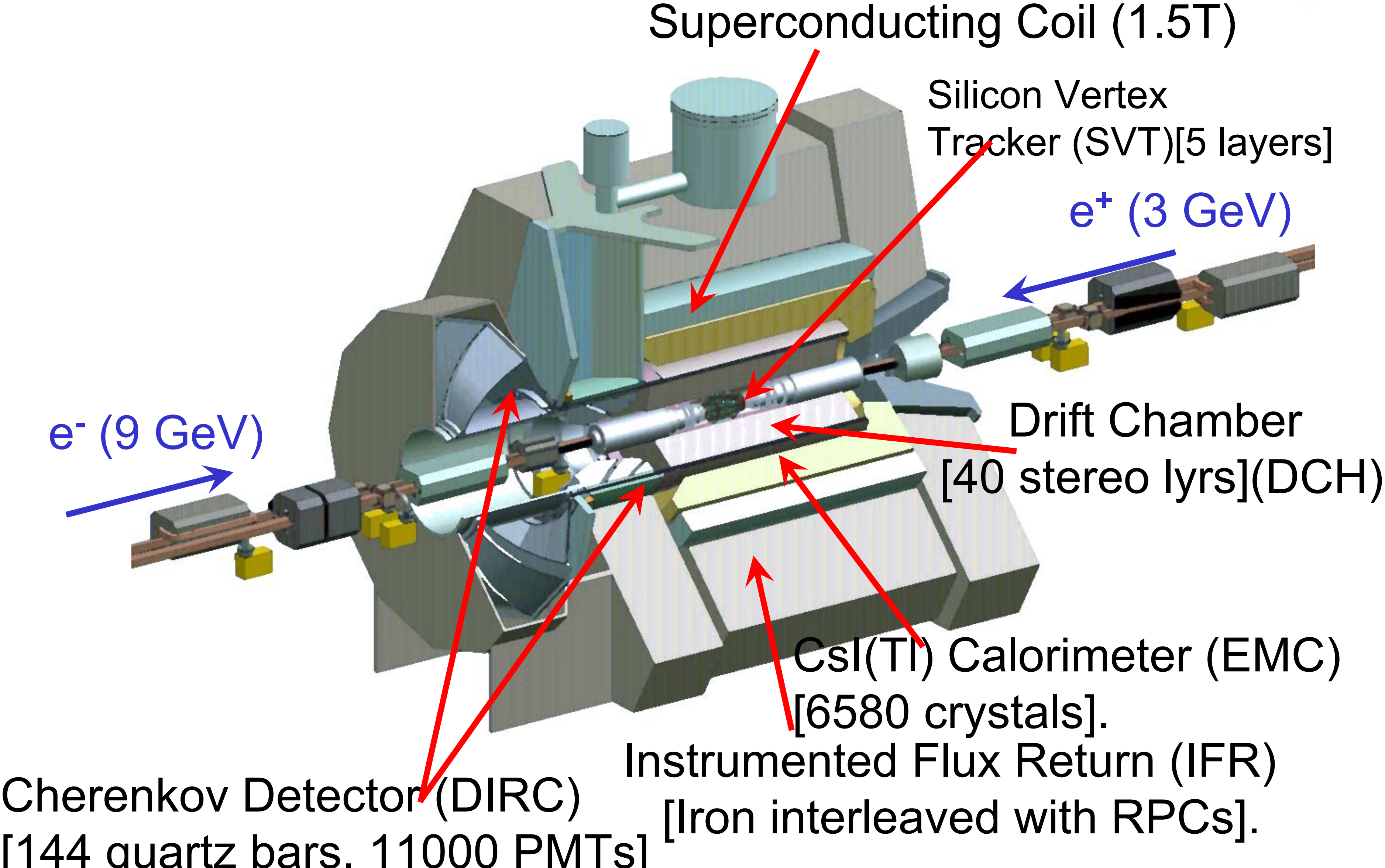
World record:

$L=(1.0 \times 10^{34})/cm^2/sec$

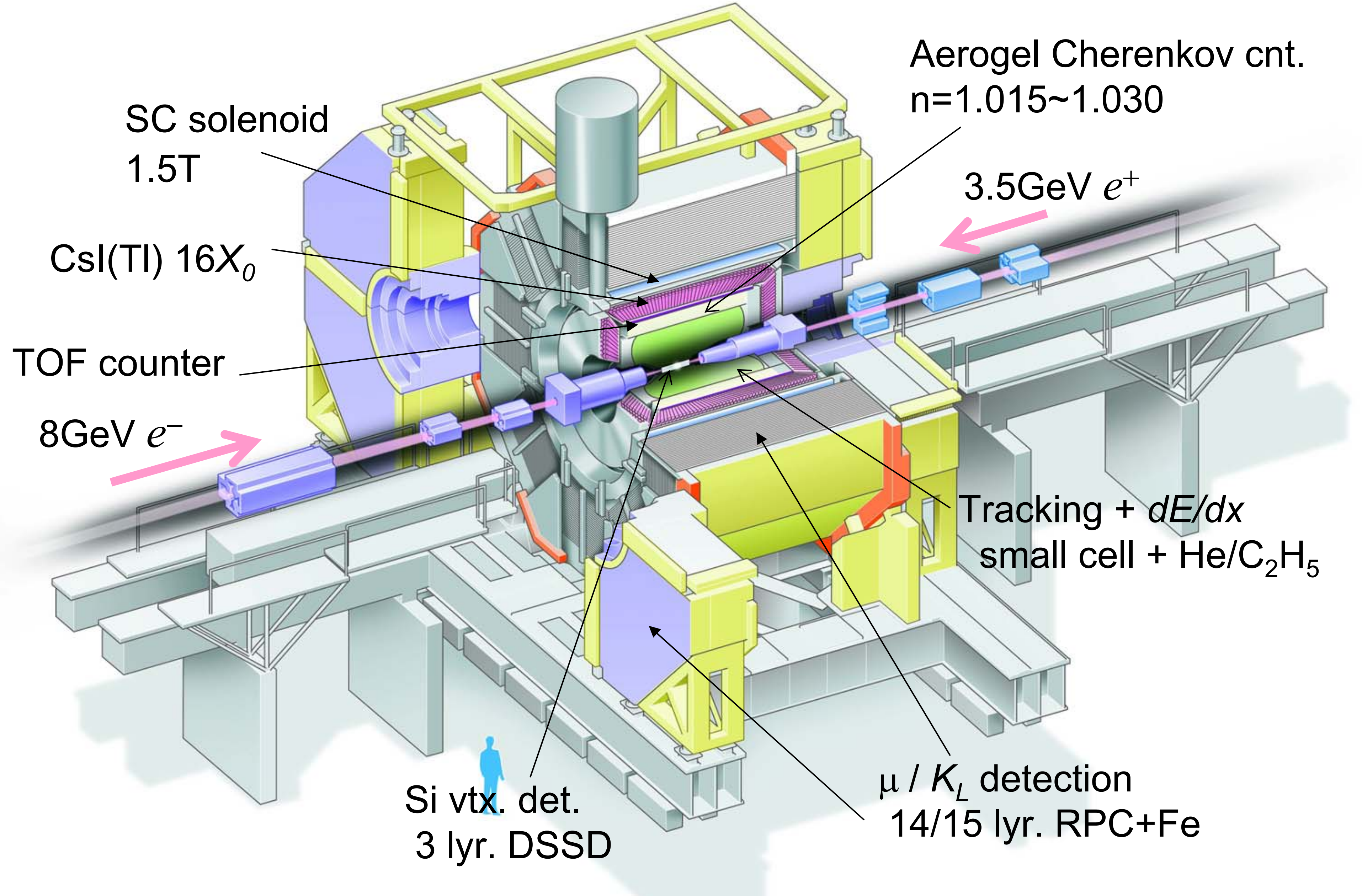
$Int(L\,dt)= 158\ fb^{-1}$

On-resonance $140\ fb^{-1}$

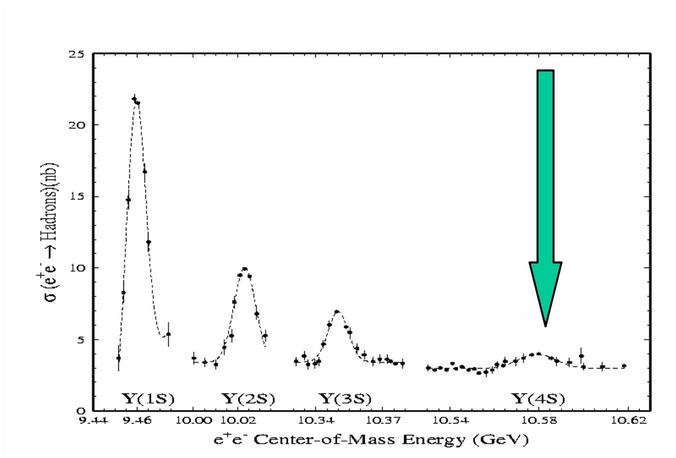
The BaBar Detector

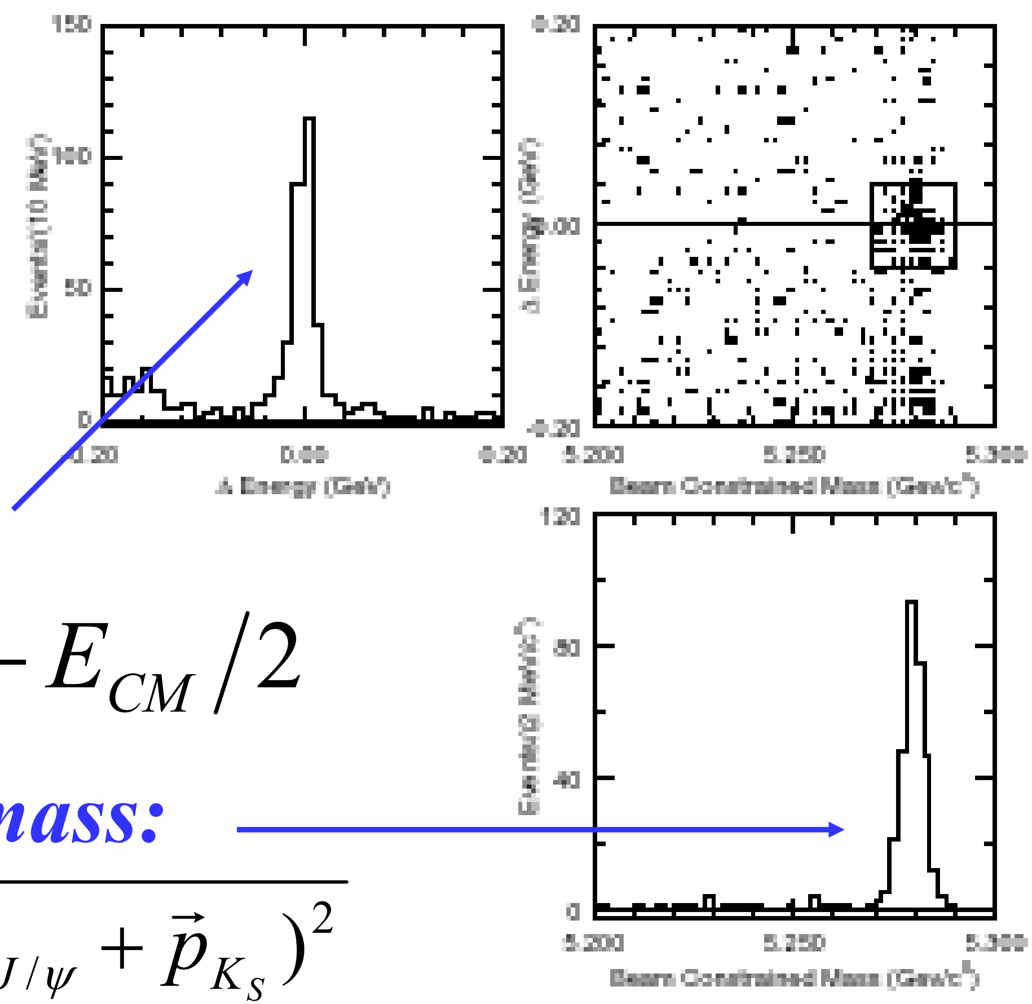


Belle Detector



Kinematic variables for the Υ(4S)





Energy difference:

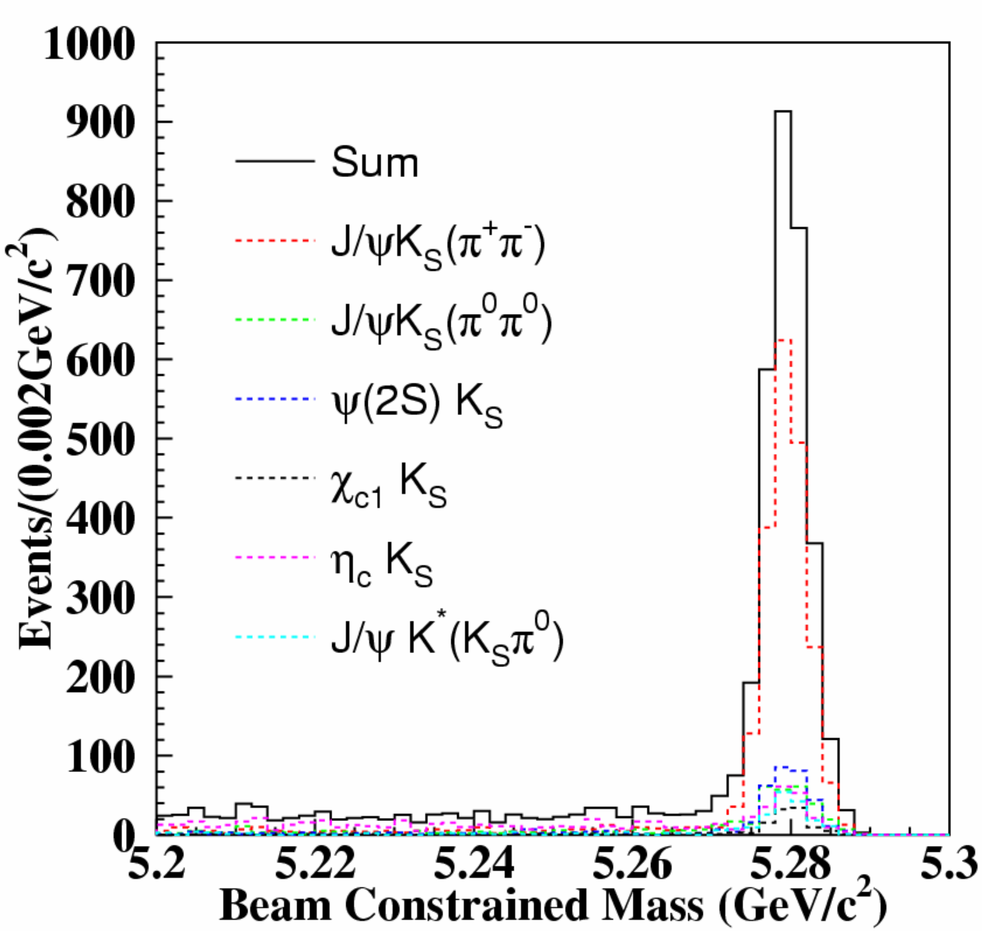
$$\Delta E \equiv E_{J/\psi} + E_{K_S} - E_{CM}/2$$

Beam-constrained mass:

$$m_{bc} = \sqrt{(E_{CM}/2)^2 - (\vec{p}_{J/\psi} + \vec{p}_{K_S})^2}$$

Belle 2003 : CP eigenstates ($b \rightarrow ccs$)

140 fb^{-1} , 152 x 10^{6} B$\overline{\text{B}}$ pairs

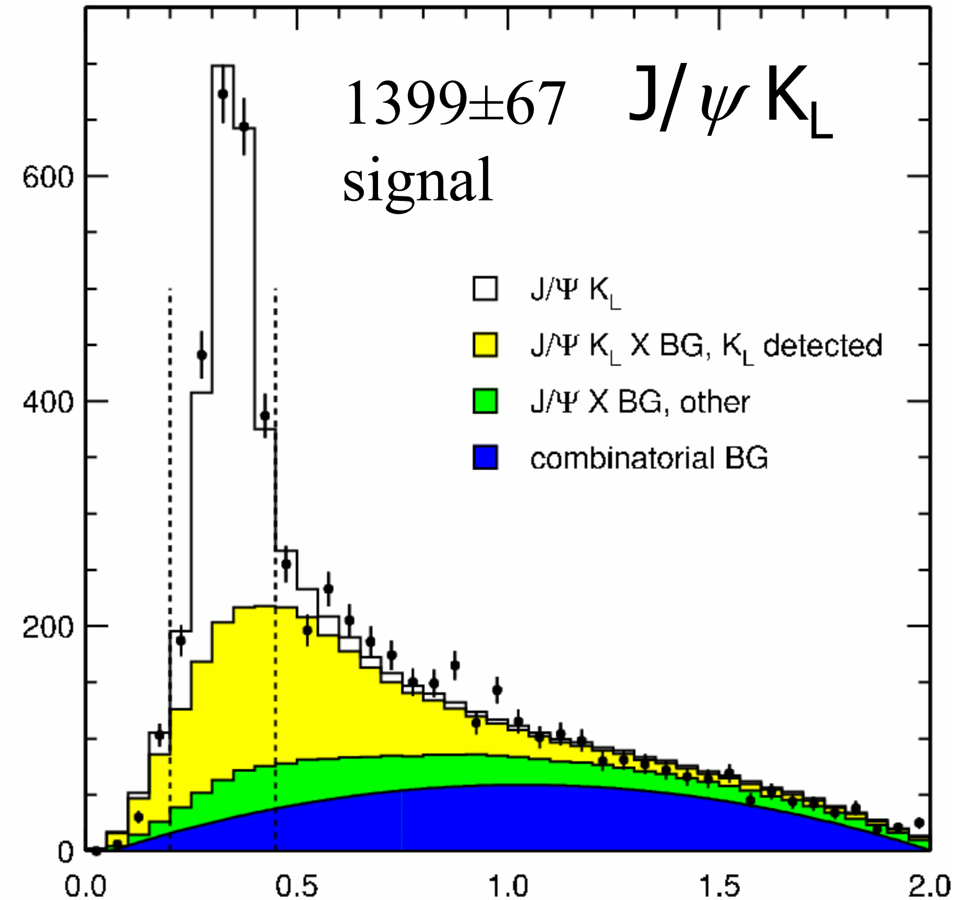


Mode	N_{ev}	Purity
$J/\psi(\ell^+\ell^-)K_S^0(\pi^+\pi^-)$	1997	0.976 ± 0.001
$J/\psi(\ell^+\ell^-)K_S^0(\pi^0\pi^0)$	288	0.82 ± 0.02
$\psi(2S)(\ell^+\ell^-)K_S^0(\pi^+\pi^-)$	145	0.93 ± 0.01
$\psi(2S)(J/\psi\pi^+\pi^-)K_S^0(\pi^+\pi^-)$	163	0.88 ± 0.01
$\chi_{c1}(J/\psi\gamma)K_S^0(\pi^+\pi^-)$	101	0.92 ± 0.01
$\eta_c(K_S^0K^-\pi^+)K_S^0(\pi^+\pi^-)$	123	0.72 ± 0.03
$\eta_c(K^+K^-\pi^0)K_S^0(\pi^+\pi^-)$	74	0.70 ± 0.04
$\eta_c(p\bar{p})K_S^0(\pi^+\pi^-)$	20	0.91 ± 0.02
All with $\xi_f = -1$	2911	0.933 ± 0.002
$J/\psi(\ell^+\ell^-)K^{*0}(K_S^0\pi^0)$	174	0.93 ± 0.01

2911 events are used in the fit.

BELLE-CONF-0344

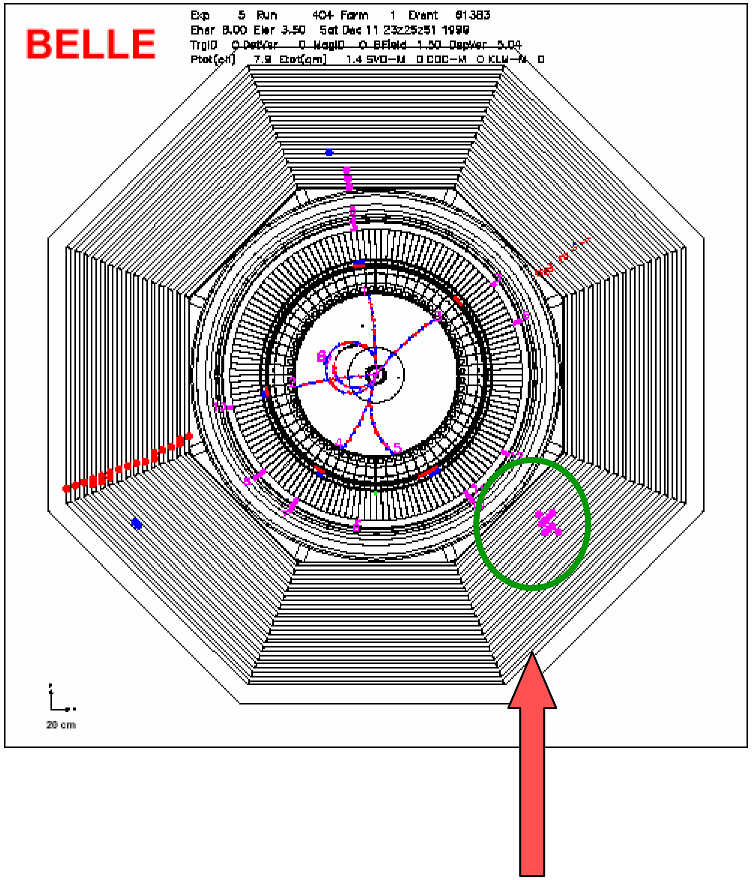
Belle 2003: $B^0 \to \psi K_L$ signal



p_B^* (cms)

[2332 events with a purity of 0.60]

Event display



Flavor-tag the other B meson

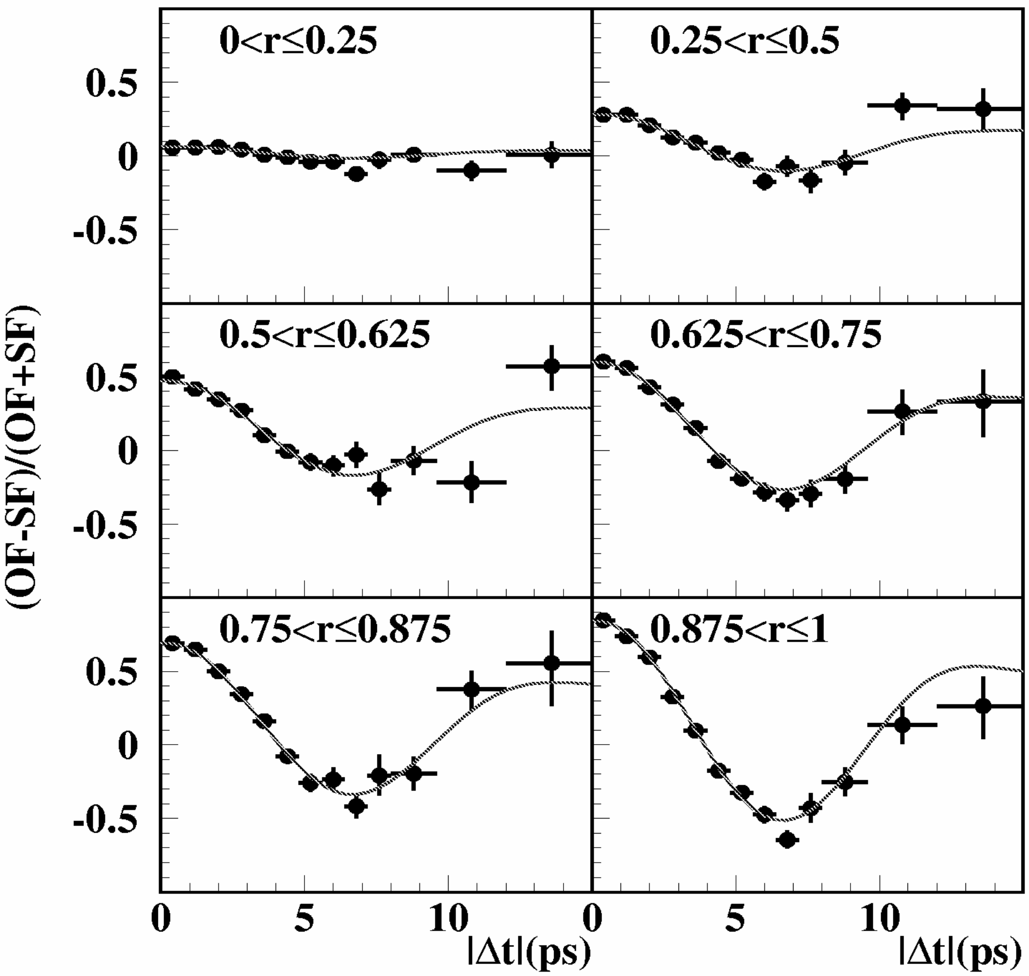
Figure of merit(Q) =ε(1-2 w)² a.k.a effective tagging efficiency

- ***Inclusive Leptons:***
  - ***high-p l^-*** $b \rightarrow c\, l^- \nu$
  - ***intermed-p l^+*** $\hookrightarrow s\, l^+ \nu$
- ***Inclusive Hadrons:***
  - ***high-p π^+*** $B^0 \rightarrow D^{(*)-} \pi^+, D^{(*)-} \rho^+$, etc.
  - ***intermed-p K^+*** $\hookrightarrow K^+ X$, $\rho^+ \hookrightarrow \pi^+ \pi^0$
  - ***low-p π^-*** $\hookrightarrow \bar{D}^0 \pi^-$

Babar: Neural Net based approach, 28.1±0.7 %

Belle: Likelihood based approach, 28.7±0.5 %

Belle Tagging Performance with $B \rightarrow D^{*+} l^- \upsilon$

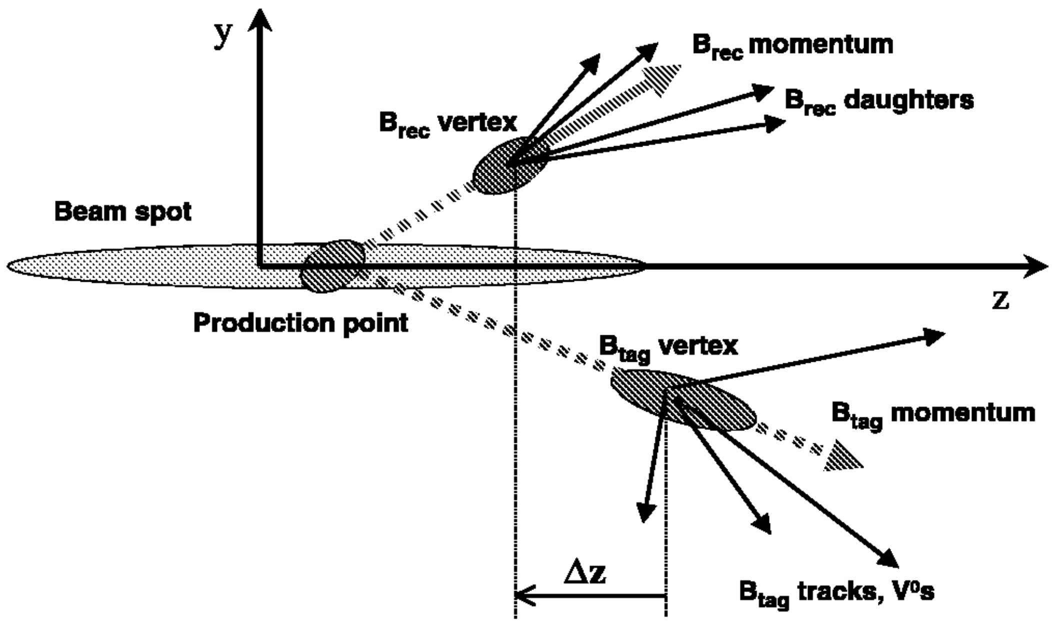


$B^0 - \bar{B}^0$ mixing

(OF-SF)/(OF+SF)

~(1-2 w)cos(Δm t)

12 r-bins, 6 divisions in r. B^0 and $\bar{B}^0$ tags treated separately.



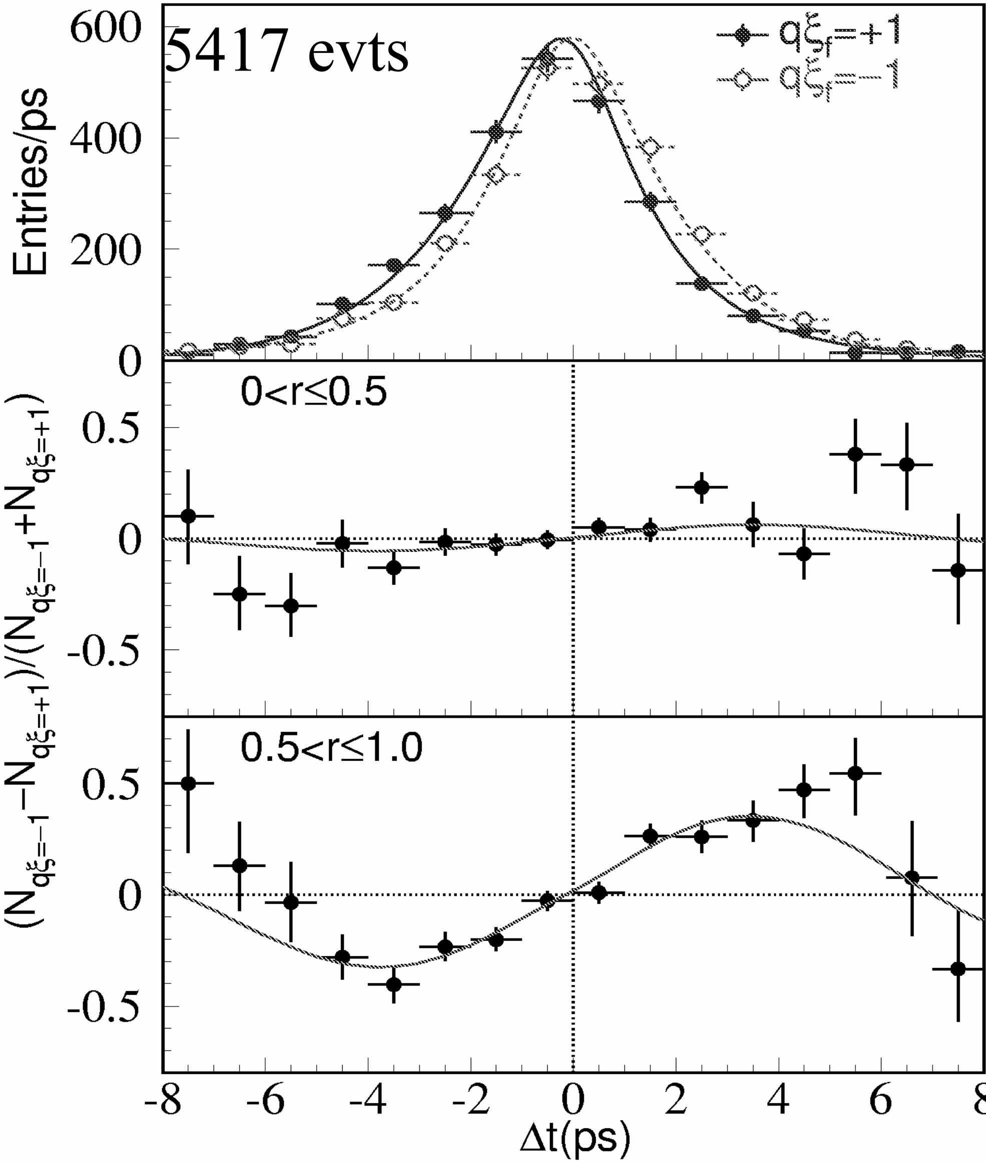
Beam spot: 110 μm x 5 μm x 0.35 cm

Both experiments use double-sided silicon strip detectors to measure Δz.

[CM Boosts] Belle: $\beta\gamma = 0.425$ BaBar: $\beta\gamma=0.56$

Vertex resolutions(Belle): ($\sigma(z_{cp}) = 75\mu m$; $\sigma(z_{tag}) = 140\mu m$)

New measurement of sin2ϕ_1 (Belle 2003)



140 fb^{-1}

$\sin 2\phi_1$ = 0.733±0.057±0.02

Poor tags

$|\lambda_{ccs}|$ =1.007±0.041(stat)

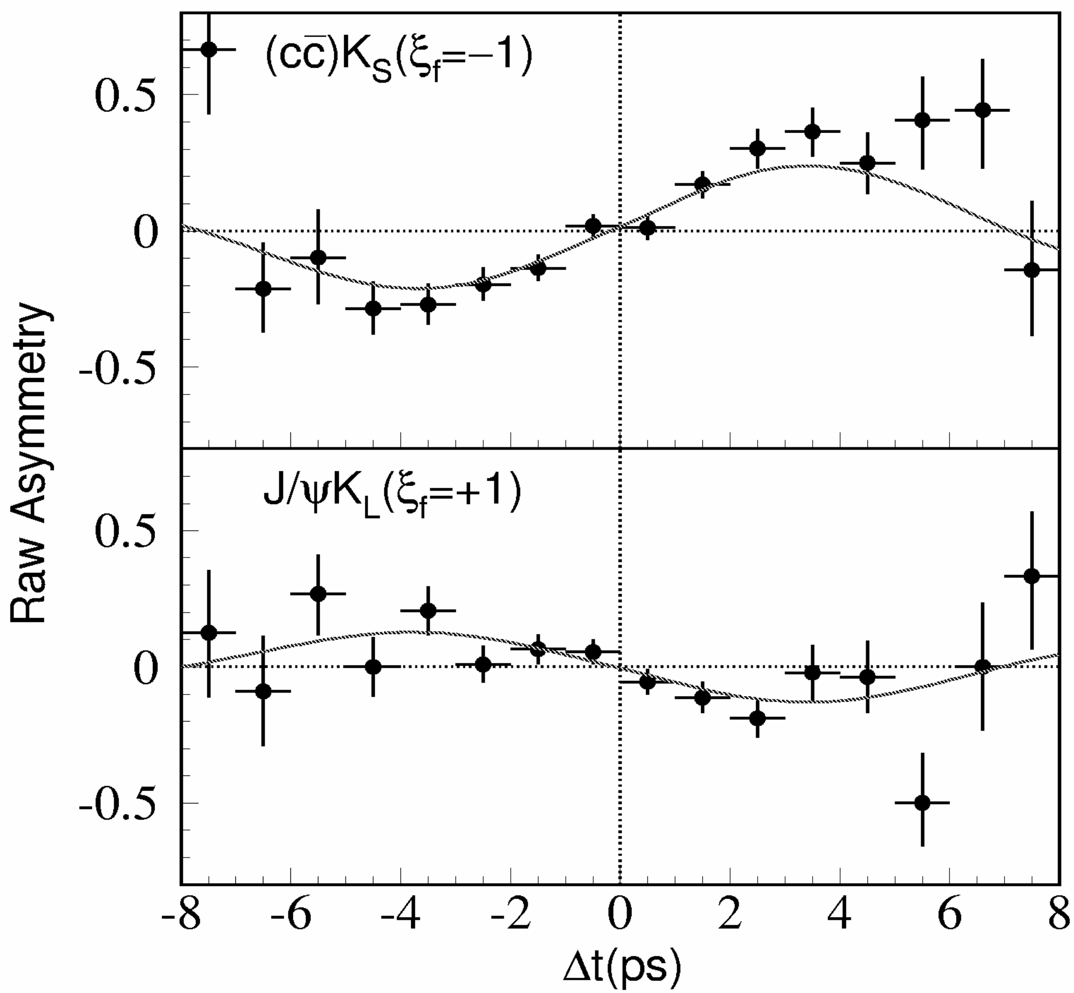
i.e., consistent with no direct CPV.

Good tags

BELLE-CONF-0353

Compare CP odd and CP even (Belle 2003)

Raw asymmetry (all r-bins)



CP = −1 sample

$\sin 2\phi_1$
= 0.73±0.06

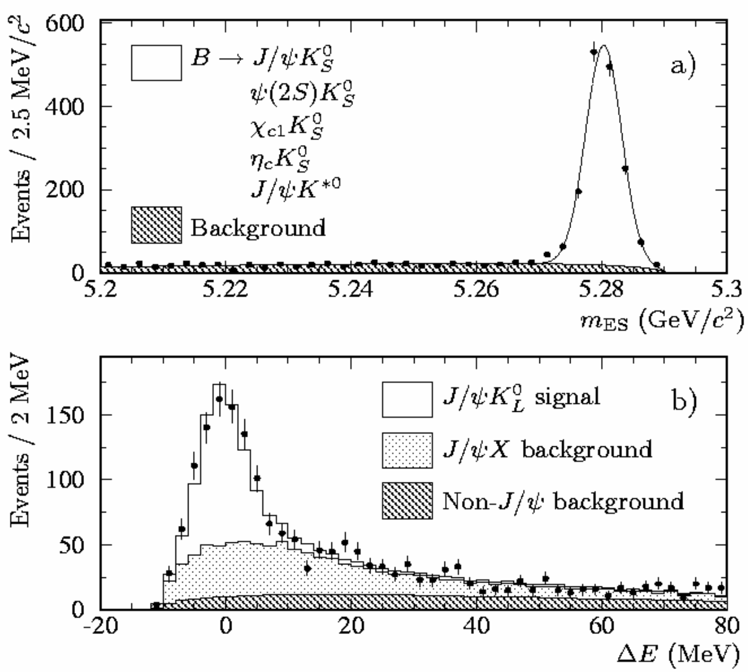
CP = +1 sample
($B^0 \rightarrow J/\psi\ K_L$)

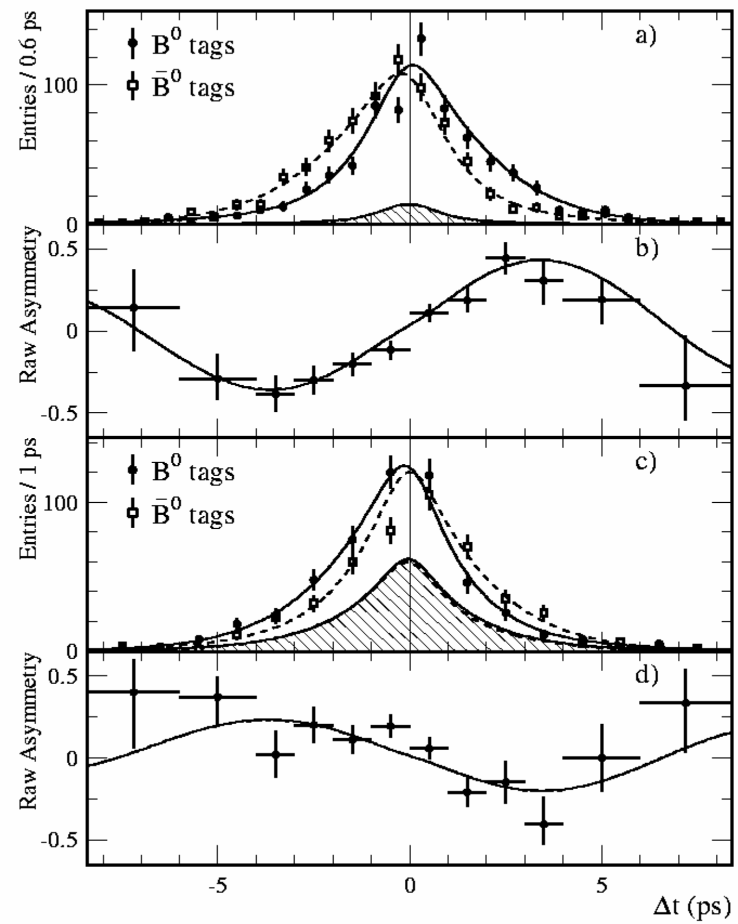
$\sin 2\phi_1$
= 0.80±0.13

BELLE-CONF-0353

Measurement of $\sin 2\phi_1$ (BaBar 2002)

81 fb^{-1}





CP Eigenstate Sample

hep-ex/0207042, PRL 89, 201802 (2002)

Status/history of results for $\sin(2\varphi_1)/\sin(2\beta)$

Belle 2001: $\sin(2\varphi_1) = 0.99 \pm 0.14 \pm 0.06$

Babar 2001: $\sin(2\varphi_1) = 0.59 \pm 0.14 \pm 0.05$

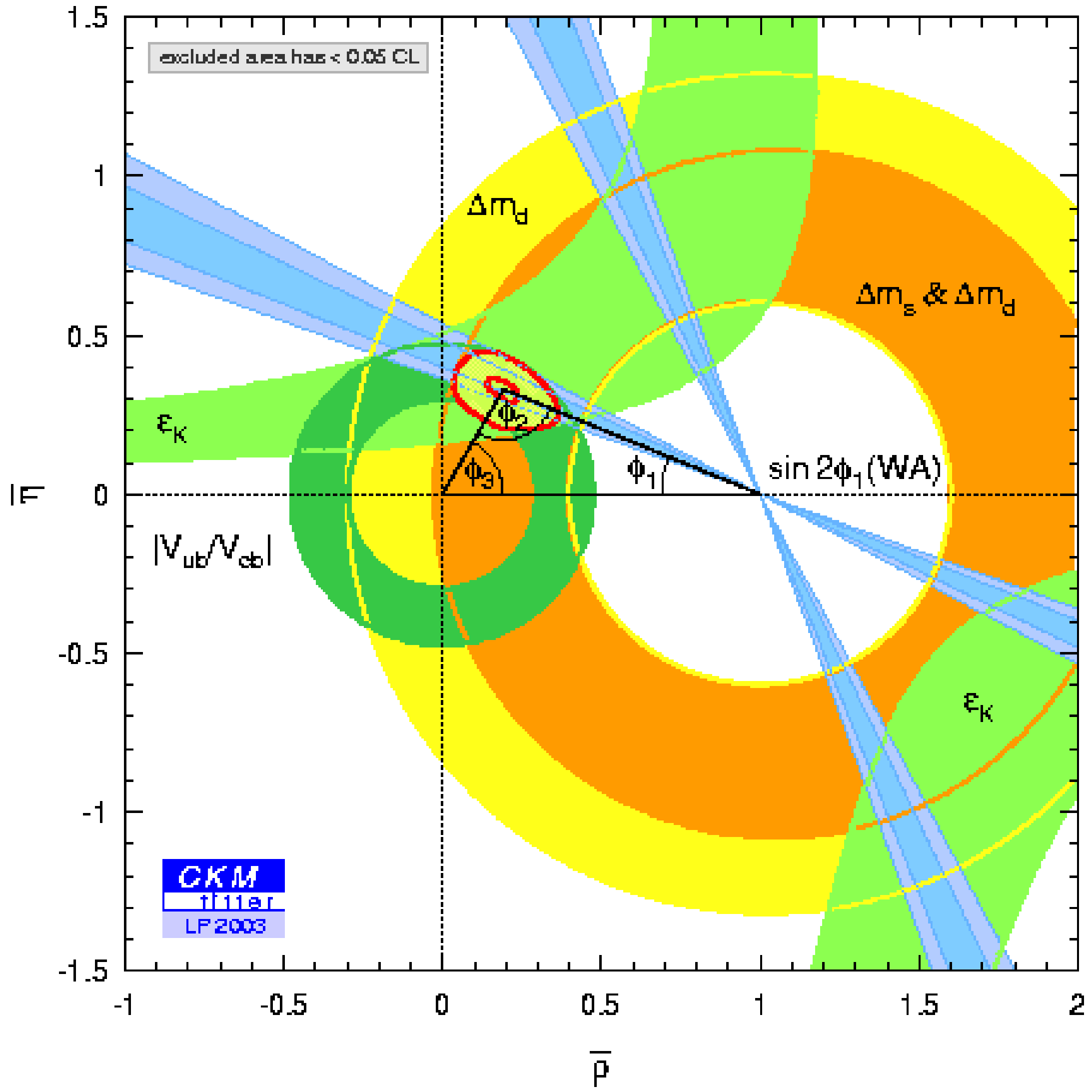
First signals for CPV outside of the kaon sector

Belle 140 fb^{-1} : $\sin(2\varphi_1) = 0.733 \pm 0.057 \pm 0.028$

BaBar 81 fb^{-1}: $\sin(2\varphi_1) = 0.741 \pm 0.067 \pm 0.033$

Now becoming a precision measurement

Current Belle and BaBar Results for $sin(2\varphi_1)$



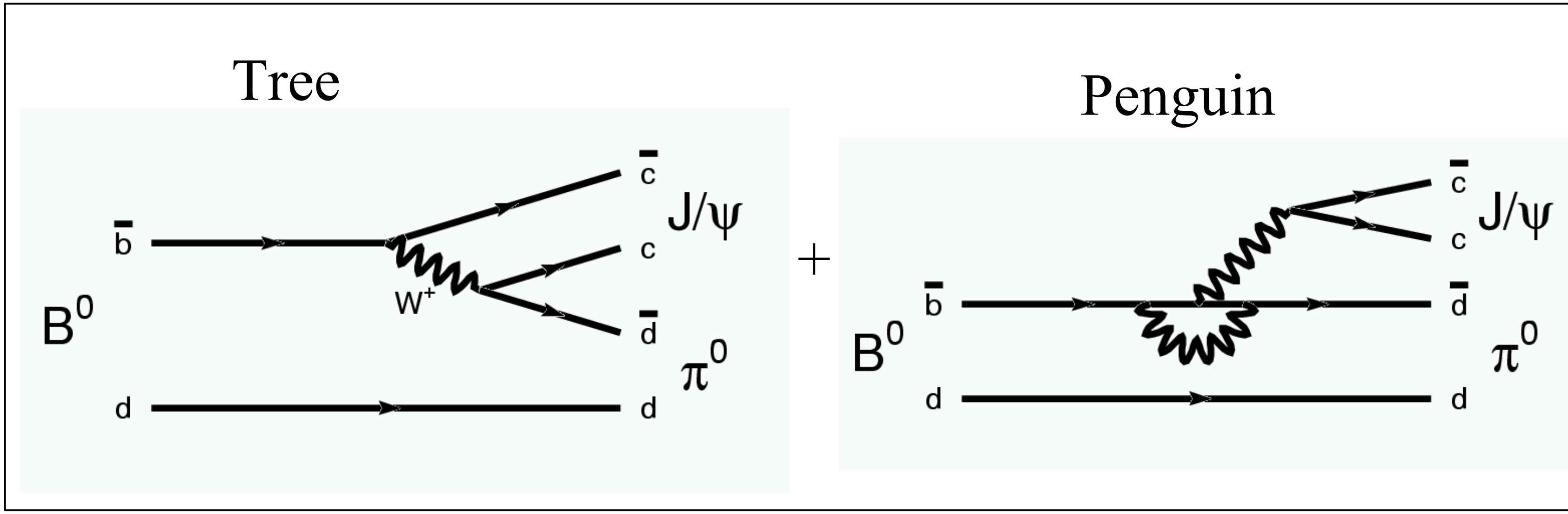
$\sin 2\phi_1$ (Belle 2003,140 fb^{-1}) =0.733±0.057±0.028

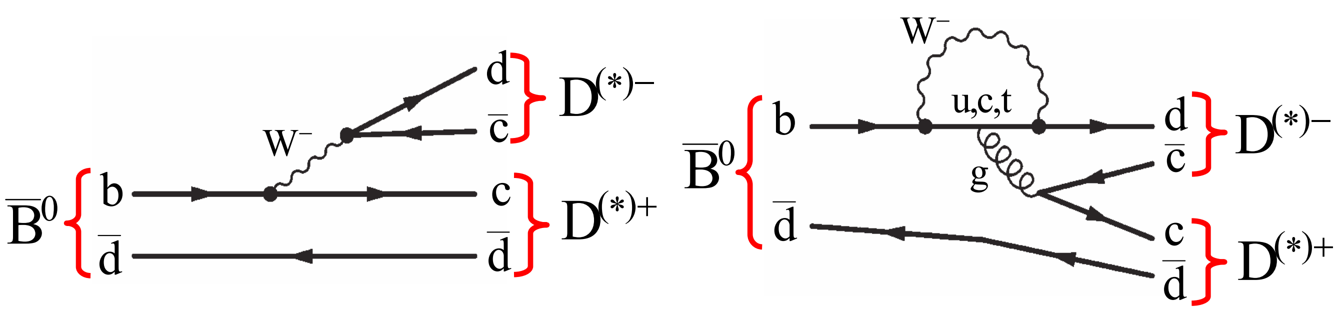
$\sin 2\phi_1$ (BaBar 2002, 81 fb^{-1}) =0.741±0.067±0.033

$\sin 2\phi_1$ (New 2003 World Av.) =0.736±0.049

Thanks to A. Hoecker

CPV in b→(c $\bar{c}$ d) decays



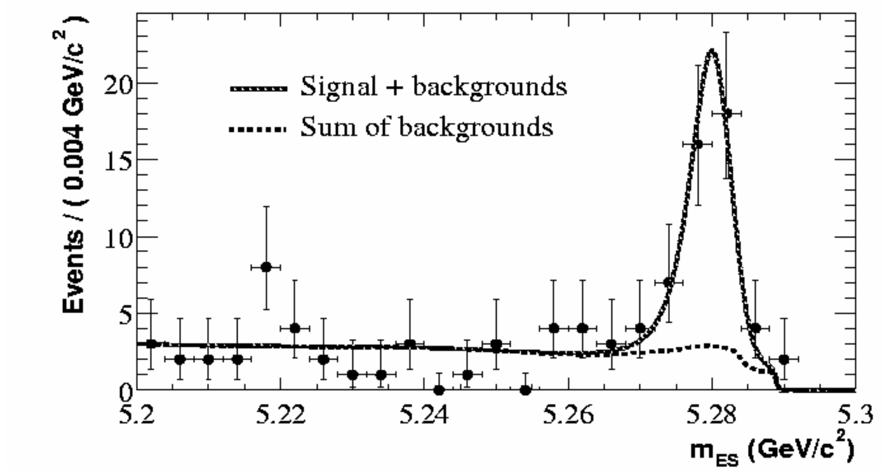


The same CPV phase as in B→ J/ψ K_S but may have penguin pollution.

CPV in $b \to (c\,\bar{c}\,d)$ decays: $B \to \psi\,\pi^0$

BaBar:

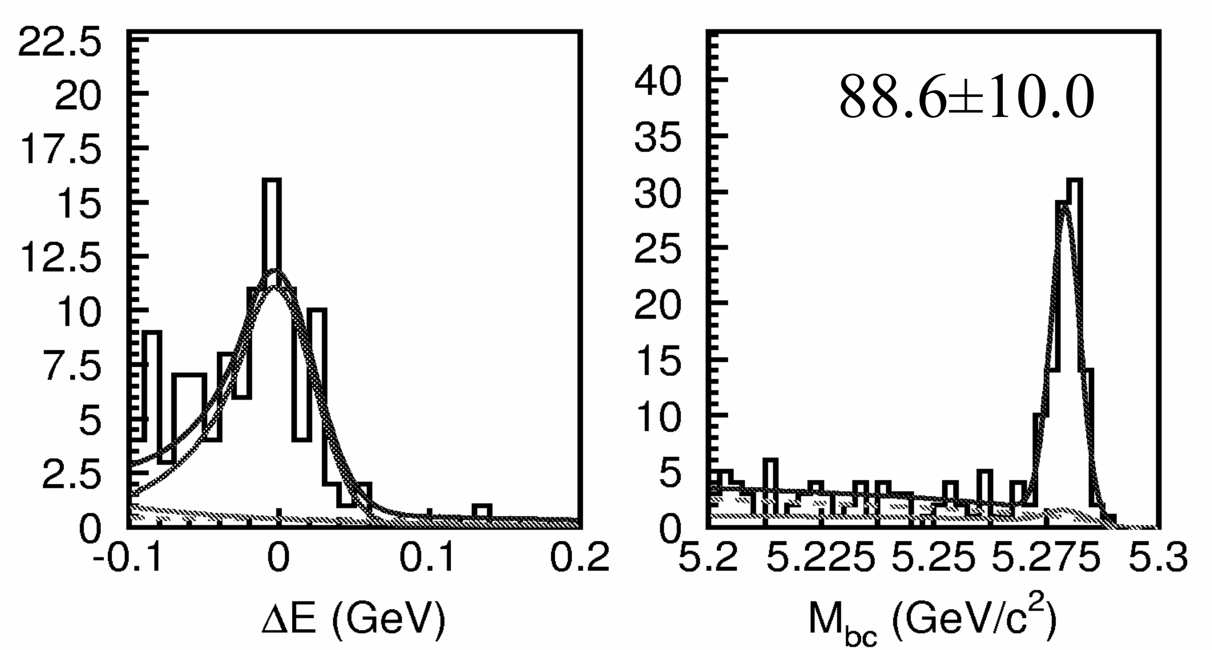
81 fb^{-1}



40±7

Belle:

140 fb^{-1}

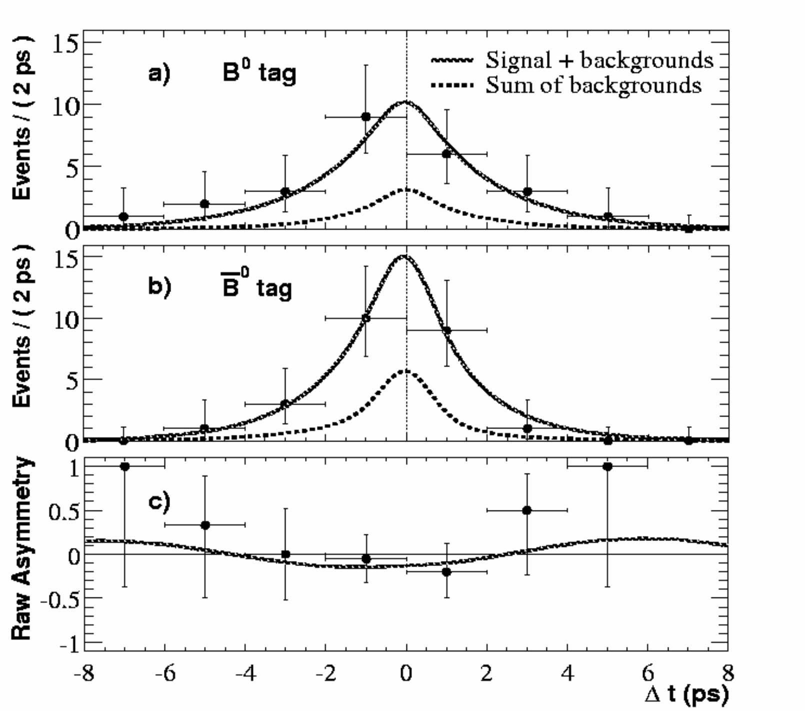


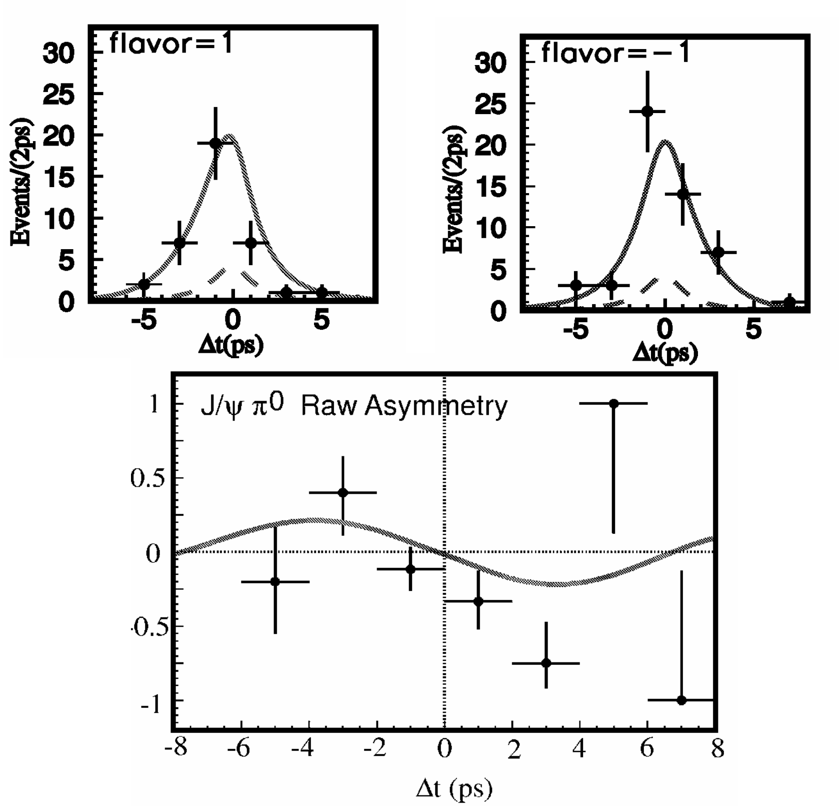
8.2 peaking bkg

CPV in $b \rightarrow (c \bar{c} d)$ decays: $B \rightarrow \psi \pi^0$

BaBar 2003

Belle 2003





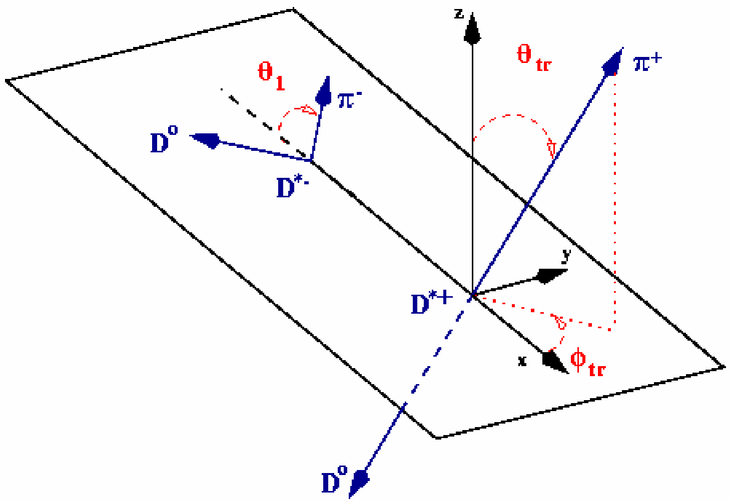
$\sin(2\varphi_{1\mathrm{eff}})=0.05\pm0.49\pm0.16$

hep-ex/0303018

$\sin(2\varphi_{1\mathrm{eff}})=0.72^{+0.37}_{-0.42}\pm0.08$

BELLE-CONF-0342

Determination of the CP content of $B \rightarrow D^{*+} D^{*-}$



D*D* transversity frame

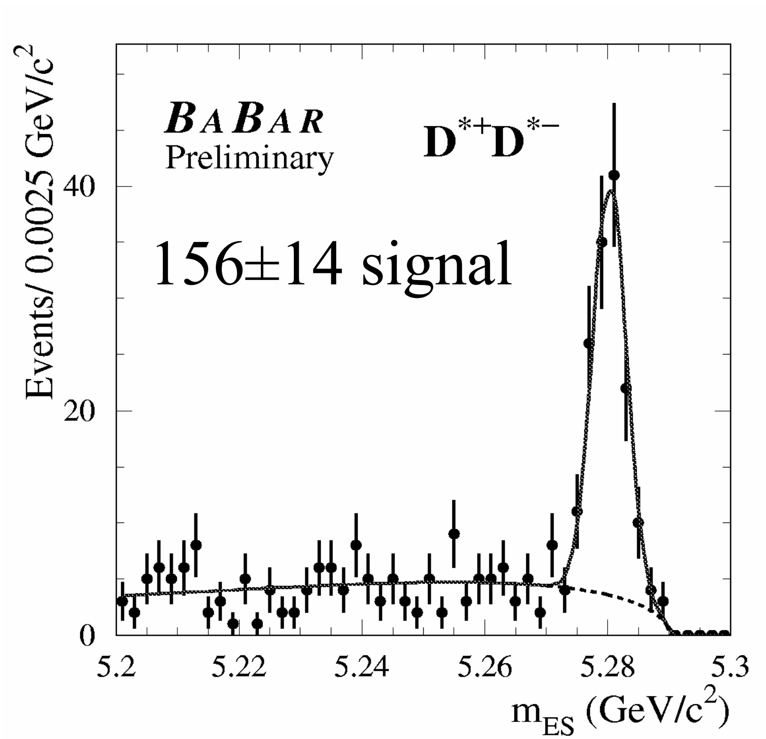
Angular PDF integrated over Φ_{tr},

Integrate ϕ_{tr}:

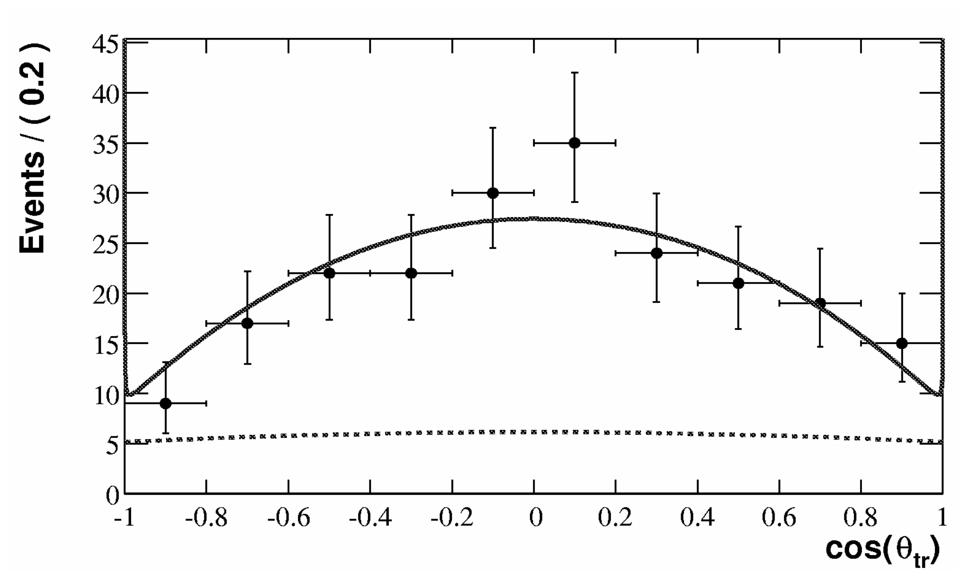
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_1 d\cos\theta_{tr}} = \frac{9}{64}\frac{1}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}\Big\{ 2|A_0|^2(1-\cos 2\theta_{tr})(1+\cos 2\theta_1) + |A_\parallel|^2(1-\cos 2\theta_{tr})(1-\cos 2\theta_1) + 2|A_\perp|^2(1+\cos 2\theta_{tr})(1-\cos 2\theta_1)\Big\}$$

Can extract the CP content from a fit to θ_{tr}

Determination of the CP content of B→D^{*+} D^{*-}



BaBar: B→ D^{*+} D^{*-}

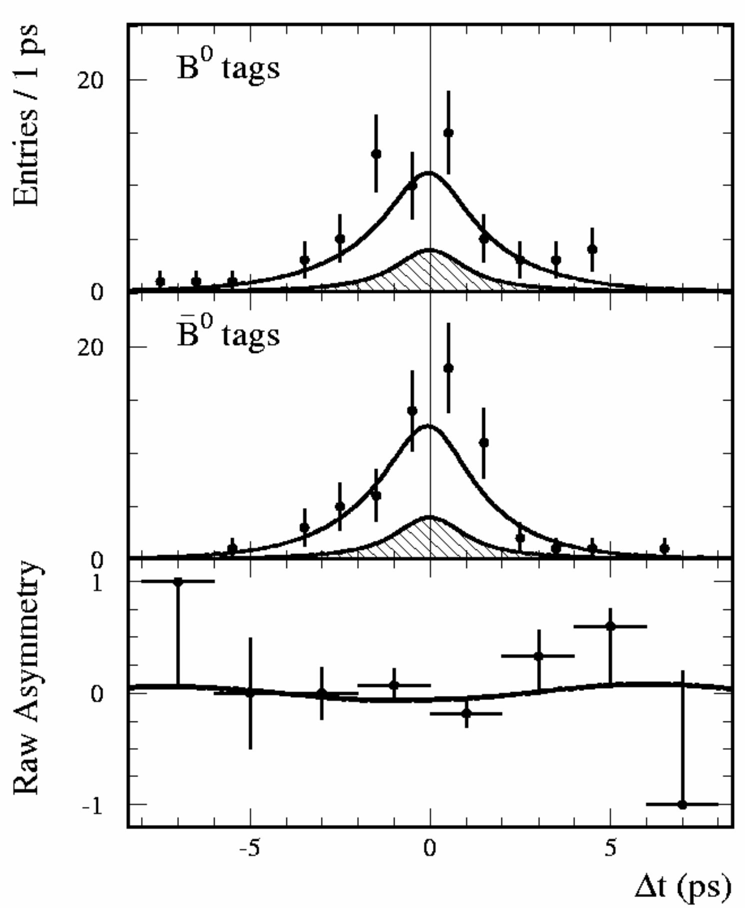


BaBar: R_{perp} =0.063±0.055±0.009

Thus B→D^{*+} D^{*-} is mostly CP even

CPV in $b \rightarrow (c\,\bar{c}\,d)$ decays: $B \rightarrow D^{*+} D^{*-}$

Babar 2003



hep-ex/0303004

$\sin(2\varphi_{1\text{eff}}) = -0.05 \pm 0.29 \pm 0.10$

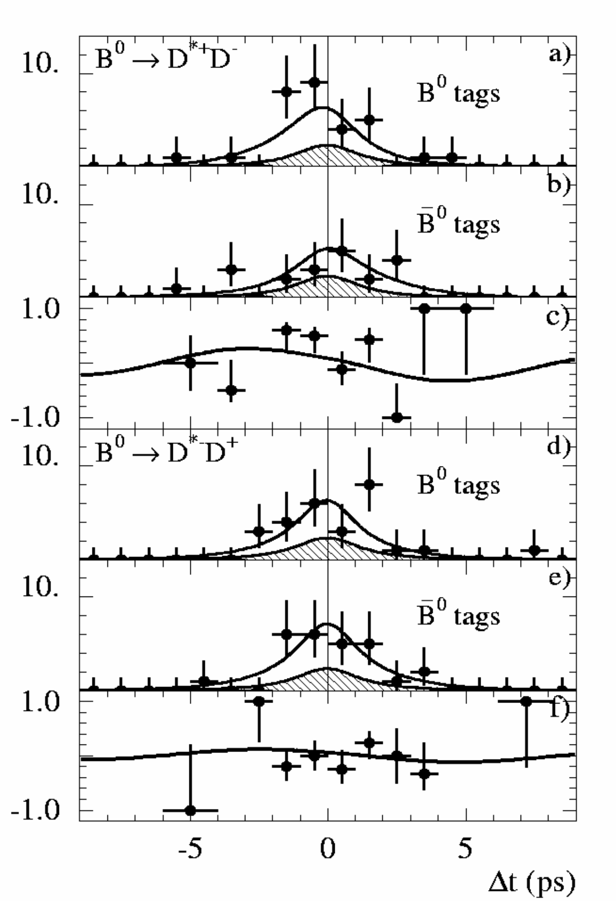
2.5 σ from $b \rightarrow c\,\bar{c}\,s$, might indicate SM penguin contribution is present.

$|\lambda| = 0.75 \pm 0.19 \pm 0.02$

Consistent with 1 or no direct CPV

CPV in $b \rightarrow (c\,\bar{c}\,d)$ decays: $B \rightarrow D^{*+} D^{-}$

BaBar



hep-ex/0306052

C_{+-}=-0.47± 0.40±0.12

S_{+-}=-0.82±0.75 ±0.14

C_{-+}=-0.22±0.37±0.10

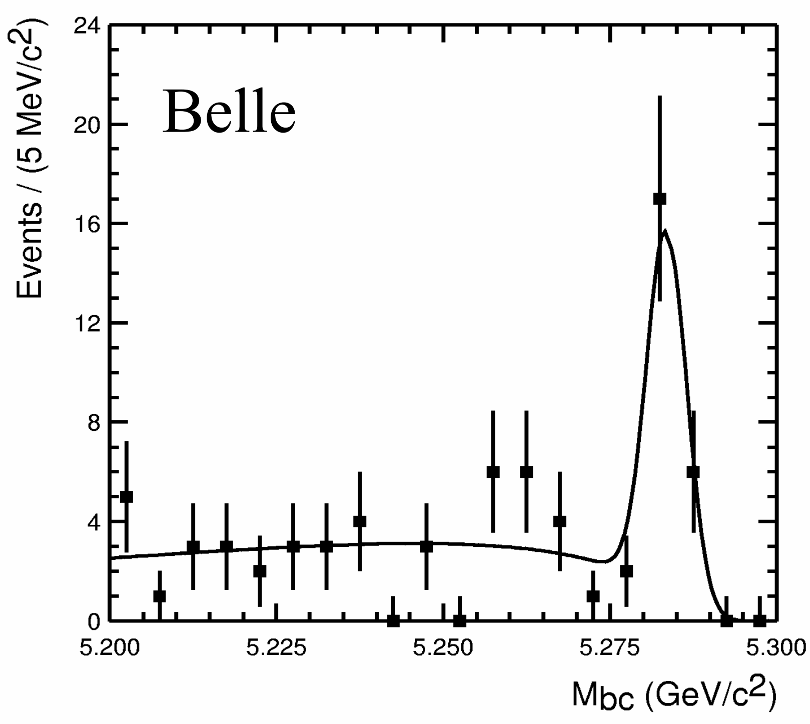
S_{-+}=-0.24±0.69 ±0.12

In the limit of no penguins and factorization.

$S_{-+}=S_{+-}= -\sin(2\varphi_1)$ and $C_{-+}=C_{+-}=0$

Belle 2003: Observation of $D^+ D^-$

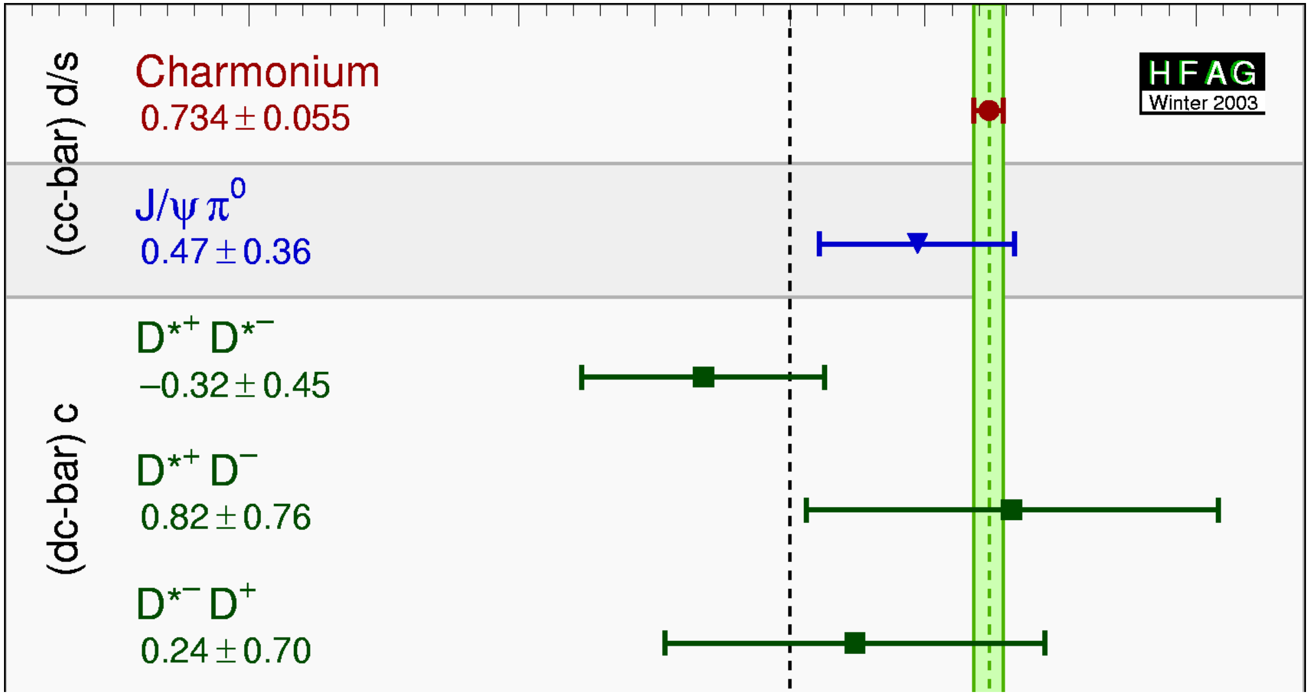
140 fb^{-1}



- Yield : 24.3 ± 6.0
- Significance : 5.0
- Efficiency : 7.95 %
- BF : $(2.46 \pm 0.61 \pm 0.42) \times 10^{-4}$
- Control sample [B→DsD]

This $b \rightarrow c\, \bar{c}\, d$ mode can also be used in the future for time dependent CPV analyses.

Summary of CPV in $b \to (c\bar{c}d)$ decays:



$\sin(2\varphi_{1\mathrm{eff}})$

Old Belle value used

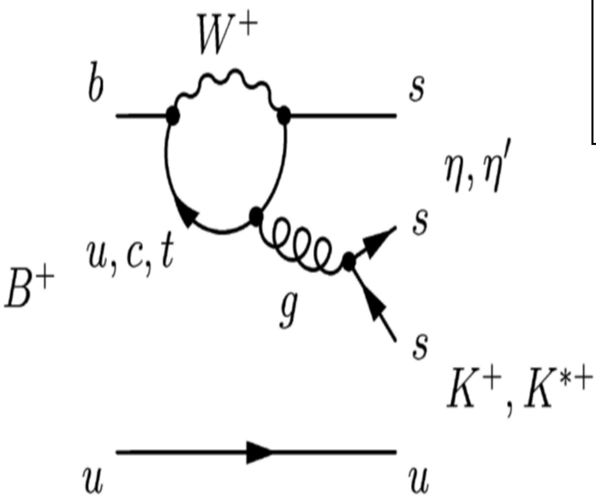
Errors are large for these modes so that it is difficult to verify whether there is large penguin pollution. There is a 2.5 σ "hint" for penguin pollution in Babar's result for $B \to D^* D^*$

Dreams of New Physics with CPV in rare B decays.

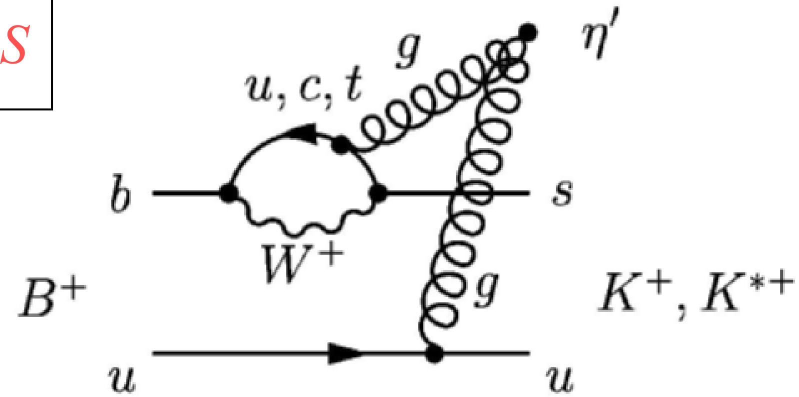
In the SM, for pure b→s modes

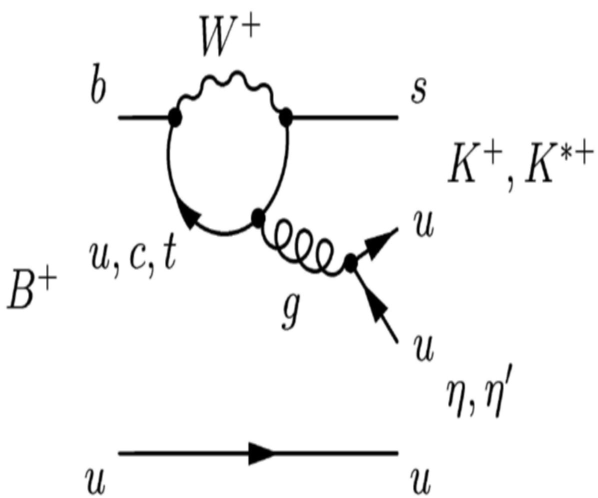
$$\sin(2\varphi_1)^{\mathrm{eff}} = \sin(2\varphi_1)(B \rightarrow \psi\, K_S)$$

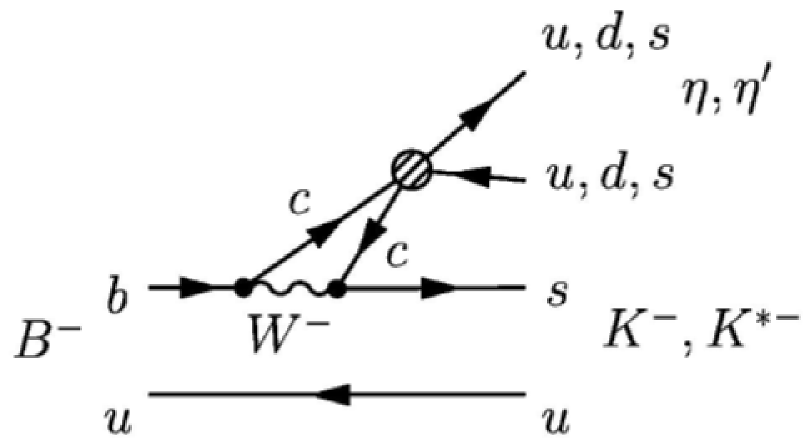
Hunting for new phases in b→s penguins



$B \rightarrow \eta' K_S$



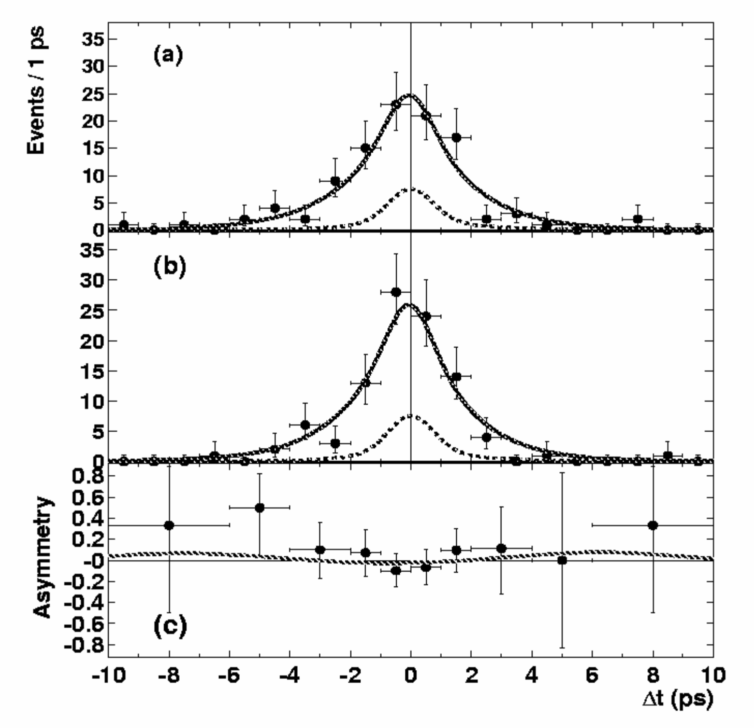




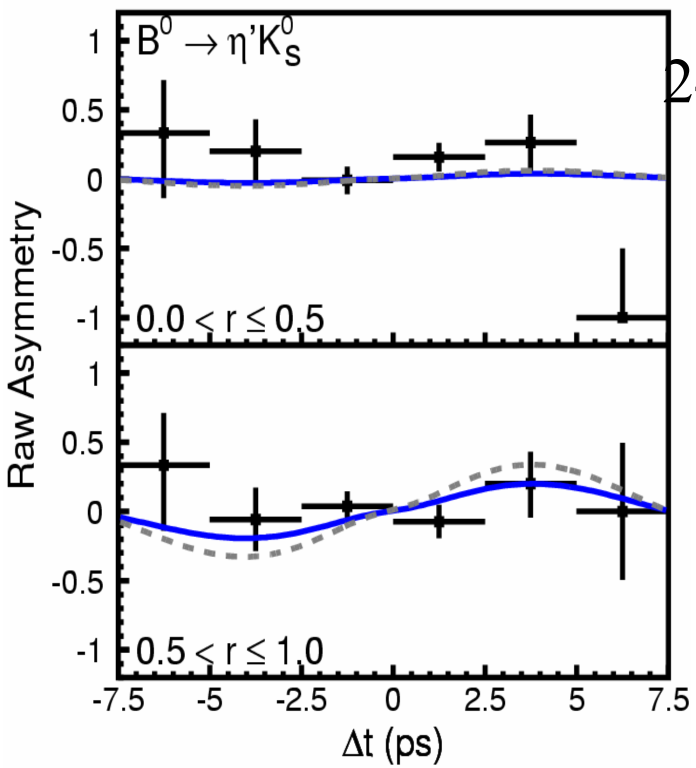
Large rates for exclusive and inclusive $B \rightarrow \eta' X_s$ decays.

Search for New Physics in the $B \rightarrow \eta' K_S$ decay

BaBar 2003 [81 fb^{-1}]



Belle 2003 [140 fb^{-1}]



244±21

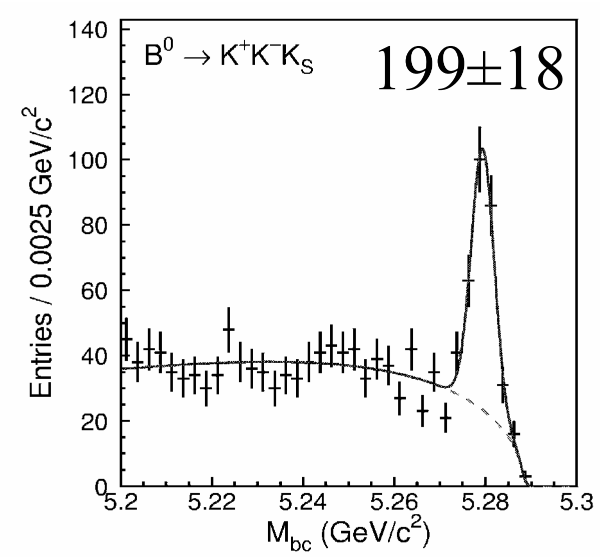
Babar: $S_{\eta' Ks}$ = 0.02±0.34±0.03

(A=-0.10±0.22±0.03)

Belle: $S_{\eta' Ks}$ = 0.43±0.27±0.05

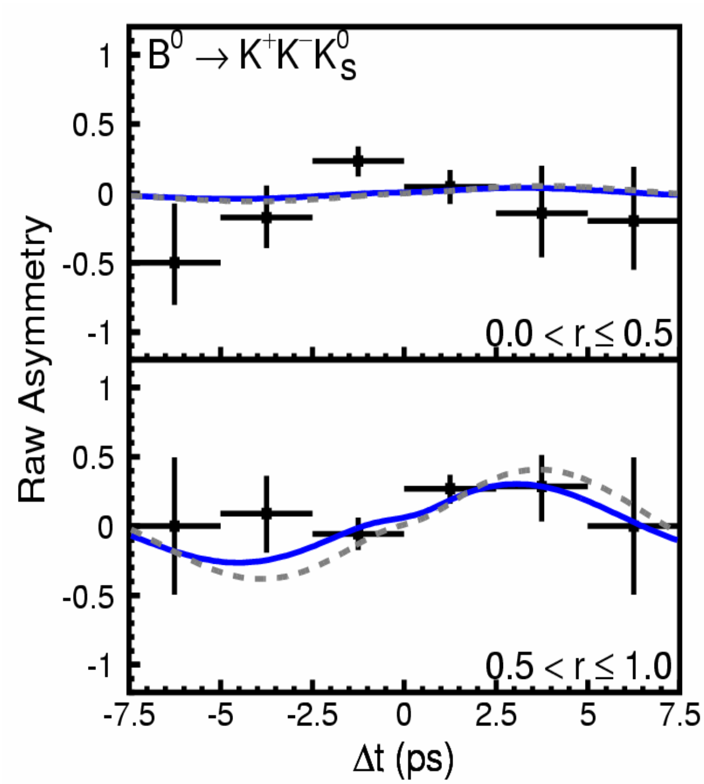
(A=-0.01±0.16±0.04)

Current WA: $\sin(2\varphi_1)$=0.731±0.056



Belle 2003:[140 fb^{-1}]

CPV in the $B \rightarrow K^+ K^- K_S$ ($b \rightarrow s$) penguin decay. (no $K_S\,\varphi$)



$$S_{KKKs} = 0.51 \pm 0.26 \pm 0.05 \;{}^{+0.18}_{-0.00}$$

The third error is due to uncertainty in the CP content.

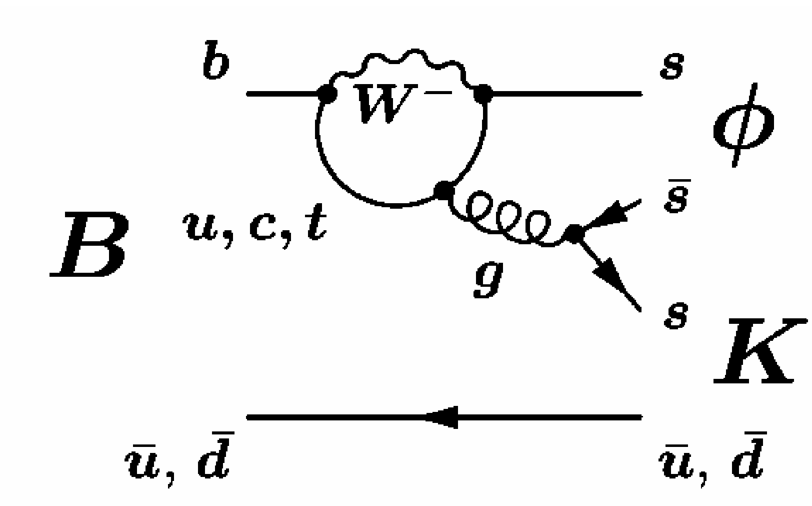
(A=-0.17±0.16±0.04)

In the absence of New Physics, $S_{KKKs} = \sin(2\varphi_1)$

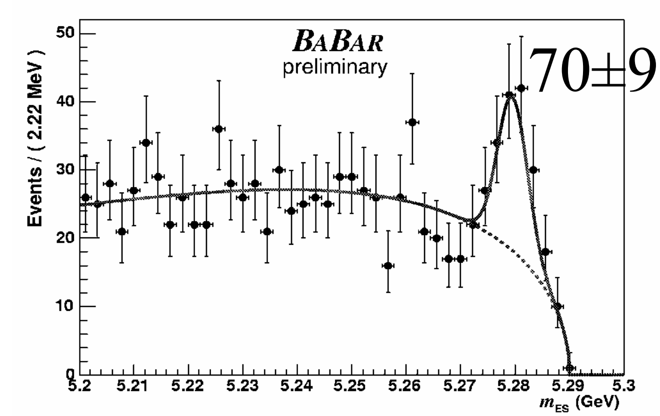
Current WA: $\sin(2\varphi_1)$=0.731±0.056

Hunting for phases from new physics

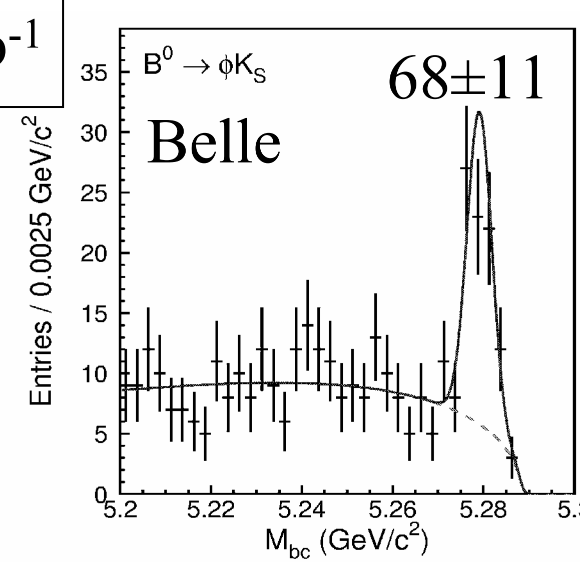
Theoretically cleanest example:



110 fb^{-1}

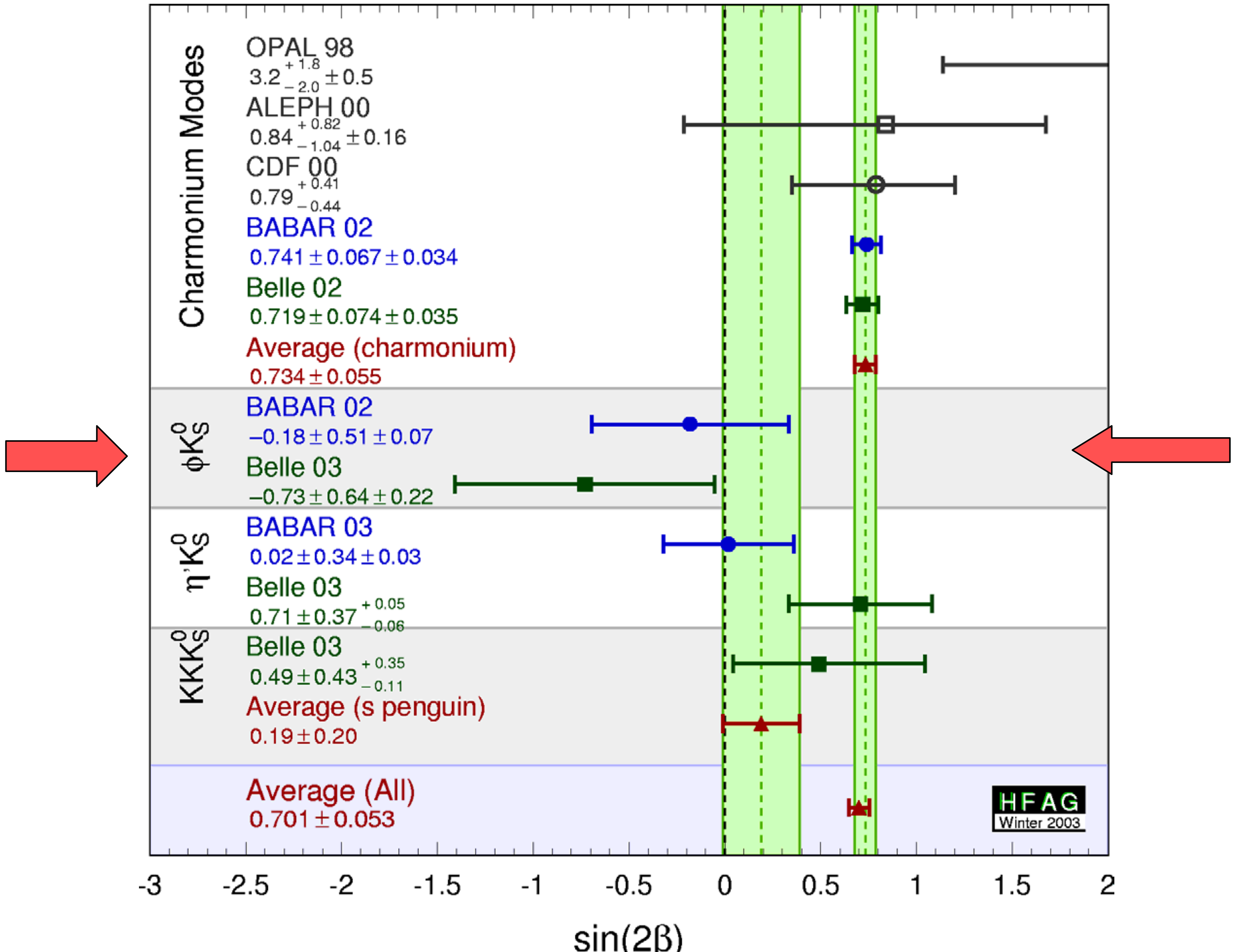


140 fb^{-1}



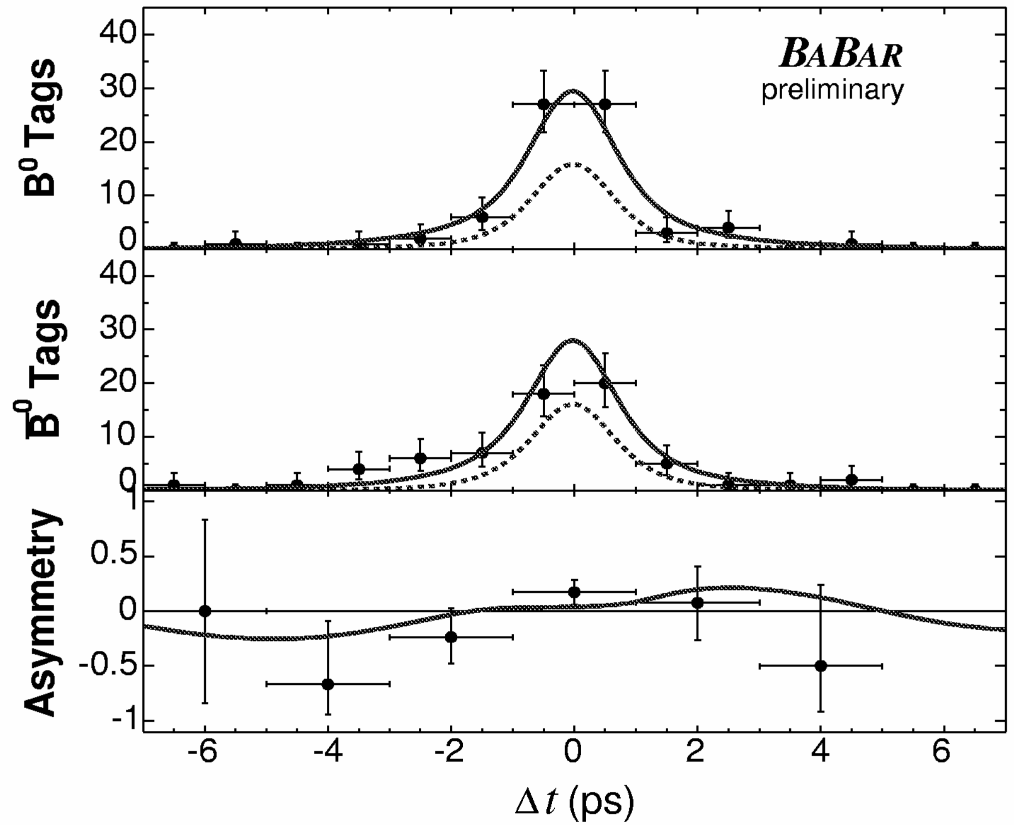
In the SM, $\sin(2\varphi_1)^{eff} = \sin(2\varphi_1)$ $(B \rightarrow \psi\ K_S)$

2002 Status of new phases in $b \rightarrow s$ penguins



BaBar 2003:CPV in B → φ K_S

BaBar 2003: 110 fb^{-1}



(A=0.38±0.37±0.12)

BaBar 2003: $\sin 2\varphi_{1\text{eff}}(\varphi\ K_S) = +0.45 \pm 0.43 \pm 0.07$

BaBar 2003: $B \to \varphi K_S$ Systematic Issues

81 fb^{-1}: $\sin 2\varphi_{1\mathrm{eff}}(\varphi K_S) = -0.18 \pm 0.51 \pm 0.09$

↓

110 fb^{-1}: $\sin 2\varphi_{1\mathrm{eff}}(\varphi K_S) = +0.45 \pm 0.43 \pm 0.07$

Data size increased and was reprocessed. Extensive checks with data and Toy MC. The large change is attributed to a 1σ statistical fluctuation.

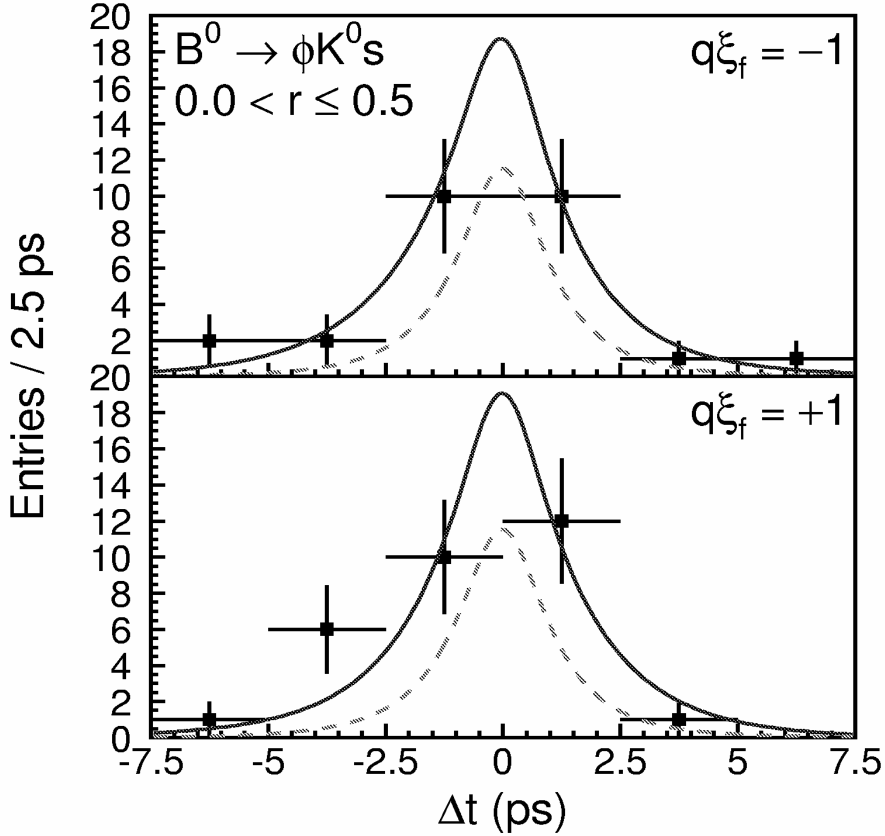
BaBar 2003: $B \rightarrow \varphi K_S$ Systematic Issues

Systematic uncertainty due to	S	C
Fit bias	0.04	0.05
Event yield	0.01	0.05
Parametrization of Δt resolution	0.03	0.02
Background composition/CP asymmetry	0.03	0.05
m_{ES} background parameterization	0.02	0.05
Uncertainties in the SVT alignment	0.01	0.01
Beamspot position	0.01	0.01
PDFs for the event yield in signal and background	0.004	0.04
Potential S-wave contamination	0.002	0.015
$B^0/\bar{B}^0$ efficiency difference	0.002	0.02
Doubly-Cabibbo-suppressed decays	0.009	0.027
Total	0.07	0.12

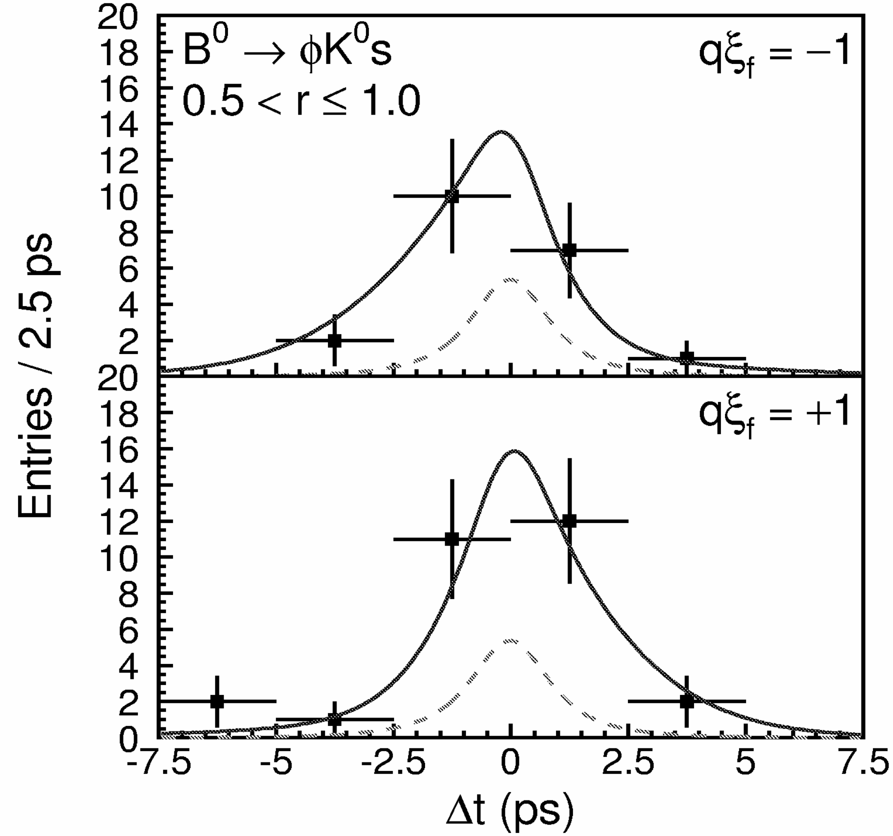
Systematics are small and well understood from b→c cbar s studies

Belle 2003: CP Asymmetry in B→φ K_S

Poor tags

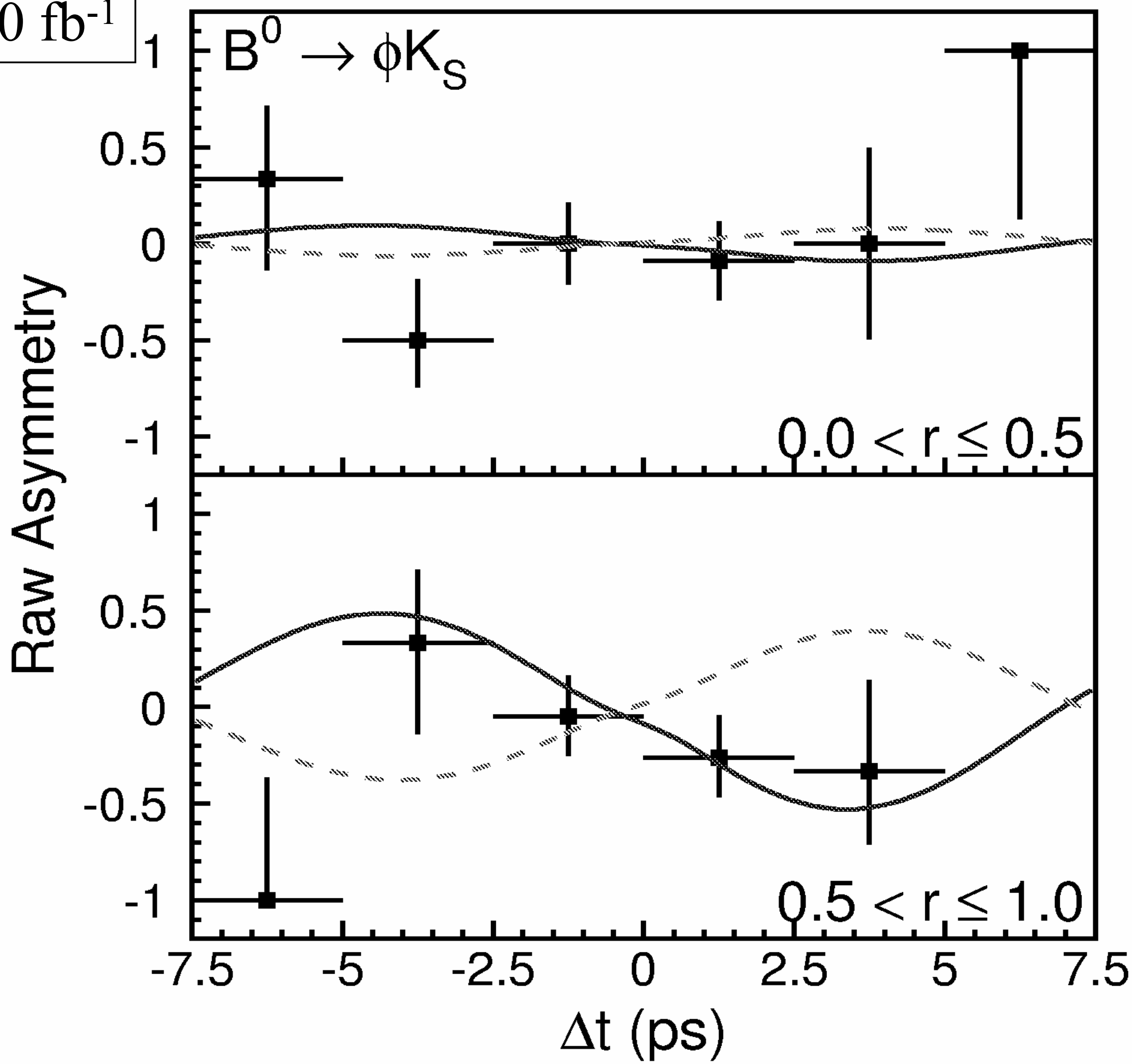


Good tags



Belle 2003: CP Asymmetry in B →φ K_S

140 fb^{-1}

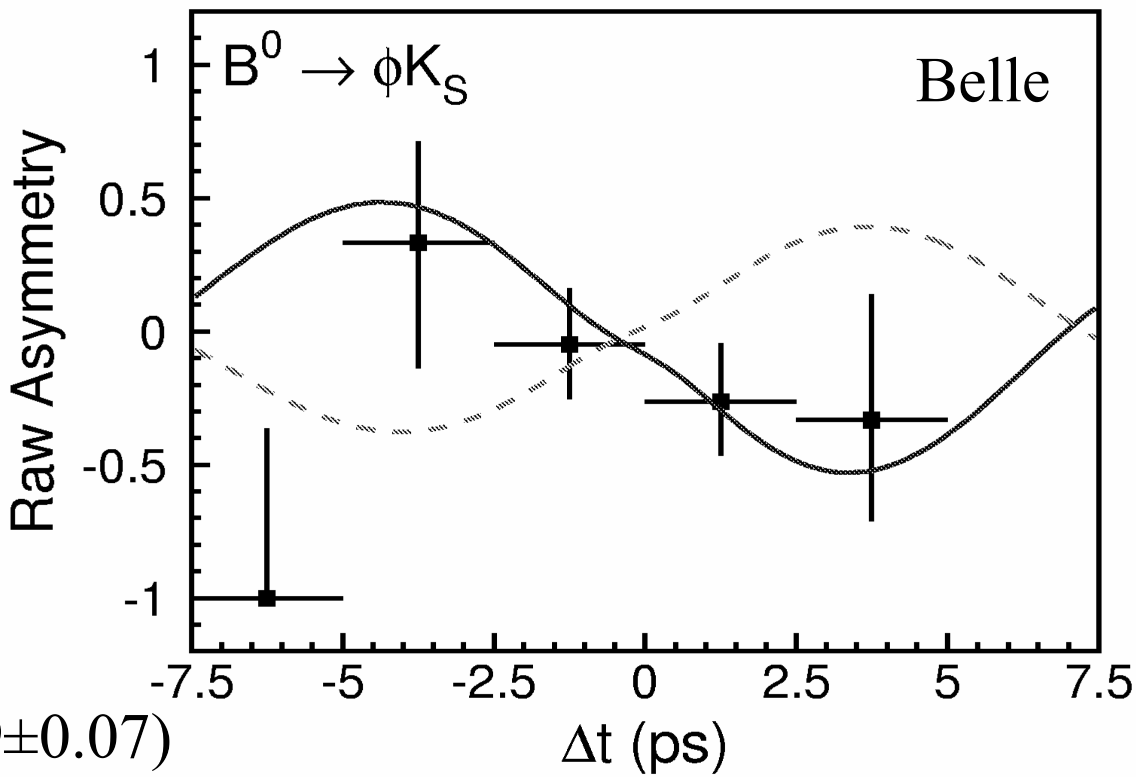


Poor flavor tags

Good flavor tags

Belle 2003: CP Asymmetry in $B \rightarrow \varphi K_S$

140 fb^{-1}



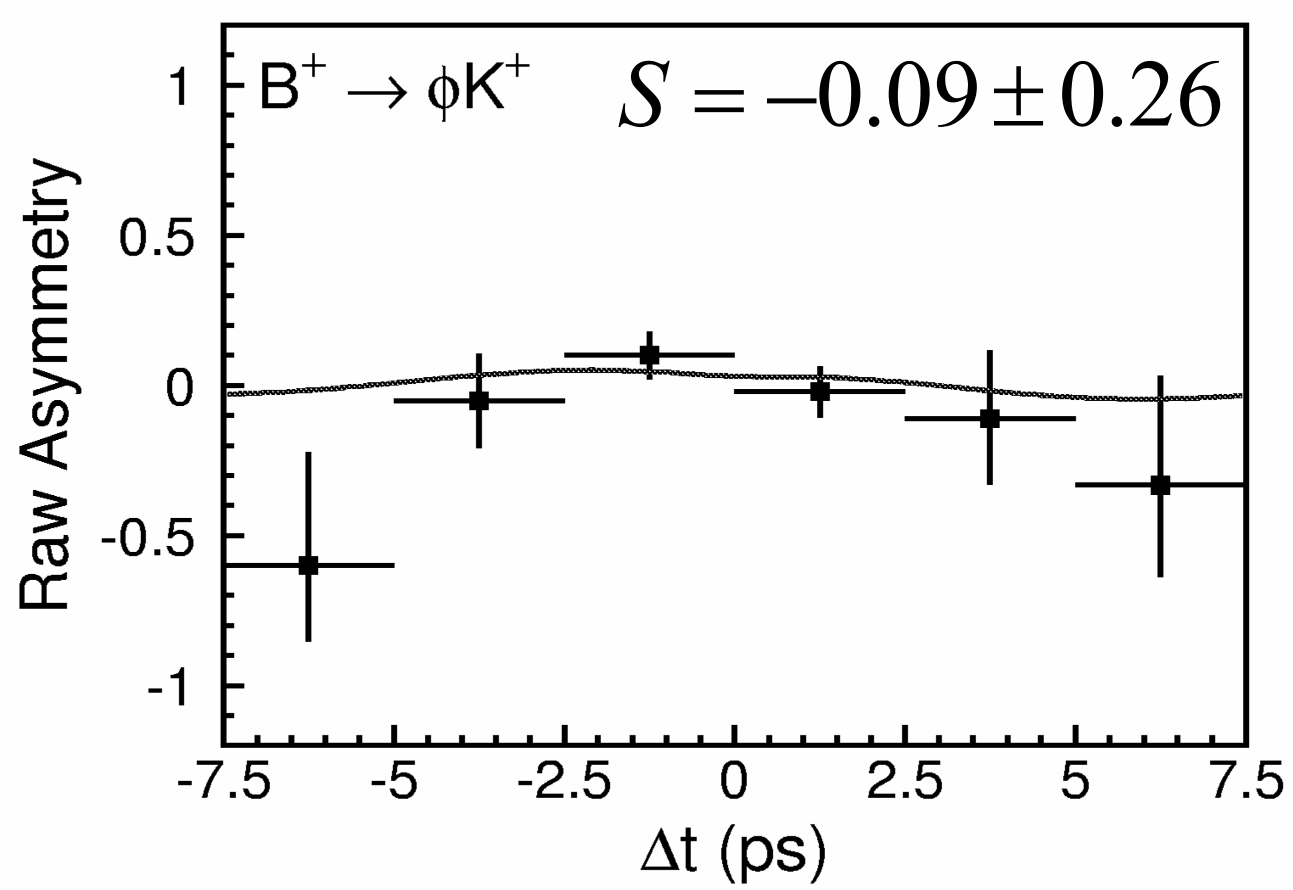
(A=-0.15±0.29±0.07)

Belle: $\sin 2\varphi_{1\mathrm{eff}} = -0.96 \pm 0.50\ ^{+0.09}_{-0.11}$

3.5σ off

Current WA: $\sin(2\varphi_1)$=0.731±0.056

Belle 2003: CP Fit for $B^{\pm} \to \varphi K^{\pm}$ Control Sample



No sin-like asymmetry.

Systematic issues in the Belle Measurement of CPV in $B \rightarrow \varphi K_S$

CP in the background: $(7.2 \pm 1.7)\%$ $K K K_S$ (measured)

: $(1.6^{+1.9}_{-1.5})\%$ $f_0 K_S$

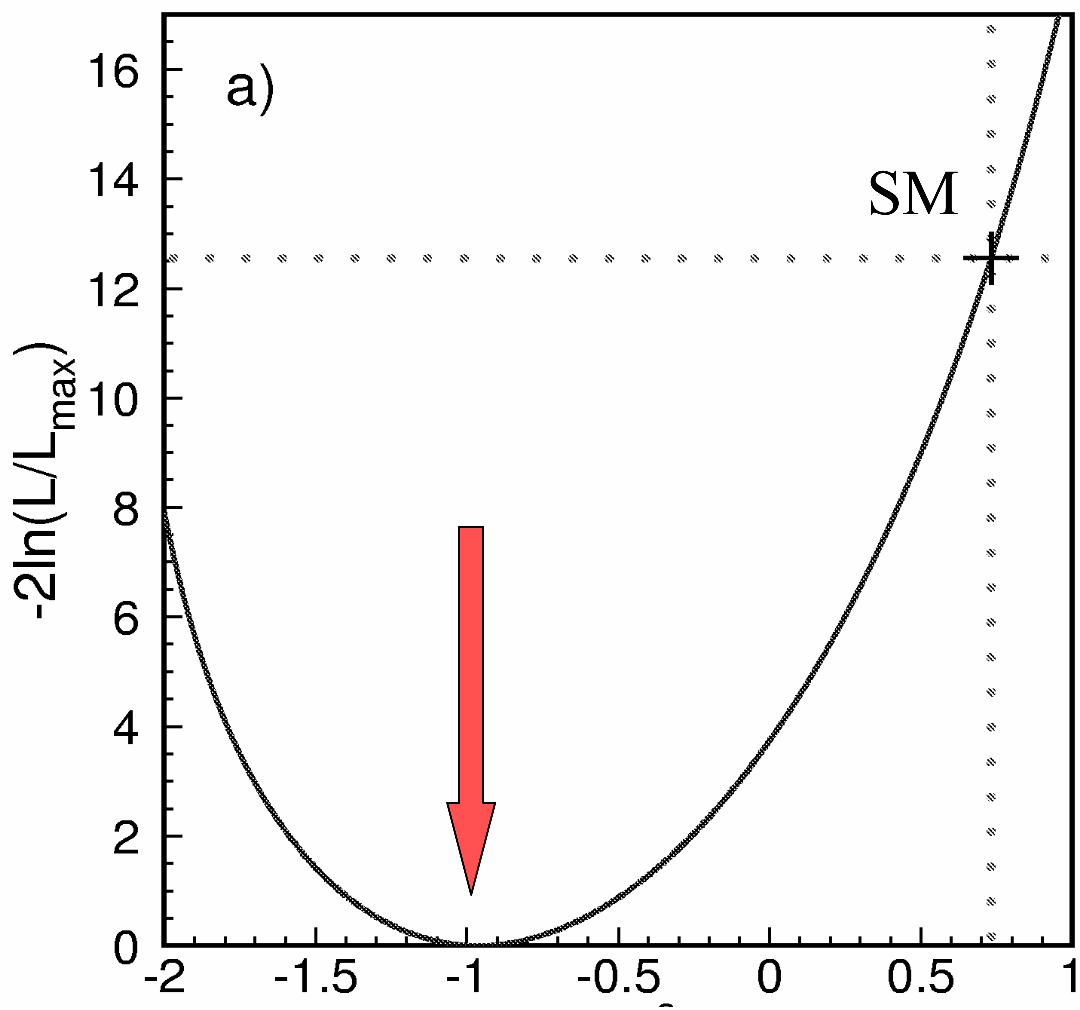
These effects are included in the systematic error

Correlation between A and S ?

$A = -0.15 \pm 0.29 \pm 0.07$

If A is fixed to zero, $S = -0.99 \pm 0.50$

Belle 2003: CP Asymmetry in B → φ K_S

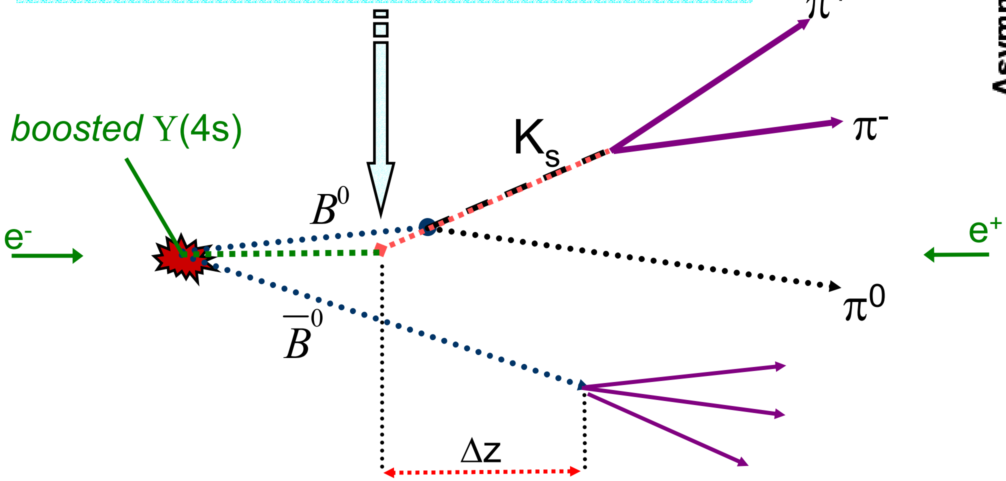


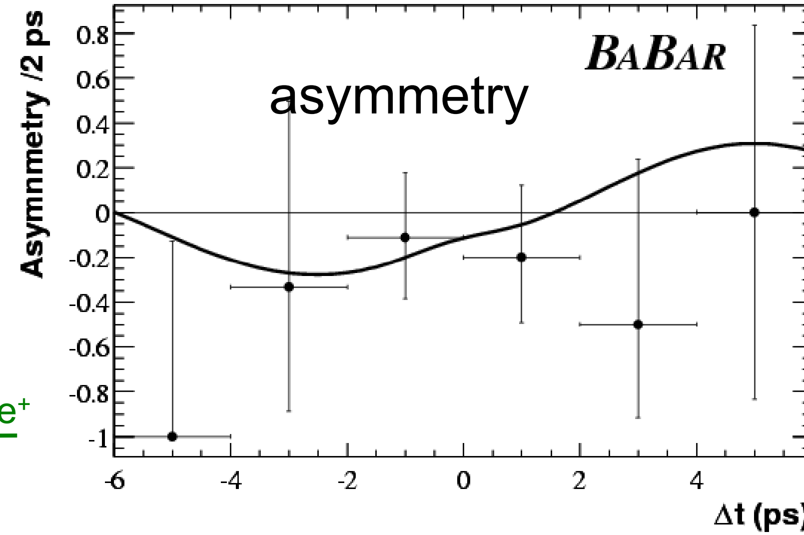
sin2φ_{1eff}(φ K_S)

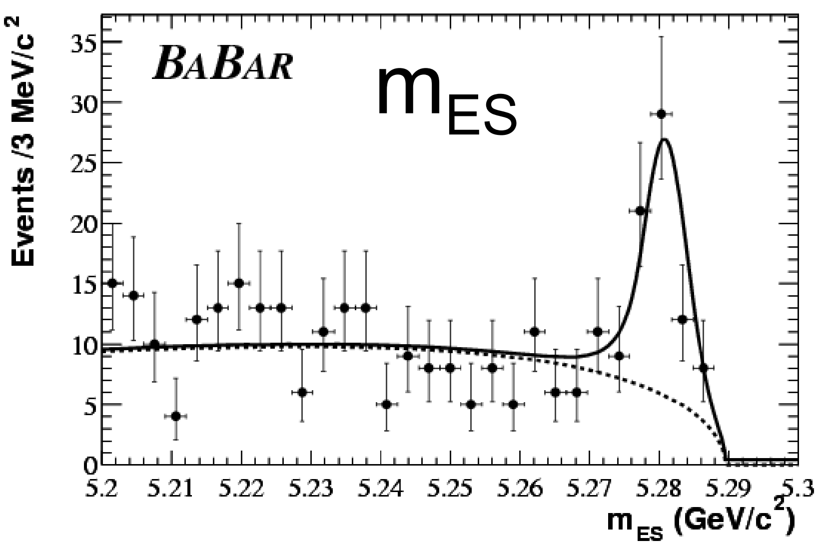
Feldman-Cousins treatment including systematic from CP in the background finds the ψ K_S value ruled out at 99.95% CL or 3.5 σ

BaBar: CPV with $B^0 \rightarrow K_s\, \pi^0$ [b→s d dbar]

Reconstruct B → $K_s\, \pi^0$ vertex using K_s trajectory and *boost* trajectory



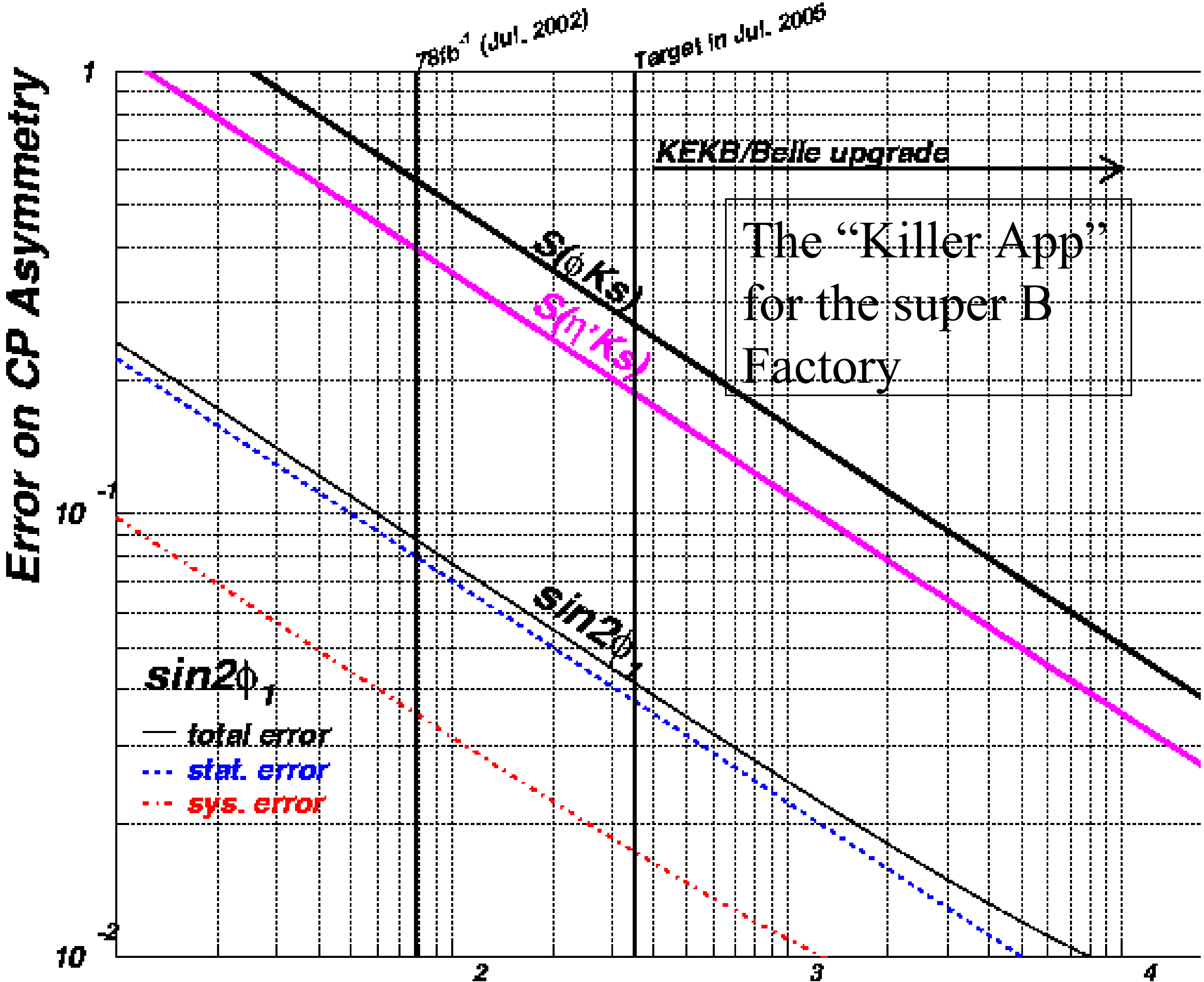




N	=	123 ± 16
C	=	$0.40^{+0.27}_{-0.28} \pm 0.10$
S	=	$0.48^{+0.38}_{-0.47} \pm 0.11$
S (C=0)	=	$0.41^{+0.41}_{-0.48} \pm 0.11$

In the absence of New Physics, S = $\sin(2\varphi_1)$ =0.731±0.056

Sensitivity to new physics phases



Conclusions

New precise measurement of $\sin(2\varphi_1)$ from Belle in $b \rightarrow c\,\bar{c}\,s$ modes. Large CPV measured in these decays by BaBar and Belle consistent with the CKM framework.

Measurements of CPV in $b \rightarrow c\,\bar{c}\,d$ modes not yet precise enough to detect whether there is penguin pollution.

CPV in $b \rightarrow s$ penguins: a surprise in $B \rightarrow \varphi K_S$.
Belle finds a 3.5σ deviation from the SM while BaBar moves closer towards the SM.

Backup Slides

Belle 2003: Table of $\sin 2\varphi_1$ values for $b \rightarrow c\ \bar{c}\ s$ CP eigenstates.

TABLE III: The numbers of candidate events, $N_{\rm ev}$, and values of $\sin 2\phi_1$ for various subsamples (statistical errors only).

Sample	$N_{\rm ev}$	$\sin 2\phi_1$
$J/\psi K_S^0(\pi^+\pi^-)$	1997	0.67 ± 0.08
$J/\psi K_S^0(\pi^0\pi^0)$	288	0.72 ± 0.20
$\psi(2S)K_S^0$	308	0.89 ± 0.20
$\chi_{c1}K_S^0$	101	1.54 ± 0.49
$\eta_c K_S^0$	217	1.32 ± 0.29
All with $\xi_f = -1$	2911	0.73 ± 0.06
$J/\psi K_L^0$	2332	0.80 ± 0.13
$J/\psi K^{*0}(K_S^0\pi^0)$	174	0.10 ± 0.45
$f_{\rm tag} = B^0$ $(q = +1)$	2717	0.72 ± 0.09
$f_{\rm tag} = \overline{B}^0$ $(q = -1)$	2700	0.74 ± 0.08
$0 < r \leq 0.5$	2985	0.95 ± 0.26
$0.5 < r \leq 0.75$	1224	0.68 ± 0.11
$0.75 < r \leq 1$	1208	0.74 ± 0.07
data set I (78 $\rm fb^{-1}$)	3013	0.73 ± 0.07
data set II (62 $\rm fb^{-1}$)	2404	0.74 ± 0.09
All	5417	0.733 ± 0.057

BELLE-CONF-0353

Belle 2003: Table of yields for b→c cbar s CP eigenstates.

Mode	ξ_f	N_{ev}	Purity
$J/\psi K_S^0$	-1	1997	0.976 ± 0.001
$J/\psi K_S^0(\pi^0\pi^0)$	-1	288	0.82 ± 0.02
$\psi(2S)K_S^0$	-1	145	0.93 ± 0.01
$\psi(2S)(J/\psi\pi^+\pi^-)K_S^0$	-1	163	0.88 ± 0.01
$\chi_{c1}(J/\psi\gamma)K_S^0$	-1	101	0.92 ± 0.01
$\eta_c(K_S^0K^-\pi^+)K_S^0$	-1	123	0.72 ± 0.03
$\eta_c(K^+K^-\pi^0)K_S^0$	-1	74	0.70 ± 0.04
$\eta_c(p\overline{p})K_S^0$	-1	20	0.91 ± 0.02
All with $\xi_f = -1$	-1	2911	0.933 ± 0.002
$J/\psi K^{*0}(K_S^0\pi^0)$	$+1(81\%)$	174	0.93 ± 0.01
$J/\psi K_L^0$	$+1$	2332	0.60 ± 0.03

BELLE-CONF-0353

Belle 2003: Systematic Uncertainties for b→s CPV modes

.

	ϕK_s		$\eta' K_s$		KKK	
	S	A	S	A	S	A
Wtag fractions	±0.018	±0.007	±0.005	±0.006	±0.005	±0.007
Physics parameters±0.033	±0.002	±0.006	±0.002	±0.003	±0.003	
Vertexing	±0.022	±0.046	±0.016	±0.027	±0.044	±0.024
Background fraction	±0.053	±0.035	±0.045	±0.026	±0.029	±0.036
Background Δt	±0.015	±0.008	±0.003	±0.003	±0.010	±0.006
Resolution function	±0.013	±0.005	±0.004	±0.003	±0.007	±0.004
KKKs + f_0Ks bkg.	+0.001 -0.084	±0.039				
Sum	**+0.09 -0.11**	**±0.07**	**±0.05**	**±0.04**	**±0.05**	**±0.04**

Systematics are small and well understood from b→c cbar s studies

Belle vs BaBar

- Belle: $\sin 2\varphi_{1\mathrm{eff}}\,(B \rightarrow \varphi K_S) = \;-0.96 \pm 0.50^{+0.09}_{-0.11}$
- BaBar: $\sin 2\varphi_{1\mathrm{eff}}(B \rightarrow \varphi K_S) = +0.45 \pm 0.43 \pm 0.07$

- There is a 2.1 σ discrepancy between the exps.

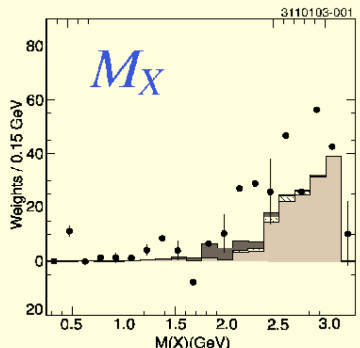
- Average =-0.15±0.33 (Still 2.7σ from the SM)

Mystery of Large Inclusive $B \to \eta' X_s$

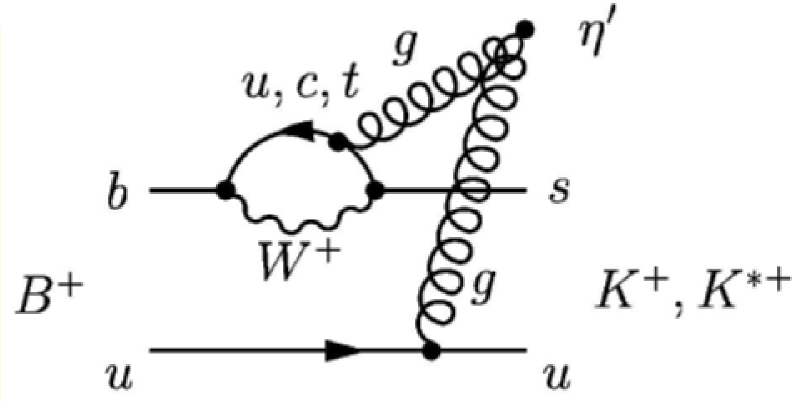
Inclusive $B \to \eta'$

CLEO

hep-ex/0303009, submitted to PRD



- Semi-inclusive reconstruction: $X_s = 1K + (1 \sim 4)\pi$
- Subtract continuum fraction using off-resonant data.
- $\mathcal{B} = (6.2 \pm 1.6 \pm 1.3^{+0.0}_{-1.5}) \times 10^{-4}$ PRL **81**, 1786 (1998)
  $8 \sim 9\times$ larger than $\mathcal{B}(\eta' K)$
- $\mathcal{B} = (4.6 \pm 1.1 \pm 0.4 \pm 0.5) \times 10^{-4}$ New!
- Rising spectrum on recoiled mass.



"gluon anomaly"

c.f. Babar: hep-ex/0109034: $B \to \eta' X_s = (6.8^{+0.7}_{-1.0} \pm 1.0_{-0.5}) \times 10^{-4}$

BaBar: B→η' X_s inclusive

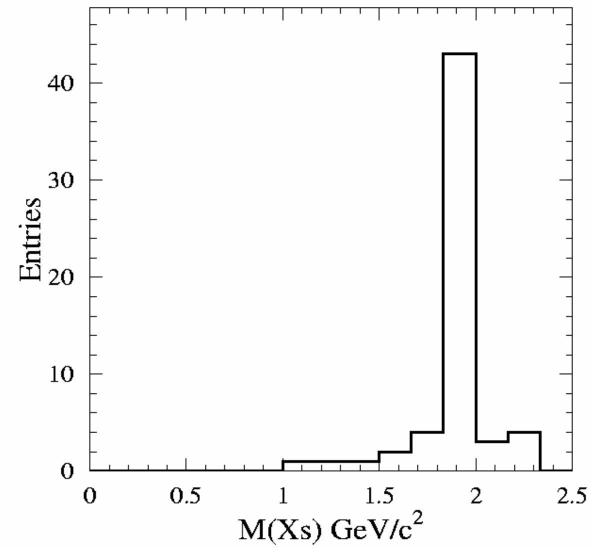
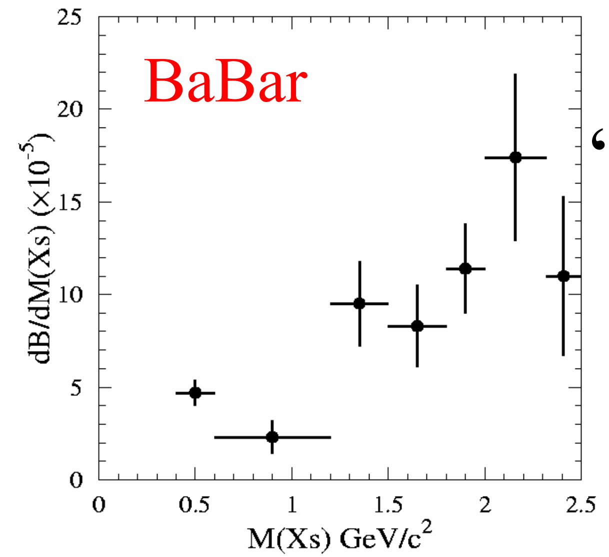


Figure 3: $M(X_s)$ spectrum predicted from simulation of $\overline{B}^0 \to \eta' D^0$ decays

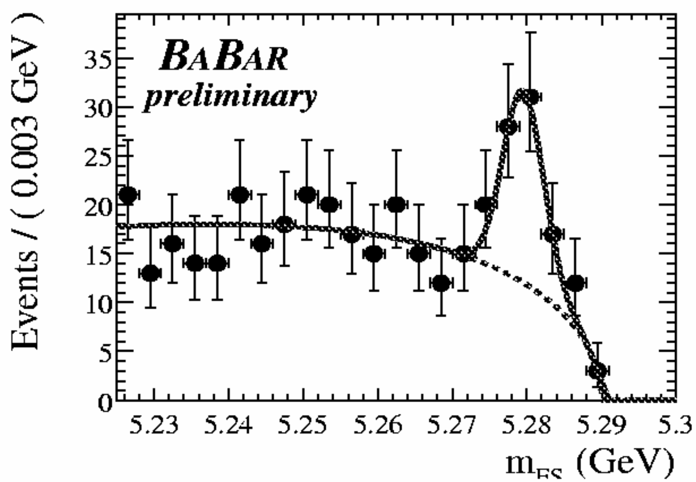
QCD anomaly: **e.g D.Atwood and A.Soni, W.S. Hou and Tseng**

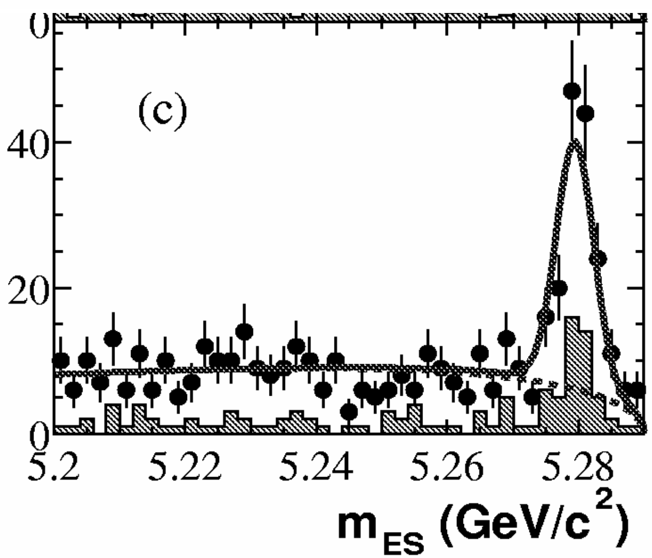


"3-body"

Kagan+Petrov: CLEO Y(1S) data show that the η' gg form factor falls off too fast. [c.f. Ali+Parkhomenko, E. Kou]

Signals for BaBar b->s

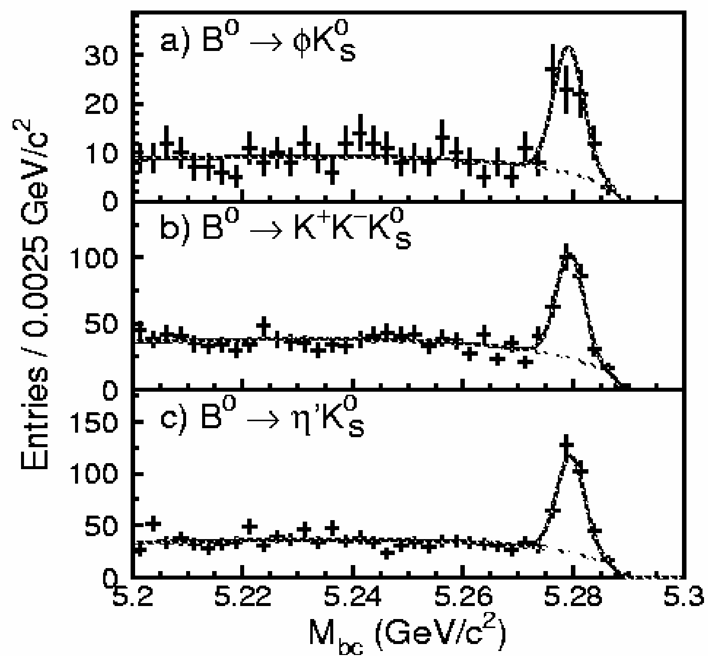




Signals for Belle b→s CPV analysis.

TABLE I: The numbers of reconstructed $B^0 \to f_{CP}$ candidates used for $\mathcal{S}$ and $\mathcal{A}$ determination, $N_{\rm ev}$, and the estimated signal purity in the ΔE-$M_{\rm bc}$ signal region for each f_{CP} mode.

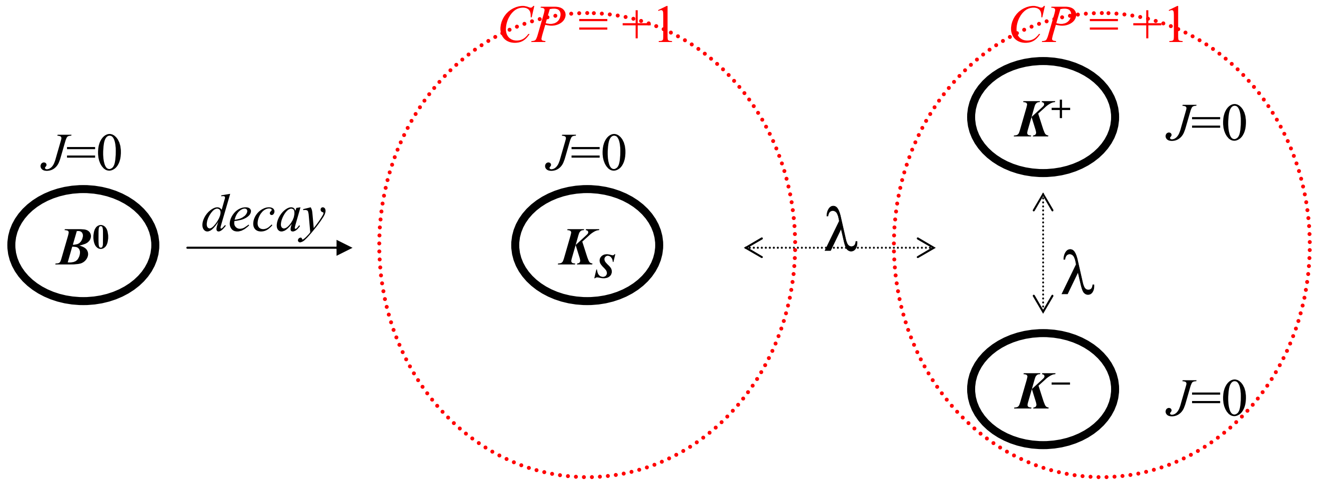
Mode	ξ_f	$N_{\rm ev}$	Purity
ϕK_S^0	-1	106	0.64 ± 0.10
$K^+K^-K_S^0$	$+1(100\%)$	361	0.55 ± 0.05
$\eta' K_S^0$	-1	421	0.58 ± 0.05



$B^0 \to K^+K^-K_S : CP = \pm 1$ Mixture

Since $B^0 \to K^+K^-K_S$ is 3-body decay,
the final state is a mixture of $CP = \pm 1$.
How can we determine the admixture ?

$CP = \pm 1$ fraction is equal to that of λ=even/odd



$CP = (-1)^{\lambda}$

$B^0 \to K^+K^-K_S$: $CP = \pm 1$ Content

λ-even fraction in $|K^0\bar{K}^0\rangle$ can be determined by $|K_S K_S\rangle$ system

$$\left|K^0\overline{K}^0\right\rangle = \frac{a}{\sqrt{2}}\left(\left|K_S K_S\right\rangle + \left|K_L K_L\right\rangle\right) + b\left|K_S K_L\right\rangle$$

$CP = +1$ λ = even λ = odd

Add K^+ to above kets

$$\left|K^+K^0\overline{K}^0\right\rangle = \frac{a}{\sqrt{2}}\left(\left|K^+K_S K_S\right\rangle + \left|K^+K_L K_L\right\rangle\right) + b\left|K^+K_S K_L\right\rangle$$

Using isospin symmetry

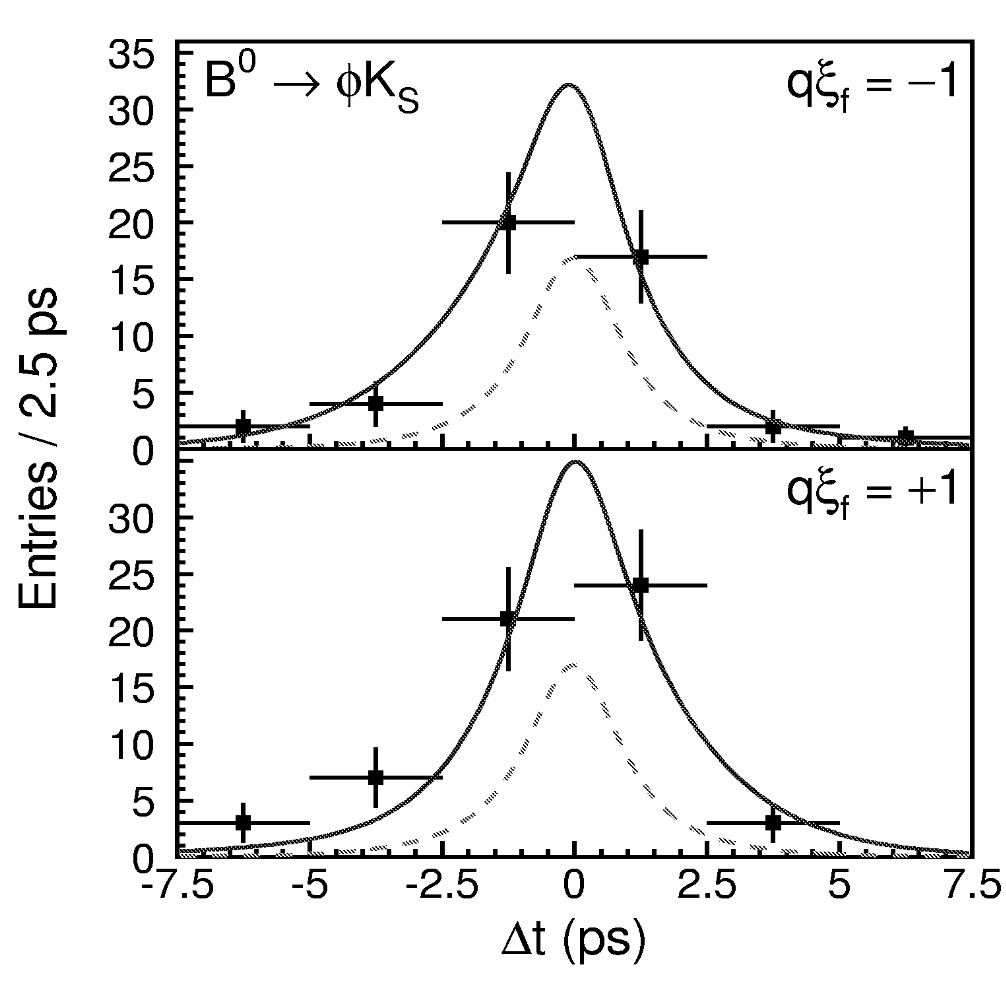
$$BF(B^+ \to K^+K^0K^0) = BF(B^0 \to K^0K^+K^-)\tau(B^+)/\tau(B^0)$$
$$= \frac{1}{2}BF(B^0 \to K^0K^+K^-)\tau(B^+)/\tau(B^0)$$

$$a^2 = \frac{2BF(B^+ \to K^+K_SK_S)\tau(B^0)}{BF(B^0 \to K^0K^+K^-)\tau(B^+)}$$
$$= \frac{BF(B^+ \to K^+K_SK_S)\tau(B^0)}{BF(B^0 \to K_SK^+K^-)\tau(B^+)}$$

$= 1.026 \pm 0.15(\text{stat}) \pm 0.05(\text{sys})$

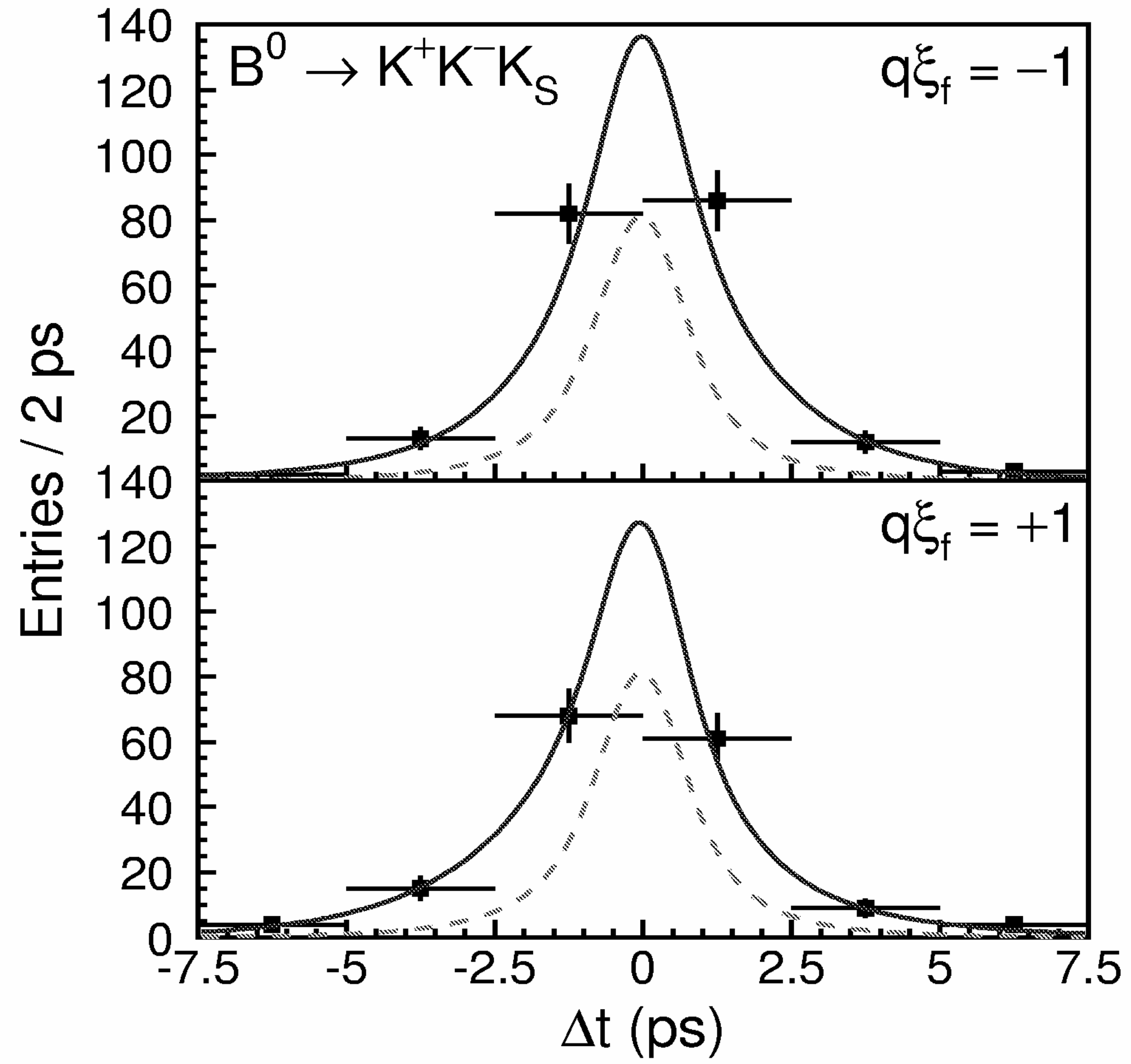
100^{+0}_{-15} % CP Even

Belle 2003: CP Asymmetry in B→φ K_S

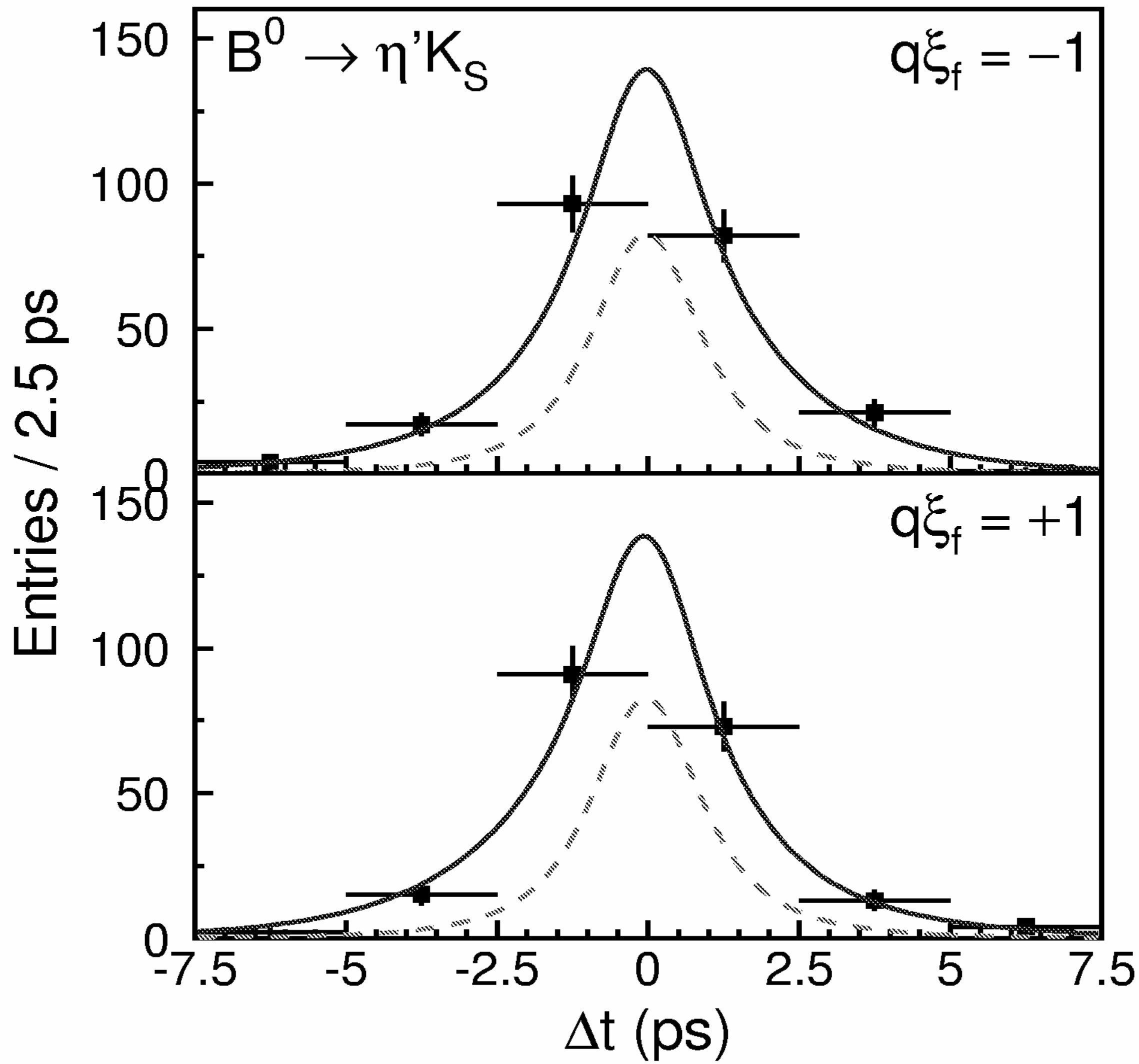


All r bins

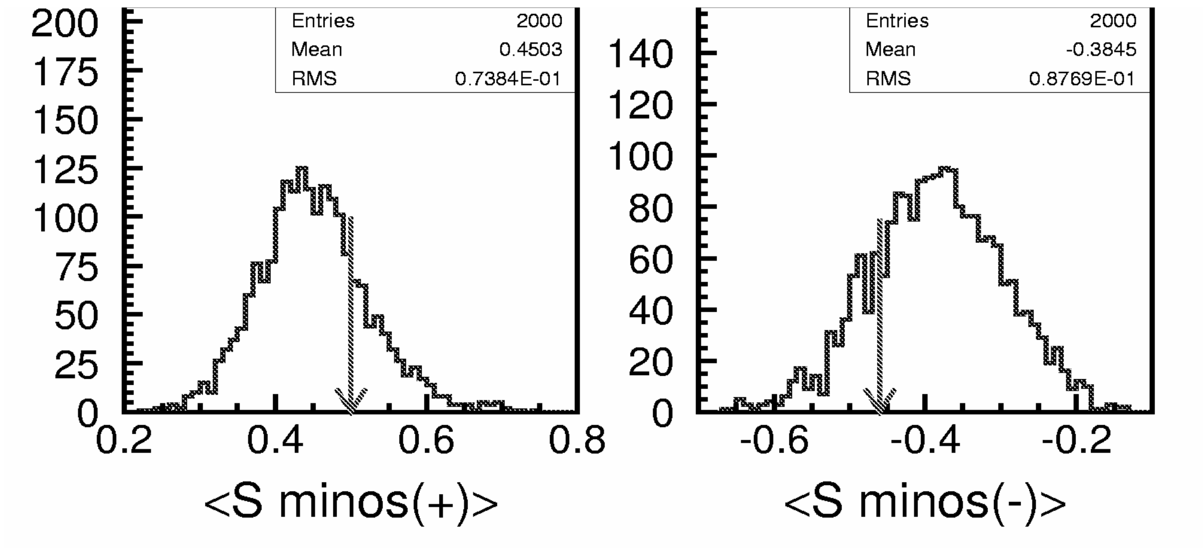
Belle 2003: CP Asymmetry in B →K⁺K⁻ K_S



Belle 2003: CP Asymmetry in B → η' K_S



Belle 2003: Toy MC studies of the errors for B→φ K_S



Errors are slightly larger than expected.

Belle 2003: CPV in b→s modes (additional details)

TABLE II: Results of the fits to the Δt distributions. The first errors are statistical and the second errors are systematic. The third error for the $K^+K^-K^0_S$ mode arises from the uncertainty in the fraction of the CP-odd component.

Mode	$-\xi_f \mathcal{S}$ (= sin $2\phi_1$ in the SM)	$\mathcal{A}$ (= 0 in the SM)
ϕK^0_S	$-0.96 \pm 0.50^{+0.09}_{-0.11}$	$-0.15 \pm 0.29 \pm 0.07$
$K^+K^-K^0_S$	$+0.51 \pm 0.26 \pm 0.05^{+0.18}_{-0.00}$	$-0.17 \pm 0.16 \pm 0.04$
$\eta' K^0_S$	$+0.43 \pm 0.27 \pm 0.05$	$-0.01 \pm 0.16 \pm 0.04$

Belle 2003: CPV in b→s modes (additional details)

TABLE I: The numbers of reconstructed $B^0 \to f_{CP}$ candidates used for $\mathcal{S}$ and $\mathcal{A}$ determination, $N_{\rm ev}$, and the estimated signal purity in the ΔE-$M_{\rm bc}$ signal region for each f_{CP} mode.

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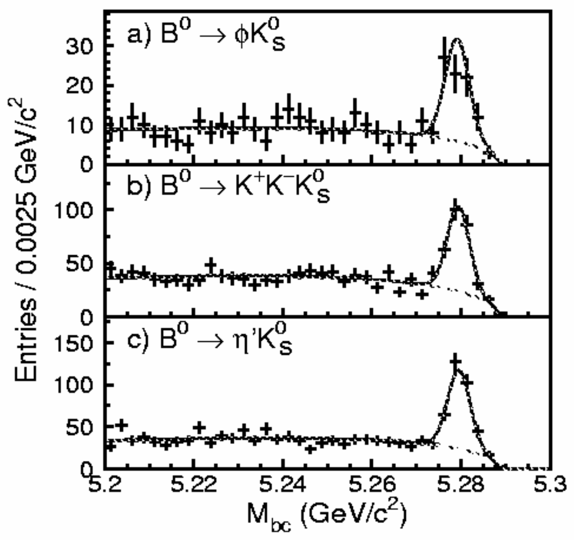
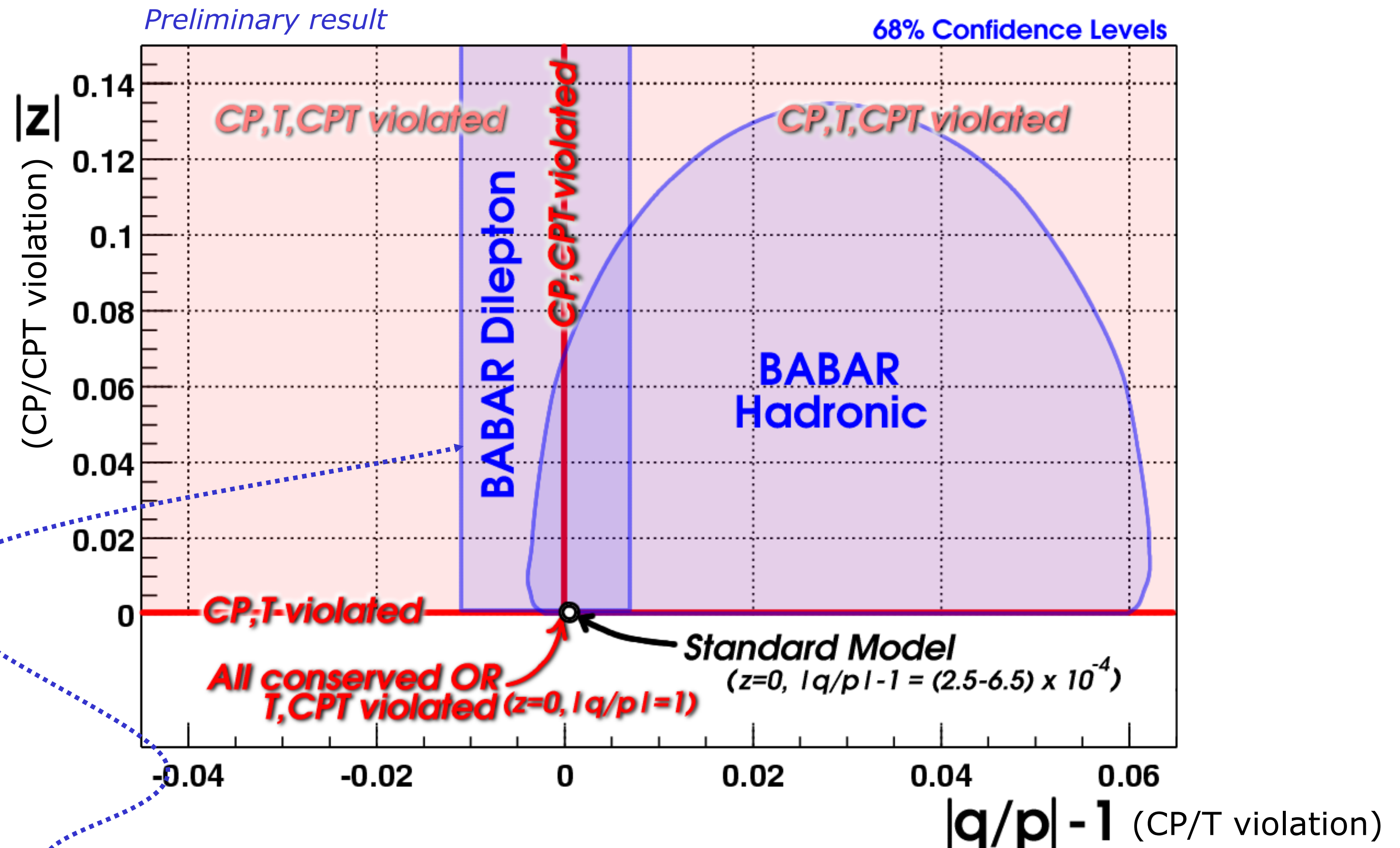


FIG. 1: The beam-energy constrained mass distributions for (a) $B^0 \to \phi K_S^0$, (b) $B^0 \to K^+K^-K_S^0$, and (c) $B^0 \to \eta' K_S^0$ within the ΔE signal region. Solid curves show the fit to signal plus background distributions, and dotted curves show the background contributions. The background for $B^0 \to \eta' K_S^0$ decay includes an MC-estimated $B\overline{B}$ background component.

Limits on ΔΓ and search for CP, T, CPT violation in mixing

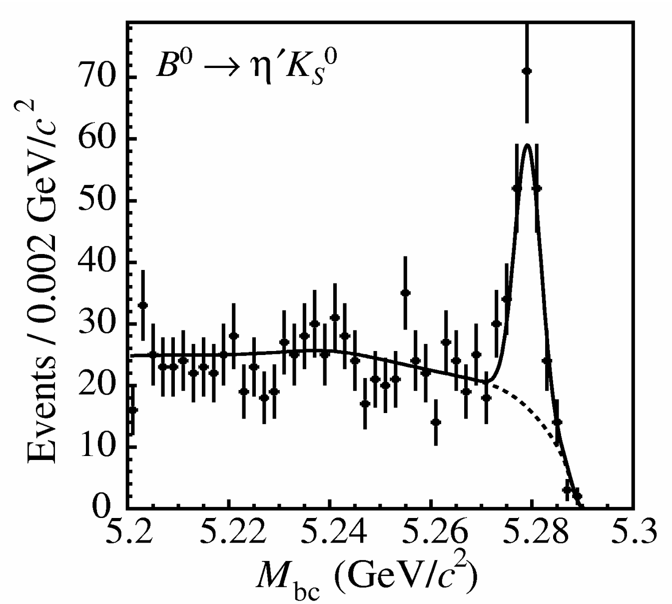


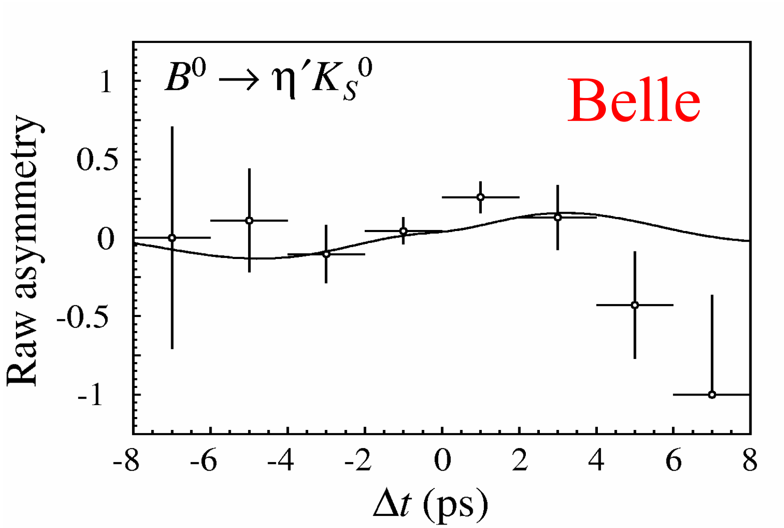
Also represented: constraint on indirect CPV using dilepton sample

$$a_T(\Delta t) \equiv \frac{\mathcal{N}(\ell^+\ell^+) - \mathcal{N}(\ell^-\ell^-)}{\mathcal{N}(\ell^+\ell^+) + \mathcal{N}(\ell^-\ell^-)} \approx \frac{1-|q/p|^4}{1+|q/p|^4} \quad \Rightarrow \quad a_T = (0.5 \pm 1.2 \pm 1.4)\%$$

Phys. Rev. Lett. **89** (2002) 201802

N(η'K_S)=146±12





Search for New Physics in the B→ η'K_S penguin decay.

Belle: $S_{\eta' K_s} = 0.71 \pm 0.37^{+0.05}_{-0.06}$

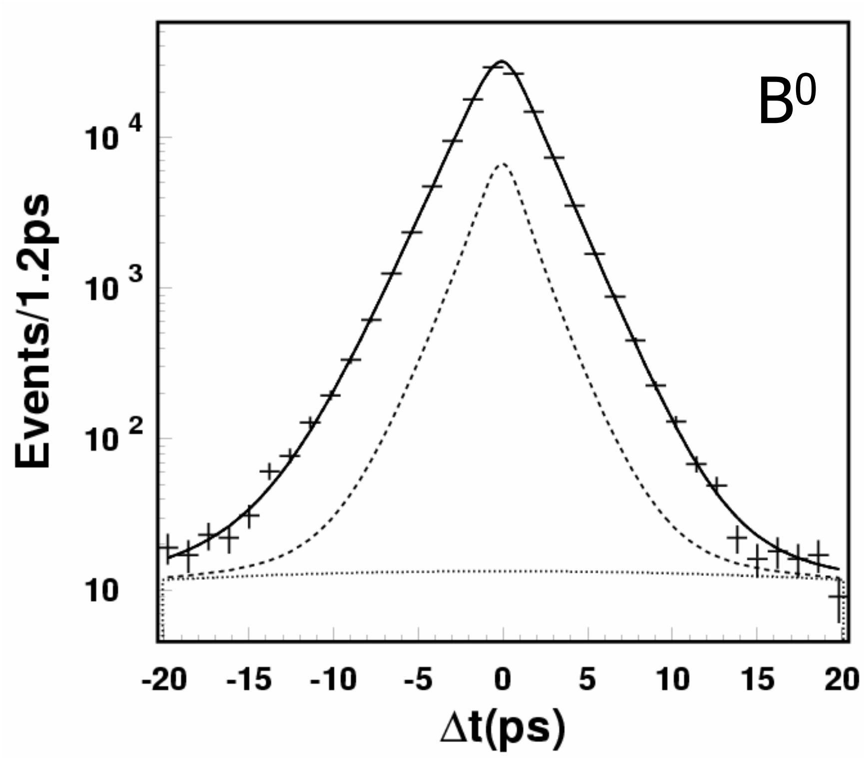
Babar: $S_{\eta' K_s} = 0.02 \pm 0.34 \pm 0.03$

In the absence of New Physics, $S_{\eta' K_s}$ = sin (2φ_1) (a.k.a. sin(2β))

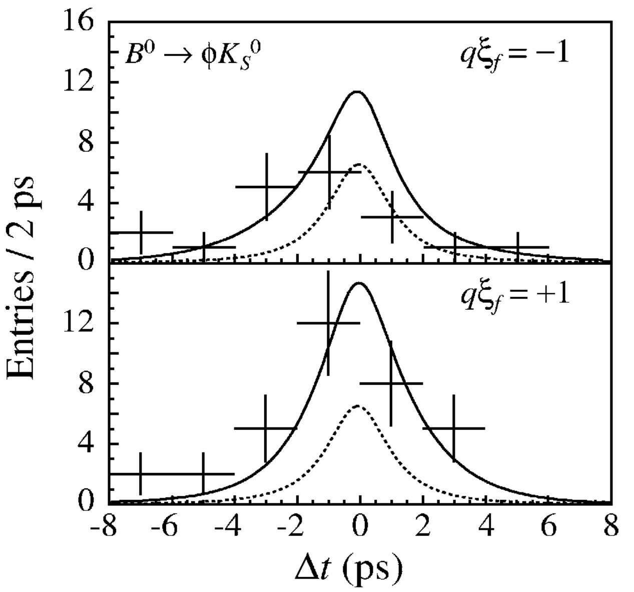
Current WA: sin(2φ_1)=0.734±0.055

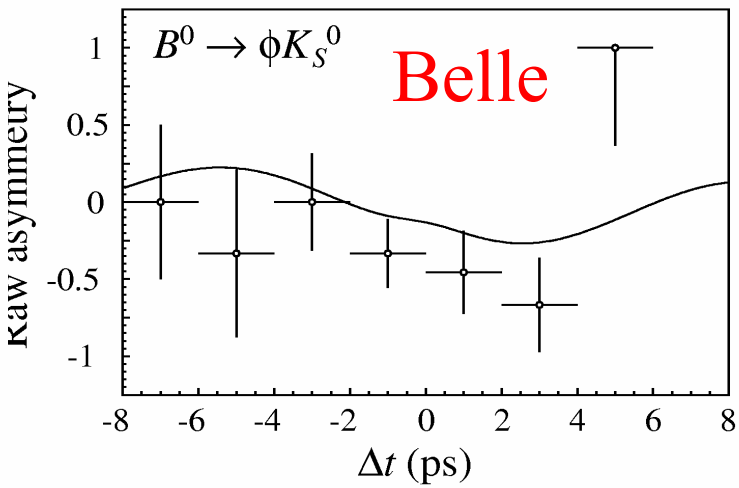
Control samples:
Resolution Parameters and B^0 and $B^{\pm}$ Lifetime

τ_{B0} = 1.533 ± 0.008(stat) ps
(PDG2003 1.537 0.015)
τ_{B+} = 1.634 ± 0.011(stat) ps
(PDG2003 1.671 0.018)



2002 Status of new phases in b→s penguins





(hep-ph/0209290), J-P Lee, K. Y. Lee; (hep-ph/0208226) B. Dutta, C.S. Kim and S. Oh; (hep-ph/0208091), M. Raidal; (hep-ph/0208087), M. Ciuchini, L. Silvestrini; (hep-ph/0208016), A. Datta;(hep-ph/0208005), H. Murayama;(hep-ph/0207356), G. Hiller; (hep-ph/0207070), M-B. Causse; (hep-ph/0208080) Y. Nir ….

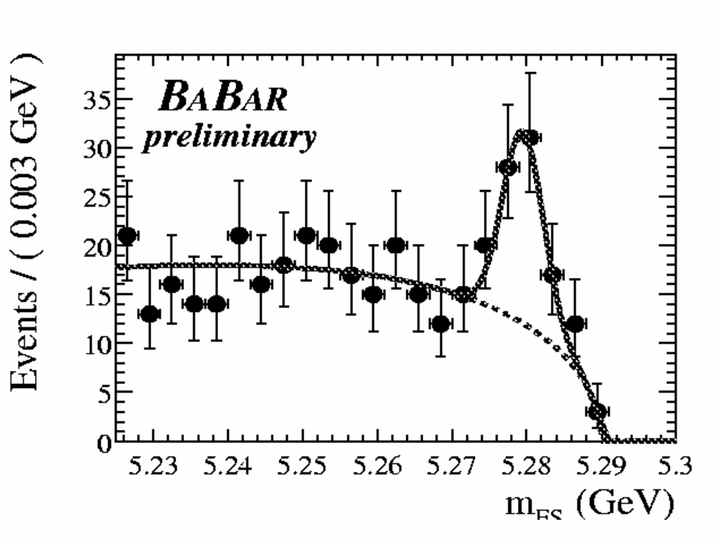
Belle: $\sin 2\varphi_{1\mathrm{eff}} = -0.73 \pm 0.64 \pm 0.22$

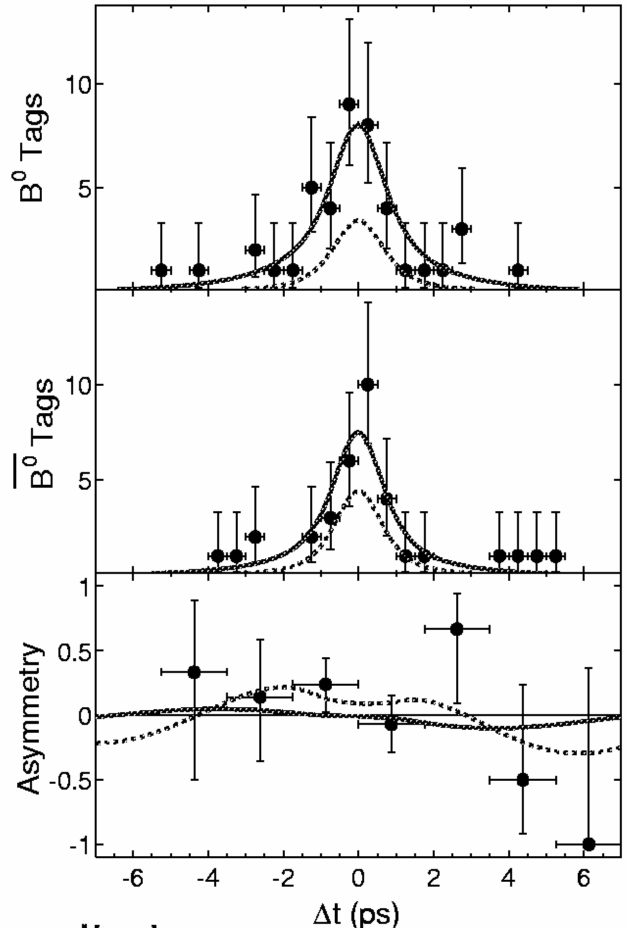
Babar: $\sin 2\varphi_{1\mathrm{eff}} = -0.18 \pm 0.51 \pm 0.09$

2.7σ off | *WA: $\sin 2\varphi_{1\mathit{eff}} (\varphi\, K_S) = -0.38 \pm 0.41$* ←

BaBar 2002:B→φ K_S

BaBar 2002: 81 fb^{-1}





preliminary

Babar 2002: $\sin 2\varphi_{1\mathrm{eff}}(\varphi\ K_S) = -0.18 \pm 0.51 \pm 0.09$