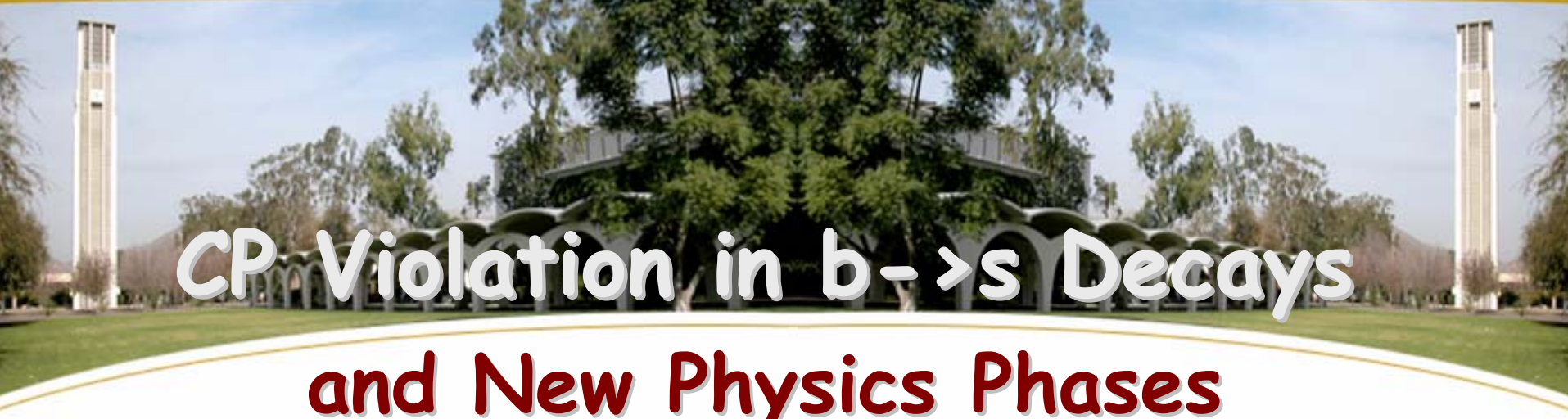


CP Violation in b->s Decays and New Physics Phases

Alexei Garmash

Princeton University

(for the Belle Collaboration)

- Introduction
- Apparatus
- Results on CPV
  - b->sqq
  - b->sγ
- Summary

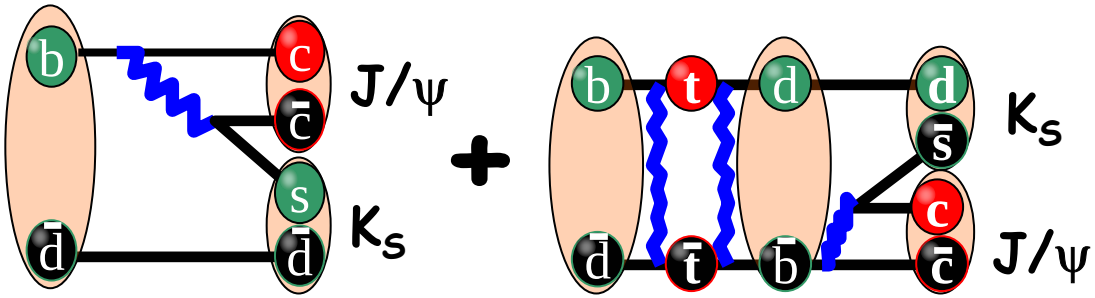
One phase to rule them all ?

BELLE

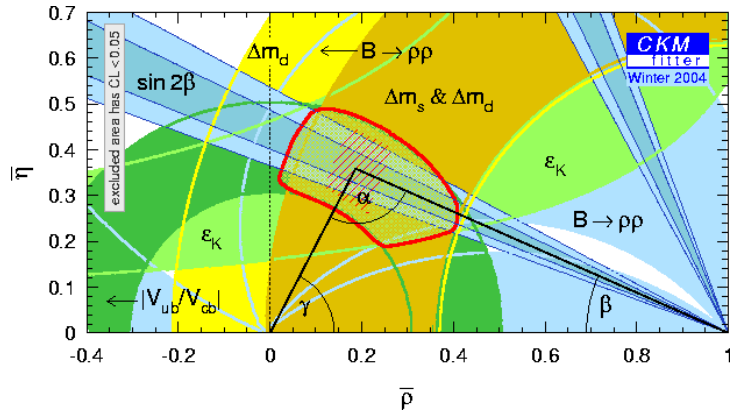
Beautiful agreements so far!

Triumph of the Kobayashi-Maskawa model of *CP* violation with a single *CP*-violating phase

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



Quantum interference between two diagrams



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

For $B^0 \to J/\psi K_S$: $\mathcal{S} = \sin(2\phi_1)$

$\mathcal{A} = 0$

WA: $\sin 2\phi_1 = 0.726 \pm 0.037$

Much more statistics is needed for precise measurements of $\phi_2(\alpha)$, $\phi_3(\gamma)$ ($1 ab^{-1}$ at least)

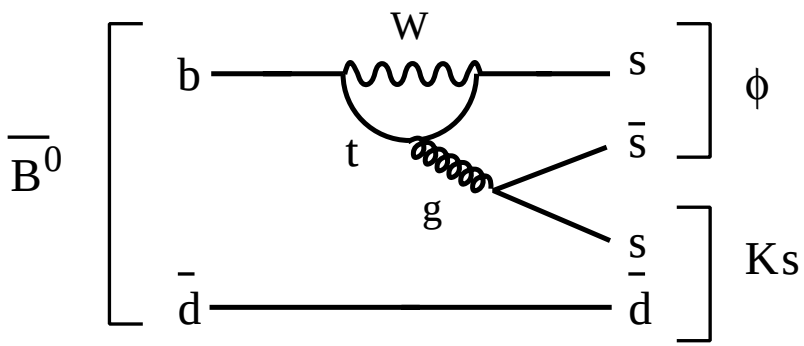
Hunt for New Physics in b->sqq̄

=> Measurement of the $\phi 1(\beta)$ phase in various quark level processes.
SM predicts the same TCPV (up to Few % corrections) in *b->sqq* penguin as in *b->ccs* tree transition

SM breaking of S=sin2β		
Mode	Reasonable expectation	Bounds* from SU(3)
ϕK_s	<0.05	<0.25
$\eta' K_s$	~0.08	<0.35
$\pi^0 K_s$	~0.08?	<0.20

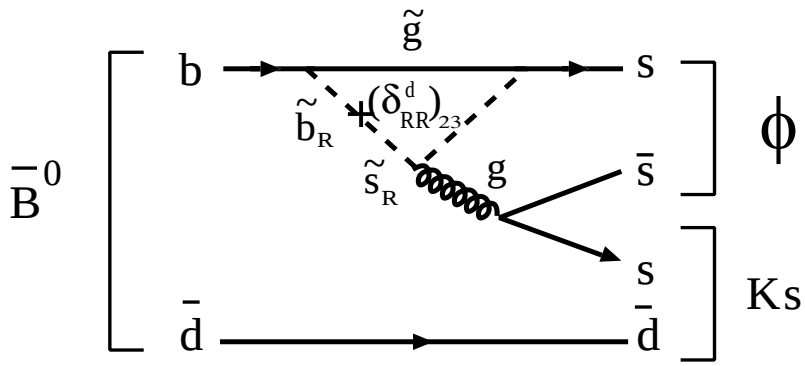
*Grossman, Ligeti, Nir, Quinn. PRD 68, 015004 (2003)
Gronau, Grossman, Rosner hep-ph/0310020

SM penguin



+

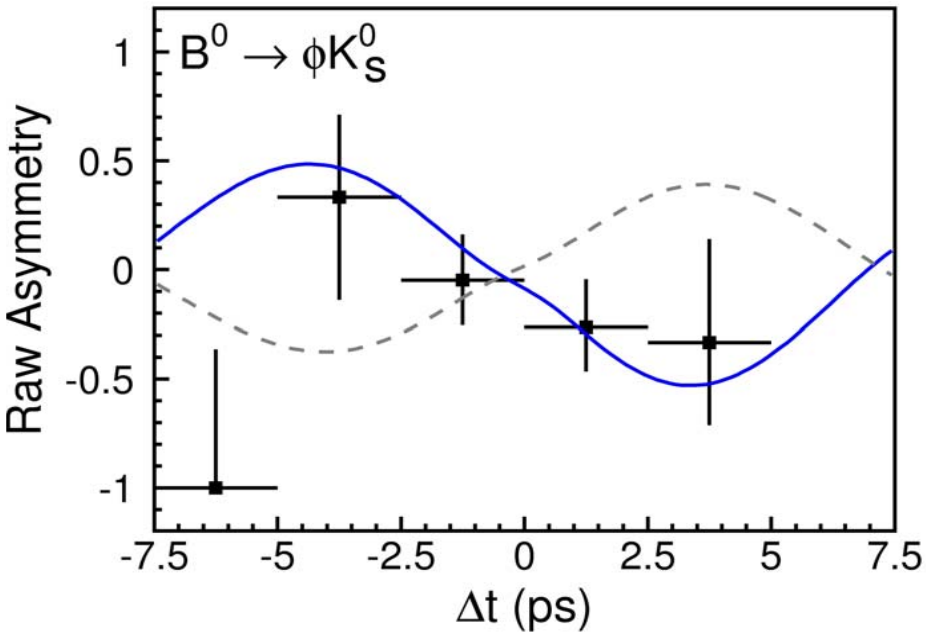
New Physics process w/ different CP phase

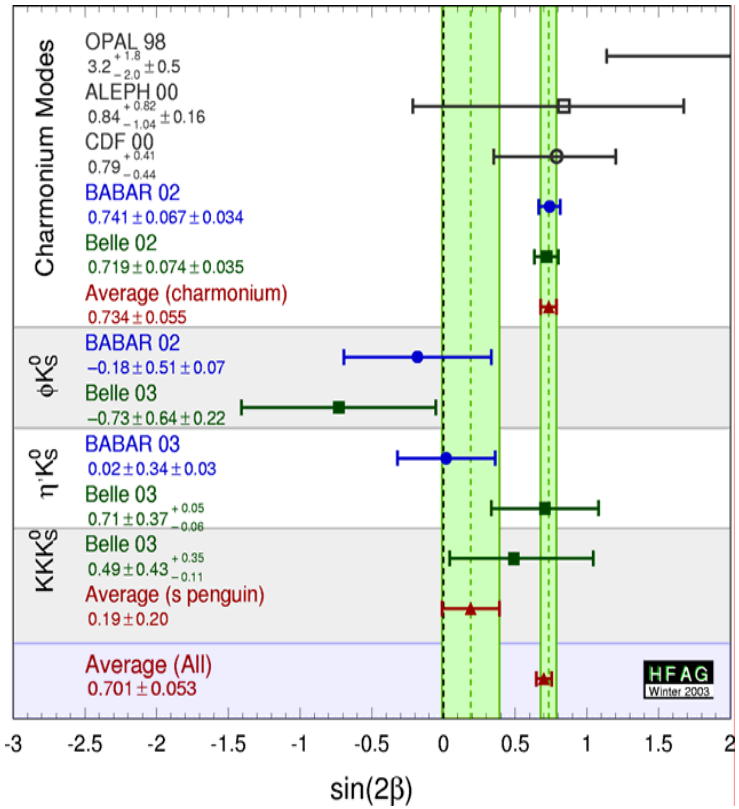


Large deviation from b->ccs ⇒ Hint for new physics

Status in 2003

Belle (140 fb^{-1})



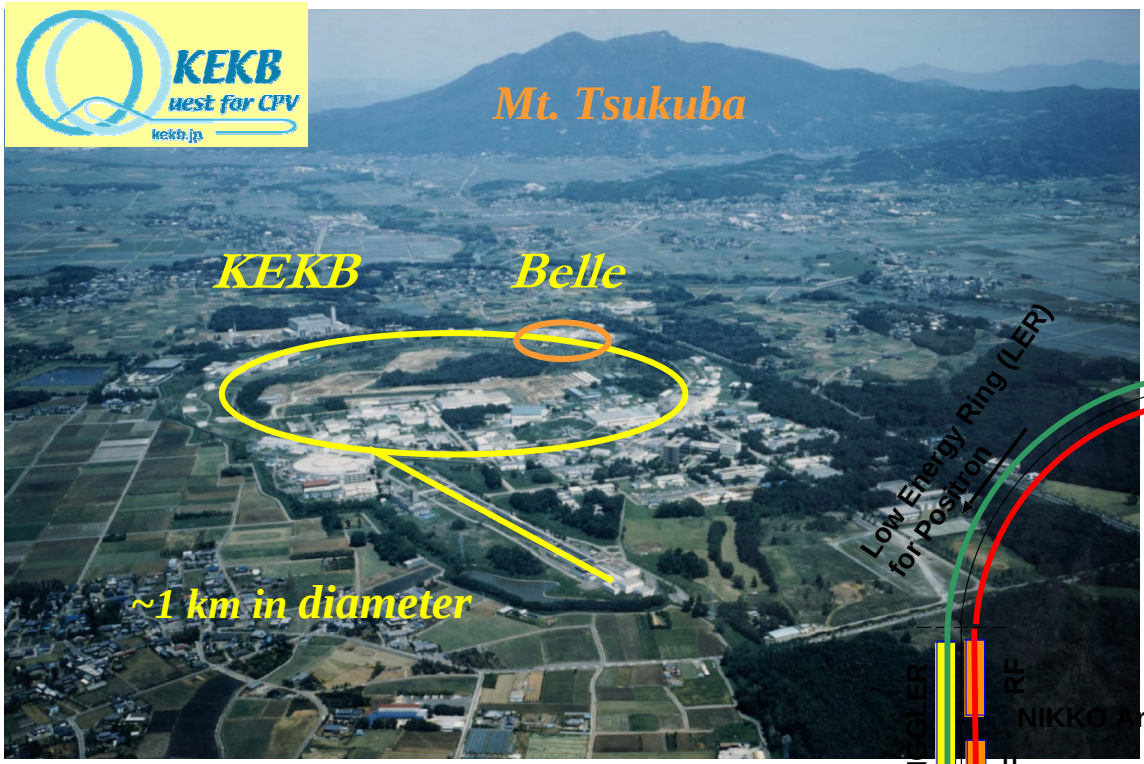


$B^0 \to \phi K_S$

Belle 140 fb^{-1}: $S = -0.96 \pm 0.50 \pm^{0.09}_{0.11}$ **3.5σ from SM !**

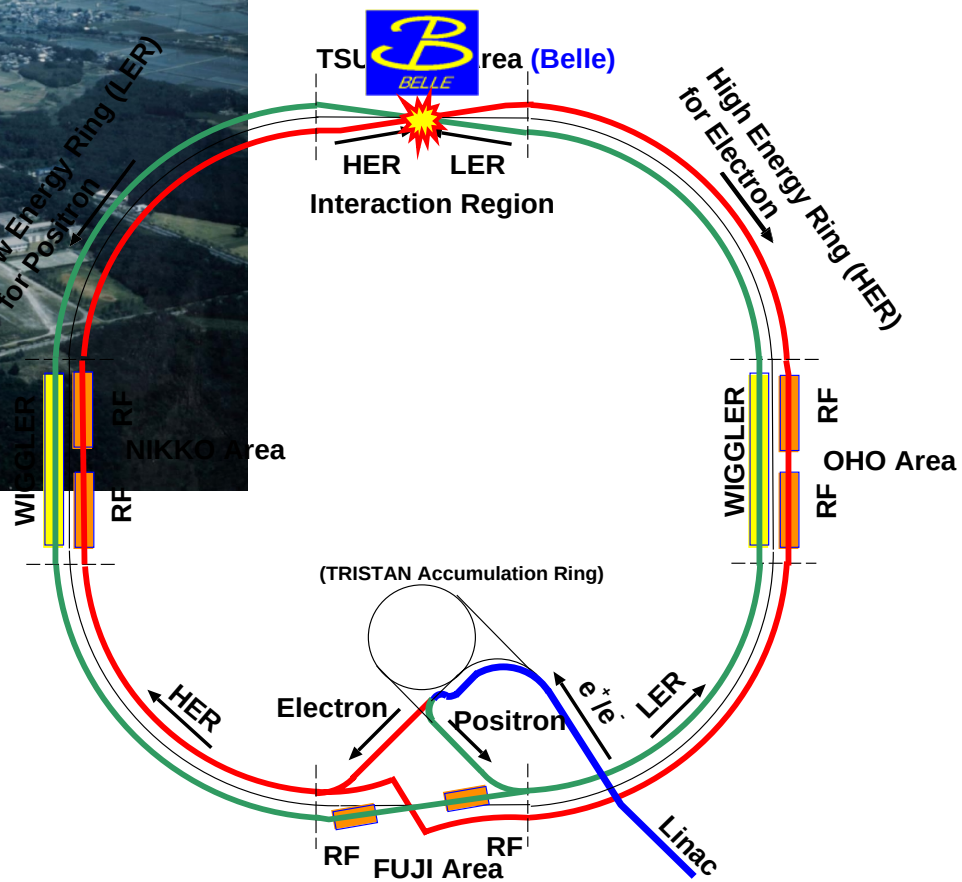
BaBar 110 fb^{-1}: $S = +0.45 \pm 0.43 \pm 0.07$

KEKB Collider



8 GeV e^- x 3.5 GeV e^+

±11mrad crossing



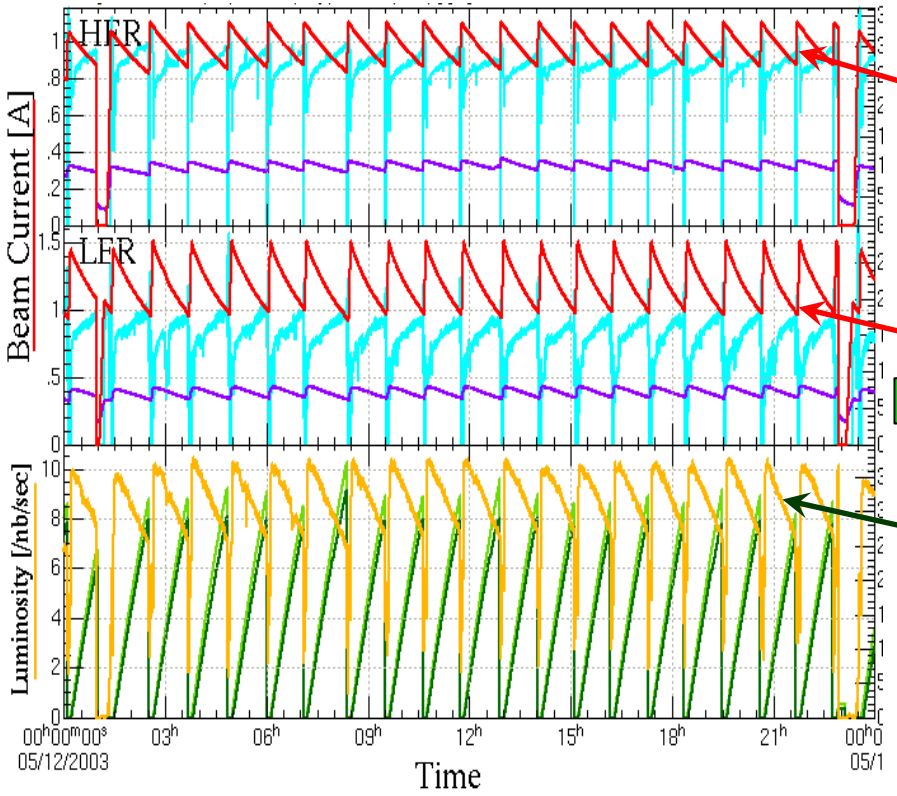
$L_{peak} = 1.39 \times 10^{34}\ sec^{-1}cm^{-2}$

@ 1.2A x 1.6A

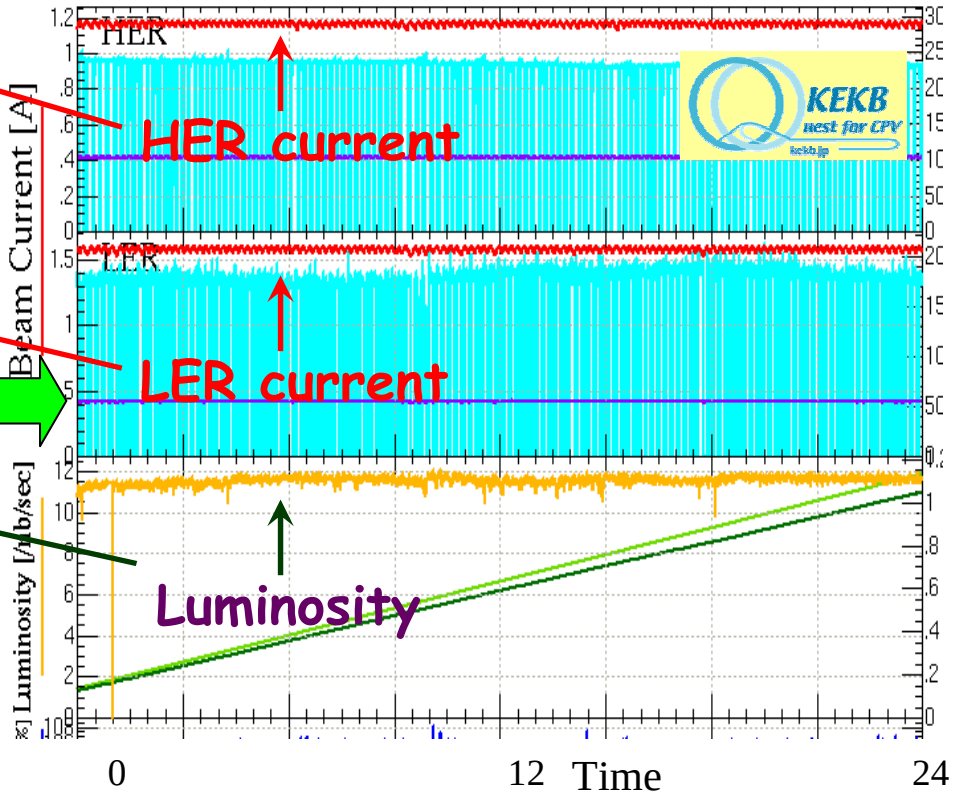
Continuous Injection

BELLE

normal injection (old)



continuous injection (since summer 2003)



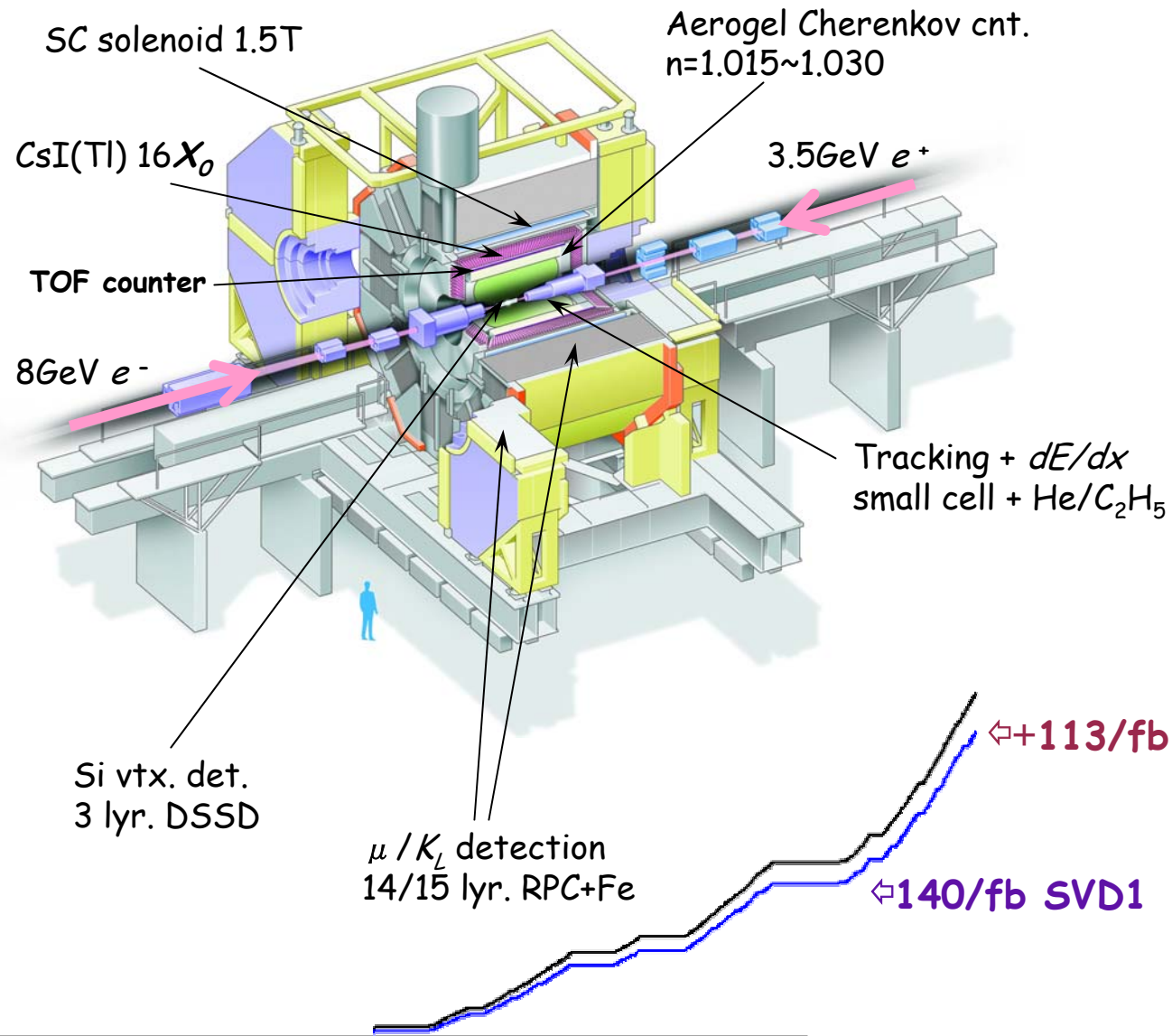
Always at ~max. currents, luminosity

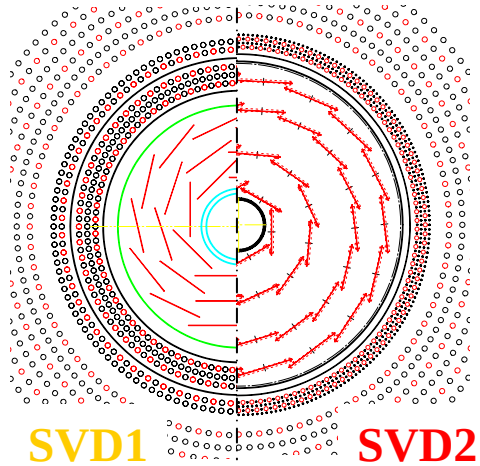
➡ ~30% more $\int L\,dt$

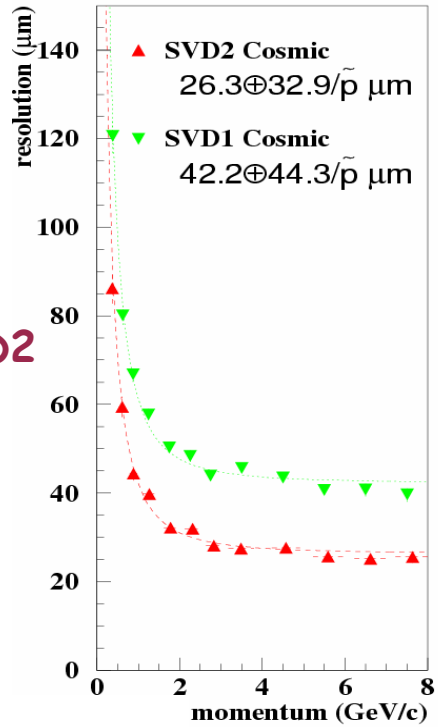
~1x10⁶ B pairs/day !

253 fb^{-1} on $\Upsilon(4S)$
28 fb^{-1} below $\Upsilon(4S)$

Belle Detector







B Signal Identification

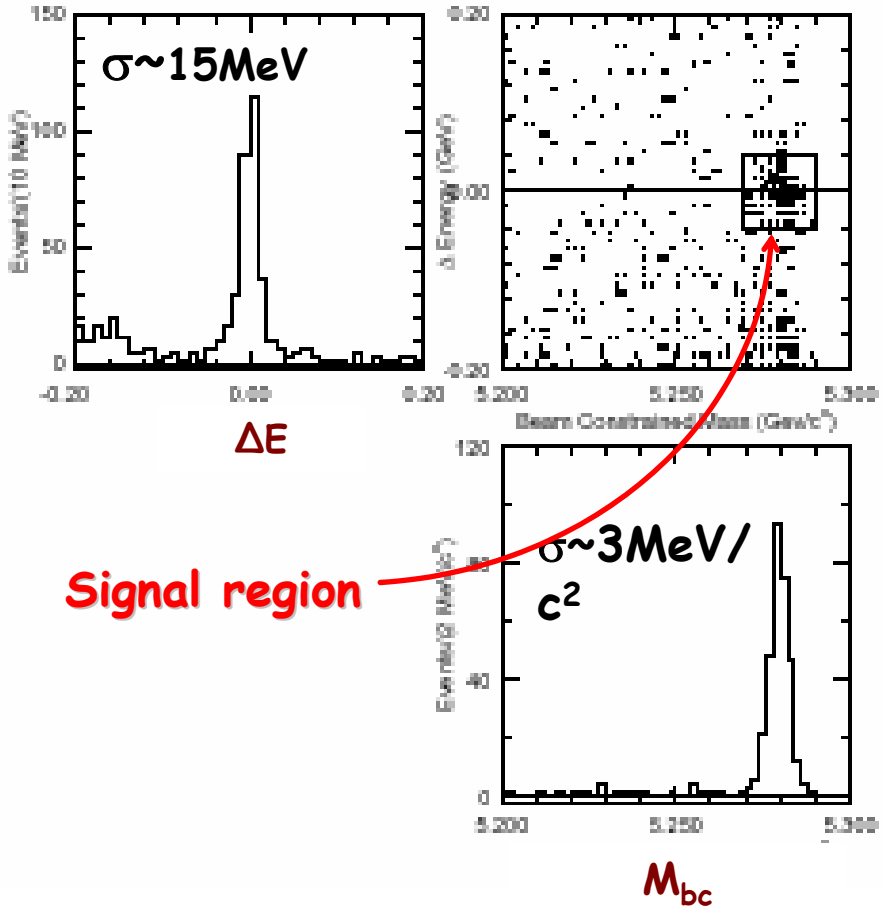
Kinematic Variables:

Energy difference

$$\Delta E = E^*_B - E^*_{beam}$$

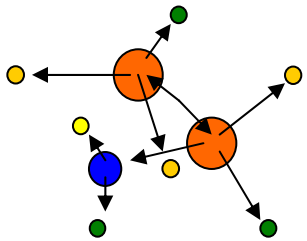
Beam constrained mass

$$M_{bc} = \sqrt{E^{*2}_{beam} - |P_B^*|^2}$$

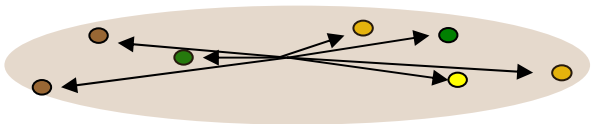


Continuum background suppression based on the event topology

Spherical BB event



Jetty continuum event



All quantities are calculated in the Υ(4S) rest frame

Belle 2004 update (274M $B\bar{B}$)

With the huge data sample collected by Belle (KEKB), we are starting to probe NP in various b->s penguin dominated decay channels !

"Standard" channels

- $B^0 -> \varphi K_S$
- $B^0 -> K^+K^-K_S$
- $B^0 -> \eta' K_S$

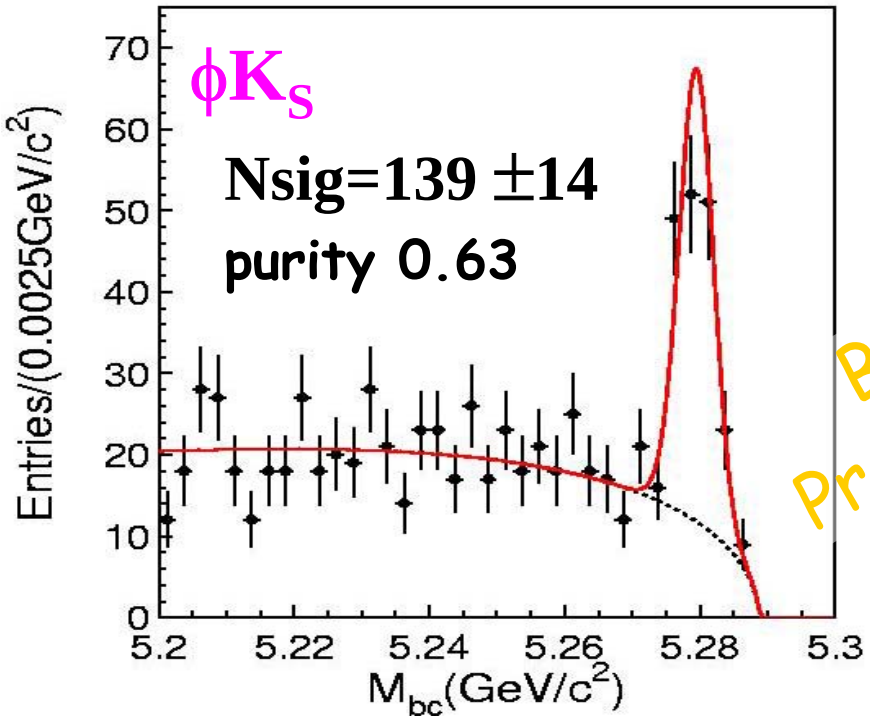
+

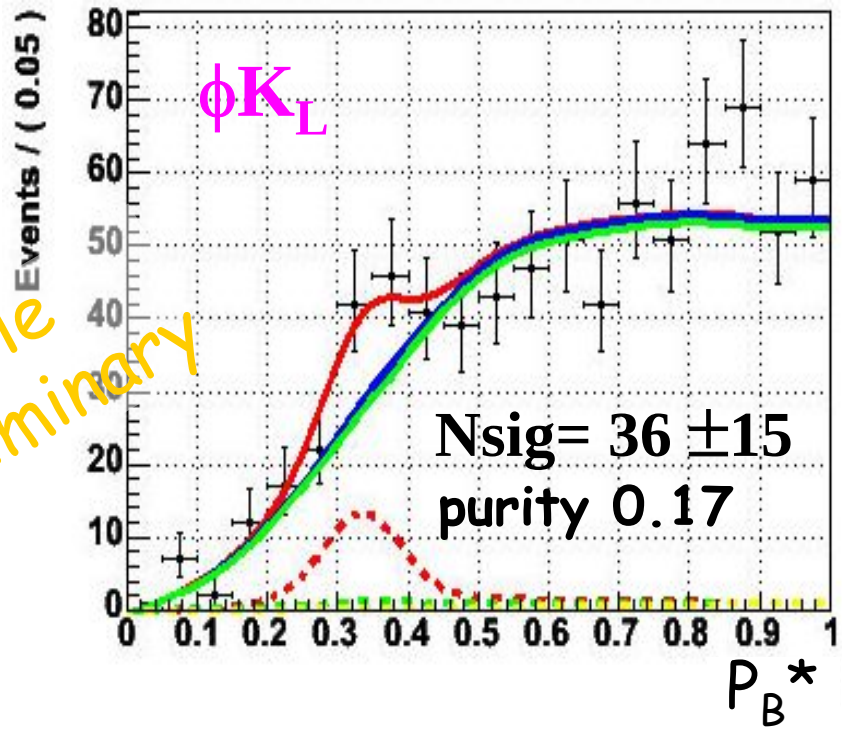
New channels

- New SubModes
  - $B^0 -> \varphi K^0(\pi^0\pi^0)$
  - $B^0 -> \varphi K^0(K_L)$
  - $B^0 -> \eta'(\eta(\pi^+\pi^-\pi^0)\pi^+\pi^-)K_S$
- New Modes
  - $B^0 -> f_0(\pi^+\pi^-)K_S$
  - $B^0 -> \omega(\pi^+\pi^-\pi^0)K_S$
- New vertexing techniques
  - $B^0 -> K_S\pi^0$
  - $B^0 -> K^*(K_S\pi^0)\gamma$

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

Belle 274M $B\bar{B}$





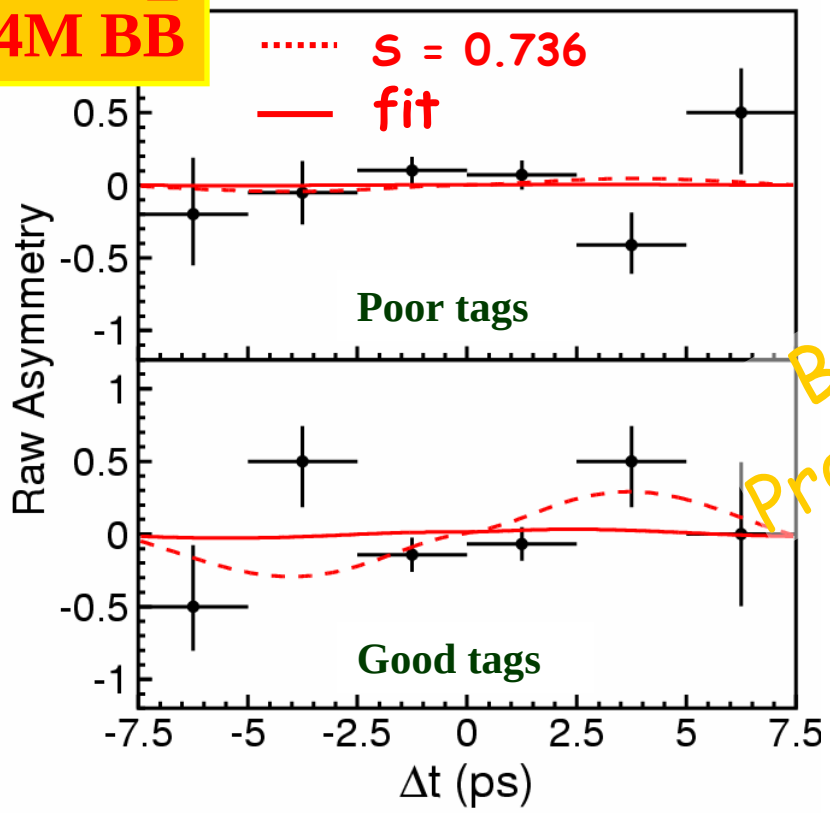
Belle Preliminary

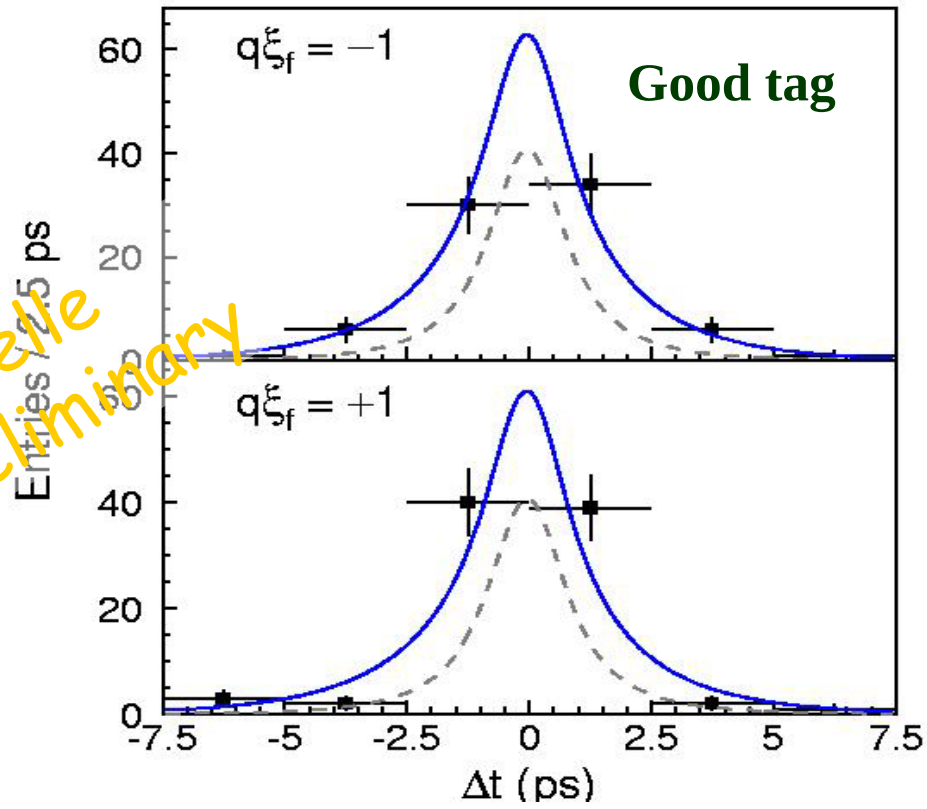
Includes $K_S \to \pi^0\pi^0$ (Nsig = 13±5)

Reconstruction similar to $J/\psi K_L$ + sophisticated continuum suppression

TCPV in $B^0 \to \phi K^0$

274M $B\bar{B}$





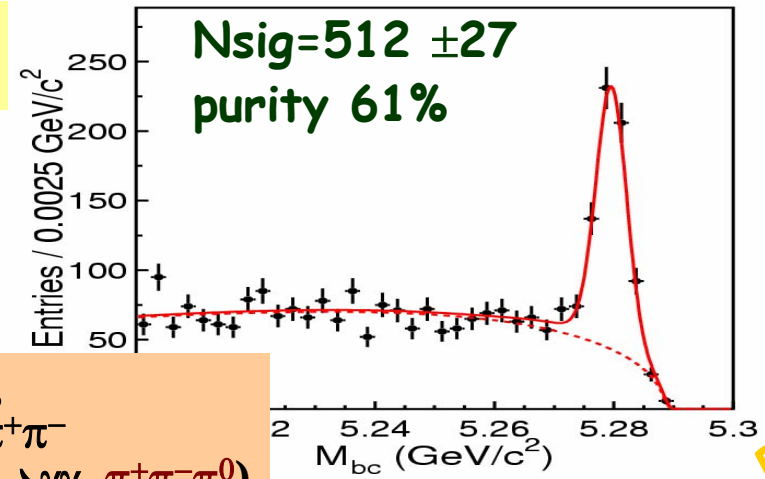
$\phi K_S + \phi K_L : S(\phi K^0) = +0.06 \pm 0.33 \pm 0.09$

$\mathcal{A}(\phi K^0) = +0.08 \pm 0.22 \pm 0.09$

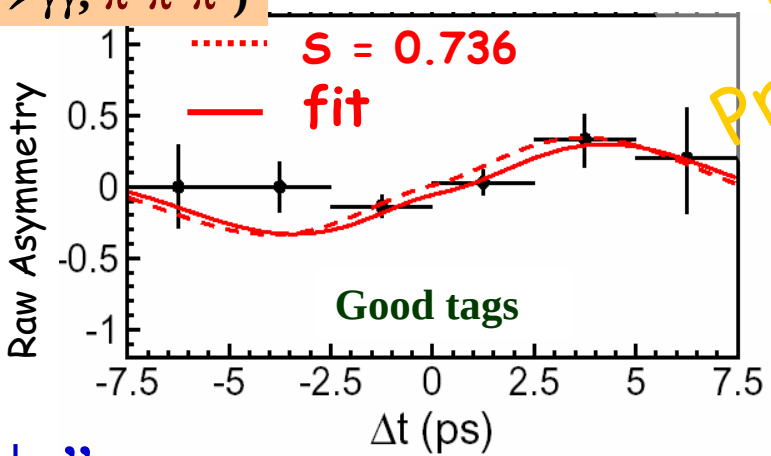
~2.2σ away from SM

TCPV in $B^0 \to \eta' K_S$ & $K^+K^-K_S$

$\eta' K_S$

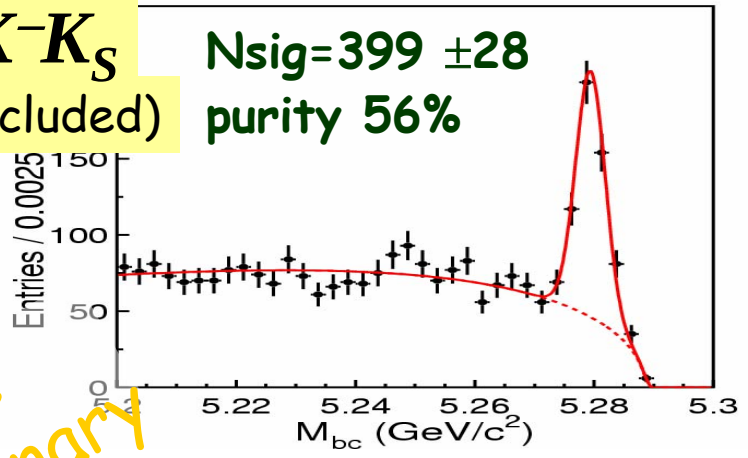


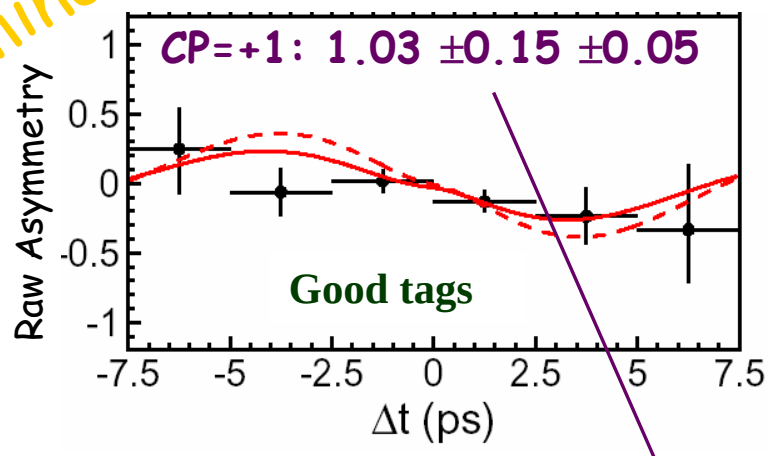
$\eta' \to \rho\gamma$,
$\eta\pi^+\pi^-$
$(\eta \to \gamma\gamma,\ \pi^+\pi^-\pi^0)$



Belle Preliminary

$K^+K^-K_S$ (ϕ excluded)





"$\sin 2\phi_1$"

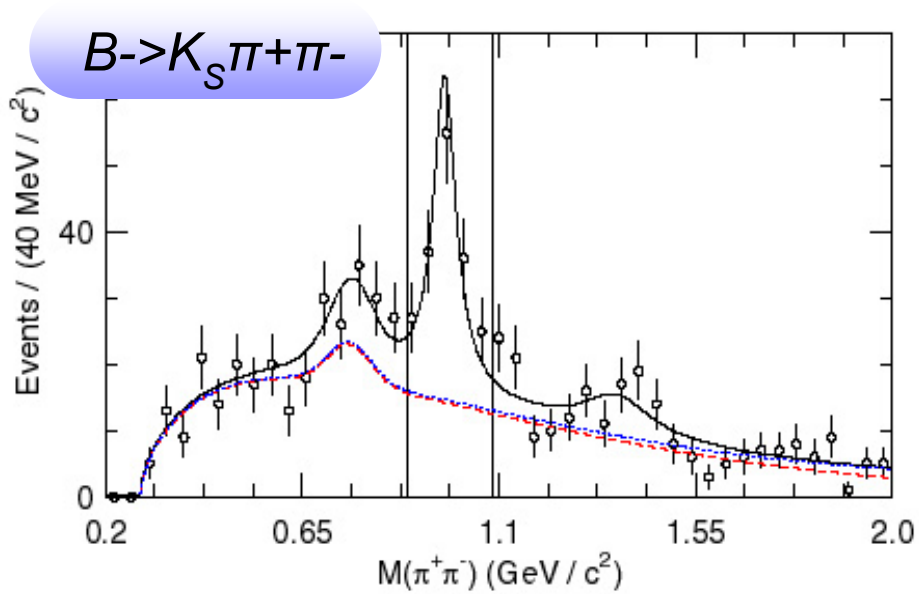
(~0.5σ from SM)

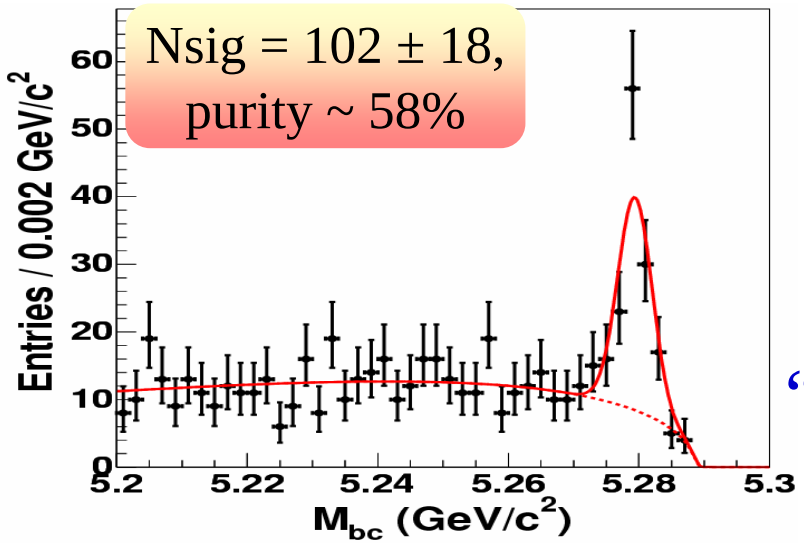
$$S = +0.65 \pm 0.18 \pm 0.04$$
$$\mathcal{A} = -0.19 \pm 0.11 \pm 0.05$$

(~1.0σ from SM)

$$-S = +0.49 \pm 0.18 \pm 0.04 \ (\pm^{0.17}_{0.0})$$
$$\mathcal{A} = -0.08 \pm 0.12 \pm 0.07$$

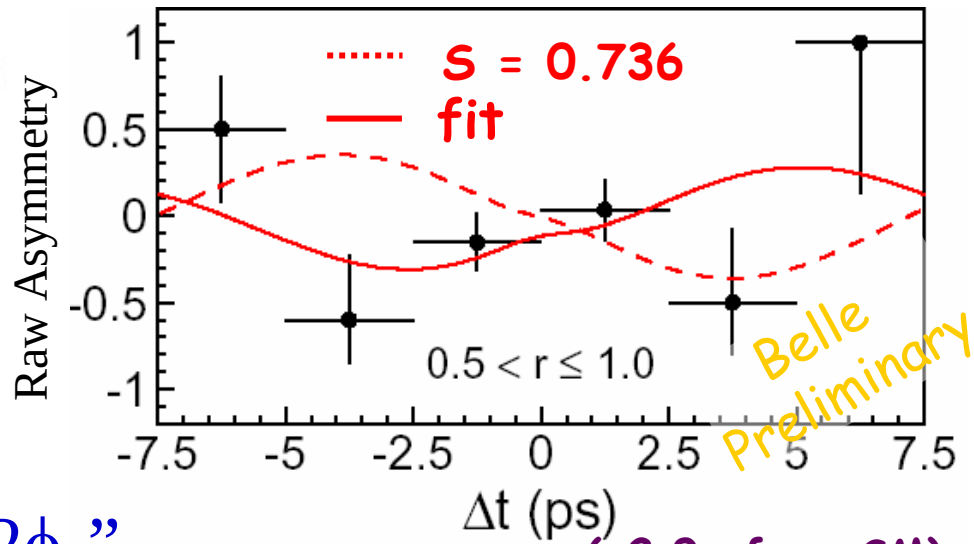
Time dependent CPV in $B^0 \to f_0(980)K_S$





Non-$f_0(980)$ components are determined from the $M(\pi^+\pi^-)$ distribution

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



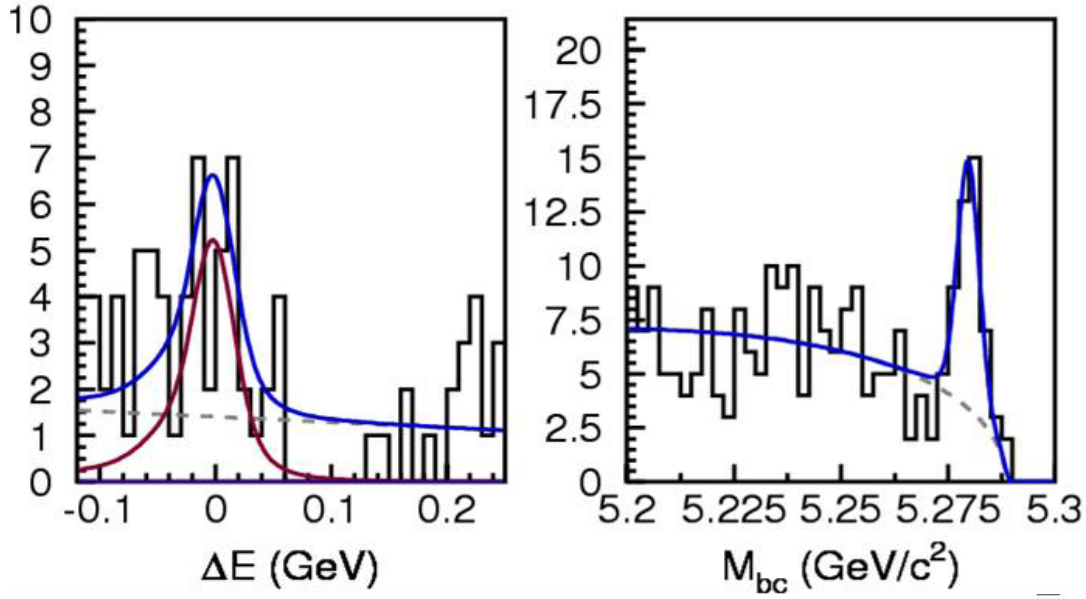
"$\sin 2\phi_1$"

(~2.9σ from SM)

$-\mathcal{S}$ = -0.47 ±0.41 ±0.08

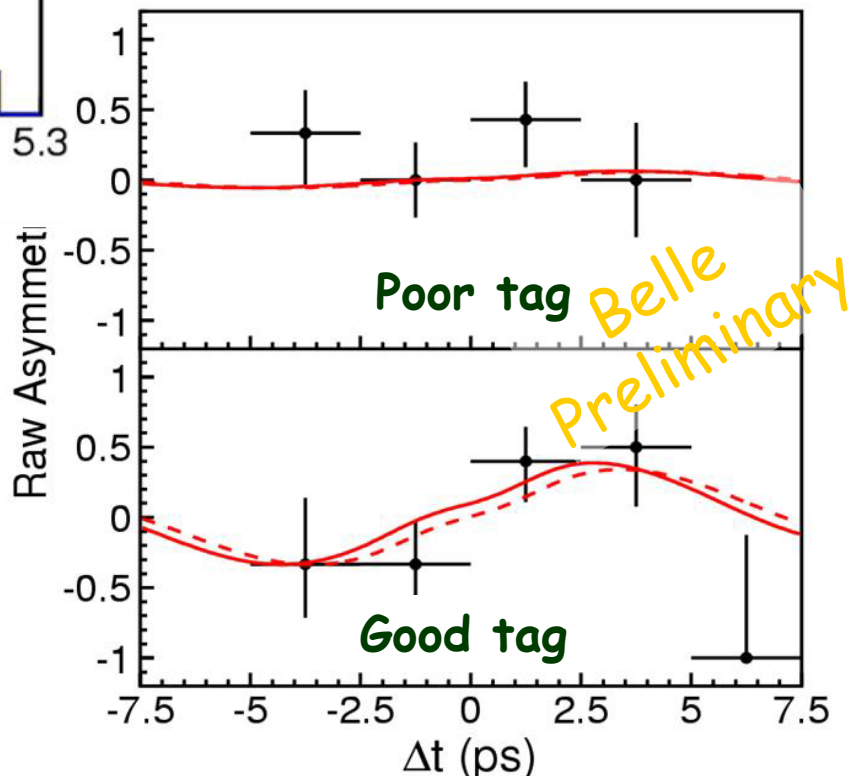
$\mathcal{A}$ = -0.39 ±0.27 ±0.08

TCPV in $B^0 -> \omega K_S$



Belle, 274M $B\bar{B}$

Nsig = 31 ± 7,
purity ~ 56%



- First observation of ωK_S (~7σ)
- First measurement of the TCPV in this mode.

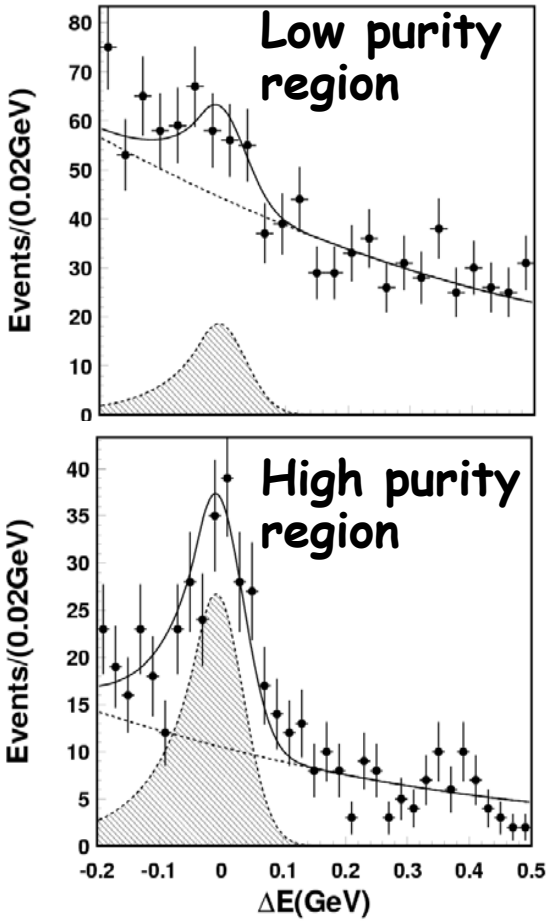
(~0σ from SM)

"$\sin 2\phi_1$"

$$\mathcal{S} = +0.75 \pm 0.64 \pm {}^{0.13}_{0.16}$$

$$\mathcal{A} = +0.26 \pm 0.48 \pm 0.15$$

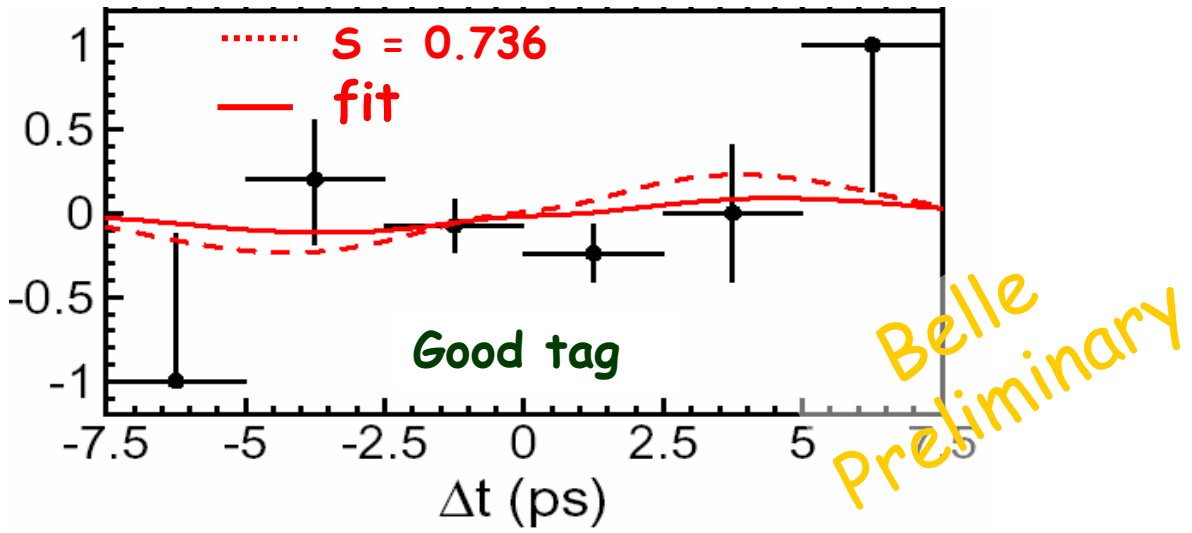
TCPV in $B^0 -> K_S\pi^0$



The S term is measured with events associated with a B vertex.

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

Events without B vertex are also used for the measurement of A with a time-integrated method.



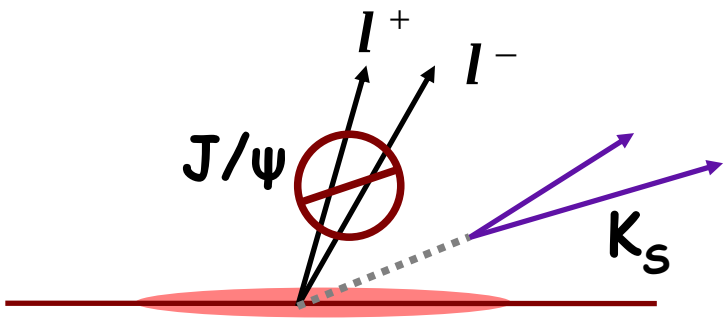
Signal Yield
w/ vertex ~ 77.5
w/o vertex ~ 173.

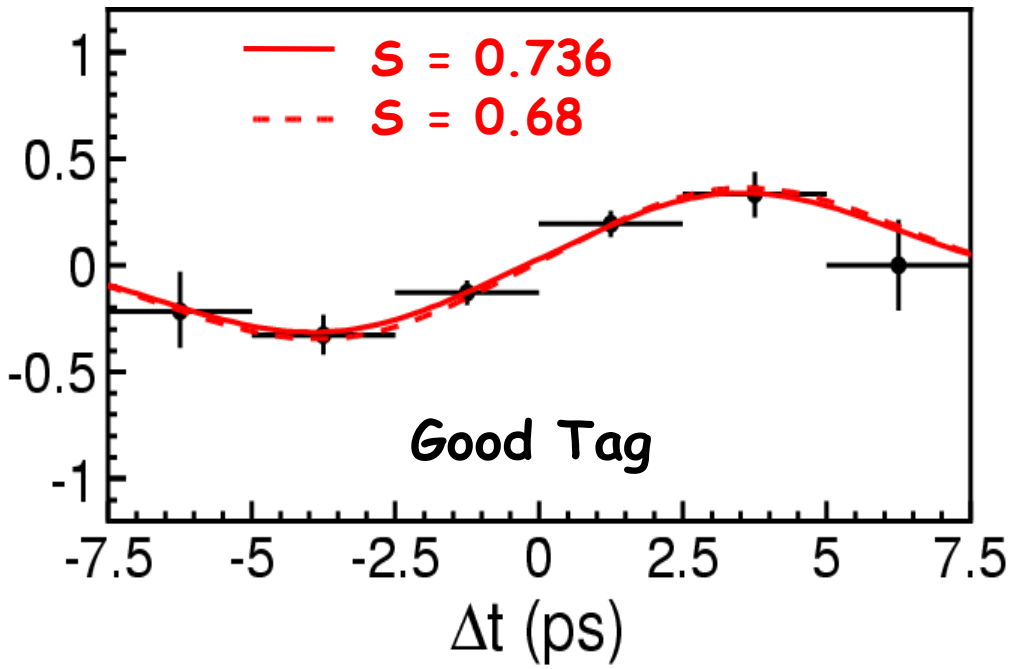
$\mathcal{S}$ = +0.30 ±0.59 ±0.11
$\mathcal{A}$ = -0.12 ±0.20 ±0.07

B Vertexing Using K_S Only (validation)

CP-Fit with Control Sample

Apply the same analysis to J/ψ Ks but ignore the J/ψ tracks and determine the vertex only with Ks.





B vertex by Ks

$S(J/\psi K_S) = +0.68 \pm 0.10$
$A(J/\psi K_S) = +0.02 \pm 0.04$

Full Sample w/ J/ψ vertex

B vertex by J/ψ

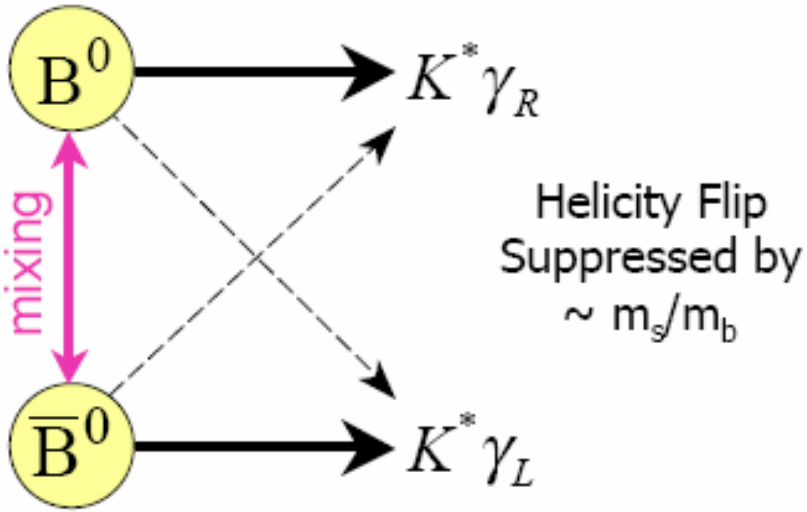
$S(J/\psi K^0) = +0.666 \pm 0.046$
$A(J/\psi K^0) = +0.023 \pm 0.031$

TCPV in $B^0 \to K^{*0}[K_S \pi^0]\gamma$

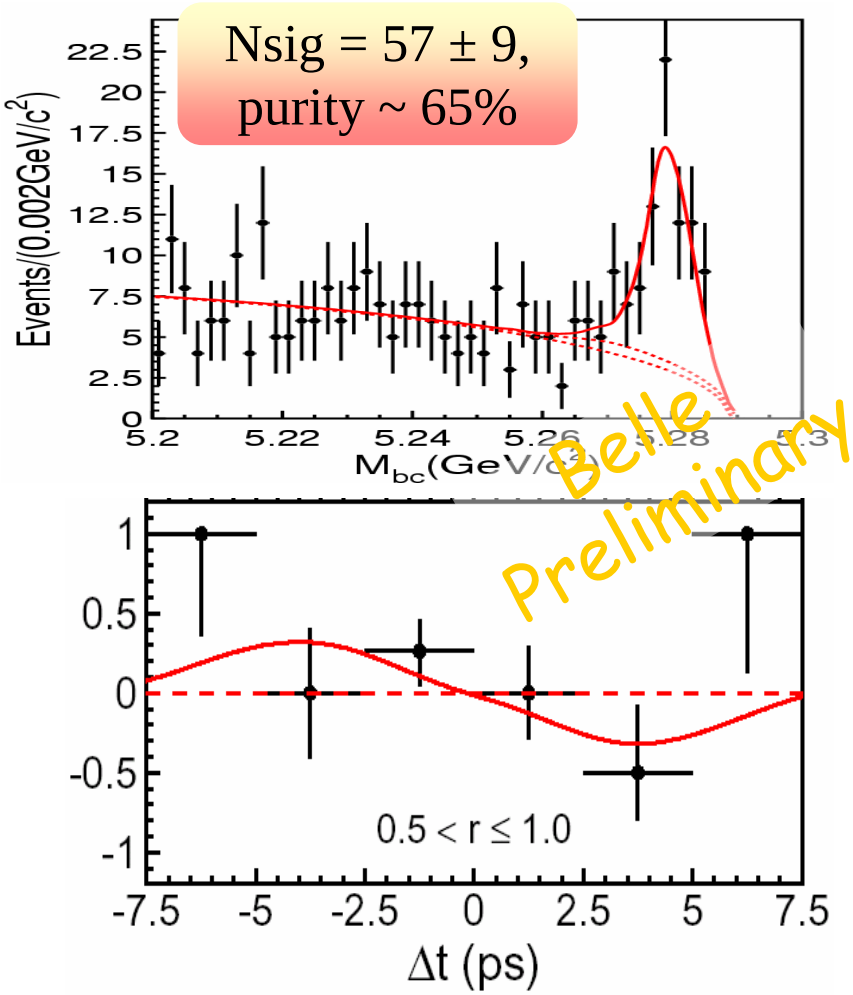
SM: $\gamma \approx$ polarized

$S \approx 2(m_s/m_b)\sin 2\phi_1 \approx 4\%$

$\mathcal{A} \sim 1\%$



New Physics ↔ Large $S, \mathcal{A}$

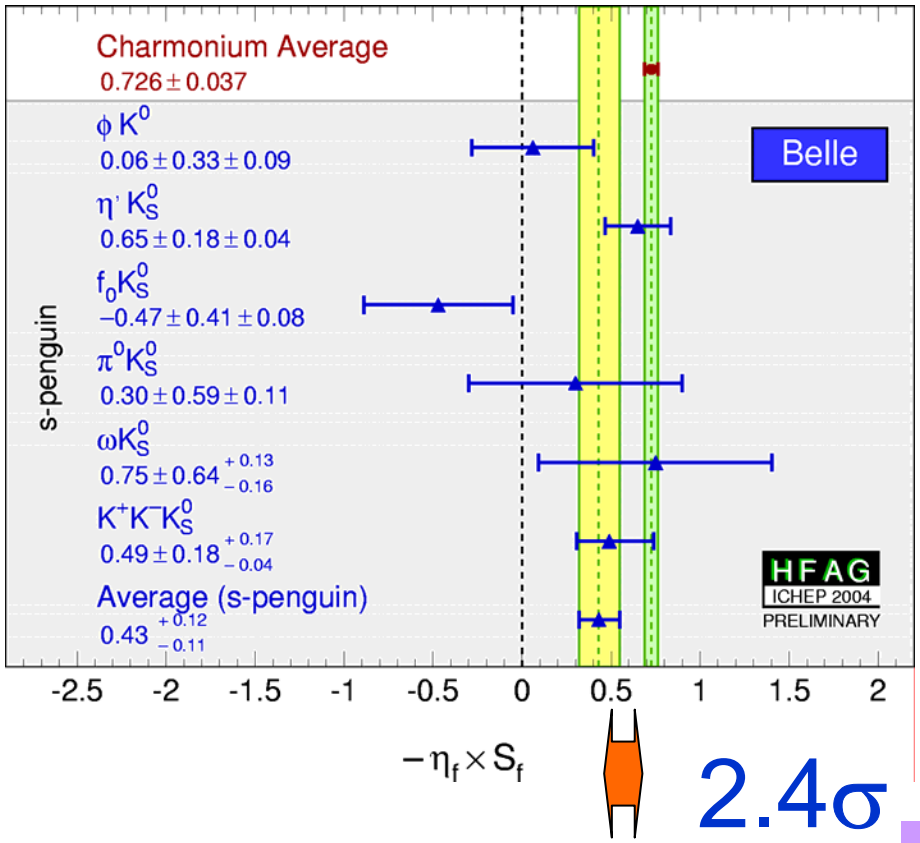


$S = -0.79 \pm^{0.63}_{0.50} \pm 0.09$

$\mathcal{A} = -0.00 \pm 0.38$

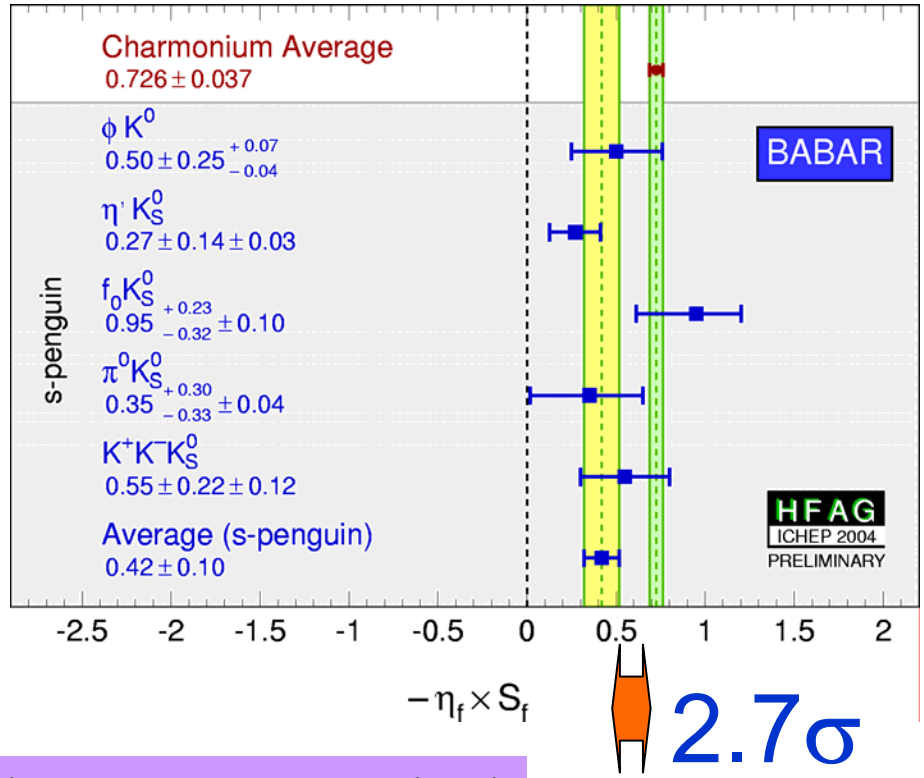
Summary of b->$s\bar{q}q$ TCPV

Belle Only, 274M B pairs



2.4σ

BaBar Only, 227M B pairs



2.7σ

($\mathcal{A}$: consistent with 0)

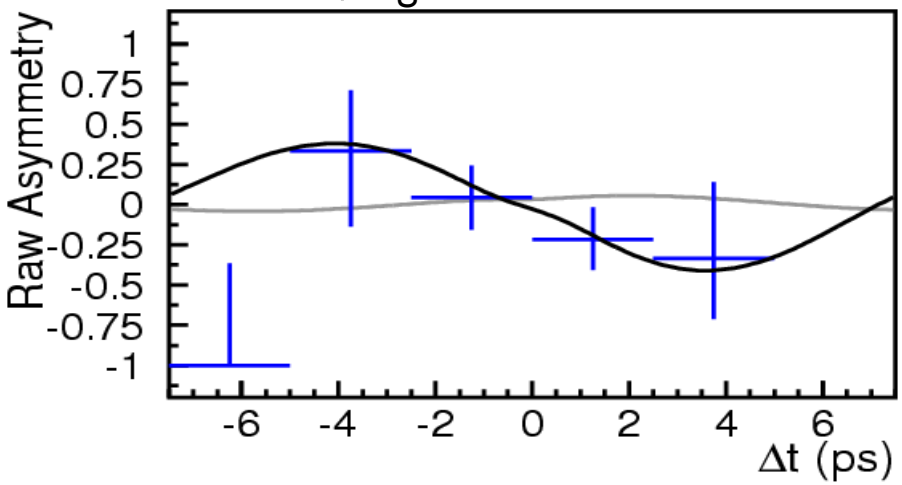
More data needed to conclusively establish New Physics

Backup Slides

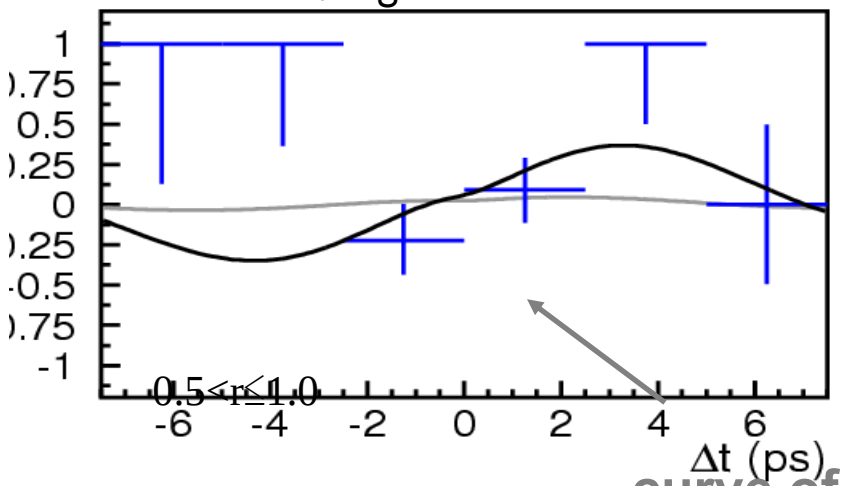
$B^0 \to \phi K_S$ Cross Checks

Results of $\phi K_S/K_L$

ϕK_S (SVD1)



ϕK_S (SVD2)



curve of combined fit

$\Sigma(\phi K_\Sigma) = -0.75 \pm 0.46$

$A(\phi K_S) = -0.03 \pm 0.28$

$S(\phi K_S) = +0.75 \pm 0.47$

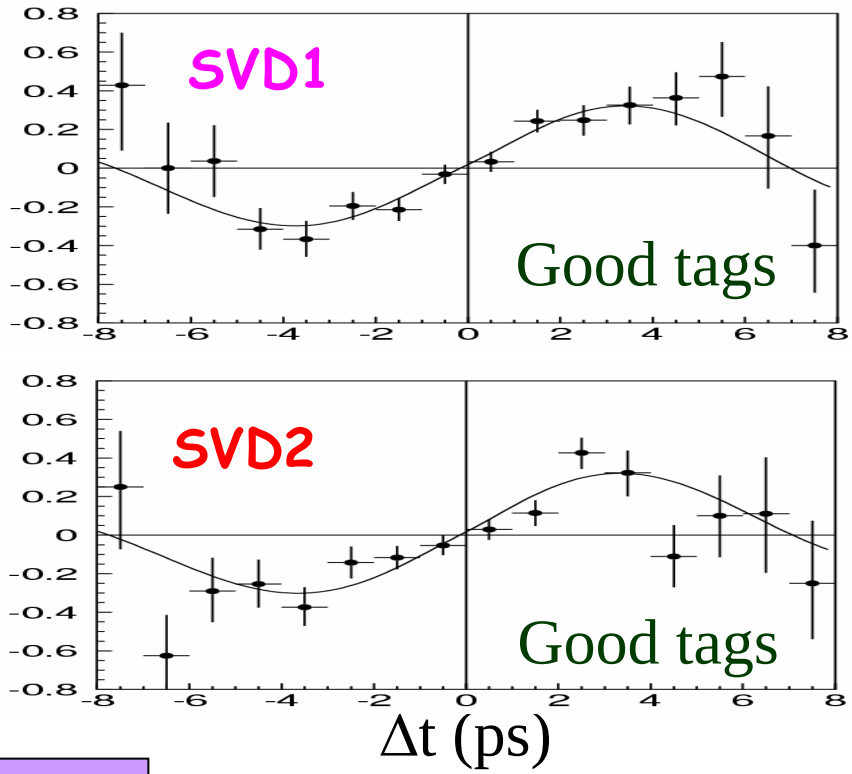
$A(\phi K_S) = +0.16 \pm 0.34$

SVD1 with $K_S \to \pi^+\pi^-$ only: $S(\phi K_S) = -0.97 \pm 0.50$, $A(\phi K_S) = -0.15 \pm 0.29$

The probability of getting this kind of difference is about 4.1% (by toy MC)

Checks: $\sin 2\phi_1$ ($B^0 \to J/\psi\, K_{S/L}$)

Validation of new data sample (SVD2)



SVD1: 152M $B\bar{B}$

$\mathcal{S} = 0.696 \pm 0.061$ (stat)
$\mathcal{A} = 0.011 \pm 0.043$ (stat)

SVD2: 122M $B\bar{B}$

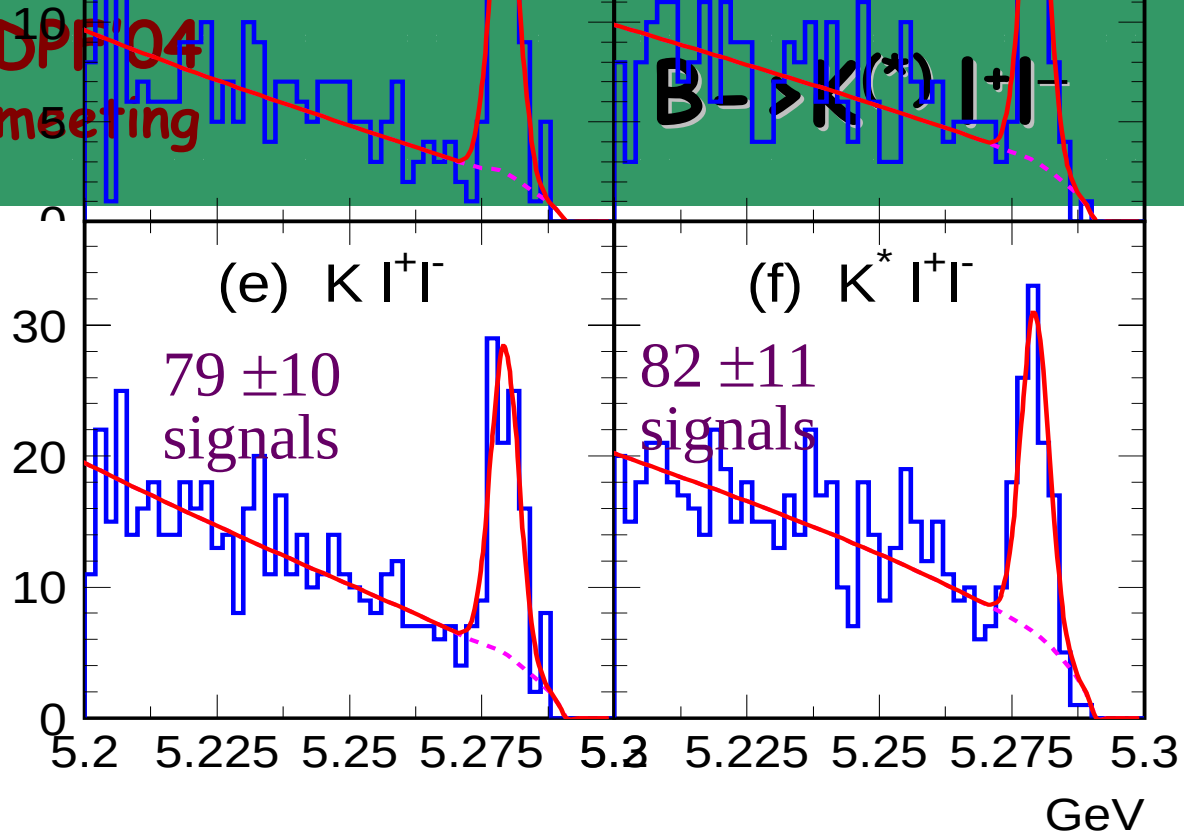
$\mathcal{S} = 0.629 \pm 0.069$ (stat)
$\mathcal{A} = 0.035 \pm 0.044$ (stat)

ϕK^0

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

~2.3σ ↔

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



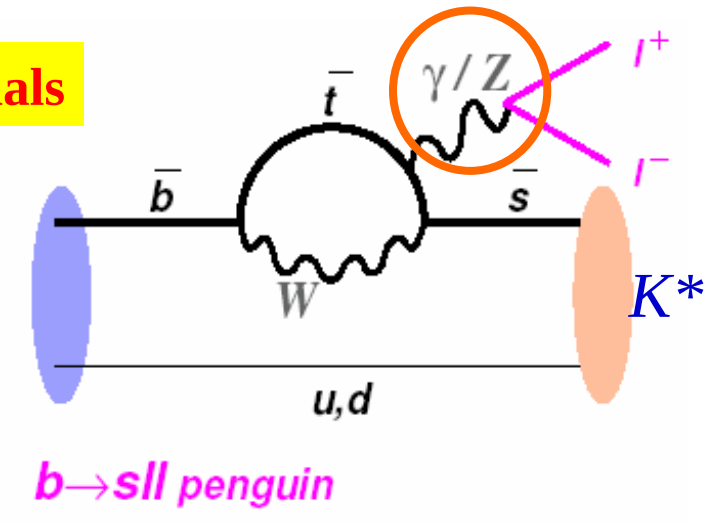
Belle, 274M $B\bar{B}$

[Belle-conf-0415]

$\mathcal{B}$(Kll) = $(5.50 \pm^{0.75}_{0.70} \pm 0.27 \pm 0.02)\times10^{-7}$

$\mathcal{B}$(K*ll)= $(16.5 \pm^{2.3}_{2.2} \pm 0.9 \pm 0.4)\times10^{-7}$

>10σ signals



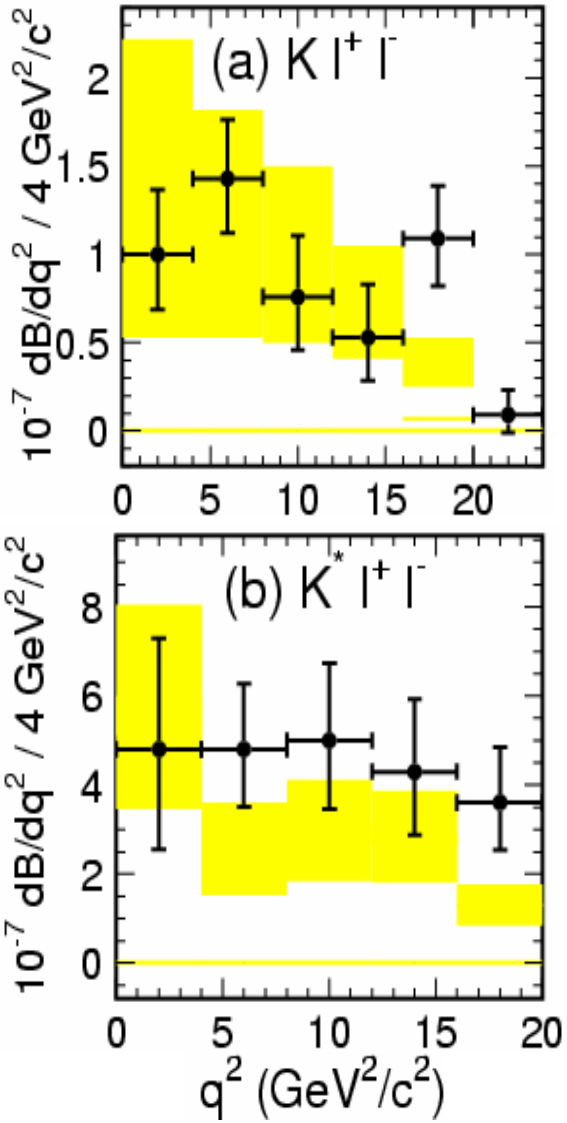
$b \to s l l$ penguin

$A_{FB}(K^*ll)$: **very sensitive to NP that may not be seen in $\mathcal{B}(b \to s\gamma)$**

B->K* l^+l^- :FB Asymmetry

[Belle-conf-0415]

$$A_{FB} = \frac{\Gamma(\Theta_{Bl^+}<\pi/2) - \Gamma(\Theta_{Bl^+}>\pi/2)}{\Gamma(\Theta_{Bl^+}<\pi/2) + \Gamma(\Theta_{Bl^+}>\pi/2)}$$



First Look !