



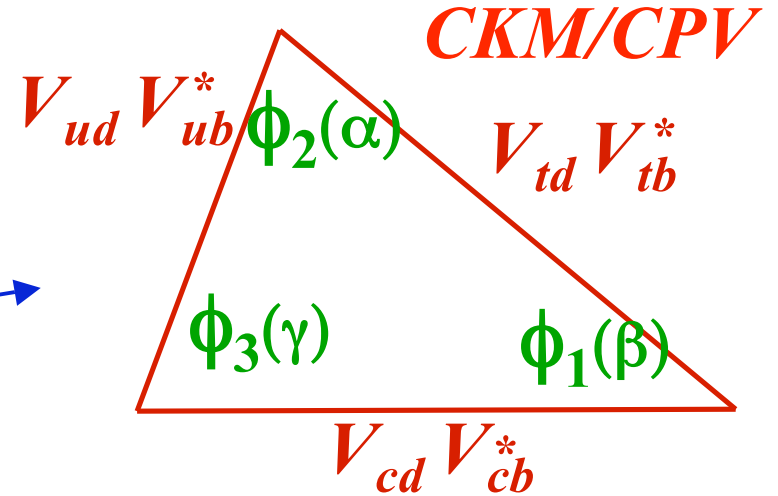
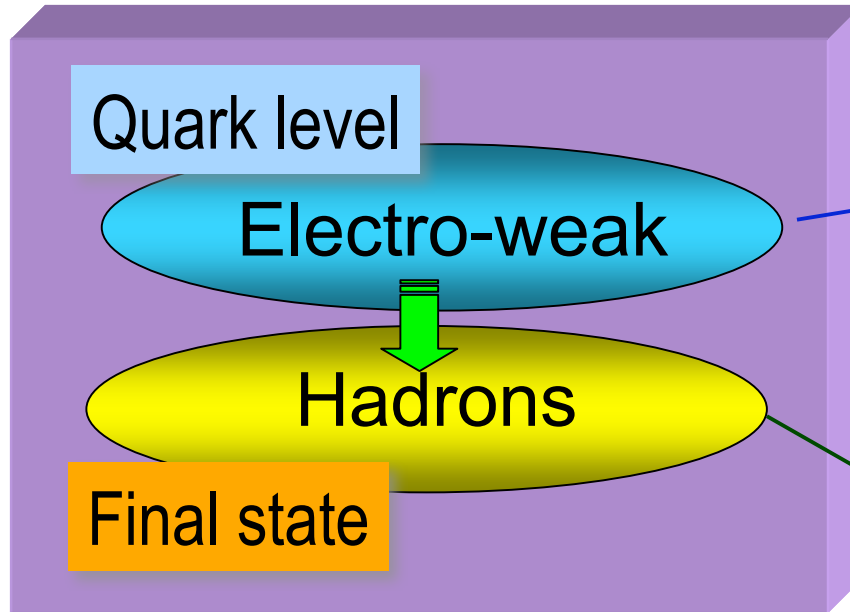
# Belle Status & Plans

Y.Sakai (KEK)



# Physics at B-factory

## B decays



**QCD/Lattice**  
**New Resonances**

*b*-quark: Heavy  $\rightarrow$  variety of decay modes

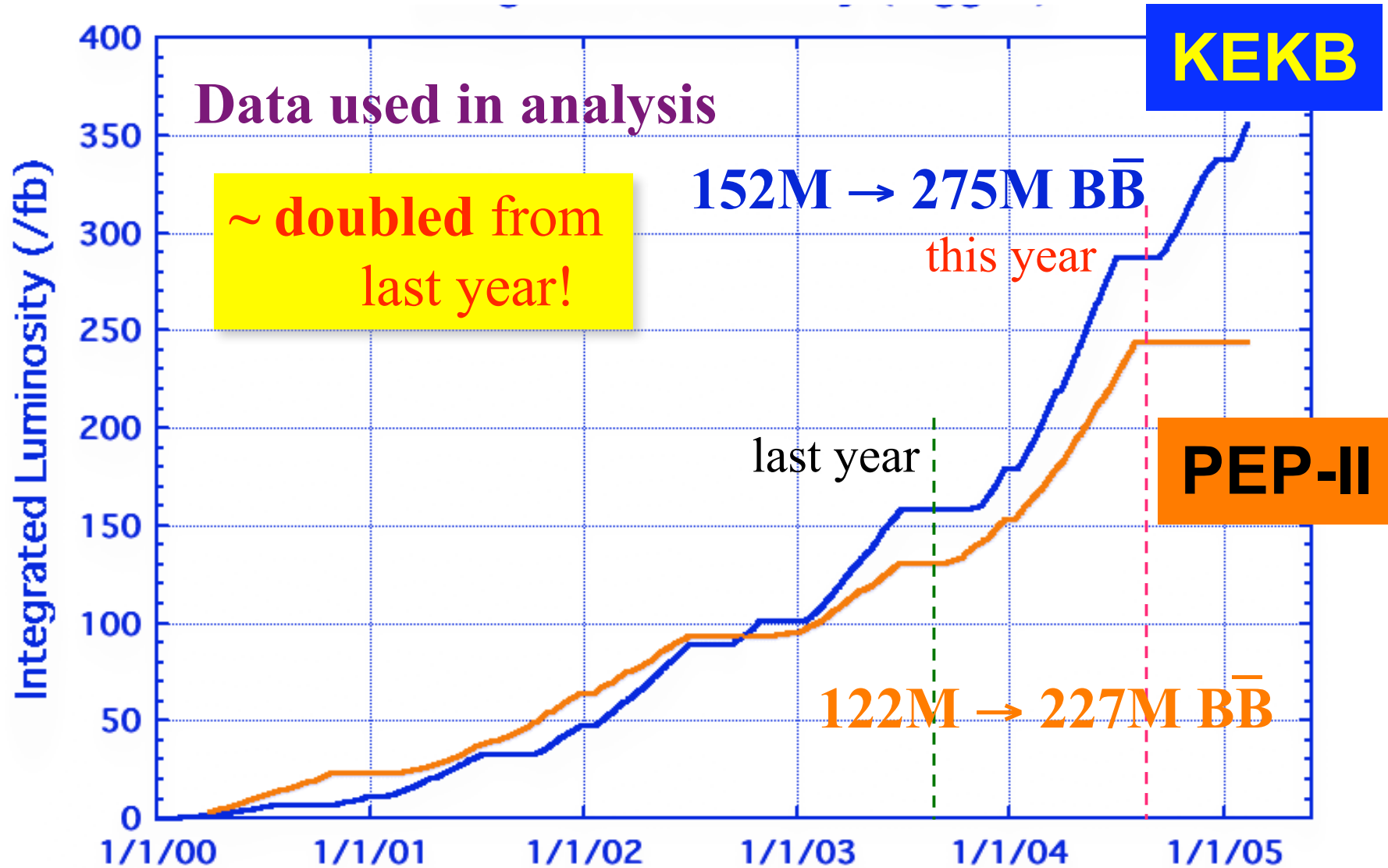
**Comparison with SM  $\rightarrow$  New Physics !**

(also excellent  $\tau$ /charm &  $\gamma\gamma$  factory)



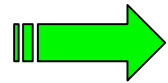


# Integrated Luminosity

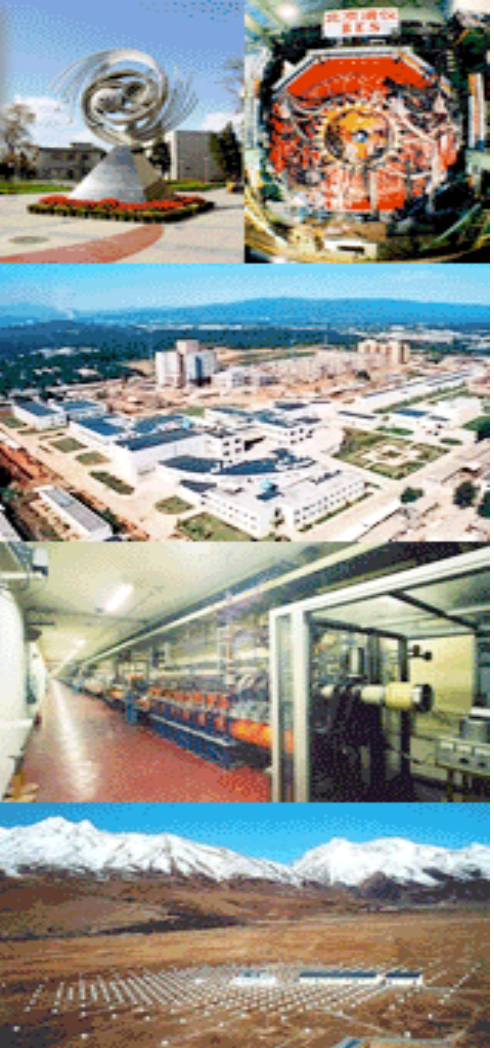




# ~Doubled Data size



## Fruitful Physics Results !



- Search for the  $b \rightarrow d \gamma$  process  
 Measurement of branching fraction  
 Evidence of  $B_0 \rightarrow \rho^0 \pi^0$   
 Measurement of Branching Fraction  
 Improved Measurements of the Par  
 Observation of  $B_0 \rightarrow \pi^0 \pi^0$   
 Measurement of Branching Fraction  
 Measurement of charmless B Deca  
 Study of  $B_0 \rightarrow \eta K \pi$  and  $\eta \pi \pi$   
 Dalitz Analysis of the three-body charmless decays  $B^{+-} \rightarrow K^+ \pi^+ \pi^-$  and  $B^{+-} \rightarrow K^+ K^+ K^-$ .  
 Observation of  $B_s \rightarrow K^* K^* \pi^0$   
 Observat  
 Observat  
 Improved  
 Improved  
 Study of  
 Measure  
 Search fo  
 Observat  
 Study of  
 An inclus  
 Moments  
 Measure  
 Search fo  
 Search fo  
 Measure  
 Search fo  
 Search for Lepton and Baryon Number Violating  $\tau^-$  Decays into  $p\text{-bar} \gamma$ ,  $p\text{-bar} \pi^0$ ,  $\Lambda\text{-bar} \pi^-$ , and  $\Lambda \pi^-$   
 Improved measurements of CP violation parameters  $2\phi_1$  and  $\phi_2$  and  $B_s$  meson Lifetimes, and  $B_0$ - $B_0$ bar Mixi  
 Improved measurement of time-dependent CP violation parameters in  $B_0 \rightarrow J/\psi K^0$  decays

**60 contributed papers**  
**24 talks (ICHEP04)**

**Highlights/Demonstration**

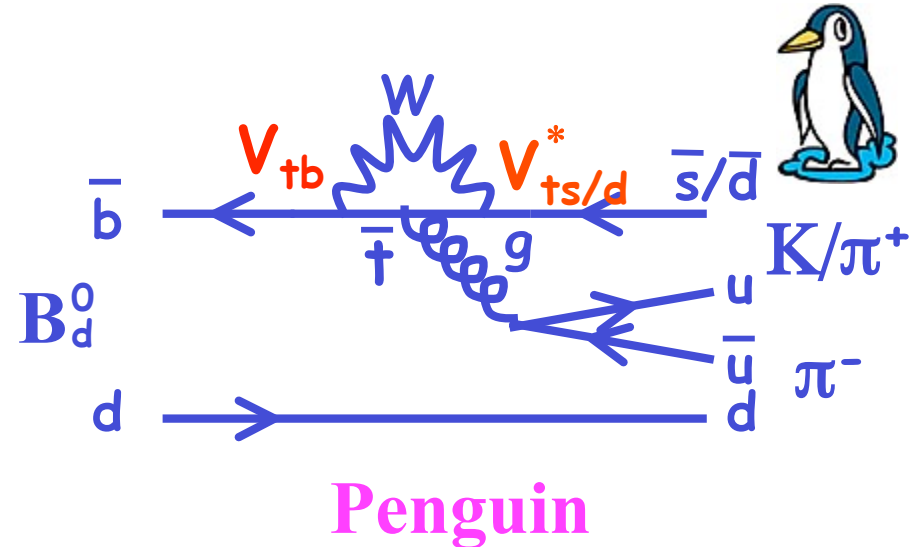
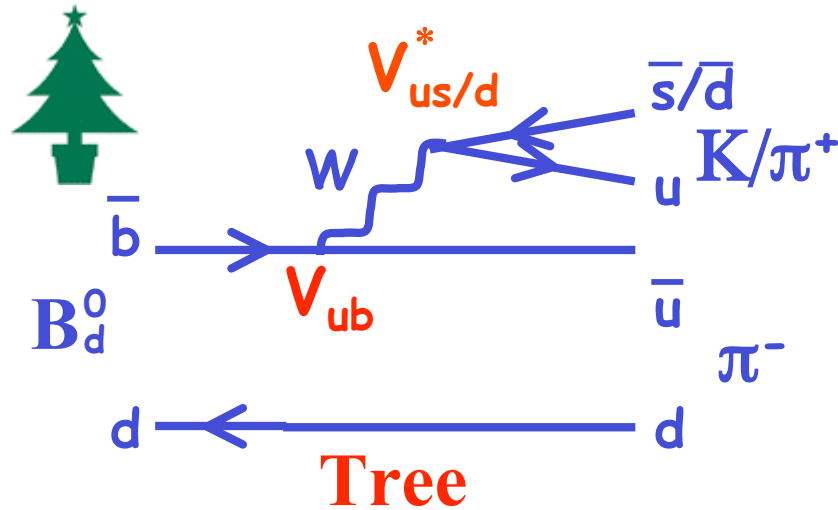
- $B \rightarrow hh$  : DCPV
- $b \rightarrow sq\bar{q}$  TCPV
- $B \rightarrow \pi^+ \pi^-$  TCPV (New)
- New “new resonances”

ICHEP04 / HPCP04

IHEP



# Direct CPV: $B \rightarrow K\pi$



- Simplest charmless rare decay modes
- Tree - Penguin interference  $\rightarrow$  **Direct CP Violation**

Key prediction of  
**Kobayashi-Maskawa model**

$$A_{CP} = \frac{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}{\Gamma(\bar{B} \rightarrow \bar{f}) + \Gamma(B \rightarrow f)}$$

Observation in  $B \rightarrow K\pi$   $\Rightarrow$  Strong support of KM



# $A_{CP}(B^0 \rightarrow K^+\pi^-)$

152M  $\bar{B}B$

$$A_{CP} = -0.088 \pm 0.035 \pm 0.018$$

$\sim 2.2\sigma$  [hep-ex/0407025]

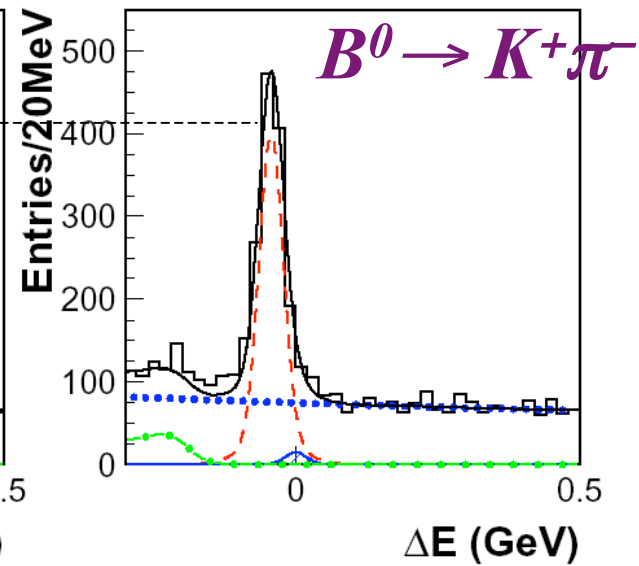
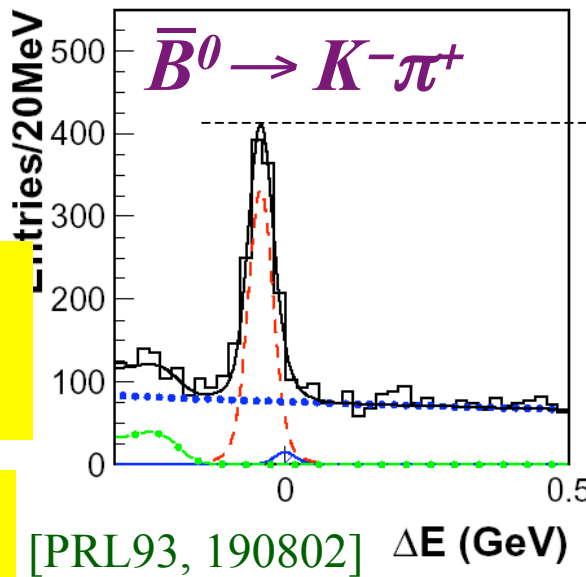
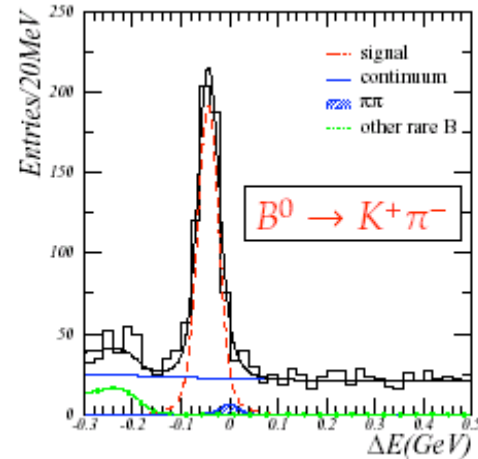
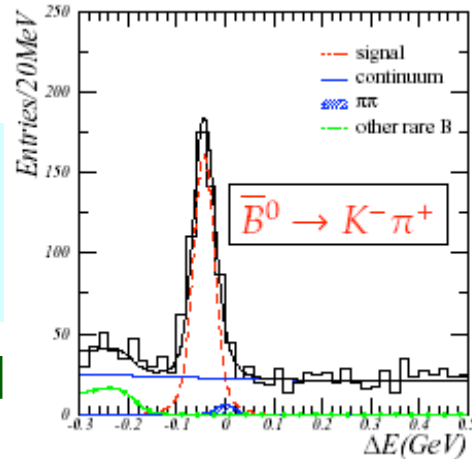


275M  $B\bar{B}$

Signal:  $2139 \pm 53$

$$A_{CP} = -0.101 \pm 0.025 \pm 0.005$$

3.9 $\sigma$  significance





# $A_{CP}(B^0 \rightarrow K^+\pi^-)$

275M  $B\bar{B}$

Signal:  $2139 \pm 53$

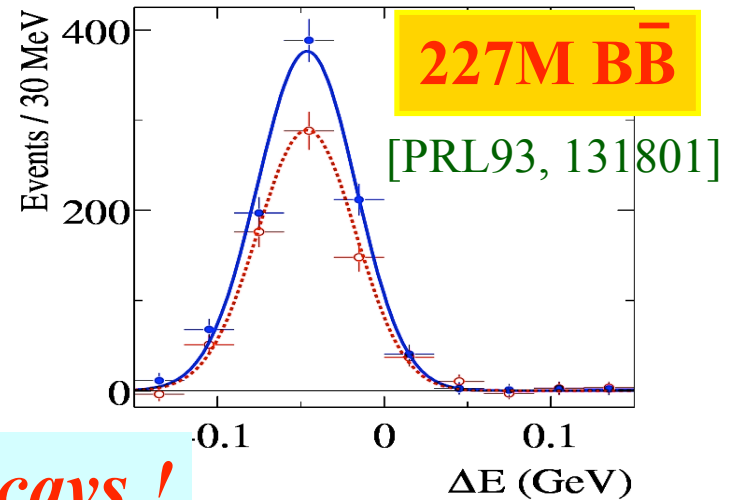
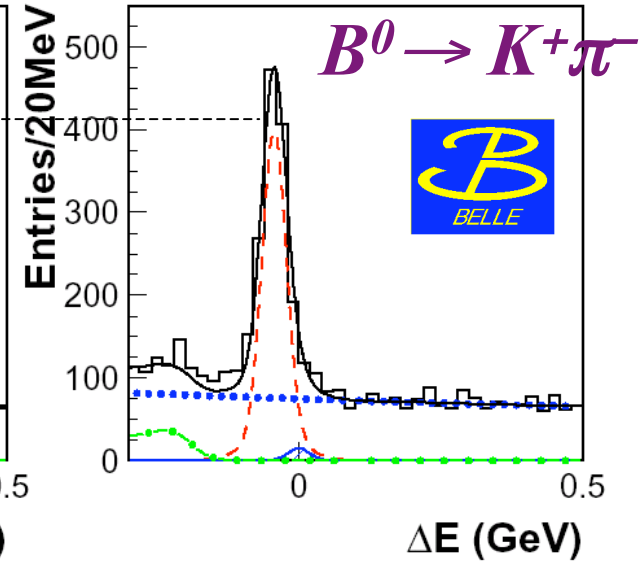
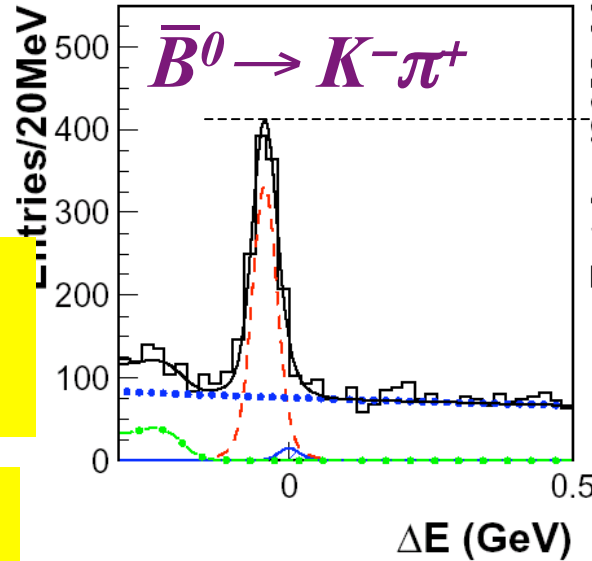
$A_{CP} = -0.101 \pm 0.025 \pm 0.005$

3.9 $\sigma$  significance

$A_{CP} = -0.133 \pm 0.030 \pm 0.009$

Average of Belle and BaBar

$A_{CP} = -0.114 \pm 0.020 > 5\sigma!$



227M  $B\bar{B}$

[PRL93, 131801]

*First established Direct CPV in B decays!*



# Observation of $B^0 \rightarrow \pi^0\pi^0$

Key mode for  $\phi_2(\alpha)$  in  $B \rightarrow \pi\pi$   
CPV isospin analysis

152M  $\bar{B}B$

Evidence !

Signal:  $26 \pm 9$  ( $3.4\sigma$ )

[PRL91, 261801]



275M  $B\bar{B}$

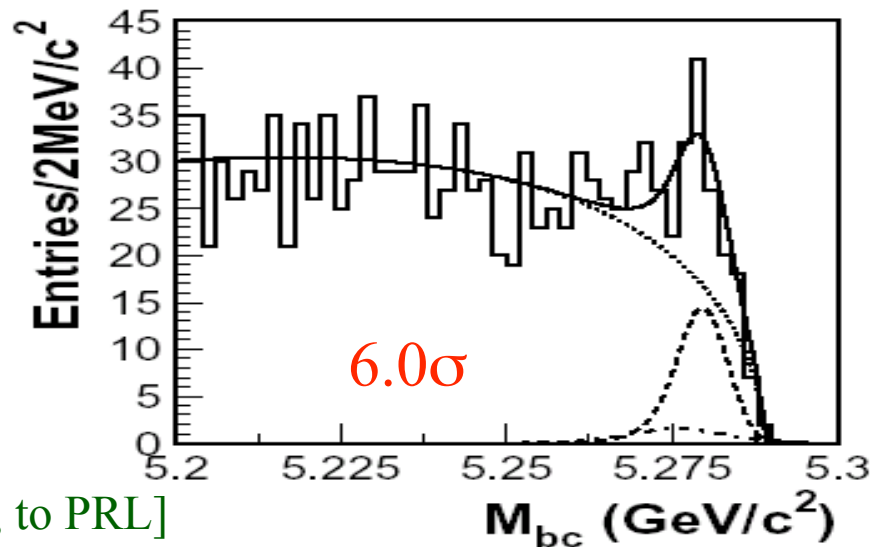
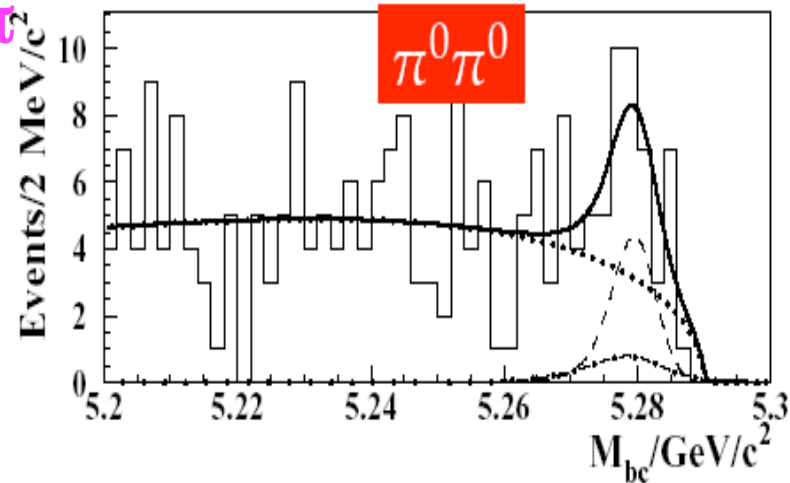
Observation !

Signal:  $82 \pm 16$  ( $6.0\sigma$ )

$B = (2.32 \pm_{-0.48}^{0.44} \pm_{-0.18}^{0.22}) \times 10^{-6}$

Large Br established

[hep-ex/0408101, to PRL]

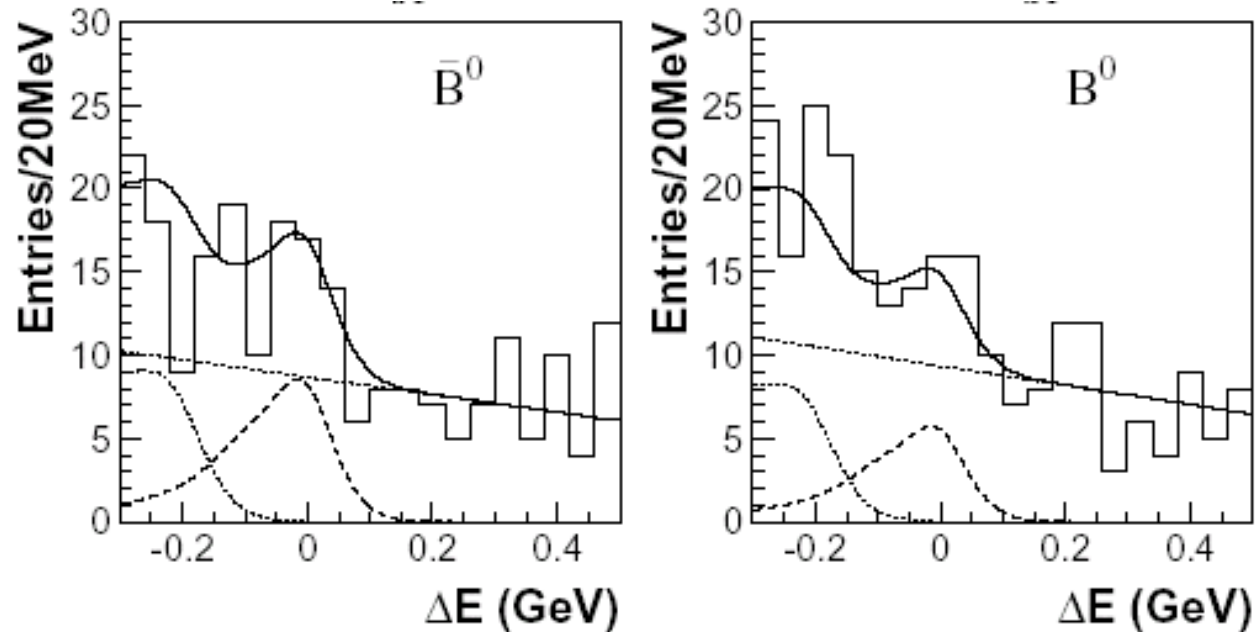






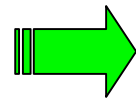
# $A_{CP}$ of $B^0 \rightarrow \pi^0\pi^0$

275M  $B\bar{B}$



uses same Flavor-tagging as TCPV analysis

$$A_{CP} = 0.44 \pm 0.51 \pm \begin{matrix} 0.17 \\ 0.16 \end{matrix}$$



used in  $\phi_2(\alpha)$  in  $B \rightarrow \pi\pi$   
CPV isospin analysis

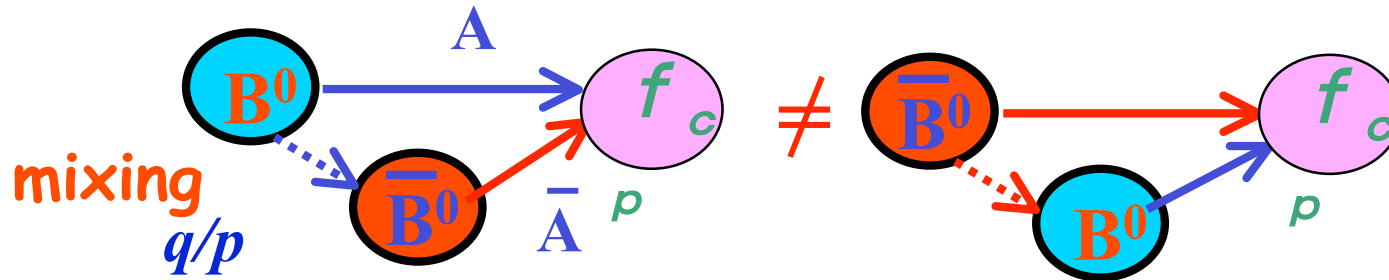
1<sup>st</sup> measurement !

[hep-ex/0408101, to PRL]



# Time Dependent CPV

## Mixing Induced CPV



Sanda  
Bigi  
Carter

$$A_{CP} \equiv \frac{\Gamma(\bar{B}_d^0 \rightarrow f_{CP}) - \Gamma(B_d^0 \rightarrow f_{CP})}{\Gamma(\bar{B}_d^0 \rightarrow f_{CP}) + \Gamma(B_d^0 \rightarrow f_{CP})} = \mathbf{S} \sin(\Delta m \Delta t) + \mathbf{A} \cos(\Delta m \Delta t)$$

Mixing induced CPV

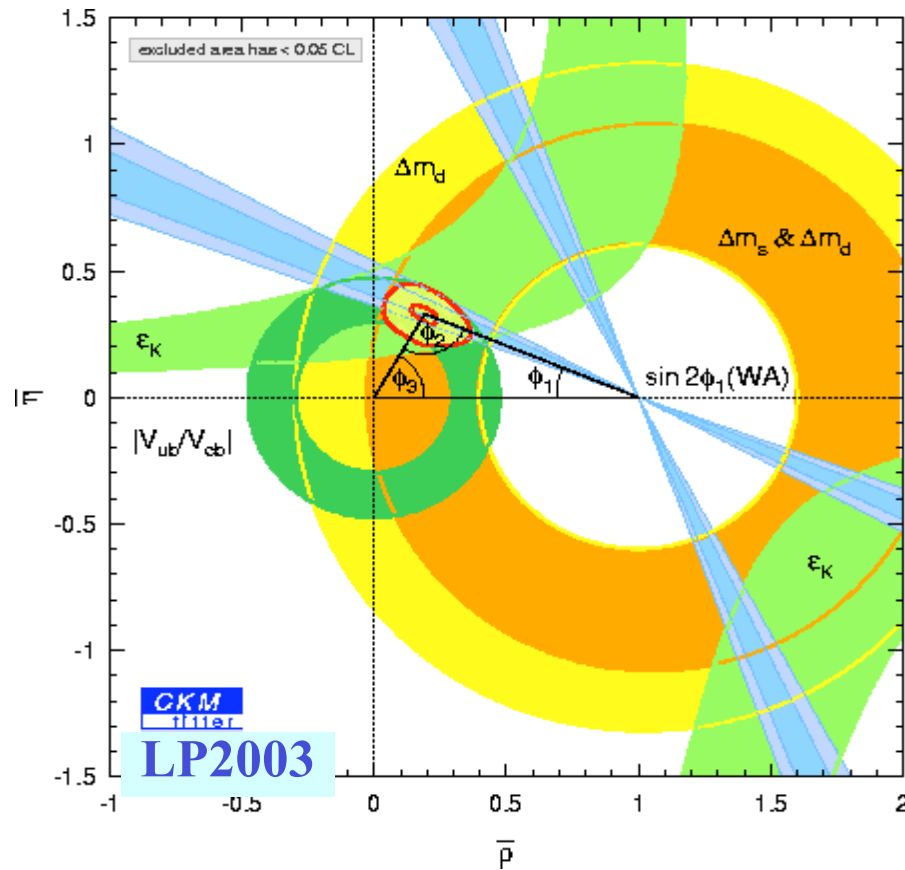
Direct CPV

$$\mathbf{S} = \frac{2Im\lambda}{1 + |\lambda|^2} \quad \mathbf{A} = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1} \quad \lambda = \frac{q}{p} \frac{\bar{A}}{A}$$

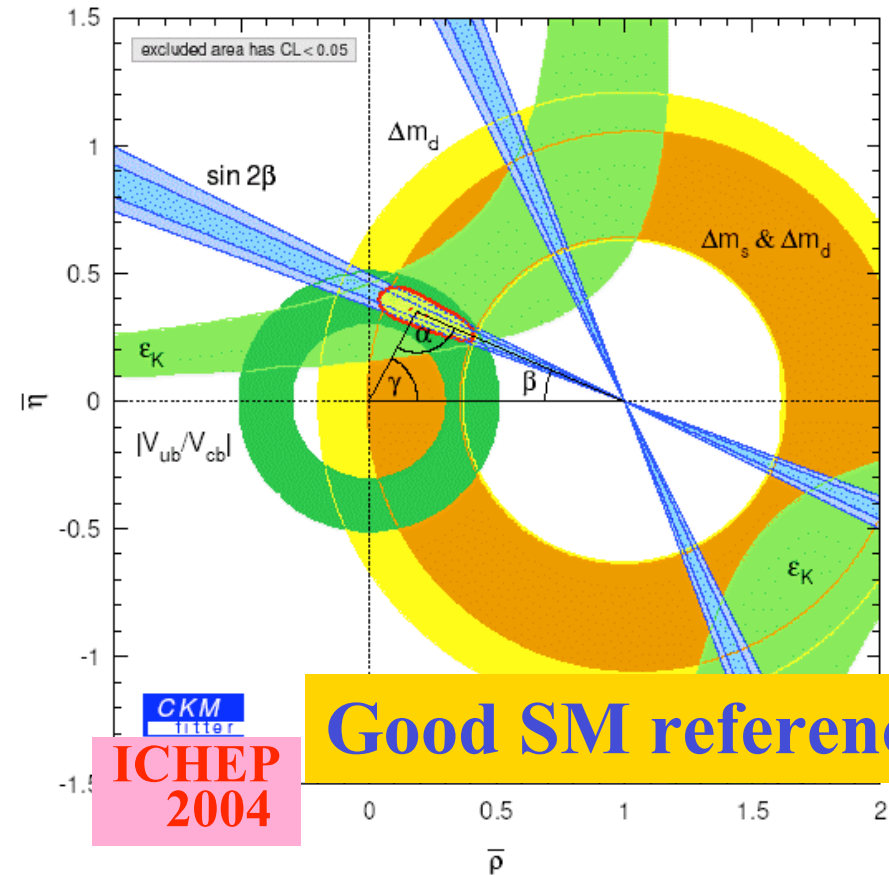
CPV in  $B \rightarrow J/\psi K_s$  etc. discovered in 2001 !



# Results for $\sin 2\phi_1$ $B \rightarrow J/\psi K_s$ etc.



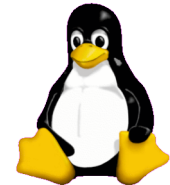
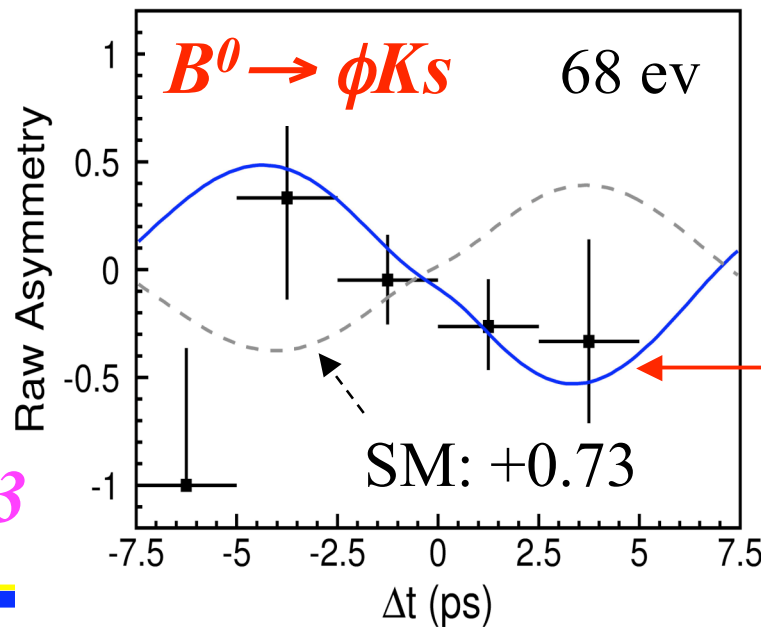
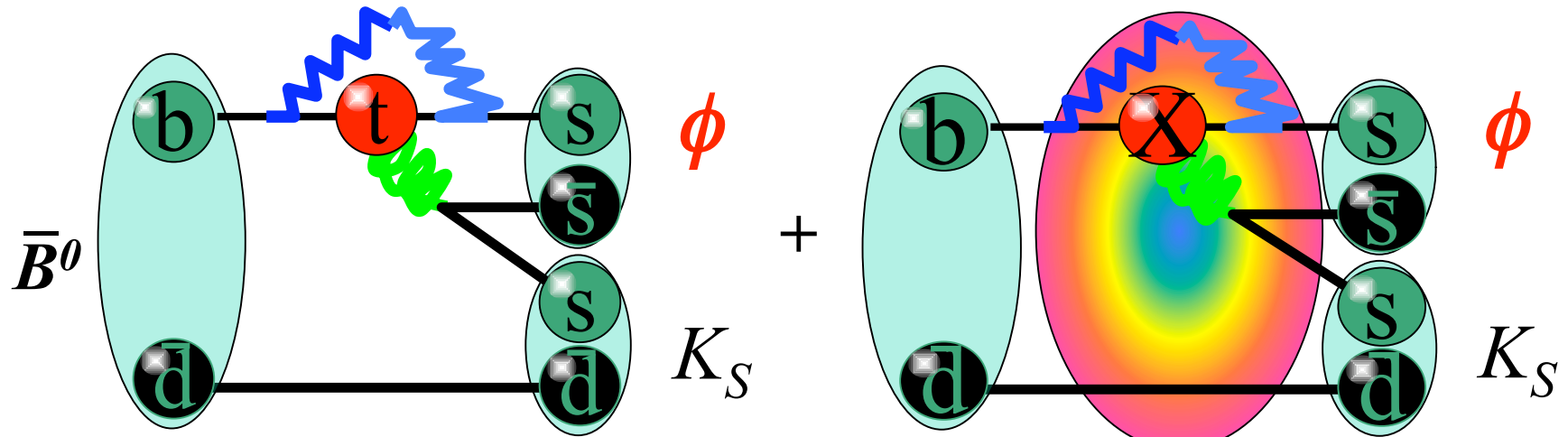
$\sin 2\phi_1$  (2003 World Av.)  
 **$= 0.736 \pm 0.049$**



$\sin 2\phi_1$  (2004 World Av.)  
 **$= 0.726 \pm 0.037$**  (~5%)



# New physics Search : $b \rightarrow s\bar{q}q$



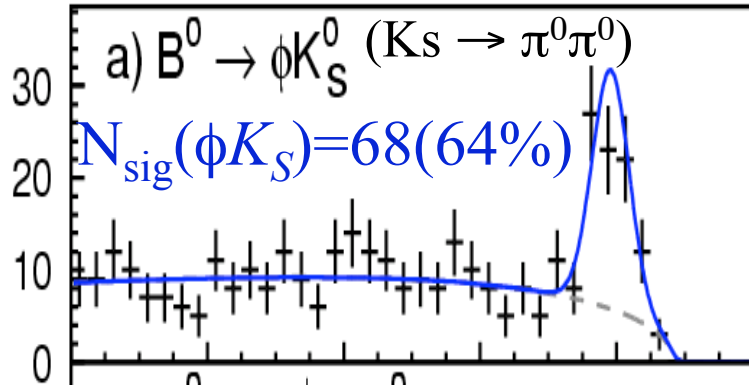
$$\begin{aligned} \text{“sin}2\phi_1\text{”} &= \xi_f \mathbf{S} \\ &= -0.96 \pm 0.51 \end{aligned}$$

**3.5 $\sigma$  deviation from the SM !**

Belle @LP03



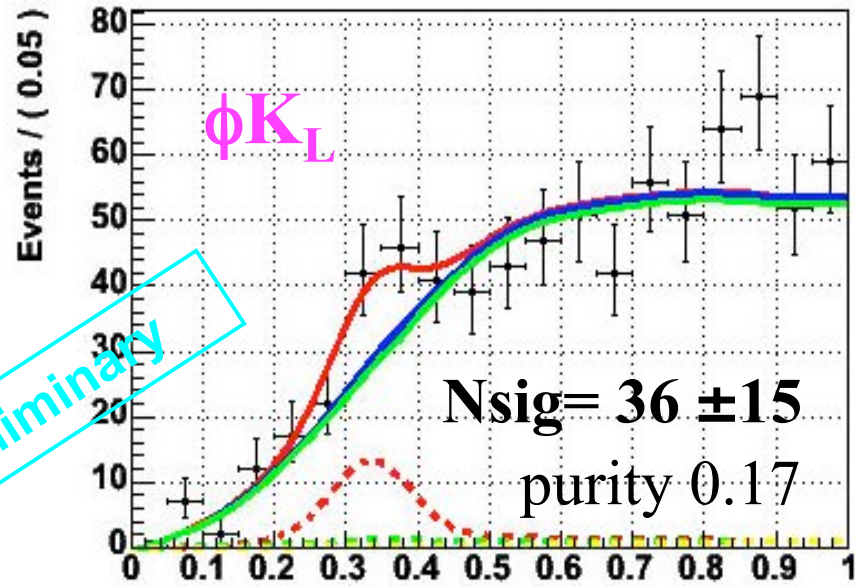
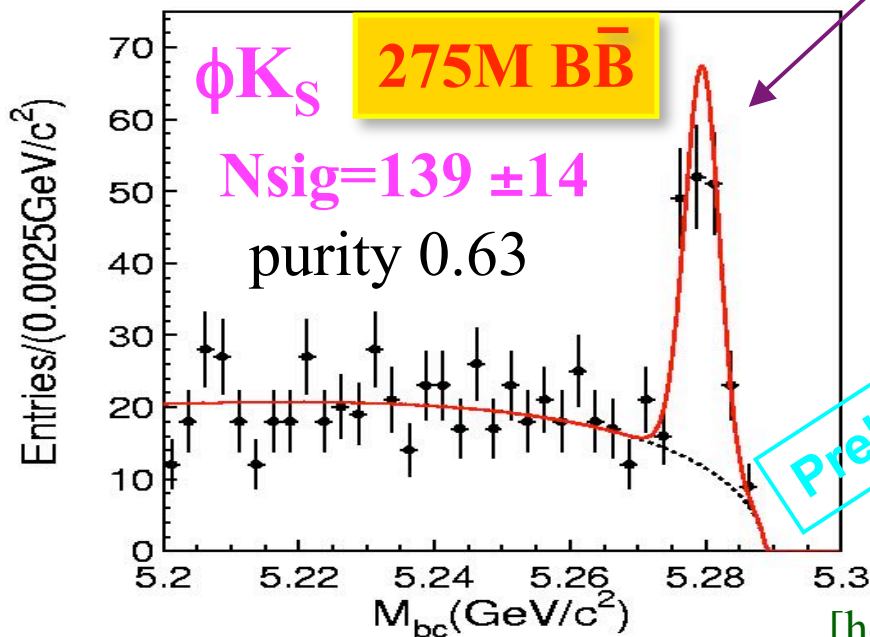
# $B^0 \rightarrow \phi K^0$



152M  $\bar{B}B$

[PRL91, 261602]

includes  $K_S \rightarrow \pi^0 \pi^0$   
( $N_{\text{sig}} = 13 \pm 5$ )



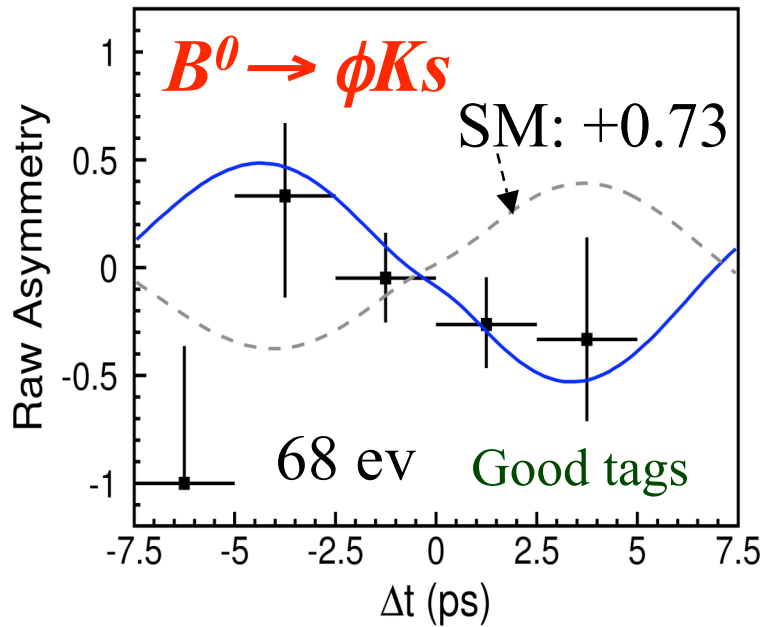
[hep-ex/0409049]



# $B^0 \rightarrow \phi K^0$ : CPV Results

152M  $B\bar{B}$

[PRL91, 261602]



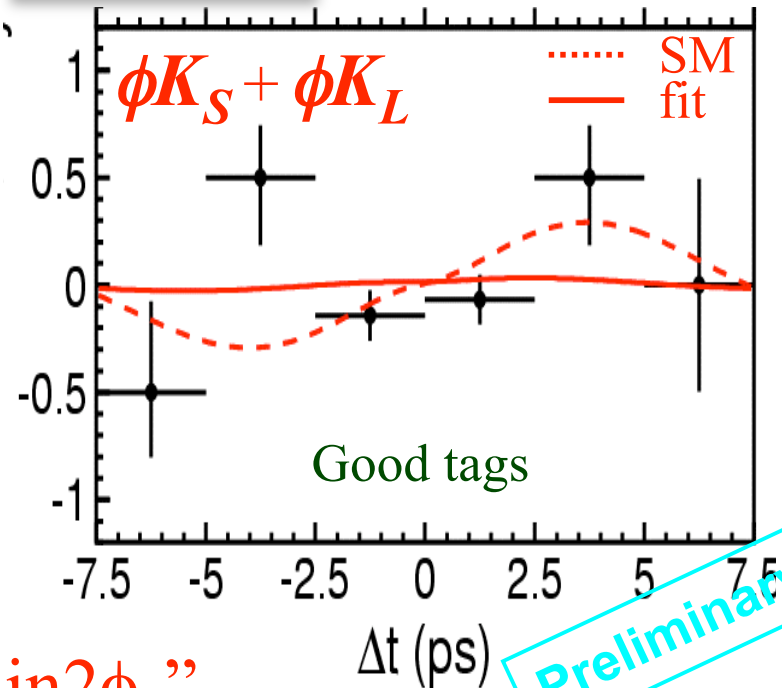
“ $\sin 2\phi_1$ ”

$$S = -0.96 \pm 0.50 \pm 0.11$$

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

275M  $B\bar{B}$

[hep-ex/0409049]



“ $\sin 2\phi_1$ ”

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

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

$\sim 2\sigma$  away from SM

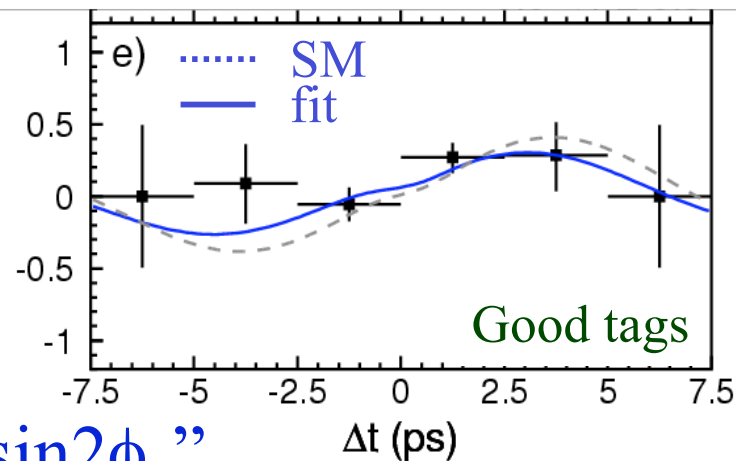
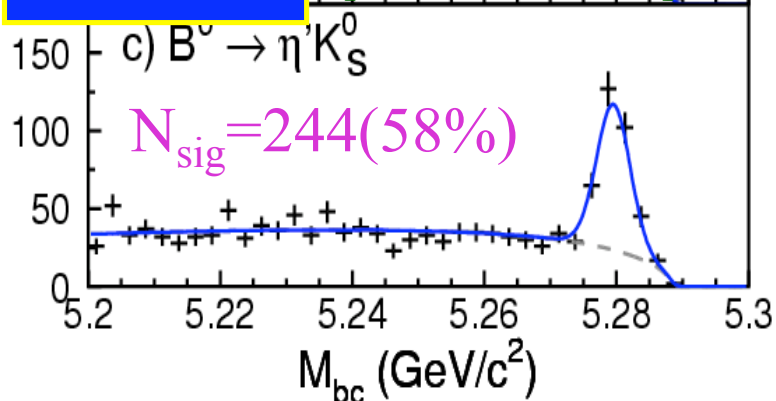


# $B^0 \rightarrow \eta' K_S$

high statistics modes

152M  $B\bar{B}$

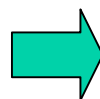
[PRL91, 261602]



“ $\sin 2\phi_1$ ”

$$S = +0.51 \pm 0.26 \pm 0.05^{+0.18}_{-0.00}$$

$$A = -0.17 \pm 0.16 \pm 0.04$$



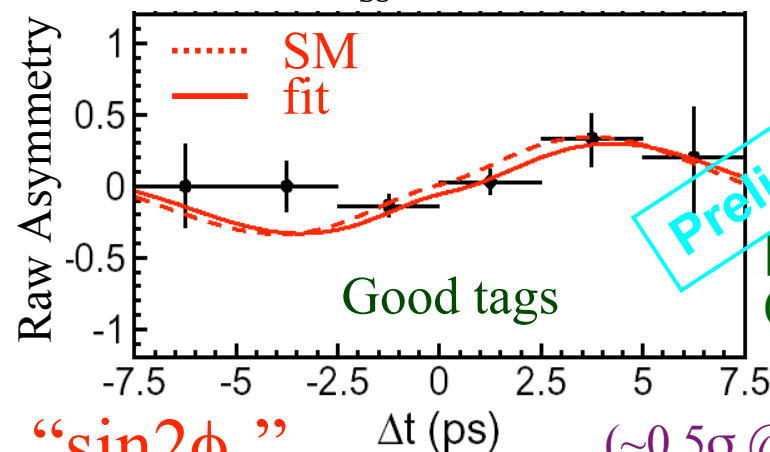
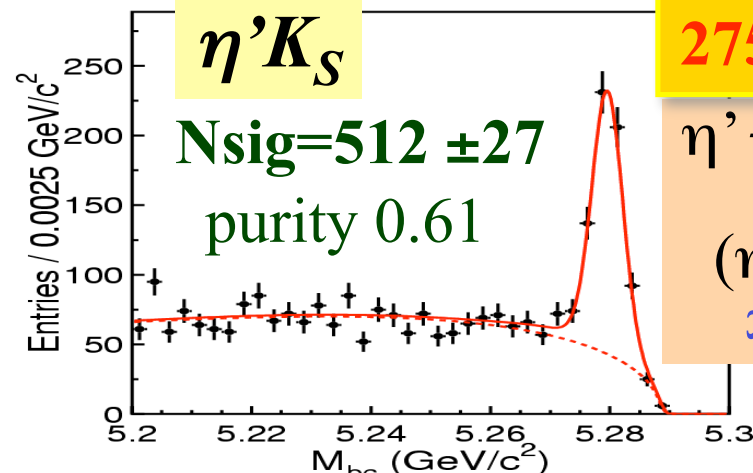
$\eta' K_S$

$N_{\text{sig}} = 512 \pm 27$

purity 0.61

275M  $B\bar{B}$

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



Preliminary

[hep-ex/0409049]

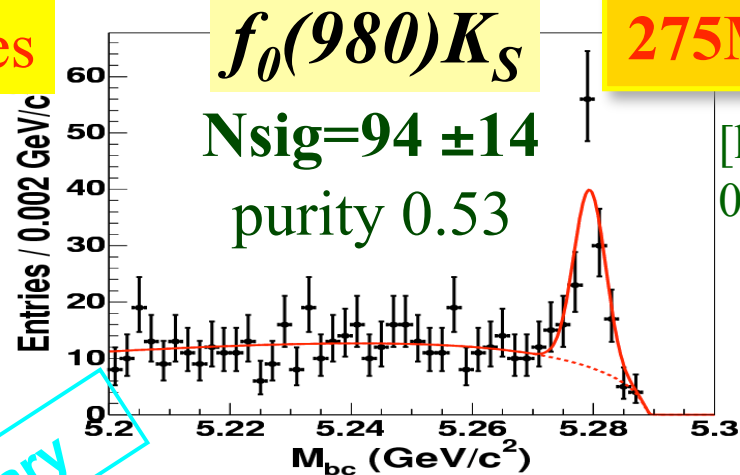
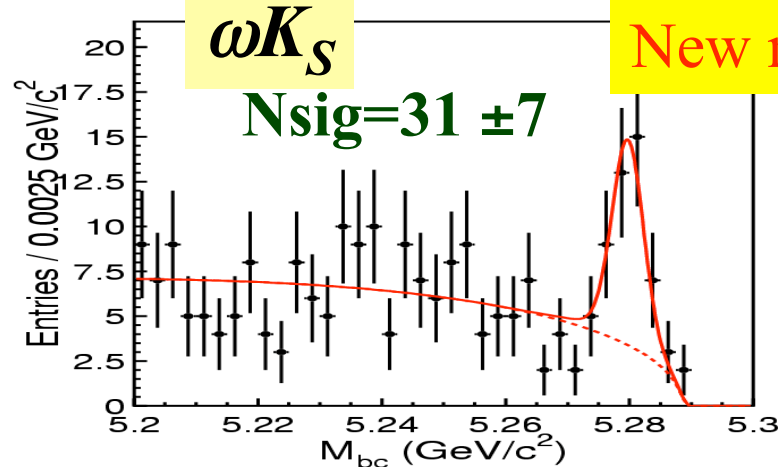
“ $\sin 2\phi_1$ ”

$$S = +0.65 \pm 0.18 \pm 0.04$$

$$A = -0.19 \pm 0.11 \pm 0.05$$

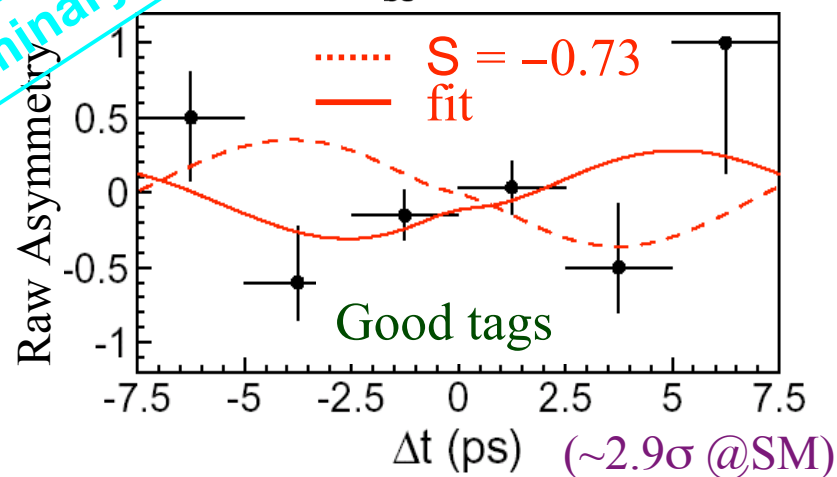
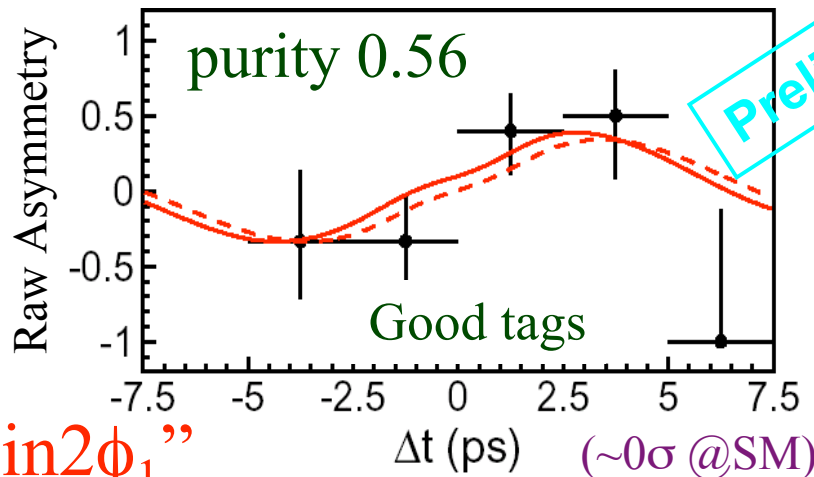


# $B^0 \rightarrow \omega K_S$ & $f_0(980) K_S$



**275M  $B\bar{B}$**

[hep-ex/  
0409049]



Preliminary

“ $\sin 2\phi_1$ ”

**$S = +0.75 \pm 0.64 \pm_{0.16}^{0.13}$**

**$A = +0.26 \pm 0.48 \pm 0.15$**

**$-S = -0.47 \pm 0.41 \pm 0.08$**

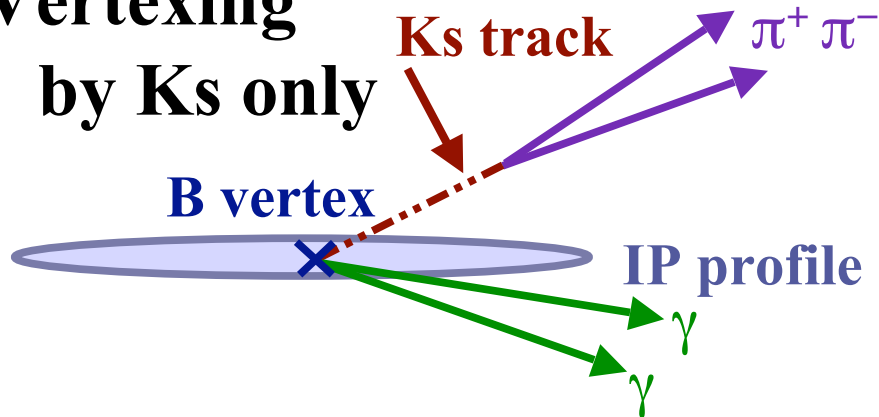
**$A = -0.39 \pm 0.27 \pm 0.08$**



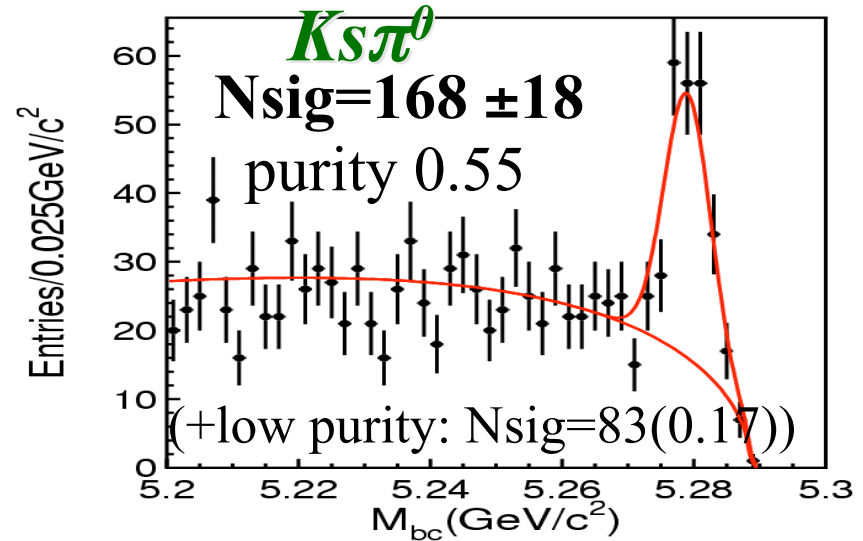


# $B^0 \rightarrow K_S \pi^0$

Vertexing  
by Ks only



Validated by  $J/\psi$  Ks (use Ks only)



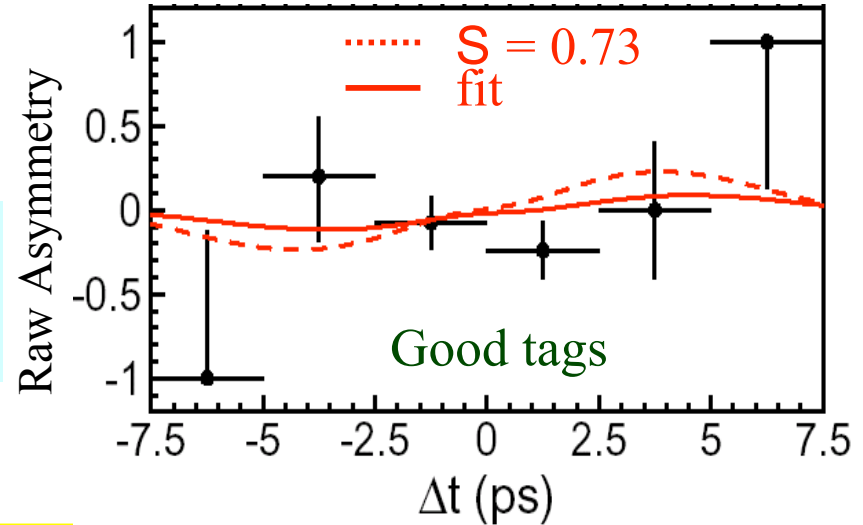
Preliminary

“ $\sin 2\phi_1$ ”

( $\sim 0.7\sigma$  @SM)

$$S = +0.30 \pm 0.59 \pm 0.11$$

$$A = -0.12 \pm 0.20 \pm 0.07$$

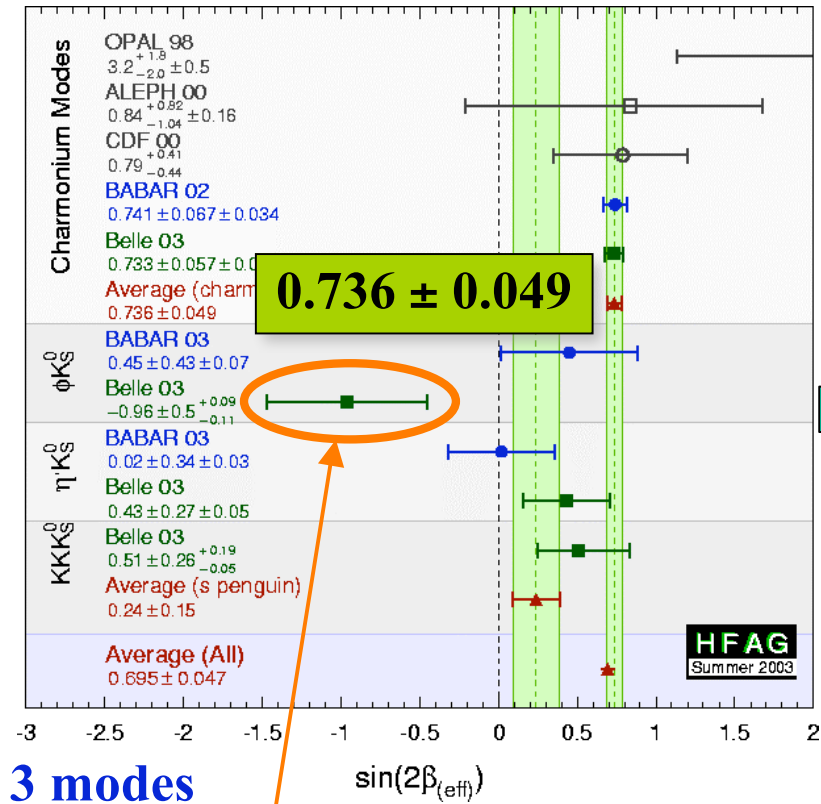


275M  $B\bar{B}$

[hepex/0409049]



# “ $\sin 2\phi_1$ ” from $b \rightarrow s$ penguins

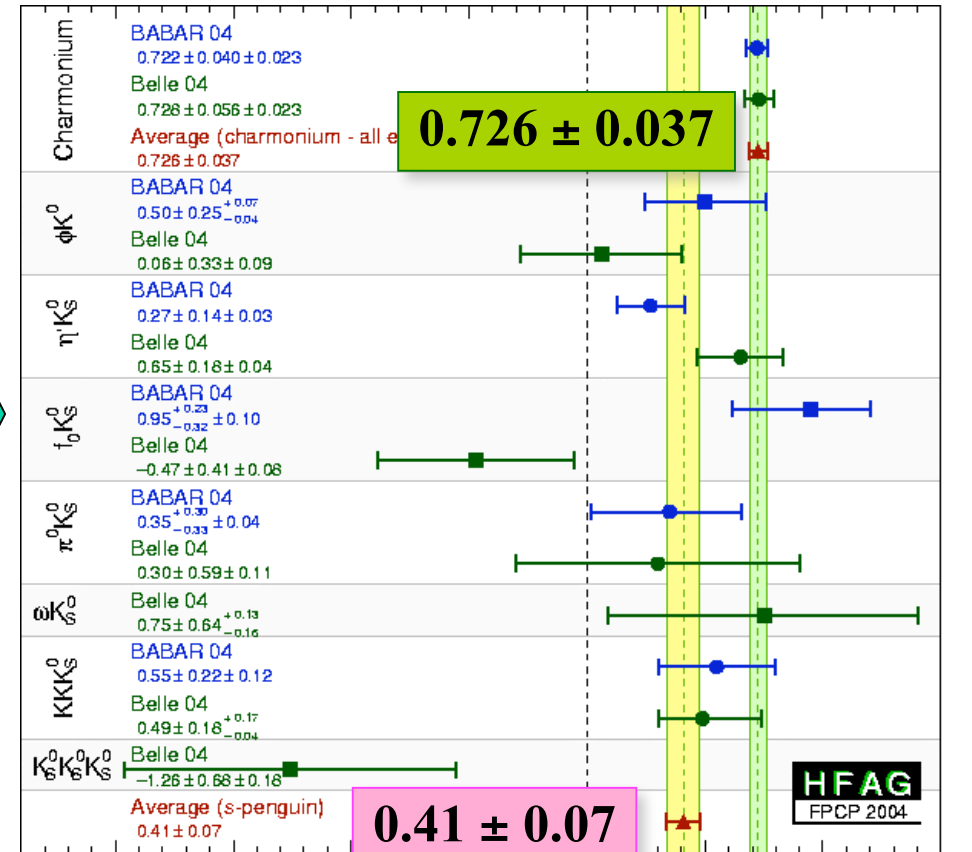


3 modes

$\sim 3.5\sigma$

$0.24 \pm 0.15$

$\sim 3.1\sigma$  from s-penguin to  $\sin 2\phi_1$  ( $c\bar{c}$ )



7 modes

$0.41 \pm 0.07$

$\sim 3.8\sigma$  from s-penguin to  $\sin 2\phi_1$  ( $c\bar{c}$ )

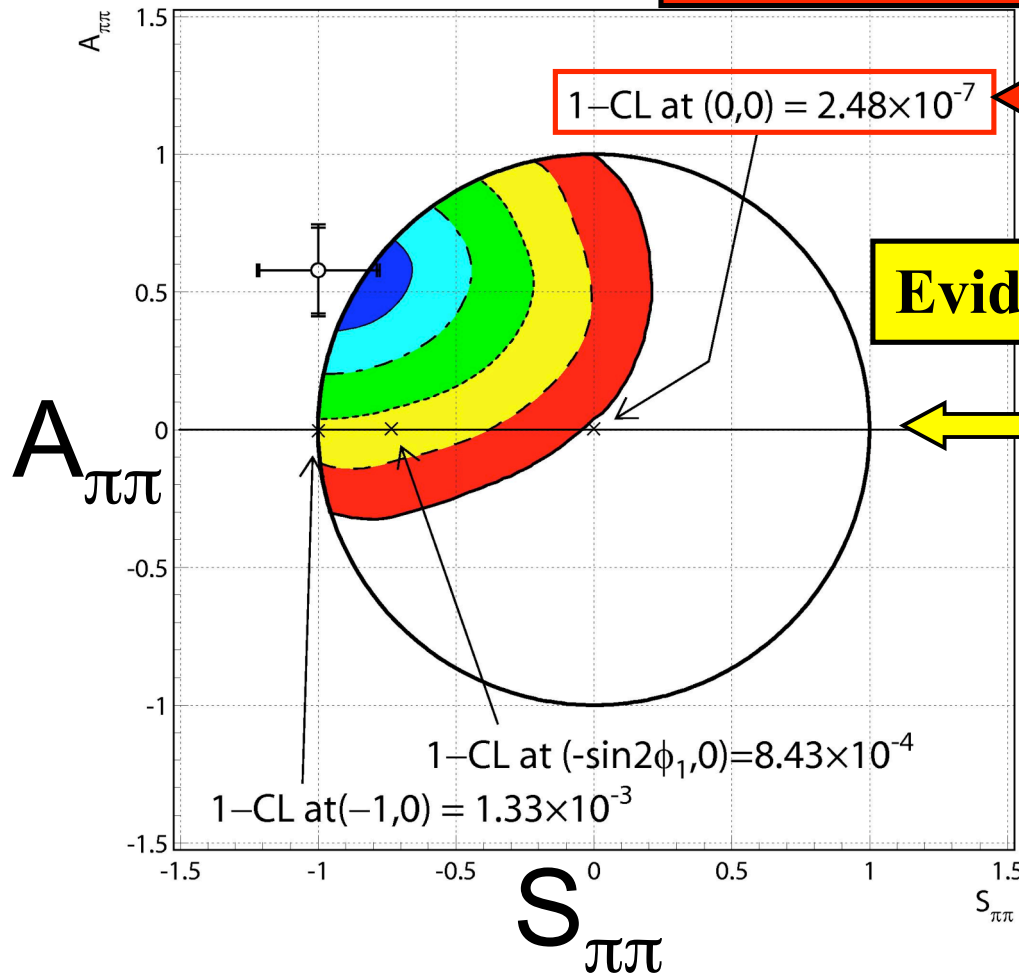


# $B^0 \rightarrow \pi^+ \pi^-$ CPV

Feldman-Cousins Analysis

Observation of  $CP$  violation

$(5.2\sigma)$



Evidence for direct  $CP$  violation

$\geq 3.2\sigma$

for  $A_{\pi\pi} = 0$  and any  $S_{\pi\pi}$

152M BB

Winter 2004

[PRL91, 021601]



# History of $A_{\pi\pi}$ and $S_{\pi\pi}$

$$B^0 \rightarrow \pi^+ \pi^-$$

TCPV

Difference

Winter04:  $\sim 2.2\sigma$



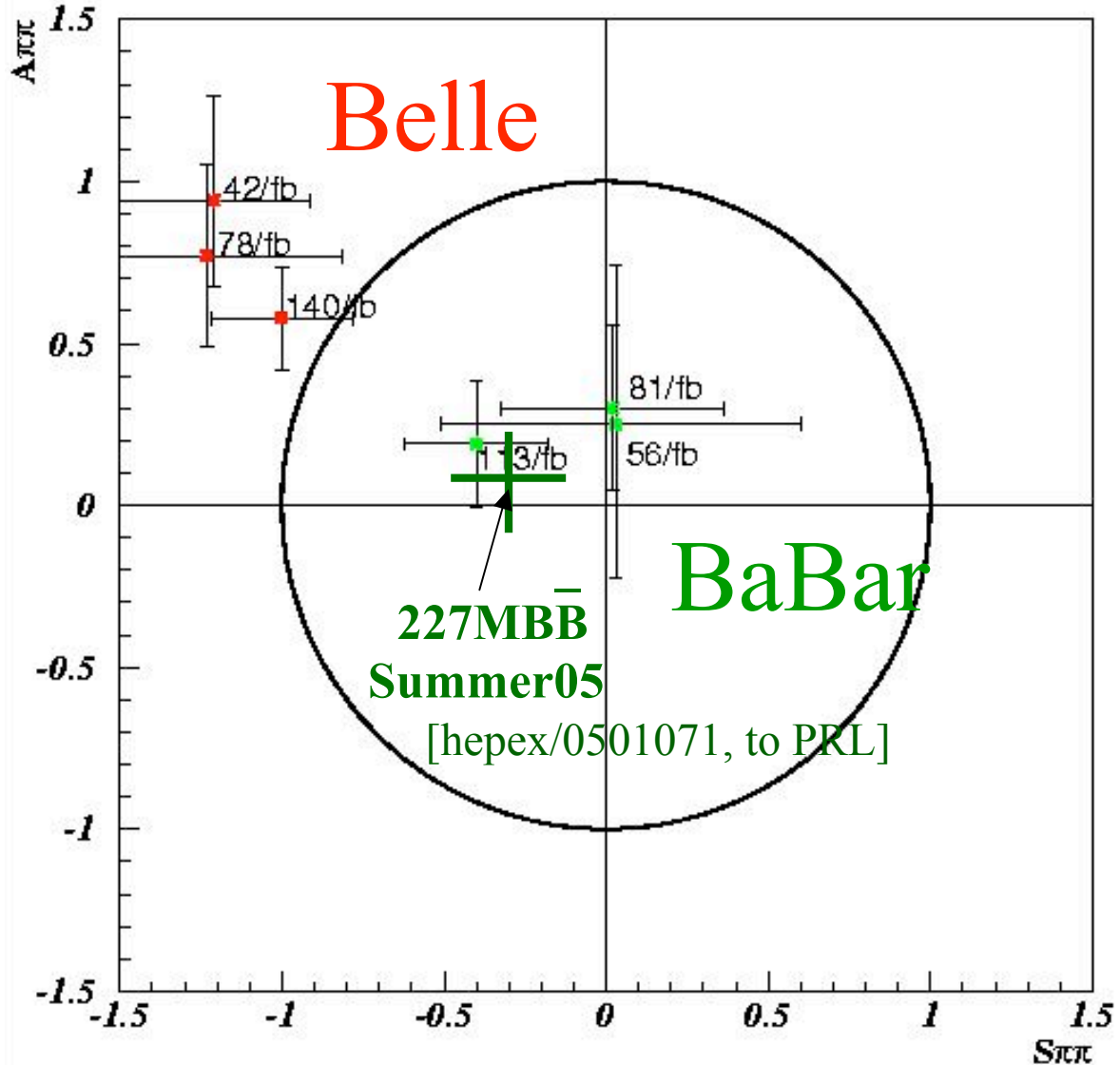
Summer05:  $\sim 3.1\sigma$



?

presented at Aspen

18-Feb-2005

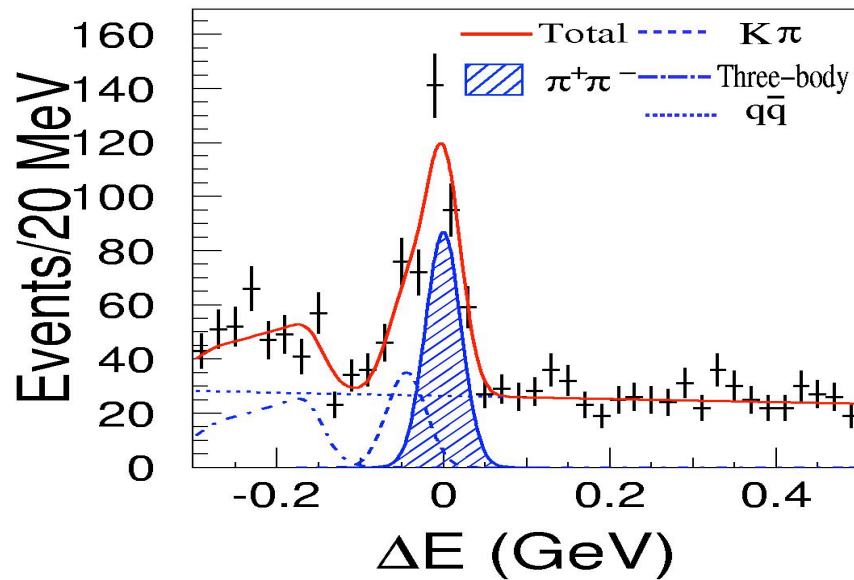




# $B^0 \rightarrow \pi^+\pi^-$ signals

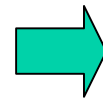
152M  $B\bar{B}$

$0.86 < LR$   
High quality

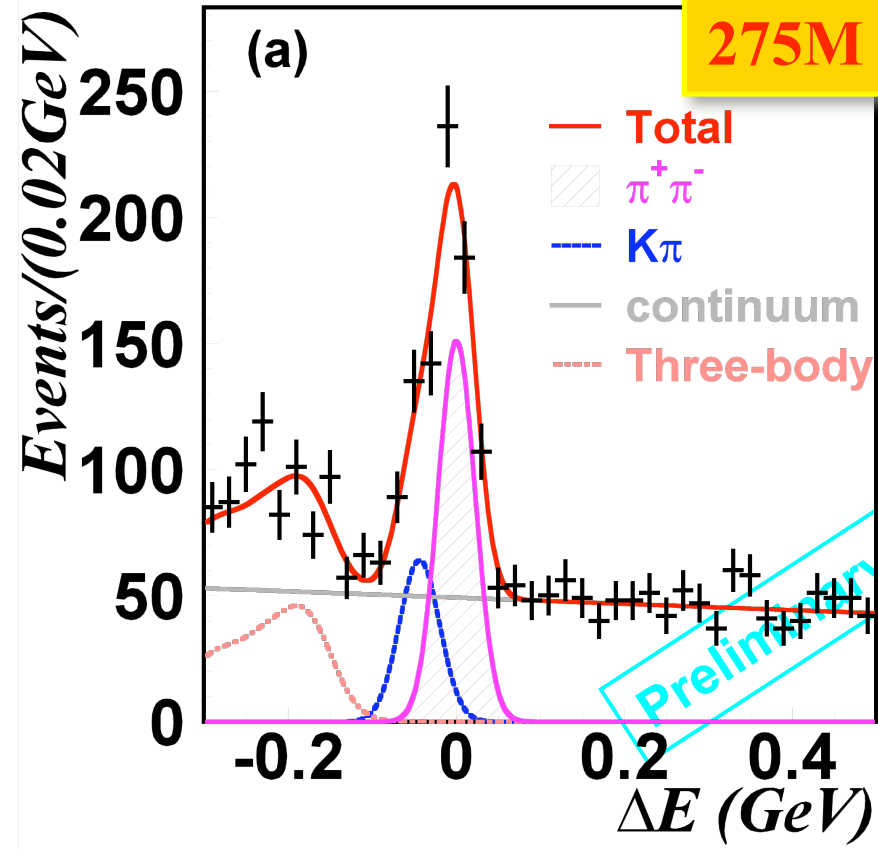


$(372 \pm 32) \pi^+\pi^-$  signals

[PRL91, 021601]



275M  $B\bar{B}$

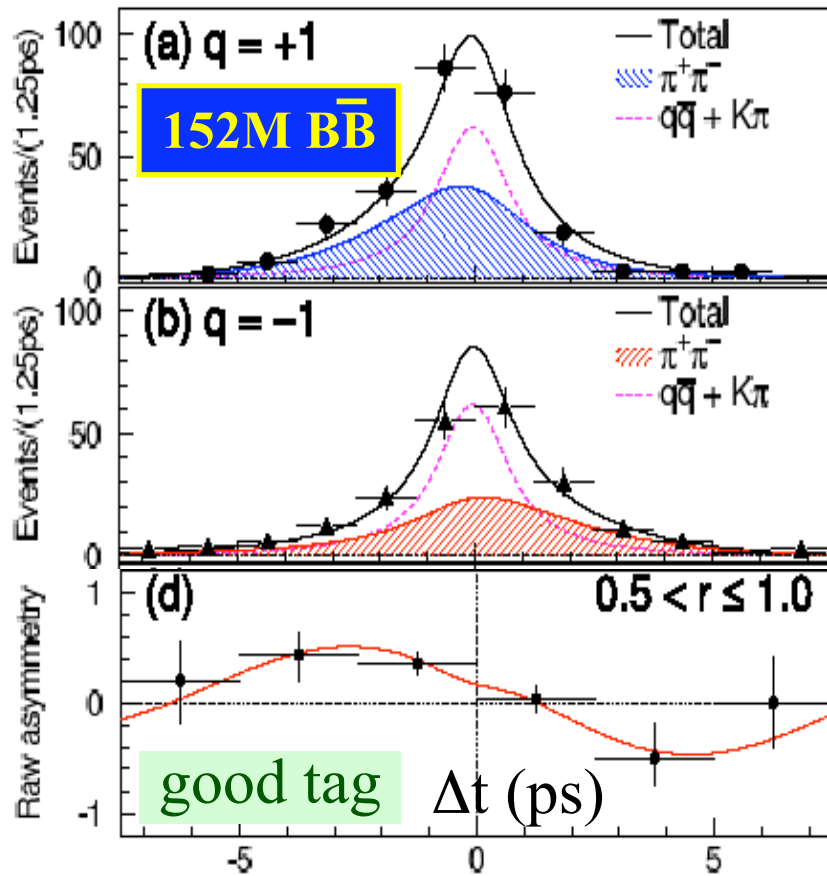


$(666 \pm 43) \pi^+\pi^-$  signals

[hepex/0502035]

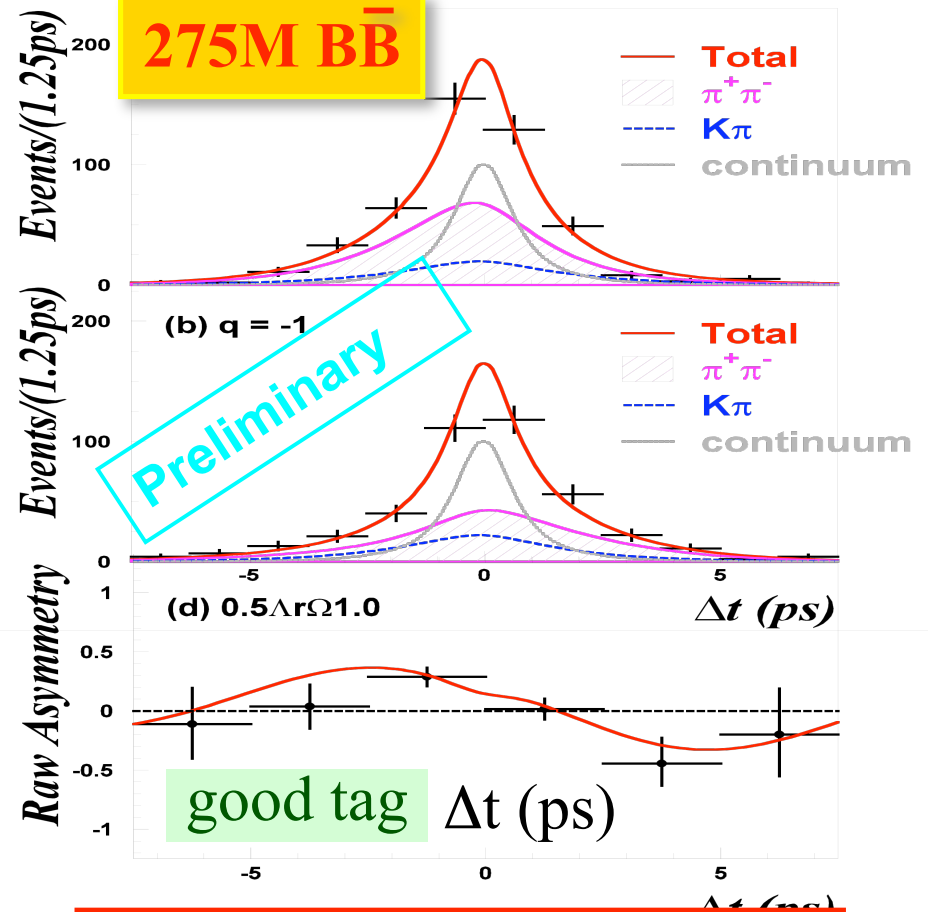
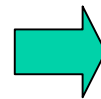


# $B^0 \rightarrow \pi^+ \pi^-$ CPV Results



$$A_{\pi\pi} = +0.58 \pm 0.15 \pm 0.07$$

$$S_{\pi\pi} = -1.00 \pm 0.21 \pm 0.07$$

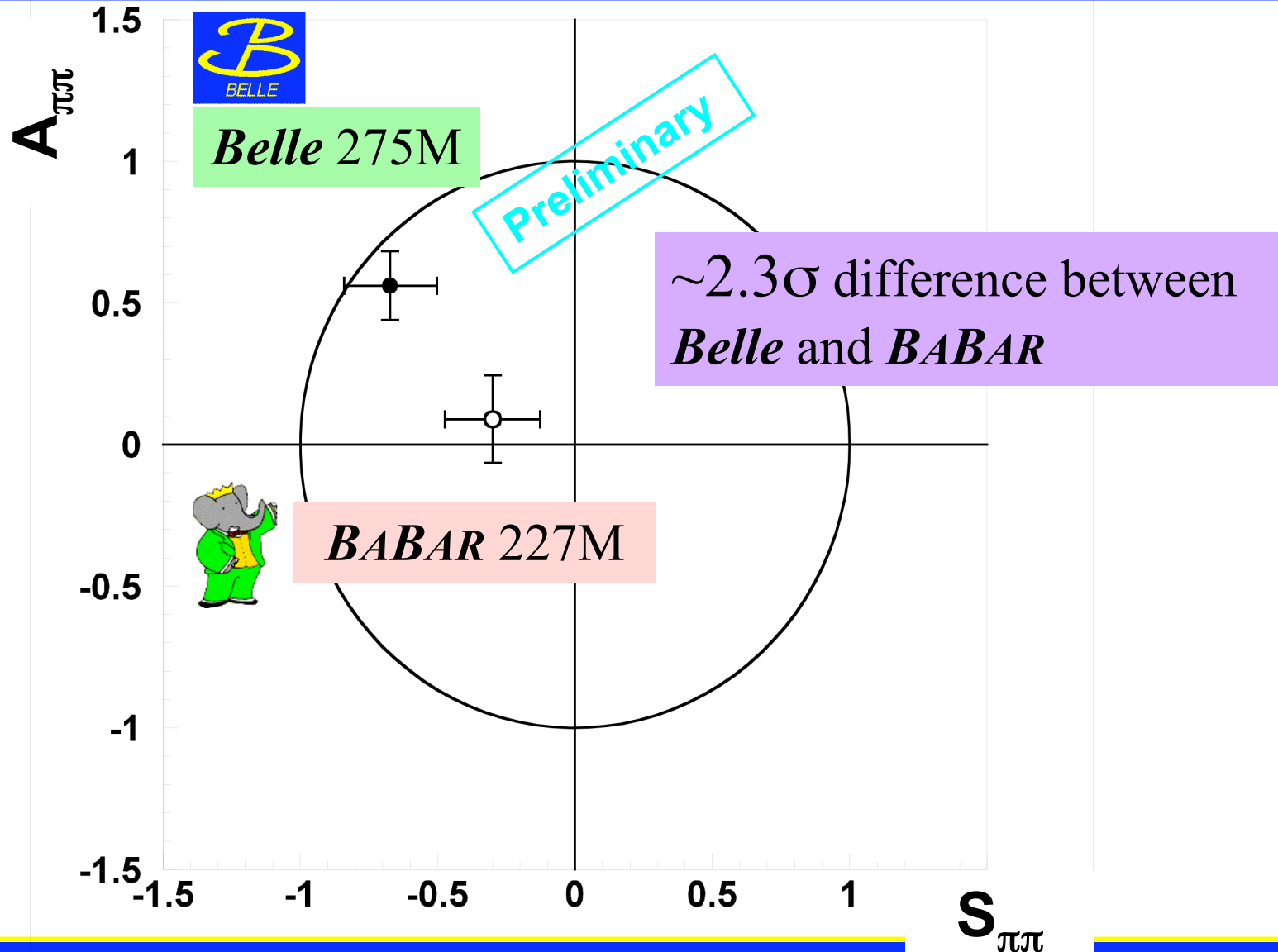


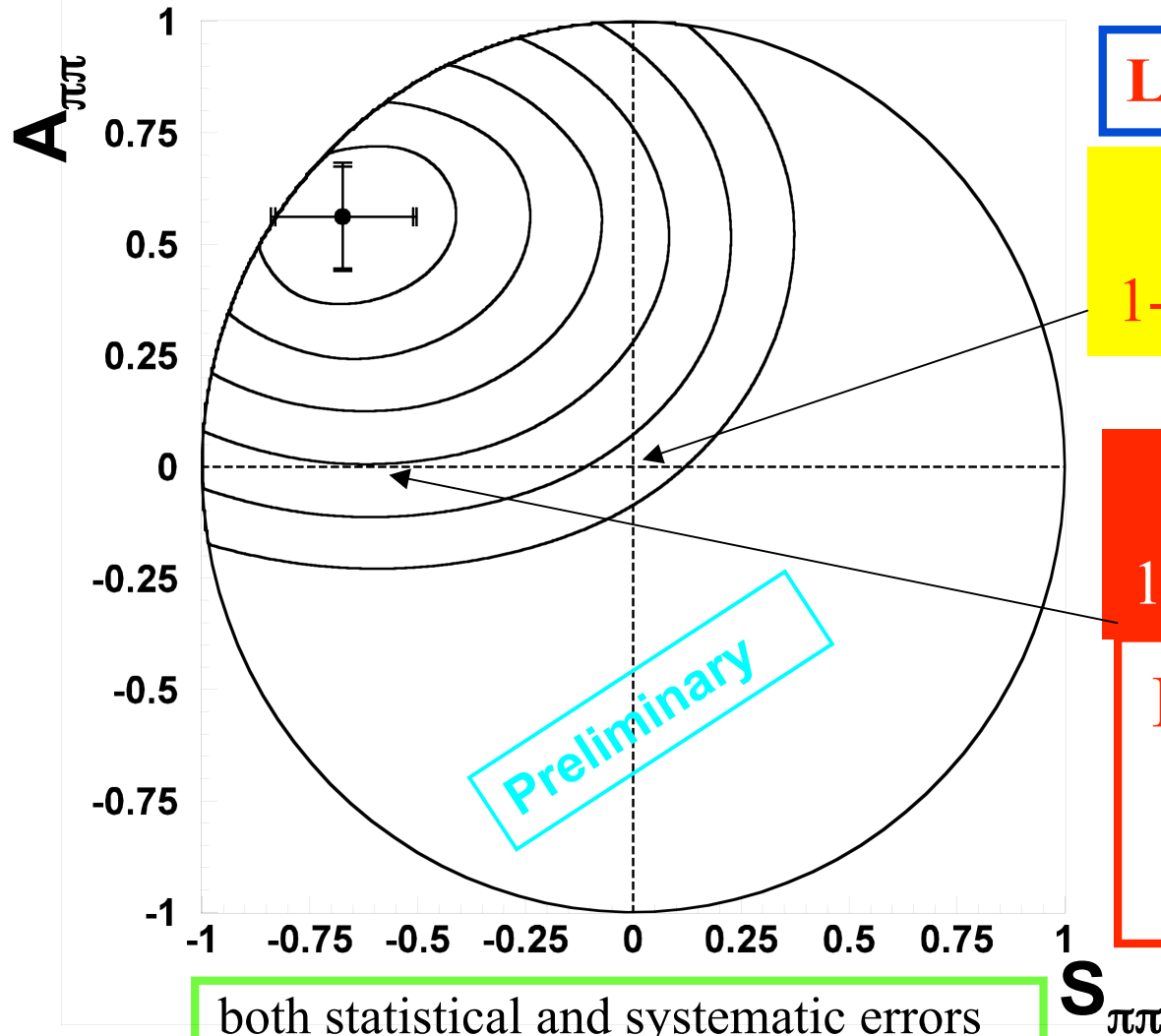
$$A_{\pi\pi} = +0.56 \pm 0.12 \pm 0.06$$

$$S_{\pi\pi} = -0.67 \pm 0.16 \pm 0.06$$



# New Exp. Summary





**Large CP Violation,**

$(A, S) = (0, 0)$   
 1-C.L. =  $5.62 \times 10^{-8}$ ,  $5.4\sigma$

$(A, S) = (0, -0.62)$   
 1-C.L. =  $5.13 \times 10^{-5}$ ,  $4.0\sigma$

**Large Direct CPV**  
 confirm previous  
**Belle results**

both statistical and systematic errors are taken into account.

[hepex/0502035]  
**Feldman-Cousins Analysis**

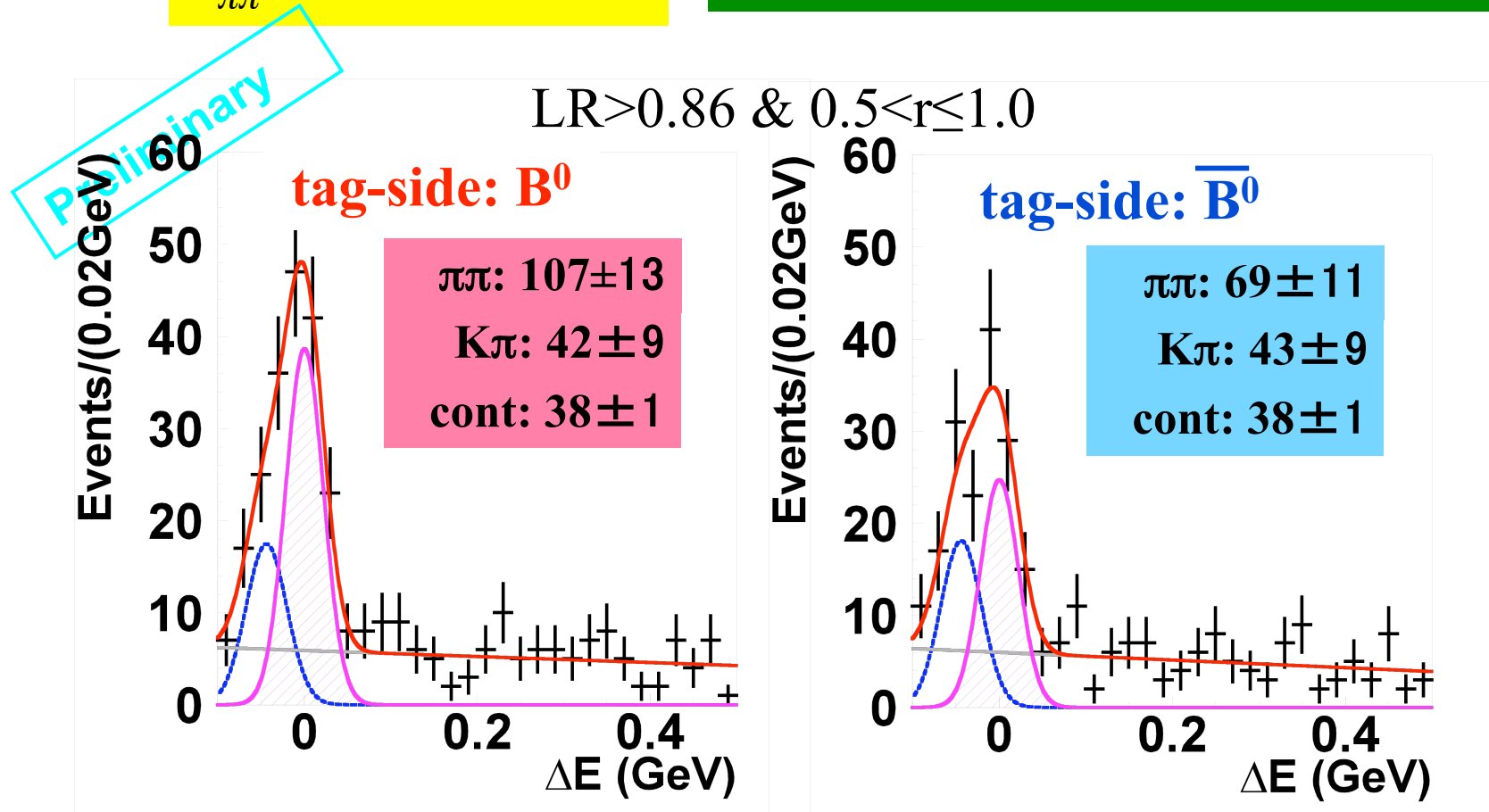




# Check: Time-Integ. CPV

$$A_{\pi\pi} = +0.52 \pm 0.14$$

consistent with time-dependent fit

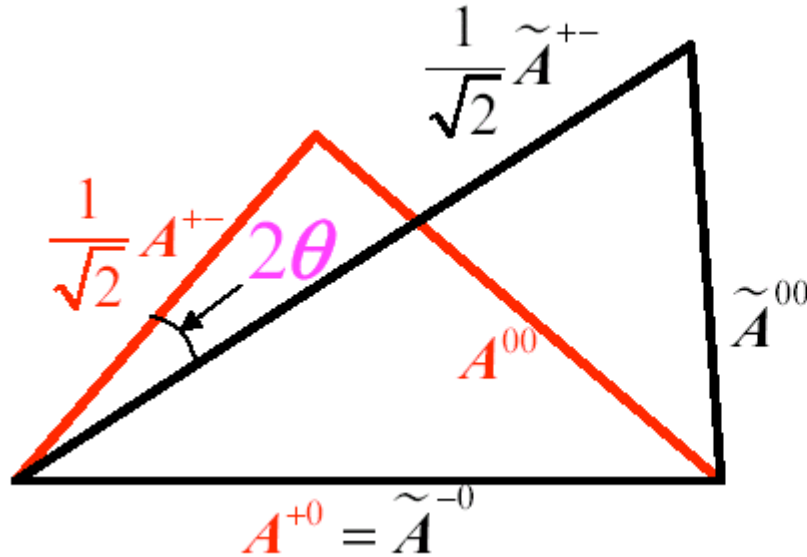


Direct CP Violation is evident!



# Isospin Analysis: $\phi_2$ constraint

M. Gronau and D. London, PRL 65, 3381 (1990)



$$S_{\pi\pi} = \sqrt{1 - A_{\pi\pi}^2} \sin(2\phi_2 + 2\theta)$$

Belle result

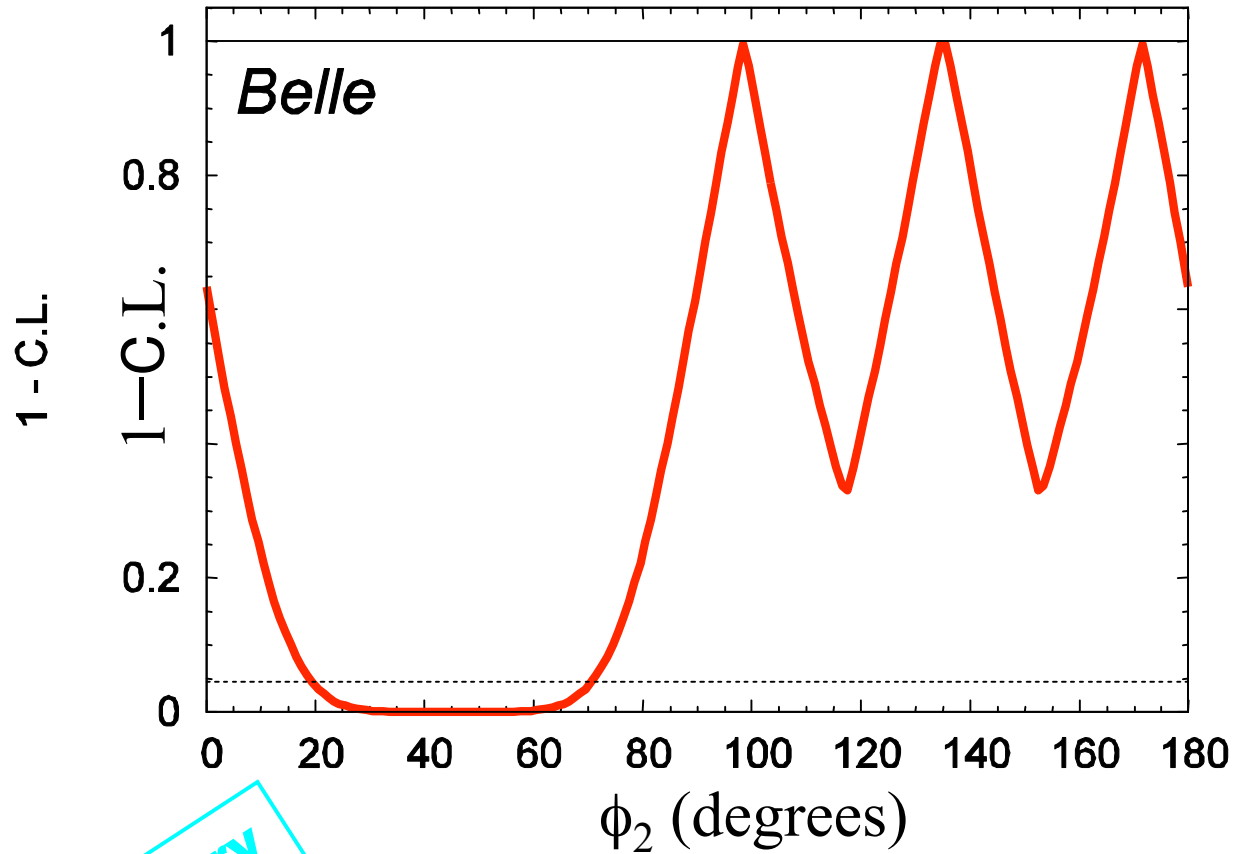
	Amplitude for
$A^{+-}(\bar{A}^{+-})$	$B^0(\bar{B}^0) \rightarrow \pi^+\pi^-$
$A^{00}(\bar{A}^{00})$	$B^0(\bar{B}^0) \rightarrow \pi^0\pi^0$
$A^{+0}(\bar{A}^{-0})$	$B^+(B^-) \rightarrow \pi^+\pi^0(\pi^-\pi^0)$

$$\tilde{A}^{ij} = e^{2\phi_3} \bar{A}^{ij}$$

**$B \rightarrow \pi\pi$  Br &  $A_{CP}$**   
 HFAG 2004 Summer  
 World Averages



# $\phi_2$ constraint



275M  $B\bar{B}$

using HFAG  
summer 2004

Fit method:

J. Charles *et al.*,  
hep-ph/0406184

Preliminary

95.4% confidence interval  
 $0^\circ < \phi_2 < 19^\circ$  and  $71^\circ < \phi_2 < 180^\circ$

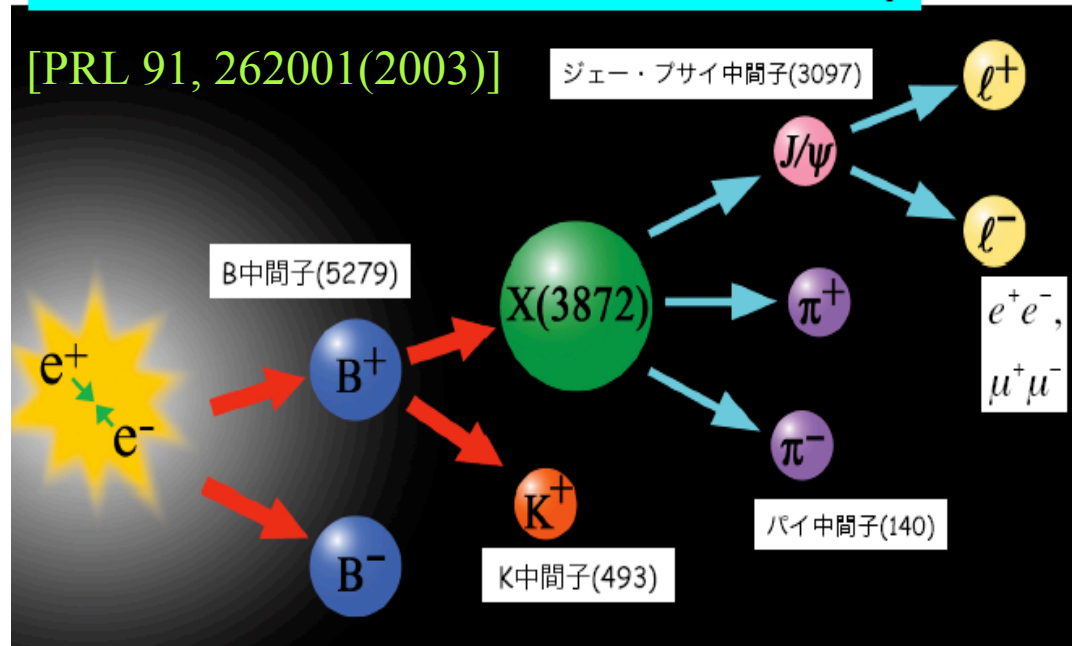
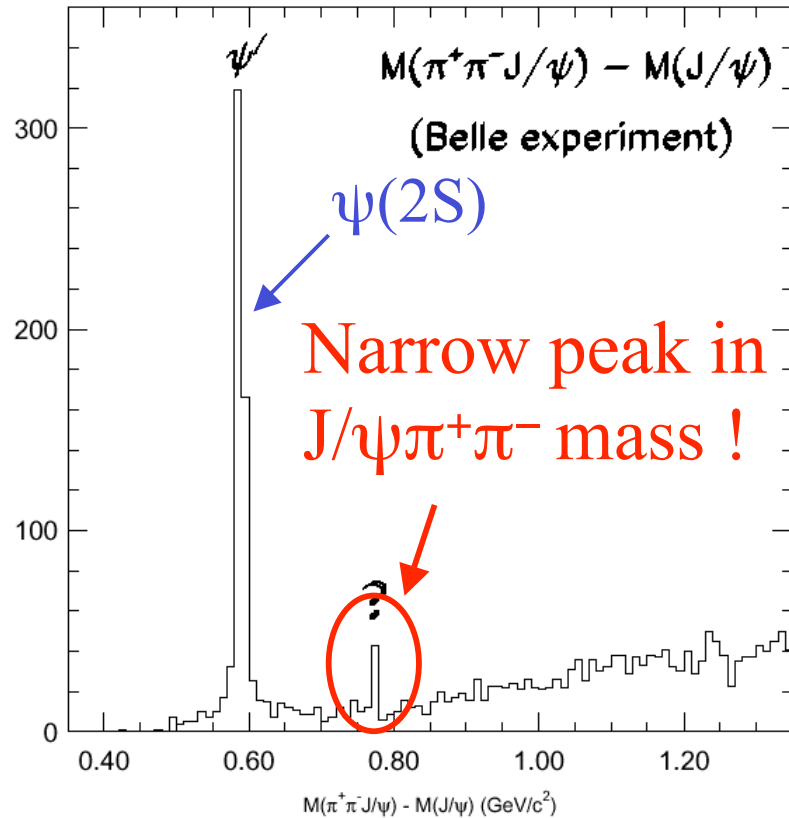
[hepex/0502035]



# New Resonances *Factory Bonuses!*

## Discovery of X(3872) LP03

$$B^+ \rightarrow K^+ X(3872) \rightarrow K^+ + \pi^+ \pi^- J/\psi$$



$$M_x = 3872.0 \pm 0.6(\text{stat}) \pm 0.5(\text{sys}) \text{ MeV}/c^2, \Gamma_x < 2.3 \text{ MeV}/c^2$$

*Still mystery: what is it?*

confirmed by CDF, D0, BaBar

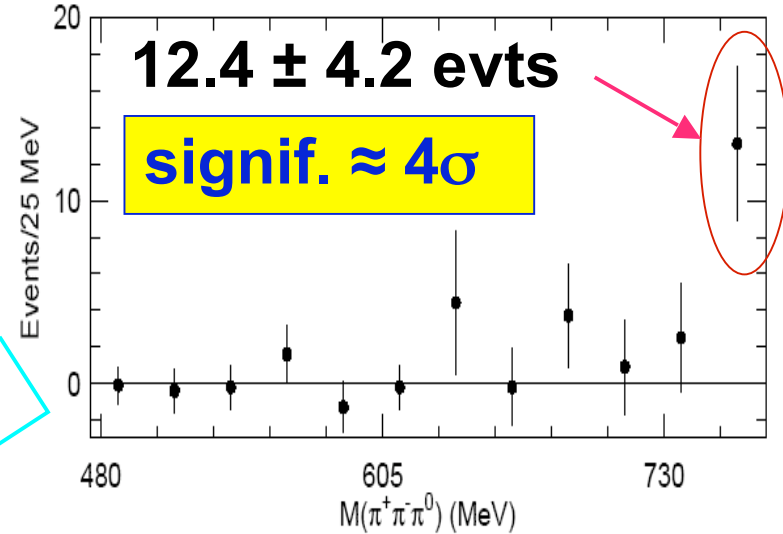
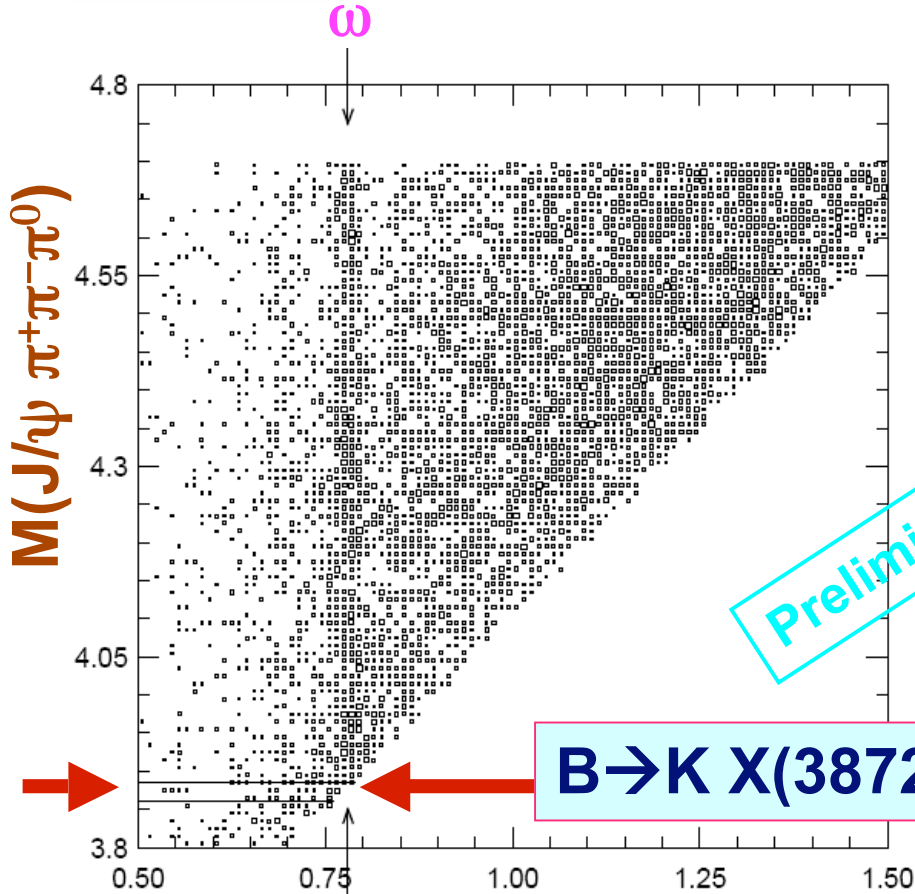


# X(3872): New decay mode

275M  $B\bar{B}$



X(3872) 2<sup>nd</sup> decay mode



$$\frac{\Gamma(X \rightarrow \pi^+\pi^-\pi^0 J/\psi)}{\Gamma(X \rightarrow \pi^+\pi^-\pi^0)} = 1.1 \pm 0.4 \pm 0.3$$

~ DD\* bound-state model

[Swanson, PLB 588,189 (2004)]

[hepex/0408116']

$M(\pi^+\pi^-\pi^0)$



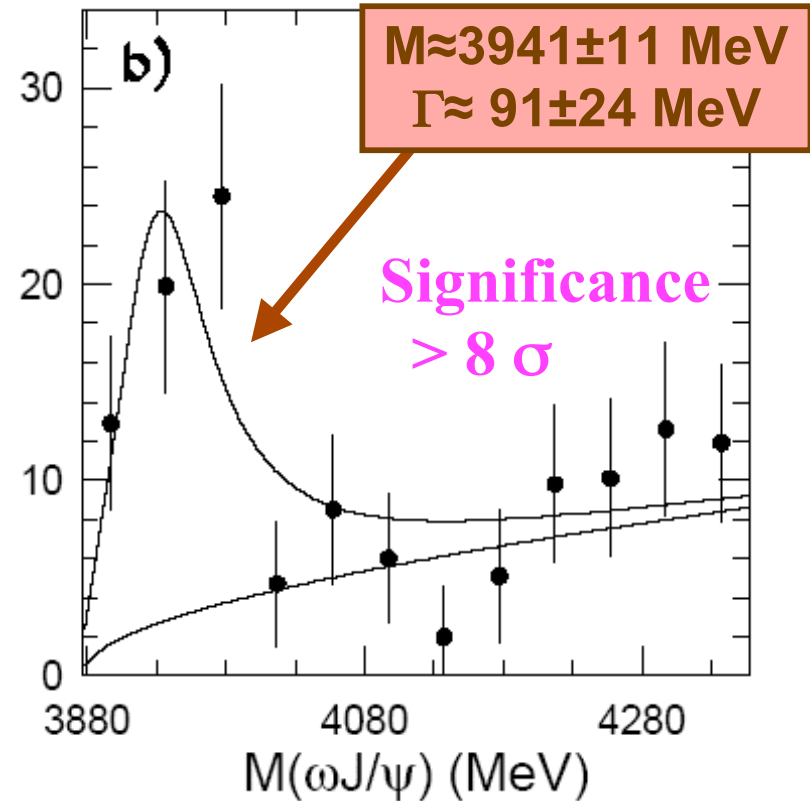
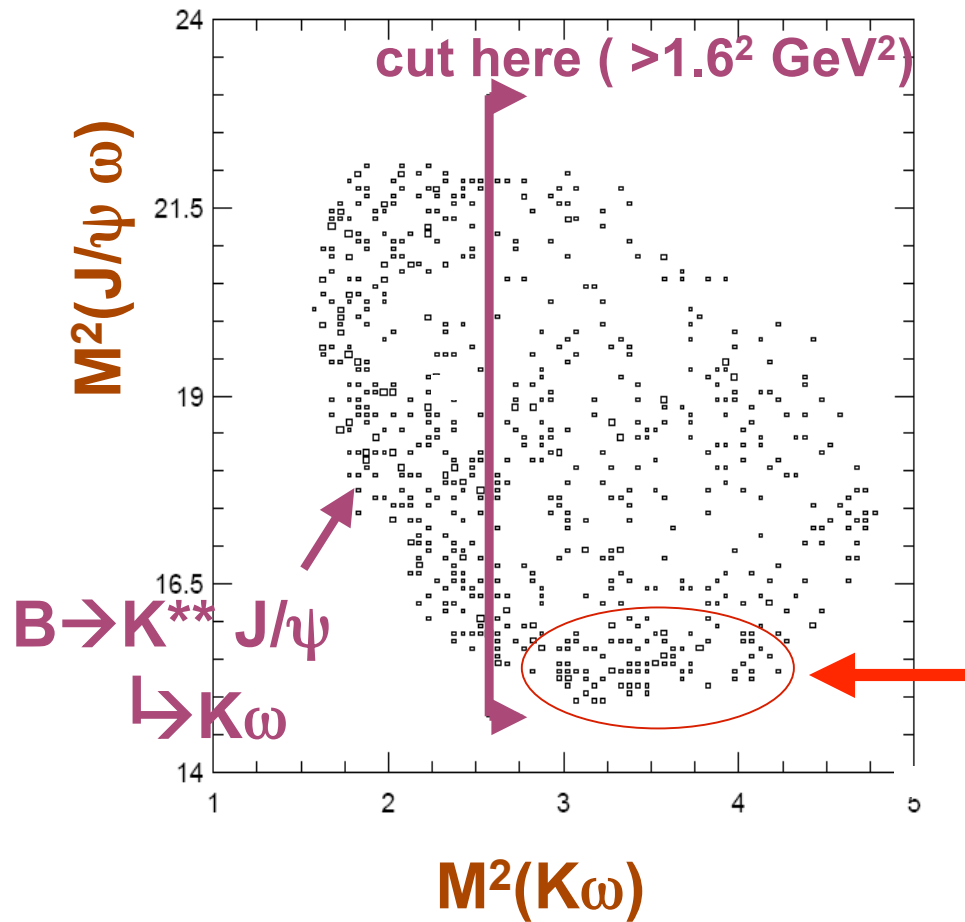
# $\omega J/\psi$ low-mass Enhancement

[hepex/0408126, to PRL]

275M  $B\bar{B}$



Y(3940)



unlikely normal ( $c\bar{c}$ ) state

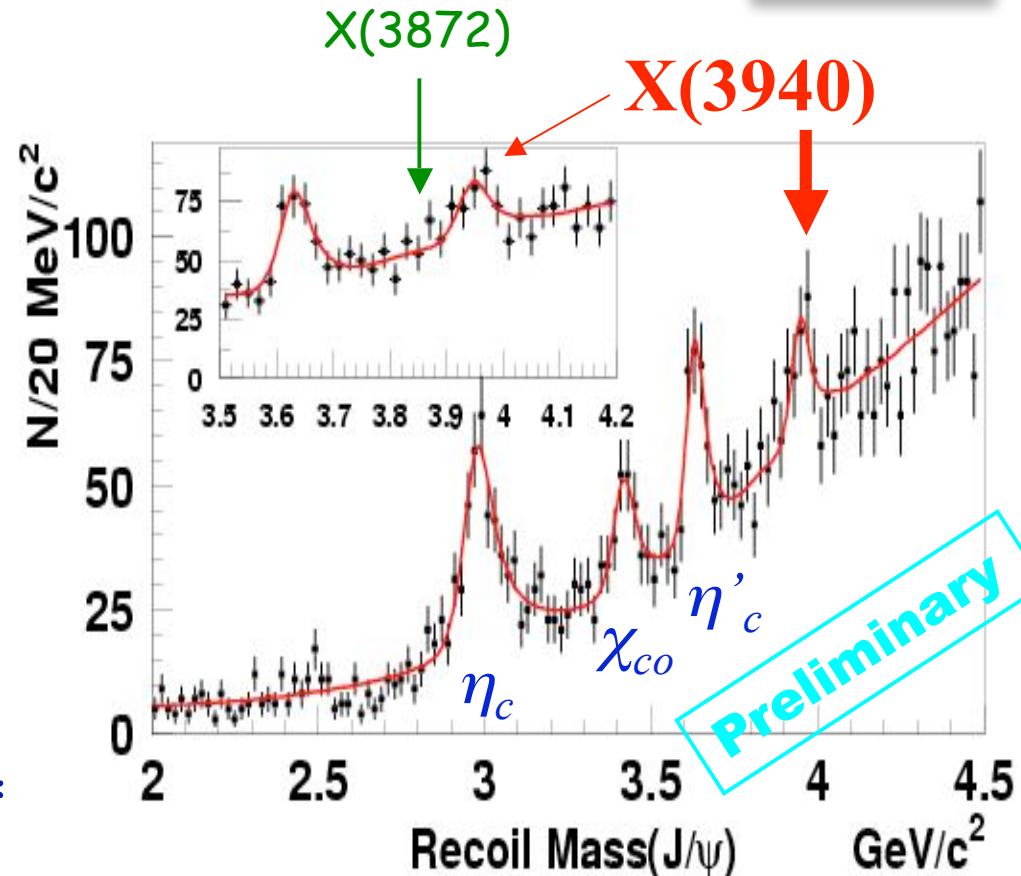


# X(3940): New ( $c\bar{c}$ ) state ?

$$e^+e^- \rightarrow J/\psi (c\bar{c})_{\text{res}}$$

287 fb<sup>-1</sup>

- No signal of X(3872)
- Significant peak at  
 $M=3.940 \pm 0.011 \text{ GeV}/c^2$   
 $N=148 \pm 33$  (4.5 $\sigma$ )  
width: narrow  
 $< \sim$  resolution  
(= 32 MeV)
- Hint of X(3940)  $\rightarrow DD^*$



[ $e^+e^- \rightarrow \gamma^* \rightarrow J/\psi J/\psi$  : forbidden by C-symmetry]

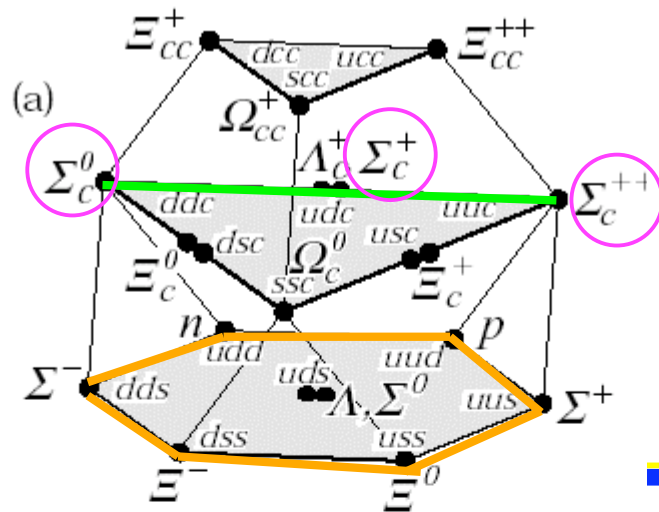
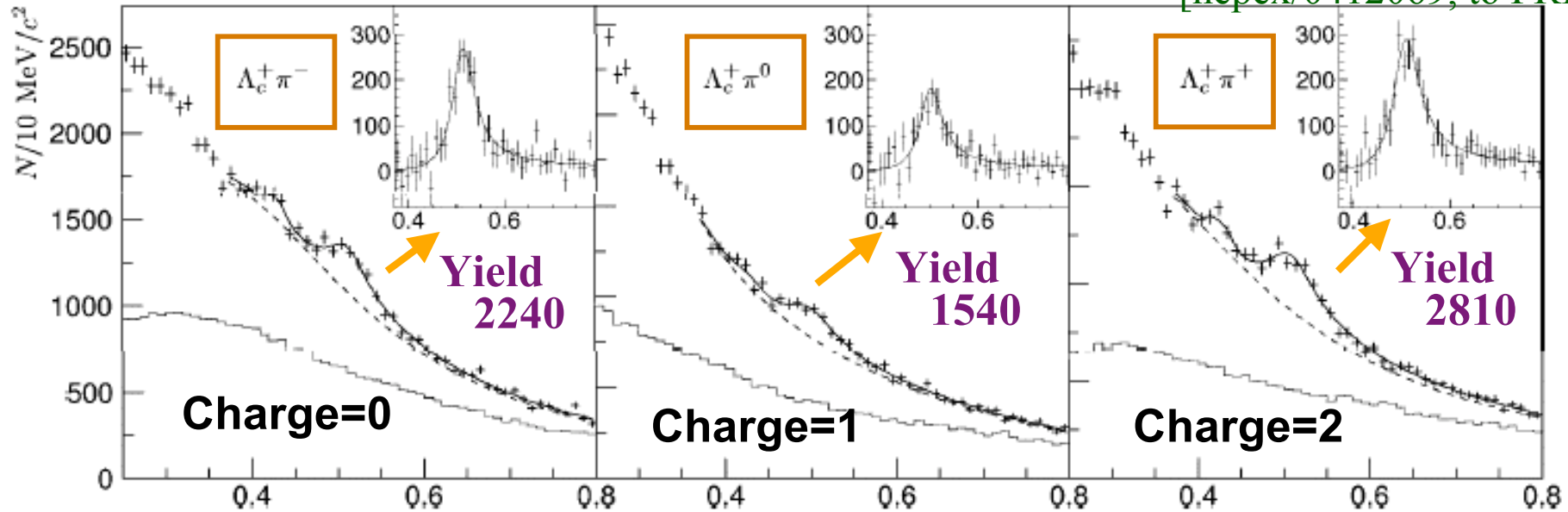
[hepex/0412042]



# $\Sigma_c(2800)$ : New c-Baryon

281 fb<sup>-1</sup>

[hepex/0412069, to PRL]



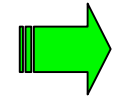
$$\Sigma_c^{0/+} \rightarrow \Lambda_c^+ \pi^{-/0/+}$$

$M(\Lambda_c^+ \pi) - M(\Lambda_c^+), \text{ GeV}/c^2$

Isospin triplet

$J^P = 1/2^+$

$L = 0$



$J^P = 3/2^-$

$L \neq 0$

(candidate)

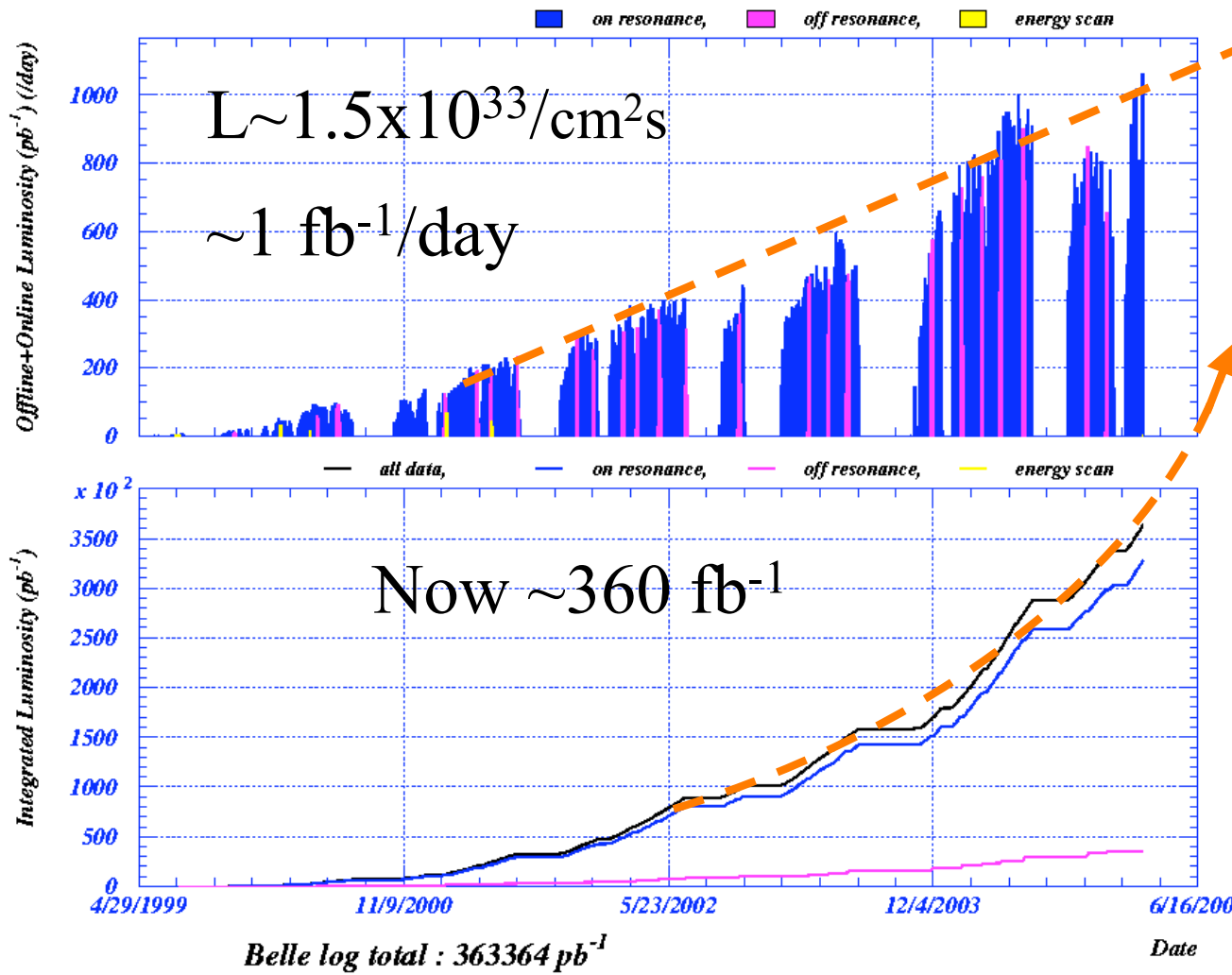
width  $\sim 70$  MeV

$> 5\sigma$  significance





# Plan



KEKB is improving

$\sim 460 fb^{-1}$   
by Summer 2005

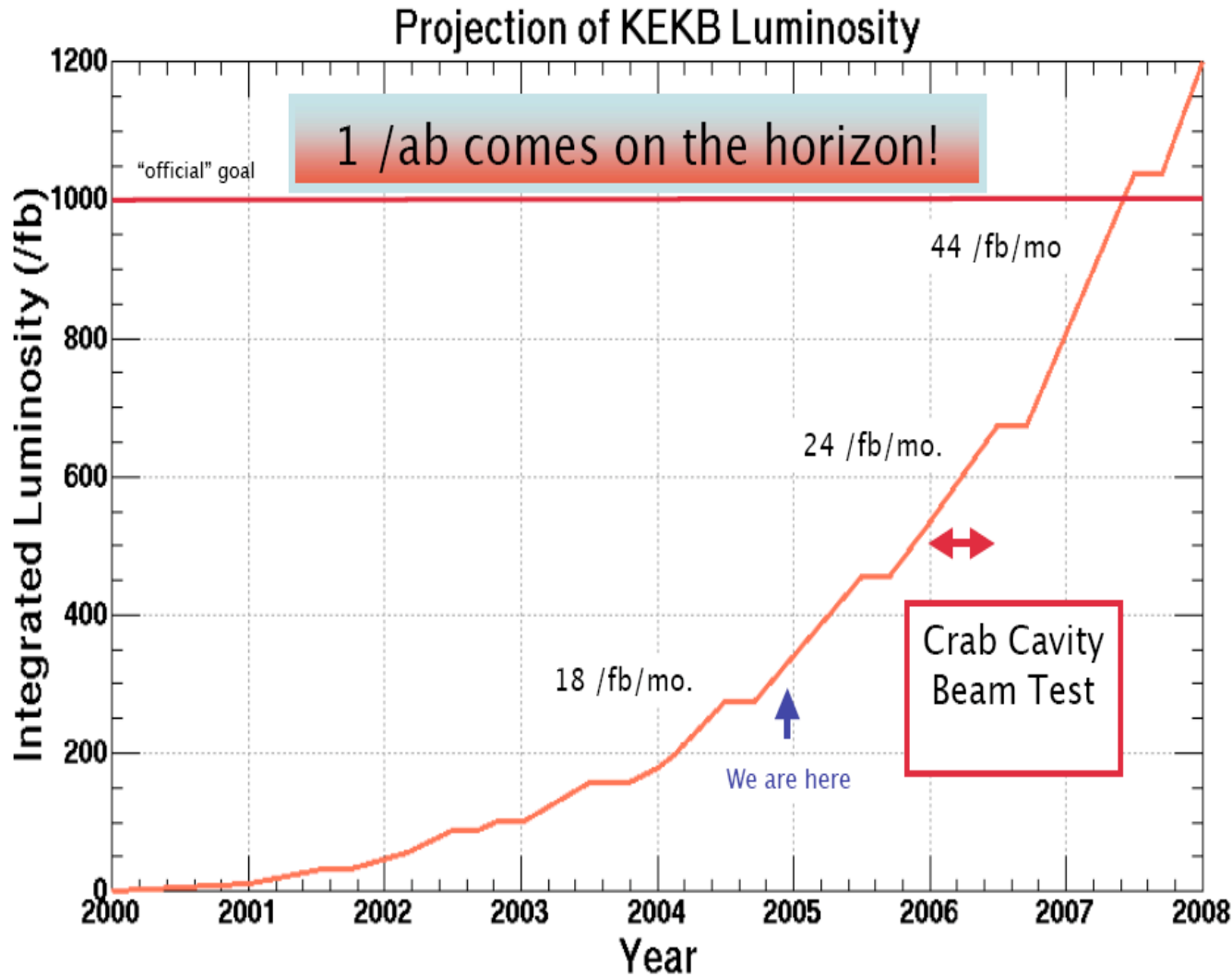
$1 ab^{-1}$   
in a few years

More New  
& improved  
results

SuperKEKB/Belle



# Plan



KEKB is improving

~460 fb<sup>-1</sup>  
by Summer 2005

1 ab<sup>-1</sup>  
in a few years



More New  
& improved  
results



SuperKEKB/Belle



# Summary

2003 summer  $\rightarrow$  2004 summer: **152M**  $\rightarrow$  **275M  $B\bar{B}$**

*Excellent KEKB performance: Data size  $\sim$  doubled !*

 Significant New/improved results !

- DCPV established !  $A_{CP}(B \rightarrow K^+\pi^-)$ ,  $A_{\pi\pi}$
- Stronger evidence: “ $\sin 2\phi_1$ ”  $\neq$  SM in  $b \rightarrow sq\bar{q}$  decays
- More New resonance observed !
- :

We (Belle) are looking forward to having  
higher/more luminosity and New excitements !