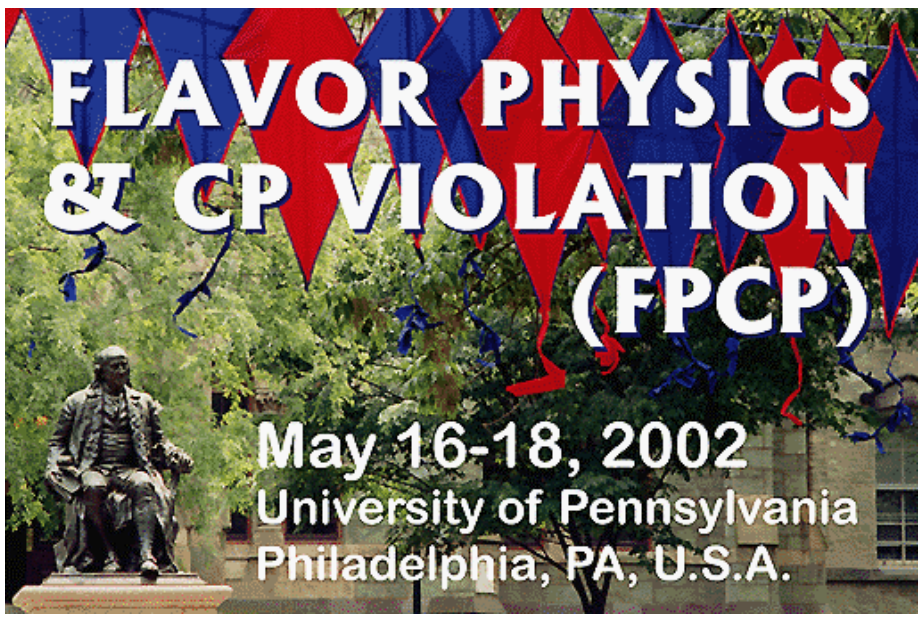
Sin2ϕ_2(=α) from Belle

Eunil Won (Korea Univ) for
the Belle Collaboration



Outline

- sin2ϕ_2 and B→ $\pi\pi$ decay
- Event Selection
- CP fit results
- Summary

Measuring CKM Angles with B decays

From time dependent decay asymmetry,

$$\frac{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) - \Gamma(B^0_{phys}(t) \to f_{CP})}{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) + \Gamma(B^0_{phys}(t) \to f_{CP})} = S_{f_{CP}} \sin(\Delta m_d \Delta t) + A_{f_{CP}} \cos(\Delta m \Delta t)$$

where $A_{f_{CP}} = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}$ and $S_{f_{CP}} = \frac{2\,\mathrm{Im}\,\lambda}{|\lambda|^2 + 1}$ $\quad \lambda = q/p\bar{A}/A$

$|B_L\rangle = p|B^0\rangle + q|\bar{B}^0\rangle$

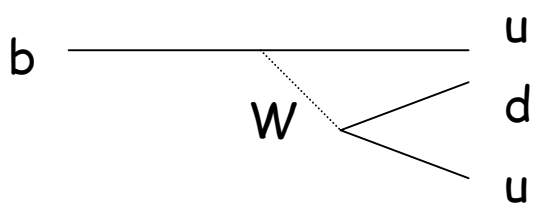
Mode	A_{fCP}	S_{fCP}
$B \to J/\psi\, K_s$	0	$\sin 2\phi_1$
$B \to \pi^+\pi^-$	nonzero	$\sim\sin 2(\phi_2+\theta)$

S_{fCP} is identical to $\sin 2\phi_2$ if there is no penguin amplitudes

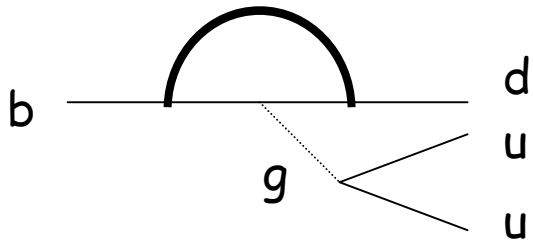
(θ :relative phase btw penguin contributions in $\bar{A}_{\pi\pi}$ and $A_{\pi\pi}$)

CP violation in B → $\pi^+\pi^-$ decay

Tree Amplitude (T)



Penguin Amplitude (P)



Possibility of significant contributions from gluonic b → d penguin amplitudes

→ $S_{\pi\pi} \neq \sin 2\phi_2$

$A_{\pi\pi} \neq 0$ (indicating direct CP violation)

$\Gamma(K\pi) \sim 3\Gamma(\pi\pi)$ → penguins~ V_{ub} trees

Isospin analysis is required for a clean determination of the angle ϕ_2

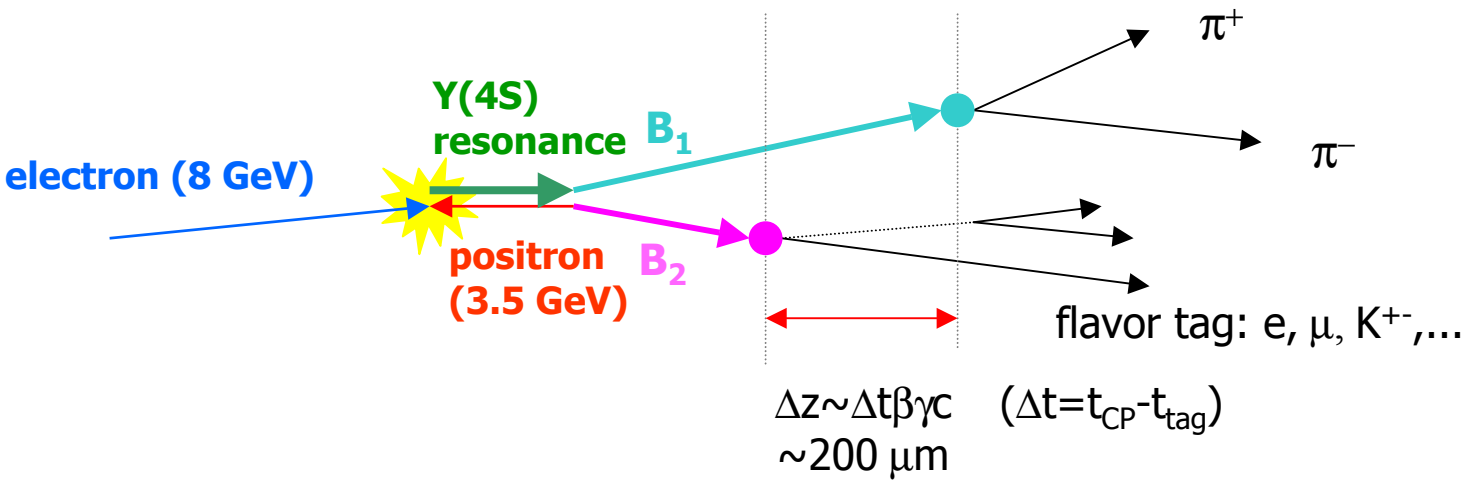
→For this, one needs to know Br($\overline{B}^0 \to \pi^0\pi^0$) and Br ($B^0 \to \pi^0\pi^0$) separately

(experimentally difficult…)

Hep-ph/ 0105308, Gronau et al:

$S_{\pi\pi} \sim \sin 2(\phi_2+\theta)$ and put an upper bound on $|2\theta|$ ("Gronau bound") with knowing $B^{00} = \frac{1}{2}(|A^{00}|^2 + |\overline{A}^{00}|^2)$ only

Measurement of CPV asymmetries in $B \to \pi^+\pi^-$



The method is very similar to that of $\sin 2\phi_1$
One needs to introduce direct CP violation term ($A_{\pi\pi}$) in the CP fitting procedure

q= +1 B tag
- 1 $\bar{B}$ tag

The decay rate distribution $R_q(\Delta t)$ is given by

$$R_q(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left[1 + q\left\{A_{\pi\pi}\cos(\Delta m \Delta t) + S_{\pi\pi}\sin(\Delta m \Delta t)\right\}\right]$$

Event Selection (42 fb^{-1})

Oppositely charged pairs of well measured track

remove electron candidates and assume all are π or K

require π identification (likelihood ratio using ACC and dE/dx)

(ε_π = 0.900±0.005, $f_{\pi\to k}$ = 0.064±0.002)

B candidate selection

Energy difference (-300 < ΔE < 500 MeV)

Beam energy constrained mass (m_{bc} > 5.2 GeV)

(includes side band at this stage)

$$\Delta E \equiv E_\pi + E_\pi - E_{CM}/2$$

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

Continuum background suppression

Likelihood ratio using event shape variables

(Modified Fox-Wolfram variables and B flight direction)

Rare B decay backgrounds

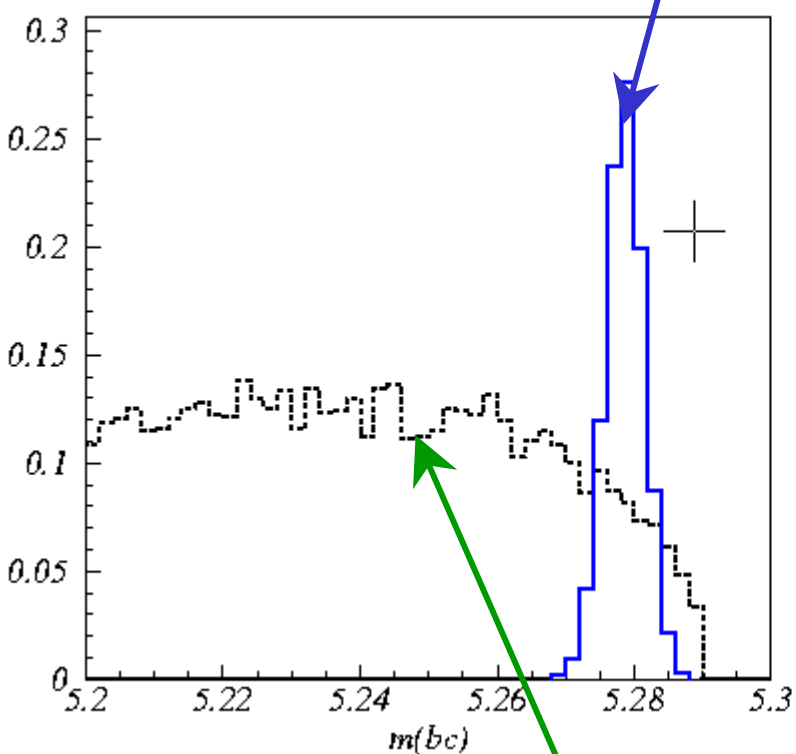
shifted in ΔE distribution

→ subtraction considered in the yield extraction

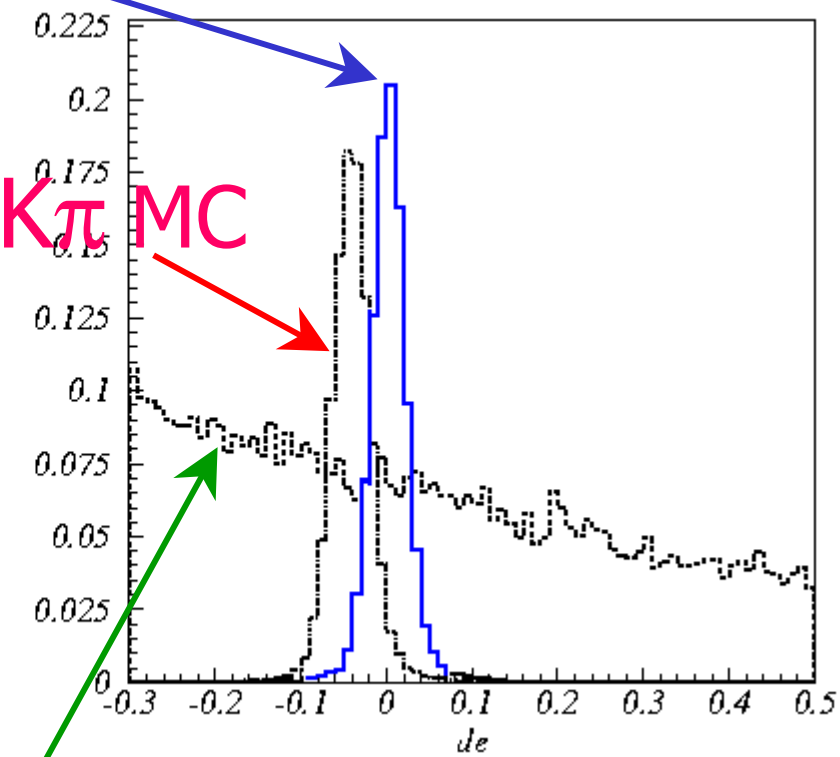
B meson Reconstruction

Kπ is indistinguishable in m_{bc} but shifted by – 45 MeV in ΔE

$\pi^+\pi^-$ MC



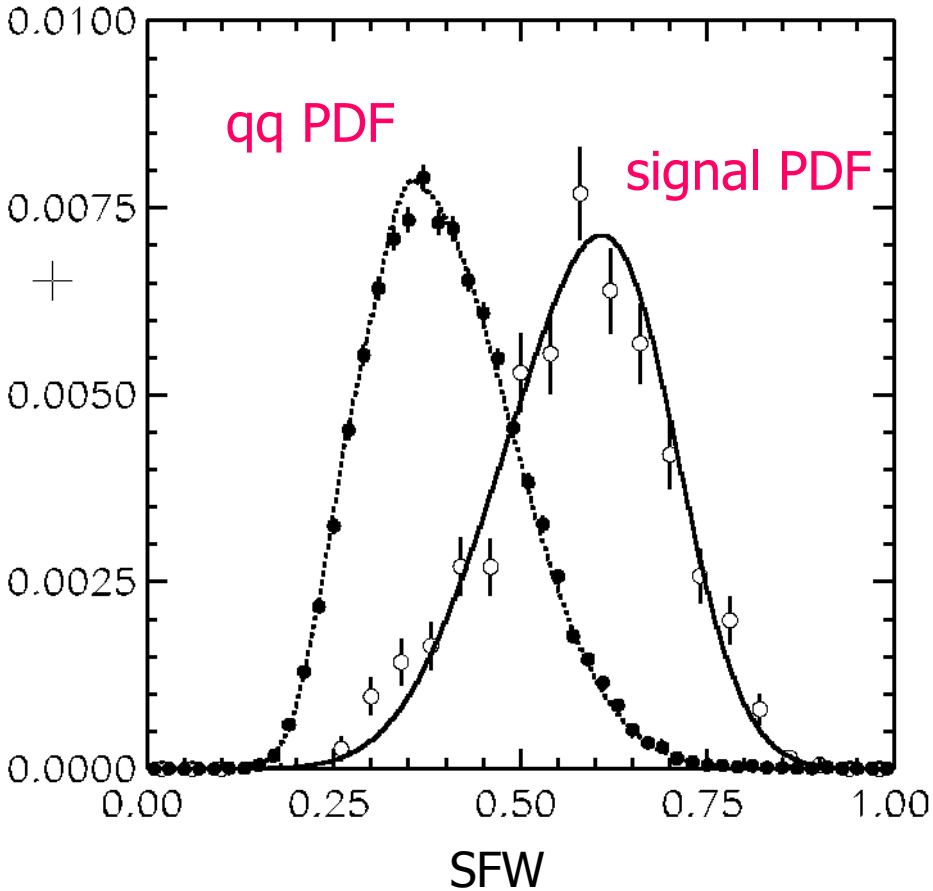
Kπ MC



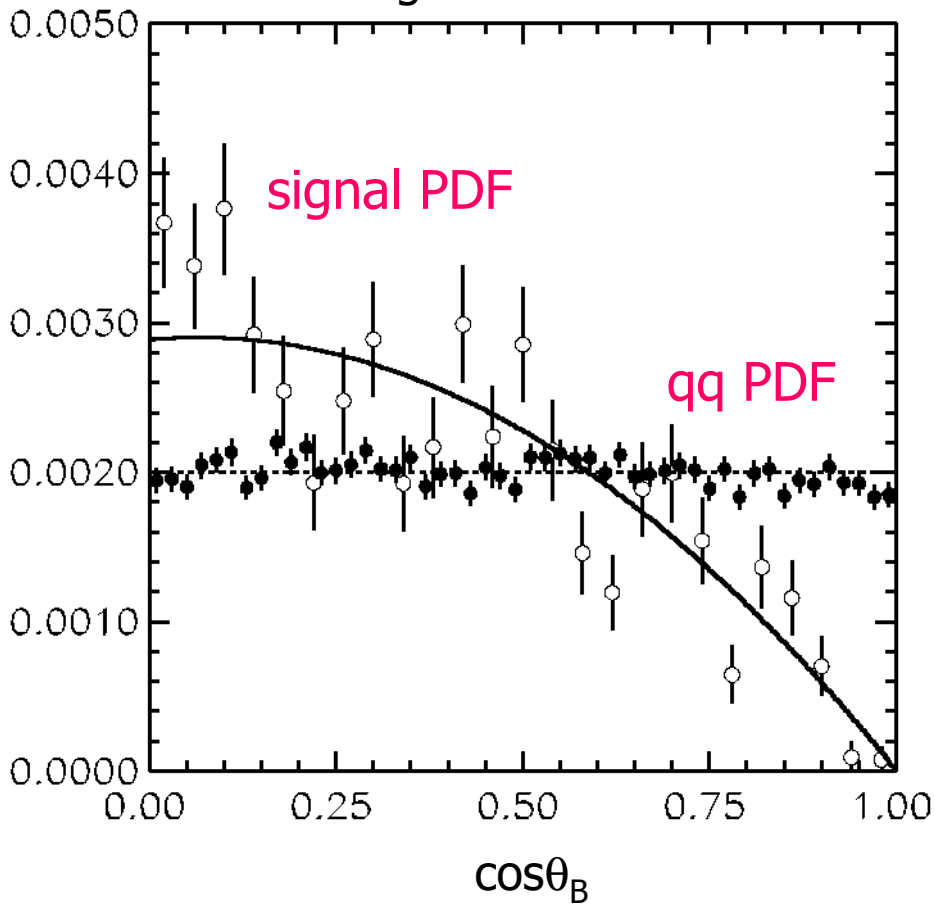
m_{bc} Off resonance Data ΔE

Continuum Suppression

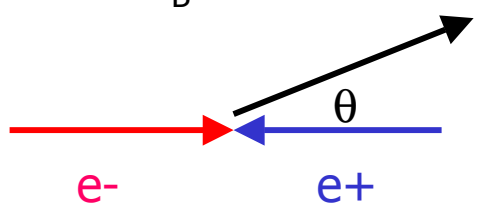
event shape variable based Fisher Disc



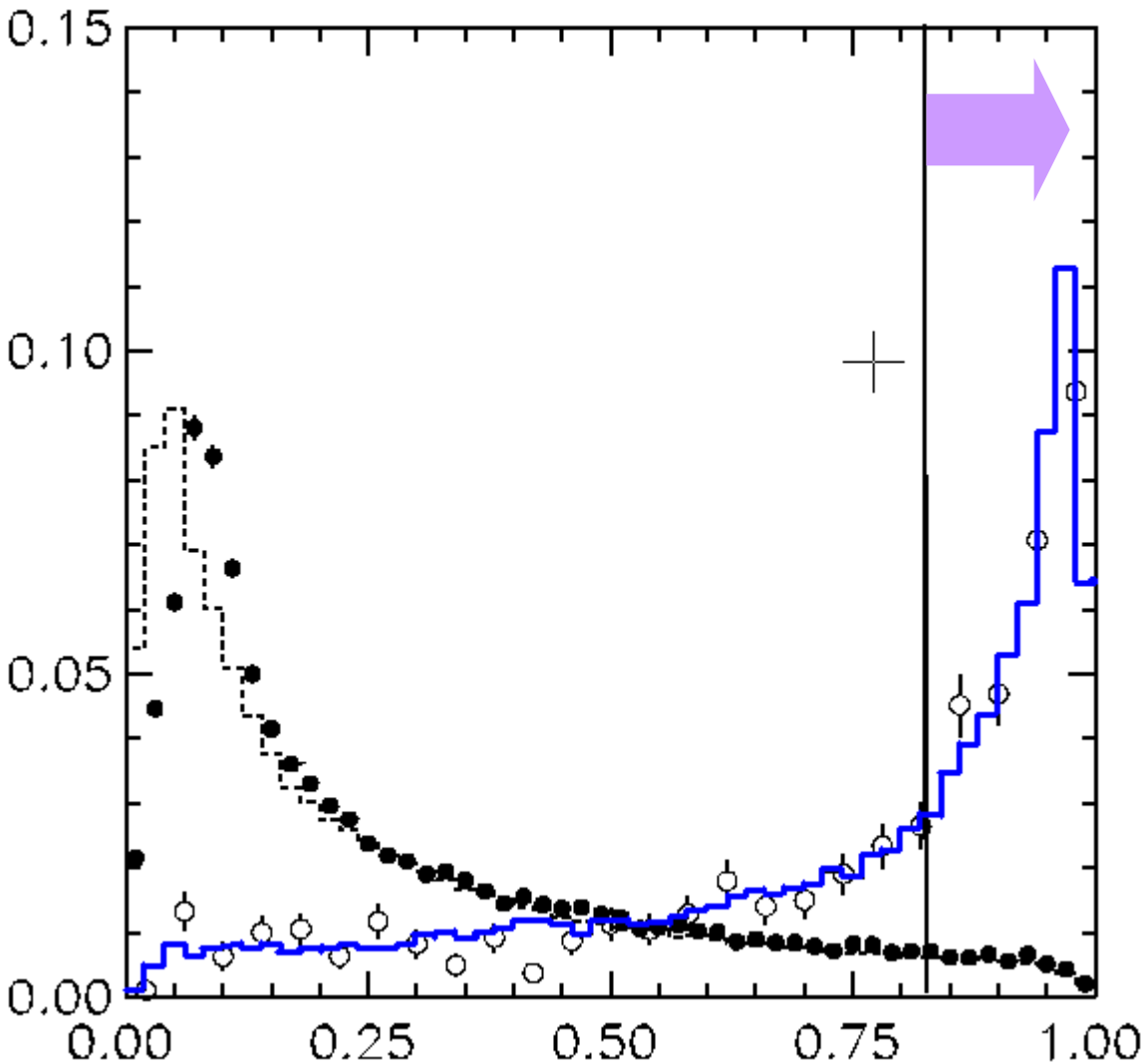
B flight direction



$$SFW = \sum_{2,4} \alpha_i \frac{h^i_{os}}{h^0_{os}} + \sum_{1-4} \beta_i \frac{h^i_{oo}}{h^0_{oo}}$$



Continuum Suppression



signal PDF

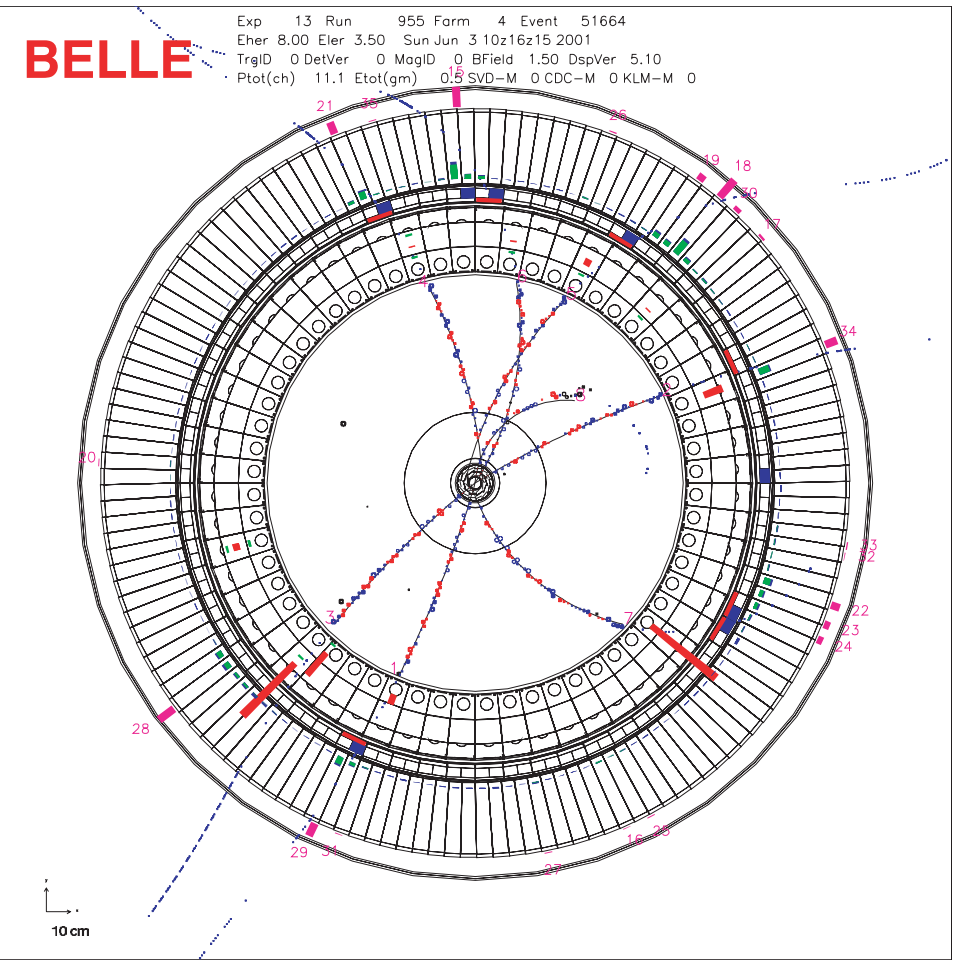
$B^+ \rightarrow D^0 (K^-\pi^+) \pi^+$

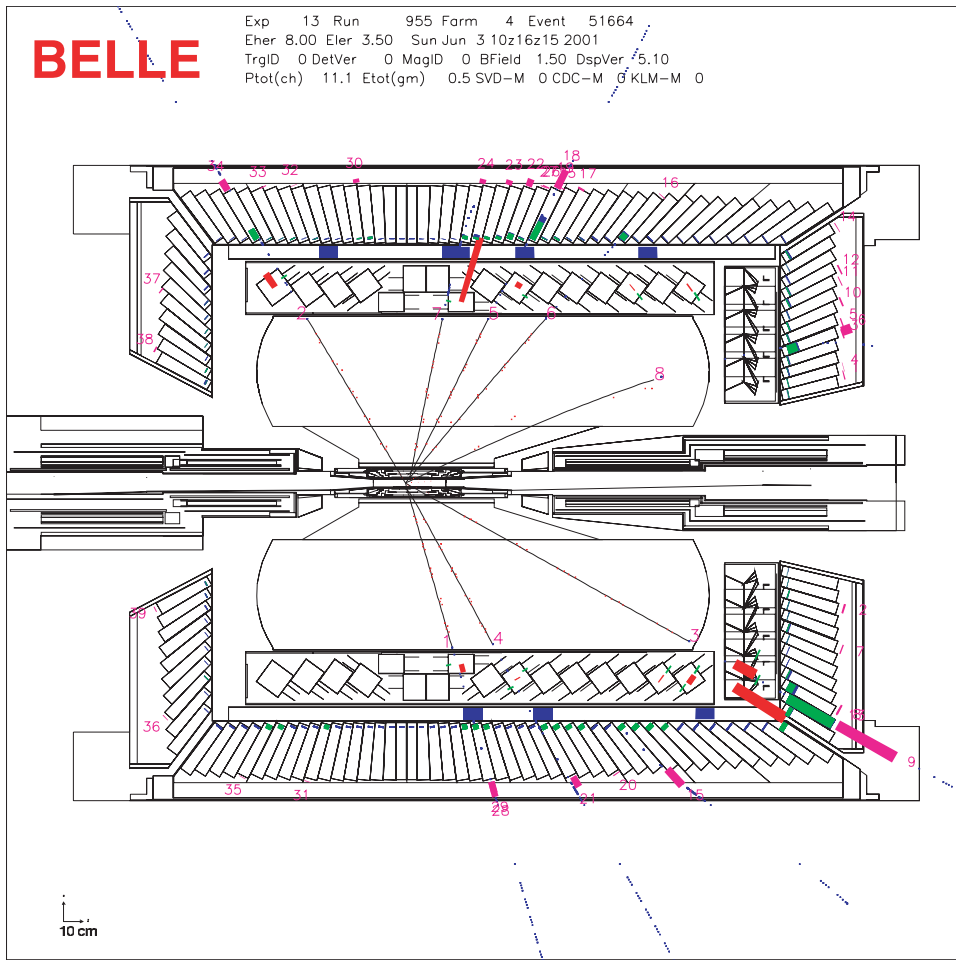
continuum PDF

off resonance DATA

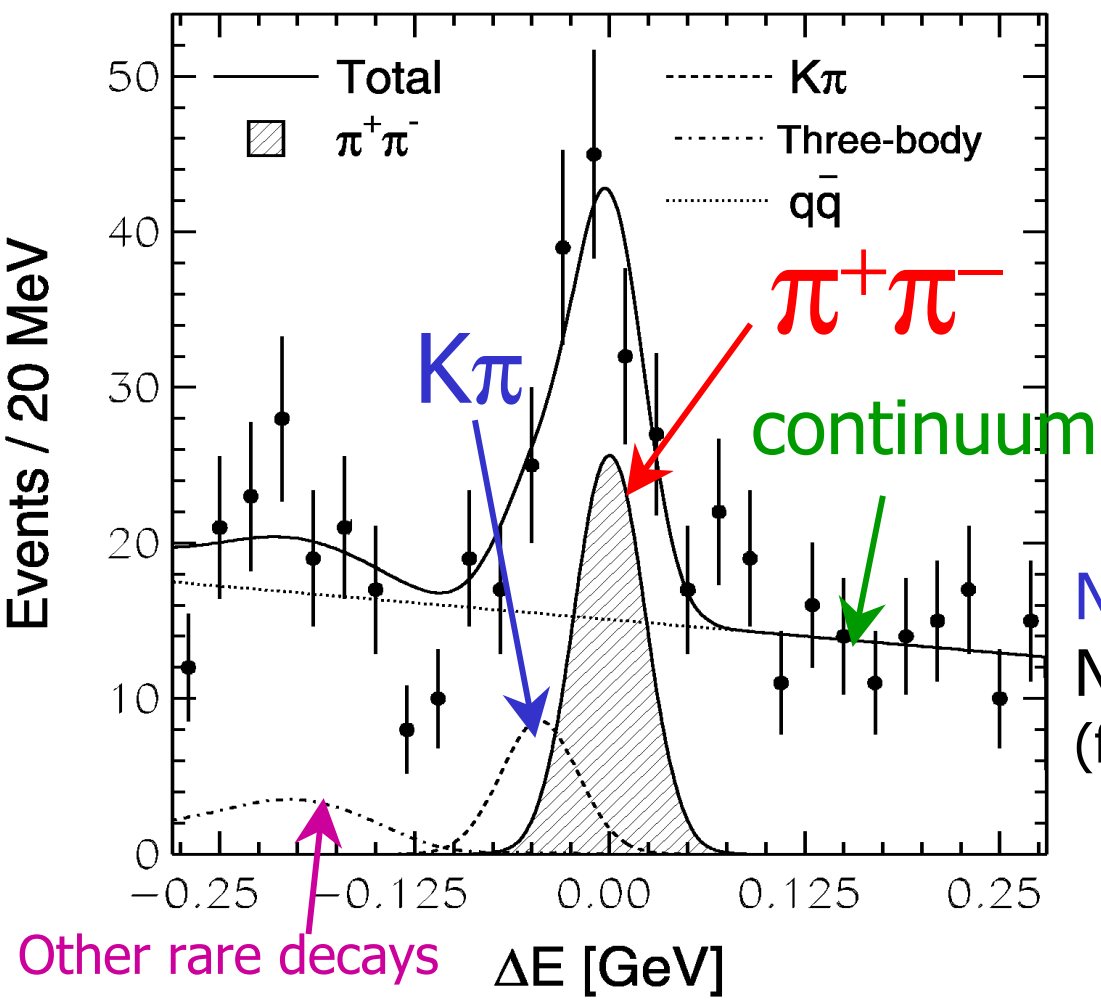
R > 0.825 removes
95% of continuum
53% of signal

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





Signal Yield for $B \rightarrow \pi^+\pi^-$



$5.271 < m_{bc} < 5.287$ GeV

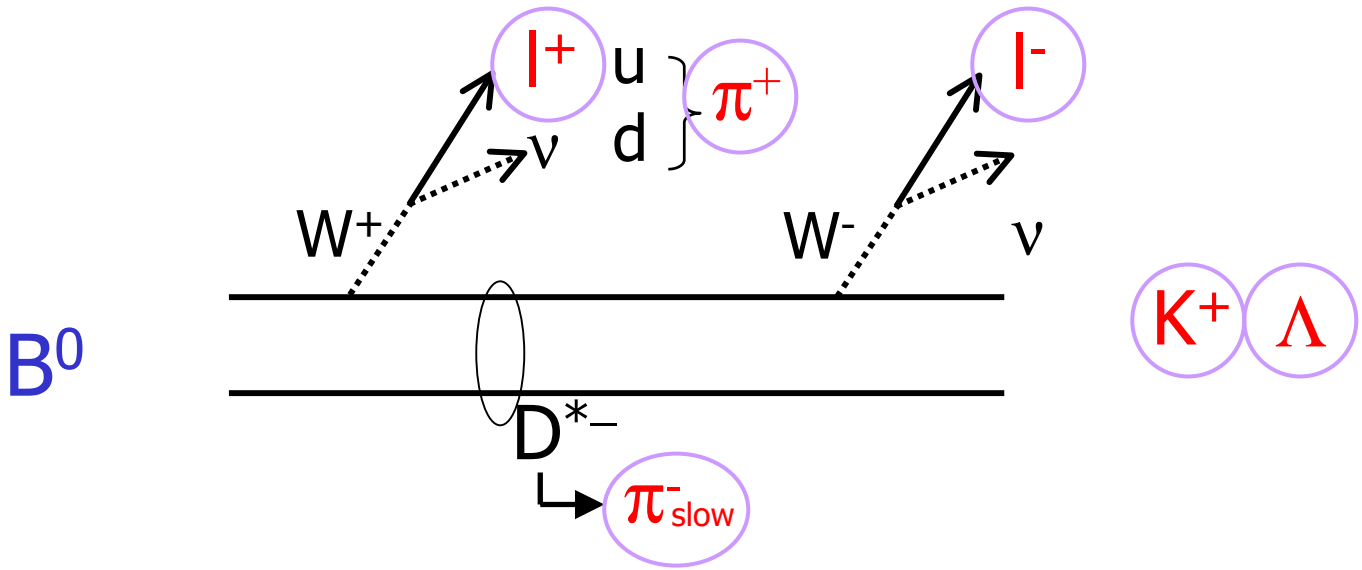
Fits in ΔE distribution w/

Signal
Continuum
Kπ feed across
Rare decays

$N(\pi\pi) = 73.5 \pm 13.8$ events

$N(K\pi) = 28.4 \pm 12.5$ events
(feed across)

Flavor Tagging



High-p (primary), low-p (secondary) leptons

Strangeness ($b \rightarrow c \rightarrow s$)

Fast π, slow π

Identical flavor tagging method as used in $\sin 2\phi_1$ measurement

two stage (track and event level) multi dimensional likelihood

Total effective tagging efficiency : 29.6%

Vertex Reconstruction

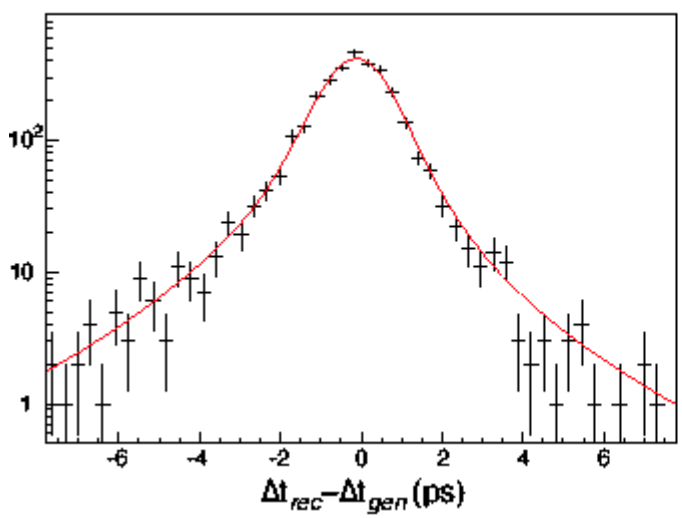
Vertex reconstruction and resolution functions are same as that used for the sin2ϕ_1 analysis of LP01

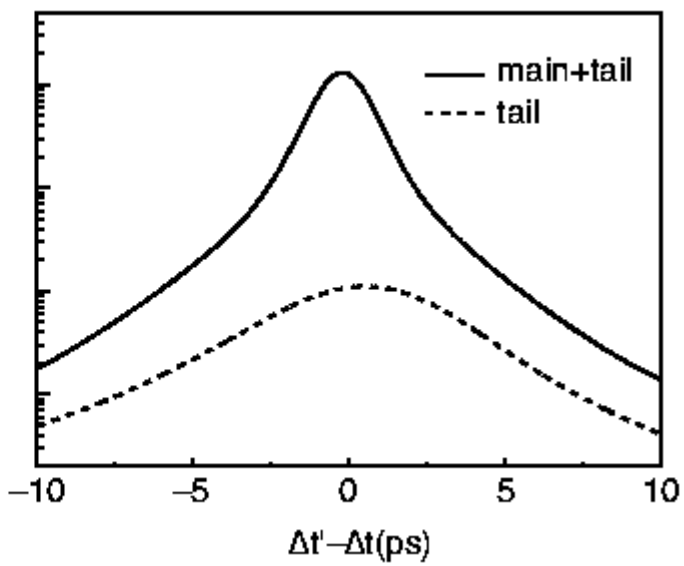
MC study shows little difference btw $\pi\pi$ and J/ψ samples

Both signal and background resolution functions are in same functional form:

$$R(\Delta t_B - \Delta t') = (1 - f_{tail}) \frac{1}{\sqrt{2\pi}\sigma_{\Delta t}} e^{-\frac{(\Delta t_B - \Delta t' - \mu_{\Delta t})^2}{2\sigma^2}} + f_{tail} \frac{1}{\sqrt{2\pi}\sigma_{tail}^{\Delta t}} e^{-\frac{(\Delta t_B - \Delta t' - \mu_{tail}^{\Delta t})^2}{2(\sigma_{tail}^{\Delta t})^2}}$$

Sum of two Gaussians modeling main and tail part respectively





CP fit for $S_{\pi\pi}$ and $A_{\pi\pi}$

PDF for $\pi\pi$ signal events

$$P_{\pi\pi}(\Delta t, q, w_l) = \frac{e^{|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 + q(1-2w_l)\times(A_{\pi\pi}\cos(\Delta m_d \Delta t) + S_{\pi\pi}\sin(\Delta m_d \Delta t))\}$$

for $K\pi$ events

$$P_{K\pi}(\Delta t, q, w_l) = \frac{e^{|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 + q(1-2w_l)\times A_{K\pi}\cos(\Delta m_d \Delta t)\}$$

for continuum background

$$P_{qq}(\Delta t) = \frac{1}{2}\left\{ f_\tau \frac{e^{|\Delta t|/\tau_{bkg}}}{2\tau_{bkg}} + (1-f_\tau)\delta(\Delta t)\right\}$$

f_τ = 0.011 ±0.004
τ_{bkg} = 2.68+0.95-0.72 ps

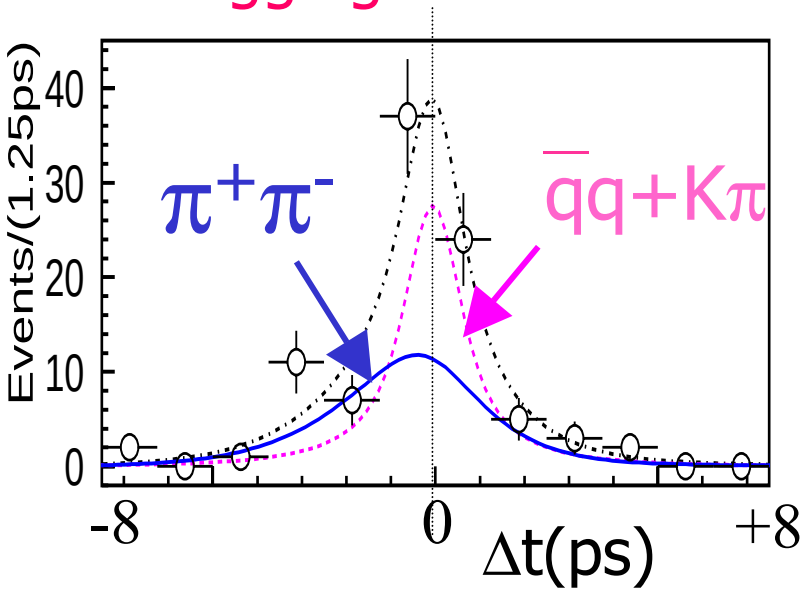
Construct event by event (unbinned) likelihood as PDF ⊗ Resolution function and maximize product of them

$$L_i = \int_{-\infty}^{\infty} d\Delta t' \{(f_{\pi\pi}P_{\pi\pi}(\Delta t', q) + f_{K\pi}P_{K\pi}(\Delta t', q)) \bullet R_{sig}(\Delta t_i - \Delta t')$$

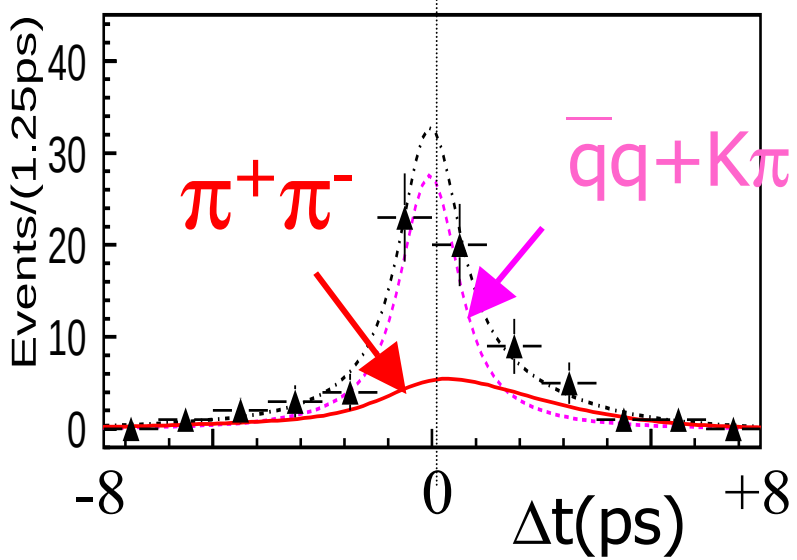
$$+ f_{q\bar{q}}P_{q\bar{q}}(\Delta t') \bullet R_{q\bar{q}}(\Delta t_i - \Delta t')\}$$

Raw asymmetries

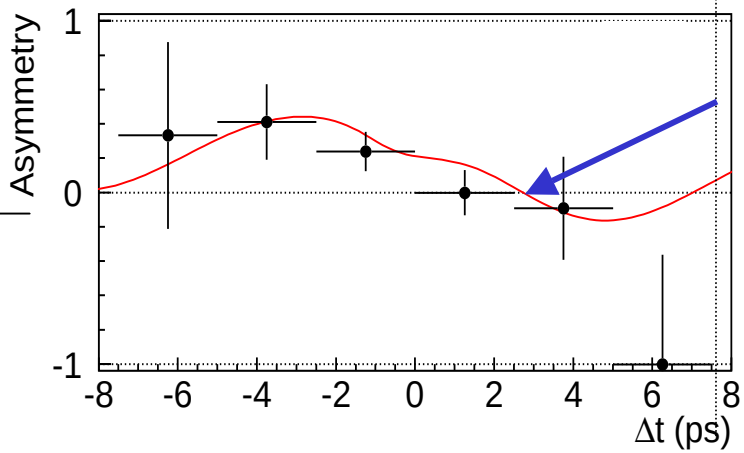
B^0 tagging



$\bar{B}^0$ tagging



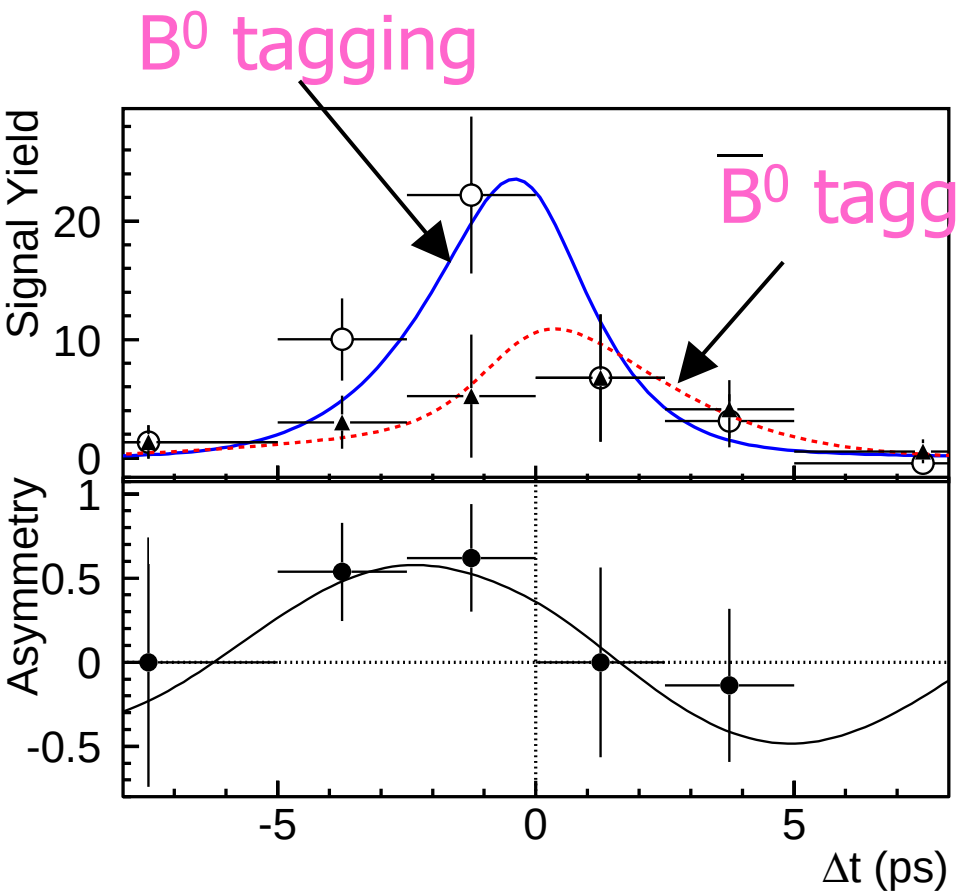
$$\frac{N_a - N_b}{N_a + N_b}$$



$\pi^+\pi^-$ + $\bar{q}q+K\pi$

More B^0 tags than $\bar{B}^0$ tags
More B^0 tags with $\Delta t<0$ than $\Delta t>0$

CP fit results : $S_{\pi\pi}$ and $A_{\pi\pi}$



extracting $\pi^+\pi^-$
by subtracting $\bar{q}q+K\pi$

$S_{\pi\pi} = -1.21\ ^{+0.38}_{-0.27}$ (stat.)

$A_{\pi\pi} = +0.94\ ^{+0.25}_{-0.31}$

Each is 2.9σ from zero

Belle's ($S_{\pi\pi}$, $A_{\pi\pi}$) is 1.2σ away from the physical boundary
Belle and Babar disagree by > 2σ

What (if any) can be wrong?

(The components of the present analysis are the same as those used to measure sin2ϕ_1, τ_B, Δm_d, etc all in reasonable agreement with BaBar and PDG averages)

Possibilities

Are the backgrounds asymmetric?
- check with Kπ and qq-sideband samples
- check with Dπ, Dρ samples

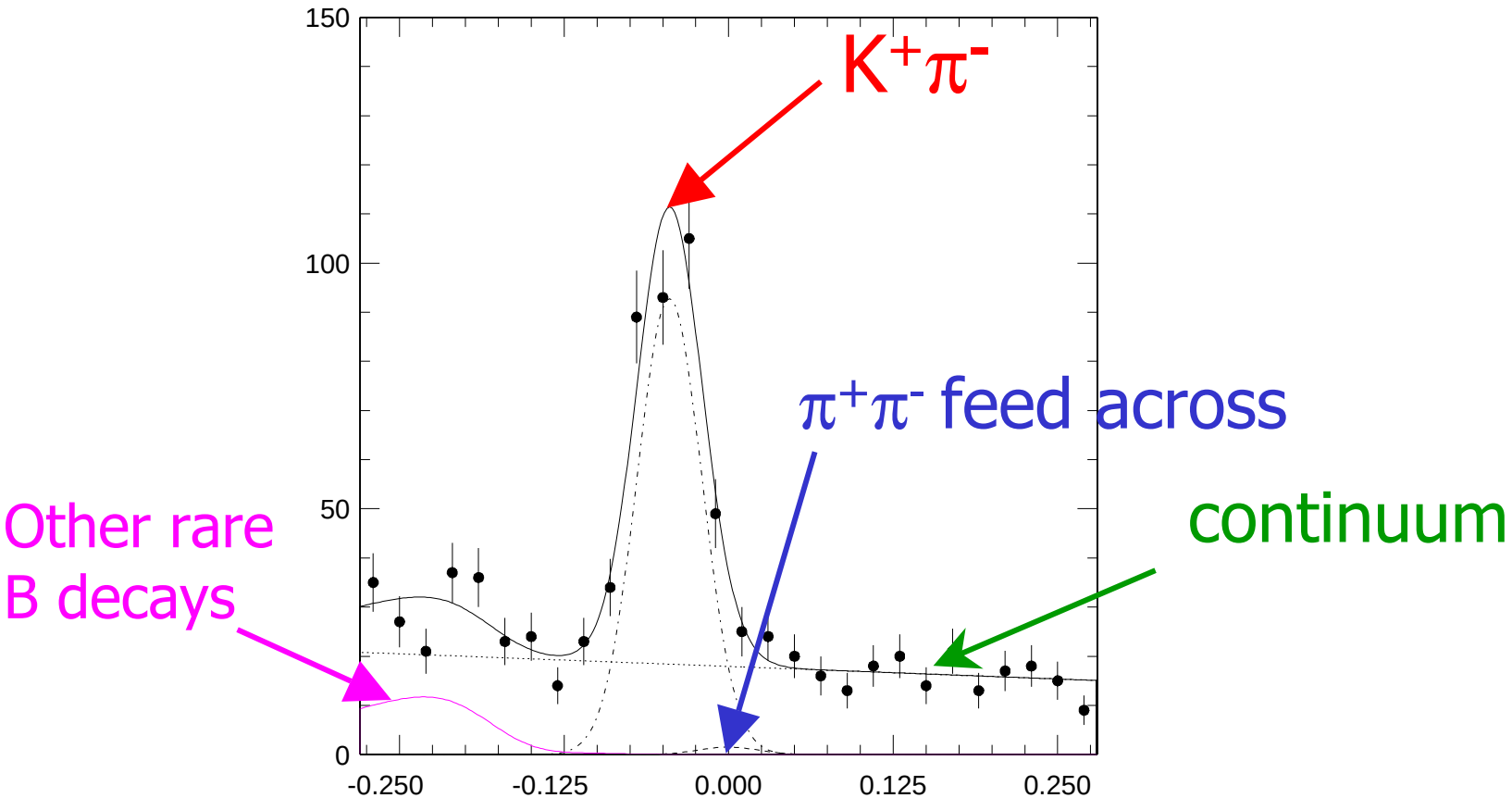
Is vertexing wrong for B→h^+h^- decays?
- Measure Δm_d, τ_B for B → $\pi\pi$ and Kπ decays

Do the likelihood values and errors make sense?
- Ensemble tests

Statistical fluctuations?

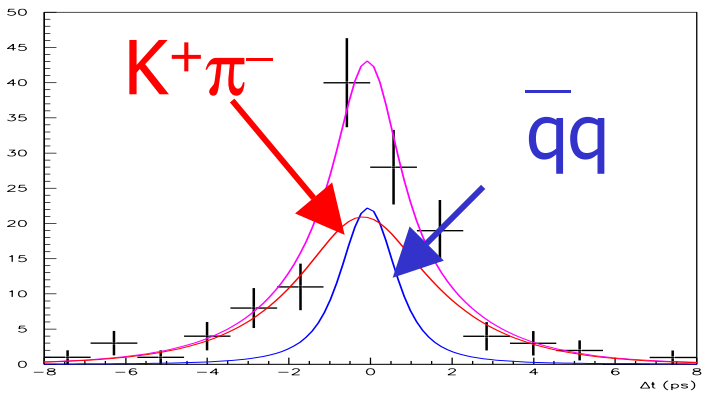
Kπ samples

$N(K^+\pi^-)$ = 289.5 ± 21.5 events (5.2 ± 13.3 $\pi^+\pi^-$ feed-across)



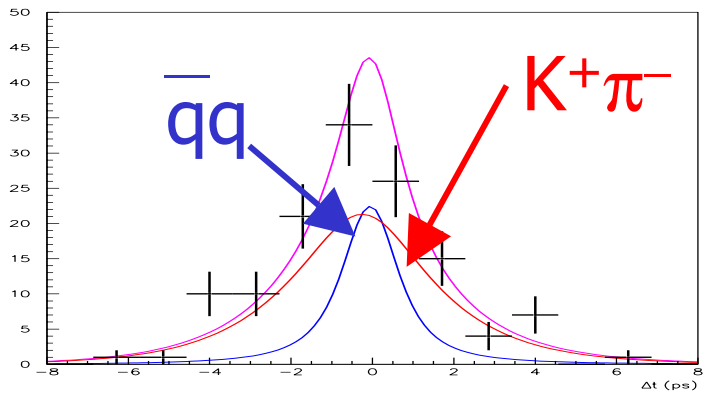
Asymmetry for $K^+\pi^-$

B^0 tagging



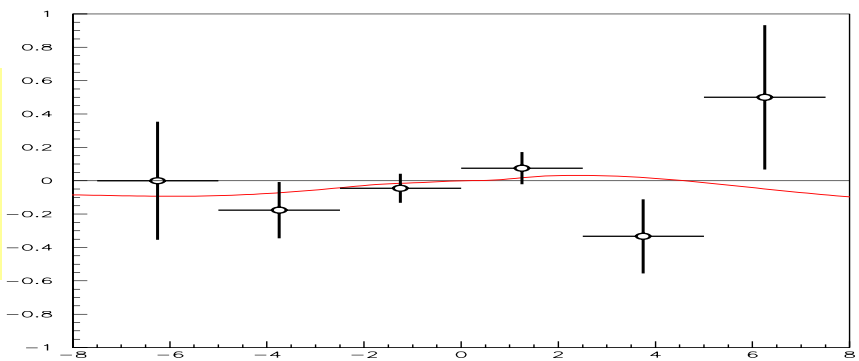
$\Delta t(ps)$

$\bar{B}^0$ tagging



$\Delta t(ps)$

Consistent with null asymmetry



$\Delta t(ps)$

	$K^+\pi^-$
τ_B(ps)	1.73 ± 0.15
S	0.15 ± 0.24
A	0.07 ± 0.17

PDG τ_B(ps) : 1.548 ± 0.032 ps

Other control samples

Other non-CP eigenstate self-tagged modes

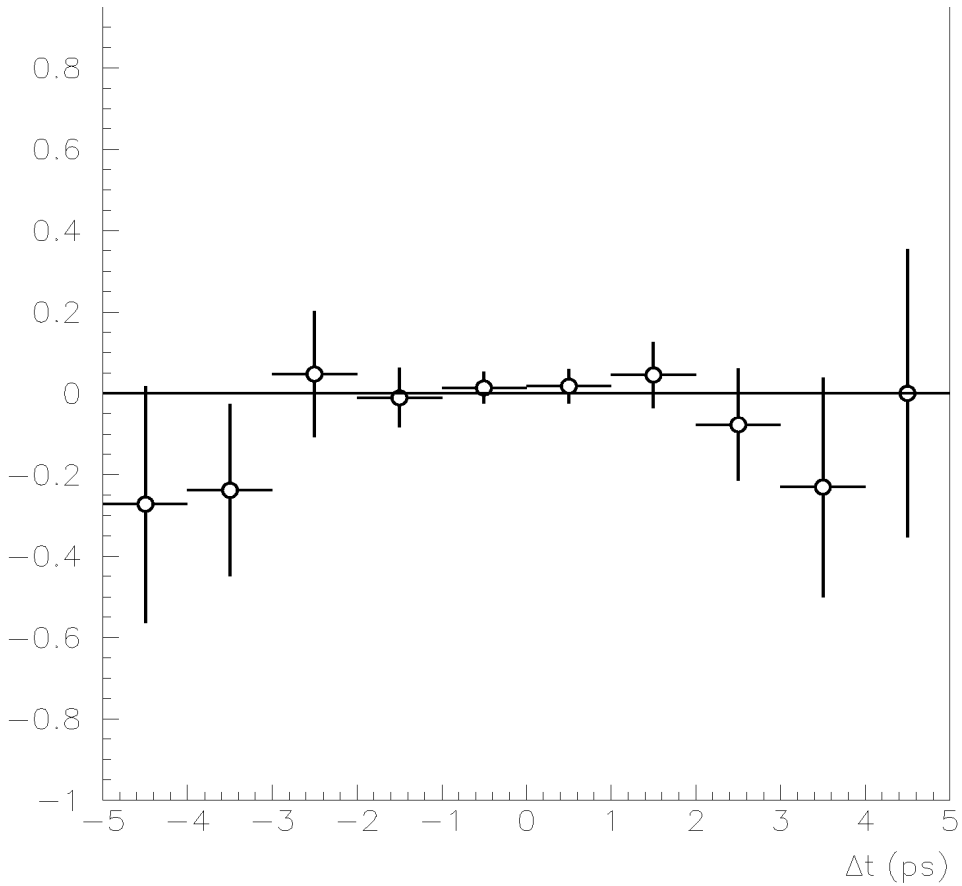
No asymmetry is expected.
$\Rightarrow$We find no asymmetries.

PDG τ_B: 1.548 $\pm$ 0.032 ps

	$D^-\pi^+$	$D^{*-}\pi^+$	$D^{*-}\rho^+$
τ_B(ps)	1.64±0.05	1.61±0.05	1.68±0.06
S	0.09±0.09	0.13±0.09	-0.04±0.10
A	0.01±0.06	-0.03±0.06	-0.10±0.07

Asymmetry for sideband data

A(Δt)



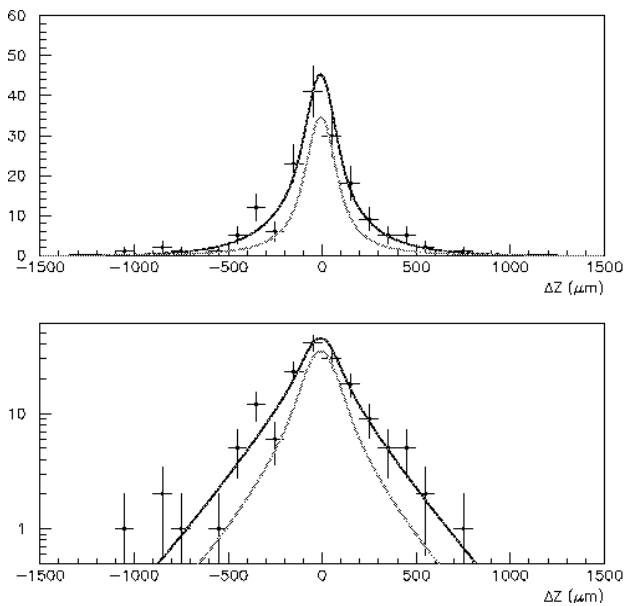
892 B^0 tag
871 $\overline{B}^0$ tag

Consistent with no asymmetry

B → Kπ,ππ lifetime validations

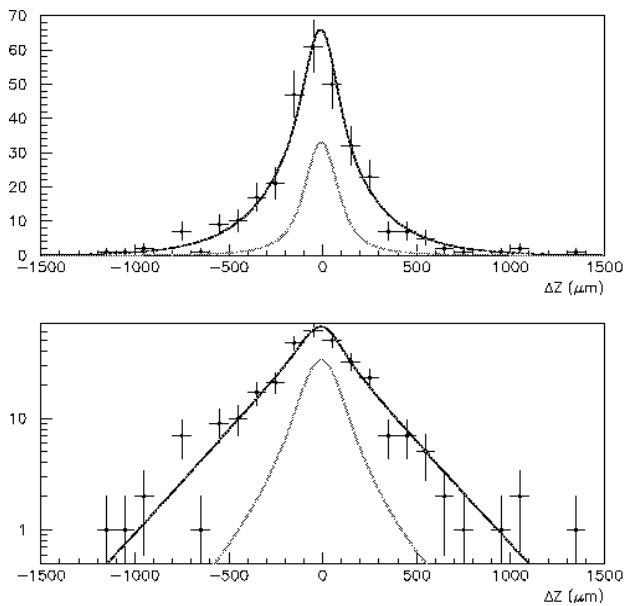
Lifetime measurements

B → ππ



1.49 ± 0.21 ps

B → Kπ

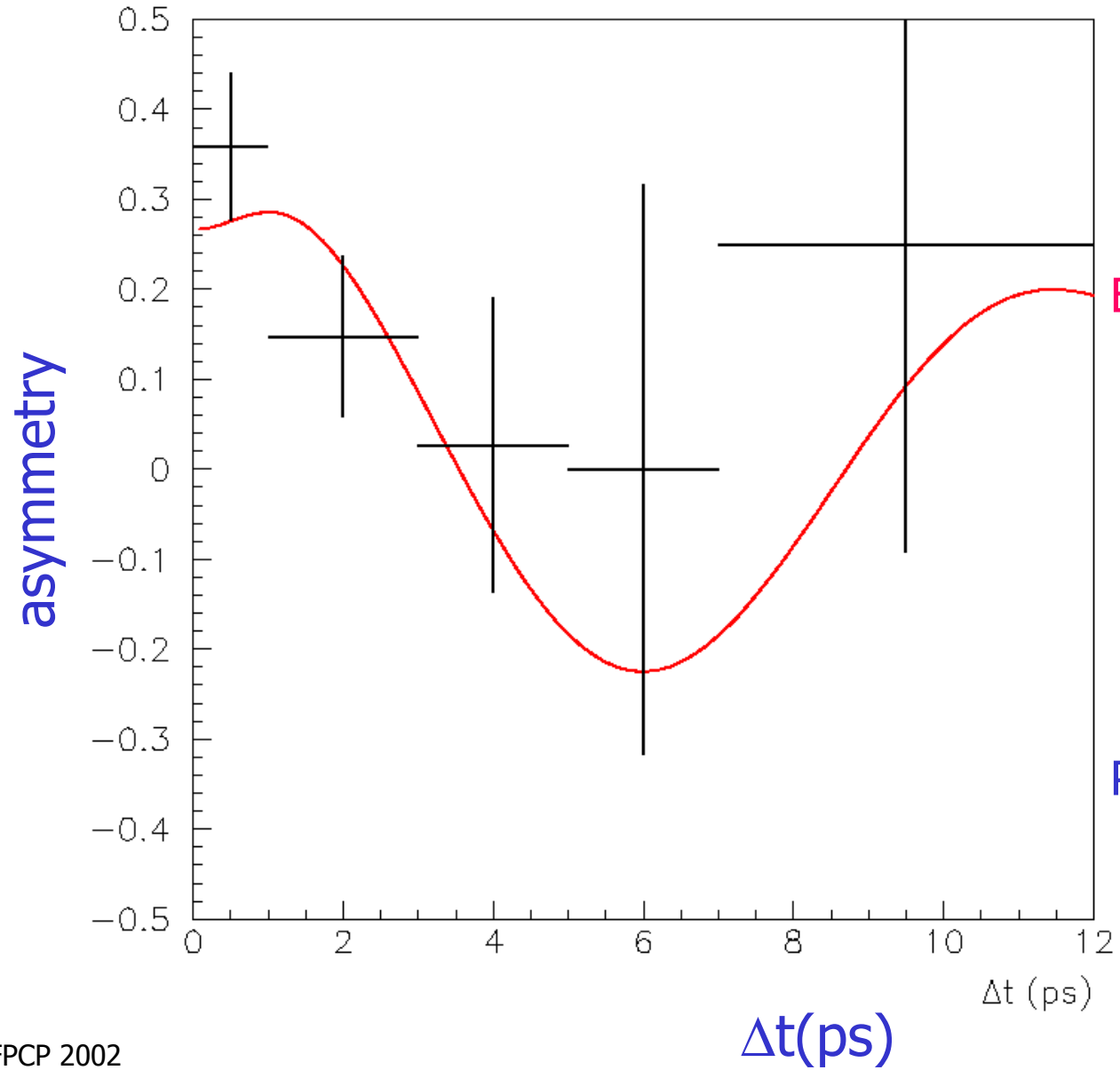


1.73 ± 0.15 ps

Δz

PDG: 1.548 ± 0.032 ps

Δm_d from $B \rightarrow K\pi$



Belle: $(0.57 \pm 0.08)\ ps^{-1}$

PDG: $(0.472 \pm 0.017)\ ps^{-1}$

$\Delta t(ps)$

Possibilities revisited

Are the backgrounds asymmetric?

- $K\pi$, qq-sideband and $D\pi/\rho$ samples show null asymmetries

Is vertexing wrong for $B \rightarrow h^+h^-$ decays?

-Lifetime for $B \rightarrow \pi\pi$ and $K\pi$ samples are OK

$-\Delta m_d$ for $B \rightarrow K\pi$ is OK

Do the likelihood values and errors make sense?

- Ensemble tests show no anomaly

Statistical fluctuations?

- Most likely at this moment

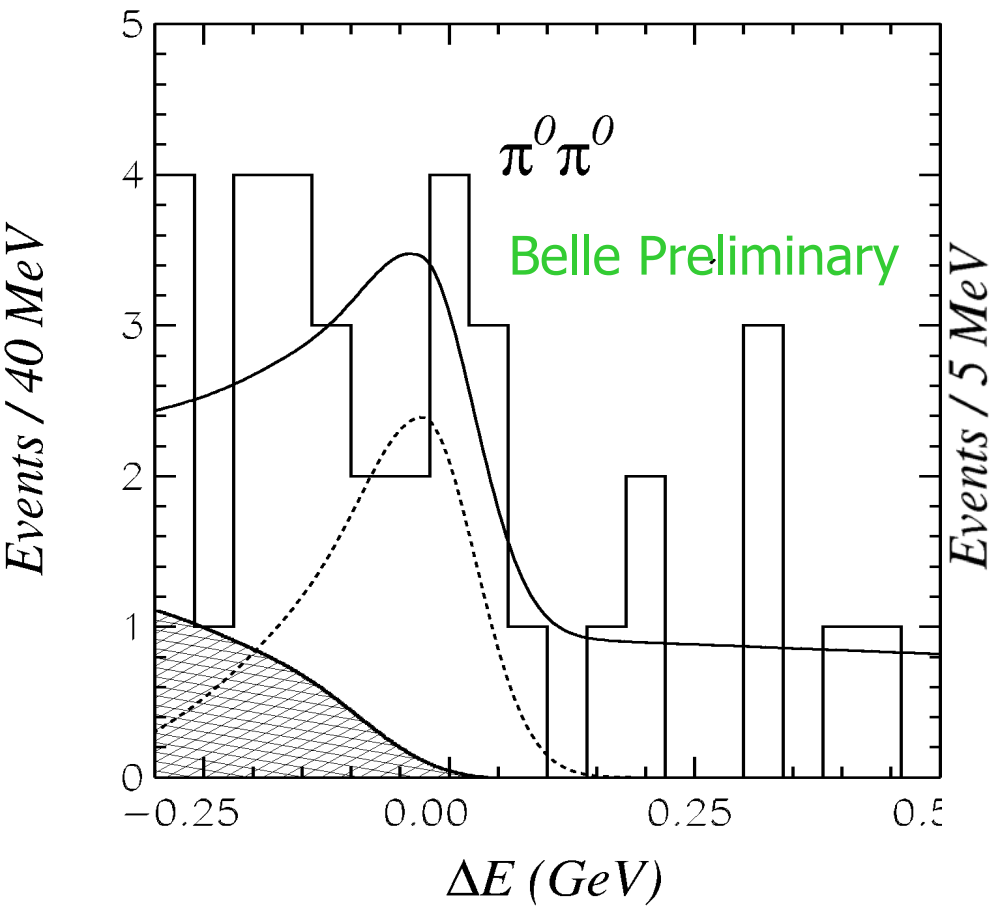
Systematic error estimation

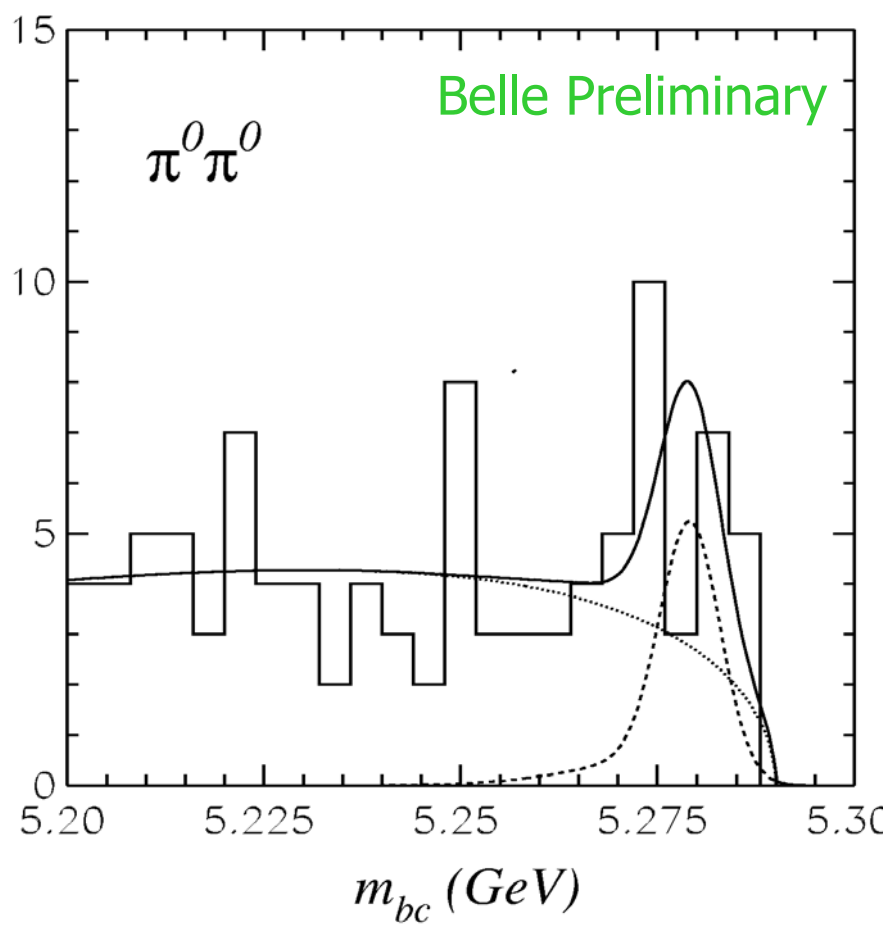
Item	δS(-)	δS(+)	δA(-)	δA(+)
Background frac.	-0.088	+0.077	-0.040	+0.057
Wrong tag	-0.071	+0.047	-0.052	+0.058
vertexing	-0.049	+0.059	-0.030	+0.017
physics	-0.039	+0.040	-0.012	+0.017
Fit bias	-0.024	+0.110	-0.051	+0.030
Background shape	-0.015	+0.015	-0.003	+0.004
Resolution function	-0.012	+0.012	-0.008	+0.008
Total	-0.133	+0.160	-0.090	+0.090

At present, statistical error is 2~3 times larger than systematic

What's going on with $B \to \pi^0\pi^0$?

Data sample: 29 fb^{-1}





2.2 σ effect at this moment

Br($B \to \pi^0\pi^0$) < 0.56×10^{-5} at 90% CL

Summary

CP violating asymmetry parameters were measured in $B \to \pi^+\pi^-$ decay using 42 fb^{-1} of data

$$S_{\pi\pi} = -1.21\ ^{+0.38}_{-0.27}\ ^{+0.16}_{-0.13}$$

(stat.) (syst.)

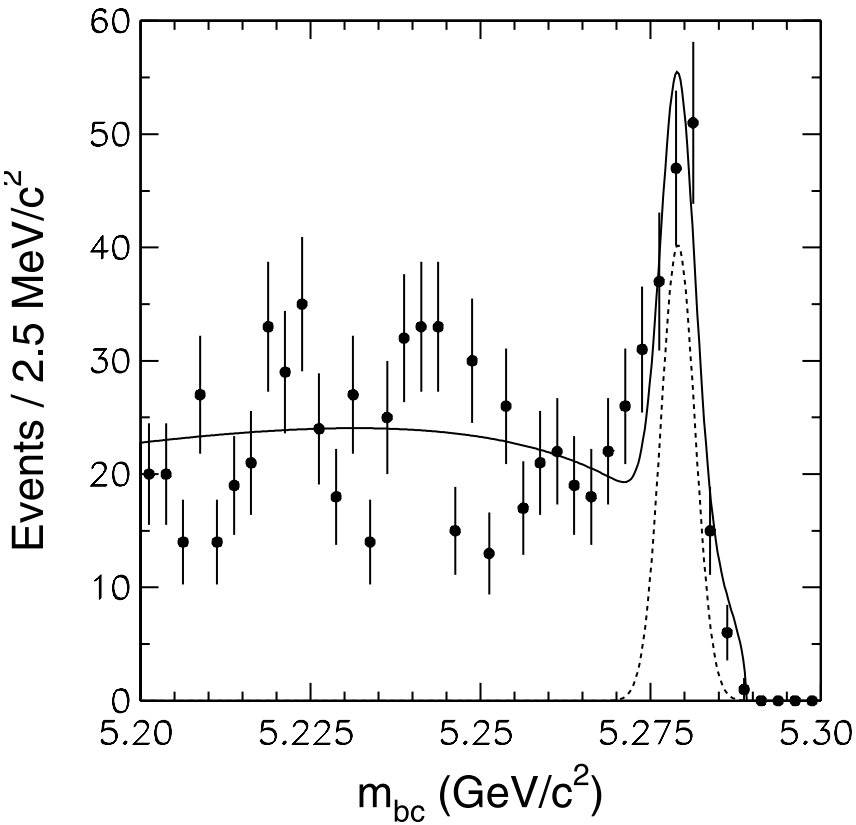
$$A_{\pi\pi} = +0.94\ ^{+0.25}_{-0.31} \pm 0.09$$

Both are 2.9σ away from zero

Br($B \to \pi^o\pi^o$) could be within reach in near future

Backup Slides for Questions

Signal Yield for $B \rightarrow \pi^+\pi^-$



Beam energy constrained mass

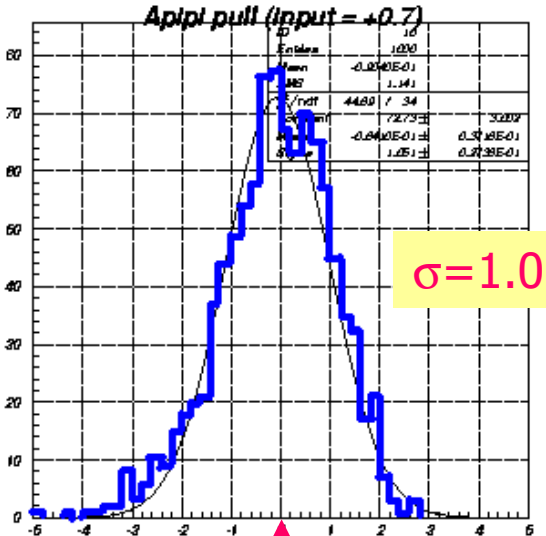
$|\Delta E| < 0.067$ GeV

Peak in m_{bc} includes both $\pi\pi$ and $K\pi$ components

Fit result in m_{bc}
101.6 ± 13.1
(consistent with ΔE fit result: 101.9 ± 18.6)

Ensemble tests: Pulls and Errors

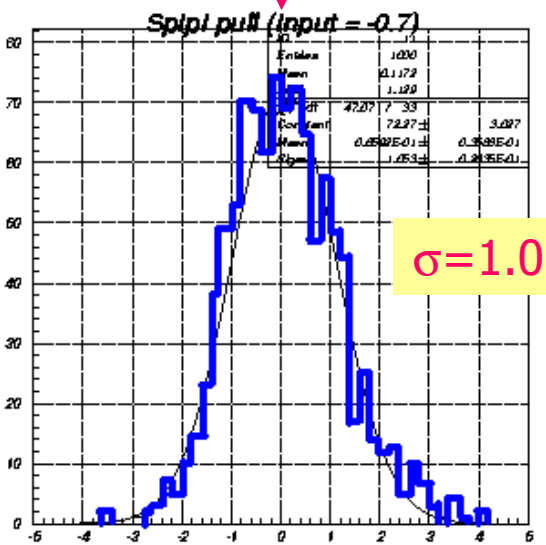
$A_{\pi\pi}$



σ=1.05

Pull = 0

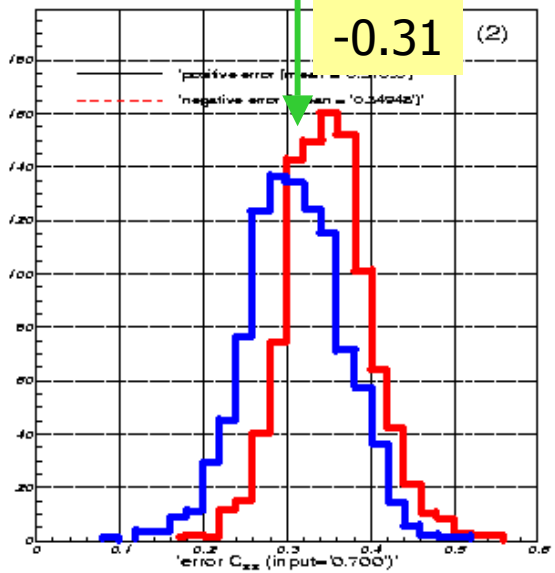
$S_{\pi\pi}$



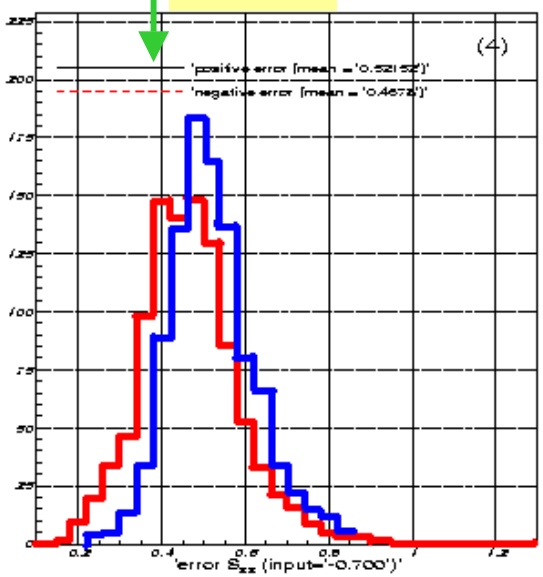
σ=1.05

Pulls

-0.31



+0.38



Errors

\+ error
\- error

Input $A_{\pi\pi}$= 0.7
$S_{\pi\pi}$= -0.7

5.4% of the time
MC expects smaller
+ errors