CP violation results from Belle

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Outline

- **Time-dependent CP asymmetry measurement**
- **KEKB accelerator and Belle detector**
- **Update of $\sin 2\phi_1$ measurement**
- **$\sin 2(\phi_1 + \phi_{NP})$ in $B \to \eta' K_S$**
- **CP asymmetry measurement for $B \to \pi^+\pi^-$**
- **Summary/Perspectives**

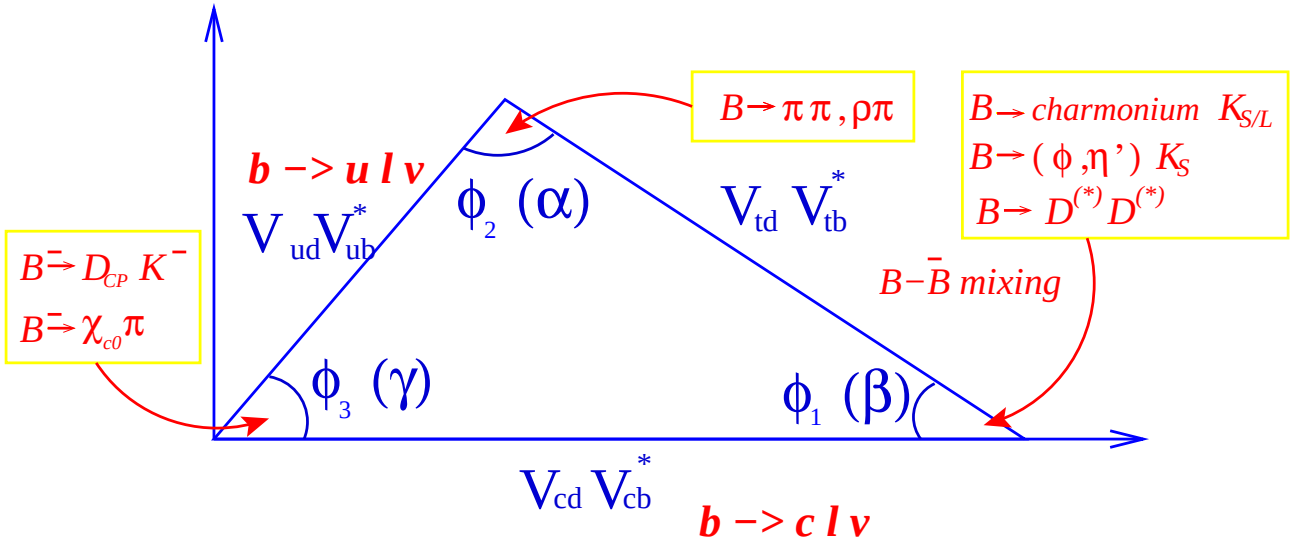
Physics motivations

CP violation is accomodated as an irreducible complex phase in the weak interaction quark mixing matrix (CKM).

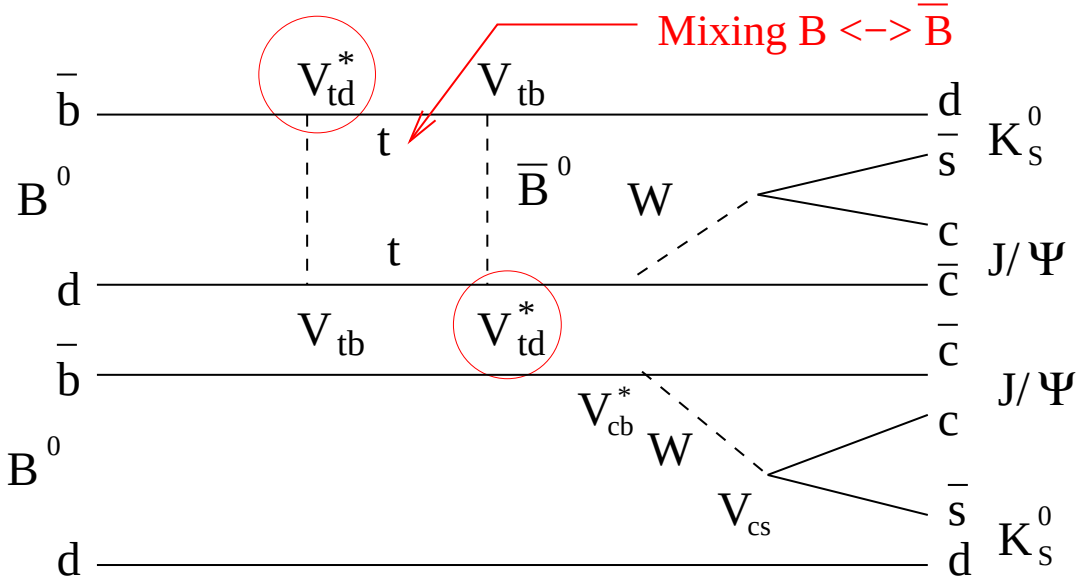
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

From the unitarity of the CKM matrix $VV^\dagger = 1$ (columns 1 and 3) :

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



Indirect CP violation in B meson decay



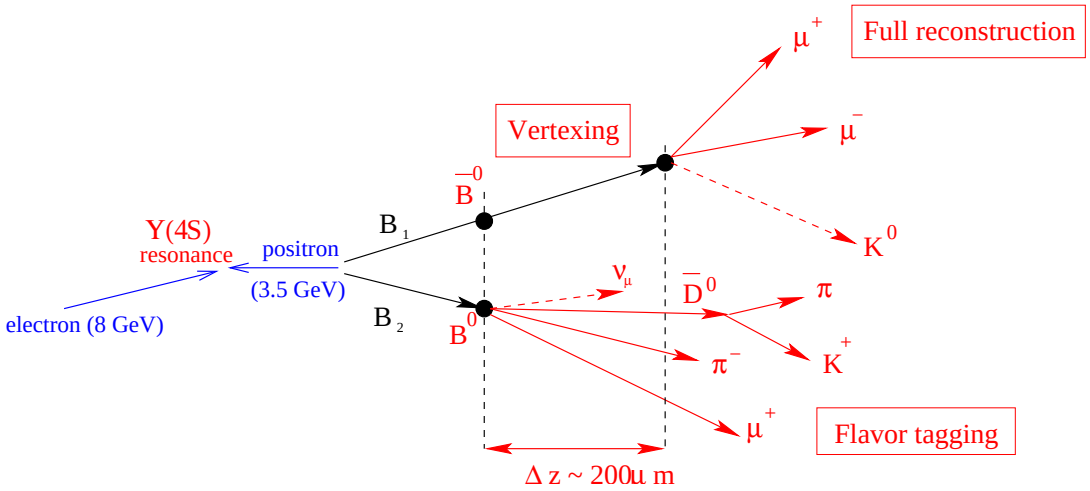
Time dependent decay rate of $B^0(\Delta t)$ and $\bar{B}^0(\Delta t)$ into a common CP eigenstate, f_{CP} :

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

with ξ_f is the CP-eigenvalue of f_{CP} (ξ_f = -1 for $J/\psi K_S$, ξ_f = +1 for $J/\psi K_L$)
Δm_d is the mass difference between the two B^0 mass eigenstates.

Principle of the measurement

Measurement of $\sin 2\phi_{CP}$ requires :

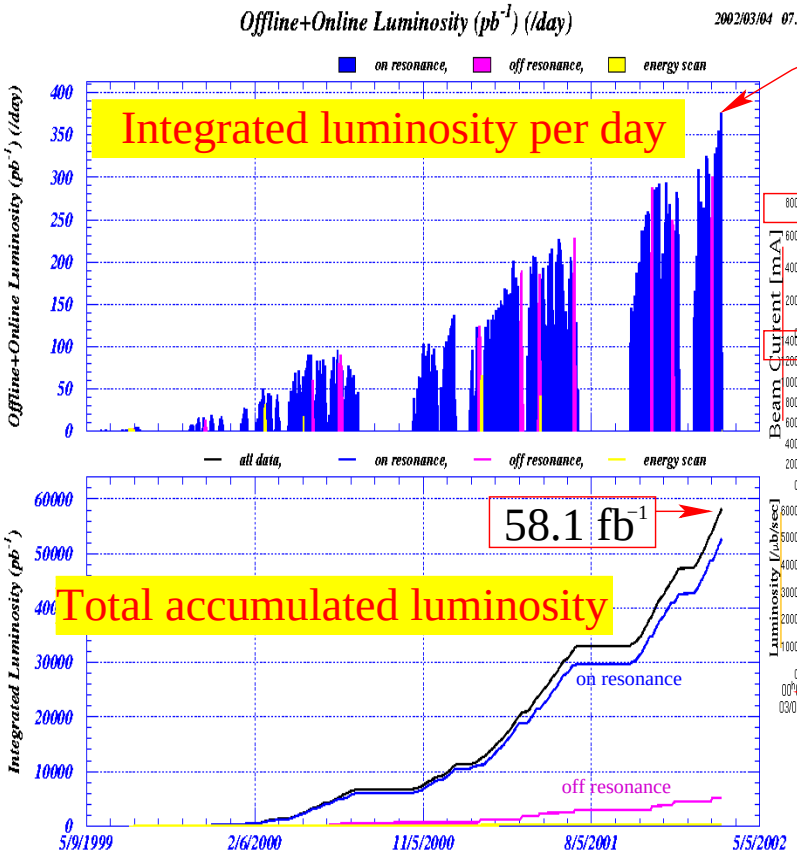


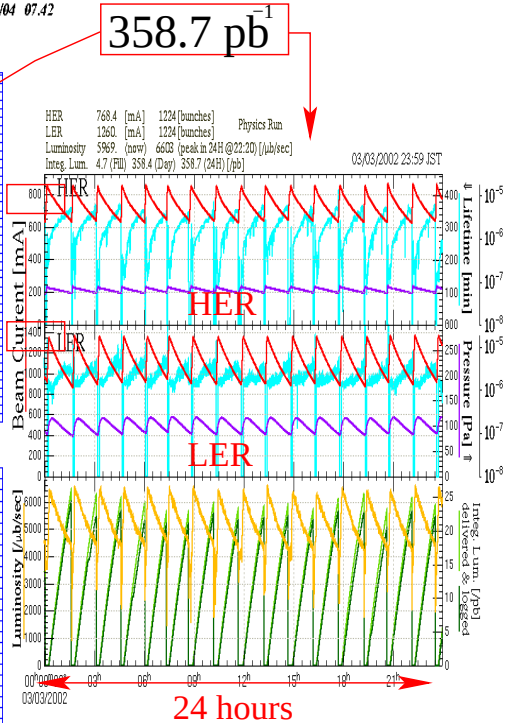
- full reconstruction of $B^0 \to f_{CP}$ decays (B_{CP}) (full angle coverage, high precision momentum/ energy measurement)
- determination of the b-flavor of the accompanying (tagging) B mesons (good particule identification)
- measurement of Δt (asymmetric collision and good vertex detection)
- fit of the expected Δt distribution to the measured distribution using a likelihood method

...and a lot of statistics !!!

KEB Performances

World record luminosity 6.64×10^{33} $cm^{-2}s^{-1}$





24 hours

other records:

L/week = 2200 pb^{-1}

L/month = 7241 pb^{-1}

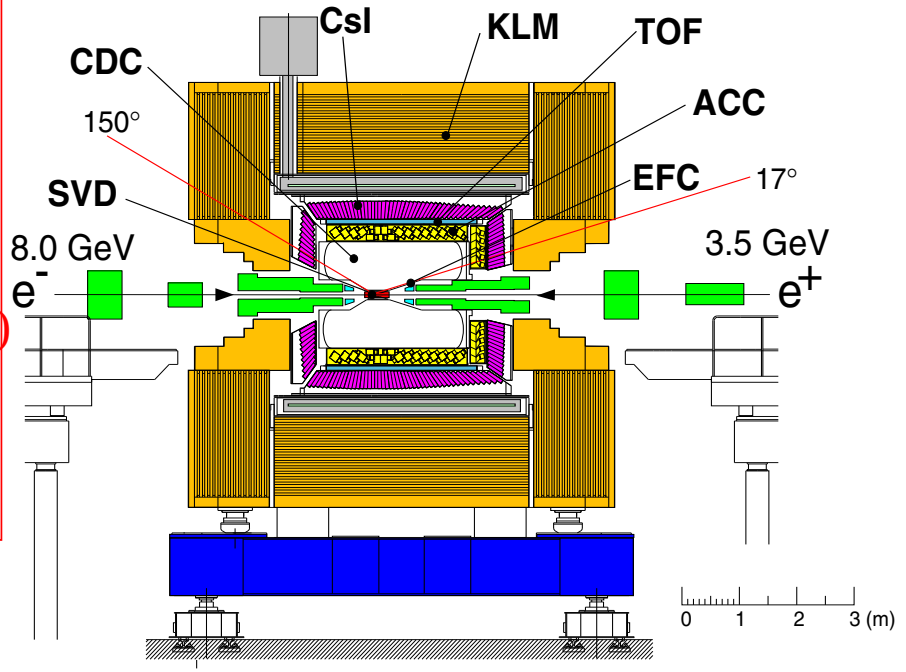
Data set used for present analysis ~ 42 fb^{-1}

All results on CP violation are preliminary results...

BELLE Detector performances

Tracking part :

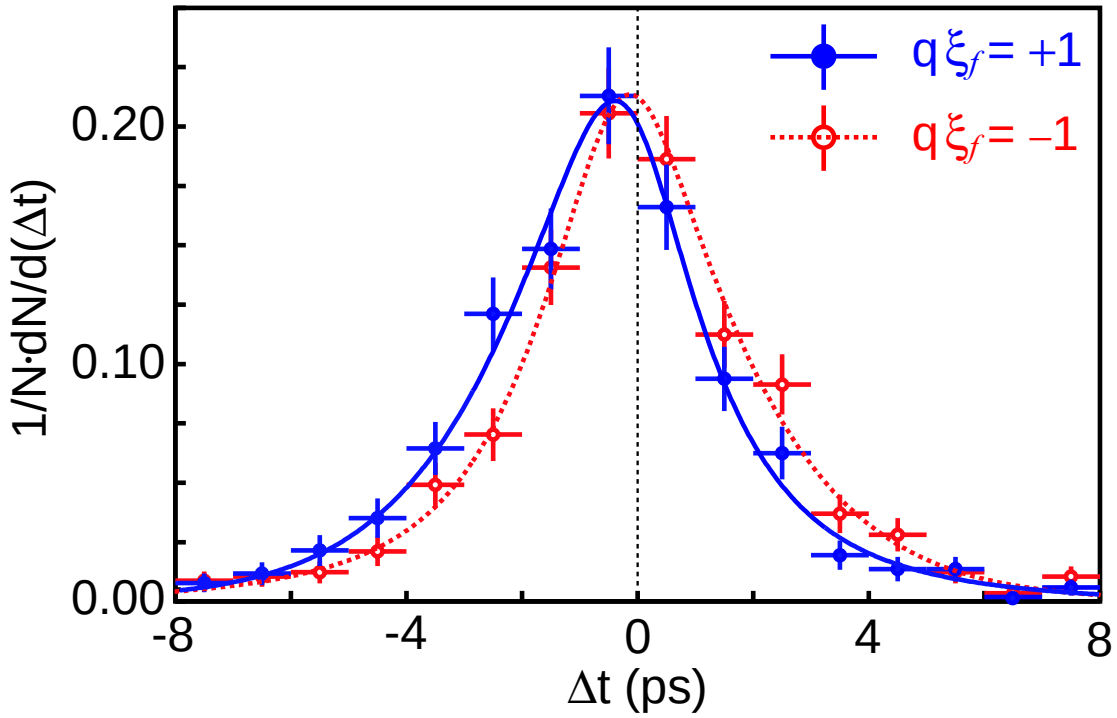
Central Drift Chamber(CDC)
(50 layers)
$\sigma_{p_t}/p_t \sim 0.35\ \%$ @ 1 GeV/c
Silicon Vertex Detector(SVD)
(3 silicon layers/double−sided)
$\sigma \sim 55\mu m$ for 1GeV/c @ 90^0



Particle identification ($K^{+/-}$ id up to 3.5 GeV/c)
Aerogel Cherenkov Counter(ACC) : n=1.01 ~ 1.03
Time of Flight (TOF) $\sigma \sim 95$ ps
CDC (dE/dx) $\sigma_{dE/dx} \sim 7\%$
Electromagnetic Calorimeter(CsI crystals) $\sigma_E / E_\gamma \sim 1.8\%$ @ 1 GeV
K_L and Muon detector (KLM = 14 layers) μ : $\varepsilon > 90\%$ and fake rate ~2%

$\sin 2\phi_1$ *(LP01 result)*

We have observed large CP violation in the B meson system (July 2001).
The effect is greater than 6 σ (using 31.3 million $B\bar{B}$ pairs)



$$\sin 2\phi_1 = 0.99 \pm 0.14(stat) \pm 0.06(syst)$$

(Papers : PRL87, 091802 (2001), hep-ex/0202027 (submitted to PRD))

CP modes reconstruction

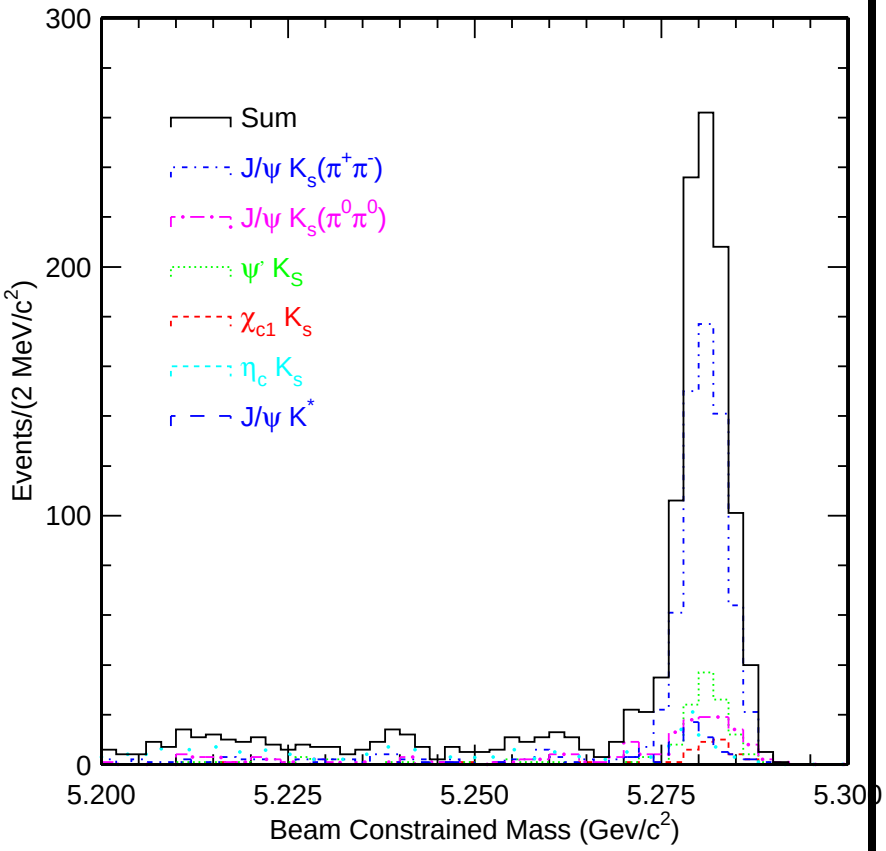
Very few modifications in the selection compared to LP01
($9.1 fb^{-1} \rightarrow 42 fb^{-1}$)

Mode	Number of events	Purity (%)
$J/\psi K_S(\rightarrow \pi^+\pi^-)$	636	95.1
$J/\psi K_S(\rightarrow \pi^0\pi^0)$	102	79.6
$\psi(2S)(\rightarrow l^+l^-)K_S$	49	95.2
$\psi(2S)(\rightarrow J/\psi\pi^+\pi^-)K_S$	57	92.5
$\chi_{c1}(\rightarrow J/\psi\gamma)K_S$	34	93.1
$\eta_c(\rightarrow K_S K^+\pi^-)K_S$	39	71.6
$\eta_c(\rightarrow K^+K^-\pi^0)K_S$	33	73.0
$J/\psi K^{*0}(\rightarrow K_S\pi^0)$	55	89.1
$J/\psi K_L$	767	60

Charmonium+$K_S(K^{*0})$ modes

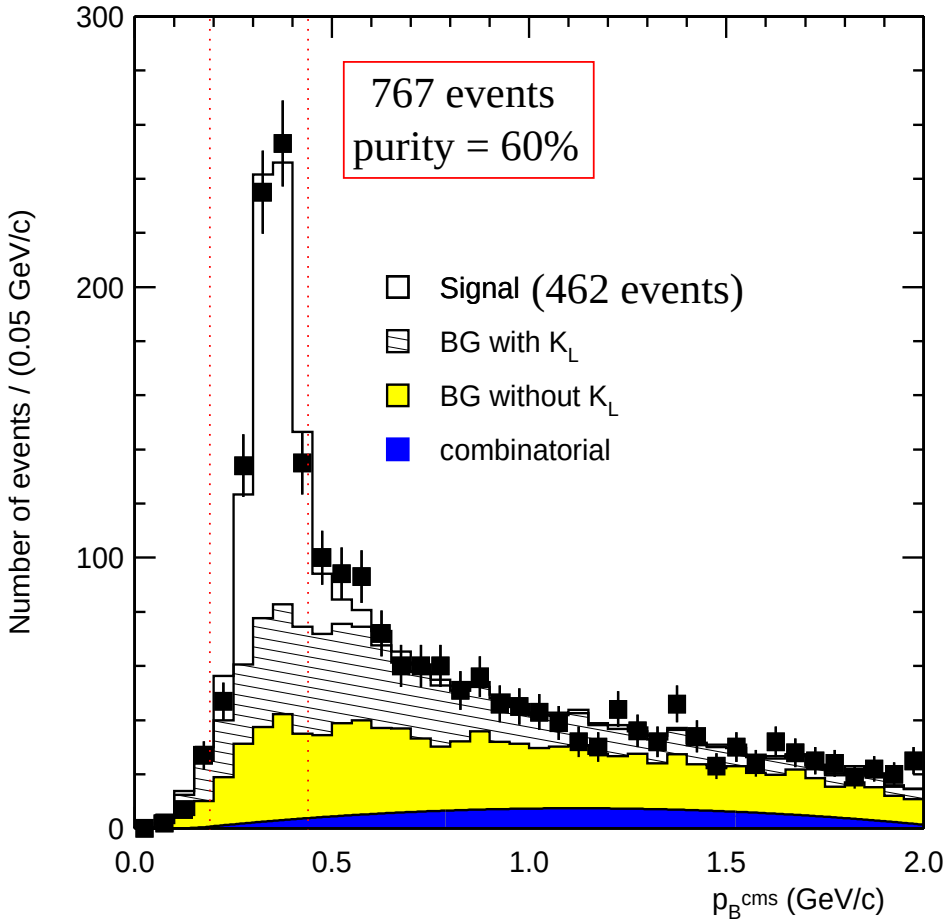
636 candidates $J/\psi K_S(\pi^+\pi^-)$
Purity = 95 %

369 candidates for other modes
Purity = 84 %



$J/\psi K_L$ mode

Take into account of run-dependent beam energy shift for p_B^* $(= |\vec{P}^*_{J/\psi} + \vec{P}^*_{K_L}|)$: better agreement between data/MC (peak position and overall p_B^* shape)



Vertex reconstruction and resolution functions

Δz is dominated by the tag-side vertexing resolution (charm effect)
for CP side : 75 μm ($\epsilon = 92\%$) / for tag-side : 140 μm ($\epsilon = 91\%$)

$$Pdf(\Delta t) = P_{SIG} \otimes R_{SIG} + P_{BG} + P_{OL}, \quad R_{SIG} = R_{det} \otimes R_{NP} \otimes R_{Kin}$$

- Separate response functions for "vtx with 1-track + IP constraint" and other
- Outlier treatment

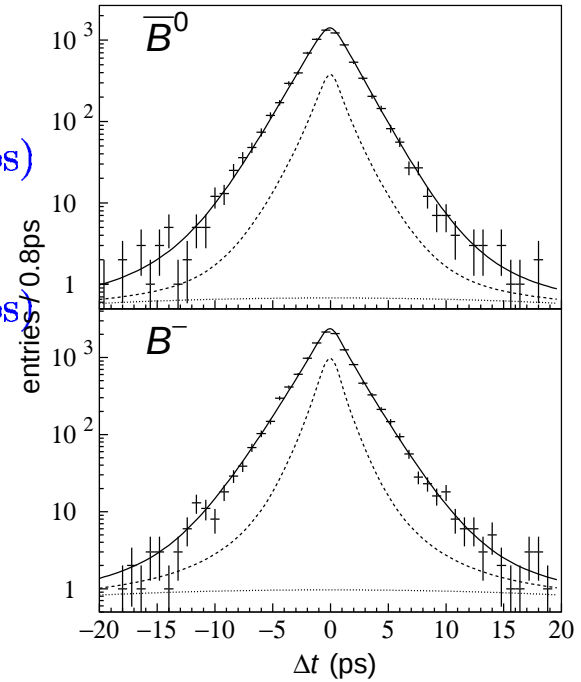
Adopted for the B lifetime analysis :

$\tau(B^{\pm}) = 1.695 \pm 0.026 \pm 0.015$ ps
(PDG 2000: 1.653 ± 0.028 ps)

$\tau(B^0) = 1.554 \pm 0.030 \pm 0.019$ ps
(PDG 2000: 1.548 ± 0.032 ps)

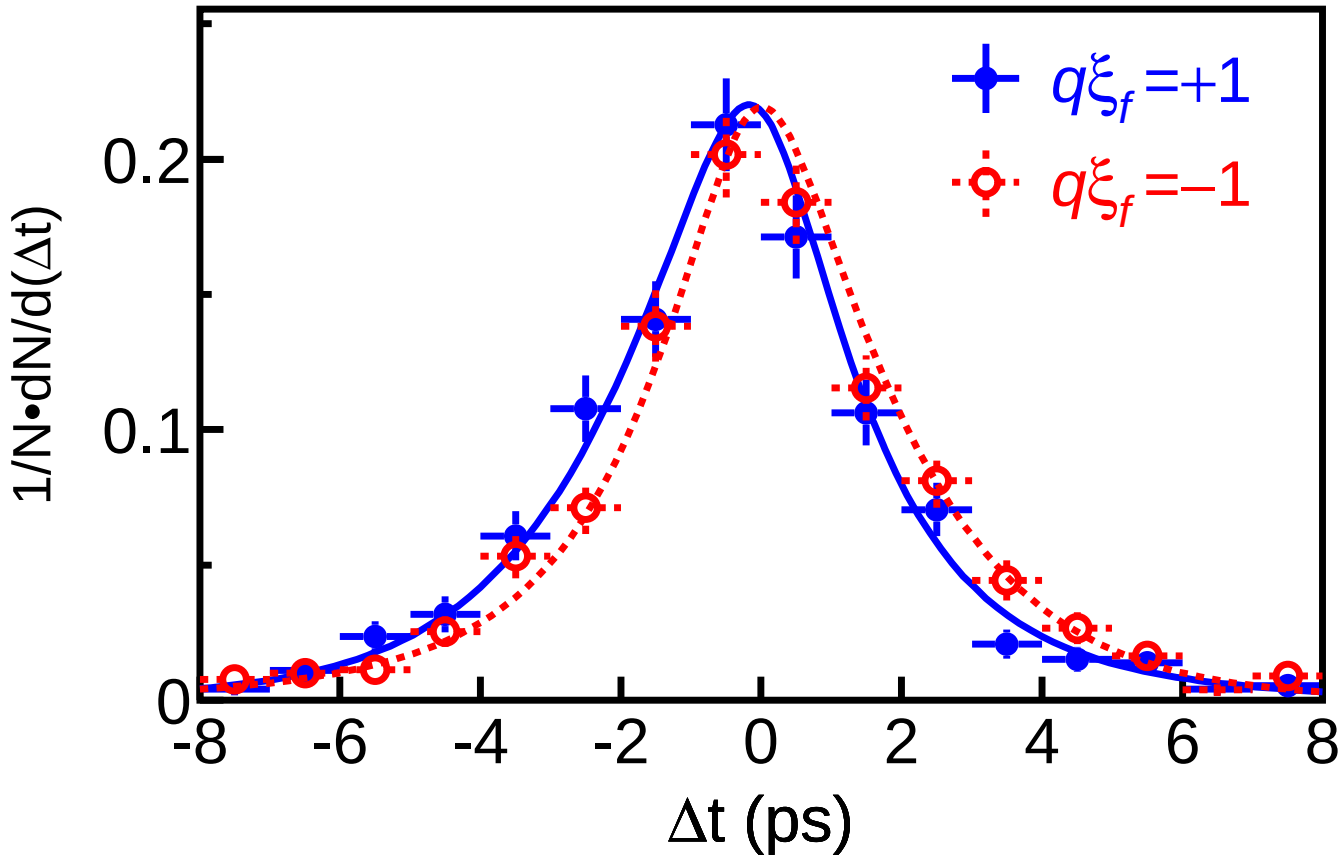
$\frac{\tau(B^{\pm})}{\tau(B^0)} = 1.091 \pm 0.023 \pm 0.014$
(PDG 2000: 1.060 ± 0.029)

$\Rightarrow$ submitted to PRL (hep-ex/0202009)

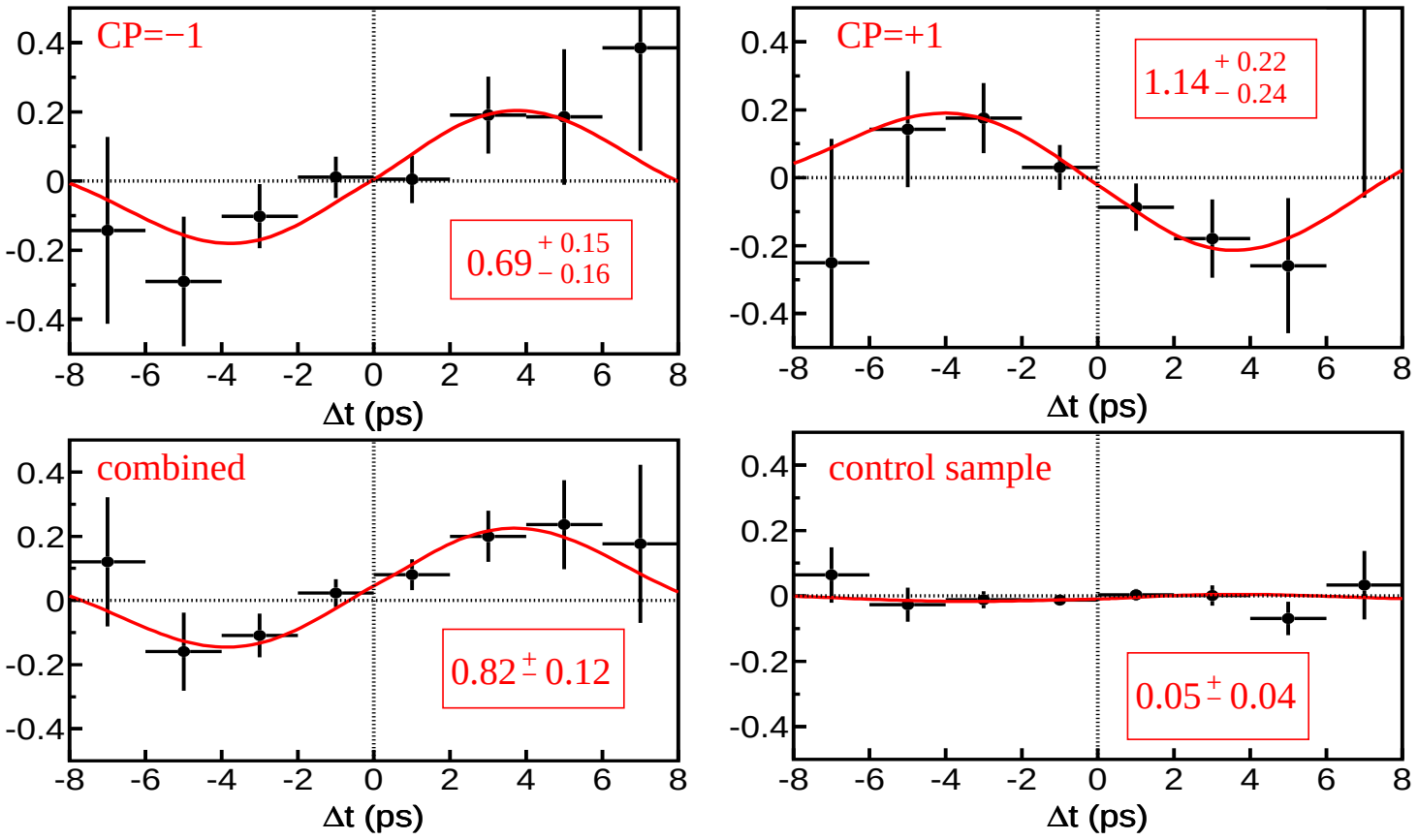


Fit result with $43 fb^{-1}$

$$\sin 2\phi_1 = 0.82 \pm 0.12(stat) \pm 0.05(s^{yst})$$



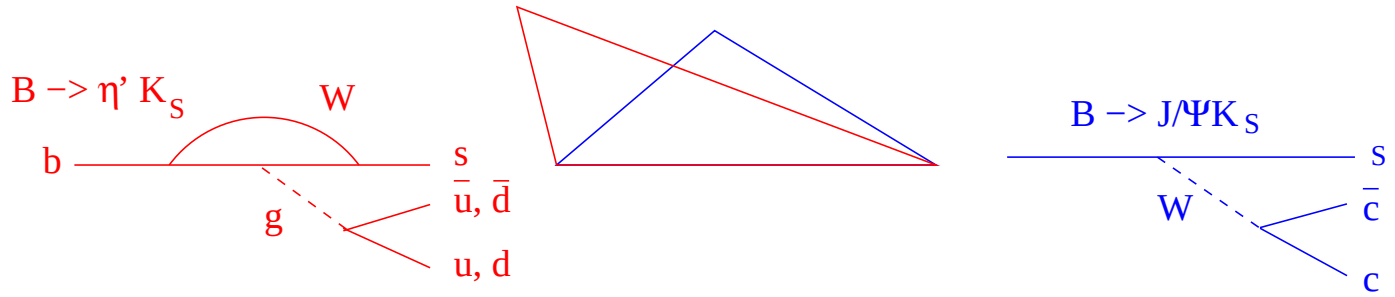
Raw asymmetries



Systematic Errors

Item	−error	+error
Vertexing	−0.030	+0.030
Flavor tag	−0.026	+0.024
Response Function	−0.019	+0.022
Background fraction (K_L)	−0.015	+0.014
Physics ($\tau_B, \Delta m_d, J/\psi K^*$ polarization)	−0.008	+0.006
Background (non K_L)	−0.006	+0.007
Background shape	−0.002	+0.002
Total	−0.048	+0.048

$\sin 2(\phi_1 + \phi_{NP})$ *in* $\eta' K_S$



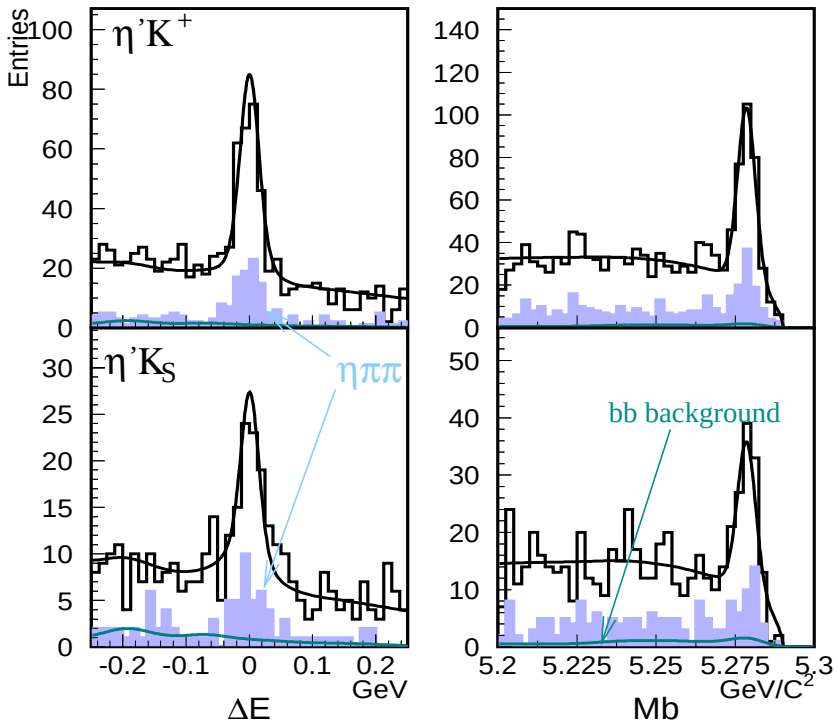
Penguin process ($b \to s\bar{u}u, s\bar{d}d$)
"tree pollution" ($b \to u\bar{u}s$) expected to be small.

$$A_{CP}(\Delta t) = -\xi_f \sin 2(\phi_1 + \phi_{NP}) \sin(\Delta m_d \Delta t)$$

(for example SUSY GUT motivated model, Moroi, PLB 493 (2000) 366)

Reconstruction of $\eta' K$

$\eta' K$ is reconstructed in following sub-modes : $\eta' \to \eta\pi\pi$ and $\eta' \to \rho\gamma$
Unbinned 2-dimensional likelihood fit is performed



$$N(\eta\pi\pi K^+) = 78.0^{+9.6}_{-9.0}$$
$$N(\rho\gamma K^+) = 152 \pm 14$$

$$N(\eta\pi\pi K_S) = 27.7^{+6.2}_{-5.5}$$
$$N(\rho\gamma K_S) = 45.5^{+8.6}_{-7.9}$$

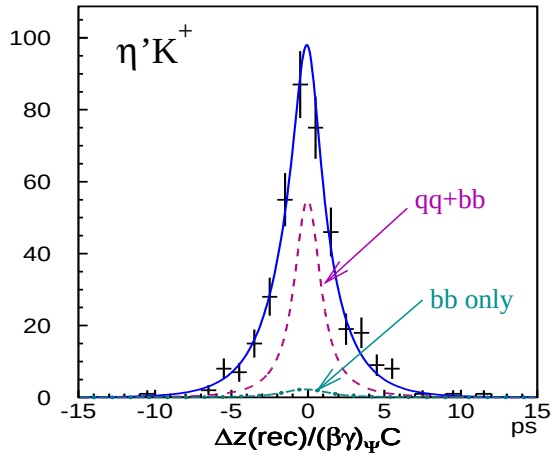
Confirm the Br larger than theoretical expectation (found by CLEO) :

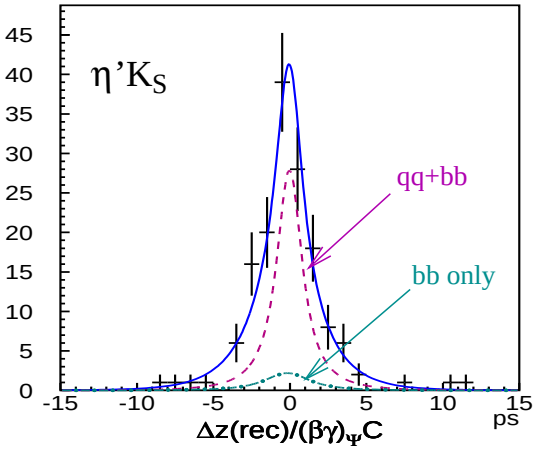
$$Br(B^+ \to \eta' K^+) = (79^{+12}_{-11} \pm 9) \times 10^{-6}$$
$$Br(B^0 \to \eta' K^0) = (55^{+19}_{-16} \pm 8) \times 10^{-6}$$

[PLB with $10.4 fb^{-1}$]

B lifetime measurement for $\eta' K_S$

Perform the B lifetime using respectively 230 $\eta' K^{\pm}$ and 73 $\eta' K_S$





$$\tau(B^{\pm}) = 1.54^{+0.14}_{-0.13}\ \text{ps}$$
$$(\text{PDG} : 1.653 \pm 0.028\ \text{ps})$$

$$\tau(B^{0}) = 1.58^{+0.31}_{-0.26}\ \text{ps}$$
$$(\text{PDG} : 1.548 \pm 0.032\ \text{ps})$$

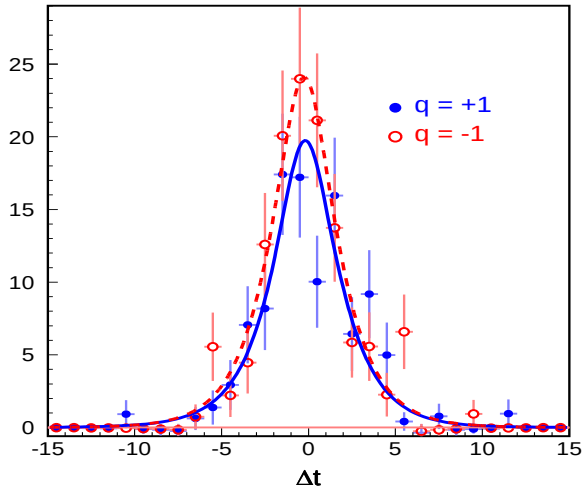
Test on non-asymmetric sample : $\eta' K^+$

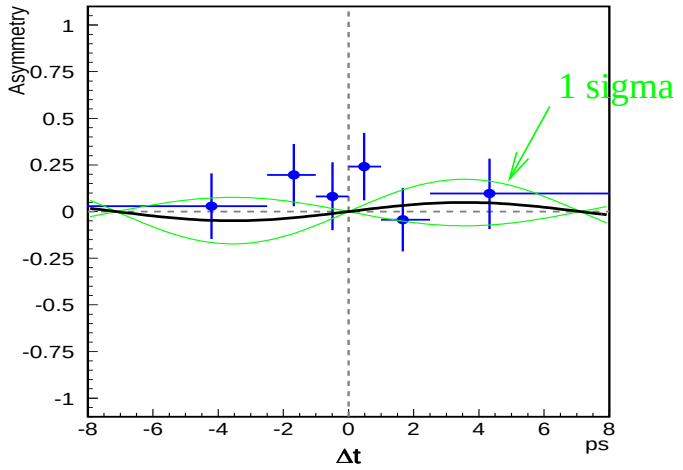
$$\text{“}\sin 2(\phi_1 + \phi_{NP})\text{”} = 0.12^{+0.39}_{-0.40}$$

By introducing both sine and cosine term :

S = 0.11 ± 0.29 (stat)

C = -0.26 ± 0.17 (stat)

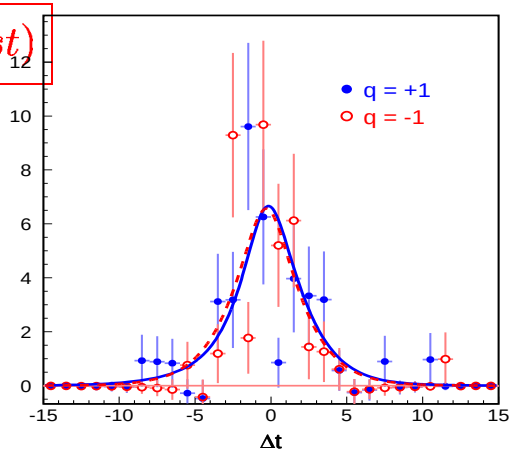




$\eta' K_S$

The CP fit is then performed with 73 $\eta' K_S$ events

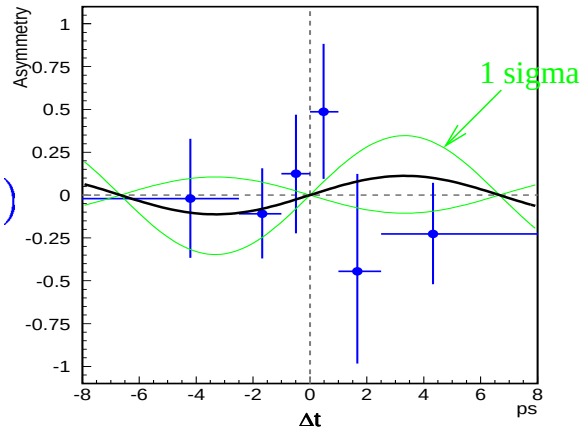
$$\sin 2(\phi_1 + \phi_{NP}) = 0.29^{+0.53}_{-0.54}(stat) \pm 0.07(syst)$$



- rules out some large phases for New Physics
- More stat in near future to get more constraint

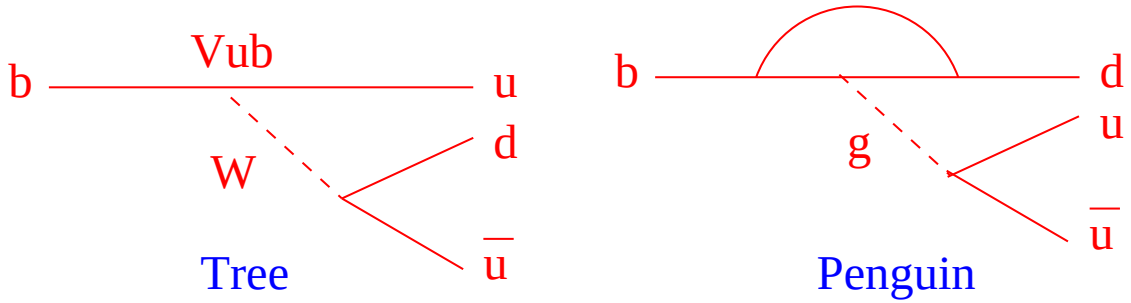
By introducing both sine and cosine term :

S = $0.27^{+0.54}_{-0.55}$ (stat) ± 0.07 (syst)
C = 0.12 ± 0.32 (stat) ± 0.07 (syst)



$B \to \pi^+\pi^-$ *CP fit*

Non−negligible penguin amplitude (~0.3)



⇒ different weak phases in tree and penguin
Cosine term (direct CPV) must be included

$$\mathcal{P}_{\pi^+\pi^-}(B \to \pi^+\pi^-;\Delta t) = \frac{e^{-|\Delta t|\tau}}{4\tau} \times (1 + q(1-2\omega)(S\sin(\Delta m \Delta t) + C\cos(\Delta m \Delta t)))$$

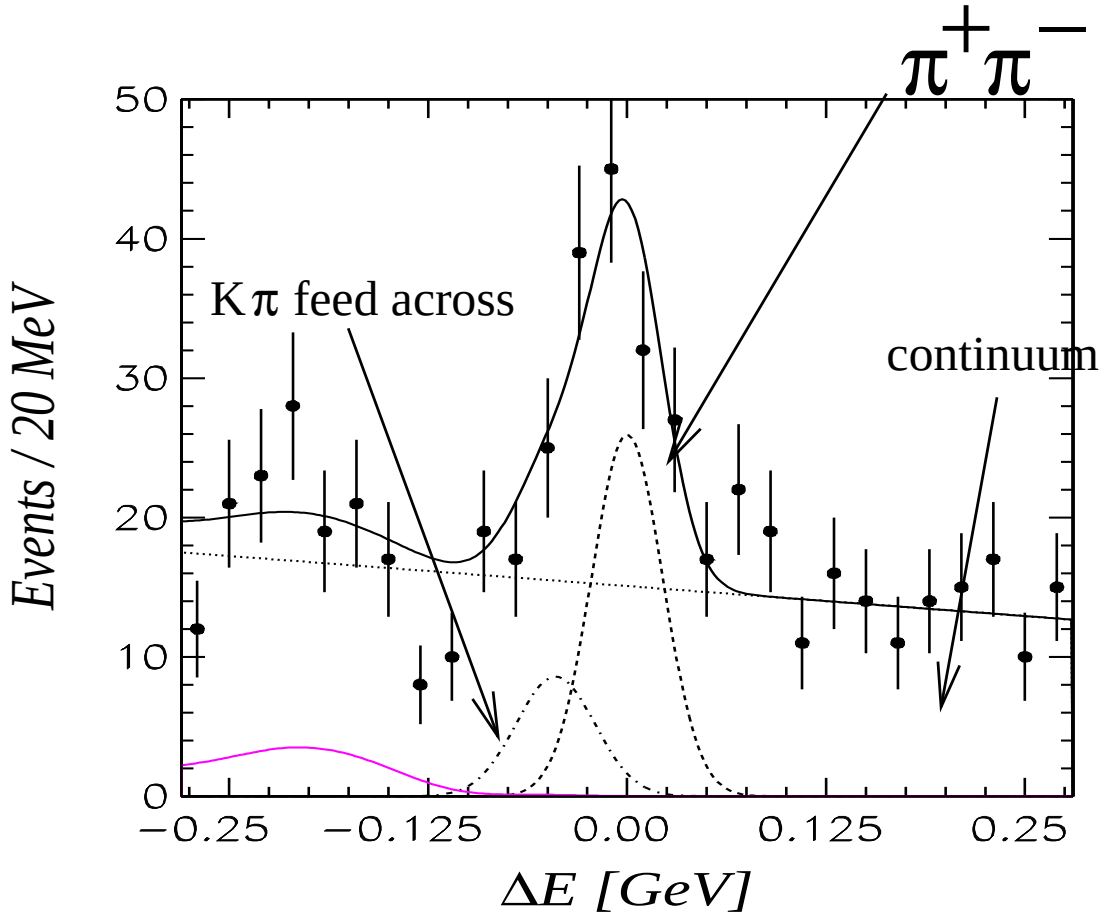
For the $B \to K\pi$ background :

$$\mathcal{P}_{K\pi}(B \to K^+\pi^-;\Delta t) = \frac{e^{-|\Delta t|\tau}}{4\tau} \times (1 + q(1-2\omega)(A_{K\pi}\cos(\Delta m \Delta t)))$$

$$P(B \to \pi^+\pi^-;\Delta t) = (f_{\pi\pi}\mathcal{P}_{\pi^+\pi^-} + f_{K\pi}\mathcal{P}_{K\pi}) \otimes R_{vtx} + (1 - f_{\pi\pi} - f_{K\pi})P_{bckg}$$

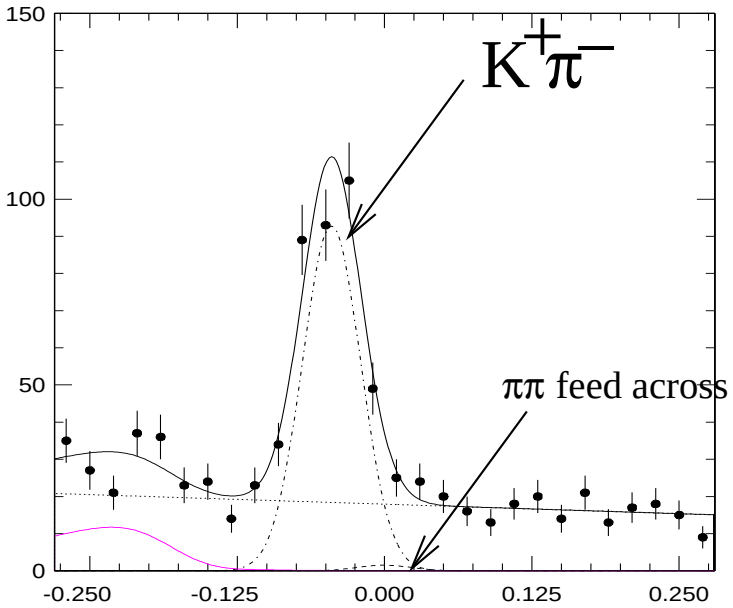
Signal yield for $B^0 \to \pi^+\pi^-$

N($\pi\pi$) = 73.5 $\pm$ 13.8 events, (28.4 $\pm$ 12.5 $K\pi$ feed-across)
(more details in coming Huang's talk about rare decays)



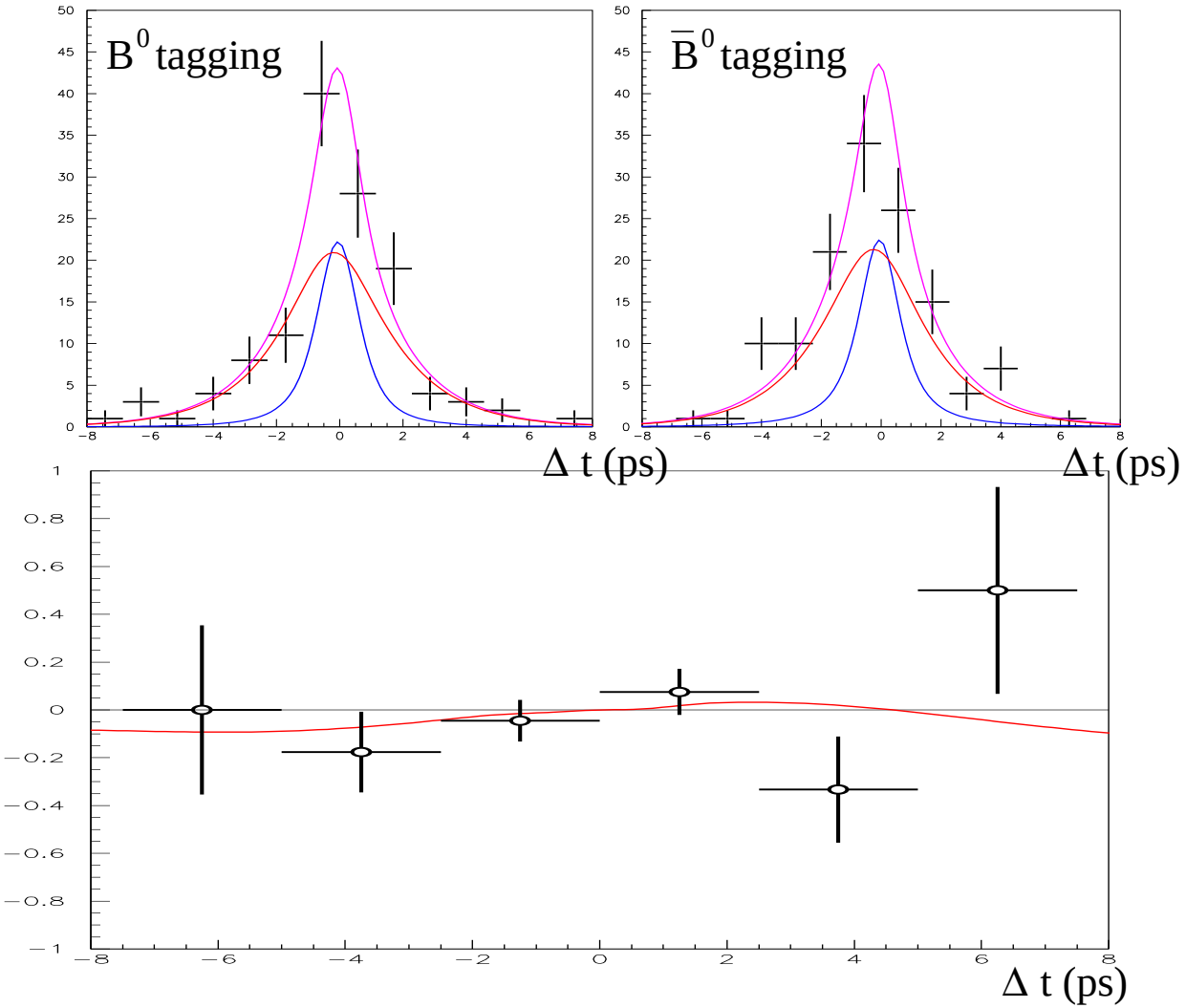
$K\pi$ and other control samples

$\mathrm{N}(K^+\pi^-) = 289.5 \pm 21.5$ events $(5.2 \pm 13.3\ \pi\pi$ feed-across)



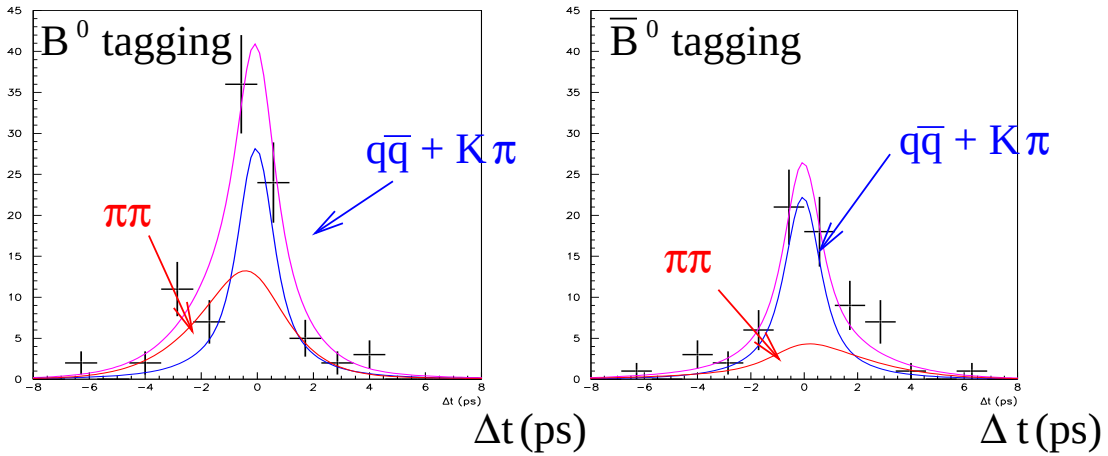
	$K^+\pi^-$	$D^+\pi^-$	$D^{*+}\pi^-$	$D^{*+}\rho^-$
τ_B(ps)	1.73 ± 0.15	1.64 ± 0.05	1.61 ± 0.05	1.68 ± 0.06
S	0.15 ± 0.24	0.09 ± 0.09	0.13 ± 0.09	-0.04 ± 0.10
C	0.07 ± 0.17	0.01 ± 0.06	-0.03 ± 0.06	-0.10 ± 0.07

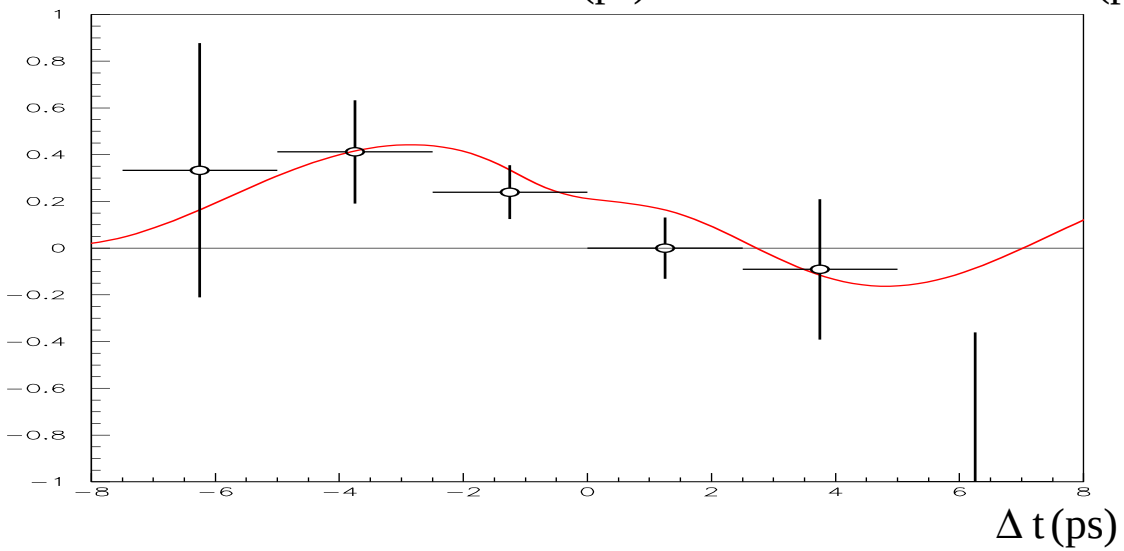
Asymmetry for $K\pi$



CP fit results for $B^0 \to \pi\pi$

$$S = -1.21^{+0.38+0.16}_{-0.27-0.13} \qquad C = +0.94^{+0.25}_{-0.31} \pm 0.09$$





Conclusion

Summary :

- New $\sin 2\phi_1$ with 40% more data :
$$\sin 2\phi_1 = 0.82 \pm 0.12(stat) \pm 0.05(syst)$$
- First measurement of Indirect CPV in $B^0 \to \eta' K_S$ (rules out some large phases from New Physics) :
$$\sin 2(\phi_1 + \phi_{NP}) = 0.29^{+0.53}_{-0.54}(stat) \pm 0.07(syst)$$
- Measurement of Indirect CPV in $B^0 \to \pi^+\pi^-$: indication of penguin pollution and direct CPV
$$S = -1.21^{+0.38}_{-0.27}(stat)^{+0.16}_{-0.13}(syst)$$
$$C = +0.94^{+0.25}_{-0.31}(stat) \pm 0.09(syst)$$

Conclusion

Perspectives :

- 8 millions of $B\bar{B}$ mesons/month $\rightarrow \sim 90 fb^{-1}$ for this summer
- Headroom for improvement :
  - $\mathcal{L} \rightarrow 10^{34} cm^{-2} s^{-1}$ (Add more RF cavities, higher currents)
  - new SVD will be installed this summer :
    $R_{beam\ pipe} = 2.0 \rightarrow 1.5$ cm
    $3 \rightarrow 4$ layers