CP violation at Belle

2003/Oct./14th

BEAUTY2003

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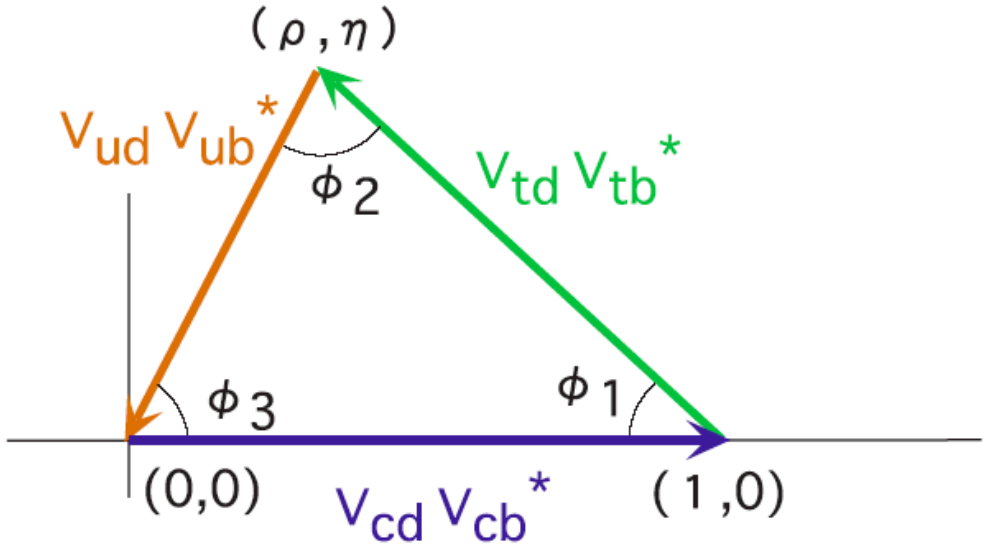
for Belle collaboration

(Nara Women's University)

KM unitarity triangle and CPV parameter convention

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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

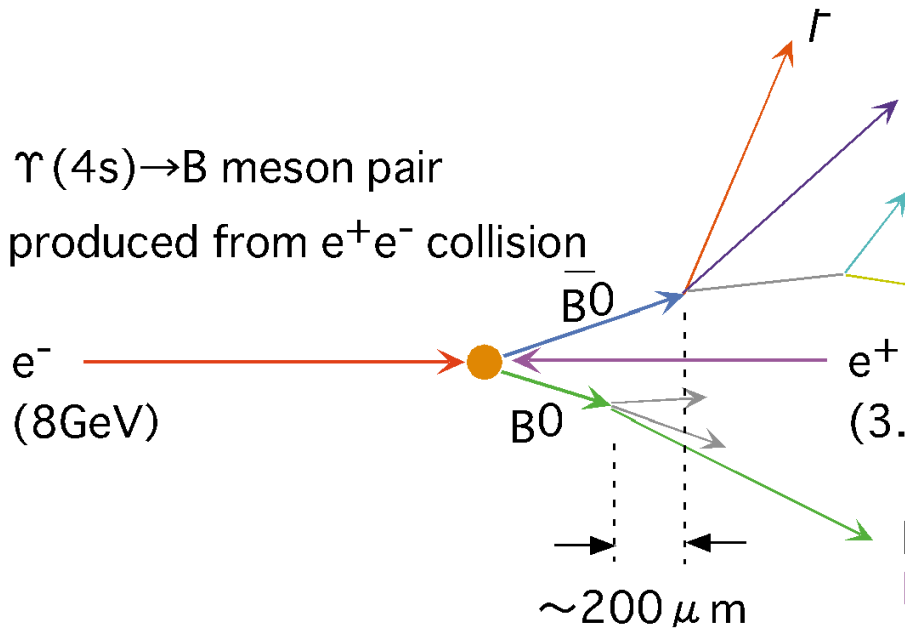


Topics to be covered…

- sin2ϕ_1 (sin2β) related (140/fb) ;
  - CPV golden mode; $B^0 \rightarrow J/\psi\ K_S$
  - CPV in $B^0 \rightarrow J/\psi\ \pi^0$

- ϕ_2 (α) related (78/fb);
  - CPV in $B^0 \rightarrow \pi^+\pi^-$

Time dependent CP asymmetry



Decay to CP eigen state (ex. J/ψ Ks); CP-side

Decay to the state telling whether B0 or $\bar{B}^0$; Tag-side

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

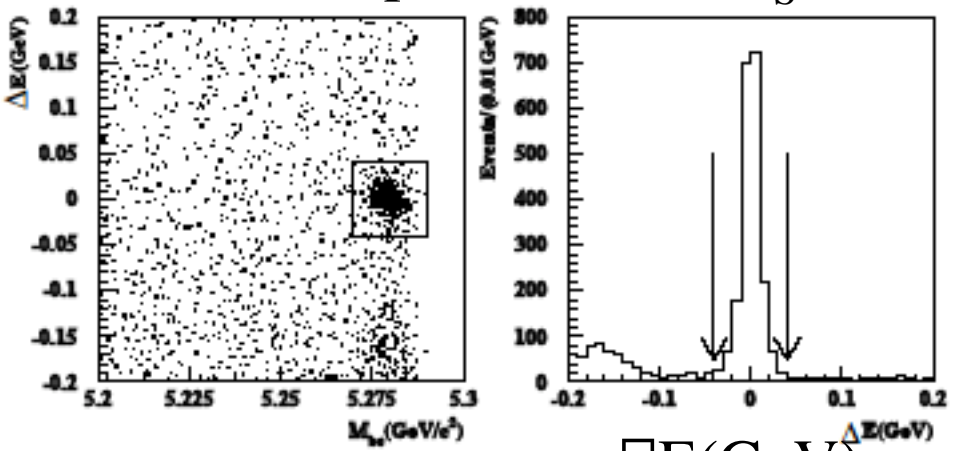
$$S_{f_{CP}} = \frac{2\,Im(\lambda)}{|\lambda|^2+1} \qquad A_{f_{CP}} = \frac{|\lambda|^2-1}{|\lambda|^2+1}$$

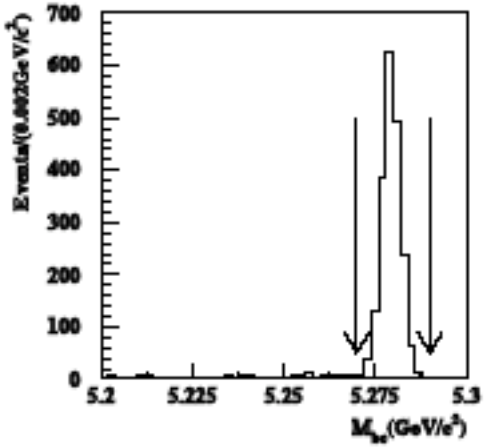
$$\lambda = \xi_{CP}\frac{q}{p}\frac{\bar{A}(f_{CP})}{A(f_{CP})}$$

$|\lambda| = 1$ if no DCPV

CP eigenstate reconstruction

Example; $B^0 \to J/\psi\, K_S$





M_{bc}(GeV)

Two key variables;

$M_{bc} = \{ (E_{CM}/2)^2 - (\sum P_i)^2 \}^{1/2}$

$\to$ B mass(5.28GeV)

$\Delta E = \sum E_i - E_{CM}/2$

$\to$ 0

Note;

These are for full-reconstructable case.

For the mode having missing π^0 or K_L, different variables are used.

Vertex recon. to measure □t

$B\bar{B}$ system is boosted □□=0.425 ; □t obtained by □z

Require consistent with run-dep. IP profile ($□_{r□}$=21□m).

- CP side vertex
  - reconstructed by dilepton from J/□, $□^+□^-$ pair, etc.
- Tag side vertex
  - Impact parameter w.r.t CP side vertex < 500□m
  - K_S veto
  - If reduced $□^2 > 20$ … remove the track having largest $□^2$
- Resolution function
  - including charmed meson lifetime, motion of B meson,
  - Validation by lifetime measurement.

Flavor tagging by other B decay products

- ***Inclusive Leptons:***
  - ***high-p l^-***
  - ***intermed-p l^+***

$b \rightarrow c\, l^- \bar{\nu}$
$\hookrightarrow s\, l^+ \nu$

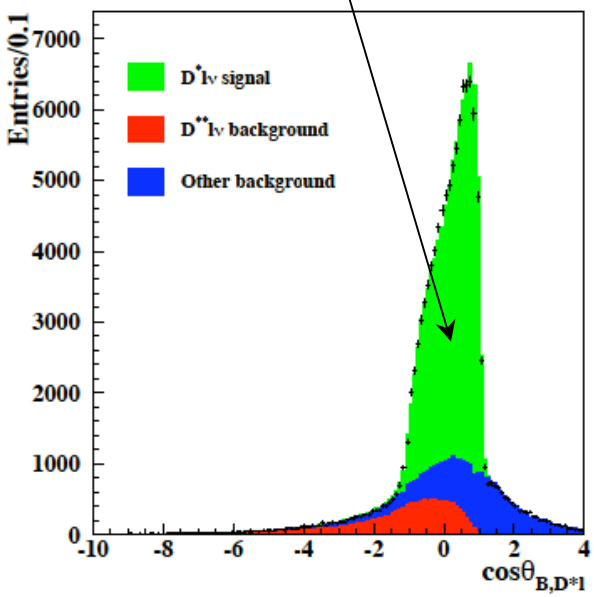
- ***Inclusive Hadrons:***
  - ***high-p π^+***
  - ***intermed-p K^+***
  - ***low-p π^-***

$B^0 \rightarrow D^{(*)-} \pi^+$, $D^{(*)-} \rho^+$, *etc.*
$\hookrightarrow K^+ X$,
$\hookrightarrow \rho^+ \pi^0$
$\hookrightarrow \bar{D}^0 \pi^-$

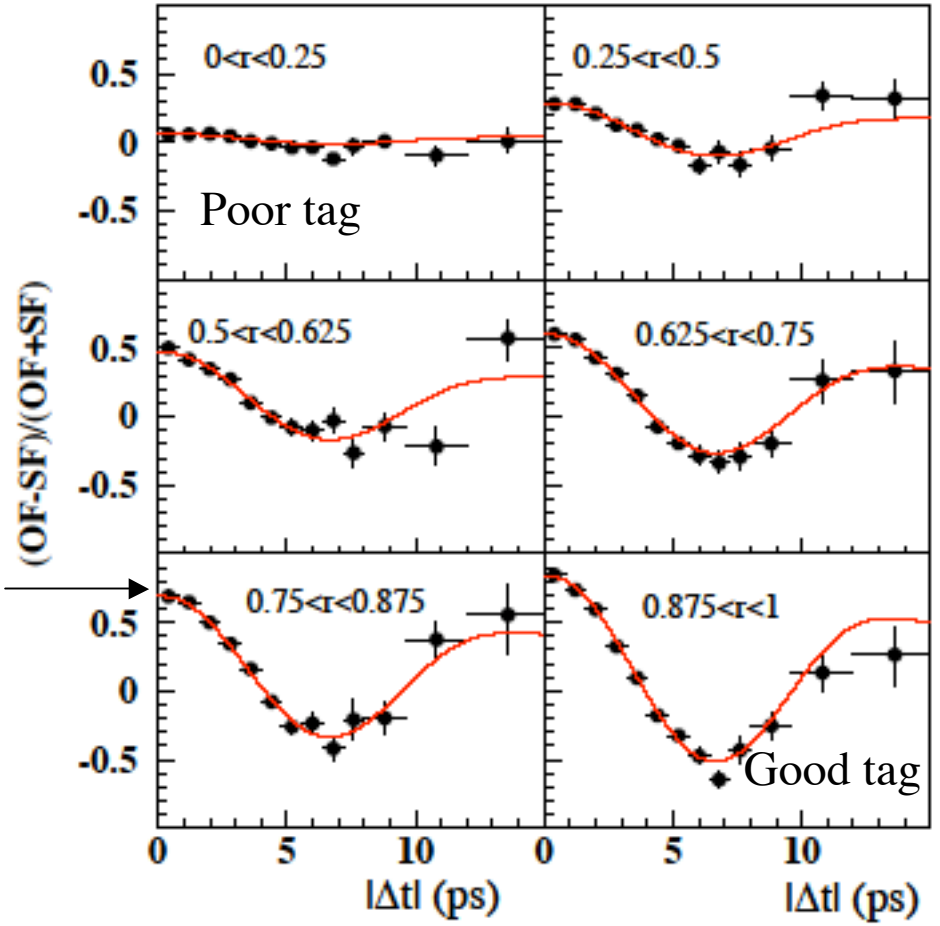
Based on the calculated likelihood,
q =+1 for B^0, -1 for $\bar{B}^0$ (Tag side)
r = from 0(no flav. info.) up to 1(perfectly confident tag).

Validation of flavor tagging

$B^0 \to D^{*-} l^+ \nu$ decay is self tagging; reconstructed with high purity



1-2w



OF-SF asymmetry ~ (1-2w)cos(Δm Δt)

Δw is also investigated.

CP fit : unbinned max. likelihood fit

Signal probability density function(PDF) is;

$P_{sig}(\Delta t, q, w_l, \Delta w_l)$

$= \exp(-|\Delta t|/\tau_B)/4\tau_B\{1-q\Delta w_l+q(1-2w_l)[S_{fCP}\sin(\Delta m\Delta t)+A_{fCP}\cos(\Delta m\Delta t)]\}$

here, l is flavor tagging class(1,2,…6).

For i-th event, likelihood value is;

$P_i(\Delta t_i, S_{fCP}, A_{fCP})$

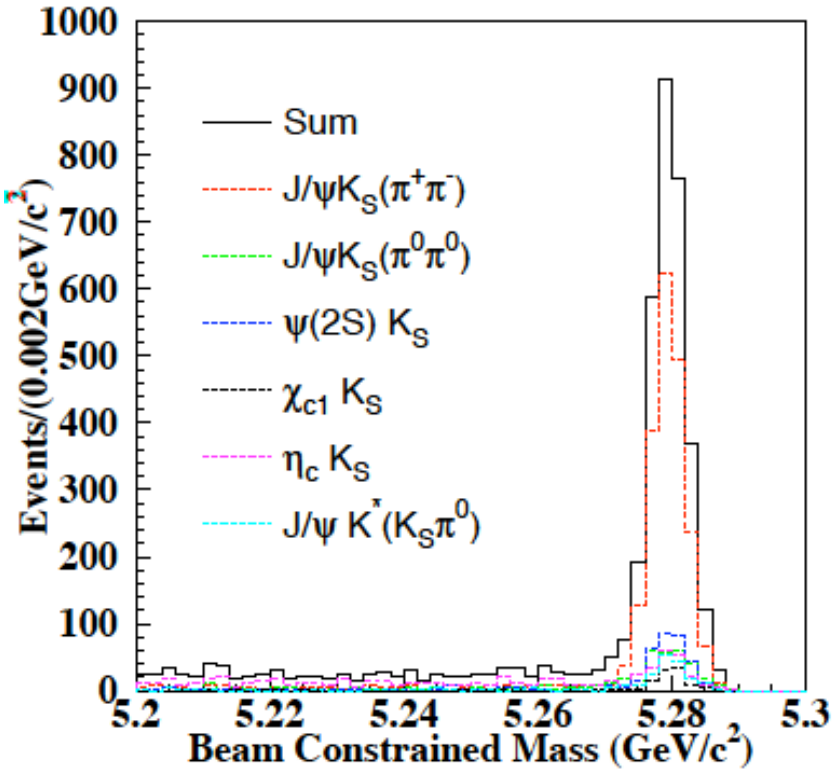
$=(1-f_{ol})[f_{sig}\, P_{sig}(\Delta t, q, w_l, \Delta w_l) \otimes R_{sig}(\Delta t_i) + f_{bg}\, P_{bg} \otimes R_{bg}(\Delta t_i)]$

$+ f_{ol}\, P_{ol}(\Delta t_i)$

Free parameters : S_{fCP} and A_{fCP} Proper resolution func. : R_{**}

B life and mixing : PDG values Fraction of each component : f_{**}

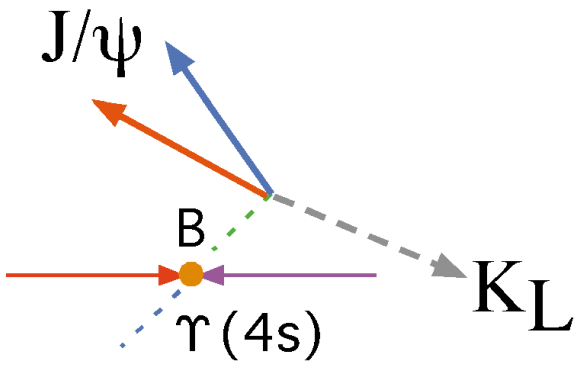
sin2β_1 ($-\eta_{CP} S_{\bar{c}cs}$) measurement
$B^0 \rightarrow$ charmonium + K recon.



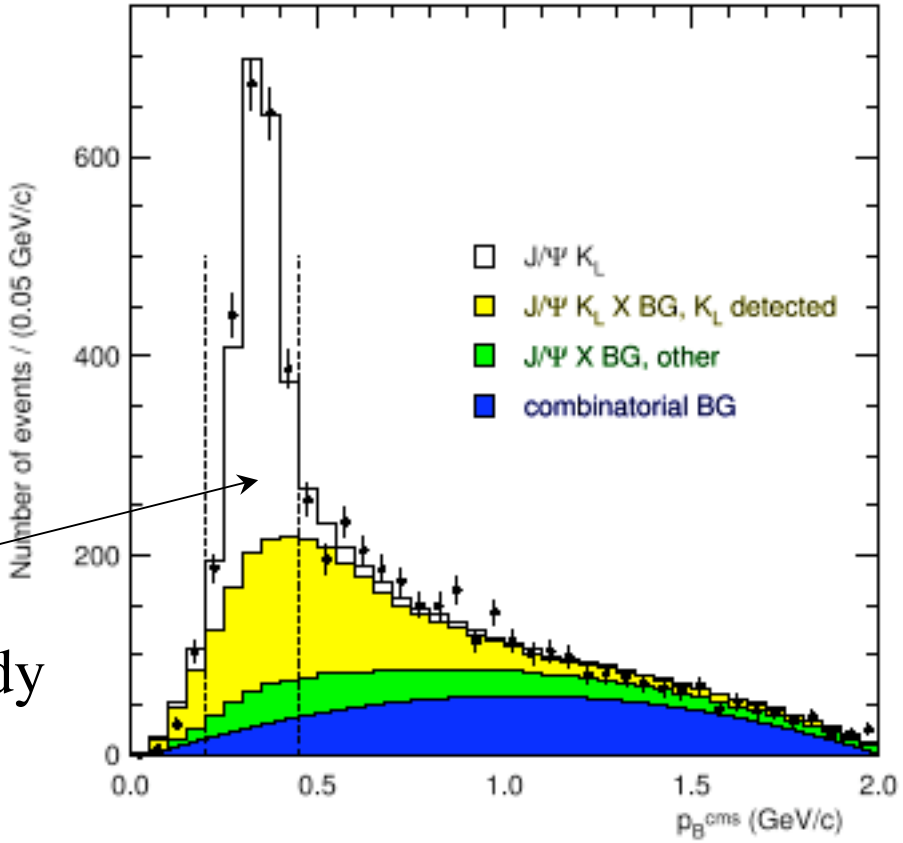
Mode	η_{CP}	Nevents	Purity
J/ψ $K_S(\pi^+\pi^-)$	-1	1997	0.98
J/ψ $K_S(\pi^0\pi^0)$	-1	288	0.82
$\psi'(l^+l^-)$ K_S	-1	145	0.93
ψ'(J/$\psi\pi\pi$) K_S	-1	163	0.88
χ_{c1} K_S	-1	101	0.96
η_c ($K_SK\pi$)K_S	-1	123	0.72
η_c ($KK\pi^0$)K_S	-1	74	0.70
η_c (pp) K_S	-1	20	0.91
J/ψ $K^{*0}(K_S\pi^0)$	+1*	174	0.93
J/ψ K_L	+1	2332	0.60

* 81%.

$B^0 \to J/\psi\ K_L$
(for $\sin 2\phi_1$ measurement)

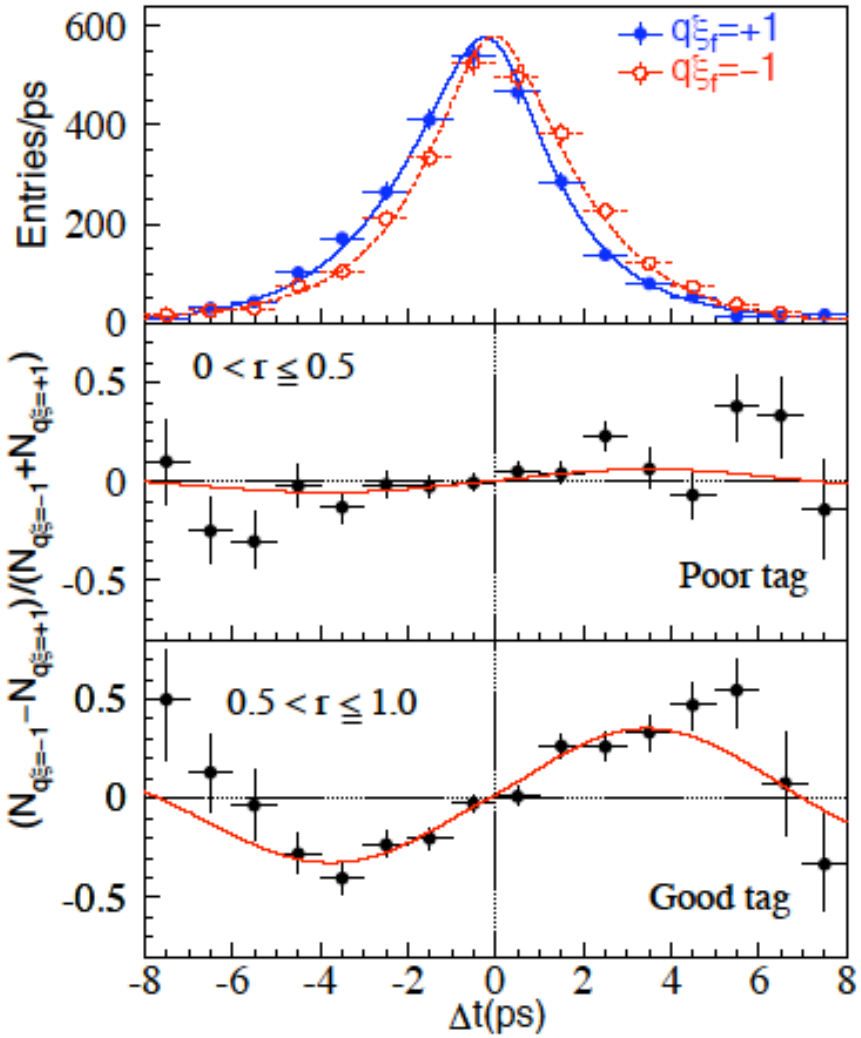


Only K_L direction known.
In Upsilon(4S) rest frame,
B has ~340MeV/c.
Reconstruct it with two-body kinematics assumption.



CPV in $B^0 \to$ charmonium+K^0: $\sin 2\beta_1$

$\sin 2\beta_1 = 0.733 \pm 0.057(\text{stat}) \pm 0.028(\text{syst})$



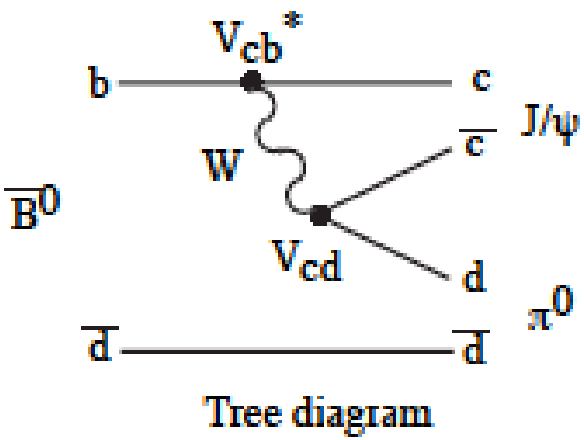
Now precision measurement!

If β is free in the fit, $|\beta| = 1.007 \pm 0.041(\text{stat})$ consistent with 1

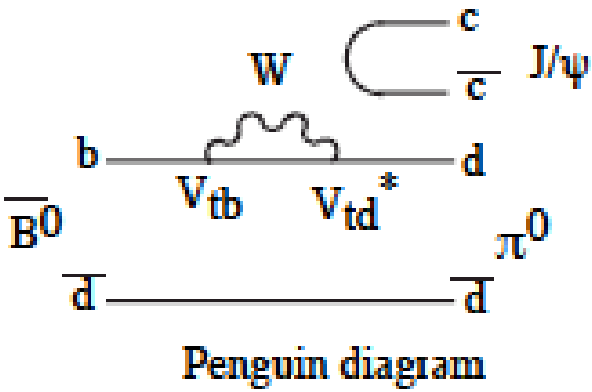
CPV in $B^0 \to J/\psi\,\pi^0$

Decay caused by $b \to c\bar{c}d$ transition

$\eta_{CP} = +1$



Tree diagram



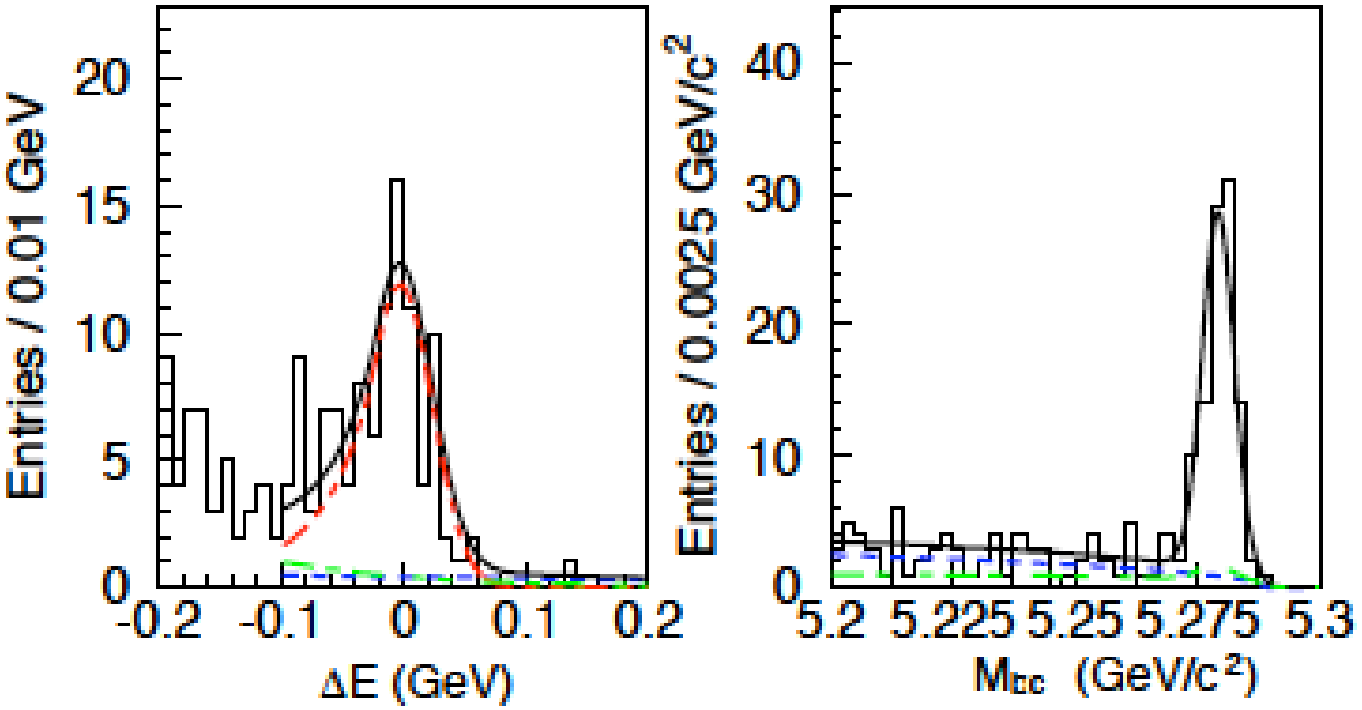
Penguin diagram

Tree has no complex phase

if it dominates $S_{J/\psi\pi^0} = -\sin 2\beta_1$ and $A_{J/\psi\pi^0} = 0$

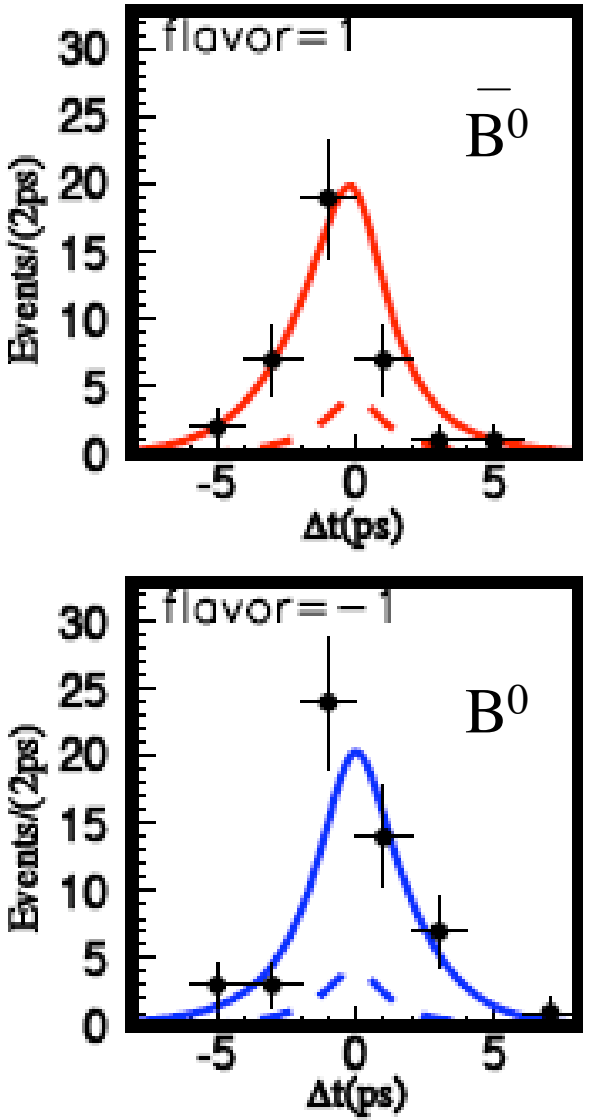
Reconstruction of $B^0 \to J/\psi\ \pi^0$

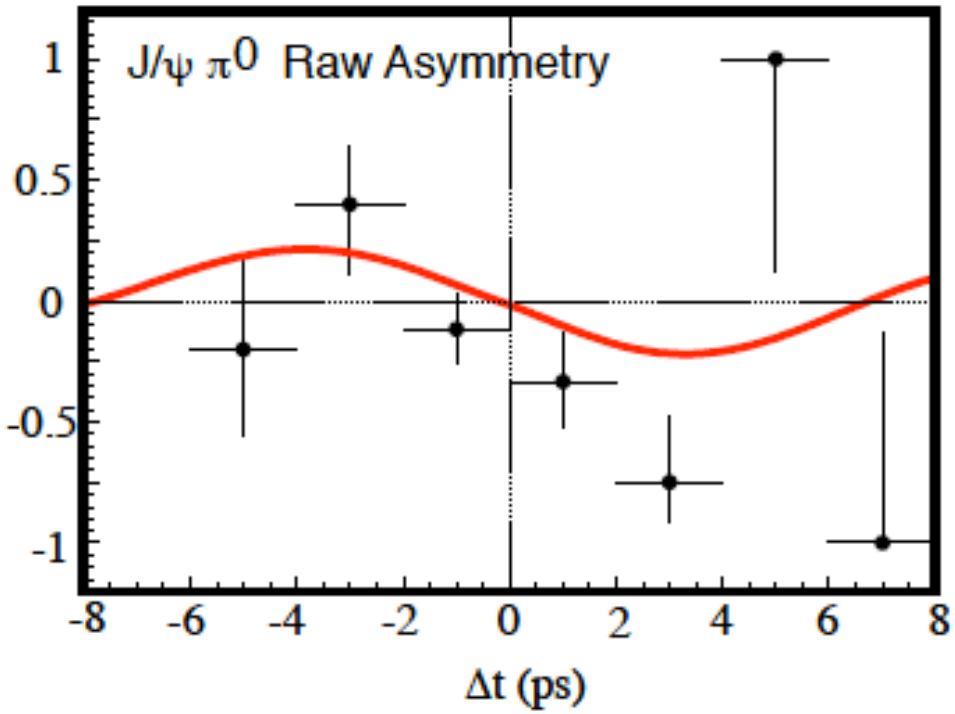
103events reconstructed.
Relatively clean; purity=86±10%



Backgrounds are separately est. for $B \to J/\psi\ X$ and combinatorial.

Results for $S_{J/\psi\pi^0}$ and $A_{J/\psi\pi^0}$



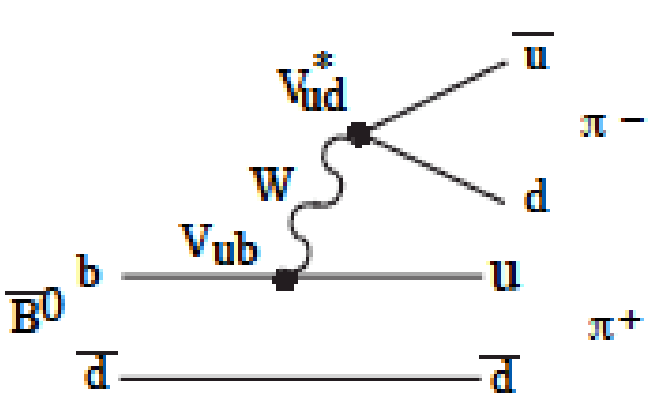


After ftag and vtx, 91 events are used.

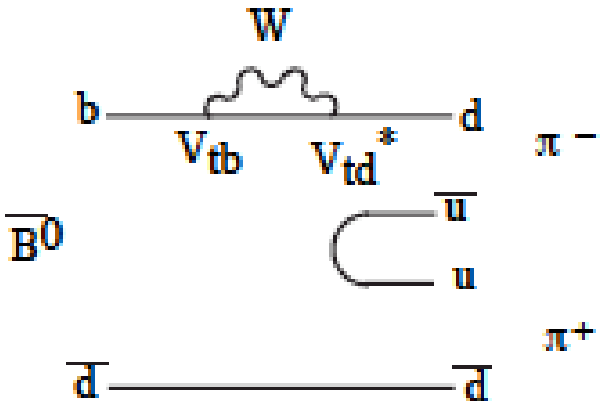
$S_{J/\psi\pi^0}$ = -0.72±0.42(stat)±0.08(syst)

$A_{J/\psi\pi^0}$= -0.01±0.29(stat)±0.07(syst)

CPV in $B^0 \to \pi^+ \pi^-$



Tree diagram



Penguin diagram

If only tree contributes, V_{ub} interferes V_{td}(in mixing)

$\longrightarrow$ extract ϕ_2!

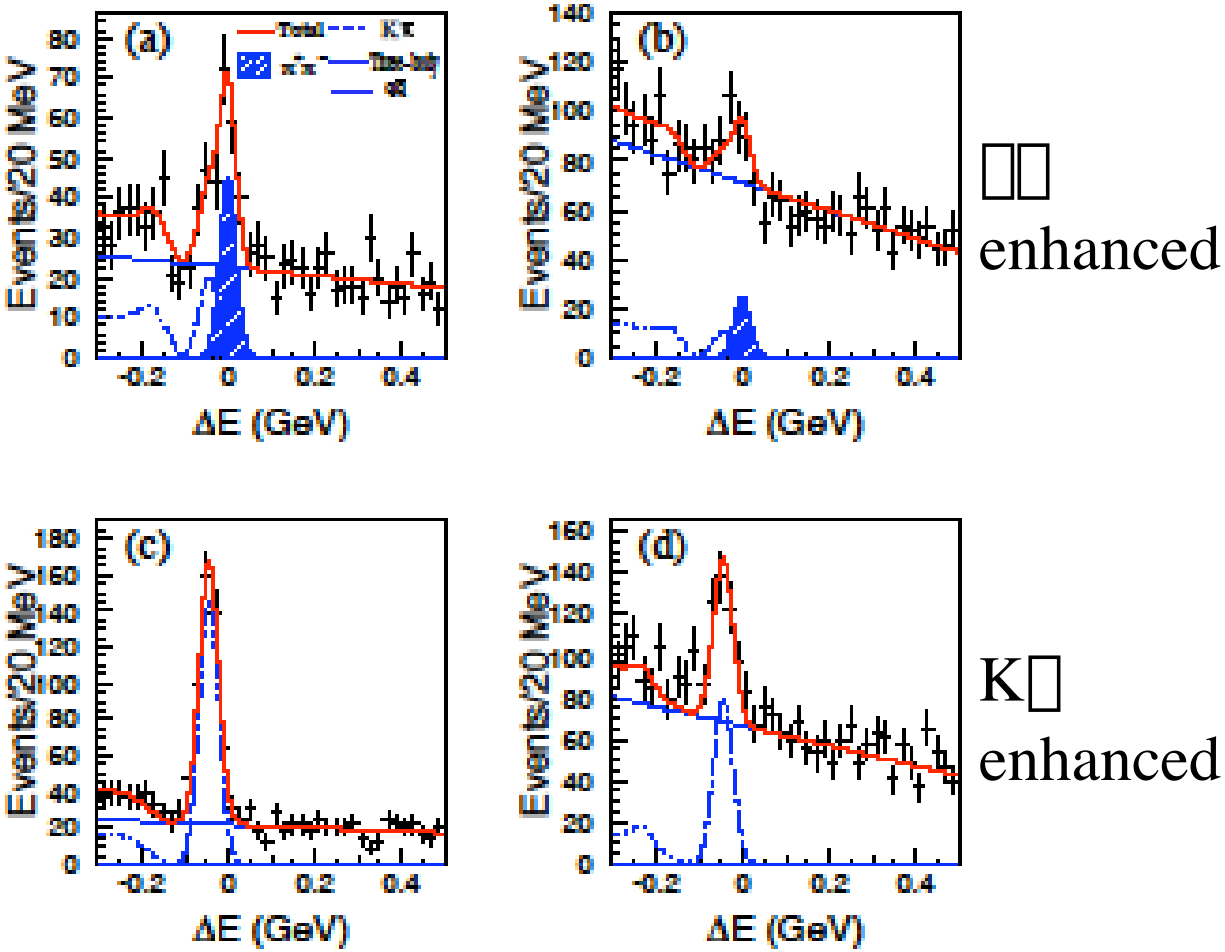
However, penguin looks significantly large

($B^0 \to \pi^0 \pi^0$, listen T.Higuchi's talk)

$\longrightarrow$ so that effect on CP asymmetry is there.

Event selection of □⁺□⁻

LR>0.825 LR≦0.825



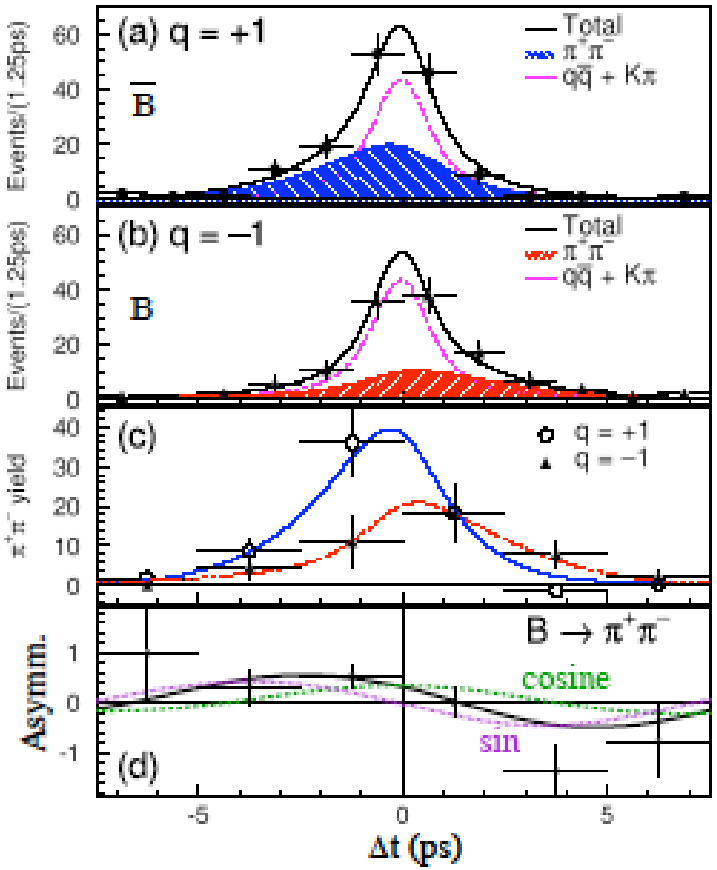
□□ enhanced

K□ enhanced

To suppress cont. bg, Likelihood Ratio(LR) is calculated by event shape and B's flight direction. Correlation with flav. tag is taken into account in the CP fit.

760 candidates; (163+24/-23 signals) are obtained by 78/fb.

Results for $S_{\pi\pi}$ and $A_{\pi\pi}$

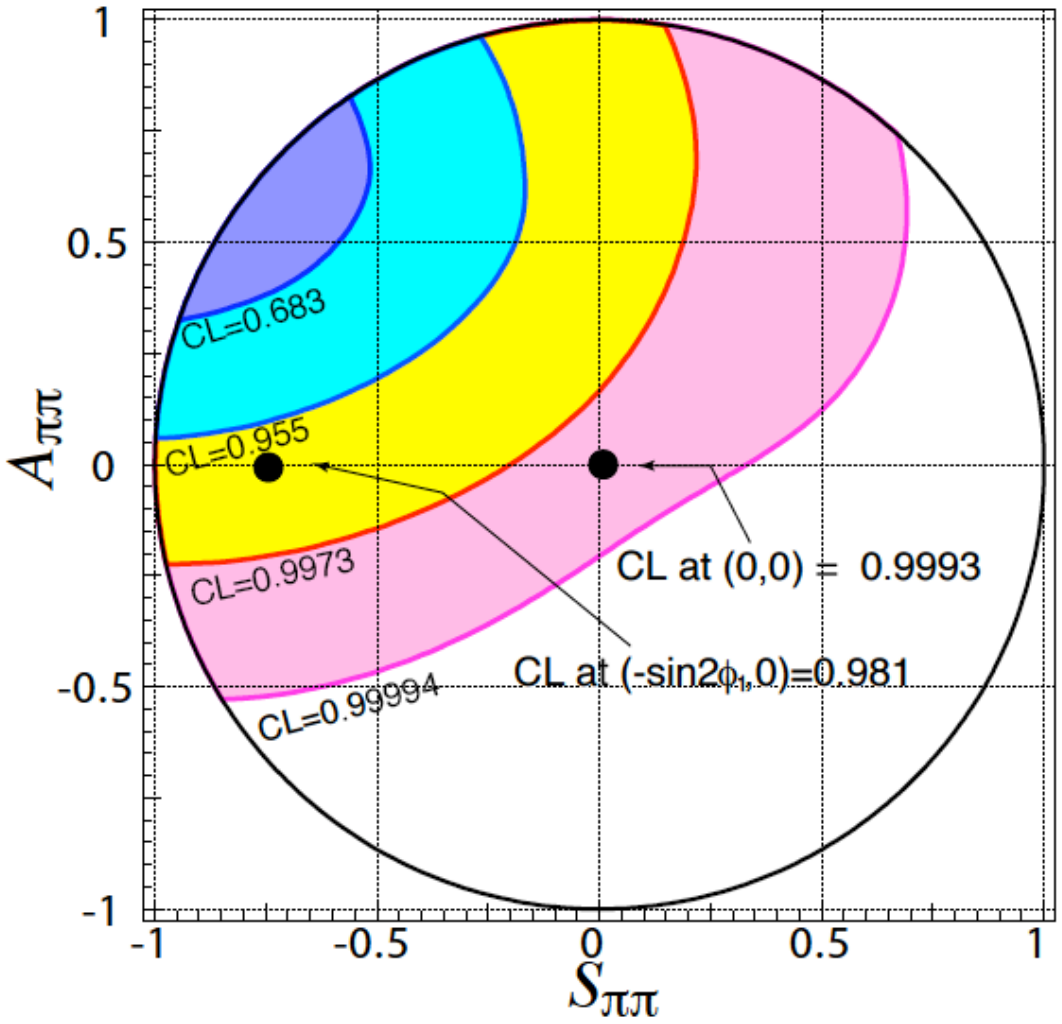


$S_{\pi\pi}$ = -1.23±0.41(stat)+0.08/-0.07(syst)

$A_{\pi\pi}$ = +0.77±0.27(stat)±0.08(syst)

Results for $S_{\pi\pi}$ and $A_{\pi\pi}$ (cont.)

Our result is 3.4σ away from CP conservation (i.e. $S_{\pi\pi}=A_{\pi\pi}=0$).



Conclusions and future

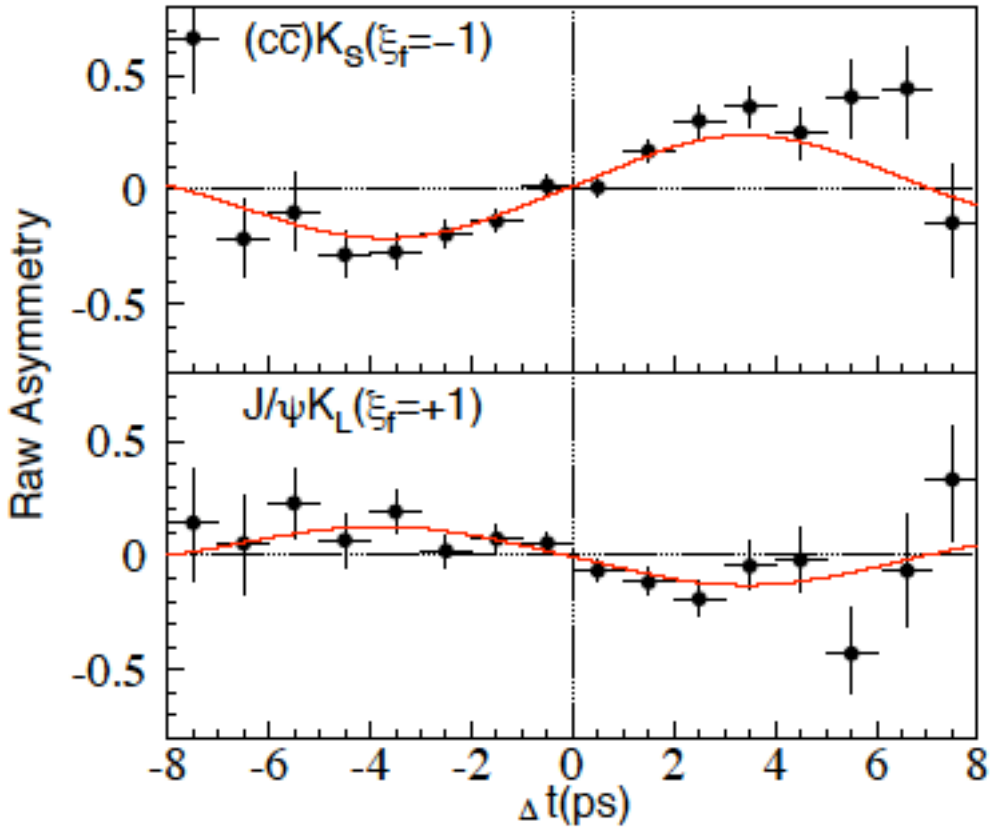
- $\sin 2\phi_1 = 0.733 \pm 0.057(\text{stat}) \pm 0.028(\text{syst})$
  - Moving into the precision measurement regime.
  - Relevant modes($b \to c\bar{c}d$) making progress.
- $B^0 \to \pi^+\pi^-$ is away from CP conserv.(3.4σ)
  - Analysis using 140/fb is in progress.

Now going to resume physics run with new SVD and smaller radius beampipe.

Backup slide

sin2β_1:charmonium + K_S and J/ψ K_L

Opposite asymmetry by diff. CP eigenvalue is clearly seen!



$B^{\pm} \longrightarrow D_{CP} K^{\pm}$

B→DK decay can be caused via Vcb and Vub, if D decays into CP eigenstate($D_1(K^+K^-, \pi^+\pi^-)$, $D_2(K_S\pi^0, K_S\omega, K_S\eta, K_S\phi, K_S\eta')$),

$\longrightarrow$ possibility to access γ_3

A_1=0.06±0,19(stat)±0.04(sys) A_2=-0.19±0.17(stat)±0.05(syst)