CP Violation Measurements in Hadronic *B* Decays at Belle

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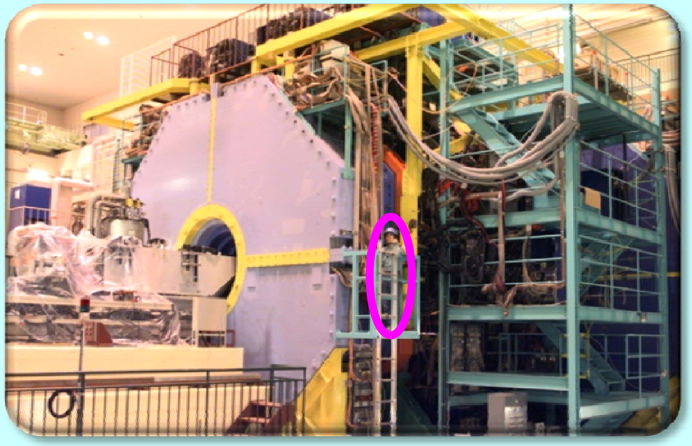
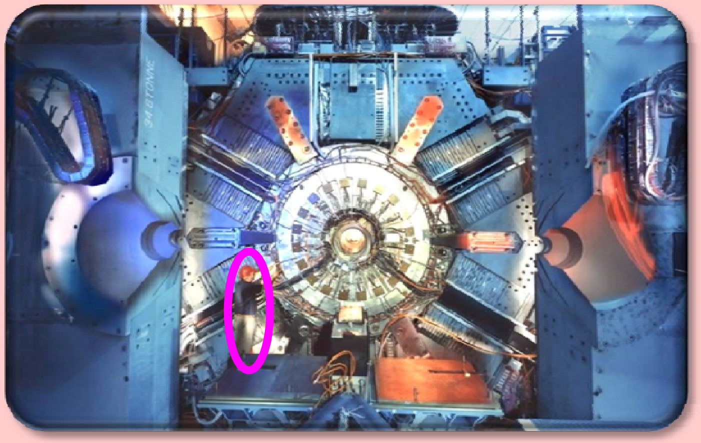
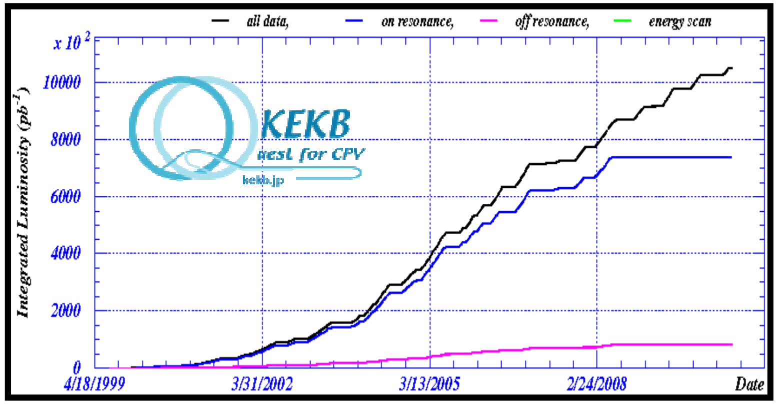
The Belle Collaboration

B-Factories in the World

	Accelerator	Detector
Belle (Japan)		
BaBar (US)		

Integrated Luminosities

- **Total recorded luminosity by Belle = 1052.79 fb^{-1}**
  - Belle finalized data taking on Jun.30th,2010.



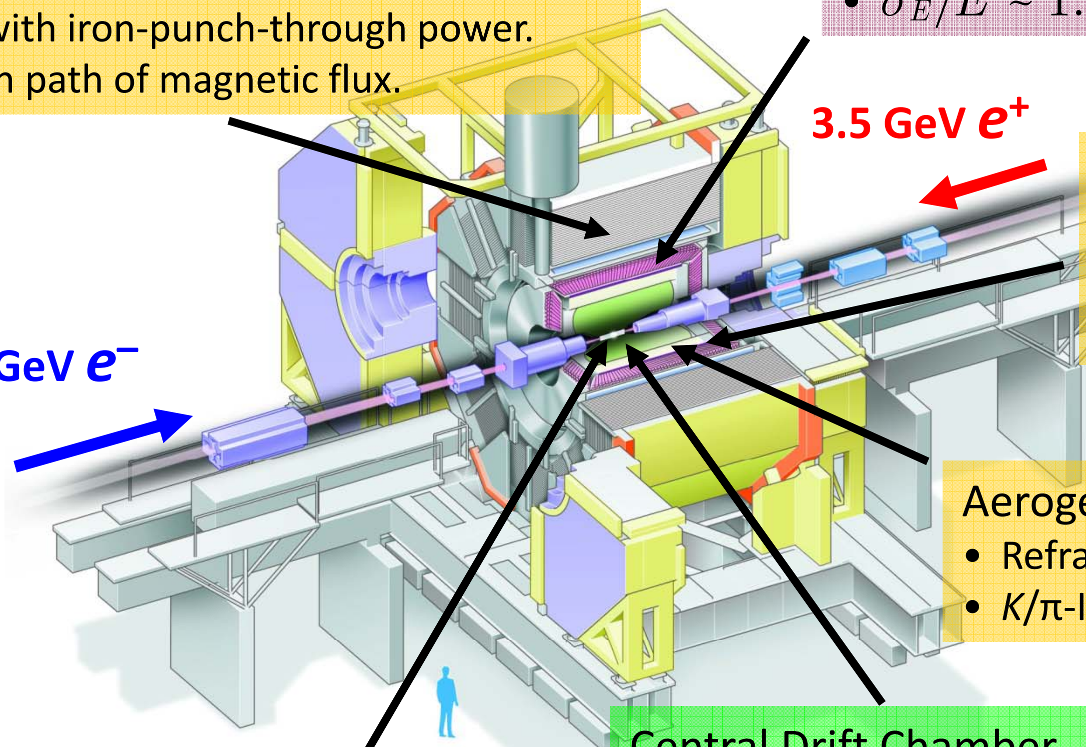
- **Total recorded luminosity by BaBar = 558 fb^{-1}**
  - BaBar finalized data taking in Apr.,2008.

- **We have recorded > 1.5 ab^{-1} data.**

Belle Detector

Electromagnetic Calorimeter
- CsI (Tl) crystal.
- Energy measurements of γ and $e^{\pm}$.
- $\sigma_E/E \sim 1.6\%$ @ 1 GeV.

$K_L\mu$ Detector
- Sandwich of 14 RPCs and 15 iron plates.
- μ-ID with iron-punch-through power.
- Return path of magnetic flux.



Time-of-Flight Counter
- Plastic scintillation counter.
- *K*/π-ID of high range *p*.
- Time resolution ~100 ps.

Aerogel Čerenkov Counter
- Refractive index *n*=1.01-1.03.
- *K*/π-ID of middle range *p*.

Silicon Vertex Detector
- Four detection layers.
- Vertex resolution ~ 100 μm.

Central Drift Chamber
- 8,400 sense wires along the beam direction.
- Momentum resolution $\sigma_{p_t}/p_t \sim 0.28\, p_t(\mathrm{GeV}) \oplus 0.3\%$
- PID with dE/dx measurement.
- 1.5 T magnetic field.

History of Belle

electron collides with positron yielding *B* meson.

- "Belle" is French word, which means beauty in English. The bottom quark is sometimes called a beauty quark

Belle · Peace · Beat · Bambi

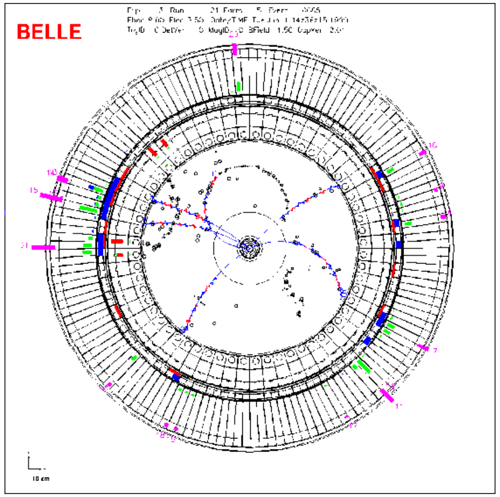
12:00 - 13:40 Lunch		
13:40 - 14:00	Computing/Reprocess/MC/GRID [PDF1][PDF2]	S. Nishida (KEK)
14:00 - 14:20	Belle radiation safety [PPT]	S. Uehara (KEK)
14:20 - 14:40	B->pi l nu untagged (cancelled)	H. Ha (Korea U)
16:00 - 16:20	New B recon [PDF]	T. Kuhr (Karlsruhe)
16:20 - 16:40	CPV in tau->K pi nu (strategy) [PDF]	M. Bischofberger (Nara)
19:00 - 20:00	Institutional Board meeting	L. Piilonen (VPI)
20:00 - 21:30	Executive Board meeting [PDF]	A. Bondar (BINP)/T.Browder (Hawaii)
11:40 - 12:00	DCPV in B->J/psi K+ [PPT][PDF]	K. Sakai (Niigata)
12:00 - 13:40 Lunch		
13:40 - 14:00	B->X_s l+ l- [PDF]	H. Nakayama (Tokyo)
14:00 - 14:20	B -> X_s eta [PDF]	K. Nishimura (Hawaii)
14:20 - 14:40	e+e- -> (ccbar)^2 [PDF]	J. Yoo (Korea)
16:40 - 17:00	EB report [PPT]	A. Bondar (BINP)/T.Browder (Hawaii)
17:00 - 17:20	Winter conference wrap-up/closeout [PPT][PDF]	Y. Sakai (KEK) / P. Chang (NTU)

History of Belle

- **Dec.,1998** **Detector construction had completed.**
- **Jan.,1999** **Cosmic-ray event taking had started.**
- **Feb.,1999** **The first e^+-e^- collision of KEKB.**
- **May.,1999** **The detector had been rolled in to the IR.**
- **Jun.4th,1999** **The first physics event.**

  …

- **9:00am Jun.30th,2010** **Data taking finished.**



CKM Matrix and Unitarity Triangle

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

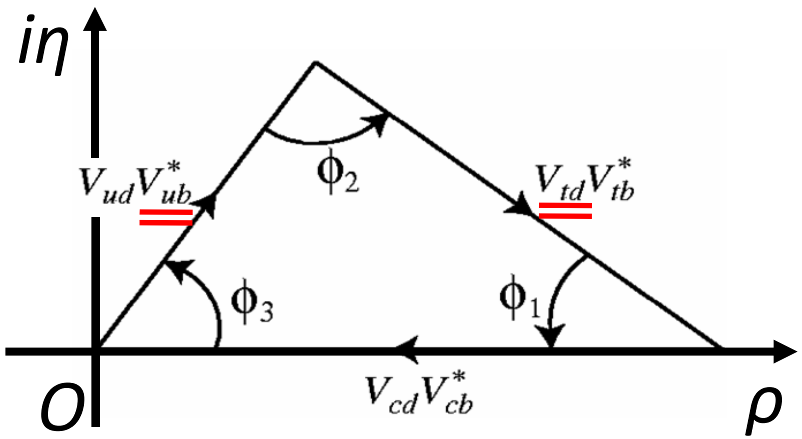
Wolfenstein Parameterization

KM ansatz: Irreducible complex phases (in V_{ub} and V_{td} in Wolfenstein parameterization) cause the *CP* violation.

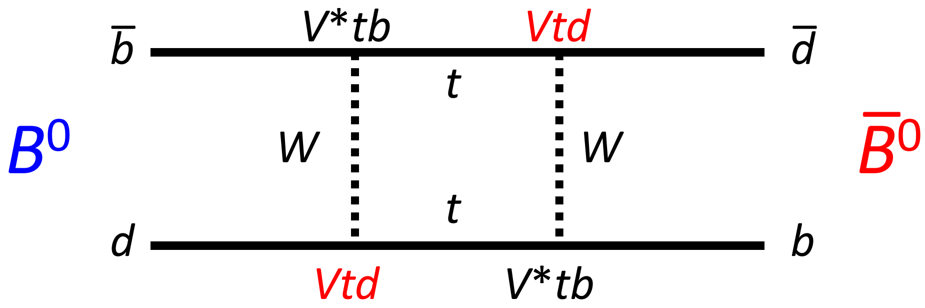
One of the unitarity conditions: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

Unitarity condition forms a untarity triangle in the complex plane.

$(\phi_1, \phi_2, \phi_3) = (\beta, \alpha, \gamma)$



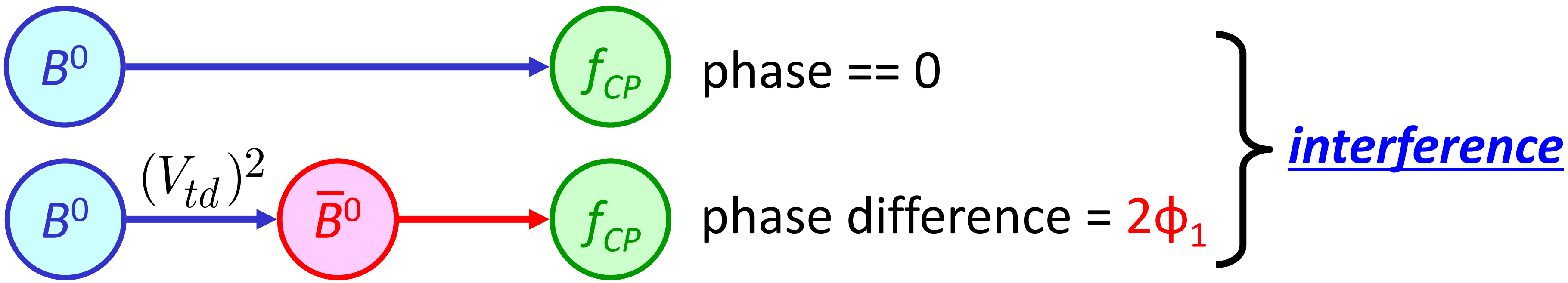
B^0-$\overline{B}^0$ Mixing and Mixing-Induced CPV



$$\overline{B}^0 \propto V_{td}^2 \propto e^{2i\phi_1}$$

B^0 and $\overline{B}^0$ mix with each other through a box diagram shown above.

Even if B^0 and $\overline{B}^0$ decay to the same final state, the phase of the decay amplitude may differ depending on the *B* flavor at the decay time.



CPV due to the interference is called "mixing-induced *CP* violation".

CP Violation in Proper-Time Distribution

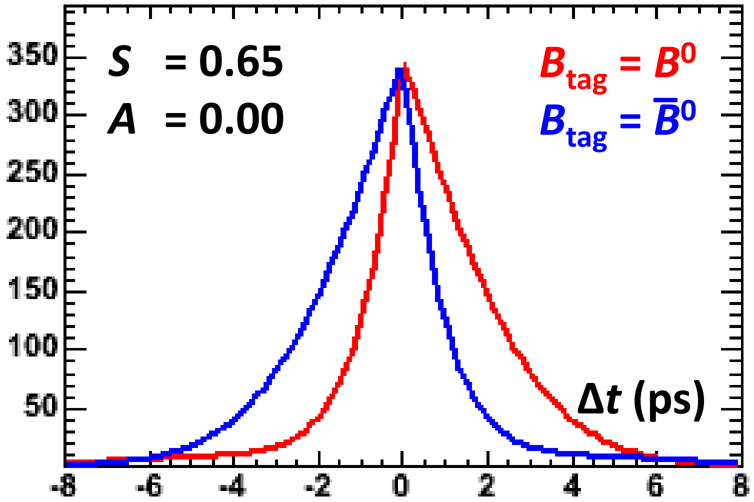
$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$$

The e^+-e^- collision produces a pair of *B* mesons through Υ(4*S*).

The mixing-induced *CP* violation manifests itself in the signed time duration "$\Delta t = t_{BCP} - t_{Btag}$", where

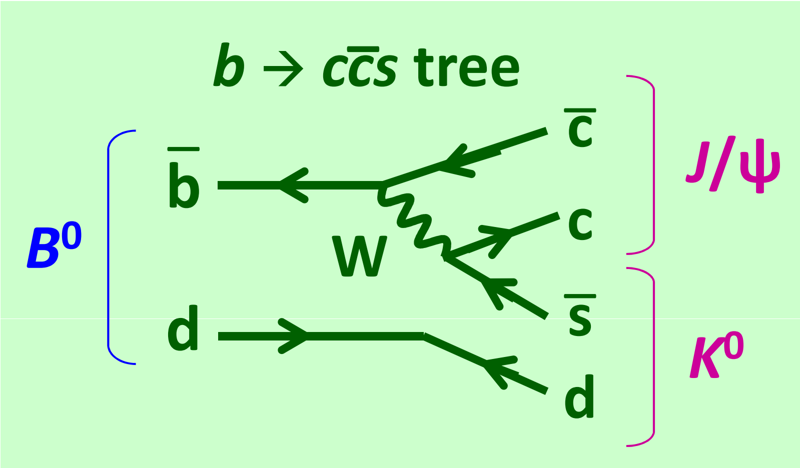
- t_{BCP} … time when one *B* decays to the *CP* eigenstate.
- t_{Btag} … time when the other *B* decays to the flavor-specific state.

$$P(\Delta t; S, A) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}[1 \pm (S \sin \Delta m_d \Delta t + A \cos \Delta m_d \Delta t)]$$



$B^0 \rightarrow J/\psi K^0$: Golden Modes for ϕ_1

- **The $B^0 \rightarrow J/\psi K^0$ is mediated by $b \rightarrow c\bar{c}s$ tree transition.**

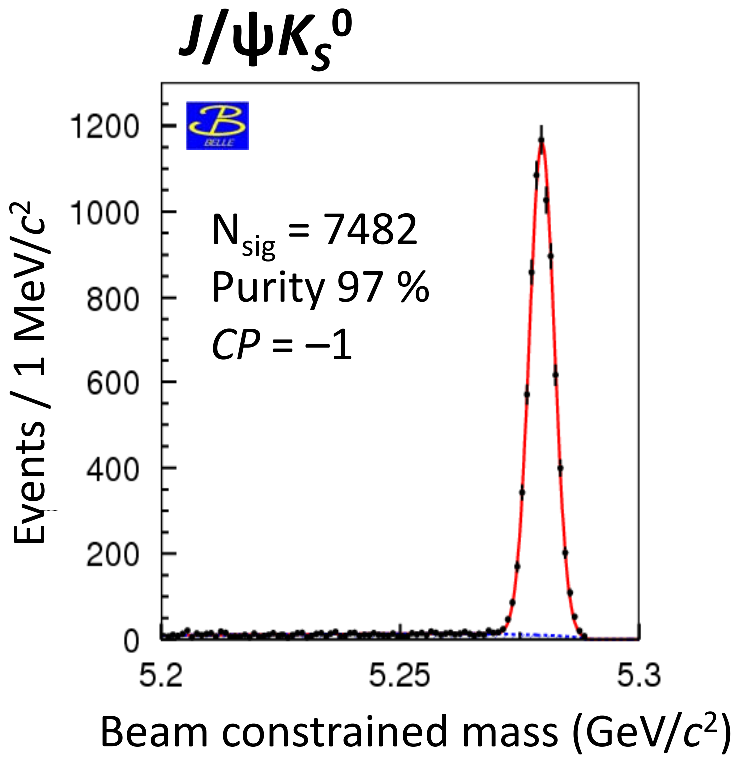


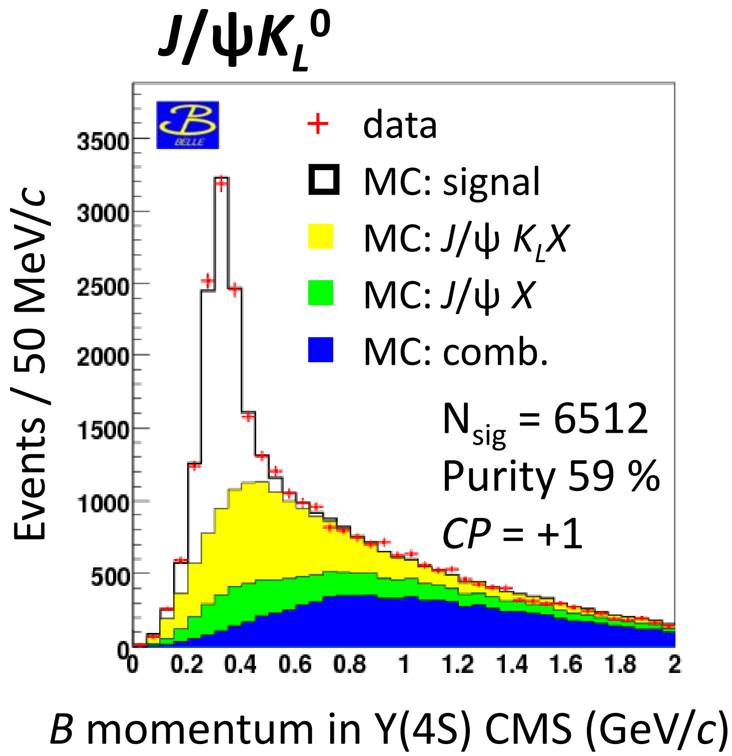
The decay diagram includes neither V_{ub} nor V_{td}.
→ The ϕ_1 is accessible.

- **SM prediction: $S = -\eta_{CP}\sin 2\phi_1$, $A \approx 0$**
  - Test of Kobayashi-Maskawa theory. → *Nobel prize in 2008*
  - Check for a NP phase with very precise unitarity tests.

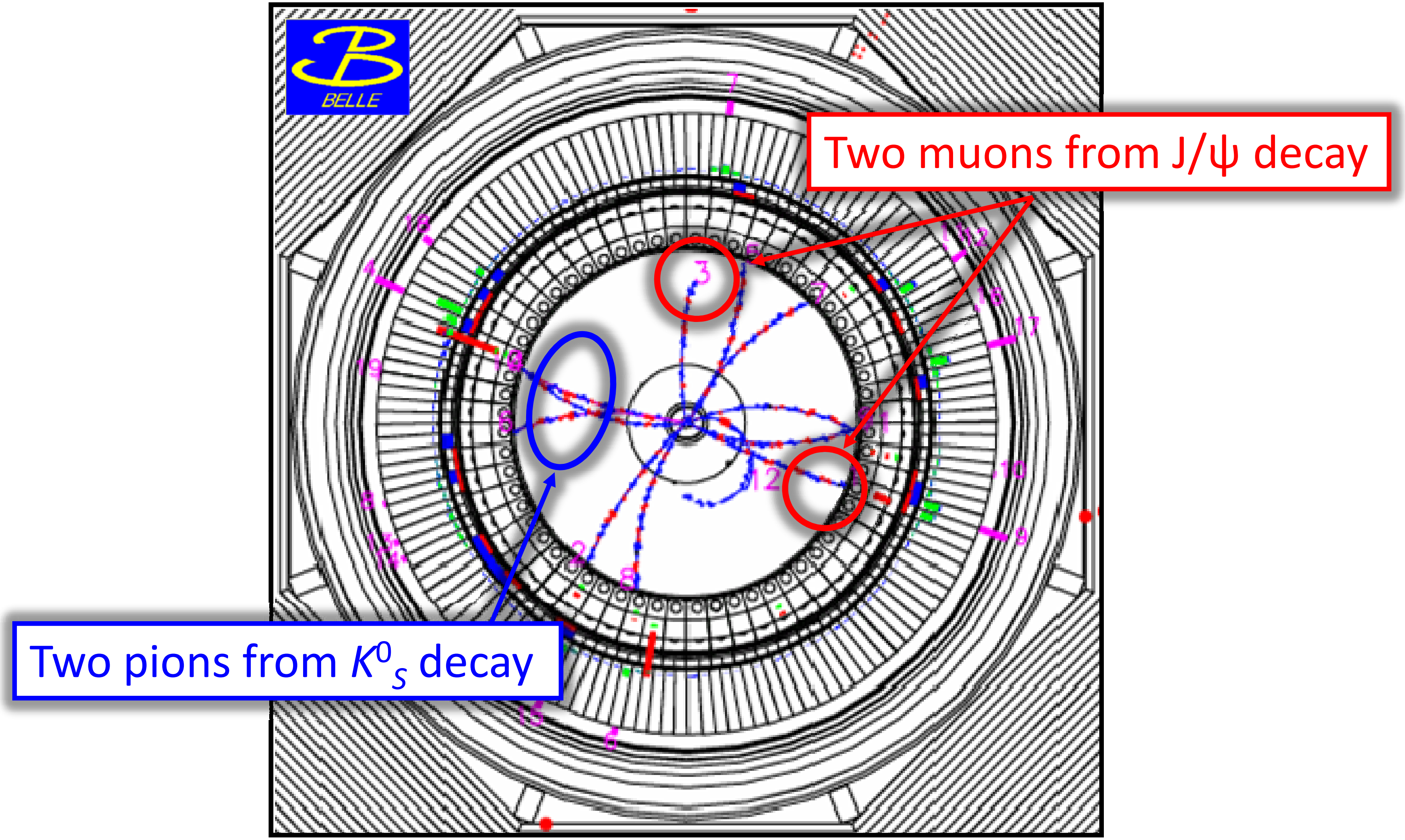
$B^0 \rightarrow J/\psi K^0$ Reconstruction (535M $B\bar{B}$)

from 535 x 10^6 $B\bar{B}$ pairs

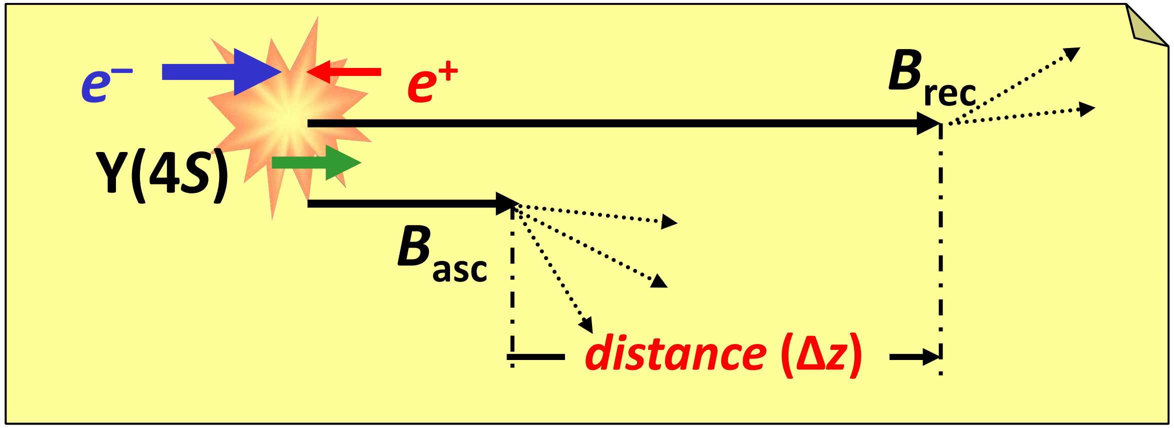




$B^0 \rightarrow J/\psi K_s^0$ Event Recorded by Belle

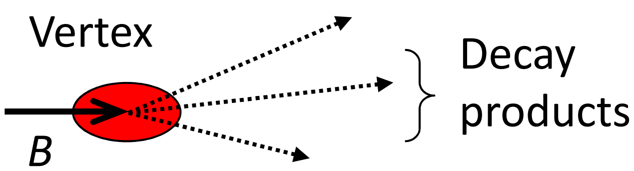


Δ*t* Reconstruction



$$\Delta t \approx \Delta z / \beta\gamma c$$

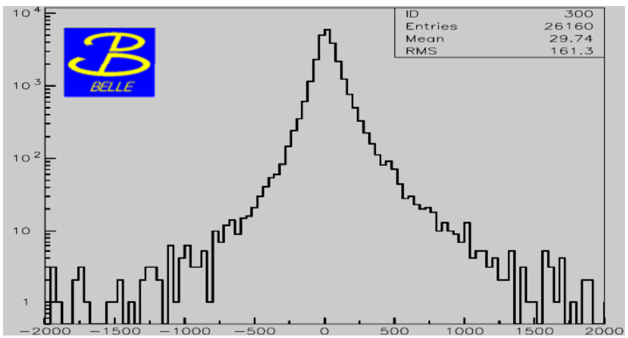
Δz ~ 200 μm; βγc ~ 0.425



Minimizes … $\chi^2_{\text{tracks}} \equiv \delta\mathbf{h}_i^T V_i \delta\mathbf{h}_i + \delta\mathbf{h}_j^T V_j \delta\mathbf{h}_j + \cdots$

h_i = *i*-th track's helix parameters

V_i = Inverse matrix of the *i*-th track's error matrix



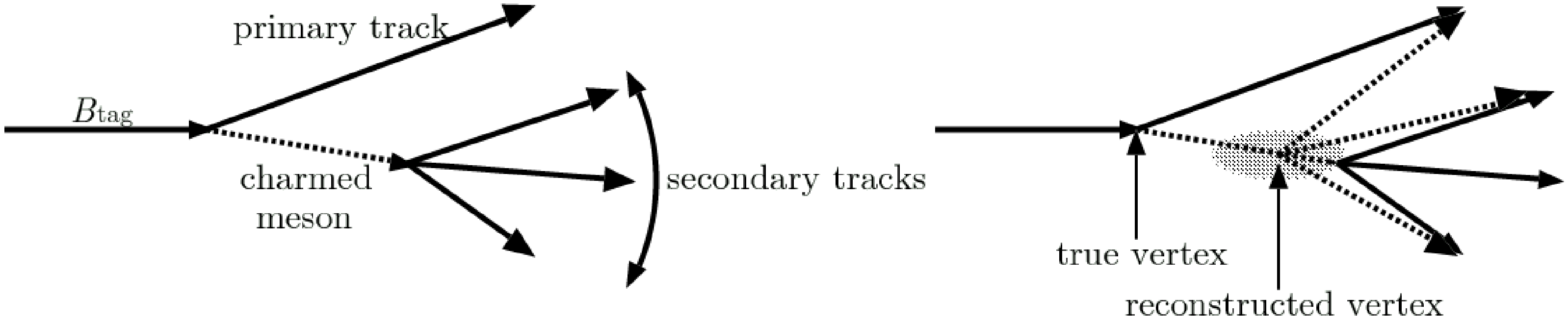
Vertex residual (μm)

RMS of vertex residual ~ 120 μm

residual distribution == resolution

Δ*t* Resolution Model

- **Convolution of following 4 items:**
  - Detector resolution.
  - Effect on B_{asc} vertex by secondary tracks.



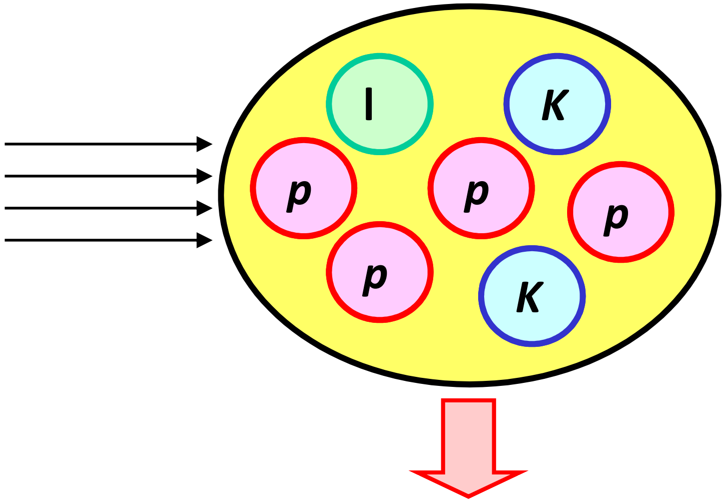
  - Smearing due to kinematical approximation:

$$\Delta t \simeq \frac{\Delta z}{c(\beta\gamma)_{\Upsilon}}$$

  - Outlier tail.

Flavor Tagging (Determine $B_{tag} = B^0/\bar{B}^0$)

B_{tag} decay



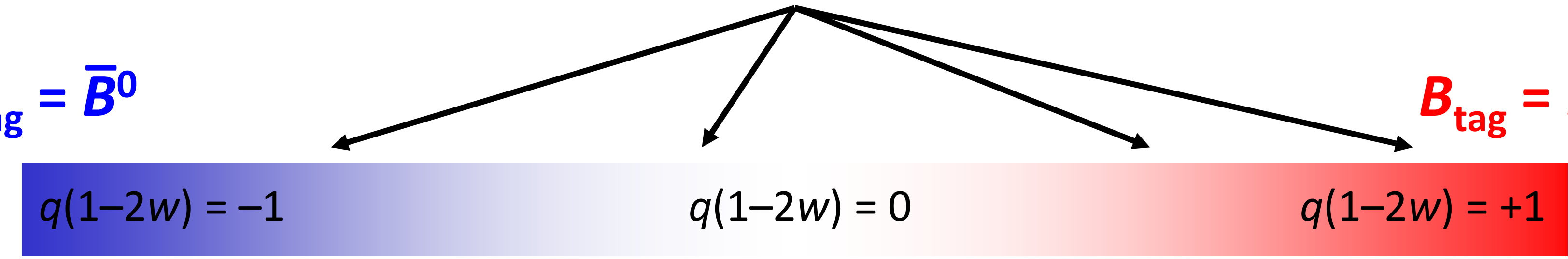
Measurements are

- Particle spices
- Charge
- Momentum, etc…

Assign flavor/ambiguity to each particle using measured info.
Combine flavors/ambiguities of all particles.
Determine flavor (q:±1) of the B_{tag} and ambiguity (w :0…1).

$B_{tag} = \bar{B}^0$

$B_{tag} = B^0$

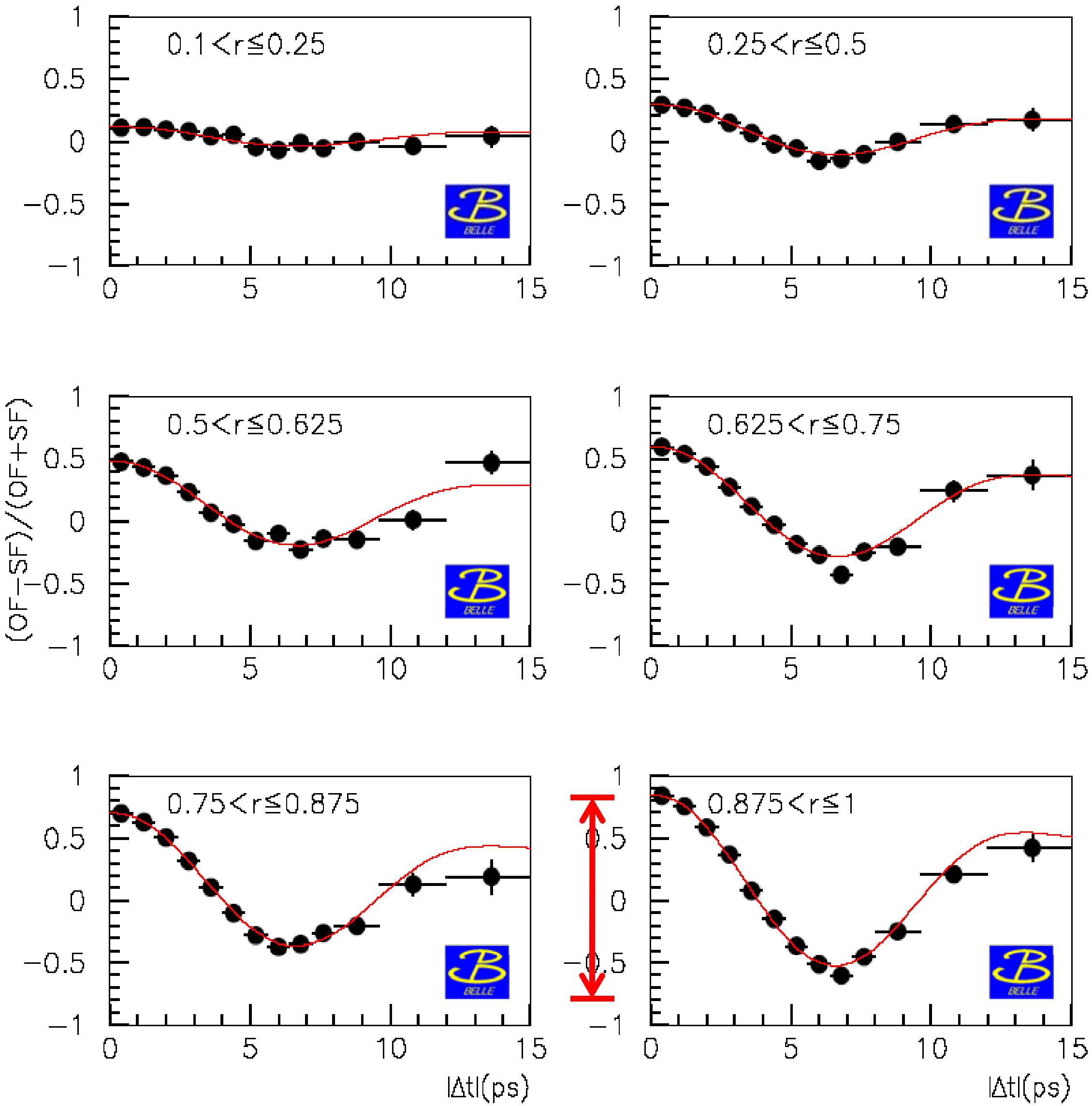


unambiguous

no flavor info.

unambiguous

Wrong Tagging Probability: *w*

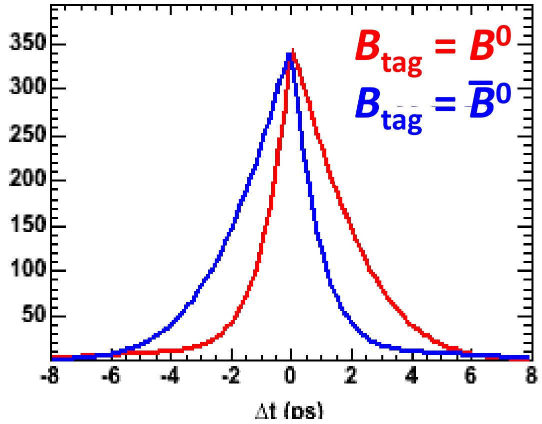


Wrong tag probability, *w*, is calibrated using the B^0-$\overline{B}^0$ mixing of the real data.

$$A_{\mathrm{chg}} = \frac{P_{OF} - P_{SF}}{P_{OF} + P_{SF}} = \cos \Delta m_d \Delta t$$

$$A_{\mathrm{chg}}^{\mathrm{meas.}} = (1 - 2w_{\mathrm{ave}}) \cos \Delta m_d \Delta t$$

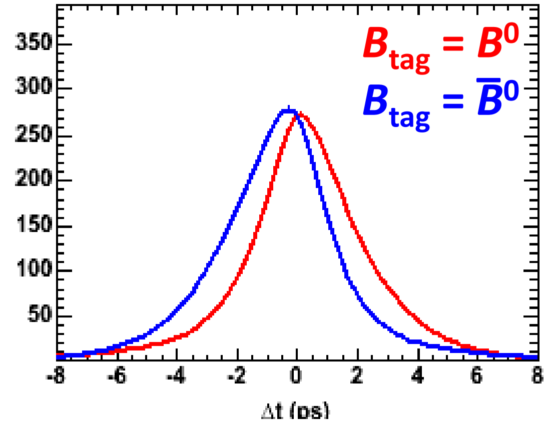
Unbinned-Maximum Likelihood Fit



Δt resolution

Wrong tagging probability

Background contamination



$$P(\Delta t, q; S, A) =$$

$$f_{\text{sig}} \frac{1}{4\tau_{B^0}} \times [1 + q \cdot (\underline{1 - 2w}) \cdot (A \cos \Delta m_d \Delta t + S \sin \Delta m_d \Delta t)] \otimes \underline{R(\Delta t)}$$

Wrong tagging probability — Δt resolution

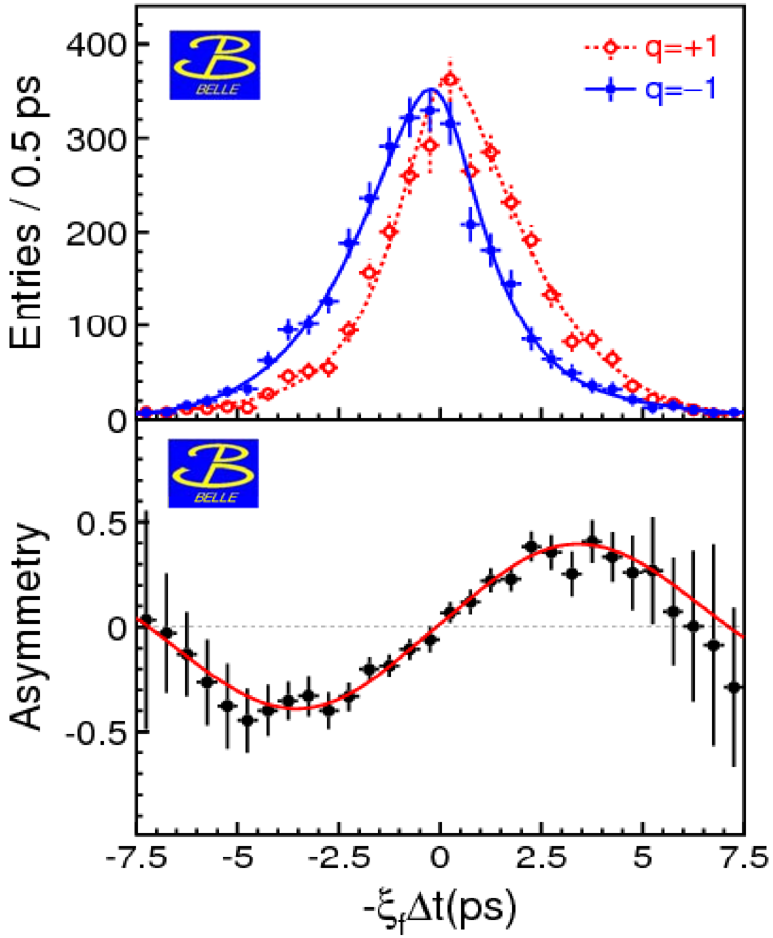
$$+(1 - f_{sig}) P_{\text{bkg}}(\Delta t)$$ ← Background

_CP_-violating parameter determination from the UML fit

$$\mathcal{L}(S, A) = \prod_{i=1}^{Nev} P(\Delta t_i, q_i; S, A) \quad \Rightarrow \quad \frac{\partial^2 \mathcal{L}}{\partial S \, \partial A} = 0$$

S and A from $B \to J/\psi K^0$ (535M $B\bar{B}$)

$B_{CP} \to J/\psi(K_S^0 + K_L^0)$



Phys. Rev. Lett. **98**, 031802 (2007).

$$S = +0.642 \pm 0.031 \pm 0.017$$

$$A = +0.018 \pm 0.021 \pm 0.014$$

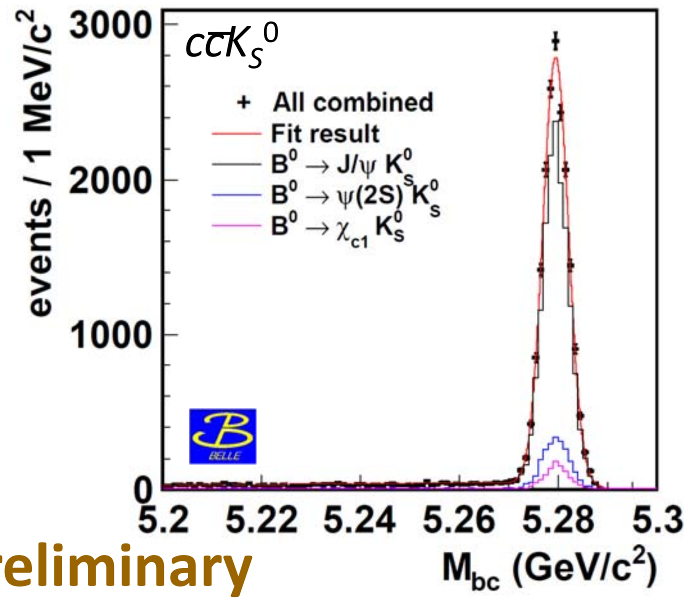
(stat) (syst)

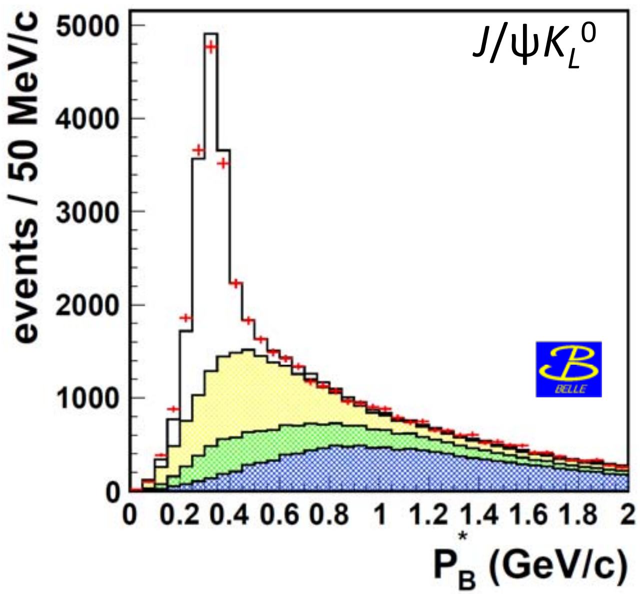
Dominant systematic error sources

Category	S	A
Vertex reconstruction	0.012	0.009
Δt resolution function	0.006	0.001
Signal fraction	0.006	0.002
Wrong tag fraction	0.004	0.003
Possible fit bias	0.007	0.004
Tag-side interference	0.001	0.009
Others	< 0.001	< 0.001

S and *A* Update (772M $B\bar{B}$)

from 772 x 10^6 $B\bar{B}$ pairs = final Belle data sample





Belle preliminary

	$J/\psi K_S^0$	$J/\psi K_L^0$	$\psi(2S)K_S^0$	$\chi_{c1}K_S^0$	N_{BB} (x 10^6)
Signal yield ('10)	**12727±115**	**10087±154**	**1981±46**	**943±33**	**772**
Purity ('10) [%]	**97**	**63**	**93**	**89**	
Signal yield ('06)	7484±87	6512±123	–	–	535
Purity ('06) [%]	97	59	–	–	

We have more yields than the N_{BB} increase, for we have improved the track finding algorithm.

Latest Status of *S* and *A* Measurements

- **We are finalizing the *S* and *A* in $b \to c\bar{c}s$ modes using the full data set.**

- **Preliminarily expected statistical sensitivity**

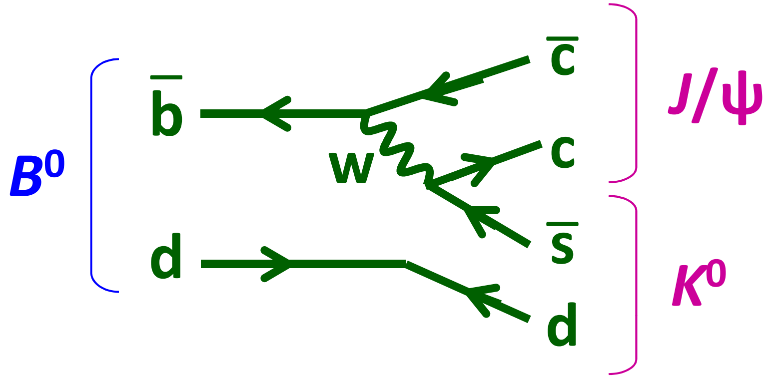
$$\sigma S \approx 0.024, \quad \sigma A \approx 0.016$$

  - Predicted by a signal-yield scale applied to the ICHEP2006 results.
  - The statistical uncertainties are getting close to the systematic ones.

$b \to sq\bar{q}$ Time-Dependent *CP* Violation

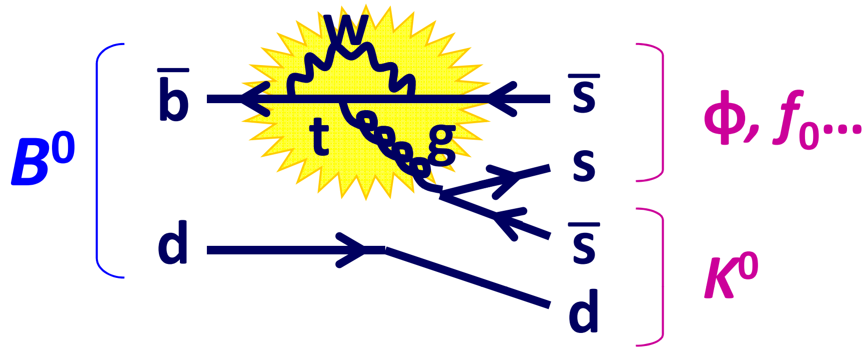
- **Physics motivation for the *CP* violation measurement in the $b \to sq\bar{q}$ transition**

$b \to c\bar{c}s$ tree



$S = \sin 2\phi_1$, $A \approx 0$

$b \to sq\bar{q}$ penguin



$S = \sin 2\phi_1^{\text{eff}}$, $A \approx 0$

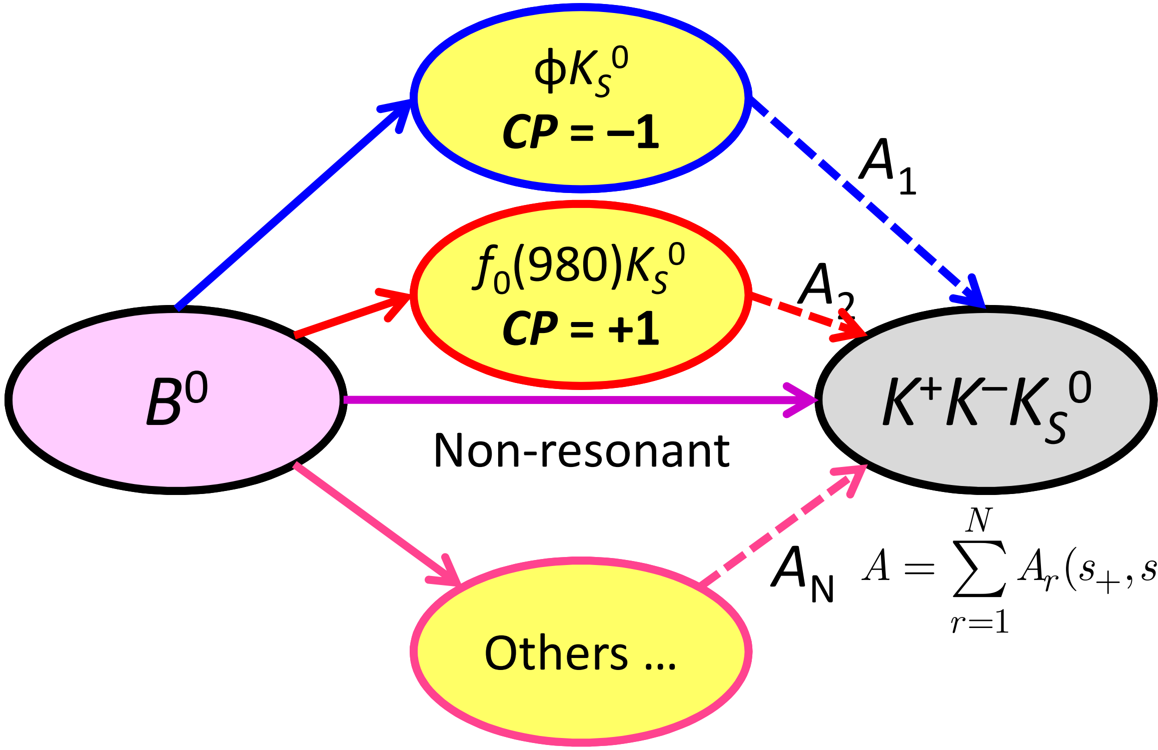
In case of an extra *CP* phase from NP in the penguin loop →

$$\delta \sin 2\phi_1 = \sin 2\phi_1^{\text{eff}} - \sin 2\phi_1 \neq 0$$

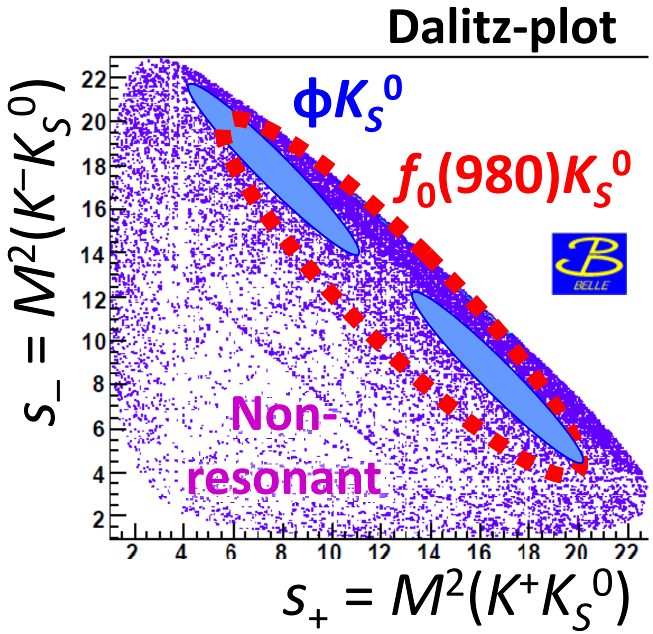
Interference in $B^0 \to K^+K^-K_S^0$ Final State

- **$B^0 \to K^+K^-K_S^0$ final state has several different paths.**
  - Fit to the Dalitz plot is need for the correct CPV measurement.

Dalitz plot



$$A = \sum_{r=1}^{N} A_r(s_+, s_-)$$

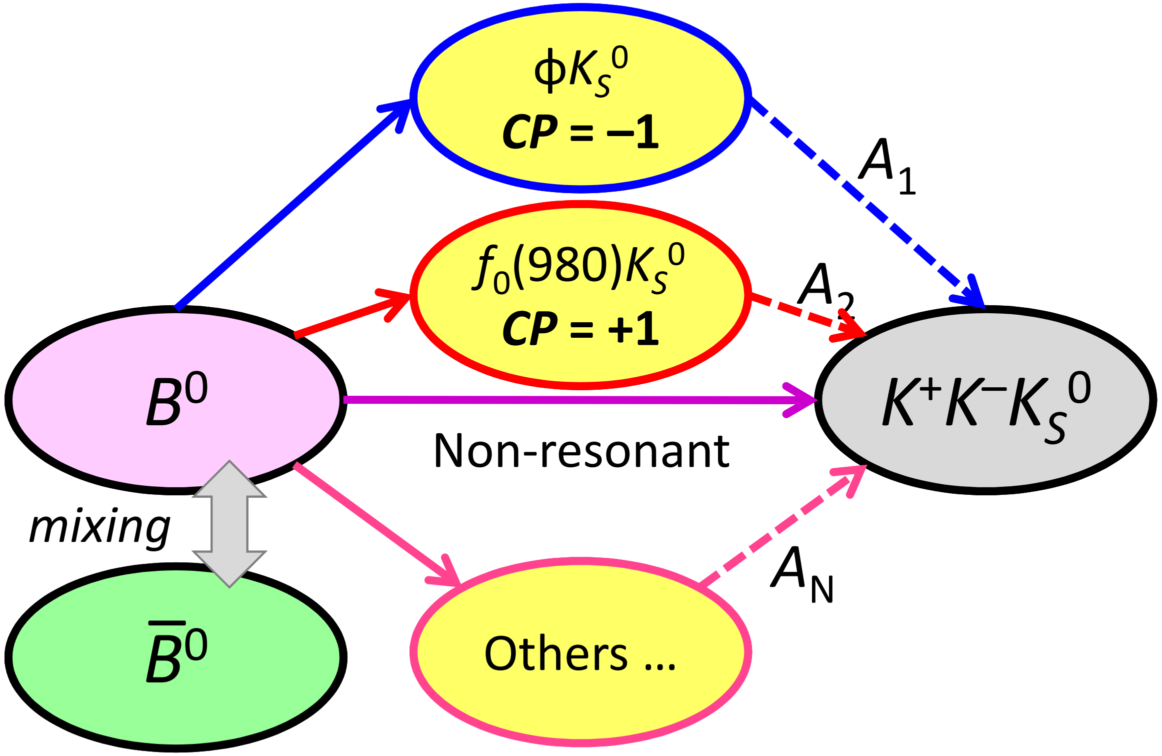


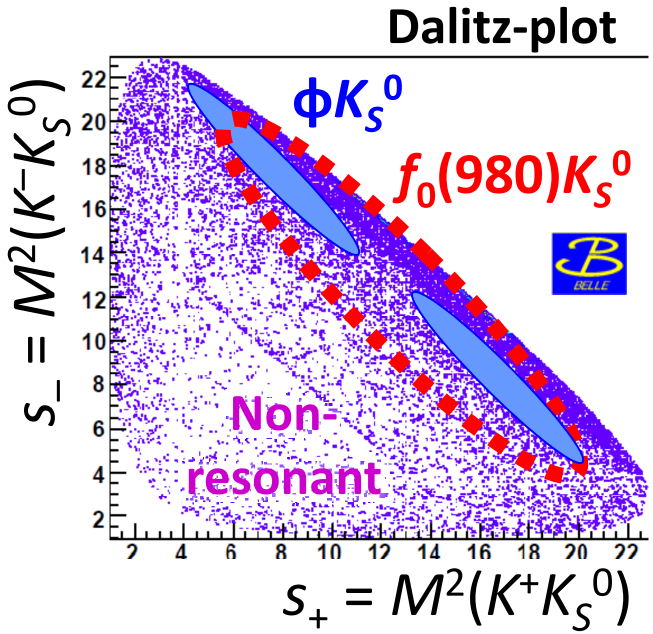
Interference in $B^0 \rightarrow K^+K^-K_S^0$ Final State

- **$B^0 \rightarrow K^+K^-K_S^0$ final state has several different paths.**
  - Fit to the Dalitz plot is need for the correct CPV measurement.

Dalitz plot

B^0-$\bar{B}^0$ mixing

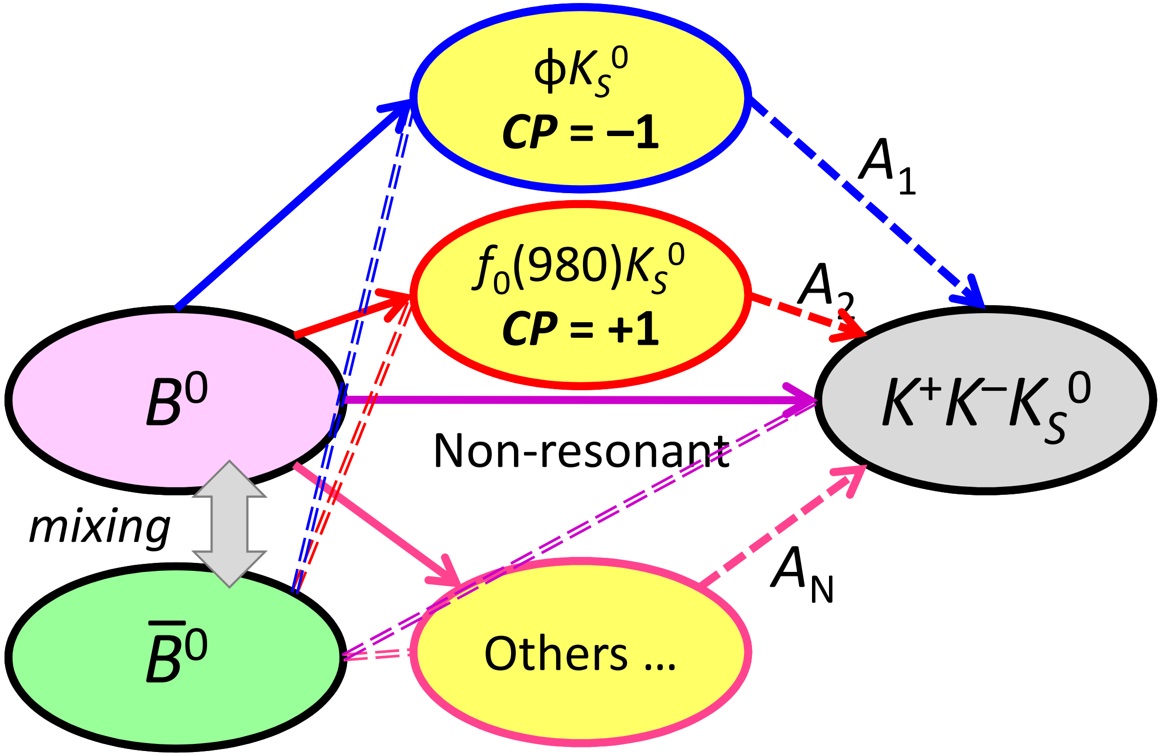


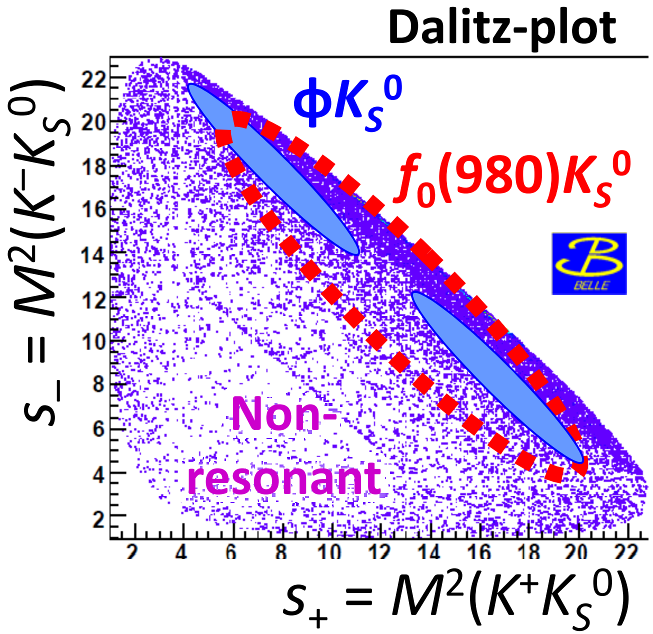


Interference in $B^0 \to K^+K^-K_S^0$ Final State

- **$B^0 \to K^+K^-K_S^0$ final state has several different paths.**
  - Fit to the Dalitz plot is need for the correct CPV measurement.

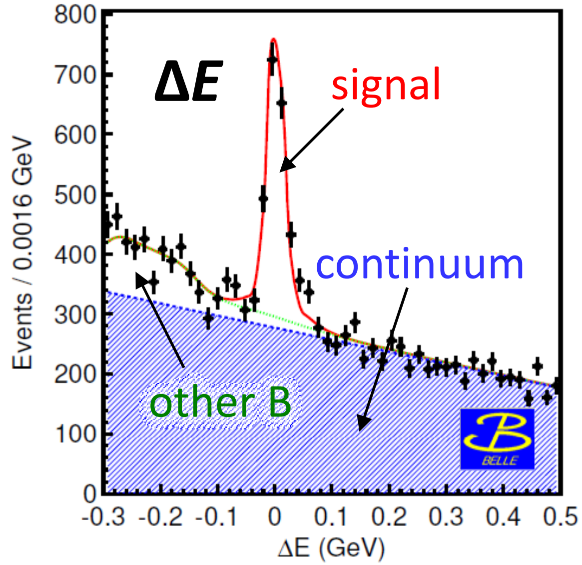
Dalitz plot + B^0-$\bar{B}^0$ mixing → CPV measurement

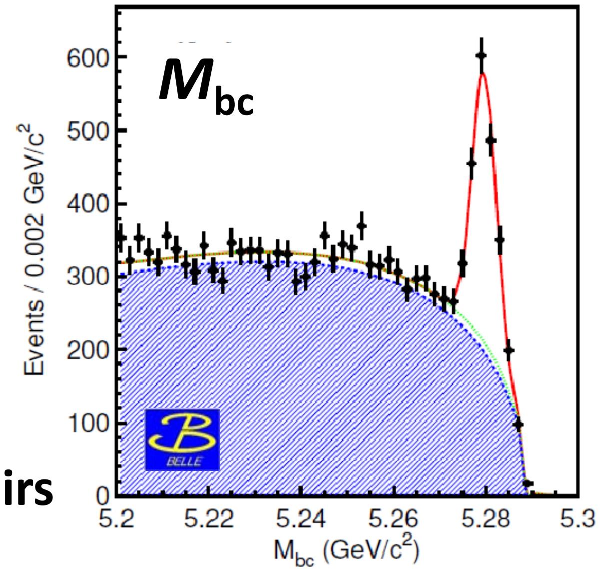




$B^0 \to K_S^0 K^+ K^-$ Reconstruction

- **# of reconstructed events**
  - Estimation by unbinned-maximum-likelihood fit to the ΔE-M_{bc} distribution
- **$B^0 \to K_S^0 K^+ K^-$ signal = 1176 ± 51**
  - Reconstruction efficiency ~16%
- **Background**
  - **Continuum ~ 47%**
  - **Other B decays ~ 3%**
  - Signal purity ~ 50%





from 657 x 10^6 $B\bar{B}$ pairs

CP Violation Measurement in $B^0 \to K_S^0 K^+ K^-$

- **The (ϕ_1, *A*) are determined by an unbinned-ML fit onto the time-dependent Dalitz distribution.**
  - The signal probability density function:

$$P_{\rm sig}(\Delta t, q; s_+, s_-) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left[\left(|\mathcal{A}|^2 + |\bar{\mathcal{A}}|^2\right) - q\left(|\mathcal{A}|^2 - |\bar{\mathcal{A}}|^2\right)\cos\Delta m_d \Delta t + 2q\mathcal{I}m\left(\bar{\mathcal{A}}\mathcal{A}^*\right)\sin\Delta m_d \Delta t\right]$$

- **Four parameter convergences from the fit**

	Solution #1	Solution #2	Solution #3	Solution #4
$\mathcal{A}_{CP}(f_0(980)K_S^0)$	$-0.30 \pm 0.29 \pm 0.11 \pm 0.09$	$-0.20 \pm 0.15 \pm 0.08 \pm 0.05$	$+0.02 \pm 0.21 \pm 0.09 \pm 0.09$	$-0.18 \pm 0.14 \pm 0.08 \pm 0.06$
$\phi_1^{\rm eff}(f_0(980)K_S^0)$	$(31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$	$(26.1 \pm 7.0 \pm 2.4 \pm 2.5)^\circ$	$(25.6 \pm 7.6 \pm 2.9 \pm 0.8)^\circ$	$(26.3 \pm 5.7 \pm 2.4 \pm 5.8)^\circ$
$\mathcal{A}_{CP}(\phi(1020)K_S^0)$	$+0.04 \pm 0.20 \pm 0.10 \pm 0.02$	$+0.08 \pm 0.18 \pm 0.10 \pm 0.03$	$-0.01 \pm 0.20 \pm 0.11 \pm 0.02$	$+0.21 \pm 0.18 \pm 0.11 \pm 0.05$
$\phi_1^{\rm eff}(\phi(1020)K_S^0)$	$(32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$	$(26.2 \pm 8.8 \pm 2.7 \pm 1.2)^\circ$	$(27.3 \pm 8.6 \pm 2.8 \pm 1.3)^\circ$	$(24.3 \pm 8.0 \pm 2.9 \pm 5.2)^\circ$
$\Delta(\ln\mathcal{L})$	-1.568	0	-2.956	-5.155

  - They are statistically consistent with each other.
  - Which is the most preferable solution?

CP Violation Measurement in $B^0 \to K_S^0 K^+ K^-$

- **Solution #1 is most preferred from an external information.**

Intermediate state-by-state fraction

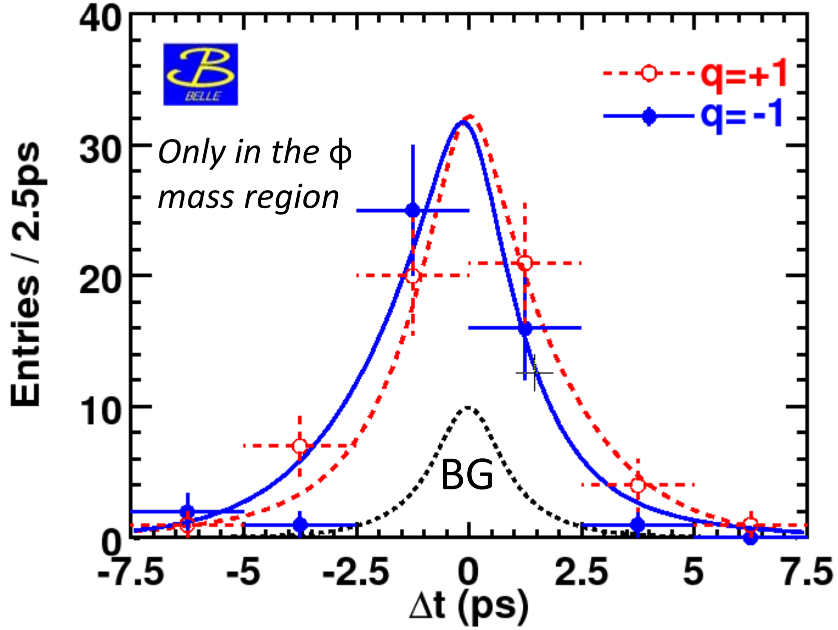
Parameter	Solution 1	Solution 2	Solution 3	Solution 4
$f_{f_0 K_S^0}$	26.0 ± 7.4	54.0 ± 9.6	26.4 ± 7.8	68.1 ± 12.3
$f_{\phi K_S^0}$	14.2 ± 1.2	14.5 ± 1.2	14.2 ± 1.2	14.4 ± 1.2
$f_{f_X K_S^0}$	5.10 ± 1.39	5.89 ± 1.86	39.6 ± 2.6	59.0 ± 3.0
$f_{\chi_{c0} K_S^0}$	3.73 ± 0.74	3.71 ± 0.73	3.68 ± 0.73	4.15 ± 0.79
$f_{(K^+K^-)_{\rm NR} K_S^0}$	138.4 ± 44.8	175.0 ± 52.6	157.4 ± 29.5	48.1 ± 11.7
$f_{(K_S^0 K^+)_{\rm NR} K^-}$	1.65 ± 4.17	21.0 ± 17.3	4.63 ± 6.76	7.87 ± 4.78
$f_{(K_S^0 K^-)_{\rm NR} K^+}$	26.0 ± 12.9	78.0 ± 36.2	38.6 ± 18.1	6.27 ± 3.81
$F_{\rm tot}$	215.2 ± 47.5	352.0 ± 66.8	284.5 ± 36.3	207.9 ± 18.4

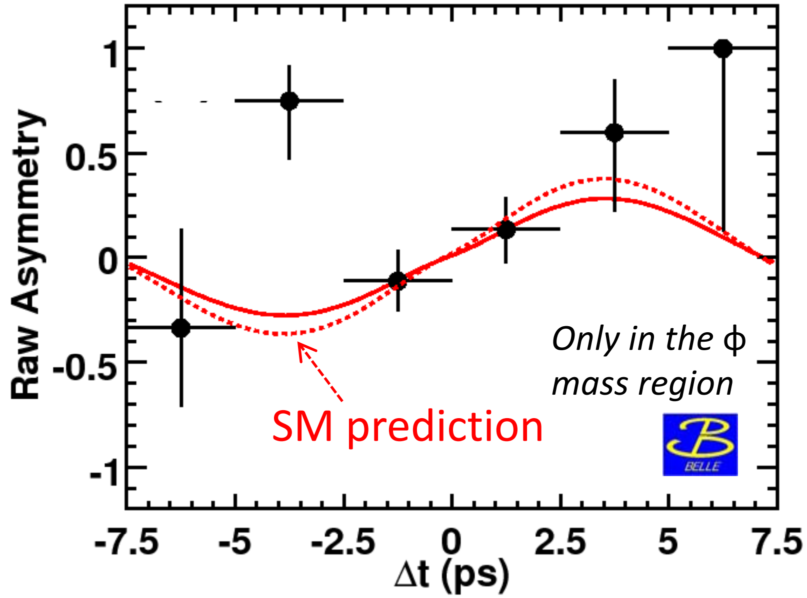
- The $Br(f_0(980) \to \pi^+\pi^-)/Br(f_0(980) \to K^+K^-)$ favors solutions with low $f_0(980)K_S^0$ fraction, when compared to the PDG.
- The $Br(f_0(1500) \to \pi^+\pi^-)/Br(f_0(1500) \to K^+K^-)$ favors solutions with low $f_0(1500)K_S^0$ fraction, when compared to the PDG.
  - Here, we assume f_X as $f_0(1500)$.

CP Violation Measurement in $B^0 \to K_S^0 K^+ K^-$

[solution #1]

submitted to PRD;
hep-ex/1007.3848 (2010)





657 x 10^6 $B\bar{B}$ pairs

ϕK_S^0	$\phi_1^{\rm eff} = (32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$	$A_{CP} = +0.04 \pm 0.20 \pm 0.10 \pm 0.02$
$f_0(980)K_S^0$	$\phi_1^{\rm eff} = (31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$	$A_{CP} = -0.30 \pm 0.29 \pm 0.11 \pm 0.09$

Belle preliminary The third error accounts for an uncertainty arises from Dalitz model.

$B^0 \to K_S^0 K^+ K^-$ CPV Systematic Uncertainty

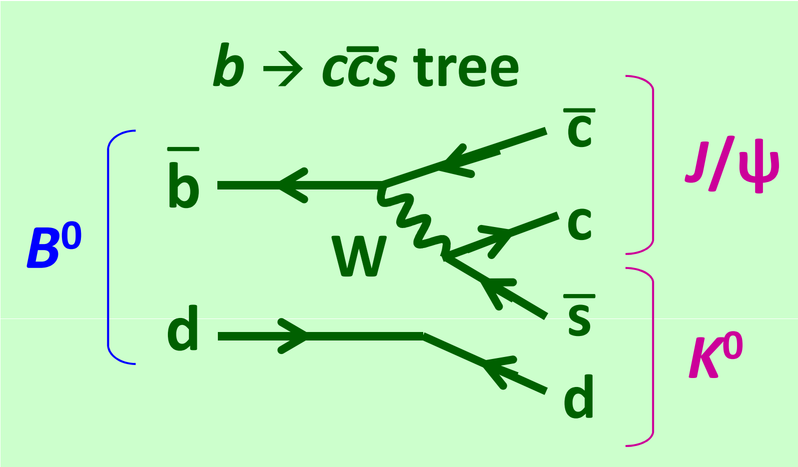
- **List of the systematic-uncertainty sources**

for the solution #1

	$f_0(980)K_S^0$	$\phi(1020)K_S^0$	others	$f_0(980)K_S^0$	$\phi(1020)K_S^0$	others
Category	$\delta\phi_1^{\mathrm{eff}}(°)$			$\delta\mathcal{A}_{CP}$		
Vertex Reconstruction	1.3	1.2	1.1	0.046	0.080	0.024
Wrong tag fraction	0.2	0.2	0.2	0.004	0.006	0.003
Δt resolution function	1.9	1.9	1.5	0.018	0.011	0.010
Possible fit bias	2.2	0.9	0.4	0.067	0.008	0.026
Physics parameters	0.1	0.0	0.1	0.002	0.001	0.001
Background PDF	1.0	0.8	0.8	0.037	0.012	0.016
Signal fraction	0.2	0.4	0.3	0.013	0.006	0.004
Misreconstruction	0.1	0.0	0.0	0.000	0.000	0.001
Efficiency	0.2	0.2	0.1	0.011	0.004	0.005
Signal model	0.7	0.4	0.4	0.040	0.017	0.006
Tag-side interference	0.0	0.0	0.0	0.043	0.054	0.066
Total w/o Dalitz model	3.4	2.6	2.1	0.110	0.100	0.078
Dalitz model	4.0	1.4	2.5	0.089	0.019	0.032

$B^0 \rightarrow J/\psi K^0$: Golden Modes for ϕ_1

- **The $B^0 \rightarrow J/\psi K^0$ is mediated by $b \rightarrow c\bar{c}s$ tree transition.**



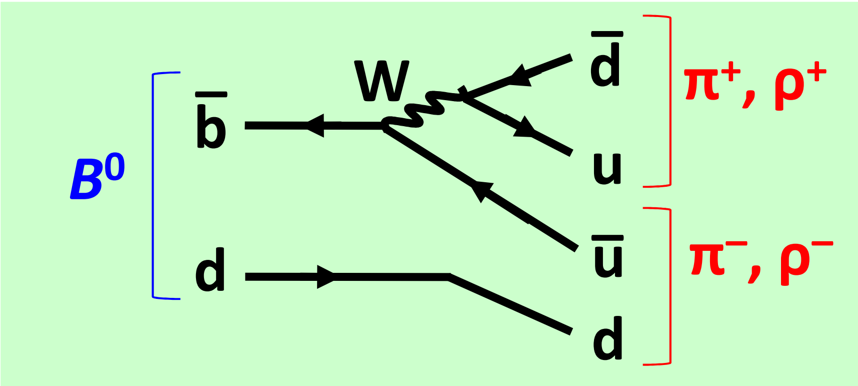
The decay diagram includes neither V_{ub} nor V_{td}.
→ The ϕ_1 is accessible.

- **SM prediction: $S = -\eta_{CP}\sin 2\phi_1$, $A \approx 0$**
  - Test of Kobayashi-Maskawa theory. → *Nobel prize in 2008*
  - Check for a NP phase with very precise unitarity tests.

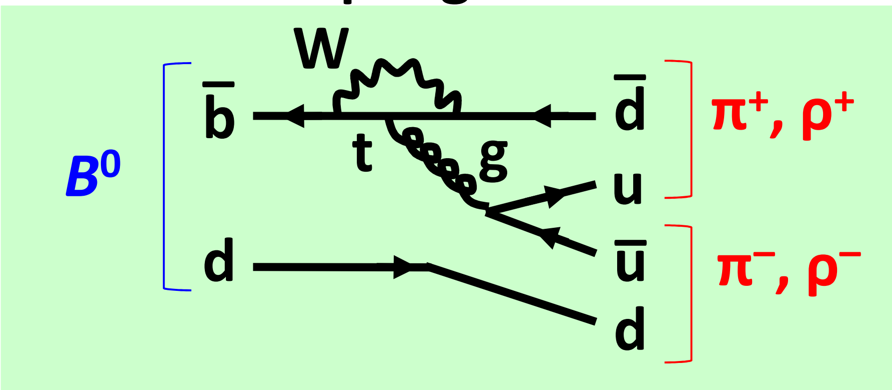
Measurement of ϕ_2

- ϕ_2 can be measured using $B^0 \rightarrow \pi^+\pi^-, \rho^+\rho^-$ decays.

tree



penguin

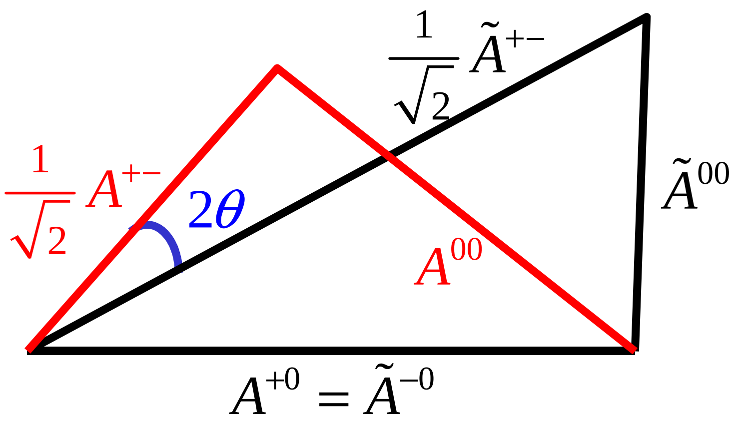


If no penguin contribution … → $S = -\sin 2\phi_2,\ A = 0$

In presence of penguin, $S = \sqrt{1 - A^2}\,\sin(2\phi_2 + 2\theta),\ A \neq 0$

(θ can be given from the isospin analysis.)

Extraction of ϕ_2 from Isospin Analysis



Complex amplitude: *A*

A^{+-}	$Amp(B^0 \to \pi^+\pi^-)$
$\tilde{A}^{+-}$	$Amp(\bar{B}^0 \to \pi^+\pi^-)$
A^{+0}	$Amp(B^+ \to \pi^+\pi^0)$
$\tilde{A}^{-0}$	$Amp(B^- \to \pi^-\pi^0)$
A^{00}	$Amp(B^0 \to \pi^0\pi^0)$
$\tilde{A}^{00}$	$Amp(\bar{B}^0 \to \pi^0\pi^0)$

Input

$$S = \sqrt{1 - A^2}\,\sin(2\phi_2 + 2\theta)$$

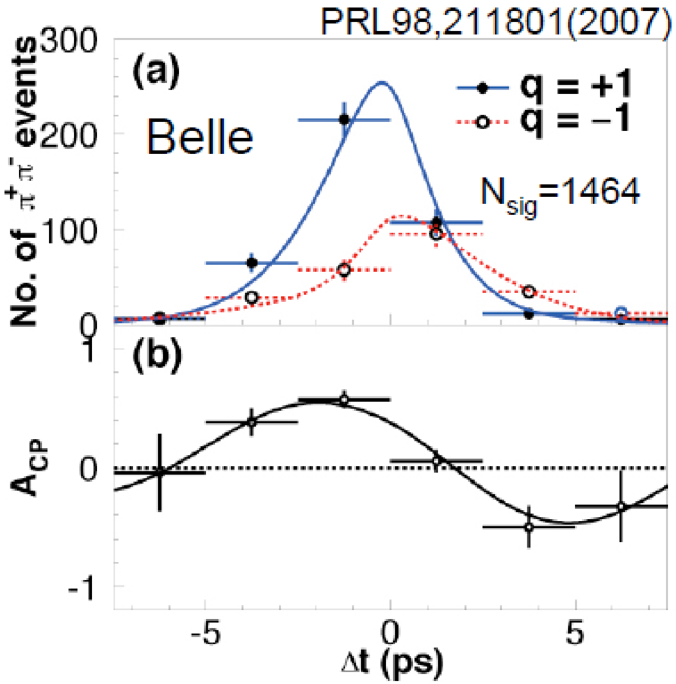
$$\begin{pmatrix} S = \ldots \\ A = \ldots \end{pmatrix}$$

- $B \to \pi\pi$ branching fraction
- $B \to \pi\pi$ DCPV parameters

ϕ_2 can be solved

S and *A* from $B^0 \to \pi^+\pi^-$, $\rho^+\rho^-$ (535M $B\bar{B}$)

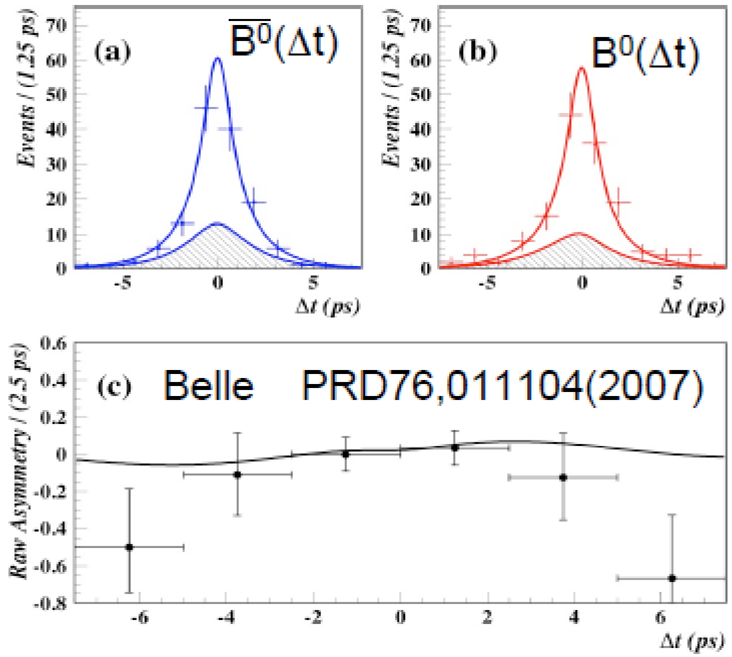
$B^0 \to \pi^+\pi^-$



$$S = -0.61 \pm 0.10 \pm 0.04$$

$$A = +0.55 \pm 0.08 \pm 0.05$$

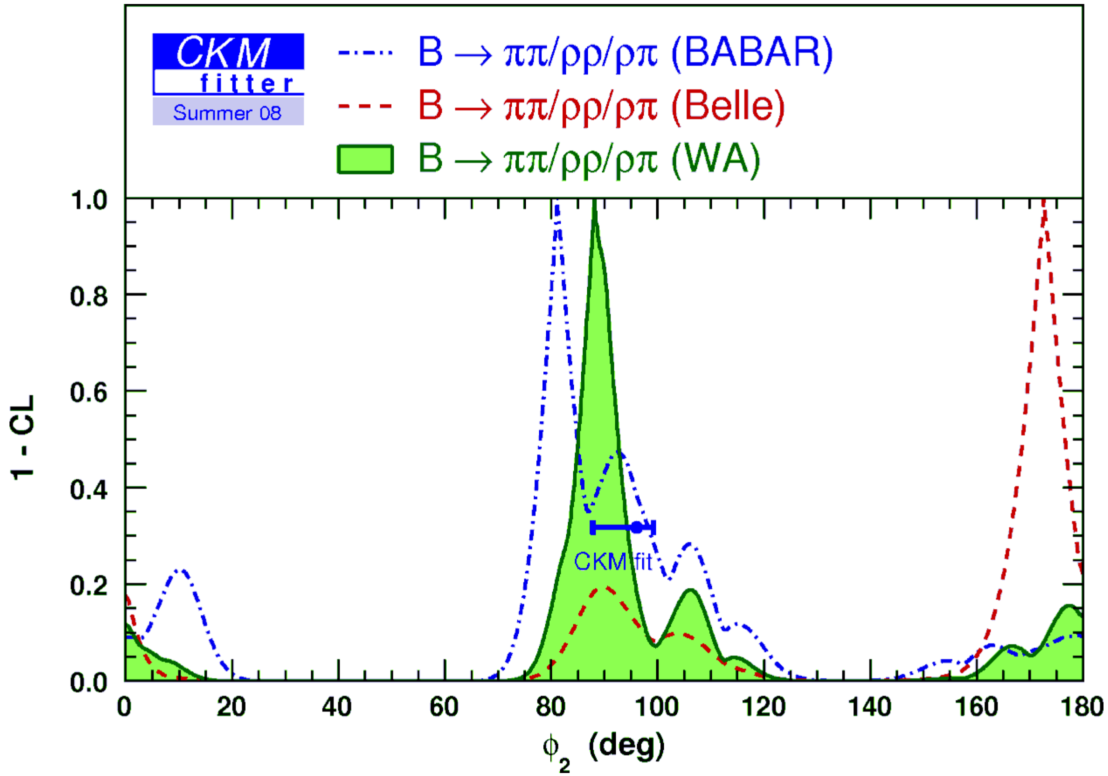
$B^0 \to \rho^+\rho^-$



$$S = +0.19 \pm 0.30 \pm 0.07$$

$$A = +0.16 \pm 0.21 \pm 0.07$$

Constraint on ϕ_2



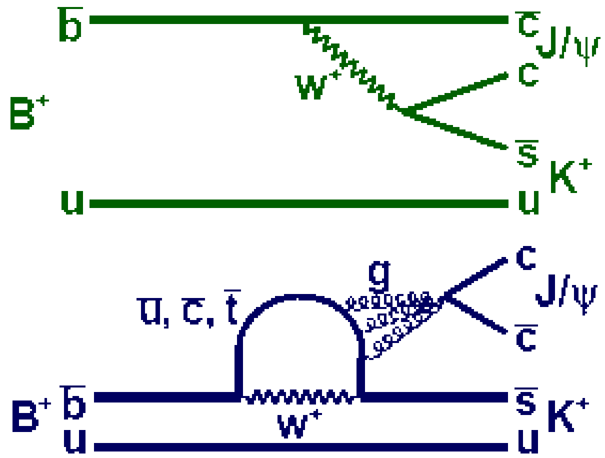
$$\phi 2 = \left(89^{+4.4}_{-4.2}\right)^{\circ}$$

Direct *CP* Violation in $B^+ \to J/\psi K^+$ *NEW!!*

- **Physics motivation**

Tree

Penguin



Previous measurements of $A_{CP}(B^+ \to J/\psi K^+)$ [%]

Belle	$-2.6 \pm 2.2 \pm 1.7$	Phys. Rev. D**67**, 032003 (2003)
BABAR	$+3.0 \pm 1.4 \pm 1.0$	Phys. Rev. Lett. **94**, 141801 (2005)
D0	$+0.75 \pm 0.61 \pm 0.30$	Phys. Rev. Lett. **100**, 211802 (2008)
W/A	$+0.9 \pm 0.8$ (PDG2009)	

- The $B^+ \to J/\psi K^+$ decay mediated by the $b \to s$ u-penguin has a different weak phase from the tree.
- The interference between the tree and penguin can cause the direct *CP* violation in $B^+ \to J/\psi K^+$.

$$A_{CP}(B^+ \to J/\psi K^+) = \frac{Br(B^- \to J/\psi K^-) - Br(B^+ \to J/\psi K^+)}{Br(B^- \to J/\psi K^-) + Br(B^+ \to J/\psi K^+)}$$

$B^+ \to J/\psi K^+$ Reconstruction

- **$B^\pm \to J/\psi K^\pm$ event reconstruction: J/ψ**
  - J/ψ candidates are reconstructed from e^+e^- or $\mu^+\mu^-$ pairs.
    - (Tightly identified lepton) + (tightly or loosely identified lepton).

Tightly identified *e*
dE/dx && E_{ECL}/p && ECL shower shape

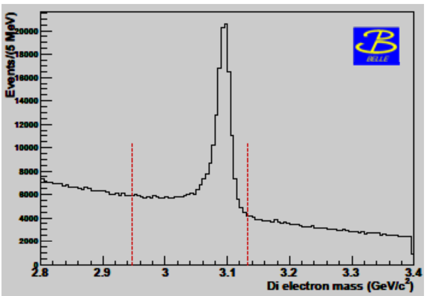
Loosely identified *e*
dE/dx || E_{ECL}/p

Tightly identified μ
# of penetrating iron plates && shower

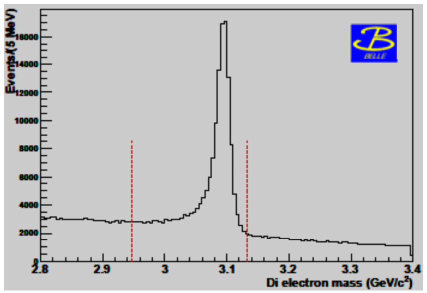
Loosely identified μ
$E_{ECL} \approx E$ deposit by MIP

e^+e^-

tight + loose



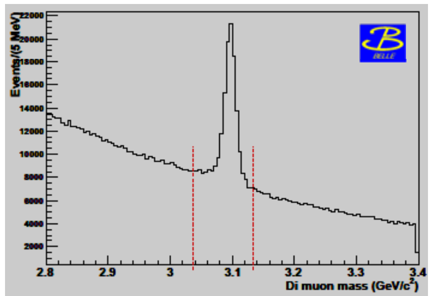
tight + tight



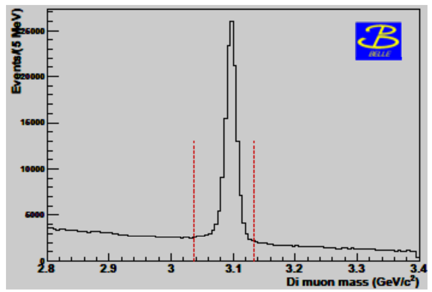
$2.947 < M_{ee} < 3.133$ GeV/c^2

$\mu^+\mu^-$

tight + loose



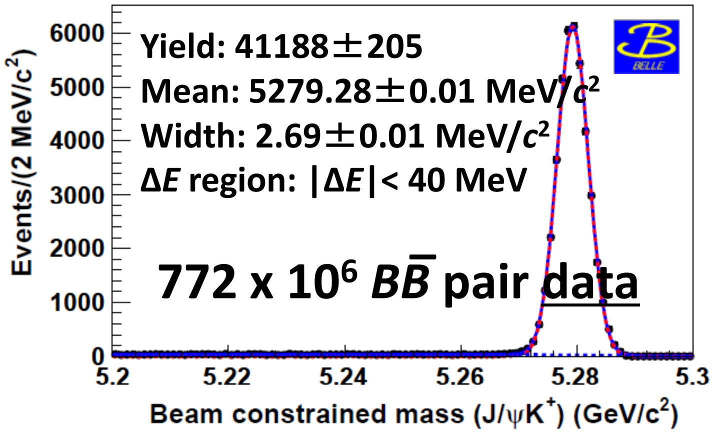
tight + tight



$3.037 < M_{\mu\mu} < 3.133$ GeV/c^2

Raw Asymmetry in $B^+ \to J/\psi K^+$

- **$B^\pm \to J/\psi K^\pm$ event reconstruction**
  - $B^\pm$ candidates are reconstructed from J/ψ and $K^\pm$.



For $K^\pm$(average), 80.5% K efficiency and 9.6% π fake rate.

K-π likelihood ratio

$$\mathcal{R}_K \equiv \frac{\mathcal{L}_K}{\mathcal{L}_K + \mathcal{L}_\pi} > 0.6$$

Signal = single Gaussian

Background = ARGUS BG

Peaking BG is negligibly small → systematic uncertainty.

- **Raw asymmetry: A_{CP}^{raw}**
  - Measured raw asymmetry, which still includes K^+/K^- charge asymmetry in detection, is: $A_{CP}^{raw} = (-0.33 \pm 0.50)\%$
    - The "raw asymmetry" is obtained from yields of the $B^+ \to J/\psi K^+$ and the $B^- \to J/\psi K^-$ in a signal region.

K^+/K^- Charge Asymmetry

- **K^+/K^- charge asymmetry in detection: A_ε^{K+}**
  - The K^+/K^- charge asymmetry in detection arises due to
    - Non-symmetric detector geometry,
    - Different interaction rates in material of K^+/K^-, and
    - Different KID efficiencies of K^+/K^-.

- **The raw asymmetry A_{CP}^{raw} should be corrected for by the K^+/K^- charge asymmetry A_ε^{K+}.**

K^+/K^- Charge Asymmetry Estimation

- **K^+/K^- charge asymmetry estimation**
  - The K^+/K^- detection asymmetry is estimated using the $D_s^+ \to \phi[K^+K^-]\pi^+$ and $D^0 \to K^-\pi^+$, and their charge conjugate.

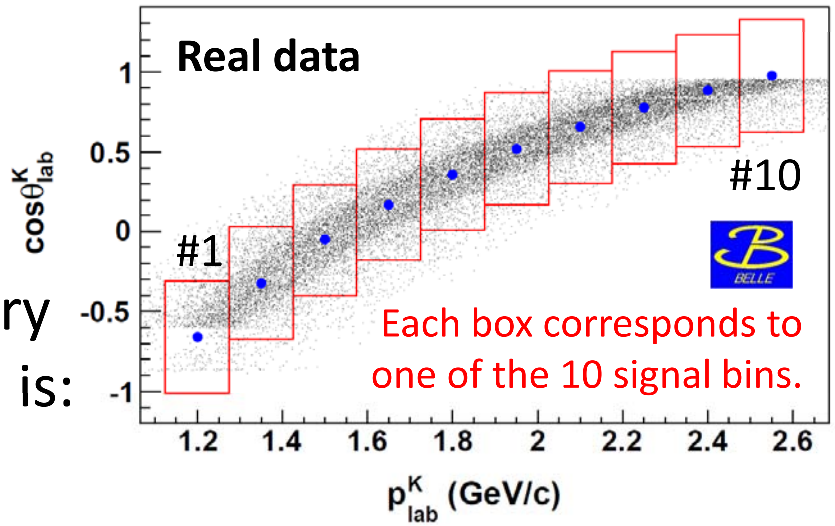
$$\left(A^{x^+} \equiv \frac{N(x^+) - N(x^-)}{N(x^+) + N(x^-)} \right)$$

$$A_{\text{rec}}^{D_s^+} = A_{\text{FB}}^{D_s^+} + A_\varepsilon^{\pi^+}$$

$$A_{\text{rec}}^{D^0} = A_{\text{FB}}^{D^0} + A_\varepsilon^{\pi^+} - A_\varepsilon^{K^+}$$

$$\Rightarrow \quad A_{\text{rec}}^{D_s^+} - A_{\text{rec}}^{D^0} = A_\varepsilon^{K^+} \text{ assuming } A_{\text{FB}}^{D_s^+} = A_{\text{FB}}^{D^0}$$

The K^+/K^- charge asymmetry depends on the $\cos\theta^K_{\text{lab}}$ and p^K_{lab}. We bin the signal regions in the ($\cos\theta^K_{\text{lab}}$, p^K_{lab}) plane into 10 boxes, and measure the charge asymmetry for each bin.



  - Estimated K^+/K^- charge asymmetry in detection (averaged over bins) is: $A_\varepsilon^{K+} = (-0.43 \pm 0.07 \pm 0.17)\%$

CP Violation Measurement in $B^+ \to J/\psi K^+$

to be submitted to PRD

- **Fit result**
  - From the sum of A_{CP}^{raw} and A_ε^{K+}, we preliminarily determine

$$A_{CP}\left(B^{\pm} \to J/\psi K^{\pm}\right) = (-0.76 \pm 0.50 \pm 0.22)\%$$

772 x 10^6 $B\bar{B}$ pairs

Belle preliminary

  - We observe no significant *CP* violation in $B^+ \to J/\psi K^+$.

$B^+ \to J/\psi K^+$ CPV Systematic Uncertainty

- **List of the systematic-uncertainty sources**

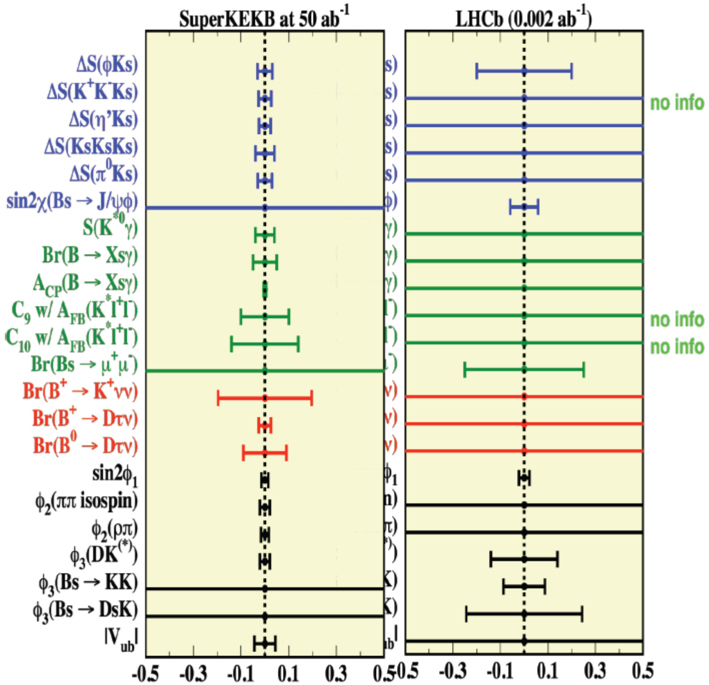
	Source	%
$A_{CP}^{\rm raw}$	Peaking background	0.01
	ARGUS background	0.022
	$M_{\rm bc}$ bin width	0.001
	$(p_{\rm lab}^K, \cos\theta_{\rm lab}^K)$ binning	0.022
$A_{\rm rec}^{D_s^+}$	$D_s^\pm \to \phi\pi^\pm$ statistics	0.17
	$M_{\phi\pi^+}$ bin width	0.004
	$M_{\phi\pi^+}$ mass window	0.015
	$\cos\theta_{\rm CMS}^{D_s^\pm}$ binning	0.02
	$\cos\theta_{\rm lab}^{\pi^\pm}$ binning	0.07
	$p_{\rm lab}^{\pi^\pm}$ binning	0.04
	No-entry bins	0.001
	$\phi \to K^+K^-$ asymmetry	0.05
$A_{\rm rec}^{D^0}$	$D^0(\bar{D}^0) \to K^\mp\pi^\pm$ statistics	0.07
	$M_{K^-\pi^+}$ bin width	0.002
	$M_{K^-\pi^+}$ mass window	0.005
	$(p_{\rm lab}^K, \cos\theta_{\rm lab}^K)$ binning	0.039
	$A_{CP}^{D^0}$	0.01
	$A_{\rm FB}^{D_s^+} = A_{\rm FB}^{D^0}$ assumption	0.01
	Total	0.22

SuperKEKB / Belle II

- **Funding status … KEKB upgrade has been approved!**
  - 5.8 oku-yen for damping ring (FY2010).
  - 100 oku-yen for machine (FY2010-2012).
  - We continue efforts to obtain additional funds to complete construction as scheduled.

90 oku-yen ≈ 100 M$

- **Complementary physics coverage with LHCb**

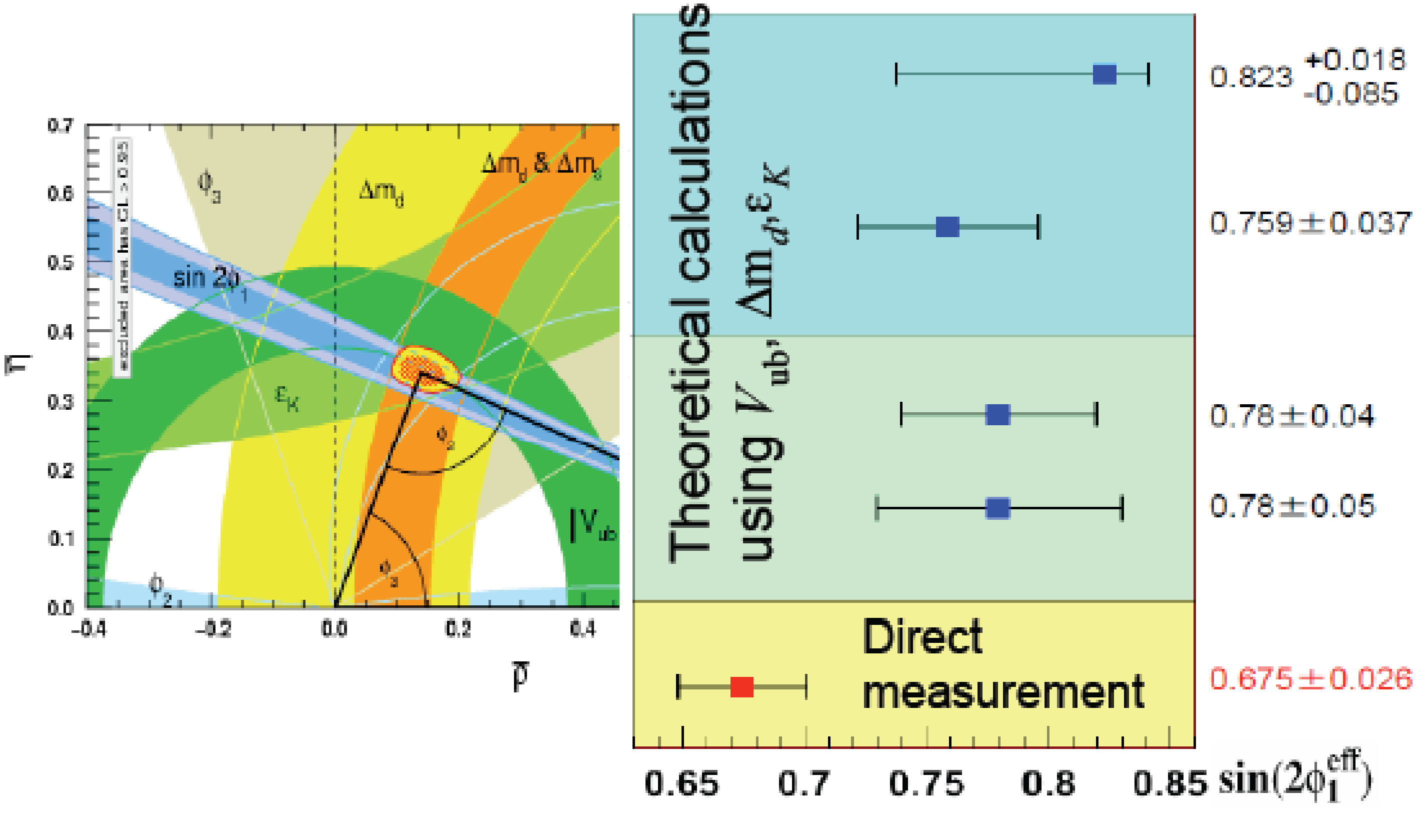


Summary

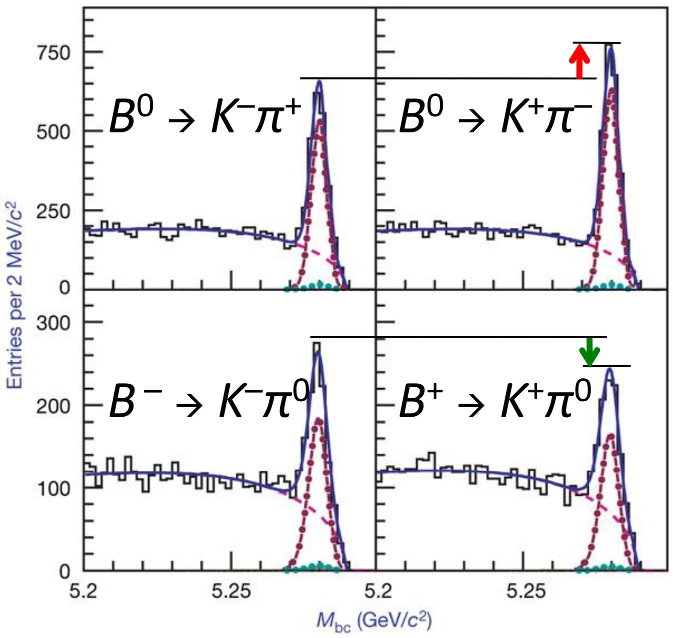
- **Following items have been presented:**
  - Mixing-induced CPV (ϕ_1) measurement in $b \rightarrow c\bar{c}s$
  - Mixing-induced CPV measurement in $b \rightarrow sq\bar{q}$
  - Mixing-induced CPV (ϕ_2) measurement in $B^0 \rightarrow \pi^+\pi^-$, $\rho^+\rho^-$
  - Direct CPV in $B^+ \rightarrow J/\psi K^+$
  - Prospects of SuperKEKB / Belle II

Appendix [1] – Triangle Opened?

- **Unitarity triangle opened?**



Appendix [2] – Kπ Puzzle



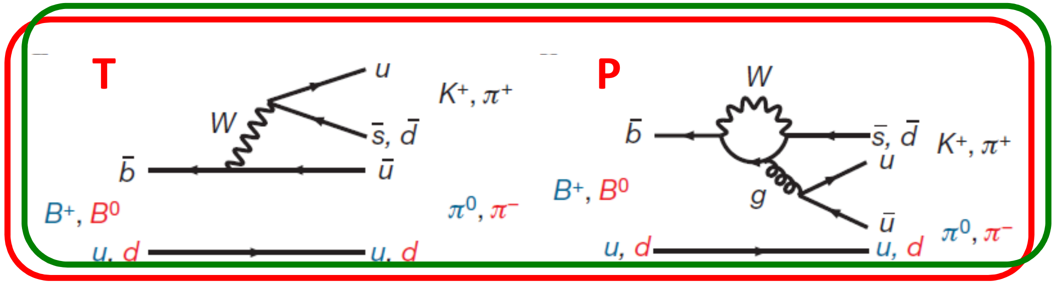
B^0

B^+

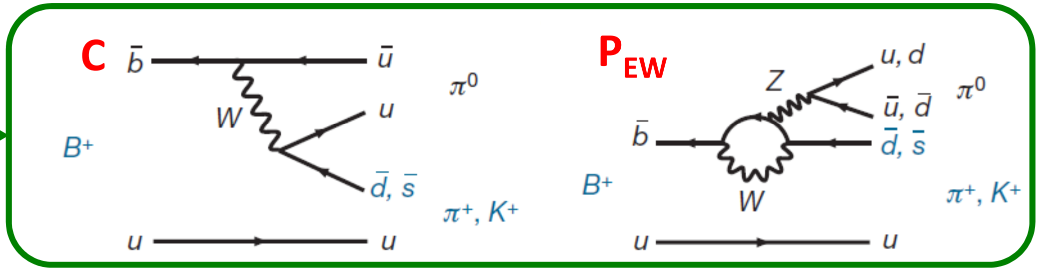
$$A_{CP}(K^+\pi^-) \quad = \quad -0.094 \pm 0.018 \pm 0.008$$

$$A_{CP}(K^+\pi^0) \quad = \quad +0.07 \pm 0.03 \pm 0.01$$

5.3σ deviation → Hint of NP



P_{EW} contribution to CPV (only to B^+ mode) may be large due to NP…?



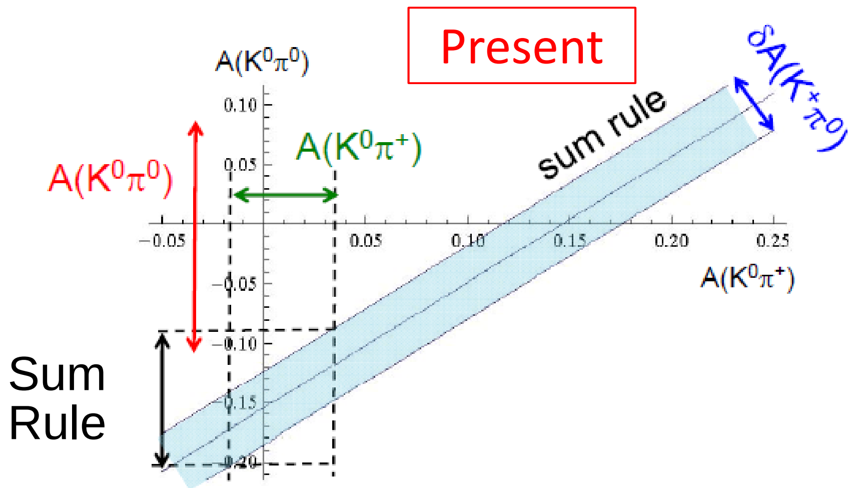
Appendix [2] – Kπ Puzzle – Cont'd

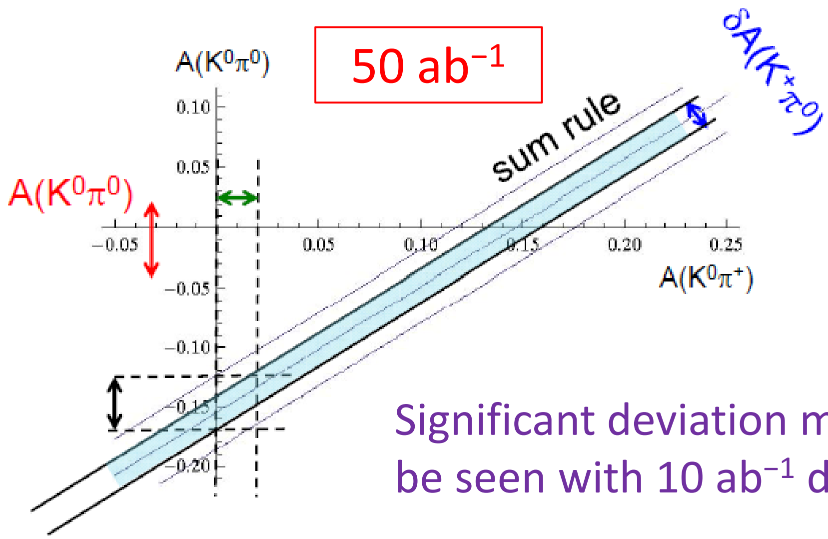
Four precise measurements of *CP*-violating parameters related to the *K*π and the "sum rule" will give the answer.

0.14 ± 0.13 ± 0.06
@ 600 fb^{-1} (Belle)

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

CPV in $K^0\pi^0$ is statistically difficult to measure → Need for SuperKEKB.





Significant deviation may be seen with 10 ab^{-1} data.

Backup Slides

CP Violation Measurement in $B^+ \to J/\psi K^+$

- **List of bin-by-bin *CP* violation and charge asymmetry**

Bin #	A_{CP} (%)	$A_{CP}^{\rm raw}$ (%)	$A_{\varepsilon}^{K^+}$ (%)
1	$+0.75$	$+2.30 \pm 2.47$	$-1.55 \pm 0.35 \pm 0.26$
2	-1.91	-1.04 ± 1.49	$-0.86 \pm 0.24 \pm 0.22$
3	-2.23	-1.65 ± 1.47	$-0.58 \pm 0.23 \pm 0.21$
4	-0.36	$+0.16 \pm 1.46$	$-0.52 \pm 0.22 \pm 0.19$
5	-0.41	$+0.01 \pm 1.46$	$-0.42 \pm 0.21 \pm 0.18$
6	-2.52	-2.19 ± 1.42	$-0.33 \pm 0.20 \pm 0.18$
7	$+1.05$	$+1.04 \pm 1.41$	$+0.01 \pm 0.20 \pm 0.19$
8	-0.14	$+0.20 \pm 1.41$	$-0.35 \pm 0.22 \pm 0.23$
9	-0.23	-0.01 ± 1.57	$-0.22 \pm 0.24 \pm 0.24$
10	-0.63	-0.68 ± 2.61	$+0.05 \pm 0.27 \pm 0.24$
Total	-0.76	-0.33 ± 0.50	$-0.43 \pm 0.07 \pm 0.17$