Measurement of branching fractions and *CP* asymmetries of $B \to \omega K$ decays at Belle

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Outline

Physics Motivation

Measurement Principles

$B \to \omega K$ Measurement and Results

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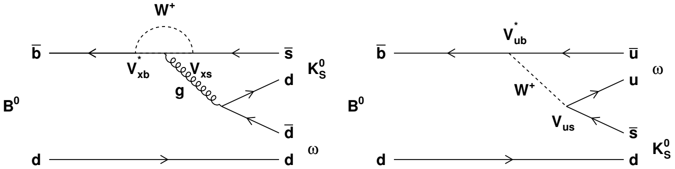
Measurement of ϕ_1: $b \to sq\bar{q}$

FCNC forbidden at tree level or tree CKM suppressed
$\Rightarrow$ penguin diagram dominates



- $\mathcal{S}_{CP} = \sin 2\phi_1$, same as $b \to c\bar{c}s$
- Penguin amplitudes highly sensitive to New Physics
- Could be affected by a heavy unknown particle in the loop
- Measure branching fraction and *CP* violation parameters
- A deviation of these measurements from SM expectations will be an indication of New Physics

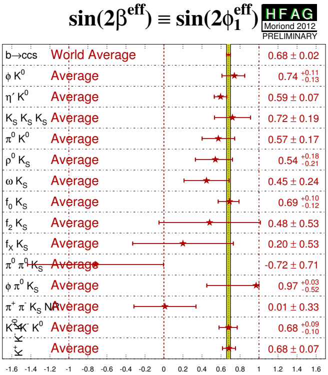
Measurement of ϕ_1: $b \to sq\bar{q}$

Theory

hep-ph/0707.1323, hep-ph/0702252

Mode	$\mathcal{S}_{CP} - \sin 2\phi_1$
$B^0 \to \phi K^0_S$	0.02 ± 0.01
$B^0 \to \eta' K^0_S$	0.01 ± 0.01
$B^0 \to K^0_S K^0_S K^0_S$	$0.02^{+0.02}_{-0.03}$
$B^0 \to K^0_S \pi^0$	$0.07^{+0.05}_{-0.04}$
$B^0 \to \rho^0 K^0_S$	$-0.08^{+0.08}_{-0.12}$
$B^0 \to \omega K^0_S$	0.13 ± 0.08
$B^0 \to K^0_S \pi^0 \pi^0$	$0.03^{+0.02}_{-0.03}$
$B^0 \to K^+ K^- K^0_S$	$0.03^{+0.02}_{-0.03}$

Experiment



Predicted in SM to have higher CP asymmetries than $b \to sq\bar{q}$

But most $b \to sq\bar{q}$ measurements at or below $b \to c\bar{c}s$ measurements

More experimental precision required

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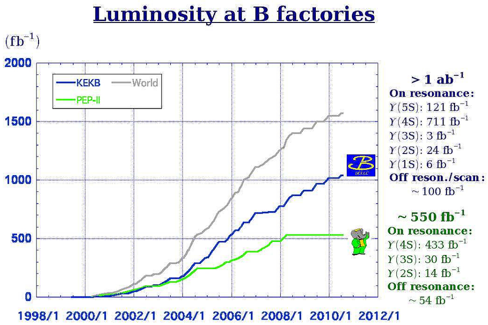
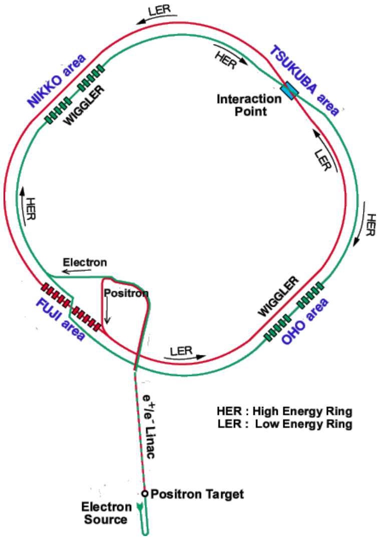
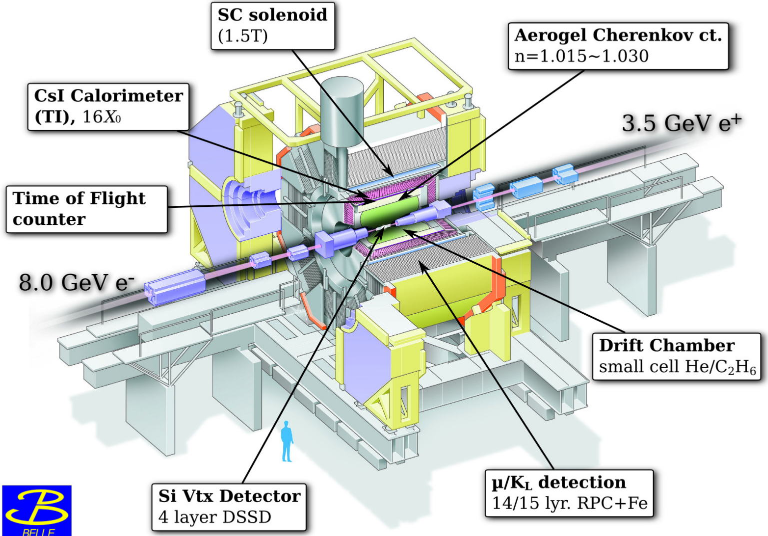
KEKB Accelerator

- Asymmetric energy e^+e^- (3.5 on 8 GeV) collider
  - $B\overline{B}$ separation increased to $\sim 200\ \mu m$
- World record peak luminosity $2.1 \times 10^{34}\ cm^{-2}s^{-1}$
  - Largest sample of 772×10^6 $B\overline{B}$ pairs



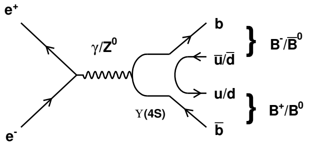


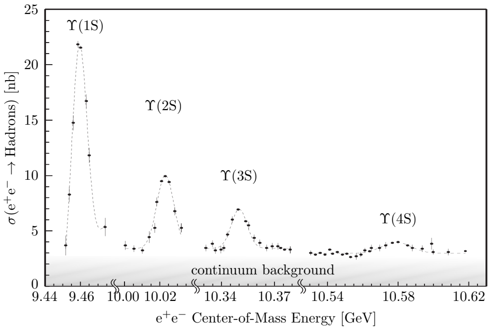
Belle Detector



Measurement Principles at Belle

Production via $e^-e^+ \to \Upsilon(4S) \to B\overline{B}$





$$m_{\Upsilon(4S)} = 10.58\,\mathrm{GeV/c^2} \approx 2 \times m_B$$
$$m_B = 5.28\,\mathrm{GeV/c^2}$$

$\Upsilon(4S)$ resonance decays almost exclusively into a $B\overline{B}$ pair

$\Upsilon(4S)$: $J^P = 1^-$

B: $J^P = 0^-$

$\Rightarrow$ B meson pair in a p-wave
$\Rightarrow$ asymmetric wave function
$\Rightarrow$ B mesons must have opposite flavour

$B\overline{B}$ pair coherent

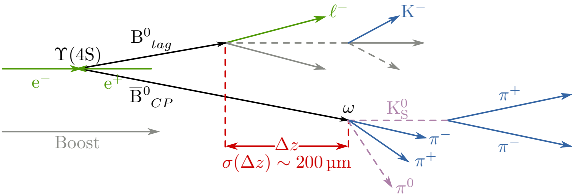
CP Violation in the *B* Meson System

Time-dependent *CP* asymmetry

$$a_{CP}(\Delta t, f_{CP}) = \frac{N_{\overline{B}^0}(\Delta t, f_{CP}) - N_{B^0}(\Delta t, f_{CP})}{N_{\overline{B}^0}(\Delta t, f_{CP}) + N_{B^0}(\Delta t, f_{CP})} = \mathcal{A}_{CP}\cos(\Delta m \Delta t) + \mathcal{S}_{CP}\sin(\Delta m \Delta t)$$

$\mathcal{A}_{CP}$: measure for the direct *CP* violation
$B^0 \to f_{CP} \neq \overline{B}^0 \to f_{CP}$

$\mathcal{S}_{CP}$: measure for the mixing induced *CP*V
$B^0 \to \overline{B}^0 \to f_{CP} \neq \overline{B}^0 \to B^0 \to f_{CP}$



B^0 or $\overline{B}^0$?
$\to$ Look at the other *B* (tag-side):
Search for flavour-specific decays on the tag side
$\Rightarrow$ Flavour of the B of interest opposite to the tag side B

Δt measurement
Asymmetric beam energies
$\Rightarrow$ Boost of the CMS
Measurement of $\Delta z \sim 100\,\mu\text{m}$ instead of $\Delta t \sim$ ps
Obtain $\Delta t = \Delta z / c\langle\beta\gamma\rangle$

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Measurement of ϕ_1: $B \to \omega K$

My PhD thesis
The final measurement of $B \to \omega K$ with the full data set of Belle 772×10^6 $B\overline{B}$ pairs

Challenging analysis

- $\mathcal{BR}(B \to \omega K) \sim 10^{-6}$ (small)
- Large background contribution from $q\overline{q}$ (u, d, s, c) background

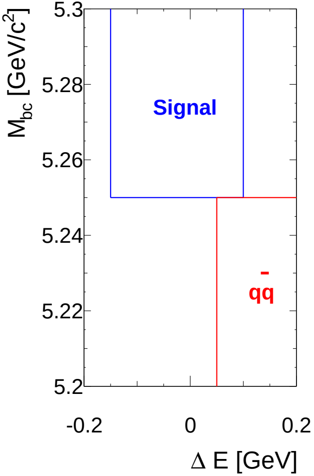
	$\mathbf{B^0 \to \omega K^0_S}$	$\mathbf{B^+ \to \omega K^+}$
signal	≈ 240	≈ 1150
$q\overline{q}(q = u, d, s, c)$ BG	≈ 17000	≈ 85000
$B\overline{B}$ BG	≈ 360	≈ 1700

Measurement of $B \to \omega K$

Measurement of the branching fraction and *CP* parameters of $B \to \omega K$ with the full Belle data set ot 772×10^6 $B\overline{B}$ pairs

Our method

- Use loose cuts on the observables for maximum signal sensitivity
- Blind analysis: Base signal and background models entirely on MC and sideband (a region in M_{bc} and ΔE next to the signal region, where only $q\overline{q}$ is found)
- A simultaneous fit to $B^0 \to \omega K^0_S$ and what otherwise would be its control sample ($B^+ \to \omega K^+$) to obtain the correction factors on the kinematic variables directly from the fit and with this to reduce the systematic uncertainties
- First attempt at Belle to fit two decay channels simultaneously



Measurement of ϕ_1: $B^0 \to \omega K^0_S$

Black font: previous measurements
Blue font: Full Belle data set of 772×10^6 $B\overline{B}$ pairs

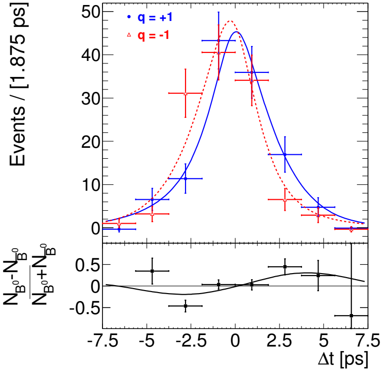
	$\mathbf{B\overline{B}}$**-pairs**	$\mathcal{BR}(\mathbf{B^0 \to \omega K^0})$	$\mathcal{A}_{CP}$	$\mathcal{S}_{CP}$
Belle	388×10^6	$(4.4^{+0.8}_{-0.7} \pm 0.4) \times 10^{-6}$	-	-
Belle	535×10^6	-	$-0.09 \pm 0.29 \pm 0.06$	$0.11 \pm 0.46 \pm 0.07$
BaBar	467×10^6	$(5.4 \pm 0.8 \pm 0.3) \times 10^{-6}$	$0.52^{+0.22}_{-0.20} \pm 0.03$	$0.55^{+0.26}_{-0.29} \pm 0.02$
Belle	772×10^6	$(4.5 \pm 0.4 \pm 0.3) \times 10^{-6}$	$-0.36 \pm 0.19 \pm 0.05$	$0.91 \pm 0.32 \pm 0.05$

	$\mathbf{B\overline{B}}$**-pairs**	$\mathcal{BR}(\mathbf{B^+ \to \omega K^+})$	$\mathcal{A}_{CP}$
Belle	388×10^6	$(8.1 \pm 0.6 \pm 0.6) \times 10^{-6}$	$0.05^{+0.08}_{-0.07} \pm 0.01$
BaBar	383×10^6	$(6.3 \pm 0.5 \pm 0.3) \times 10^{-6}$	$-0.01 \pm 0.07 \pm 0.01$
Belle	772×10^6	$(6.8 \pm 0.4 \pm 0.4) \times 10^{-6}$	$-0.03 \pm 0.04 \pm 0.01$

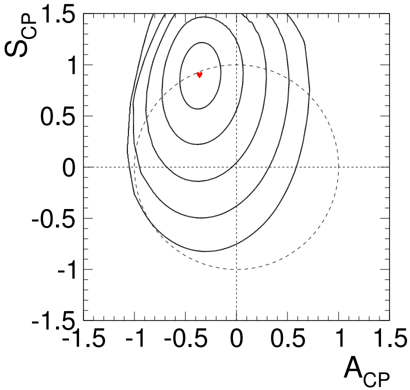
Paper submitted to PRD, in review; arXiv 1311.6666

Measurement of ϕ_1: $B^0 \to \omega K^0_S$

First evidence of *CP* violation in $B^0 \to \omega K^0_S$



Clear asymmetry can be seen in the difference between the B^0 and $\overline{B}^0$ distributions



CP conservation $(\mathcal{A}_{CP}, \mathcal{S}_{CP}) = (0, 0)$ ruled out by 3.1 standard deviations

Conclusion

- ϕ_1 is the most precisely measured parameter of the B unitarity triangle
- ϕ_1 accessible in penguin-dominated decays, sensitive to New Physics
- Measurement of $B \to \omega K$ with the full Belle data set finished, in review at PRD
- So far, measurements of the unitarity triangle consistent with the Standard Model prediction but with huge uncertainties
- More precise theoretical calculations and measurements needed to challenge the Standard Model

Thank you for your attention