Measurement of time-dependent CP violation in $B^0 \to \eta' K_S^0$ decays

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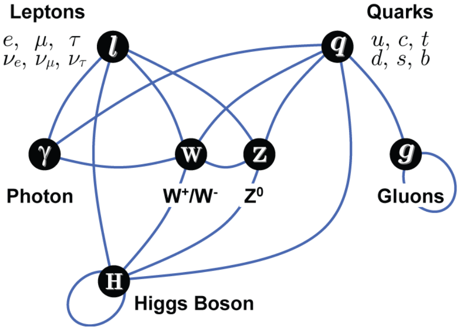
OUTLINE

The Standard Model

- A theory of **three** fundamental forces (EM,weak,strong).
- Experimentally very well confirmed (up to $\sim$ TeV energy scale).



But nobody is **perfect**:

- No gravity.
- Massless neutrinos.
- Cosmological origin: DM, CPV, ...
- Naturalness (Hierarchy, strong CP)
- 19 free parameters.

Hadrons

- The strong interaction bounds quarks into hadrons.

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

Mesons $q\bar{q}$

Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

CP symmetry

C - Charge conjugation

particle $\to$ **anti-particle**

$e^- \to e^+$

P - Parity

$\vec{x} \to -\vec{x}$, mirror image

$e^-_L \to e^-_R$

- most phenomena are **C and P** symmetric (EM, strong, gravity).
- **Weak interaction** affects only **left-handed** particles (right-handed anti-particles).

Obviously **C and P** are violated.

- Combined **CP** symmetry is preserved in most of weak processes.
- It was widely believed to be exact symmetry of nature (matter $\leftrightarrow$ anti-matter).
- However, **violated** in certain rare processes.
  (as discovered in neutral K decays (1964))

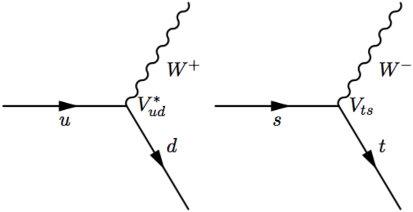
Example:

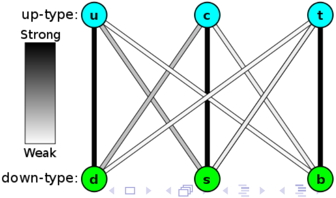
CP violation in the SM

- The weak interaction allows for quarks to swap their flavor for another.
- Information on the relative strength of the **flavor-changing** weak current:

CKM matrix (Cabibbo-Kobayashi-Maskawa): 3x3 unitary matrix

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$





- Almost a **unit** matrix.
- Couples quarks from **different families** and **different charges**.

CP violation in the SM

- If $\boxed{V_{ij} = V^\star_{ij} \quad \Longrightarrow \quad \mathcal{L} = \mathcal{L}_{CP} \quad \Longrightarrow \quad \textbf{CP conservation}}$.
- The CKM has three real parameters and one complex phase (KM phase).

since $\boxed{\text{KM phase} \neq 0}$ $\Longrightarrow$ **CP violation (CPV)**

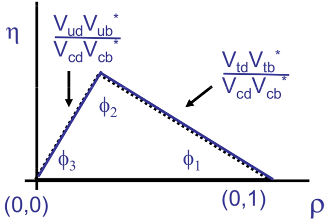
- **Unitarity triangle:**
  CKM matrix is **unitary**: $V_{ud}V^\star_{ub} + V_{cd}V^\star_{cb} + V_{td}V^\star_{tb} = 0$, etc ...

Wolfenstein parametrization:

Utilizes the observed hierarchy $|V_{ub}|^2 \ll |V_{cb}|^2 \ll |V_{us}|^2$

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

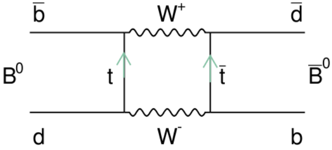
$\lambda \equiv |V_{us}| \simeq 0.22$, parameters A, ρ, η are $\mathcal{O}(1)$.

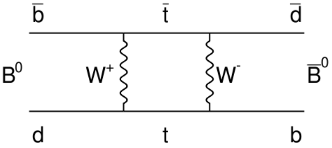


- Single parameter η describes all CP violating phenomena.
- B meson decays $\Rightarrow$ sides and angles of the UT $\Rightarrow$ consistency check of the SM

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

- The KM mechanism (with measured values of the CKM matrix elements) predicts **large CPV** in the **B meson system**.
- One of CPV manifestations is the asymmetry in decay rates of B^0 and $\bar{B}^0$.
- However, **flavor eigenstates** B^0 $(d\bar{b})$ and $\bar{B}^0$ $(\bar{d}b)$ **are not mass eigenstates**.
- As an initially produced B^0 propagates in time, it gains $\bar{B}^0$ component $\Longrightarrow$ **mixing**.





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

- Mixing phenomenology $\Rightarrow$ time-dependent decay rates of states $B^0(t)$ ($\bar{B}^0(t)$), which were pure B^0 ($\bar{B}^0$) at $t = 0$, to a final state f

$$\Gamma(B^0(t) \to f) \propto e^{-t/\tau_{B^0}} \left[1 - \mathcal{A}_f \cos \Delta M t - \mathcal{S}_f \sin \Delta M t\right],$$
$$\Gamma(\bar{B}^0(t) \to f) \propto e^{-t/\tau_{B^0}} \left[1 + \mathcal{A}_f \cos \Delta M t + \mathcal{S}_f \sin \Delta M t\right].$$

$$\boxed{\text{Asymmetry: } a_f(t) \equiv \frac{\Gamma(B^0(t)\to f) - \Gamma(\bar{B}^0(t)\to f)}{\Gamma(B^0(t)\to f) + \Gamma(\bar{B}^0(t)\to f)} = \mathcal{A}_f \cos \Delta M t + \mathcal{S}_f \sin \Delta M t}$$

- Values of $\mathcal{A}_f$ and $\mathcal{S}_f$ can be calculated within the SM.
- Prime example: $B^0 \to J/\psi\ K^0_S$ decay

$$\mathcal{A}_{J/\psi K^0_S} \simeq 0 \quad \text{and} \quad \mathcal{S}_{J/\psi K^0_S} \simeq \sin(2\phi_1)$$ (accurate to $\mathcal{O}(0.01)$)

- By measuring the asymmetry $a_{J/\psi K^0_S}$ one can determine the ϕ_1 angle of the unitarity triangle.
- Current experimental value (HFAG 2012): $\sin 2\phi_1 = 0.68 \pm 0.02$.
- In great agreement with the SM predictions! $\Longrightarrow$ Kobayashi and Maskawa won the 2008 Nobel Prize in Physics.

CP violation and new physics

- Despite **great success!** of the Kobayashi-Maskawa mechanism, it cannot represent a complete CP violation story.
- The SM is an effective low energy theory valid up to energy scale Λ (exp: $\Lambda \gtrsim 1$ TeV). Additional CP violating phases are inevitable in most of theories of physics **beyond the SM**.
- CP violation in the **SM** alone **fails** by many orders of magnitude to explain the **matter-antimatter** asymmetry of the Universe.

CP violation in the SM

$$\frac{n_B - n_{\bar{B}}}{n_\gamma} \sim 10^{-16}$$

The Universe

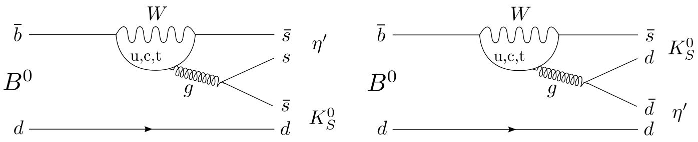
$$\frac{n_B - n_{\bar{B}}}{n_\gamma} \sim 10^{-9}$$

$\Longrightarrow$ In the early Universe processes that severely violate CP were present.

- Many methods how to find new CP violating phases in **B meson decays** were proposed.

CP violation in $B^0 \to \eta' K_S^0$ decay

- This decay is dominated by the $b \to s\bar{q}q$ quark transition. In the SM these transitions can only happen through a so-called **penguin diagram**.



- The values of the CPV parameters within the SM

$$\mathcal{A}_{\eta' K_S^0} \simeq 0 \quad \text{and} \quad \mathcal{S}_{\eta' K_S^0} \simeq \sin(2\phi_1)$$ (accurate to $\lesssim 0.1$)

Same as in $B^0 \to J/\psi K_S^0$ decay!

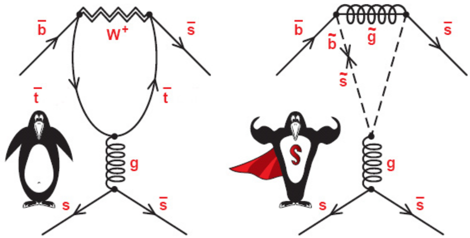
Why this is **interesting** ?

- Processes that are dominated by **penguin diagrams** (like $b \to s\bar{q}q$) are known to be **sensitive to new physics** effects.

CP violation in $B^0 \to \eta' K_S^0$ decay

- Heavy **new particles** may contribute inside the loop:

usual penguin $\Rightarrow$

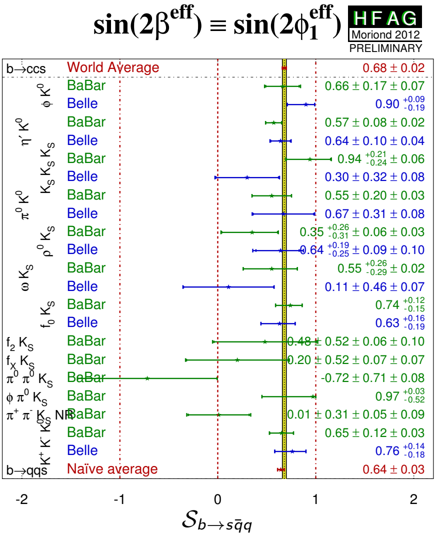


$\Leftarrow$ **Super penguin** (SUSY)

- In general these new particles carry new CP violating phases, which can cause a deviation of $\mathcal{S}_{\eta' K_S^0}$ from $\sin 2\phi_1$.
- On the other hand, the decay $B^0 \to J/\psi K_S^0$ is **tree dominated** ($b \to c$) and is unlikely to receive large new physics contributions.
- Measuring $\mathcal{S}_{\eta' K_S^0} - \sin(2\phi_1)$ is one of **gold-plated** observables for new CP violating phases.

Previous experimental results

- CPV parameters were measured in several $b \to s\bar{q}q$ transition dominated decays.



- At the present level of experimental uncertainties no significant deviations from $\sin 2\phi_1$ are observed.
- Rather large uncertainties still allow for sizable new physics contributions.
- CPV in $B^0 \to \eta' K_S^0$:

Belle 2007, 534 M $B\bar{B}$ pairs

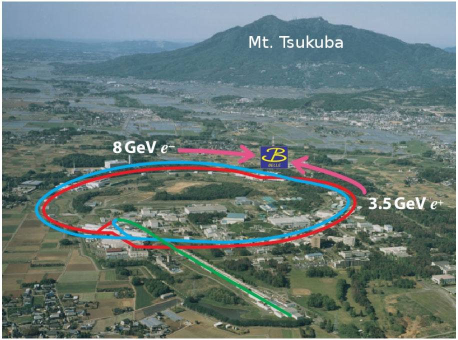
$$\mathcal{S}_{\eta' K_S^0} = 0.67 \pm 0.11 \pm 0.04$$
$$\mathcal{A}_{\eta' K_S^0} = -0.03 \pm 0.07 \pm 0.05$$

BaBar 2009, 467 M $B\bar{B}$ pairs

$$\mathcal{S}_{\eta' K_S^0} = 0.53 \pm 0.08 \pm 0.02$$
$$\mathcal{A}_{\eta' K_S^0} = +0.11 \pm 0.06 \pm 0.02$$

How to measure time-dependent CPV

- We need B mesons $\Longrightarrow$ **B factories**.



- The **KEK-B** is an electron-positron collider designed for B physics studies.
- Located in Tsukuba, Japan.
- Consists of linear injector and two 3km storage rings.
- e^+ and e^- beams cross at a single point (interaction point).
- There the Belle detector is placed.

- B mesons are produced in:

$$e^- \xrightarrow{8\ \text{GeV}} \xleftarrow{3.5\ \text{GeV}} e^+ \Longrightarrow \Upsilon(4S) \Longrightarrow B^0\ \bar{B}^0\ (B^+ B^-)$$

Principle of measurement

- We need to measure decay time distributions of states that were at $t = 0$ pure B^0 and $\bar{B}^0$ states, into $\eta' K^0_S$ final state. But how ?

Quantum coherence

$B_{tag} \to B^0$ $(\bar{B}^0)$ flavor specific at t_{tag}
$\Longrightarrow$ B_{CP} was $\bar{B}^0$ (B^0) at t_{tag}.

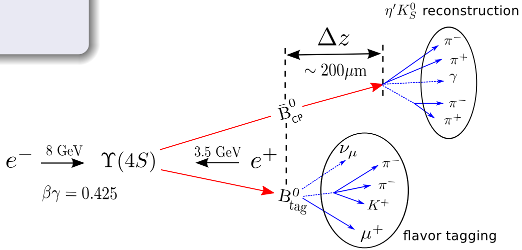
$$t = \Delta t \equiv t_{CP} - t_{tag}$$

Mass of the $\Upsilon(4S)$

$M_{\Upsilon(4S)}$ is just above $2M_{B^0}$
$\Longrightarrow$ $B\bar{B}$ at rest in the CMS.

Asymmetric beam energies

$$\Delta t \simeq \frac{\Delta z}{\beta\gamma c}$$

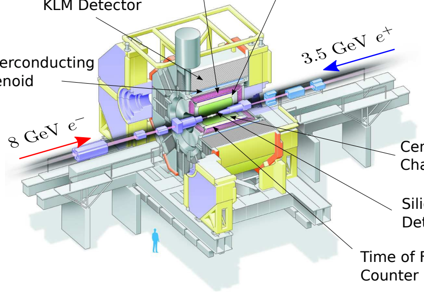


- We therefore need to:

1. Determine the flavor of B_{tag}.
2. Reconstruct B_{CP} decaying into $\eta' K^0_S$.
3. Measure the distance between B_{CP} and B_{tag} decay vertices.

The BELLE detector

- Efficient detection and identification of long-lived final state particles $(e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}, K_L, \gamma)$.



- Drift chamber in magnetic field (1.5 T) $\Rightarrow$ momenta of charged particles.
- Particle identification:
  - velocity measurement (ACC and TOF).
  - nature of interaction with material. (ECL and KLM).
- Decay vertex position: from charged particle's hits in the Silicon Vertex Detector.

- Belle and KEKB operated during 1999-2010 and recorded about 772 millions of $B\bar{B}$ decays.

Preparation of measurement procedure

- **Basic idea**: determine the values of $\mathcal{S}_{\eta' K^0_S}$ and $\mathcal{A}_{\eta' K^0_S}$ by a fit of

$$\mathcal{P}^{sig}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{\eta' K^0_S}\cos\Delta M \Delta t + \mathcal{S}_{\eta' K^0_S}\sin\Delta M\Delta t\right)\right],$$

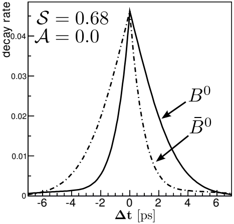
  where $q = +1$ ($q = -1$) for $B_{tag} = B^0$ ($\bar{B}^0$), to measured $\Delta t, q$ distribution.
- However, several **experimental limitations** have to be included:

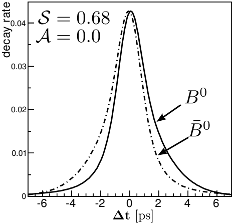
$$\mathcal{P}^{sig} \to \mathcal{P}^{sig} \otimes \mathcal{R}^{sig} \qquad \textbf{Δt resolution,}$$

$$\mathcal{P}^{sig} \otimes \mathcal{R} \to f_{sig}\mathcal{P}^{sig} \otimes \mathcal{R} + (1 - f_{sig})\mathcal{P}^{bkg} \qquad \textbf{background events,}$$

$$\mathcal{P}^{sig}(\Delta t, q) \to \mathcal{P}^{sig}(\Delta t, (1 - 2w)q) \qquad \textbf{wrongly determined flavor,}$$

> These limitations obscure the asymmetry.
>
> To obtain **unbiased** $\mathcal{S}_{\eta' K^0_S}$ and $\mathcal{A}_{\eta' K^0_S}$ we have to understand them well!

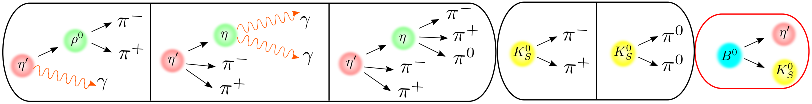




- Determine $\mathcal{R}^{sig}$, f_{sig}, w **event-by-event** $\Rightarrow$ maximize fit sensitivity.

Event reconstruction and selection

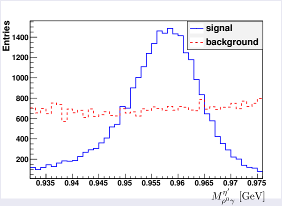
- Branching fraction for $B^0 \to \eta' K_S^0$ decay is $(3.3 \pm 0.2) \times 10^{-5}$.
- To reconstruct B_{CP} decay into $\eta' K_S^0$ we combine 4-momentum vectors of decay final state particles.



- Several selection criteria $\Rightarrow$ reduce the number of background events.

The most efficient are criteria on **invariant masses** of reconstructed ρ^0, η, η' mesons ($0.932 < M^{\eta'}_{\rho^0\gamma} < 0.975$ GeV, $M_{\eta'} \simeq 0.957$ GeV).

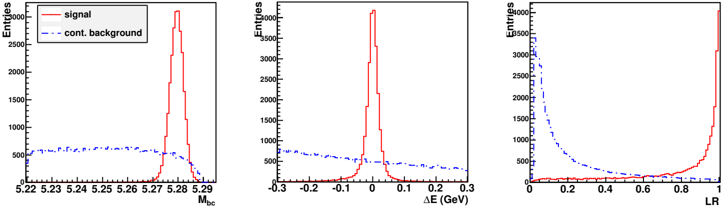
Not a free lunch:
background $\Downarrow$ $\rightarrow$ **signal** $\Downarrow$.



- Optimized to minimize the statistical uncertainty of $\mathcal{S}_{\eta' K_S^0}$ (using simulated events).
- Remaining background mainly arises from $e^+e^- \to q\bar{q}$ events ($q = u, d, s, c$).

Signal/Background fraction fit

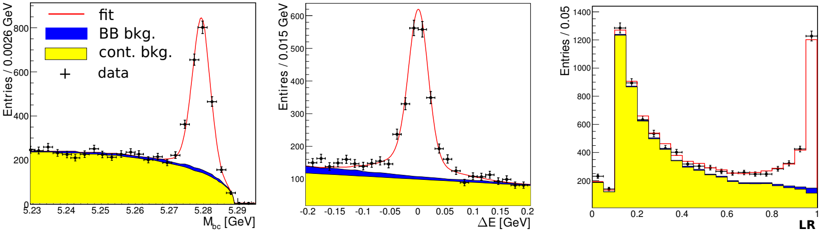
- To determine f_{sig} $\Rightarrow$ distribution of reconstructed events in $M_{bc}, \Delta E, LR$.
  $M_{bc} = \sqrt{(E^{cms}_{beam})^2 - (p^{cms}_B)^2}$, $\Delta E = E^{cms}_B - E^{cms}_{beam}$, LR- event shape variable



- Based on the distributions of simulated events we construct the PDFs $\mathcal{F}^{sig}(M_{bc}, \Delta E, LR)$ and $\mathcal{F}^{bkg}(M_{bc}, \Delta E, LR)$.
- f_{sig} is determined by a fit of $\mathcal{F} = f_{sig}\mathcal{F}^{sig} + (1 - f_{sig})\mathcal{F}^{bkg}$ to the measured events distribution (each decay mode separately).
- Finally, $f_{sig}\mathcal{F}^{sig}/\mathcal{F}$ gives us event-by-event signal probability.

Signal/Background fraction fit

- Fit result (all decay modes with $K^0_S \to \pi^+\pi^-$ combined):



- Obtained signal yields and fractions

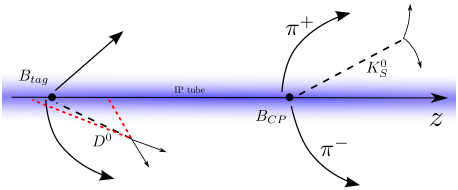
mode	N_{sig}	f_{sig}	f_{cont}	f_{BB}
$K^0_S \to \pi^+\pi^-$				
ρ^0	1410.5 ± 48.5	0.19	0.79	0.02
$\eta \to \gamma\gamma$	648.3 ± 27.9	0.49	0.50	< 0.01
$\eta \to 3\pi$	174.3 ± 13.5	0.65	0.35	< 0.01
sum	2233.1 ± 57.6			
$K^0_S \to \pi^0\pi^0$				
ρ^0	168.2 ± 21.4	0.04	0.93	0.03
$\eta \to \gamma\gamma$	104 ± 14.2	0.16	0.84	< 0.01
sum	272 ± 25.7			

Only events in signal region $M_{bc} > 5.27$ GeV, $|\Delta E| < 0.08$ GeV, are counted and used for Δt analysis.

Decay vertex reconstruction

- We determine Δt by measuring Δz.
- Decay vertex of B_{CP}: vertexing algorithm extrapolates tacks of π^+, π^- from η' decay into a common origin point.
- Decay vertex of B_{tag}: all remaining tracks in event are used.

  Tracks that spoil the vertex quality significantly are discarded (likely from D, K_S^0).



- Only good quality tracks, with at least two hits in the SVD, are used.
- The position resolution of reconstructed vertices is $\sim 80\ \mu$m for B_{CP} and $\sim 100\ \mu$m for B_{tag} vertex.
- Vertex reconstruction efficiency is 95% for B_{CP} and 93% for B_{tag} vertices.

Signal Δt resolution function

- We compose $\mathcal{R}^{sig}$ as a convolution of **4 different contributions**

$$\mathcal{R}^{sig} = \mathcal{R}^{CP}_{det} \otimes \mathcal{R}^{tag}_{det} \otimes \mathcal{R}_{np} \otimes \mathcal{R}_{kin}$$

  $\mathcal{R}^{CP,tag}_{det}$ - detector resolution (Δz), $\mathcal{R}_{np}$ - non-primary tracks,
  $\mathcal{R}_{kin}$ - kinematic assumption that B mesons are at rest in the CMS

- $\mathcal{R}_{det}$ is event dependent (number of SVD hits, ...)

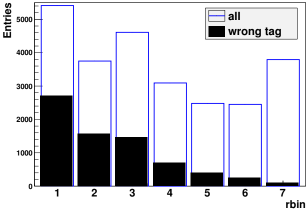
$$\mathcal{R}_{det}(x) \sim \frac{1}{s\sigma_z} \exp\left[-\frac{x^2}{2(s\sigma_z)^2}\right]$$

  s - scale factor, σ_z - uncertainty from vertex fit

- Several $\mathcal{R}^{sig}$ shape parameters are determined by fitting large control and simulated data samples.
- Using simulated events and performing B meson **lifetime fits** we validate the resolution function.

Flavor tagging

- Determination of B^{tag} flavor: **charge** of decay products $\Leftrightarrow$ B_{tag} **flavor**.
- The most important are high momentum lepton and kaon tracks.
  e.g. $B^0 \to Xl^+\nu$ ($\bar{B}^0 \to Xl^-\nu$), and K^+ from $\bar{b} \to \bar{c} \to \bar{s}$ (K^- from $b \to c \to s$)
- Algorithm returns q and r ($r \to 1$ for unambiguously determined q, and $r \to 0$ for no flavor information).
- We divide reconstructed events into 7 bins according to r and determine w in each bin (using large control samples of self-tagged decays).
- From simulated signal events:



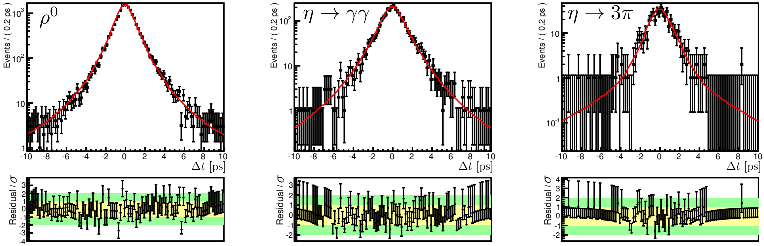
Background Δt shape

- We compose the PDF as $\mathcal{P}^{bkg}(\Delta t) = \mathcal{P}^{bkg}_{phys}(\Delta t) \otimes \mathcal{R}^{bkg}(\Delta t)$ with

$$\mathcal{P}^{bkg}_{phys}(\Delta t) = f_\delta \delta(\Delta t - \mu_\delta) + (1 - f_\delta) \exp\left(-\frac{|\Delta t - \mu_\tau|}{\tau_{bkg}}\right)$$

and $\mathcal{R}$ is a sum of 3 Gaussian functions (again with the width $\propto \sigma_z$).

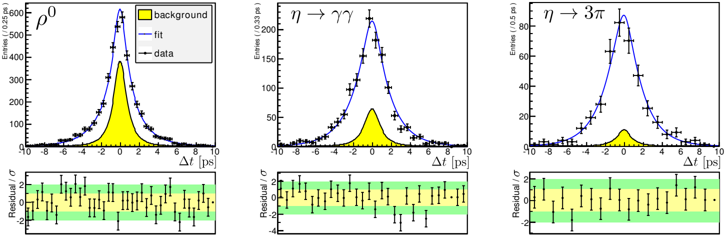
- $P^{bkg}(\Delta t)$ shape parameters $\Rightarrow$ fit of candidates in $M_{bc} - \Delta E - LR$ sideband. ($M_{bc} < 5.265$ GeV, $-0.1 < \Delta E < 0.25$ GeV, $LR < 0.9$, less than 0.1% signal.)
- Comparison: data distribution - fitted PDF (for $K^0_S \to \pi^+\pi^-$ modes)



Validation tests

- Make sure that the prepared method gives unbiased values of $\mathcal{S}_{\eta' K_S^0}$ and $\mathcal{A}_{\eta' K_S^0}$.
- Simulated events:
  - We prepare samples of simulated events that fully mimic measured data sample (signal+background)
  - Obtain $\mathcal{S}_{\eta' K_S^0}$ and $\mathcal{A}_{\eta' K_S^0}$ with the prepared method, compare with input values.

- Measured events (nominal sample $B^0 \to \eta' K_S^0$ + control sample $B^\pm \to \eta' K^\pm$).
  - **Lifetime fit**: $\mathcal{P}^{sig}(\Delta t) \Rightarrow \frac{1}{2\tau_B} \exp(-|\Delta t|/\tau_B) \otimes \mathcal{R}^{sig}$, τ_B free parameter.
  - Fit results: $\tau_{B^+} = 1.65 \pm 0.03$ ps (W.A. $\tau_{B^+} = 1.64 \pm 0.01$ ps),
    $\tau_{B^0} = 1.49 \pm 0.04$ ps (W.A. $\tau_{B^0} = 1.52 \pm 0.01$ ps)



Measurement results

- Final PDF is event dependent $\Rightarrow$ **unbinned maximum likelihood fit method**.
- Fitting measured events $\Delta t, q$ distribution we obtain (uncertainties are stat. only):

mode	772 M $B\bar{B}$	
	$\mathcal{S}_{\eta' K^0}$	$\mathcal{A}_{\eta' K^0}$
$B^0 \to \eta' K^0_S$	0.711 ± 0.074	$+0.021 \pm 0.052$
$K^0_S \to \pi^+\pi^-$	0.728 ± 0.079	-0.002 ± 0.054
ρ^0	0.718 ± 0.098	-0.071 ± 0.069
$\eta \to \gamma\gamma$	0.724 ± 0.151	$+0.161 \pm 0.098$
$\eta \to 3\pi$	0.800 ± 0.259	-0.058 ± 0.181
$K^0_S \to \pi^0\pi^0$	0.576 ± 0.206	$+0.284 \pm 0.180$

- We study several possible sources of **systematic uncertainty**:

source	$\Delta\mathcal{S}$	$\Delta\mathcal{A}$
$\mathcal{F}^{sig}, \mathcal{F}^{cont}$ param.	0.004	0.002
fractions f^i_{sig}	0.005	0.003
fractions f^i_{BB}	0.015	0.004
signal LR PDF	0.005	0.002
Δt resolution	0.020	0.006

source	$\Delta\mathcal{S}$	$\Delta\mathcal{A}$
flavor tagging	0.006	0.005
poor quality vertex	0.010	0.007
SVD missalignment	0.006	0.004
Δz bias	0.005	0.007
tag-side interference	0.002	0.020

Together: $\boxed{\Delta\mathcal{S}^{syst} = 0.03, \quad \Delta\mathcal{A}^{syst} = 0.03}$

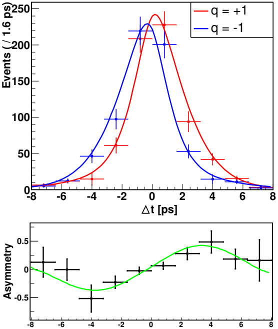
Measurement results

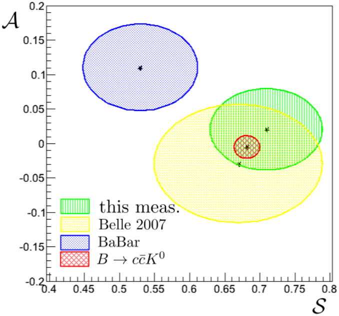
- Final result

$$\begin{aligned} \mathcal{S}_{\eta' K_S^0} &= +0.71 \pm 0.07(stat) \pm 0.03(syst) \\ \mathcal{A}_{\eta' K_S^0} &= +0.02 \pm 0.05(stat) \pm 0.03(syst) \end{aligned}$$

- The **most accurate** values up-to-date (among all $b \to s\bar{q}q$ modes).

Asymmetry plot





- Consistent with previous measurements.

- We observe **no** significant **deviation** from **the SM prediction**.

Conclusions

- We presented a measurement of the CPV parameters in $B^0 \to \eta' K_S^0$ decay, based on the Belle full data sample, containing 772 M $B\bar{B}$ pairs.

$$\mathcal{S}_{\eta' K_S^0} = +0.71 \pm 0.07 \pm 0.03, \quad \mathcal{A}_{\eta' K_S^0} = +0.02 \pm 0.05 \pm 0.03$$

- The obtained values are the most accurate up-to-date.
- We find no significant deviation from the SM prediction.
- However, the quest to discover new CP violating phases, and possibly answer one of the most intriguing questions about the Universe, is ongoing.

  In 2016 **SuperKEKB and Belle II** will start operation
  $\Rightarrow$ 50x larger sample of B mesons
  $\Rightarrow$ we expect $\Delta\mathcal{S}_{\eta' K_S^0} \simeq 0.02$.

Thank you for your attention!

"The important thing is not to stop questioning. Curiosity has its own reason for existing." - A. Einstein