Recent results on hadronic B and B_s^0 decays at Belle

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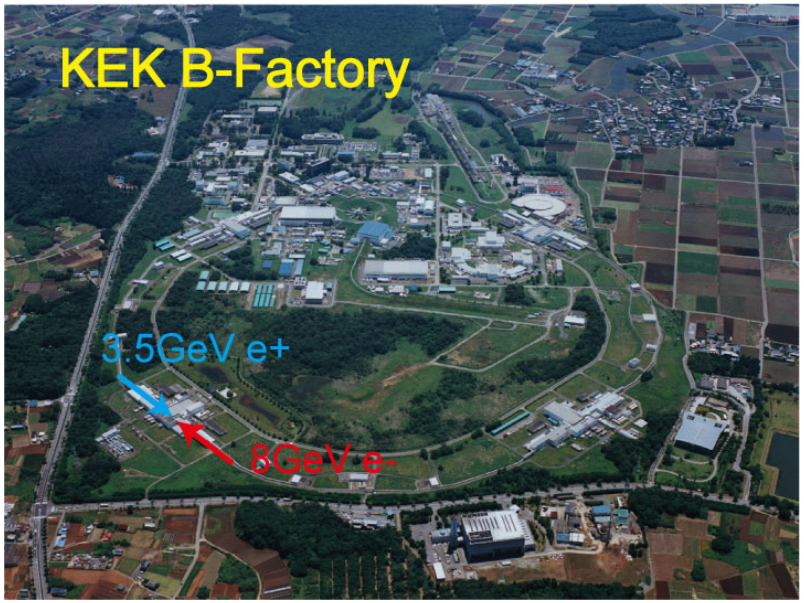
Outline of the talk

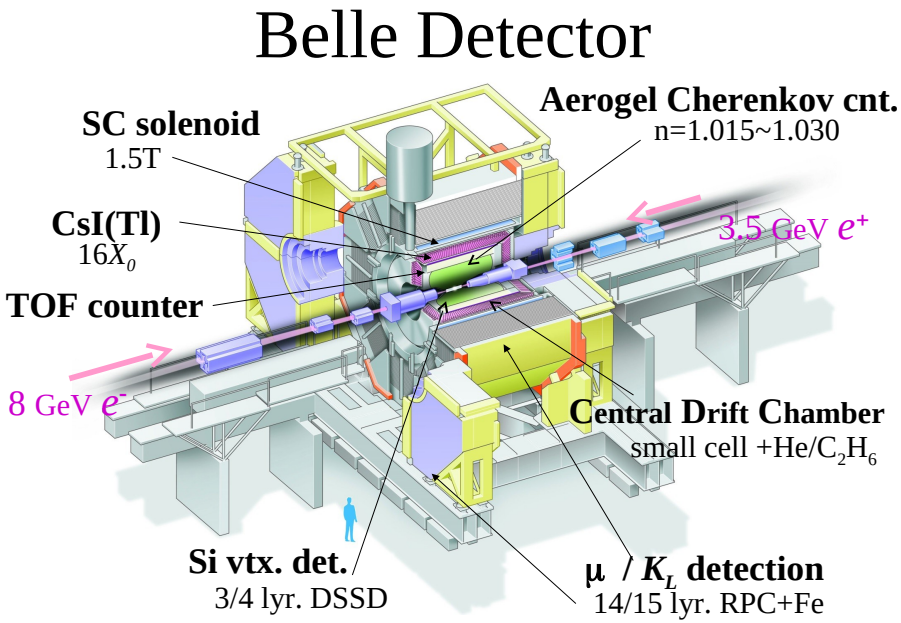
- Experimental overview
- Search for $B_s^0 \to \eta'\eta$ decay
- Search for B^0 decays to invisible final states $(+\gamma)$

KEKB and belle detector



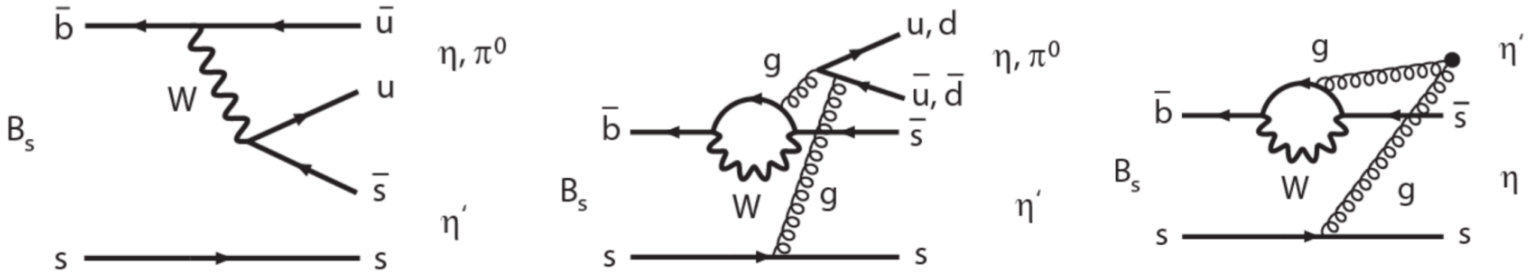
- Asymmetric e^+e^- collider at the High Energy Accelerator Research Organization(KEK), Japan
- 8 GeV e^- collides to 3.5 GeV e^+ at $\Upsilon(4S)$ resonance

- Integrated luminosity of $\sim 1\ \mathrm{ab}^{-1}$
- The main goal was to search for *CP* violation in *B* meson decays



Search for $B_s^0 \to \eta'\eta$ decay

Motivation



- Charmless hadronic decay $B_s^0 \to \eta'\eta$ proceeds via $b \to u$ and $b \to s$ transitions
- Sensitive to physics beyond the Standard Model (SM)
- Once branching fractions for decays $B_{d,s} \to \eta\eta,\ \eta'\eta,\ \eta'\eta'$ are measured, it would be possible to extract CP violating parameters (PRD, **93** 114002)
- $B_s^0 \to \eta'\eta$ has not been observed yet
- The expected branching fraction spans a wide range: $(2-4) \times 10^{-5}$ (PRD **74** 014003, PRD **76** 074018, PRD **91** 014011)

Data and reconstruction

- The analysis is performed using $121.4\ \mathrm{fb}^{-1}$ (6.5 million $B_s^0\bar{B}_s^0$ pairs) of data collected by belle at $\Upsilon(5S)$ resonance.

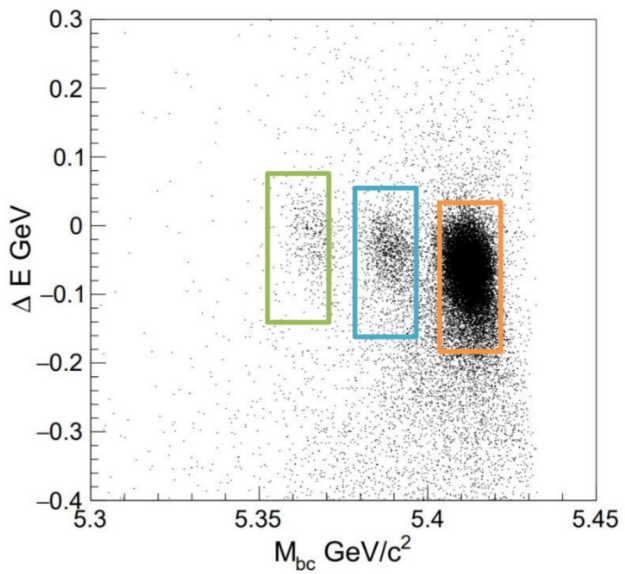
- $\Upsilon(5S)$ could decay (20%) into pairs of $B_s^{*0}\bar{B}_s^{*0}$, $B_s^0\bar{B}_s^{*0}$ $(+c.c.)$ and $B_s^0\bar{B}_s^0$. The excited B_s^{*0} transitions to B_s^0 by emitting a photon.

- We reconstruct $B_s^0 \to \eta'\eta$; $\eta' \to \pi^+\pi^-\eta$; $\eta \to \gamma\gamma$

- Two kinematic variables to identify signal:

$$M_{\mathrm{bc}} = \sqrt{E_{\mathrm{beam}}^2 - p_{B_s}^2}$$

$$\Delta E = E_{B_s} - E_{\mathrm{beam}}$$



Signal selection requirements

Particle	Criteria
γ	$E \geq 50$ MeV (barrel) $E \geq 100$ MeV (endcap) $E9/E25 \geq 0.75$
$\pi^{\pm}$	$dr \leq 0.3$ cm $\lvert dz \rvert \leq 4$ cm $p_T \geq 100$ MeV/c $KID \leq 0.6$ $EID \leq 0.85$ MeV/c
η	$0.515\ \mathrm{GeV/c^2} \leq M(\gamma\gamma) \leq 0.580\ \mathrm{GeV/c^2}$ $\lvert \cos\theta_{hel} \rvert < 0.97$
η'	$0.92\ \mathrm{GeV/c^2} \leq M(\pi^+\pi^-\eta) \leq 0.98\ \mathrm{GeV/c^2}$
B_s	$M_{bc} \geq 5.3\ \mathrm{GeV/c^2}$ -0.4 GeV $\leq \Delta E \leq 0.3$ GeV

Background rejection

- Background events:

$\rightarrow$ Hadronic continuum: coming from light quark pairs, $e^+e^- \rightarrow q\bar{q}$

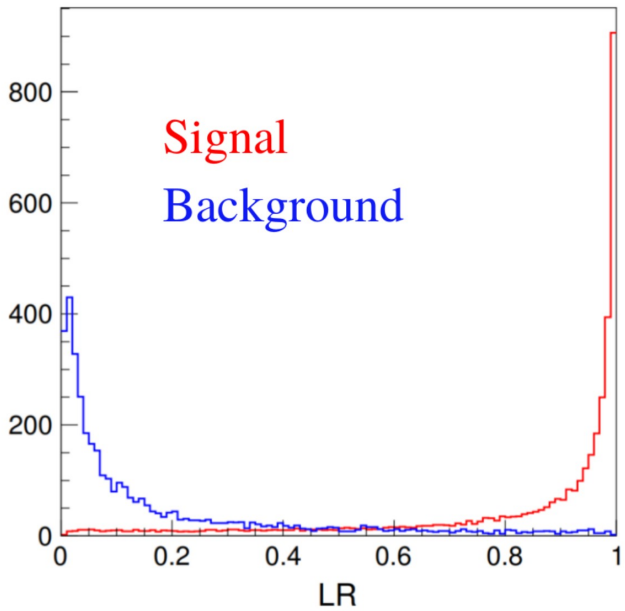
$\rightarrow$ Peaking background: Coming from background events with a real η' (included in 3D fit)

- A likelihood ratio ($\mathcal{LR}$) derived from Modified FW moments is used to suppress the continuum background.

$\rightarrow$ Optimized selection, $\mathcal{LR} > 0.95$

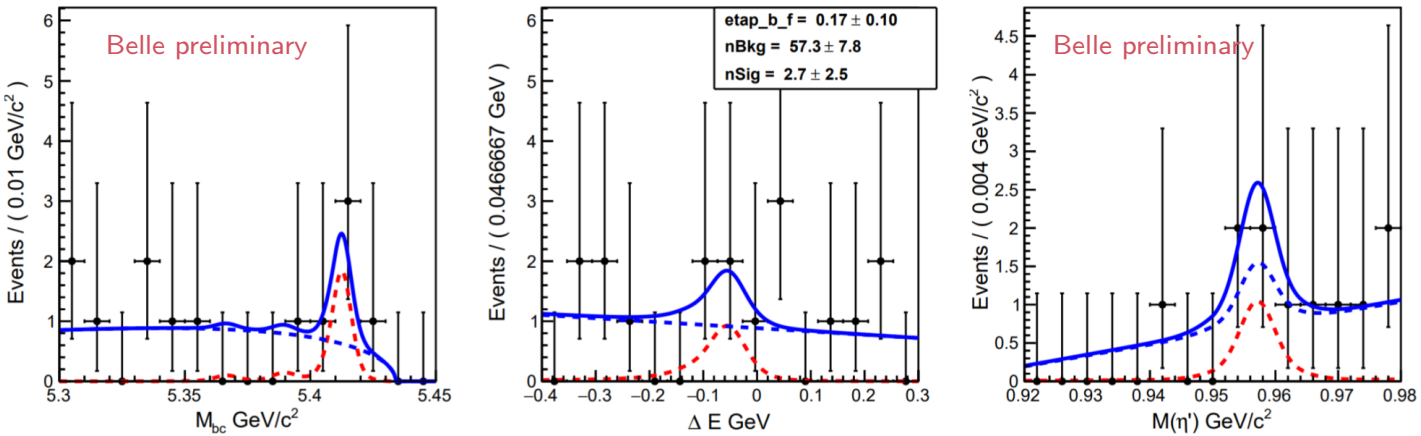
$\rightarrow$ This rejects 99% of background (with $\sim$ 9% signal loss)

- Final signal efficiency (ϵ) for $B_s \rightarrow \eta'\eta$ is 10%



Signal yield from data

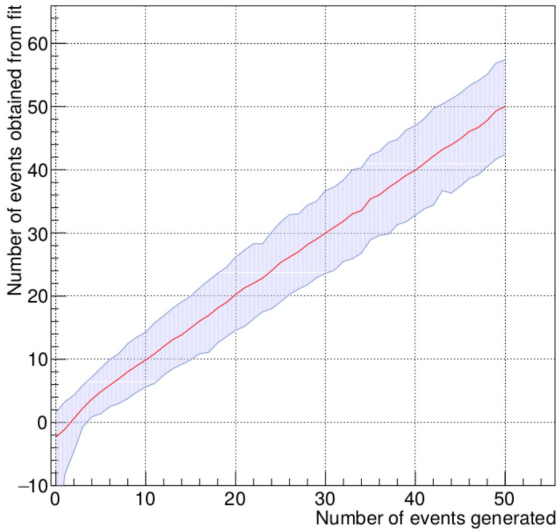
- Signal yield is extracted using unbinned extended maximum likelihood fit to M_{bc}, ΔE and $M(\eta')$
- Signal and background shapes (PDFs) are obtained from MC simulation
- Signal PDFs are calibrated using the control sample, $B^0 \to \eta' K_S$ signal events in the $\Upsilon(4S)$ data



- Obtained number of signal events $= 2.7 \pm 2.5$

Upper limit on $\mathcal{B}(B_s^0 \to \eta'\eta)$

- In absence of significant number of signal events, we estimate an upper limit on the branching fraction
- The fitting model is validated using the ensembles of pseudo-experiments and we prepare a 80% confidence belt using Neyman Construction



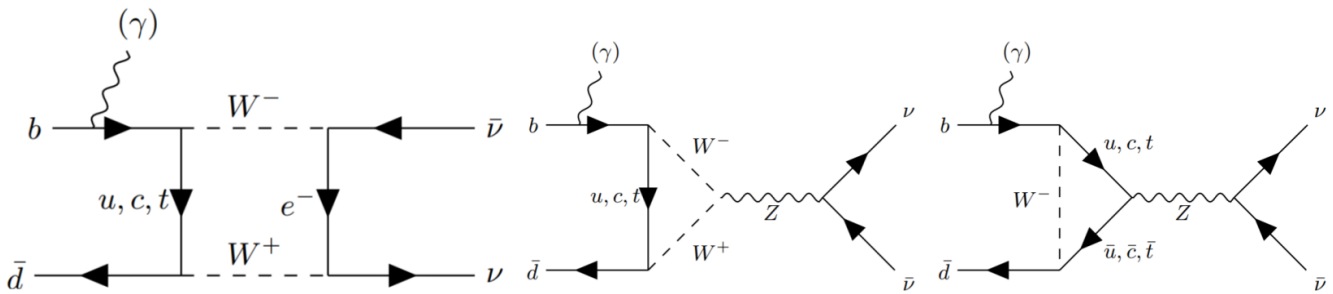
$\to$ 90% confidence level (CL) upper limit on branching fraction:

$$\mathcal{B}(B_s^0 \to \eta'\eta) < \frac{N_{UP}^{90\%}}{2 \times N_{B_s^* \bar{B}_s^*} \times \epsilon \times \mathcal{B}_{daughters}}$$

- Total systematic uncertainty is estimated to be 19%
- Upper limit on the branching fraction; $\boxed{\mathcal{B}(B_s^0 \to \eta'\eta) < 7.1 \times 10^{-5}}$

Search for B decays to invisible final states ($+\gamma$)

Motivation



- Sensitive to beyond the SM physics
- Models with $R-$parity violation or dark matter contributions predict a branching fraction as high as 10^{-6} to 10^{-7} (PRD **65** 015001, PRD **82** (034005))
- The SM prediction for $B^0 \to \nu\nu$ ($B^0 \to \gamma\nu\nu$) is of order $10^{-25}(10^{-9})$ (Nucl. Phys. **B400** 225, Phys. Lett. B 381, **348**))
- A very low background from the SM indicates that a signal of $B^0 \to \nu\nu(+\gamma)$ in the current B-factory data would indicate new physics.

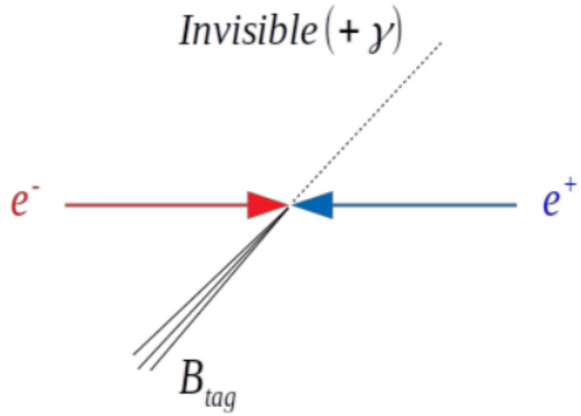
Exp.	Data (fb^{-1})	$\mathcal{B}(B^0 \to \text{invisible})$	$\mathcal{B}(B^0 \to \text{invisible} + \gamma)$	Reference
Belle	424	$< 1.2 \times 10^{-4}$	–	PRD **86**, 032002
BaBar	606	$< 2.4 \times 10^{-5}$	$< 1.7 \times 10^{-5}$	PRD **86**, 051105

Data and selection

- $711\ \mathrm{fb}^{-1}$ (772 million $B\bar{B}$ pairs) of data collected at $\Upsilon(4S)$ resonance

- One B^0 is fully reconstructed (B_{tag}). Nothing ($B^0 \to \mathrm{invisible}$) or a photon ($B^0 \to \mathrm{invisible} + \gamma$) in the remaining part of the event is considered as a signal candidate.

- 1.4 million B_{tag} candidates are reconstructed from hadronic decay channels using an improved algorithm based on a neural network (NN)
- Reconstruction efficiencies of B_{tag} is 0.41% (0.47%) in $B^0 \to \nu\nu$ ($B^0 \to \gamma\nu\nu$) simulation
- γ selection : $E_\gamma > 0.5\ \mathrm{GeV}$



Background rejection

1. $e^+e^- \to q\bar{q}$ (non-B)
2. B-decays through $b \to c$ (charmed-B)

- Two separate NN is used :

$\to$ Fake B_{tag} (O_{tag})

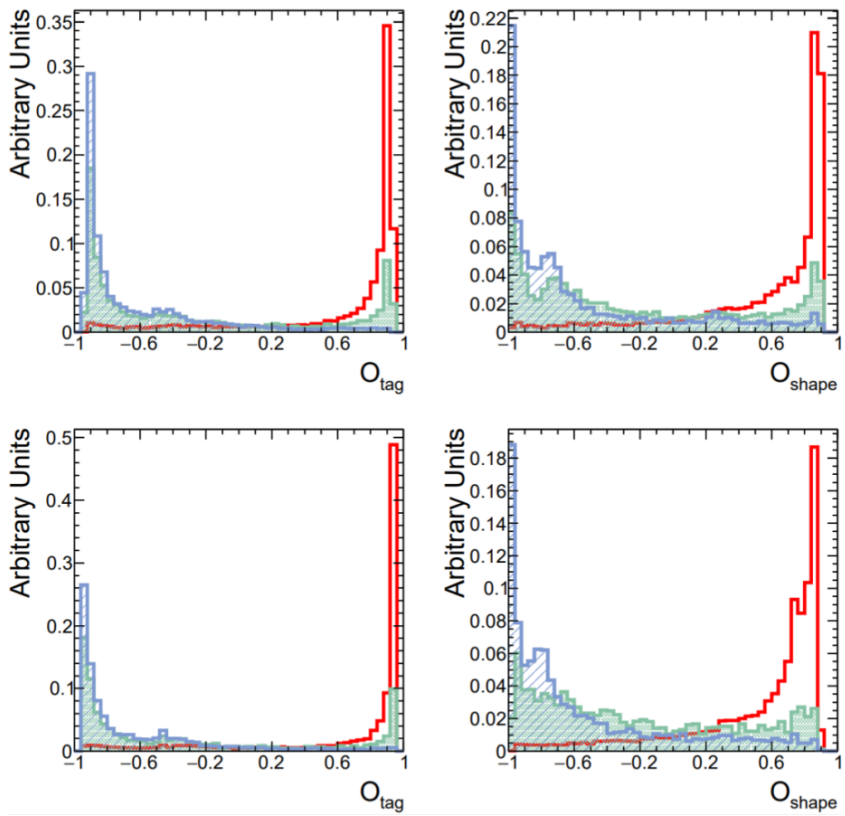
$\to$ Events with jet-like topology (O_{shape})

- Selection variables:

$\mathbf{E_{ECL}}$: sum of all the remaining energies of ECL clusters

$\mathbf{cos\theta_T}$: cosine of the angle between the two thrust axes (B_{tag} and the rest of the event) in the CM frame.

$B^0 \to$ invisible



$B^0 \to$ invisible $+ \gamma$

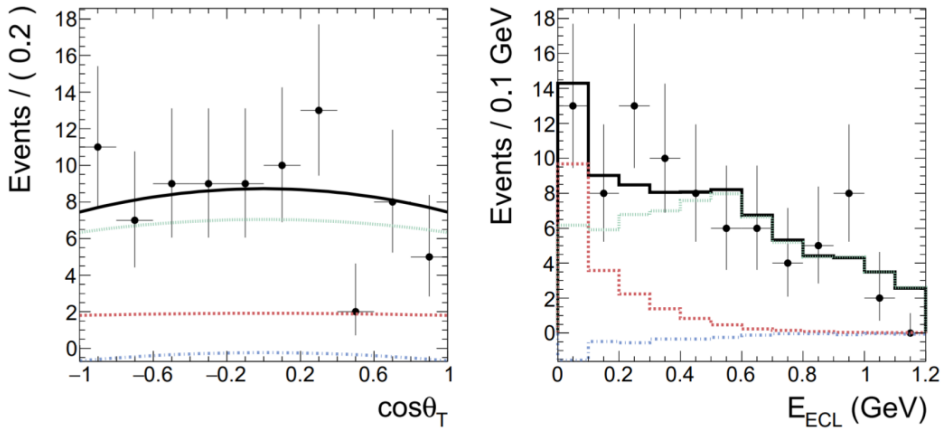
Results on $B^0 \to$ invisible

- The signal yield is extracted by an extended unbinned maximum likelihood fit to $E_{\rm ECL}$ and $\cos\theta_T$
- PDFs are obtained from MC simulation (non-B component is from off-resonance data)
- $B^{0,\pm} \to D^{*,\pm} l\nu$ are used as control sample
- Total systematic uncertainty is estimated to be 7.9%

Component	Yields
Signal	$18.8^{+15.3}_{-14.5}$
Generic B	$68.1^{+12.2}_{-11.7}$
Non-B	$-3.9^{+19.5}_{-17.5}$

$\to$ UL on branching fraction;

$$\mathcal{B}(B^0 \to \text{invisible}) < 7.8 \times 10^{-5}$$



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Results on $B^0 \to \text{invisible} + \gamma$

- Signal yield is extracted by counting events in the bins of $M^2_{\text{miss}} = (\vec{P}_{\text{beam}} - \vec{P}_{B_{tag}} - \vec{P}_{\gamma})^2$ in E_{ECL} signal box ($E_{\text{ECL}} < 0.3$ GeV)
- The number of background events in the signal box is estimated from the E_{ECL} data sideband multiplied by a scaling factor obtained from MC
- Observed number of events are all consistent within uncertainties with the expected backgrounds

	$N^{\text{data}}_{\text{bkg,box}}$	$N^{\text{data}}_{\text{box}}$
$B^0 \to \text{invisible} + \gamma$	16.1 ± 6.3	11
bin1	3.2 ± 2.1	2
bin2	1.0 ± 0.8	2
bin3	4.4 ± 2.6	3
bin4	7.1 ± 2.9	4
bin5	6.6 ± 2.9	7

- Total systematic uncertainty is estimated to be 8.4%
- UL on branching fraction: $\mathcal{B}(B^0 \to \text{invisible} + \gamma) < 1.6 \times 10^{-5}$

Summary

- We present a preliminary result of the first search for the decay $B_s^0 \to \eta' \eta$ using full data sample collected by Belle at $\Upsilon(5S)$ resonance
- In absence of a statistically significant signal, a 90% CL upper limit is set on its branching fraction at 7.1×10^{-5}
- We report searches for $B^0 \to \text{invisible}$ and $B^0 \to \text{invisible} + \gamma$ decays using full Belle data sample collected at $\Upsilon(4S)$ resonance
- We observe no significant signal for either decay and set UL on their branching fractions at 90% confidence level as $\mathcal{B}(B^0 \to \text{invisible}) < 7.8 \times 10^{-5}$ and $\mathcal{B}(B^0 \to \text{invisible} + \gamma) < 1.6 \times 10^{-5}$
- The results on $B^0 \to \text{invisible}\ (+\gamma)$ decays are published in Phys. Rev. D **102**, 012003 (2020)

Thank you!

Backup:

TABLE I: Summary of systematic uncertainties in the $B_s^0 \to \eta'\eta$ analysis.

Source	Uncertainty (%)
Number of $B_s^{(*)0}\overline{B}_s^{(*)0}$ pairs	10.1
Branching fraction of η	0.5
Branching fraction of η'	1.2
MC statistics	0.1
η reconstruction	4.2
Tracking	0.7
$\mathcal{LR}$ selection	15.3

Backup: Systematic uncertainties for $B^0 \to$ invisible

TABLE II. Summary of systematic uncertainties on fitting yield.

Sources	Systematic uncertainty (Events)
Signal PDF	± 0.6
Generic B PDF	$^{+1.9}_{-1.8}$
Non-B PDF	$^{+6.6}_{-6.7}$
Signal PDF correlation	$^{+0.3}_{-0.0}$
Total	$^{+6.8}_{-7.0}$