Joint IJCLAB - IFJ PAN Heavy Flavour meeting

Search for the decay $B_s^0 \to J/\psi\pi^0$ at Belle Experiment

Dr. Devender Kumar
Institute of Nuclear Physics - Polish Academy of Sciences, Krakow

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Ph.D. Supervisor
Prof. Bipul Bhuyan
Indian Institute of Technology Guwahati, India

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4. Maximum Likelihood Fit Analysis
5. MC Simulation Validation
6. Fit Validation
7. Results and Summary

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D. Kumar, B. Bhuyan, H. Aihara, D. M. Asner, T. Aushev, R. Ayad, V. Babu, Sw. Banerjee, M. Bauer, P. Behera, K. Belous, J. Bennett, M. Bessner, T. Bilka, D. Biswas, A. Bobrov, D. Bodrov, J. Borah, M. Bračko, P. Branchini, T. E. Browder, A. Budano, M. Campajola, D. Červenkov, M.-C. Chang, C. Chen, B. G. Cheon, K. Chilikin, K. Cho, S.-K. Choi, Y. Choi, S. Choudhury, S. Das, N. Dash, G. De Nardo, G. De Pietro, R. Dhamija, Z. Doležal, T. V. Dong, P. Ecker, D. Epifanov, D. Ferlewicz, B. G. Fulsom, R. Garg, V. Gaur, A. Garmash, A. Giri, P. Goldenzweig, E. Graziani, K. Gudkova, C. Hadjivasiliou, K. Hayasaka, H. Hayashii, S. Hazra, D. Herrmann, W.-S. Hou, C.-L. Hsu, N. Ipsita, A. Ishikawa, R. Itoh, M. Iwasaki, W. W. Jacobs, S. Jia, Y. Jin, D. Kalita, A. B. Kaliyar, C. Kiesling, C. H. Kim, D. Y. Kim, K.-H. Kim, Y.-K. Kim, K. Kinoshita, P. Kodyš, A. Korobov, S. Korpar, E. Kovalenko, P. Križan, P. Krokovny, T. Kuhr, R. Kumar, K. Kumara, T. Kumita, A. Kuzmin, Y.-J. Kwon, T. Lam, S. C. Lee, D. Levit, L. K. Li, Y. Li, Y. B. Li, L. Li Gioi, J. Libby, D. Liventsev, Y. Ma, M. Masuda, T. Matsuda, D. Matvienko, S. K. Maurya, F. Meier, M. Merola, F. Metzner, K. Miyabayashi, R. Mizuk, G. B. Mohanty, R. Mussa, M. Nakao, Z. Natkaniec, A. Natochii, L. Nayak, M. Nayak, S. Nishida, S. Ogawa, H. Ono, P. Pakhlov, G. Pakhlova, S. Pardi, J. Park, S.-H. Park, A. Passeri, S. Paul, T. K. Pedlar, R. Pestotnik, L. E. Piilonen, T. Podobnik, M. T. Prim, N. Rout, G. Russo, S. Sandilya, L. Santelj, V. Savinov, G. Schnell, C. Schwanda, Y. Seino, M. E. Sevior, W. Shan, C. Sharma, C. P. Shen, J.-G. Shiu, J. B. Singh, E. Solovieva, M. Starič, Z. S. Stottler, M. Sumihama, M. Takizawa, K. Tanida, F. Tenchini, R. Tiwary, T. Uglov, Y. Unno, S. Uno, Y. Ushiroda, S. E. Vahsen, K. E. Varvell, A. Vinokurova, D. Wang, X. L. Wang, S. Watanuki, E. Won, B. D. Yabsley, W. Yan, J. Yelton, J. H. Yin, L. Yuan, Z. P. Zhang, V. Zhilich, and V. Zhukova

(Belle Collaboration)

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We have analyzed 121.4 fb^{-1} of data collected at the $\Upsilon(5S)$ resonance by the Belle experiment using the KEKB asymmetric-energy e^+e^- collider to search for the decay $B_s^0 \to J/\psi\pi^0$. We observe no signal and report an upper limit on the branching fraction $\mathcal{B}(B_s^0 \to J/\psi\pi^0)$ of 1.21×10^{-5} at 90% confidence level. This result is the most stringent, improving the previous bound by 2 orders of magnitude.

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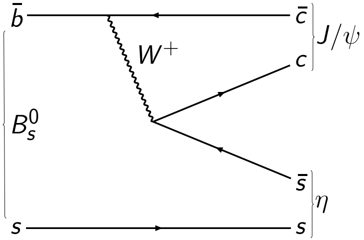
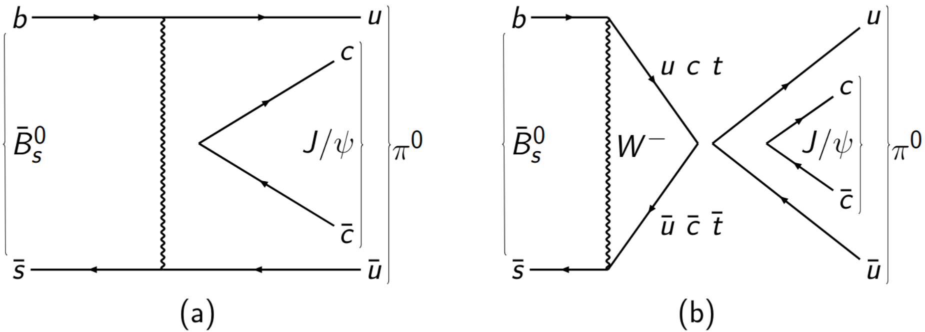
Theoretical Motivation for the Decay $B_s^0 \to J/\psi\pi^0$

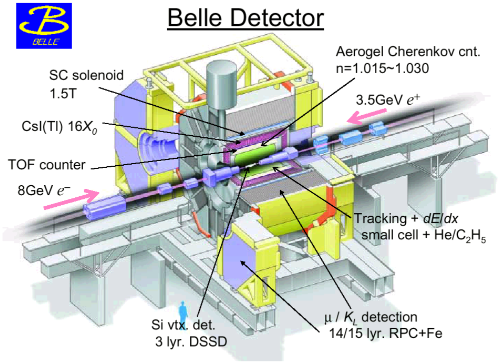
- The B mesons, composited of a heavy anti-b quark and a light quark provide a rich environment for the flavour physics analysis.
- The $\mathcal{B}$ for decay $B_s^0 \to J/\psi\pi^0$ is predicted from the measurement of $\mathcal{B}(B_s^0 \to J/\psi\eta)$, where η can transit to π^0 under the assumption of isospin-zero admixture in π^0.
- Suppression factor due to the violation of strong isospin in the $\eta - \pi^0$ transition is of the order of 10^{-2}.
- The factor is predicted from $\frac{\Gamma(\psi' \to J/\psi\pi^0)}{\Gamma(\psi' \to J/\psi\eta)}$ [PRD 86, 092008 (2012)] and the corresponding theoretical prediction for $\frac{\Gamma(\Upsilon(2S) \to \Upsilon(1S)\pi^0)}{\Gamma(\Upsilon(2S) \to \Upsilon(1S)\eta)}$ [Prog. Part. Nucl. Phys. 61, 455 (2008), PRL 101, 192001 (2008)].
- Theoretical prediction of $\mathcal{B}(B_s^0 \to J/\psi\pi^0) \sim 4 \times 10^{-6}$.



- The contributions from W exchange and annihilation processes are of the order of 10^{-8} or less (based on the measured branching fractions of $B_s^0 \to \pi^+\pi^-$ and $B_d^0 \to K^+K^-$ [PRL 118, 081801 (2017)]).



- Any significant deviation from the theoretical prediction can hint to NP phenomenon.
- The existing limit on the branching fraction $\mathcal{B}(B_s^0 \to J/\psi\pi^0)$ of 1.2×10^{-3} at 90% confidence level was first set by L3 collaboration in 1997 [Phys. Lett. B 391, 481 (1997)].

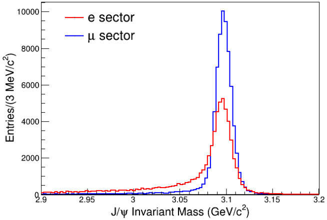


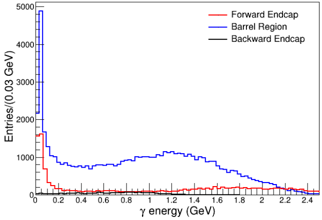
1. Silicon Vertex Detector (SVD)
2. Central Drift Chamber (CDC)
3. Aerogel Cherenkov Counter (ACC)
4. Time-of-Flight scintillation counter (TOF)
5. Electromagnetic Calorimeter (ECL)
6. K_L^0 and μ detector (KLM)
7. Extreme Forward Calorimeter (EFC)

- The first five sub-detectors are housed inside a solenoidal magnetic field of strength 1.5 T pointing along the electron beam direction.
- The Belle detector collected a total of $\sim 1\ ab^{-1}$ of collision data during its operation.

Particle Identification and Event Reconstruction

- We performed a "`blind`" analysis using simulated Monte Carlo (MC) data to optimize the $B_s^0 \to J/\psi\pi^0$ selection criteria: Event Generator (`EvtGen`) and Simulator (`Geant3`).



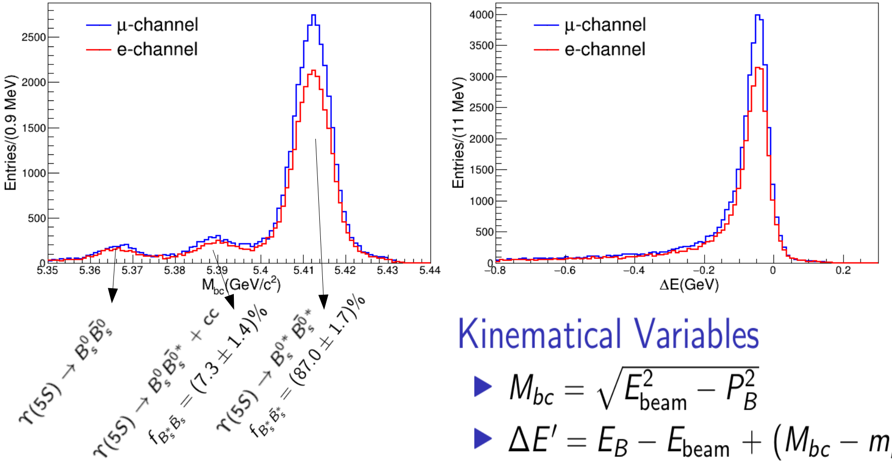


Particle Identification

- e: Charged track matching with the energy cluster deposited in the ECL.
- μ: The penetration depth and lateral spread of the charged-particle hits in the KLM.
- γ: Electromagnetic clusters with no associated charged tracks.

- J/ψ mass-window cuts: Approximately $\pm 3\sigma$ around the nominal J/ψ mass.
- π^0 selection: We require the photon candidates to have a minimum threshold energy of 50 and 100 MeV in the barrel and both end-cap regions.

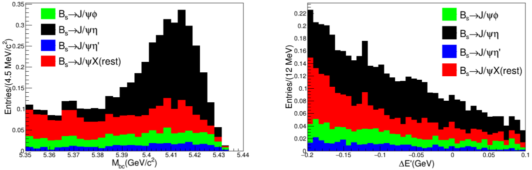
$B_s^0 \to J/\psi\pi^0$ Reconstruction



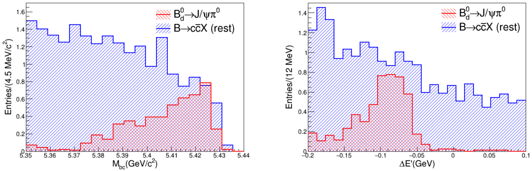
REF: PRD87, 031101(R) (2013)

Kinematical Variables

- $M_{bc} = \sqrt{E_{beam}^2 - P_B^2}$
- $\Delta E' = E_B - E_{beam} + (M_{bc} - m_{B_s^0})$



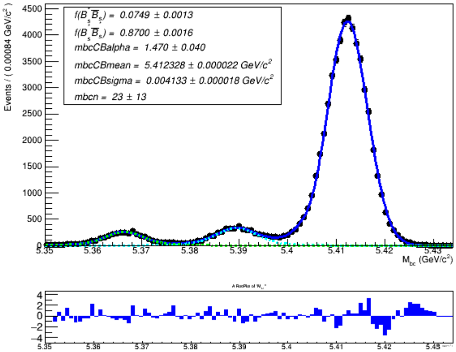
$B_s^0 \to c\bar{c}X$ background

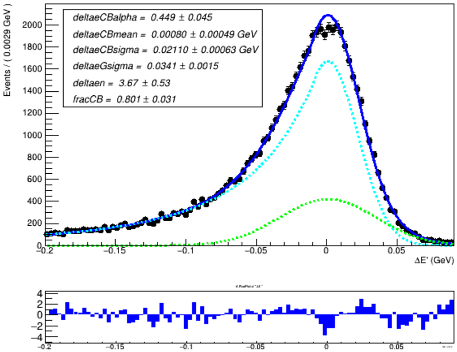


$B \to c\bar{c}X$ background

- The tagged components exist only at the generated level.
- The selected events have correctly reconstructed J/ψ more than 95% of the time, whereas a random combination of photons or a π^0 from the other end satisfies the $B_s^0 \to J/\psi\pi^0$ selection criteria.
- Combinatorial events from the continuum background are suppressed using the reduced Fox-Wolfram variable.

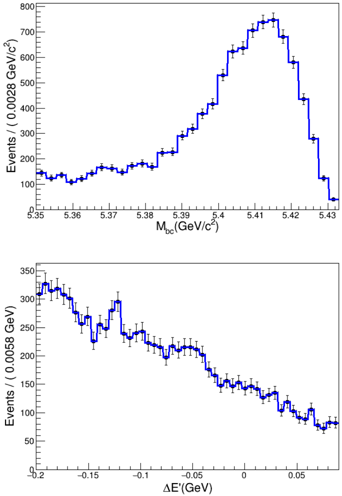
Maximum Likelihood Fit Analysis: Signal PDF



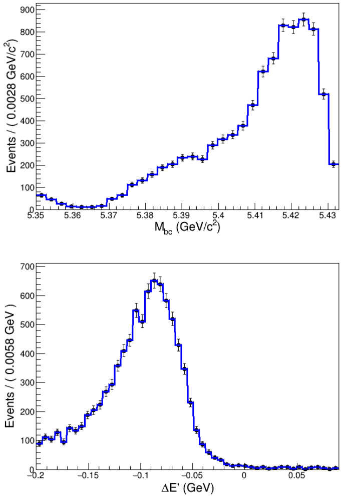


- Mean and width of the 2nd & 3rd Gaussian components are fixed (Determined from MC $\Upsilon(5S) \to B_s^0 \bar{B}_s^0$ and $\Upsilon(5S) \to B_s^{0^*} \bar{B}_s^0/cc$ signals).
- Crystal Ball function for the primary M_{bc} peak.
- Crystal Ball and Gaussian function for the $\Delta E'$ distribution.

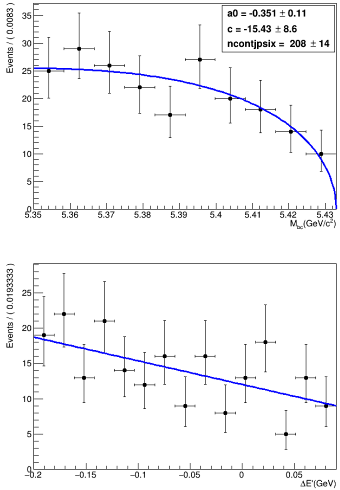
Fit Projections to the MC Simulated Backgrounds



$B_s^0 \to J/\psi X$

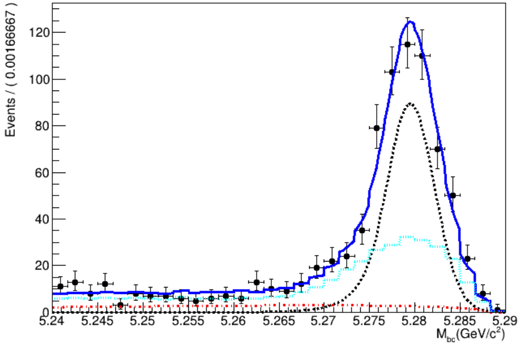


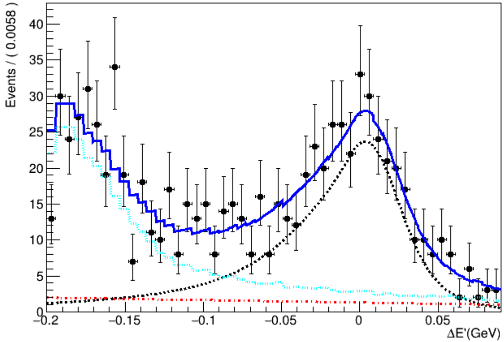
$B_d^0 \to J/\psi \pi^0$



Continuum + $B \to J/\psi X$

MC Simulation Validation: $B_d^0 \to J/\psi\pi^0$ at $\Upsilon(4S)$ Resonance



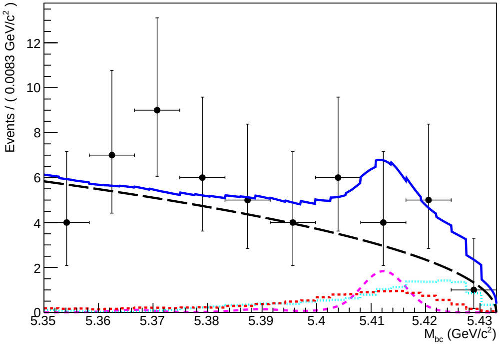


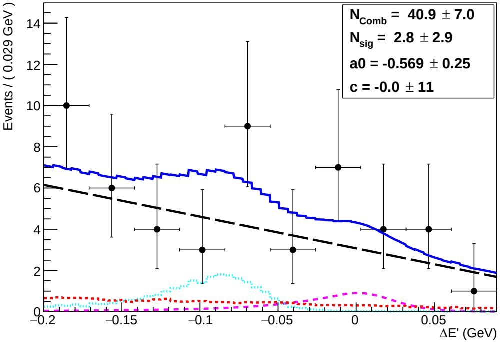
- $\mathcal{B}(B_d^0 \to J/\psi\pi^0) = \frac{Y_{\text{sig}}}{2\times N_{B\bar{B}}\times\epsilon_{\text{MC}}\times\mathcal{B}_{J/\psi\to l^+l^-}\times\mathcal{B}_{\pi^0\to\gamma\gamma}}$
- $\mathcal{B}(B_d^0 \to J/\psi\pi^0) = (1.63 \pm 0.12) \times 10^{-5}$

  Belle meas. $(1.62 \pm 0.11) \times 10^{-5}$ [PRD 98, 112008 (2018)]

  PDG meas. $(1.66 \pm 0.10) \times 10^{-5}$ [PTEP 083C01 (2022)].

- $\epsilon_{\text{MC}} = (30.9 \pm 0.1)\%$
- $Y_{\text{sig}} = 369.0 \pm 26.6$
- $2 \times N_{B\bar{B}} = (619 \pm 9) \times 10^6$



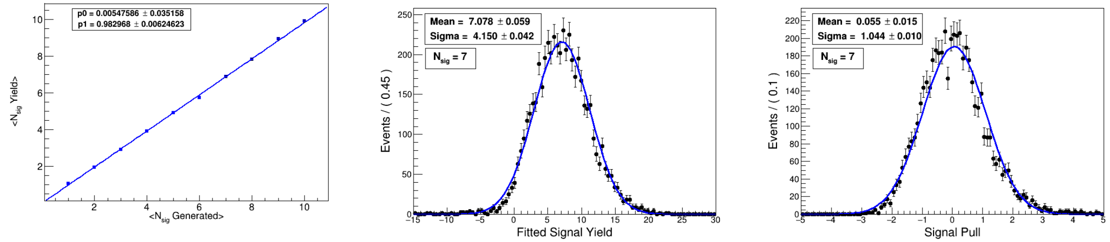


Projections of the 2D fit to GSim data with three $B_s^0 \to J/\psi\pi^0$ input signals.

- Ensembles of 5000 identical samples for different pseudo-experiments having $N_{\text{sig}} = (1, 2, .., 10)$ signals are generated.

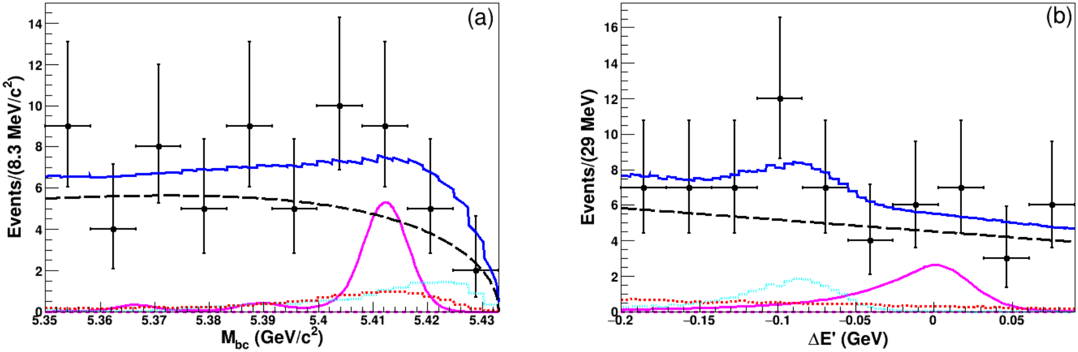
$$\text{Signal Pull} = \frac{N_{\text{sig}}^{\text{Yield}} - N_{\text{sig}}^{\text{exp}}}{N_{\text{sig}}^{\text{Error}}}$$

The Linearity Test and Pull Bias



- The mean of the extracted yield is linear to the generated signals with a slope ~ 1.
- The Fit bias is computed for an input of 7 $B_s^0 \to J/\psi\pi^0$ signal events.
- Estimated bias of $(5.5 \pm 1.5)\%$ corresponds to an systematic uncertainty of $+0.23$ events in the signal yield extraction.

Data Unblinding for the $B_s^0 \to J/\psi\pi^0$ Events



Projections of the fit to selected $B_s^0 \to J/\psi\pi^0$ events in the 121.4 fb^{-1} of e^+e^- collision data.

- Based on the MC, the yields corresponding to $B_s^0 \to c\bar{c}X$ and $B_d^0 \to J/\psi\pi^0$ background components are fixed to $4.33 \pm 2.08^{+0.51}_{-0.52}$ and $5.17 \pm 2.27^{+0.49}_{-0.53}$ events, respectively.
- We obtain the signal and combinatorial background yields of 0.0 ± 3.2 and 50.0 ± 4.0, where the uncertainties are statistical only.

TABLE I. Additive systematic uncertainties on $\mathcal{B}(B_s^0 \to J/\psi\pi^0)$.

Source	Uncertainty (events)
PDF parametrization	$^{+0.7}_{-0.8}$
Fit bias	$^{+0.2}_{-0.0}$
Total (quadratic sum)	$^{+0.7}_{-0.8}$

TABLE II. Multiplicative systematic uncertainties on $\mathcal{B}(B_s^0 \to J/\psi\pi^0)$.

Source	Uncertainty (%)
π^0 reconstruction	2.2
Tracking	2×0.35
Lepton-ID selection	2×2.25
MC statistics	0.32
Number of B_s^0 mesons	$^{+10.3}_{-10.7}$
$\mathcal{B}(J/\psi \to l^+l^-)$	0.77
$\mathcal{B}(\pi^0 \to \gamma\gamma)$	0.03
J/ψ mass-vertex fit $\chi^2 < 60$	2.25
Total (quadratic sum)	$^{+11.7}_{-12.1}$

- Additive and multiplicative uncertainties affect the measurements, differently.

- The upper limit on the branching fraction is calculated using the Bayesian approach:

$$\mathcal{B}(B_s^0 \to J/\psi\pi^0) = \frac{N_{\text{sig}}^{\text{Yield}} \text{ (at 90\% CL)}}{2 \times N_{B_s^0\bar{B}_s^0} \times \epsilon \times \mathcal{B}_{J/\psi} \times \mathcal{B}_{\pi^0}},$$

- $N_{\text{sig}}^{\text{Yield}}$ is 8.03 (7.64) $B_s^0 \to J/\psi\pi^0$ events with (without) systematic uncertainties.
- $N_{B_s^0\bar{B}_s^0} = (9.08^{+0.94}_{-0.98}) \times 10^6$ and $\epsilon = 0.310 \pm 0.001$.

Branching fraction	UL at 90% CL
$\mathcal{B}(B_s^0 \to J/\psi\pi^0)$ without systematic	$< 11.51 \times 10^{-6}$
$\mathcal{B}(B_s^0 \to J/\psi\pi^0)$ with systematic	$< 12.10 \times 10^{-6}$

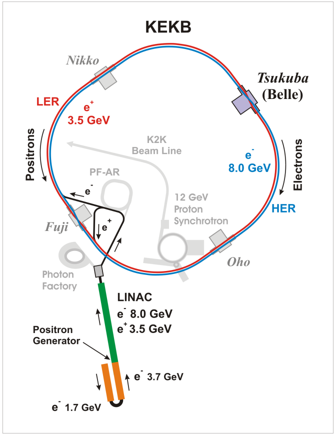
- The reported UL is the most stringent limit and **improves the previous upper bound by two orders of magnitude** set by the L3 collaboration in 1997.

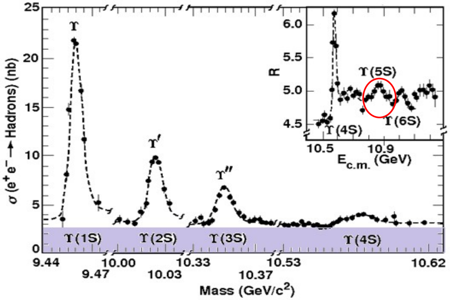
- In summary, we analyzed the 121.4 fb^{-1} of e^+e^- collision data at $\Upsilon(5S)$ resonance to search for the decay $B_s^0 \to J/\psi\pi^0$.
- As no signals are observed, we set a UL on the branching fraction $\mathcal{B}(B_s^0 \to J/\psi\pi^0)$ of 12.10×10^{-6} at 90% CL [PRD 109, 032007 (2024)].
- The reported UL is the most stringent limit and **improves the previous upper bound by two orders of magnitude** set by the L3 collaboration in 1997.
- The predicted branching fraction of $B_s^0 \to J/\psi\pi^0$ of order 4×10^{-6} is within the acceptable region of the measured UL.
- The precise measurement of this branching fraction can be performed at the Belle II experiment, a successor of the Belle experiment, which plans to collect approximately 5 ab^{-1} of data at $\Upsilon(5S)$ resonance in the near future.

Thank you!

Reference slides

- The KEKB is an asymmetric-energy e^+e^- collider at KEK(Japan), which operated for around 10 year (1999-2010) producing the $B\bar{B}$ mesons like in a factory.



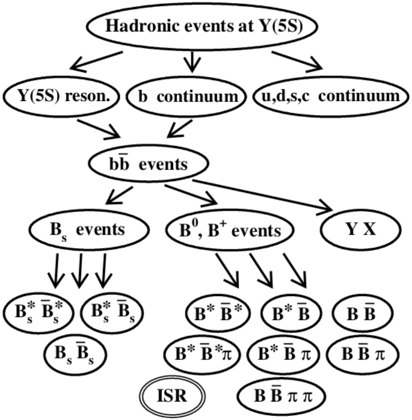


Results of CUSB Collaboration.

- The KEKB accelerator set a world record of instantaneous luminosity of 2.11×10^{34} cm^{-2}s^{-1} in 2009; Current holder: SuperKEKB, 4.7×10^{34} cm^{-2}s^{-1}

$B_s^0 \bar{B}_s^0$-mesons production

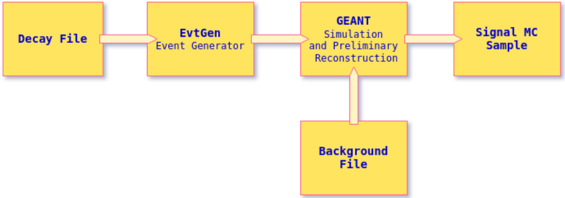
- $\Upsilon(5S)$ resonance is the 4^{th} excited state of the $b\bar{b}$ system with a J^{PC} value of 1^{--} and rest mass energy of 10.885 GeV$/c^2$.



1. $\sigma(e^+e^- \to b\bar{b}) = 0.340 \pm 0.016$ nb. [PRD 87, 031101(R) (2013)]
2. Fraction of $b\bar{b}$ events producing B_s^0 mesons, $f_s = 22.0^{+2.0}_{-2.1}$ [JHEP 08, 131 (2023)].
3. Total int. lum. $= (121.4 \pm 1.6)\text{fb}^{-1}$.
4. The number of analysed $B_s^0 \bar{B}_s^0$ mesons:

$$2 \times N_{B_s^0 \bar{B}_s^0} = 2 \times 121.4 \text{ fb}^{-1} \times \sigma_{b\bar{b}}^{\Upsilon(5S)} \times f_s$$
$$= (18.16^{+1.87}_{-1.95}) \times 10^6$$

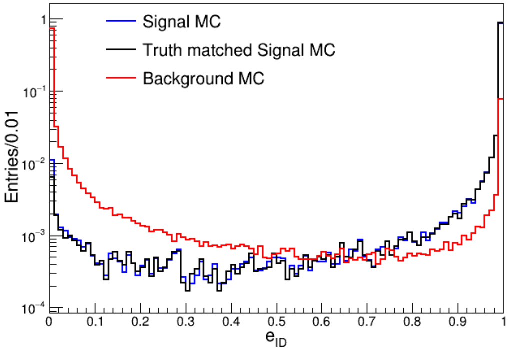
We perform a "blind" analysis using simulated Monte Carlo (MC) data to optimize the $B_s^0 \to J/\psi\pi^0$ selection criteria.

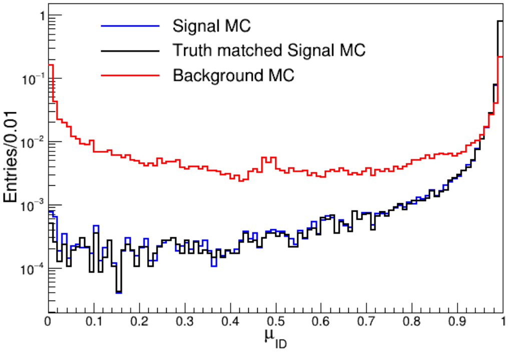


Decay Table	
Decay mode	Decay Model
$\Upsilon(5S) \to B_s^{0*} \bar{B}_s^{0*}$	PHSP
$\Upsilon(5S) \to B_s^0 \bar{B}_s^{0*} + cc$	PHSP
$\Upsilon(5S) \to B_s^0 \bar{B}_s^0$	VSS
$B_s^{0*} \to B_s^0 \gamma$	VSP_PWAVE
$B_s^0 \to J/\psi\ \pi^0$	SVS
$J/\psi \to \mu^+\mu^-$	VLL + PHOTOS
$J/\psi \to e^+e^-$	VLL + PHOTOS
$\pi^0 \to \gamma\gamma$	PHSP

- We have generated 100,000 experimental dependent MC simulated events for each of the leptonic mode (Signals with $J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$ channels).
- For background study: MC samples dedicated for $e^+e^- \to q\bar{q}$ (continuum), $e^+e^- \to B_s^{0(*)} \bar{B}_s^{0(*)}$, and $e^+e^- \to$ non-$B_s^0 \bar{B}_s^0$ events are analysed. (six times more events than expected in the data)

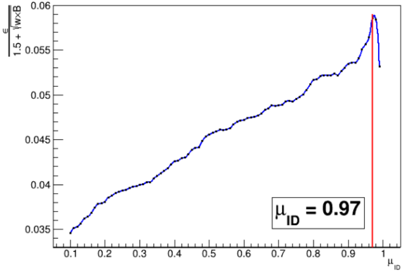
- We select oppositely charged particles whose closest approach to the nominal IP is within 0.5 cm and 3 cm along the radial and z-axis, respectively.



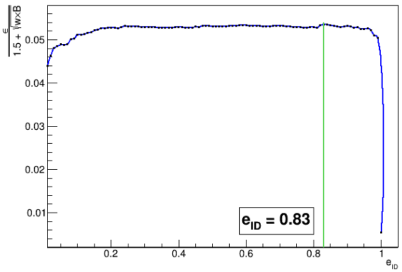


- Tracks satisfying the $e_{\text{ID}} > 0.01$ and $\mu_{\text{ID}} > 0.4$ are identified as electrons and muons.

Figure 2 shows the sensitivity of conditions on likelihood ratio (LH) to reject background over signal events for (a) μ_{ID} and (b) e_{ID}. We employ the loose requirements of $\mu_{ID} = 0.4$ and $e_{ID} = 0.01$ in contrast to the optimized values of 0.97 and 0.83, respectively.

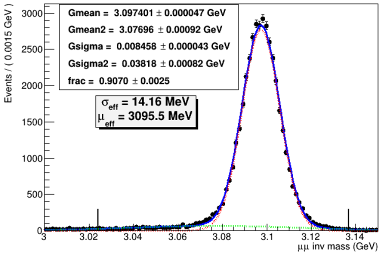


(a)

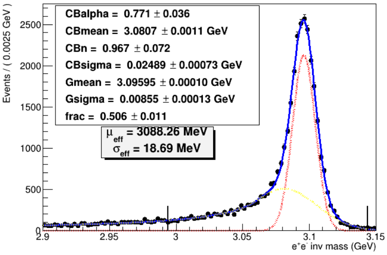


(b)

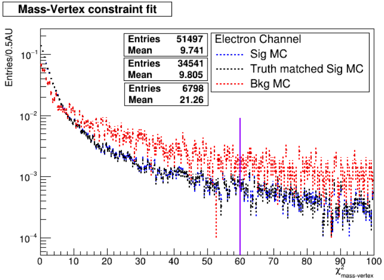
Figure 2: Punzi's FOM optimization: (a) μ_{ID} and (b) e_{ID}.



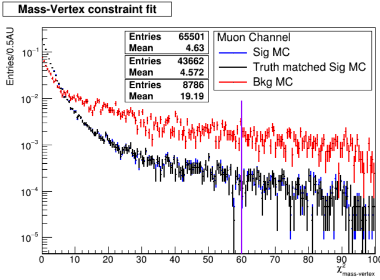
(a) $M_{\mu^+\mu^-}$



(b) $M_{e^+e^-\gamma}$



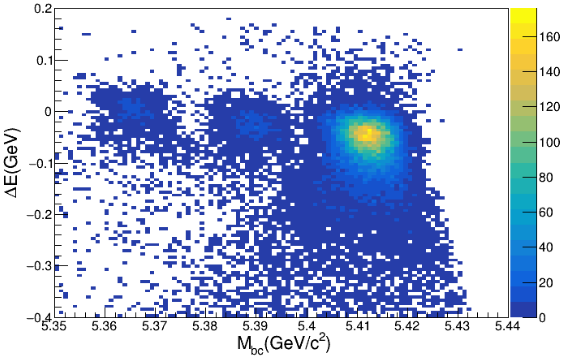
(c) $e-$channel



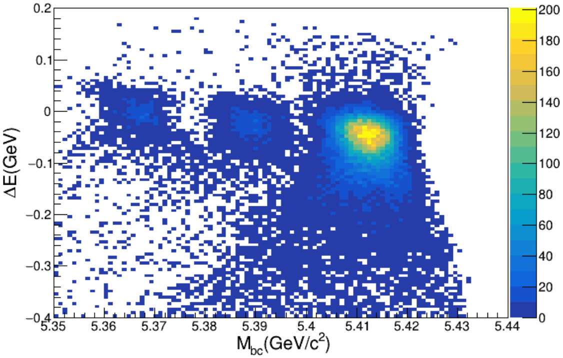
(d) $\mu-$channel

Mass-Window: $-5\sigma_{eff} < \Delta M_{l^+l^-(\gamma)} \equiv M_{l^+l^-(\gamma)} - m_{J/\psi} < 3\sigma_{eff}$

Requirements	Signals	Continuum	$B_s\bar{B}_s$	non-$B_s\bar{B}_s$
$e-$channel				
$\chi^2_{kMVF} < 10$	25.8%	73.9%	29.5%	34.9%
$\chi^2_{kMVF} < 50$	8.6%	34.8%	12.5%	13.4%
$\chi^2_{kMVF} < 60$	6.9%	31.1%	11.1%	11.2% ✓
$\mu-$channel				
$\chi^2_{kMVF} < 10$	9.5%	67.6%	16.9%	20.2%
$\chi^2_{kMVF} < 50$	1.6%	23.1%	2.6%	5.4%
$\chi^2_{kMVF} < 60$	1.1%	17.9%	1.8%	3.7% ✓

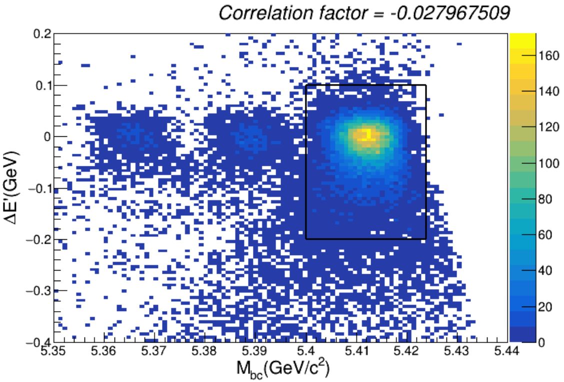


e-sector

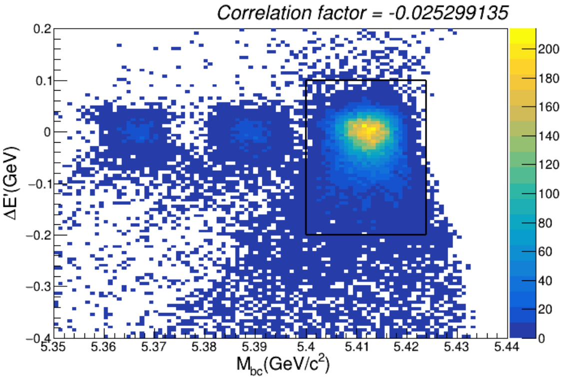


μ-sector

- Negative slope of the cluster positions is due to the unaccounted energy loss from the exotic states.



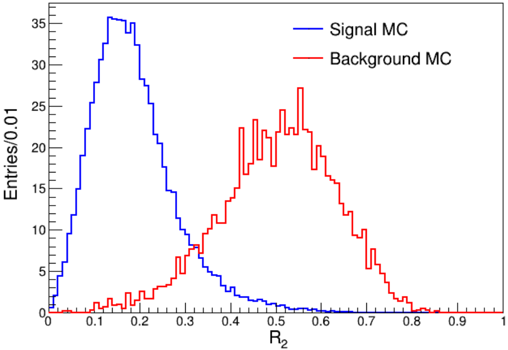
e-sector

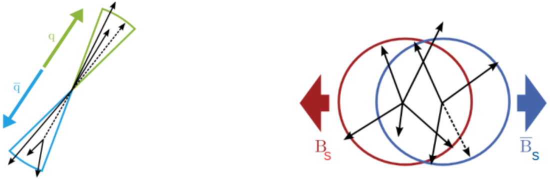


μ-sector

- We redefine the ΔE variable as,

$$\Delta E \to \Delta E' = \Delta E + (M_{\rm bc} - m_{B_s^0})c^2$$

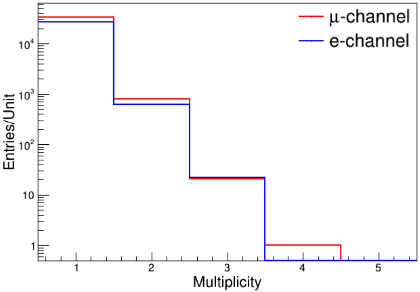




Topology of the continuum and $B\bar{B}$ events in the CM frame

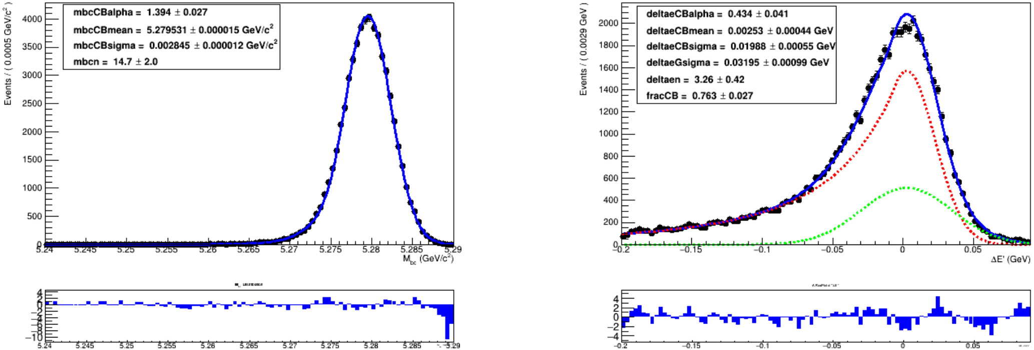
- Reduced Fox-Wolfram: $R_2 = \frac{H_2}{H_0}$, where $H_l = \sum |p_i||p_j|P_l(\cos(\theta_{ij}))$.
- The continuum background is suppressed by R_2 to be < 0.4

Best $B_s^0 \to J/\psi\pi^0$ Candidate Selection



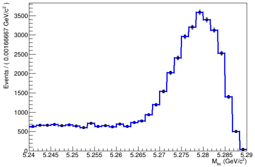
- The best candidate with the least χ^2 sum of the J/ψ mass-vertex constraint fit and π^0 mass constraint fit is kept.
- This procedure retains the correct B_s^0 candidates in more than 77.0% of time.
- The efficiency of selecting the $B_s^0 \to J/\psi\pi^0$ events is estimated to be $(31.02 \pm 0.10)\%$, which includes both leptonic modes.

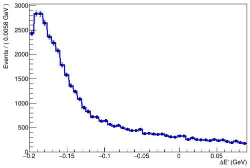
- To validate the selection criteria and estimating the discrepancy between the simulated and actual data.

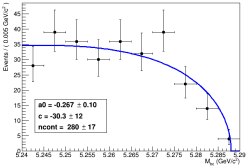


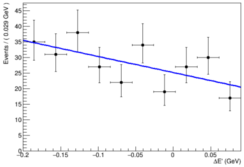
Projections of the 2D-fit to $B_d^0 \to J/\psi\pi^0$ MC simulated data.

PDFs for the Candidates in the Simulated Background Events









- Left: The distributions are modeled using a non-parameterized 2D histogram PDF determined from an MC simulated event sample, which is 100 times more than the expected $b \to c\bar{c}q$ events in data.
- Right: The distributions are parameterized using an ARGUS with an endpoint at 5.289 GeV/c^2 for M_{bc} and a first-order Chebychev polynomial for $\Delta E'$.

Variable	Function	Parameter	Value (MC)	Value(Data)
M_{bc}	Crystal Ball	Mean (MeV/c²)	5279.53 ± 0.02	5279.6 ± 0.17
		Sigma (MeV/c²)	2.85 ± 0.01	2.52 ± 0.15
$\Delta E'$	Crystal Ball	Mean (MeV)	2.53 ± 0.44	1.68 ± 2.92
		Sigma (MeV)	19.88 ± 0.55	20.71 ± 4.25
	Gaussian	Sigma (MeV)	31.95 ± 0.99	34.04 ± 8.85

Variable	Parameter	Correction Factor
M_{bc}	Shift in mean (MeV/c²)	0.07 ± 0.17
	Fudge factor for sigma	0.89 ± 0.05
$\Delta E'$	Shift in mean (MeV)	-0.94 ± 2.51
	Fudge factor for sigma	1.05 ± 0.10

- Fudge factor = $\frac{\sigma_{Data}}{\sigma_{MC}}$
- Shift in mean = $\mu_{data} - \mu_{MC}$

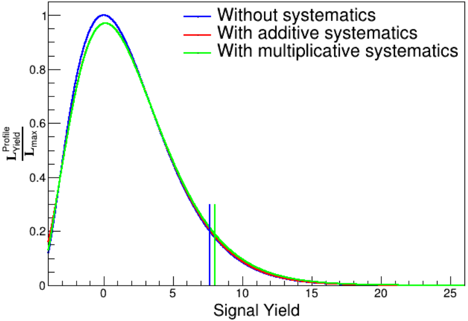
- We find that the statistical uncertainties dominate the slight difference between the simulated and actual distributions.
- Small discrepancies between the simulated and actual data are accounted for in the systematic evaluation after data unblinding.

Systematic Uncertainty due to Fixed Parameters

Variable	$B_s^{0(*)}\bar{B}_s^{0(*)}$	Function	Parameter	Yield($+\sigma$)	Yield($-\sigma$)	ΔYield
M_{bc}	$B_s^{0*}\bar{B}_s^{0*}$	CB	μ^* (GeV/c^2)	-0.20 $\pm$ 3.10	0.20 $\pm$ 3.30	$^{+0.19}_{-0.21}$
			σ^* (GeV/c^2)	-0.20 $\pm$ 3.10		+0.19
			α	-0.05 $\pm$ 3.10	0.00 $\pm$ 3.20	$^{+0.04}_{-0.01}$
			n	-0.02 $\pm$ 3.20	0.10 $\pm$ 3.20	$^{+0.01}_{-0.11}$
			$f^{\dagger}_{B_s^{0*}\bar{B}_s^{0*}}$	0.00 $\pm$ 3.10	-0.03 $\pm$ 3.20	$^{+0.02}_{-0.01}$
	$B_s^{0*}\bar{B}_s^0$ or $B_s^0\bar{B}_s^{0*}$	Double-G with common mean	μ	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
			σ (G$_1$) (GeV/c^2)	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
			σ (G$_2$) (GeV/c^2)	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
			fraction (G$_1$)	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
			$f^{\dagger}_{B_s^{0*}\bar{B}_s^0}$	0.00 $\pm$ 3.20	-0.06 $\pm$ 3.10	$^{+0.05}_{-0.01}$
	$B_s^0\bar{B}_s^0$	Double-G with common mean	μ	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
			σ (G$_1$) (GeV/c^2)	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
			σ (G$_2$) (GeV/c^2)	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
			fraction (G$_1$)	-0.01 $\pm$ 3.20	-0.01 $\pm$ 3.20	$^{+0.00}_{-0.00}$
	All	ARGUS	Endpoint (GeV/c^2)	0.00 $\pm$ 3.20	-0.05 $\pm$ 3.20	$^{+0.04}_{-0.01}$
$\Delta E'$	All	CB+G with common mean	μ^* (GeV)	-0.19 $\pm$ 3.20	0.20 $\pm$ 3.20	$^{+0.18}_{-0.21}$
			σ^* (CB) (GeV)	0.00 $\pm$ 3.10		-0.01
			α	-0.17 $\pm$ 3.10	0.20 $\pm$ 3.30	$^{+0.16}_{-0.21}$
			n	-0.06 $\pm$ 3.10	0.10 $\pm$ 3.20	$^{+0.05}_{-0.11}$
			σ^* (G) (GeV)	0.00 $\pm$ 3.20		-0.01
			fraction (CB)	0.00 $\pm$ 3.20	-0.03 $\pm$ 3.20	$^{+0.02}_{-0.01}$
Events corresponding to $B_d^0 \to J/\psi\pi^0$ PDF				-0.26 $\pm$ 3.10	0.30 $\pm$ 3.30	$^{+0.25}_{-0.31}$
Events corresponding to $B_s^0 \to c\bar{c}X$ PDF				-0.52 $\pm$ 3.10	0.60 $\pm$ 3.30	$^{+0.51}_{-0.61}$
Total systematic due to the fixed PDF parameters (events)						$^{+0.67}_{-0.79}$

Upper Limit Calculation

- With the absence of any significant signal yield, we report an upper limit (UL) on the branching fraction using the Bayesian approach.



Convolution function: Gaussian(μ = 0, σ = systematic uncertainty)

- Additive systematic = 0.8 events
- Multiplicative systematic = 0.12 $\times$ signal yield

- ULs on the yields at 90% confidence level (CL) are estimated to be 8.03 and 7.64 $B_s^0 \to J/\psi\pi^0$ events with and without systematic uncertainties, respectively.

The Hadron-B criteria select the B-meson and continuum events with an efficiency of 99% and 84% while rejecting the non-hadronic (two-photon, Bhabha, and lepton pairs) by more than 95%.

- Good charged tracks nTrk$\geq$ 3; $|dr|$ <2cm, $|dz|$ <4cm, and $|P_t^*| > 100$MeV.
- E_{sum}(sum of good cluster's energy)$> 0.18\sqrt{s}$ or $HJM > 1.8$ GeV.
- $|P_z^*|$(sum of z-comp. of good tracks and photon momenta)$< 0.5\sqrt{s}$.
- $nECL > 1$.
- $HJM/E_{vis} > 0.25$ or $HJM > 1.8$ GeV.
- $E_{sum}/nECL < 1$ GeV.
- J/ψ Condition: An event with at least one combination of oppositely charged tracks with momentum $p > 0.8$ GeV/c and invariant mass between $2.4 - 4.0$ GeV/c^2.