Charmless B decay measurements at Belle

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on behalf of the Belle collaboration

CKM 2021 WG5

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Introduction

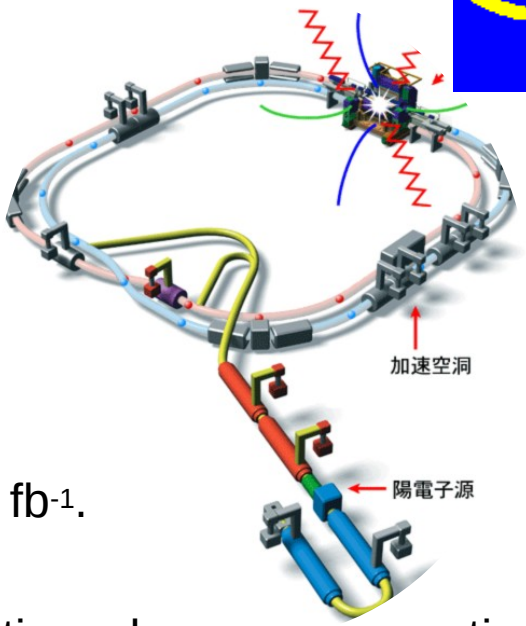
- Charmless B decays:
  - Suppressed in Standard Model with small BF (usually < 10^{-5}).
  - Sensitive to non-SM physics within the penguin loop in many decays.
  - Some SM sensitivity tests with precision measurement in the flavor sector.
  - Discrepency in measurement: indicate non-SM physics.
- Main challenge in experimental measurement: Small BF and large $ee \to q\bar{q}$ (q=u,d,s,c) background.
  - Combinatorial background in reconstruction with the same final state.
  - PID & comnitnuum suppression.

Results of these six decay modes will be reported.

- **$B \to p\bar{p}\pi\pi$** PRD 101, 052012 (2020)
- **$B^+ \to K^+K^-\pi^+$**
- **$B^+ \to \pi^+\pi^0\pi^0$**
- **$B^0_s \to \eta' X_{s\bar{s}}$** PRD 104, 012007 (2021)
- **$B^0_s \to \eta'\eta$** PRD 104, L031101 (2021)
- **$B^0_s \to \eta' K^0_S$**

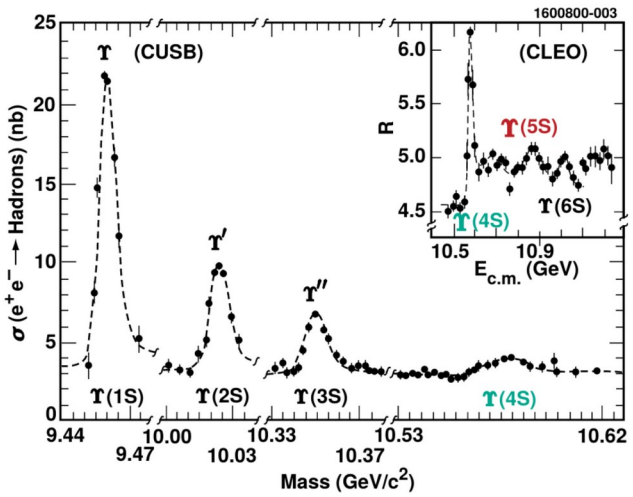
KEKB collider

- An asymmetric energy e^+e^- collider at KEK.
  - LER(e^+) 3.5 GeV.
  - HER(e^-) 8 GeV.
  - Crossing angle: ±11 mrad.

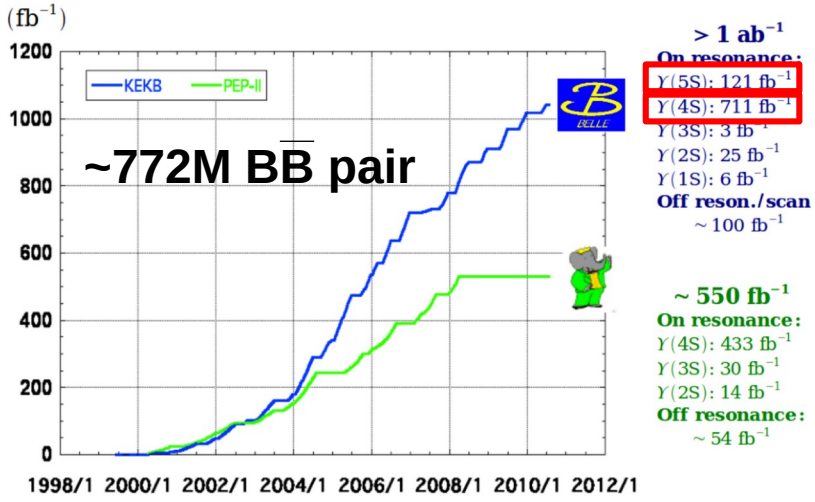


- Target:
  - $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ for B decay: 711 fb^{-1}.
  - $e^+e^- \to \Upsilon(5S) \to B^{(*)0}_s \bar{B}^{(*)0}_s$ for B^0_s decay: 121 fb^{-1}.

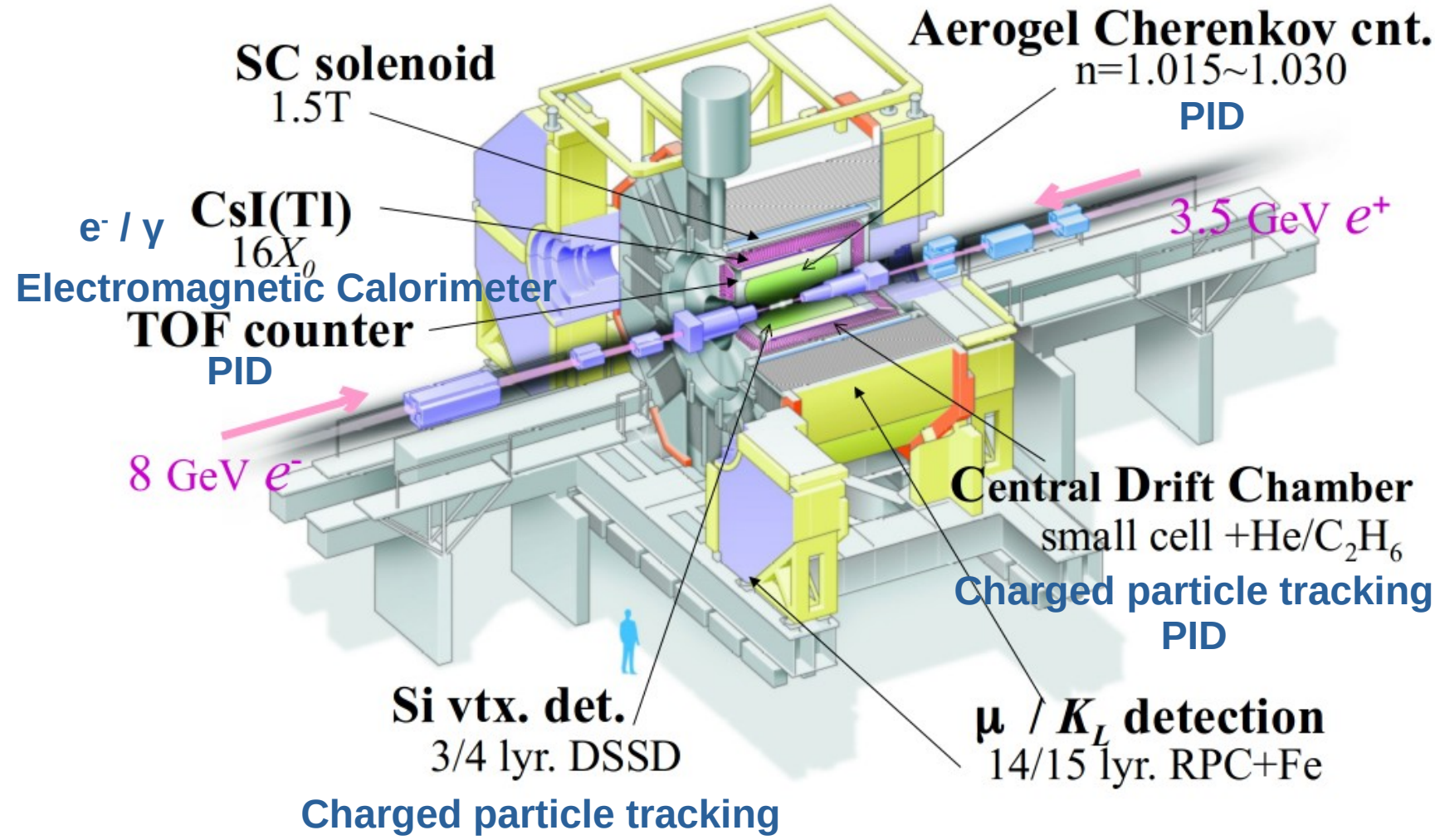
- Main background: $e^+e^- \to q\bar{q}$ (q=u,d,s,c) with 3 times larger cross section.



Annu. Rev. Nucl. Part. Sci. 1993.43:333-78



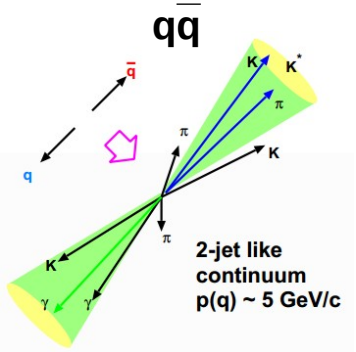
Belle detector

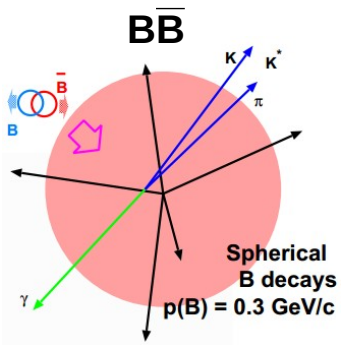


Analysis overview

- Blind analysis:
  - Use Monte Carlo (MC) samples for signal and backgrounds study.
  - Signal is scaled with an assumed BF.

- Backgrounds:
  - Continuum $e^+e^- \to q\bar{q}$ (q=u,d,s,c):
    Based on the decay shape difference, use multivariate tools (Fisher, Neuro-Network) with various event topology variables.





Ann. Human Genet. 7, 179 (1936)
PRL 41, 1581 (1978)
PRL 91, 261801 (2003)
Nucl. Instrum. Methods Phys. Res., Sect. A 559, 190 (2006)

  - $B\bar{B}$ background: Looking for peaking background (usually from charmed) and apply proper veto on invariant mass.
    "Generic" B background: $b \to c$.
    "Rare" B background: $b \to u,d,s$.

Analysis overview (cont'd)

- Major variables for signal B identification:
  - Energy difference: $\Delta E \equiv E_B - E_{\rm beam}$ in C.M. frame
  - Beam-energy constrained mass: $M_{\rm bc} \equiv \sqrt{E^2_{\rm beam}/c^4 - |\vec{p}_B/c|^2}$ in C.M. frame
  - Discriminant for continuum suppression.

- Signal extraction:
  Extended unbinned maximun likelihood fit on data with above variables.

- Branching fraction determination:
  - $N_{B\overline{B}}$ = 772M for Y(4S) data of 771 fb^{-1}.
  - Y(5S): 121 fb^{-1} with 3 branches:
    $B^{*0}_s\overline{B}^{*0}_s$ 87.0%, $B^{*0}_s\overline{B}^{0}_s$ 7.3%, $B^{0}_s\overline{B}^{0}_s$ 5.7%.
    - ► Fraction containing B^0_s:
      $f_s = 0.201 \pm 0.031$ (world average)
    - ► $N_{B0s} = (16.60 \pm 2.68)\times10^6$

Fitted signal yield

$$\mathcal{B} = \frac{N_{\rm sig}}{\underbrace{\epsilon \times \eta}_{} \times N_{B\overline{B}}}$$

Signal reconstruction eff. & calibration due to systematic effects.

Total number of $B_{(s)}$ events in Belle.

$B \to p\bar{p}\pi\pi$: Introduction

PRD 101, 052012 (2020)

- Charmless B decays: good field to search for CP violation due to inteference between $b \to s$ penguin and $b \to u$ tree.
  - Evidence of direct CP violation in $B^+ \to p\bar{p}K^+$ by LHCb. PRL 113, 141801 (2014)
  - $M_{p\bar{p}}$ peaks near threshold. PRL 88, 181803 (2002)
  - In $p\bar{p}$ reset frame, K is produced preferably in the $\bar{p}$ direction. Opposite to that of $B^+ \to pp\pi^+$, in which $b \to u$ dominates. PLB 659, 80 (2008)

PRD 75, 094013 (2007)

- Most of baryonic B decays presumably proceed predominantly via $b \to s$.
  - Measurement of $b \to u$ modes is important for theoretical investigation based on a generalized factorization approach. PRD 96, 051103 (2017)

- $B^0 \to p\bar{p}\pi^+\pi^-$: Measured by LHCb.
- $B^+ \to pp\pi^+\pi^0$: First measurement by this study.

$B \to p\bar{p}\pi\pi$: Data result

PRD 101, 052012 (2020)

1st uncertainty: stat.
2nd uncertainty: syst.

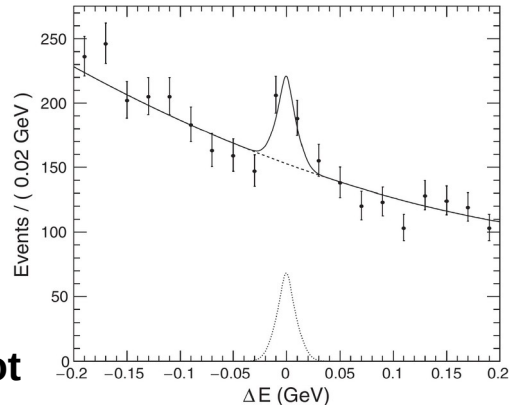
- 2D fit with ΔE, M_{bc}.
- Signal + continuum bkg.

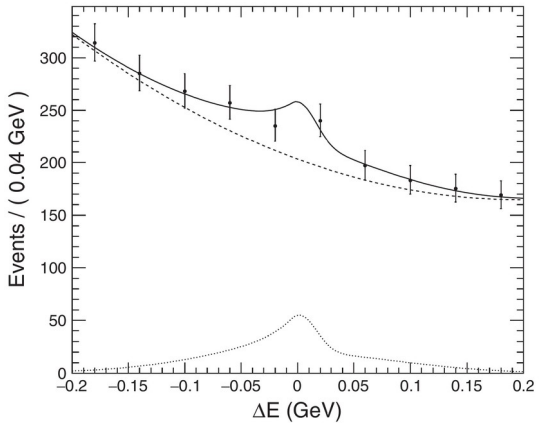
	$B^0 \to p\bar{p}\pi^+\pi^-$	$B^+ \to p\bar{p}\pi^+\pi^0$
Signal yield	$73.8^{+15.4}_{-14.9}$	151 ± 39
Significance (σ)	5.5	5.4
BF (10^{-6})	0.83 ± 0.17 ± 0.17	4.58 ± 1.17 ± 0.67

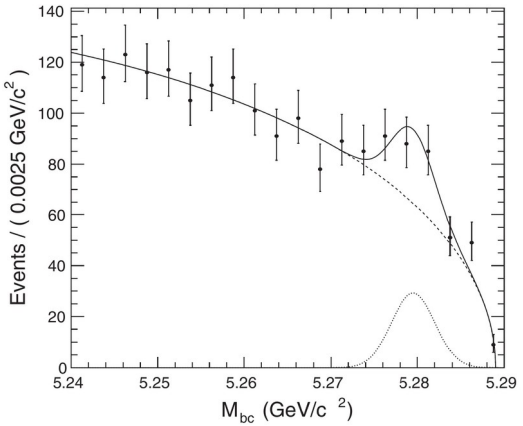
$M_{bc} > 5.27$ GeV/c^2

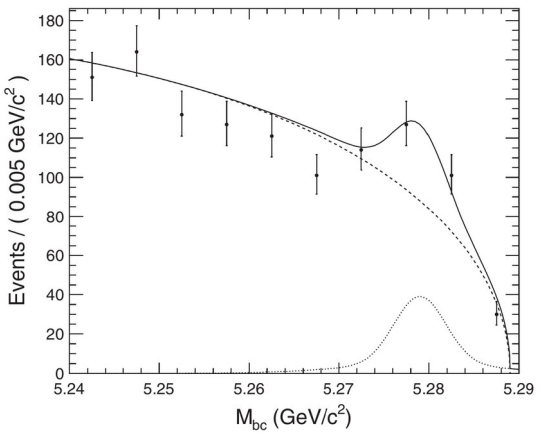
Signal-enhanced projection plot of data fit result

$|\Delta E| < 0.03$ GeV







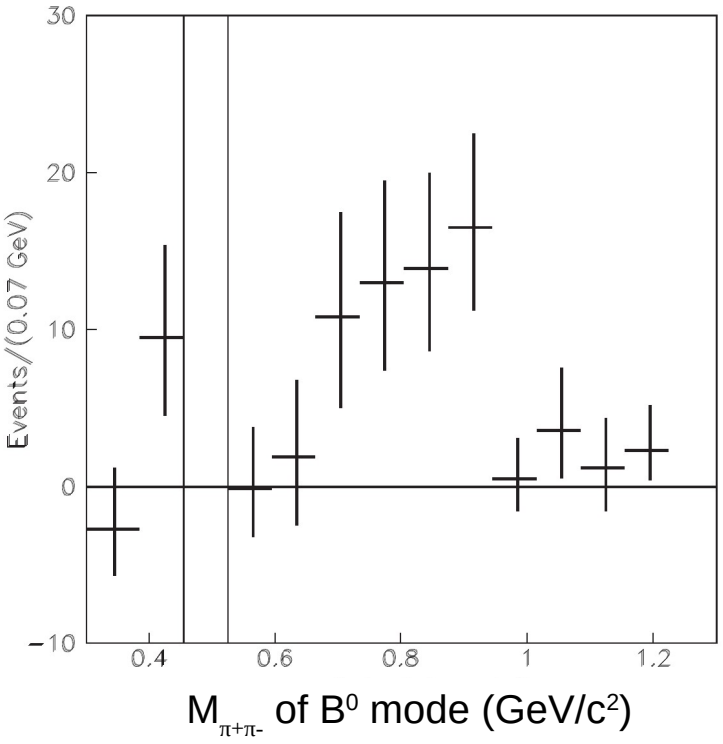


$B \to p\bar{p}\pi\pi$: $M_{\pi\pi}$ distribution

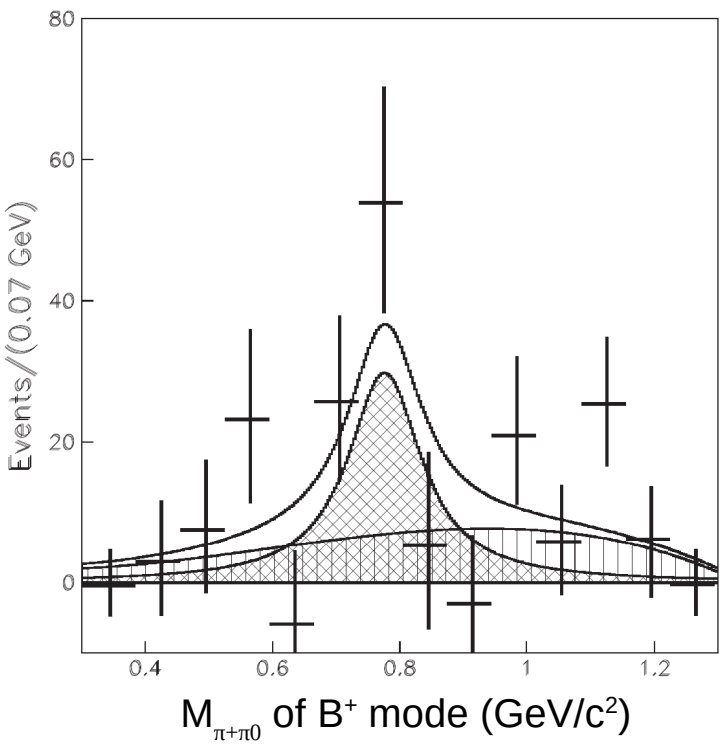
PRD 101, 052012 (2020)

- Measure the signal yields in different bins with the same 2D fit method.
- B^+ mode: a χ^2 fit to separate $B^+ \to p\bar{p}\rho^+$ and nonresonant.
  - $B^+ \to p\bar{p}\rho^+$: Breit-Widner convolved with a Gaussian resolution function.
    Signal yield = 86 ± 41.
    Measured $B(B^+ \to p\bar{p}\pi^+\pi^0)$: ~10X smaller than predicted $B(B^+ \to p\bar{p}\rho^+)$.

PRD 75, 094013 (2007)



$M_{\pi^+\pi^-}$ of B^0 mode (GeV/c^2)



$M_{\pi^+\pi^0}$ of B^+ mode (GeV/c^2)

$B \to p\bar{p}\pi\pi$: $M_{p\bar{p}}$ distribution

- Measure the signal yields in different bins with the same 2D fit method.
- Dibaryon mass system tends to peak near the low mass threshold.
- 2.85 - 3.128 GeV/c^2: charmonium-enhanced region. e.g. J/ψ.

Equally distributed below and above the charmonium-enhanced region

BF in threshold enhancement region is consistent with LHCb result.

The lowest bin dominates.

$M_{p\bar{p}}$ of B^0 mode

$M_{p\bar{p}}$ (GeV/c^2)	N_s	σ	ε_{eff} (%)
$M_{p\bar{p}} < 2.85$	$26.1^{+10.0}_{-9.1}$	4.0	9.8
$2.85 < M_{p\bar{p}} < 3.128$	$19.6^{+10.2}_{-9.3}$	2.9	9.9
$3.128 < M_{p\bar{p}}$	$29.1^{+16.2}_{-13.1}$	3.5	9.4

$M_{p\bar{p}}$ of B^+ mode

$M_{p\bar{p}}$ (GeV/c^2)	N_s	σ	ε_{eff} (%)
$M_{p\bar{p}} < 2.85$	$133.5^{+26.6}_{-25.2}$	5.1	4.8
$2.85 < M_{p\bar{p}} < 3.128$	$12.3^{+10.3}_{-9.7}$	1.4	4.0
$3.128 < M_{p\bar{p}}$	$-3.8^{+15.1}_{-13.8}$	...	3.4

$B^+ \to K^+K^-\pi^+$: Introduction

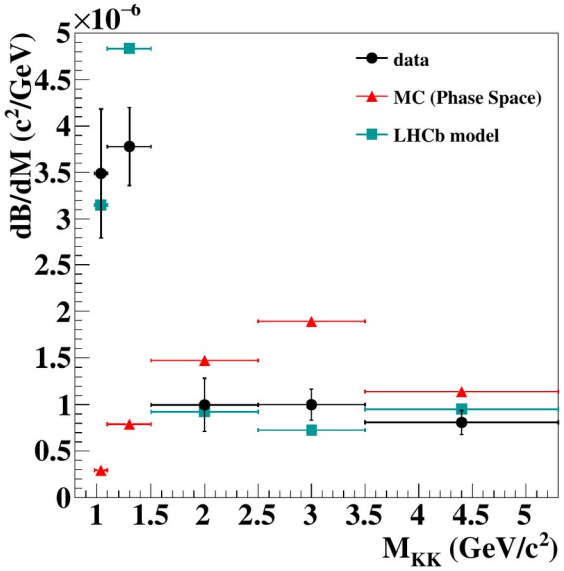
- Possible contributions in SM:
  - Tree, W-exchange (KK*), strong penguin, electroweak penguin ($\phi\pi$), where experimental limit of $B(B^+ \to \phi\pi^+)$: 1.5×10^{-7} PLB 728, 85 (2014)
- An unidentified structure observed Babar and LHCb. PRL 99, 221801 (2007) PRL 112, 011801 (2014) PRD 90, 112004 (2014) PRL 123, 231802 (2019)
  - LHCb reported large CP asymmetry in low M_{KK} as well.
- Theoretical explanation: PLB 726, 337 (2013) PRD 89, 094013 (2014)
  - Final-state state interactions may enhance CP violation.
  - LHCb also suggests the large CP asymmtry in low M_{KK} originates from $\pi\pi \leftrightarrow KK$ rescattering.
- Previous report by full Belle data: Inclusive BF and A_{CP}. PRD 96, 031101(R) (2017)
- This study will update the following with a re-optimized binning:
  - Angular distribution of KK at low mass.
  - dBF along $M_{K\pi}$.

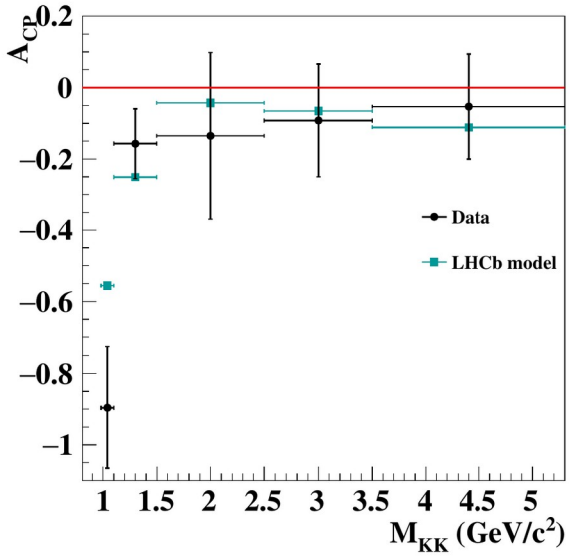
$B^+ \to K^+K^-\pi^+$: M_{KK} distribution & $\cos\theta_{hel}$

Preliminary

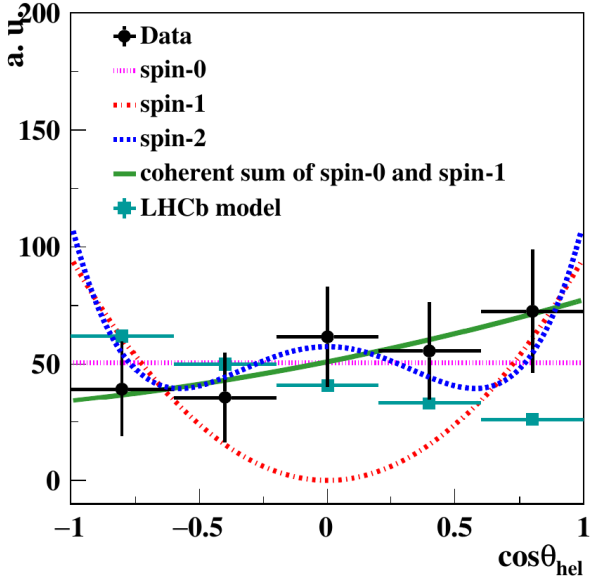
- 2D fit with ΔE, M_{bc} within each bin.

LHCb model: from
PRL 123, 231802 (2019)





$M_{KK} < 1.1$ GeV/c^2:
$A_{CP} = -0.90 \pm 0.17 \pm 0.03$
with 4.8σ significance



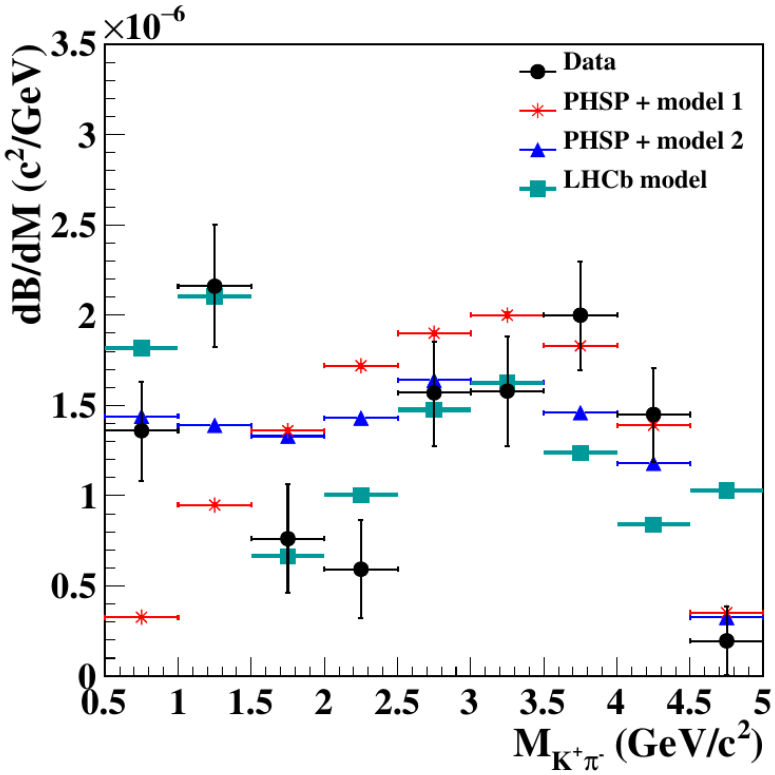
- Events within $M_{KK} < 1.1$ GeV/c^2
- Angle between B^+ and K^+ in KK rest frame.
- Consistent with a coherent sum of spin-0 and spin-1.
- P-wave and S-ware fraction:
  $r = A_P/A_S = 0.31 \pm 1.21$
- Forward-backward asymmetry:
  $A_{FB} = 0.21 \pm 1.09$

	$X_{J=0}$	$X_{J=1}$	$X_{J=2}$	coherent sum	LHCb model
χ^2/ndf	1.9/4	14.4/4	1.6/3	0.5/2	7.0/4
p-value	0.750	0.006	0.815	0.792	0.136

$B^+ \to K^+K^-\pi^+$: $M_{K\pi}$ distribution

Preliminary

- 2D fit with ΔE, M_{bc} within each bin.
- LHCb model: from **PRL 123, 231802 (2019)**
  - Consistent with our data.
- Model 1: 10% of $X_{KK}\pi$ with spin-0.
- Model 2: Expected resonances $K^{*0}K^+$ and $K^{*0}_0K^+$.



$B^+ \to \pi^+\pi^0\pi^0$: Introduction

- Charmless three-body B decays are useful to study the properties of the weak interaction in the quark sector.

- Dalitz plot analysis: search for intermediate resonances and localized A_{CP}. Also to constrain magnitudes and phases of the CKM matrix elements. For instance, $B \to \rho\pi$ for ϕ_2 (α) and also $B^+ \to \chi_{c0}\pi^+$ for ϕ_3 (γ).

- Similar measurement on $B^+ \to \pi^+\pi^-\pi^+$ by Babar and LHCb. PRD 79, 072006 (2009) PRD 101, 012006 (2020)
  - BF = $(15.2 \pm 0.6 \pm 1.2 \pm 0.4)\times10^{-6}$
  - Full amplitude analysis.

- Upper limit of $B^+ \to \pi^+\pi^0\pi^0$ was reported: 8.9×10^{-4} at 90 C.L. by CLEO. PLB 241 278-282 (1990)

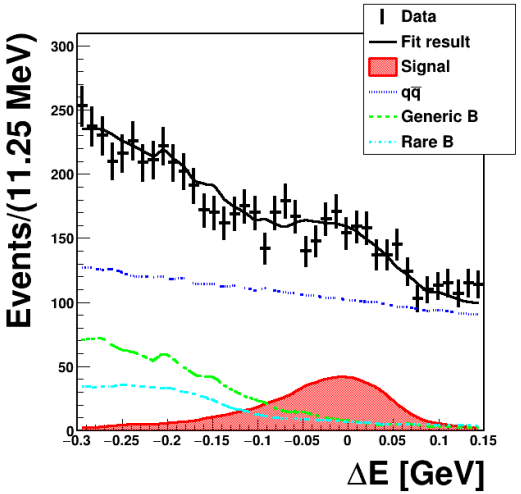
- $B^+ \to \rho(770)^+\pi^0$: $(10.9 \pm 1.4)\times10^{-6}$, by Belle and Babar. PRL 94 031801 (2005) PRD 75 091103 (2007)
  - Majority of the $B^+ \to \pi^+\pi^0\pi^0$ decays.

$B^+ \to \pi^+\pi^0\pi^0$: Data result

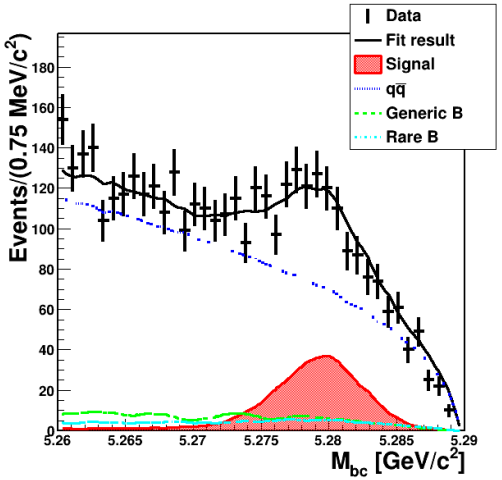
Preliminary

- Major challenge: Shower leakage due to 2 π^0 and correlation between energy and other variables.
  - A π^0 momentum threshold 0.5 GeV/c is adopted.
- 3D fit with ΔE, M_{bc}, C'_{NN} (Continuum suppression with Neuro-Network).
- Signal yield = $1062.8^{+86.8}_{-85.4}$
  - Inclusive BF = $(19.0 \pm 1.5 \pm 1.4)\times10^{-6}$
- $A_{CP} = (9.2 \pm 6.8)\%$

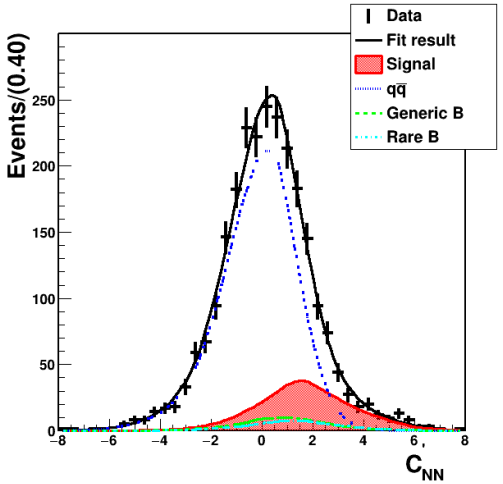
Signal-enhanced projection plot of data fit result



$M_{bc} > 5.27$ GeV/c^2
& $C'_{NN} > 0.5$



$|\Delta E| < 0.1$ GeV
& $C'_{NN} > 0.5$



$|\Delta E| < 0.1$ GeV &
$M_{bc} > 5.27$ GeV/c^2

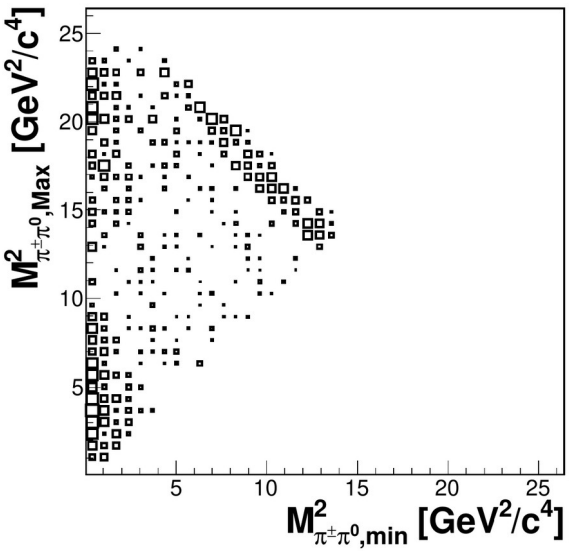
$B^+ \to \pi^+\pi^0\pi^0$: Structure in Dalitz plot

Preliminary

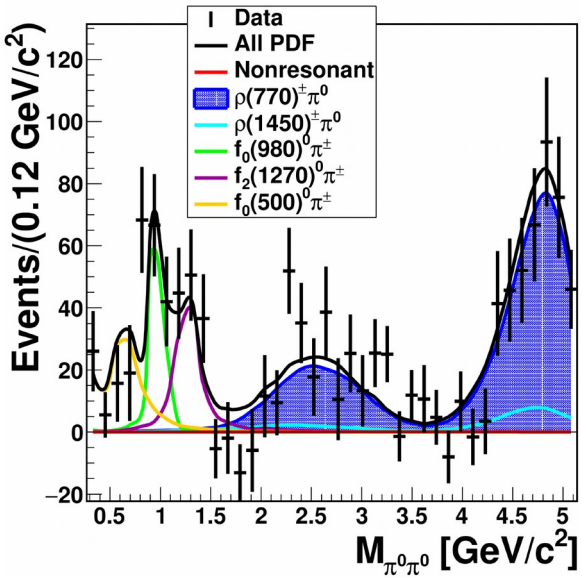
- Signal isolation on Dalitz plot ($M_{\pi\pi}$): sPlot technique.
  - 2D binned fit on sWeights $M_{\pi\pi}$ histogram: Incoherent sum of PDFs.
- Small contribution from non-resonant: $< 6\times10^{-7}$ @ 90% C.L.
- $B(B^+ \to \rho(770)^+\pi^-) = (11.2 \pm 1.1 \pm 0.9 \pm 1.4)\times10^{-6}$
- New structure at low $M_{\pi0\pi0}$ region from multiple resonances with a significance of 9.2σ.
  - Combined BF = $(6.4 \pm 0.9 \pm 0.6)\times10^{-6}$

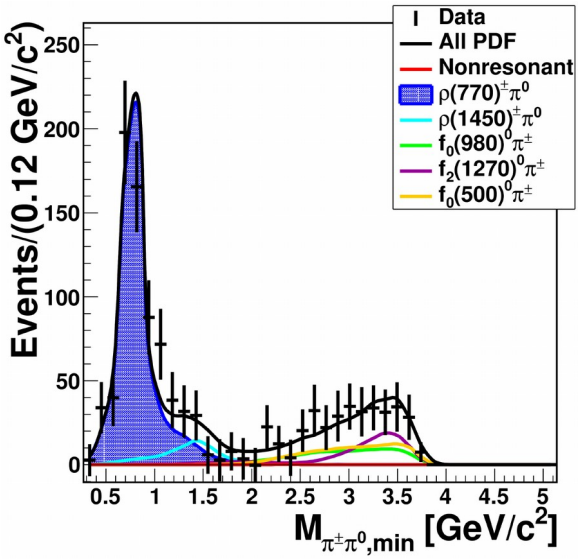
1st uncertainty: stat.
2nd uncertainty: syst.
3rd uncertainty (if any): interference effect.

sWeighted Dalitz plot



2D fit result





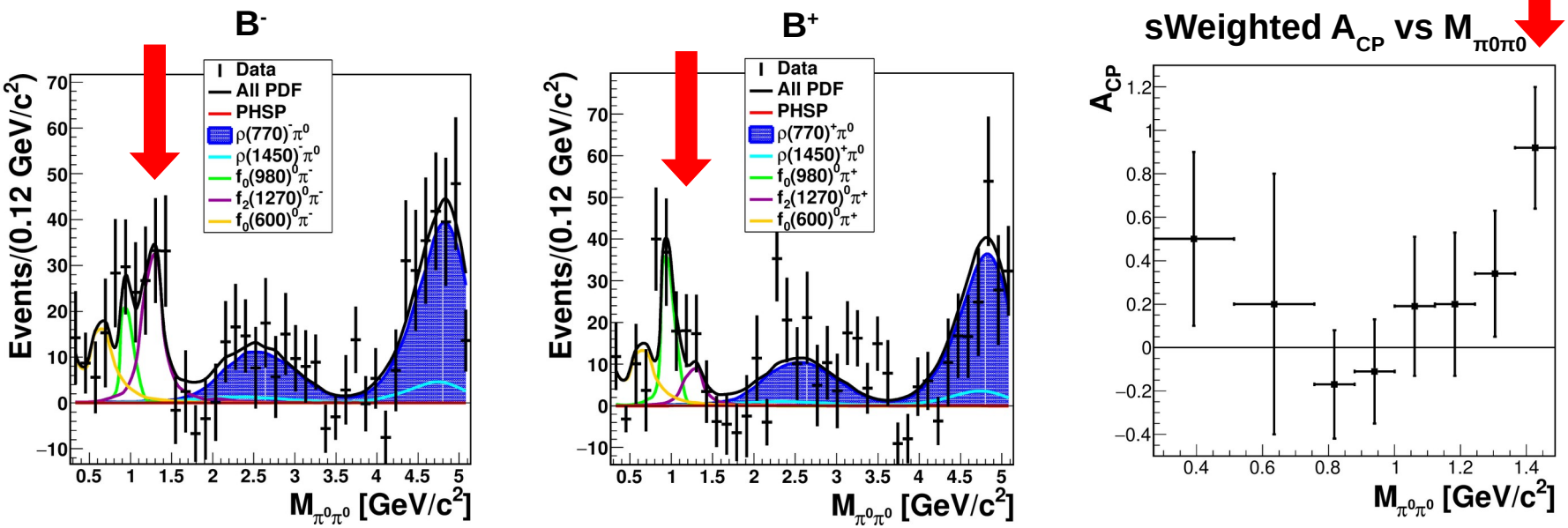
$B^+ \to \pi^+\pi^0\pi^0$: Localized A_{CP}

Preliminary

- 2D fit on the charge-separated sWeights $M_{\pi\pi}$ histograms.
- An asymmetry is found at $M_{\pi 0\pi 0} \sim 1.4$ GeV/c^2.
  - Corresponding to $f_2(1270)^0\pi^+$.
  - Also seen in $B^+ \to \pi^+\pi^-\pi^+$ by Babar and LHCb.

$A_{CP} = (92 \pm 28)\%$
3.2σ confirmed by 3D fit within selected region.

PRD 79, 072006 (2009) PRD 101, 012006 (2020)



Introduction on η' modes study

- η': anomalous production in B decays.
  - First observed at CLEO. PRL 81, 1786–1790 (1998) PRD 68, 011101 (2003)
  - η' mass is higher than is expected from symmetry considerations. PRD 97, 054508 (2018)
  - Unexpected BF enhancement seen in some inclusive measurements e.g. $B \to \eta' X_s$.
  - Large rate of exclusive modes (e.g. $B^+ \to \eta' K^+$) could be accounted for SM factorization. hep-ph/9707354
  - New observation on decay with η' could provide information for better understanding on it.

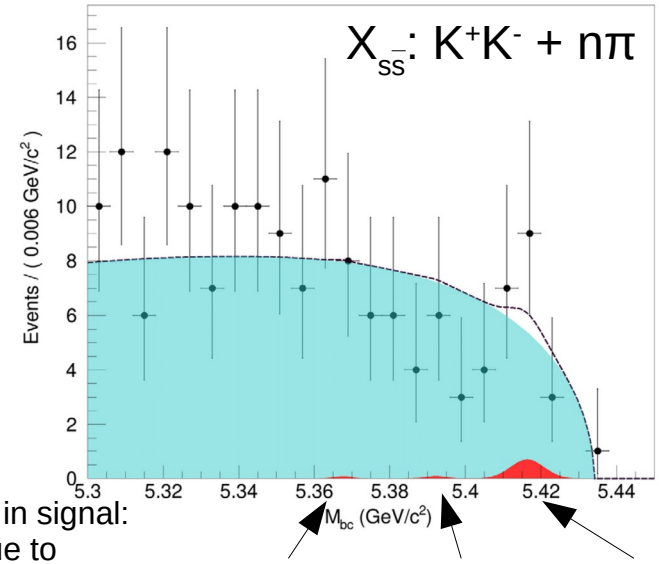
$B^0_s \to \eta' X_{s\bar{s}}$: Data result

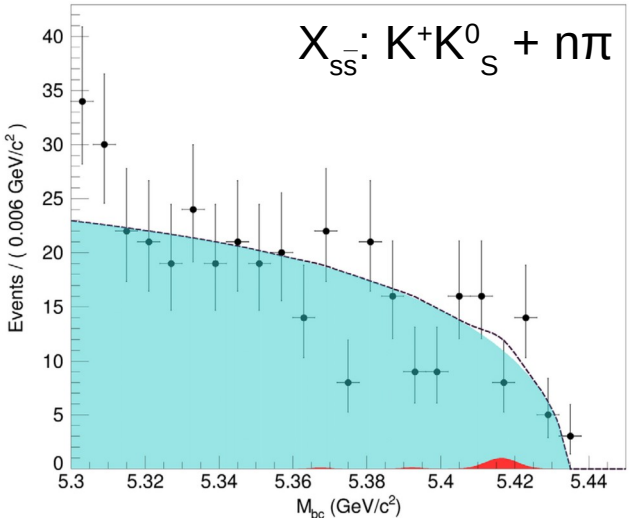
PRD 104, 012007 (2021)

- First measurement based on semi-inclusive method.
  - To have better understanding on η' mass and BF issues by models such as glueball coupling. PRD 97, 054508 (2018)

- 1D fit with M_{bc} in bins of $M(X_{s\bar{s}})$: with $-0.12 < \Delta E < 0.05$ GeV.
  - $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$.
  - $X_{s\bar{s}}$: Use PYTHIA6 for MC.
    Reconstruct K^+K^- + nπ and $K^+K^0_S$ + nπ: sum-of-exclusive

Sum of fits to all $M(X_{s\bar{s}})$ bins





Multiple peaks in signal:
Energy shift due to
missing γ in $B^{*0}_s \to B^0_s \gamma$ decay.

$B^0_s \to \eta' X_{s\bar{s}}$: Data result (cont'd)

PRD 104, 012007 (2021)

uncertainty:
1st: stat.
2nd: syst.
3rd: $X_{s\bar{s}}$ fragmentation in PYTHIA6
4th: $N(B^{(*)0}_s \bar{B}^{(*)0}_s)$

- $B(B^0_s \to \eta' X_{s\bar{s}}) = (-0.7 \pm 8.1 \pm 0.7\ ^{+3.0}_{-6.0} \pm 0.1) \times 10^{-4}$
  - UL: 1.4×10^{-3} @ 90 C.L.
- $R(\eta') = B(B^0_s \to \eta' X_{s\bar{s}})/B(B \to \eta' X_s) = -0.2 \pm 2.1 \pm 0.2\ ^{+0.8}_{-1.5} \pm 0.03$
  - UL: 3.5 @ 90% C.L.
  - ~1 assuming naive SU(3) symmetry.

$M(X_{s\bar{s}})$	ϵ' (%)	$N_{\rm sig}$	$\mathcal{B}(B^0_s \to \eta' X_{s\bar{s}})$ (10^{-4})
1.0–1.2	3.60 ± 0.08	$0.4^{+2.6}_{-1.9}$	$0.05^{+0.30}_{-0.22}$ (stat) $^{+0.004}_{-0.005}$ (syst)
1.2–1.4	2.82 ± 0.08	$0.08^{+2.4}_{-1.7}$	$0.01^{+0.36}_{-0.28}$ (stat) $^{+0.001}_{-0.001}$ (syst)
1.4–1.6	0.90 ± 0.04	$0.7^{+2.5}_{-1.8}$	$0.3^{+1.1}_{-0.8}$ (stat) $^{+0.04}_{-0.05}$ (syst)
1.6–1.8	0.54 ± 0.03	$0.4^{+2.1}_{-1.4}$	$0.3^{+1.6}_{-1.1}$ (stat) $^{+0.05}_{-0.1}$ (syst)
1.8–2.0	0.34 ± 0.03	$1.4^{+2.6}_{-2.0}$	$1.7^{+3.3}_{-2.5}$ (stat) $^{+0.4}_{-0.6}$ (syst)
2.0–2.2	0.22 ± 0.02	$0.3^{+3.7}_{-3.4}$	$0.6^{+7.1}_{-6.4}$ (stat) $^{+0.2}_{-0.2}$ (syst)
2.2–2.4	0.14 ± 0.02	$-2.3^{+3.8}_{-3.4}$	$-7.0^{+11.6}_{-10.4}$ (stat) $^{+1.7}_{-4.1}$ (syst)

$X_{s\bar{s}}$: K^+K^- + nπ

$M(X_{s\bar{s}})$	ϵ' (%)	$N_{\rm sig}$	$\mathcal{B}(B^0_s \to \eta' X_{s\bar{s}})$ (10^{-4})
1.0–1.2	0.016 ± 0.006	0.0	...
1.2–1.4	0.24 ± 0.02	$0.3^{+1.4}_{-0.8}$	$0.5^{+2.5}_{-1.5}$ (stat) $^{+0.1}_{-0.04}$ (syst)
1.4–1.6	0.86 ± 0.04	$2.0^{+3.0}_{-2.2}$	$1.0^{+1.4}_{-1.1}$ (stat) $^{+0.1}_{-0.07}$ (syst)
1.6–1.8	0.65 ± 0.04	$1.2^{+3.3}_{-2.6}$	$0.8^{+2.1}_{-1.6}$ (stat) $^{+0.1}_{-0.1}$ (syst)
1.8–2.0	0.45 ± 0.03	$4.8^{+4.2}_{-3.4}$	$4.4^{+3.9}_{-3.1}$ (stat) $^{+0.9}_{-0.7}$ (syst)
2.0–2.2	0.36 ± 0.03	$-2.4^{+3.9}_{-3.2}$	$-2.8^{+4.6}_{-3.8}$ (stat) $^{+0.9}_{-0.7}$ (syst)
2.2–2.4	0.16 ± 0.02	$-1.1^{+3.6}_{-2.9}$	$-2.6^{+8.9}_{-7.1}$ (stat) $^{+0.2}_{-1.9}$ (syst)

$X_{s\bar{s}}$: $K^+K^0_S$ + nπ

$B^0_s \to \eta'\eta$: Data result

PRD 104, L031101 (2021)

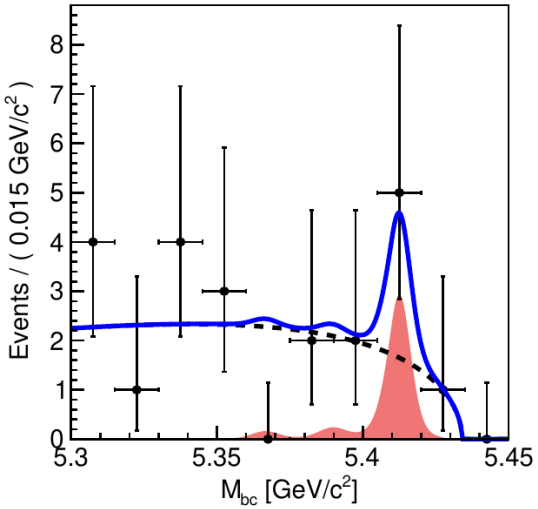
- Only through transitions sensitive to BSM physics. Eur. Phys. J. C 74, 3026 (2014) Prog. Theor. Exp. Phys. 2019, 123C01 (2019)
  - SM prediction: (2 - 4)x10^{-5}.
  - BF of $B^0_{d,s} \to \eta(')\eta(')$: extract CPV parameters from SU(3)/U(3) symmetry. PRD 93, 114002 (2016)
- 3D fit with ΔE, M_{bc}, $M_{\eta'}$.
  - $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$.
- Signal yield = 2.7 ± 2.5.

$$f_s \times \mathcal{B}(B^0_s \to \eta'\eta) \quad (0.51 \pm 0.44 \pm 0.09) \times 10^{-5}$$
$$< 1.3 \times 10^{-5} \ @ \ 90\% \ \mathrm{CL}$$

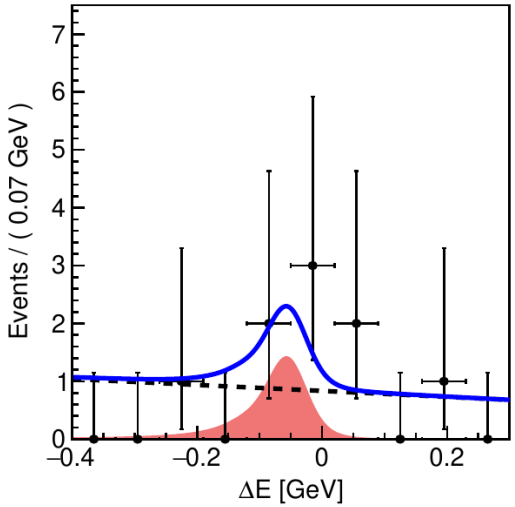
$$\mathcal{B}(B^0_s \to \eta'\eta) \quad (2.5 \pm 2.2 \pm 0.6) \times 10^{-5}$$
$$< 6.5 \times 10^{-5} \ @ \ 90\% \ \mathrm{CL}$$

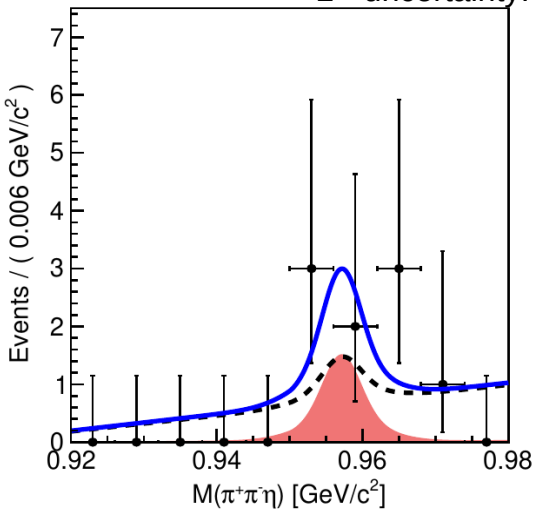
1st uncertainty: stat.
2nd uncertainty: syst.

Signal-enhanced projection plot of data fit result



$5.23 < M_{bc} < 5.43$ GeV/c^2





$5.23 < M_{bc} < 5.43$ GeV/c^2

$B^0_s \to \eta' K_S$: Data result

Preliminary

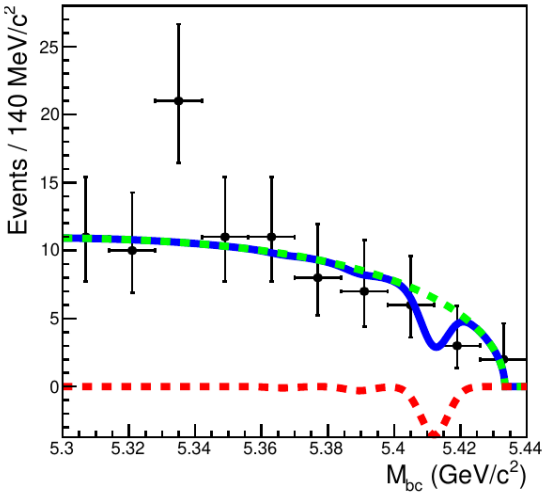
- Contributions from gluonic and electroweak penguin amplitudes.
  - Sensitive to BSM physics which could affect decay rates and CPV.
  - SM prediction: (0.72 - 4.5)x10^{-6} Prog. Theor. Exp. Phys. 2019, 123C01 (2019)

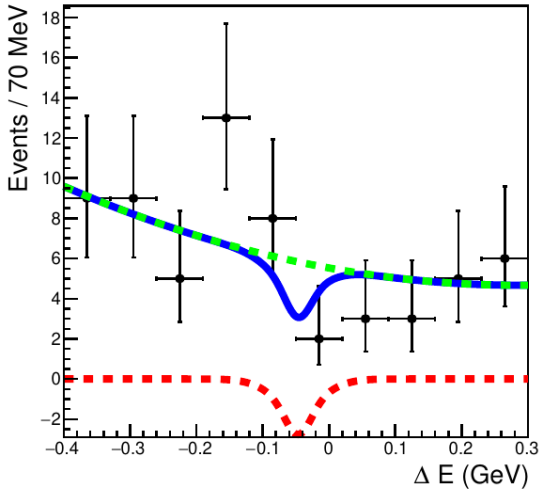
- 3D fit with ΔE, M_{bc}, $M_{\eta'}$.
  - $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$.

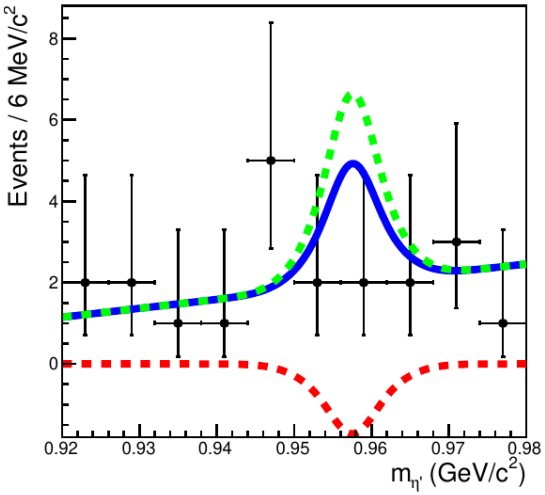
- Signal yield = -3.21 ± 1.85.
  - UL @ 90% C.L.: $f_s \times \mathcal{B}(B^0_s \to \eta' K^0_S) < 1.64 \times 10^{-6}$

$$\mathcal{B}(B^0_s \to \eta' K^0_S) < 8.16 \times 10^{-6}$$

Signal-enhanced projection plot of data fit result







Summary

- $B \to p\bar{p}\pi\pi$:
  - First measurement for $B^+ \to p\bar{p}\pi^+\pi^0$. Search for ρ modes.
- $B^+ \to K^+K^-\pi^+$:
  - Angular study on KK system at low mass with large A_{CP}.
- $B^+ \to \pi^+\pi^0\pi^0$:
  - New $\pi^0\pi^0$ structure with multiple resonances, and large A_{CP} at $M_{\pi^0\pi^0} \sim 1.4$ GeV/c^2.
- $B^0_s \to \eta' X_{s\bar{s}}$, $B^0_s \to \eta'\eta$, $B^0_s \to \eta' K^0_S$:
  - UL on BF is set.
- Looking forward to larger data from Belle II to improve these studies and to have more new resutls.

Backup

$B^+ \to \pi^+\pi^0\pi^0$: Summary of results

Preliminary

- Inclusive BF: Efficiency is determined by the signal model from 2D fit.
- BF($B^+ \to \rho(770)^+\pi^0$): We consider the interference effect with $B^+ \to \rho(1450)^+\pi^0$.
- BF of the $\pi^0\pi^0$ structure can't be reported separated due to lack of information: highly overlapping PDFs, large variations of masses and widths, interference.

Decay mode	Mass	Width	ϵ (%)	Fitted yield	$\mathcal{B}$ (10^{-6})	$\mathcal{A}_{CP}$ (%)
$\pi^+\pi^0\pi^0$ (inclusive)			8.1	1063 ± 86	$19.0 \pm 1.5 \pm 1.4$	$9.2 \pm 6.8 \pm 0.5$
Non-resonant			12.5	3 ± 14	$0.03 \pm 0.16^{+0.12}_{-0.15}$ (< 0.6)	–
$\rho(770)^+\pi^0$, $\rho(770)^+ \to \pi^+\pi^0$	775.5	150.3	8.5	637 ± 65	$11.2 \pm 1.1 \pm 0.9 \pm 1.4$	$8.0 \pm 15.0^{+2.2}_{-7.5}$
$\rho(1450)^+\pi^0$, $\rho(1450)^+ \to \pi^+\pi^0$	1465	400	9.9	80 ± 51	$1.2 \pm 0.6 \pm 0.2$ (< 2.5)	–
$f_0(980)\pi^+$, $f_0(980)^0 \to \pi^0\pi^0$	980	50	10.2	102 ± 30	–	$-27.0 \pm 30.0^{+44.8}_{-56.3}$
$f_2(1270)\pi^+$, $f_2(1270)^0 \to \pi^0\pi^0$	1275.4	185.1	6.6	119 ± 32	–	$57.0 \pm 23.0^{+11.4}_{-25.9}$
$f_0(600)\pi^+$, $f_0(600)^0 \to \pi^0\pi^0$	600	400	8.3	123 ± 37	–	$10 \pm 34^{+12.9}_{-22.6}$
$X\pi^+$, $X \to \pi^0\pi^0$	–	–	8.0	345 ± 48	$6.4 \pm 0.9 \pm 0.6$	–
$f_0(1370)\pi^+$, $f_0(1370)^0 \to \pi^0\pi^0$	1400	300	10.4	< 75	< 1.1	–
$\chi_{c0}\pi^+$, $\chi_{c0} \to \pi^0\pi^0$	3415.2	10.2	13.3	< 39	< 0.5	–
$\chi_{c2}\pi^+$, $\chi_{c2} \to \pi^0\pi^0$	3556.3	2.0	13.6	< 63	< 0.7	–

1st uncertainty: stat.
2nd uncertainty: syst.
3rd uncertainty (if any): interference effect.