30 September

BEAUTY 2019

Heavy flavour spectroscopy at CMS

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On behalf of CMS Collaboration

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Outline

- Study of P-wave B_s^0 states

[CMS-BPH-16-003](), [Eur. Phys. J. C 78 (2018) 939]()

- Study of the $B^+ \to J/\psi \overline{\Lambda} p$ decay

[CMS-BPH-18-005](), [arXiv:1907.05461]()

- First observation of the $\Lambda_b^0 \to J/\psi \Lambda \varphi$ decay

[CMS-BPH-19-002]()

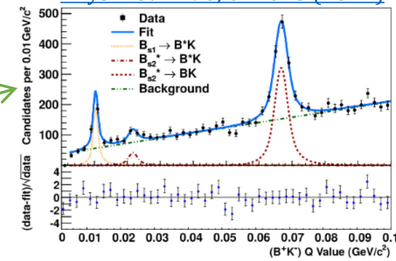
Not included:

- Observation of two excited B_c^+ states →

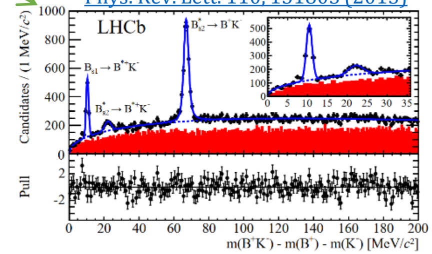
see a separate talk by Leonardo Cristella later today

Study of P-wave B_s^0 states

[Phys. Rev. D 90, 012013 (2014)](#)

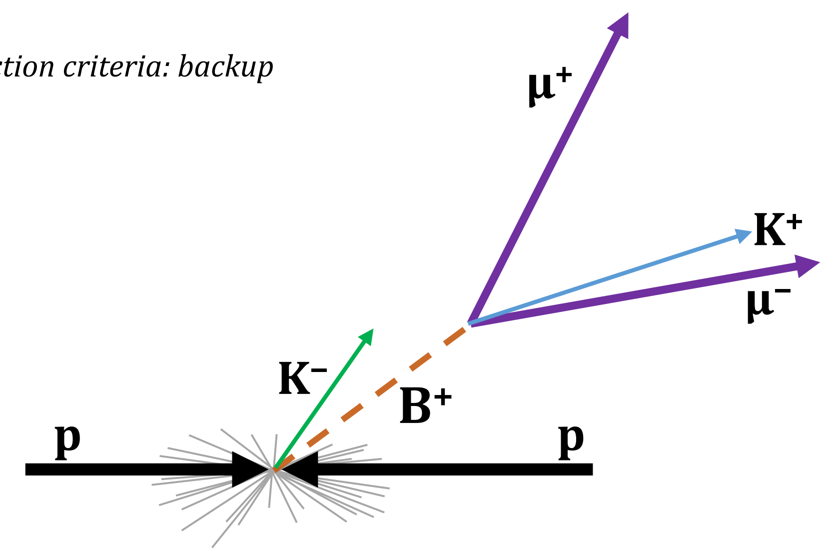


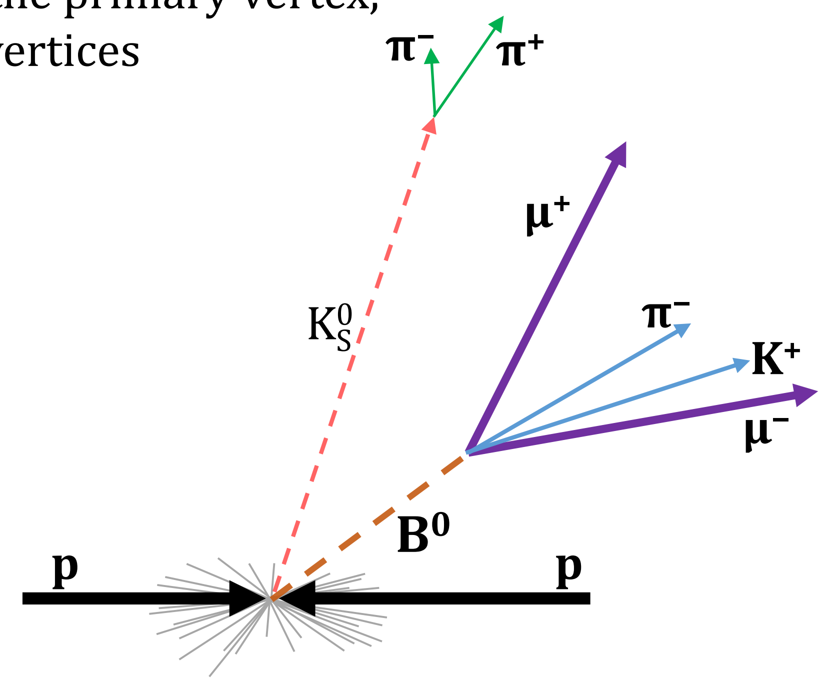
[Phys. Rev. Lett. 110, 151803 (2013)](#)



- P-wave B_s^0 mesons were studied in B^+K^- channel by D0, CDF, LHCb
- CMS: study in B^+K^- channel and search in the new $B^0K_S^0$ channel
- Using 8 TeV pp collision data (20 fb^{-1})
- Use $B^0 \to J/\psi K^+\pi^-$ and $B^+ \to J/\psi K^+$ decays to reconstruct ground state B mesons ($J/\psi \to \mu^+\mu^-$ trigger)
- Select additional K^- from the tracks forming the primary vertex, additional K_S^0 from displaced 2-prong vertices

all selection criteria: backup





[CMS-BPH-16-003](#), [Eur. Phys. J. C 78 (2018) 939](#)

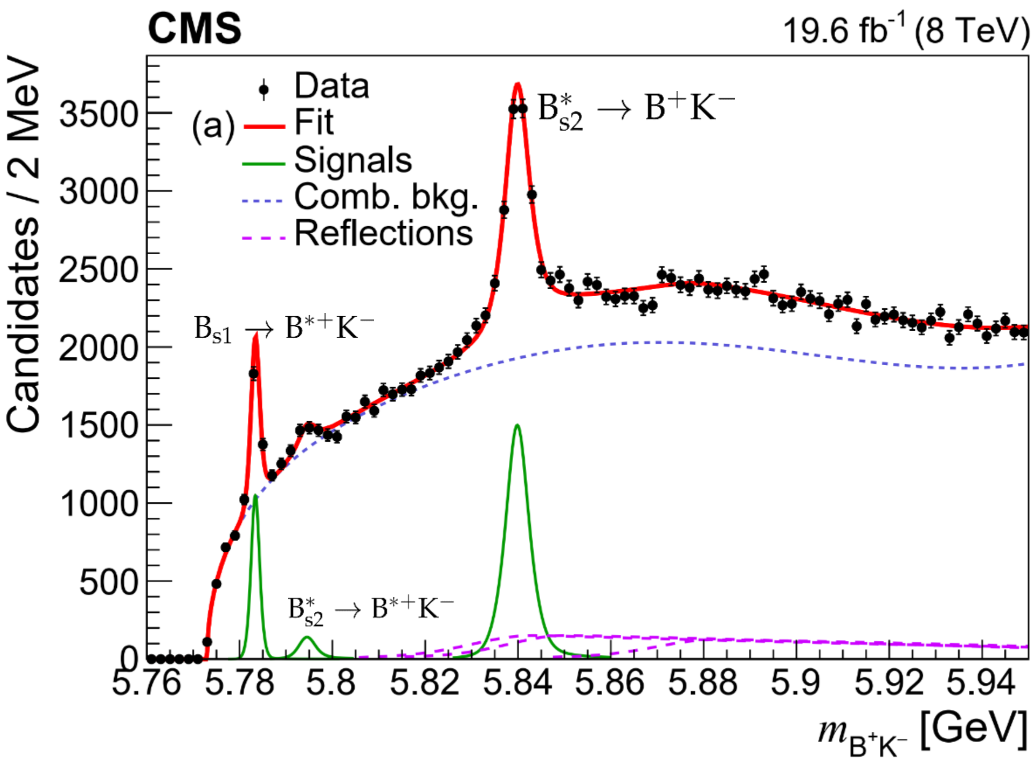
B^+K^- invariant mass distribution

Fit to B^+K^- invariant mass distribution:

3 D-wave RBW functions convolved with resolutions

+ $(x-x_0)^a \bullet Pol_6(x)$ for background,
x_0 is threshold value

+ contributions from excited B^0:
$B_2^* \to B^+\pi^-$, $B_2^* \to B^{*+}\pi^-$, and $B_1^* \to B^+\pi^-$ (shapes fixed to MC, yields fixed to the fit results to the $B^+\pi^-$ invariant mass distribution)



$N(B_{s2}^* \to BK)$	$N(B_{s2}^* \to B^*K)$	$N(B_{s1} \to B^*K)$	$\Gamma(B_{s2}^*)$, MeV	$\Gamma(B_{s1})$, MeV
5424 ± 269	455 ± 119	1329 ± 83	1.52 ± 0.34	0.10 ± 0.15

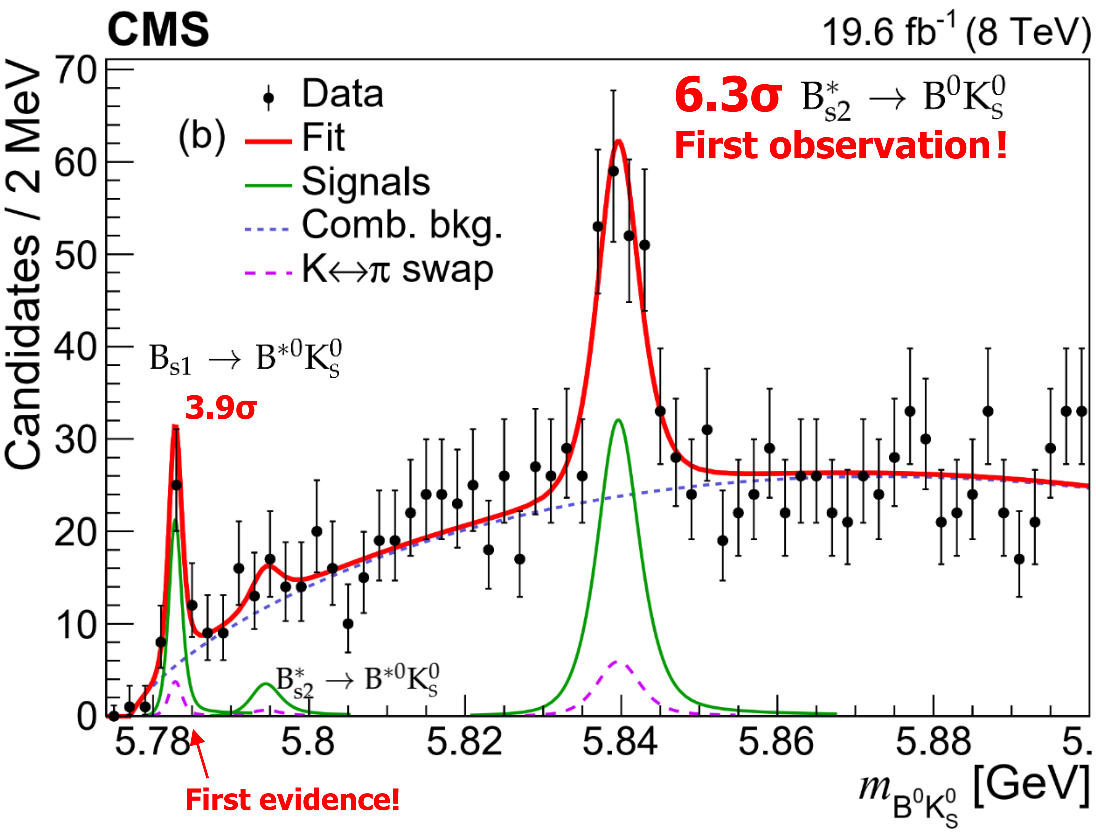
$M(B_{s2}^*) - M(B) - M(K)$, MeV	$M(B_{s1}) - M(B^*) - M(K)$, MeV
66.926 ± 0.093	10.495 ± 0.089

CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

$B^0K^0_S$ invariant mass distribution

Fit $B^0K^0_S$ invariant mass distribution

- 3 D-wave RBW functions convolved with resolutions
- $(x\text{-}x_0)^a \bullet Pol_1(x)$ for bkg,
  x_0 is threshold value
- 3 contributions from K↔π swap
  ($B^0 \to J/\psi K^+\pi^-$, in 19% of cases wrong mass assignment, yields fixed relative to signal)



$N(B^*_{s2} \to BK)$	$N(B^*_{s2} \to B^*K)$	$N(B_{s1} \to B^*K)$	$\Gamma(B^*_{s2})$, MeV	$\Gamma(B_{s1})$, MeV
128 ± 22	12 ± 11	34.5 ± 8.3	2.1 ± 1.3	0.4 ± 0.4

$M(B^*_{s2}) - M(B) - M(K)$, MeV	$M(B_{s1}) - M(B^*) - M(K)$, MeV
62.42 ± 0.48	5.65 ± 0.23

CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

Sources of systematic uncertainty

Systematic uncertainties in the branching fraction ratios, mass differences and Γ, are related to:

- **Choice of the fit model**
  separate uncertainties related to the fits of $B^+\pi^-$, B^+K^- and $B^0K^0_S$ invariant mass distributions; largest deviation in the results under changes of the fit model is used as systematic uncertainty
- **Track reconstruction efficiency (3.9% per extra track)**
  7.8% since 2 more tracks to reconstruct in $B^0K^0_S$ final state
- Mass resolution
  largest change of the results under simultaneous variations of the resolution by ±3%
- Fraction of K↔π swapped component
  largest change of the results under variations of this fraction by ±3%
- Uncertainty on m_{B*}-m_B
  largest change of the results under variations of m_{B*}-m_B by ± PDG uncertainty
- Non-K^* contribution in $B^0 \to J/\psi K^+\pi^-$ decay
  estimated by fitting background-subtracted $K^+\pi^-$ invariant mass distribution
- Possible detector misalignment
  estimated using additional MC samples with distorted detector geometries
- Finite size of the simulation samples
  uncertainties in efficiencies = $N_{reconstructed}$ / $N_{generated}$

CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

Results

Uncertainties here are, respectively, statistical, systematic, related to PDG uncertainties

new $R_2^{0\pm} = \frac{\mathcal{B}(B_{s2}^* \to B^0 K_S^0)}{\mathcal{B}(B_{s2}^* \to B^+ K^-)} = 0.432 \pm 0.077 \pm 0.075 \pm 0.021,$

Theory: 0.42-0.46 arXiv:1202.1224, arXiv:1607.02812

new $R_1^{0\pm} = \frac{\mathcal{B}(B_{s1} \to B^{*0} K_S^0)}{\mathcal{B}(B_{s1} \to B^{*+} K^-)} = 0.49 \pm 0.12 \pm 0.07 \pm 0.02,$

Theory: 0.23-0.46 arXiv:1202.1224

$R_{2*}^{\pm} = \frac{\mathcal{B}(B_{s2}^* \to B^{*+} K^-)}{\mathcal{B}(B_{s2}^* \to B^+ K^-)} = 0.081 \pm 0.021 \pm 0.015,$

LHCb 0.093±0.013±0.012
CDF 0.10±0.03±0.02

new $R_{2*}^{0} = \frac{\mathcal{B}(B_{s2}^* \to B^{*0} K_S^0)}{\mathcal{B}(B_{s2}^* \to B^0 K_S^0)} = 0.093 \pm 0.086 \pm 0.014.$

LHCb 0.232±0.014±0.013

$R_{\sigma}^{\pm} = \frac{\sigma(pp \to B_{s1} X)\, \mathcal{B}(B_{s1} \to B^{*+} K^-)}{\sigma(pp \to B_{s2}^* X)\, \mathcal{B}(B_{s2}^* \to B^+ K^-)} = 0.233 \pm 0.019 \pm 0.018,$

new $R_{\sigma}^{0} = \frac{\sigma(pp \to B_{s1} X)\, \mathcal{B}(B_{s1} \to B^{*0} K_S^0)}{\sigma(pp \to B_{s2}^* X)\, \mathcal{B}(B_{s2}^* \to B^0 K_S^0)} = 0.266 \pm 0.079 \pm 0.063$

Results agree with existing measurements of LHCb and CDF, and with theoretical predictions

CMS 2018: CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939
LHCb 2013: doi:10.1103/PhysRevLett.110.151803
CDF 2014: doi:10.1103/PhysRevD.90.012013

Results

$$\Delta M^{\pm}_{B^*_{s2}} = M(B^*_{s2}) - M^{PDG}_{B^+} - M^{PDG}_{K^-} = 66.87 \pm 0.09 \pm 0.07\,\text{MeV},$$

new $$\Delta M^{0}_{B^*_{s2}} = M(B^*_{s2}) - M^{PDG}_{B^0} - M^{PDG}_{K^0_S} = 62.37 \pm 0.48 \pm 0.07\,\text{MeV},$$

$$\Delta M^{\pm}_{B_{s1}} = M(B_{s1}) - M^{PDG}_{B^{*+}} - M^{PDG}_{K^-} = 10.45 \pm 0.09 \pm 0.06\,\text{MeV},$$

new $$\Delta M^{0}_{B_{s1}} = M(B_{s1}) - M^{PDG}_{B^{*0}} - M^{PDG}_{K^0_S} = 5.61 \pm 0.23 \pm 0.06\,\text{MeV}.$$

$$\Gamma_{B^*_{s2}} = 1.52 \pm 0.34 \pm 0.30\,\text{MeV}$$

Comparison to previous measurements:

Consistent with LHCb and CDF

	$M(B^*_{s2})-M(B^+)-M(K^-)$	$M(B_{s1})-M(B^{*+})-M(K^-)$	$\Gamma(B^*_{s2})$
LHCb	67.06±0.12	10.46±0.06	1.56±0.49
CDF	66.73±0.19	10.35±0.19	1.4±0.44
CMS	**66.87±0.12**	**10.45±0.11**	**1.52±0.43**

We also measure the mass differences between neutral and charged $B^{(*)}$ mesons:

$$M_{B^0} - M_{B^+} = 0.57 \pm 0.49 \pm 0.10 \pm 0.02\,\text{MeV}$$ ↔(0.31±0.06) MeV [PDG]

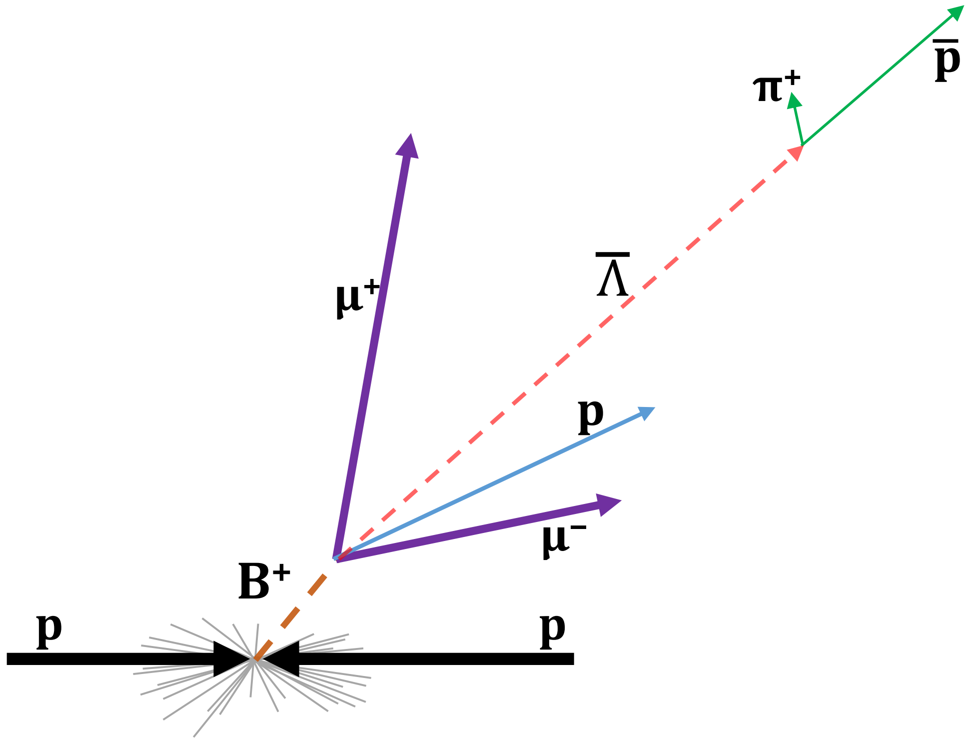
new $$M_{B^{*0}} - M_{B^{*+}} = 0.91 \pm 0.24 \pm 0.09 \pm 0.02\,\text{MeV}$$

We present a new method to measure these mass differences!
It may become very precise with more data

CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

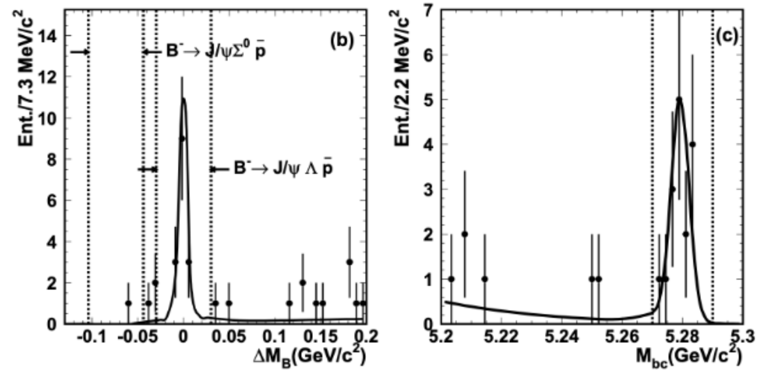
Study of the $B^+ \to J/\psi \overline{\Lambda} p$ decay

CMS-BPH-18-005, arXiv:1907.05461



$B^+ \to J/\psi \bar{\Lambda} p$ decay

10.1103/PhysRevD.72.051105



- Previously studied by Belle with 17 signal events

- CMS: study using 8 TeV pp collision data (20 fb^{-1})

- <u>Possibility to search for exotic hadron contributions</u>
  in the $J/\psi\bar{\Lambda}$ and $J/\psi p$ mass distributions (pentaquarks, similar to $\Lambda_b^0 \to J/\psi p K^-$, $P_c^+ \to J/\psi p$)

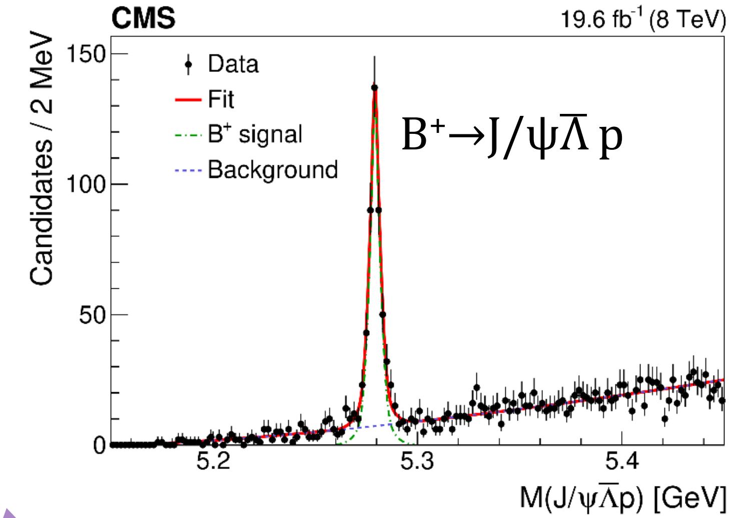
- For the BF measurement, $B^+ \to J/\psi K^{*+}$, $K^{*+} \to K_S^0 \pi^+$ channel is used as normalization
  - uses the same $J/\psi \to \mu^+\mu^-$ trigger and has similar decay topology

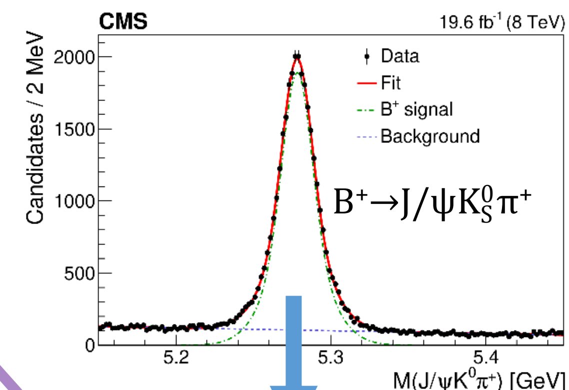
- Event selection:
  - $\mu^+\mu^-$ form a good quality-vertex, $p_T(\mu)$>4 GeV, $M(\mu\mu)$ in ±100 MeV from J/ψ mass
  - $\bar{\Lambda} \to \bar{p}\pi^+$ candidates formed from displaced 2-prong vertices, $p_T(\bar{\Lambda})$ > 1 GeV
  - Additional proton track, OS to p from $\bar{\Lambda}$, $p_T(p)$ > 1 GeV,
  - B^+ obtained by vertex fitting $\mu^+\mu^-\bar{\Lambda}p$, with $\mu^+\mu^-$ mass constrained to $m_{J/\psi}$
  - K_S^0 contribution to $\bar{\Lambda}$ removed, $\bar{\Lambda}$ momentum points to B^+ vertex
  - B^+ vertex L_{xy}/σ_{Lxy} > 3, cos(B^+ pointing angle) > 0.99, vertex fit probability > 1%

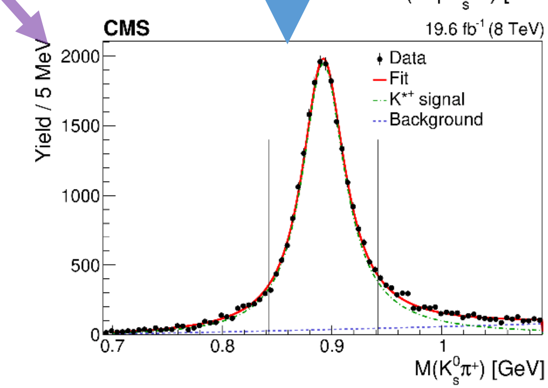
CMS-BPH-18-005, arXiv:1907.05461

$B^+ \to J/\psi\bar{\Lambda}\,p$ branching fraction

- Unbinned ML fit to $J/\psi\bar{\Lambda}\,p$ distribution in data:
  - Triple Gaussian with common mean for B^+
  - $+ (x\text{-}x_0)^\beta$ for bkg
- **452±23** signal events
- Normalization channel $B^+ \to J/\psi K^0_S \pi^+$:
  - Double Gaussian with common mean for B^+
  - + 2nd order polynomial for bkg
  - ⟶ bkg-subtracted $K^0_S\pi^+$ mass distribution
    - Relativistic Breit-Winer for K^{*+}
    - $+ (y\text{-}y_0)^\gamma$ for bkg
    - **20863±357** normalization $B^+ \to J/\psi K^{*+}$ events







$$\frac{\mathcal{B}(B^+ \to J/\psi\bar{\Lambda}p)}{\mathcal{B}(B^+ \to J/\psi K^{*+})} = \frac{N(B^+ \to J/\psi\bar{\Lambda}p)\mathcal{B}(K^{*+} \to K^0_S\pi^+)\mathcal{B}(K^0_S \to \pi^+\pi^-)\epsilon(B^+ \to J/\psi K^{*+})}{N(B^+ \to J/\psi K^{*+})\mathcal{B}(\bar{\Lambda} \to \bar{p}\pi^+)\epsilon(B^+ \to J/\psi\bar{\Lambda}p)}$$

Dominant systematics: MC sample size and data/MC difference

ε from MC

$$\frac{\mathcal{B}(B^+ \to J/\psi\bar{\Lambda}\,p)}{\mathcal{B}(B^+ \to J/\psi K^{*+})} = (1.054 \pm 0.057_{(stat)} \pm 0.035_{(syst)} \pm 0.011_{(\mathcal{B})})\%$$

$$\mathcal{B}(B^+ \to J/\psi\bar{\Lambda}\,p) = (15.1 \pm 0.8_{(stat)} \pm 0.5_{(syst)} \pm 0.9_{(\mathcal{B})}) \cdot 10^{-6}$$

most precise measurement

CMS-BPH-18-005, arXiv:1907.05461

Model-independent approach to the intermediate resonance study in $B^+ \to J/\psi \bar{\Lambda} p$ decay

Introduced by BaBar [Phys.Rev.D79:112001 (2009)], used by LHCb [Phys.Rev.D.92:112009 (2015)]

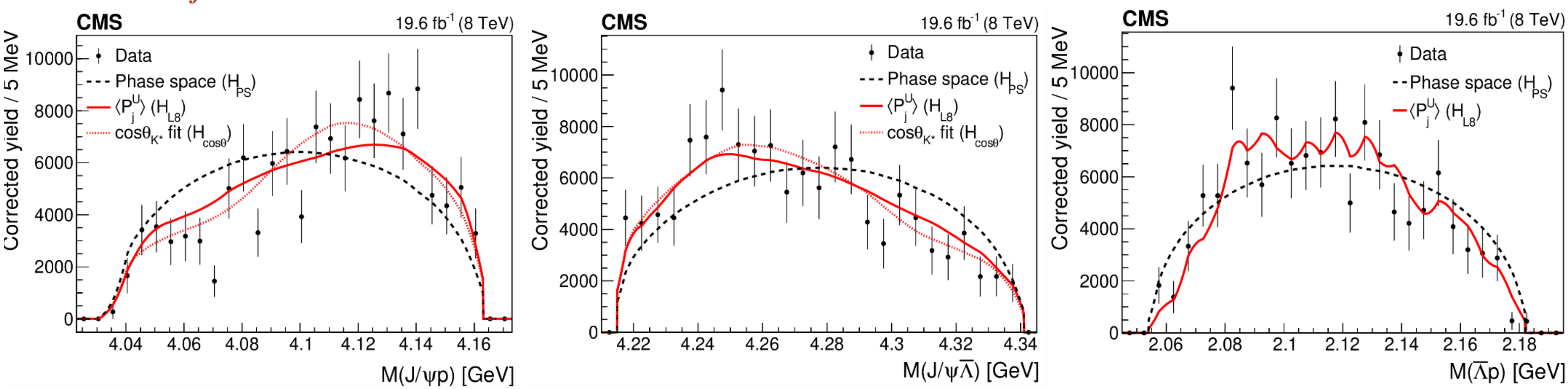
The only known contributions come from $K_4^*(2045)^+$, $K_2^*(2250)^+$, $K_3^*(2320)^+ \to p\bar{\Lambda}$ decays

Their possible contributions are taken into account by reweighting 3-body phase-space MC

$$w^i = 1 + \sum_{j=1}^{l_{max}=8} < P_j^N > P_j(cos\theta^i_{K^*})$$

$$P_j^N = 2 \bullet \sum_{i=1}^{N_{reco}} \frac{P_j(\cos\theta_{K^*})}{\epsilon^i} / N^{reco}_{corr}$$

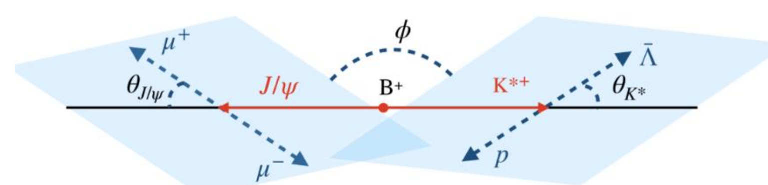
in each $M(\bar{\Lambda}p)$ bin



- - - Phase-space (incompatible with data 6.1, 5.5, 3.4σ)

— Reweighted with $l_{max} = 8$

······ Reweighted on 1D $\cos\theta_{K^*}$ distribution



Accounting for K* resonances with spin up to 4 brings the agreement between efficiency-corrected data and reweighted MC to **2.8σ** level: <u>no need for extra exotic states to describe the observed data</u>

CMS-BPH-18-005, arXiv:1907.05461

Summary of the study of $B^+ \to J/\psi \bar{\Lambda} p$ decay

The **branching fraction is measured** with the **best precision** to date

$$\frac{\mathcal{B}(B^+ \to J/\psi \bar{\Lambda} p)}{\mathcal{B}(B^+ \to J/\psi K^{*+})} = (1.054 \pm 0.057_{(stat)} \pm 0.035_{(syst)} \pm 0.011_{(\mathcal{B})})\%$$

$$\mathcal{B}(B^+ \to J/\psi \bar{\Lambda} p) = (15.1 \pm 0.8_{(stat)} \pm 0.5_{(syst)} \pm 0.9_{(\mathcal{B})}) \bullet 10^{-6}$$

The intermediate invariant mass distributions $J/\psi p$, $J/\psi \bar{\Lambda}$, $\bar{\Lambda} p$ are **incompatible with phase-space** hypothesis (>6.1, 5.5, 3.4σ)

Using a model-independent approach that accounts for K* resonances with spin up to 4, decaying into $\bar{\Lambda} p$, the agreement is improved significantly:

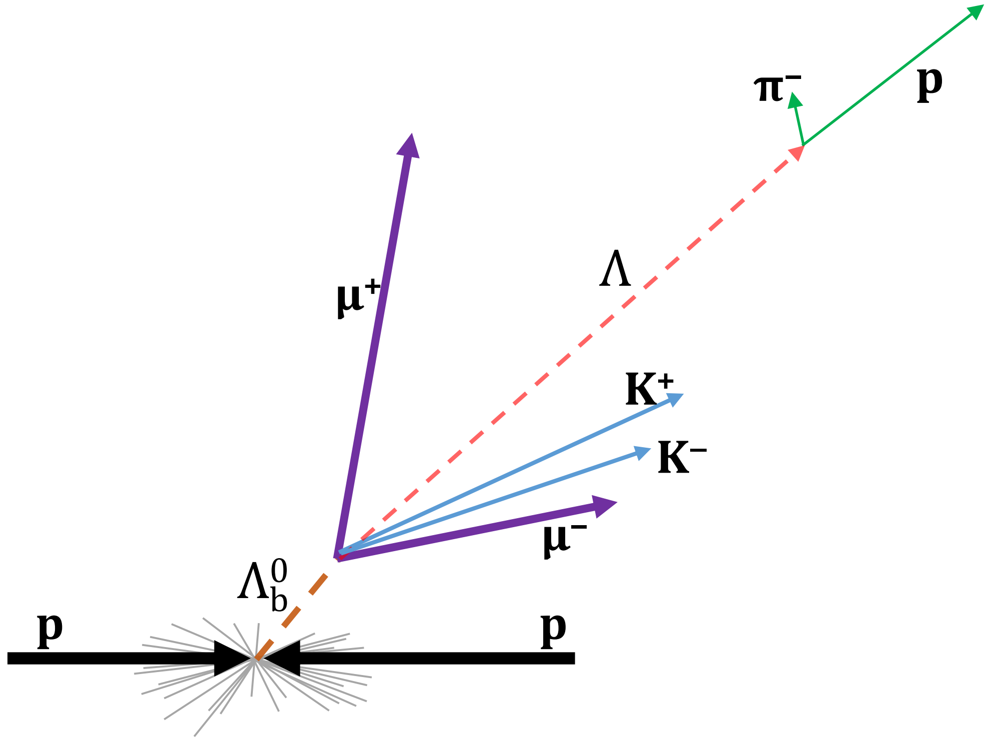
the significance of discrepancy is below 3σ

Therefore, there is **<u>no need for extra exotic states to describe the observed data</u>**

CMS-BPH-18-005, arXiv:1907.05461

First observation of the $\Lambda_b^0 \to J/\psi \Lambda \varphi$ decay

CMS-BPH-19-002



$\Lambda_b^0 \to J/\psi \Lambda \varphi$ decay

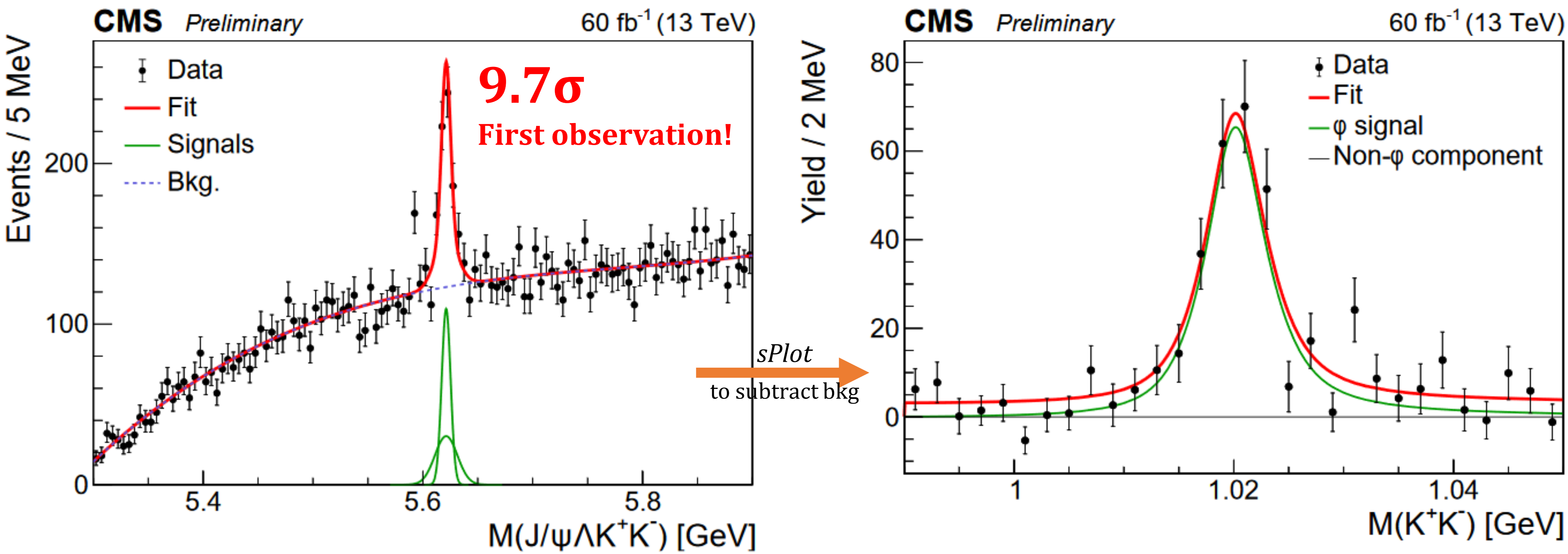
- Not studied previously
- CMS: study using 13 TeV pp collision data (60 fb^{-1}, 2018 only)
- Possibility to search for exotic hadron contributions in the $J/\psi\Lambda$ and $J/\psi\varphi$ mass distributions (pentaquarks→ $J/\psi\Lambda$, tetraquarks → $J/\psi\varphi$)
- For the BF measurement, $\Lambda_b^0 \to \psi(2S)\Lambda$, $\psi(2S) \to J/\psi\pi^+\pi^-$ channel is used as normalization
  - uses the same J/ψ + 2 Trk trigger and has similar decay topology

$$\frac{\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda\phi)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)} = \frac{N(\Lambda_b^0 \to J/\psi\Lambda\phi)\mathcal{B}(\psi(2S) \to J/\psi\pi^-\pi^+)\epsilon(\Lambda_b^0 \to \psi(2S)\Lambda)}{N(\Lambda_b^0 \to \psi(2S)\Lambda)\epsilon(\Lambda_b^0 \to J/\psi\Lambda\phi)\mathcal{B}(\phi \to K^+K^-)}$$

- Event selection:
  - $\mu^+\mu^-$ form a good quality-vertex, $p_T(\mu)>4$ GeV, $M(\mu\mu)$ in ±100 MeV from J/ψ mass
  - $\Lambda \to p\pi^-$ candidates formed from displaced 2-prong vertices, $p_T(\Lambda) > 1$ GeV
  - Two OS tracks form $\varphi \to K^+K^-$ candidate, $p_T(K) > 0.8$ GeV, $0.99 < M(KK) < 1.05$ GeV
  - Λ_b^0 obtained by vertex fitting $\mu^+\mu^-K^+K^-\Lambda$, with $\mu^+\mu^-$ mass constrained to $m_{J/\psi}$
  - Λ_b^0 vertex $L_{xy}/\sigma_{Lxy} > 3$, cos(Λ_b^0 pointing angle) > 0.99, vertex fit probability > 1%

CMS-BPH-19-002

Observation of the $\Lambda_b^0 \to J/\psi \Lambda \varphi$ decay



Double-Gaussian for Λ_b^0
+ 3rd order polynomial for bkg

380±32 signal $\Lambda_b^0 \to J/\psi \Lambda K^+ K^-$ events

Signal resolutions fixed to simulation

Gaussian convolved with BW for φ
+ 1st order polynomial for bkg

286±29 signal $\Lambda_b^0 \to J/\psi \Lambda \varphi$ events

Γ(φ) fixed to PDG

Not enough signal to perform intermediate invariant mass distribution studies

CMS-BPH-19-002

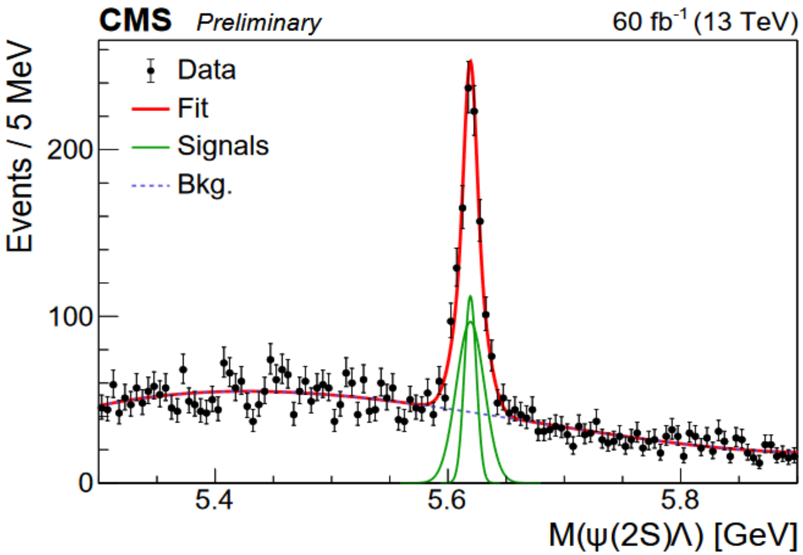
Branching fraction measurement

Normalization channel

$\Lambda_b^0 \to \psi(2S)\Lambda,\ \psi(2S) \to J/\psi\pi^+\pi^-$

- Double-Gaussian for Λ_b^0
- + 3rd order polynomial for bkg

884±37 normalization $\Lambda_b^0 \to \psi(2S)\Lambda$ events



$$\frac{\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda\phi)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)} = \frac{N(\Lambda_b^0 \to J/\psi\Lambda\phi)\mathcal{B}(\psi(2S) \to J/\psi\pi^-\pi^+)\epsilon(\Lambda_b^0 \to \psi(2S)\Lambda)}{N(\Lambda_b^0 \to \psi(2S)\Lambda)\epsilon(\Lambda_b^0 \to J/\psi\Lambda\phi)\mathcal{B}(\phi \to K^+K^-)}$$

ε from MC → $\frac{\varepsilon(\Lambda_b^0 \to \psi(2S)\Lambda)}{\varepsilon(\Lambda_b^0 \to J/\psi\Lambda\varphi)} = 0.36 \pm 0.01$

Systematic uncertainties:

- Data/MC difference in mass resolution
- MC sample size
- Variations of background models
- Variations of signal models
- Data/MC difference in kinematic distributions

Total systematic uncertainty **8.2%**

$$\frac{\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda\varphi)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)} = (8.26 \pm 0.90_{(stat)} \pm 0.68_{(syst)} \pm 0.11_{(\mathcal{B})})\%$$

CMS-BPH-19-002

Summary

First observation (6.3σ) of the $B^{*}_{s2} \to B^{0} K^{0}_{S}$ decay

First evidence (3.9σ) for the $B_{s1} \to B^{*0} K^{0}_{S}$ decay

CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

Measured $R_2^{0\pm} = \frac{\mathcal{B}(B^{*}_{s2} \to B^{0} K^{0}_{S})}{\mathcal{B}(B^{*}_{s2} \to B^{+} K^{-})} = 0.432 \pm 0.077 \pm 0.075 \pm 0.021$, 5 other ratios, $\Gamma(B^{*}_{s2}(5840)^{0}) = 1.52 \pm 0.32 \pm 0.30$ MeV,

$M_{B^{*0}} - M_{B^{*+}} = 0.91 \pm 0.24 \pm 0.09 \pm 0.02$ MeV and 5 other mass differences

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$\mathcal{B}(B^{+} \to J/\psi \bar{\Lambda} p) = (15.1 \pm 0.8_{(stat)} \pm 0.5_{(syst)} \pm 0.9_{(\mathcal{B})}) \cdot 10^{-6}$ *most precise measurement to date*

The intermediate mass distributions $J/\psi p$, $J/\psi \bar{\Lambda}$, $\bar{\Lambda} p$ are **incompatible with phase-space** hypothesis

Using a model-independent approach that accounts for K^{*} resonances decaying into $\bar{\Lambda} p$, the agreement is improved significantly, to the level of **< 3 σ** discrepancy

Therefore, there is **no need for extra exotic states to describe the observed data**

CMS-BPH-18-005, arXiv:1907.05461

First observation (9.7σ) of the $\Lambda^{0}_{b} \to J/\psi \Lambda \varphi$ decay

$$\frac{\mathcal{B}(\Lambda^{0}_{b} \to J/\psi \Lambda \varphi)}{\mathcal{B}(\Lambda^{0}_{b} \to \psi(2S) \Lambda)} = (8.26 \pm 0.90_{(stat)} \pm 0.68_{(syst)} \pm 0.11_{(\mathcal{B})})\%$$

CMS-BPH-19-002

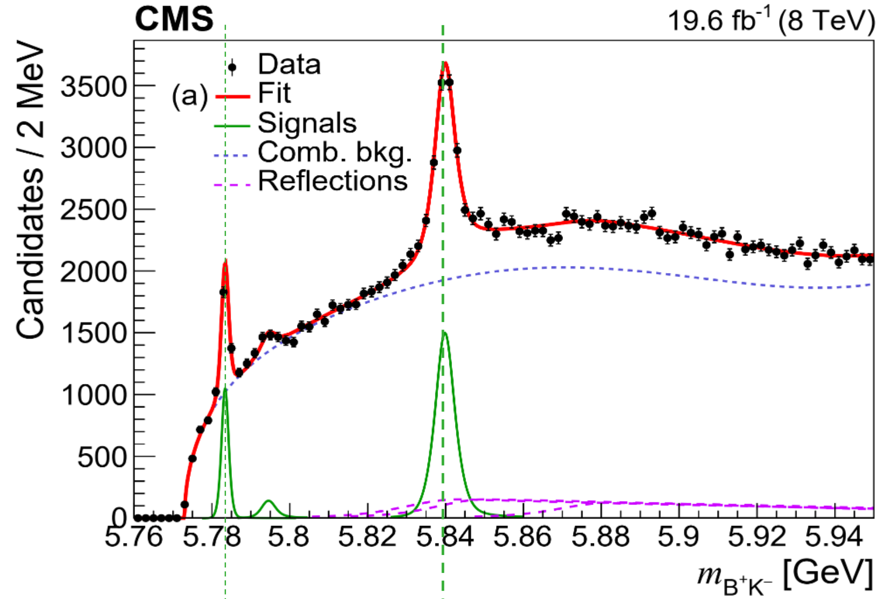
Thank you !

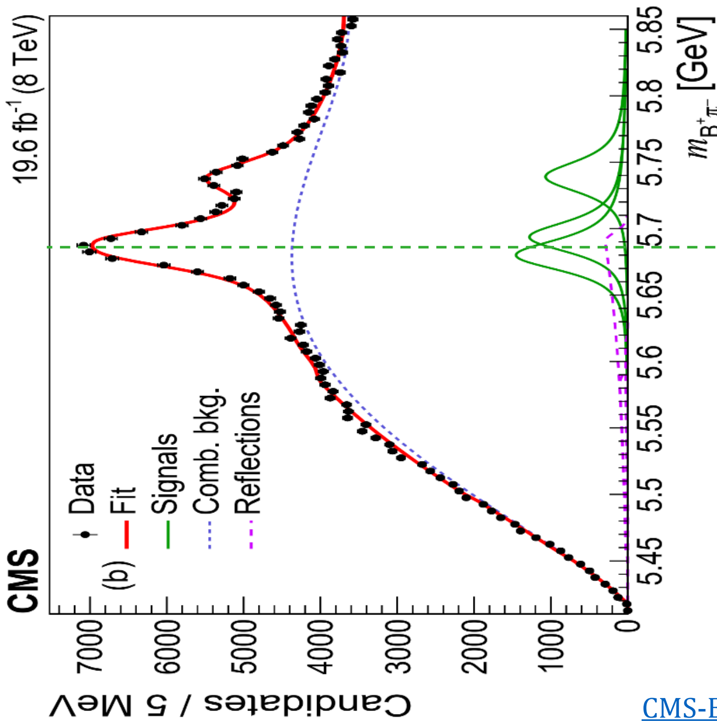
BACKUP

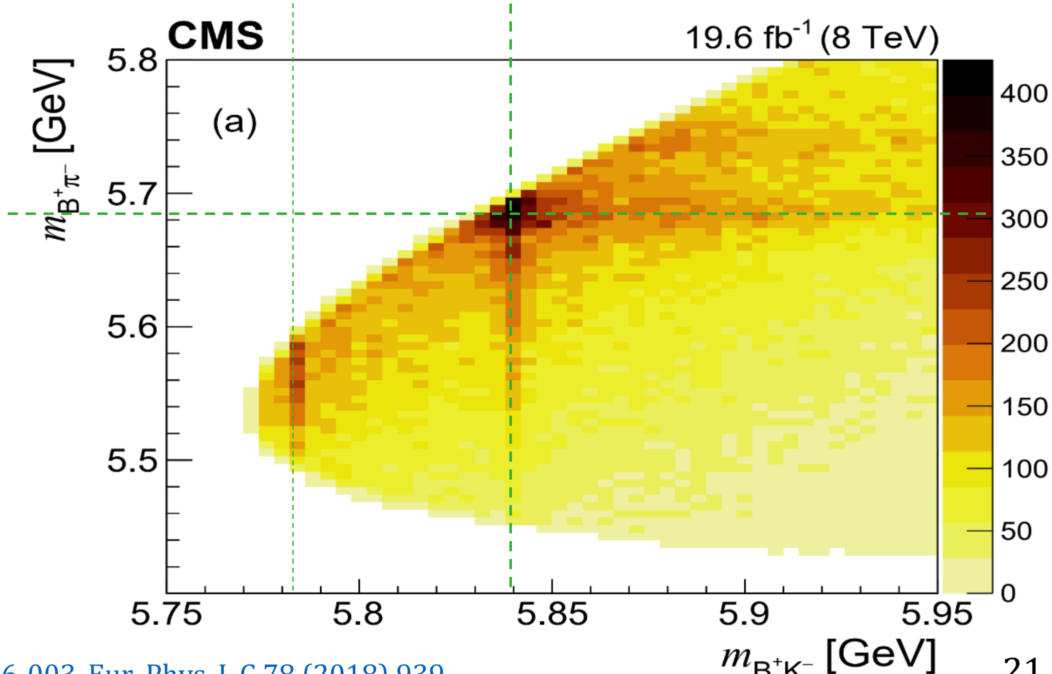
B⁺h⁻ invariant mass distributions

To describe the signal **B⁺K⁻** invariant mass distribution, we need to take into account the **reflections from excited B⁰ decays into B⁽*⁾⁺π⁻**

(see backup for details on the procedure)

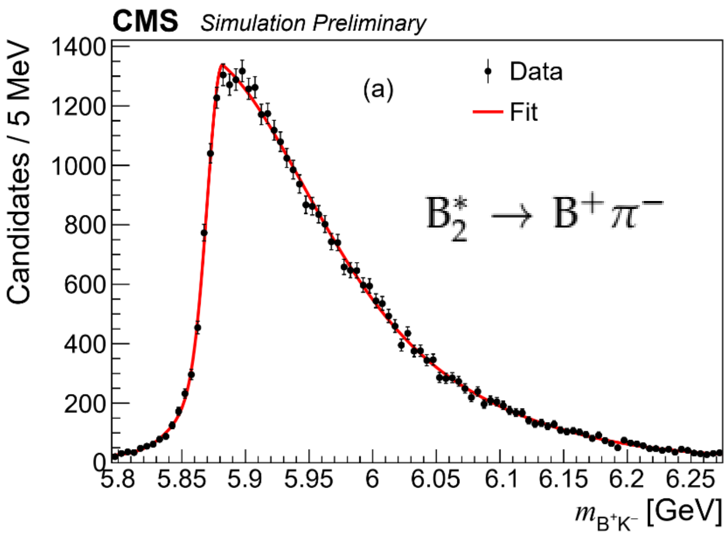


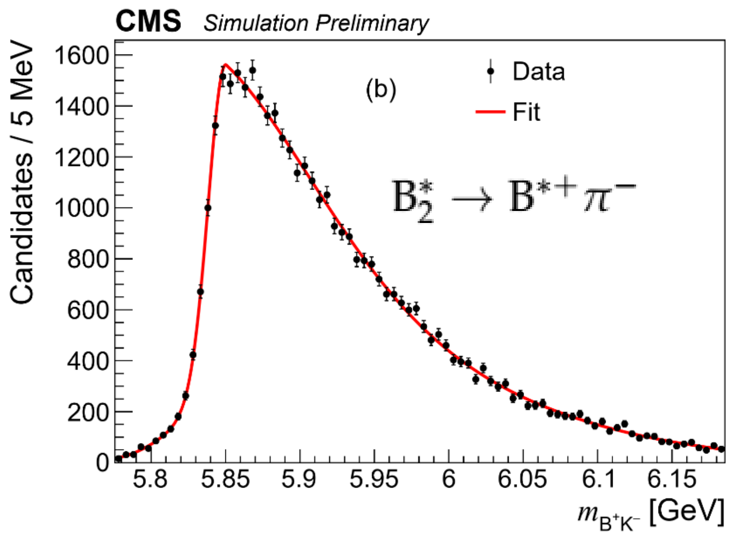


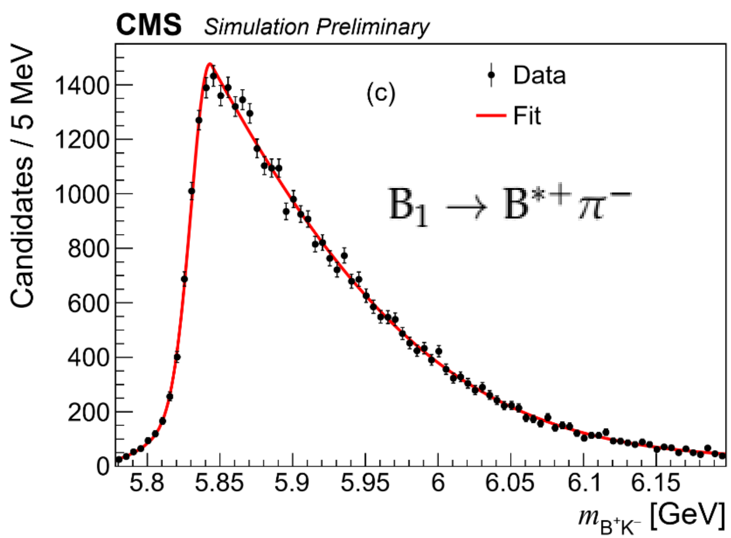


CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

Shapes of reflections from $\mathbf{B^{*0} \to B^{(*)+} \pi^-}$ decays **in $\mathbf{B^+K^-}$** invariant mass distribution







The shapes obtained using simulated events are approximated with a product of one-sided double-Gaussian function and sum of two Gaussian functions

CMS-PAS-BPH-16-003

Measuring BF ratios

Ratio of the signal yields in data

Ratio of total efficiencies from MC ~ 16

$$R_2^{0\pm} = \frac{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_\mathrm{S}^0)}{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} = \frac{N(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_\mathrm{S}^0)}{N(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} \times \frac{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)}{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_\mathrm{S}^0)} \times \frac{\mathcal{B}(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+)}{\mathcal{B}(\mathrm{B}^0 \to \mathrm{J}/\psi\mathrm{K}^{*0})\mathcal{B}(\mathrm{K}^{*0} \to \mathrm{K}^+\pi^-)\mathcal{B}(\mathrm{K}_\mathrm{S}^0 \to \pi^+\pi^-)}$$

Known branching fractions from PDG

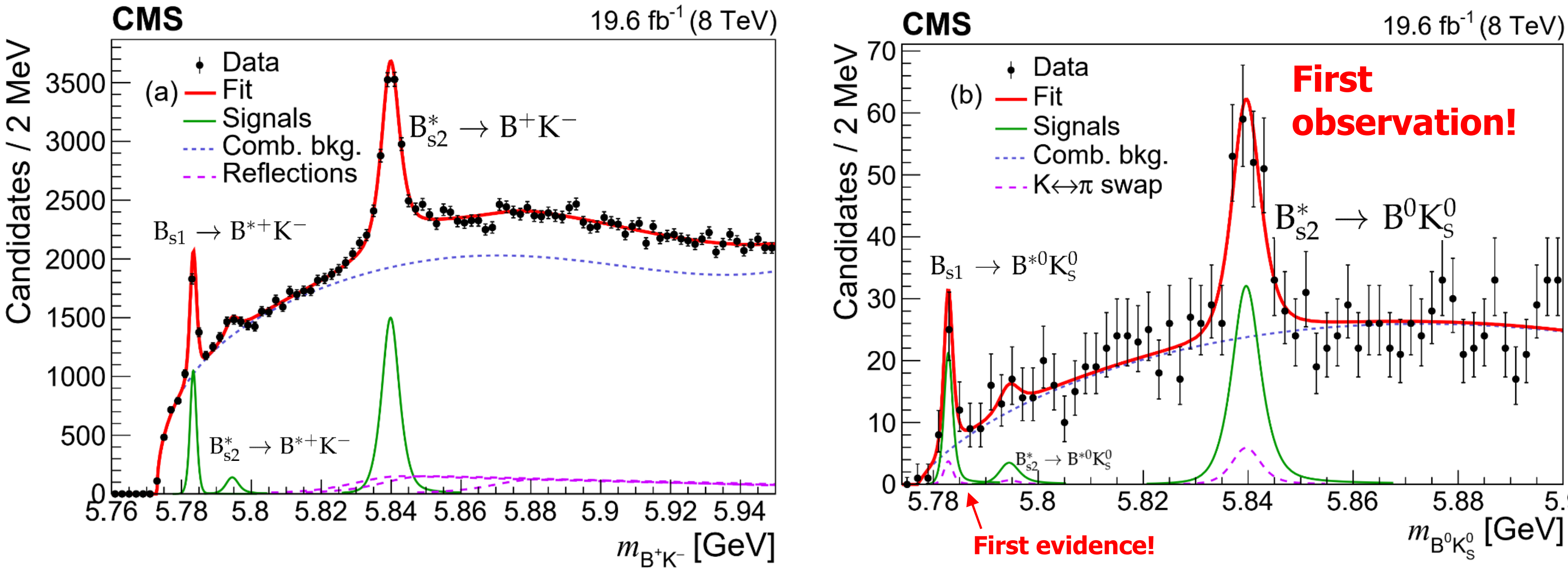
$\mathcal{B}(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+) = (1.026 \pm 0.031) \times 10^{-3}$, $\mathcal{B}(\mathrm{K}_\mathrm{S}^0 \to \pi^+\pi^-) = (0.6920 \pm 0.0005)$

$\mathcal{B}(\mathrm{B}^0 \to \mathrm{J}/\psi\mathrm{K}^{*0}) = (1.28 \pm 0.05) \times 10^{-3}$, $\mathcal{B}(\mathrm{K}^{*0} \to \mathrm{K}^+\pi^-) = (0.99754 \pm 0.00021)$

Formulae and efficiencies ratios for all 6 measured ratios – in backup

CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

Overview



Final state	$N(B_{s2}^* \to BK)$	$N(B_{s2}^* \to B^*K)$	$N(B_{s1} \to B^*K)$
B^+K^-	5424 ± 269	455 ± 119	1329 ± 83
$B^0K_S^0$	128 ± 22	12 ± 11	34.5 ± 8.3

B^+ is reconstructed in $J/\psi K^+$ channel

B^0 is reconstructed in $J/\psi K^+\pi^-$ channel

“Reflections”:

From $B^{**} \to B^{(*)+}\pi^-$ in B^+K^- channel, yields fixed from the fit to $B^+\pi^-$ invariant mass;

From K↔π swap in $B^0K_S^0$ channel, yields fixed relative to the signal yields

We also measure masses, mass differences and $\Gamma(B_{s2}^*)$ in these decays

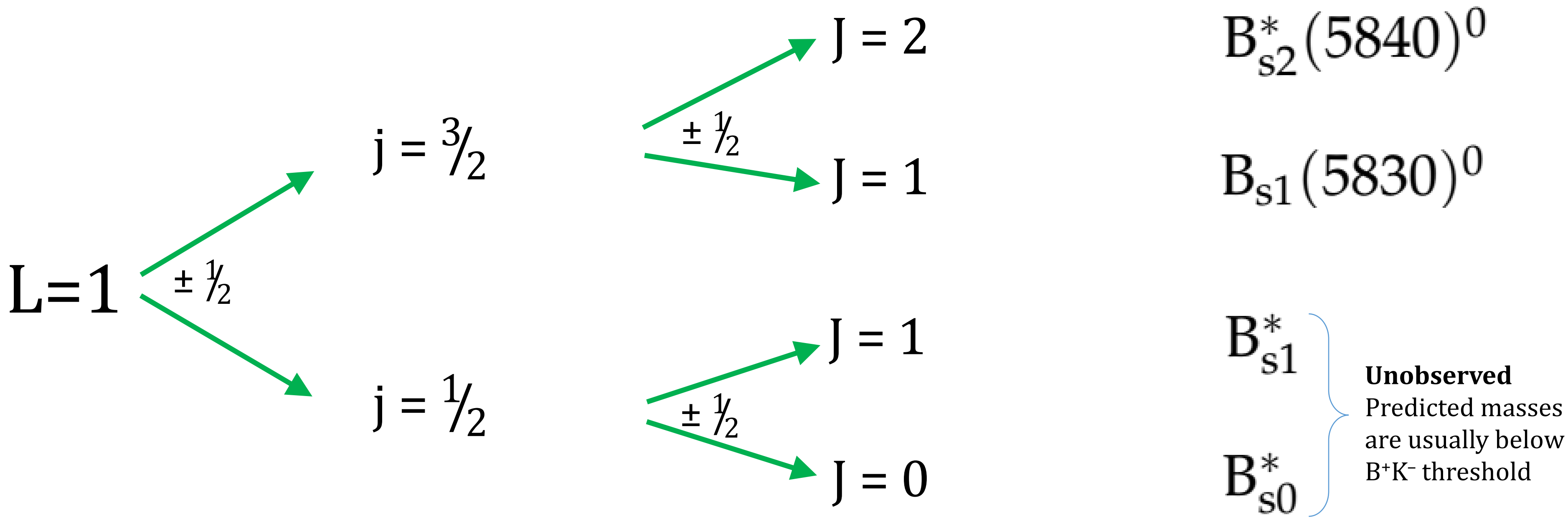
CMS-BPH-16-003, arXiv:1809.03578

P-wave B_s^0 states

Orbital momentum L

Total angular momentum of light subsystem j
$j = L \pm 1/2$

Total angular momentum
$J = j \pm 1/2$



The decay $B_{s1} \to B^+K^-$ corresponds to (in J^P) $1^+ \to 0^-0^-$ and is forbidden

The decay $B_{s1} \to B^{*+}K^-$ corresponds to (in J^P) $1^+ \to 1^-0^-$ and $3/2^- \to 1/2^+\, 0^-$ in j^p
In HQET j^p is also conserved ⇒ it cannot proceed in S-wave; but can proceed in D-wave.

Similarly, $B^*_{s2} \to B^+K^-$ and $B^*_{s2} \to B^{*+}K^-$ decays are expected to proceed in D-wave.

CMS-BPH-16-003,
Eur. Phys. J. C 78 (2018) 939

Summary of all reported measurements

$$R_2^{0\pm} = \frac{\mathcal{B}(B_{s2}^* \to B^0 K_S^0)}{\mathcal{B}(B_{s2}^* \to B^+ K^-)} = 0.432 \pm 0.077\,(\text{stat}) \pm 0.075\,(\text{syst}) \pm 0.021\,(\text{PDG})$$

$$R_1^{0\pm} = \frac{\mathcal{B}(B_{s1} \to B^{*0} K_S^0)}{\mathcal{B}(B_{s1} \to B^{*+} K^-)} = 0.492 \pm 0.122\,(\text{stat}) \pm 0.068\,(\text{syst}) \pm 0.024\,(\text{PDG})$$

$$R_{2*}^{\pm} = \frac{\mathcal{B}(B_{s2}^* \to B^{*+} K^-)}{\mathcal{B}(B_{s2}^* \to B^+ K^-)} = 0.081 \pm 0.021\,(\text{stat}) \pm 0.015\,(\text{syst}),$$

$$R_{2*}^{0} = \frac{\mathcal{B}(B_{s2}^* \to B^{*0} K_S^0)}{\mathcal{B}(B_{s2}^* \to B^0 K_S^0)} = 0.093 \pm 0.086\,(\text{stat}) \pm 0.014\,(\text{syst}),$$

$$R_{\sigma}^{\pm} = \frac{\sigma(pp \to B_{s1}\ldots) \times \mathcal{B}(B_{s1} \to B^{*+} K^-)}{\sigma(pp \to B_{s2}^*\ldots) \times \mathcal{B}(B_{s2}^* \to B^+ K^-)} = 0.233 \pm 0.019\,(\text{stat}) \pm 0.018\,(\text{syst})$$

$$R_{\sigma}^{0} = \frac{\sigma(pp \to B_{s1}\ldots) \times \mathcal{B}(B_{s1} \to B^{*0} K_S^0)}{\sigma(pp \to B_{s2}^*\ldots) \times \mathcal{B}(B_{s2}^* \to B^0 K_S^0)} = 0.266 \pm 0.079\,(\text{stat}) \pm 0.063\,(\text{syst})$$

$$\Delta M_{B_{s2}^*}^{\pm} = M(B_{s2}^*) - M(B^+) - M(K^-) = 66.870 \pm 0.093\,(\text{stat}) \pm 0.073\,(\text{syst})\,\text{MeV},$$

$$\Delta M_{B_{s2}^*}^{0} = M(B_{s2}^*) - M(B^0) - M(K_S^0) = 62.37 \pm 0.48\,(\text{stat}) \pm 0.07\,(\text{syst})\,\text{MeV},$$

$$\Delta M_{B_{s1}}^{\pm} = M(B_{s1}) - M(B^{*+}) - M(K^-) = 10.452 \pm 0.089\,(\text{stat}) \pm 0.063\,(\text{syst})\,\text{MeV},$$

$$\Delta M_{B_{s1}}^{0} = M(B_{s1}) - M(B^{*0}) - M(K_S^0) = 5.61 \pm 0.23\,(\text{stat}) \pm 0.06\,(\text{syst})\,\text{MeV},$$

$$M(B_{s2}^*) = 5839.86 \pm 0.09 \pm 0.07 \pm 0.15\,\text{MeV}$$

$$M(B_{s1}) = 5828.78 \pm 0.09 \pm 0.06 \pm 0.28\,\text{MeV}$$

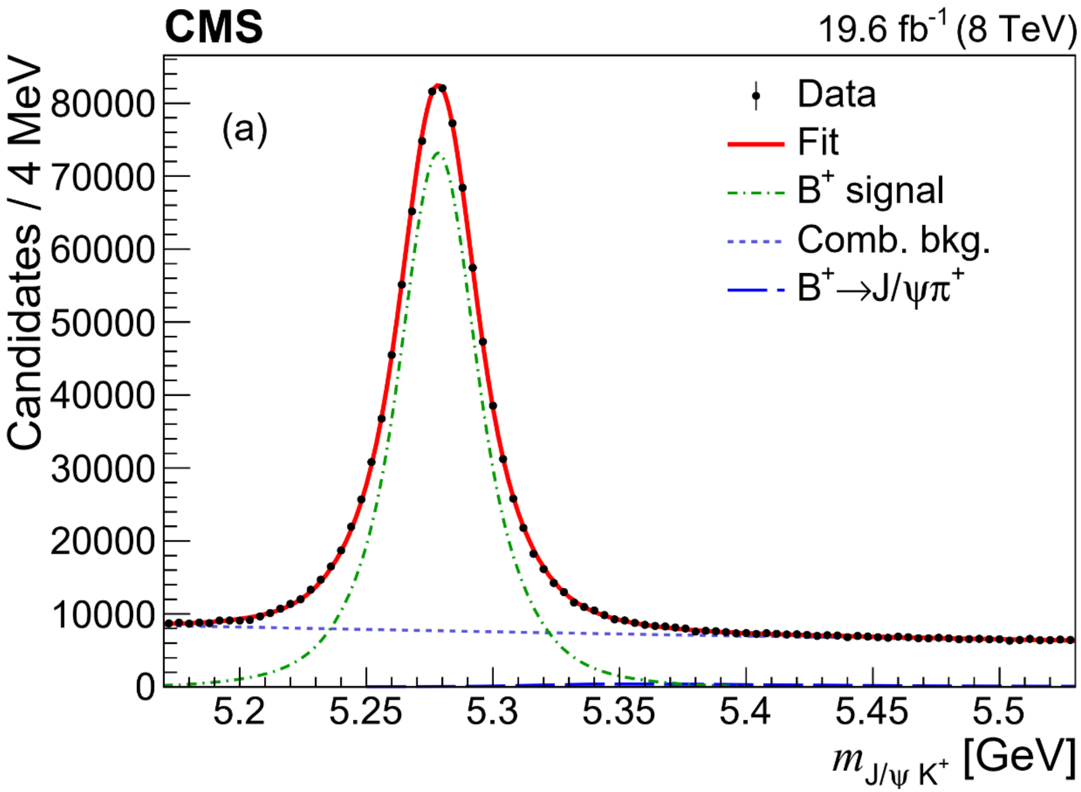
$$m_{B^0} - m_{B^+} = 0.57 \pm 0.49\,(\text{stat}) \pm 0.10\,(\text{syst}) \pm 0.02\,(\text{PDG})\,\text{MeV}$$

$$m_{B^{*0}} - m_{B^{*+}} = 0.91 \pm 0.24\,(\text{stat}) \pm 0.09\,(\text{syst}) \pm 0.02\,(\text{PDG})\,\text{MeV}$$

$$\Gamma(B_{s2}^*) = 1.52 \pm 0.34\,(\text{stat}) \pm 0.30\,(\text{syst})\,\text{MeV}$$

Highlighted in yellow are the first measurements

B^+ invariant mass distribution



Modelled with triple Gaussian function with common mean for signal, exponential for bkg
additional small contribution to account for Cabibbo suppressed $B^+ \to J/\psi\pi^+$ decay

The B^+ invariant mass resolution is consistent between data and MC
Effective resolution* is about 24 MeV

$$* \ \sigma_{eff} = \sqrt{f_1\sigma_1^2 + f_2\sigma_2^2 + (1 - f_1 - f_2)\sigma_3^2}$$

A small difference of ~3% is used in the estimation of the systematic uncertainties

Now combine B^+ with a track from the same PV

CMS-BPH-16-003, Eur. Phys. J. C 78 (2018) 939

More details on $B^+ \to J/\psi\bar{\Lambda}p$ decay study

In each $M(\bar{\Lambda}p)$ bin, the $\cos\theta_{K^*}$ distribution can be expressed as an expansion in terms of Legendre polynomials:

$$\frac{dN}{d\cos\theta_{K^*}} = \sum_{j=0}^{l_{max}} \langle P_j^U \rangle P_j(\cos\theta_{K^*}), \quad (2)$$

$$\langle P_j^U \rangle = \sum_{i=1}^{N_{reco}} \frac{P_j(\cos\theta_{K^*})}{\epsilon^i},$$

Calculated in data events
Using 2D efficiency from MC

$$\frac{dN}{d\cos\theta_{K^*}} = \frac{N}{2} + \sum_{j=1}^{l_{max}} \langle P_j^U \rangle P_j(\cos\theta_{K^*}) = \frac{N}{2}\left(1 + \sum_{j=1}^{l_{max}} \langle \frac{2\langle P_j^U \rangle}{N} \rangle P_j(\cos\theta_{K^*})\right).$$

$$w^i = 1 + \sum_{j=1}^{l_{max}} \langle P_j^N \rangle P_j(\cos\theta_{K^*}),$$

Weights applied to MC

$$\langle P_j^N \rangle = 2\langle P_j^U \rangle / N_{reco}^{corr}$$

Source	Relative uncertainty (%)
Discrepancy between data and simulation	2.2
Background model in the $M(J/\psi\bar{\Lambda}p)$ distribution	1.1
Background model in the $M(J/\psi K_S^0\pi^+)$ distribution	0.1
Background model in the $M(K_S^0\pi^+)$ distribution	1.2
Signal model in the $M(J/\psi\bar{\Lambda}p)$ distribution	0.9
Signal model in the $M(J/\psi K_S^0\pi^+)$ distribution	0.6
Simulated sample event count	1.7
Total systematic uncertainty	3.3

CMS-BPH-18-005, arXiv:1907.05461

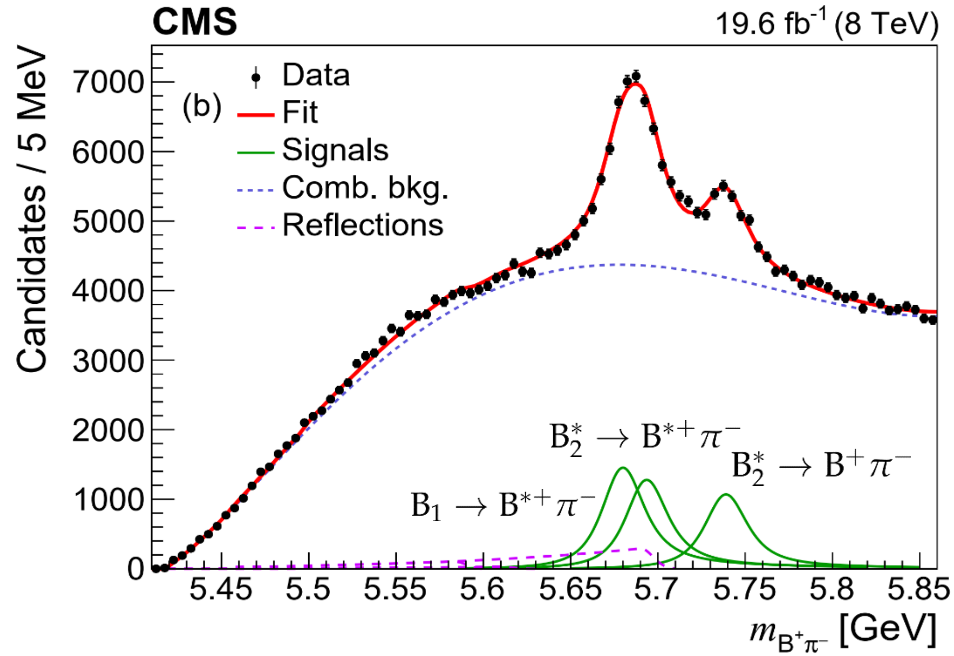
$B^+\pi^-$ invariant mass distribution

To obtain yields of these reflections,
we fit $B^+\pi^-$ invariant mass distribution:

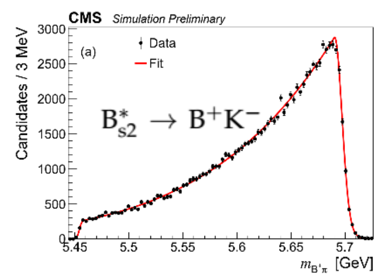
3 D-wave RBW functions convolved
with resolutions *(from MC)*

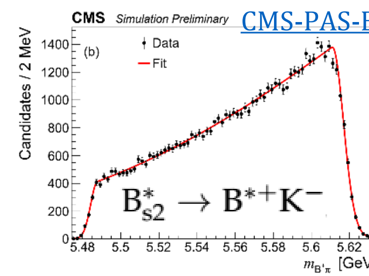
+ $(x-x_0)^a \bullet Pol_m(x)$ for background,
x_0 is threshold value, $Pol_m(x)$ is polynomial of degree m

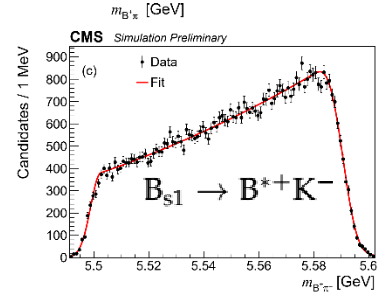
+ (small) contributions from $B^{(*)}_{s1,2}$



CMS-PAS-BPH-16-003







Shapes from simulation

In the baseline fit, masses and natural widths of excited B^0 states are fixed to PDG

The fit returns yields of about
8500, 10500 and 12000 events for the
$B_2^*\to B^+\pi^-$, $B_2^*\to B^{*+}\pi^-$, and $B_1^*\to B^+\pi^-$ decays,
respectively

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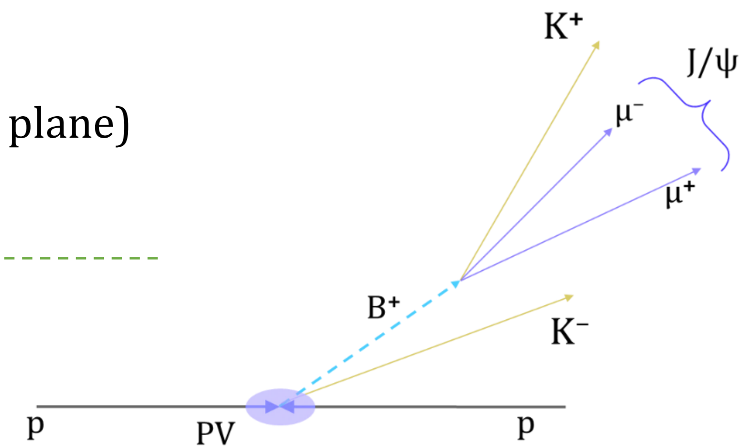
Data and event selection

Common selection for B^+ and B^0

2012 dataset (19.6 fb^{-1}), trigger optimized to select $B \to J/\psi$... decays
Muons matched to trigger; $p_T(\mu^\pm) > 3.5$ GeV/c, $|\eta(\mu^\pm)| < 2.2$
Standard CMS "high purity" tracks, $p_T > 1$ GeV

$P_{vtx}(B)$ > 1%
PV is chosen as the one with best pointing angle
L_{xy}/σ_{Lxy} (B) > 5.0
$\cos\alpha_{xy}$ >0.99 (B momentum points to PV in xy plane)
B mass in $\sim\pm 2\sigma_{eff}$ from PDG

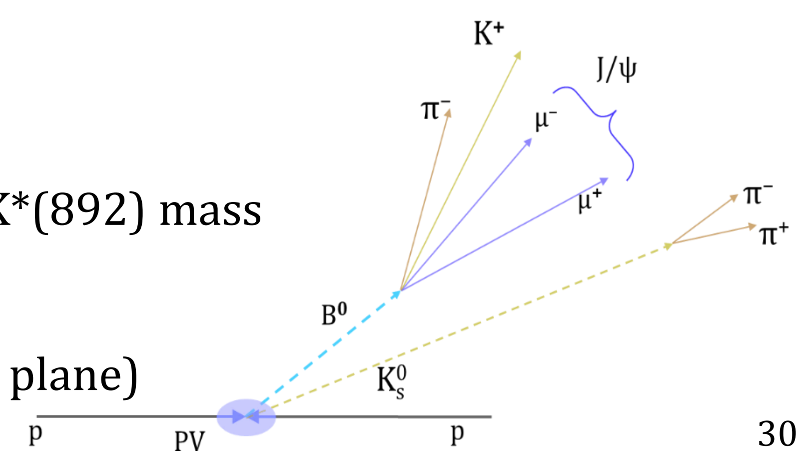


B^+K^- channel: K^- is chosen from PV track collection

$B^0K^0_S$ channel:

$M(K^+\pi^-)$ in ±90 MeV from K*(892) mass,
$M(K^+,K^-)$ > 1.035 GeV to cut out $B^0_s \to J/\psi\varphi$
K/π mass assignment: chose the candidate closer to K*(892) mass

K^0_S is build from displaced 2-prong vertices
$\cos\alpha_{xy}$ >0.999 (K^0_S momentum points to PV in xy plane)



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$B^{+}K^{-}$ signal extraction logic

Fit to $B^{*0} \to B^{+}\pi^{-}$ MC samples to obtain signal resolutions

Fit to $B_{s1,2}^{(*)} \to B^{+}K^{-}$ MC samples to obtain reflection shapes (if reconstructed as $B^{+}\pi^{-}$)

Fit to $B^{+}\pi^{-}$ invariant mass distribution in data, with signal resolutions from MC and fixed shapes of reflections from $B_{s1,2}^{(*)} \to B^{+}K^{-}$

Yields of $B^{*0} \to B^{+}\pi^{-}$ contributions

Fit to $B^{*0} \to B^{+}\pi^{-}$ MC samples to obtain reflection shapes (if reconstructed as $B^{+}K^{-}$)

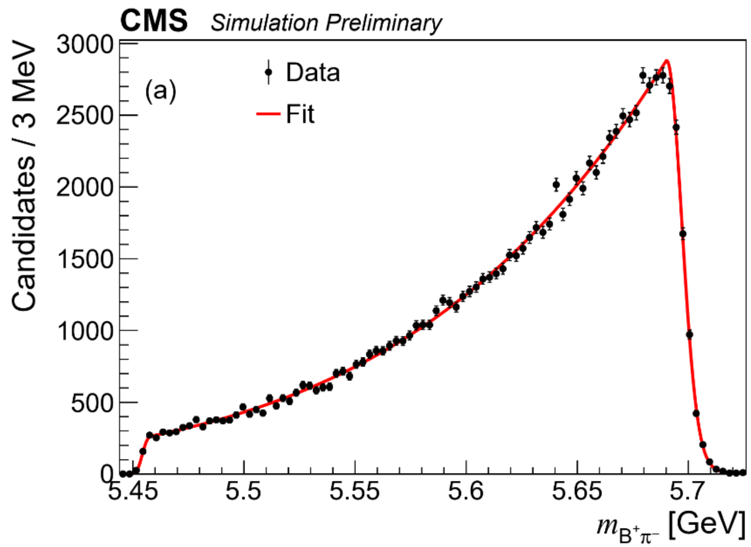
Fit to $B_{s1,2}^{(*)} \to B^{+}K^{-}$ MC samples to obtain signal resolutions

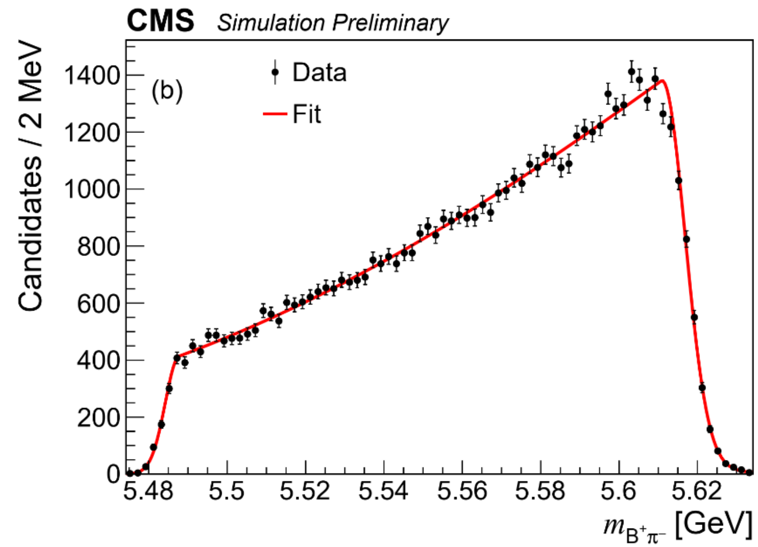
Fit to $B^{+}K^{-}$ distribution in data, with

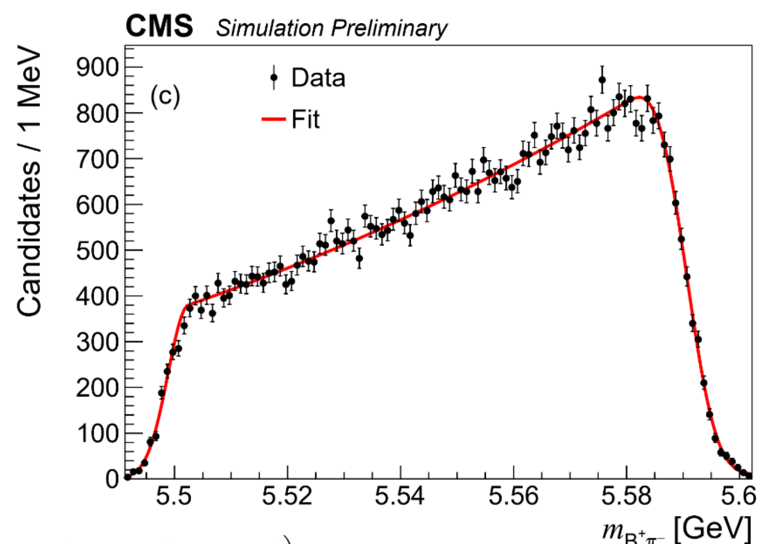
- reflections from B^{*0} shapes and yields fixed
- Signal resolutions fixed to MC

Signal yields, mass differences, Γ

The shapes of reflections from $B^0_{s1,2}$ decays in $B^+\pi^-$ invariant mass







Product of a Gaussian function and 1-sided Gaussian function

$$F(x;\ ...) = G_L(x; m_L, \sigma_L) * exp\left(-\frac{(x-m_c)^2}{2\sigma_c^2}\right) * \left((1-f)\, G_R(x; m_R, \sigma_{R1}) \ + f\, G_R(x; m_R, \sigma_{R2})\right)$$

$$\text{where } G_L(x; m, \sigma) = \begin{cases} exp(-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^{\lambda_L}) & \text{if } x \leqslant m \\ 1 & \text{if } x \geqslant m \end{cases}$$

$$\text{and } \quad G_R(x; m, \sigma) = \begin{cases} 1 & \text{if } x \leqslant m \\ exp(-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^{\lambda_R}) & \text{if } x \geqslant m \end{cases}$$

CMS-PAS-BPH-16-003

B^0 invariant mass distribution (MC)

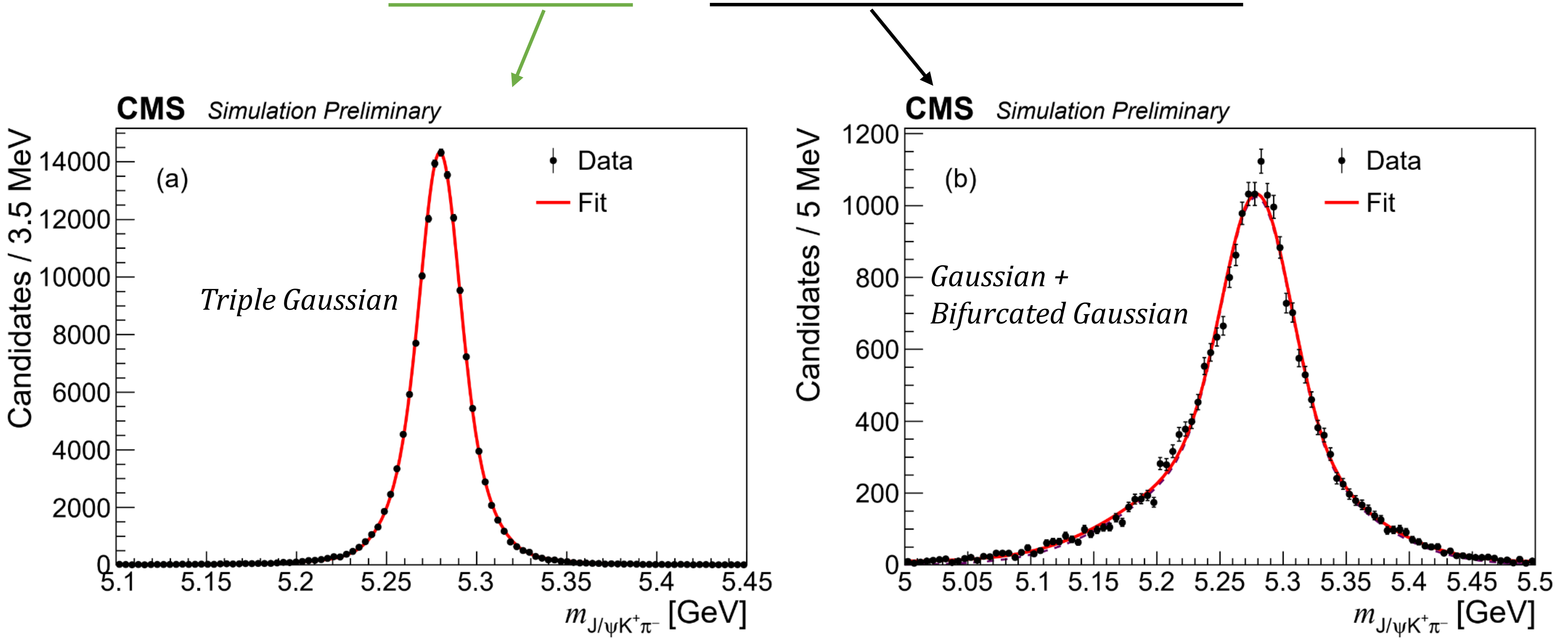
B^0 is reconstructed in the decay to $J/\psi K^+\pi^-$, where kaon and pion can be misidentified (swapped) in the reconstruction. The selection requirements are

$M(K^+\pi^-)$ in ±90 MeV from K(892) mass,*

$M(K^+,K^-) > 1.035$ GeV to cut out $B_s^0 \to J/\psi\varphi$, as in P5' analysis

K/π mass assignment: as in P5' , chose the candidate closer to K(892) mass*

We use MC to obtain the signal resolution and shape of K↔π swapped component:



B^0 invariant mass distribution

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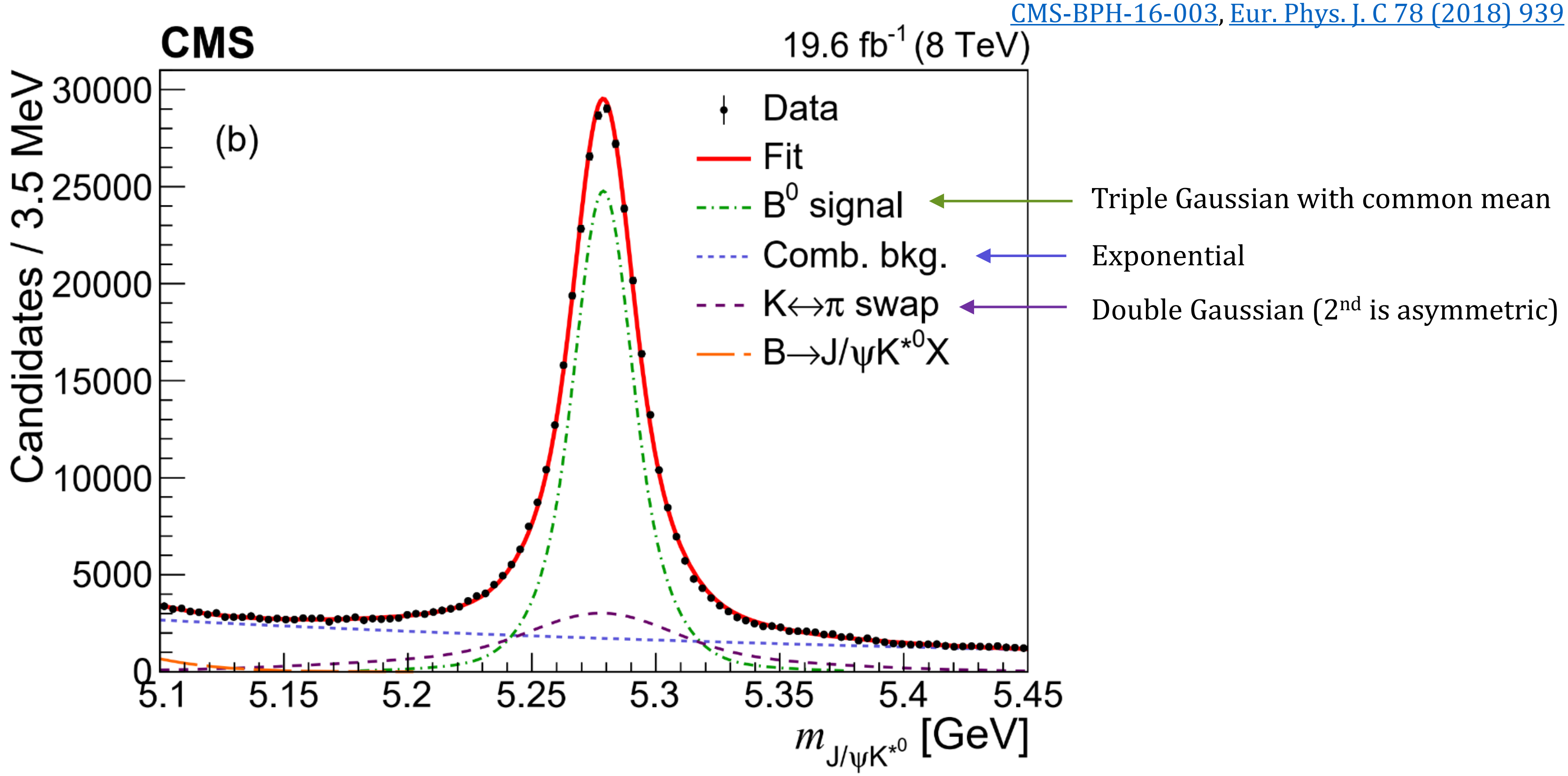

The resolution parameters and the shape of K↔π swapped component are fixed from simulation (see backup)

The B^0 signal region [5245, 5313] MeV includes ~220000 signal candidates and ~41000 K↔π swap candidates ⇒ “fraction of swapped component w.r.t. signal” = (18.9±0.3)%

Vary the signal resolution by + and – 3% (see B^+ fit) ⇒ variation of this fraction is (18.9±3.0)% (uncertainty will be considered as systematics source)

Systematic uncertainties in the branching fraction ratios

$$R_2^{0\pm} = \frac{\mathcal{B}(B_{s2}^* \to B^0 K_S^0)}{\mathcal{B}(B_{s2}^* \to B^+ K^-)}$$

$$R_1^{0\pm} = \frac{\mathcal{B}(B_{s1} \to B^{*0} K_S^0)}{\mathcal{B}(B_{s1} \to B^{*+} K^-)}$$

Source	Systematic uncertainty in % $R_2^{0\pm}$	$R_1^{0\pm}$
Track reconstruction efficiency	7.8	7.8
$m_{B^+\pi^-}$ distribution model	2.5	2.0
$m_{B^+K^-}$ distribution model	2.4	4.6
$m_{B^0K_S^0}$ distribution model	14	8.1
Mass resolution	0.7	2.2
Fraction of KPS	2.6	2.6
Non-K^{*0} contribution	5.0	5.0
Finite size of simulated samples	1.2	1.2
Total	18	14

$$R_{2*}^{\pm} = \frac{\mathcal{B}(B_{s2}^* \to B^{*+} K^-)}{\mathcal{B}(B_{s2}^* \to B^+ K^-)} \quad R_{2*}^{0} = \frac{\mathcal{B}(B_{s2}^* \to B^{*0} K_S^0)}{\mathcal{B}(B_{s2}^* \to B^0 K_S^0)}$$

$$R_{\sigma}^{\pm} = \frac{\sigma(pp \to B_{s1} \dots) \times \mathcal{B}(B_{s1} \to B^{*+} K^-)}{\sigma(pp \to B_{s2}^* \dots) \times \mathcal{B}(B_{s2}^* \to B^+ K^-)}$$

$$R_{\sigma}^{0} = \frac{\sigma(pp \to B_{s1} \dots) \times \mathcal{B}(B_{s1} \to B^{*0} K_S^0)}{\sigma(pp \to B_{s2}^* \dots) \times \mathcal{B}(B_{s2}^* \to B^0 K_S^0)}$$

Source	Systematic uncertainty in % $R_{2*}^{\pm}$	R_{2*}^{0}	$R_{\sigma}^{\pm}$	R_{σ}^{0}
$m_{B^+\pi^-}$ distribution model	2.9	—	2.7	—
$m_{B^+K^-}$ distribution model	17	—	7.1	—
$m_{B^0K_S^0}$ distribution model	—	13	—	24
Mass resolution	1.2	3.0	1.5	1.1
Uncertainties in $M_{B^*}^{PDG} - M_{B}^{PDG}$	7.7	4.8	—	—
Finite size of simulated samples	1.1	1.3	1.1	1.3
Total	19	15	7.8	24

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Systematic uncertainties

Four mass differences obtained from the fits

$$\Delta M^{\pm}_{B^*_{s2}} = M(B^*_{s2}) - M^{PDG}_{B^+} - M^{PDG}_{K^-}, \qquad \Delta M^{\pm}_{B_{s1}} = M(B_{s1}) - M^{PDG}_{B^{*+}} - M^{PDG}_{K^-}$$

$$\Delta M^{0}_{B^*_{s2}} = M(B^*_{s2}) - M^{PDG}_{B^0} - M^{PDG}_{K^0_S}, \qquad \Delta M^{0}_{B_{s1}} = M(B_{s1}) - M^{PDG}_{B^{*0}} - M^{PDG}_{K^0_S}$$

allow to measure the mass differences between neutral and charged $B^{(*)}$ mesons:

$$M_{B^0} - M_{B^+} = \Delta M^{\pm}_{B^*_{s2}} - \Delta M^{0}_{B^*_{s2}} + M^{PDG}_{K^-} - M^{PDG}_{K^0_S}$$

$$M_{B^{*0}} - M_{B^{*+}} = \Delta M^{\pm}_{B_{s1}} - \Delta M^{0}_{B_{s1}} + M^{PDG}_{K^-} - M^{PDG}_{K^0_S}$$

Additional systematic uncertainties are related to

> Shift from reconstruction: values obtained from the reconstructed MC differ a bit from those in the generation configuration. Our measurements are corrected by these shifts, and value of each shift is used as systematic uncertainty.

> Detector misalignment: 18 additional MC samples for each measurement are produced with differently distorted detector geometry, and maximum deviation from the case of no misalignment is taken as systematic uncertainty.

Source	$\Delta M^{\pm}_{B^*_{s2}}$	$\Delta M^{\pm}_{B_{s1}}$	$\Delta M^{0}_{B^*_{s2}}$	$\Delta M^{0}_{B_{s1}}$	$M_{B^0} - M_{B^+}$	$M_{B^{*0}} - M_{B^{*+}}$	$\Gamma_{B^*_{s2}}$
$m_{B^+\pi^-}$ distribution model	0.024	0.008	—	—	0.024	0.008	0.11
$m_{B^+K^-}$ distribution model	0.011	0.043	—	—	0.011	0.043	0.11
$m_{B^0K^0_S}$ distribution model	—	—	0.039	0.038	0.039	0.038	—
Uncertainties in $M^{PDG}_{B^*} - M^{PDG}_{B}$	0.012	0.003	0.003	0.0001	0.012	0.003	0.03
Shift from reconstruction	0.056	0.044	0.050	0.042	0.075	0.061	—
Detector misalignment	0.036	0.005	0.031	0.006	0.038	0.008	0.15
Mass resolution	0.007	0.005	0.005	0.005	0.009	0.007	0.20
Total	0.073	0.063	0.071	0.057	0.098	0.085	0.30

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Measured BF ratios

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$$R_2^{0\pm} = \frac{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)}{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} = \frac{N(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)}{N(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} \times \frac{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)}{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)} \times \frac{\mathcal{B}(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+)}{\mathcal{B}(\mathrm{B}^0 \to \mathrm{J}/\psi\mathrm{K}^{*0})\mathcal{B}(\mathrm{K}^{*0} \to \mathrm{K}^+\pi^-)\mathcal{B}(\mathrm{K}_S^0 \to \pi^+\pi^-)}$$

$$R_1^{0\pm} = \frac{\mathcal{B}(\mathrm{B}_{s1} \to \mathrm{B}^{*0}\mathrm{K}_S^0)}{\mathcal{B}(\mathrm{B}_{s1} \to \mathrm{B}^{*+}\mathrm{K}^-)} = \frac{N(\mathrm{B}_{s1} \to \mathrm{B}^{*0}\mathrm{K}_S^0)}{N(\mathrm{B}_{s1} \to \mathrm{B}^{*+}\mathrm{K}^-)} \times \frac{\epsilon(\mathrm{B}_{s1} \to \mathrm{B}^{*+}\mathrm{K}^-)}{\epsilon(\mathrm{B}_{s1} \to \mathrm{B}^{*0}\mathrm{K}_S^0)} \times \frac{\mathcal{B}(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+)}{\mathcal{B}(\mathrm{B}^0 \to \mathrm{J}/\psi\mathrm{K}^{*0})\mathcal{B}(\mathrm{K}^{*0} \to \mathrm{K}^+\pi^-)\mathcal{B}(\mathrm{K}_S^0 \to \pi^+\pi^-)},$$

$$R_{2*}^{\pm} = \frac{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^{*+}\mathrm{K}^-)}{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} = \frac{N(\mathrm{B}_{s2}^* \to \mathrm{B}^{*+}\mathrm{K}^-)}{N(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} \times \frac{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)}{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^{*+}\mathrm{K}^-)},$$

$$R_{2*}^{0} = \frac{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^{*0}\mathrm{K}_S^0)}{\mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)} = \frac{N(\mathrm{B}_{s2}^* \to \mathrm{B}^{*0}\mathrm{K}_S^0)}{N(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)} \times \frac{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)}{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^{*0}\mathrm{K}_S^0)},$$

$$R_{\sigma}^{\pm} = \frac{\sigma(\mathrm{pp} \to \mathrm{B}_{s1}\ldots) \times \mathcal{B}(\mathrm{B}_{s1} \to \mathrm{B}^{*+}\mathrm{K}^-)}{\sigma(\mathrm{pp} \to \mathrm{B}_{s2}^*\ldots) \times \mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} = \frac{N(\mathrm{B}_{s1} \to \mathrm{B}^{*+}\mathrm{K}^-)}{N(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)} \times \frac{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^+\mathrm{K}^-)}{\epsilon(\mathrm{B}_{s1} \to \mathrm{B}^{*+}\mathrm{K}^-)},$$

$$R_{\sigma}^{0} = \frac{\sigma(\mathrm{pp} \to \mathrm{B}_{s1}\ldots) \times \mathcal{B}(\mathrm{B}_{s1} \to \mathrm{B}^{*0}\mathrm{K}_S^0)}{\sigma(\mathrm{pp} \to \mathrm{B}_{s2}^*\ldots) \times \mathcal{B}(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)} = \frac{N(\mathrm{B}_{s1} \to \mathrm{B}^{*0}\mathrm{K}_S^0)}{N(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)} \times \frac{\epsilon(\mathrm{B}_{s2}^* \to \mathrm{B}^0\mathrm{K}_S^0)}{\epsilon(\mathrm{B}_{s1} \to \mathrm{B}^{*0}\mathrm{K}_S^0)},$$

Relative efficiencies

$$\frac{\epsilon(B_{s2}^{*} \to B^{+}K^{-})}{\epsilon(B_{s2}^{*} \to B^{0}K_{S}^{0})} = 15.77 \pm 0.18, \quad \frac{\epsilon(B_{s1} \to B^{*+}K^{-})}{\epsilon(B_{s1} \to B^{*0}K_{S}^{0})} = 16.33 \pm 0.20,$$

$$\frac{\epsilon(B_{s2}^{*} \to B^{+}K^{-})}{\epsilon(B_{s2}^{*} \to B^{*+}K^{-})} = 0.961 \pm 0.010, \quad \frac{\epsilon(B_{s2}^{*} \to B^{0}K_{S}^{0})}{\epsilon(B_{s2}^{*} \to B^{*0}K_{S}^{0})} = 0.970 \pm 0.012,$$

$$\frac{\epsilon(B_{s2}^{*} \to B^{+}K^{-})}{\epsilon(B_{s1} \to B^{*+}K^{-})} = 0.953 \pm 0.010, \quad \frac{\epsilon(B_{s2}^{*} \to B^{0}K_{S}^{0})}{\epsilon(B_{s1} \to B^{*0}K_{S}^{0})} = 0.987 \pm 0.012,$$

Their uncertainties are used as systematic uncertainties

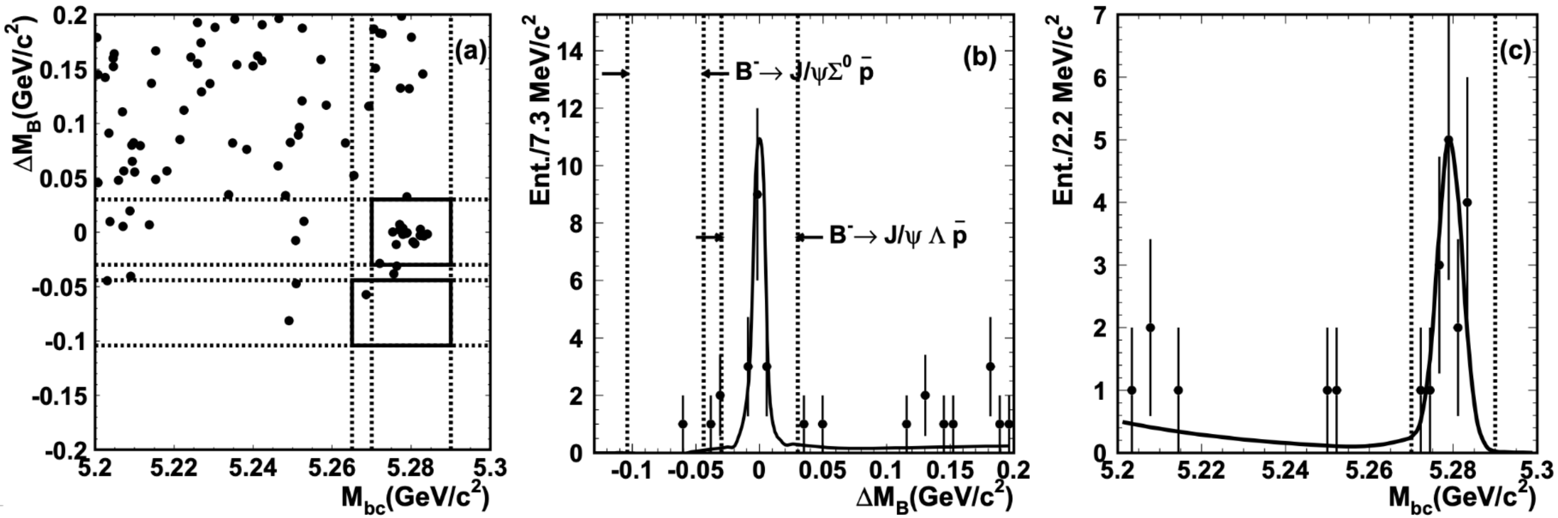
Previous results on P-wave B_s^0 states

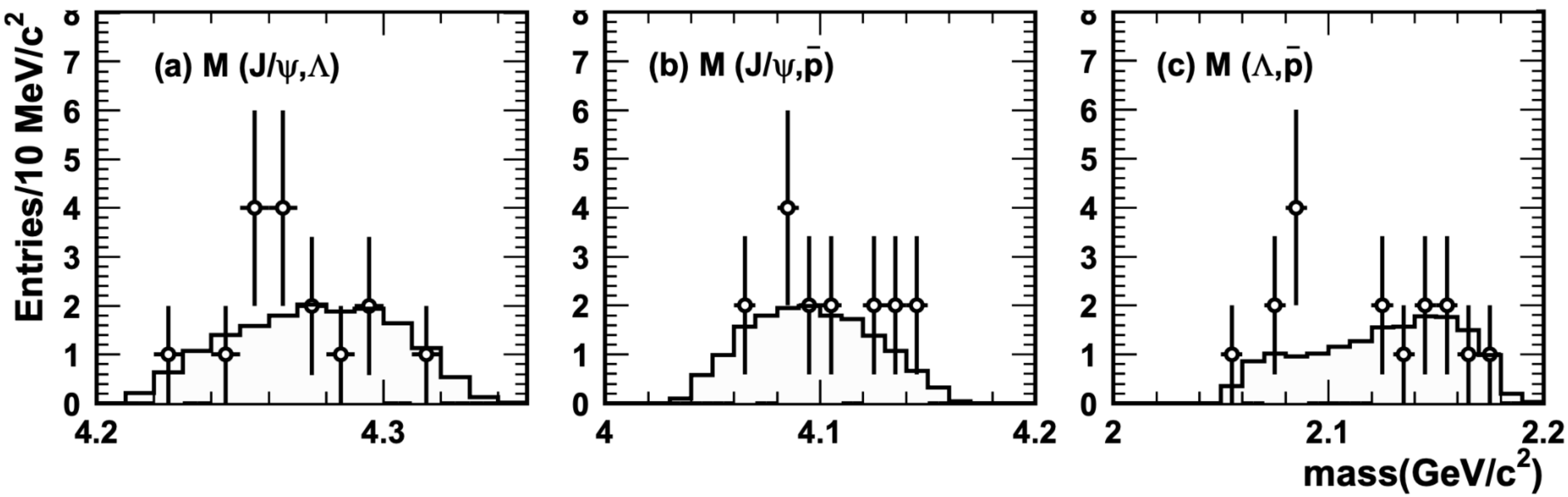
observed and studied only by CDF, D0, and LHCb, only in B^+K^- channel

Result	CDF 2008 [2]	D0 2008 [3]	LHCb 2013 [4]	CDF 2014 [5]
$N(B_{s2}^* \to B^+K^-)$	95 ± 23	125 ± 25	3140 ± 100	1110 ± 60
$N(B_{s2}^* \to B^{*+}K^-)$	–	–	307 ± 46	$?? \sim 100$
$N(B_{s1} \to B^{*+}K^-)$	39 ± 9	25 ± 10	750 ± 36	280 ± 40
$M(B_{s2}^*)$, MeV	5839.6 ± 0.7	5839.6 ± 1.3	5839.99 ± 0.21	5839.7 ± 0.2
$M(B_{s1})$, MeV	5829.4 ± 0.7	–	5828.40 ± 0.41	5828.3 ± 0.5
$M(B_{s2}^*) - M(B^+) - M(K^-)$, MeV	66.96 ± 0.41	66.7 ± 1.1	67.06 ± 0.12	66.73 ± 0.19
$M(B_{s1}) - M(B^{*+}) - M(K^-)$, MeV	10.73 ± 0.25	11.5 ± 1.4	10.46 ± 0.06	10.35 ± 0.19
$\Gamma(B_{s2}^*)$, MeV	–	–	1.56 ± 0.49	1.4 ± 0.4
$\Gamma(B_{s1})$, MeV	–	–	–	0.5 ± 0.4

Belle observation of the $B^+ \to J/\psi \bar{\Lambda} p$ decay

mode	Y	b	n_0	$\epsilon(\%)$	Y_{90}	$\mathcal{B}$
$B^- \to J/\psi \Lambda \bar{p}$	17.2 ± 4.1	0.41 ± 0.09(stat.)	16	$7.2^{+1.1}_{-1.4}$	–	$11.6 \pm 2.8(\text{stat.})^{+1.8}_{-2.3}(\text{sys.}) \times 10^{-6}$





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CMS experiment