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Search for QCD exotic states at CMS

Sergey Polikarpov[1,2]
on behalf of the CMS collaboration
[1]LPI RAS, [2]NRNU MEPhI

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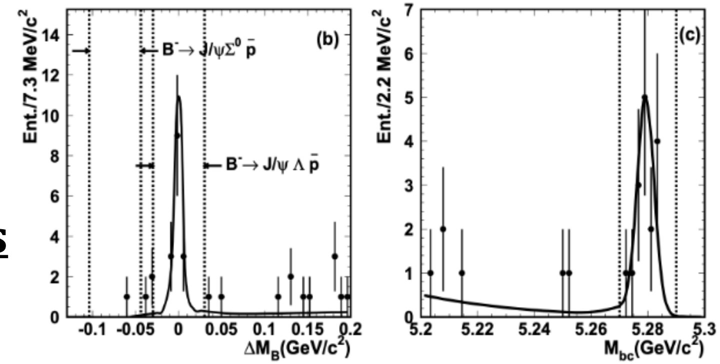
Outline

- Study of the $B^+ \to J/\psi \overline{\Lambda}$ p decay
- Search for exotic states decaying into $\Upsilon(1S)\mu^+\mu^-$
- Observation of the $B_s^0 \to X(3872)\varphi$ decay

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

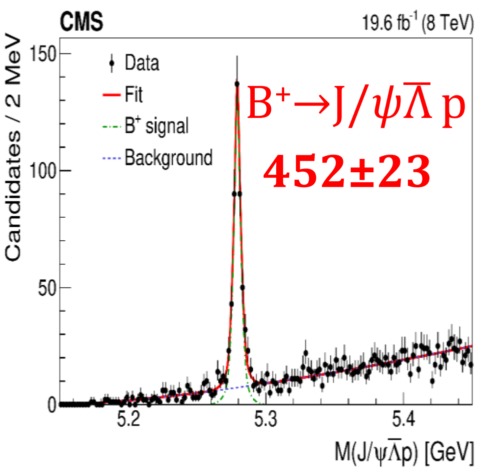
10.1103/PhysRevD.72.051105

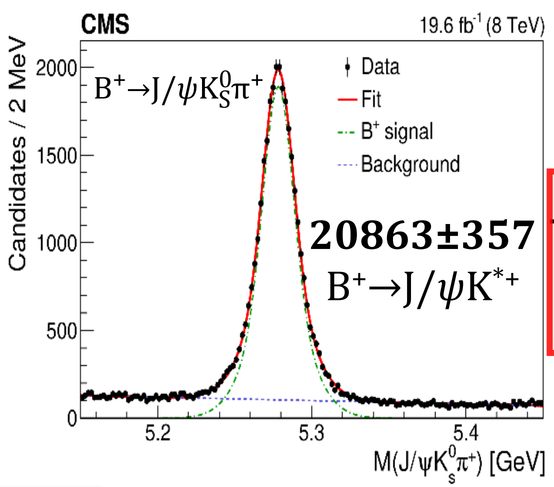


- Previously studied by Belle with 17 signal events
- **CMS: study using 8 TeV pp collision data (20 fb^{-1})**

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

- For the BF measurement, $B^+ \to J/\psi K^{*+}$, $K^{*+} \to K_S^0\pi^+$ channel is used as normalization
- Event selection:
  - $\bar{\Lambda} \to \bar{p}\pi^+$ candidates formed from displaced 2-prong vertices, $p_T(\bar{\Lambda}) > 1$ GeV
  - B^+ obtained by vtx fit $\mu^+\mu^-\bar{\Lambda}p$, with $M(\mu^+\mu^-)$ constrained to $m_{J/\psi}$, $p(\bar{\Lambda})$ points to B^+ vertex
  - B^+ vertex $L_{xy}/\sigma_{Lxy} > 3$, $\cos(B^+$ pointing angle$) > 0.99$, vtx fit probability > 1%





Dominant systematics: MC sample size and data/MC difference

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

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

most precise measurement

CMS-BPH-18-005, JHEP12(2019)100

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

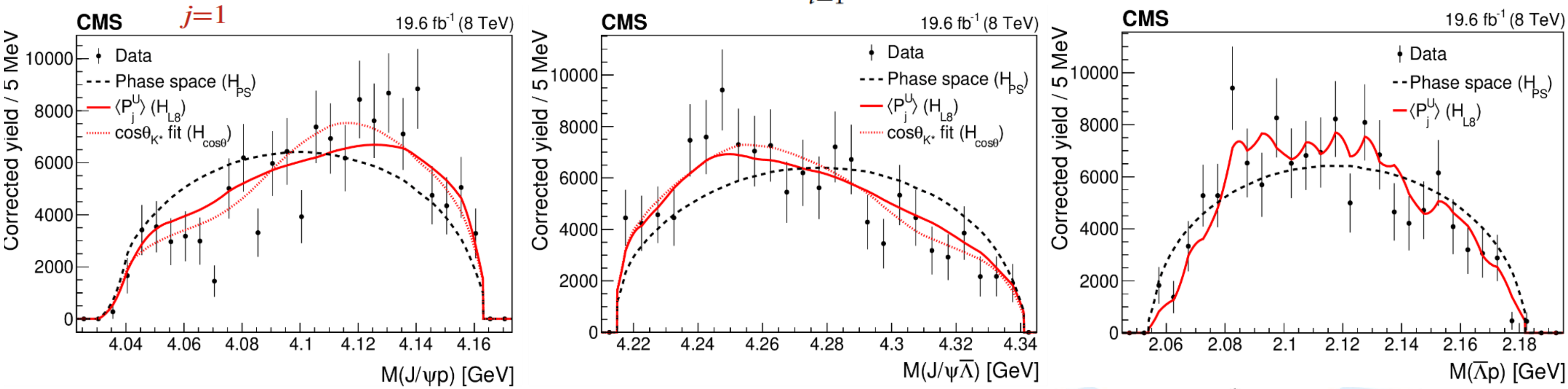
Introduced by BaBar [Phys.Rev.D79:112001 (2009)], used by LHCb [Phys.Rev.D.92:112009 (2015)]

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

Taken into account by reweighting 3-body phase-space MC

$$w^i = 1 + \sum_{j=1}^{l_{max}=8} \langle P_j^N \rangle P_j(\cos\theta^i_{K^*}) \qquad P_j^N = 2 \bullet \sum_{i=1}^{N_{reco}} \frac{P_j(\cos\theta_{K^*})}{\epsilon^i} / N^{reco}_{corr}$$

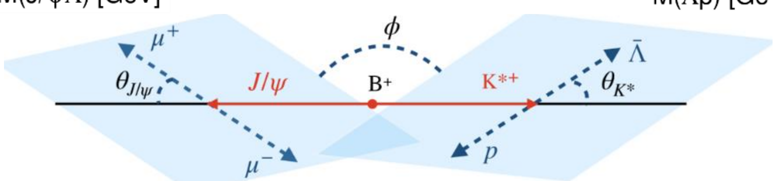
in each $M(\bar{\Lambda}p)$ bin



- - - 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: <u>no need for extra exotic states to describe the observed data</u>**

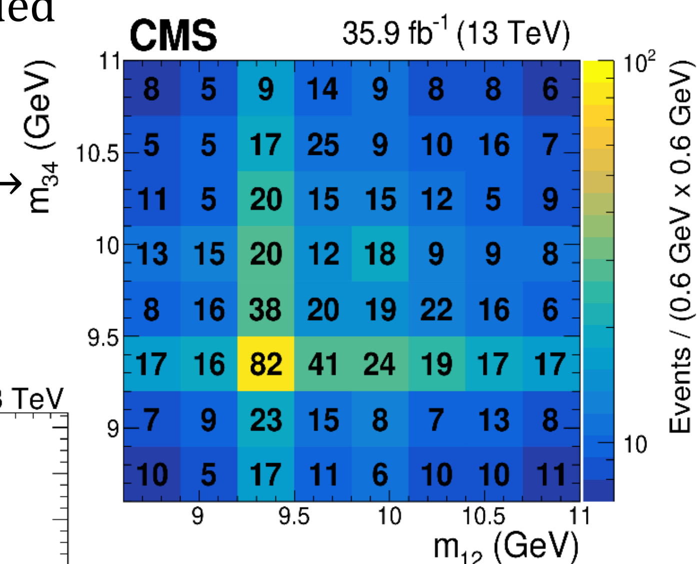
CMS-BPH-18-005, JHEP12(2019)100

Search for exotic states decaying into $\Upsilon(1S)\mu^+\mu^-$

$bb\bar{b}\bar{b}$ tetraquarks are predicted with mass close to twice the η_b or $\Upsilon(1S)$ mass
Such states would decay into $\Upsilon(1S)l^+l^-$
CMS performed a search in $\Upsilon(1S)\mu^+\mu^-$ decay channel, where $\Upsilon(1S)\to\mu^+\mu^-$
Analysis uses 2016 pp collision data (35.9 fb^{-1})

4μ events are selected with $p_T(\mu)$>2.5 GeV and $P_{vtx}(4\mu)$ > 5%
$M(\mu^+\mu^-)_1$ in $\pm 2\sigma$ from $\Upsilon(1S)$ mass
if any OS muons are compatible with J/ψ, event is discarded

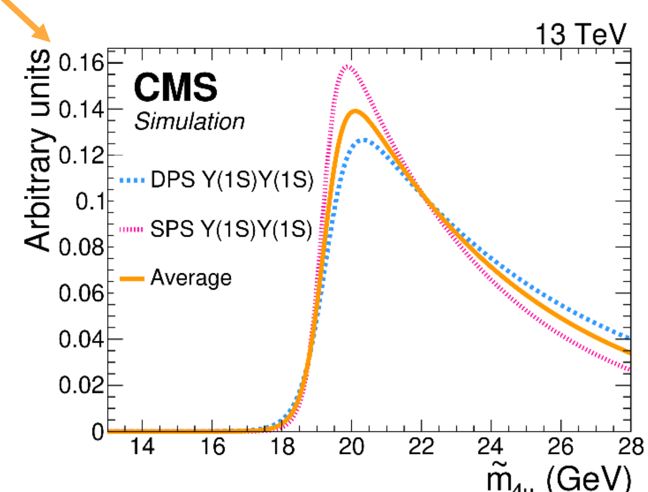
Double Υ production is a background source
Its yield estimated in data with 2D fit to dimuon masses →



The shape of $\Upsilon(1S)\Upsilon(1S)$ contribution in the $\Upsilon(1S)\mu^+\mu^-$ spectrum is estimated in MC

To improve the mass resolution, use the mass difference:

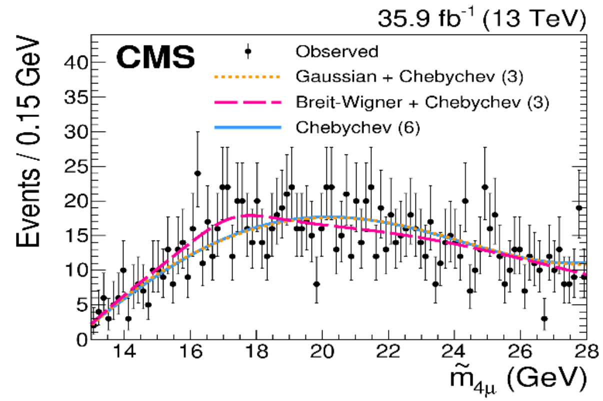
$$\widetilde{m}_{4\mu} = m_{4\mu} - m_{\mu\mu} + m_{\Upsilon(1S)}$$



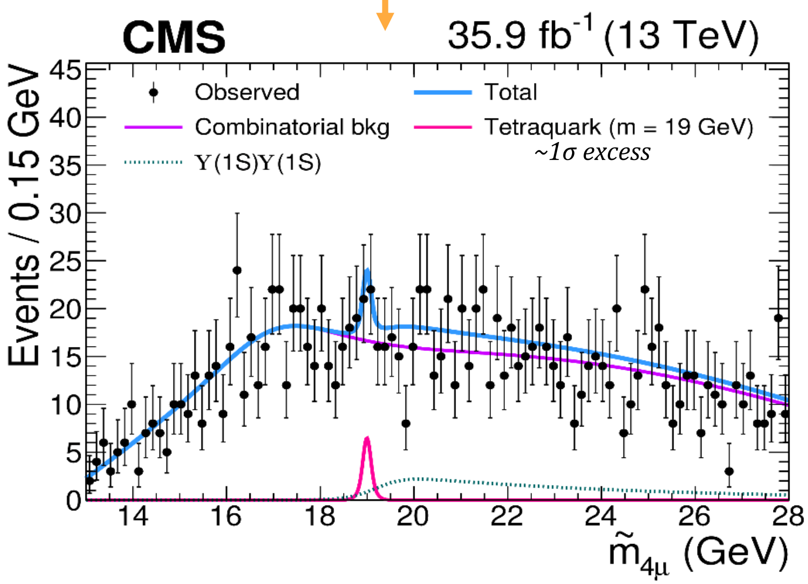
CMS-BPH-18-002, PLB808(2020)135578

Search for exotic states decaying into $\Upsilon(1S)\mu^+\mu^-$

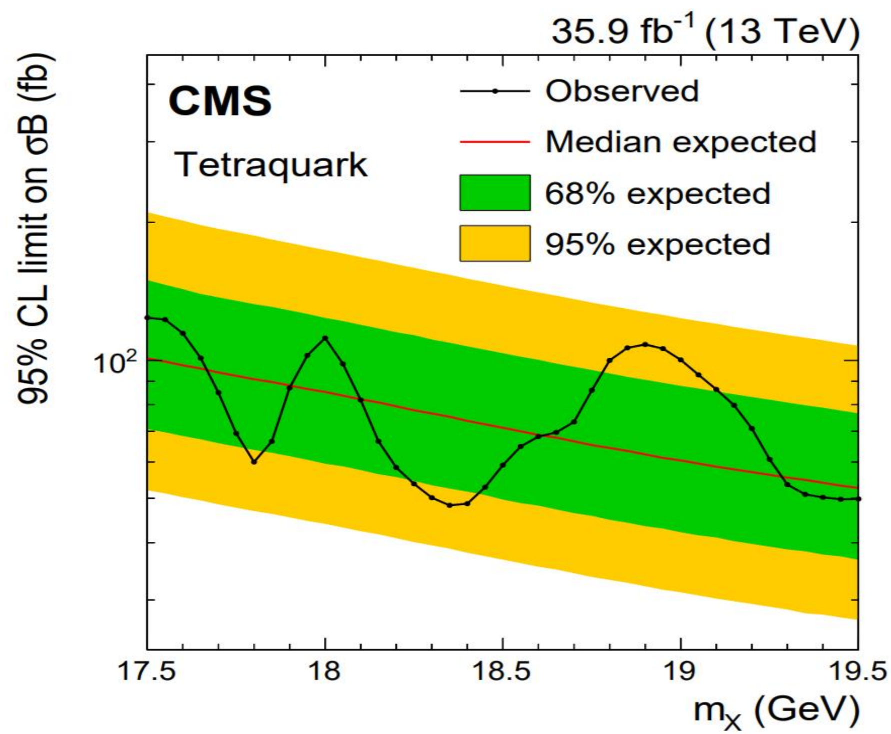
Background shape parametrization is defined using events with low 4μ vertex fit probability



Observed distribution does not show any unexpected peaks



Mass-dependent upper limit is set on $\sigma_{pp\to X}$ × $\mathcal{B}(X\to\Upsilon(1S)\mu\mu\to4\mu)$



Limits are also set in wider mass range for scalar, pseudoscalar and spin-2 states.

CMS-BPH-18-002, PLB808(2020)135578

More details in a talk by Sheila Silva Do

X(3872)

- X(3872) was observed in 2003 by Belle, but its nature is still unclear
- Mass is very close to $D^0\overline{D}^{*0}$ threshold, while the natural width $\Gamma \sim 0.5-1.5$ MeV
- $J^{PC} = 1^{++}$ corresponds to charmonium χ_{c1}, PDG calls it "χ_{c1}(3872), also known as X(3872)"
- The decay rate of X(3872) into $J/\psi\omega$ w.r.t $J/\psi\rho$ violate isospin
- Evidence for enhanced X(3872) production in PbPb collisions reported by CMS *(next slide)*
- Many theoretical interpretations exist, e.g. tetraquark, molecule, or mixture of those with a conventional charmonium state
- The X was never observed in B_s^0 decays, only from B^0, B^+ and Λ_b^0, and promptly so far
- Measurement of its production in B_s^0 decays helps understanding the properties of X(3872), in particular dynamics of its formation in B hadron decays
- We measure the ratio

$$R \equiv \frac{\mathcal{B}(B_s^0 \to X(3872)\phi)\,\mathcal{B}(X(3872) \to J/\psi\,\pi^+\pi^-)}{\mathcal{B}(B_s^0 \to \psi(2S)\phi)\,\mathcal{B}(\psi(2S) \to J/\psi\,\pi^+\pi^-)} = \frac{N(B_s^0 \to X(3872)\phi)}{N(B_s^0 \to \psi(2S)\phi)}\,\frac{\epsilon_{B_s^0 \to \psi(2S)\phi}}{\epsilon_{B_s^0 \to X(3872)\phi}}$$

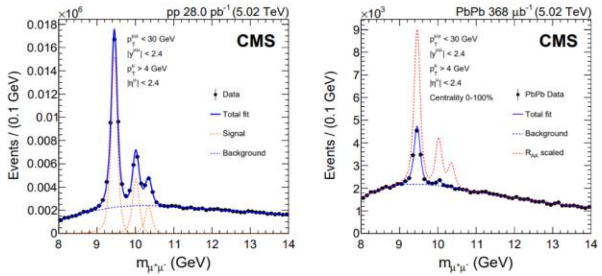
where $B_s^0 \to \psi(2S)\varphi$ decay with the same 2μ+4trk topology is used for the normalization, cancelling many systematic uncertainties

X(3872) production in PbPb

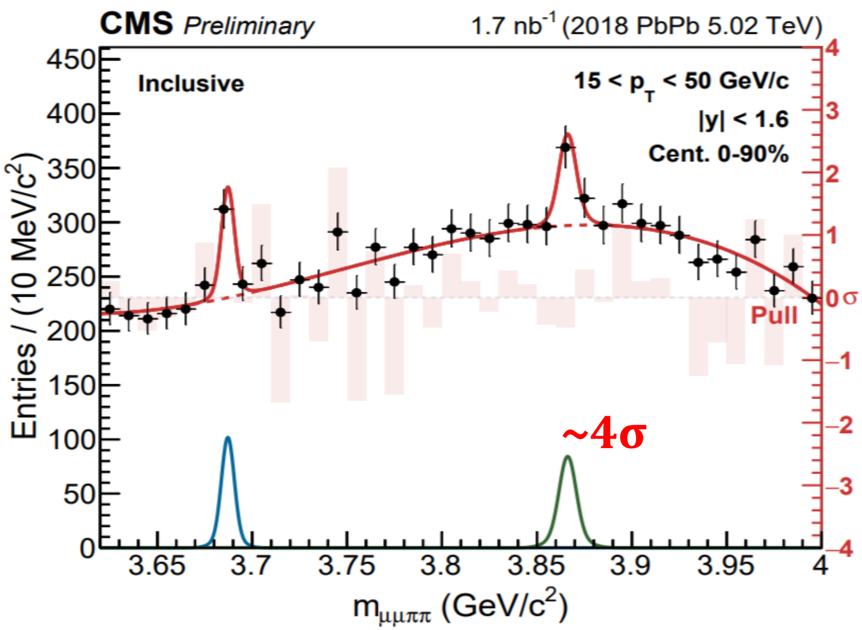
Excited states production is known to be suppressed in heavy ion collisions

$R_{AA}(\Upsilon(1S)) > R_{AA}(\Upsilon(2S)) > R_{AA}(\Upsilon(3S))$

CMS finds a **first evidence** for X(3872) production in PbPb collisions *CMS-PAS-HIN-19-005 (Preliminary)*



Phys. Lett. B 790 (2019) 270

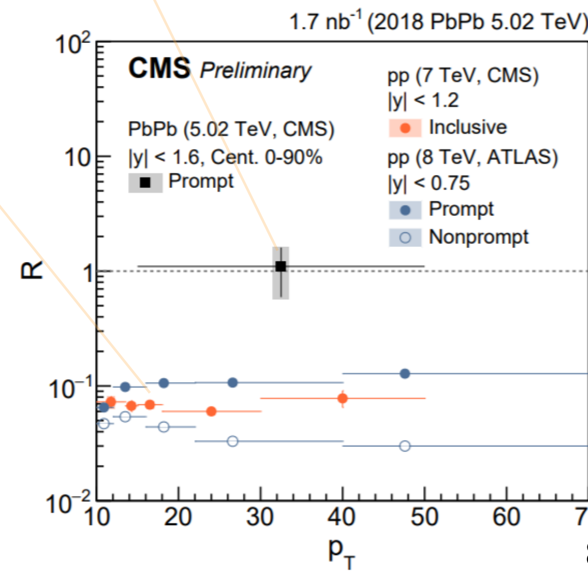


Ratio of efficiency-corrected yields $X/\psi(2S)$

after non-prompt subtraction

$\mathbf{R_{X/\psi} = 1.10 \pm 0.51 \pm 0.53}$

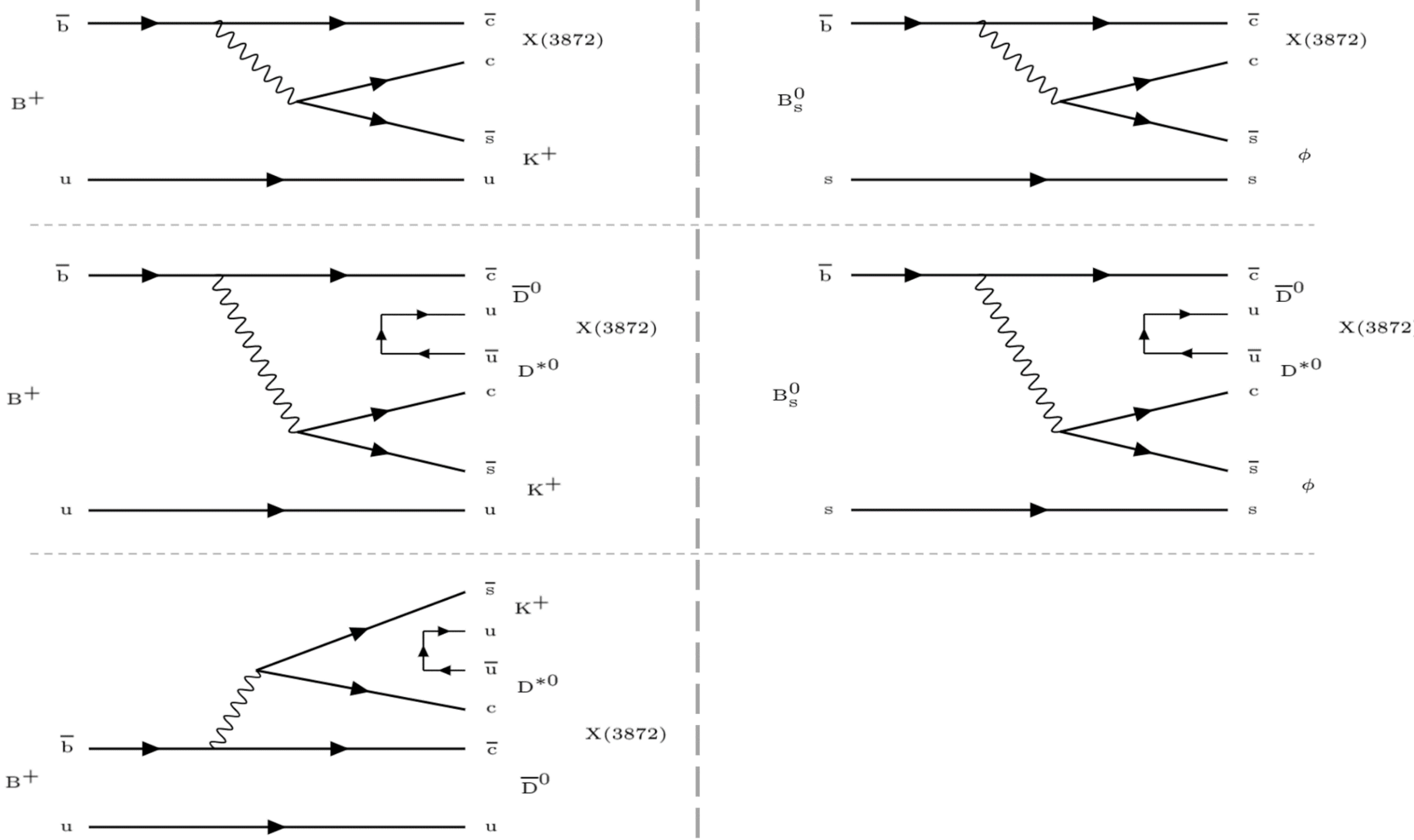
Same ratio in pp collisions is $\lesssim 0.1$



X(3872) production enhanced w.r.t. ψ(2S) in PbPb collisions, additional hint/constraint on X(3872) nature ?

X(3872) formation in b hadron decays

$B^+ \to X(3872)\,K^+$ | **$B^0_s \to X(3872)\varphi$**



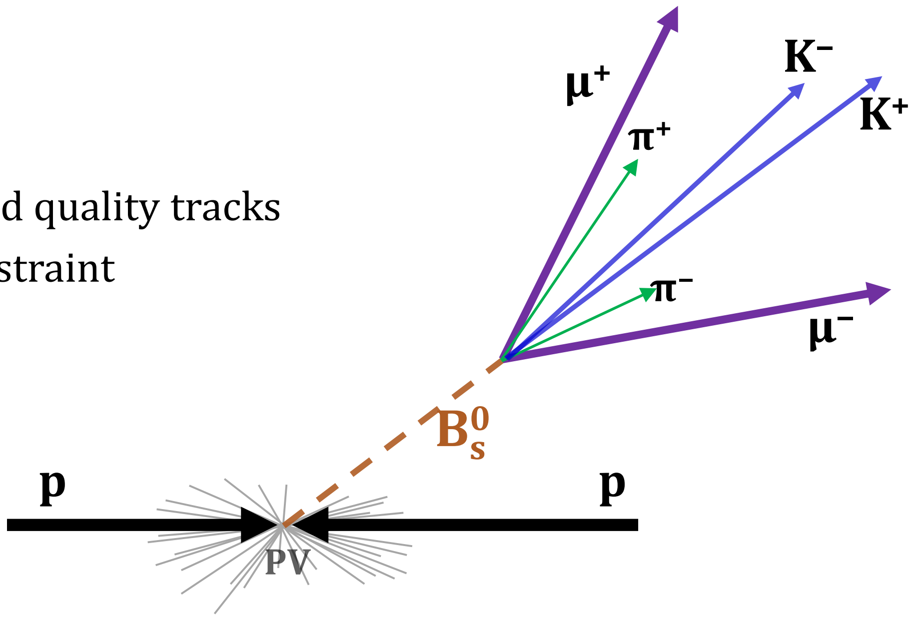
in case of B^+ there is additional contribution from DD^* rescattering (for molecular model)

Event selection

Charge-conjugate states are implied

Run-2 pp collision data set 2016-2018 (140 fb^{-1})

Selection optimized with Punzi figure of merit



$\mu^+\mu^-$ forming J/ψ and matching the trigger + 4 good quality tracks
→ fit B_s^0 candidate decay vertex with J/ψ mass constraint

B_s^0 vtx fit probability > 7%
$p_T(B_s^0)$ > 10 GeV
cos(2D B_s^0 pointing angle to PV) > 0.999
$L_{xy}/\sigma_{Lxy}(B_s^0$ vtx → PV) > 15

PV selected as the one with smallest pointing angle

tracks:
$p_T(K^\pm)$ > 2.2 and 1.5 GeV
$p_T(\pi^\pm)$ > 0.7 GeV

X(3872) channel: $M(\pi^+\pi^-)>0.7$ GeV
ψ(2S) channel: $M(\pi^+\pi^-)>0.45$ GeV

covers both X and $\psi(2S)\to J/\psi\pi\pi$

$M(J/\psi\pi^+\pi^-)$	in [3.60, 3.95] GeV	
$M(K^+K^-)$	in [1.00, 1.04] GeV	*(φ mass window)*
$M(J/\psi K^+K^-\pi^+\pi^-)$	in [5.32, 5.42] GeV	*(B_s^0 mass window)*

If the J/ψ+4trk passes these selections with any swapped mass assignments to kaons and pions, it is discarded

CMS-BPH-17-005, arXiv:2005.04764

Signal extraction: $\psi(2S)$ normalization channel

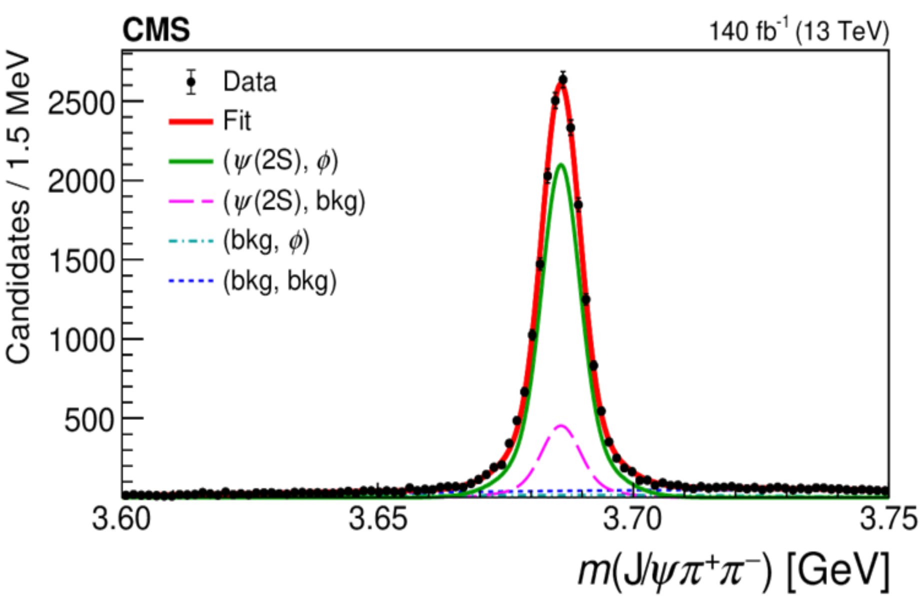
+ Signal x Signal
+ Signal x Background
+ Background x signal
+ Background x background

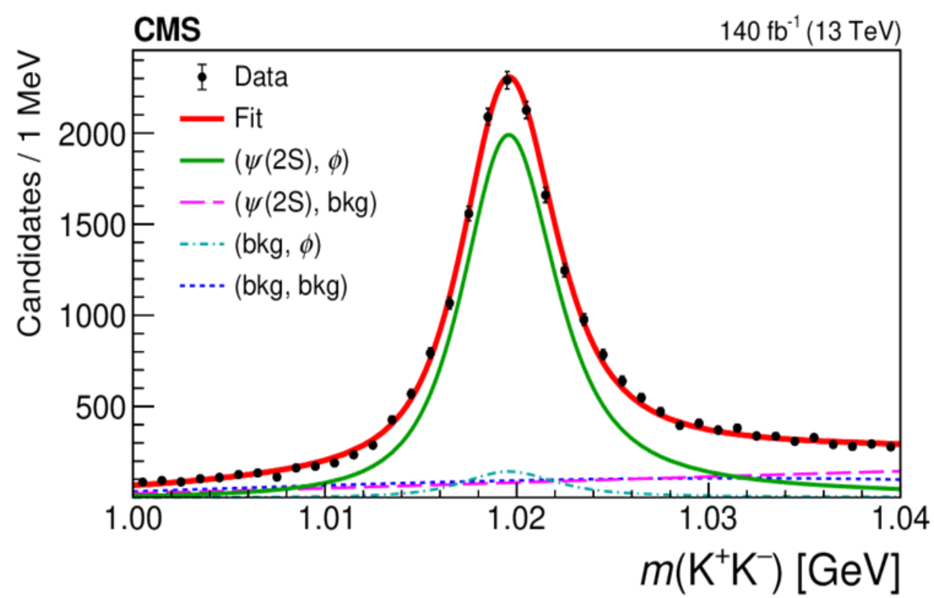
2D fit to $M(J/\psi\pi^+\pi^-)$: $M(K^+K^-)$

Each component factorized into a product of two one-dimensional pdfs

- $\psi(2S)$ signal: Double-Gaussian with common mean
- $\psi(2S)$ background: $(y-y_0)^\beta \bullet Pol_1(y)$
- φ signal: RBW convolved with DG resolution
- φ background: $(x-x_0)^\alpha \bullet Pol_1(x)$

CMS-BPH-17-005, arXiv:2005.04764



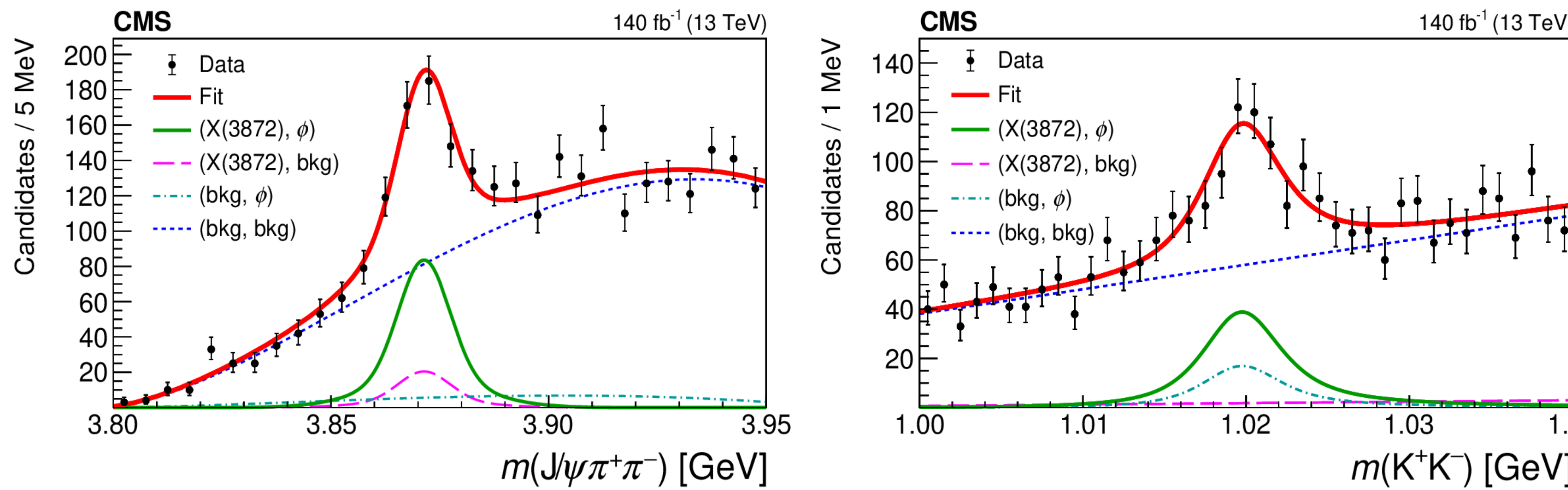


Signal yield $\psi(2S)$ x φ : **15359±171 = $N(B_s^0 \to \psi(2S)\varphi)$** *neglecting non-$B_s^0$ background*

Signal extraction: signal X(3872) channel

For the X mass region, use similar 2D fit, with fixed X(3872) signal shape, leaving free to float only a resolution scaling factor

CMS-BPH-17-005, arXiv:2005.04764



Signal yield X(3872) **x** φ : **299±39 = N(B^0_s→X(3872)φ)** *neglecting non-B^0_s background*

Statistical significance of Xφ signal:

7.2σ → First Observation of B^0_s→X(3872)φ decay

*varies in the range **6.5-8.0σ** under systematic uncertainty studies*

Ratio of efficiencies for calculation of ratio *R* : $\frac{\epsilon_{B^0_s \to \psi(2S)\phi}}{\epsilon_{B^0_s \to X(3872)\phi}} = 1.136 \pm 0.026$

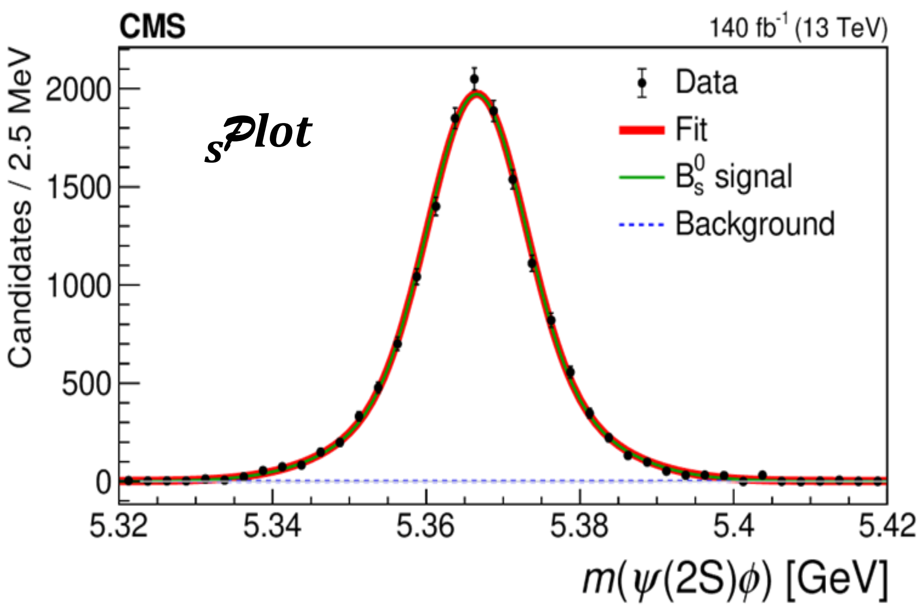
Background-subtracted $M(B_s^0)$

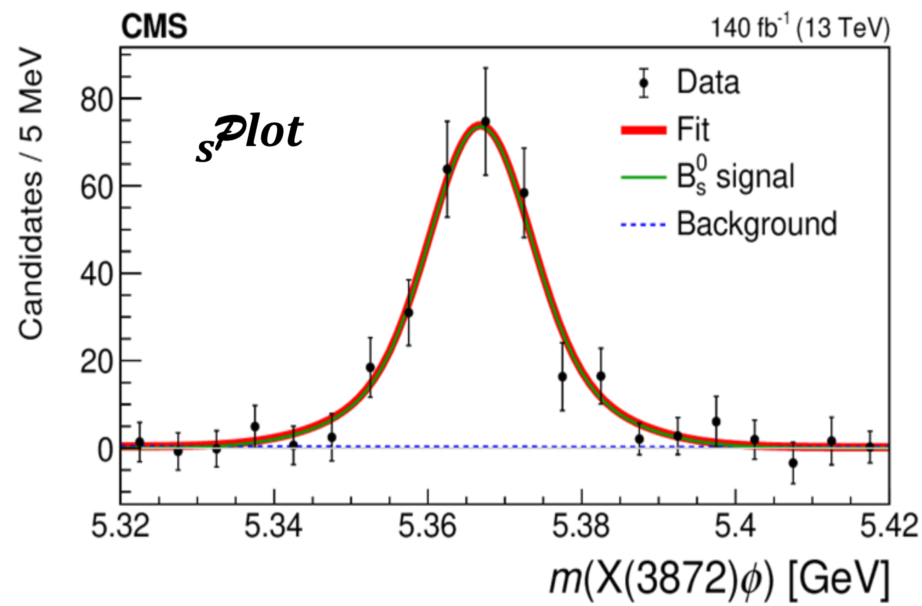
sPlot is used to subtract non-resonant $J/\psi\pi^+\pi^-$ and K^+K^- combinations

The mass variable $M(B_s^0) = M(J/\psi\pi^+\pi^-K^+K^-) - M(J/\psi\pi^+\pi^-) + M^{PDG}(X/\psi(2S))$
slightly improves the mass resolution and removes correlation between $M(B_s^0)$ and $M(J/\psi\pi^+\pi^-)$

Cross-check to ensure that non-B_s^0 background can be neglected

CMS-BPH-17-005,
arXiv:2005.04764





Bkg fraction: **0.5%** **1.7%**

$N(B_s^0 \to X\varphi) / N(B_s^0 \to \psi(2S)\varphi)$ changes by 1.2% after removing non-B_s^0 background

Use as systematic uncertainty

Systematic uncertainties

Uncertainties in $\frac{N(\mathrm{B_s^0} \to X(3872)\phi)}{N(\mathrm{B_s^0} \to \psi(2S)\phi)} \frac{\epsilon_{\mathrm{B_s^0} \to \psi(2S)\phi}}{\epsilon_{\mathrm{B_s^0} \to X(3872)\phi}}$

Source	Uncertainty (%)
$m(\mathrm{K^+K^-})$ signal model	< 0.1
$m(\mathrm{K^+K^-})$ background model	2.5
$m(\mathrm{J}/\psi\,\pi^+\pi^-)$ signal model	5.3
$m(\mathrm{J}/\psi\,\pi^+\pi^-)$ background model	4.3
Non-$\mathrm{B_s^0}$ background	1.2
Simulated sample size	2.2
Total	7.7

CMS-BPH-17-005, arXiv:2005.04764

Results

CMS-BPH-17-005, arXiv:2005.04764

Observation of the $B_s^0 \to X(3872)\varphi$ decay and measurement of the ratio

$$R \equiv \frac{\mathcal{B}(B_s^0 \to X(3872)\phi) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B_s^0 \to \psi(2S)\phi) \times \mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)} = (2.21 \pm 0.29\,(\text{stat}) \pm 0.17\,(\text{syst}))\%$$

Putting in the known denominator branching fractions

$$\mathcal{B}(B_s^0 \to X\phi) \times \mathcal{B}(X \to J/\psi\pi^+\pi^-) = (4.14 \pm 0.54\,(\text{stat}) \pm 0.32\,(\text{syst}) \pm 0.46(\mathcal{B})) \times 10^{-6}$$

Product of $B \to Xh$ **×** $X \to J/\psi\pi\pi$ branching fractions for different B hadrons is (in 10^{-6})

- **8.6±0.8** for $B^+ \to X K^+$
- **4.3±1.3** for $B^0 \to X K^0$
- **4.0±1.5** for $B^0 \to X K^*(892)^0$

4.14±0.78 for $B_s^0 \to X\varphi$ (our measurement)

Using the first of these measurements one gets the ratio

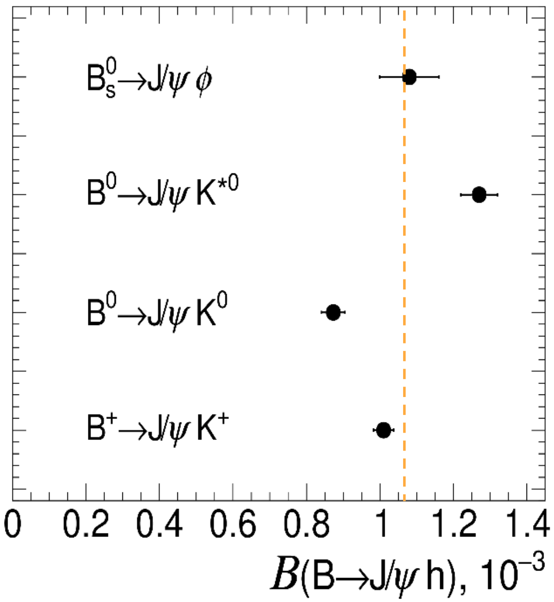
$$\frac{\mathcal{B}(B_s^0 \to X(3872)\phi)}{\mathcal{B}(B^+ \to X(3872)K^+)} = 0.482 \pm 0.063\,(\text{stat}) \pm 0.037\,(\text{syst}) \pm 0.070(\mathcal{B})$$

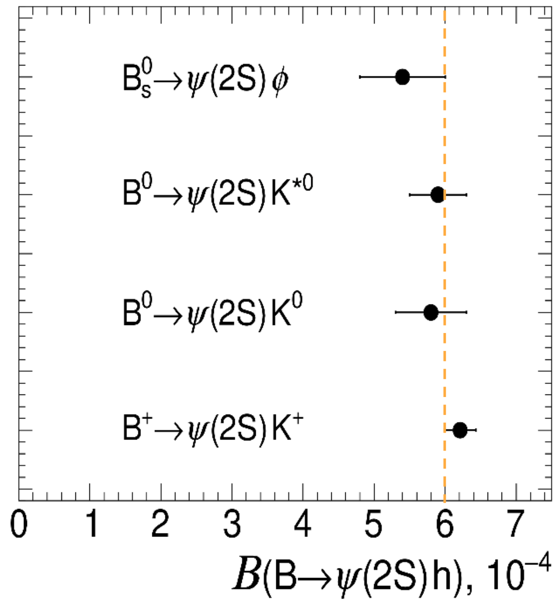
If the difference was only in spectator quark, the ratio would be ≈ 1

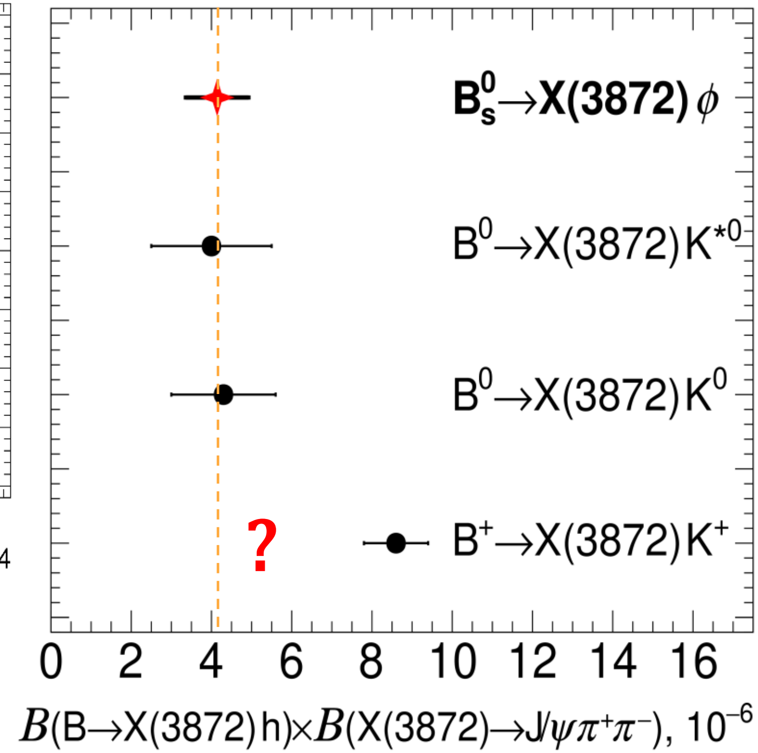
$$\frac{\mathcal{B}(B_s^0 \to \psi(2S)\phi)}{\mathcal{B}(B^+ \to \psi(2S)K^+)} = 0.87 \pm 0.10$$

Comparison to other measurements

CMS-BPH-17-005, arXiv:2005.04764







(see also slide 9)

$\mathcal{B}(B^+ \to \mathbf{J/\psi} K^+)$, $\mathcal{B}(B^0 \to \mathbf{J/\psi} K^0)$, and $\mathcal{B}(B^0 \to \mathbf{J/\psi} K^{*0})$ are close (in ±20%)
$\mathcal{B}(B^+ \to \boldsymbol{\psi(2S)} K^+)$, $\mathcal{B}(B^0 \to \boldsymbol{\psi(2S)} K^0)$, and $\mathcal{B}(B^0 \to \boldsymbol{\psi(2S)} K^{*0})$ are consistent (in ±20%)

while

$\mathcal{B}(B^+ \to X(3872) K^+)$ is ~2 times larger than $\mathcal{B}(B^0 \to \mathbf{X(3872)} K^0)$ and $\mathcal{B}(B^0 \to \mathbf{X(3872)} K^{*0})$

Theoretical paper "The X(3872) tetraquarks in B and B_s decays" [arXiv:2005.08764 by L.Maiani, A.D.Polosa, and V.Riquer] **explains** the discussed ratios of branching fractions **in tetraquark model of X(3872)**

Summary

- **The $B^+ \to J/\psi \bar{\Lambda} p$ decay was measured** CMS-BPH-18-005, JHEP12(2019)100
  - Data are consistent with no exotic resonances decaying to $J/\psi \bar{\Lambda}$ or $J/\psi p$

- **Exotic states decaying into $\Upsilon(1S)\mu^+\mu^-$ were searched for** CMS-BPH-18-002, PLB808(2020)135578

  No significant signal observed, mass-dependent UL set

- **The $B^0_s \to X(3872)\varphi$ decay was observed** CMS-BPH-17-005, arXiv:2005.04764

  Measured branching fraction is similar to B^0, twice smaller than that of B^+

$$\frac{\mathcal{B}(B^0_s \to X(3872)\phi)}{\mathcal{B}(B^+ \to X(3872)K^+)} = 0.482 \pm 0.063\,(\text{stat}) \pm 0.037\,(\text{syst}) \pm 0.070\,(\mathcal{B})$$

  indicating different production dynamics of X(3872) in B^+ and $B^0_{(s)}$ decays

CMS experiment provides new results in spectroscopy and properties of exotic hadrons, stay tuned for more !

Thank you !

BACKUP

CMS-BPH-17-005

Event selection

Charge-conjugate states are implied

Full Run-2 Charmonim data set (140 fb^{-1})

Optimized cuts with Punzi figure of merit

$\mu^+\mu^-$ forming J/ψ and matching the JpsiTrk_Displaced trigger

4 additional high-purity tracks

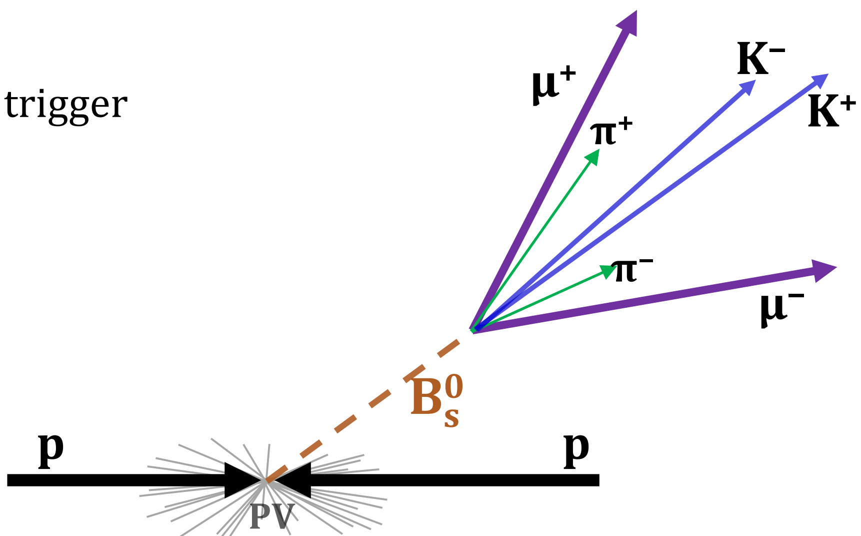
Fit B_s^0 vertex with J/ψ mass constraint

B_s^0 vtx fit probability > 7%

$p_T(B_s^0) > 10$ GeV

cos(2D B_s^0 pointing angle to PV) > 0.999

$L_{xy}/\sigma_{Lxy}(B_s^0 \text{ vtx} \to PV) > 15$



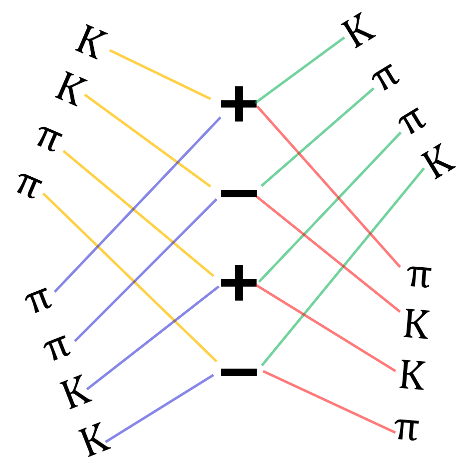
PV selected as the one with smallest pointing angle

Selection of tracks:

$p_T(K^\pm) > 1.5$ and 2.2 GeV

$p_T(\pi^\pm) > 0.7$ GeV

- $M(J/\psi\pi^+\pi^-)$ in [3.60, 3.95] GeV
- $M(K^+K^-)$ in [1.00, 1.04] GeV
- $M(J/\psi K^+K^-\pi^+\pi^-)$ in [5.32, 5.42] GeV
- *If the J/ψ+4trk passes these selections with any swapped mass assignments to kaons and pions, it is discarded*



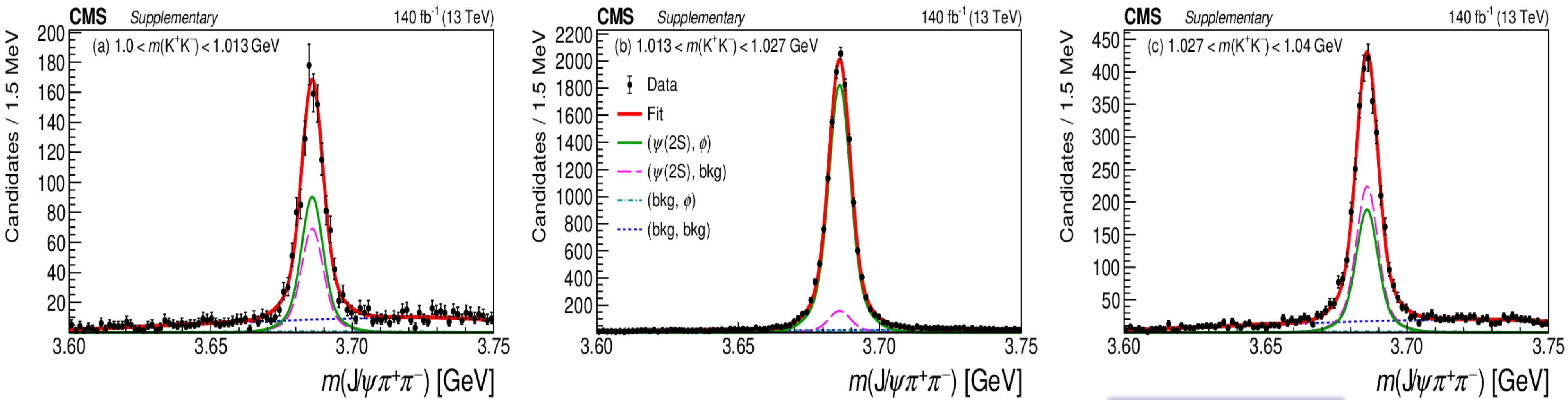
Efficiency of this selection is >99%

For X channel: additional cut $M(\pi^+\pi^-)$>0.7 GeV

For $\psi(2S)$ channel: additional cut $M(\pi^+\pi^-)$>0.45 GeV

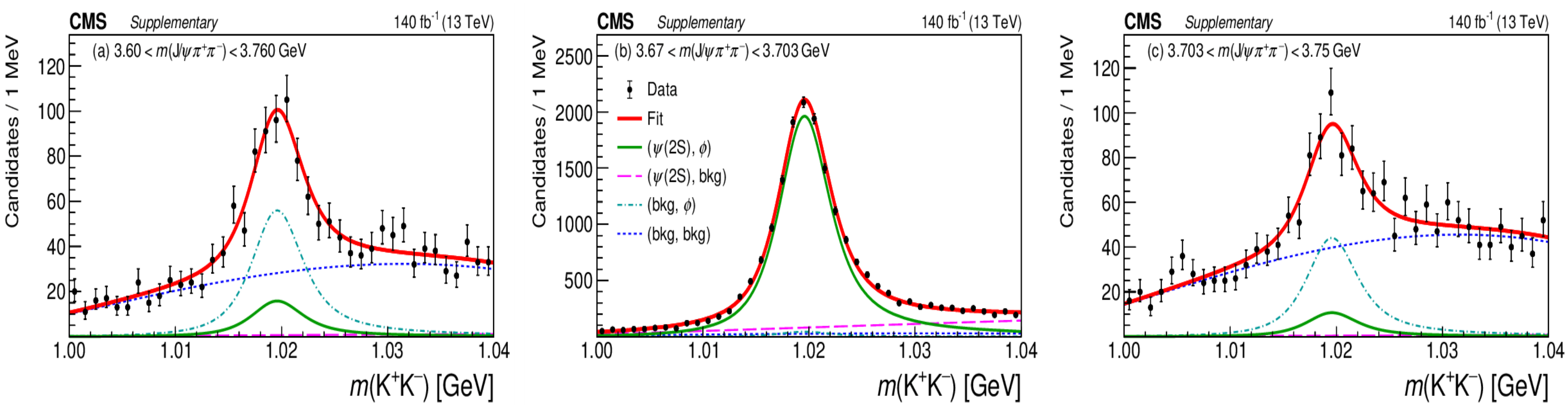
Fit projections in ranges of the other variable

M(J/$\psi\pi^+\pi^-$) in ranges of M(K^+K^-): left sideband, signal region, right sideband



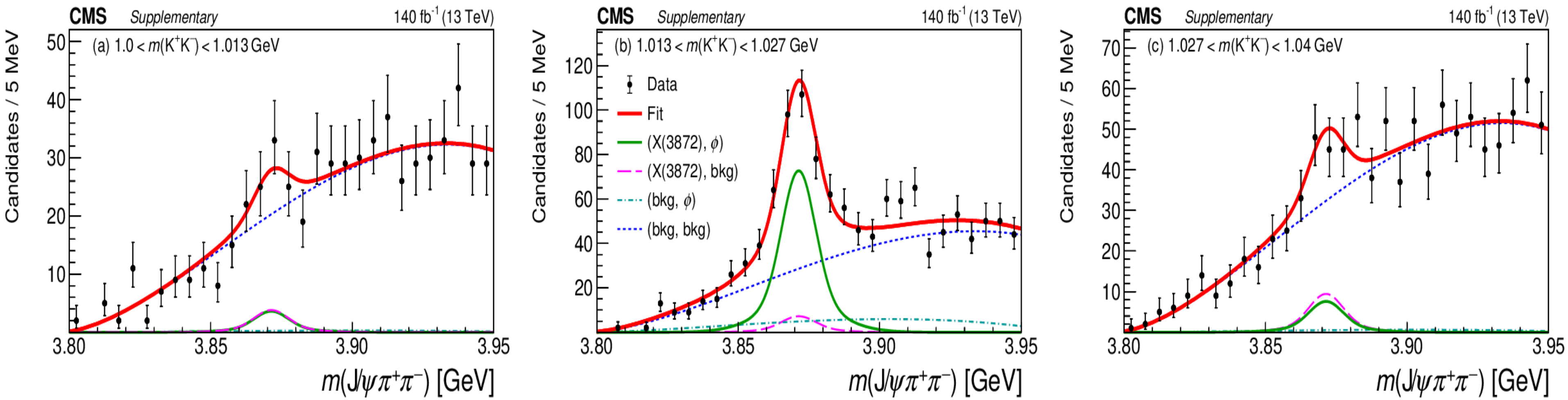
CMS-BPH-17-005

M(K^+K^-) in ranges of M(J/$\psi\pi^+\pi^-$): left sideband, signal region, right sideband



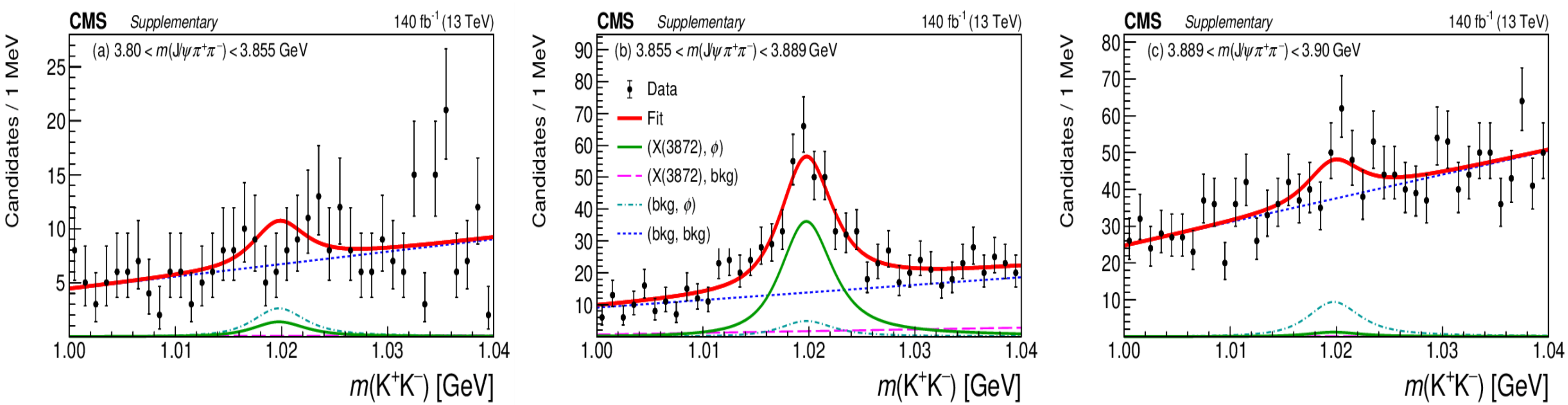
Fit projections in ranges of the other variable

M(J/$\psi\pi^+\pi^-$) in ranges of M(K^+K^-): left sideband, signal region, right sideband



CMS-BPH-17-005

M(K^+K^-) in ranges of M(J/$\psi\pi^+\pi^-$): left sideband, signal region, right sideband



Systematic uncertainties

1. Uncertainties related to the fit model choice evaluated by changing *(simultaneously for X and ψ channels, where possible)* the fit model, repeating the 2DFit and calculating the largest deviation in X/ψ(2S) ratio

Alternative models:

- For φ signal, vary Γ by + and − its PDG uncertainty
- For φ signal, vary resolution by + and − its uncertainty from MC

- For φ bkg, **change $(x-x_0)^{\alpha}\bullet Pol_1(x)$ into $Pol_2(x)$**
- For φ bkg, force shapes of bkg-bkg and ψ(2S)/X-bkg to be equal

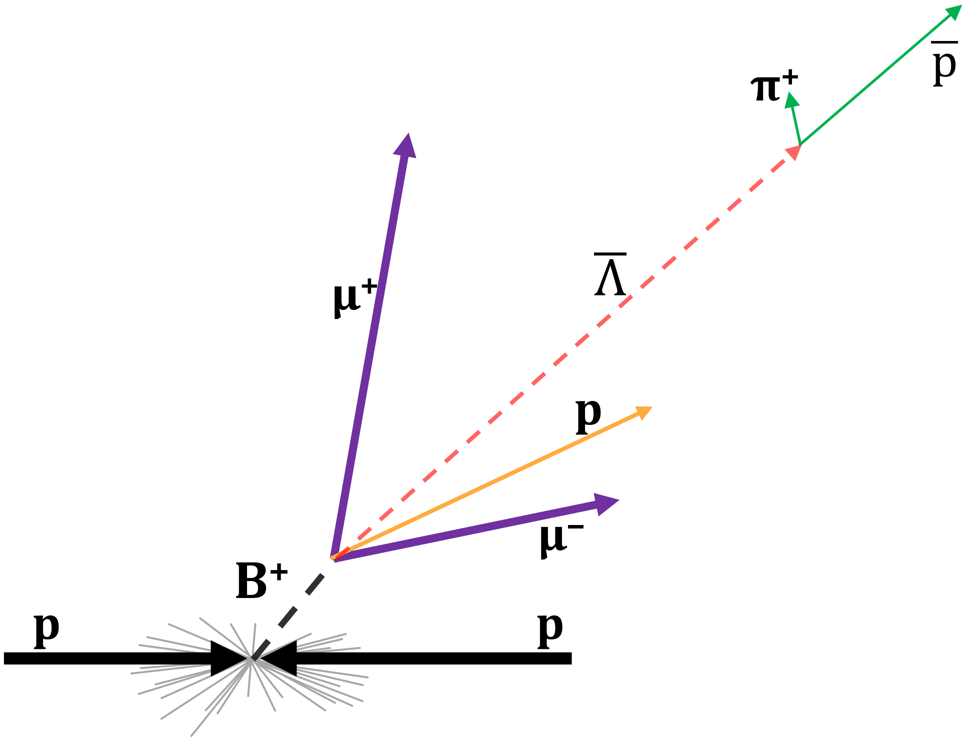
- For X/ψ signal, replace DG by Student-T
- For X/ψ signal, vary fraction of 1^{st} Gauus by ±σ from ψ(2S) fit result
- For X/ψ signal, **fix the resolution scaling in X channel to MC**

- For X/ψ bkg, **change $(y-y_0)^{\beta}\bullet Pol_1(y)$ into $(y-y_0)^{\beta}\bullet Pol_2(y)$**
- For X/ψ bkg, force shapes of bkg-bkg and bkg-φ to be equal

2. Efficiency has uncertainty related to finite size of MC samples (2.2%)

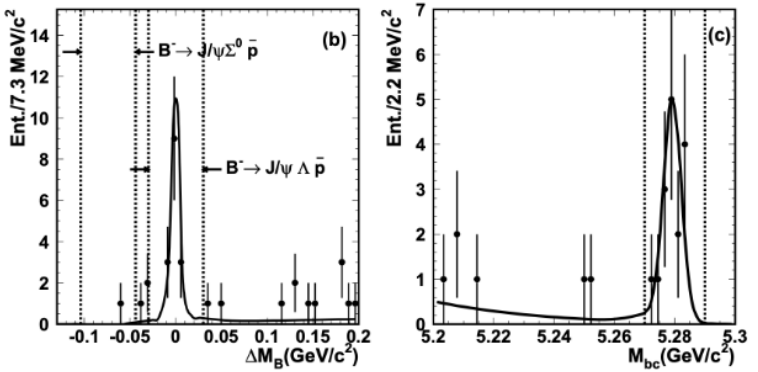
Study of the $B^+ \to J/\psi \bar{\Lambda} p$ decay

CMS-BPH-18-005, JHEP12(2019)100



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

10.1103/PhysRevD.72.051105

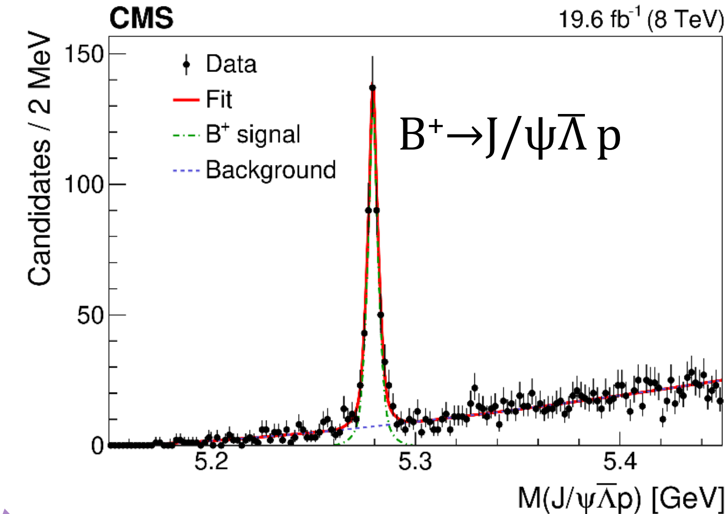


- Previously studied by Belle with 17 signal events
- CMS: study using 8 TeV pp collision data (20 fb^{-1})
- Possibility to search for exotic hadron contributions in the $J/\psi\bar{\Lambda}$ and $J/\psi p$ mass distributions (pentaquarks, similar to $\Lambda_b^0 \to J/\psi pK^-$, $P_c^+ \to J/\psi p$)
- 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 $L_{xy}/\sigma_{Lxy} > 3$, cos(B^+ pointing angle) > 0.99, vertex fit probability > 1%

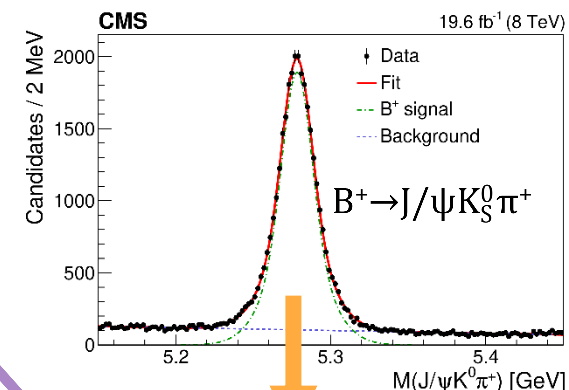
CMS-BPH-18-005, JHEP12(2019)100

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

- Unbinned ML fit to $J/\psi \bar{\Lambda} p$ distribution in data:
  - Triple Gaussian with common mean for B^+
  - $+ (x-x_0)^\beta$ 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^{*+}
    - $+ (y-y_0)^\gamma$ for bkg
    - **20863±357** normalization $B^+ \to J/\psi K^{*+}$ events



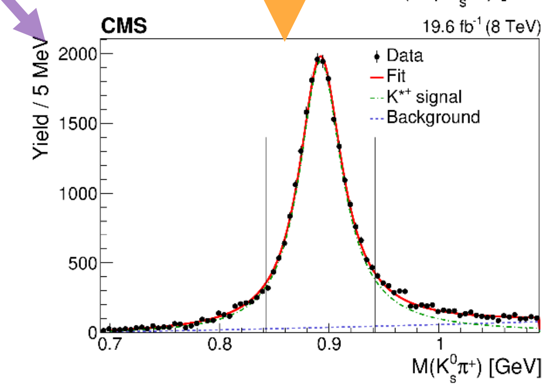
$$\frac{\mathcal{B}(B^+ \to J/\psi \bar{\Lambda} p)}{\mathcal{B}(B^+ \to J/\psi K^{*+})} = \frac{N(B^+ \to J/\psi \bar{\Lambda} p)\mathcal{B}(K^{*+} \to K^0_S \pi^+)\mathcal{B}(K^0_S \to \pi^+\pi^-)\epsilon(B^+ \to J/\psi K^{*+})}{N(B^+ \to J/\psi K^{*+})\mathcal{B}(\bar{\Lambda} \to \bar{p}\pi^+)\epsilon(B^+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

Dominant systematics: MC sample size and data/MC difference

ε from MC

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

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



CMS-BPH-18-005, JHEP12(2019)100

most precise measurement

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

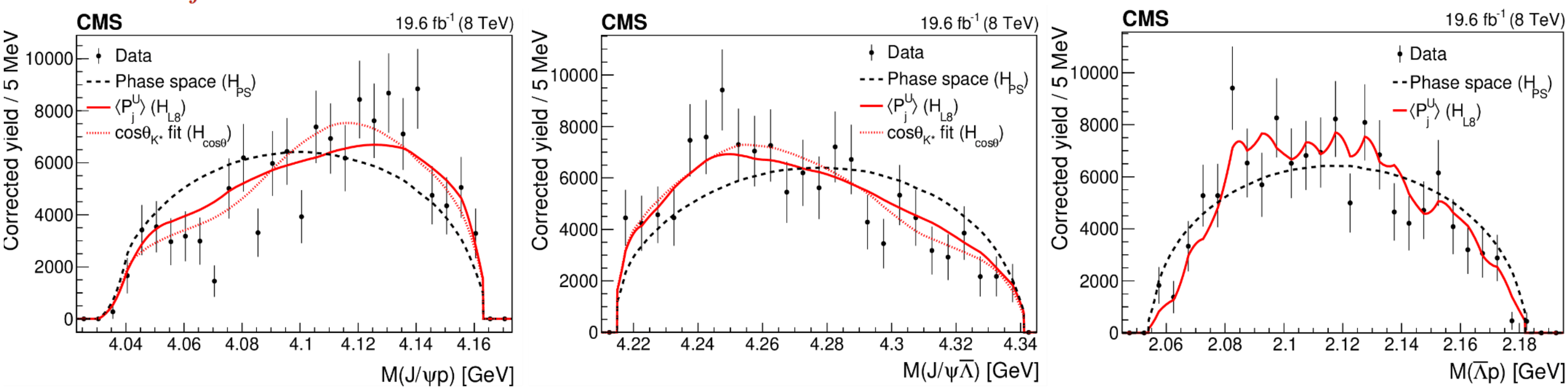
Introduced by BaBar [Phys.Rev.D79:112001 (2009)], used by LHCb [Phys.Rev.D.92:112009 (2015)]

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

$$w^i = 1 + \sum_{j=1}^{l_{max}=8} < P_j^N > P_j(\cos\theta^i_{K^*}) \qquad P_j^N = 2 \bullet \sum_{i=1}^{N_{reco}} \frac{P_j(\cos\theta_{K^*})}{\epsilon^i} / N^{reco}_{corr}$$

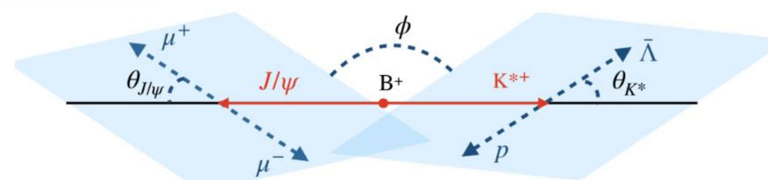
in each $M(\bar{\Lambda} p)$ bin



- - - 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: no need for extra exotic states to describe the observed data

CMS-BPH-18-005, JHEP12(2019)100

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

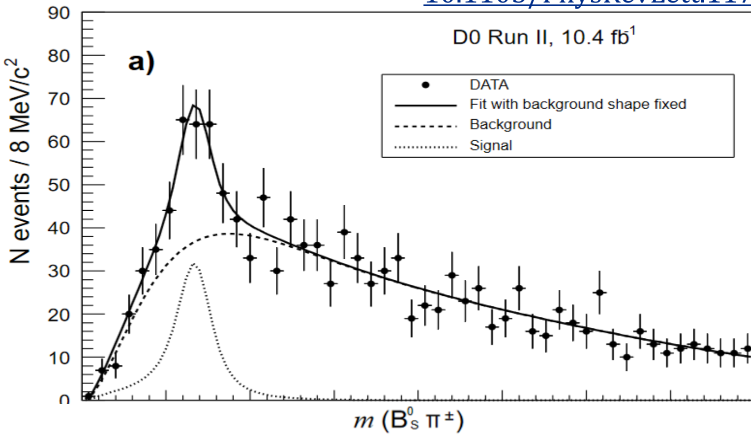
Therefore, there is **<u>no need for extra exotic states to describe the observed data</u>**

CMS-BPH-18-005, JHEP12(2019)100

X(5568)

Observed by D0 *Tetraquark state ?*

10.1103/PhysRevLett.117.022003

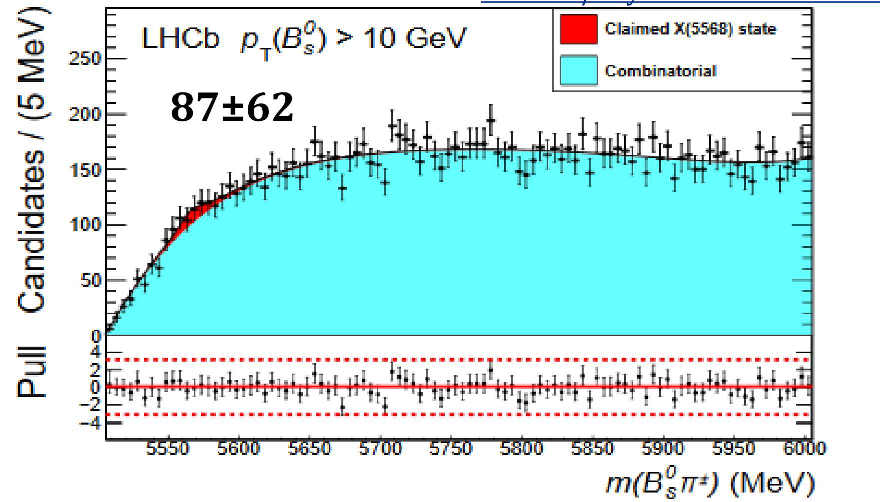


Significance **5.1σ** N_X = 133 ± 31

M_X = 5567.8 ± 2.9 MeV Γ_X = 21.9 ± 6.4 MeV

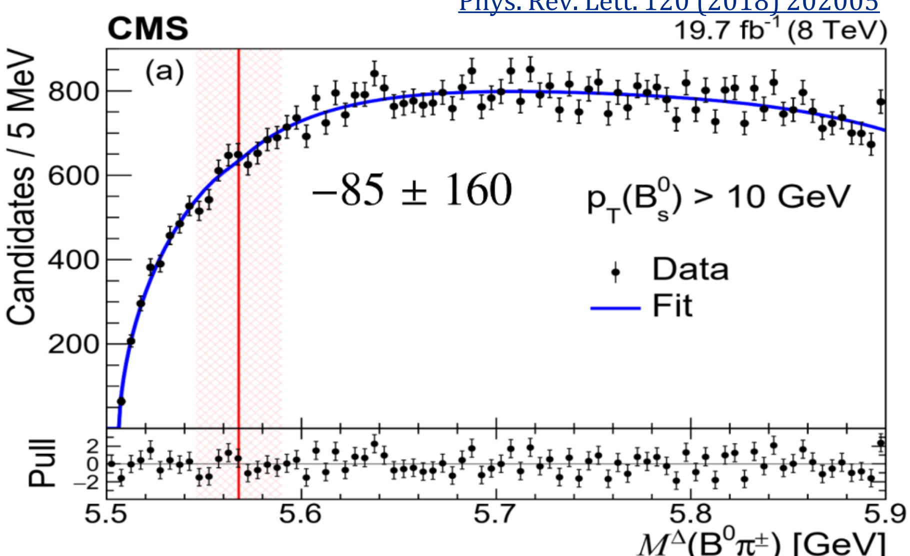
No signal at LHCb

10.1103/PhysRevLett.117.152003



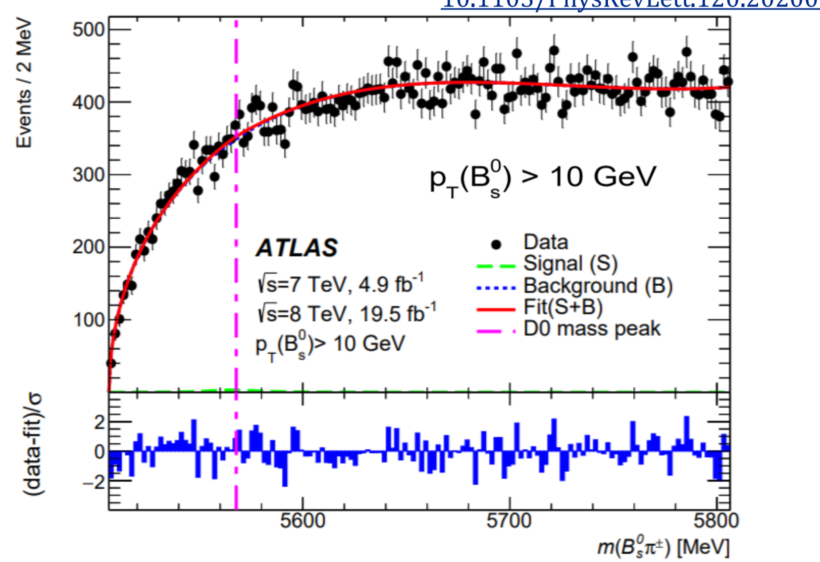
No signal at CMS

Phys. Rev. Lett. 120 (2018) 202005



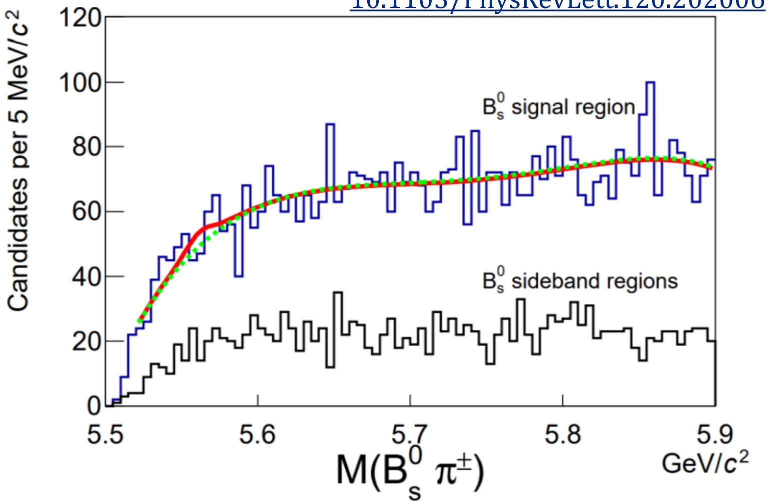
No signal at ATLAS

10.1103/PhysRevLett.120.202007

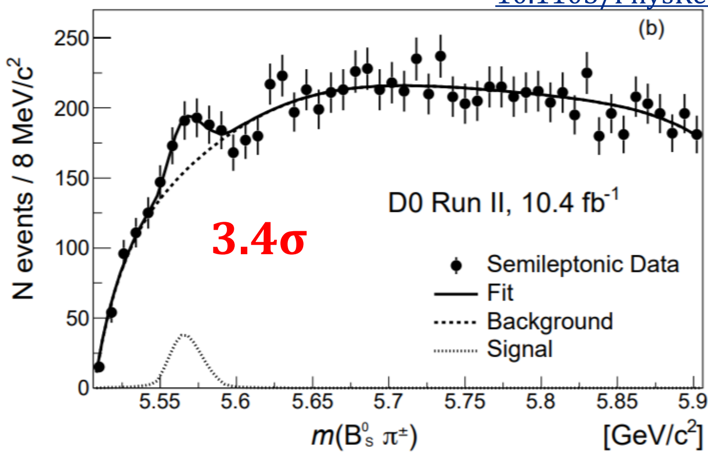


X(5568)

No signal at CDF 10.1103/PhysRevLett.120.202006



D0 claims signal with SL B_s^0 decays 10.1103/PhysRevD.97.092004



Combined significance ***6.7σ***

Comparison of the ρ_x measurements – fraction of B_s^0 produced from X(5568) decays

	ρ_X $p_T(B_s^0) > 10$ GeV
D0 2016 10.1103/PhysRevLett.117.022003	8.6 ± 2.4 %
LHCb 10.1103/PhysRevLett.117.152003	< 2.4 % @95% CL
CMS Phys. Rev. Lett. 120 (2018) 202005	**< 1.1 % @95% CL**
ATLAS 10.1103/PhysRevLett.120.202007	< 1.5 % @95% CL
CDF 10.1103/PhysRevLett.120.202006	< 6.7 % @95% CL
D0 2018, SL + had 10.1103/PhysRevD.97.092004	7.3 ± 2.9 %

ATLAS also reported mass-dependent UL, CMS and LHCb – mass and width-dependent UL

CMS experiment