

## Abstract

**CMS** *Preliminary* Using a data sample corresponding to an integrated luminosity of 103.7  $fb^{-1}$  of  $\sqrt{s} = 13$  TeV in pp collisions, collected Signal yields: Data MeV Signal yield:  $B^0: 16660 \pm 140$ Data  $\frac{2}{10^3}$ 600  $B^0: 3498 \pm 87$  $B_s^0: 113 \pm 23$ Э  $2x Gaus - B^0 signal$  $\sigma^{MC}(B_s^0)$  $--B^0$  signal -2x Gaus 500  $\sigma(B_s^0)$ Sandidates  $\overline{\sigma^{MC}(B^0)}$  $\sigma(B^0)$ andidates  $- - - - B_{s}^{0} \rightarrow \psi(2S) K_{s}^{0} K^{\pm} \pi^{\mp}$  $2x Gaus \cdots B_s^0 signal$ The neutral B meson decays with charmonium resonances  $(J/\psi, \psi(2S), \text{etc.})$  are well suited for studying CP violation. 400 **> 30σ** — Comb. bkg. - Exp Exp — Comb. bkg. 300 In the last decade, interest in b hadron decays to final states containing a charmonium resonance has increased after  $K^{\pm}$  from  $B_s^0 \rightarrow \psi(2S) K_s^0 K^{\pm} \pi^{\mp}$  $B^0$ decay taken as  $\pi^{\pm}$ .  $\mathbf{O}$ 200 Shape from MC, N - free.  $\bigcirc$ The first charged tetraquark candidate,  $Z(4430)^+$ , was discovered in the  $B^0 \rightarrow \psi(2S)K^+\pi^-$  decay as a peak in  $\psi(2S)\pi^+$ 10 5.10 5.15 5.20 5.25 5.35 5.40 5.30  $m_{\psi(2S)K_{2}^{0}\pi^{+}\pi^{-}}$  [GeV] 5.30 We search for the  $B_s^0 \rightarrow \psi(2S)K_s^0$  and  $B^0 \rightarrow \psi(2S)K_s^0 \pi^+\pi^-$  decays using a data sample of 103.7  $fb^{-1}$  of pp collisions 5.25 5.35 5.40 5.20 5.45 Source  $R_s \mid R_{\pi^+\pi^-}$  $m_{\psi(2S)K_{2}^{0}}$  [GeV] Background model 2.50.81.5**Systematics** Signal model 0.8 Shape of reflection 0.5\_\_\_\_ The systematic uncertainty related to the choice of the fit model is evaluated by testing different fit models: the largest deviation in the measured ratio from Finite size of MC 1.3 1.1 the baseline value is taken as systematic uncertainty. MC simulation does not take into account the intermediate resonance structure, leading to significant 5.0Intermediate resonances  $\frac{S)K_s^0}{S)K_s^0}$ disagreement between data and MC in intermediate mass distributions, what leads to a potential bias in the efficiency. To estimate the corresponding 4.2, and Tracking efficiency \_\_\_\_ systematic uncertainty, the MC sample is reweighted to be consistent with the data, and the difference between the baseline efficiency and the efficiency 3.2 +6.7Total  $\rightarrow \psi(2S) K_s^0 \pi^+ \pi^$ obtained on the weighted MC is taken as a systematic uncertainty.  $B^0 \rightarrow \psi(2S) K_s^0$ Exotics, where are you? The mass distributions of  $\psi(2S)$  and one or two light mesons do not present any significant narrow peaks that could indicate a contribution from an exotic charmonium state. **CMS** *Preliminary* 103.7 fb<sup>-1</sup> (13 TeV, 2017-2018) CMS Preliminary 103.7 fb<sup>-1</sup> (13 TeV, 2017-2018) CMS Preliminary 103.7 fb<sup>-1</sup> (13 TeV, 2017-2018) CMS Preliminary **CMS** *Preliminary* 103.7 fb<sup>-1</sup> (13 TeV, 2017-2018) The efficiency ratios are in agreement with our expectations: for the  $B_s^0$  channel efficiency is very close to the one for  $B^0$ VeV 600 500 **0**00 **♦** 300 Bkg.-subtracted data Bkg.-subtracted data 600 Bkg.-subtracted data Bkg.-subtracted data MC **4** 500 **4** 500 MC e 250 OG 400 OG 500 MC Weighted MC Weighted MC Weighted MC Weighted MC Weighted MC 400 400 v 400 300 300 300 F  $= 2.29 \pm 0.03$ <del>R</del> 200 200 Ö 100 F  $K^{*}(892)^{-1}$ 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.4 4.5 4.6 4.7 4.8 4.9 5.0 5.1 4.2 4.3 4.4  $m_{\mathsf{K}^0_{\mathsf{s}}\pi^+}$  [GeV]  $m_{\mathsf{K}^0_{\mathtt{c}\pi^-}}$  [GeV]  $m_{\psi(2S)K^0\pi^-}$  [GeV]  $m_{\psi(2S)\pi^{-}}$  [GeV] 103.7 fb<sup>-1</sup> (13 TeV, 2017-201 103.7 fb<sup>-1</sup> (13 TeV, 2017-2018) 103.7 fb<sup>-1</sup> (13 TeV, 2017-2018) **CMS** *Preliminarv* 103.7 fb<sup>-1</sup> (13 TeV, 2017-2018) CMS Preliminary CMS Preliminary **CMS** Preliminary | **∂** 300 <sup>†</sup> Bkg.-subtracted data **₩** 350  $|M(K_S^0) - M_{PDG}(K_S^0)| < 20 \text{ MeV} \quad \pi^+ \P \uparrow \pi^-$ Bkg.-subtracted data Bkg.-subtracted data Bkg.-subtracted data ≥ 600 ♦ Bkg.-subtracted data 600 F MC The reconstructed  $\psi(2S)$  decays into two 8 300 **O** 250 MC OG 400 Weighted MC MC 500 500 Weighted MC Weighted MC Weighted MC muons that must also satisfy general muon vn 250 Weighted MC 400 400 300 identification criteria and basic kinematic 200 300 150 requirements to reduce the combinatorial Ö<sup>100</sup> ပ္မိ 200 200  $\mathbf{O}$ background. <sup>₽</sup> ₽ <u>↓</u> <u>≜ • • • •</u>}  $K_1(1270)^0$ 100 ⊨ 📲 📲 We also apply standard 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6  $oldsymbol{\pi}^{}$ 1.3 1.4 1.5 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.8 0.9 1.0 1.1 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 1.2 1.0 4.4 4.5  $m_{\psi(\mathrm{2S})\pi^{+}}$  [GeV]  $m_{\mathrm{K_s^0}\pi^+\pi^-}$  [GeV] topological requirement on the  $m_{\psi({
m 2S})\pi^{+}\pi^{-}}$  [GeV]  $m_{\pi^{^+}\pi^{^-}}$  [GeV]  $B^0$  and  $K_s^0$  flight lengths. References Results

$$R_{s} \cdot \frac{f_{s}}{f_{d}} \equiv \frac{\mathcal{B}(\mathrm{B}_{\mathrm{s}}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0})}{\mathcal{B}(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0})} \cdot \frac{f_{s}}{f_{d}} = \frac{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{\epsilon \left(\mathrm{B}_{\mathrm{s}}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)} \cdot \frac{N\left(\mathrm{B}_{\mathrm{s}}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)} = \frac{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)} \cdot \frac{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)} = \frac{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)} \cdot \frac{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)} = \frac{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)} \cdot \frac{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\right)}{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)} = \frac{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)}{\epsilon \left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)} \cdot \frac{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)}{N\left(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}_{\mathrm{s}}^{0}\pi^{+}\pi^{-}\right)}$$

by the CMS experiment at 2017–2018, the  $B^0 \rightarrow \psi(2S)K_s^0\pi^+\pi^-$  and  $B_s^0 \rightarrow \psi(2S)K_s^0$  decays are observed. Measurements of their branching fractions, relative to the  $B^0 \rightarrow \psi(2S)K_s^0$  decay, are reported. Why it's important? CP asymmetries provide valuable tests of the flavour sector of the Standard Model (SM) and offer opportunities to search for signs of New Physics. several exotic states have been observed as intermediate resonances in multibody decays. Starting from the observation of X(3872) [1], several neutral charmonium-like states have been observed, whose properties (mass, width, decay patterns) were not fitting into the landscape of traditional charmonium states. spectrum [2]. Introduction at  $\sqrt{s} = 13$  TeV collected by CMS experiment in 2017 and 2018. Both decays can potentially be used for CP violation measurements, while 4-body decay can also be used to search for intermediate exotic resonances. The  $\psi(2S)$  and  $K_S^0$  mesons are reconstructed using their decays into  $\mu^+\mu^-$  and  $\pi^+\pi^-$ , respectively. The relative branching fraction ratios are measured using the relations where N is the number of reconstructed events in data,  $\epsilon$  is the total efficiency, and  $f_d/f_s$  is the ratio of production crosssections of  $B^0$  and  $B_s^0$  mesons (also called fragmentation fractions ratio). due to the same products of the reactions and similar masses of the decaying particles; the efficiency is lower for the 2 tracks channel due to additional track reconstruction.

$$\frac{\epsilon(B^0 \to \psi(2S)K_s^0)}{\epsilon(B_s^0 \to \psi(2S)K_s^0)} = 1.019 \pm 0.013; \quad \frac{\epsilon(B^0 \to \psi(2S)K_s^0)}{\epsilon(B^0 \to \psi(2S)K_s^0\pi^+\pi^-)}$$

# **Event reconstruction, selection and topology**



Observation of 2 new decays with charmonium

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## **Observation of the decays**

The CMS experiment has a perfect muon identification: in dimuon channel,  $\psi(2S)$ separates from other charmonium states by only requiring mass window : M( $m{\psi}(2S)$ ) in [3.55, 3.95] GeV

estimation the branching fraction ratios:

 $\mathcal{B}(\mathrm{B}^0_{\mathrm{s}} \to \psi(2\mathrm{S})\mathrm{K}^0_{\mathrm{s}}) \quad f_s$  $\mathcal{B}(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}^{0}_{\mathrm{S}}) \quad f_{d}$  $\mathcal{B}(B^0 \to \psi(2S) K_s^0 \pi^+ \pi^-)$  $\mathcal{B}(\mathrm{B}^{0} \to \psi(2\mathrm{S})\mathrm{K}^{0}_{\mathrm{S}})$ 

not reveal any additional exotic narrow structure.





$$= (0.69 \pm 0.14 \,(\text{stat}) \pm 0.02 \,(\text{syst}))\%,$$

$$= (48.0 \pm 1.3 \,(\text{stat}) \pm 3.2 \,(\text{syst}))\%.$$

Inspection of the phase-space distributions of the  $B^0 \rightarrow \psi(2S)K_S^0\pi^+\pi^-$  decay **does** 



arXiv:0708.1790.





[2] Belle Collaboration, "Observation of a resonance-like structure in the  $\pi^{\pm}\psi'$  mass distribution in exclusive  $B \rightarrow K\pi^{\pm}\psi'$  decays", Phys. Rev. Lett. **100** (2008) 142001, doi:10.1103/PhysRevLett.100.142001,

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