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Observation of 2 new decays with charmonium

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Abstract

Using a data sample corresponding to an integrated luminosity of 103.7 fb^{-1} of $\sqrt{s}$ = 13 TeV in pp collisions, collected by the CMS experiment at 2017–2018, the $B^0 \to \psi(2S)K_S^0\pi^+\pi^-$ and $B_s^0 \to \psi(2S)K_S^0$ decays are observed. Measurements of their branching fractions, relative to the $B^0 \to \psi(2S)K_S^0$ decay, are reported.

Why it's important?

The neutral B meson decays with charmonium resonances ($J/\psi, \psi(2S)$, etc.) are well suited for studying CP violation. CP asymmetries provide valuable tests of the flavour sector of the Standard Model (SM) and offer opportunities to search for signs of New Physics.

In the last decade, interest in b hadron decays to final states containing a charmonium resonance has increased after 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.

The first charged tetraquark candidate, $Z(4430)^+$, was discovered in the $B^0 \to \psi(2S)K^+\pi^-$ decay as a peak in $\psi(2S)\pi^+$ spectrum [2].

Introduction

We search for the $B_s^0 \to \psi(2S)K_S^0$ and $B^0 \to \psi(2S)K_S^0\pi^+\pi^-$ decays using a data sample of 103.7 fb^{-1} of pp collisions 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

$$R_s \cdot \frac{f_s}{f_d} \equiv \frac{\mathcal{B}(B_s^0 \to \psi(2S)K_S^0)}{\mathcal{B}(B^0 \to \psi(2S)K_S^0)} \cdot \frac{f_s}{f_d} = \frac{\epsilon(B^0 \to \psi(2S)K_S^0)}{\epsilon(B_s^0 \to \psi(2S)K_S^0)} \cdot \frac{N(B_s^0 \to \psi(2S)K_S^0)}{N(B^0 \to \psi(2S)K_S^0)}, \text{ and}$$

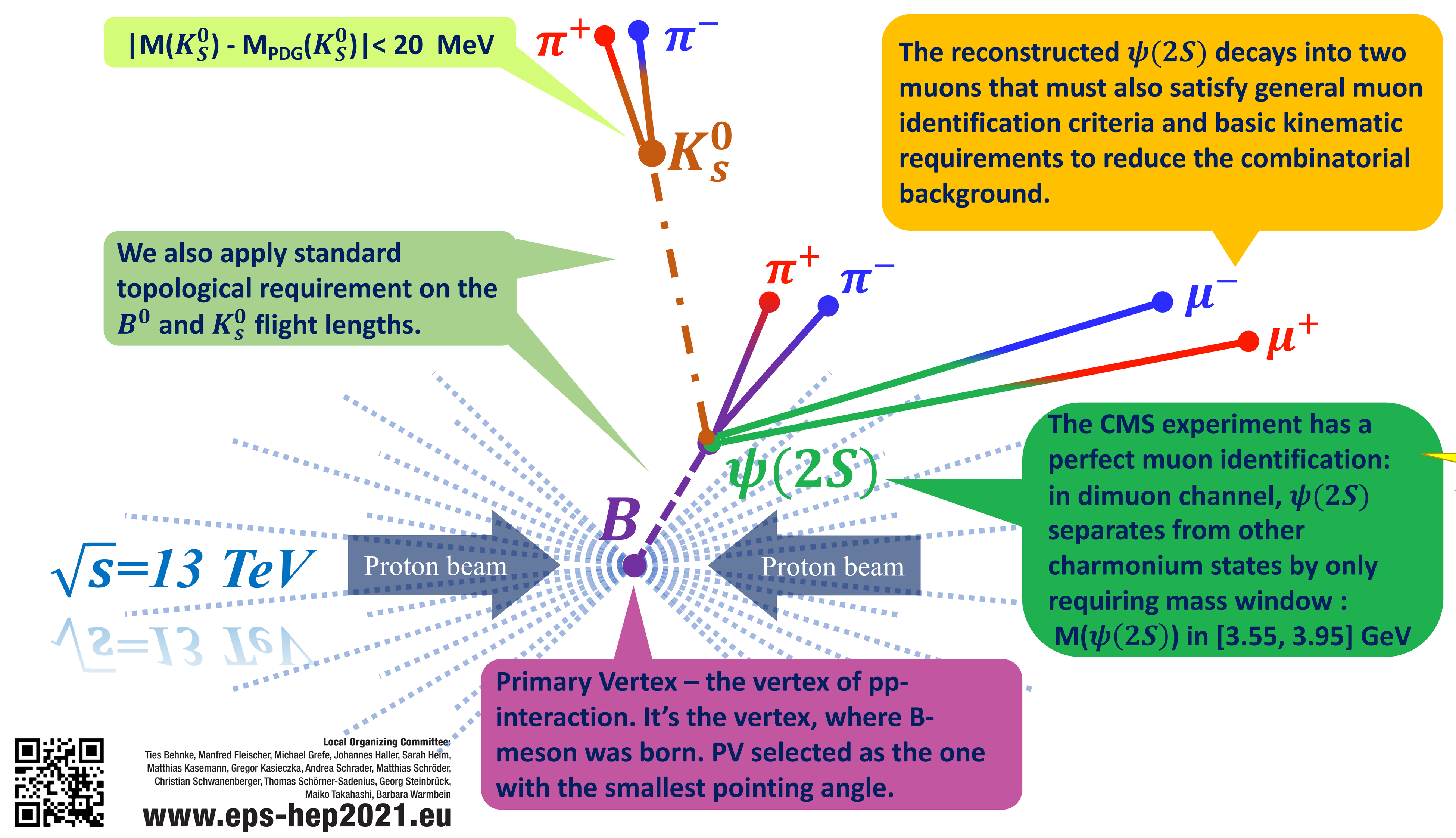
$$R_{\pi^+\pi^-} \equiv \frac{\mathcal{B}(B^0 \to \psi(2S)K_S^0\pi^+\pi^-)}{\mathcal{B}(B^0 \to \psi(2S)K_S^0)} = \frac{\epsilon(B^0 \to \psi(2S)K_S^0)}{\epsilon(B^0 \to \psi(2S)K_S^0\pi^+\pi^-)} \cdot \frac{N(B^0 \to \psi(2S)K_S^0\pi^+\pi^-)}{N(B^0 \to \psi(2S)K_S^0)},$$

where N is the number of reconstructed events in data, ϵ is the total efficiency, and f_d/f_s is the ratio of production cross-sections of B^0 and B_s^0 mesons (also called fragmentation fractions ratio).

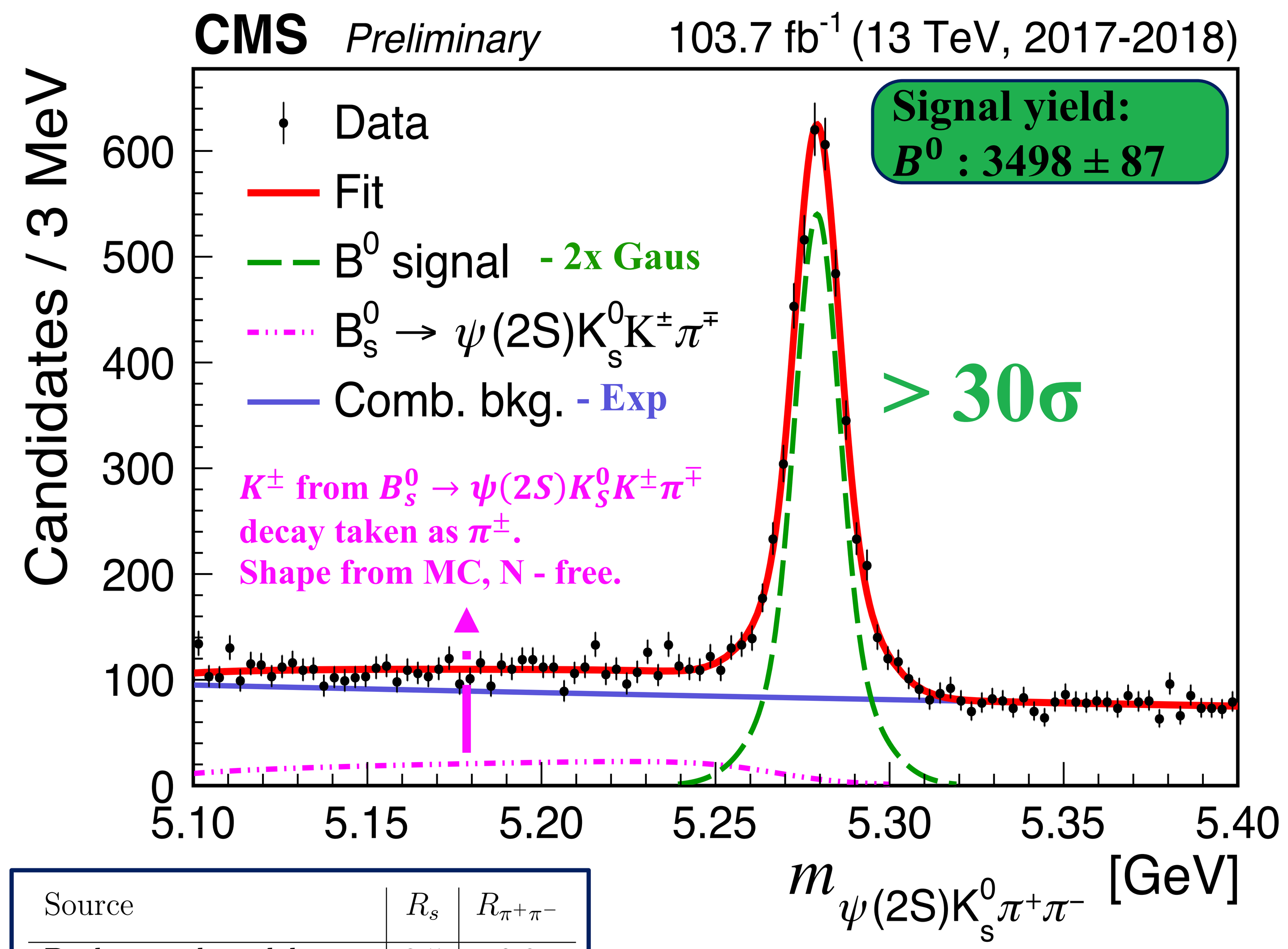
The efficiency ratios are in agreement with our expectations: for the B_s^0channel efficiency is very close to the one for B^0 due to the same products of the reactions and similar masses of the decaying particles; the efficiency is lower for the 2 tracks channel due to additional track reconstruction.

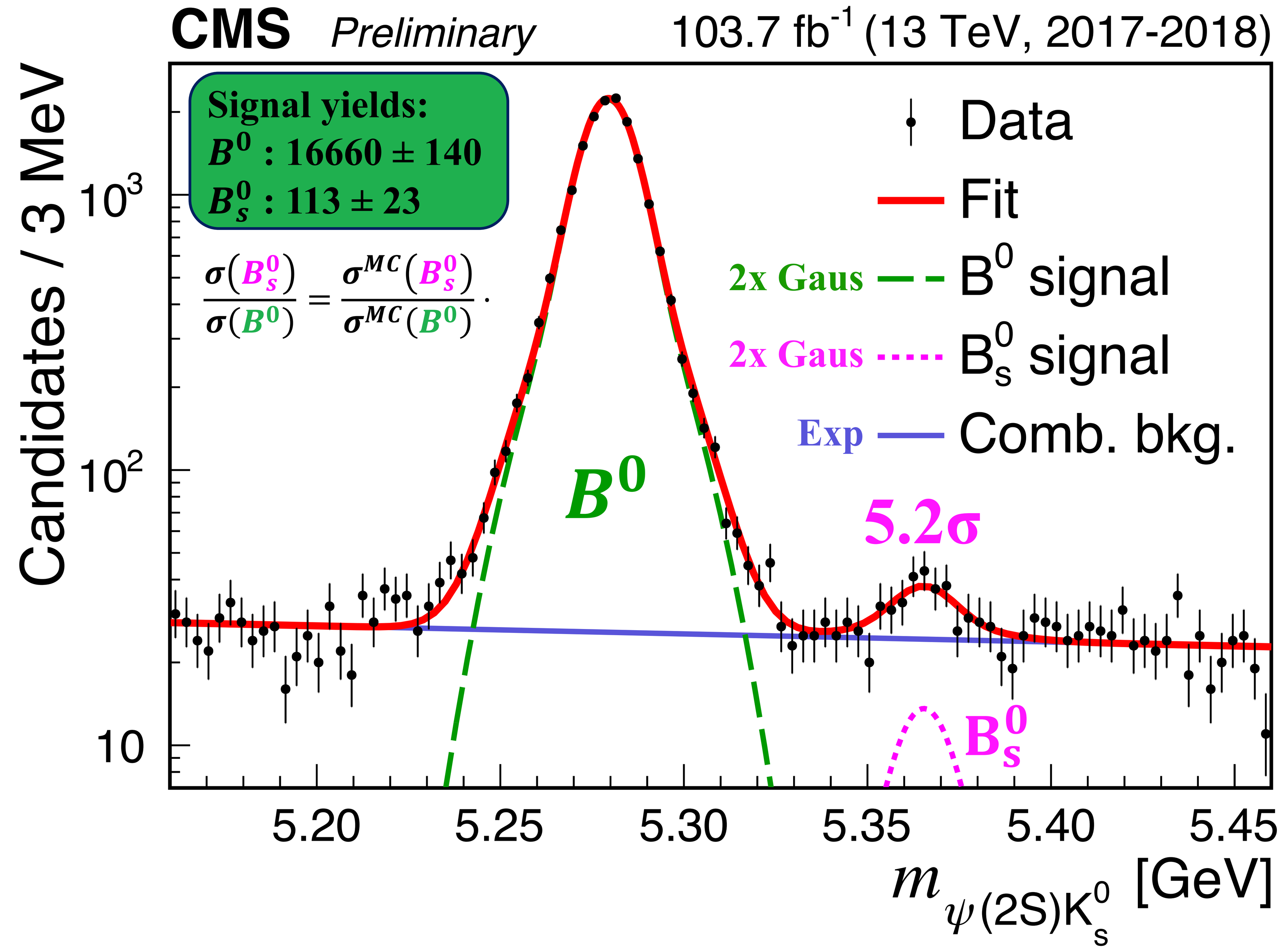
$$\frac{\epsilon(B^0 \to \psi(2S)K_S^0)}{\epsilon(B_s^0 \to \psi(2S)K_S^0)} = 1.019 \pm 0.013; \quad \frac{\epsilon(B^0 \to \psi(2S)K_S^0)}{\epsilon(B^0 \to \psi(2S)K_S^0\pi^+\pi^-)} = 2.29 \pm 0.03$$

Event reconstruction, selection and topology



Observation of the decays





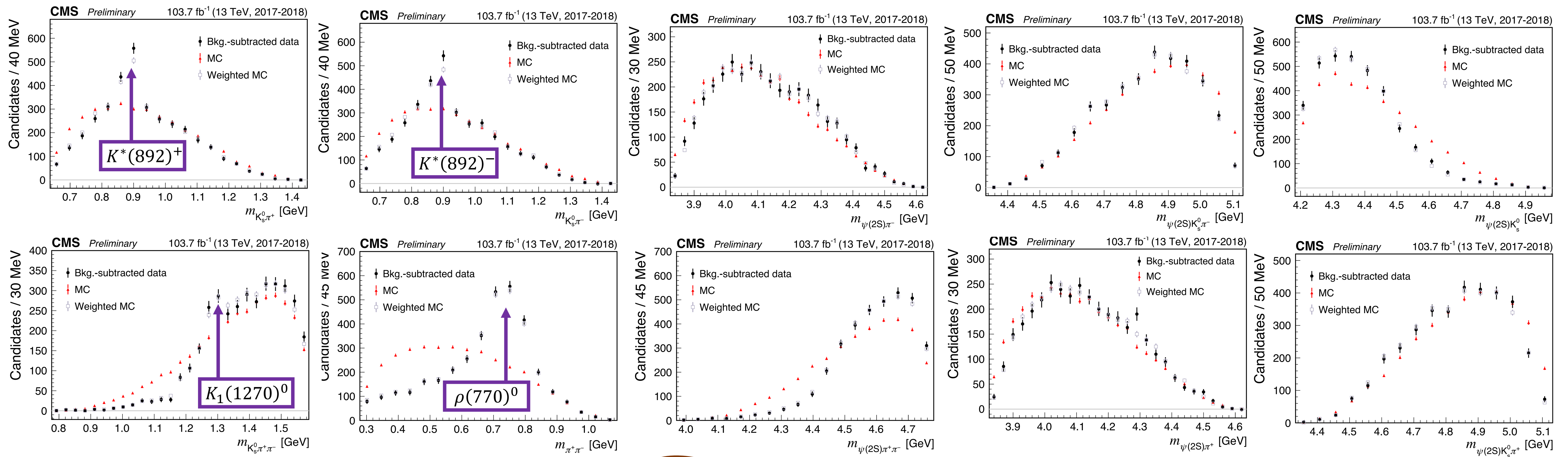
Source	R_s	$R_{\pi^+\pi^-}$
Background model	2.5	0.8
Signal model	1.5	0.8
Shape of reflection	—	0.5
Finite size of MC	1.3	1.1
Intermediate resonances	—	5.0
Tracking efficiency	—	4.2
Total	3.2	6.7

Systematics

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 the baseline value is taken as systematic uncertainty. MC simulation does not take into account the intermediate resonance structure, leading to significant disagreement between data and MC in intermediate mass distributions, what leads to a potential bias in the efficiency. To estimate the corresponding systematic uncertainty, the MC sample is reweighted to be consistent with the data, and the difference between the baseline efficiency and the efficiency obtained on the weighted MC is taken as a systematic uncertainty.

Exotics, where are you?

The mass distributions of ψ(2S) and one or two light mesons do not present any significant narrow peaks that could indicate a contribution from an exotic charmonium state.



Results

The first observation!

The first observation of the decays $B_s^0 \to \psi(2S)K_S^0$ and $B^0 \to \psi(2S)K_S^0\pi^+\pi^-$ and estimation the branching fraction ratios:

$$\frac{\mathcal{B}(B_s^0 \to \psi(2S)K_S^0)}{\mathcal{B}(B^0 \to \psi(2S)K_S^0)} \cdot \frac{f_s}{f_d} = (0.69 \pm 0.14\,(\text{stat}) \pm 0.02\,(\text{syst}))\%,$$

$$\frac{\mathcal{B}(B^0 \to \psi(2S)K_S^0\pi^+\pi^-)}{\mathcal{B}(B^0 \to \psi(2S)K_S^0)} = (48.0 \pm 1.3\,(\text{stat}) \pm 3.2\,(\text{syst}))\%.$$

Inspection of the phase-space distributions of the $B^0 \to \psi(2S)K_S^0\pi^+\pi^-$ decay **does not reveal any additional exotic narrow structure.**

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References

[1] Belle Collaboration, "Observation of a narrow charmonium - like state in exclusive $B^\pm \to K^\pm\pi^+\pi^- J/\psi$ decays", *Phys. Rev. Lett.* **91** (2003) 262001, doi:10.1103/PhysRevLett.91.262001, arXiv:hep-ex/0309032.

[2] Belle Collaboration, "Observation of a resonance-like structure in the $\pi^\pm\psi'$ mass distribution in exclusive $B \to K\pi^\pm\psi'$ decays", *Phys. Rev. Lett.* **100** (2008) 142001, doi:10.1103/PhysRevLett.100.142001, arXiv:0708.1790.

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