Observation of new structure in the $J/\psi J/\psi$ mass spectrum in proton-proton collisions at $\sqrt{s} = 13\,\mathrm{TeV}$

—Supplemental Material—

The CMS Collaboration

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FIT PROJECTIONS IN FULL RANGE

The $J/\psi J/\psi$ invariant mass spectrum for the full range of the fit is shown in Fig. 1 for the no-interference and the interference models.

FITTING WITH THE LHCB MODELS

In order to make a direct comparison with the results from the LHCb Collaboration [1] we also used their two principal models (I and II) to fit the CMS data. The details are provided here.

Model I consists of two auxiliary relativistic Breit–Wigner (BW) functions below the $X(6900)$ BW. The parameter values for these two BWs are not reported in Ref. [1], but the second auxiliary BW is in the same mass region as the CMS "BW$_1$" and so we extend this labeling to the LHCb models.

The Model I fit is shown in Fig. 2 (upper), with numerical results listed in Table I. The fit quality is poor with a signal-region χ^2 probability of 0.9%. The no-interference

fit using the CMS model with three structures—and roughly the same number of $J/\psi J/\psi$ candidates after the final selection as LHCb—has a signal-region χ^2 probability of 9%.

Model II has, aside from the signal BW, a single auxiliary BW (here labeled as 'BW$_1$'), which interferes with the NRSPS background. This interference was introduced to better model the dip around 6750 MeV. Our fit results for Model II are shown in Fig. 2 (lower) and Table I. The 6750 MeV dip is now well described: the pulls in Fig. 2 (lower) are well behaved in the vicinity of the $X(6900)$ peak. However, systematic deviations are evident elsewhere in the pulls, and the signal-region χ^2 probability of 0.8% for this fit is actually lower than for Model I.

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[1] LHCb Collaboration, Observation of structure in the J/ψ-pair mass spectrum, Sci. Bull. **65**, 1983 (2020).
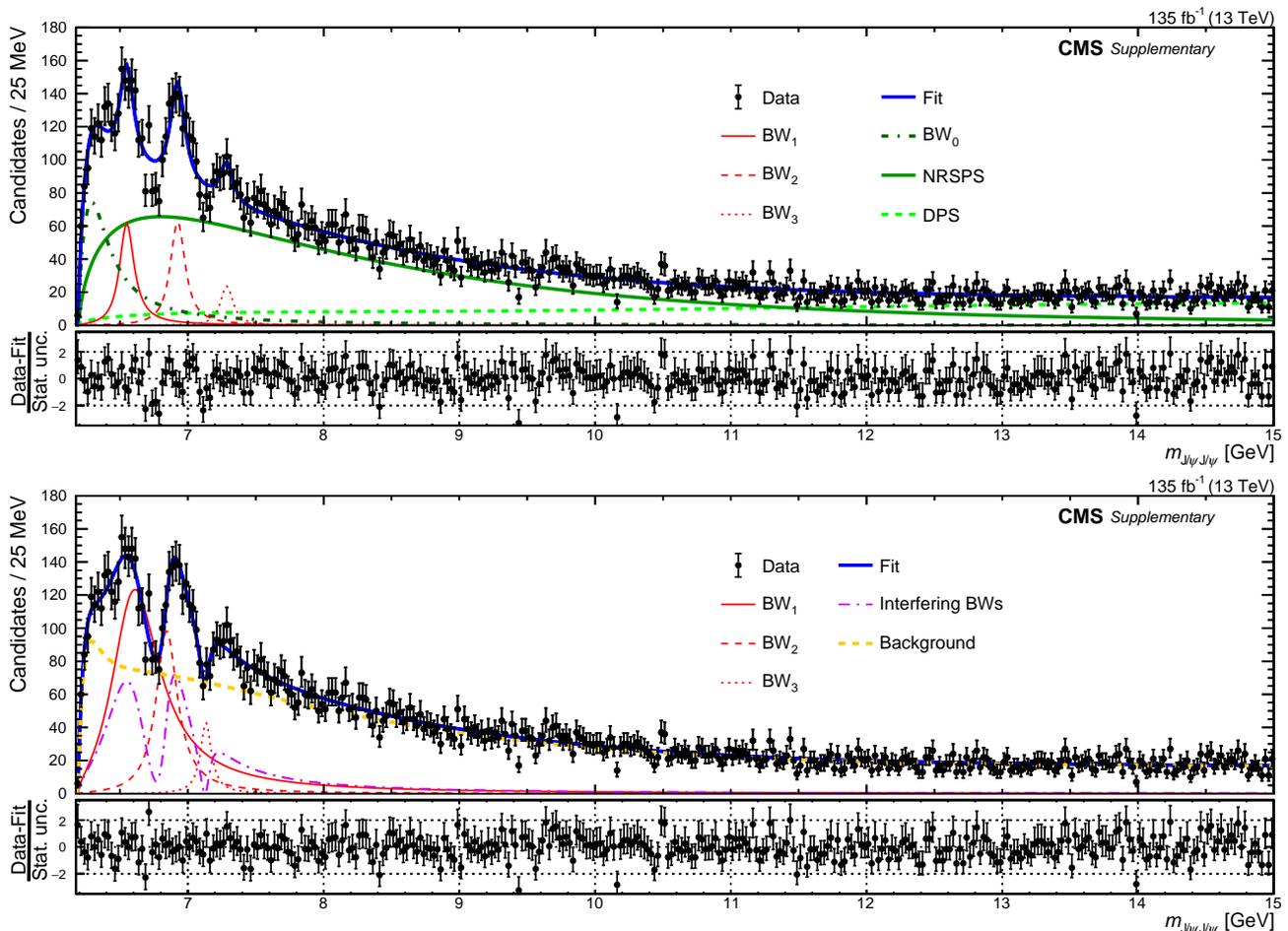
FIG. 1. The $J/\psi J/\psi$ invariant mass spectrum with the no-interference fit (upper) and the interference fit (lower) in the full fit range (see text for model details). The "Interference BWs" curve is the total contribution of all the interference amplitudes and their cross terms. The lower portion of the plots shows the pulls, i.e., the number of standard deviations (statistical uncertainties only) that the binned data differ from the fit.

TABLE I. Summary of results for the two LHCb fit models from LHCb and CMS: the mass m and natural width Γ, in MeV, are given for the principal structures (the Breit–Wigner function at the threshold is not included in Model I), and LHCb values not reported in Ref. [1] are marked as "$\cdots$". Single uncertainties are statistical only.

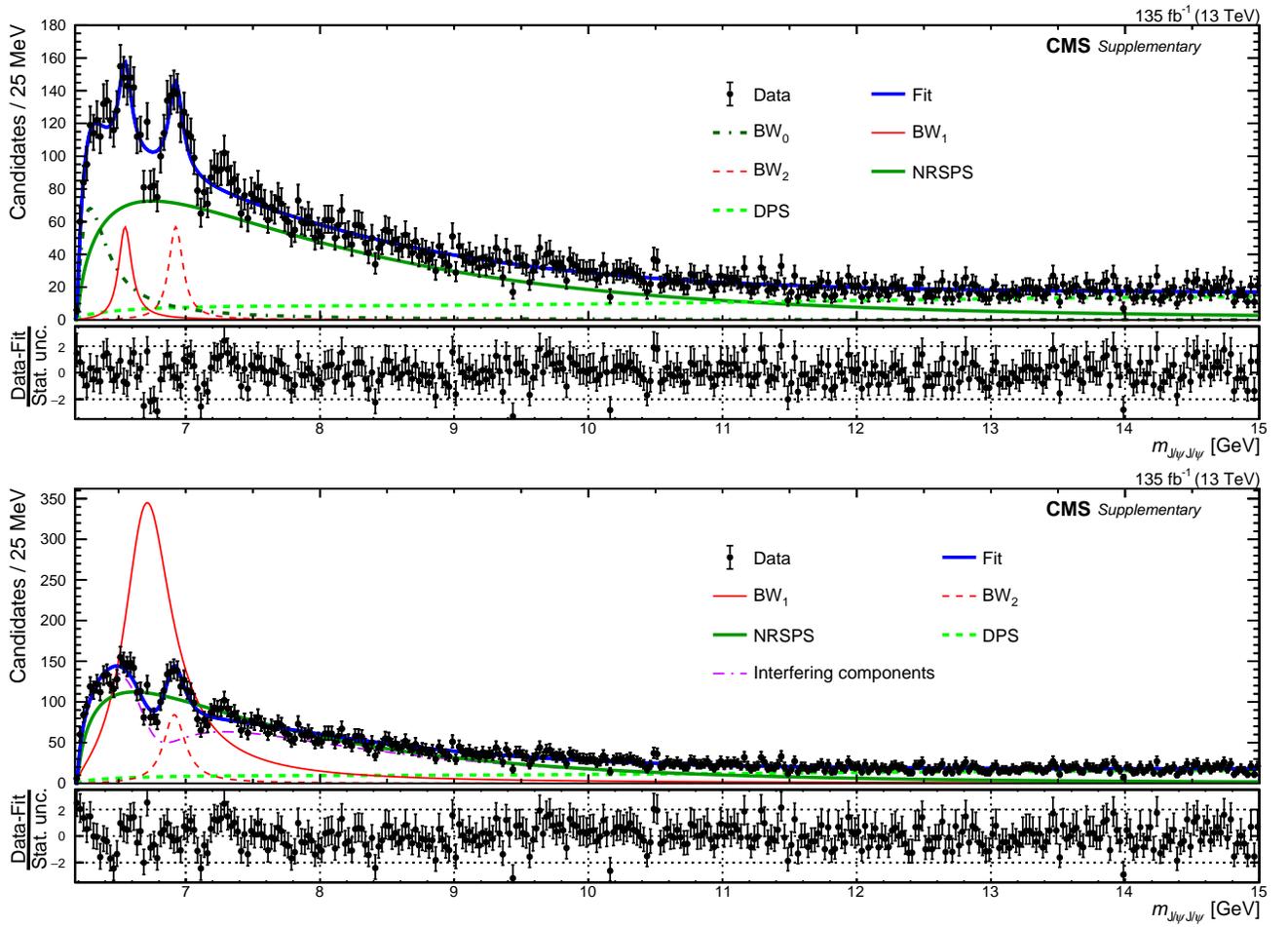| Exp.	Fit	M_{BW_1}	Γ_{BW_1}	$M_{X(6900)}$	$\Gamma_{X(6900)}$
LHCb [1]	Model I	$\cdots$	$\cdots$	$6905 \pm 11 \pm 7$	$80 \pm 19 \pm 33$
CMS	Model I	6550 ± 10	112 ± 27	6927 ± 10	117 ± 24
LHCb [1]	Model II	6741 ± 6	288 ± 16	$6886 \pm 11 \pm 11$	$168 \pm 33 \pm 69$
CMS	Model II	6736 ± 38	439 ± 65	6918 ± 10	187 ± 40

FIG. 2. The $J/\psi J/\psi$ invariant mass spectrum with fits using LHCb models [1]: Model I (no-interference) (upper) and Model II (interference) (lower). Model details are given in the text. The "Interfering components" is the total contribution of BW_1, NRSPS, and their interference. The lower portion of the plots shows the pulls between the binned data and the fit.