Supplementary material for LHCb-PAPER-2020-008

Breit–Wigner mass of the $\chi_{c1}(3872)$ state

The precision of the mass measurement made here is similar to that found in an analysis of $B^+ \to J/\psi\,\pi^+\pi^-K^+$ decays using full LHCb data sample [1]. That analysis finds $185.488 \pm 0.062 \pm 0.030\,\mathrm{MeV}/c^2$, in good agreement with the result found here. The averaging procedure is described in detail in the supplementary material for Ref. [1]. This gives

$$m_{\chi_{c1}(3872)} - m_{\psi(2S)} = 185.542 \pm 0.060\,\mathrm{MeV}/c^2\,. \qquad (1)$$

This is converted into an estimate of the $\chi_{c1}(3872)$ mass using the value $m_{\psi(2S)} = 3686.097 \pm 0.010\,\mathrm{MeV}/c^2$ [2] to give

$$m_{\chi_{c1}(3872)} = 3871.639 \pm 0.060 \pm 0.010\,\mathrm{MeV}/c^2\,,$$

where the second uncertainty is due to the knowledge of the $\psi(2S)$ mass.

The measured mass has been averaged with the previous measurements summarized in the Review of Particle Properties (PDG). The results are shown in Fig. S1. Also included on this plot is a comparison with $m_{D^0} + m_{D^{*0}}$ which is calculated to be $3871.70 \pm 0.11\,\mathrm{MeV}$ using the data Ref. [2] and taking into account that several of the measurements of the D^0 mass measurements quote sizeable uncertainties due to the knowledge of the charged kaon mass. The central value of $m_{D^0} + m_{D^{*0}}$ found in this way is equal that found using the averages the PDG quotes for for m_{D^0} and the mass splitting between the m_{D^0} and $m_{D^{*0}}$ directly. However, the uncertainty is larger: the PDG procedure gives $\pm 0.1\,\mathrm{MeV}$. Using the new world average, including the LHCb result presented here the binding energy $\delta E \equiv m_{D^0} + m_{D^{*0}} - m_{\chi_{c1}(3872)}$ is estimated to be $0.01 \pm 0.14\,\mathrm{MeV}$.

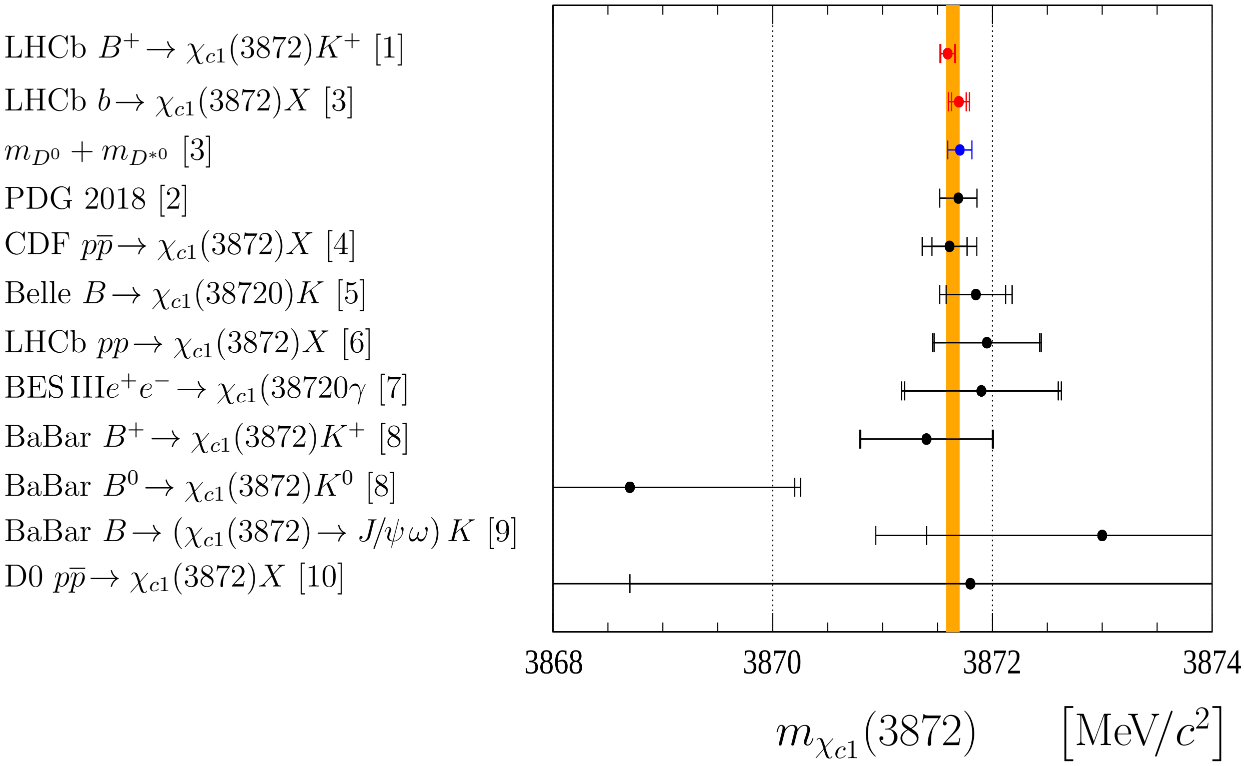

Figure S1: Measurements of the Breit–Wigner mass of the $\chi_{c1}(3872)$ state. The inner error bars indicate the statistical uncertainty, and the outer error bars correspond to the quadratic sum of the statistical and systematic uncertainties. A sum of D^0 and D^{*0} masses, $m_{D^0} + m_{D^{*0}}$, is shown with blue color. The orange band represents the value and the uncertainty on world average of the $\chi_{c1}(3872)$ mass measurements including the new LHCb results.

Table S1: Measurements of the mass of the $\chi_{c1}(3872)$ state. The third uncertainty is due to the finite knowledge of $\psi(2S)$ mass.

Experiment			$m_{\chi_{c1}(3872)}$ [MeV/c^2]
LHCb	[3]	$b \to \chi_{c1}(3872)X$	$3871.695 \pm 0.067 \pm 0.068 \pm 0.010$
LHCb	[1]	$B^+ \to \chi_{c1}(3872)K^+$	$3871.593 \pm 0.062 \pm 0.031 \pm 0.010$
LHCb average			$3871.639 \pm 0.060 \quad \pm 0.010$
$m_{D^0} + m_{D^{*0}}$	[3]		3871.70 ± 0.11
PDG 2018	[2]		3871.69 ± 0.17
CDF	[4]	$p\overline{p} \to \chi_{c1}(3872)X$	$3871.61 \pm 0.16 \pm 0.19$
Belle	[5]	$B \to \chi_{c1}(3872)K$	$3871.85 \pm 0.27 \pm 0.19$
LHCb	[6]	$pp \to \chi_{c1}(3872)X$	$3871.95 \pm 0.48 \pm 0.12$
BES III	[7]	$e^+e^- \to \gamma\chi_{c1}(3872)$	$3871.9 \pm 0.7 \pm 0.2$
BaBar	[8]	$B^+ \to \chi_{c1}(3872)K^+$	$3871.4 \pm 0.6 \pm 0.1$
BaBar	[8]	$B^0 \to \chi_{c1}(3872)K^0$	$3868.7 \pm 1.5 \pm 0.4$
BaBar	[9]	$B \to (\chi_{c1}(3872) \to J/\psi\,\omega)\,K$	$3873.0\ ^{+1.8}_{-1.6} \pm 1.3$
D0	[10]	$p\overline{p} \to \chi_{c1}(3872)X$	$3871.8 \pm 3.1 \pm 3.0$
Our average			3871.64 ± 0.06

Uncertainty on the binding energy $\boldsymbol{E_b}$.

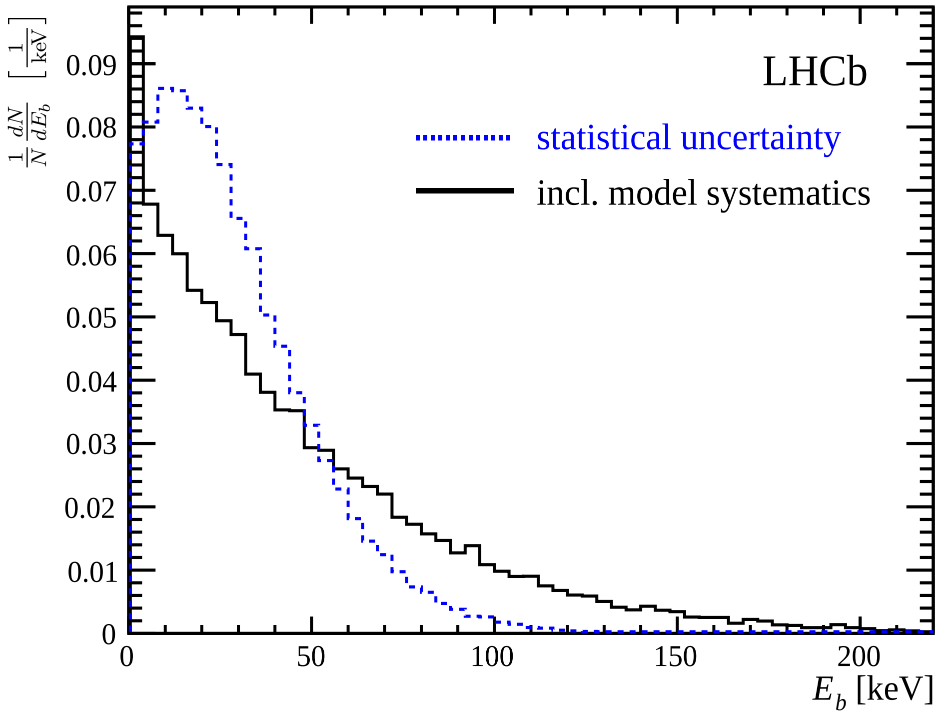

Figure S2: Distribution of the binding energy for the bound-state solution found in the default fit. The uncertainties are propagated from the uncertainties on the Flatté parameters by using a large number of simulated pseudoexperiments. In dashed blue the statistical uncertainties only. In black are the combined statistical and systematic model uncertainties. The best estimate is $E_b = 24\,\mathrm{keV}$. The upper limits at 90% confidence are 57 keV and 100 keV, respectively. When including the systematic model uncertainties the chance to find the pole on sheet IV increases. In those cases no binding energy is computed and therefore the shape of the distribution changes.

References

[1] LHCb collaboration, R. Aaij *et al.*, *Study of the* $\psi_2(3823)$ *and* $\chi_{c1}(3872)$ *states in the* $B^+ \to (J/\psi\,\pi^+\pi^-)\,K^+$ *decays* , `arXiv:2005.13422`, submitted to JHEP.

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[6] LHCb collaboration, R. Aaij *et al.*, *Observation of* $X(3872)$ *production in pp collisions at* $\sqrt{s} = 7$ *TeV*, Eur. Phys. J. **C72** (2012) 1972, `arXiv:1112.5310`.

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