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Multiplicity dependent production of $\chi_{c1}(3872)$

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In the last two decades, many hadronic resonances were discovered which are incompatible with the theoretical framework describing conventional mesons and baryons. Among these is the $\chi_{c1}(3872)$, a suspected tetraquark state, first observed in decays of B hadrons into $J/\psi\pi^+\pi^-$. The hadronic medium produced in high multiplicity pp collisions allows us to study the onset of nuclear effects on these hadrons, and can thus help us to unveil more about the nature of the $\chi_{c1}(3872)$. The common decay channel with that of a conventional charmonium state $\psi(2S)$ makes the latter an excellent reference for such studies, as we know more about its phenomenology. This talk discusses the recent preliminary results from LHCb on the measurement of the relative suppression of $\chi_{c1}(3872)$ over $\psi(2S)$ exploring their shared $J/\psi\pi^+\pi^-$ decay channel in pp collisions at $\sqrt{s} = 8$ TeV.

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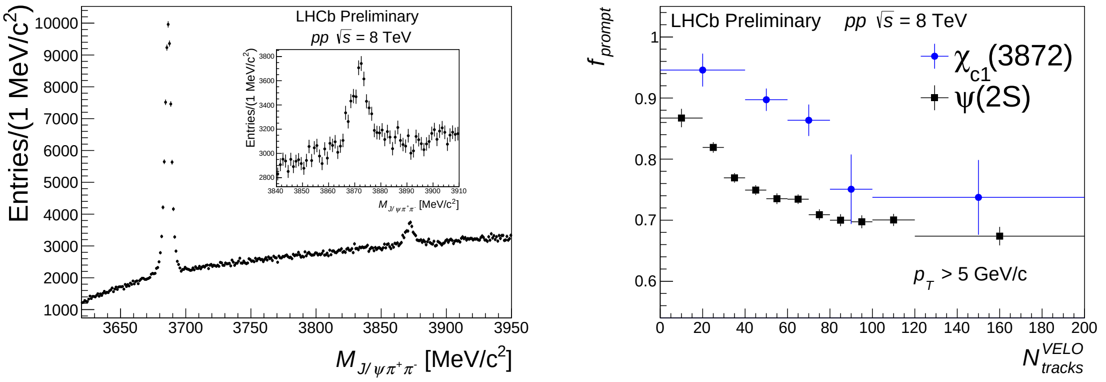

Figure 1: Left: Invariant mass spectrum of $J/\psi\pi^+\pi^-$ at $p_T > 5$ GeV in the forward region $2 < \eta < 5$ in pp collisions at $\sqrt{s} = 8$ TeV. The insert shows the region around the mass of $\chi_{c1}(3872)$. Right: Fraction of prompt over inclusive $\psi(2S)$ (black squares) and $\chi_{c1}(3872)$ (blue disks) as a function of number of tracks reconstructed in VELO.

1. Introduction

The last decades saw a large leap in particle spectroscopy with observation of multiple suspected exotic states, which do not fit the description of conventional hadrons. One of these new particles is the $\chi_{c1}(3872)$ state, first discovered in decays of $B \to J/\psi\pi^+\pi^-$ by Belle [1]. LHCb determined the quantum numbers of $\chi_{c1}(3872)$ as $J^{PC} = 1^{++}$ [2], thus ruling out the option of $\chi_{c1}(3872)$ being another conventional charmonium state. Up until now, the nature of $\chi_{c1}(3872)$ remains a mystery, with such explanations at play as a $D^{*0}\bar{D}^0$ molecule [3, 4], a tetraquark state [5–7], or a mixture of exotic and conventional states [8].

The environment produced in nuclear and high multiplicity proton-proton collisions provides an excellent opportunity to scrutinise the nature of $\chi_{c1}(3872)$ by studying its multiplicity dependent relative suppression compared to a conventional charmonium state such as $\psi(2S)$, exploring their common $J/\psi\pi^+\pi^-$ decay channel. Should the $\chi_{c1}(3872)$ be a hadronic molecule, its large radius of order ~ 10 fm and weak bond will make it highly susceptible to dissociation with other particles created at the primary vertex. In contrast, a compact tetraquark $\chi_{c1}(3872)$ with radius ~ 1 fm will be less prone to break up. This talk discusses recent preliminary LHCb results on multiplicity dependent relative suppression of $\chi_{c1}(3872)$ over $\psi(2S)$ in pp collisions at $\sqrt{s} = 8$ TeV.

2. Analysis

LHCb is a single arm forward experiment fully instrumented at $2 < \eta < 5$ [9]. Its outstanding vertexing, tracking, and PID capabilities make it an excellent detector to study heavy flavour quarks. In the present analysis, J/ψ candidates in pp collisions at $\sqrt{s} = 8$ TeV are reconstructed from dimuon pairs and coupled with a pair of opposite sign pions. The resulting $J/\psi\pi^+\pi^-$ invariant mass spectrum at $p_T > 5$ GeV in LHCb acceptance $2 < \eta < 5$ is shown in Figure 1 on left hand side, with the $\psi(2S)$ and $\chi_{c1}(3872)$ peaks clearly visible in the spectrum.

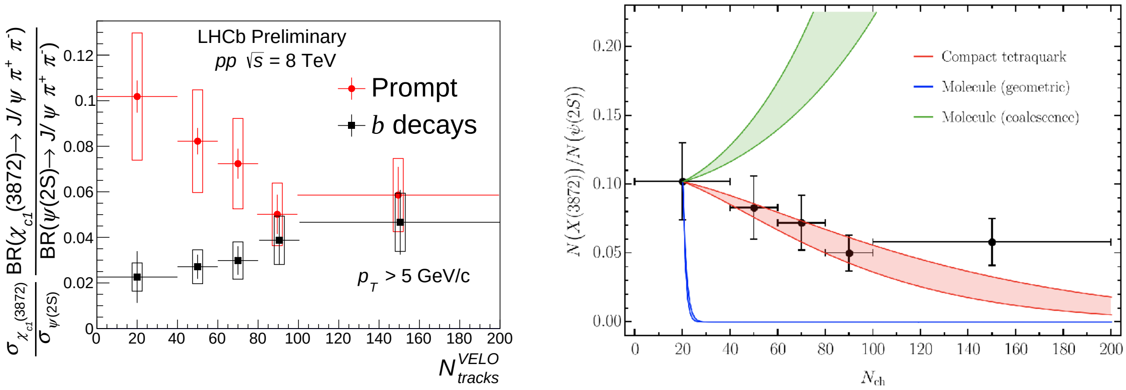

Figure 2: Left: The ratio of cross-section times respective branching ratio of $\chi_{c1}(3872)$ over $\psi(2S)$ measured in the $J/\psi\pi^+\pi^-$ decay channel as a function of event activity quantified with number of tracks reconstrcuted in VELO N_{tracks}^{VELO} in pp collisions at $\sqrt{s}$ = 8 TeV. Right: Relative yield of $\chi_{c1}(3872)$ over $\psi(2S)$ as a function of event multiplicity in pp collisions at $\sqrt{s}$ = 8 TeV. Compared are results of the presented LHCb analysis (data points) with comover model calculations for different scenarios of nature of $\chi_{c1}(3872)$, i. e. $\chi_{c1}(3872)$ being a compact tetraquark (red curve) or a molecule (green and blue curves). Taken from Ref. [14].

In order to separate the states which were produced at the collision vertex ("prompt") from those originating in decays of B hadrons further away from the interaction point ("nonprompt"), one performs a simultaneous fit to the invariant mass spectrum and the pseudo-propertime distribution of the candidates. Such fitting procedure is performed in bins of event activity, for which the chosen proxy is the number of tracks reconstructed in VELO N_{tracks}^{VELO} (for more details, see Refs. [10, 11]). The result of this procedure is the fraction of prompt over inclusive states f_{prompt} shown in the right panel of Figure 1.

3. Results

The cross-section ratio of $\chi_{c1}(3872)$ over $\psi(2S)$ multiplied by the respective branching fraction ratio is defined as

$$\frac{\sigma_{\chi_{c1}(3872)}}{\sigma_{\psi(2S)}} \frac{\mathcal{B}[\chi_{c1}(3872) \to J/\psi\pi^+\pi^-]}{\mathcal{B}[\psi(2S) \to J/\psi\pi^+\pi^-]} = \frac{N_{\chi_{c1}(3872)}}{N_{\psi(2S)}} \frac{f_{\text{prompt}}^{\chi_{c1}(3872)}}{f_{\text{prompt}}^{\psi(2S)}} \frac{\varepsilon_{\psi(2S)}}{\varepsilon_{\chi_{c1}(3872)}}, \tag{1}$$

where N_X is the inclusive signal of the hadron of interest X, f_{prompt}^X represents the fraction of prompt over inclusive states of the same hadron, and ε_X denotes the efficiency of reconstructing and selecting X. The ratio as a function of event activity is shown in Figure 2, left. The prompt and nonprompt (from b-hadrons) states are displayed separately. The corresponding error bars represent uncorrelated uncertainty that is dominated by the statistical uncertainty. The boxes show the correlated systematic uncertainty, whose main source is the efficiency correction.

The ratio of the prompt states decreases with increasing event activity. On the other hand, the ratio of nonprompt $\chi_{c1}(3872)/\psi(2S)$ is consistent, within uncertainties, with a flat behaviour. This suggests that the promtply produced $\chi_{c1}(3872)$ are suppressed by the comoving matter created in the collisions more than the $\psi(2S)$, while in the absence of the created matter their behaviour is similar and the value of the ratio is driven by the ratio of the two respective branching fractions, constant in multiplicity. Such behaviour is consistent with the $\chi_{c1}(3872)$ being weaker bound than the $\psi(2S)$ and thus more prone to dissociations.

In the comovers model [12–14], the charmonia emerging at the collisions vertex are broken up by the final state interactions with comoving matter produced in the collision. The relative break-up of $\chi_{c1}(3872)$ over $\psi(2S)$ was calculated considering a scenario in which the $\chi_{c1}(3872)$ is a tetraquark with a radius only slightly larger than that of $\psi(2S)$ and compared with the LHCb data for promptly produced ratio in right panel of Figure 2. Taking into account the difference in the multiplicity axes, we see a remarkable agreement of the observed trend between data and theory, clearly showing the measured decrease of the relative yields with increasing event activity. In contrast, the model predicts vastly different multiplicity dependence of the relative yield should the $\chi_{c1}(3872)$ be a molecule.

4. Summary

Studies of modification of $\chi_{c1}(3872)$ relative to conventional charmonia in high multiplicity proton-proton collisions may shed light on the nature of this exotic hadron. Measurement of relative suppression of $\chi_{c1}(3872)$ over $\psi(2S)$ as a function of multiplicity in pp collisions at $\sqrt{s} = 8$ TeV in LHCb showed that the ratio of prompt states decreases with multiplicity, while the nonprompt ratio remains constant, indicating stronger suppression of $\chi_{c1}(3872)$ by comoving particles, suggesting its weaker bond relative to conventional $\psi(2S)$. Comovers model calculations attribute such behaviour to $\chi_{c1}(3872)$ being a compact tetraquark slightly larger than $\psi(2S)$.

References

[1] S. K. Choi *et al.* (Belle Coll.), Phys. Rev. Lett. **91** (2003), 262001.

[2] R. Aaij *et al.* (LHCb Coll.), Phys. Rev. Lett. **110** (2013), 222001.

[3] E. Braaten and M. Kusunoki, Phys. Rev. D **71** (2005), 074005.

[4] N. A. Tornqvist, Phys. Lett. B **590** (2004), 209-215.

[5] L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D **71** (2005), 014028.

[6] S. Dubnicka, A. Z. Dubnickova, M. A. Ivanov and J. G. Korner, Phys. Rev. D **81** (2010), 114007.

[7] S. Dubynskiy and M. B. Voloshin, Phys. Lett. B **666** (2008), 344-346.

[8] C. M. Zanetti, M. Nielsen and R. D. Matheus, Phys. Lett. B **702** (2011), 359-363.

[9] A. A. Alves, Jr. *et al.* (LHCb Coll.), JINST **3** (2008), S08005.

[10] The LHCb Collaboration, LHCb-CONF-2019-005, CERN-LHCb-CONF-2019-005.

[11] J. Matthew Durham (for LHCb Coll.), submitted to Nucl. Phys. A, *e-print* arXiv:2002.01551 [hep-ex].

[12] A. Capella, E. G. Ferreiro and A. B. Kaidalov, Phys. Rev. Lett. **85** (2000), 2080-2083.

[13] E. G. Ferreiro, Phys. Lett. B **749** (2015), 98-103.

[14] A. Esposito *et al.*, *e-print* arXiv:2006.15044 [hep-ph].

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