Study of $\eta_c(1S)$ and $\eta_c(2S)$ production via hadronic decays

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on behalf of the LHCb collaboration

- Powerful tests of NRQCD description of charmonium production via of **hadroproduction** and **production in inclusive b-decays**
- All charmonia states accessible via decays to hadrons, **possible in LHCb due to powerful PID and flexible trigger**
- **LHCb selection** using transverse momentum, vertex quality and particle identification

Heavy flavour production in NRQCD

- Two scales of production: hard process of **$Q\bar{Q}$ formation** followed by **hadronization of $Q\bar{Q}$** at softer scales
- **Factorization**:

$$d\sigma_{A+B\to H+X} = \sum_n d\sigma_{A+B\to Q\bar{Q}+X} \times \langle \mathcal{O}^H(n) \rangle$$

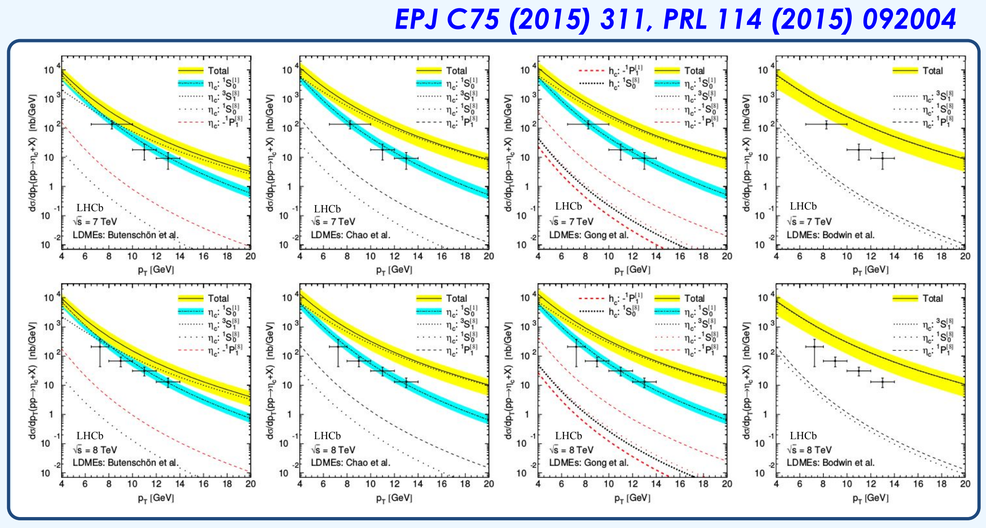
- **Short distance**: perturbative cross-sections + pdf for the production of a QQ pair
- **Long distance matrix elements (LDME)**, non-perturbative, from experimental data

- Colour-singlet (CS) model: intermediate $Q\bar{Q}$ state is colourless and has the same J^{PC} quantum numbers as the final-state quarkonium
- Colour-octet (CO) model: all viable colours and J^{PC} allowed for the intermediate QQ state. They are adjusted in the long-distance part with a given probability.
- **Universality**: *same LDME for prompt production and production in b-decays*
- Heavy-Quark **Spin-Symmetry**: links between CS and CO LDMEs of different quarkonium states

$\eta_c(1S)$ production at $\sqrt{s}$ = 7,8 TeV

- **First measurement of $\eta_c(1S)$ production** at $\sqrt{s}$ = 7 and 8 TeV
- Prompt production and production in b-decay
- **Differential cross-sections of the $\eta_c(1S)$ production**

EPJ C75 (2015) 311, PRL 114 (2015) 092004

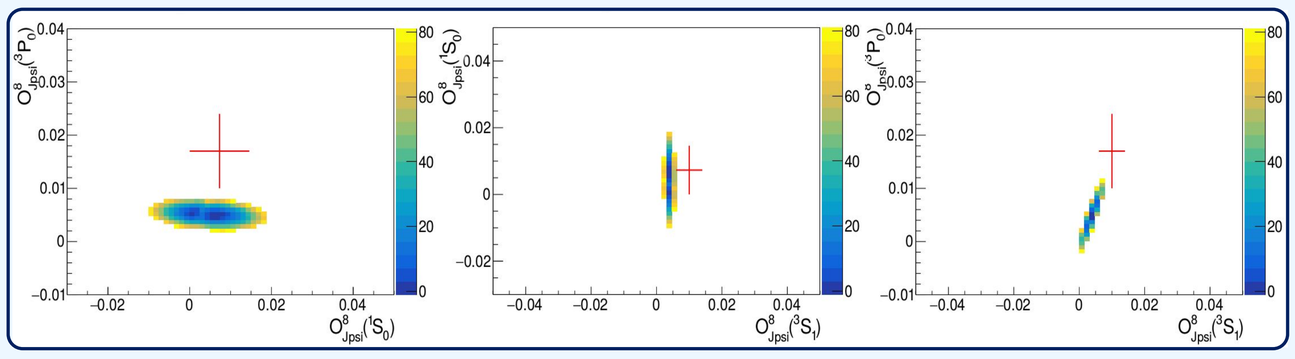


- **Strong impact on theory models**: contrary to theory expectations, **$\eta_c(1S)$ prompt production entirely described by CS contribution**.

- **Phenomenological fits to J/ψ and $\eta_c(1S)$ LDMEs**
- $\langle O(^1S_0) \rangle$ is fixed at 1.16/3. GeV^3, sequentially fix other LDMEs according to theoretical prediction
- Red points describe theoretical prediction from Ref. *PRL 114 (2015) 092005*

$$\langle \mathcal{O}^{\eta_c}_{1,8}(^1S_0) \rangle = \tfrac{1}{3} \langle \mathcal{O}^{J/\psi}_{1,8}(^3S_1) \rangle$$
$$\langle \mathcal{O}^{\eta_c}_{8}(^3S_1) \rangle = \langle \mathcal{O}^{J/\psi}_{8}(^1S_0) \rangle$$
$$\langle \mathcal{O}^{\eta_c}_{8}(^1P_1) \rangle = 3 \langle \mathcal{O}^{J/\psi}_{8}(^3P_0) \rangle$$

LAL-17-051 and updates

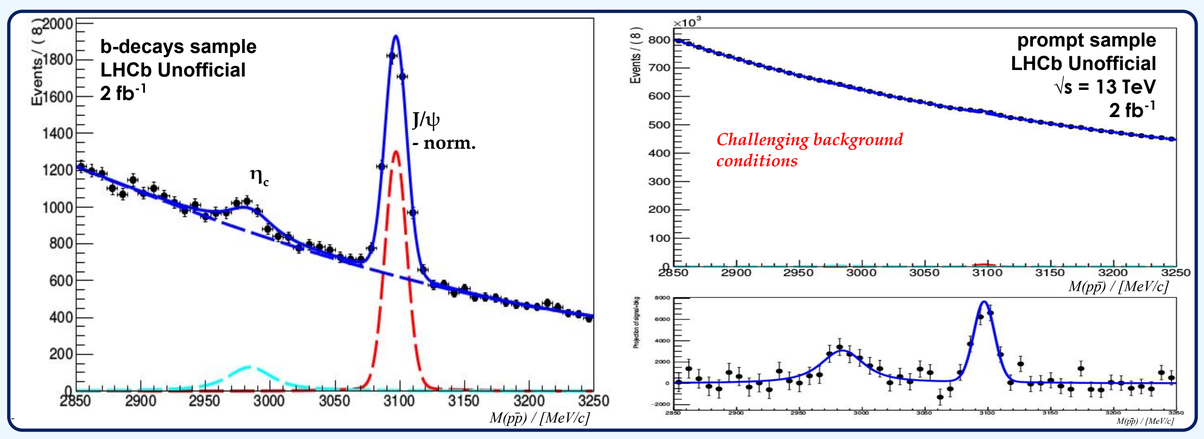


• Difference within 3-4σ, more precise measurement of $\eta_c(1S)$ required

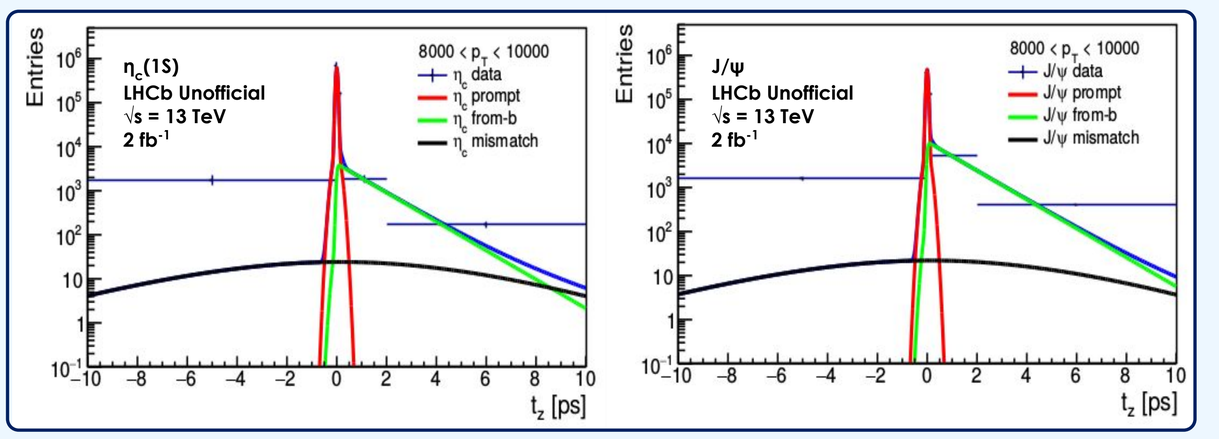
$\eta_c(1S)$ production at $\sqrt{s}$ = 13 TeV

Prompt and b-decay production distinguished via decay time value: $t_z = \frac{z_{SV} - z_{PV}}{p_z} M_{p\bar{p}}$, two analysis techniques

- Selection **to separate prompt** and **b-decay production samples**
- Efficiencies and cross-talk from simulation



- Simultaneous fit to M(pp) in bins of [p_T, t_z] **to extract charmonia yields**
- Simultaneous $\eta_c(1S)$ and J/ψ t_z-fit in p_T bins **to separate prompt** and **b-decays sample**

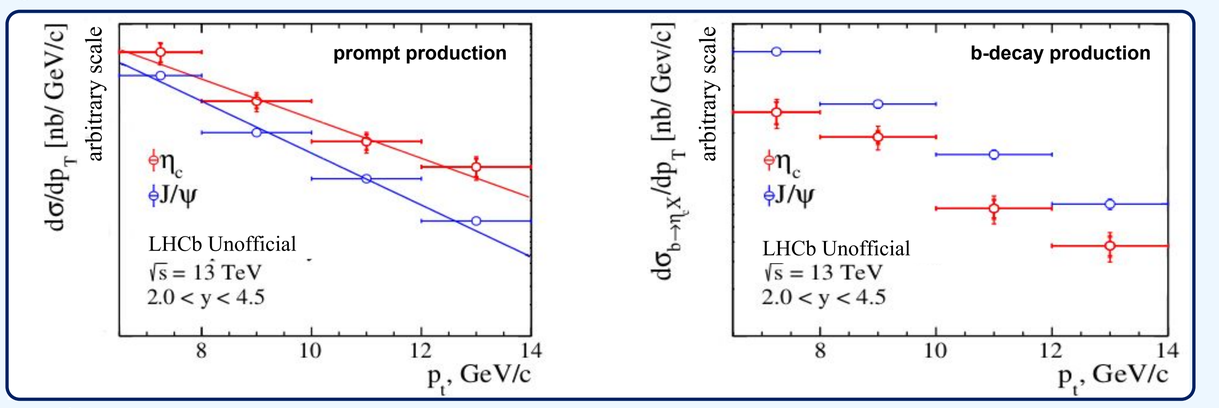


- Both techniques yield consistent result
- **Preliminary internal result:** (6.5 GeV/c <p_T<14.0 GeV/c , 2.0<y<4.5)

$$\sigma_{\eta_c} = \boxed{} \pm 0.1_{stat} \pm 0.1_{syst} \pm 0.2_{BR}\ \mu b$$

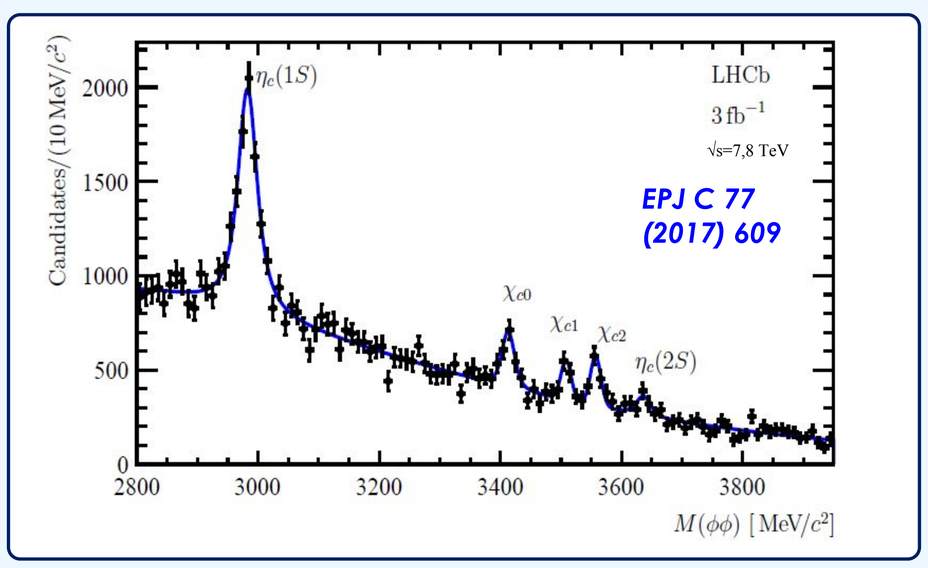
$$\frac{BR_{b\to\eta_c X}}{BR_{b\to J/\psi X}} = \boxed{} \pm 0.08_{stat} \pm 0.03_{syst} \pm 0.05_{BR}$$

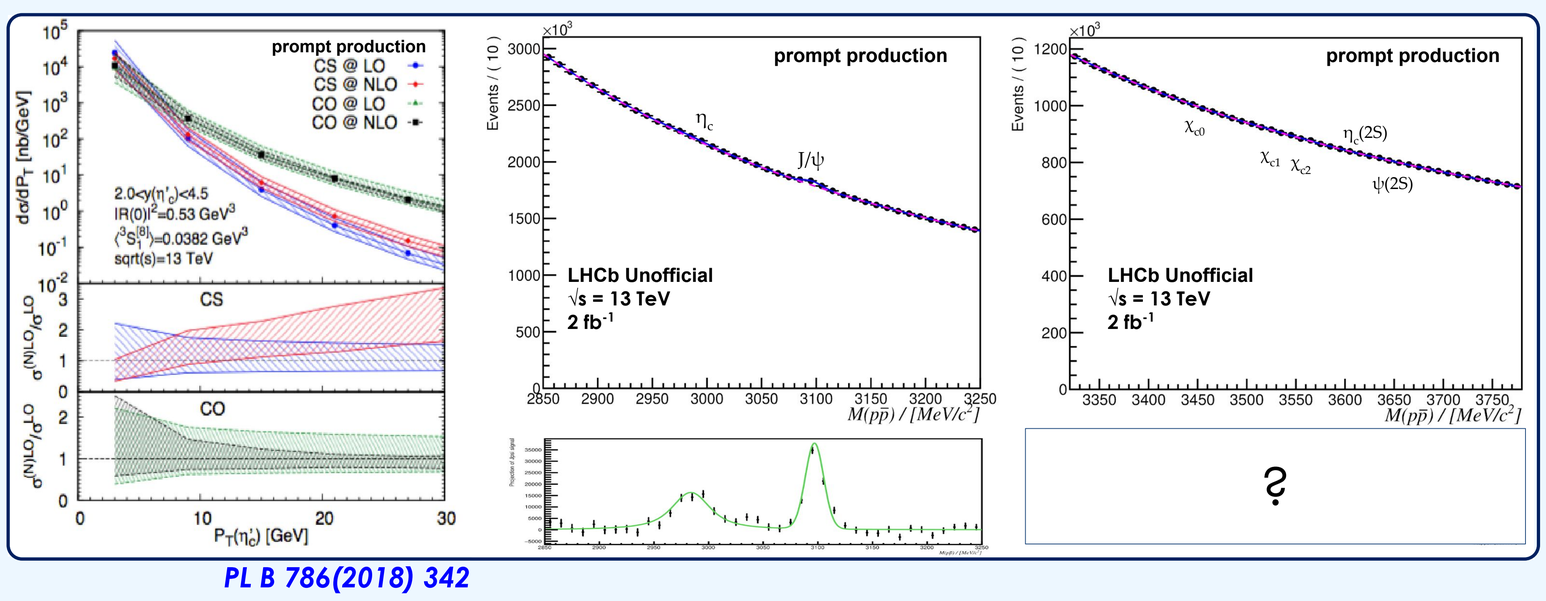
- $\eta_c(1S)$ and J/ψ differential production cross-section



$\eta_c(2S)$ production at $\sqrt{s}$ = 13 TeV

- **First evidence of $\eta_c(2S) \to \phi\phi$ in b-decays** with Run I data
- No feed-down for $\eta_c(2S)$ and $\psi(2S)$ from higher states, clear theoretical interpretation of the result
- Same links between LDMEs for **$\eta_c(2S)$** and **$\psi(2S)$** are expected
- **Dedicated trigger line** in 2018





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- New tests of NRQCD description with **$\eta_c(1S)$** and **$\eta_c(2S)$ production**
- Powerful tests of NRQCD charmonium production mechanism if both **hadroproduction** and **production in inclusive b-decays studied jointly**