Studies of quarkonia production and polarization at LHCb

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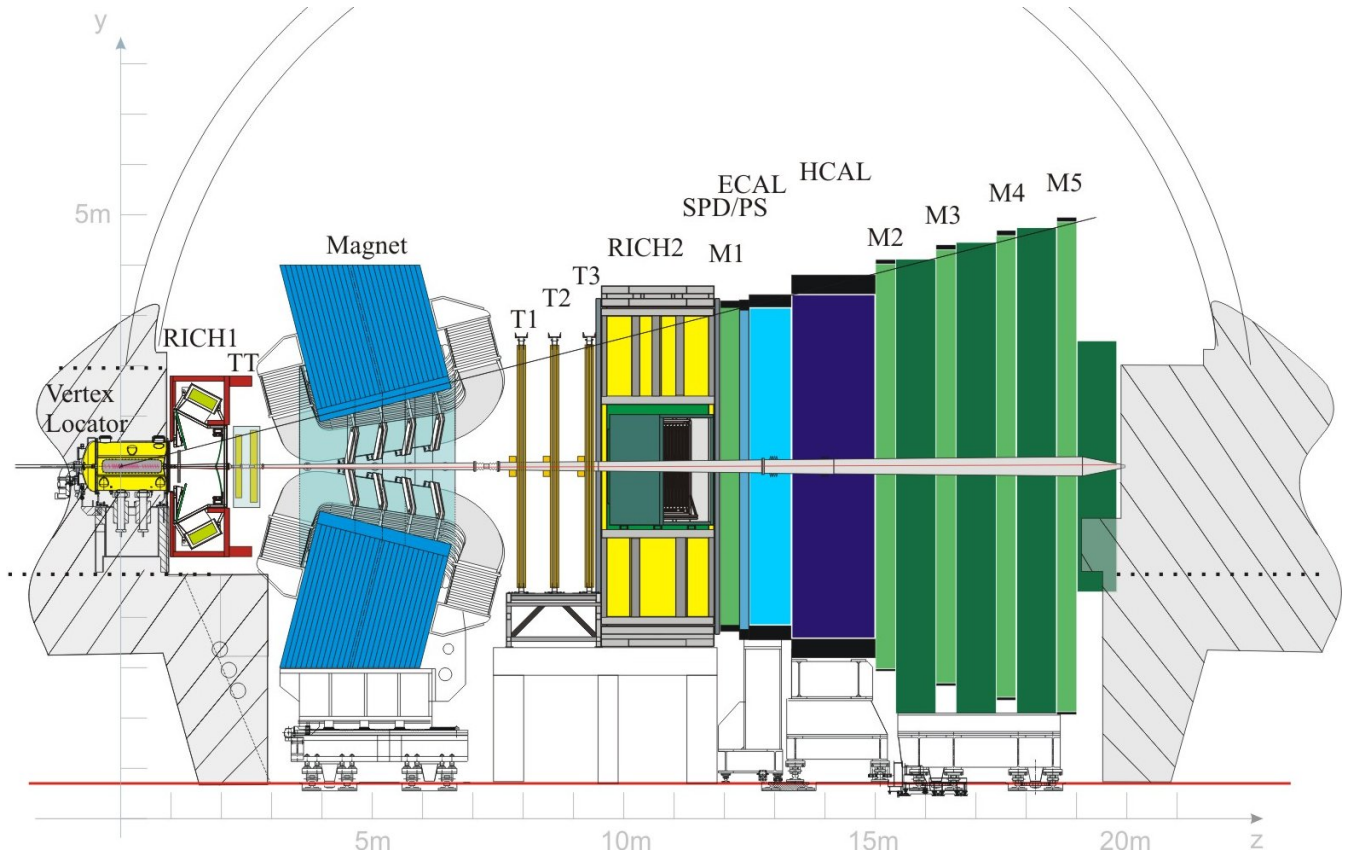
Outline

- View of the LHCb experiment
- Results on heavy quark(onium) production
  - Preliminary results of J/ψ production cross section at $\sqrt{s} = 8$ TeV.
  - J/ψ production cross section at $\sqrt{s} = 2.76$ TeV.
  - Preliminary results of Υ production cross section at $\sqrt{s} = 8$ TeV.
  - χ_c studies: χ_c to J/ψ cross section ratio and χ_{c2} to χ_{c1} cross section ratio.
  - Λ_b production.
- Conclusion and prospect.

The LHCb experiment

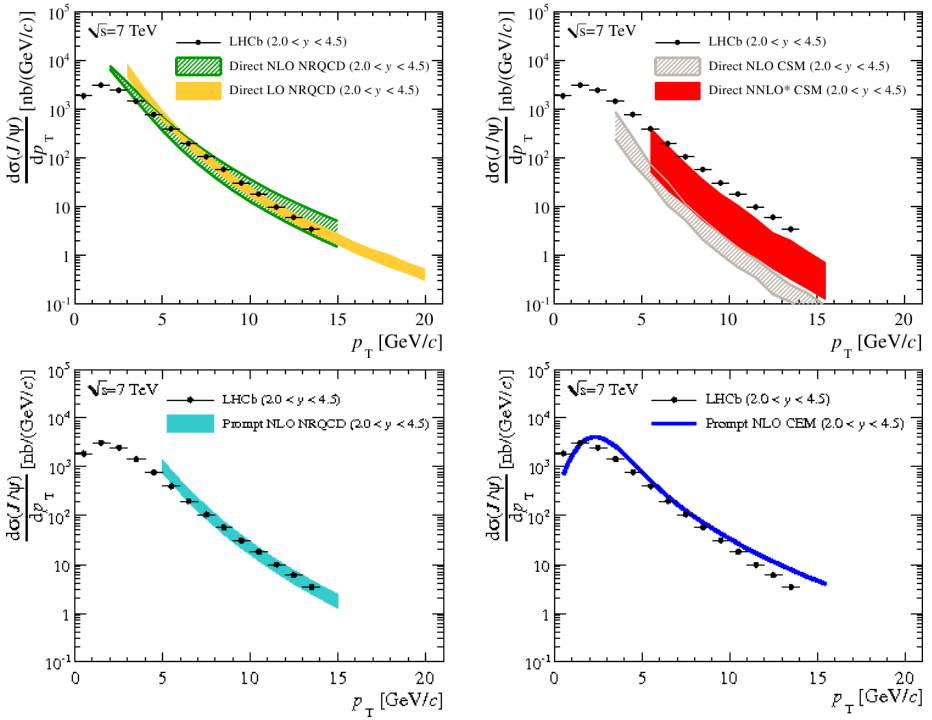
- Single-arm forward spectrometer. Pseudorapidity range: $2 < \eta < 5$.
- Characteristics and performances:
  - Vertexing: proper time resolution 30-50 fs
  - MuonId: $\epsilon(\mu \to \mu) = 97\%$ $\epsilon(\pi \to \mu) = 2\%$
  - Charged tracks $\Delta p/p < 0.4\% - 0.6\%$

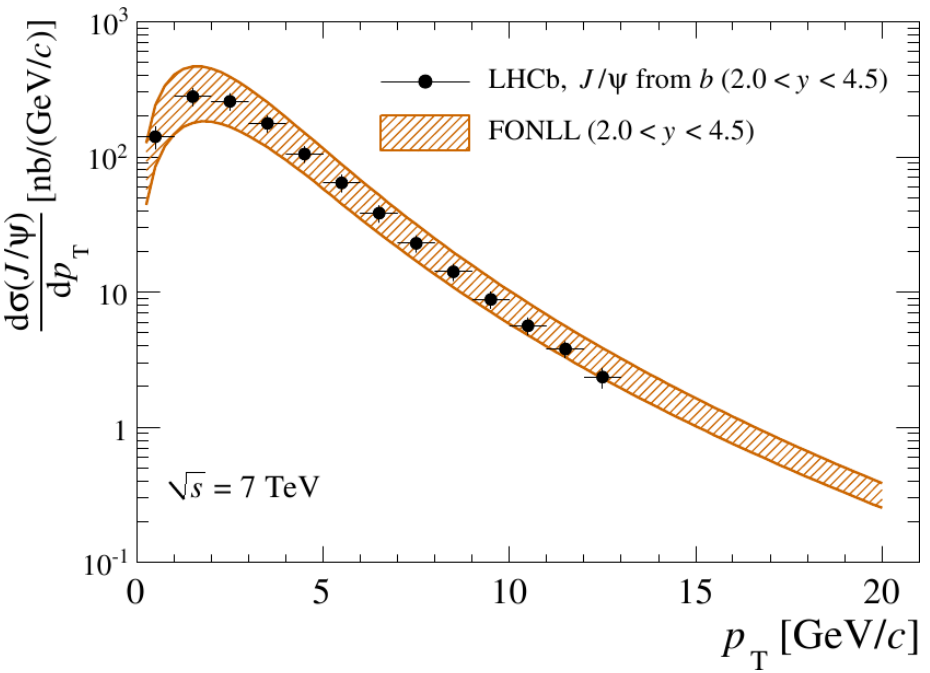


Year	L
2010	**37** pb^{-1} at 7 TeV
2011	**1.1** fb^{-1} at 7 TeV
2012	**2.1** fb^{-1} at 8 TeV

J/ψ and Υ production

- J/ψ and Υ cross section already measured by LHCb at $\sqrt{s} = 7$ TeV with dimuon events (Eur. Phys. J. C 71 (2011) 1645 , Eur. Phys. J. C 71 (2012) 6).



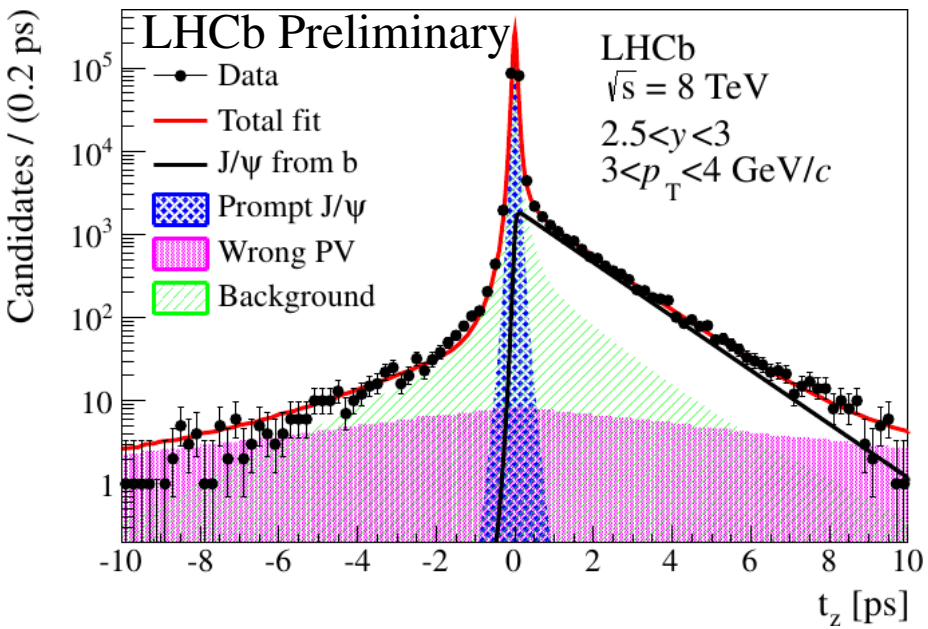


- New measurements at $\sqrt{s} = 8$ TeV and $\sqrt{s} = 2.76$ TeV (only J/ψ cross section) can provide new inputs for theoretical models.
- Same strategy as for the J/ψ and Υ analysis at 7 TeV.

J/ψ and Υ production

$$\frac{d^2\sigma}{dp_T dy} = \frac{N}{L \times \varepsilon_{tot} \times \mathcal{B} \times \Delta p_T \times \Delta y}$$

- 8 TeV data sample: 18 pb^{-1} (J/ψ) and 51 pb^{-1} (Υ).
- 2.76 TeV data sample: 70 nb^{-1}
- Efficiency from Monte Carlo sample and cross-checked with data.



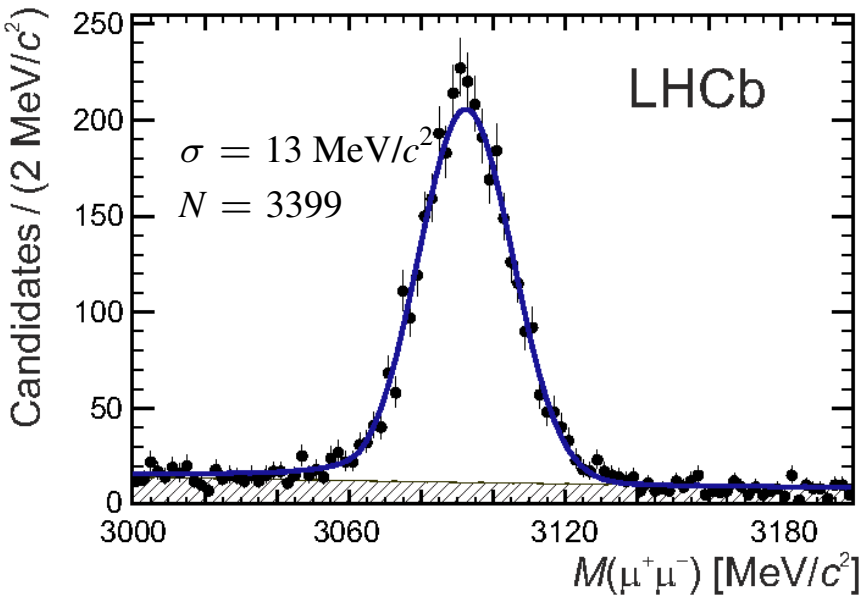
- Use J/ψ pseudo proper time to disentangle prompt J/ψ and J/ψ from b.

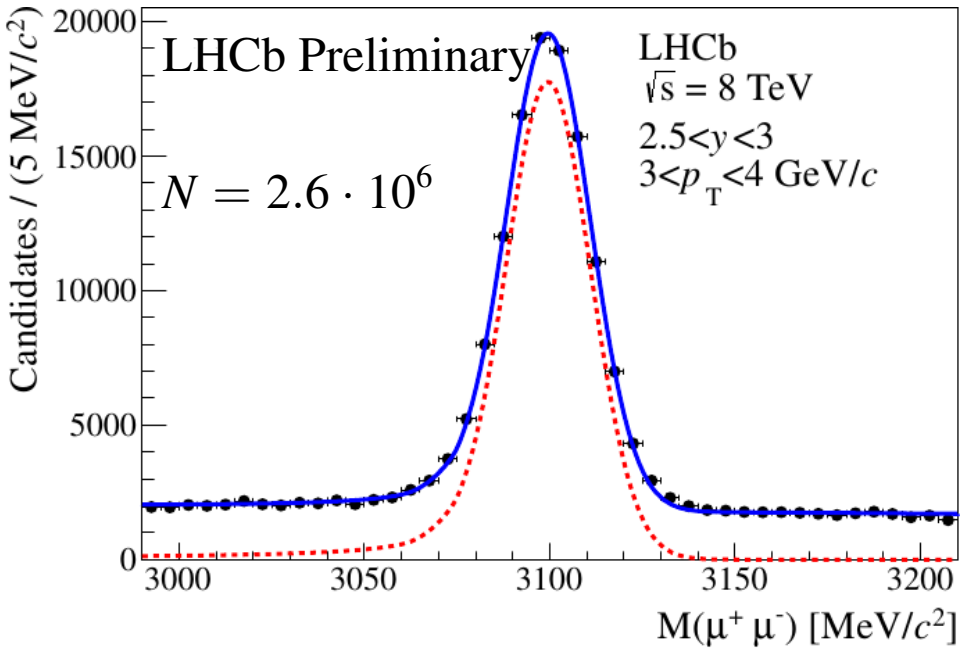
$$t_z = \frac{(z_{J/\psi} - z_{PV})m_{J/\psi}}{p_z}$$

- LHCB-PAP-2013-016 , JHEP 1302 (2013) 041 .

Reconstruction and selection

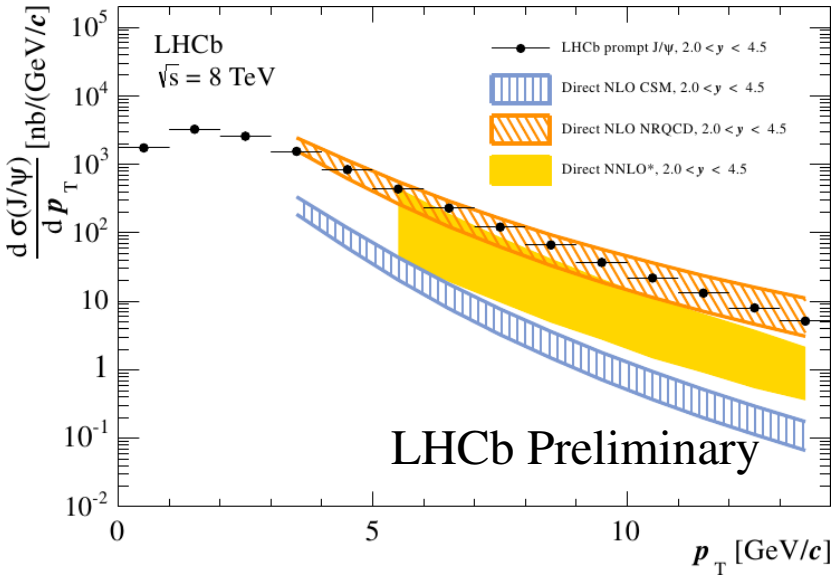
- Same selection as for the J/ψ and Υ analysis at 7 TeV.
- Dimuon trigger to select pair of opposite charged tracks with common vertex.
- Further selection based on track and dimuon vertex quality

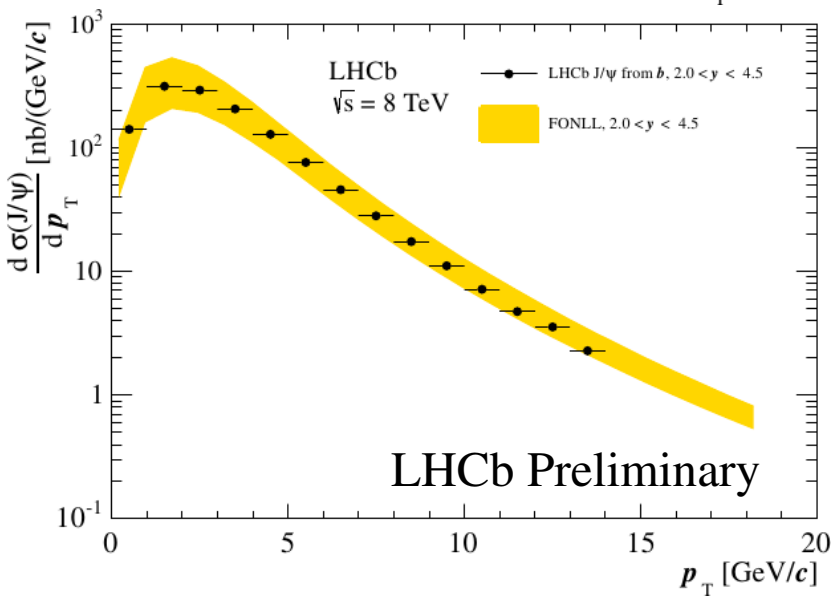




- Signal peaks fitted with Crystal Ball functions.

Prompt and from b cross section at $\sqrt{s} = 8$ TeV

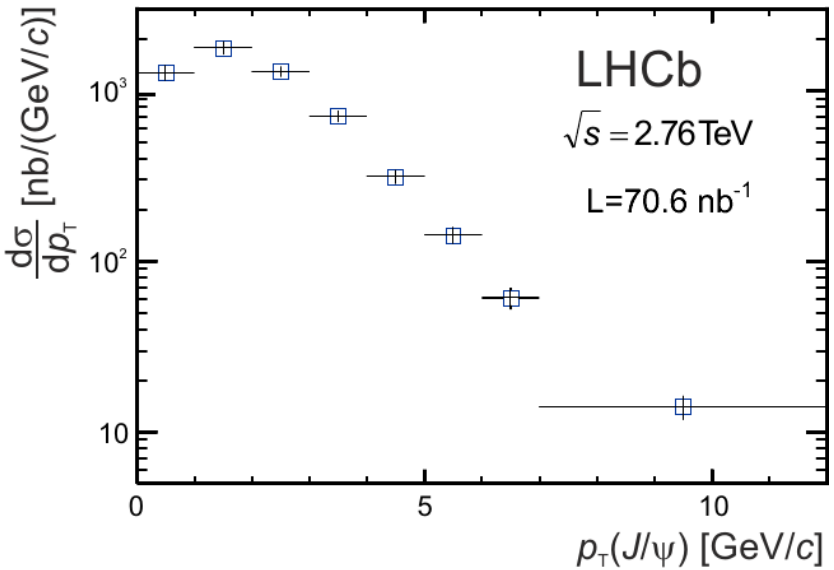




- NRQCD: PRD 84, 051501(R) (2011), PRL 106, 022003 (2011)
- NNLO* CSM: arXiv:0807.3282, arXiv:0811.4005
- NLO CSM: arXiv:hep-ph/0703113

- FONLL: JHEP 1210 (2012) 137, arXiv:hep-ph/9803400

Results at $\sqrt{s} = 2.76$ TeV



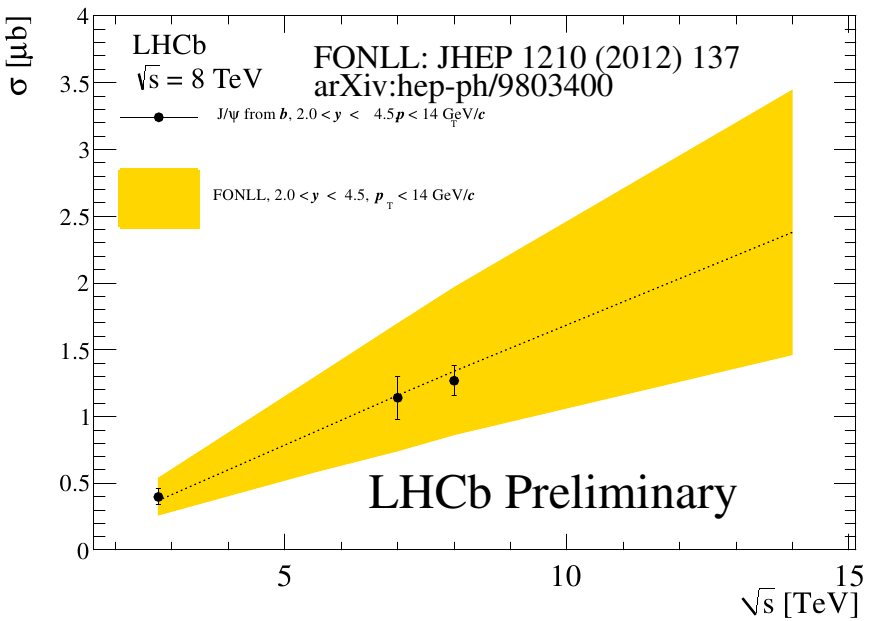
- Inclusive J/ψ cross section at $\sqrt{s} = 2.76$ TeV
- Total cross section in $p_T < 15$ GeV/c and $2 < y < 4.5$ at 2.76 TeV

$$\sigma_{J/\psi} = 5.6 \pm 0.1(\text{stat}) \pm 0.4(\text{syst})\mu\text{b}$$

- Total cross section in $p_T < 15$ GeV/c and $2 < y < 4.5$ at 8 TeV

$$\sigma_{\text{prompt } J/\psi} = 10.94 \pm 0.02(\text{stat}) \pm 0.79(\text{sys})\mu\text{b}$$

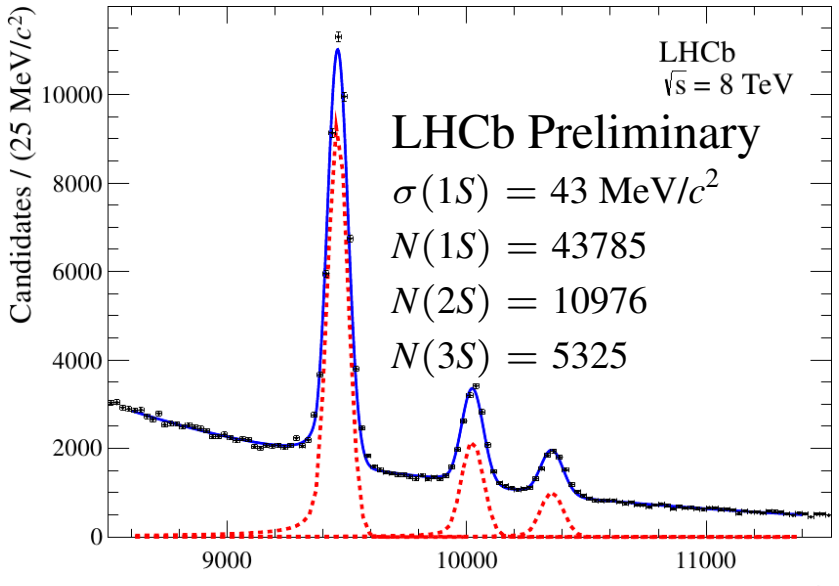
$$\sigma_{J/\psi \text{ from } b} = 1.28 \pm 0.01(\text{stat}) \pm 0.11(\text{sys})\mu\text{b}$$

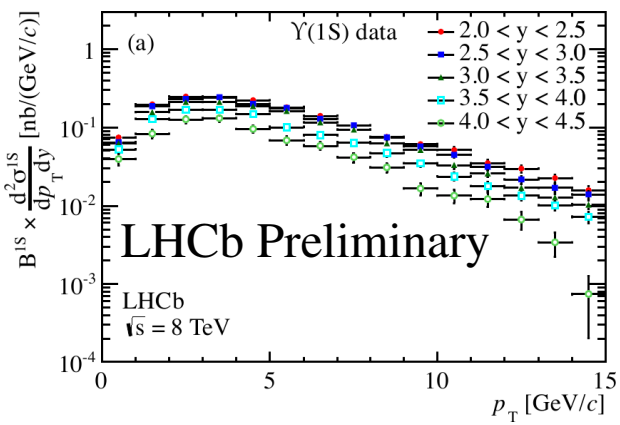


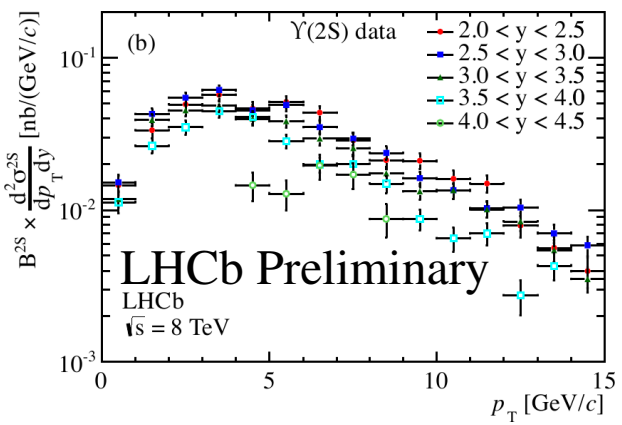
Results: Υ at $\sqrt{s} = 8$ TeV

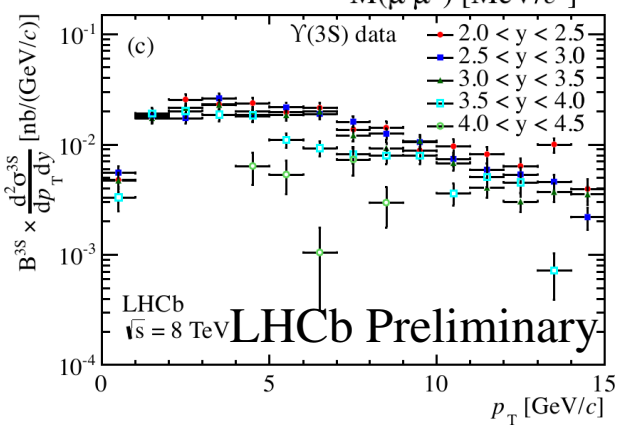
Total cross section in $p_T < 15$ GeV/c and $2 < y < 4.5$:

- $\sigma_{\Upsilon(1S)} \cdot \mathcal{B}^{1S} = 3.241 \pm 0.018 \pm 0.231$nb
- $\sigma_{\Upsilon(2S)} \cdot \mathcal{B}^{2S} = 0.761 \pm 0.008 \pm 0.055$nb
- $\sigma_{\Upsilon(3S)} \cdot \mathcal{B}^{3S} = 0.369 \pm 0.005 \pm 0.027$nb

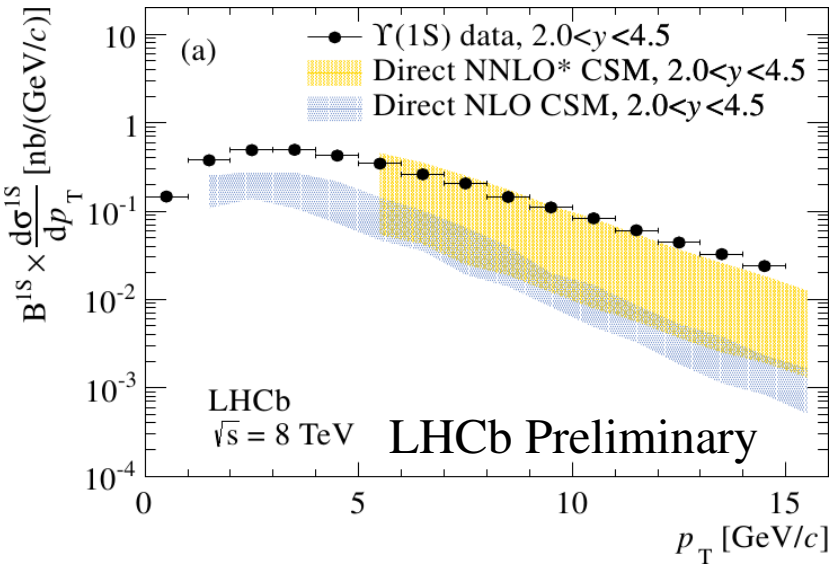


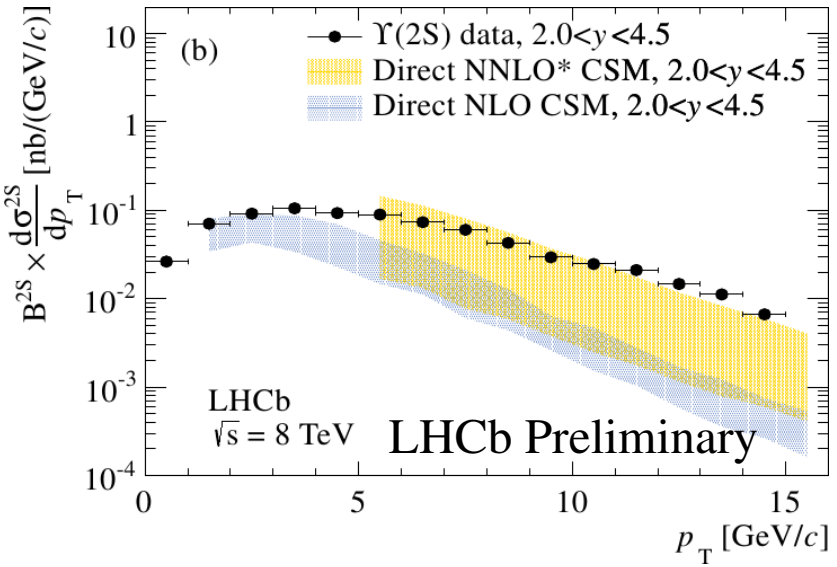


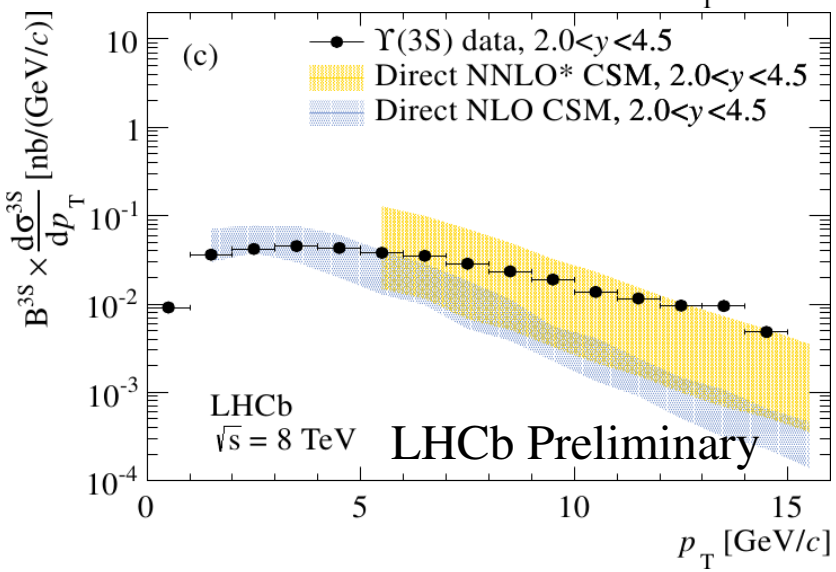




Comparison with theory







- NNLO* CSM: PRL 101 (2008) 152001, EPJ C60:693-703 (2009)
- NLO CSM: PRL 98 (2007) 252002

χ_c production and decay to J/ψ

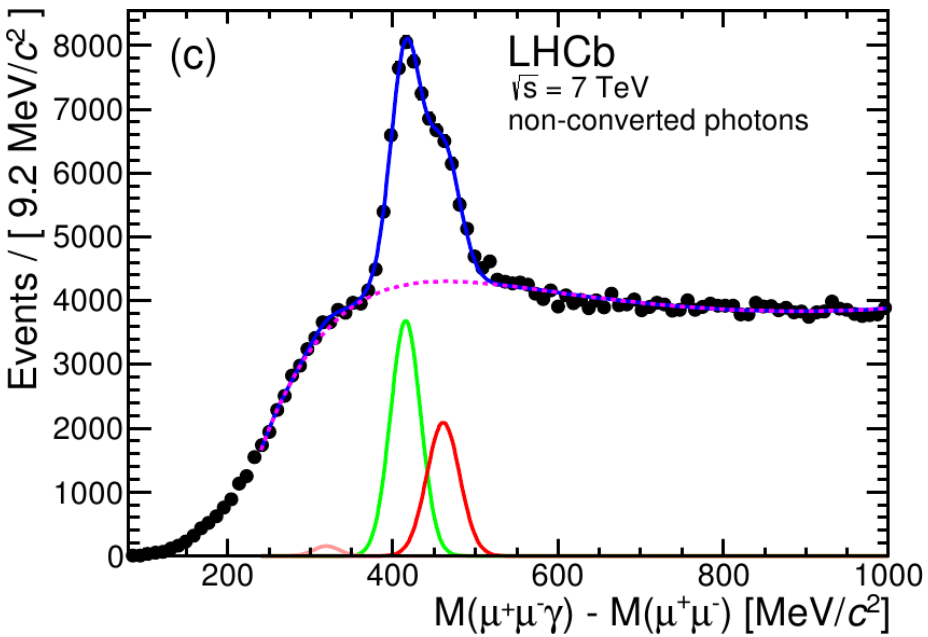
- Studies on χ_c production provide an important test for understanding quarkonium production.
- Production rate of χ_{c2} to χ_1 sensitive to the Color Singlet and Color Octet approach.
- Feed down contribution to prompt J/ψ from χ_c states has consequences on polarization measurement:
  - polarization measured for prompt component, including directly produced + feed from intermediate charmonium states (such as χ_c);
  - polarization of J/ψ from radiative decays from χ_c can be different from directly produced $J/\psi \Rightarrow$ possible source of uncertainty;
  - amount of J/ψ from χ_c decays can quantify the uncertainty.

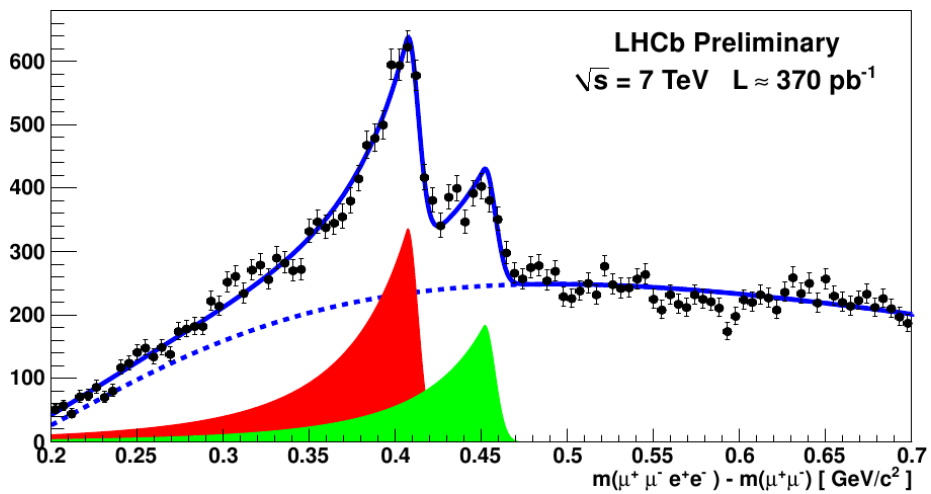
LHCb contributions:

- Ratio of prompt χ_c to J/ψ production cross section through the radiative decay $\chi_c \to J/\psi\gamma$ with $J/\psi \to \mu^+\mu^-$ (PLB 718 (2012), 431).
- Ratio of χ_{c2} to χ_{c1} production cross sections with $\chi_c \to J/\psi\gamma$, $J/\psi \to \mu^+\mu^-$, photons reconstructed in the calorimeter (2010 results PLB 714 (2012), 215) and converted photons (2011 preliminary results LHCb-CONF-2011-062).

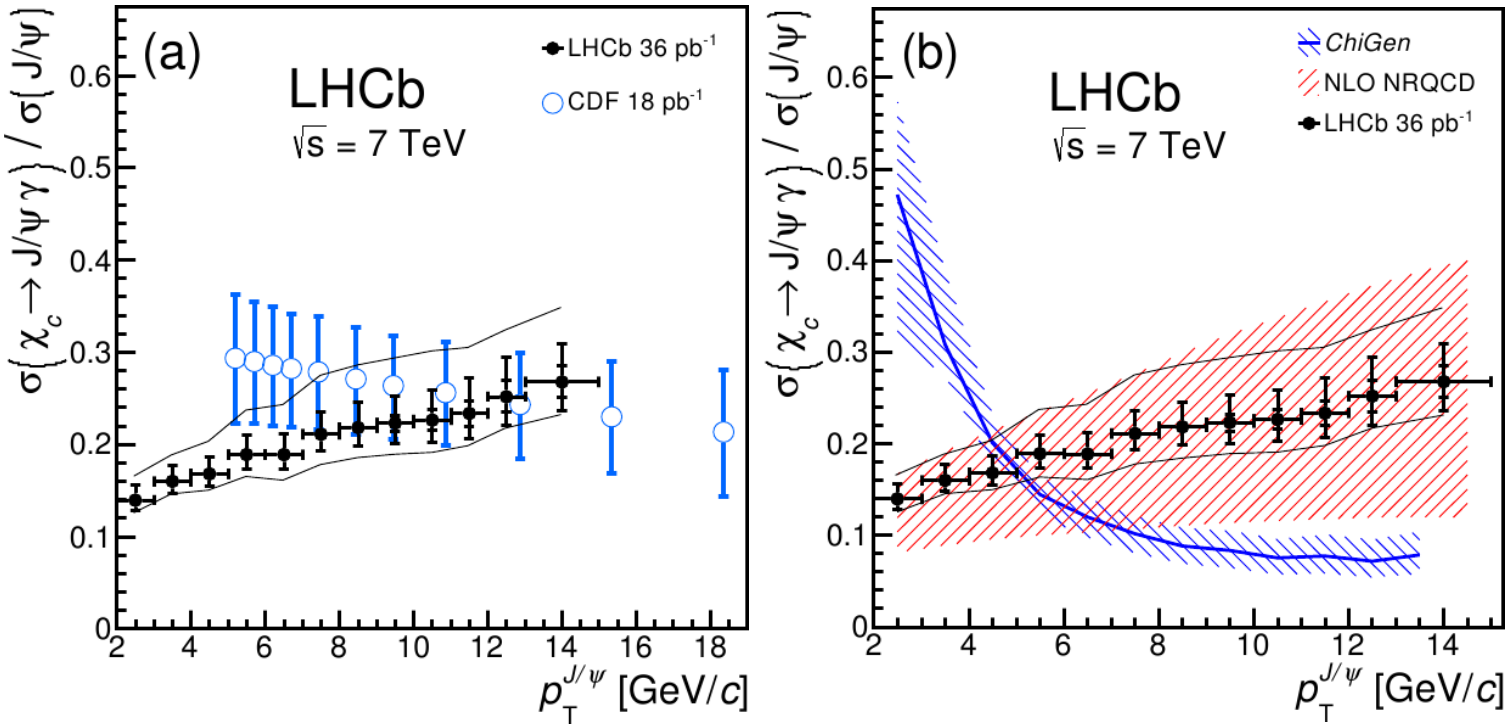
χ_{c2} and χ_{c1} signal yields

- Number of signal events extracted with fit in bins of J/ψ momentum.
- Two kinds of photons used
  - **photons reconstructed in the calorimeter**: high statistics but poor resolution to separate the χ_{cJ} states;
  - **photons converted** in the detector material before the magnet $\gamma \rightarrow e^+e^-$: possibility to resolve the individual χ_{cJ} states (take advantage of the tracker resolution) but low statistics (light material budget in the vertex detector).





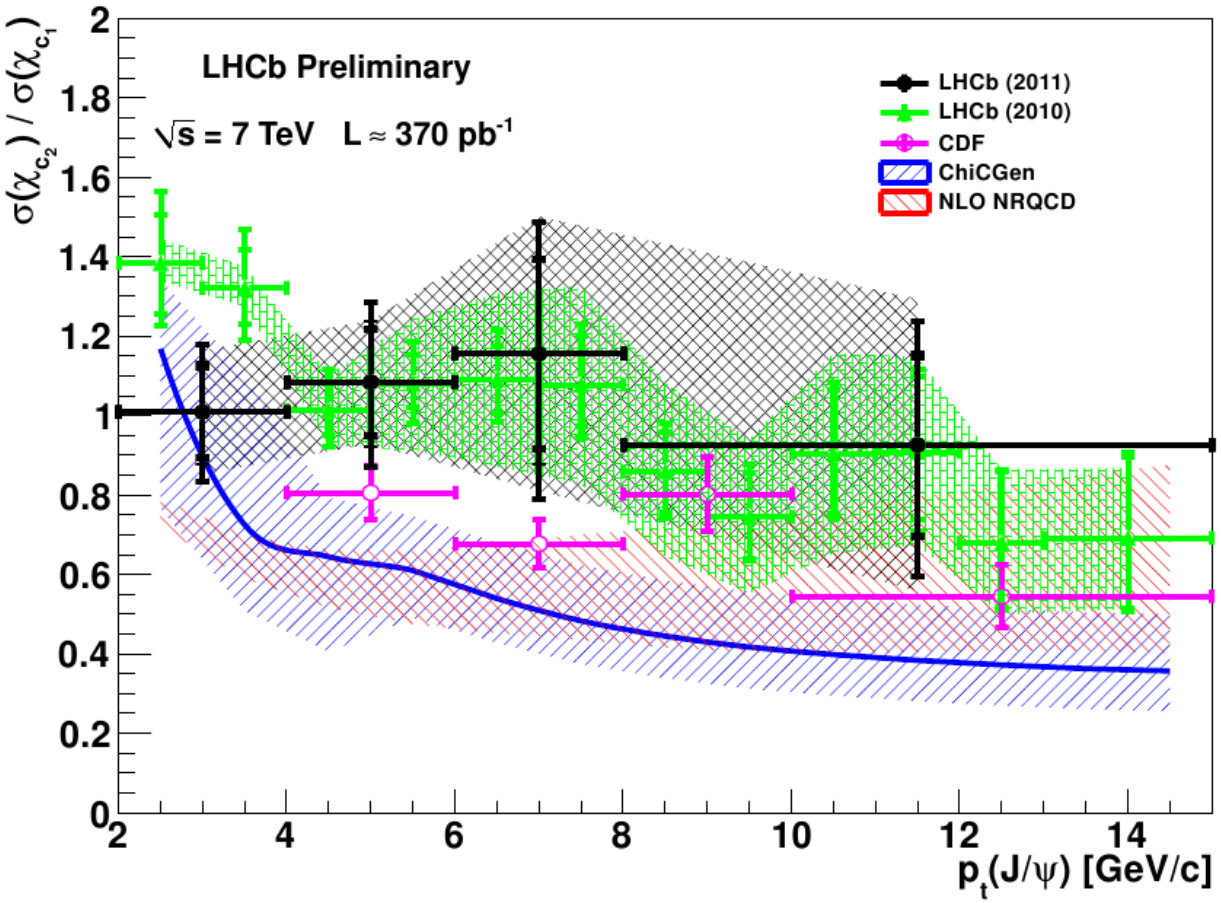
χ_c to J/ψ ratio



- **ChiGen → CSM** (http://projects.hepforge.org/superchic/chigen.html)
- **NRQCD → COM** (Phys. Rev. D 83 111503 R, 2011)

- Main systematic coming from the photon efficiency.
- Good agreement with theoretical expectation from NRQCD models.
- PLB 718 (2012), 431 .

χ_{c2} to χ_{c1} ratio



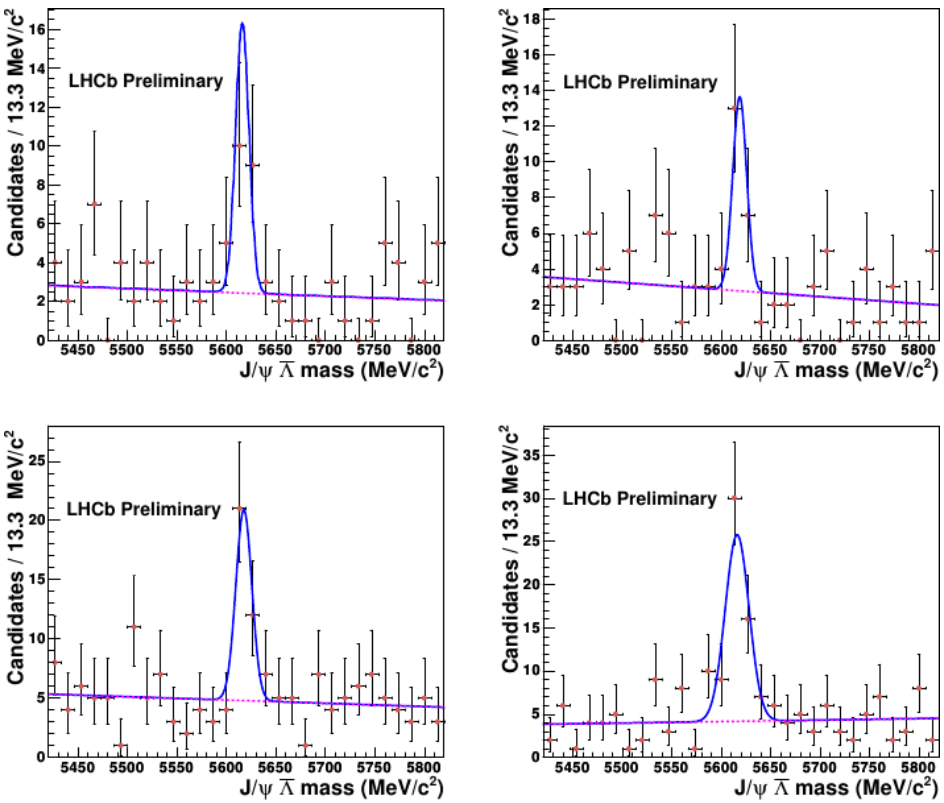
- **ChicGen → CSM** (http://projects.hepforge.org/superchic/chigen.html)
- **NRQCD → COM** (Phys. Rev. D 83 111503 R, 2011)

Good agreement between

- 2011 results with converted photons (LHCb-CONF-2011-062);
- 2010 results, based on 36 pb^{-1} 2010 statistics, using photon detected in the calorimeters (PLB 714 (2012), 215).

Λ_b production

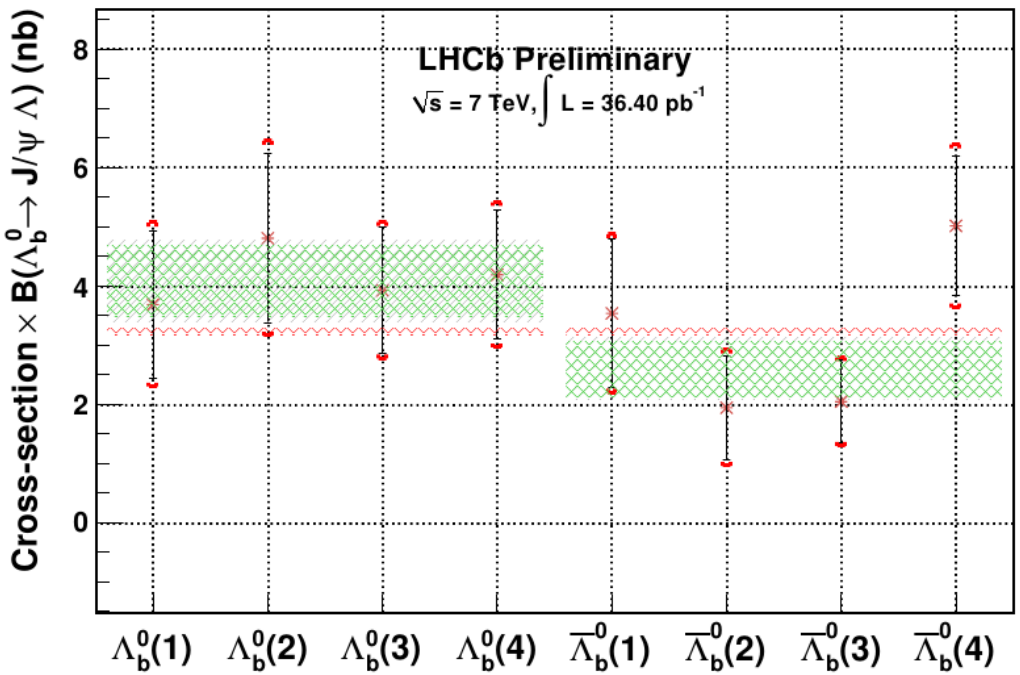
- First measurement of Λ_b^0 production cross section by CMS in the low rapidity region (PL B714 (2012) 136).
- Preliminary measurement from LHCb in the forward region $2.2 < y < 4.5$.



- Using decay mode $\Lambda_b^0 \to \Lambda^0 J/\psi$ with $\Lambda^0 \to p\pi^-$ and $J/\psi \to \mu^+\mu^-$.
- Λ^0 long lived particle $\Rightarrow$ p and π^- reconstructed as long tracks or downstream tracks (only tracking system information).
- Sample divided into 8 categories according to the b quark content, magnet polarity and track type.
- Efficiency correction event-by-event.

Results on Λ_b cross section

- Cross section results in each category.
- Green band: average on Λ_b^0 and $\overline{\Lambda_b}^0$. Red line: expected from LHCb simulation.



- Integrated results (LHCb-CONF-2012-031):

$$\sigma_{\Lambda_b^0} \times \mathcal{B}(\Lambda_b \to \Lambda^0 J/\psi) = [4.08 \pm 0.59(\text{stat}) \pm 0.36(\text{sys})]\,\mu\text{b}$$

$$\sigma_{\overline{\Lambda_b}^0} \times \mathcal{B}(\overline{\Lambda_b} \to \overline{\Lambda^0} J/\psi) = [2.60 \pm 0.46(\text{stat}) \pm 0.26(\text{sys})]\,\mu\text{b}$$

Conclusion

- LHCb performed provides lots of contributions in the heavy quark and quarkonium sector.
- J/ψ production cross section has been measured at $\sqrt{s} = 8$ TeV and $\sqrt{s} = 2.76$ TeV for prompt and from b J/ψ.
- Υ production cross section has been measured at $\sqrt{s} = 8$ TeV.
- Measurement of χ_{c2} to χ_{c1} production cross section and study of relative χ_c to J/ψ production using radiative decays.
- Production cross section of Λ_b.
- More other analysis published:
  - Measurement of the fraction of $\Upsilon(1S)$ originating from $\chi_b(1P)$ decays in pp collisions at $\sqrt{s} = 7$ TeV **J. High Energy Phys. 11 (2012) 031**
  - Measurement of $\psi(2S)$ meson production in pp collisions at $\sqrt{s} = 7$ TeV **Eur. Phys. J. C 72 (2012) 2100**
  - Measurements of the $\Lambda_b^0 \to \Lambda J/\psi$ decay amplitudes and the Λ_b^0 polarisation in pp collisions at $\sqrt{s} = 7$ TeV **arXive 1302.5578**
  - Observation of double charm production involving open charm in pp collisions at $\sqrt{s} = 7$ TeV **J. High Energy Phys. 06 (2012) 141**