Double Charmonium Production

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Outline

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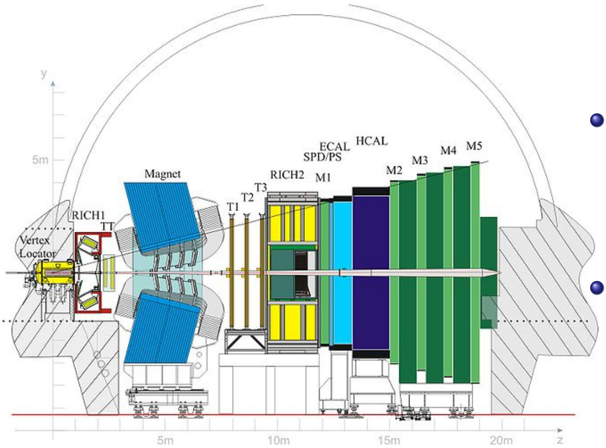
Why Double Charmonium Production Studies?

- Quarkonium production at hadron colliders has represented a tough challenge since its first evidence.
- A combination of Color Octect and Color Singlet mechanisms describe the p_T spectrum and cross-sections but the polarization remains elusive, see for example Giulia's talk.
- Double charmonium provides a good testing ground to test CO v. CS.

Studying Double Charmonium Production

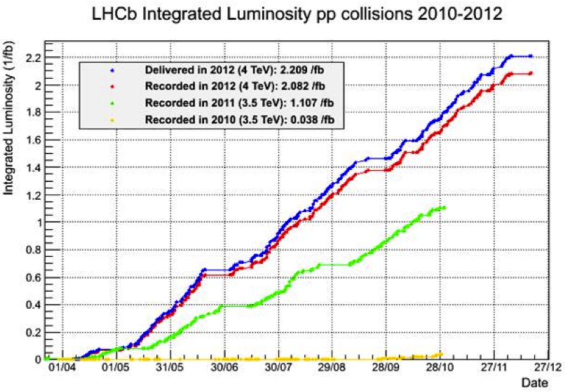
- We are looking for:
  - The production of $c\bar{c}c\bar{c}$ with 2 J/ψ in the final state, but it is also possible to look for the final states J/ψ + Open Charm (OC) or same sign OC+OC.
  - It is worth noticing opposite sign OC+OC comes as a freebie in this kind of analysis.
- We need excellent:
  - Tracking and momentum resolution and ultimately mass resolution.
  - Efficient trigger for muons and hadrons.
  - Muon identification, vertex resolution, impact parameter resolution etc..
- LHCb is the natural place!

The LHCb Detector



- Momentum resolution $\sim 0.5\%$ with J/ψ mass resolution of $\sim 13\,\mathrm{MeV}/c^2$
- Pion $\rightarrow$ Muon misidentification $\sim 0.7\%$.

The Dataset



- 2 J/ψ analysis based, on the 0.038 fb^{-1} collected in 2010 with sneak preview on the results obtained with the 1.107 fb^{-1} from 2011.
- J/ψ +OC and OC+OC based on the first 0.355 fb^{-1} collected in 2011.

The Trigger

- Three stages trigger: the first hardware, the others software.
- 2 J/ψ events:
  - L0 One or two high p_T muons.
  - Hlt1 Reconstruct the muon(s), or a muon and an high p_T hadron, selection applied based on IP, p_T and mass
  - Hlt2 Confirmation of the muons and/or hadron.
- J/ψ +OC and OC+OC
  - L0 High p_T μ, 2μ, $e^{\pm}$, hadron or γ.
  - Hlt1 Reconstruct the muon(s) or the hadron, selection applied based on IP, p_T and mass.
  - Hlt2 Reconstruct the J/ψ and/or the OC.

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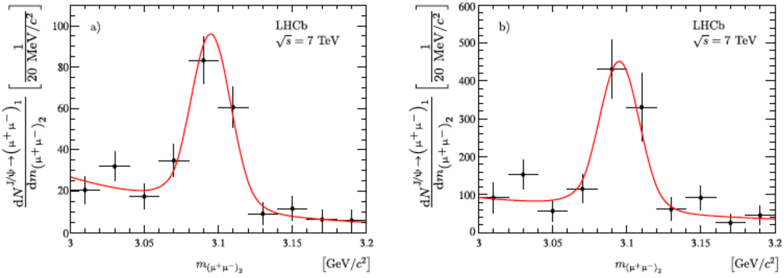
The Analysis Strategy

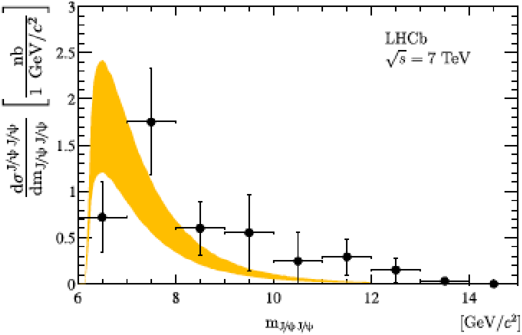
- Define a fiducial volume in the LHCb acceptance: $2.0 < y < 4.5$ and $p_T < 10\,\mathrm{GeV}/c$.
- Reconstruct $J/\psi \rightarrow \mu^+\mu^-$
- Remove background as much as possible:
  - Cuts on the usual kinematic and reconstruction variables.
  - Require that both J/ψ originate from the same interaction.
  - Require both J/ψ decay vertices are compatible with the primary vertex.
  - This removes the background from double $B \rightarrow J/\psi X$ decays.
- Require one of the J/ψ triggered the event.
- Subtract the remaining background.
- Apply per-event efficiency corrections, with efficiency determined as much as possible from data.

The Double Charmonium Signal



- $m_{(\mu^+\mu^-)_1}$ is fitted in bins of $m_{(\mu^+\mu^-)_2}$ and vice-versa.
- From the fitted yields one can extract the double charmonium yield.
- The yield of double charmonium events in 0.038 fb^{-1} with both J/ψ in the fiducial volume and triggered by at least one J/ψ candidate is 116 $\pm$ 16.
- The measured cross-section is $\sigma = 5.1 \pm 1.0 \pm 1.1$ nb.
- To be compared to theoretical CS prediction of 4 nb.

The Double Charmonium Production Cross Section



- Repeating the analysis in bins of $m_{J/\psi\, J/\psi}$ one can obtain the differential cross section as function of the mass of the J/ψ J/ψ system.
- Theoretical prediction taking into account both prompt and feed-down from $\Psi(2s)$ is also shown, Berezhnoy et al. [arXiv:1101.5881]

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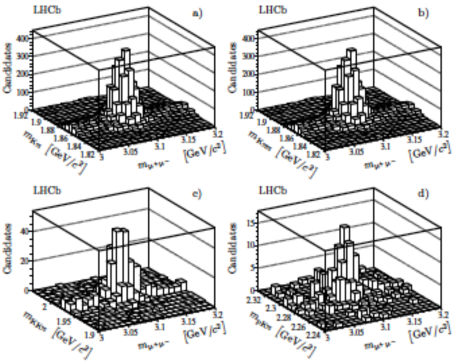
The Analysis Strategy

- Similar to the one for double charmonium.
- Define a fiducial volume in the LHCb acceptance: $2.0 < y < 4.0$ and $p_T < 12\,\mathrm{GeV}/c$.
- Reconstruct $J/\psi \to \mu^+\mu^-$
- Reconstruct $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to (K^+K^-)_\Phi\pi^+$, and $\Lambda_c \to p^+K^-\pi^+$.
- Remove background as much as possible:
  - Cuts on the usual kinematic and reconstruction variables.
  - Require that both originate from the same interaction.
  - Require both decay vertices are compatible with the primary vertex.
- J/ψ +OC require the J/ψ to have triggered the event, OC+OC require one of the hadrons to have triggred the event.
- Subtract the remaining background.
- Apply per-event efficiency corrections, with efficiency determined as much as possible from data.

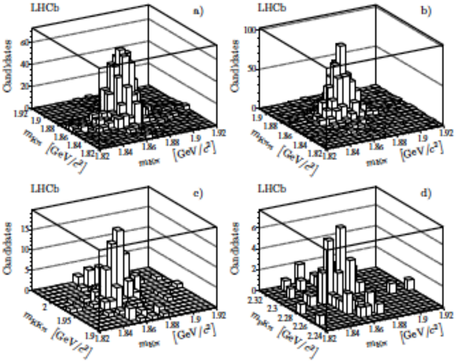
J/ψ + Open Charm



Clear $c\bar{c}c\bar{c}$ signals:

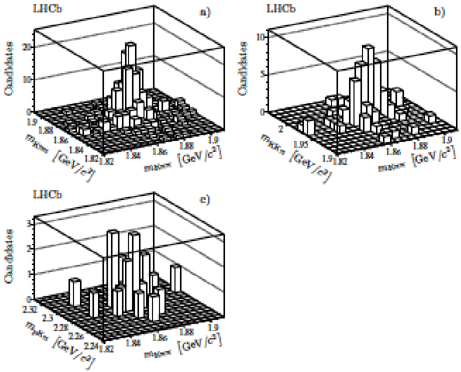
	Mode	Yield
a)	J/ψ D^0	4875 ± 86
b)	J/ψ D^+	3323 ± 71
c)	J/ψ D_s^+	328 ± 22
d)	J/ψ Λ_c^+	116 ± 14

Open Charm + Open Charm: D^0 channels



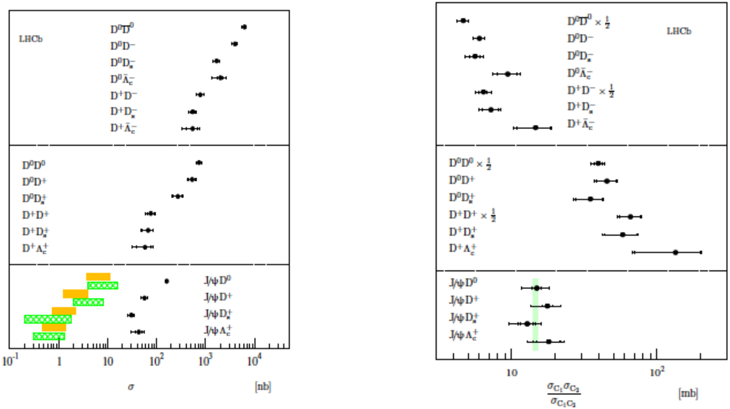
	Mode	Yield
a)	$D^0\ D^0$	1087 ± 37
b)	$D^0\ D^+$	1177 ± 39
c)	$D^0\ D_s^+$	111 ± 12
d)	$D^0\ \Lambda_c^+$	41 ± 8
	$D^0\ \bar{D}^0$	10080 ± 105
	$D^0\ D^-$	11224 ± 112
	$D^0\ D_s^-$	859 ± 31
	$D^0\ \Lambda_c^-$	208 ± 19

Open Charm + Open Charm: D^+ channels



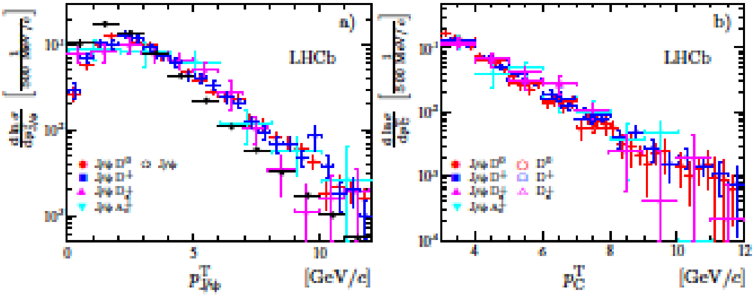
	Mode	Yield
a)	$D^+ D^+$	249 ± 19
b)	$D^+ D_s^+$	52 ± 9
c)	$D^+ \Lambda_c^+$	21 ± 5
	$D^+ D^-$	3236 ± 61
	$D^+ D_s^-$	419 ± 22
	$D^+ \Lambda_c^-$	127 ± 14

Cross Sections



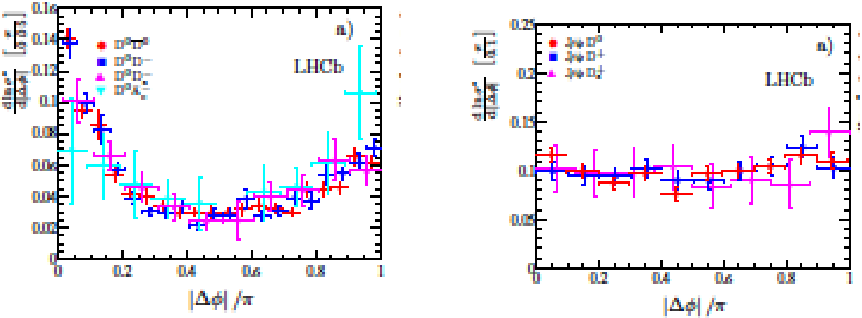
- J/ψ +OC cross section compared to $gg \to J/\psi\, c\bar{c}$ calculations (Berezhnoy et al. Phys. Rev. D 57 (1998) 4385, Baranov Phys. Rev. D73 (2006) and Lansberg Eur. Phys. J. C 61(2009) 693)
- Ratios compared to DPS extrapolation of Tevatron data.

J/ψ p_T in J/ψ +OC events



- The J/ψ p_T spectrum appears to be harder than the one of the prompt J/ψ.
- This does not seem to be the case for the open charm hadron.

Azimuthal Angle Correlation



- There appears to be no correlation between the azimuthal angle of the J/ψ and the open charm.
- The same behaviour is observed in same sign OC+OC.
- On the other hand opposite sign OC+OC show a peak at $\Delta\Phi \to 0$ suggesting a $g \to c\bar{c}$ splitting contribution.

Outline

Conclusions

- LHCb has made the first observation of double charmonium production at hadron colliders.
- The first results, based on only 0.038 fb^{-1} at 7 TeV indicate agreement with theoretical predictions.
- The analysis of the full 1 fb^{-1} statististics at 7 TeV is ongoing so stay tuned for new results soon.
- Samples of J/ψ + Open Charm and Open Charm + Open Charm, both same sign and opposite sign, have also been identified.
- Cross section and ratios have been measured and various kinematic quantities have been investigated.