Recent results in B_c physics at LHCb

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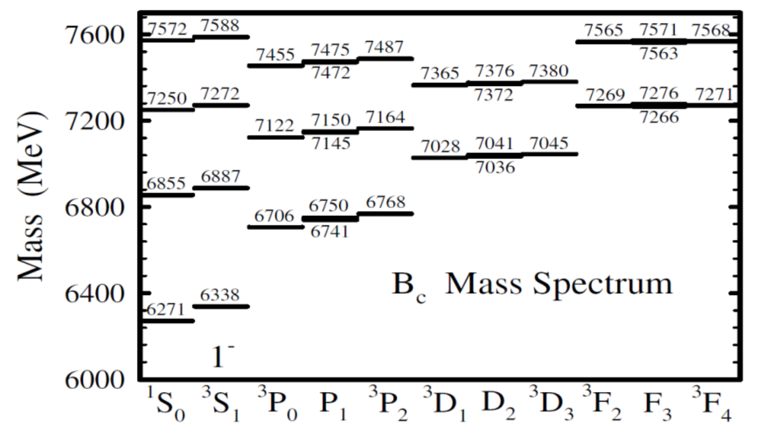
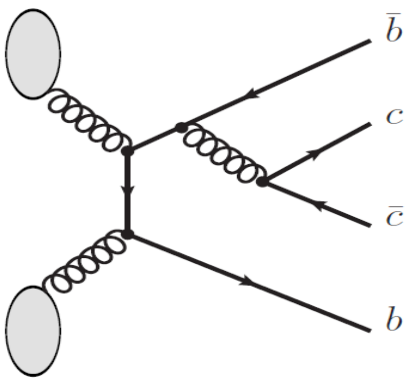
B_c physics

- The only meson composed of different heavy flavour quarks
- Mass spectrum similar to quarkonium states
- Production: mainly through gg fusion at hadron colliders
- Large production rate at LHC!
  - $\sigma(B_c)_{LHC}/\sigma(B_c)_{Tevatron} \sim O(10)$
  - $\sigma(B_c)\sim 0.4$ μb at $\sqrt{s} = 7$ TeV, ~ 0.9 μb at 14 TeV



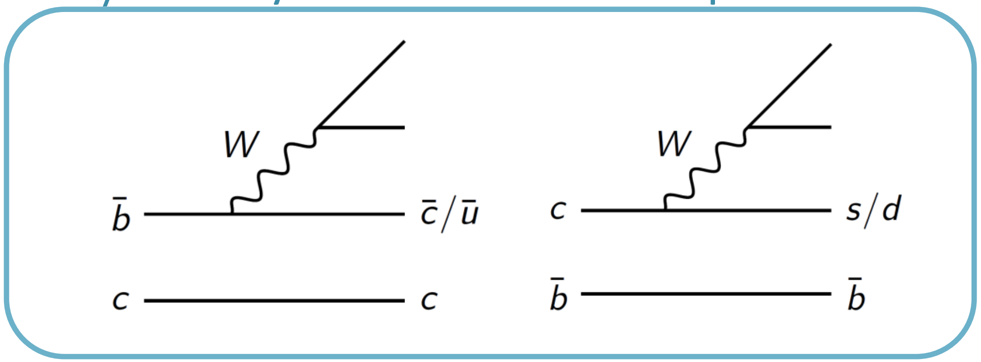
Godfrey, PRD.70(2004) 054017



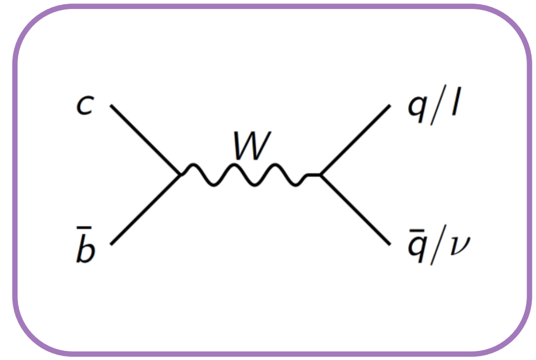
B_c decays

- Excited states decay to B_c through strong/EM interaction
- Ground state only decays weakly

$\bar{b}/c$ decay with the other as spectator



annihilation



~ 20% | **~ 70%** | **~ 10%**

$B_c^+ \to$

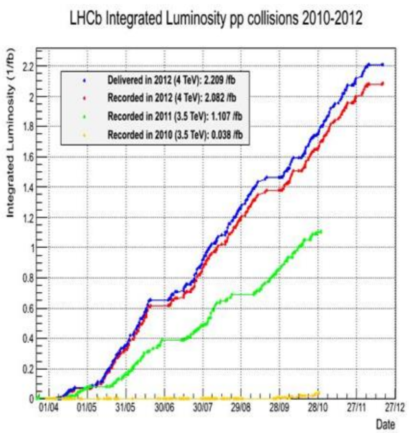
- ~20%: $J/\psi\, l\nu, J/\psi\, \pi^+$, $J/\psi\, \pi^+\pi^-\pi^+$, $\psi(2S)\pi^+, J/\psi D_s^{(*)+}$, …
- ~70%: $B_s\pi^+, B_s\, l\nu$, …
- ~10%: $\overline{K^*}K^+, \tau^+\nu$ …

Only $\bar{\mathrm{b}} \to \bar{\mathrm{c}}W$ observed so far

- Rich decay modes ⇒ lifetime shorter than other B mesons
  - $\tau = 0.453 \pm 0.041$ ps CDF,PRL 97(2006)012002; D0,PRL 102(2009)092001

LHCb detector

See Previous talks by
J. Bressieux, M. Adinolfi, Y. Zhang



Successful data taking since 2010

---- 2010: 37 pb^{-1}

---- 2011: 1.0 fb^{-1}

---- 2012: 2 fb^{-1}

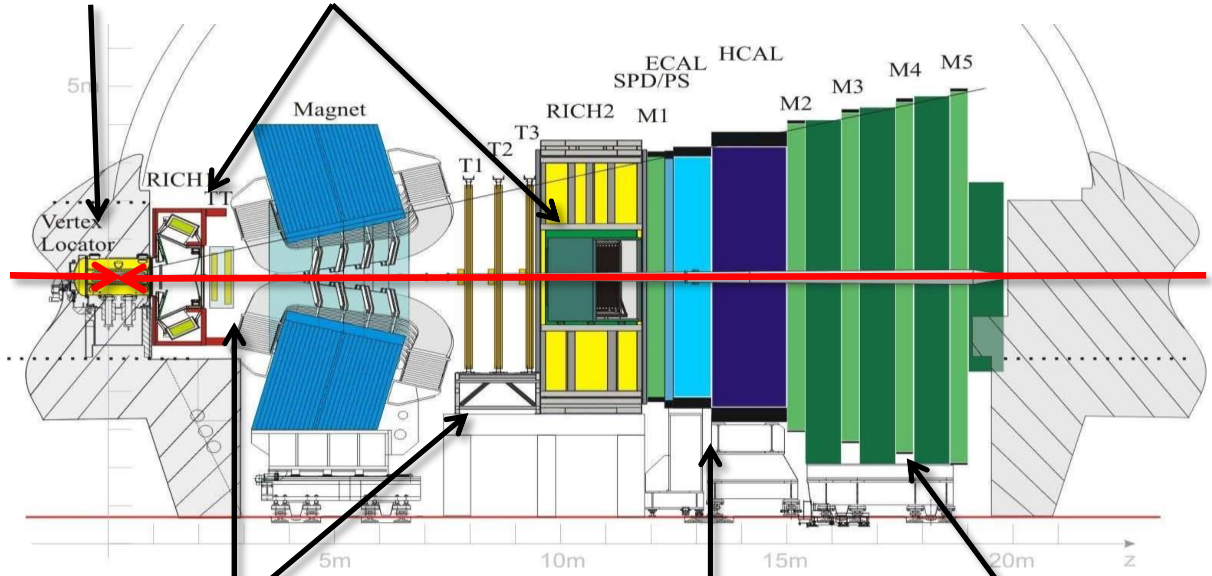
VELO

σ_{IP}~ 20μm for high p_T tracks

RICH

$\varepsilon(K \to K)$~95%

$\pi - K$ misID ~5%



Tracking

>96% efficiency for long tracks

CALO

ECAL resolution:

$1\% + 10\%/\sqrt{E}$[GeV])

Muon system

$\varepsilon(\mu \to \mu)$~95%

$\pi - \mu$ misID ~5%

Trigger system reduces the data rate from 40MHz to 3—5kHz

- 90% efficiency for dimuon channels; ~ 30% efficiency for hadronic final states

B_c production using $B_c \to J/\psi\pi^+$

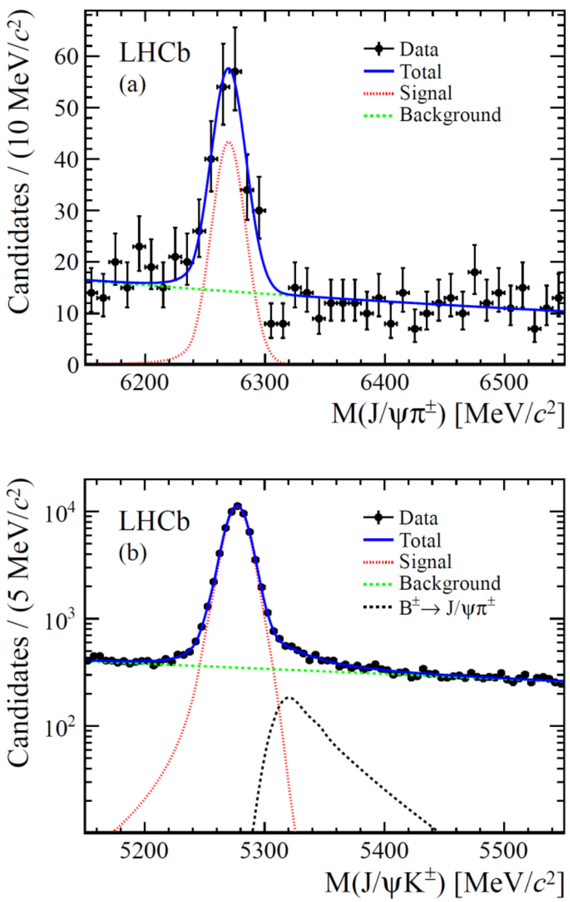
PRL109(2012) 232001

- $B_c^+ \to J/\psi\,\pi^+$, $J/\psi \to \mu^+\mu^-$, normalisation channel $B^+ \to J/\psi\,K^+$
- Based on 0.37 fb^{-1} data @ 7 TeV
  - Signal fitted with double-sided Crystal Ball function
  - Cabibbo suppressed background for $B^+ \to J/\psi K^+$ is considered

$p_T > 4$ GeV, $2.5 < \eta < 4.5$

$$\frac{\sigma(pp \to B_c^+ X)\cdot\mathcal{B}(B_c^+ \to J/\psi\pi^+)}{\sigma(pp \to B^+ X)\cdot\mathcal{B}(B^+ \to J/\psi K^+)} = (0.68 \pm 0.10(\text{stat.}) \pm 0.03(\text{syst.}) \pm 0.05(\text{lifetime}))\%$$

  - Efficiencies are calculated in individual (p_T, η) bins
  - Systematic uncertainty is dominated by uncertainty on B_c lifetime



B_c mass

PRL109(2012) 232001

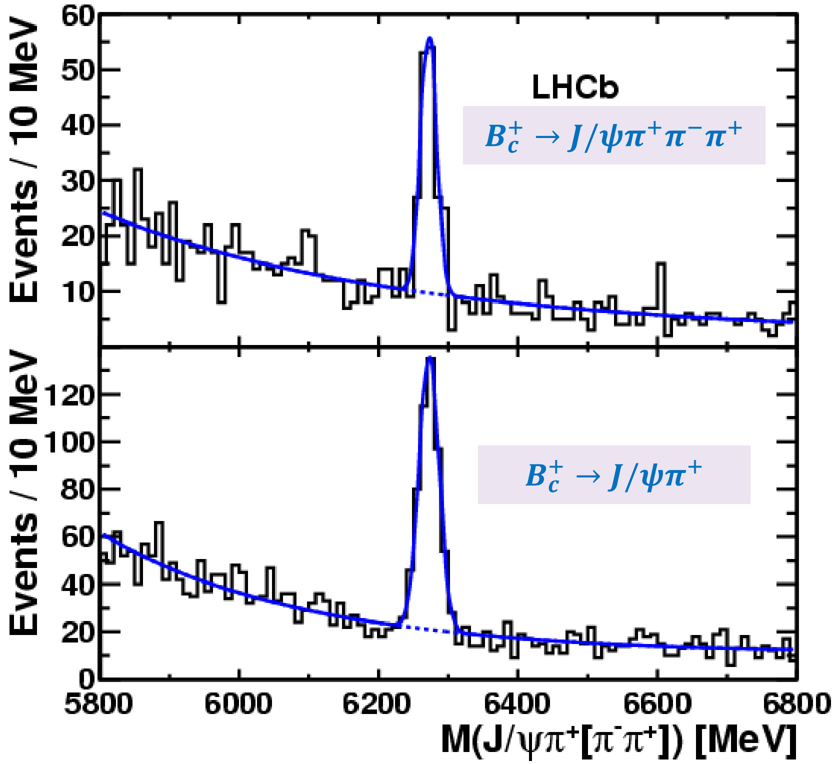
- Measurement of mass difference $M(B_c^+) - M(B^+)$ is obtained by simultaneous fit of $J/\psi\pi^+$ and $J/\psi K^+$ invariant mass spectra
- The uncertainties due to detector description and alignment are cancelled in mass difference measurement
- The main systematic uncertainty comes from momentum scale calibration

$$M(B_c^+) = 6273.7 \pm 1.3(\text{stat.}) \pm 1.6(\text{syst.})\ \text{MeV}/c^2$$
$$M(B_c^+) - M(B^+) = 994.6 \pm 1.3(\text{stat.}) \pm 0.6(\text{syst.})\ \text{MeV}/c^2$$

Observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$

PRL108(2012) 251802

- Expected BR larger than $B_c^+ \to J/\psi\,\pi^+$ by 1.5 − 2.3
  Rakitin and Koshkareav, PRD80,014005
  Likhoded and Luchinsky, PRD81,014015
- The yield is smaller due to the limited detector acceptance
- 0.8 fb^{-1} data at $\sqrt{s} = 7$ TeV
- Selection based on ratio of S/B likelihood as functions of discriminating variables:
  - *IP, vertex fit quality, angle between final state particles*



N($B_c^+ \to J/\psi\,\pi^+\,\pi^-\,\pi^+$) = 135 ± 14
N($B_c^+ \to J/\psi\,\pi^+$) = 414 ± 25

First observation!

Confirmed by CMS CMS-PAS-BPH-11-003

Branching fraction

PRL108(2012) 251802

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 2.41 \pm 0.30(\text{stat.}) \pm 0.33(\text{syst.})$$

- Main contribution to the systematic uncertainty: model dependence of the efficiency estimation
- Consistent with the theoretic prediction $1.9 - 2.3$
  Likhoded and Luchinsky, PRD81,014015
- Also in agreement with $\frac{\mathcal{B}(B^+ \to \bar{D}^{*0}\pi^+\pi^-\pi^+)}{\mathcal{B}(B^+ \to \bar{D}^{*0}\pi^+)} = 2.0 \pm 0.3$

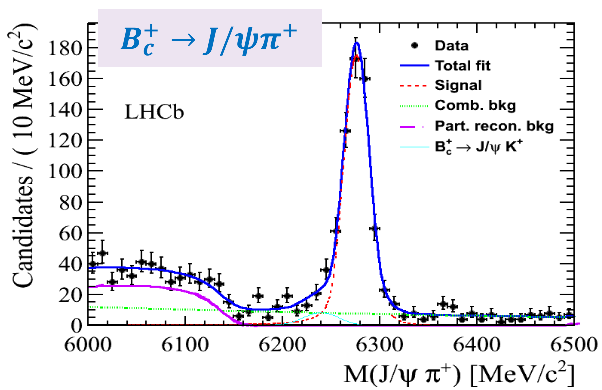
PDG 2010

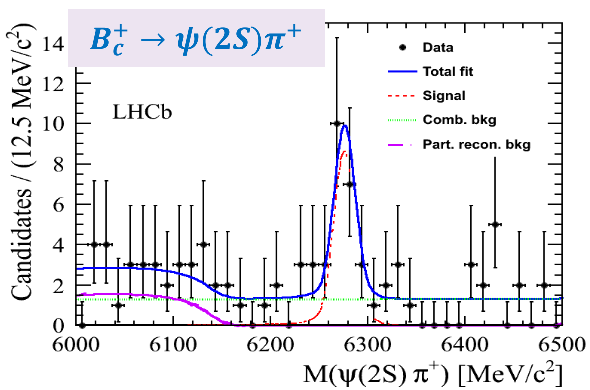
The first test of theoretical predictions for B_c^+ decay branching fractions

Observation of $B_c^+ \to \psi(2S)\pi^+$

arXiv:1303.1737, to appear in PRD

- Similar event topology and identical final states
- Search for the decay performed with 1 fb^{-1} data @ 7 TeV
- Event selection using boosted decision tree (BDT)
  - Input variables based on kinematics and event geometry





Signal: double-sided CB
background components:
- Combinatorial
- Partially reco'd eg. $J/\psi\rho^+$
- $B_c^+ \to J/\psi K^+$

First observation with 5.2σ significance!

Theoretical predictions range from 0.13 to 0.42

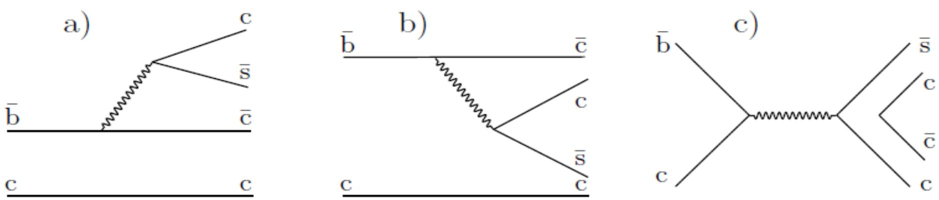
Chang and Chen, PRD49(1994) 3399
Liu and Chao, PRD56(1994) 4133
Colangelo and De Fazio, PRD(2000)034012 ← Favours relativistic quark model
Ebert, Faustov and Galkin, PRD68(2003) 094020
Qiao et al, arXiv:1209.5859

$$\frac{\mathcal{B}(B_c^+ \to \psi(2S)\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 0.250 \pm 0.068(\text{stat}) \pm 0.014(\text{syst}) \pm 0.006(\mathcal{B})$$

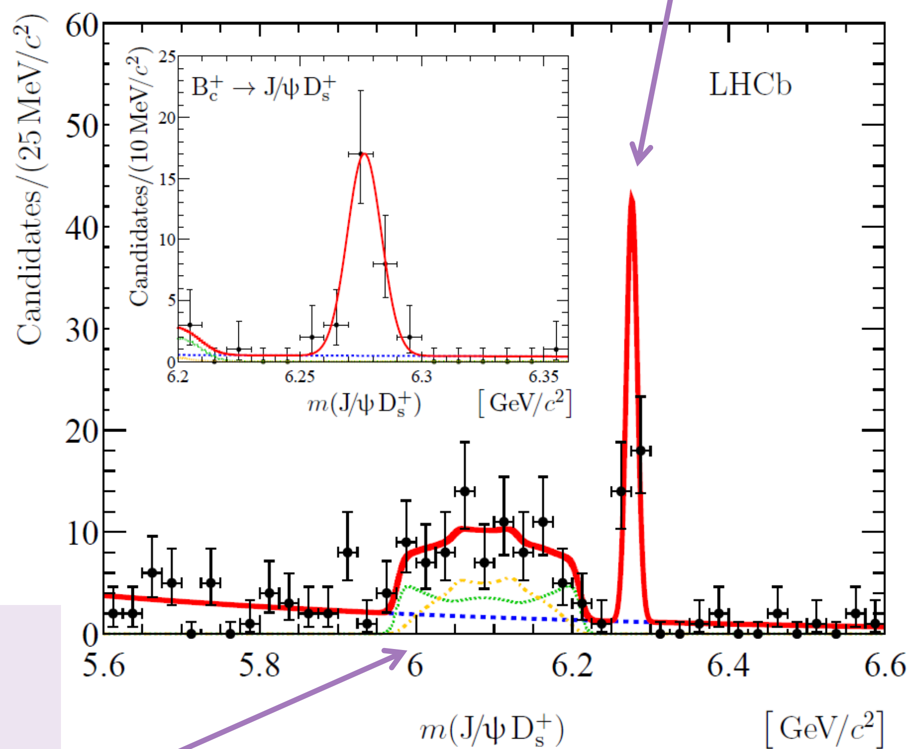
Uncertainty of $\frac{Br(J/\psi \to \mu\mu)}{Br(\psi(2S) \to \mu\mu)}$

Observation of $B_c^+ \to J/\psi D_s^{(*)+}$

arXiv:1303.1737



$B_c^+ \to J/\psi D_s^+$: $J/\psi \to \mu^+\mu^-$, $D_s^+ \to (K^+K^-)_\phi \pi^+$



- Hadronic mode w/o first generation quarks
- Colour-suppressed spectator and annihilation diagrams also contribute
- Search performed with 3 fb^{-1} (1 fb^{-1} @ 7 TeV; 2 fb^{-1} @ 8 TeV)

$B_c^+ \to J/\psi D_s^{*+}$: $D_s^{*+} \to D_s^+\gamma / D_s^+\pi^0$ partial reconstruction;
$J/\psi D_s^{*+}$ shape from simulation for both $A_{\pm\pm}$ and A_{00} helicity amplitudes

Both > 9σ significance. First observation!

Branching fraction

arXiv:1303.1737

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} = 2.90 \pm 0.57 \pm 0.24$$

In agreement with:

- Naïve factorization $\sim \frac{Br(B \to \bar{D}^* D_s^+)}{Br(B \to \bar{D}^* \pi^+)}$

2.90±0.42 (B^0), 1.58±0.34 (B^+) PDG12

- Prediction from PRD61(2000)034012

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^{*+})}{\mathcal{B}(B_c^+ \to J/\psi D_s^+)} = 2.37 \pm 0.56 \pm 0.10$$

- Naïve factorization $\sim \frac{Br(B \to \bar{D}^* D_s^{*+})}{Br(B \to \bar{D}^* D_s^+)}$

2.20 ±0.35±0.62 (B^0), 2.07±0.52±0.52 (B^+) PDG12

- Prediction from PRD61(2000)034012, arXiv:hep-ph/0308214

The fraction of polarization amplitude in the $B_c^+ \to J/\psi D_s^{*+}$

$$\frac{\Gamma_{\pm\pm}(B_c^+ \to J/\psi D_s^{*+})}{\Gamma_{\text{tot}}(B_c^+ \to J/\psi D_s^{*+})} = (52 \pm 20)\%$$

Consistent with:

- simple estimation of 2/3
- $B^0 \to D_s^{*+} \bar{D}^*$ assuming factorization

CLEO,PRD62(2000)112003, BaBar,PRD67(2003)092003

- Expectation from $B_c^+ \to J/\psi l\nu$ decays

PRD68(2003)094020, PRD81(2010)014015

B_c^+ mass measurement

arXiv:1303.1737

- Good opportunity for precise mass measurement using $B_c^+ \to J/\psi\, D_s^+$:
  - low Q-value, excellent mass resolution, low background …
- Systematic uncertainty is highly correlated with $M(D_s)$

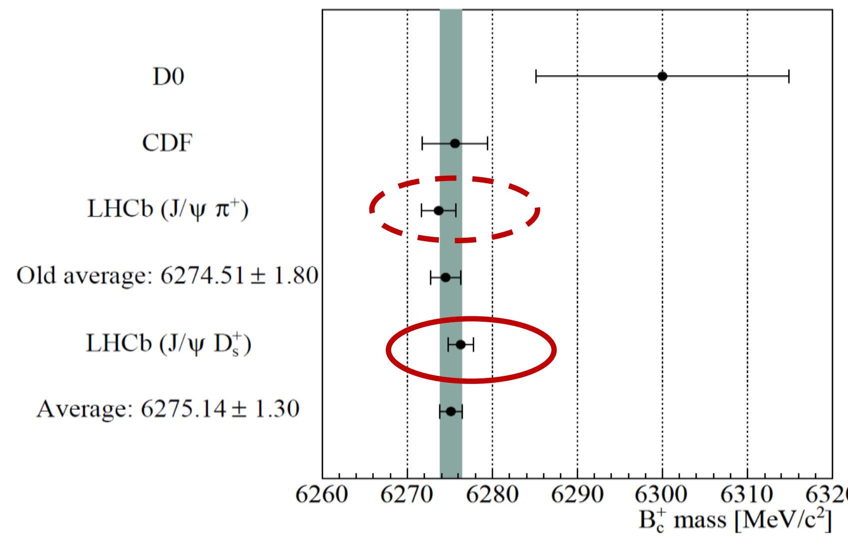
$$m_{B_c^+} = 6276.28 \pm 1.44(\text{stat.}) \pm 0.36(\text{syst.})\ \text{MeV}/\text{c}^2$$

$$m_{B_c^+} - m_{D_s^+} = 4307.97 \pm 1.44(\text{stat.}) \pm 0.20(\text{syst.})\ \text{MeV}/\text{c}^2$$

Using latest D_s mass result
LHCb-PAPER-2013-011 (in preparation)

Most precise B_c^+ mass measurement!

- Consistent with LHCb result using $B_c^+ \to J/\psi\pi^+$
- New world average is calculated: 6275.14 $\pm$ 1.30 MeV/c^2



Prospects

- There are still 2 fb^{-1} data @ 8 TeV to be analysed!

  NB: $\sigma(\bar{b}b)$ also increases by ~8/7 ⇒ more than doubled wrt 2011
- Precision measurement of B_c lifetime
  - $B_c^+ \to J/\psi\,\pi^+$: 1 fb^{-1}, improvement wrt world average expected
  - $B_c^+ \to J/\psi\,\mu\nu$: large BR, clean signal, yet only partial reconstruction
- New decay modes:
  - More possibilities with $\bar{b} \to \bar{c}W$: $J/\psi\,K^+K^-\pi^+$, $\psi(2S)\mu\nu$, ...
  - New diagram $c \to sW$: eg. $B_s\pi^+$, with $B_s \to J/\psi\phi$ or $B_s \to D_s^-\pi^+$
  - Annihilation : $\bar{K}^{*0}K^+$, ...
- Search for excited B_c states: $B_c(2S) \to B_c^+\pi^+\pi^-$
- B_c production: differential cross-section down to zero p_T

Summary

- LHCb has successfully extended our knowledge on B_c meson
  - Production cross-section measured wrt B^+
  - World best mass measurement(s)
  - New decay channels observed
    - $J/\psi\pi^+\pi^-\pi^+$, $\psi(2S)\pi^+$, $J/\psi\, D_s^{(*)+}$
- With data analyses for the 2 fb^{-1} @ 8 TeV actively onging, more excitement is expected in the near future!