B_c physics at LHCb

Yuanning Gao (Tsinghua Univ.)

On behalf of the LAL/Tsinghua LHCb Group

LAL/Tsinghua Collaboration

- Started in 2006

- LAL members Patrick Robbe (leader) , Marie-Helene Schune, Yiming Li, Sergey Barsuk
- Tsinghua members Zhenwei Yang (leader) ,
  Liupan An (PhD), Yuanning Gao

- Research activities in 2014 B_c physics at LHCb
  (Collaborated with Bo Liu & Giulia Manca from Cagliari Group)
- In LHCb *B hadrons and Quarkonia Group*
  - Zhenwei Yang: group convener
  - Yiming Li: subgroup convener – *B* hadrons and B_c

LAL/Tsinghua Collaboration

- Long term exchanges

  - Jibo He

    Tsinghua PhD → LAL Postdoc → CERN Fellow

  - Wenbin Qian

    Embassy co-tutelle PhD → LAPP Annecy Postdoc

  - Bo Liu

    Tsinghua PhD (CSC, 1 year at LAL) → Cagliari Postdoc

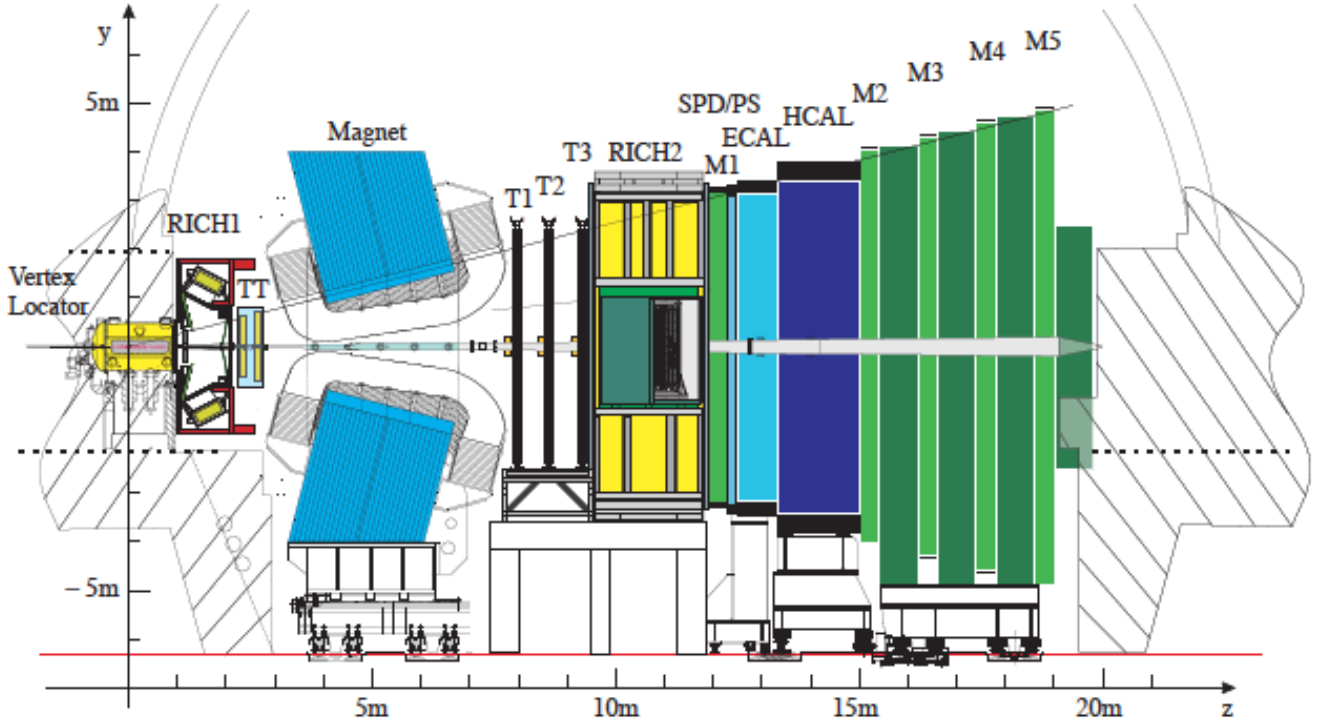
  - Yiming Li

    Tsinghua Postdoc → LAL Postdoc

LHCb Detector

[JINST 3 (2008) S08005]

- Acceptance $2<\eta<5$, with excellent vertexing, tracking, PID
- $\mathcal{L}_{\rm int} = 1\ \text{fb}^{-1}$ @ 7 TeV in 2011, & $2\ \text{fb}^{-1}$ @ 8 TeV in 2012



Vertex Locator	$\sigma_{\text{PV},x/y} \sim 10\ \mu\text{m}$, $\sigma_{\text{PV},z} \sim 60\ \mu\text{m}$
Tracking (TT, T1-T3)	$\Delta p/p$: 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c
RICHs	$\varepsilon(K \to K) \sim 95\%$, mis-ID rate $(\pi \to K) \sim 5\%$
Muon system (M1-M5)	$\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(\pi \to \mu) = 1-3\%$
ECAL	$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
HCAL	$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (E in GeV)

B_c Studies at LHCb

Production	$\frac{\sigma(B_c^+)}{\sigma(B^+)} \frac{\mathcal{B}(B_c^+ \to J/\psi \pi^+)}{\mathcal{B}(B^+ \to J/\psi K^+)}$	[PRL 109 (2012) 232001]
	$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \mathcal{B}(B_c^+ \to B_s^0 \pi^+)$	[PRL 111 (2013) 181801]
	$\frac{\sigma(B_c^+)}{\sigma(B^+)} \frac{\mathcal{B}(B_c^+ \to J/\psi \pi^+)}{\mathcal{B}(B^+ \to J/\psi K^+)}$ double differential ratio	[LHCb-Paper-2014-050, in preparation]
Mass	$M_{B_c^+ \to J/\psi \pi^+}$	[PRL 109 (2012) 232001]
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Decay	$B_c^+ \to J/\psi 3\pi$	[PRL 108 (2012) 251802]
	$B_c^+ \to J/\psi K^+$	[JHEP 09 (2013) 075]
	$B_c^+ \to \psi(2S)\pi^+$	[PRD 87 (2013) 071103(R)]
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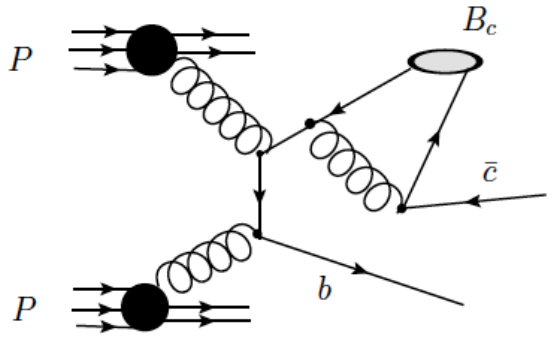
B_c Production at LHC

- Production rate – theoretical predictions

$$gg \to B_c + b + \bar{c}$$



Theoretical prediction (in nb) [C.-H. Chang, *et al.*, PRD 71 (2005) 074012]

-	$\|(^1S_0)_1\rangle$	$\|(^3S_1)_1\rangle$	$\|(^1S_0)_8g\rangle$	$\|(^3S_1)_8g\rangle$	$\|(^1P_1)_1\rangle$	$\|(^3P_0)_1\rangle$	$\|(^3P_1)_1\rangle$	$\|(^3P_2)_1\rangle$
(14 TeV)	71.1	177.	(0.357, 3.21)	(1.58, 14.2)	9.12	3.29	7.38	20.4
TEVATRON	5.50	13.4	(0.0284, 0.256)	(0.129, 1.16)	0.655	0.256	0.560	1.35

- ★ $\sigma(^3S_1)/\sigma(^1S_0) \sim 2.5$
- ★ Color octets and 1st P-wave contributions are small
- ★ $\sigma(B_c^+)_{\rm LHC}/\sigma(B_c^+)_{\rm Tevatron} \sim {\rm O}(10)$

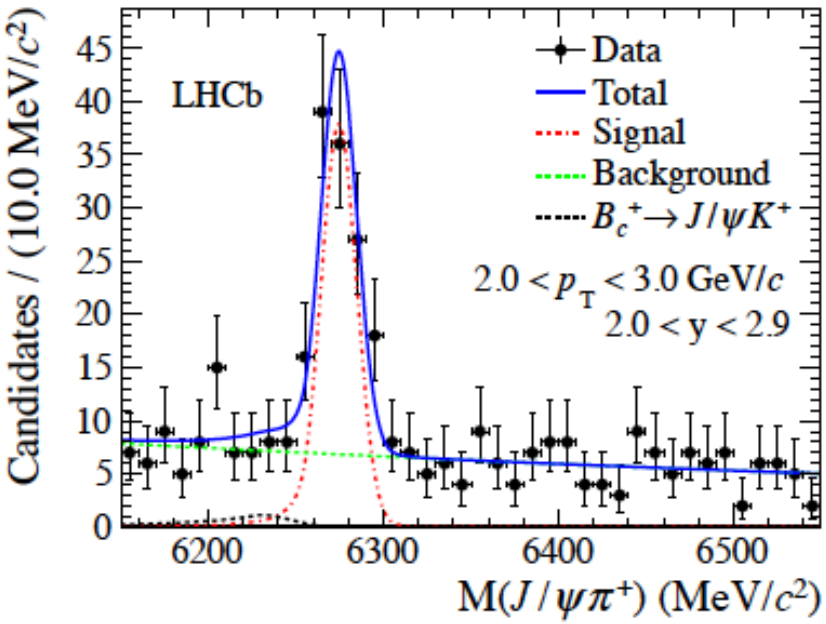
B_c double differential ratio

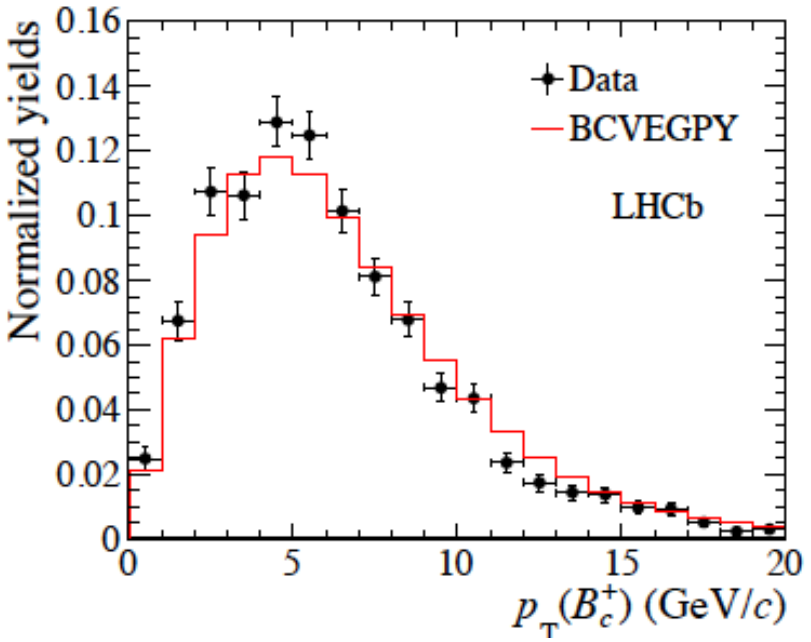
- $\mathcal{R} = \dfrac{\sigma(B_c^+) \times \mathcal{B}(B_c^+ \to J/\psi\,\pi^+)}{\sigma(B^+) \times \mathcal{B}(B^+ \to J/\psi\,K^+)}$

PRL 114 (2015) 132001

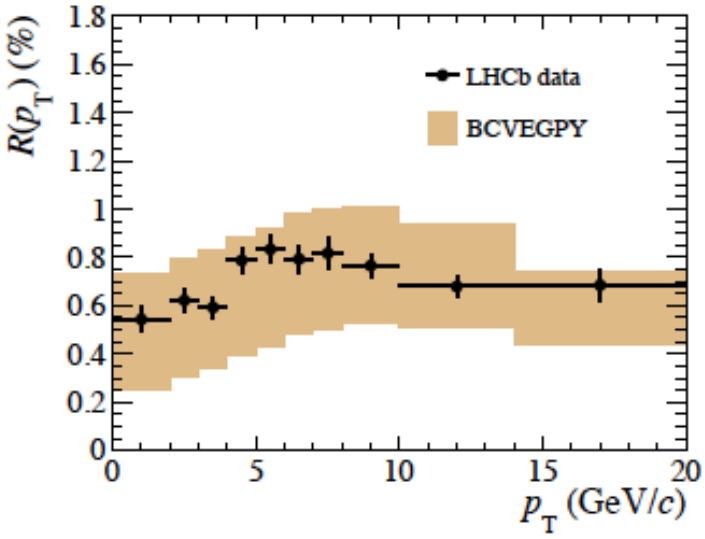
- With 2012 (8 TeV) data, $\mathcal{R}$ measured as function of $(p_{\rm T}, y)$, for $p_{\rm T}(B) < 20$ GeV/c and $2 < y(B) < 4.5$
  - MVA-based selection, $B^+ \to J/\psi\,K^+$ as control channel
  - $p_{\rm T}(B_c^+)$ well described by BcVegPy (complete α_s^4 calculation)

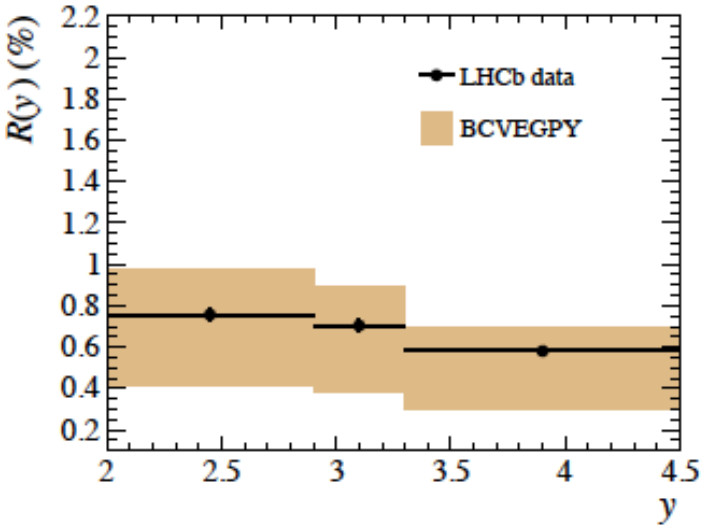
[C.-H. Chang *et al.*, Comput. Phys. Commun. 174 (2006) 241]





- Good agreement with theoretical predictions
  - Differential $p_{\rm T}$ shapes, B^+ from FONLL, B_c^+ from BcVegPy (α_s^4)
  - Normalization
    - ★ $\sigma(B_c^+) = 0.47\ \mu$b, theoretical prediction by BcVegPy
    - ★ $\mathcal{B}(B_c^+ \to J/\psi\,\pi^+) = 0.33\%$ [C.-F. Qiao *et al.*, PRD 89 (2014) 034008]
    - ★ $\sigma(B^+,\ p_{\rm T}(B) < 40\ {\rm GeV}/c,\ 2.0 < y < 4.5) = 38.9\,\mu$b at $\sqrt{s} = 7$ TeV, measured by LHCb [JHEP 08 (2013) 117], scaled up by 1.2 for 8 TeV
    - ★ $\mathcal{B}(B^+ \to J/\psi\,K^+) = (0.1016 \pm 0.0033)\%$, PDG'12





Production ratio in the range $0 < p_{\rm T} < 20\,{\rm GeV}/c$ and $2.0 < y < 4.5$

$\mathcal{R} = (0.683 \pm 0.018 \pm 0.009)\%$ (3% relative precision)

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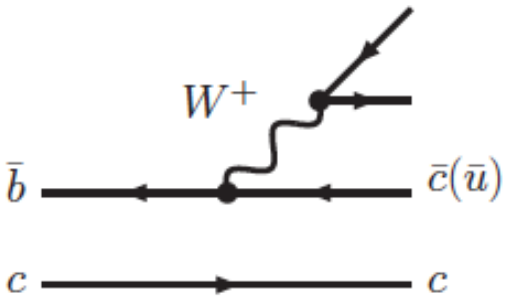
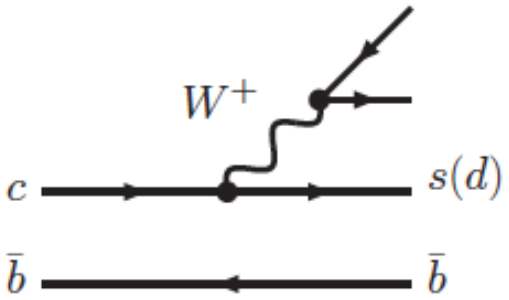
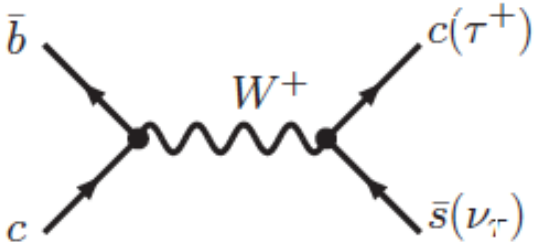
B_c Decays

- B_c mesons' decays
  - Excited states (below BD threshold), decay through the Strong or EM interactions into B_c^+
  - Ground state B_c^+: decay only weakly
- B_c^+ decay modes
  - $\bar{b} \to \bar{c} W^+$, e.g., $J/\psi\,\pi^+$, $J/\psi\,\ell^+\nu_\ell$
  - $c \to s W^+$, e.g., $B_s^0\pi^+$, $B_s^0\ell^+\nu_\ell$
  - $c\bar{b} \to W^+$, e.g., $\bar{K}^{*0}K^+$, ϕK^+, $\tau^+\nu_\tau$
- B_c^+ lifetime predictions
  - Inclusive rates or $\sum$(exclusive rates)
  - $\tau(B_c^+)_{\rm SR} = 0.48 \pm 0.05$ ps

    [V. V. Kiselev, *et al.*, NPB 585 (2000) 353]
  - PDG'14: 0.500 ± 0.013 ps

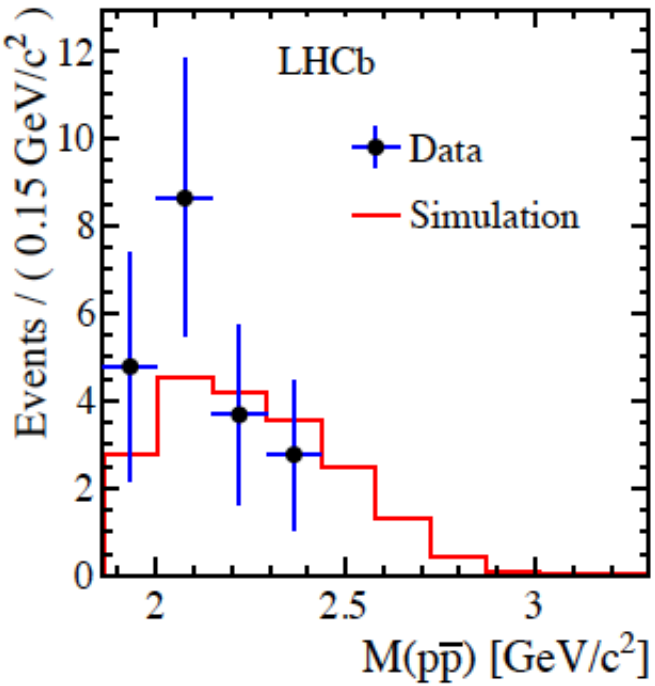


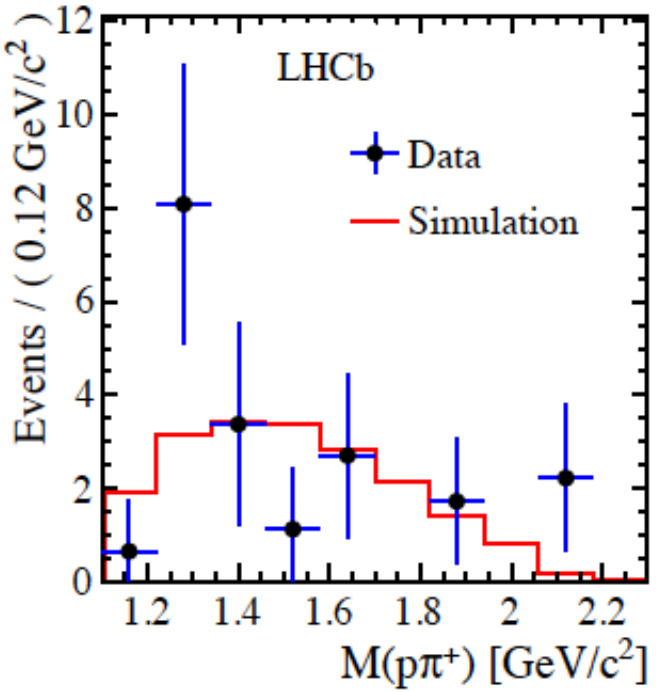




First observation of B_c baryonic decay

- Searched with all Run-I data, $N_{\rm sig} = 23.9 \pm 5.3$ [PRL 113 (2014) 152003]
- $\frac{\mathcal{B}(B_c^+ \to J/\psi\, p\bar{p}\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.143^{+0.039}_{-0.034} \pm 0.013$
- consistent with $\frac{\mathcal{B}(B^0 \to D^{*-} p\bar{p}\pi^+)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)} = 0.17 \pm 0.02$ (PDG)
- $M(p\bar{p})$ and $M(p\pi^+)$ distributions consistent with phase-space
- distribution, no significant structure yet





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PRL 113 (2014) 152003

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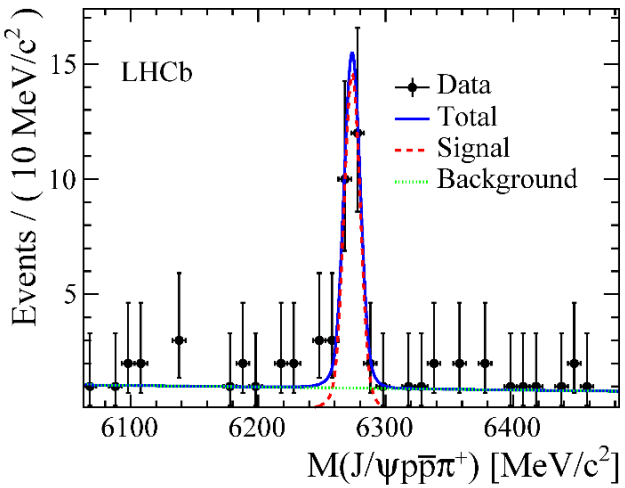
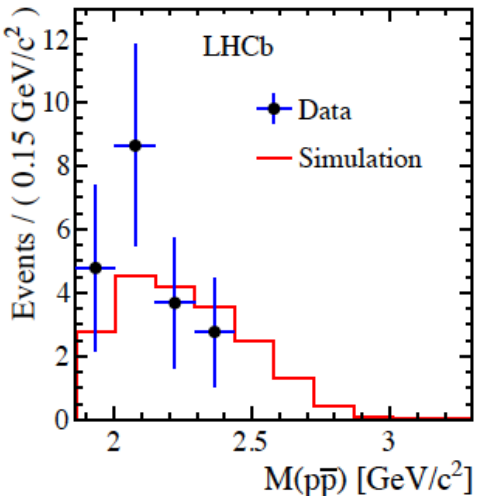
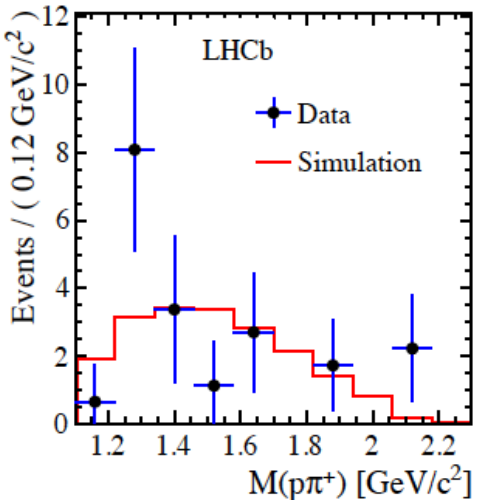
$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, p\bar{p}\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.143^{+0.039}_{-0.034} \pm 0.013$$

- Low Q, good for (future) mass measurement

$$M_{B_c^+ \to J/\psi\, p\bar{p}\pi^+} = 6274.0 \pm 1.8 \pm 0.4 \text{ MeV}$$







Perspectives

- Ongoing analyses (to be finished in 2015)
  - $B_c \to J/\psi D K^{(*)}$
  - LHCb result for the excited state
- Ready for RUN-II data: higher cross-section, more effective trigger…