Study of B_c physics at LHCb

Jiesheng Yu

(On behalf of the LHCb collaboration)

Center China Normal University

Quarkonium Working Group

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Outline

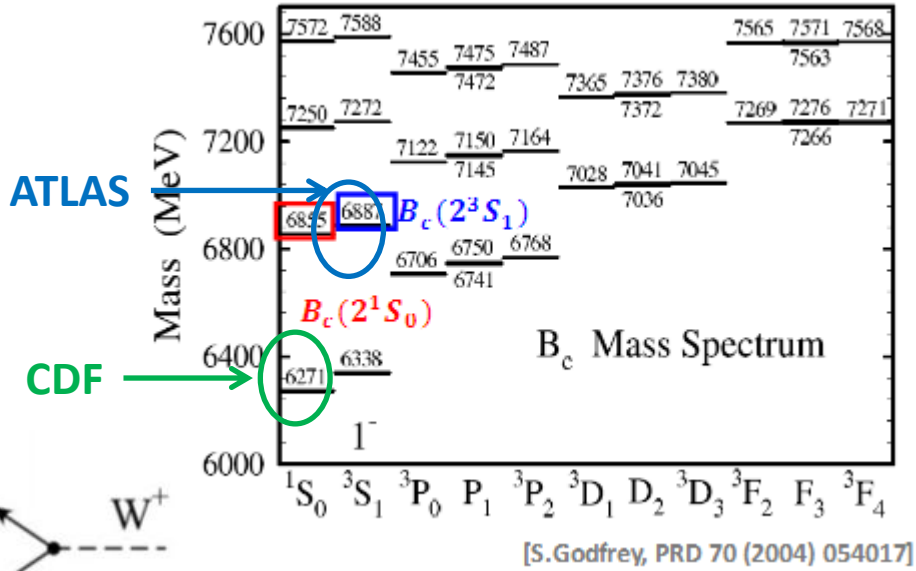
- **Introduction**
- **Recent results of B_c^+ study**
  - New decays, branching fractions and the mass
- **Search for excited states**
- **Conclusion and outlook**

B_c physics

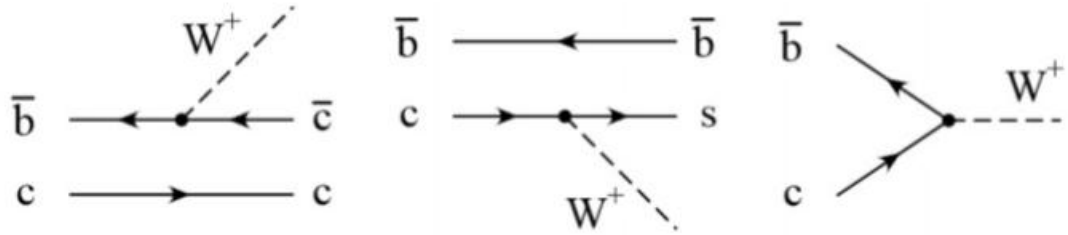
- **Unique state that contains two heavy quarks of different flavors**
- **Mass Spectra are calculated in QCD models**
  - B_c^+ was first observed by CDF in 1998, confirmed by D0 **Phys. Rev. Let. 81 (1998)**
  - B_c^{*+} was first observed by ATLAS, no independent confirmation

    PRL 113 (2014) 12004

- **Rich decay modes**
  1. *b* quark decay ~20%
  2. *c* quark decay ~70%
  3. annihilation decay ~10%



[S.Godfrey, PRD 70 (2004) 054017]



- **Precise measurements of mass, lifetime, branching fractions can provide information to test theoretical models**

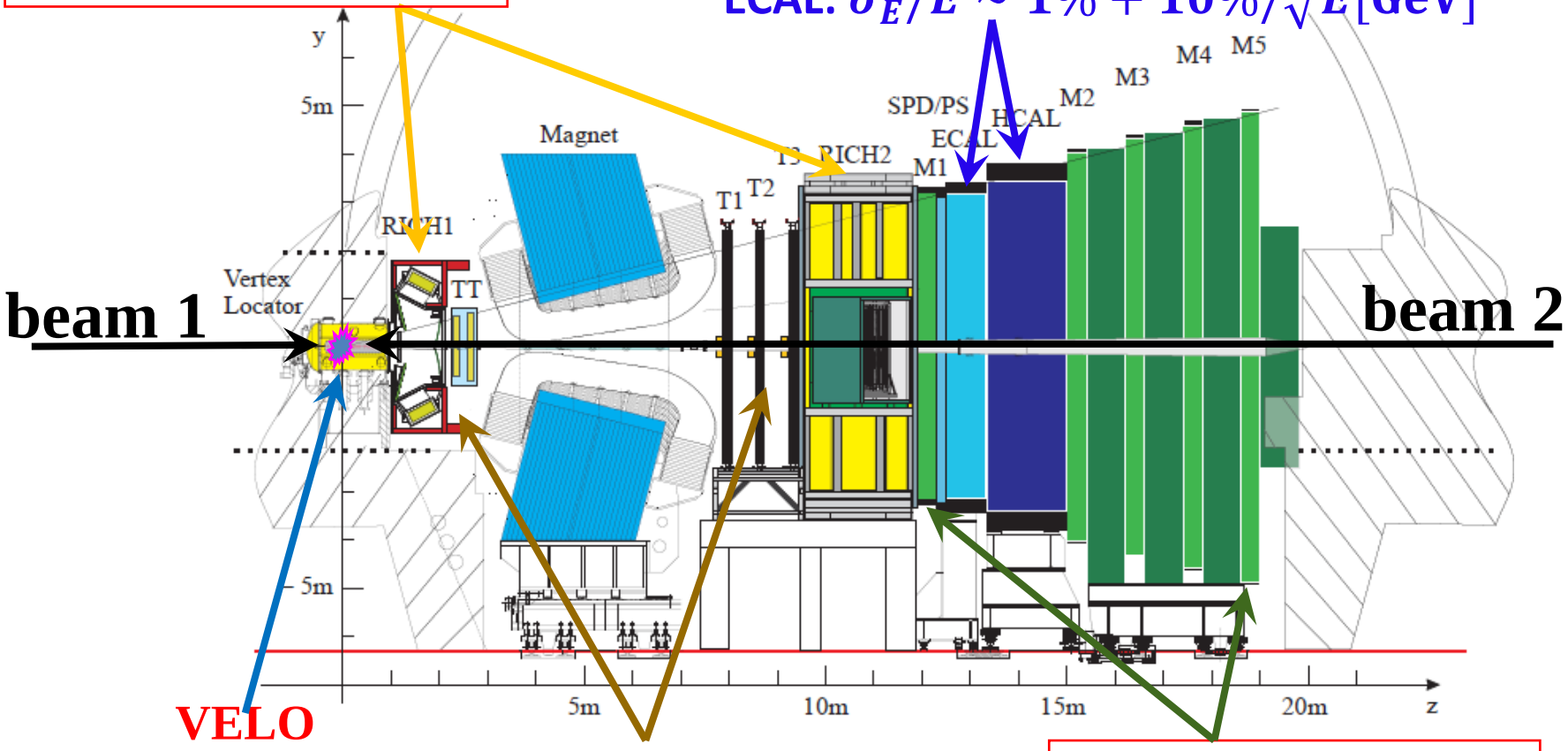
LHCb detector

JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

Pseudorapidity acceptance
$2 < \eta < 5$

RICH1 & RICH2
$\epsilon(K \to K) \sim 95\%$
$\pi \to K$ mis-id: $\sim 5\%$

Calorimeters
ECAL: $\sigma_E/E \sim 1\% + 10\%/\sqrt{E[\text{GeV}]}$

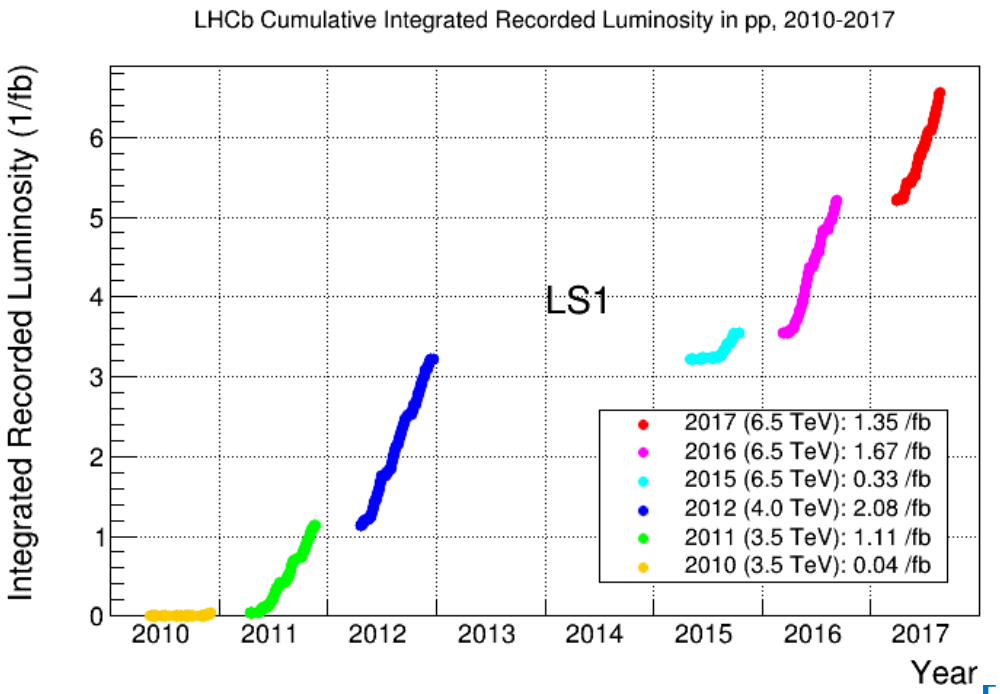


VELO
$\sigma_{IP} \sim 20$ μm
Decay time resolution:
45 fs (τ)~1.5 p

Tracking System
$\Delta p/p = 0.5\%@5\ \text{GeV}/c$
to $1\%@200\ \text{GeV}/c$

Muon System
$\epsilon(\mu \to \mu) \sim 97\%$
$\pi \to \mu$ mis-id: $1 \sim 3\%$

LHCb data



RUN-I

1 fb^{-1} of pp collisions at 7 TeV

2 fb^{-1} of pp collisions at 8 TeV

RUN-II (2015~2018 13 TeV)

$\boldsymbol{\sigma}$(RUN-II)≈ $\mathbf{2}\boldsymbol{\sigma}$(RUN-I)

- **All *b* hadrons:**

  $\boldsymbol{B^0, B^{\pm}, B_s^0, B_c^{\pm}}$ …

LHCb: $\boldsymbol{\sigma(pp \to B_c^+)_{\text{incl}} \approx 0.3\ \mu b}$

	B^0	B^+	B_s^0	*b* baryons (Λ_b …)	B_c^+
Fraction(%)	40	40	10	10	0.1
Component	$\bar{b}d$	$\bar{b}u$	$\bar{b}s$	bqq	$\bar{b}c$

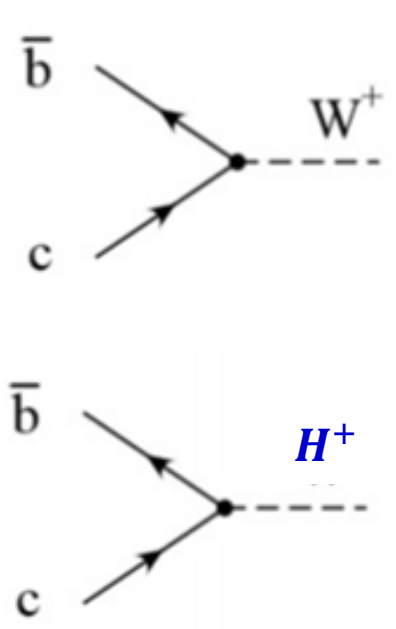
PRD 85.032008

B_c studies at LHCb

Mass	$M(B_c^+ \to J/\psi\pi^+)$	[PRL 109 (2012) 232001]
	$M(B_c^+ \to J/\psi D_s^+)$	[PRD 87 (2013) 112012]
	$M(B_c^+ \to J/\psi p\bar{p}\pi^+)$ *	[PRL 113 (2014) 152003]
	$M(B_c^+ \to J/\psi D^{(*)}K^{(*)})$ *	[PRD 95 (2017) 032005]
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] **7 TeV** [PRL 114 (2015) 132001] **8 TeV**
	$\frac{\sigma(B_c^+)}{\sigma(B_s^0)}\mathcal{B}(B_c^+ \to B_s^0\pi^+)$ *	[PRL 111 (2013) 181801]
Lifetime	$\tau(B_c^+ \to J/\psi\mu^+\nu_\mu X)$	[EPJC 74 (2014) 2839]
	$\tau(B_c^+ \to J/\psi\pi^+)$	[PLB 742 (2015) 29-37]
Decays (also those used to measure mass and production, marked with *)	$B_c^+ \to J/\psi\pi^+\pi^-\pi^+$	[PRL 108 (2012) 251802]
	$\mathcal{B}(B_c^+ \to J/\psi K^+)/(\mathcal{B}(B_c^+ \to J/\psi\pi^+)$	[JHEP 09 (2013) 075] **7 TeV** [JHEP 09 (2016) 153] **7&8 TeV**
	$\mathcal{B}(B_c^+ \to \psi(2S)\pi^+)/\mathcal{B}(B_c^+ \to J/\psi\pi^+)$	[PRD 87 (2013) 112012] **7 TeV** [PRD 92 (2015) 072007] **7&8 TeV**
	$B_c^+ \to J/\psi K^+K^-\pi^+$	[JHEP 11 (2013) 094]
	$B_c^+ \to J/\psi 3\pi^+2\pi^-$(evidence)	[JHEP 05 (2014) 148]
	$\mathcal{B}(B_c^+ \to J/\psi\pi^+)/\mathcal{B}(B_c^+ \to J/\psi\mu^+\nu_\mu)$	[PRD 90 (2014) 032009]
	$B_c^+ \to p\bar{p}\pi^+$(upper limit)	[PLB 759 (2016) 313-321]
	$B_c^+ \to K^+K^-\pi^+$	[PRD 94(2016) 091102]
	$B_c^\pm \to D^0\pi^\pm$	[PRL 118 (2017) 111803]
	$B_c^{(*)+}(2S) \to B_c^+\pi^+\pi^-$	[LHCB-PAPER-2017-042] **in preparation**

$B_c^+ \to h_1^+ h_2^- h_3^+$ (h: K, π, p)

- In the SM, theoretical prediction B_c^+ annihilation decays :10^{-8}~10^{-6})



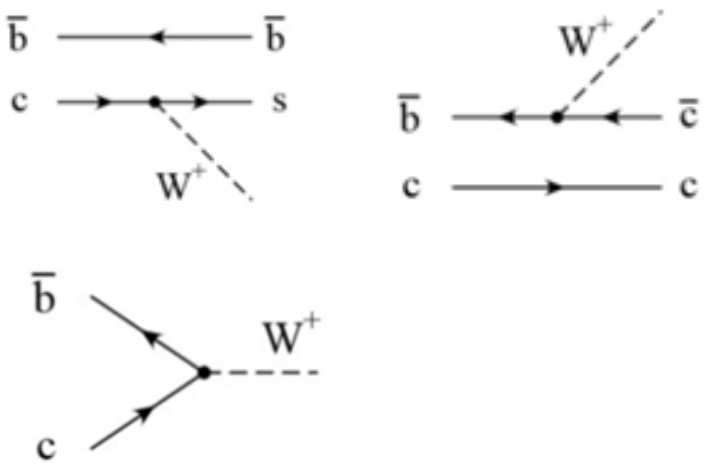
- Any significant enhancement could indicate the particles beyond the SM (like H^+)

- $B^+ \to h_1^+ h_2^- h_3^+$ as a normalization mode

$$R_f \equiv \frac{\sigma(B_c^+)}{\sigma(B^+)} \times \mathcal{B}(B_c^+ \to f)$$

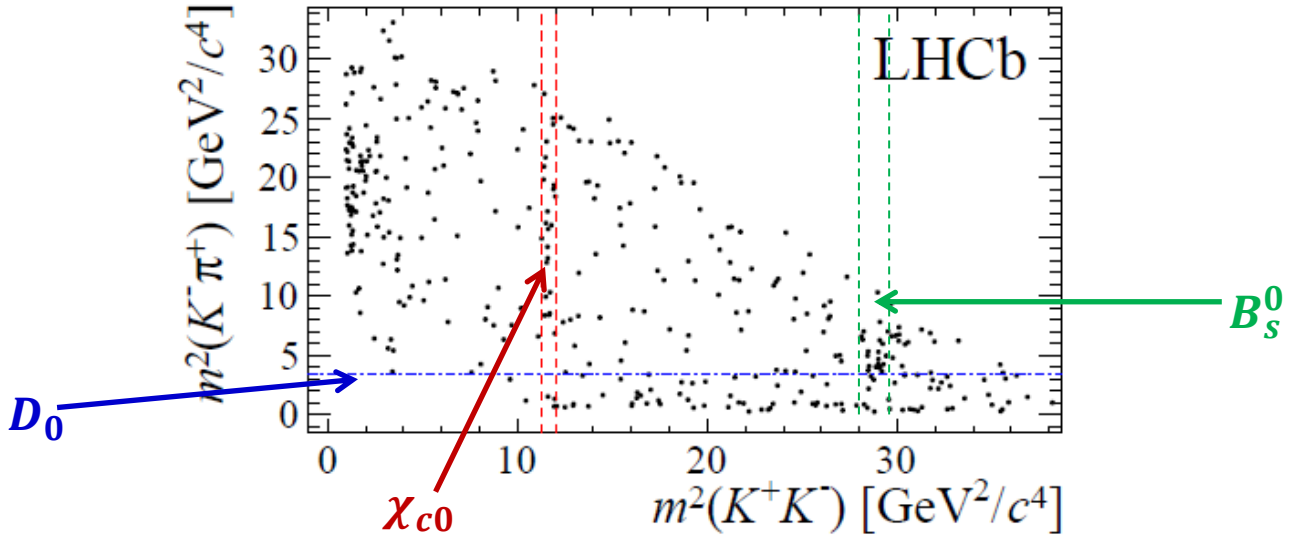
$B_c^+ \to K^+K^-\pi^+$

- Decay modes for $B_c^+ \to K^+K^-\pi^+$
  1. $\bar{b} \to \bar{q} : B_c^+ \to K^+D^0(\to K^-\pi^+)$
  2. $\bar{c} \to \bar{q} : B_c^+ \to \pi^+B_q^0(\to K^-K^+)$
  3. $\bar{b} \to \bar{c} : B_c^+ \to \pi^+[c\bar{c}](\to K^-K^+)$
  4. **$\bar{b}c$ annihilation: NR**



- First time perform the $B_c^+ \to K^+K^-\pi^+$ decay using Run-I data

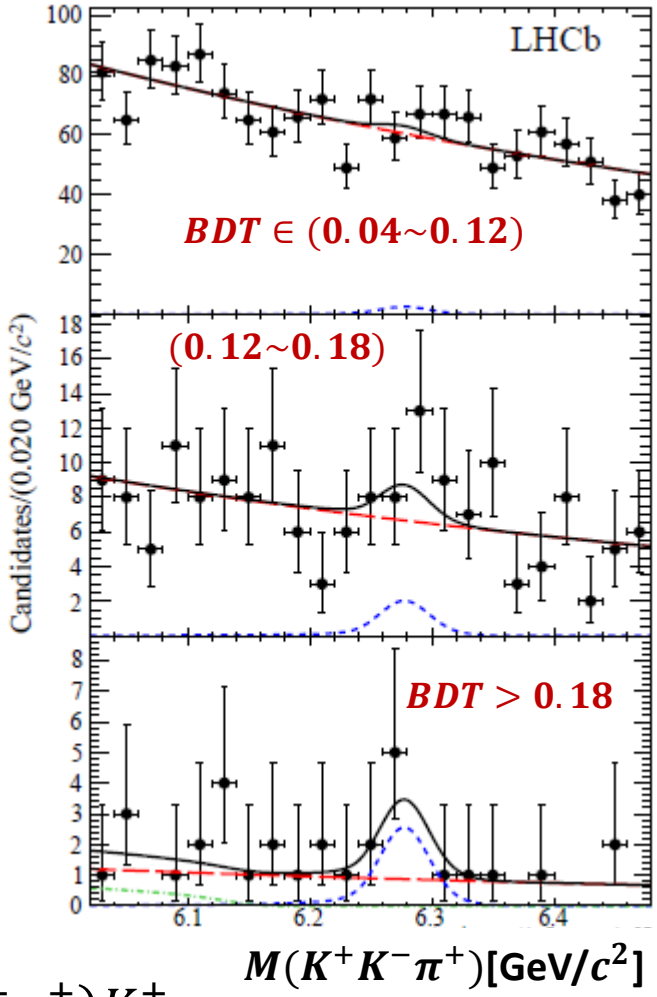
PRD 94(2016) 091102



$B_c^+ \to K^+K^-\pi^+$ ($\bar{b}c$ annihilation)

PRD 94(2016) 091102

- Veto the χ_{c0} and B_s^0
  - ✓ $m(K^-K^+)$ in (3380, 3460) and (5200, 5500) MeV/ c^2
- $N_{B_c^+} = 20.8^{+11.4}_{-9.9}$
- **Significance: 2.5σ**
- $2 < \eta < 4.5$ && $p_T < 20$ GeV/c



$$\frac{\sigma(B_c^+)}{\sigma(B^+)} \times \mathcal{B}(B_c^+ \to K^+K^-\pi^+) =$$
$$(8.0^{+4.4}_{-3.8}(\text{stat}) \pm 0.6(\text{syst})) \times 10^{-8}$$

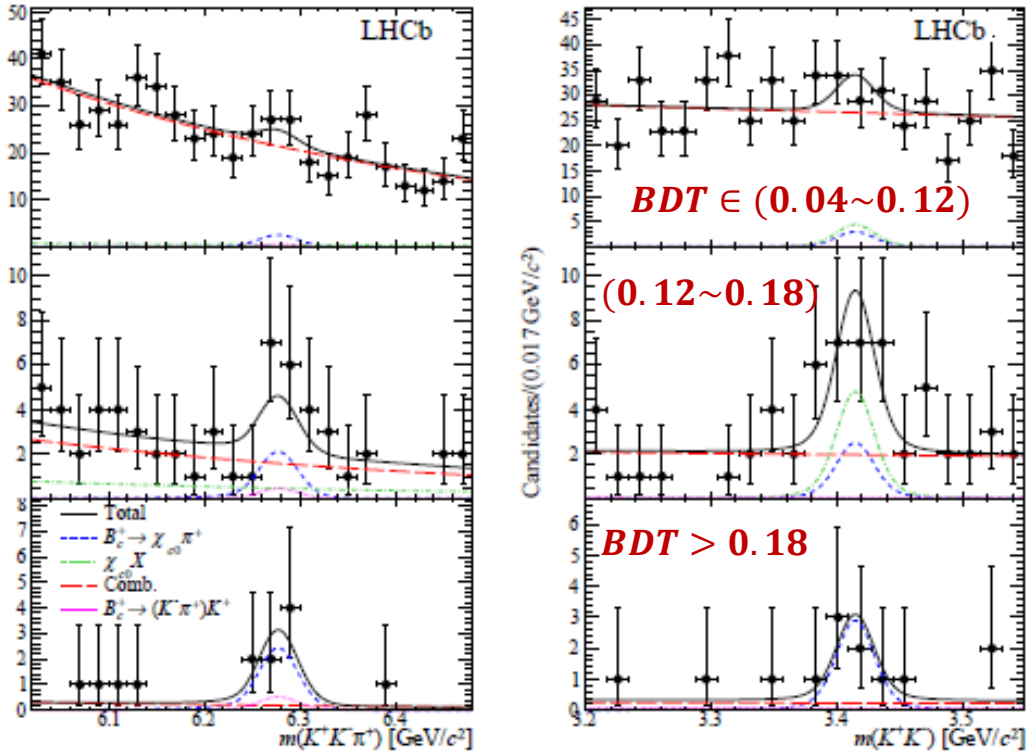
- Theo. Prediction: $\frac{\sigma(B_c^+)}{\sigma(B^+)} \times \mathcal{B}(B_c^+ \to \bar{K}^{*0}(\to K^-\pi^+)K^+$
  $\sim[0.1 \sim 1.7] \times 10^{-8}$

Chin. Sci. Bull. 59 (2014) 3748,

$B_c^+ \to K^+K^-\pi^+(\bar{b} \to \bar{c})$ PRD 94(2016) 091102

Signal yields

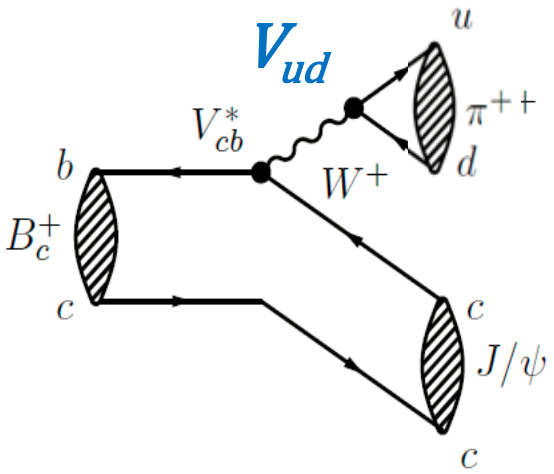
- $m(K^-K^+)$ in resonance $\in (3200,3550)$ MeV/ c^2
- Two-dimensional simultaneous fit for the three BDT bins
- $N_{B_c^+} = 20.8^{+7.2}_{-6.4}$
- **Significance: 4.1σ**
- $2 < \eta < 4.5$ && $p_T < 20$ GeV/c

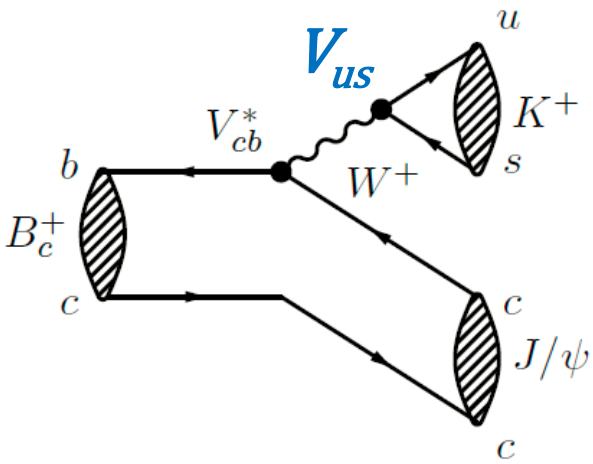


$$\frac{\sigma(B_c^+)}{\sigma(B^+)} \times \mathcal{B}(B_c^+ \to \chi_{c0}\pi^+) = (9.8^{+3.4}_{-3.1}(\text{stat}) \pm 0.8(\text{syst})) \times 10^{-6}$$

- This result can be compared to $\frac{\sigma(B_c^+)}{\sigma(B^+)} \times \mathcal{B}(B_c^+ \to J/\psi\pi^+) = (7.0 \pm 0.3) \times 10^{-6}$

$B_c^+ \to J/\psi\pi^+$ VS $B_c^+ \to J/\psi K^+$





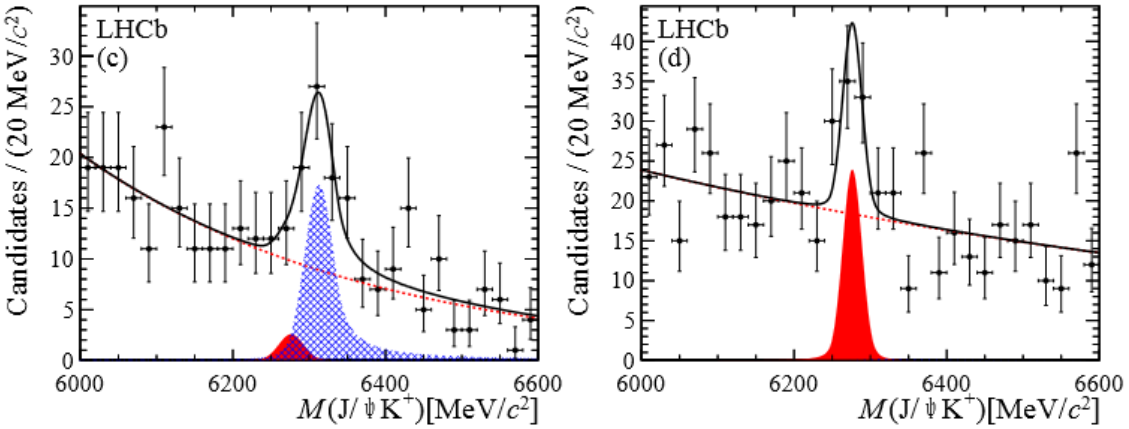
A Cabibbo suppressed channel, naïve estimate is $R_k = \frac{\mathcal{B}(B_c^+ \to J/\psi K^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} \approx \left|\frac{V_{us}}{V_{ud}}\right|^2 \sim 0.05$

- Test of some theoretical models: $R_k(0.052 \sim 0.096)$

Model	R_k
QCD relativistic potential model [10]	0.052
Relativistic model [14]	0.074
Relativistic quark model [15]	0.078
QCD sum rules [12, 13]	0.085
Relativistic constituent quark model [16]	0.079
Relativistic constituent quark model [17]	0.076
Relativistic independent quark model [18]	0.078
NLO NRQCD [19]	0.076
Heavy quark effective theory [20]	0.077
light-front constituent quark model [11]	0.096

$B_c^+ \to J/\psi K^+$ in 1 fb^{-1} 7 TeV data

- $B_c^+ \to J/\psi K^+$ first observed by LHCb using 1 fb^{-1} 7 TeV data



JHEP 09 (2013) 075)

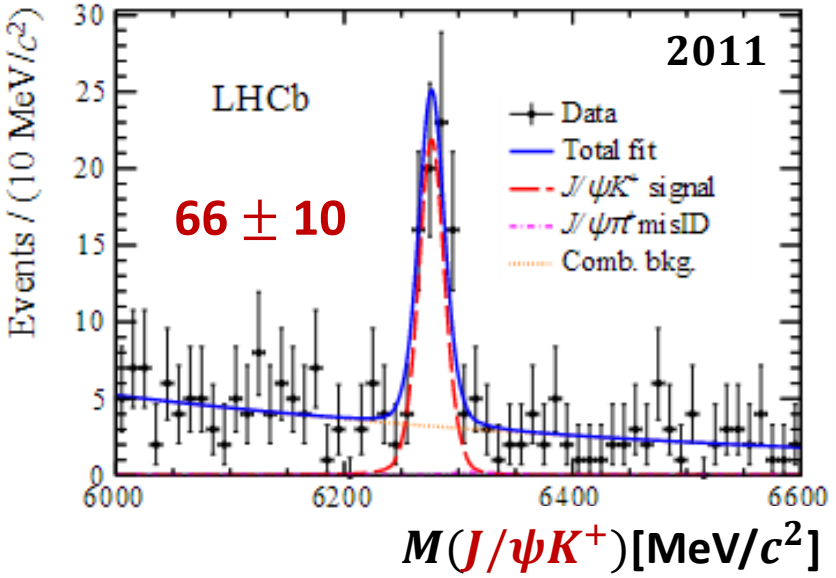
N($B_c^+ \to J/\psi K^+$)= 46 ± 12

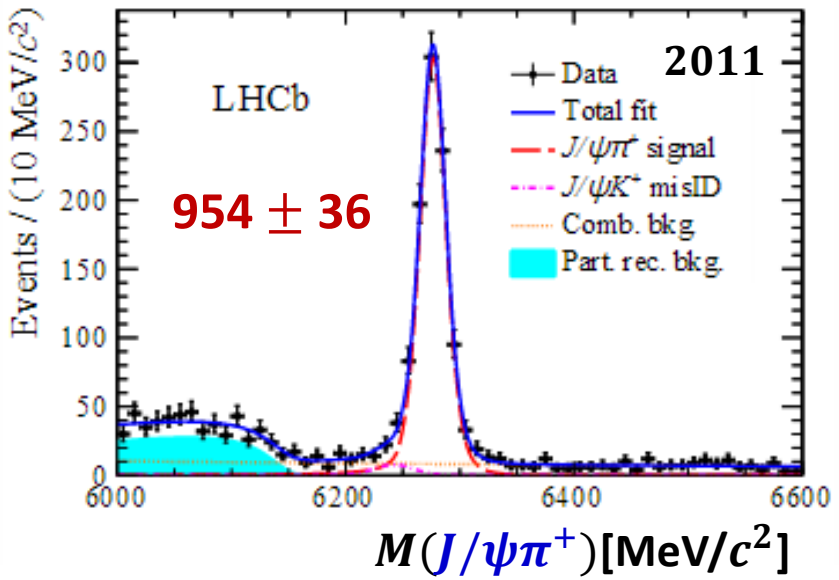
Significance: 5σ

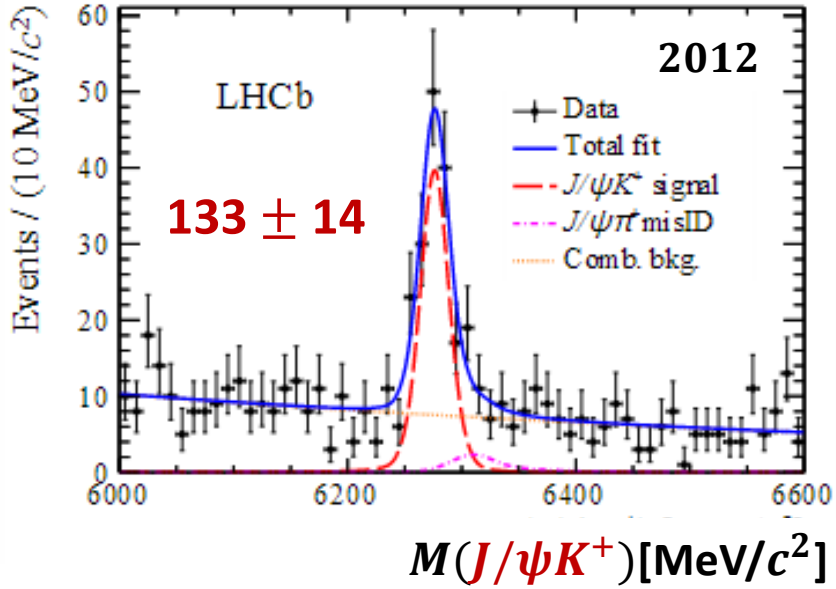
$$R_k = \frac{\mathcal{B}(B_c^+ \to J/\psi K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = \mathbf{0.069 \pm 0.019(stat) \pm 0.005(syst)}$$

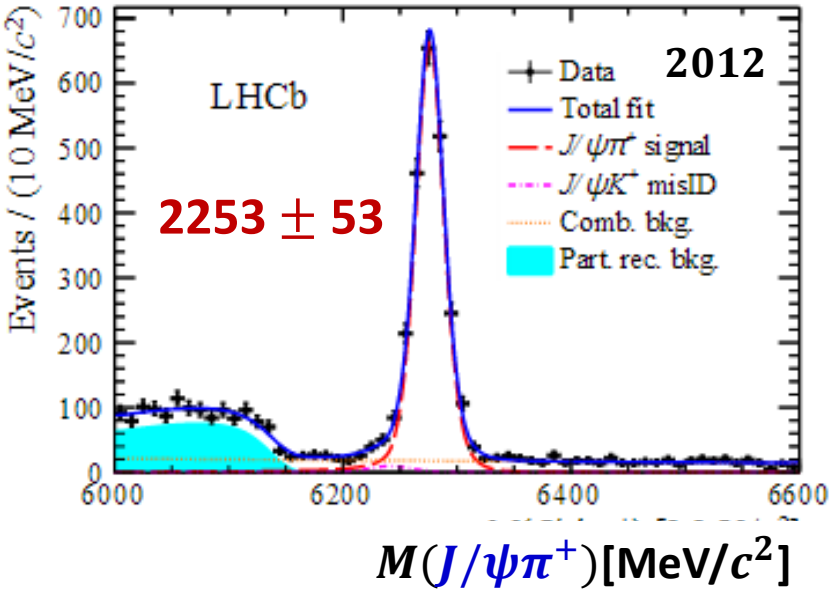
- Uncertainty still large, need to be improved
- Update the result with 3 fb^{-1} data at $\sqrt{s} = 7$ & 8 TeV (RUN-I)
  - Improved particle identification
  - Use more information in multivariate analysis to suppress background

Signal yields in RUN-I data









JHEP 09 (2016) 153

Results of $B_c^+ \to J/\psi K^+$

- 3 fb^{-1} result: JHEP 09 (2016) 153

$$\frac{\mathcal{B}(B_c^+ \to J/\psi K^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} = 0.077 \pm 0.007(\text{stat}) \pm 0.002(\text{syst})$$

- Consistent with 1 fb^{-1} result:

$$\frac{\mathcal{B}(B_c^+ \to J/\psi K^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} = 0.069 \pm 0.019(\text{stat}) \pm 0.005(\text{syst})$$

- Both statistical and systematic uncertainties greatly reduced

- Consistent with most of theoretical models

Model	R_k
QCD relativistic potential model [10]	0.052
Relativistic model [14]	0.074
Relativistic quark model [15]	0.078
QCD sum rules [12, 13]	0.085
Relativistic constituent quark model [16]	0.079
Relativistic constituent quark model [17]	0.076
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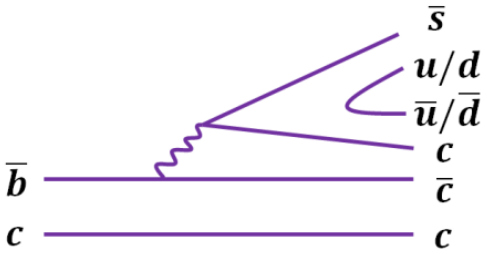
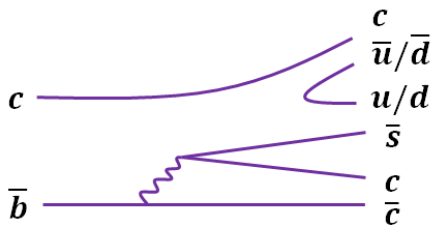
light-front constituent quark model [11]	0.096

$B_c^+ \to J/\psi D^{(*)} K^{(*)}$

- Search for decays $B_c^+ \to J/\psi D^{(*)0} K^+$ and $B_c^+ \to J/\psi D^{(*)+} K^*$
  - The BFs provide info on yet unobserved $B \to D^{(*)} \overline{D}^{(*)} K^{(*)}$





- Potential in D_{sj} spectroscopy studies
  - $D_{s1}(2536) \to D^* K$

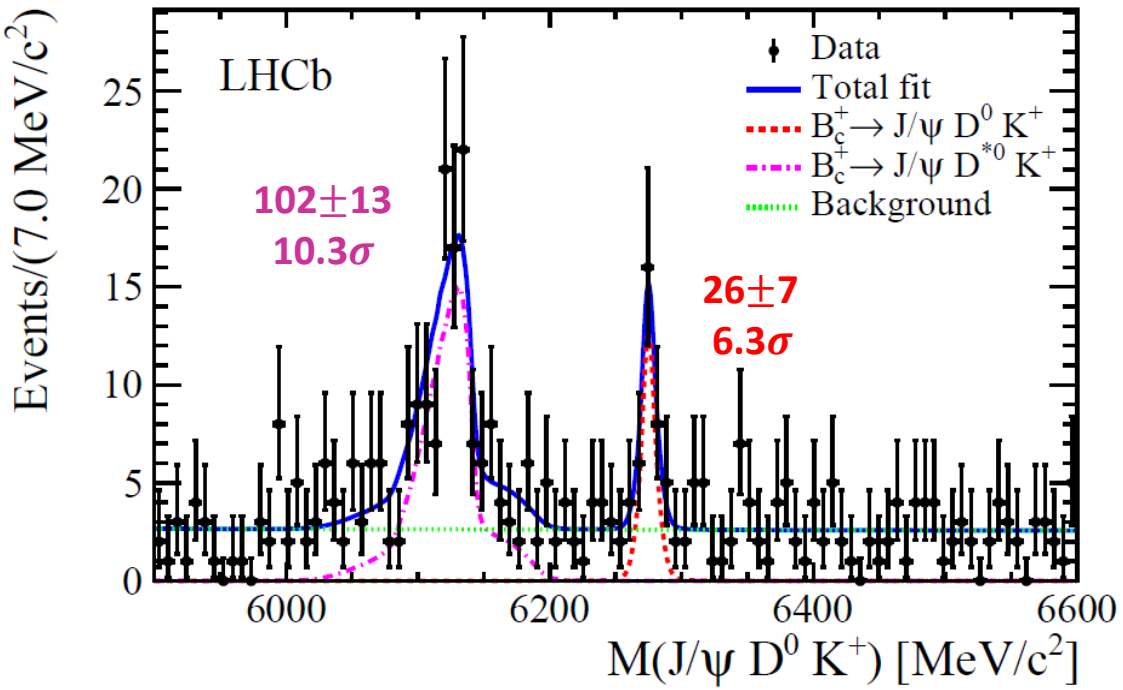
final state f	$\mathcal{B}(B_c^+ \to \bar{f})$	$\mathcal{B}(B_c^- \to f)$
$J/\psi\, D_{s1}^-(2460)$	5.339×10^{-3}	5.348×10^{-3}
$J/\psi\, D_{s1}^-(2536)$	1.123×10^{-3}	1.124×10^{-3}

JHEP 06(2011)015

- The small Q-value help to improve mass B_c^+ measurement

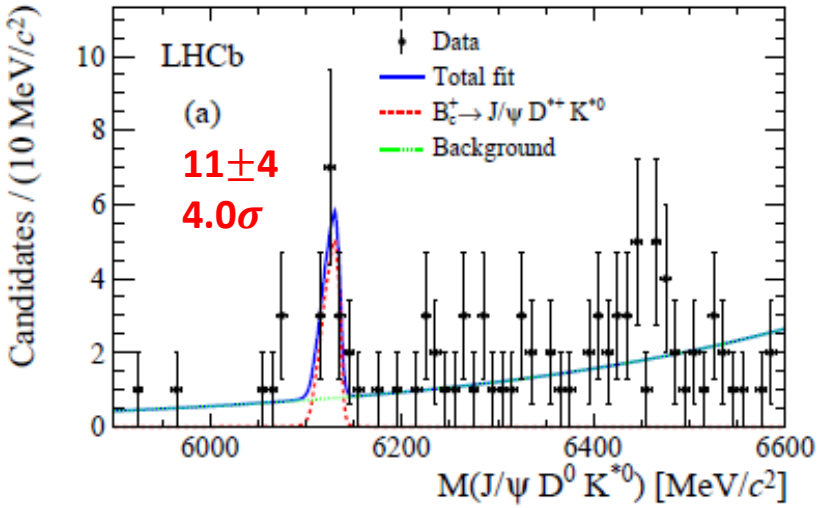
Final state	$Q(\mathrm{MeV}/c^2)$	Final state	$Q(\mathrm{MeV}/c^2)$
$J/\psi\pi^+$	3039	$J/\psi D_s^+$	1211
$J/\psi p\bar{p}\pi^+$	1163	**$J/\psi D^0 K^+$**	**820**

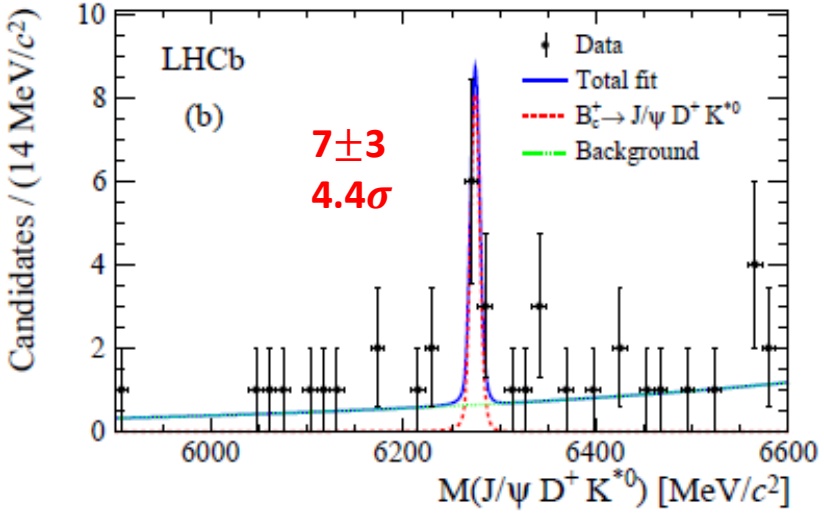
Signal yields



Combine $D^0 \to K\pi$ and $D^0 \to K\pi\pi\pi$

PRD 95 (2017) 032005





Branching fraction ratios

$$\frac{\mathcal{B}_{sig}}{\mathcal{B}_{ref}} = \frac{N_{sig}}{N_{ref}} \times \frac{\varepsilon_{ref}}{\varepsilon_{sig}} \times \frac{\mathcal{B}_{int,ref}}{\mathcal{B}_{int,sig}}$$

$\mathcal{B}(D \to \cdots)$ from PDG

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, D^0 K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.432 \pm 0.136 \pm 0.028,$$

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, D^{*0} K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, D^0 K^+)} = 5.1 \pm 1.8 \pm 0.4,$$

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, D^{*+} K^{*0})}{\mathcal{B}(B_c^+ \to J/\psi\, D^0 K^+)} = 2.10 \pm 1.08 \pm 0.34,$$

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, D^{+} K^{*0})}{\mathcal{B}(B_c^+ \to J/\psi\, D^0 K^+)} = 0.63 \pm 0.39 \pm 0.08,$$

PRD 95 (2017) 032005

B_c^+ mass

- Theoretical predictions range: 6.2 ~ 6.4 GeV/c^2

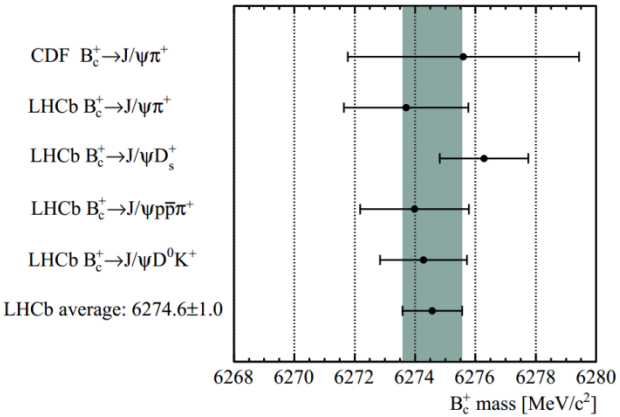
- First measured at Tevatron with $B_c^+ \to J/\psi\pi^+$: PRL 100(2008)182002, PRL 101(2008)012001

$$m(B_c^+) = 6275.6 \pm 2.9(\text{stat}) \pm 2.5(\text{syst}) \text{ MeV}/c^2$$

- LHCb measured B_c^+ mass with $B_c^+ \to J/\psi\pi^+$, $B_c^+ \to J/\psi D_s^+$, $B_c^+ \to J/\psi p\bar{p}\pi^+$ and $B_c^+ \to J/\psi D^0 K^+$ PRL 109,232001(2012) PRD 87.112012 PRL 113(2014)152003

PRD 95.032005

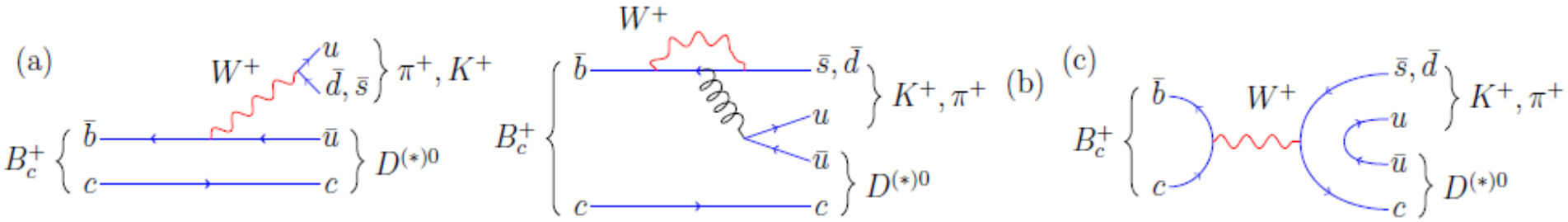
$$\mathbf{LHCb_{average} = 6274.6 \pm 1.0\ MeV/c^2}$$



Mode	Lum (fb^{-1})	Result (MeV/c^2)	Run-II (error) (MeV/c^2)	Upgrade (error) (MeV/c^2)
$B_c^+ \to J/\psi\pi^+$	1.0	$6273.7 \pm 1.3 \pm 1.6$	~0.4	~0.2
$B_c^+ \to J/\psi D_s^+$	3.0	$6276.3 \pm 1.4 \pm 0.3$	~0.7	~0.4
$B_c^+ \to J/\psi p\bar{p}\pi^+$	3.0	$6274.0 \pm 1.8 \pm 0.4$	~0.9	~0.5
$B_c^+ \to J/\psi D^0 K^+$	3.0	$6274.3 \pm 1.4 \pm 0.3$	~0.7	~0.4

$B_c^{\pm} \to D^0 h^{\pm}$

- To test QCD factorisation and explore new physics in B_c^+ rare decays
  - Tree-level $b \to u$ (a), $\left|\frac{V_{bu}}{V_{bc}}\right|^2 \approx 0.007$ at limit of LHCb data
  - Would be enhanced by $b \to s$ loop-mediated (b) and annihilation (c) amplitudes
  - No charmless B_c^+ decays have been reported ($B_c^+ \to K^+K^-\pi^+$ 2.5σ)

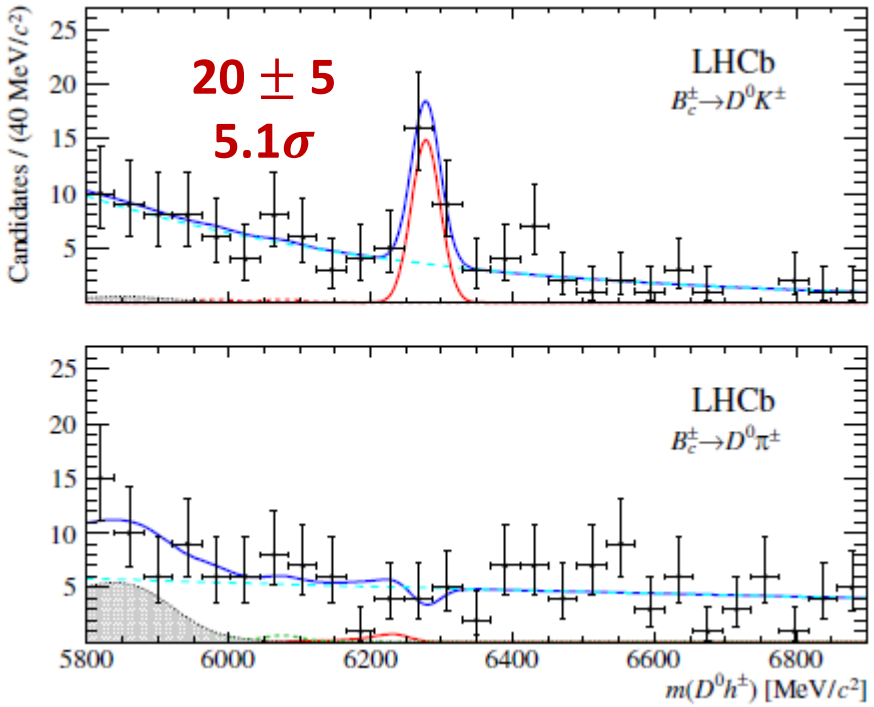


- To be reported $R_{D^0 h} = \frac{f_c}{f_u} \times \mathcal{B}(B_c^+ \to D^{(*)0} h^+)$
  - For K is $9 \times 10^{-10} \sim 3 \times 10^{-8}$
  - For π is $5 \times 10^{-10} \sim 8 \times 10^{-7}$

JHEP 06 (2011) 15 Eur. Phys. J. C5(1998) 705

Eur. Phys. J. C63 (2009) 435

Results of $B_c^{\pm} \to D^0 h^{\pm}$



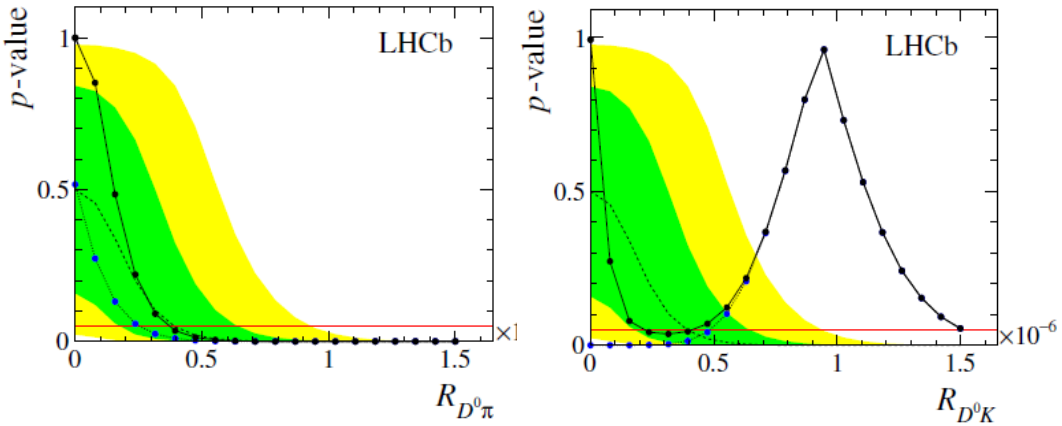
$$R_{D^0 K} = (9.3^{+2.8}_{-2.5} \pm 0.6) \times 10^{-7}$$

The upper limits at 95% CL:

$$R_{D^0\pi} < 3.9 \times 10^{-7},$$
$$R_{D^{*0}\pi} < 1.1 \times 10^{-6},$$
$$R_{D^{*0}K} < 1.1 \times 10^{-6}.$$

$$\mathcal{B}(B_c^+ \to D^0 K^+)/\mathcal{B}(B_c^+ \to J/\psi \pi^+) = 0.23 \pm 0.04 \pm 0.01 \pm 0.01$$

From $R_{J/\psi\pi}$

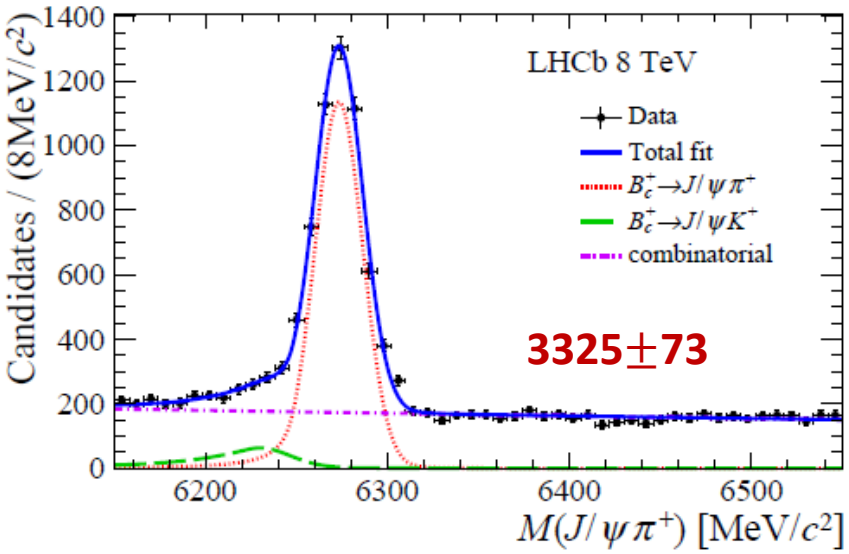


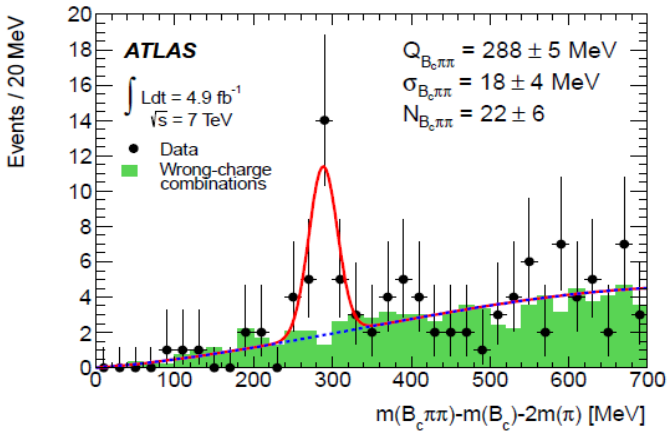
First observation of the penguin and/or weak annihilation amplitudes in the decay of B_c^+ meson

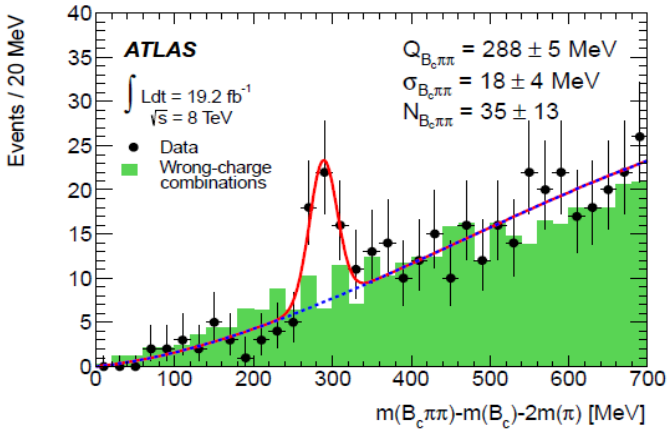
PRL 118 (2017) 111803

$B_c^{(*)+}(2S) \to B_c^+\pi^+\pi^-$

- ATLAS claimed observation of $B_c^+(2S)$
  - $M_{B_c^+(2S)} = 6842 \pm 4 \pm 5\ \mathrm{MeV}/c^2$
- Search for $B_c^+(2S)$ by LHCb using 2 fb^{-1} @8 TeV data
  - A Large and clear B_c^+ sample
  - $2 < \eta < 4.5\ \&\&\ p_T < 20\ \mathrm{GeV}/c$
- More detail see Lucio's talk





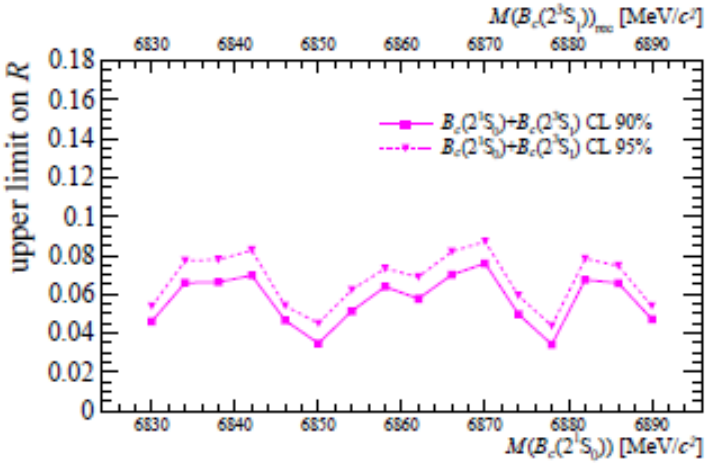


[PRL 113 (2014) 212004]

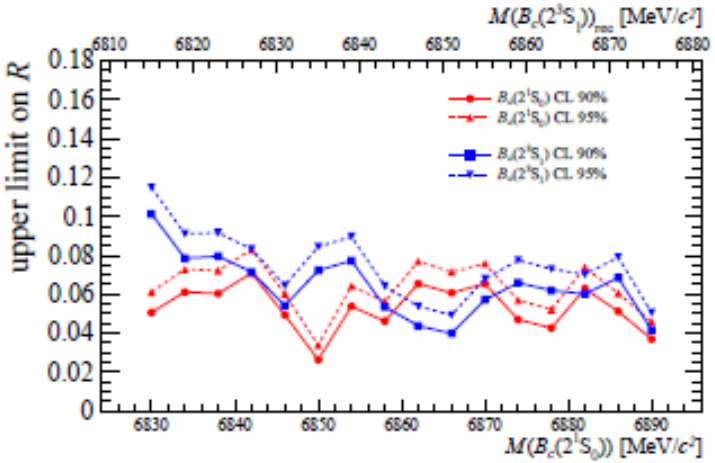
Only about **300** B_c^+ events in ATLAS

LHCB-PAPER-2017-042 in preparation

Scan window and upper limits

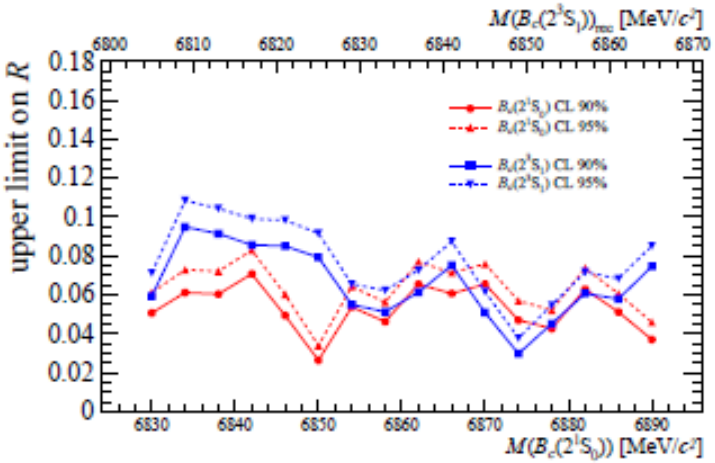


(a) $\Delta M = 0\,\mathrm{MeV}/c^2$

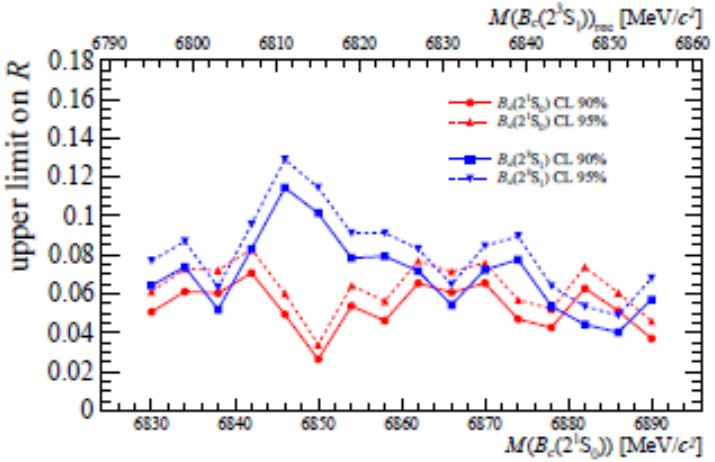


(b) $\Delta M = 15\,\mathrm{MeV}/c^2$

LHCB-PAPER-2017-042 in preparation



(c) $\Delta M = 25\,\mathrm{MeV}/c^2$



(d) $\Delta M = 35\,\mathrm{MeV}/c^2$

$$\Delta M = \left[M_{B_c^{*+}} - M_{\boldsymbol{B_c^+}}\right] - \left[M_{B_c^+(2^3S_1)} - M_{\boldsymbol{B_c^+(2^1S_0)}}\right]$$

- No significant signal is found.

Conclusions and Outlook

- Many results on B_c^+ mesons physics by LHCb
  - First time search for the $B_c^+ \to K^+K^-\pi^+$ decay and evidence for the decay $B_c^+ \to \chi_{c0}\pi^+$
  - $\mathcal{B}(B_c^+ \to J/\psi K^+)/\mathcal{B}(B_c^+ \to J/\psi\,\pi^+)$=$0.077 \pm 0.007(\mathrm{stat}) \pm 0.002(syst)$
  - First observation of the $B_c^+ \to J/\psi D^{(*)}K^{(*)}$ decays (more precise mass measurement by combining previous results)
  - First observed of the $B_c^\pm \to D^0K^\pm$
  - Search for $B_c^+(2S)$, no signal is found
- More analyses based on RUN-I and RUN-II data are still under way

Thank you!

Back up

References of $B_c^+ \to J/\psi K^+$

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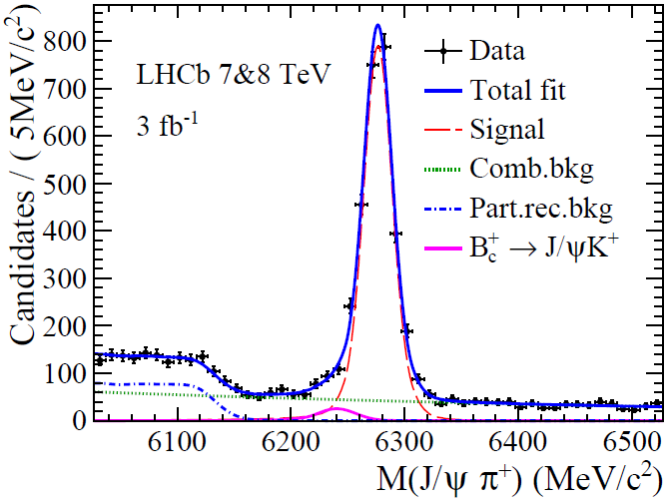
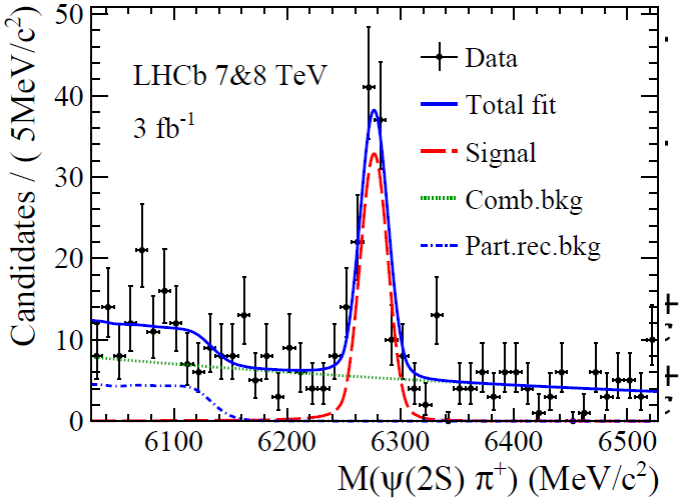
$B_c^+ \to \psi(2s)\pi^+$ [PRD 87(2013) 071103(R)]

LHCb searched for this decay in 1 fb^{-1} 7 TeV data, observing it **for the first time.**





$\to \psi(2s)\pi^+) = 20 \pm 5$

$\to J/\psi\pi^+) = 595 \pm 29$

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

Uncertainty from $\frac{\mathcal{B}(J/\psi \to \mu\mu)}{\mathcal{B}(\psi(2s) \to \mu\mu)}$

Test of theoretical models:

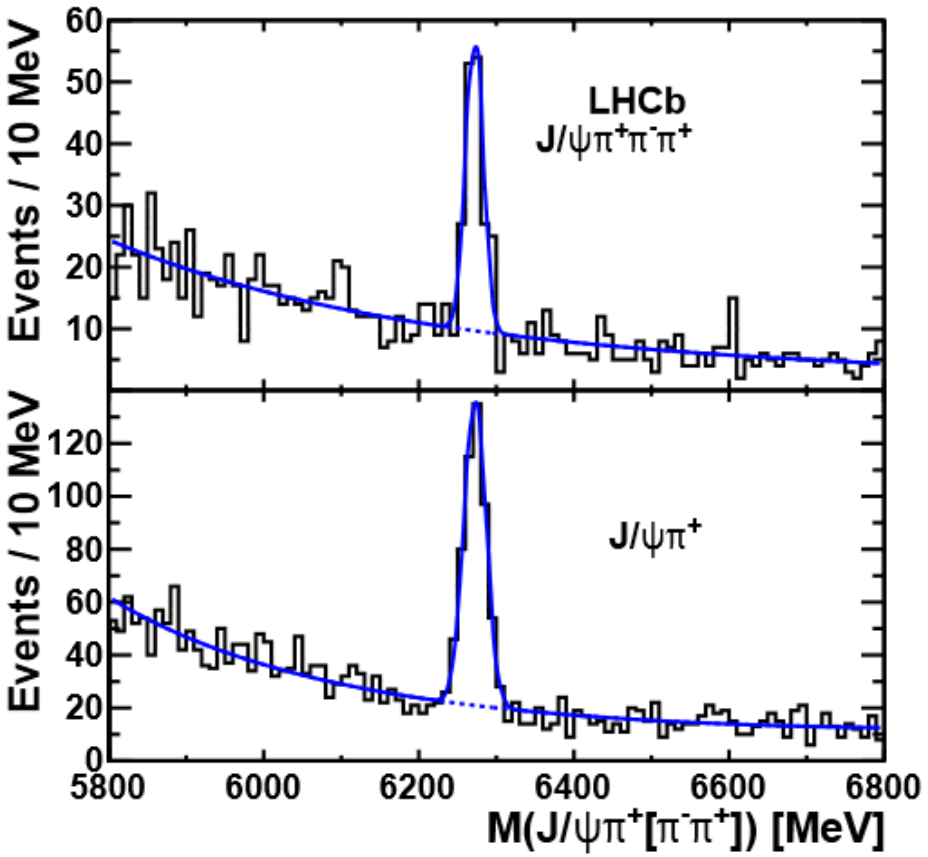
0.127	0.070	0.149	0.180	0.26
PRD 49(1994) 3399	PRD 56(1997) 4133	PRD 61(2000) 034012	PRD 68(2003) 094020	PRD 89(2014),034008

➢ **Favor NLO NRQCD calculations: 0.26**

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

First observation of this decay

0.8 fb^{-1} at 7 TeV

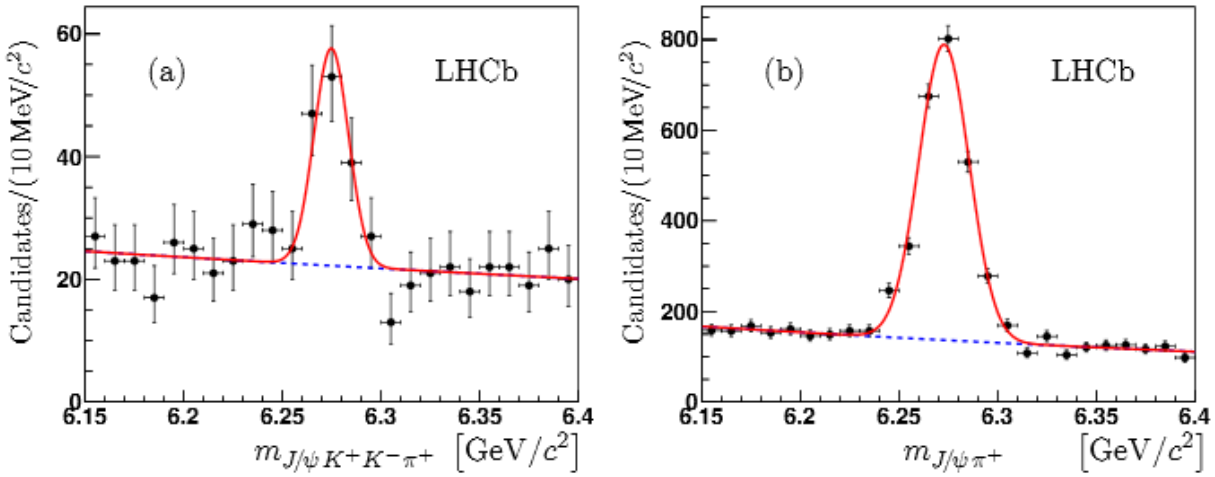


PRL 108,251802 (2012)

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

$B_c^+ \to J/\psi K^+ K^- \pi^+$

First observation of this decay *3 fb^{-1} at 7/8 TeV*



Significance: 6.2σ

JHEP11(2013)094

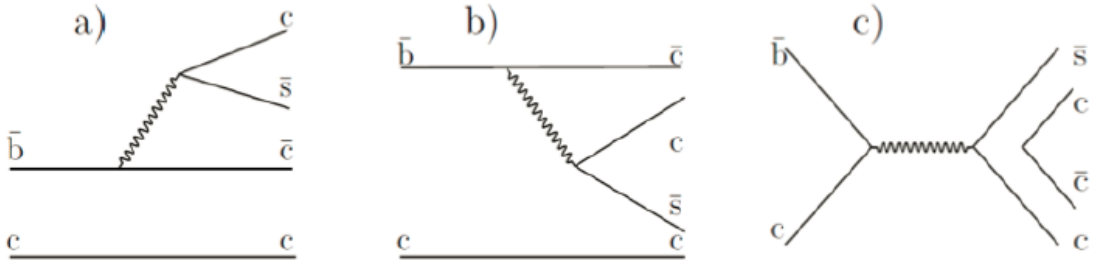
N($B_c^+ \to J/\psi K^+$)= 78±14

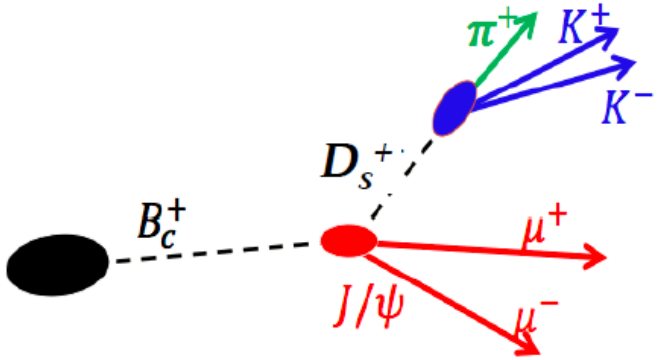
N($B_c^+ \to J/\psi \pi^+$)= 2099±59

$$\frac{\mathcal{B}(B_c^+ \to J/\psi K^+ K^- \pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = \mathbf{0.53 \pm 0.10\ (stat) \pm 0.05(syst)}$$

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

First observation of this mode 3 fb^{-1} at 7/8 TeV



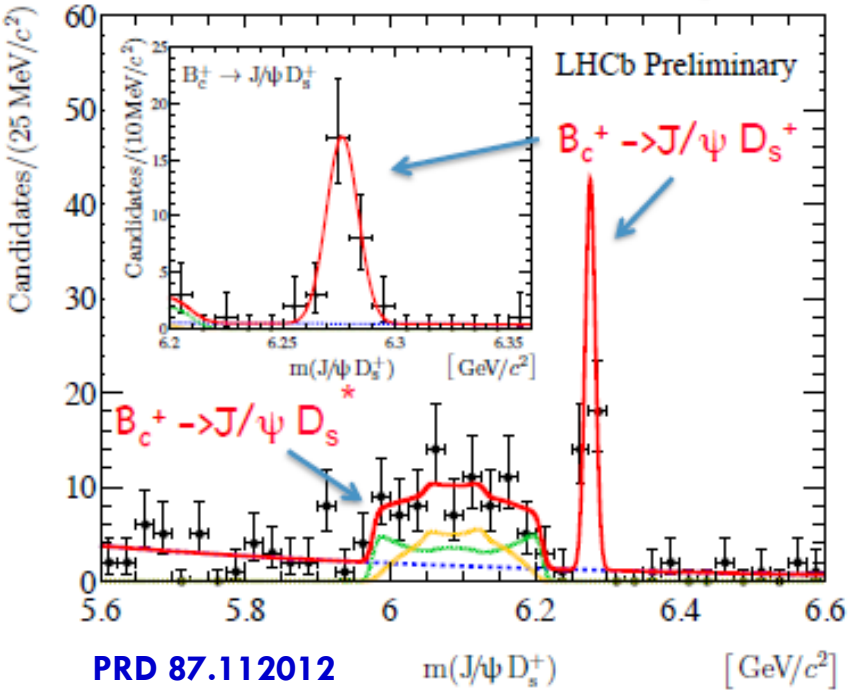


$N(B_c^+ \to J/\psi D_s^+) = 28.9 \pm 5.6$

$N(B_c^+ \to J/\psi D_s^{*+}) = 68.4 \pm 9.6$

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

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

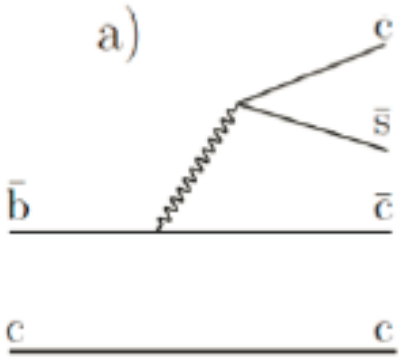


Significance >7σ for each

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

Theory predictions disagree (References [see Pag.27])

$\mathcal{R}_{D_s^+/\pi^+}$	$\mathcal{R}_{D_s^{*+}/D_s^+}$	
2.90 ± 0.42	$2.20 \pm 0.35 \pm 0.62$	Eqs. (1) with B^0
1.58 ± 0.34	$2.07 \pm 0.52 \pm 0.52$	Eqs. (1) with B^+
1.3	3.9	Ref. [7]
2.6	1.7	Ref. [8]
2.0	2.9	Ref. [9]
2.2	—	Ref. [10]
1.2	—	Ref. [11]



Comparative theoretical predictions of view, we assume that the diagram dominates.

Eqs.(1)

$$\mathcal{R}_{D_s^+/\pi^+} = \frac{\Gamma(B_c^+ \to J/\psi D_s^+)}{\Gamma(B_c^+ \to J/\psi \pi^+)} \approx \frac{\Gamma(B \to \overline{D}^* D_s^+)}{\Gamma(B \to \overline{D}^* \pi^+)},$$

$$\mathcal{R}_{D_s^{*+}/D_s^+} = \frac{\Gamma(B_c^+ \to J/\psi D_s^{*+})}{\Gamma(B_c^+ \to J/\psi D_s^+)} \approx \frac{\Gamma(B \to \overline{D}^* D_s^{*+})}{\Gamma(B \to \overline{D}^* D_s^+)},$$

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

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[8] P. Colangelo and F. De Fazio, *Using heavy quark spin symmetry in semileptonic* B_c^+ *decays*, Phys. Rev. **D61** (2000) 034012, arXiv:hep-ph/9909423.

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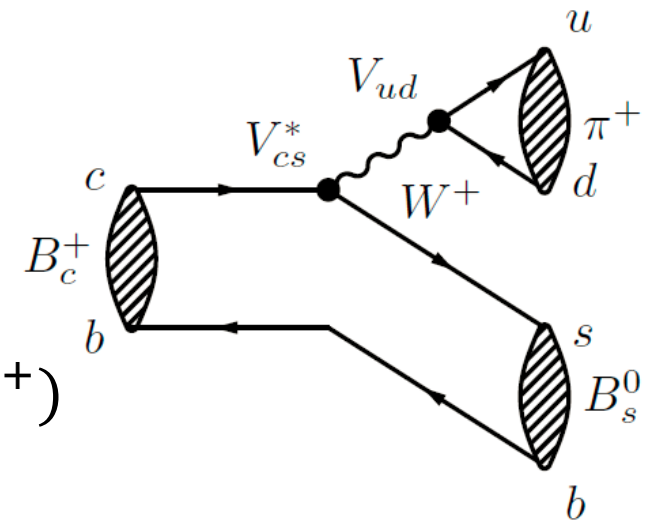
$B_c^+ \to B_s^0 \pi^+$



1. Models predict large range of $\mathcal{B}(B_c^+ \to B_s^0 \pi^+)$

2. $B_c^+ \to B_s^0 \pi^+$ as source of B_s^0 mesons
   - ✓ Flavor self-tagging
   - ✓ Decay time determination

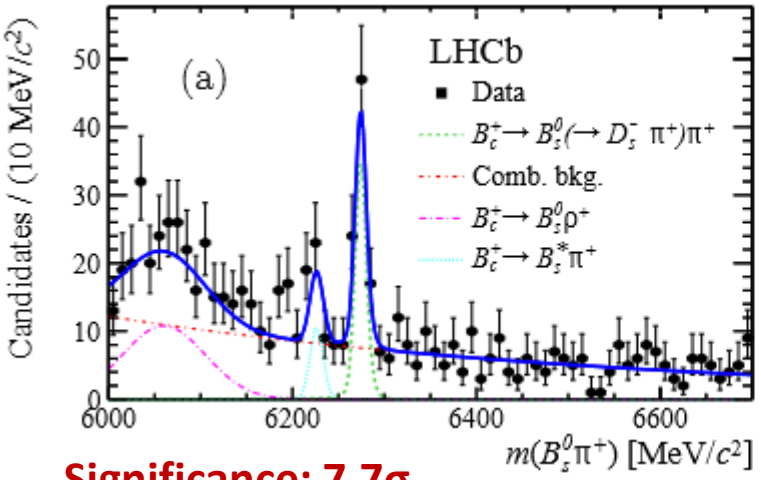
Some theoretical predictions:

16.4%	3.9%	3.42%,	5.75%	1.87%	12.01%
PAN B67(2004) 1559	PRD 73(2006) 054024	PLB 452(1999) 129	PRD 49(1994) 3399	PJG 35(2008) 085002	PRD 86(2012) 094028
QCD sum rule	**RCQM**	**RCQM**	**HQET**	**BSW**	**RIQM**
V.V.Kiselev	M. A. Ivanov	A. Y. Anisimov	C. H. Chang	R. Dhir	S. Naimuddin

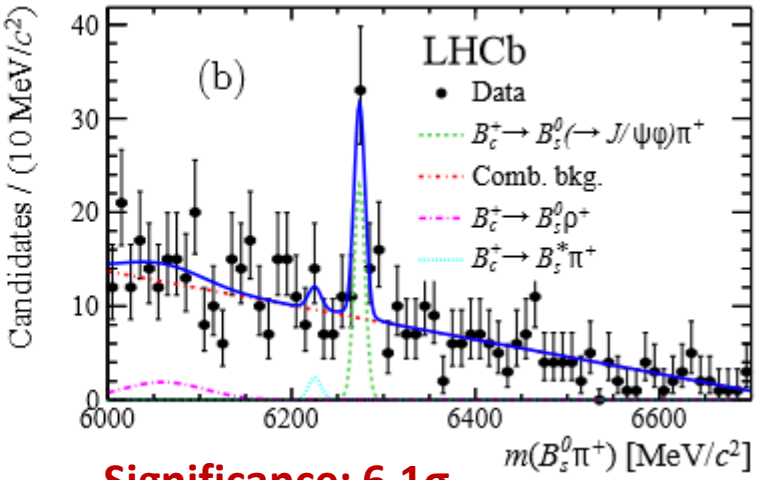
The range of $\mathcal{B}(B_c^+ \to B_s^0 \pi^+)$: 1.87%~16.4%

$B_c^+ \to B_s^0 \pi^+$

3 fb^{-1} at 7/8 TeV



Significance: 7.7σ



Significance: 6.1σ

PRL 111,181801

- First observation of a B meson weakly decaying to another B meson

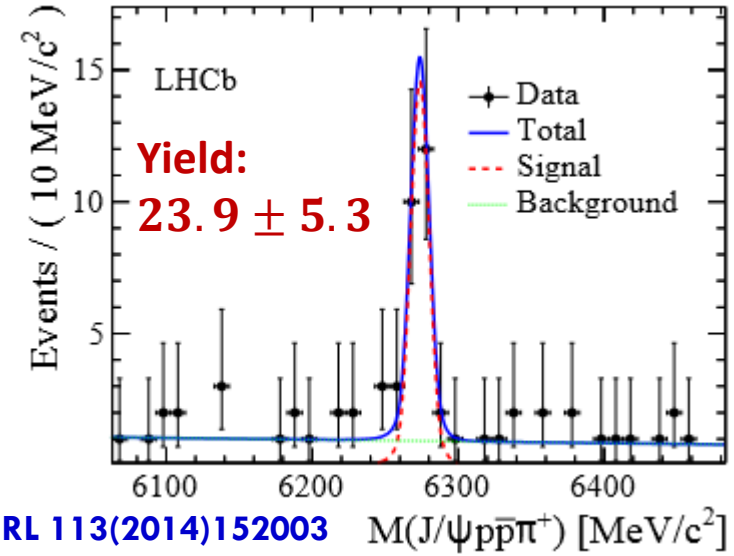
$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \to B_s^0 \pi^+) = \left(\mathbf{2.37 \pm 0.31\,(stat) \pm 0.05(syst)^{+0.09}_{-0.07}}\left(\tau_{B_c^+}\right)\right) \times \mathbf{10^{-3}}$$

- ~ 1/500 B_s^0 originates from $B_c^+ \to B_s^0 \pi^+$
- To extract BR needs to know B_c^+ production rate

$B_c^+ \to J/\psi p\bar{p}\pi^+$

Significance: 7.3σ

- Baryonic decays of *B* mesons provide good opportunities to study the mechanism of baryon production and to search for excited baryon resonances



PRL 113(2014)152003

- First observation of a baryonic B_c^+ decay by LHCb using Run-I data

$$R_p \equiv \frac{\mathcal{B}(B_c^+ \to J/\psi p\bar{p}\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 0.134^{+0.039}_{-0.034}(\text{stat}) \pm 0.013(\text{syst})$$

- R_p is consistent with the expectation in the spectator model

$$R_p \approx \frac{\mathcal{B}(B^0 \to D^{*-} p\bar{p}\pi^+)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)} \sim 0.17$$

- Further theoretical research is need!

B_c^+ lifetime

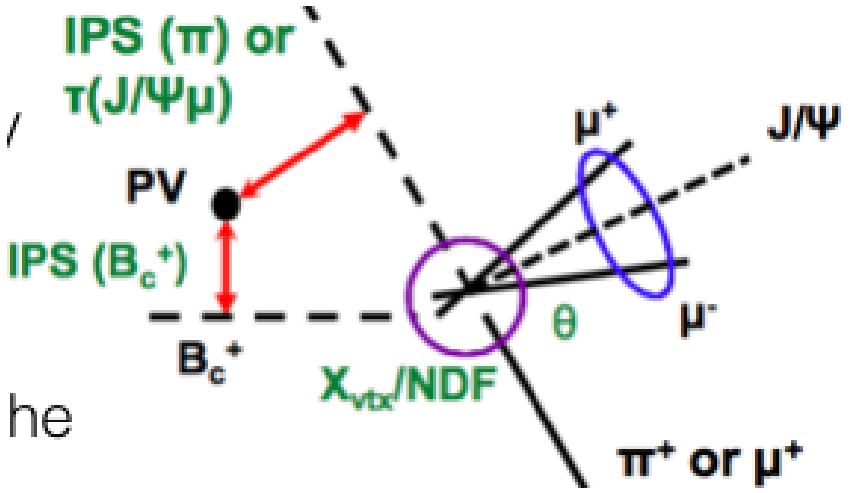
- Theoretical predictions range: 300 ~ 700 fs
- PDG value (only Tevatron) : $\tau_{B_c^+} = 452 \pm 32$ fs
- Precision measurement can test theoretical models
- LHCb measurement with $B_c^+ \to J/\psi\mu^+\nu_\mu X$ and $B_c^+ \to J/\psi\pi^+$ decays

[EPJ C74(2014) 2839] PLB 742 (2015)

Mode	Lum (fb^{-1})	Result (fs)	Run-II (stat)	Upgrade (stat)
$B_c^+ \to J/\psi\mu^+\nu_\mu X$	2.0	$509 \pm 8 \pm 12$	~3.3	~1.7
$B_c^+ \to J/\psi\pi^+$	3.0	$513.4 \pm 11.0 \pm 5.7$	~5.5	~2.3

- **Further theoretical research is need!**

Multivariate analysis



- IPS(B_c^+), IPS(J/ψ), IPS(H), IPS($\mu^{\pm}$), PT(J/ψ), PT(H), PT($\mu^{\pm}$) ,Bc_τ, Bc_L, $\chi^2_{DTF}(B_c^+)$