



B_c^+ physics at LHCb

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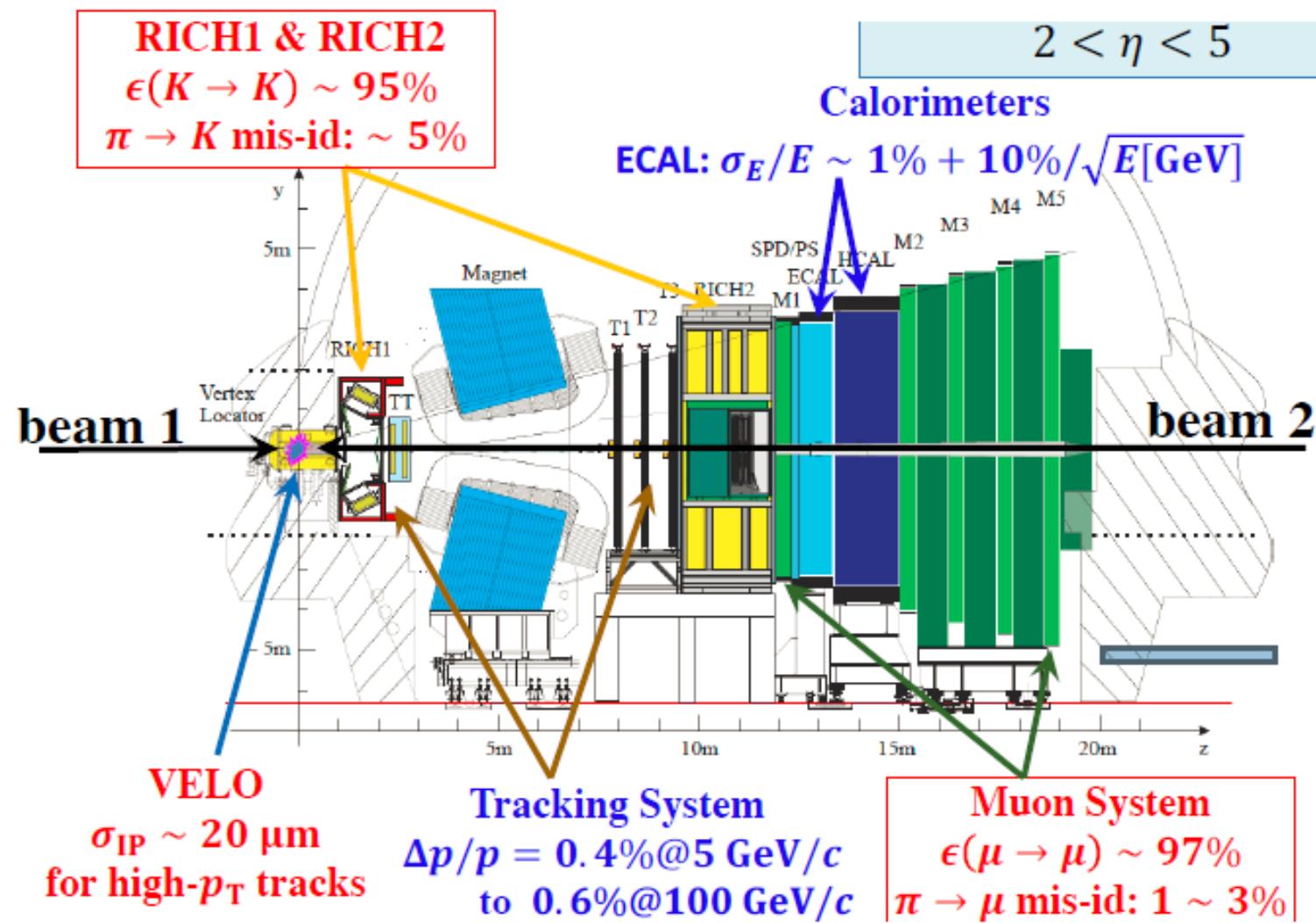
Outline

- Introduction
- Selected topics: (Chinese group contributions)
 - $\mathcal{B}(B_c^+ \rightarrow J/\psi K^+)/\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)$ [JHEP 09 \(2016\) 153](#)
 - $B_c^+ \rightarrow J/\psi D^{(*)} K^{(*)}$ [LHCb-PAPER-2016-055](#)
- Summary

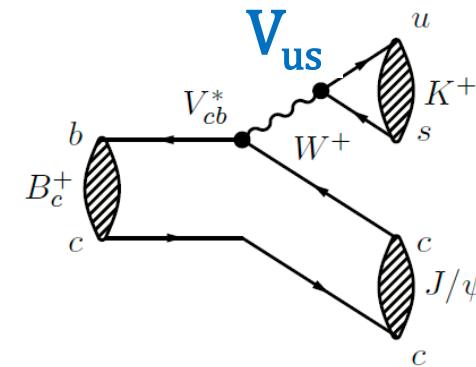
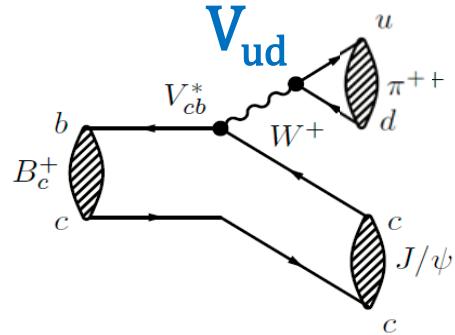
Introduction

- B_c^+ meson discovered by CDF in 1998 [Phys. Rev. Lett. 81, 2432 \(1998\)](#)
 - With only ~ 10 decay channels are currently known
 - The measured mass has larger uncertainty compared with that of other B meson: 6275.1 ± 1.0 MeV [PDG2016](#)
- B_c^+ meson is the ground state of the $(\bar{b}c)$ bound state
- B_c^+ has a much **shorter lifetime** than other B mesons
- Heavy quark-antiquark pair of different flavours: unique state in the Standard Model
- Great potential for the LHC, especially the **LHCb** experiment

LHCb detector



$\mathcal{B}(B_c^+ \rightarrow J/\psi K^+)/\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)$



- Kaon channel is Cabibbo suppressed channel, naïve estimate is $R_k =$

$$\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi K^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)} \approx \left| \frac{V_{us}}{V_{ud}} \right|^2 \times g^2$$

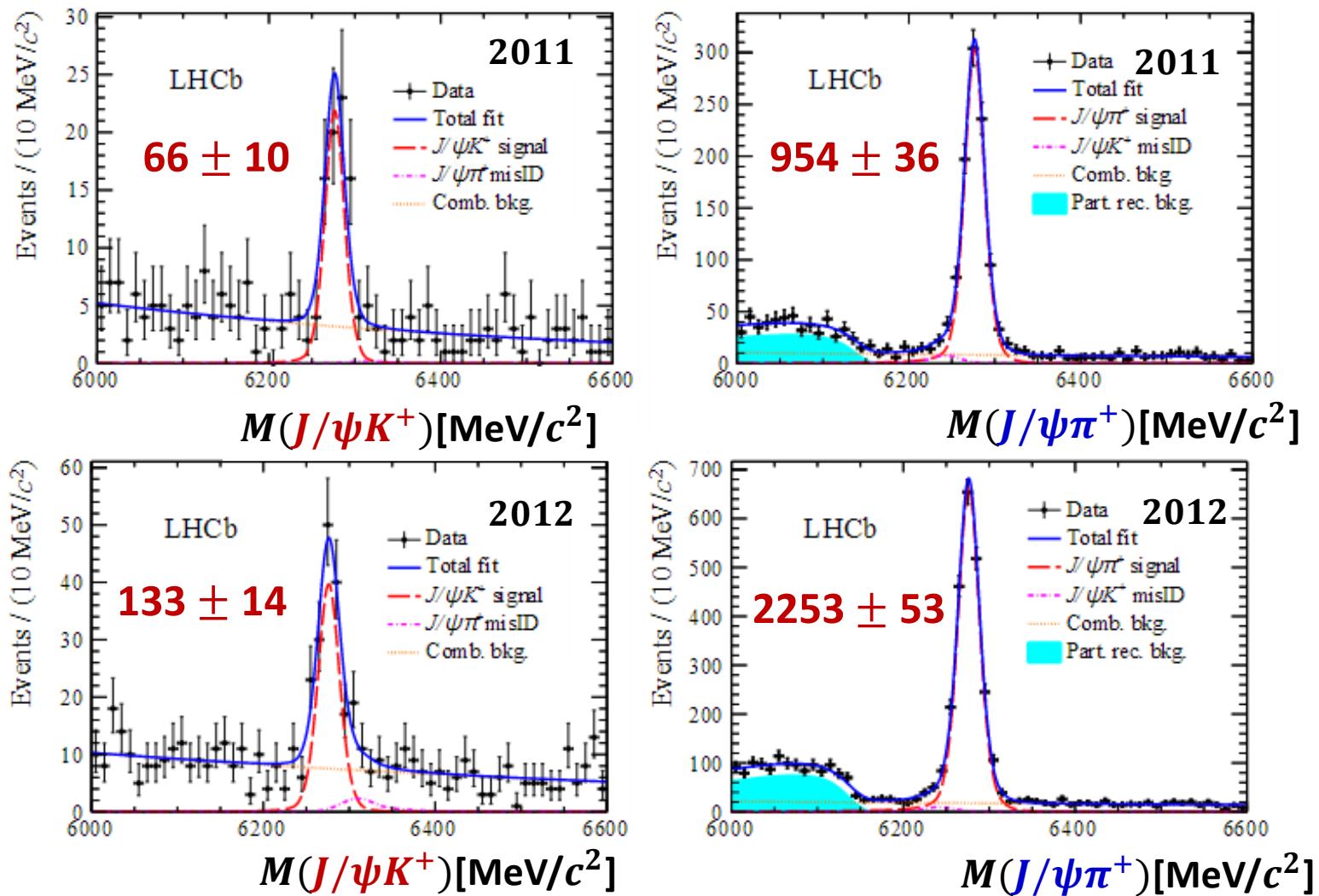
- Test of theoretical models:
 - R_K (0.052 – 0.096)

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

$\mathcal{B}(B_c^+ \rightarrow J/\psi K^+)/\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+) @\text{LHCb}$

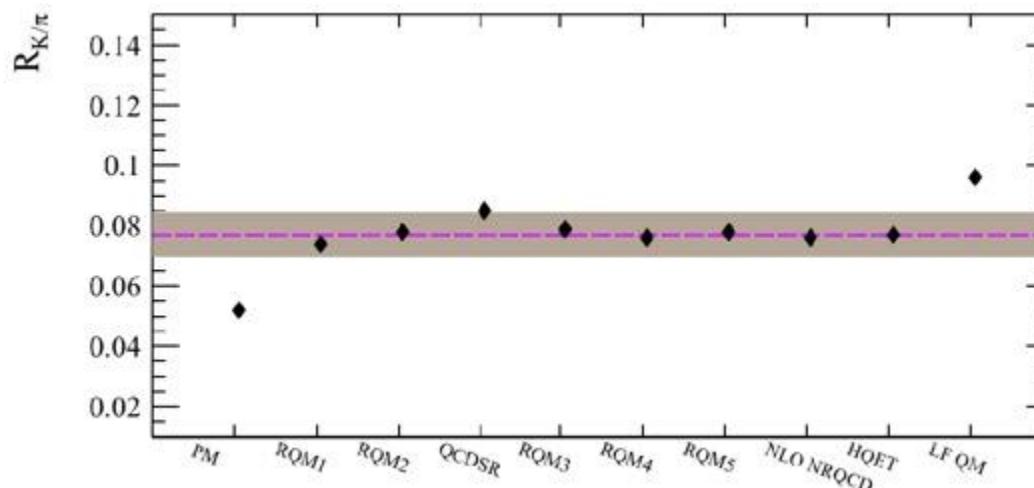
- Update results with entire 7+8 TeV data
 - Previous analysis with 1 fb^{-1} data, limited by statistics uncertainty [JHEP 09 \(2013\) 075](#)
- More powerful variable used in TMVA to suppress background
- B_c^+ lifetime alignment
 - With latest LHCb measurement: $\tau = 509 \pm 8 \pm 12 \text{ fs}$, to reduce systematic uncertainty

Signal yields



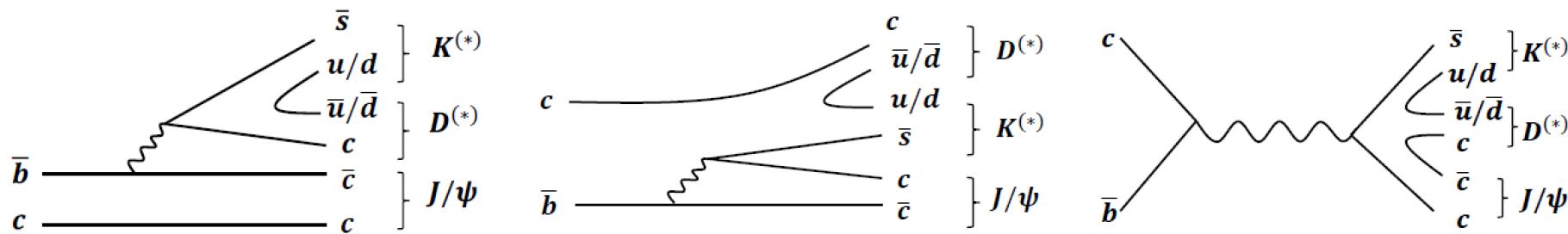
Results

- $\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi K^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)} = 0.077 \pm 0.007(\text{stat}) \pm 0.002(\text{syst})$
- Consistent with previous LHCb results:
 - $\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi K^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)} = 0.069 \pm 0.019(\text{stat}) \pm 0.005(\text{syst})$
- The results can be used to distinguish the different theoretical models



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

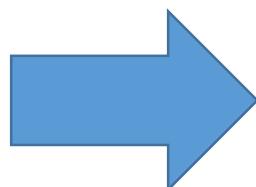
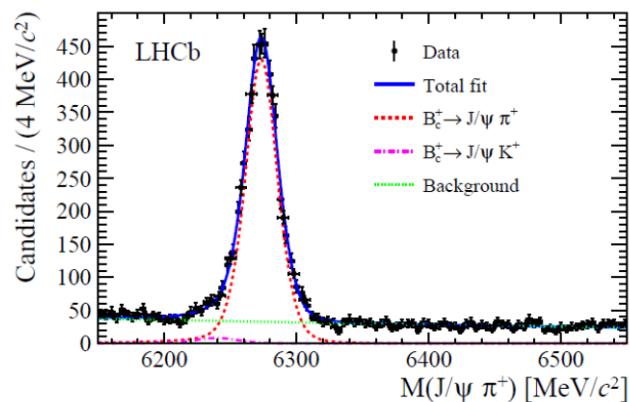
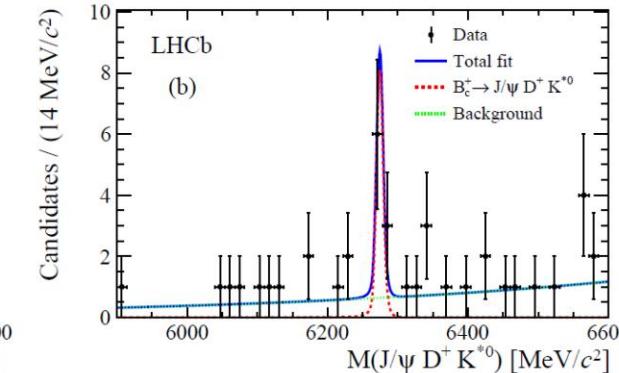
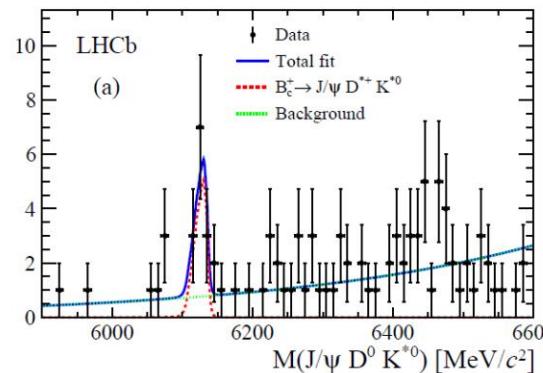
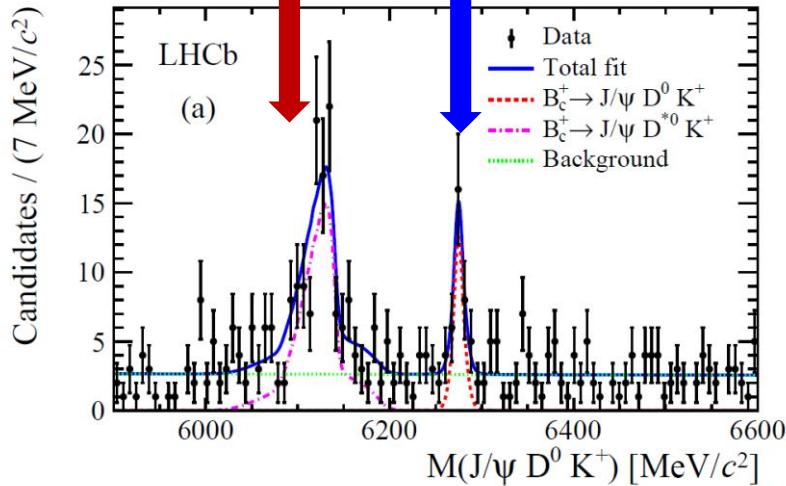
- B_c triply charmed decay: $\bar{b} \rightarrow c\bar{c}\bar{s} + \text{annihilation contribution}$



- Search for $J/\psi D^0 K^+$, $J/\psi D^{*0} K^+$, $J/\psi D^+ K^{*0}$, $J/\psi D^{*+} K^{*0}$
 - $J/\psi \rightarrow \mu^+ \mu^-$
 - $D^0 \rightarrow K^- \pi^+$, $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$ in $J/\psi D^{(*)0} K^+$ measurement
 - $D^+ \rightarrow K^- \pi^+ \pi^-$
 - $D^0 \rightarrow K^- \pi^+$ in other mode searches
 - D^{*0} and D^{*+} are partial reconstructed

Results

$$B_c^+ \rightarrow J/\psi D^{*0} K^+: 10.3 \sigma \quad B_c^+ \rightarrow J/\psi D^0 K^+: 6.3 \sigma$$



$$B_c^+ \rightarrow J/\psi D^{*+} K^{*0}, 4.0 \sigma$$

$$B_c^+ \rightarrow J/\psi D^+ K^{*0}, 4.4 \sigma$$

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

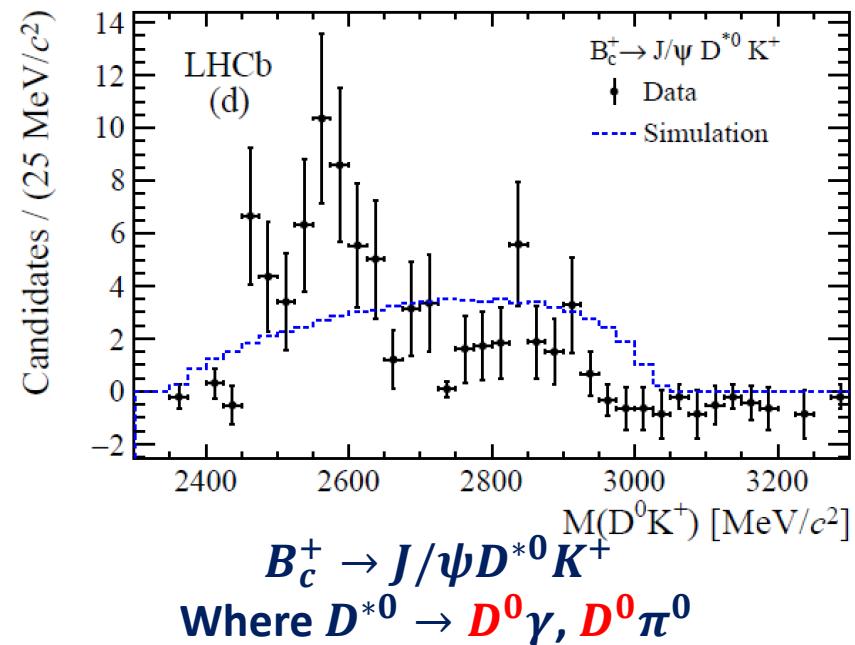
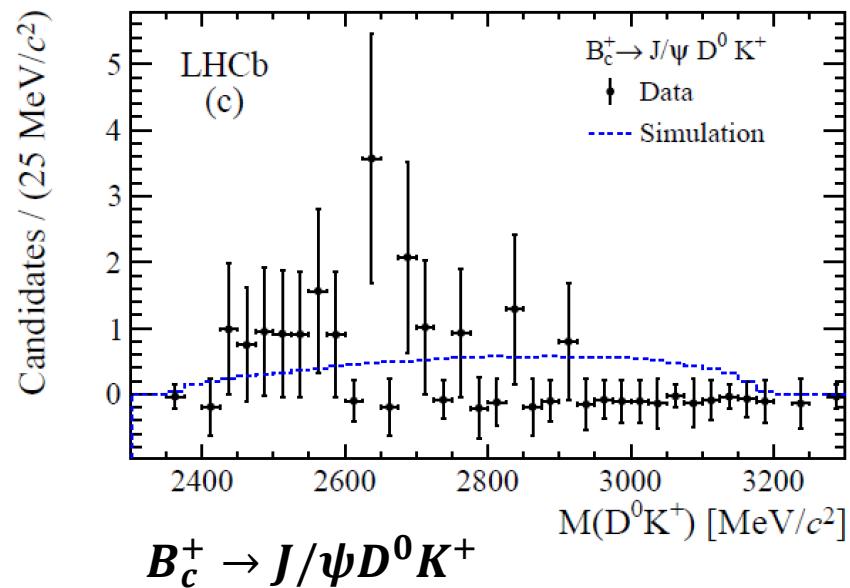
$$\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi D^{*0} K^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi D^0 K^+)} = 5.1 \pm 1.8 \pm 0.4,$$

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

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

D_{SJ} spectrum in B_c decays

- Interesting to study excited D_{SJ}

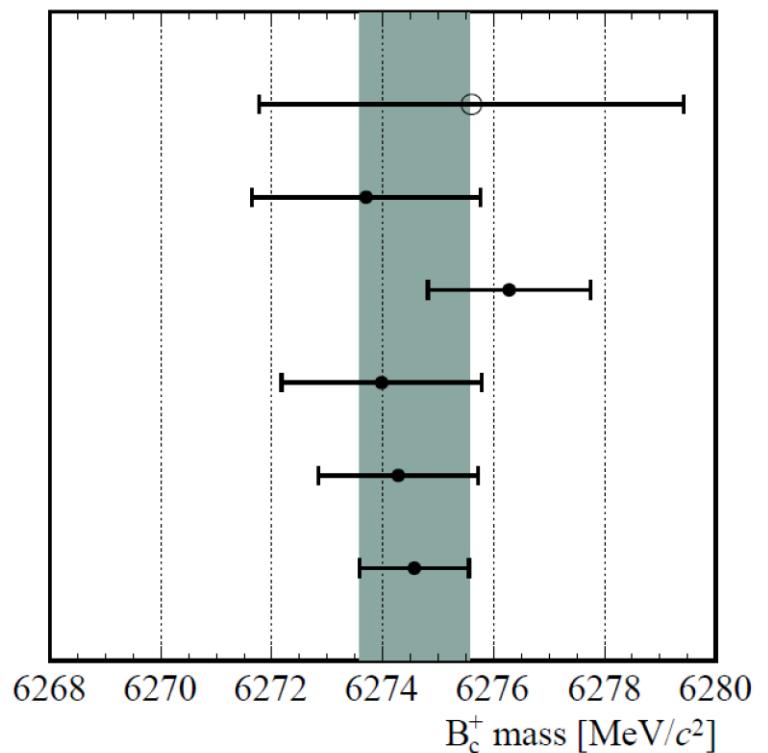


B_c^+ mass measurement

- With channel $B_c^+ \rightarrow J/\psi D^0(\rightarrow K^-\pi^+)K^\pm\pm$
 - $6274.28 \pm 1.40(\text{stat.}) \pm 0.32(\text{syst.}) \text{ MeV}/c^2$

Source	Uncertainty (MeV/c^2)
Momentum scale	0.26
Fit model	0.18
Final state radiation	0.01
Energy loss correction	0.05
D^0 , J/ψ mass uncertainties	0.05
Total	0.32

CDF $B_c^+ \rightarrow J/\psi \pi^+$
LHCb $B_c^+ \rightarrow J/\psi \pi^+$
LHCb $B_c^+ \rightarrow J/\psi D_s^+$
LHCb $B_c^+ \rightarrow J/\psi p\bar{p}\pi^+$
LHCb $B_c^+ \rightarrow J/\psi D^0 K^+$
LHCb average:
 $6274.6 \pm 1.0 \text{ MeV}/c^2$



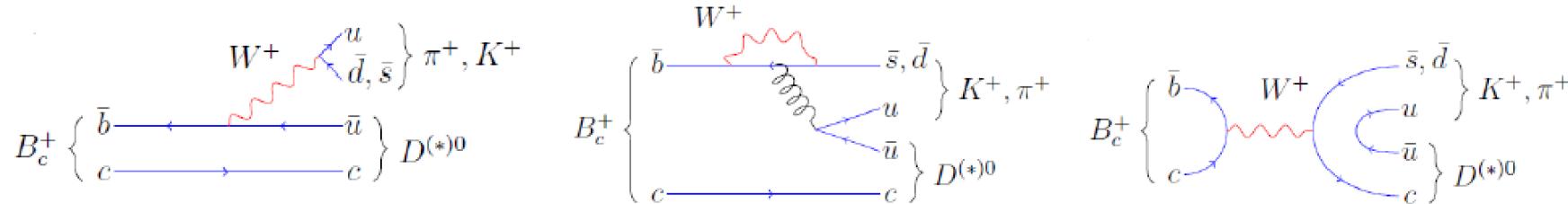
Conclusion

- For B_c^+ measurement, LHCb achieved the world best measurement of
 - Production cross section
 - Mass
 - Lifetime
- In the LHCb Run-II, with increasing luminosity, enhanced production cross section
 - Precision measurement of B_c^+ meson
 - Yielding to new exciting results: excited states

Backup

Observation of $B_c^+ \rightarrow D^0 K^+$

LHCb-PAPER-2016-058, in prep.



- $B^+ \rightarrow D^0 \pi^+$ as normalization channel
- $B_c^+ \rightarrow D^0 \pi^+$ Cabibbo favoured at tree-level, yet not observed;
- $B_c^+ \rightarrow D^0 K^+$ observed (5.1σ), Penguin or annihilation dominating!

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

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

NB: theory predicts: $(5\sim 8) \times 10^{-7}$

$$R_{D^0 \pi^+} < 3.9 \times 10^{-7}$$

$$R_{D^{*0} \pi^+} < 3.9 \times 10^{-6} \quad @ \text{95% C.L.}$$

$$R_{D^{*0} K^+} < 3.9 \times 10^{-6}$$

