Measurement of $B_c^{\pm}$ Mass and Lifetime at LHCb

Wenbin Qian
on behalf of the LHCb Collaboration

LAL, Orsay, France
Tsinghua University, Beijing, China

Outline

- Introduction
- $B_c^{\pm}$ mass measurement
- $B_c^{\pm}$ lifetime measurement
- Other B_c studies in LHCb
- Summary

Introduction to B_c Physics(1)

B_c System:

➢ **Heaviest open flavour mesons (top quark lifetime is too small)**

➢ **Heavy quarks (b and c), precise QCD calculations**

➢ **Discovered in 1998 (Tevatron), many properties are still unknown**

$B_c^\pm$

$I(J^P) = 0(0^-)$
I, J, P need confirmation.
Quantum numbers shown are quark-model predicitions.

Mass $m = 6.277 \pm 0.006$ GeV (S = 1.6)
Mean life $\tau = (0.453 \pm 0.041) \times 10^{-12}$ s

B_c^- modes are charge conjugates of the modes below.

B_c^+ DECAY MODES × B($\bar{b} \to B_c$)	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times$ B($\bar{b} \to B_c$).			
$J/\psi(1S)\ell^+\nu_\ell$ anything	$(5.2^{+2.4}_{-2.1}) \times 10^{-5}$		–
$J/\psi(1S)\pi^+$	$< 8.2 \times 10^{-5}$	90%	2372
$J/\psi(1S)\pi^+\pi^+\pi^-$	$< 5.7 \times 10^{-4}$	90%	2352
$J/\psi(1S)a_1(1260)$	$< 1.2 \times 10^{-3}$	90%	2171
$D^*(2010)^+\overline{D}^0$	$< 6.2 \times 10^{-3}$	90%	2468

$B_c^\pm$ Production

➢ **Main Process: $gg \to B_c^+ + \bar{c} + b$ with production fraction ~ 0.1% of other B mesons (B^0,B^+,B_s^0)**

➢ **Production in LHC:**

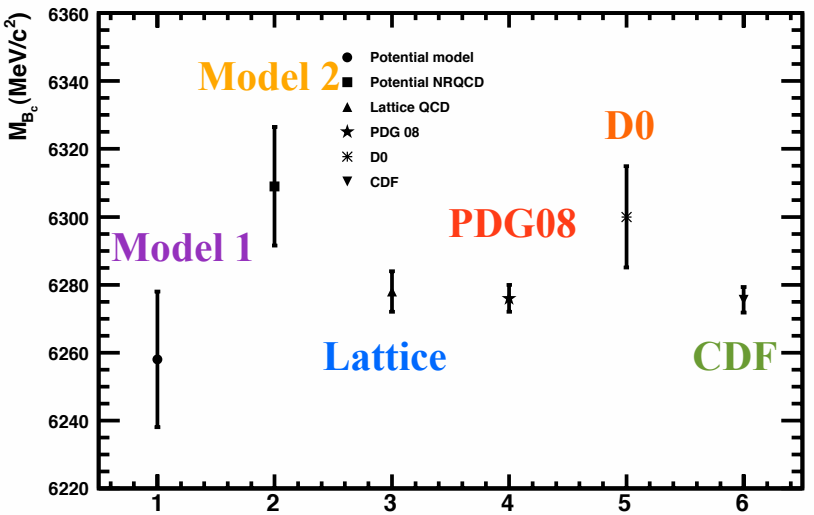
$$\sigma(B_c^\pm) \sim 0.4\mu b \text{ at } 14 \text{ TeV pp collision}$$

$$\sigma(B_c^\pm)_{\text{LHC}}/\sigma(B_c^\pm)_{\text{Tevatron}} \sim O(10)$$

➢ **$B_c^\pm$ cross section measurement ➠ Production mechanism understanding (For example, Colour octet, colour singlet)**

Introduction to Bc Physics(2)

$B_c^{\pm}$ Mass



➢ B_c system mass spectrum ➠ Quark model and pQCD test

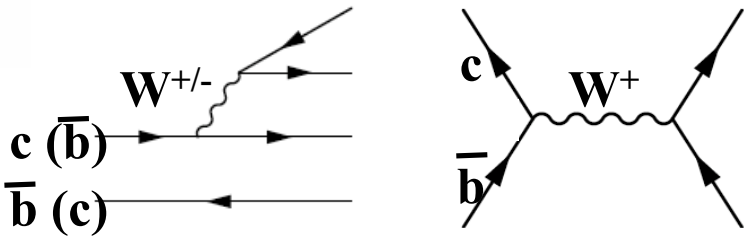
➢ Only $B_c^{\pm}$ mass measured, Compatible with calculation

➢ Mass measurement errors are of the Same order than lattice QCD

$B_c^{\pm}$ Lifetime and Branching Ratio

➢ $B_c^{\pm}$ lifetime measurement ➠ Dynamics of heavy quark decay

➢ $B_c^{\pm}$ decay branching ratios ➠ few decay modes observed



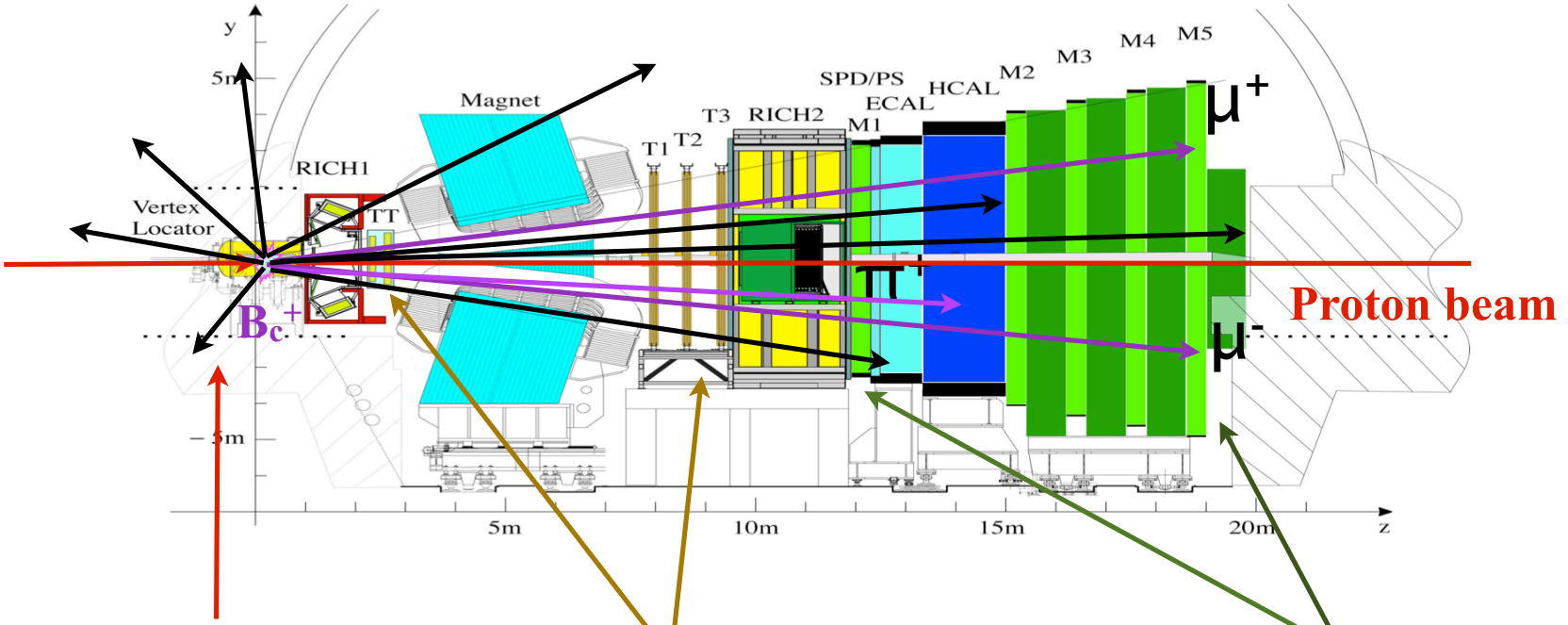
Sum Rules $\tau = 0.48 \pm 0.05$ ps

D0 $\tau = 0.448^{+0.038}_{-0.036} \pm 0.032$ ps

CDF $\tau = 0.463^{+0.073}_{-0.0655} \pm 0.036$ ps

$B_c^{\pm} \rightarrow J/\psi(\mu^+\mu^-)\pi^{\pm}$

LHCb Performance



Silicon strip detector:
- $\sigma_{x/y}$ ~ 10 μm
- σ_z ~ 60 μm
- σ_{IP} ~ 25 μm

Tracking System (TT,T1-T3):
- Tracking Efficiency ~ 95%
- Ghost ~ 5%
- Δp/p~ 0.5%(long tracks)

Muon System (M1-M5):
- μ identification, μ/π separation

*long tracks: tracks passing trough VELO,TT,T1-T3

Event Selection and Yield

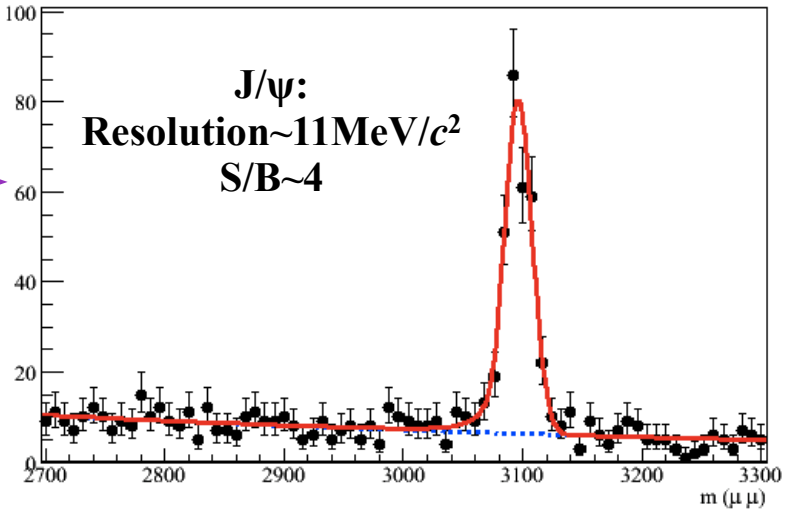
➢ Loose cuts on final state tracks and J/ψ

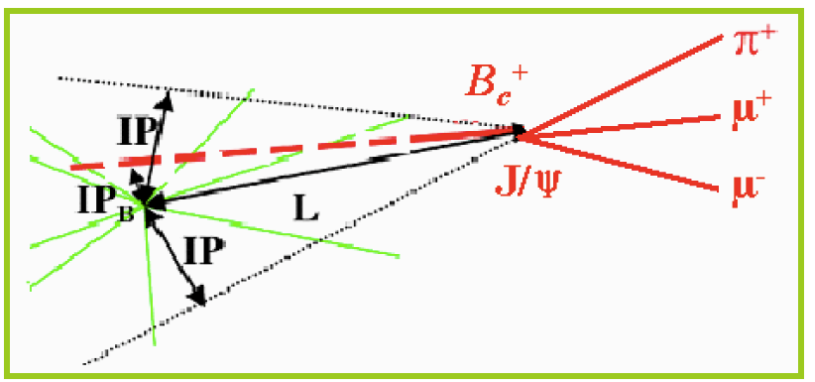
➢ Clean J/ψ reconstruction

➢ Main background: real J/ψ and π from primary vertex and other B decays

➢ Additional impact parameter cuts and P_t cuts

from minimum bias





➢ Total efficiency ~ 1.0%

➢ B/S with 90% CL : [1,2]

➢ Assumptions:

☢ Cross section of $B_c^{\pm}$ = 0.4 μb

☢ Br($B_c^{\pm} \rightarrow J/\psi\pi^{\pm}$) = 1.3×10^{-3}

➢ 310 events for $1fb^{-1}$ data at 14 TeV

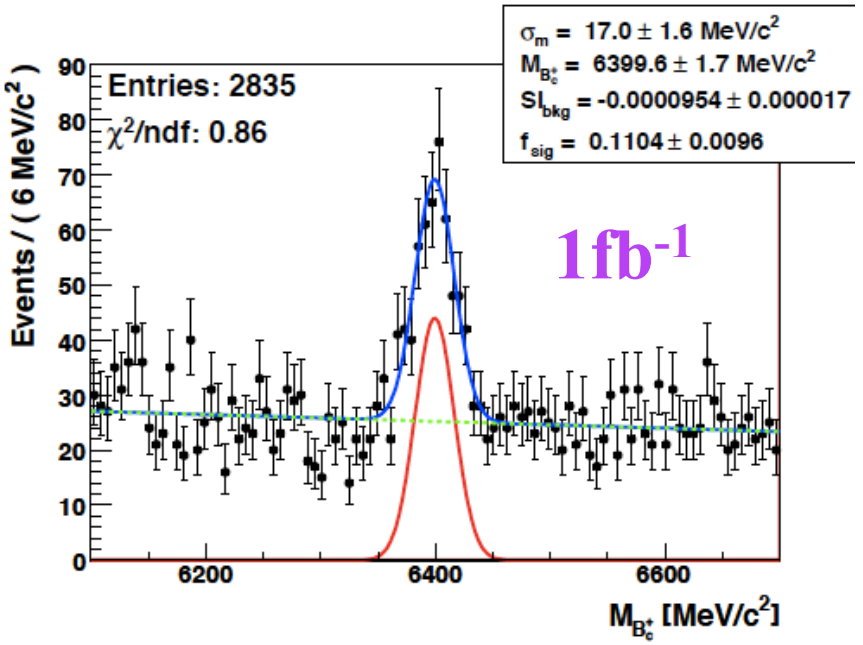
$B_c^{\pm}$ Mass Measurement

Mass measurement sensitivity is estimated by unbinned likelihood fit with MC sample corresponding to $1fb^{-1}$ of LHCb data:

- **➢ Signal events are obtained from full MC simulation (Gaussian)**
- **➢ Background generated by toy MC reproducing behaviour from full MC sample (Linear function)**
- **➢ J/ψ mass constraint fit to improve $B_c^{\pm}$ mass resolution**

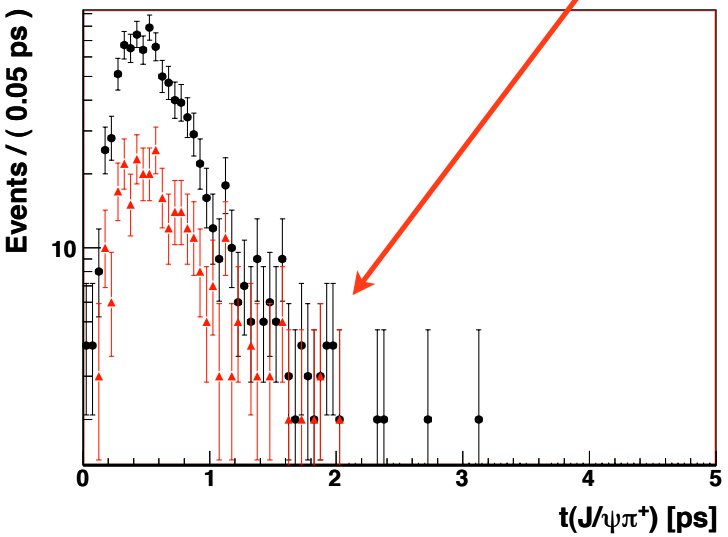
$M(B_c^{\pm}) = 6399.6 \pm 1.7(stat.)$ MeV/c^2 (input: 6400 MeV/c^2)

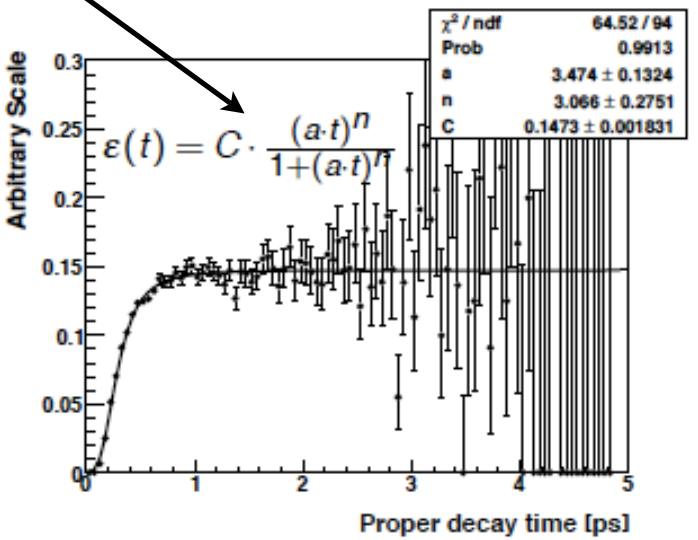
$\sigma = 17 MeV/c^2$



$B_c^{\pm}$ Lifetime Fit: Combined Fit with Mass

$$F(t,mass,\sigma) = f \times (E(t,\tau) \otimes G(t,\sigma,s)) \times \varepsilon(t) \times M(mass) + (1-f) \times Bkg(t,mass)$$





Background: From mass sidebands

Signal Shape: $E(t,\tau) \otimes G(t,\sigma,s) \times \varepsilon(t)$:

- ➢ $E(t,\tau)$ is an exponential dist. with lifetime τ
- ➢ $G(t,\sigma,s)$ is resolution function with σ and scale factor s

Acceptance function: $\varepsilon(t)$

- ➢ Not flat over t because of lifetime cuts to reduce prompt background
- ➢ Efficiency from MC
- ➢ Modelled by $(at)^n/(1+(at)^n)$

Robustness Study for Lifetime Fit

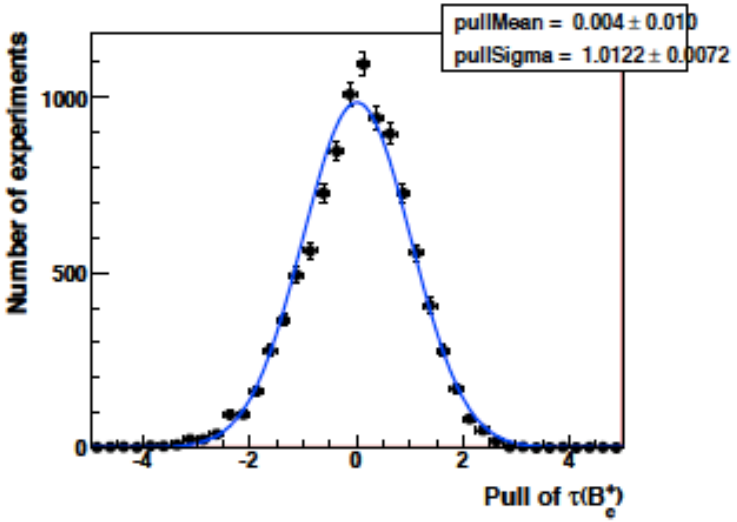
➢ Toy MC with 10^4 experiments

$$\text{Pull} = \frac{\tau_{\text{fit}} - \tau_{\text{input}}}{\sigma_{\text{fit}}}$$

➢ Pull distribution: compatible with normal distribution

σ = 1.012±0.007

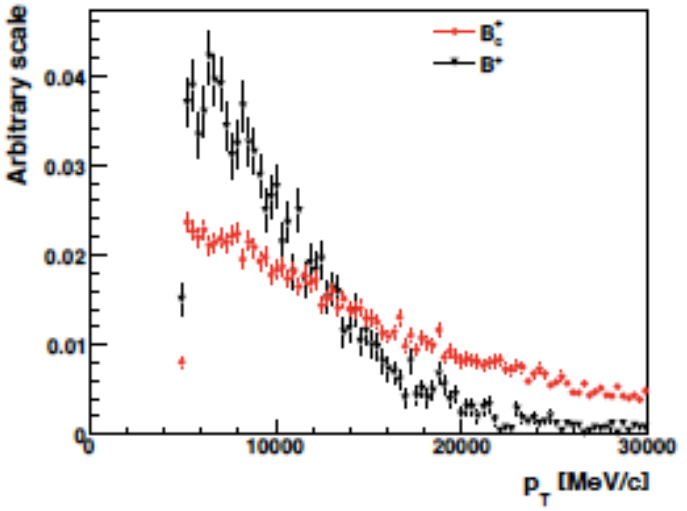
mean = 0.004±0.010



➢ Effect from $B_c^{\pm}$ P_t distribution

☢ P_t dist. is unknown and difference between MC and data could lead to a bias in lifetime

☢ Repeating the measurement using $B^{\pm}$ P_t spectrum for $B_c^{\pm}$ gives a bias around 0.023 ps because of changes in efficiency



$B_c^{\pm}$ Lifetime Fit: Simultaneous Fit over P_t Bins

➢ Simultaneous fit over 2 P_t bins adopted

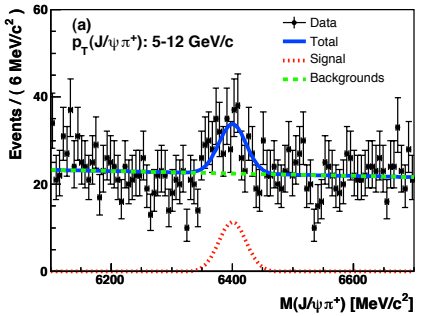
☢ Minimize effect from P_t, bias reduced from 0.023 ps to 0.004 ps

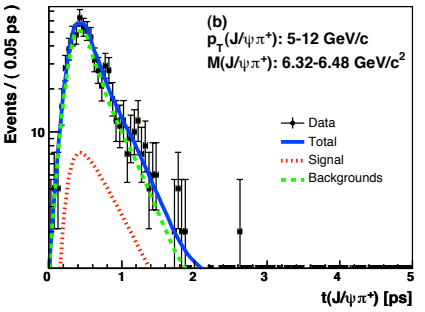
☢ Improve significance of signal (Different Background level over P_t)

➢ Final lifetime value $\tau = 0.438 \pm 0.027(\text{stat.})$ ps (input:0.46 ps)

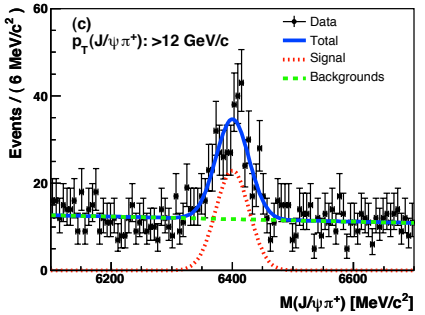
➢ Better systematic error control than Tevatron channel

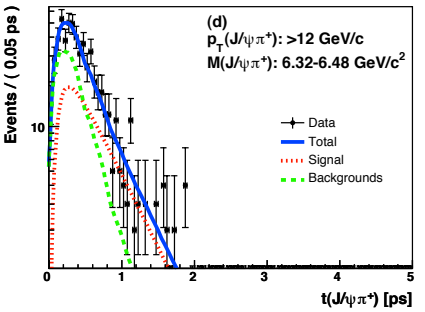
P_t: 5~12GeV/c





P_t: >12GeV/c





$1fb^{-1}$

Other B_c Topics in LHCb

➢ Differential cross section measurement

➢ $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\mu^{\pm}\nu_\mu$

☢ 10 times more statistic than $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$

☢ Candidate for early lifetime measurement at LHCb

☢ Pre-look: ~5k events for $1fb^{-1}$ with B/S~11

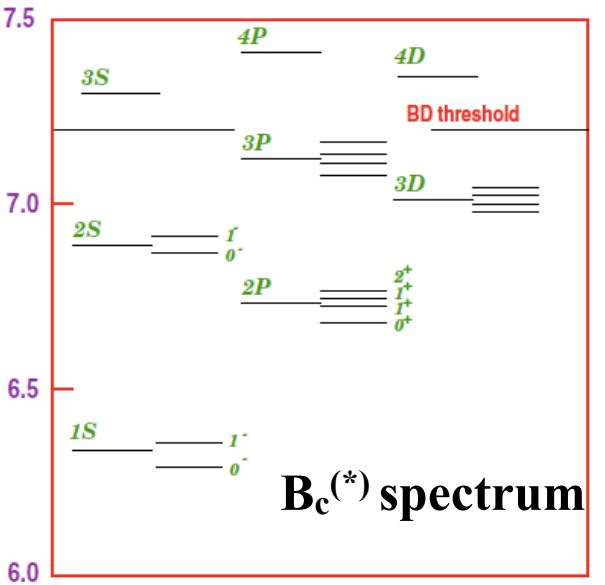
➢ B_c excited states

☢ 16 states below BD threshold

☢ Radiative decays of excited states ➠ QCD sum rules test

➢ $B_c^{\pm} \to B_s^0 \pi^{\pm}$

☢ Self-tagging channel



Summary

With 1fb^{-1} data, for channel $B_c^{\pm} \rightarrow J/\psi\pi^{\pm}$ in LHCb

➢ Around 310 events expected with B/S <2

➢ Statistical error around 1.7MeV/c^2 for mass measurement

➢ Simultaneous fit over P_t bins for lifetime

➢ Statistical error for lifetime measurement around 0.027 ps with better systematic error control

➢ Other studies in progress

Thank You for Your Attention