Measurement of B_c mass and lifetime at LHC*b*

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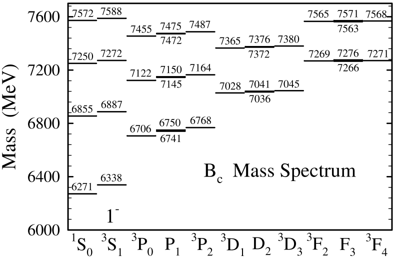
Introduction

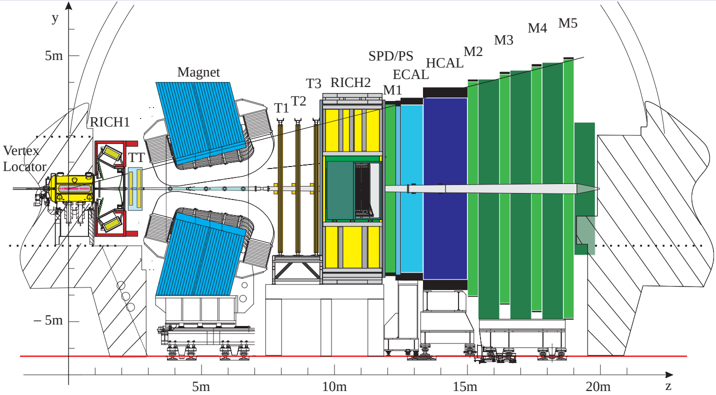
- B_c spectrum
  - Estimated using potential models
- $B_c^{\pm}$ mass
  - Potential: 6.2-6.4 GeV/c^2
  - pQCD: 6326^{+29}_{-9} MeV/c^2
  - Lattice QCD: 6278(6)(4) MeV/c^2
  - PDG'08: 6276 ± 4 MeV/c^2



Taken from CERN-2005-005

- $B_c^{\pm}$ lifetime
  - Inclusive decay rates or $\sum$(exclusive decay rates)
  - $\tau(B_c^{\pm})_{\mathrm{SR}} = 0.48 \pm 0.05$ ps
  - PDG'08: 0.46 ± 0.07 ps
- $B_c^{\pm}$ cross section
  - Considering the contributions of the decays of the excited states, $\sigma(B_c^{\pm}) \sim 0.4\ \mu$b @ 14 TeV $\Rightarrow \sim 4 \times 10^8\ B_c^{\pm}/\mathrm{fb}^{-1}$.
  - $\sigma(B_c^{\pm})_{\mathrm{LHC}}/\sigma(B_c^{\pm})_{\mathrm{Tevatron}} \sim$ O(10)
- Using $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$ to measure $B_c^{\pm}$ mass and lifetime at LHCb.

The LHC*b* detector



Vertex Locator $\sigma_{\mathrm{PV},x/y} \sim 10\ \mu$m, $\sigma_{\mathrm{PV},z} \sim 60\ \mu$m, $\sigma_L \sim 250\ \mu$m.

Tracking system (TT, T1-T3) $\Delta p/p$: 0.35%-0.55%, σ_m:12-25 MeV/c^2.

Muon system (M1-M5) $\varepsilon(\mu \to \mu) \sim 94\%$, $w(\pi \to \mu) \sim 3\%$.

Trigger system (L0, HLT) 600 Hz di-μ trigger (in 2 kHz@HLT).

$B_c^\pm \to J/\psi(\mu^+\mu^-)\pi^\pm$ event selection

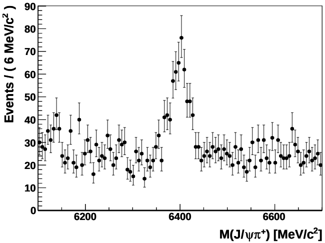
- Main issue: large background (remind: $\sigma(B_c^\pm) \sim 0.4\ \mu$b)
  - Real J/ψ + π from fragmentation or from b decays
    - Prompt J/ψ (cross section: $\sim 300\ \mu$b)
    - $b \to J/\psi X$ (cross section: O(100) μb)
  - Combinatorial J/ψ + π from fragmentation or from b decays
    - Inclusive $b\bar{b}$ (cross section: $\sim 700\ \mu$b)
- Selection variables
  - Final states
    - Track fit quality to reduce ghost rate
    - Loose particle identity
    - Transverse momentum
    - Lifetime cuts to suppress prompt backgrounds
  - J/ψ
    - Di-μ invariant mass (resolution $\sim$15 MeV/c^2)
    - Vertex fit quality
    - Lifetime cuts to suppress prompt backgrounds
  - $B_c^\pm$
    - Vertex fit quality
    - Transverse momentum

Signal yields and background level

- Assuming
  - Cross section $\sigma(B_c^\pm)$: $0.4\ \mu$b
  - BR($B_c^\pm \to J/\psi\pi^\pm$): 1.3×10^{-3} (0.6-4.5) $\times 10^{-3}$
- Selection results in the $B_c^\pm$ $\pm 3\sigma$ mass window

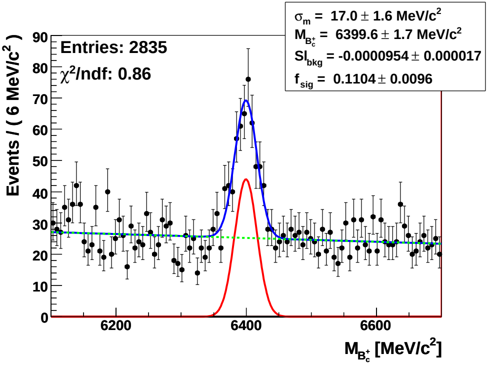
Description	Result
Total efficiency ε_{tot} (including trigger)	(1.01 ± 0.02) %
Signal yield (1 fb^{-1} @ 14 TeV)	~ 310
B/S @ 90% CL	[1, 2]

- Mass distribution after event selection (1 fb^{-1})



$B_c^{\pm}$ mass measurement

- Signal events taken from the full Monte Carlo simulation, background events generated by toy MC (shape from full MC).
- J/ψ mass constraint vertex fit applied to improve $\sigma_m(B_c^{\pm})$.
- Signal described by a Gaussian, background by 1st order polynomial.
- Un-binned maximum likelihood method, fitting result (1 fb^{-1}):
  - $M(B_c^{\pm}) = 6399.6 \pm 1.7$ (stat.) MeV/c^2 (input: 6400 MeV/c^2).



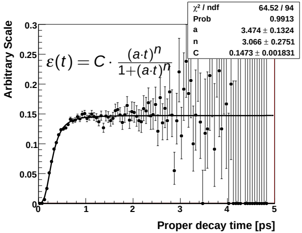
- Mass lifetime combined fitting, likelihood function

$$f(m_i, t_i, \sigma_{t_i} | M, \sigma_m, sl_{\mathrm{pol1}}, \tau, S_t)$$

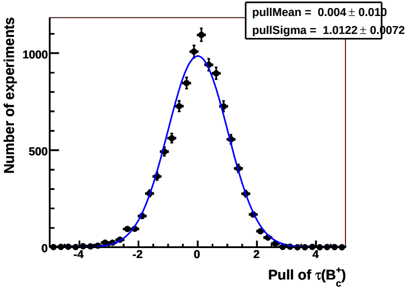
$$= f_s \cdot f^m_{\mathrm{sig}}(m_i | M, \sigma_m) \cdot \boxed{\left[E(t_i|\tau) \otimes G(t_i|\sigma_{t_i}, S_t)\right] \cdot f_{\mathrm{sig}}(\sigma_{t_i}) \cdot \varepsilon(t_i)}$$

$$+ (1 - f_s) \cdot f^m_{\mathrm{bkg}}(m_i | sl_{\mathrm{pol1}}) \cdot \boxed{f_{\mathrm{bkg}}(t_i) \cdot f_{\mathrm{bkg}}(\sigma_{t_i})}$$

  - $\left[E(t_i|\tau) \otimes G(t_i|\sigma_{t_i}, S_t)\right]$: exponential convoluted with a Gaussian, in which S_t is the scale factor of σ_t to account for the effects that the σ_t can be over- or under-estimated.
  - $\varepsilon(t_i)$: proper decay time acceptance



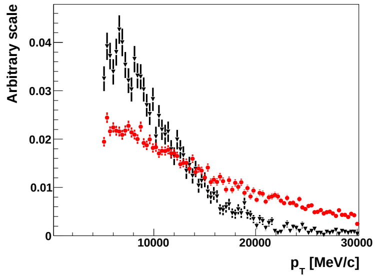
- Input Parameters
  $\tau_{B_c^{\pm}}$ = 0.46 ps, $M_{B_c^{\pm}} = 6400$ MeV/c^2, σ_m=26.89 MeV/c^2,
  $f_s = 0.11$, $sl_{\text{pol1}} = -9.7 \times 10^{-5}$.
- 10^4 experiments.
- Lifetime pull
  - Pull $= \frac{\tau^{\text{fit}} - \tau^{\text{input}}}{\sigma_t^{\text{fit}}}$
  - Follow N(0,1) if there is no bias.
  - Pull mean: 0.004 ± 0.010
    $\Rightarrow$ No bias induced by fitting.



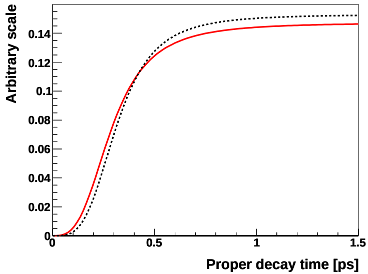
Dependence on $p_{\mathrm{T}}(B_c^{\pm})$ distribution

- If $p_{\mathrm{T}}(B_c^{\pm})$ distribution in real data is different from that in MC...

Different $p_{\mathrm{T}}(B_c^{\pm})$ distributions



Effects of $p_{\mathrm{T}}(B_c^{\pm})$ distrib. on $\varepsilon(t)$



- Toy Monte Carlo study, $B_c^{\pm}$ lifetime biased by 0.023 ps.

Event selection in the two $p_{\mathrm{T}}(B_c^{\pm})$ intervals

- To reduce the dependence of the lifetime measurement on the $B_c^{\pm}$ p_{T} distribution (theoretical model), $p_{\mathrm{T}}(B_c^{\pm})$ divided into two intervals, 5-12 GeV/c and > 12 GeV/c.
- Event selection re-optimized, lifetime cuts in the high p_{T} region loosened.
- Selection results

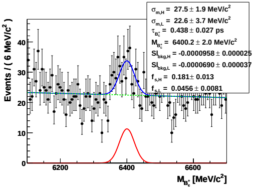
p_{T} intervals of $B_c^{\pm}$	5-12 GeV/c	≥ 12 GeV/c
Total efficiency $\varepsilon_{\mathrm{tot}}$[1] (including trigger)	(0.34 ± 0.01) %	(0.86 ± 0.02) %
Signal yield (1 fb^{-1} @ 14 TeV)	~ 100	~ 260
B/S @ 90% CL	[3, 6]	[0.6, 1.2]

[1] ε in the two p_{T} intervals are both defined with respect to the total number of the events in the full p_{T} range.

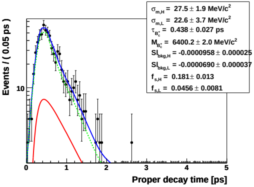
$B_c^{\pm}$ lifetime fitting results

- Doing the mass lifetime combined fitting in the two $p_{\rm T}$ intervals simultaneously, $\tau(B_c^{\pm}) = 0.438 \pm 0.027$ (stat.) ps (input: 0.46 ps).

$p_{\rm T}$: 5-12 GeV/c

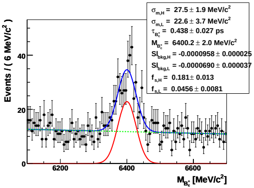


(a) Mass

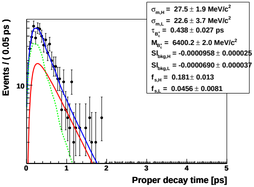


(b) t in signal region

$p_{\rm T}$: $>$ 12 GeV/c



(c) Mass



(d) t in signal region

Comparison with present measurements

Collab.	$\mathcal{L}_{\text{int}}$ [pb^{-1}]	Mode	Signal events	Mass [MeV/c^2]	Lifetime [ps]
CDF	110	$J/\psi\ell^{\pm}\nu$	$20.4^{+6.2}_{-5.5}$	$6400 \pm 390 \pm 130$	$0.46^{+0.18}_{-0.16} \pm 0.03$
D0	210	$J/\psi\mu^{\pm}X$	$95 \pm 12 \pm 11$	$5950^{+140}_{-130} \pm 340$	$0.45^{+0.12}_{-0.10} \pm 0.12$
CDF	360	$J/\psi\pi^{\pm}$	14.6 ± 4.6	$6285.7 \pm 5.3 \pm 1.2$	—
CDF	360	$J/\psi e^{\pm}\nu_e$	238	—	$0.463^{+0.073}_{-0.065} \pm 0.036$
CDF	2400	$J/\psi\pi^{\pm}$	108 ± 15	$6275.6 \pm 2.9 \pm 2.5$	—
D0	1300	$J/\psi\pi^{\pm}$	54 ± 12	$6300 \pm 14 \pm 5$	—
D0	1300	$J/\psi\mu^{\pm}X$	881 ± 80	—	$0.448^{+0.038}_{-0.036} \pm 0.032$
CDF	1000	$J/\psi\ell^{\pm}\nu$	—	—	$0.475^{+0.053}_{-0.049} \pm 0.018$
LHCb	1000	$J/\psi\pi^{\pm}$	$\sim$310	$\pm$1.7(stat.)	—
LHCb	1000	$J/\psi\pi^{\pm}$	$\sim$360	—	$\pm$0.027(stat.)

Summary

- $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$ from the first 1 fb^{-1} of data
  - Signal yield $\sim$ 310, B/S<2 @ 90% CL
  - Mass measurement precision: $\pm$1.7 (stat.) MeV/c^2
  - Lifetime measurement precision: $\pm$0.027(stat.) ps
- 0.3 fb^{-1} in 2010
  - Mass measurement precision: $\sim$ 3.1 (stat.) MeV/c^2
  - Lifetime measurement precision: $\sim$ 0.049(stat.) ps
- Systematics under study.

Backup

$B_c^\pm \to J/\psi(\mu^+\mu^-)\pi^\pm$ event selection

- Final states
  - Track $\chi^2/\mathrm{ndf} < 4$
  - $\Delta\ln L_{\mu\pi}(\mu) > -5$
  - $\Delta\ln L_{\pi K}(\pi) > -5$
  - $p_\mathrm{T}(\mu) > 1.0$ GeV/c
  - $p_\mathrm{T}(\pi) > 1.6$ GeV/c
  - IPS(π)>3.0 [a]

[a] IPS = $\sqrt{\chi^2_\mathrm{IP}} \sim \mathrm{IP}/\sigma_\mathrm{IP}$

- J/ψ selection
  - Mass: (3.04, 3.14) GeV/c^2
  - Vertex fit quality: $\chi^2/\mathrm{ndf} < 9$
  - IPS(J/ψ)>3.5
- $B_c^\pm$ selection
  - Vertex fit quality: $\chi^2/\mathrm{ndf} < 4$
  - $p_\mathrm{T}(B_c^\pm) > 5.0$ GeV/c
  - IPS($B_c^\pm$)<3.0