Results on Bc from CMS

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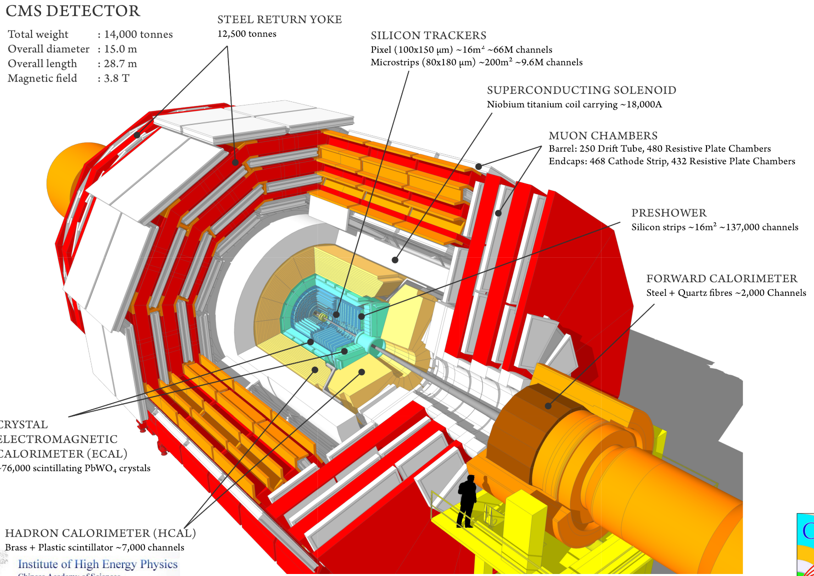
CMS

Introduction

- Being the ground state, the B_c is lightest meson of the $\bar{b}c$ ($b\bar{c}$) system.
- Consists of different heavy flavors and provides a unique platform to study the heavy flavor dynamics.
- B_c properties measurement is of unique interest and the predictions of the effective models inspired by QCD can also be tested.
- The lowest order mechanism for creating a $\bar{b}c$ ($b\bar{c}$) system is α_s^4, $q\bar{q}$, $g\bar{g} \rightarrow \bar{b}c$ ($b\bar{c}$).
- The decay process can proceed with the decay of b quark, decay of c quark of or annihilation of b and c quarks.
- The first observation was made by CDF in $B_c \rightarrow J/\psi\, \ell^+\nu$ ($\ell = e,\ \mu$). PRL 81 (1998) 2432
- Overview of the CMS results:
    - Measurement of the production cross section times branching ratio fraction of $B_c^\pm$ and $B^\pm$: $\frac{\sigma(B_c^\pm)\times\mathcal{B}(B_c^\pm \rightarrow J/\psi\pi^\pm)}{\sigma(B^\pm)\times\mathcal{B}(B^\pm \rightarrow J/\psi K^\pm)}$ and $\frac{\mathcal{B}(B_c^\pm \rightarrow J/\psi\pi^\pm\pi^\pm\pi^\pm)}{\mathcal{B}(B_c^\pm \rightarrow J/\psi\pi^\pm)}$ JHEP01(2015)063
    - Precision lifetime measurement in the final state with a J/ψ meson. (arXiv:1710.08949, submitted to EPJC)

CMS Detector



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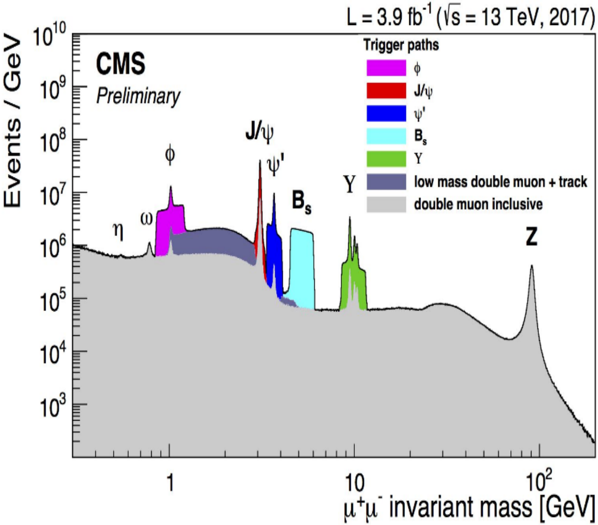
Dimuon mass spectrum



- Dimuon mass distribution collected with various dimuon triggers for dataset corresponding to an integrated luminosity of 3.9fb^{-1}

CERN-CMS-DP-2017-029

Cross section times branching ratio measurement

- Less studied : Only produced in hadron colliders so far. Several Decays have been seen by CDF, LHCb, and CMS.
- Very limited information on the production and decays of the B_c meson and its possible excited states.
- Efficient muon identification system and tracker detectors of CMS allows to study final states containing J/ψ with $J/\psi \to \mu^+\mu^-$
- Measurement of cross section of $B_c \to J/\psi\ \pi$ relative to $B^+ \to J/\psi\ K^+$.
- Measurement of the the ratio of the branching fractions of $B_c \to J/\psi\ \pi\pi\pi$ to $B_c \to J/\psi\pi$ which is a first confirmation of the LHCb results (PRL. 108 (2012) 251802).
- Performed using 7 TeV data corresponding to integrated luminosity 5.1 fb^{-1} in the phase space defined by $p_T > 15$ GeV/c and $|y| > 1.6$
- $R_{B_c} \to$ ratio of the production cross section times branching fractions.

$$R_{B_c} = \frac{\sigma(B_c^\pm)\times\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm)}{\sigma(B^\pm)\times\mathcal{B}(B^\pm \to J/\psi K^\pm)} = \frac{N(B_c^+ \to J/\psi\ \pi^+) \times \epsilon_{B^+}}{N(B^+ \to J/\psi\ K^+) \times \epsilon_{B_c^+}} = \frac{Y_{B_c^+ \to J/\psi\pi^+}}{Y_{B^+ \to J/\psi K^+}}$$

Efficiency from MC

Efficiency Corrected yield

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The fits are performed with an unbinned maximum likelihood estimator.

$B_c \rightarrow J/\psi\pi$

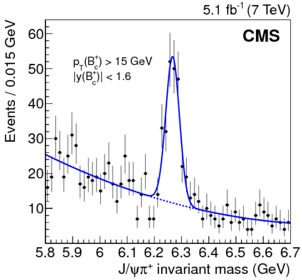
- Signal $\rightarrow$ Gaussian
- Background $\rightarrow$ 2^{nd} order Cheb. Pol

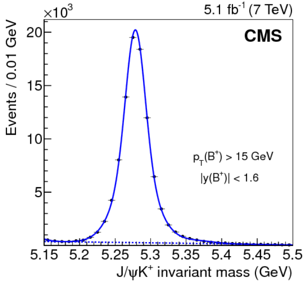
$B^+ \rightarrow J/\psi\ K$

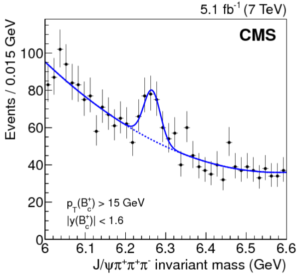
- Signal $\rightarrow$ two Gaussian
- Background $\rightarrow$ 2^{nd} order Cheb. Pol

$B_c \rightarrow J/\psi\pi\pi\pi$

- Signal $\rightarrow$ two Gaussian
- Background $\rightarrow$ 2^{nd} order Cheb. Pol







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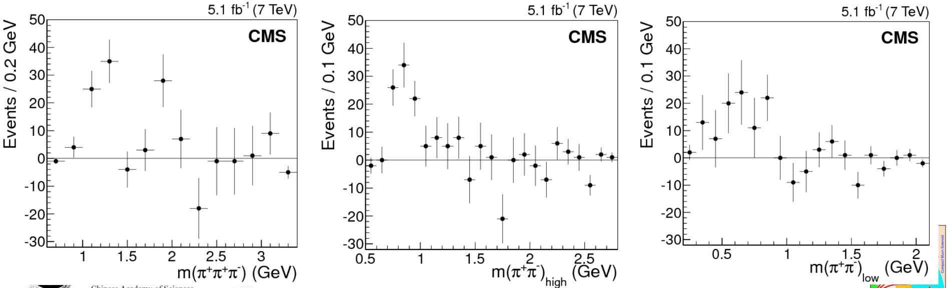
Resonant Structures

- $B_c \rightarrow J/\psi\pi\pi\pi$ was witnessed by LHCb and CMS.
- Resonant structure are seen in 3-body $(\pi^+\pi^+\pi^-)$ and 2-body $(\pi^+\pi^-)$ invariant mass distributions e.g a1(1260) and $\rho(770)$.
- The efficieny estimation is challenging and needs understanding of the decay.
- Efficiency parameterized in a decay model independent 5-body phase-space with a non-resonant simulated sample.



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Results

- $\frac{\sigma(B_c^\pm)\times\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm)}{\sigma(B^\pm)\times\mathcal{B}(B^\pm \to J/\psi K^\pm)} = [0.48 \pm 0.05\ (\text{stat}) \pm 0.03\ (\text{syst}) \pm 0.05\ (\tau_{B_c})]\%$

  Uncertainty due to B_c lifetime

  Complementary to the measurement by LHCb (PRL. 109 (2012) 232001).
  In different kinematic regions
  Softer p_T distribution of B_c w.r.t B^+ implies the lower value of ratio at higher p_T

- $\frac{\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm\pi^\pm\pi^\pm)}{\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm)} = 2.55\ \pm\ 0.80\ (\text{stat}) \pm 0.33(\text{syst})^{+0.04}_{-0.01}\ (\tau_{B_c})$

  Consistent with the measurement by LHCb (PRL. 108 (2012) 251802)

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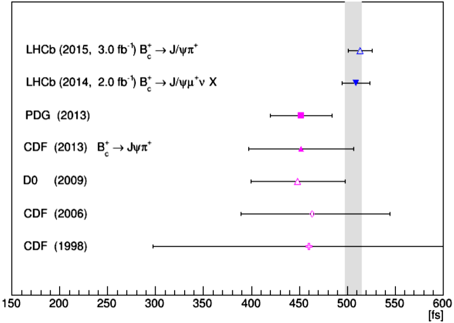
- Plays an important role in the study of nonperturbative aspects of quantum chromodynamics (QCD).
- First measurement came from Tevatron experiments in $B_c \rightarrow J/\psi\ \mu\ \nu\ X$ and $B_c \rightarrow J/\psi\ \pi$
- More precise measurements by LHCb preferred long life time:
  $\tau_{B_c}\ (B_c \rightarrow J/\psi\ \mu\ \nu\ X) = 509 \pm 8 \pm 12$ fs (Eur.Phys.J. C74 (2014) 5, 2839)
  $\tau_{B_c}\ (B_c \rightarrow J/\psi\ \pi) = 513.4 \pm 11.0 \pm 5.7$ fs (Phys.Lett. B742 (2015) 29-37)



- Based on 2012 data using 8 TeV data (19.7 fb^{-1})
- $p_T(B_c^+,\ B^+) > 10$ GeV/c and $|y| > 2.2$
- CMS measurement can help to answer the disagreement.

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arXiv:1710.08949

Measurement Strategy

- The proper decay time can be calculated using:

  $t \;=\; L_{xy}\frac{M_{B_c}}{p_T}$

  L_{xy} = is the distance between primary and secondary vertices projected on p_T

  M_{B_c} = World average-mass of B_c meson.

- τ_{B_c} is obtained using the difference between the total width of the B_c^+ and B^+ mesons (LHCb strategy).

ratio of efficiency functions

$$\frac{N_{B_c^+}(t)}{N_{B^+}(t)} = \mathcal{R}_\epsilon(t) = \frac{\epsilon_{B_c^+}(t)\; r(t) \otimes E_{B_c^+}(t)}{\epsilon_{B^+}(t)\; r(t) \otimes E_{B^+}(t)} = R_\epsilon(t)\; exp(-\Delta\Gamma t)$$

Efficiency *resolution with no significant effect*

where: $\Delta\Gamma \equiv \Gamma_{B_c^+} - \Gamma_{B^+} = \frac{1}{\tau_{B_c^+}} - \frac{1}{\tau_{B^+}}$

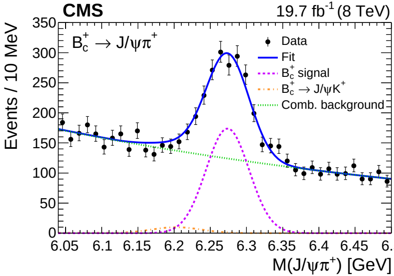
- The ratio method allows to cancel out some contributions to the systematic uncertainties.

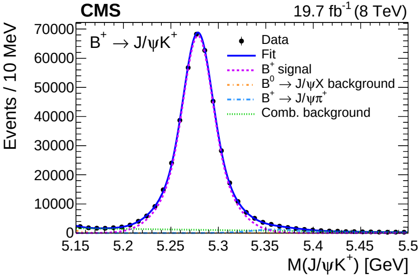
Signal Extraction

- Extended unbinned maximum likelihood approach used to fit $J/\psi\ \pi^+$ and $J/\psi\ K^+$ invariant mass distribution.

- $B_c^+ \rightarrow J/\psi\ \pi^+$ signal $\rightarrow$ Gaussian
- comb. background $\rightarrow$ Expo. function
- $B_c^+ \rightarrow J/\psi\ K^+$ by Crystal ball

- $B^+ \rightarrow J/\psi\ K^+$ signal $\rightarrow$ Double Gaussian
- comb. background $\rightarrow$ 2^{nd} order Chebyshev Pol.
- $B^+ \rightarrow J/\psi\ \pi^+$ Contribution $\rightarrow$ Gaussian
- $B^0 \rightarrow J/\psi\ X$ Contribution $\rightarrow$ Gaussian





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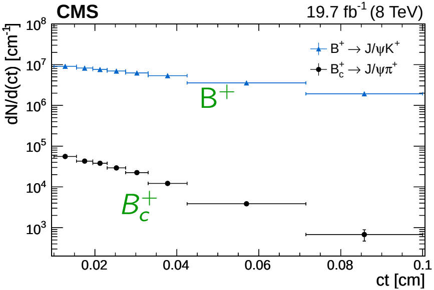
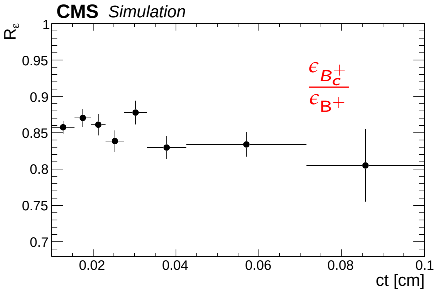
- Proper time (ct) distributions of B_c^+ and B^+ signal obtained from unbinned mass fits to the data splitted in ct regions.
- $R_\epsilon(t)$ is computed from the B_c^+ and B^+ efficiencies are calculated using the MC simulation.





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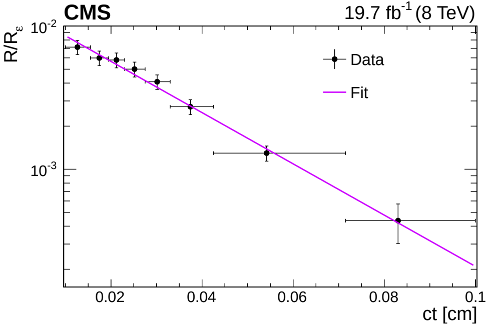
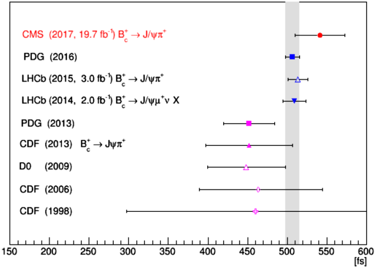
B_c Lifetime Measurement

- $\Delta\Gamma$ obtained from a binned χ^2 fit to the ratio of B_c^+ and B^+ ct-distributions corrected by the ratio of efficiencies using an exponential function.
- Used the fit returned $\Delta\Gamma$ and world average B^+ lifetime value to extract τ_{B_c}.
  $c\tau_{B_c} \;=\; 162.3 \pm 8.2(\text{stat}) \pm 4.7\text{syst.} \pm 0.1(\tau_{B^+})\mu\text{m}$
  higher than measured at the Tevatron and in agreement with measurement from LHCb.





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Summary

- Several Decays have been seen by CDF, LHCb, and CMS. Enhanced luminosity will help to precisely measure the properties of B_c and conduct a test to the predictions of the effective model inspired by QCD.
- An overview of the results for the cross section times branching ratio has been presented.

$$\frac{\sigma(B_c^\pm)\times\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm)}{\sigma(B^\pm)\times\mathcal{B}(B^\pm \to J/\psi K^\pm)} = [0.48 \pm 0.05 \text{ (stat)} \pm 0.03 \text{ (syst)} \pm 0.05 \ (\tau_{B_c})]\%$$

$$\frac{\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm\pi^\pm\pi^\pm)}{\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm)} = 2.55 \pm 0.80 \text{ (stat)} \pm 0.33\text{(syst)}^{+0.04}_{-0.01} \ (\tau_{B_c})$$

The results show agreement with the corresponding measurements from LHCb.

- We have also presented the precision lifetime measurement of B_c.

$$c\tau_{B_c} = 162.3 \pm 8.2\text{(stat)} \pm 4.7\text{syst.} \pm 0.1(\tau_{B^+})\mu\text{m}$$

The measurement is agreement with the measurement from LHCb and prefers longer life time in comparison what was reported at Tevatron.

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Stay tunned for more results.

Thanks !