B_c and b baryons studies at LHCb

Zhenwei YANG @Tsinghua University

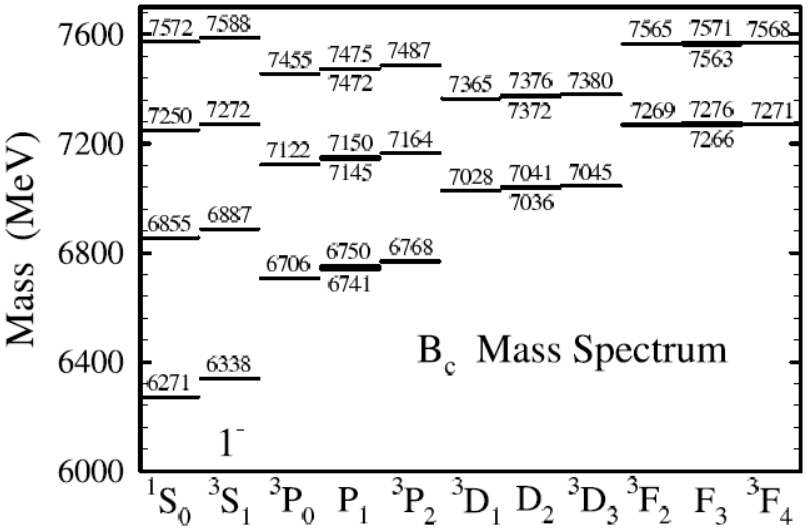
on behalf of the LHCb collaboration

- Introduction
- B_c studies: mass, production, $B_c \to J/\psi 3\pi$
- b baryons ($\Lambda_b^0, \Xi_b^-, \Omega_b^-, \Xi_b^0$) :
  mass, lifetime, productions
- Summary & prospects

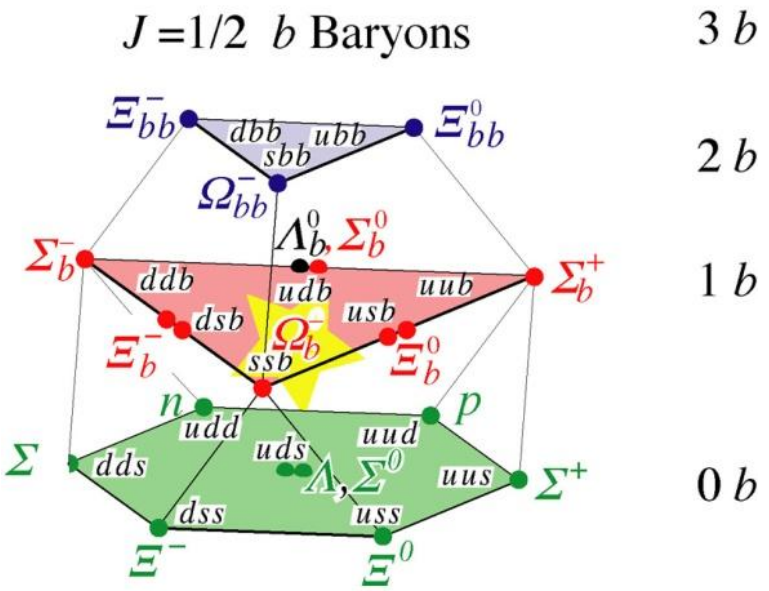
B_c and b baryons

- B_c: unique meson family in Standard Model with two different open heavy flavors, formed by $\bar{b}c$ or $b\bar{c}$
  - Precise measurements on mass, lifetime, production and decay modes needed to verify theoretical models

- b-baryons: poor knowledge of b-baryons predicted by quark model.
  - a lot of measurements are awaited (masses, lifetimes, branching ratios, CP asymmetries, …)



S. Godfrey, PRD 70, 054017 (2004)

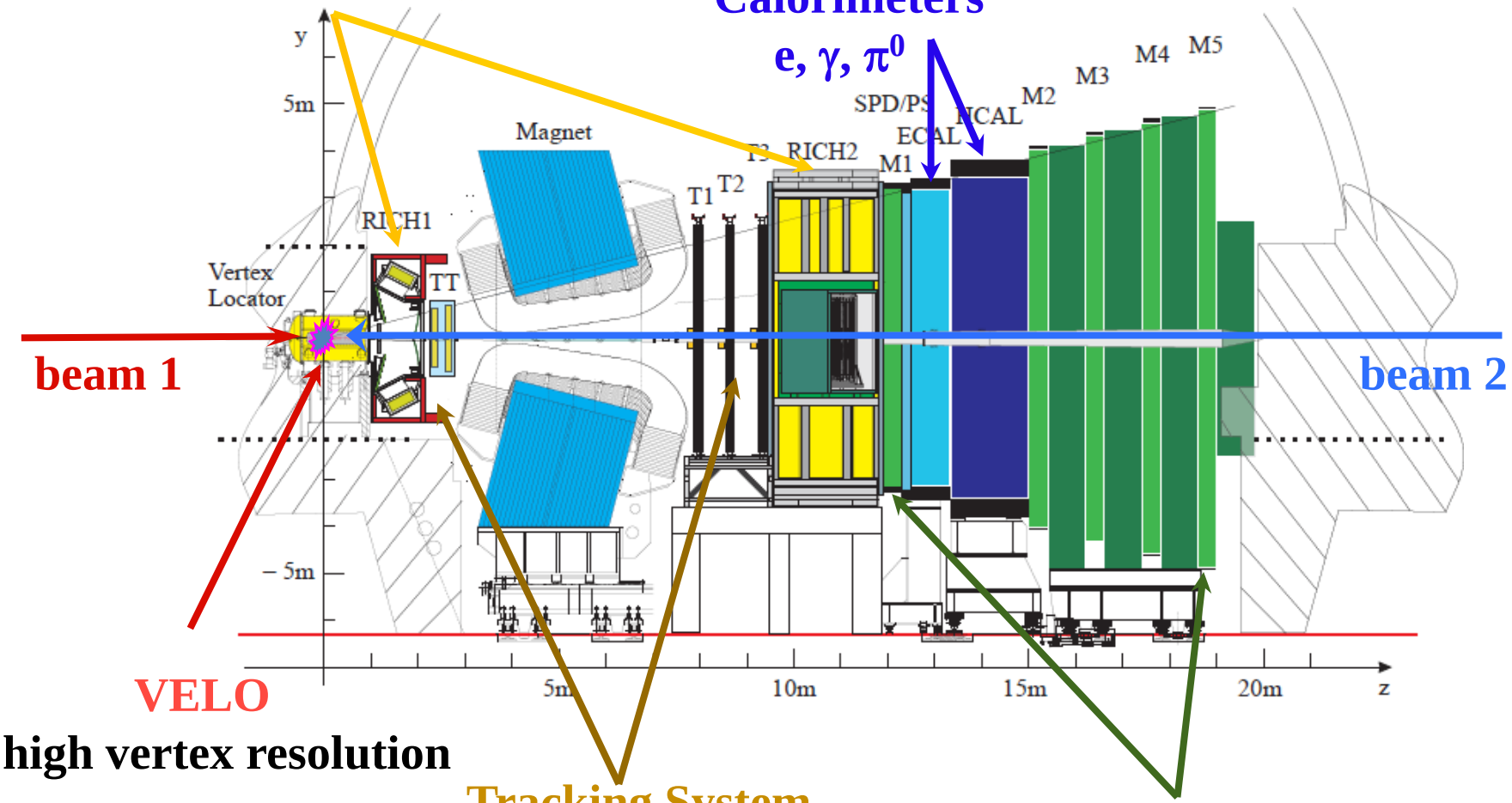


LHCb detector

see Giovanni Sabatino's talk
"Quarkonium results from LHCb"
early this afternoon

RICH1 & RICH2
Excellent PID of *K*-π

Calorimeters
e, γ, π^0



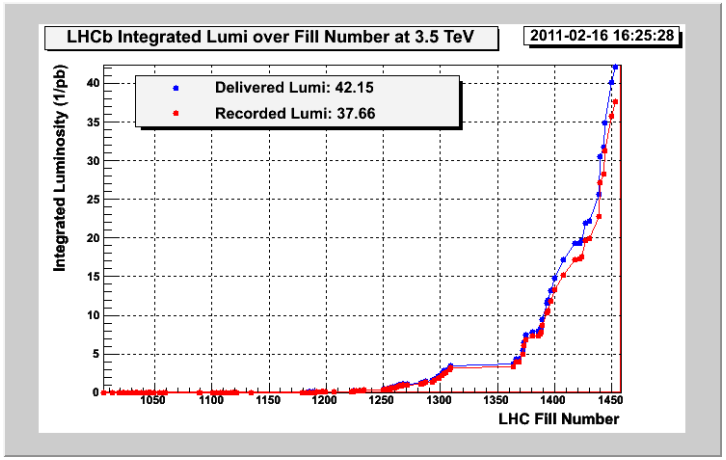
VELO
high vertex resolution

Tracking System
good tracking efficiency
& momentum resolution

Muon System
good muon-ID

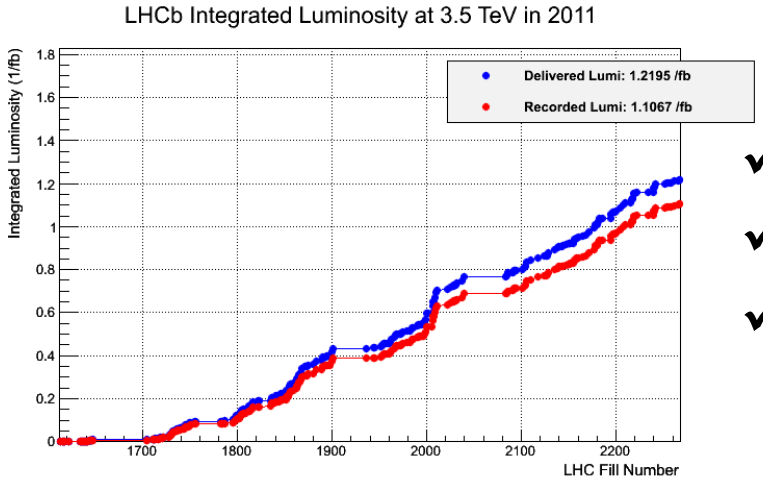
LHCb's data taking in 2010/2011

High efficiency ($> 90\%$) & good performance



2010 (37 $\mathbf{pb^{-1}}$ recorded)

- ✓ B_c^+ mass & cross section measurements
- ✓ Λ_b^0 mass & lifetime using $\Lambda_b^0 \to J/\psi\Lambda$
- ✓ $\mathrm{Br}(\Lambda_b^0 \to \Lambda_c^+\pi^-\pi^+\pi^-)$
- ✓ $\frac{f_{\Lambda_b^0}}{f_u+f_d}$ measurement



2011 (1 $\mathbf{fb^{-1}}$ recorded)

- ✓ Observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$
- ✓ Masses of Ξ_b^- and Ω_b^- measurement
- ✓ Observation of Λ_b^0 and Ξ_b^0 in D^0pK^- mode

B_c studies at LHCb

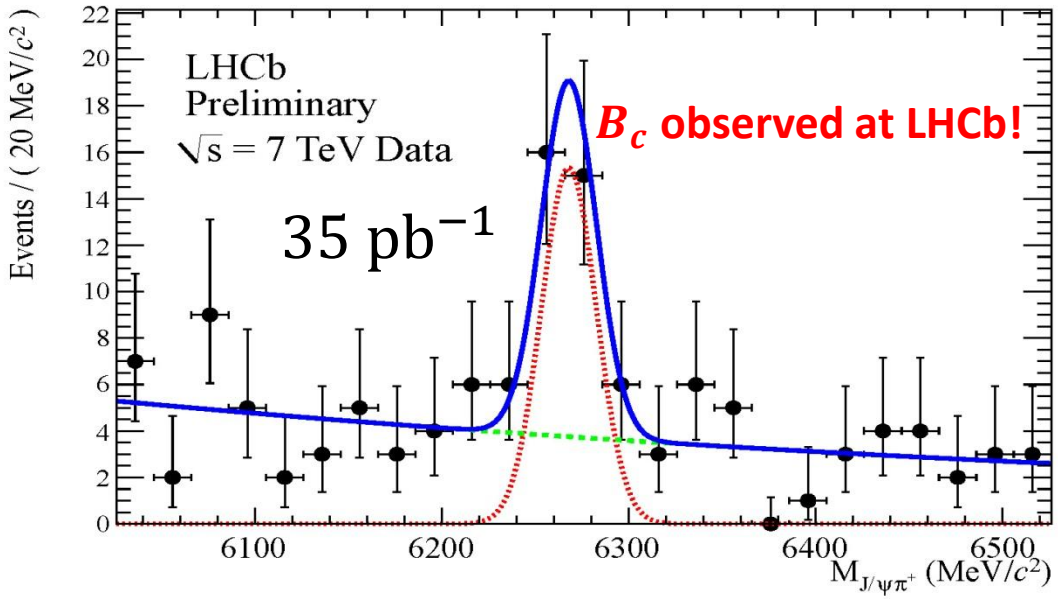
B_c^+ mass measurement

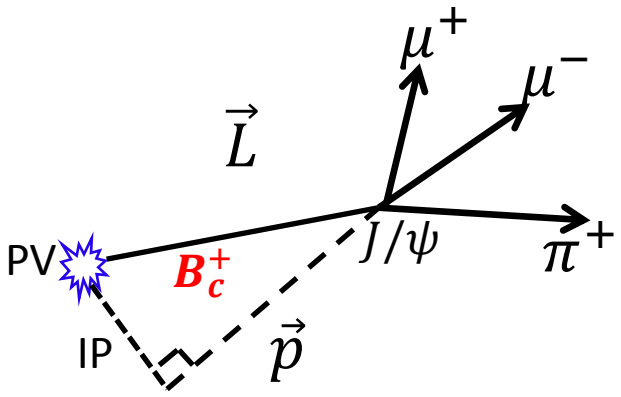
CERN-LHCb-CONF-2011-027

- Based on data of $35\ \mathrm{pb}^{-1}$ accumulated in 2010

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

- Lifetime biased cut used to suppress background
  - Fit Model: Gaussian(signal) + Exponential(background)
  - $N_{\mathrm{sig}} = 28 \pm 7$





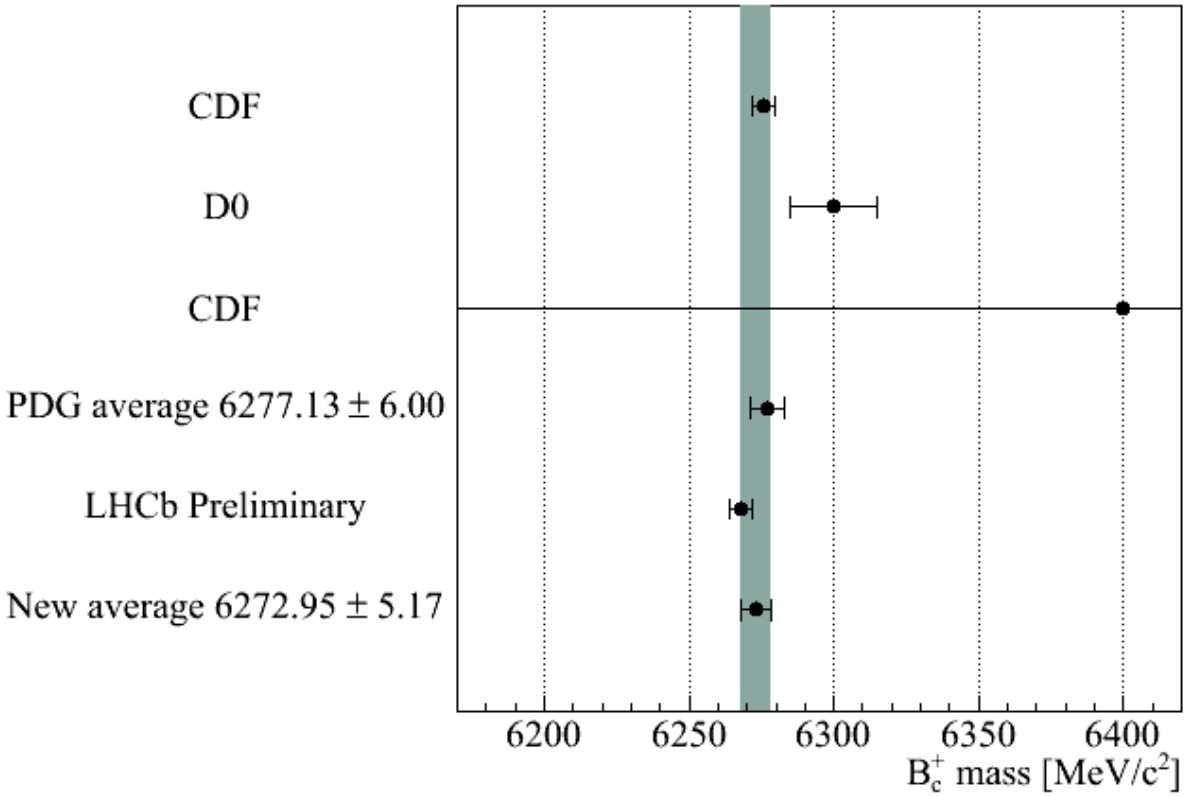
(Charge conjugation assumed throughout this talk.)

B_c^+ mass measurement: Preliminary

CERN-LHCb-CONF-2011-027

- $M(B_c^+) = (6268.0 \pm 4.0_{\text{stat}} \pm 0.6_{\text{syst}})\ \text{MeV}/c^2$ (Preliminary)
- Statistical uncertainty dominated, will be improved with 2011 data
- Systematics dominated by uncertainties of momentum scale calibration and background model in mass fitting

Good agreement with CDF



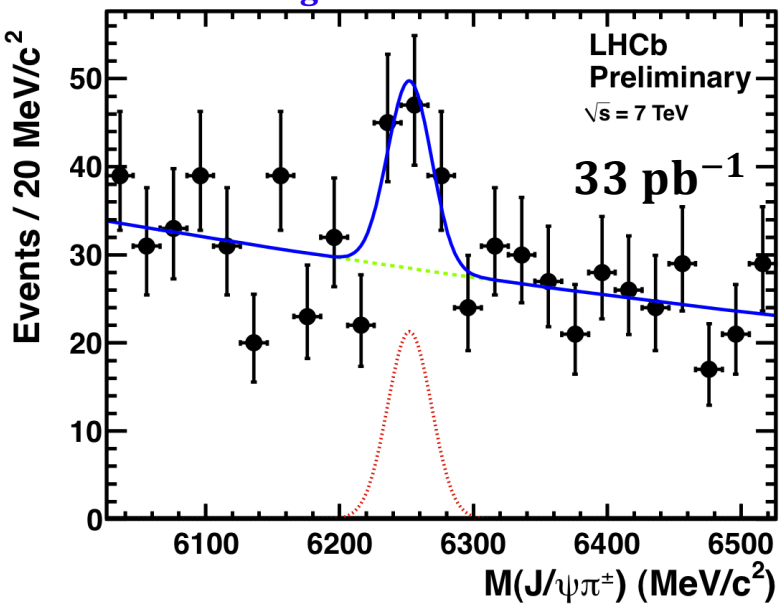
Production of $B_c^+ \to J/\psi(\mu^+\mu^-)\pi^+$

CERN-LHCb-CONF-2011-017

- Based on data of $33\ \mathrm{pb}^{-1}$ taken in 2010
- Relative cross section measured for $p_{\mathrm{T}}(B) > 4\ \mathrm{GeV}/c$ and $\eta \in (2.5, 4.5)$ using large sample of $B^+ \to J/\psi K^+$ as reference channel
- Event selection/trigger: lifetime unbiased

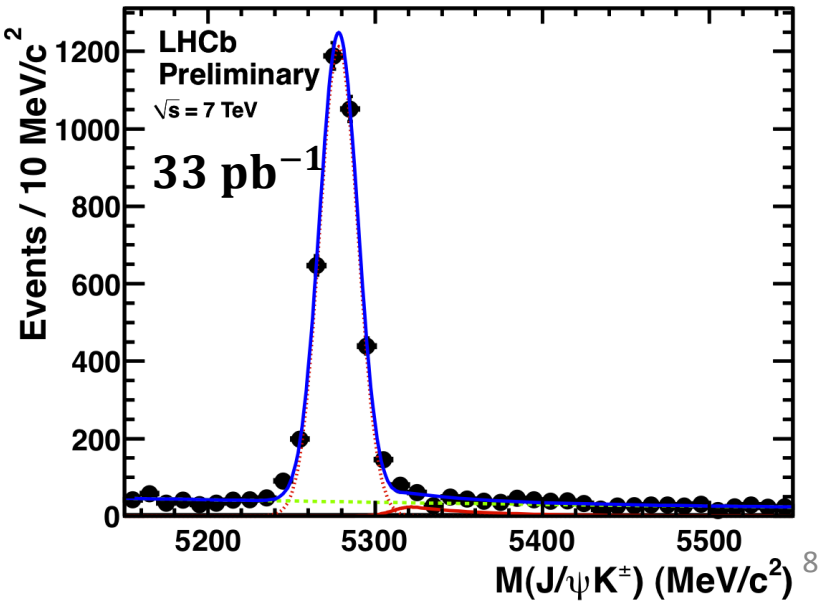
$B_c^+ \to J/\psi(\mu^+\mu^-)\pi^+$

$N_{\mathrm{sig}} = 43 \pm 13$



$B^+ \to J/\psi(\mu^+\mu^-)K^+$

$N_{\mathrm{sig}} = 3476 \pm 62$



Production of $B_c^+ \to J/\psi\pi^+$: Preliminary

CERN-LHCb-CONF-2011-017

- **Preliminary result**

$$\checkmark \frac{\boldsymbol{\sigma(B_c^+)\times \mathrm{Br}(B_c^+ \to J/\psi\pi^+)}}{\boldsymbol{\sigma(B^+)\times \mathrm{Br}(B^+ \to J/\psi K^+)}} = \boldsymbol{\left(2.2 \pm 0.8_{\mathrm{stat}} \pm 0.2_{\mathrm{syst}}\right)\%}$$

for $p_{\mathrm{T}}(B) > 4\ \mathrm{GeV}/c$ and $\eta \in (2.5, 4.5)$

- **Total efficiencies computed from MC in (p_{T}, η) bins to reduce the dependence on theoretical model**
- **Uncertainties**
  - Systematics dominated by B_c^+ lifetime (0.453 ± 0.041) ps, and will be reduced after better lifetime measurement ($\sigma_\tau < 0.03$ ps expected)
  - Statistical uncertainty will be reduced by using 2011 data

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

LHCb-PAPER-2011-044

Knowledge of hadronic decay is very limited, only $J/\psi\pi^+$ mode observed before. Theoretical predictions quite differ from each other…

- **Based on data of $0.8\ \mathrm{fb}^{-1}$ accumulated in 2011**
- **First observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ was made by LHCb**
- **Relative branching fraction measured**

$$\frac{\mathrm{Br}(B_c^+ \to J/\psi\pi^+\pi^-\pi^+)}{\mathrm{Br}(B_c^+ \to J/\psi\pi^+)} = \varepsilon_{rel} \times \frac{N(B_c^+ \to J/\psi\pi^+\pi^-\pi^+)}{N(B_c^+ \to J/\psi\pi^+)}$$

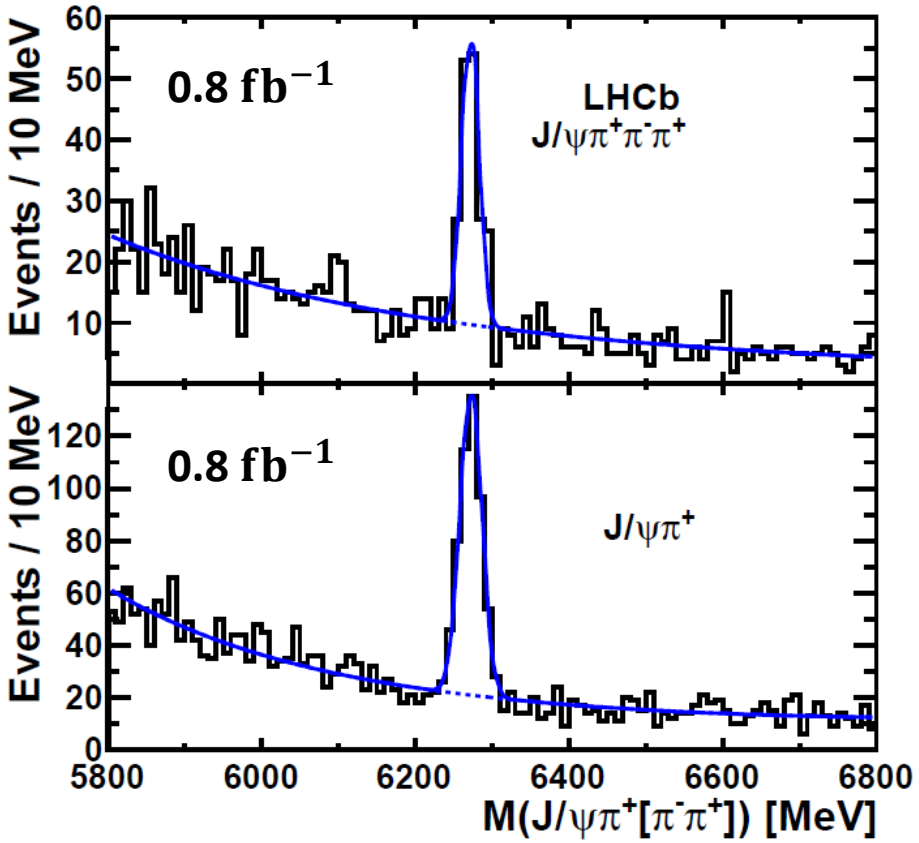
$B_c^+ \to J/\psi\pi^+\pi^-\pi^+$: Results

LHCb-PAPER-2011-044

- $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$
  $N_{\text{sig}} = 135 \pm 14$
  - First observation by LHCb
  - significance of 6.8σ
- $B_c^+ \to J/\psi\pi^+$
  $N_{\text{sig}} = 414 \pm 25$

Result

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



Systematics dominated by model dependence of efficiency.

Theo. prediction for the ratio: ~ 1.5 PRD 81, 014005 (2010)
~ 2.3 PRD 81, 014015 (2010)

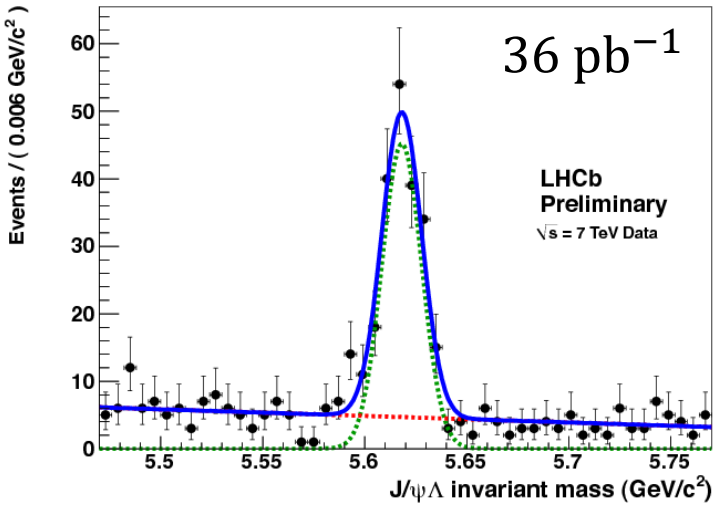
b baryons studies at LHCb

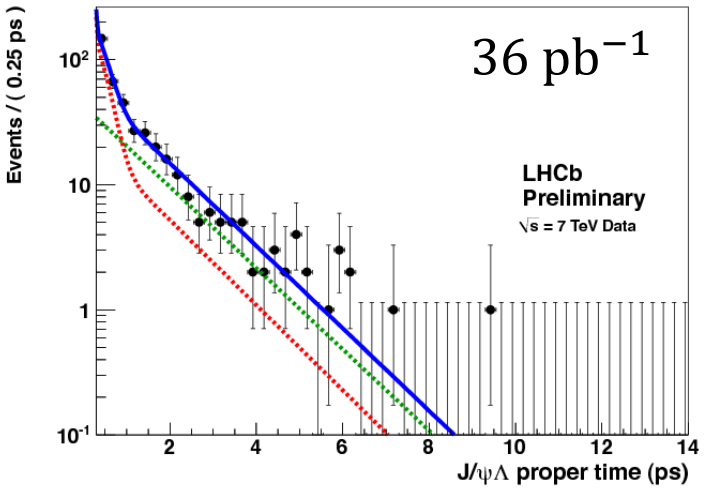
Lifetime of Λ_b^0 : Preliminary

LHCb-CONF-2011-001

Precise measurements of mass and lifetime are helpful to the understanding of QCD factorization …

- **Based on data of $36\ \mathrm{pb}^{-1}$ collected in 2010, using $\Lambda_b^0 \to J/\psi\Lambda$**
- $\tau(\Lambda_b \to J/\psi\Lambda) = 1.353 \pm 0.108_{\mathrm{stat}} \pm 0.035_{\mathrm{syst}}$ ps(preliminary) consistent with PDG value ($1.391^{+0.038}_{-0.037}$ ps)
- **Systematics dominated by imperfect knowledge of dependence of event reconstruction efficiency on proper time**





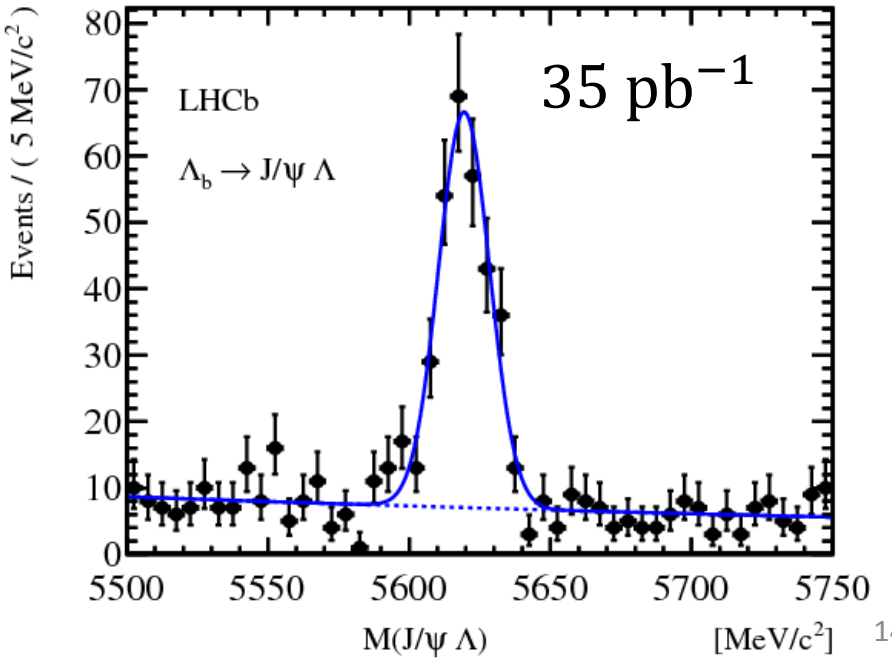
Mass of Λ_b^0

LHCb-PAPER-2011-035

- Based on data of $35\ \mathrm{pb}^{-1}$ collected in 2010
- Using decay mode of $\Lambda_b^0 \to J/\psi(\mu^+\mu^-)\Lambda$
  - $\boldsymbol{N_{\mathrm{sig}} = 279 \pm 19}$
  - $\boldsymbol{M(\Lambda_b) = 5619.19 \pm 0.70_{\mathrm{stat}} \pm 0.30_{\mathrm{syst}}\ \mathrm{MeV}/c^2}$
- Systematics dominated by momentum scale calibration

World best measurement by LHCb

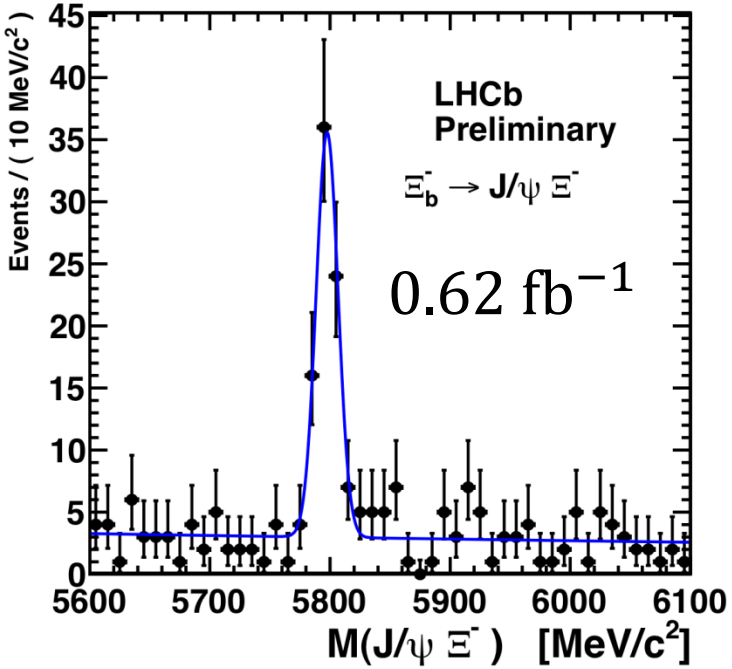
(PDG: $5620.2 \pm 1.6\ \mathrm{MeV}/c^2$)

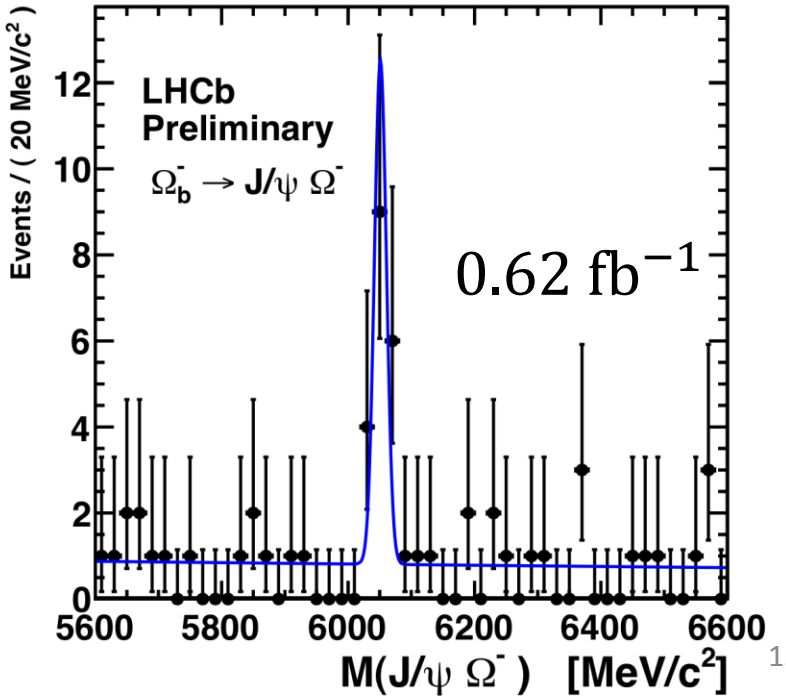


Masses of Ξ_b^-, Ω_b^- LHCb-CONF-2011-060

First observed by D0 and CDF, large discrepancy for Ω_b^-

- Based on data of $0.62\ \text{fb}^{-1}$ collected in 2011
- Reconstructed modes
  - $\Xi_b^- \to J/\psi(\mu^+\mu^-)\Xi^-(\Lambda(p\pi^-)\pi^-)$ $\quad N_{\text{sig}} = 72.2 \pm 9.4$
  - $\Omega_b^- \to J/\psi(\mu^+\mu^-)\Omega^-(\Lambda(p\pi^-)K^-)$ $\quad N_{\text{sig}} = 13.9^{+4.5}_{-3.8}$
- Decay time cuts used to suppress background

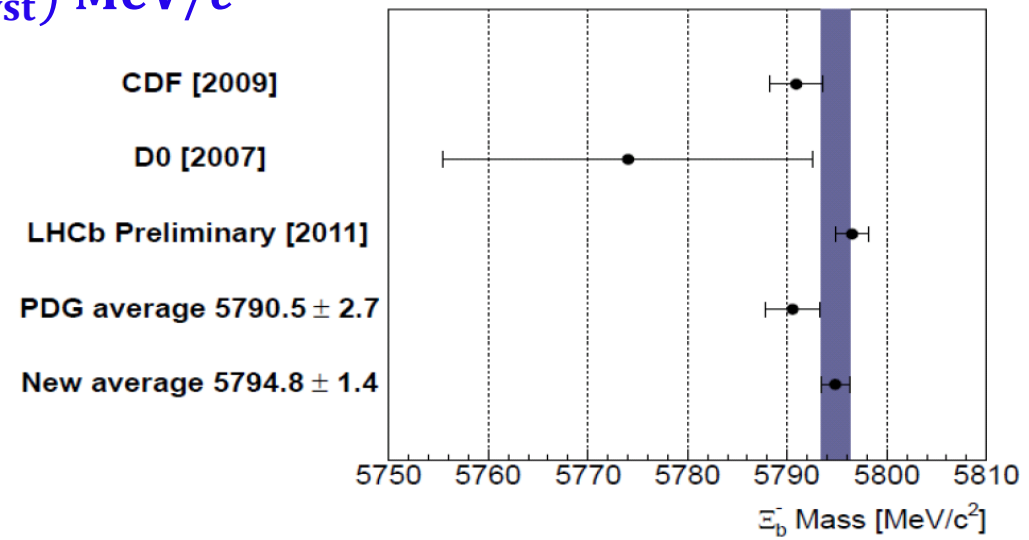




Masses of Ξ_b^-, Ω_b^- : Preliminary

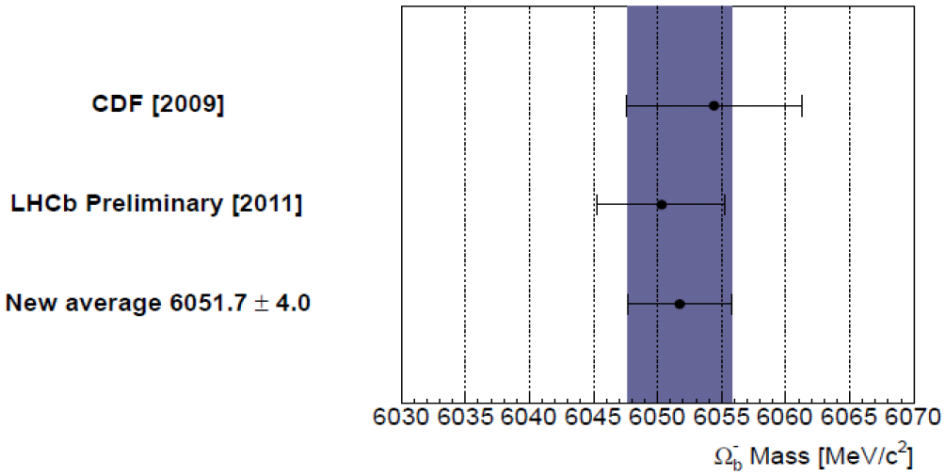
LHCb-CONF-2011-060

$$M(\Xi_b^-) = \left(5796.5 \pm 1.2_{\text{stat}} \pm 1.2_{\text{syst}}\right) \text{MeV}/c^2$$



- ✓ **Best mass measurements for Ξ_b^- and Ω_b^- by LHCb**
- ✓ **Systematics dominated by momentum scale calibration**

$$M(\Omega_b^-) = \left(6050.3 \pm 4.5_{\text{stat}} \pm 2.2_{\text{syst}}\right) \text{MeV}/c^2$$



Refs:
CDF: PRD 80, 072003 (2009)
D0 : PRL 99, 052001 (2007)
D0 : PRL 101, 232002 (2008)

6.8σ discrepancy between CDF+LHCb result and that of D0 (far to the right on the plot)

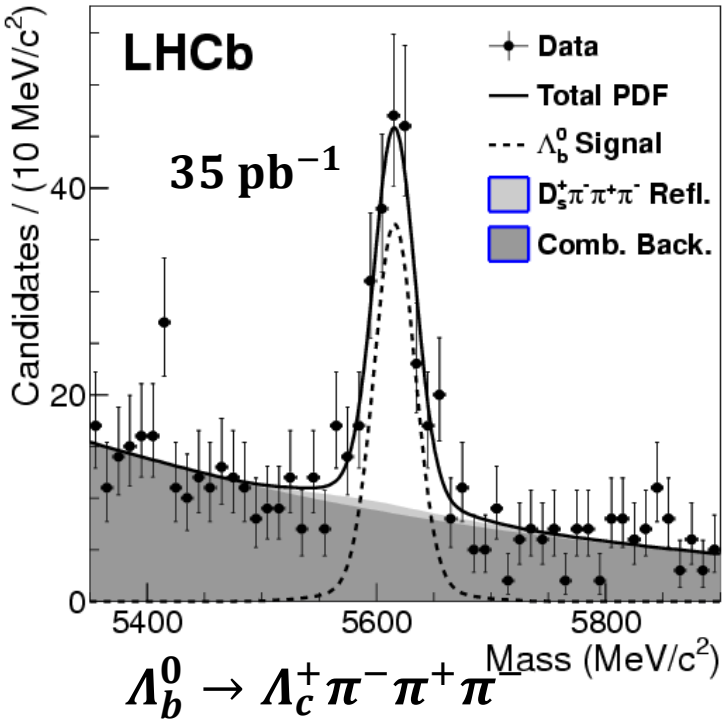
Production of $\Lambda_b^0(\rightarrow \Lambda_c^+\pi^-\pi^+\pi^-)$

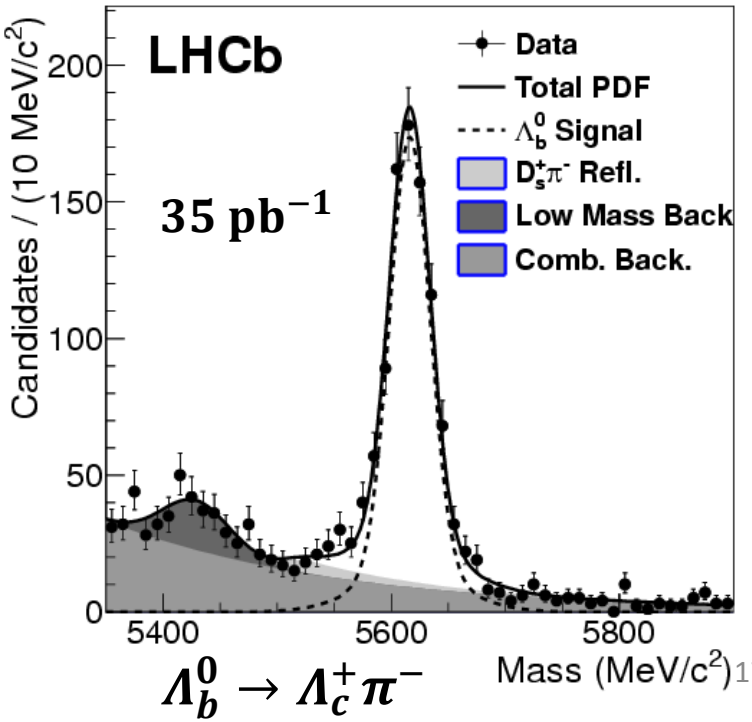
LHCb-PAPER-2011-016

- **Based on data of $35\ \mathrm{pb}^{-1}$ taken in 2010**
- **Ratio measured**

✓ $\frac{\mathrm{Br}(\Lambda_b^0\rightarrow\Lambda_c^+\pi^-\pi^+\pi^-)}{\mathrm{Br}(\Lambda_b^0\rightarrow\Lambda_c^+\pi^-)} = 1.43 \pm 0.16_{\mathrm{stat}} \pm 0.13_{\mathrm{syst}}$

- **Systematics dominated by track reconstruction efficiency and production/decay model.**



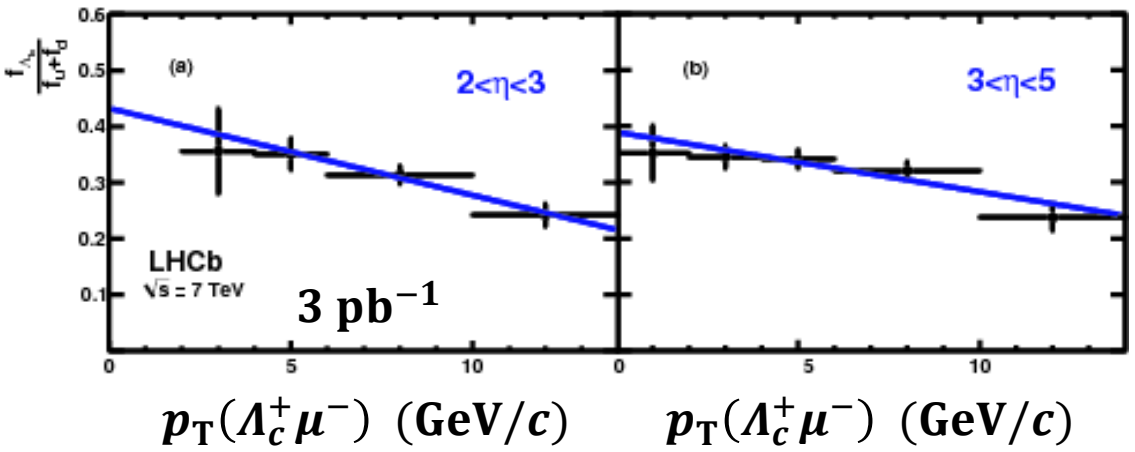


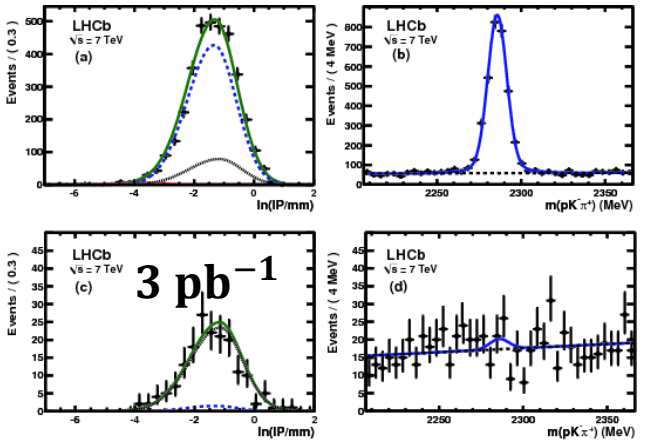
Production of Λ_b^0: Semi-leptonic decays

Knowledge of fragmentation functions allows one to relate pQCD derived $\bar{b}b$ production cross section to observed hadrons

LHCb-PAPER-2011-018

- **Base on data of $3\ \mathrm{pb}^{-1}$ collected in 2010**
- **Measured the ratio using $\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu} X$: preliminary**
  - ✓ $f_{\Lambda_b^0}/(f_u + f_d) = (0.404 \pm 0.017_{\mathrm{stat}} \pm 0.027_{\mathrm{syst}} \pm 0.105_{\mathrm{Br}}) \times [1 - (0.031 \pm 0.004_{\mathrm{stat}} \pm 0.003_{\mathrm{syst}}) \times p_{\mathrm{T}}(\mathrm{GeV}/c)]$
  - ✓ **Dependence on $p_{\mathrm{T}}(\Lambda_c^+ \mu^-)$ observed**
  - ✓ **Uncertainty dominated by that of $\mathrm{Br}(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$**
  - ✓ **Systematics dominated by background modeling, PID efficiency, etc**
  - ✓ **CDF result: $f_{\Lambda_b}/(f_u + f_d) = 0.281 \pm 0.012^{+0.011+0.128}_{-0.056-0.086}$**

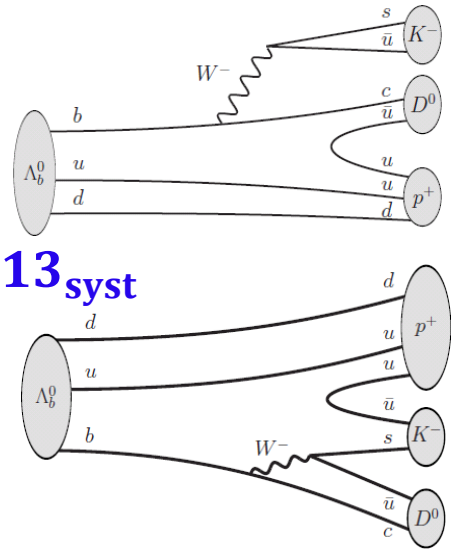




Λ_b^0 and Ξ_b^0 in D^0pK^- mode: Preliminary

LHCb-CONF-2011-036

- **Based on data of $333\ \mathrm{pb}^{-1}$ in 2011**
- **Measured the ratio**
  - ✓ $\frac{\mathrm{Br}(\Lambda_b^0 \to D^0 p K^-) \times \mathrm{Br}(D^0 \to K^-\pi^+)}{\mathrm{Br}(\Lambda_b^0 \to \Lambda_c^+ \pi^-) \times \mathrm{Br}(\Lambda_c^+ \to pK^-\pi^+)} = 0.119 \pm 0.006_{\mathrm{stat}} \pm 0.013_{\mathrm{syst}}$
- **First observation of $\Lambda_b^0 \to D^0 p K^-$ (6.3σ)**
  - ✓ $\frac{\mathrm{Br}(\Lambda_b^0 \to D^0 p K^-)}{\mathrm{Br}(\Lambda_b^0 \to D^0 p \pi^-)} = 0.112 \pm 0.019(\mathrm{stat})^{+0.011}_{-0.014}(\mathrm{syst})$
- **$\Xi_b^0 \to D^0 p K^-$ observed (2.6σ)**
  - ✓ $\frac{f_{b\to\Xi_b^0} \times \mathrm{Br}(\Xi_b^0 \to D^0 p K^-)}{f_{b\to\Lambda_b^0} \times \mathrm{Br}(\Lambda_b^0 \to D^0 p \pi^-)} = 0.29 \pm 0.12_{\mathrm{stat}} \pm 0.08_{\mathrm{syst}}$
- **Systematics dominated by mass fitting, PID efficiencies, etc.**



Summary

- **B_c studies at LHCb**
  - **Mass and cross section measured using 2010 data**
  - **First observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ (6.8σ)**
- **b baryons studies at LHCb**
  - **Mass and lifetime of Λ_b^0 measured using 2010 data**
    - **World best mass measurement by LHCb**
  - **Masses of Ξ_b^- and Ω_b^- measured using 2011 data**
    - **World best mass measurements by LHCb**
  - **Productions of Λ_b^0 measured with various decay modes using 2010 and/or 2011 data**
    - **First observation of $\Lambda_b^0 \to D^0 p K^-$ (6.3σ) and $\Xi_b^0 \to D^0 p K^-$ (2.6σ) at LHCb**

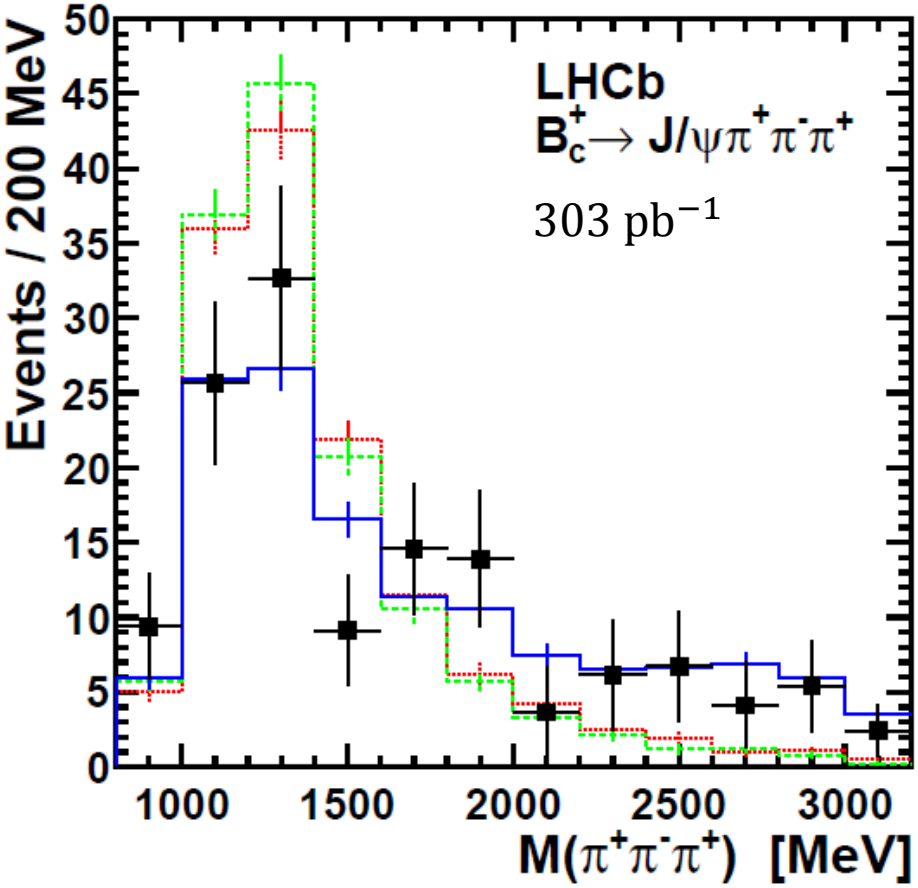
Prospects

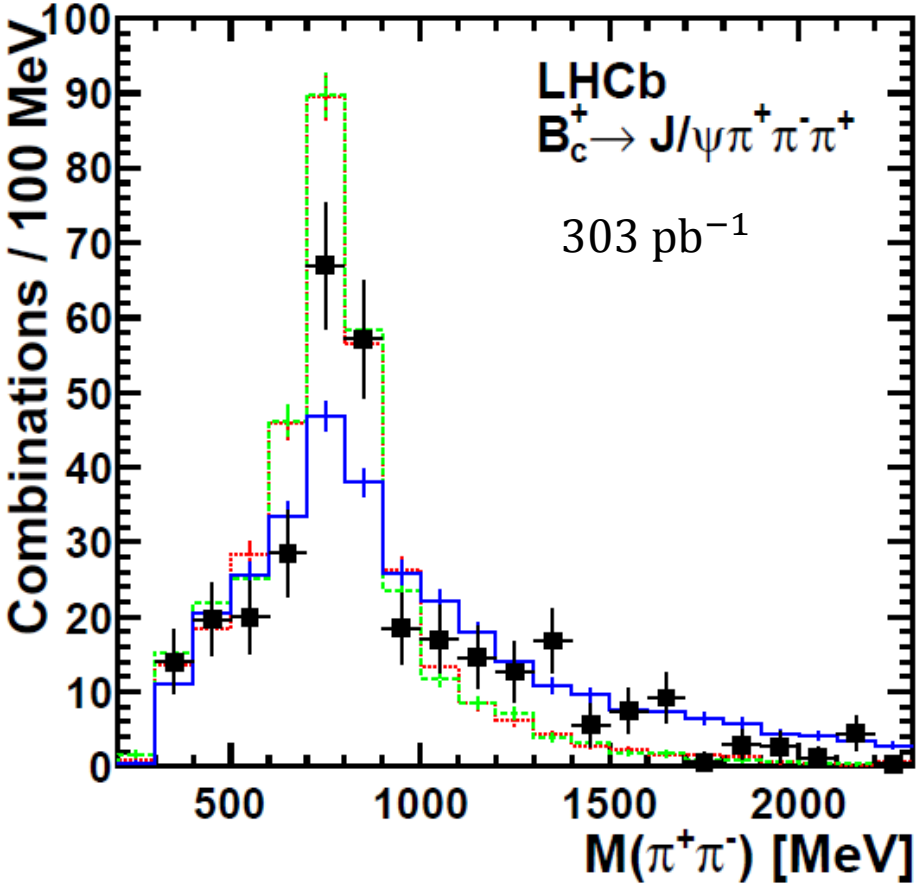
- **B_c studies**
  - Mass measurement update using 2011 data
  - Lifetime measurement by combining various decay modes ($\sigma_\tau < 0.03$ ps expected)
  - Searching for new decay channels and excited states $B_c^+ \to J/\psi K^+, B_c^+ \to \psi(2S)\pi^+, B_c^+ \to B_s^0\pi^+$, ……
  - **……**
- **b baryons studies**
  - Update measurements using 2011 data
  - New b baryons and/or new decay modes searches
  - Excited states
  - Measurements of polarization, ……
  - ……
- Run in 2012 at $\sqrt{s} = 8$ TeV, $\sim 10\%$ gain in cross sections, $1.5\sim2$ fb^{-1} expected

Backup slides

Resonance structure in $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$

LHCb-PAPER-2011-044



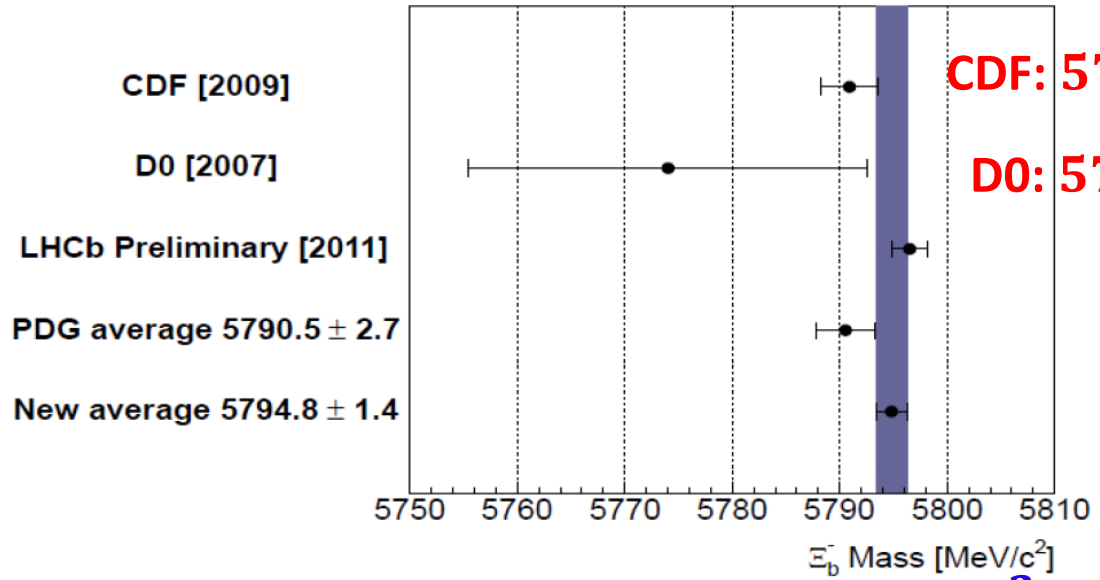


Resonance structure: dominated by

$B_c^+ \to J/\psi a_1^+(1260)$ with $a_1^+(1260) \to \rho^0\pi^+$

Masses of Ξ_b^-, Ω_b^-: Compare to CDF&D0

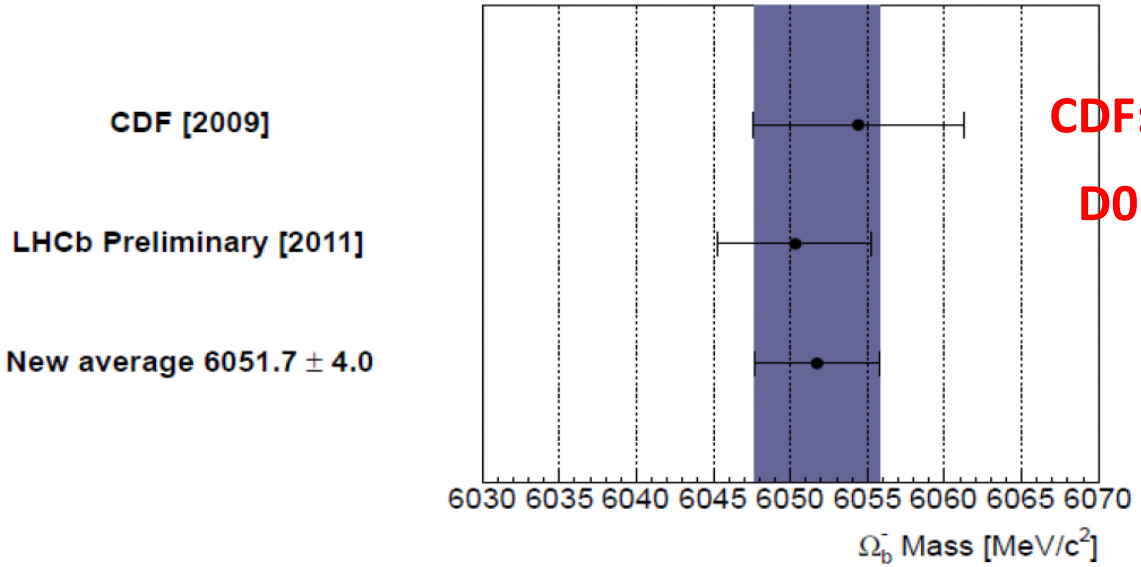
$M(\Xi_b^-) = 5796.5 \pm 1.2 \pm 1.2\ \mathrm{MeV}/c^2$



CDF: $5790.9 \pm 2.6 \pm 0.8\ \mathrm{MeV}/c^2$

D0: $5774 \pm 11 \pm 15\ \mathrm{MeV}/c^2$

$M(\Omega_b^-) = 6050.3 \pm 4.5 \pm 2.2\ \mathrm{MeV}/c^2$



6σ discrepancy between CDF&D0

CDF: $6054.4 \pm 6.8 \pm 0.9\ \mathrm{MeV}/c^2$

D0: $6165 \pm 10 \pm 13\ \mathrm{MeV}/c^2$

Refs:

CDF: PRD 80, 072003 (2009)

D0 : PRL 99, 052001 (2007)

D0 : PRL 101, 232002 (2008)