Charm and beauty production at LHCb

2013.04.23 (Marseille, France, April 22-26, DIS2013)

Alexandr Kozlinskiy (Nikhef)
on behalf of the LHCb collaboration

DIS2013 LHCb presentations

Tuesday:

- "Inclusive particle production at LHCb" *by D. Volyanskyy*
- "Properties and decays of B_c meson and b baryons" *by Y. Xunao*
- "Studies of excited charm and beauty mesons at LHCb"

by V. Gligorov

- "Quarkonia and quarkonia-like spectroscopy at LHCb"

by C. Fitzpatrick

- "Studies of quarkonia production and polarization at LHCb"

by M. Frosini

Wednesday:

- "Exclusive J/ψ and ψ(2S) production in *pp* collisions at 7 TeV"

by R. McNulty

- "Electroweak boson production at LHCb" *by S. Tourneur*
- "The LHCb upgrade" *by U. Marconi*

Outline

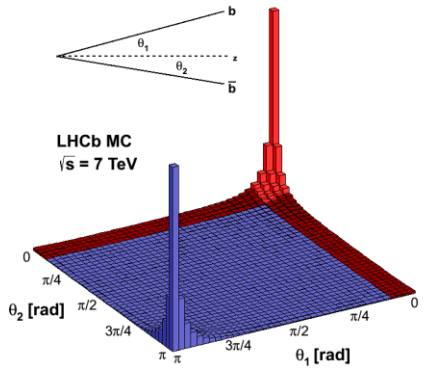
- LHCb detector & performance

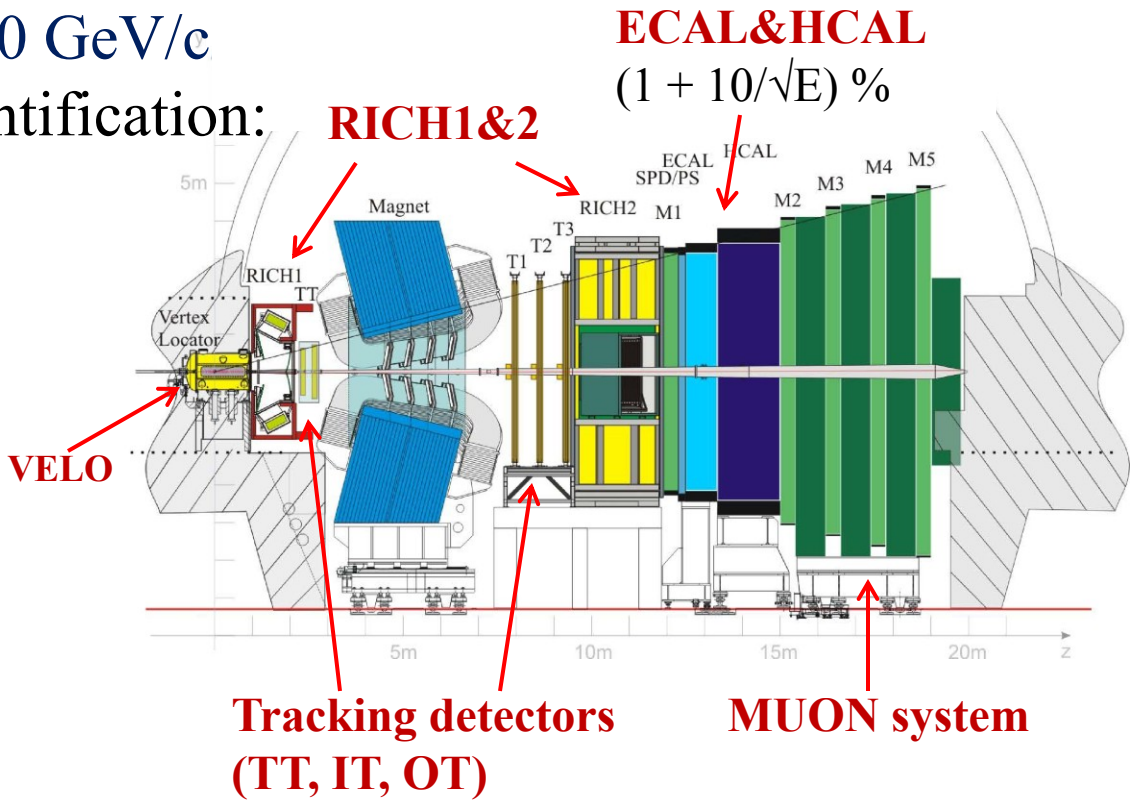
- Beauty and charm production:
  - Open charm production: D^0, $D^{*\pm}$, D^+, D_s^+, Λ_c^+.
    Nucl.Phys.B871 (2013) 1-20
  - B mesons production: B^+, B^0, B_s^+.
    LHCb-PAPER-2013-004 (Preliminary)
  - $\sigma(b\bar{b})$: using inclusive final states.
    LHCb-CONF-2013-002
  - Forward-central (A_{FC}) $b\bar{b}$ production asymmetry.
    LHCb-CONF-2013-001

- Summary

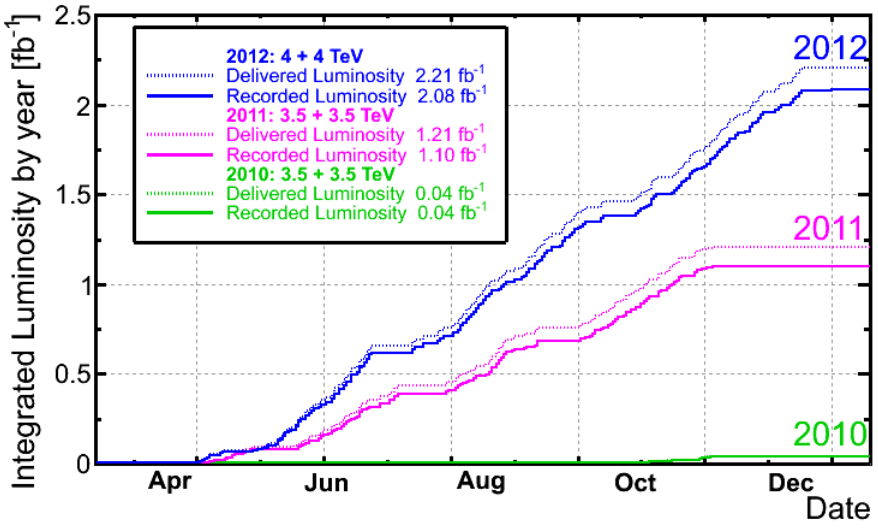
LHCb detector

- LHCb is a single arm forward spectrometer:
  - Unique rapidity coverage: $2.0 < \eta < 5.0$
  - Forward $q\bar{q}$ pairs production.
- Excellent vertex and track momentum resolution:
  - $\sigma_{IP} \sim 20\ \mu m$
  - $\Delta p/p = 0.6\%$ at 100 GeV/c
- Excellent Particle Identification:
  - RICH detectors
  - MUON system



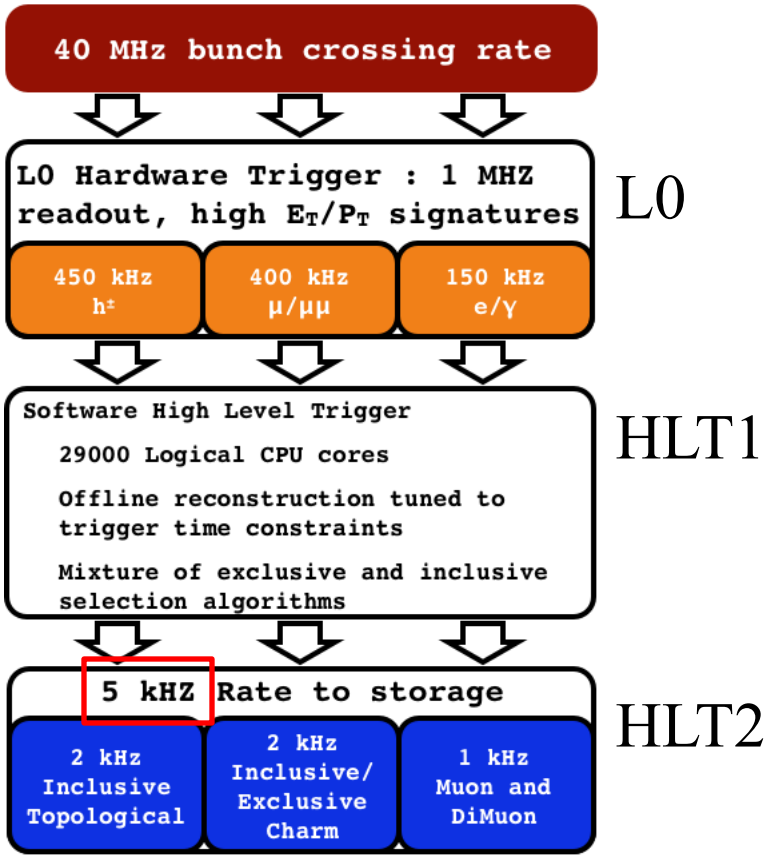


Trigger & Performance



- Data taking efficiency: > 90%
- Data quality: > 99%
- Integrated Luminosity:
  - 2010: 37 pb^{-1}
  - 2011: 1.0 fb^{-1}
  - 2012: 2 fb^{-1}

Trigger scheme



Motivation

- Beauty and charm production:
  - Understanding of QCD in *pp* at new energy scale.
  - Background estimate for SM processes, such as Higgs production.
  - Powerful test of QCD@NLO calculations.

- LHCb:
  - Unique forward rapidity coverage.
  - Measurement of cross sections down to $p_T = 0$

Previous measurements:

- Beauty production:
  - **LHCb** (forward rapidity at 7 TeV, PLB694(2010)209-216, JHEP04(2012)93) & **CMS** (central at 7 TeV, JHEP03(2011)090)
  - **CDF** (central at 1.96 TeV, PRD71(2005)032001)
- Charm production:
  - **CDF** (central at 1.96 TeV, PRL91(2003)241804)
  - **Alice** (central at 2.76 TeV and 7 TeV, JHEP07(2012)191 and JHEP01(2012)128)

Open charm production

• Open charm cross section is essential for sensitivity estimate of CPV, mixing and rare decays.

- Dataset:
  - L = 15 nb^{-1} (2010 @ 7 TeV)
  - Low pileup (~1 interaction per BX)
  - Simple trigger (at least one reconstructed track in the detector)
- Unique rapidity range and low p_T:
  - $0 < p_T < 8$ GeV (8 bins)
  - $2.0 < y < 4.5$ (5 bins)
- Selections tuned independently for each decay mode:
  - Track quality, IP, PID
  - Vertex quality, flight distance
  - Pointing to primary vertex

Decay modes:

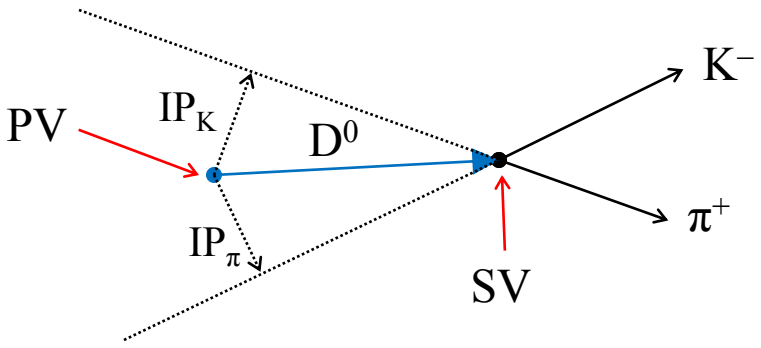
$D^0 \to K^-\pi^+$

$D^{*+} \to (D^0 \to K^-\pi^+)\pi^+$

$D^+ \to K^-\pi^+\pi^+$

$D_s^+ \to (\varphi \to K^-K^+)\pi^+$

$\Lambda_c^+ \to pK^-\pi^+$



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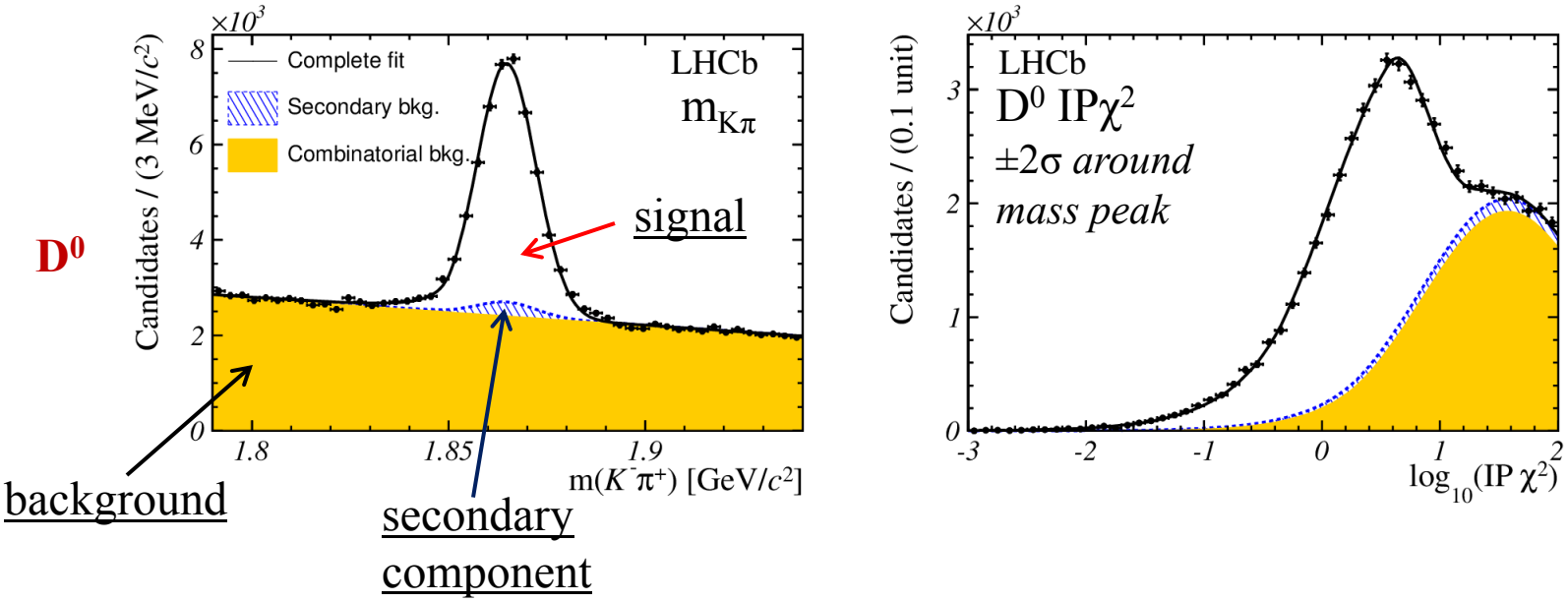
Open charm production: yields



Yields extracted in bins of p_T and rapidity:

- Simultaneous fit to mass variables and $\log_{10}(\mathrm{IP}\ \chi^2)$
- Disentangle prompt and secondary components.

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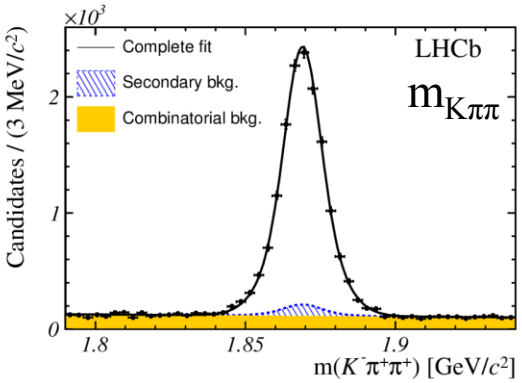
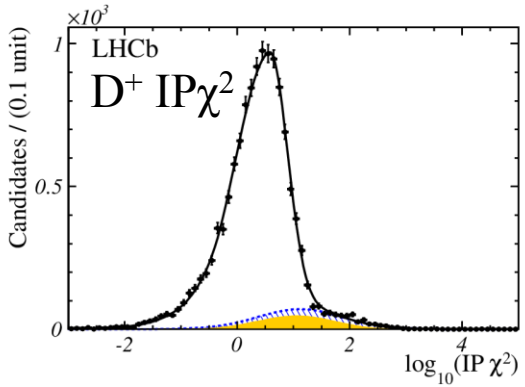
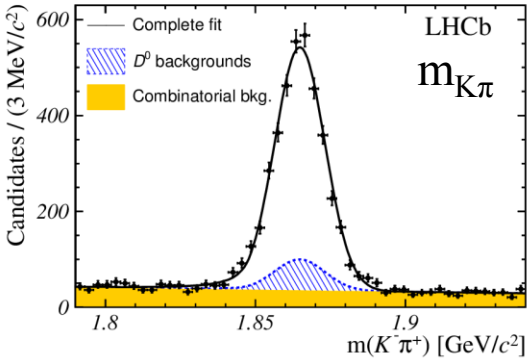
Open charm production: yields

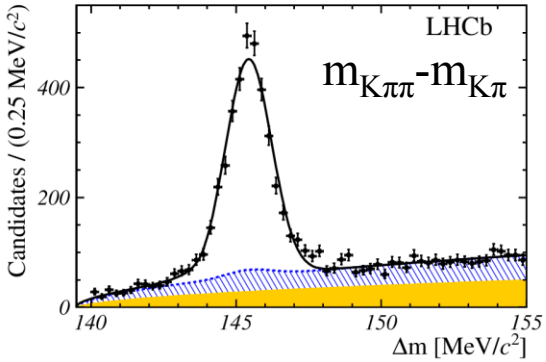
D^+

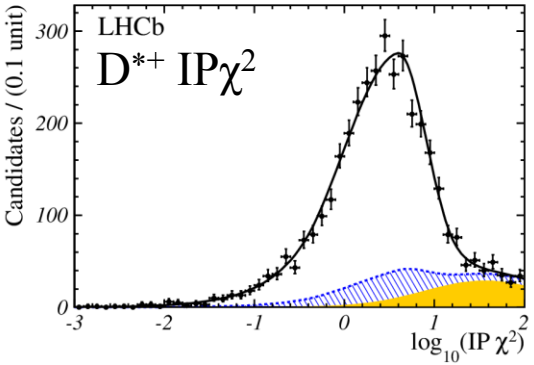




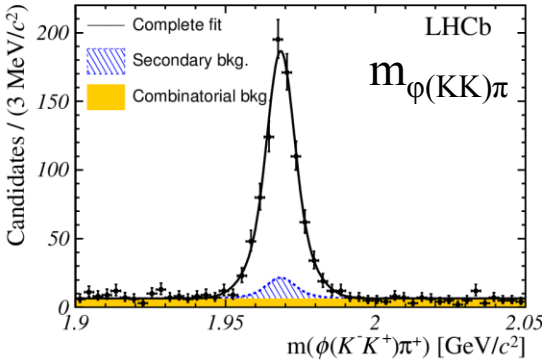
D^{*+}



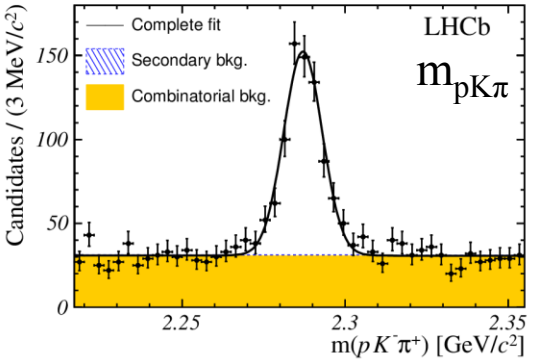




D_s^+



Λ_c^+



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Open charm production: systematic unc.

Systematic uncertainties:

Source	D^0	D^{*+}	D^+	D_s^+	Λ_c^+
Selection and reconstruction (correlated)	1.6	2.6	4.3	5.3	0.4
(uncorrelated)	1–12	3–9	1–10	4–9	5–17
Yield determination (correlated)	2.5	2.5	0.5	1.0	3.0
(uncorrelated)	–	–	1–5	2–14	4–9
PID efficiency	1–5	1–5	6–19	1–15	5–9
Tracking efficiency	6	10	9	9	9
Branching fraction	1.3	1.5	2.1	5.8	26.0
Luminosity	3.5	3.5	3.5	3.5	3.5

Main systematic uncertainties:

- Tracking efficiency (3% per track)
- Branching fractions (Λ_c^+)
- MC and PID

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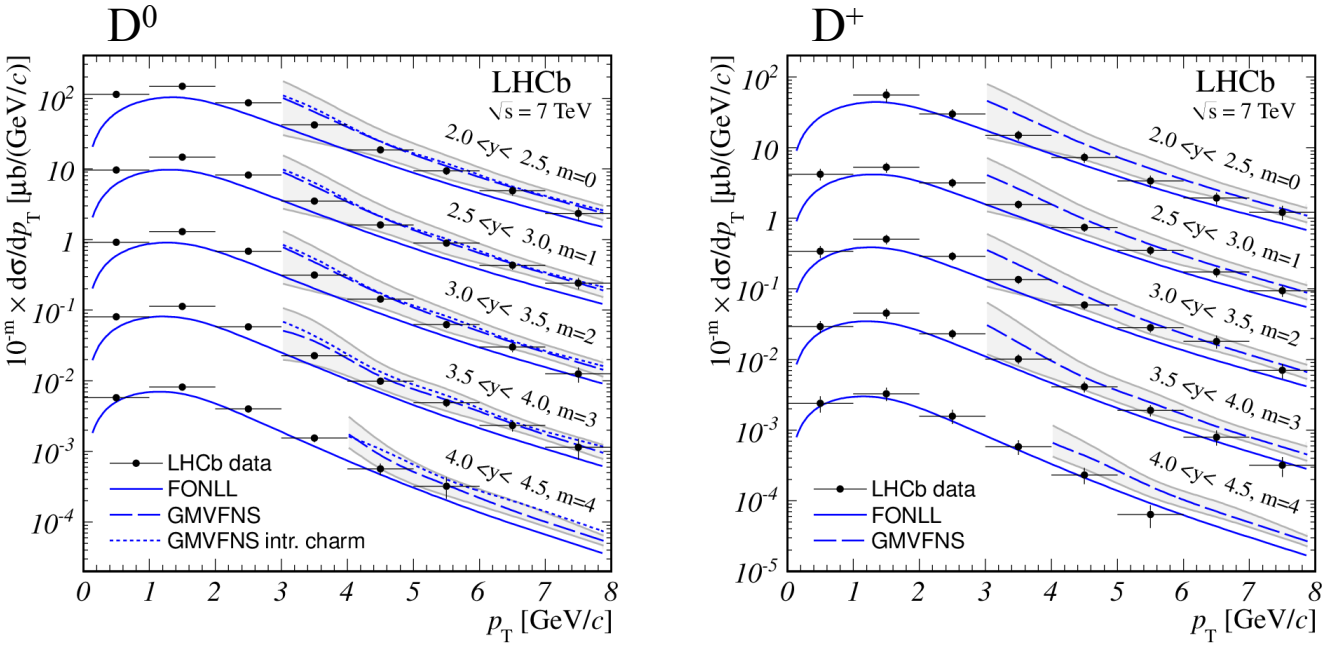
Open charm production: results

$$\frac{\mathrm{d}\sigma_i(H_c)}{\mathrm{d}p_T} = \boxed{\frac{1}{\Delta p_T}} \cdot \frac{N_i(H_c \to f + \mathrm{c.c.})}{\varepsilon_{i,\mathrm{tot}}(H_c \to f) \cdot L_{\mathrm{int}} \cdot Br(H_c \to f)}$$



- **G**eneral **M**ass **V**ariable **F**lavor **N**umber **Sc**heme:
  - EPJC72(2012)2082 (B. Kniehl et al.)
- **F**ixed-**O**rder **N**ext-to-**L**eading-**L**ogarithm:
  - JHEP10(2012)137 (M. Cacciari et al.)

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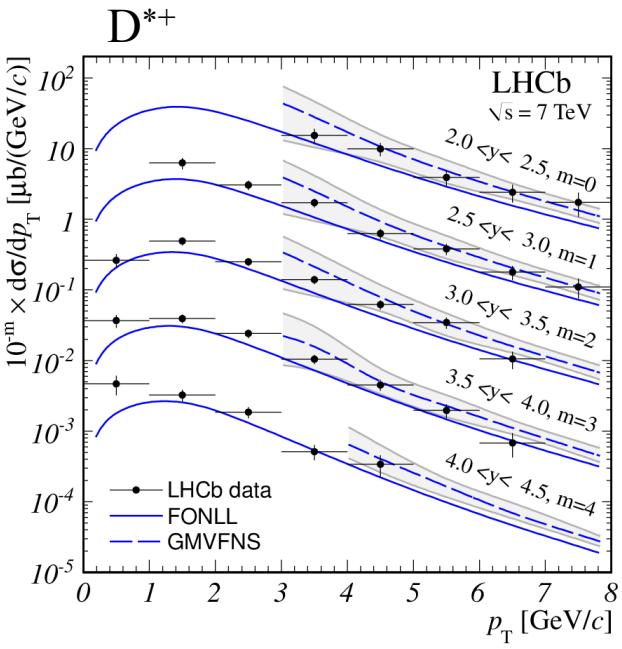
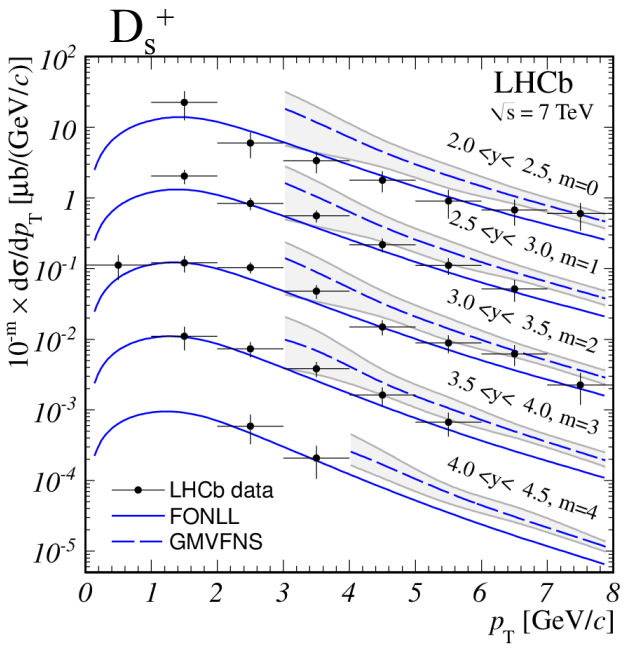
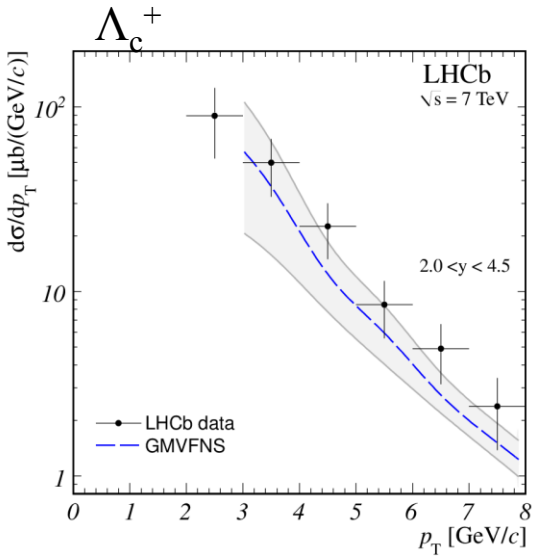
Open charm production: results







- Integrated cross section ($p_T < 8$ GeV & $2.0 < y < 4.5$):
  - $\sigma_{c\bar{c}} = (1419 \pm 12_{stat} \pm 116_{syst} \pm 65_{frag})$ μb
- Extrapolation to 4π (PYTHIA):
  - $\sigma_{c\bar{c}} \sim 7$ mb (factor 20 larger than $\sigma_{b\bar{b}}$)

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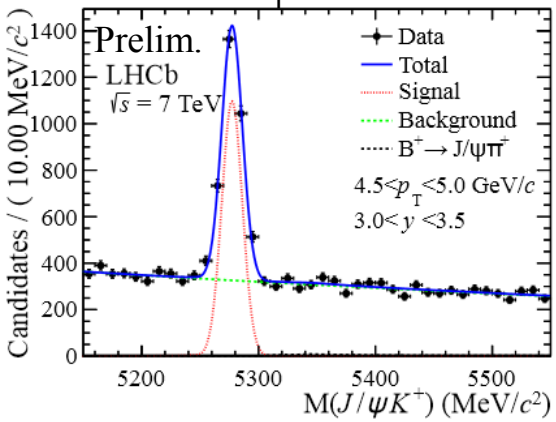
B mesons production

- Dataset: L = 362 pb^{-1} (2011 @ 7 TeV)
- Decay modes:
  - $B^+ \rightarrow J/\psi K^+$, where $J/\psi \rightarrow \mu^+\mu^-$
  - $B^0 \rightarrow J/\psi K^{*0}$, where $K^{*0} \rightarrow K^+\pi^-$
  - $B_s^0 \rightarrow J/\psi\varphi$, where $\varphi \rightarrow K^+K^-$

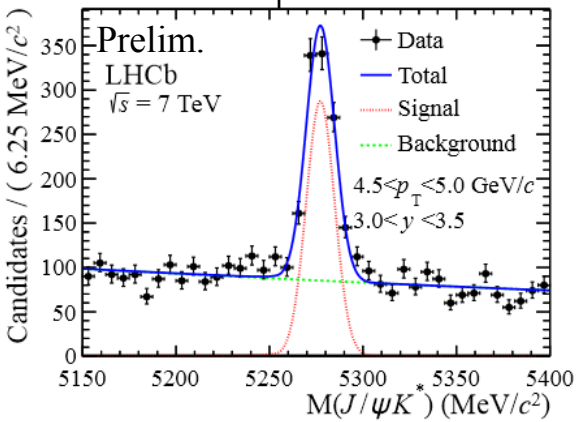
- Kinematic region:
  - $0 < p_T < 40$ GeV & $2.0 < y < 4.5$

Selections:
- Track quality, PID, p_T
- Vertex quality
- B life time

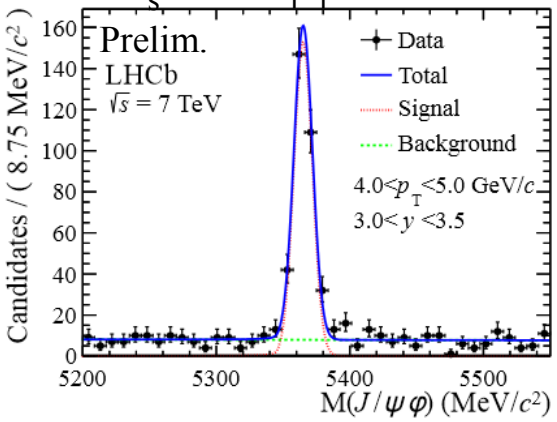
$B^+ \rightarrow J/\psi K^+$



$B^0 \rightarrow J/\psi K^{*0}$



$B_s^0 \rightarrow J/\psi\varphi$



To be submitted to JHEP (Preliminary)

B mesons production: results (preliminary)

Main systematic uncertainties:

- Trigger efficiency (2.4-7.9%)
- Tracking efficiency (2.4-8.5%)
- Branching fractions (3.3%, 12.3% and 10% for B^+, B^0 and B_s^+)
- Luminosity (3.5%)

$$\frac{d^2\sigma_B}{dp_T dy} = \frac{N_B(p_T, y)}{\varepsilon_{tot}(p_T, y) \cdot L_{int} \cdot Br(B \to J/\psi X) \cdot \Delta p_T \Delta y}$$

Integrated cross section ($0 < p_T < 40$ GeV & $2.0 < y < 4.5$):

- $\sigma(pp \to B^+ X) = (38.9 \pm 0.3_{stat} \pm 2.8_{syst})$ μb
  - good agreement with prev. result:
    $\sigma = (41.4 \pm 1.5_{stat} \pm 3.1_{syst})$ μb (JHEP04(2012)093)

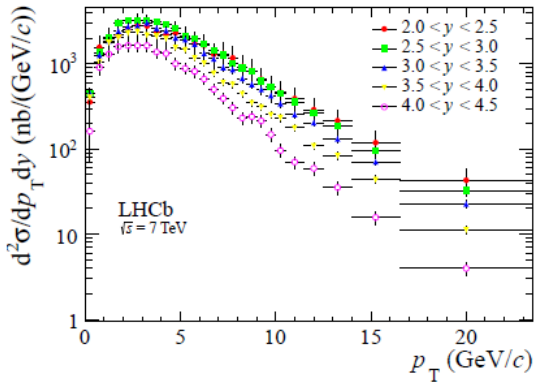
- $\sigma(pp \to B^0 X) = (38.9 \pm 0.6_{stat} \pm 3.6_{syst} \pm 4.8_{Br})$ μb
- $\sigma(pp \to B_s^0 X) = (10.5 \pm 0.2_{stat} \pm 0.8_{syst} \pm 4.8_{Br})$ μb

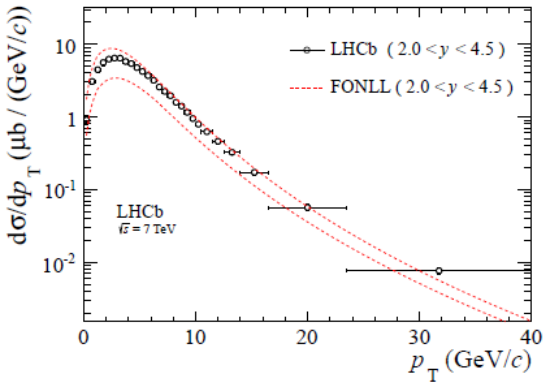
First measurement at 7 TeV in forward region

To be submitted to JHEP (Preliminary)

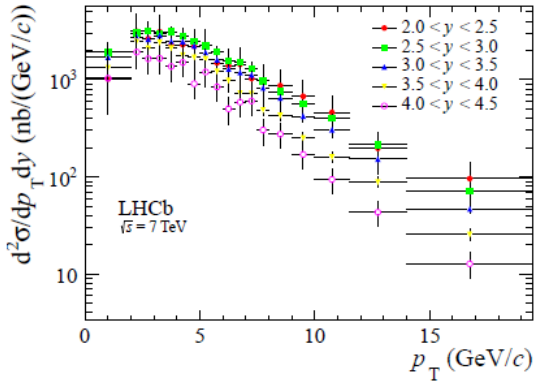
B mesons production: results (preliminary)

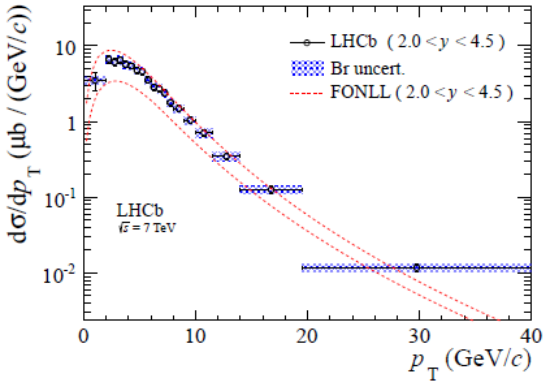
B^+



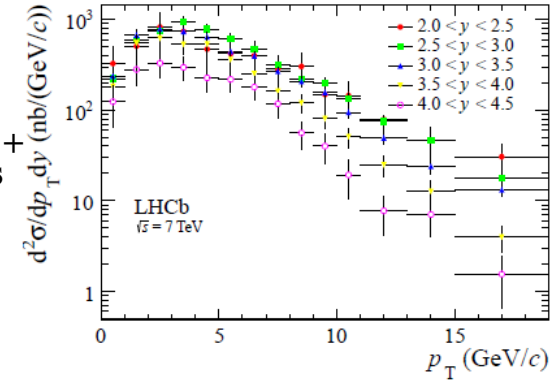


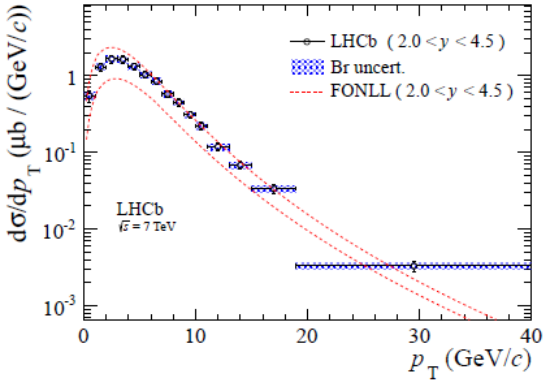
B^0





B_s^+





Fragmentation fractions are used to fix overall scale of FONLL:

- $f(b \to B^0/B^+) = (33.7 \pm 2.2)\%$
- $f(b \to B_s^+) = (9.0 \pm 0.9)\%$

PRD85(2012)032008

To be submitted to JHEP (Preliminary)

$b\bar{b}$ production

LHCb measured $b\bar{b}$ production using inclusive b-hadron final states:

- Less dependence of fragmentation fractions.
- Larger kinematic region compared to exclusive reconstruction.
- Possible to measure cc production as well.

Dataset:

- $L = 18\ pb^{-1}$ (2010 @ 7 TeV)

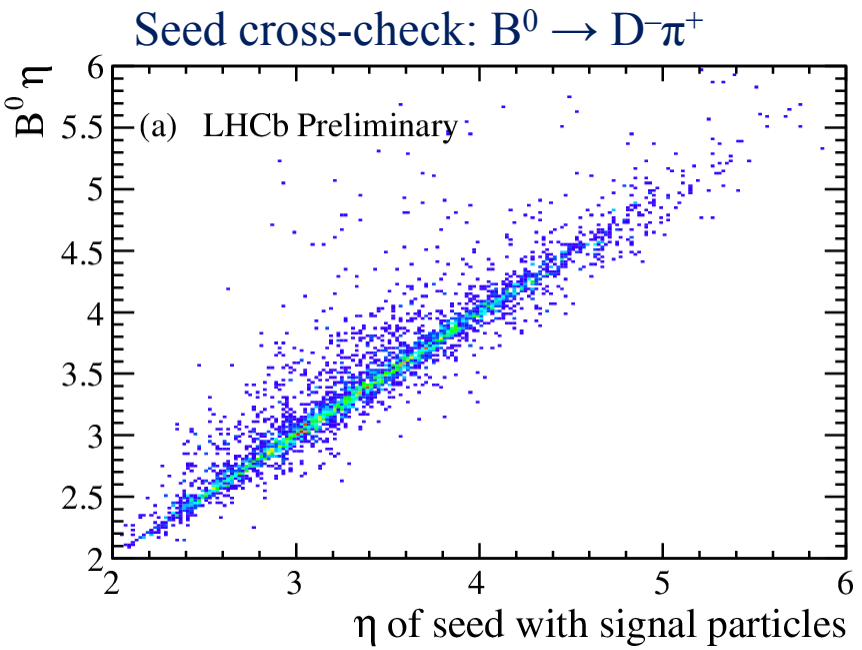
Kinematic region:

- $2.5 < \eta < 4.0$ & $p_T > 5$ GeV

LHCb-CONF-2013-002

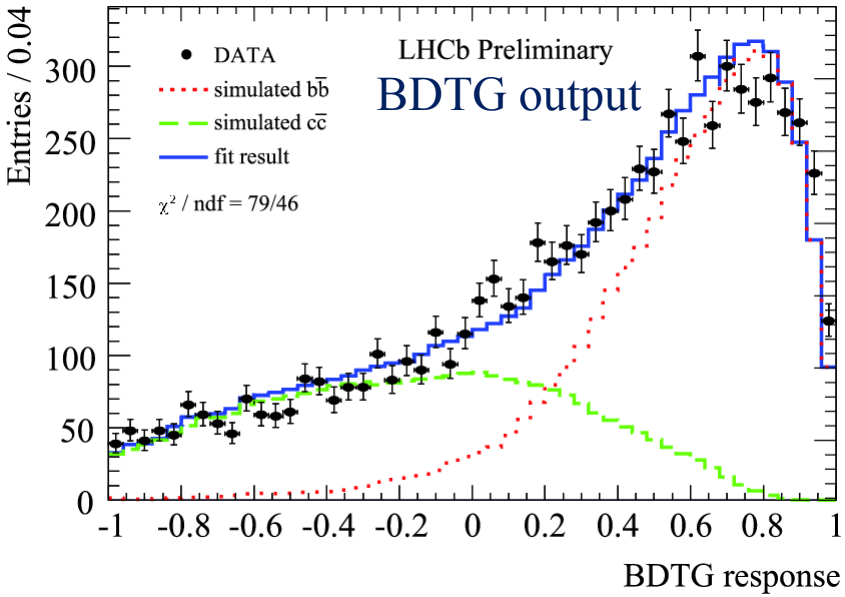
$b\bar{b}$ production

- Seed reconstruction:
  - Two B candidates: secondary vertexes from 2 or 3 tracks.
  - Energy calibration from MC.
  - Angular resolution:
    - $\sigma\varphi_{seed} \sim 13$ mrad
    - $\sigma\theta_{seed} \sim 1.3$ mrad
- BDTG:
  - Decompose $c\bar{c}$ and $b\bar{b}$ using fit templates.
  - Input: seed p_T and invariant mass, sum of IP significances, p_T wrt seed.
- Main systematic uncertainties:
  - Luminosity (3.5%)
  - MC description (10%)



LHCb-CONF-2013-002

$b\bar{b}$ production: results



- $2.5 < \eta < 4.0$ & $p_T > 5$ GeV:

$\sigma_{b\bar{b}} = (7.7 \pm 0.12_{stat} \pm 0.84_{syst})$ μb

- LHCb acceptance: $79.7 \pm 1.1_{stat} \pm 8.7_{syst}$
- Prev. LHCb result ($2 < \eta < 6$):
  - $75.3 \pm 5.4_{stat} \pm 13.0_{syst}$ (PLB694(2010)209-216)

PowHeg: $\sigma_{b\bar{b}} = (5.3 \pm 2.1)$ μb
Phys. Rev. Lett. 89 (2002) 122003

- $2.5 < \eta < 4.0$ & $p_T > 5$ GeV:

$\sigma_{c\bar{c}} = (104.6 \pm 2.7_{stat} \pm 11.4_{syst})$ μb

FONLL: $\sigma_{c\bar{c}} = [170, 300]$ μb
Phys. Rev. Lett. 89 (2002) 122003

LHCb-CONF-2013-002

Forward-central $b\bar{b}$ production asymmetry

• Forward-central production asymmetry (A_{FC}) predicted to be small in SM ~ O(0.1%)

• CDF and D0 measured larger than SM forward-backward asymmetry in $t\bar{t}$ (1211.1003, PRD84(2011)112005)

• Atlas & CMS measurements of A_{FC} are consistent with SM (EPJC72(2012)2039, PLB717(2012)129)

LHCb measured A_{FC}:

$$A_{FC}^{b\bar{b}} = \frac{N_{\Delta y>0} - N_{\Delta y<0}}{N_{\Delta y>0} + N_{\Delta y<0}}, \Delta y = |y_b| - |y_{\bar{b}}|$$

Dataset: L = 1.0 fb^{-1} (2011 @ 7 TeV)

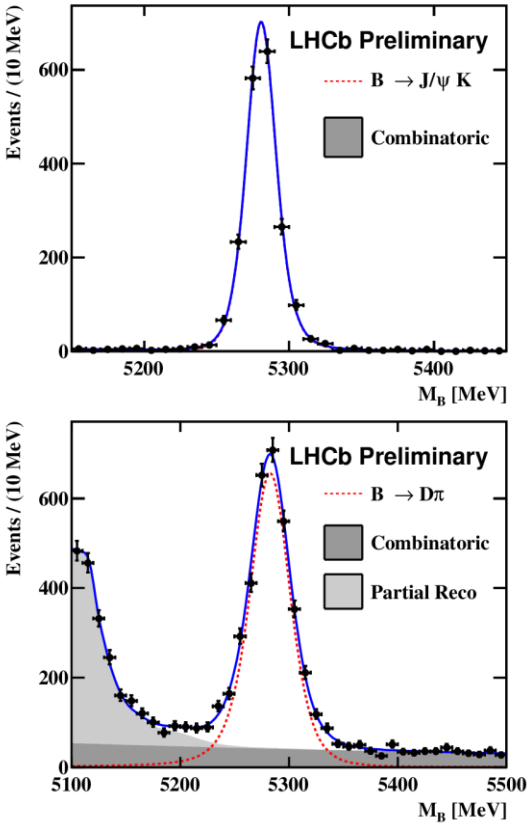
LHCb-CONF-2013-001

Forward-central $b\bar{b}$ production asymmetry

Selections:

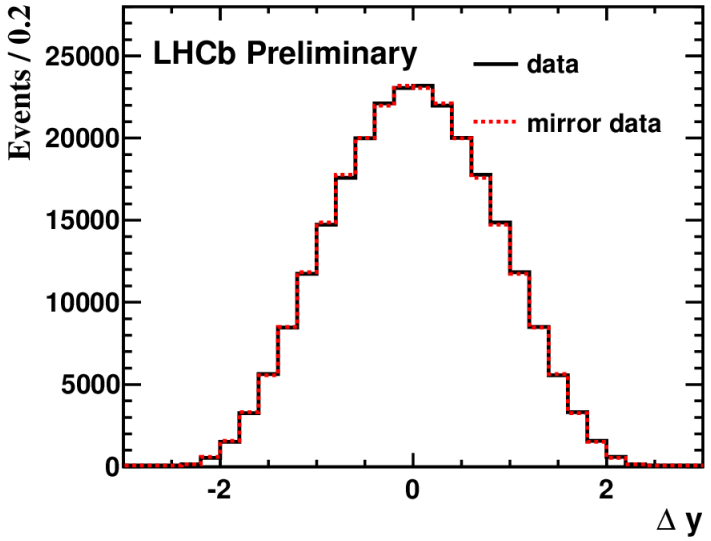
- Require 2 back-to-back ($\Delta\varphi > 2.5$) b-tagged jets (anti-k_T, $p_T > 15$ GeV):
  - Tag with displaced secondary vertexes.
- At least one jet flavor tagged:
  - Displaced track identified as muon.
  - Tag flavor by muon charge.
  - 10% of selected di-jet events are flavor tagged.
- Jet energy correction:
  - Derived from MC (acceptance, noise, pile-up, etc).
  - Order of (20-30)% correction.
  - Resolution $\sigma_E \sim (15\text{-}20)\%$

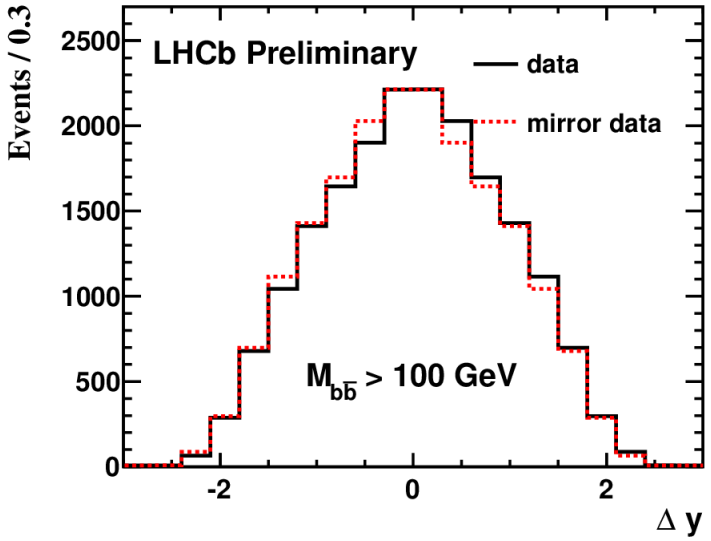
Cross-check:
B flavor tagging.



LHCb-CONF-2013-001

Forward-central $b\bar{b}$ production asymmetry





$$A_{FC}^{b\bar{b}} = (-0.5 \pm 0.5_{stat} \pm 0.5_{syst})\ \%$$

$$A_{FC}^{b\bar{b}}(M_{b\bar{b}} > 100\ \text{GeV}) = (-4.3 \pm 1.7_{stat} \pm 2.4_{syst})\ \%$$

LHCb-CONF-2013-001

Summary

- LHCb has unique coverage at LHC:
  - Forward rapidity.
  - Low p_T.
- Measured cross sections:
  - Charm: D^0, $D^{*\pm}$, D^+, D_s^+, Λ_c^+.
  - B mesons: B^+, B^0, B_s^+.
  - $b\bar{b}$ production.
  - $b\bar{b}$ forward-central asymmetry.
- Good agreement with theoretical predictions.
- Other LHCb measurement:
  - $D^{\pm}$ production asymmetry (PLB718(2013)902-907)
  - f_s/f_d measurement (APhysPolB.43.1561)
  - J/ψ production (JHEP02(2013)041@2.76TeV, EPJC71(2011)1645@7TeV) and B production.
- Analysis of 2012/13 (8 TeV and pA) data is ongoing:
  - *Many more results are expected. Stay tuned!*