Charm and beauty production in pp collisions at $\sqrt{s} = 13\,\text{TeV}$ at LHCb

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on behalf of the LHCb collaboration

Wednesday 6th September 2017
PDF4LHC meeting

Topics[1]

1. Prompt and secondary J/ψ production at $\sqrt{s} = 13\,\text{TeV}$;
2. Open charm production for D^0, D^+, D_s^+, and D^{*+} at 13 and 5 TeV;
3. Open beauty production for $B^0_{(s)}$, B^+, and Λ_b^0, with $H_b \to H_c \mu X$ at 13 and 7 TeV;

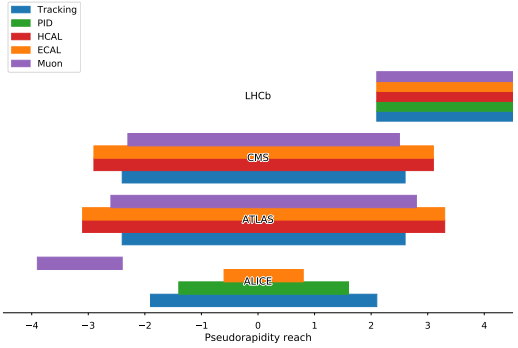
[1] Erratum published for 1, 2; submitted for 3. All arXiv and HepData records now updated.

Why LHCb?

Reach in x is a function of quark mass and kinematics:

$$e^{-y\frac{\sqrt{p_T^2+m_q^2}}{\sqrt{s}}} < x < e^{y\frac{\sqrt{p_T^2+m_q^2}}{\sqrt{s}}}$$

LHCb *uniquely* can reach $x \sim 10^{-6}$ at LHC[2]



[2]PROSA collaboration: epjc/s10052-015-3618-z

Cross-section measurements

$$\frac{\mathrm{d}^2\sigma_i(pp \to H_q X)}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y} = \frac{1}{\Delta p_\mathrm{T} \Delta y} \cdot \frac{N_i(H_q \to f + \text{c.c.})}{\varepsilon_{i,\mathrm{tot}}(H_q \to f)\mathcal{B}(H_q \to f)\mathcal{L}_\mathrm{int.}}$$

Cross-section measurements

$$\frac{\mathrm{d}^2\sigma_i(pp \to H_q X)}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y} = \frac{1}{\Delta p_\mathrm{T} \Delta y} \cdot \frac{N_i(H_q \to f + \mathrm{c.c.})}{\varepsilon_{i,\mathrm{tot}}(H_q \to f)\mathcal{B}(H_q \to f)\mathcal{L}_{\mathrm{int.}}}$$

1. J/ψ directly from pp interaction;
2. J/ψ from b decays;

$$\sigma(pp \to b\overline{b}) = \alpha_{4\pi} \frac{\sigma(J/\psi \text{ from } b)}{(2\mathcal{B}(b \to J/\psi X))};$$

3. D^0, D^+, D_s^+, and D^{*+} directly from pp interaction;
4. $B^0_{(s)}$, B^+, and Λ_b^0, with $H_b \to H_c \mu X$;

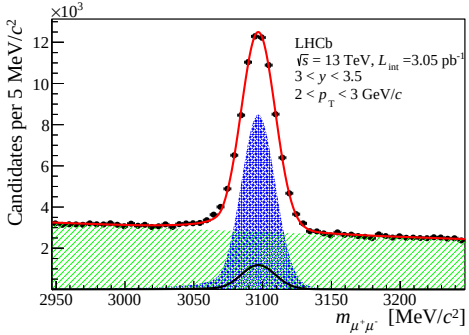
Related measurements

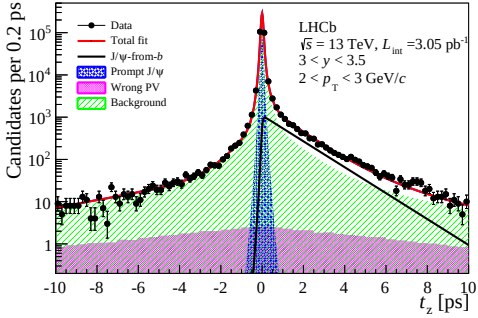
- Ratios between open charm hadrons, e.g. $\sigma(D^0)/\sigma(D^+)$
- Ratios between measurements at different $\sqrt{s}$
- Integrated over p_{T}, y, or both
- Total $c\overline{c}$ cross-section using $f(c \to H_c)$
- Total $b\overline{b}$ cross-section using semileptonic decays

J/ψ production

JHEP10(2015)172, JHEP05(2017)063

- Data collected in July 2015, around $3\,\text{pb}^{-1}$





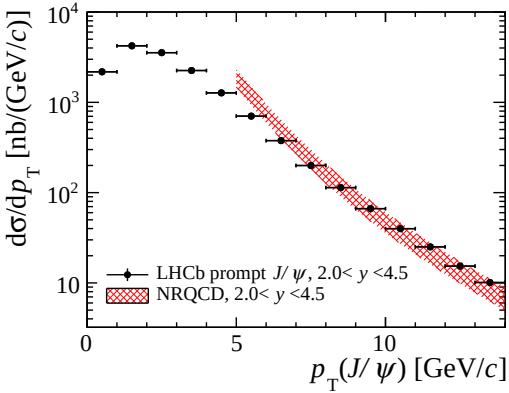
- Count signal by fitting the final state invariant mass distribution
- Separate J/ψ from pp and J/ψ from b using pseudo-proper time

$$t_z = \frac{(z_{J/\psi} - z_{\text{PV}}) \cdot M_{J/\psi}}{p_z}$$

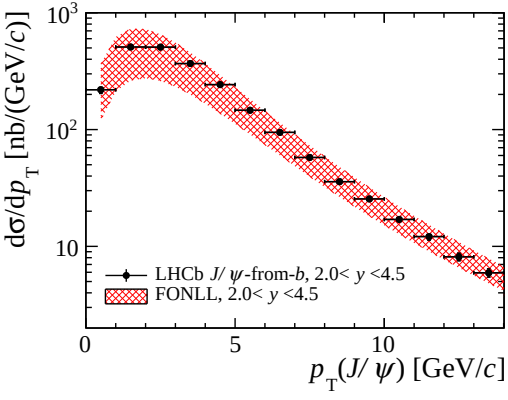
J/ψ production

JHEP10(2015)172, JHEP05(2017)063

Theory comparison for prompt



Theory comparison for J/ψ-from-b



J/ψ cross-section in LHCb acceptance

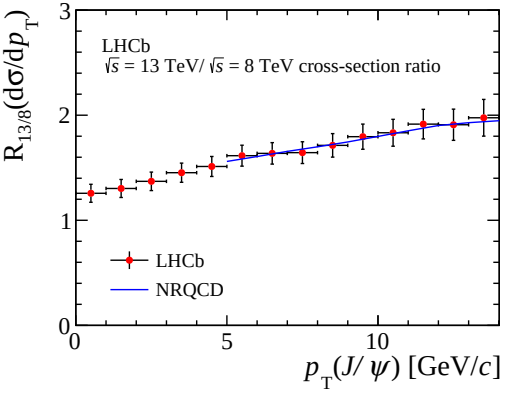
$\sigma_{\text{Prompt}} = 15.30 \pm 0.03(\text{stat}) \pm 0.86(\text{syst})\ \mu\text{b}$
$\sigma_{\text{from-}b} = 2.34 \pm 0.01(\text{stat}) \pm 0.13(\text{syst})\ \mu\text{b}$

$b\bar{b}$ cross-section with 4π extrapolation

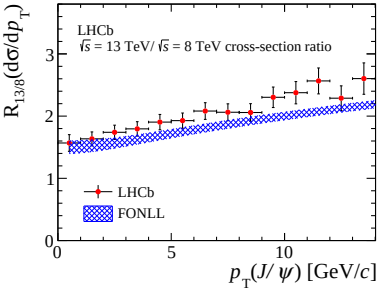
$\sigma = 515 \pm 2(\text{stat}) \pm 53(\text{syst})\ \mu\text{b}$

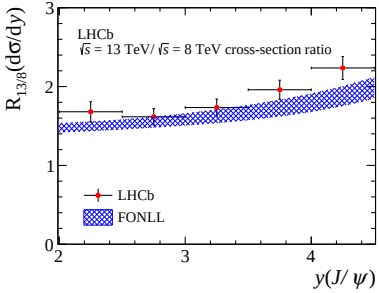
JHEP10(2015)172, JHEP05(2017)063

Theory comparison for prompt



Theory comparison for J/ψ-from-b

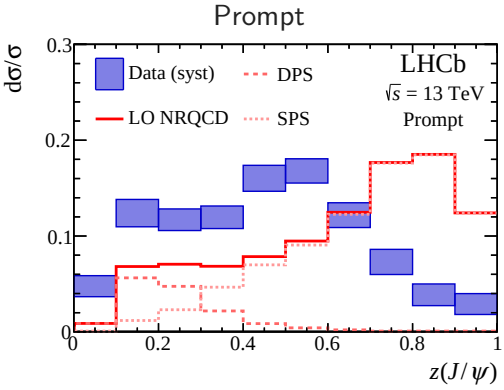


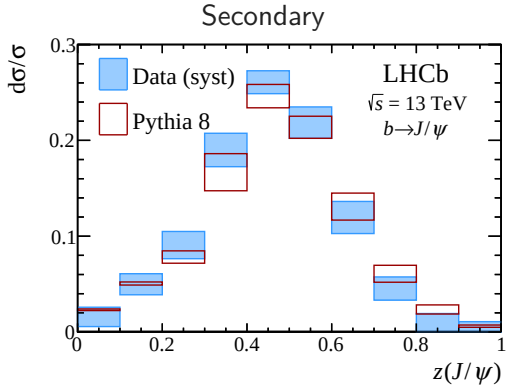


J/ψ production in jets

PhysRevLett.118.192001

- New data processing for Run 2, Turbo, allowed us to save J/ψ + reconstructed event directly out of HLT2
- With 2016 data, use special trigger line to reconstruct dimuons down to $p_T = 1\,\text{GeV}$ with no PV separation requirement
- Build anti-k_T jets, measure fraction z of jet momentum carried by J/ψ

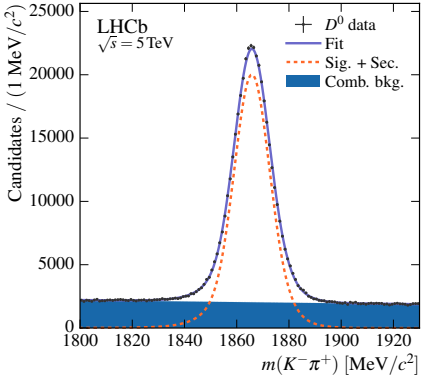


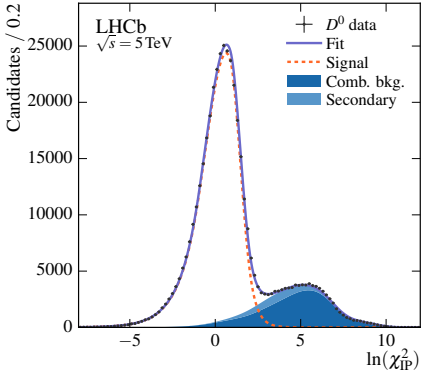


Open charm production

JHEP03(2016)159, JHEP05(2017)074, JHEP06(2017)147

- Data at $\sqrt{s} = 13\,\text{TeV}$ collected July 2015, around $3\,\text{pb}^{-1}$
- At $\sqrt{s} = 5\,\text{TeV}$, collected November 2015, around $9\,\text{pb}^{-1}$ (shown here)

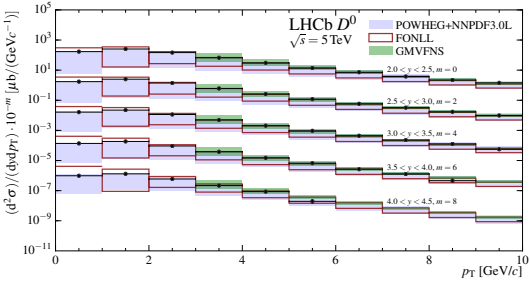


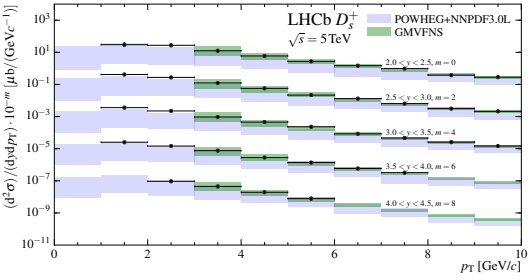


- Count signal by fitting the final state invariant mass distribution
- Separate H_c from pp and H_c from b using impact parameter significance χ^2_{IP}

Open charm production

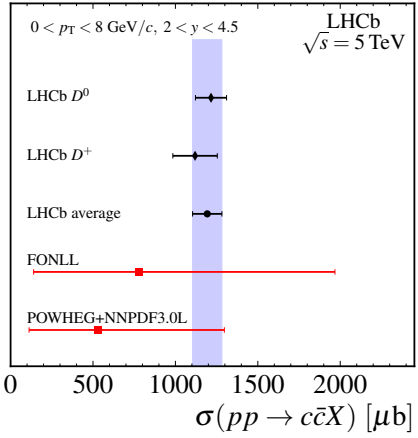
JHEP06(2017)147

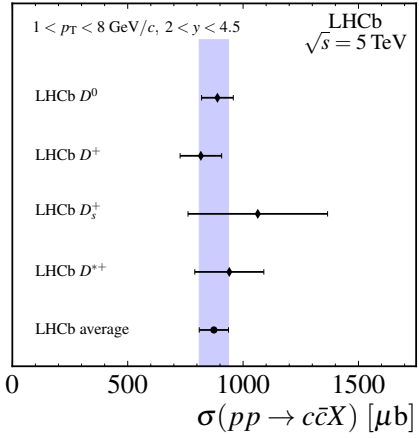




Open charm production

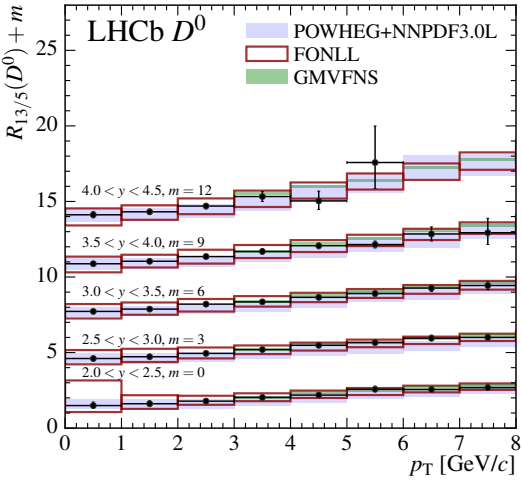
JHEP06(2017)147

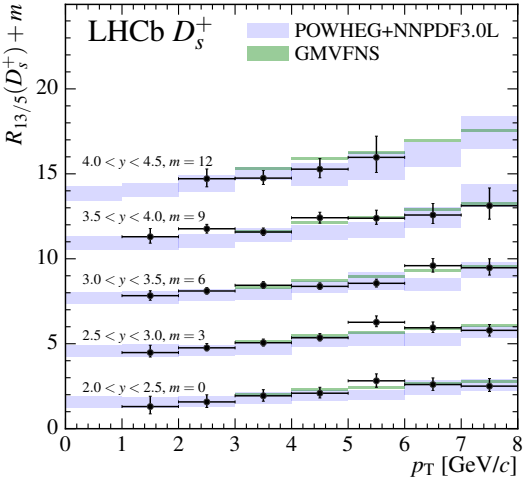




Open charm production

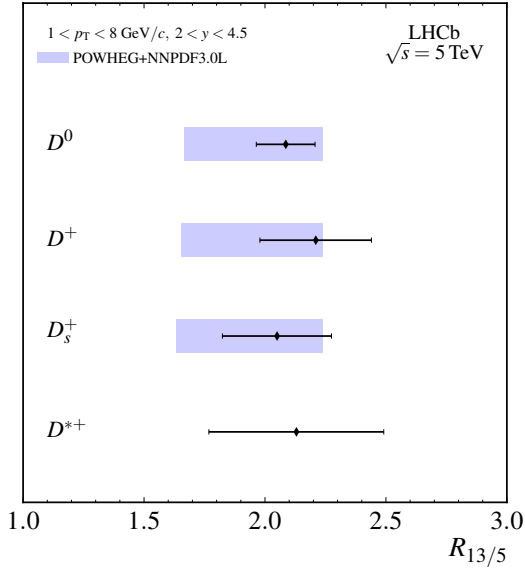
JHEP03(2016)159, JHEP05(2017)074, JHEP06(2017)147





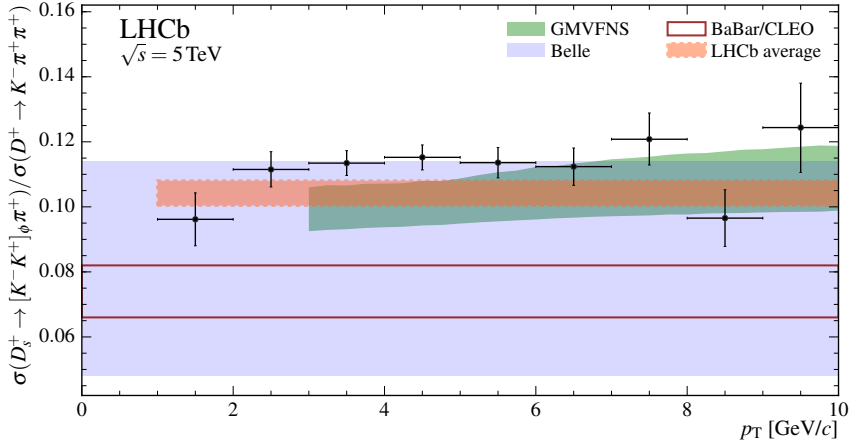
Open charm production

JHEP03(2016)159, JHEP05(2017)074, JHEP06(2017)147



Open charm production

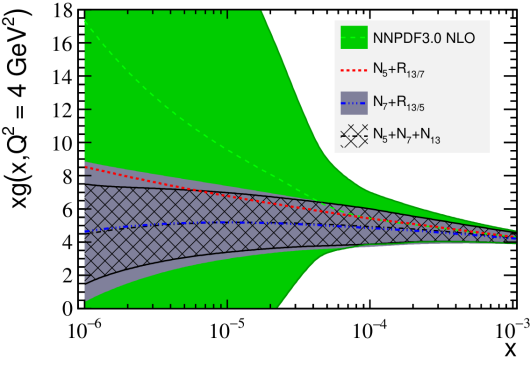
JHEP06(2017)147

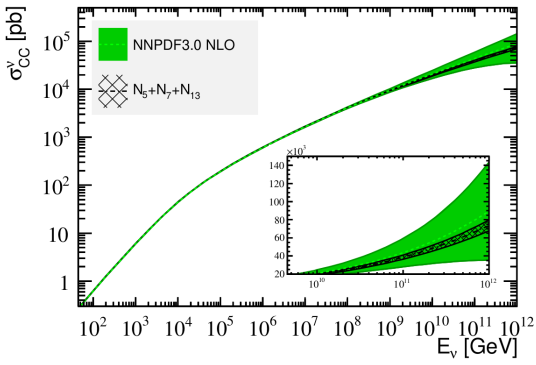


- Test fragmentation fraction invariance to production mechanism and kinematics

Using open charm results

PhysRevLett.118.072001





- Constrains gluon PDFs at low x
- PDFs used as inputs to atmospheric neutrino experiments

Open beauty production

PhysRevLett.118.052002, erratum submitted

- Idea: measure b-quark production 'inclusively' using semileptonic decays.

$$\sigma(pp \to H_b) = \frac{1}{2}[\sigma(B^0) + \sigma(\overline{B}^0)] + \frac{1}{2}[\sigma(B^+) + \sigma(B^-)] + \quad (1)$$

$$\frac{1}{2}[\sigma(B_s^0) + \sigma(\overline{B}_s^0)] + \frac{1+\delta}{2}[\sigma(\Lambda_b^0) + \sigma(\overline{\Lambda}_b^0)] \quad (2)$$

- Correct with missing Ξ_b and Ω_b components using δ, estimated to be 0.25 ± 0.10
- Neglect B_c^+ as predicted to be 0.1 % of b-hadron production
- Exploit the equality and large magnitude $H_b \to H_c \mu\nu$ branching fractions

Open beauty production

PhysRevLett.118.052002, erratum submitted

- Idea: measure b-quark production 'inclusively' using semileptonic decays.

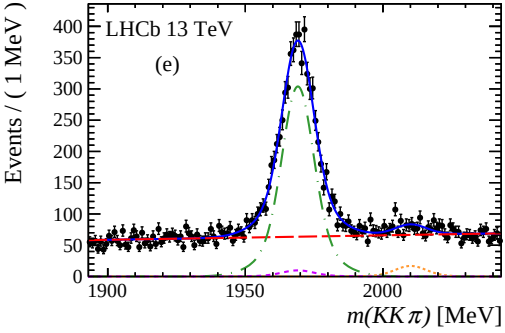
$$\sigma(pp \to H_b) = \frac{1}{2\mathcal{L}} \left\{ \left[\frac{N(D^0\mu)}{\epsilon_{D^0}\mathcal{B}_{D^0}} + \frac{N(D^+\mu)}{\epsilon_{D^+}\mathcal{B}_{D^+}} \right] \frac{1}{\mathcal{B}(B \to DX\mu\nu)} + \left[\frac{N(D^+\mu)}{\epsilon_{D^+}\mathcal{B}_{D^+}} \right] \frac{1}{\mathcal{B}(B_s \to D_s X\mu\nu)} + \left[\frac{N(\Lambda_c^+\mu)}{\epsilon_{\Lambda_c^+}\mathcal{B}_{\Lambda_c^+}} \right] \frac{1+\delta}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ X\mu\nu)} \right\}$$

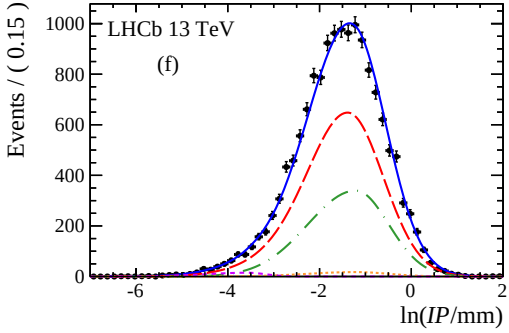
- Reconstruct fully hadronic H_c decays with branching fractions $\mathcal{B}_{H_c}$
- Measure $H_c + \mu$ event efficiency as ϵ_{H_c}
- Neglect cross-feed, such as $\Lambda_b^0 \to DN\mu^- X$, due to lack of sensitivity to these backgrounds

Open beauty production

PhysRevLett.118.052002, erratum submitted

- Use $300\,\text{pb}^{-1}$ at $\sqrt{s} = 7\,\text{TeV}$ and $4.6\,\text{pb}^{-1}$ at $13\,\text{TeV}$

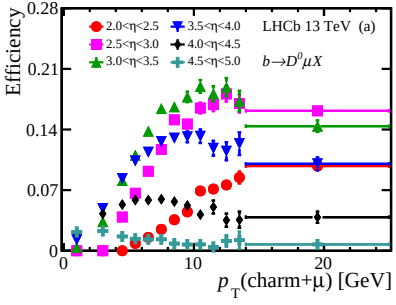




- Count signal by fitting the H_c final state invariant mass distribution
- Separate H_c from b from H_c directly from pp using impact parameter
- Measure pseudorapidity η using difference between $H_c\mu$ vertex and PV

Open beauty production

PhysRevLett.118.052002, erratum submitted



- Most efficiencies derived using data:
  - Trigger and muon ID using calibration samples of $b \to J/\psi X$ decays
  - Hadronic PID using $\Lambda \to p\pi^-$ and D^{*+}-tagged $D^0 \to K^-\pi^+$ decays
  - Data-MC differences in tracking efficiencies evaluated using $J/\psi \to \mu^-\mu^+$
- Correct for missing low-p_T regions, due to very small efficiencies, using MC

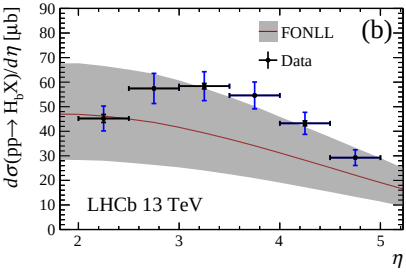
Open beauty production

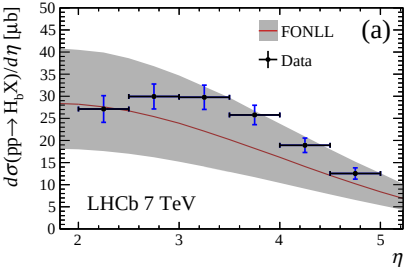
PhysRevLett.118.052002, erratum submitted

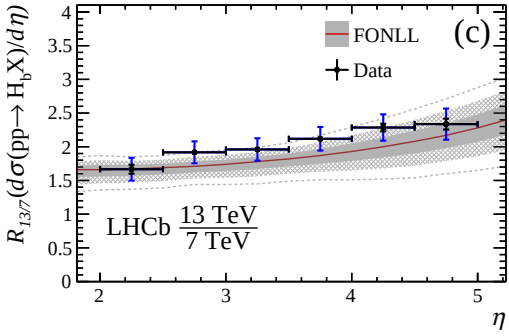
Source	7 TeV	13 TeV	Ratio 13/7
Luminosity	1.7 %	3.9 %	3.8 %
Tracking efficiency	3.8 %	4.3 %	2.5 %
b semileptonic $\mathcal{B}$	2.1 %	2.1 %	0
Charm hadron $\mathcal{B}$	2.6 %	2.6 %	0
b decay cocktail	1.0 %	1.0 %	0
Ignoring b cross-feeds	1.0 %	1.0 %	0
Background	0.2 %	0.3 %	0
$b \to u$ decays	0.3 %	0.3 %	0
δ	2.0 %	2.0 %	0.2 %
Total	5.9 %	7.1 %	4.6 %

Open beauty production

PhysRevLett.118.052002, erratum submitted



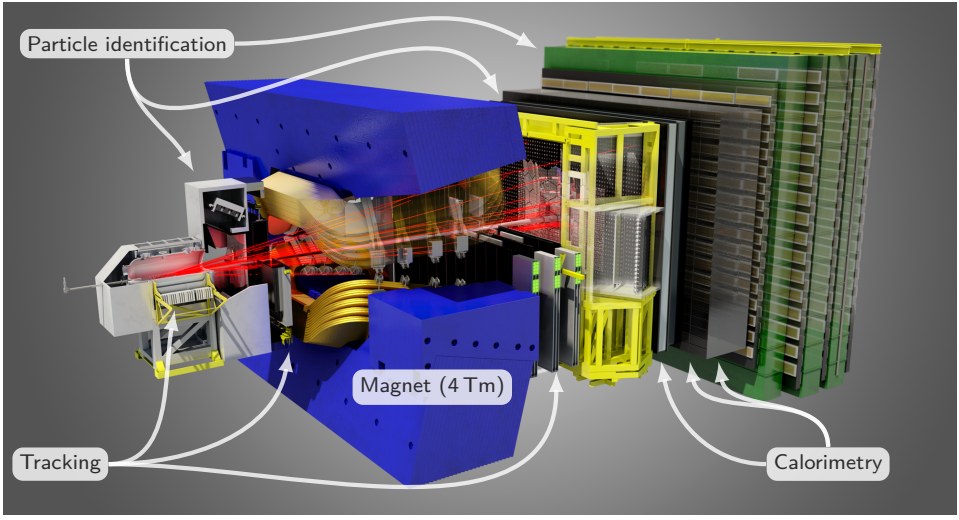




Summary

- LHCb has measured J/ψ, H_c, and H_b production cross-sections at $\sqrt{s} = 13\,\text{TeV}$
- Latest results are published, with H_b measurement pending
- Always looking to help improve understanding of parton distribution functions through our results

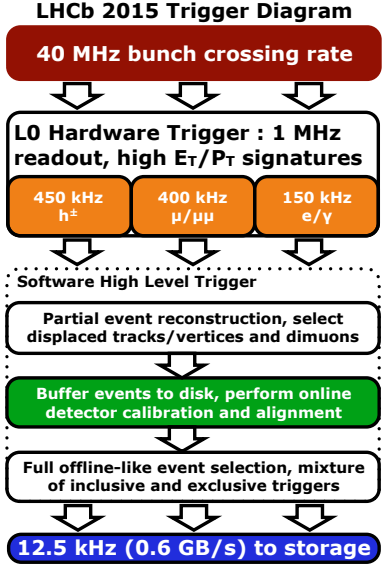
Detector



VELO	Primary and secondary vertex, impact parameter
TT, IT, OT	Momentum of charged particles
RICHs	$K^{\pm}$, $\pi^{\pm}$, and $p/\overline{p}$ PID
MUON	Trigger on high p_{T} $\mu^{\pm}$, add PID
SPD/PS	Separate $\gamma/e^{\pm}$ and $h^{\pm}/e^{\pm}$
ECAL/HCAL	EM/hadronic energy

Trigger

- Minimum bias at L0 for charm, MUON trigger for J/ψ and $B \to D\mu X$
- Fully reconstruct J/ψ and D in HLT2
- Thanks to offline-quality full event reconstruction...
- ...and an increase in HLT farm resources
- Buffer HLT1 output to a 10 PB disk array, large effective increase in HLT2 processing time
- Allows for publication-level analysis in near-real time



Figure

Errata

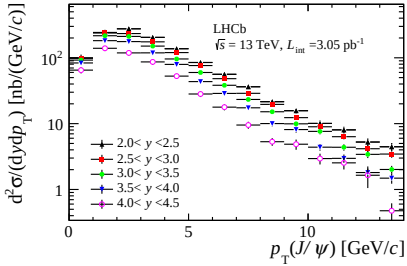
The charge collected in the LHCb VELO sensors is affected by radiation damage. One such effect, which is more pronounced in the outer regions of downstream sensors, arises from charge induction on second metal layer routing lines[3]. Prior to the start of Run 2, modifications were made to the digitization step in the LHCb simulation framework to model this effect. An error was made in the parametric implementation resulting in a reduction of the track reconstruction efficiency in simulation compared to data for tracks with low pseudorapidity. The tracking efficiency calibration procedure that was applied to the data and simulation[4] was unable to correct the mismodelling.

[3] LHCb-DP-2012-005
[4] LHCb-DP-2013-002

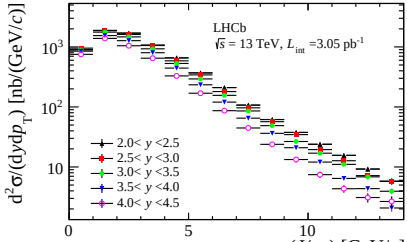
J/ψ production

JHEP10(2015)172, JHEP05(2017)063

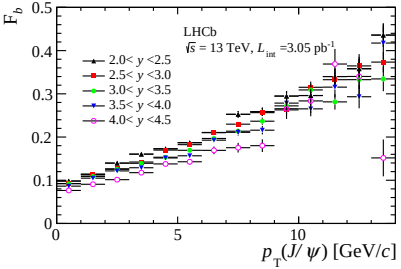
J/ψ from b-decays

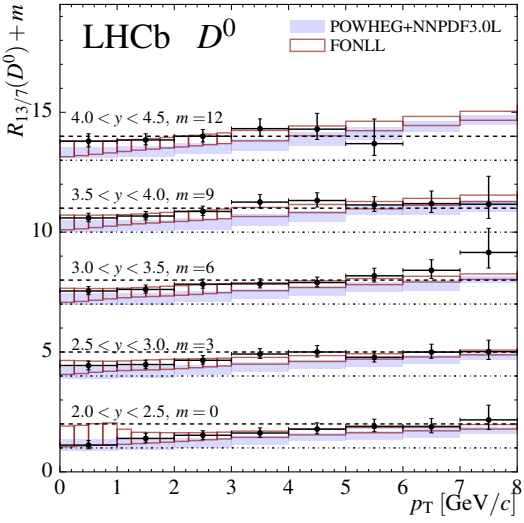
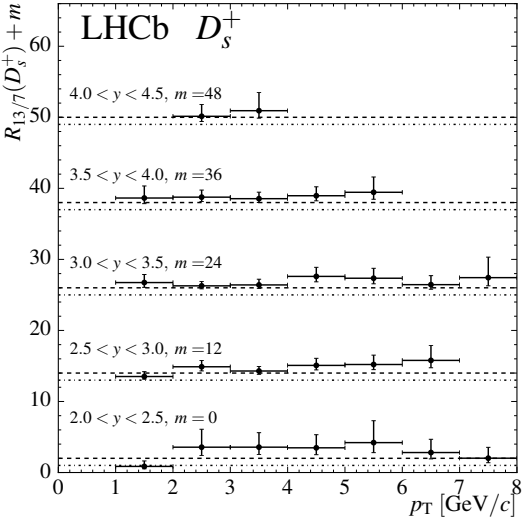


Prompt J/ψ



J/ψ-from-b production fraction



Open charm production

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