Inclusive measurements of beauty production by ATLAS

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on behalf of the ATLAS Collaboration

ICHEP2012 - Melbourne

Motivation

- Predicting the production rate of heavy quarks in hadron collisions provides a challenging test of the validity various QCD models
  - *b* production cross section routinely calculated to NLO accuracy and tested against exhaustively at UA1, D0, CDF
  - The LHC provides a higher centre-of-mass energy against which these calculations can be refined and uncertainties reduced
- Production of B-hadrons can form important backgrounds to searches for new physics processes
  - Better understanding of B-hadron production means better modelling of these backgrounds in the simulation

ATLAS inclusive b/c production measurements

Differential non-prompt J/ψ production (April 2011, part of a general paper J/ψ paper)	2.3pb^{-1}	Nucl. Phys. B 850 (2011) 387-444
Electron and muon inclusive cross-sections (September 2011)	1.4pb^{-1}	Phys.Lett. B707 (2012) 438-458
Inclusive and dijet cross-sections of b-jets (September 2011)	34pb^{-1}	Eur.Phys.J.C 71 (2011) 1846
$D^{*\pm}$ meson production in jets (December 2011)	0.3pb^{-1}	Phys. Rev. D85 (2012) 052005
b-hadron production cross section using decays to $D^{*}\mu X$ final states (June 2012; based on 2010 data)	3.3pb^{-1}	arXiv:1206.3122 Submitted to Nucl. Phys. B

Luminosity after trigger pre-scales (total 2010 dataset ~40pb^{-1})

$D^*\mu X$ analysis strategy

Aim: differential cross section for open beauty production from pp collisions

$$\frac{d\sigma}{dp_T\left(H_b\right)}\left(pp \to b(\bar{b}) \to H_b\right)$$

$$\frac{d\sigma}{d\eta\left(H_b\right)}\left(pp \to b(\bar{b}) \to H_b\right)$$

- Access the B-hadrons via their semi-leptonic decays of the form

$$H_b \to D^{*\pm}\mu^{\mp}X\ ;\ D^{*\pm} \to D^0\pi^{\pm}\ ;\ D^0 \to \pi^{\pm}K^{\mp}$$

- Inclusive branching ratio (2.75±0.19)%
  - Main source: $B^0 \to D^{*-}\mu^+\nu_\mu$ + c.c.
- Muon acts as a trigger and the D-decays can be fully reconstructed with the tracking detector
  - Allows us to tag the B-production

$D^* \mu X$ analysis strategy

This is what we measure:

Fraction from B-decays (from MC)

Total reconstructed $D^* \mu$

$$\frac{d\sigma}{dp_T\left(D^*\mu\right)}\left(pp \to H_b X \to D^{*+}\mu^- X'\right) = \frac{\boxed{f_b}\boxed{N^{D^{*\pm}\mu^\mp}}}{\boxed{2}\boxed{\epsilon}\boxed{\mathscr{B}}\boxed{\mathscr{L}}\boxed{\Delta p_T}}$$

Accounts for charge conjugate

Reconstruction/ trigger/selection efficiency

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

Integrated luminosity

Bin width

Unfolding $\longrightarrow$ $$\frac{d\sigma}{dp_T\left(H_b\right)}\left(pp \to H_b X \to D^{*+}\mu^- X'\right)$$

Acceptance corrections × BR($H_b \to D^{*+}\mu X$) $\longrightarrow$ $$\frac{d\sigma}{dp_T\left(H_b\right)}\left(pp \to H_b X\right)$$

$D^*\mu X$ analysis strategy

1. Trigger on events containing μ

2. Reconstruct $B \to D^*\mu$ decays

3. Divide into p_T and $|\eta|$ bins; extract yield via a fit to the mass distribution

4. Correct for trigger, reconstruction and selection efficiency

Efficiencies from data and PYTHIA MC

5. $\sigma(pp \to H_b \to D^*\mu X)$ as function of $D^*\mu$ p_T, η

6. Unfold to correct for the 'X' particles

6. $\sigma(pp \to H_b \to D^*\mu)$ as function of H_b p_T, η

8. Acceptance/branching correction

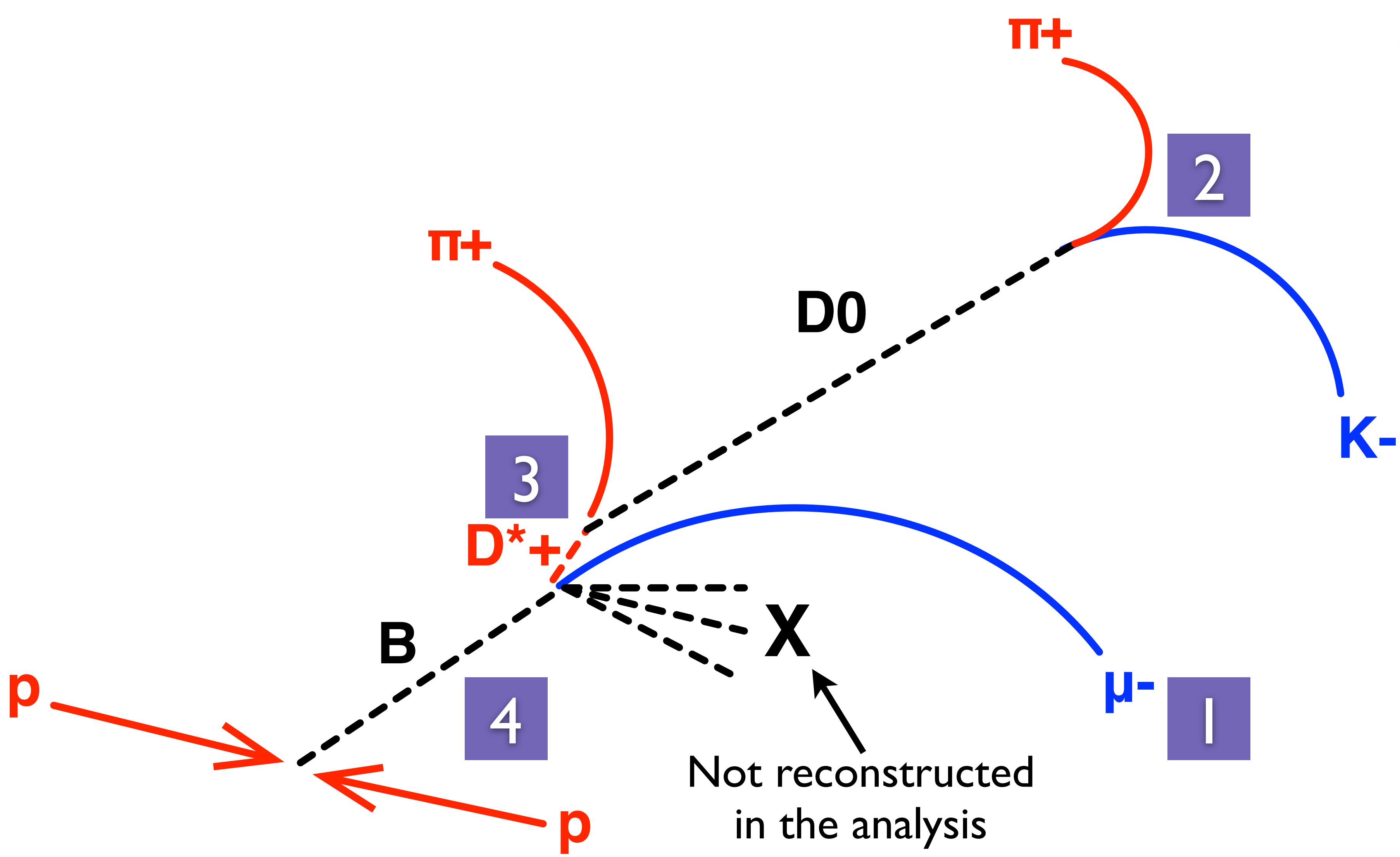
9. Inclusive $\sigma(pp \to H_b X)$

10. Total $\sigma(pp \to H_b)$

Unfolding, acceptance and extrapolation via NLO MC:
- POWHEG+PYTHIA baseline
- POWHEG+HERWIG / MC@NLO+HERWIG for cross-checks

Decay topology and reconstruction

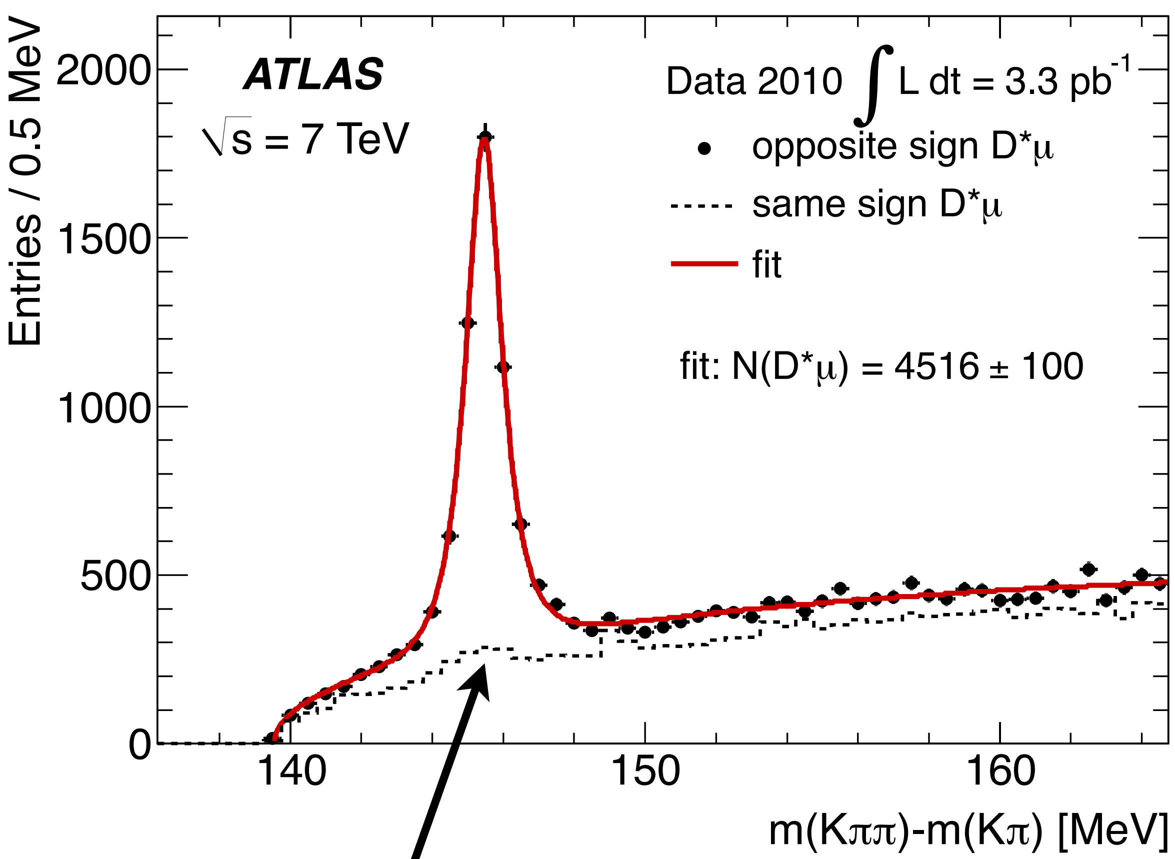
For illustration only; cτs and kinematics not represented accurately
Charge conjugates always implied



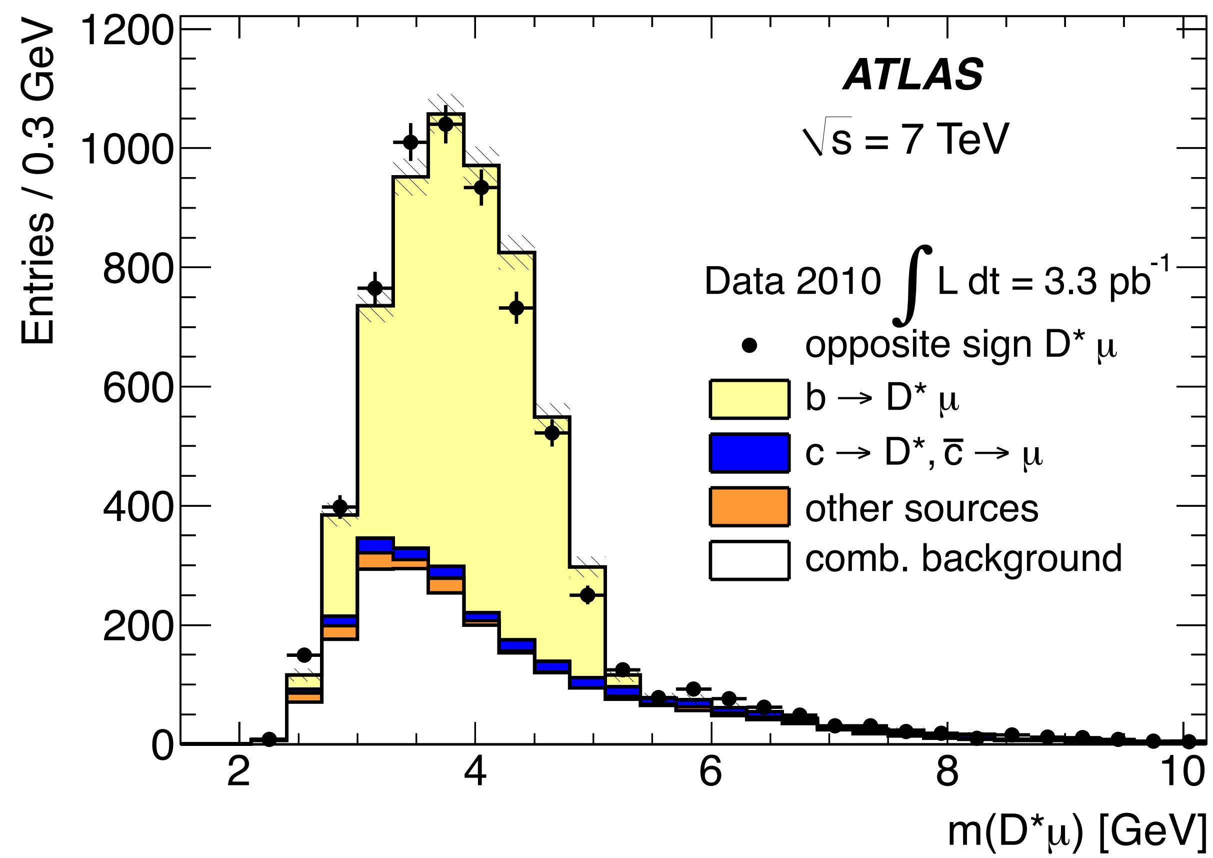
1	Select events using a single **muon trigger p_T>6GeV** Require matched offline muon p_T>6GeV, $\lvert\eta\rvert$<2.4
2	In accepted events seek oppositely charged track pairs with pT>1GeV; fit to common vertex to form D^0 candidate
3	Combine D^0 candidate with a track of opposite charge to the kaon candidate track, with p_T>250MeV, to form the D^{*+} candidate. D^{*+} p_T > 4.5 GeV D^{*+} $\lvert\eta\rvert$ < 2.5 For D^{*+} p_T > 4.5 GeV and $\lvert\eta\rvert$ >1.3: $\lvert m(K\pi)-m(D^0)\rvert$ < 64 MeV Otherwise: $\lvert m(K\pi)-m(D^0)\rvert$ < 40 MeV
4	Simultaneously fit the D^0 vertex and the B-vertex (the triggered muon track and the pion) 2.5 GeV < $m(D^*\mu)$ < 5.4 GeV

Reconstructed candidates

D*



D*μ



Due to real B→D*X plus the other B decaying semi-leptonically, giving a "wrong" sign muon

Sources of the D*μ sample from MC (excluding combinatorial):

- Signal $B\rightarrow D^{*}\mu$; $D^{*}\rightarrow D^{0}(\pi K)\pi$: **93.2±0.3 %**
- Two c-hadrons, one decaying to μνX : **3.8±0.2 %**
- $B\rightarrow D^{*}\tau X$; $\tau\rightarrow\mu X'$: **1.5±0.1%**
- $B\rightarrow D^{*}DX$; $D\rightarrow\mu X'$: **0.9±0.1 %**
- Real D^{*} + other B decays to μνX
- Real D^{*} + fake muon
- Others

} **0.6±0.1%**

Trigger and reconstruction efficiency corrections

$$\epsilon = \boxed{\epsilon_{\text{reco}}(\text{MC})}\boxed{\epsilon_{\text{trigger}}(\text{data})}\boxed{\epsilon_{\text{selection}}(\text{MC})}$$

(31.3±0.4)% (48.3±0.4)% (81.9±0.4)% (79.1±0.5)%

$$\epsilon_{\text{reco}} = \frac{N(\text{true } D^{*\pm}\mu^{\mp} \text{ with } \mu \text{ and tracks reconstructed})}{N(\text{true } D^{*\pm}\mu^{\mp})}$$

Evaluated with simulated inclusive b-bbar MC

$$\epsilon_{\text{trigger}} = \frac{N(\text{true } D^{*\pm}\mu^{\mp} \text{ with } \mu \text{ and tracks reconstructed, } \mu \text{ matched to trigger})}{N(\text{true } D^{*\pm}\mu^{\mp} \text{ with } \mu \text{ and tracks reconstructed})}$$

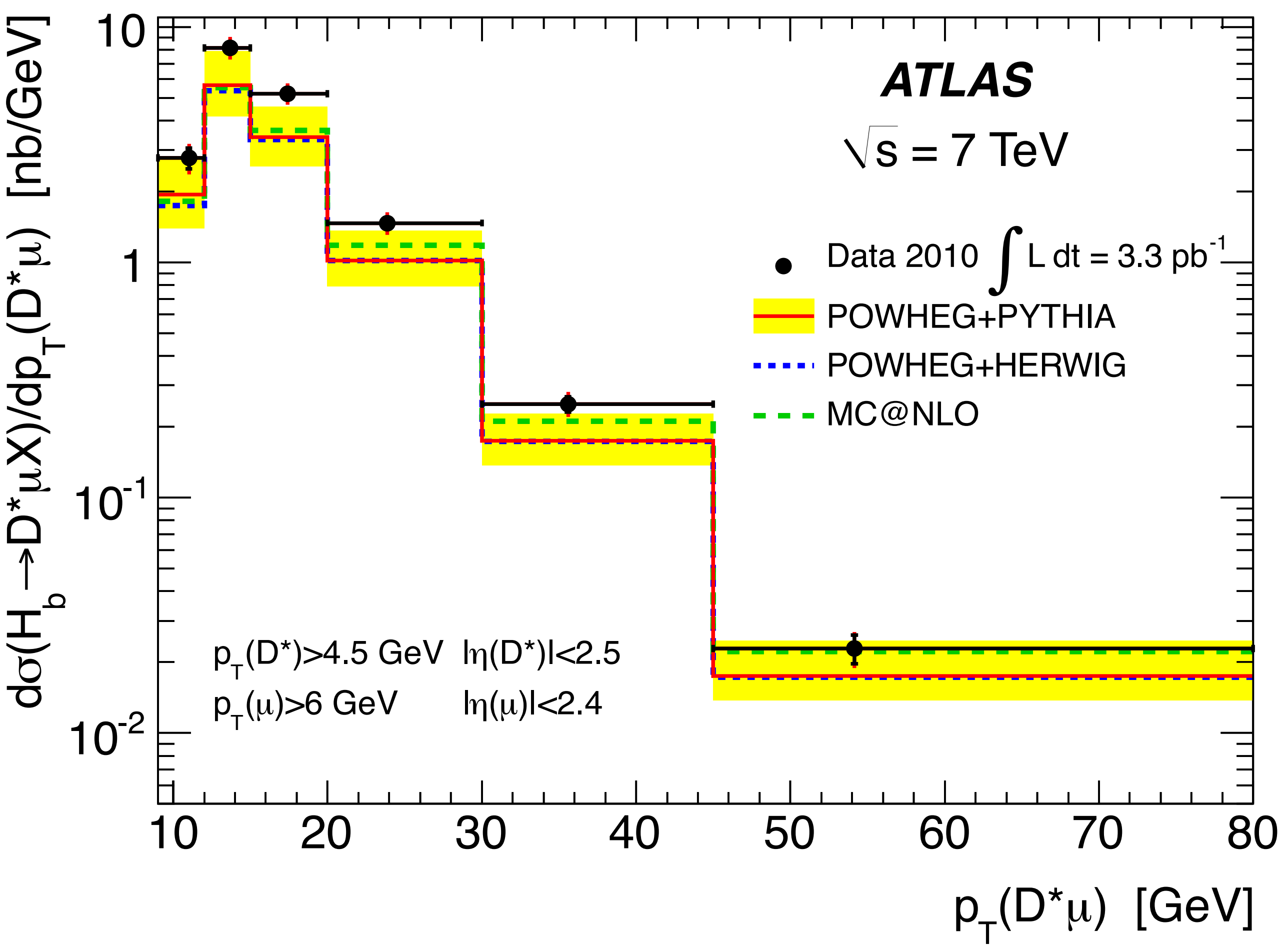
Evaluated with a tag-and-probe method using J/ψ→μμ decays found in the same data-taking period, with the same trigger

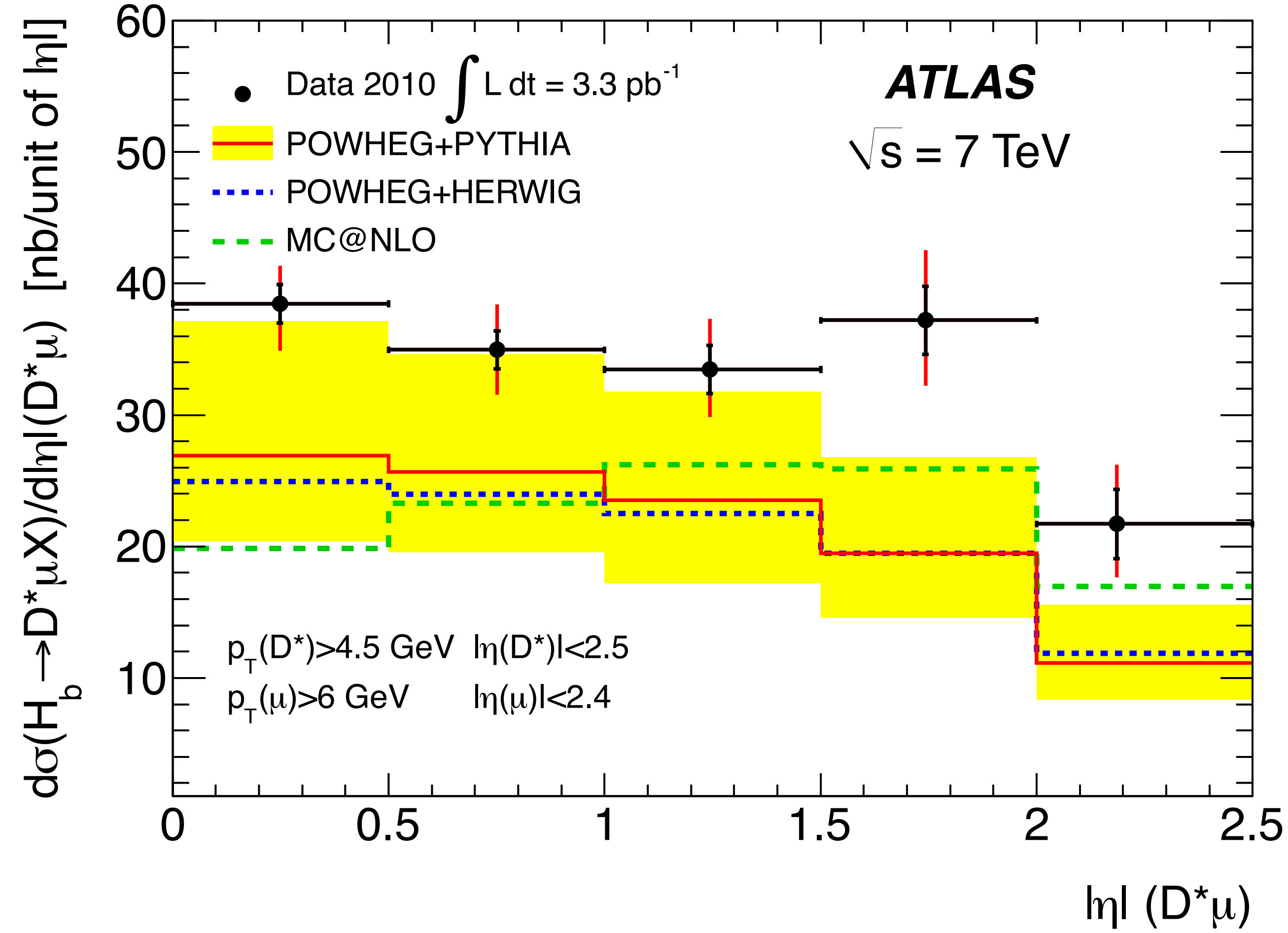
$$\epsilon_{\text{selection}} = \frac{N(\text{true } D^{*\pm}\mu^{\mp} \text{ with } \mu \text{ and tracks rec., } \mu \text{ matched to trigger, } D^{*\pm}\mu^{\mp} \text{ selection})}{N(\text{true } D^{*\pm}\mu^{\mp} \text{ with } \mu \text{ and tracks rec., } \mu \text{ matched to trigger})}$$

Evaluated with simulated inclusive b-bbar MC

Measured $\sigma(pp \to H_b X \to D^* \mu X')$

$p_T(D^*\mu)>4.5$ GeV; $|\eta|(D^*\mu)<2.5$
$p_T(\mu)>6$GeV; $\eta|(\mu)<2.4$



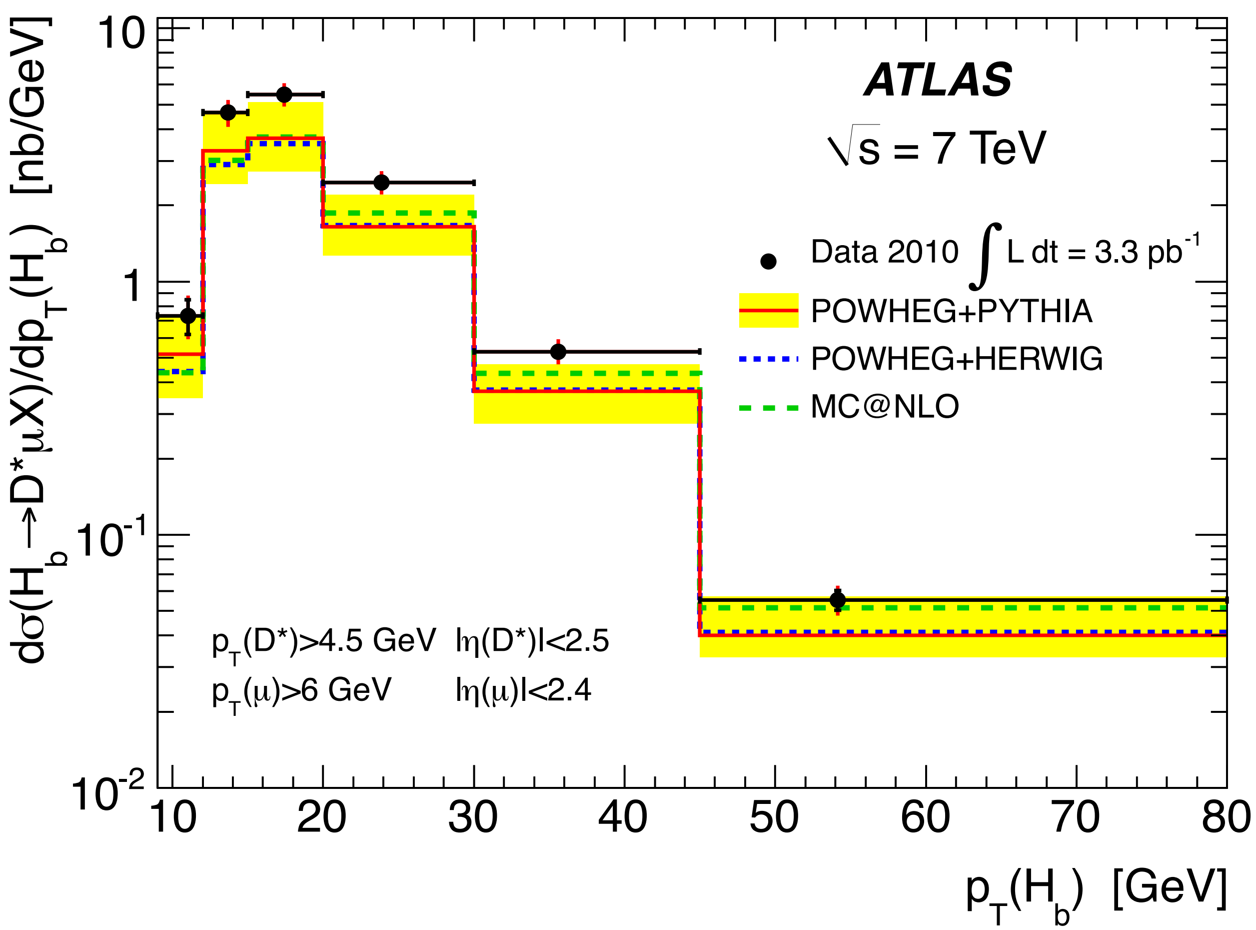


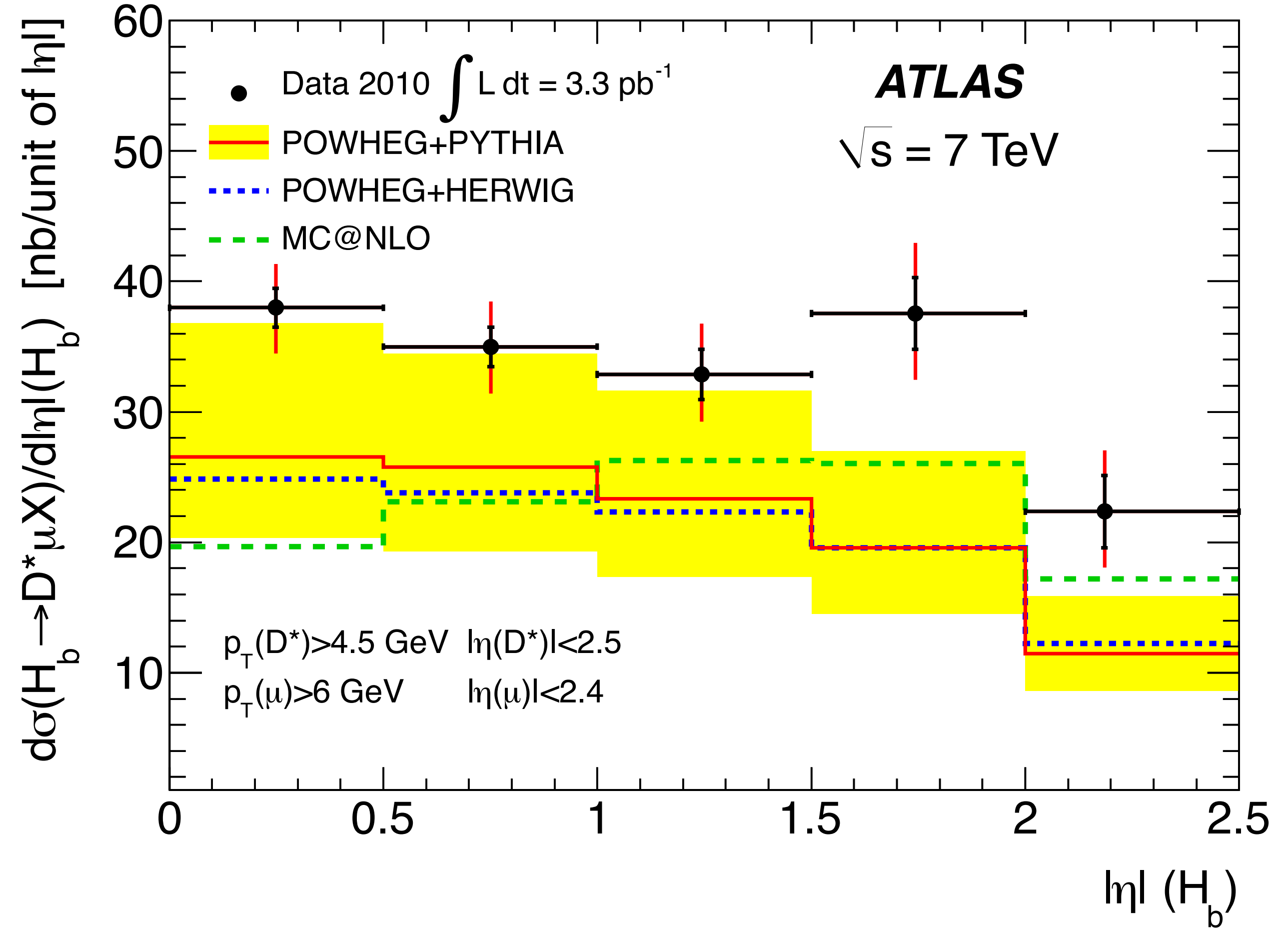
Not yet unfolded to correct for the particles not included in the analysis ('X') so still a function of $D^*\mu$ p_T, η

Unfolded $\sigma(pp\to H_bX\to D^*\mu X')$

$p_T(D^*\mu)>4.5$ GeV; $|\eta|(D^*\mu)<2.5$
$p_T(\mu)>6$GeV; $\eta|(\mu)<2.4$

NLO QCD predictions seem to underestimate the cross section but theoretical uncertainties cover the difference (just)





Unfolded $\sigma(pp\to H_bX\to D^*\mu X') =$ **78.7** $\pm$ 2.0(stat) $\pm$ 7.3(syst) $\pm$ 1.2 (Br) $\pm$ 2.7 (Lumi) nb

POWHEG+PYTHIA $\sigma(pp\to H_bX\to D^*\mu X') =$ $\mathbf{53}^{+18}_{-12}$(scale) $\pm$ 3(m_b) $\pm$ 3(PDF)$^{+6}_{-5}$(hadr.) nb

Extraction of σ(pp→H_bX)

- Ingredients
  - Branching fraction Br(H_b→D^*μ)
  - Identification of the B-hadron kinematic region selected by the D^* and μ cuts
    - Only H_b with $p_T(H_b)$ > 9GeV and |η| < 2.5 can pass the cuts
  - Decay acceptance α (evaluated with POWEG+PYTHIA NLO)

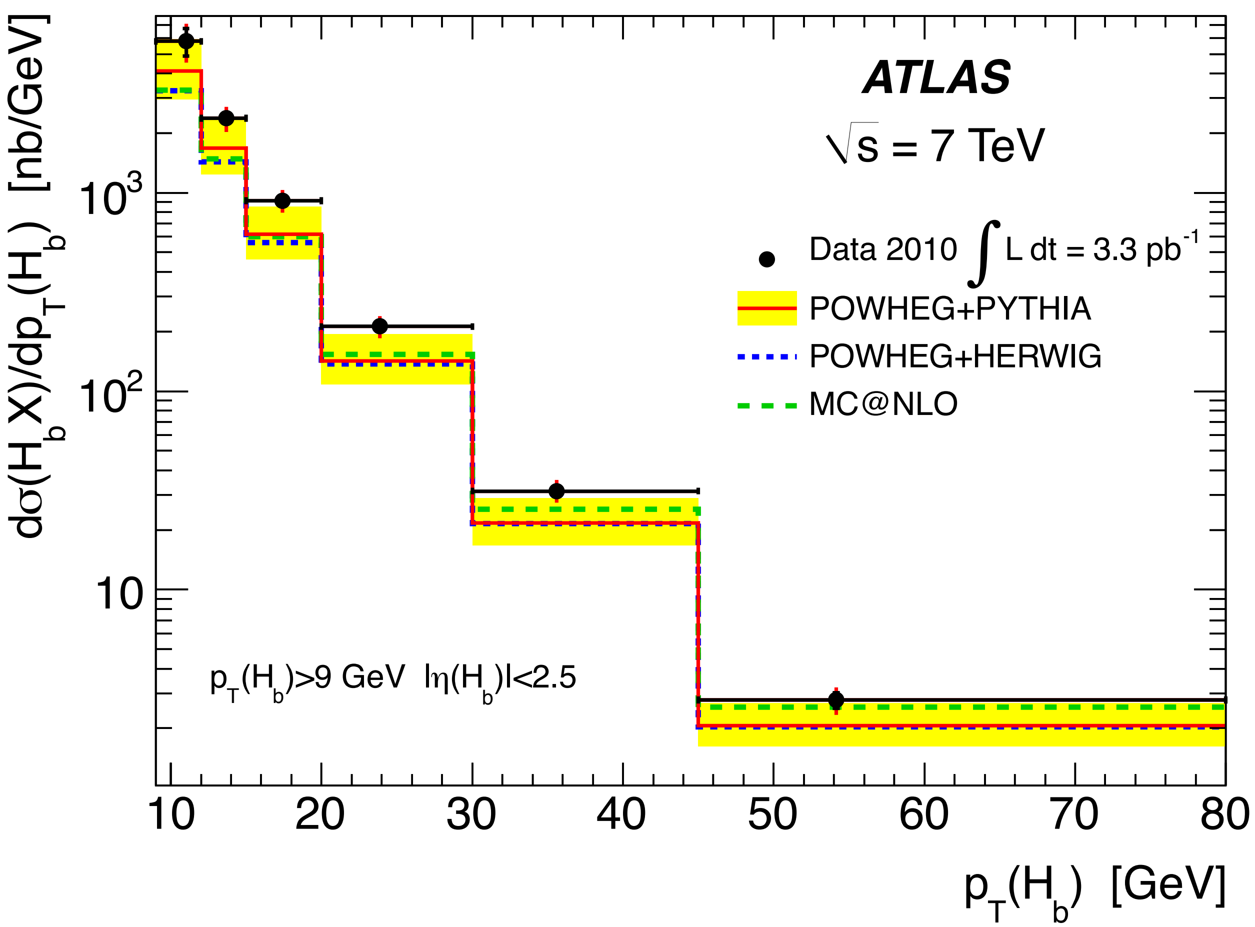
$$\alpha = \frac{\text{number of } H_b(\to D^{*\pm}\mu^{\mp}) \text{ passing the } D^* \text{ and } \mu \text{ kinematic cuts}}{\text{number of } H_b(\to D^{*\pm}\mu^{\mp}) \text{ passing the } H_b \text{ kinematic cuts}}$$

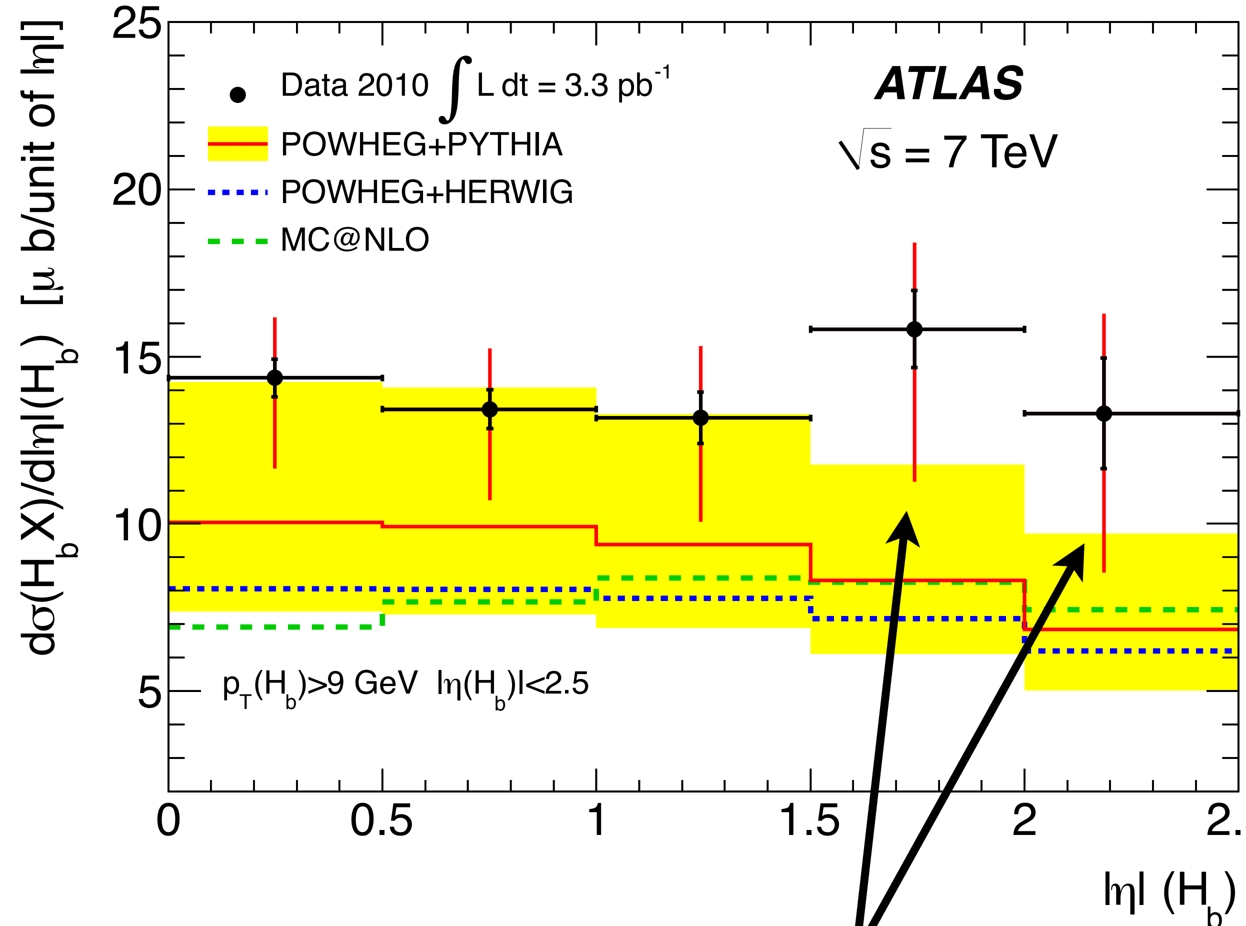
  - Then:

$$\frac{\mathrm{d}\sigma(H_b\,X)}{\mathrm{d}p_{\mathrm{T}}(\eta)} = \frac{1}{\alpha_{p_{\mathrm{T}}(\eta)}\mathscr{B}(b \to D^{*+}\mu^- X)} \frac{\mathrm{d}\sigma(pp \to H_b\,X \to D^{*+}\mu^- X')}{\mathrm{d}p_{\mathrm{T}}(\eta)}$$

$\sigma(pp \to H_b X)$

$p_T(H_B)>9$ GeV; $|\eta|(H_B)<2.5$





Systematics are much bigger here due to uncertainties in the theoretical prediction used for the acceptance (α)

Note that α is p_T and η dependent so the shapes are not the same as for $pp \to H_b \to D^* \mu$
Again the NLO QCD predictions seem to underestimate the cross section but are still just within theoretical uncertainties

Integrated $\sigma(pp \to H_B X)$ = **32.7** ± 0.8(stat) ± 3.1(syst) $^{+2.1}_{-5.6}$ (α) ± 2.3 (Br) ± 1.1 (Lumi) nb

Sources of systematic uncertainty

- Yields from the mass distribution fits (~1-3%)
- Data-driven trigger efficiency (~1-2%)
- Luminosity uncertainty (3.4%)
- Reconstruction/selection efficiency (~10-15%)
- Data/MC differences (~1-2%)
- Branching fractions and fb (~1-2%)
- NLO uncertainties feeding into unfolding$\oplus$acceptance (~1-30%)

Note that many systematics are heavily pT and η dependent

Comparison with LHCb and conclusions

- Extrapolating to the full phase space including regions outside of the ATLAS acceptance (using NLO MC):

Extrapolated $\sigma(pp \to H_b X)$ = **360** ± 9(stat) ± 34(syst) ± 25(Br) ± 12(Lumi) $^{+77}_{-69}$ (extrap⊕accpt) nb

- This allows a comparison directly with an LHCb measurement of inclusive open-beauty production which uses $H_b \to D^0 \mu X$ (measured in $2<\eta< 6$):

Extrapolated $\sigma(pp \to H_b X)$ = **284** ± 20(stat) ± 49(syst) nb

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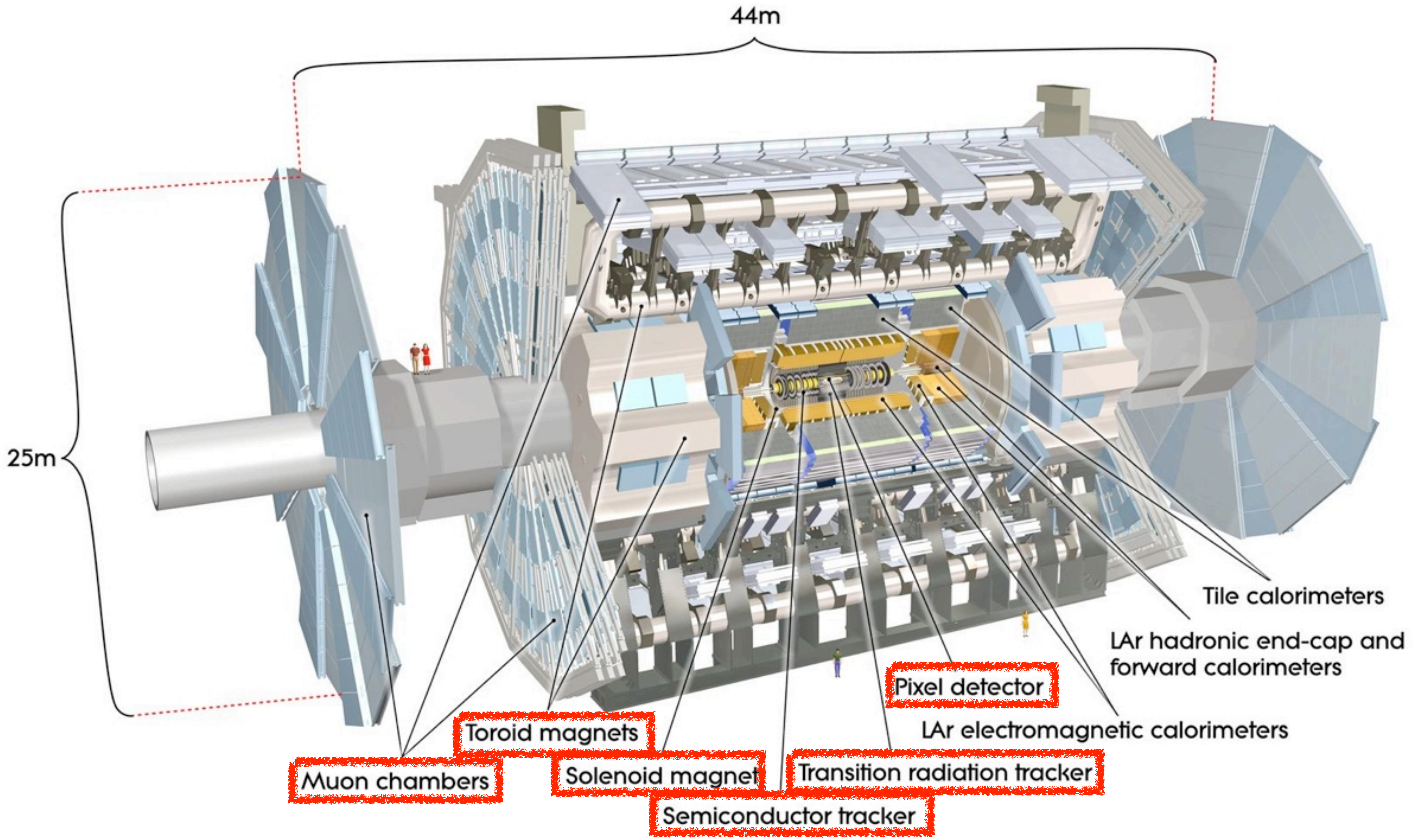
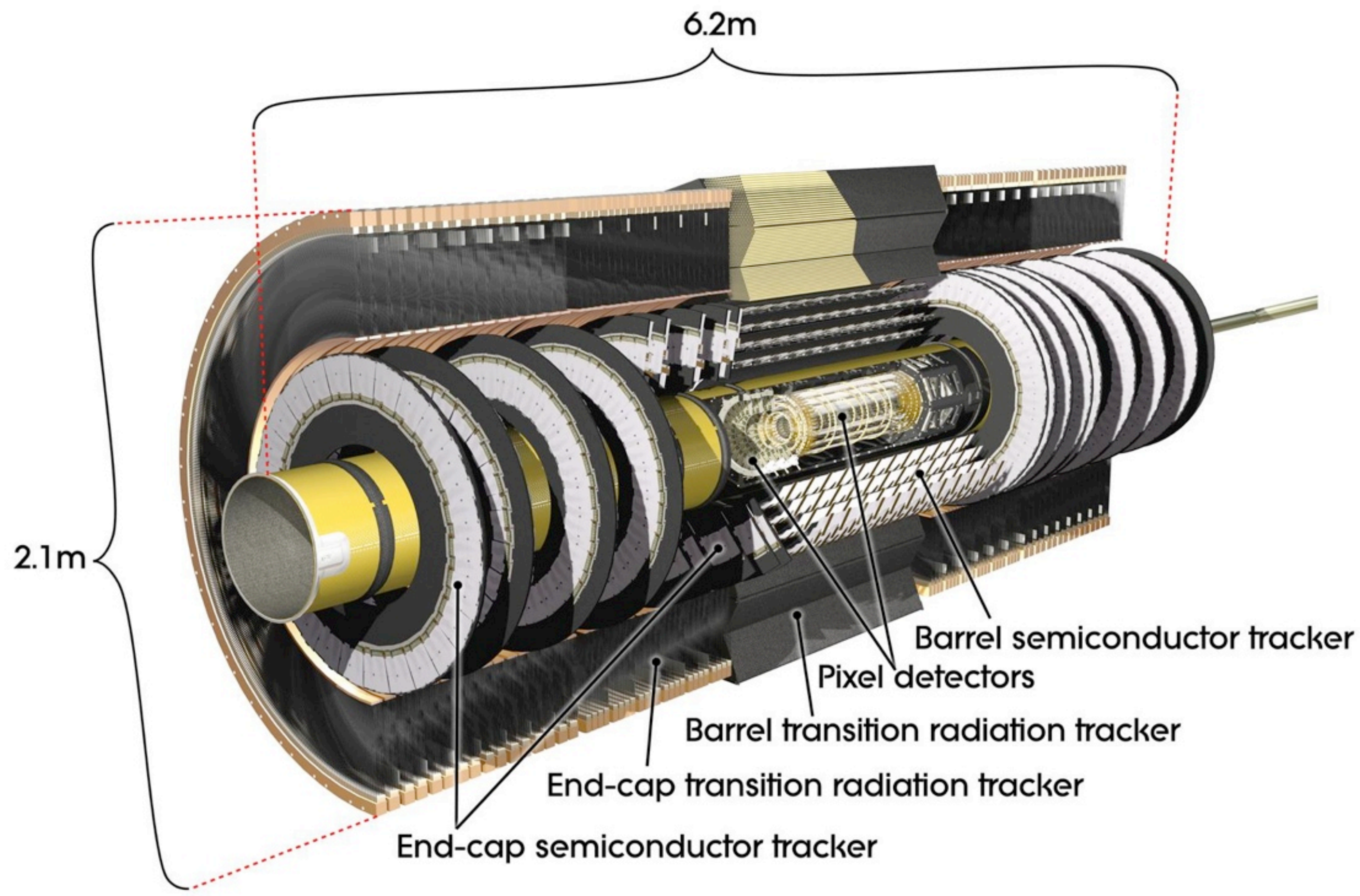
- Measurements are consistent within errors
- Some evidence of underestimation by the NLO QCD predictions but still (just) covered by the theoretical uncertainties
- Other measurements of b-production are ongoing using a variety of processes

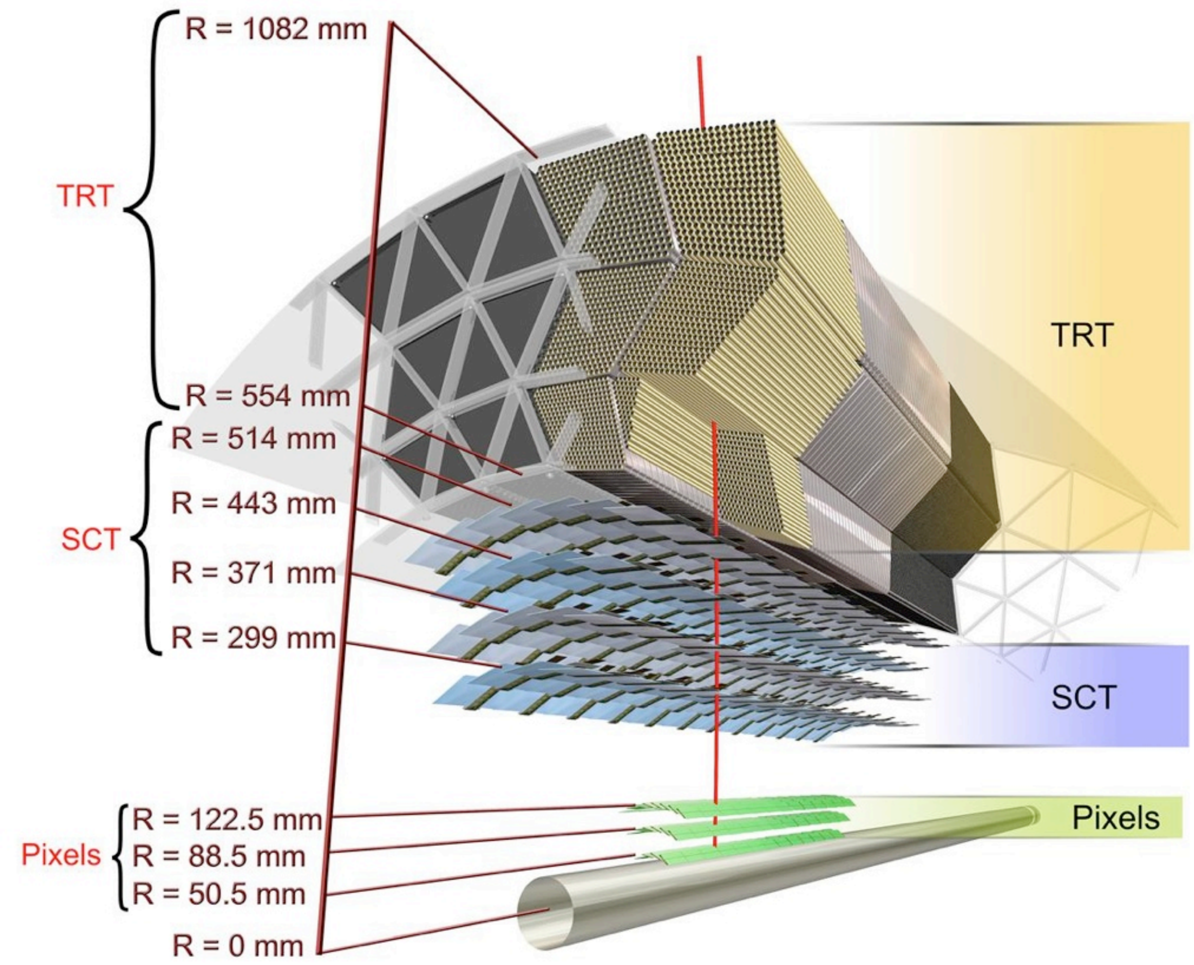
Additional information

ATLAS detector

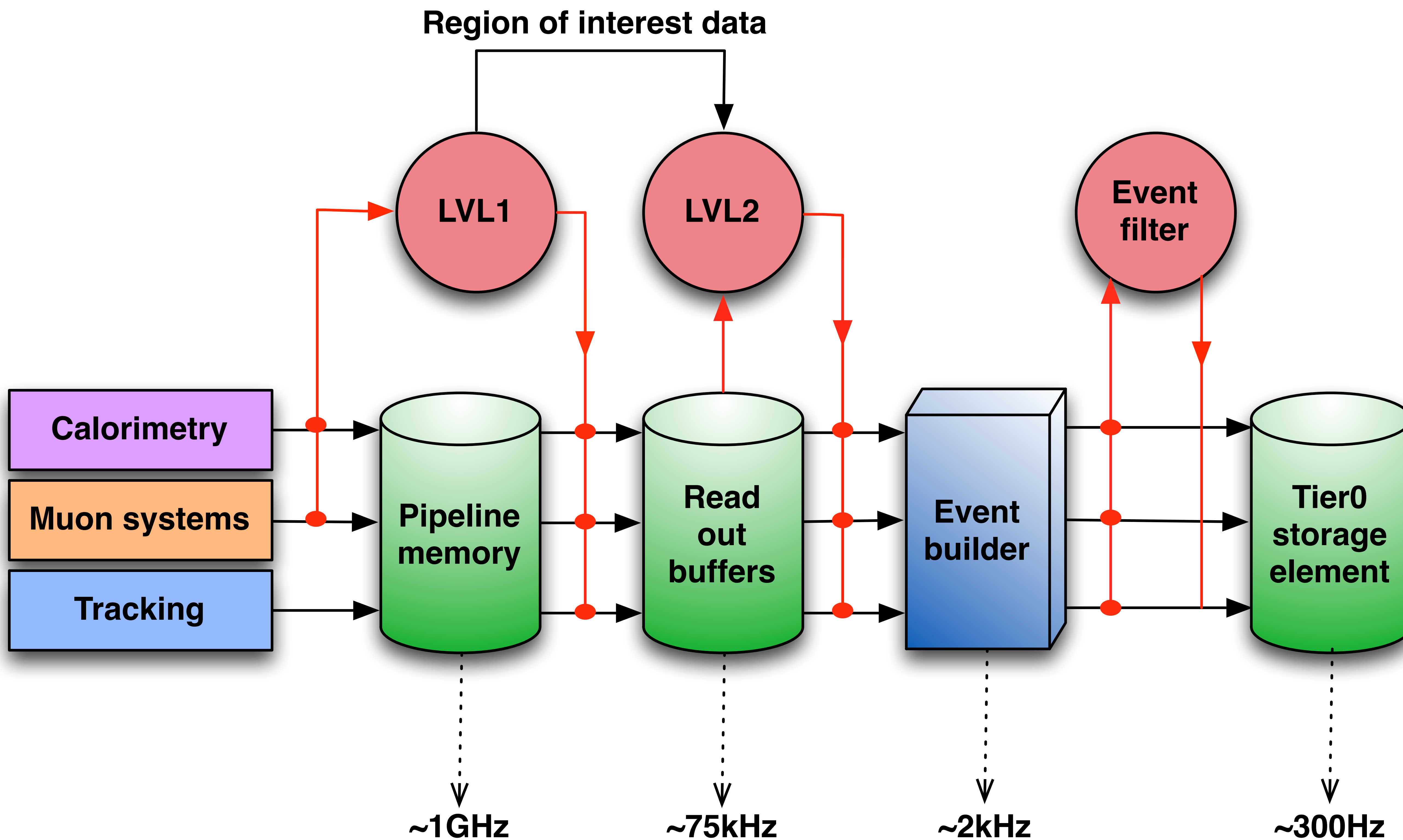


ATLAS inner detector





- 2T magnetic field, coverage $|\eta| < 2.5$
- Momentum scale: ~0.1% at low energy, ~1% up to ~100 GeV
- Momentum resolution: $\sigma/p_T = 3.8 \times 10^{-4}\ (\mathrm{GeV}) \oplus 0.015$
- Primary vertex resolution: ~30 μm transverse, ~50 μm longitudinal



Region of interest data
LVL1
LVL2
Event filter
Calorimetry
Muon systems
Tracking
Pipeline memory
Read out buffers
Event builder
Tier0 storage element
~1GHz
~75kHz
~2kHz
~300Hz

Monte Carlo and QCD predictions input

- MC and QCD predictions are used extensively in this analysis
- PYTHIA(6) + GEANT(4): reconstruction and selection efficiency, signal composition estimation
- QCD NLO generators: unfolding, acceptance corrections, extrapolation to full phase space, theory predictions
  - MC@NLO(4) + HERWIG(6.5)
  - POWHEG-HVQ(1.01) + HERWIG(6.5)
  - POWHEG-HVQ(1.01) + PYTHIA(6) [used for default predictions; others used for systematic checks]
  - Main sources of uncertainty
    - Scaling, hadronization, heavy quark PDFs, *b*-quark mass

NLO QCD input and uncertainties

- Inputs
  - CTEQ6.6 for proton PDFs
  - m_b = 4.75GeV
  - Renormalisation and factorisation scales set equal $\mu_r = \mu_f = \mu$ where

MC@NLO $\mu^2 = m_Q^2 + \frac{(p_{\mathrm{T},Q} + p_{\mathrm{T},\bar{Q}})^2}{4}$ POWHEG $\mu^2 = m_Q^2 + (m_{Q\bar{Q}}^2/4 - m_Q^2)\sin^2(\theta_Q)$

  - Hadronization models: cluster model for HERWIG, Lund string model for PYTHIA
- Theoretical uncertainties
  - Scale uncertainty: vary μ_r and μ_f independently between $\mu/2$ and 2μ, given $0.5<\mu_f/\mu_r<2$; select largest variations
  - Vary *b*-quark mass by ±0.25
  - PDF uncertainties: use the CTEQ6.6 error eigenvectors
  - Hadronization uncertainties: switch from Bowler to Peterson fragmentation functions

Signal extraction

D*μ yields

$p_{\mathrm{T}}(D^{*+}\mu^-)$	$N(D^{*+}\mu^-)$
9–12 GeV	334 ± 33
12–15 GeV	1211 ± 56
15–20 GeV	1527 ± 55
20–30 GeV	1049 ± 42
30–45 GeV	310 ± 21
45–80 GeV	76 ± 10

$\lvert\eta(D^{*+}\mu^-)\rvert$	$N(D^{*+}\mu^-)$
0.0–0.5	1330 ± 47
0.5–1.0	1207 ± 47
1.0–1.5	919 ± 48
1.5–2.0	890 ± 60
2.0–2.5	317 ± 37

Signal fit model: modified Gaussian

$$G^{\mathrm{mod}}(x) \propto \exp[-0.5 \cdot x^{1+\frac{1}{1+0.5x}}] \qquad x = |(\Delta m - \Delta m_0)/\sigma|$$

Combinatorial background fit model: power function x exponential

$$B(\Delta m) \propto (\Delta m - m_\pi)^\alpha e^{-\beta(\Delta m - m_\pi)}$$

Composition of D*μ sample

Source	Fraction (%)
$b \to D^{*+}\mu^- X$	93.2 ± 0.3
$c \to D^{*+}X,\ \bar{c} \to \mu^- X'$	3.8 ± 0.2
$b \to D^{*+}\tau^- X,\ \tau^- \to \mu^- X'$	1.5 ± 0.1
$b \to D^{*+}\bar{D}X,\ \bar{D} \to \mu^- X'$	0.9 ± 0.1
others	0.6 ± 0.1

Composition of the signal

$p_{\mathrm{T}}(D^{*+}\mu^-)$	f_b (%)
9–12 GeV	90.8 ± 1.2
12–15 GeV	92.7 ± 0.5
15–20 GeV	93.8 ± 0.4
20–30 GeV	93.2 ± 0.5
30–45 GeV	93.8 ± 0.9
45–80 GeV	93.1 ± 1.9

$\lvert\eta(D^{*+}\mu^-)\rvert$	f_b (%)
0.0–0.5	93.0 ± 0.5
0.5–1.0	92.6 ± 0.5
1.0–1.5	93.4 ± 0.6
1.5–2.0	93.5 ± 0.6
2.0–2.5	94.6 ± 0.9

Contribution from B-decays to the D*μ sample

Binned overall efficiencies and α

$p_{\mathrm{T}}(D^{*+}\mu^-)$	ϵ (%)
9–12 GeV	21.2 ± 0.9
12–15 GeV	26.7 ± 0.6
15–20 GeV	32.1 ± 0.6
20–30 GeV	38.8 ± 0.9
30–45 GeV	45.2 ± 1.7
45–80 GeV	52 ± 4

$\lvert\eta(D^{*+}\mu^-)\rvert$	ϵ (%)
0.0–0.5	37.5 ± 0.7
0.5–1.0	37.2 ± 0.8
1.0–1.5	29.9 ± 0.8
1.5–2.0	26.1 ± 0.8
2.0–2.5	16.1 ± 0.9

$p_{\mathrm{T}}(H_b)$	α
9–12 GeV	0.005
12–15 GeV	0.071
15–20 GeV	0.219
20–30 GeV	0.422
30–45 GeV	0.614
45–80 GeV	0.723

$\lvert\eta(H_b)\rvert$	α
0.0–0.5	0.096
0.5–1.0	0.095
1.0–1.5	0.091
1.5–2.0	0.086
2.0–2.5	0.061

Unfolding procedure

- In order to express the cross section in terms of the B-hadron kinematics we must transform (unfold) the measured D*μ pT and η distributions to those of the B-hadrons
  - This implies correcting for the 'X' particles which we do not include in the analysis, so Monte Carlo must therefore be used

1 Generate response matrix F_{ij} from MC: $F_{ij} = P(D^*\mu \text{ in bin } i | H_b \text{ in bin } j)$

2 Generate probabilities p_i for B-hadrons to be found in the various kinematic bins, using MC

3 Obtain estimate for number of B-hadrons in bin *i* given a measured D*μ distribution:

$$N_i^{H_b} = \sum_{j=1}^{N_{\text{bin}}} P(H_b \text{ in bin } i | D^*\mu \text{ in bin } j) N_j^{D^*\mu} = \sum_{j=1}^{N_{\text{bin}}} \left(\frac{F_{ji} p_i}{\sum_k F_{jk} p_k} \right) N_j^{D^*\mu}$$

4 Re-estimate the probabilities from 2 using the results of 3 : $p_i = N_i^{H_b} / N_{\text{tot}}^{H_b}$

5 Continue for a defined number of iterations*

* in principle this would lead to the inversion of the response matrix in the limit of an infinite number of iterations, which is what we are after in theory, but this tends to amplify statistical fluctuations and so only works given infinite statistics

Tabulated cross sections: pp→H_BX→$D^*\mu$X’

$p_T(D^*\mu)$>4.5 GeV; $|\eta|(D^*\mu)$<2.5
$p_T(\mu)$>6GeV; $\eta|(\mu)$<2.4

$p_{\mathrm{T}}(D^{*+}\mu^-)$ [GeV]	$\frac{\mathrm{d}\sigma(H_b\to D^{*+}\mu^- X)}{\mathrm{d}p_{\mathrm{T}}(D^{*+}\mu^-)}$ [nb/GeV]
9–12	$2.78 \pm 0.29^{+0.30}_{-0.30}$
12–15	$8.2 \pm 0.4^{+0.8}_{-0.8}$
15–20	$5.2 \pm 0.2^{+0.5}_{-0.5}$
20–30	$1.47 \pm 0.06^{+0.15}_{-0.14}$
30–45	$0.250 \pm 0.018^{+0.025}_{-0.024}$
45–80	$0.0229 \pm 0.0030^{+0.0023}_{-0.0023}$

$\lvert\eta(D^{*+}\mu^-)\rvert$	$\frac{\mathrm{d}\sigma(H_b\to D^{*+}\mu^- X)}{\mathrm{d}\lvert\eta(D^{*+}\mu^-)\rvert}$ [nb/unit of $\lvert\eta\rvert$]
0.0–0.5	$38.4 \pm 1.5^{+3.4}_{-3.4}$
0.5–1.0	$34.9 \pm 1.4^{+3.1}_{-3.1}$
1.0–1.5	$33.5 \pm 1.8^{+3.4}_{-3.1}$
1.5–2.0	$37.2 \pm 2.6^{+4.7}_{-4.2}$
2.0–2.5	$21.7 \pm 2.6^{+3.7}_{-3.1}$

$p_T(H_b)$ [GeV]	$\frac{d\sigma(H_b \to D^{*+}\mu^- X)}{dp_T(H_b)}$ [nb/GeV]	$\frac{d\sigma(H_b X)}{dp_T(H_b)}$ [nb/GeV]
9–12	$0.73 \pm 0.12^{+0.09}_{-0.11}$	$(5.8 \pm 0.9^{+0.8}_{-1.0}) \cdot 10^3$
12–15	$4.65 \pm 0.27^{+0.50}_{-0.50}$	$(2.37 \pm 0.14^{+0.30}_{-0.33}) \cdot 10^3$
15–20	$5.48 \pm 0.19^{+0.57}_{-0.54}$	$(9.1 \pm 0.3^{+1.1}_{-1.1}) \cdot 10^2$
20–30	$2.46 \pm 0.08^{+0.26}_{-0.24}$	$212 \pm 7\,^{+26}_{-26}$
30–45	$0.530 \pm 0.025^{+0.056}_{-0.062}$	$31.3 \pm 1.5^{+3.9}_{-3.9}$
45–80	$0.055 \pm 0.005^{+0.007}_{-0.006}$	$2.78 \pm 0.25^{+0.38}_{-0.33}$

$\lvert\eta(H_b)\rvert$	$\frac{d\sigma(H_b \to D^{*+}\mu^- X)}{d\lvert\eta(H_b)\rvert}$ [nb/unit of $\lvert\eta\rvert$]	$\frac{d\sigma(H_b X)}{d\lvert\eta(H_b)\rvert}$ [μb/unit of $\lvert\eta\rvert$]
0.0–0.5	$38.0 \pm 1.5^{+3.3}_{-3.3}$	$14.3 \pm 0.6^{+1.7}_{-2.7}$
0.5–1.0	$35.0 \pm 1.5^{+3.2}_{-3.2}$	$13.4 \pm 0.6^{+1.8}_{-2.7}$
1.0–1.5	$32.9 \pm 1.9^{+3.3}_{-3.1}$	$13.1 \pm 0.7^{+2.1}_{-2.9}$
1.5–2.0	$37.5 \pm 2.7^{+4.7}_{-4.3}$	$15.8 \pm 1.1^{+2.4}_{-4.4}$
2.0–2.5	$22.3 \pm 2.8^{+3.8}_{-3.2}$	$13.3 \pm 1.6^{+2.5}_{-4.5}$

p_{T} bin (GeV)	9–12	12–15	15–20	20–30	30–45	45–80
data statistics	±15.8	±5.9	±3.4	±3.1	±4.7	±9.0
$\sigma(H_b \to D^{*+}\mu^- X)$ and $\sigma(H_b)$ relative systematic error (%)						
$D^*\mu$ fit	±3.5	±1.8	±1.0	±1.4	±1.7	±2.0
f_b	$^{+2.5}_{-3.8}$	$^{+2.3}_{-3.5}$	$^{+1.8}_{-2.8}$	$^{+1.6}_{-2.5}$	$^{+1.4}_{-2.2}$	$^{+1.8}_{-2.9}$
μ trigger	$^{+1.3}_{-1.2}$	$^{+1.3}_{-1.3}$	$^{+1.7}_{-1.6}$	$^{+2.2}_{-2.0}$	$^{+2.5}_{-2.2}$	$^{+2.7}_{-2.5}$
tracking + μ reconstruction	$^{+9.1}_{-8.2}$	$^{+9.0}_{-8.1}$	$^{+8.9}_{-8.0}$	$^{+8.7}_{-7.9}$	$^{+8.5}_{-7.7}$	$^{+8.3}_{-7.5}$
MC p_{T}/η reweight	$^{+0.2}_{-1.3}$	$^{+0.2}_{-1.2}$	$^{+0.4}_{-1.1}$	$^{+0.5}_{-1.1}$	$^{+0.4}_{-1.0}$	$^{+0.2}_{-0.8}$
D^0 and H_b vertices fit	±2.0	±2.0	±2.0	±2.0	±2.0	±2.0
D^0 mass correction	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$
luminosity	±3.4					
$\mathscr{B}(D^{*+} \to D^0\pi^+)$	±0.7					
$\mathscr{B}(D^0 \to K^-\pi^+)$	±1.3					
$\sigma(H_b \to D^{*+}\mu^- X)$ relative systematic error (%)						
unfolding	$^{+6.6}_{-10.0}$	$^{+2.3}_{-3.8}$	$^{+1.7}_{-1.5}$	$^{+2.3}_{-1.3}$	$^{+3.2}_{-6.7}$	$^{+9.1}_{-3.5}$
$\sigma(H_b)$ relative systematic error in (%)						
$\mathscr{B}(b \to D^{*+}\mu^- X)$	±7					
unfolding $\oplus$ acceptance	$^{+3.4}_{-11.3}$	$^{+1.6}_{-6.4}$	$^{+2.3}_{-4.0}$	$^{+0.7}_{-2.5}$	$^{+1.7}_{-4.4}$	$^{+6.0}_{-1.0}$
total syst $\sigma(H_b \to D^{*+}\mu^- X)$	$^{+12.9}_{-14.7}$	$^{+10.7}_{-10.8}$	$^{+10.3}_{-9.9}$	$^{+10.4}_{-9.8}$	$^{+10.6}_{-11.7}$	$^{+13.6}_{-10.3}$
total syst $\sigma(H_b)$	$^{+13.4}_{-17.1}$	$^{+12.6}_{-14.0}$	$^{+12.5}_{-12.5}$	$^{+12.3}_{-12.1}$	$^{+12.3}_{-12.5}$	$^{+13.5}_{-11.8}$

Tabulated uncertainties in η bins

$\|\eta\|$ bin	0–0.5	0.5–1	1–1.5	1.5–2	2–2.5	0–2.5
data statistics	± 3.9	± 4.3	± 5.8	± 7.3	± 12.5	± 2.5
$\sigma(H_b \to D^{*+}\mu^- X)$ and $\sigma(H_b)$ relative systematic error (%)						
$D^*\mu$ fit	± 0.7	± 0.9	± 0.7	± 1.2	± 1.0	± 0.5
f_b	$^{+1.6}_{-2.6}$	$^{+2.0}_{-3.5}$	$^{+1.5}_{-2.4}$	$^{+1.5}_{-2.6}$	$^{+1.3}_{-2.1}$	$^{+1.7}_{-2.8}$
μ trigger	$^{+2.0}_{-1.9}$	$^{+2.1}_{-1.9}$	$^{+1.8}_{-1.6}$	$^{+1.7}_{-1.6}$	$^{+1.6}_{-1.5}$	$^{+1.9}_{-1.9}$
tracking + μ reconstruction	$^{+7.0}_{-6.5}$	$^{+7.1}_{-6.6}$	$^{+8.5}_{-7.7}$	$^{+11.4}_{-10.0}$	$^{+16.2}_{-13.4}$	$^{+8.6}_{-8.0}$
MC p_{T}/η reweight	$^{+1.5}_{-0.1}$	$^{+1.2}_{-0.1}$	$^{+1.4}_{-0.1}$	$^{+1.1}_{-0.2}$	$^{+2.0}_{-0.5}$	$^{+1.3}_{-1.3}$
D^0 and H_b vertices fit	± 2.0	± 2.0	± 2.0	± 2.0	± 2.0	± 2.0
D^0 mass correction	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$	$^{+0.8}_{-1.0}$
luminosity	± 3.4					
$\mathscr{B}(D^{*+} \to D^0\pi^+)$	± 0.7					
$\mathscr{B}(D^0 \to K^-\pi^+)$	± 1.3					
$\sigma(H_b \to D^{*+}\mu^- X)$ relative systematic error (%)						
unfolding	$^{+1.3}_{-0.9}$	$^{+1.1}_{-1.5}$	$^{+1.4}_{-0.8}$	$^{+0.7}_{-1.0}$	$^{+1.1}_{-2.0}$	-
$\sigma(H_b)$ relative systematic error (%)						
$\mathscr{B}(b \to D^{*+}\mu^- X)$	± 7					
unfolding $\oplus$ acceptance	$^{+5.1}_{-15.0}$	$^{+7.3}_{-16.2}$	$^{+10.7}_{-19.1}$	$^{+4.8}_{-24.6}$	$^{+4.3}_{-29.6}$	$^{+6.4}_{-17.1}$
total syst $\sigma(H_b \to D^{*+}\mu^- X)$	$^{+8.8}_{-8.5}$	$^{+9.0}_{-9.0}$	$^{+10.0}_{-9.4}$	$^{+12.5}_{-11.4}$	$^{+17.1}_{-14.5}$	$^{+10.0}_{-9.8}$
total syst $\sigma(H_b)$	$^{+12.2}_{-18.5}$	$^{+13.4}_{-19.7}$	$^{+16.1}_{-22.3}$	$^{+15.0}_{-27.9}$	$^{+18.8}_{-33.5}$	$^{+13.8}_{-20.9}$