XXI International Workshop on Deep-Inelastic Scattering and Related Subjects

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Marseille, Parc Chanot

"Production cross section of B-meson in ATLAS"

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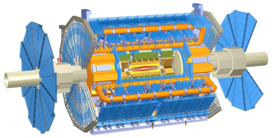
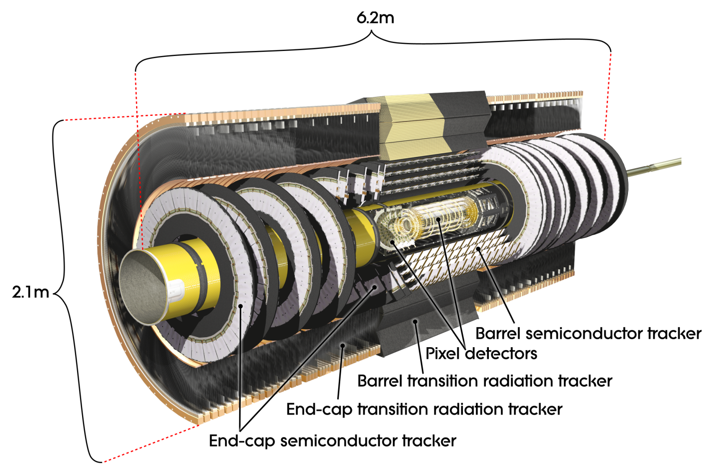
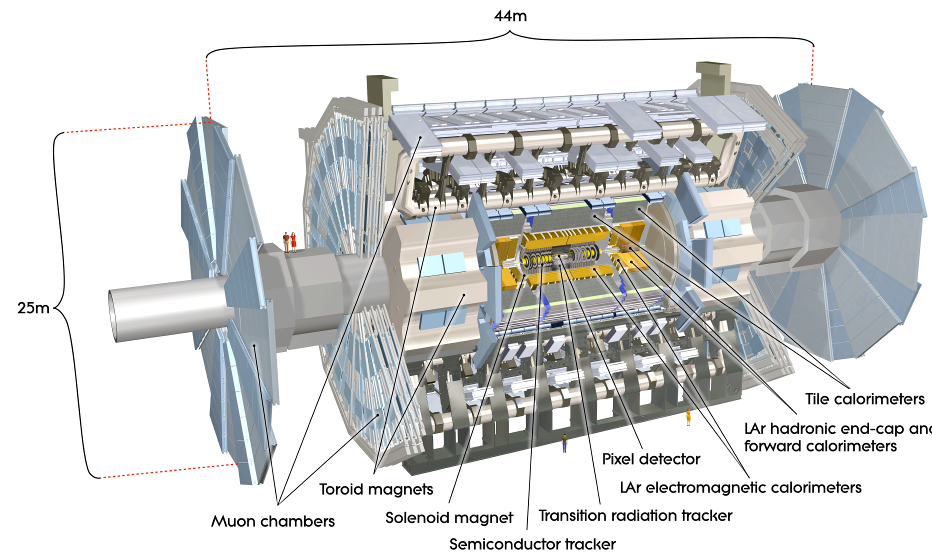
On behalf of ATLAS Collaboration



The ATLAS detector

ATLAS is a general purpose detector, designed to be sensitive to a wide range of physical phenomena: EWK, Higgs, SUSY, BSM,… also Flavour physics (Large b production cross-section [few100μb], excellent muon detection and tracking performance)





Inner Detector

- $|\eta|<2.5$,
- 2 T solenoidal magnetic field
- Si Pixels: resolution 10/115 **μ**m in **Rφz**
- Si strips: resolution 17/580 resolution 130 **μ**m in **R**m in **Rφz**
- Transition Radiation Tracker (TRT) resolution 130 **μ**m in **Rφ**
- $\sigma/p_T \sim 3.4\text{x}10^{-4}\ p_T + 0.015$ for ($|\eta|<1.5$)
- Used for Tracking and Vertexing

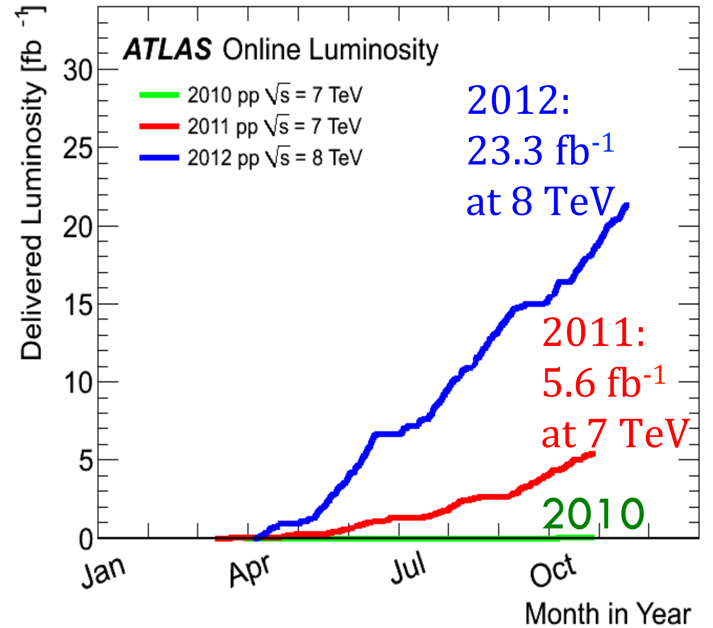
Precise momentum and lifetime measurements

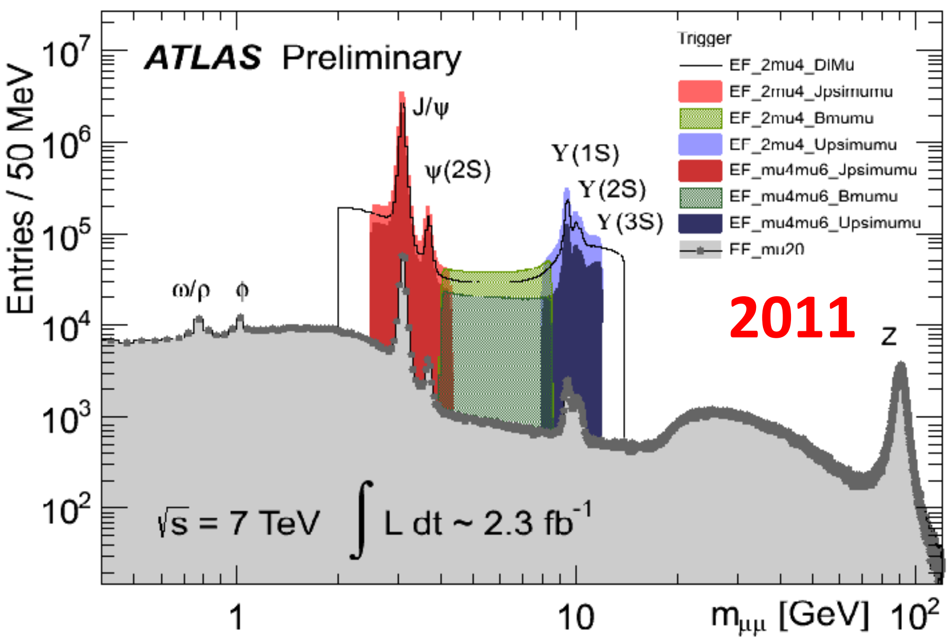
Muon Spectrometer

- $|\eta|<2.7$
- Toroid B-Field, average ~0.5 T
- Muon Momentum resolution $\sigma/p < 10\%$ up to ~ 1 TeV

ATLAS performances

Excellent ATLAS performance
Data-taking efficiency: 93%
Good quality data fraction used for analysis: 95.8%
Challenge: harsh pile-up conditions [trigger, computing, reconstruction of physics objects]





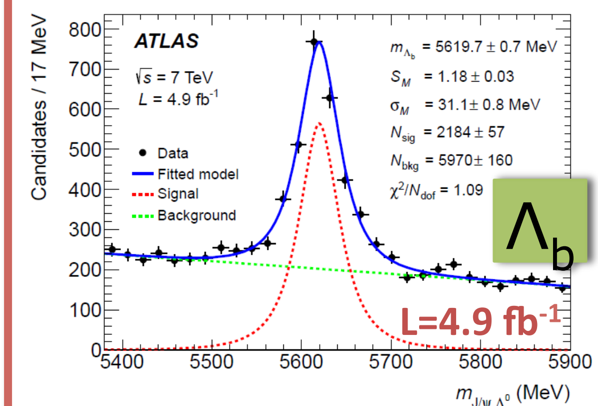
Heavy Flavour sensitive to new physics
ATLAS advantage: high luminosity and efficient muon triggers

B-physics triggers based on single and di-muons: in 2010 and 2011 lower threshold, on both muons, at 4 GeV

ATLAS Heavy Flavours overview

- Inclusive b, c production
- Production with jets
- Charm production
- Onia production (see D. Price talk)
- *B-hadron production*
- Rare decays (see S. Turchikhin talk)
- CP violation (see A. Dewhurst talk)

Phys. Rev. Lett. 108 (2012) 152001



Best Λ_b lifetime measurement
Competitive mass measurement

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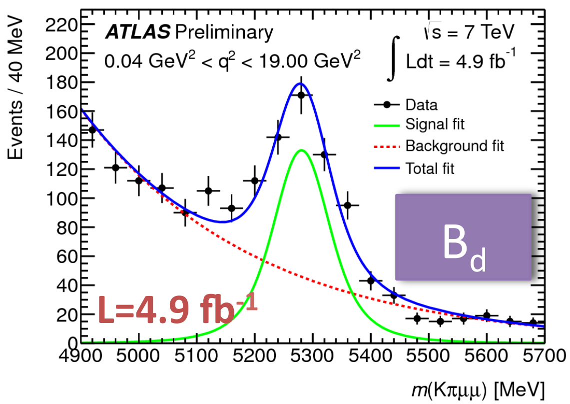

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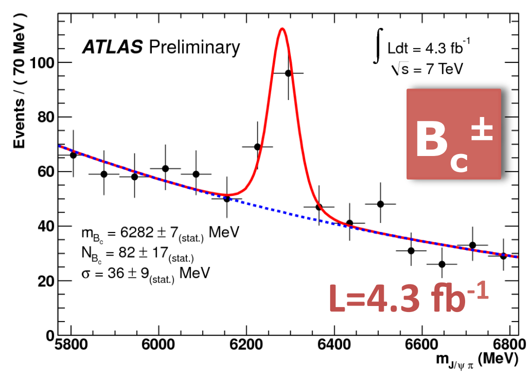
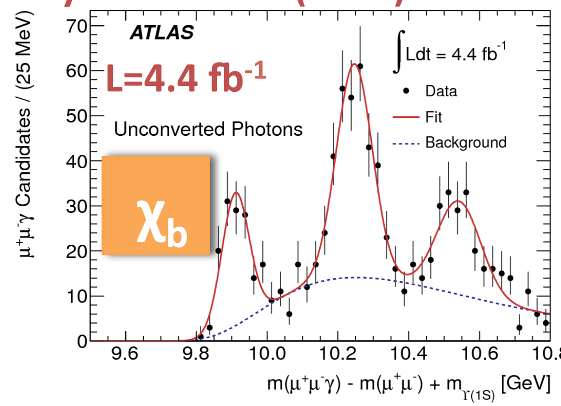


Phys. Rev. D 87 (2013) 032002



Search for rare decays ($B^o_s \rightarrow \mu\mu$): Phys. Lett. B713 (2012) 180-196

b-hadron production at LHC and ATLAS

The production of heavy quarks at LHC provides a challenging test of QCD predictions calculations at the new regime, in wider range of rapidity (**y**) and transverse momentum (**p_T**) than previous studies at hadron colliders.

- b-hadron production cross section has been predicted at NLO accuracy for long time
- b-hadrons are important backgrounds for many new physics searches, therefore a better understanding of their production is crucial
- ***ATLAS*** *measures the production of B-hadrons in the central rapidity region and can reach B-hadrons of high transverse momentum (~100 GeV). The measurements are interesting for testing the validity of FONLL approximations, which are expected to be valid for $p_T >> m_b$. They provide a double differential cross section measurement, allowing detailed comparisons with NLO predictions*

Open beauty production presented results:

- b-hadron (**H_b**) production cross section from D*μX final states
- B+ production cross-section from $J/\psi\mu^{\pm}$ final states

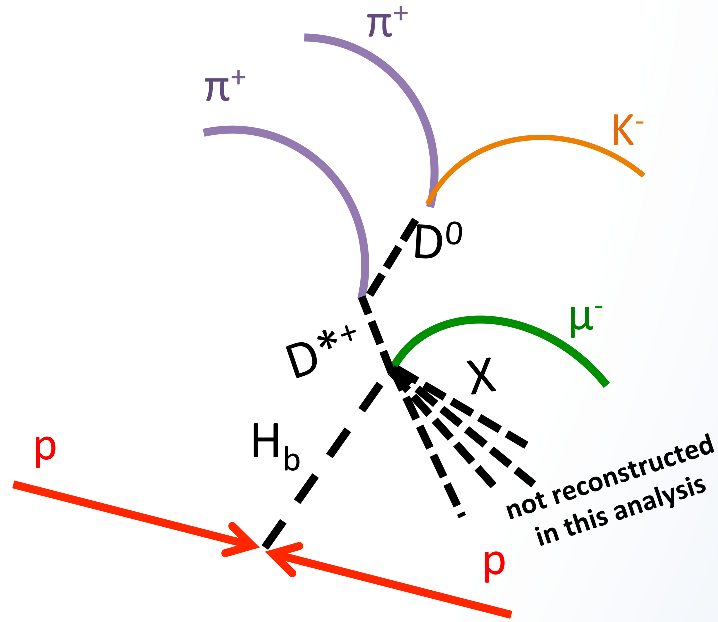
$H_b \rightarrow D^*\mu X$: candidates selection

Nucl. Phys. B864 (2012) 341-381

Data sample: $\int \mathcal{L}dt = 3.3\,pb^{-1}\ (2010, 7TeV)$

Selection:

- ✧Trigger on single muon with $p_T >$ 6 GeV
- ✧**X:** not reconstructed in this analysis
- ✧Fit D^0-vertex and b -vertex simultaneously
- ✧**D^0 candidate**: Fit oppositely charged tracks pairs with $p_T >$ 1 GeV to common vertex to form the D^0 candidate
- ✧**D* candidate**: Combine D^0 candidate with a track of opposite charge to the kaon candidate track with $p_T >$ 250 MeV to form the D* candidate:
  - $p_T(D^*) > 4.5$ GeV
  - $|m(K\pi) - m(D^0)| < 64(40)$ MeV if $|\eta| > 1.3$ and $p_T(D^*) > 12$ GeV (elsewhere)
- ✧**H_b candidate:** if $2.5GeV < m(D^*\mu) < 5.4$ GeV

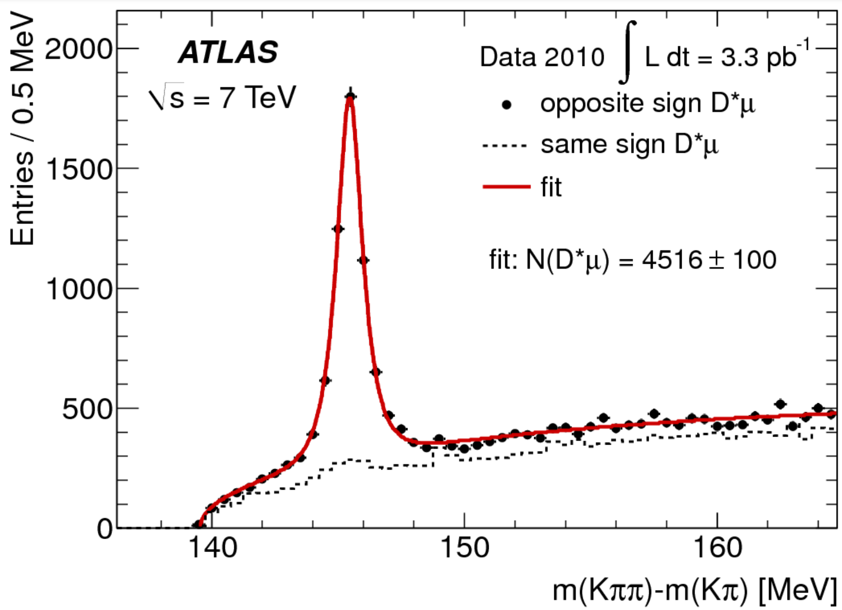


$H_b \rightarrow D^*\mu X$
↳ πD^0
↳ $K\pi$

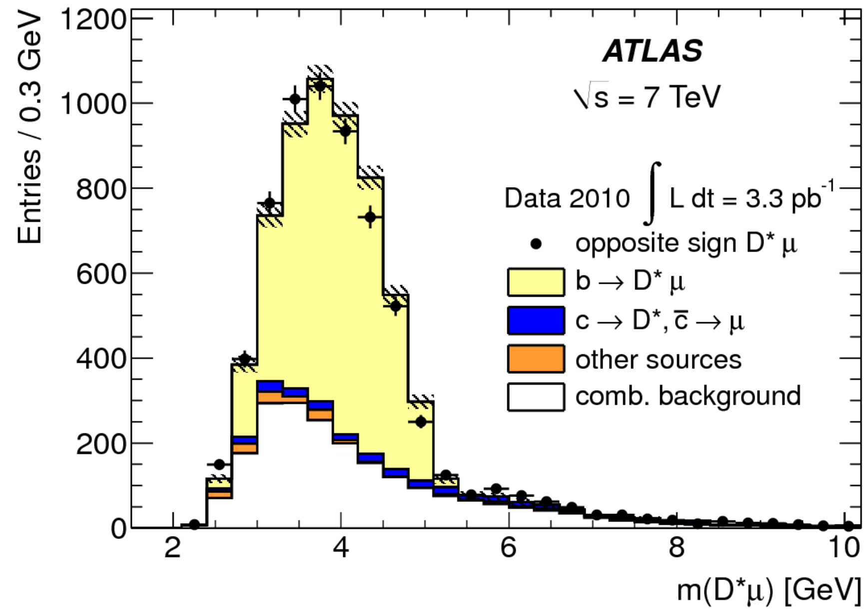
H_b can be a $B^0/B^\pm/B_s$/b-barion

$H_b \rightarrow D^*\mu$: reconstructed candidates

B candidates identied as opposite sign D*μ excess in the m(D*)-m(Kπ) distribution



Signal composition in the D*μ invariant mass distribution



fitted yield: 4516±100 events

m_0 = 145.463±0.015 MeV

σ = 0.49±0.03 MeV

world average value m_0 =145.421±0.010 MeV

The uncertainties on the fitted m_0 and σ values are statistical only

$H_b \rightarrow D^*\mu$: analysis method

$$\frac{d\sigma(pp \to H_b X \to D^* \mu X')}{dp_T(dy)} = \frac{f_b N^{D^*\mu}}{2\epsilon \mathcal{B} \mathcal{L} \Delta p_T(\Delta y)}$$

- $N^{D^*\mu}$: number of reconstructed $D^*\mu$ pairs
- f_b: fraction of $D^*\mu$ candidates from a single b decay (MC)
- ε: reconstruction, trigger and selection efficiency
- $\mathcal{L}$: integrated luminosity of the collected data sample
- $\mathcal{B}$: total branching ratio combining the world average value of the $B(D^* \rightarrow D^0\pi)$ and $B(D^0 \rightarrow K\pi) \rightarrow (2.63\pm0.04)\%$
- factor 2: $N^{D^*\mu}$ counts both $D^{*+}\mu^-$ and $D^{*-}\mu^+$

Differential cross section as a function of p_T (η)

$$\frac{d\sigma(H_b X)}{dp_T(\eta)} = \frac{1}{\alpha_{dp_T(\eta)} \mathcal{B}(b \to D^{*+}\mu^- X)} \frac{d\sigma(pp \to H_b X' \to D^{*+}\mu^- X)}{dp_T(\eta)}$$

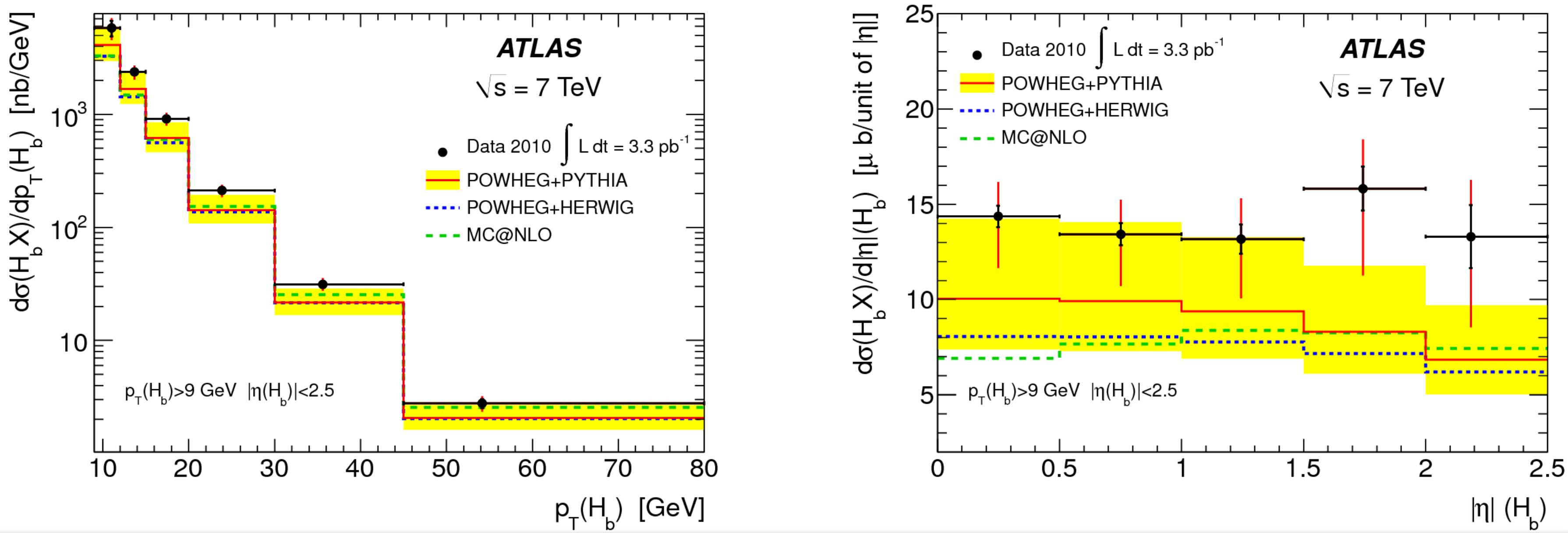
Unfolding is used to account for kinematics of the missing particles

Acceptance corrections and branching ratio $B(b \rightarrow D^*\mu X) = (2.75\pm0.19)\%$ are used to obtain the b-hadron production cross section

Unfolded cross section σ ($pp \rightarrow H_b X$)

H_b can be a $B^0/B^{\pm}/B_s$/b-barion

- Unfolded distributions: correct p_T and η distributions with MC to account for the kinematics of X
- Correct with branching fraction $B(H_b \rightarrow D^*\mu)$
- Decay acceptance evaluated with POWHEG+PYTHIA NLO



Hint of underestimation by NLO QCD predictions (though covered by theoretical uncertainties)

Extrapolate to full phase space:

ATLAS: σ ($pp \rightarrow H_b X$) = 360 ±9(stat) ±34(syst) ±25(Br) ±12(Lumi) ±77(ext. +acc.)μb

LHCb [Phys. Lett. B694 (2010) 209]: σ($pp \rightarrow H_b X$) = 284 ±20(stat) ±49(syst) μb

(LHCb result doesn't include extrapolation uncertainty)

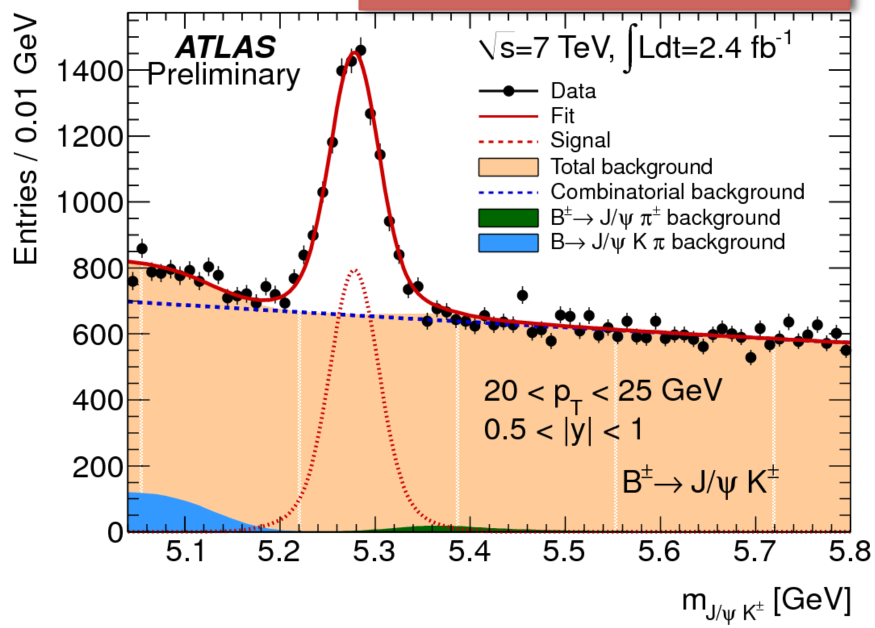
Results are compatible

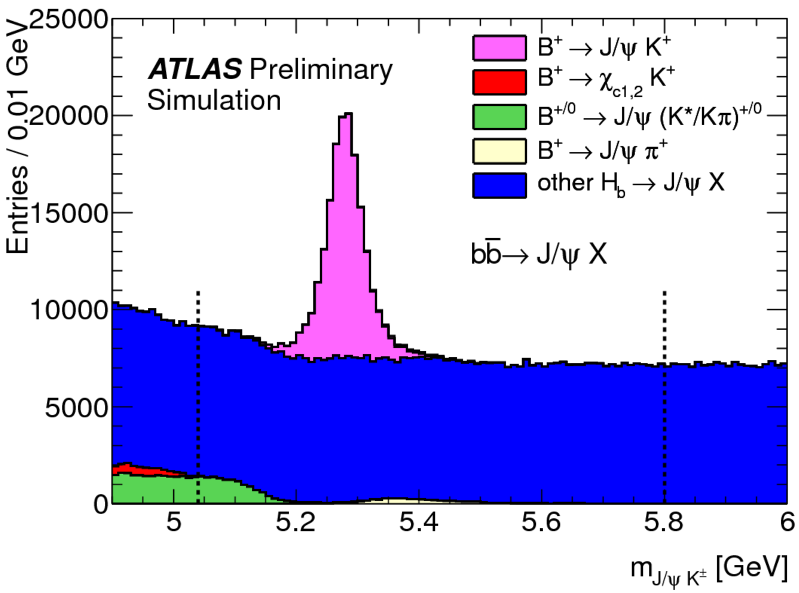
$B^\pm \to J/\psi K^\pm$: candidates selection

Selection:

- ✧ **$J/\psi \to \mu^+\mu^-$:** J/ψ candidate with mass in the range [2.7,3.5] GeV
- ✧ muon tracks of the selected J/ψ candidate are fitted to a common vertex with an additional charged track of $p_T >$ 1 GeV
- ✧ **$B^\pm$ candidate:** retain $B^\pm$ candidate if $p_T >$ 9 GeV and $|y| <$ 2.25

ATLAS-CONF-2013-008





Backgrounds:

- ✧ Resonant ($B^\pm \to J/\psi\, \pi^\pm$, $B \to J/\psi\, K\, \pi$)
- ✧ Combinatorial ($pp \to J/\psi\, X$, $B \to J/\psi\, X$)

B^+: 63531 ± 838(stat.)
B^-: 62093 ± 842(stat.)

~3% difference in reconstruction efficiencies of K^+/K^- mesons

A total of 125k $B^\pm$ signal events is used for the cross section measurement

$B^{\pm}\rightarrow J/\psi K^{\pm}$: cross-section measurement procedure

$$\frac{d^2\sigma\left(pp\rightarrow B^{+}X\right)}{dp_T\, d\eta} = \frac{N^{B^+}}{\mathcal{L}\cdot\mathcal{B}\cdot\Delta p_T\cdot\Delta\eta}$$

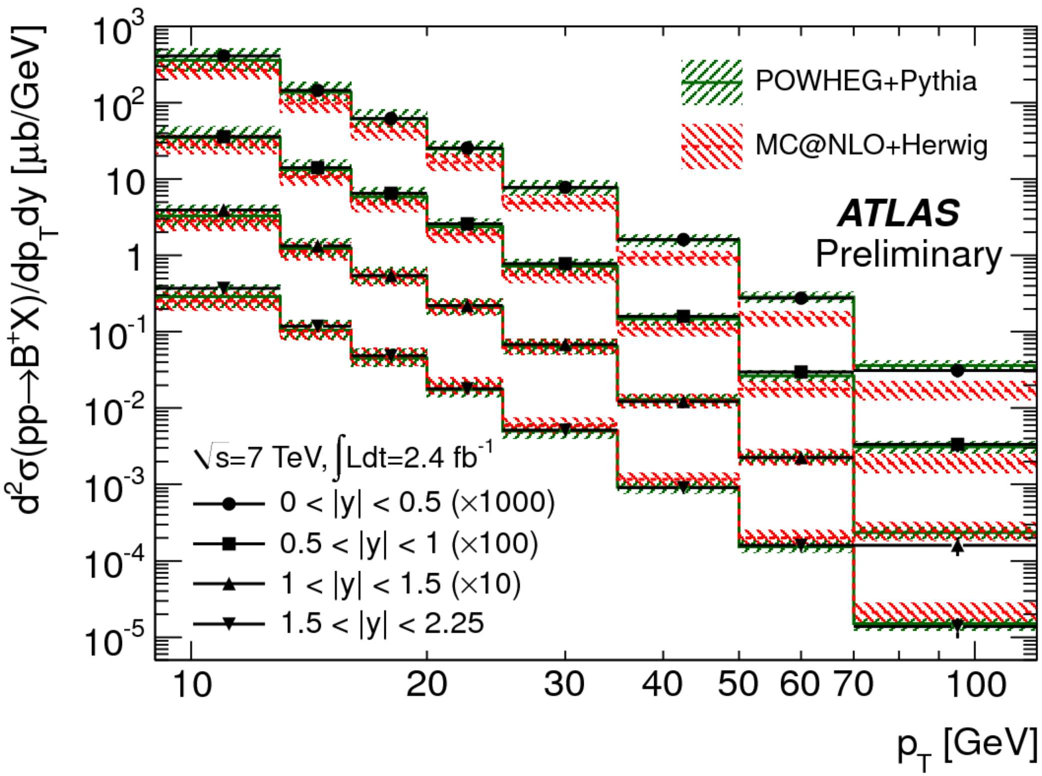
$\mathcal{L}$: integrated luminosity of the collected data sample

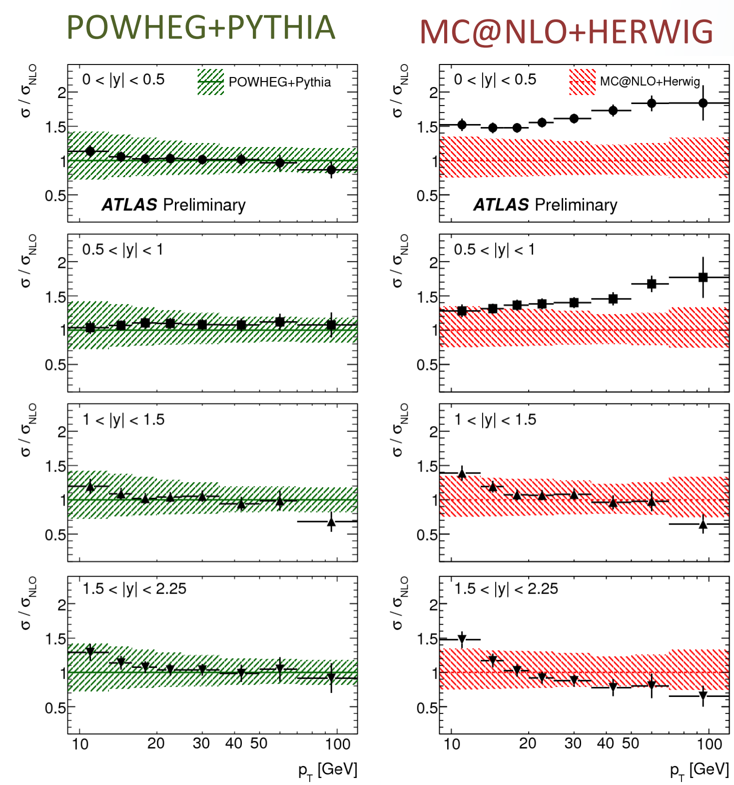
$\mathcal{B}$: total branching ratio

$$N^{B^+} = N^{B^-} = \frac{1}{A}\frac{N^{B^+}_{reco}}{\varepsilon^{B^+}} = \frac{1}{A}\frac{N^{B^-}_{reco}}{\varepsilon^{B^-}} = \frac{1}{A}\frac{N^{B^\pm}_{reco}}{\varepsilon^{B^+}+\varepsilon^{B^-}}$$

- **N^{B+}:** number of the $B^+\rightarrow J/\psi K^+$ signal decay produced
- **$N^{B^\pm}_{reco}$:** number of reconstructed signal events obtained from data with a fit to the invariant mass distribution of the $B^\pm$ candidates
- **A:** kinematic acceptance
- **ε^{B+} and ε^{B+}:** reconstruction efficiency for B^+ and B^-

B±→ J/ψK±: cross-section measurement

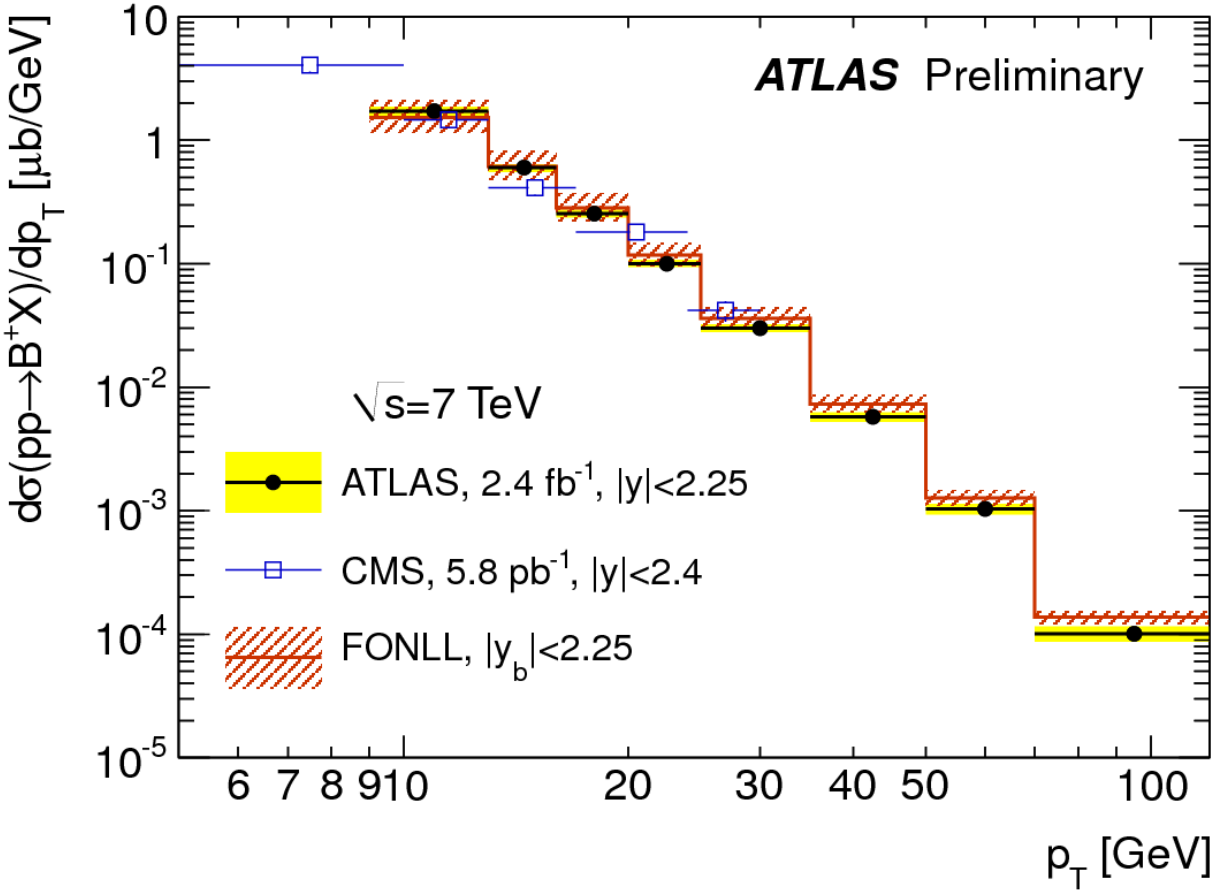




POWHEG+PYTHIA and MC@NLO+HERWIG are in good agreement with data.

POWHEG+PYTHIA: good agreement in absolute scale and in the dependence of p_T and y
MC@NLO+HERWIG: predicts lower production cross section due to a softer p_T spectrum than the one observes in data, which becomes harder for |y| > 1.

$B^{\pm} \rightarrow J/\psi K^{\pm}$: cross-section measurement



Fixed-Order-Next-to-Leading Logarithm (FONLL) (with $f_b \rightarrow B^+ = (0.401 \pm 0.008)$) is in good agreement with the measured $d\sigma/dp_T$.

Summary and Outlook

- **ATLAS has an active heavy flavour programm:** benefits from higher luminosity (and sometimes increased p_T thresholds) but also more difficult environment due to pileup

- **Presented results:**
  - **b-hadron production cross-section from D*μX final states 3.3 pb^{-1} (Nucl. Phys. B864 (2012) 341-381):** Differential cross sections as functions of p_T and $|y|$ are produced for both H_b and $H_b \rightarrow D^*\mu X$ production. These measurements are found to be higher than the NLO QCD predictions, but consistent within the experimental and theoretical uncertainties.
  - **Production cross section of B^+ at $\sqrt{s}$ = 7TeV ($B^\pm \rightarrow J/\psi K^\pm$) (ATLAS-CONF-2013-008):** The measured differential cross section is in agreement with the predictions of next-to-leading order and a FONLL QCD computations within the experimental and theoretical uncertainties

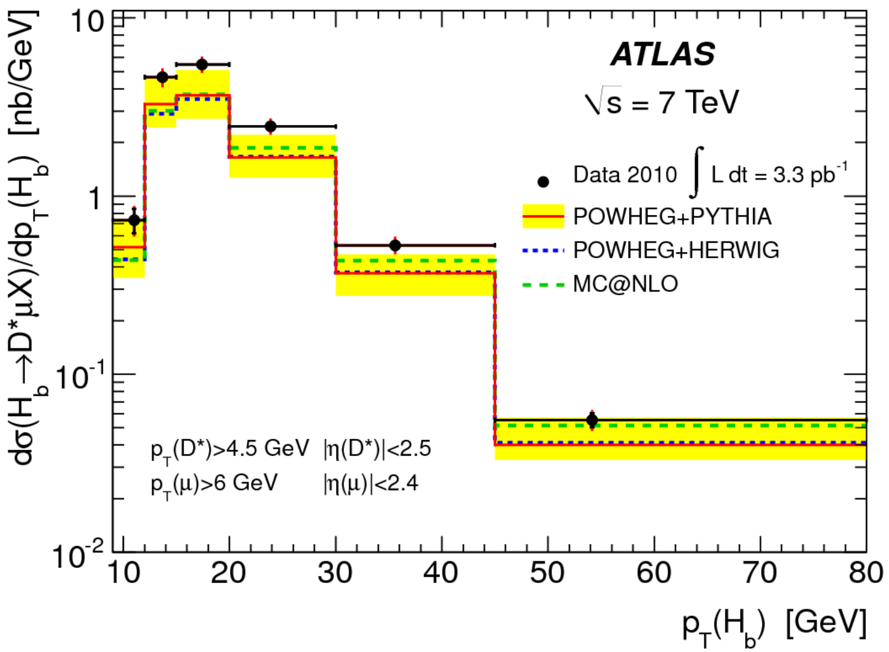
- **More ATLAS results on b-production:**
  - with b-jets **Eur.Phys.J.C 71 (2011) 1846**
  - inclusive muons/electrons **Phys.Lett. B707 (2012) 438-458**
- **Other interesting results:**
  - Rare decays: $Br(B_s \rightarrow \mu\mu) < 4.2\times10^{-9}$ at 95%
  - CP Violation: $\varphi_s = 0.22 \pm 0.41_{stat.} \pm 0.1_{syst.}$ rad (see A. Dewhurst talk)
  - Quarkonia results update (see D. Price talk)
- ***Further results and updates in progress***

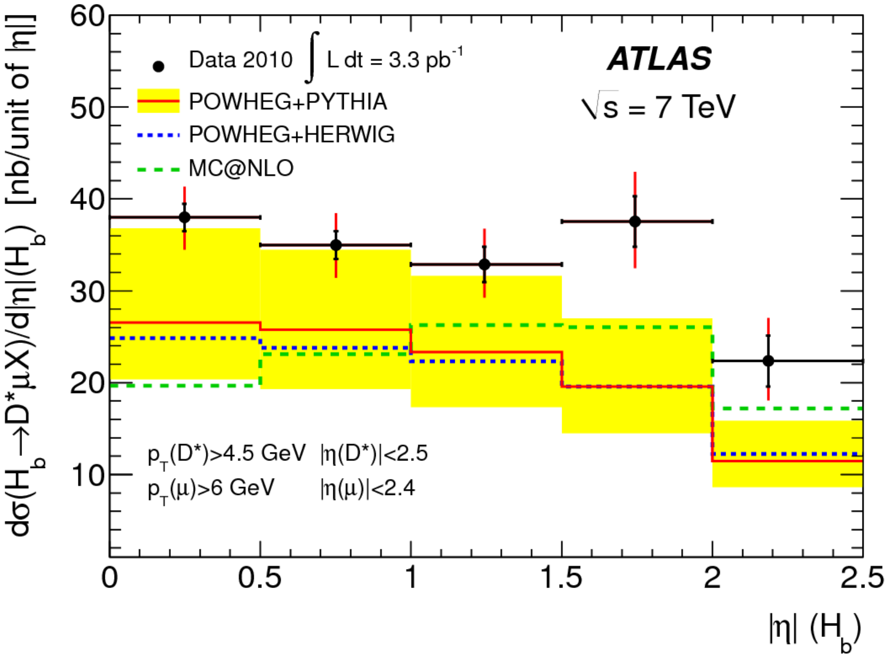
Backup

Measured cross section σ $(pp \rightarrow H_b X \rightarrow D^* \mu X)$

$\sigma\ (H_b \rightarrow D^* \mu X)$ measured in the kinematic intervals:

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





Systematics on the measurement of the σ ($pp \rightarrow H_b X \rightarrow D^* \mu X$)

- ✧ Uncertainty of the yields from the fits, obtained by varying the fitting procedure
- ✧ Uncertainty of the sample composition estimate
- ✧ Uncertainties of the muon trigger, tracking and reconstruction efficiency
- ✧ Model dependence of the reconstruction efficiency
- ✧ Uncertainty due to differences in the fit of the D^0 and b-hadron vertices and in in D^0 mass resolution between data and MC simulation
- ✧ Uncertainty of the luminosity measurement
- ✧ Relative uncertainty on the branching fractions of the dierent decay chains, obtained from the world averages
- ✧ NLO prediction uncertainty:
  - ✧ Scale uncertainty
  - ✧ m_b uncertainty
  - ✧ PDF uncertainty
  - ✧ Hadronisation uncertainty

$p_T(H_b)$ [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	$22.3 \pm 2.8^{+3.8}_{-3.2}$	$13.3 \pm 1.6^{+2.5}_{-4.5}$

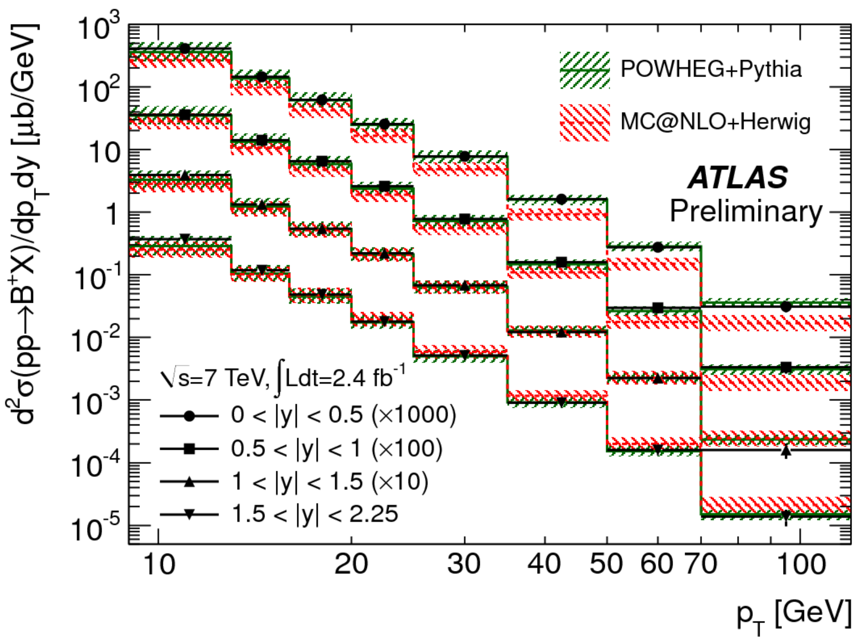
(details in: Nucl. Phys. B864 (2012) 341-381)

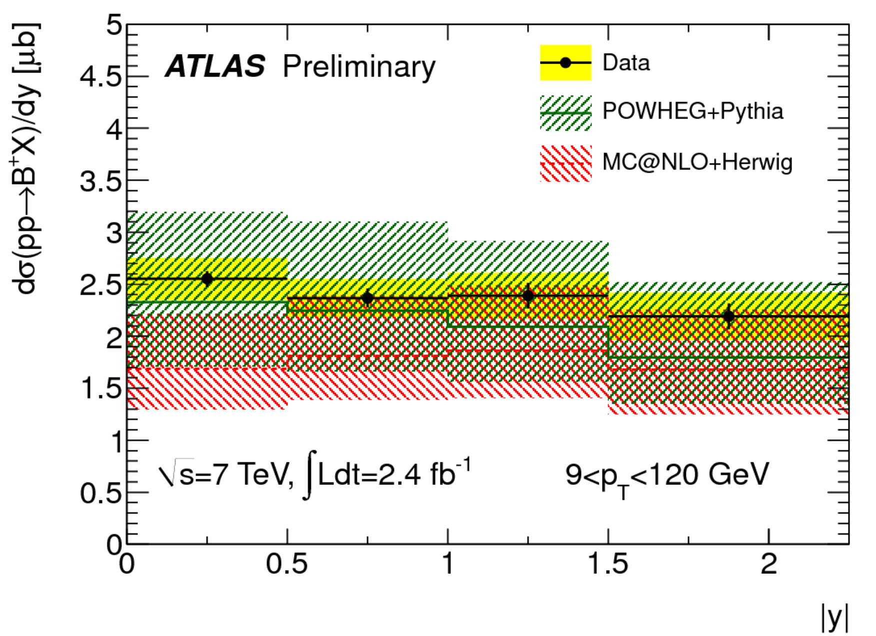
$B^{\pm} \rightarrow J/\psi K^{\pm}$: cross-section

Differential cross-section

$$\frac{d\sigma(pp \rightarrow B^{+}X)}{dp_T\, dy} = \frac{N^{B^{\pm}}_{reco}}{A(\epsilon^{B^{+}} + \epsilon^{B^{-}})\mathcal{B}\mathcal{L}\Delta p_T \Delta y}$$

- N^{B}_{reco}: number of reconstructed signal events
- A: kinematic acceptance
- ε^{B}: efficiency reconstruction for signal events
- $\mathcal{L}$: integrated luminosity of the collected data sample
- $\mathcal{B}$: total branching ratio



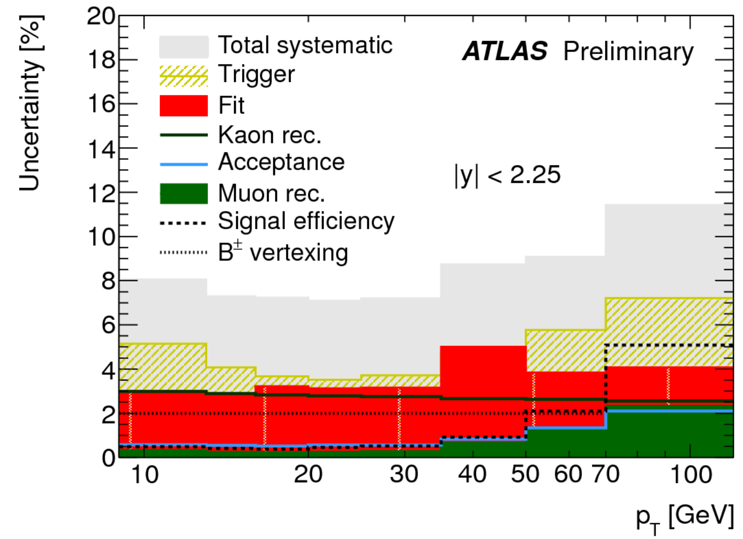


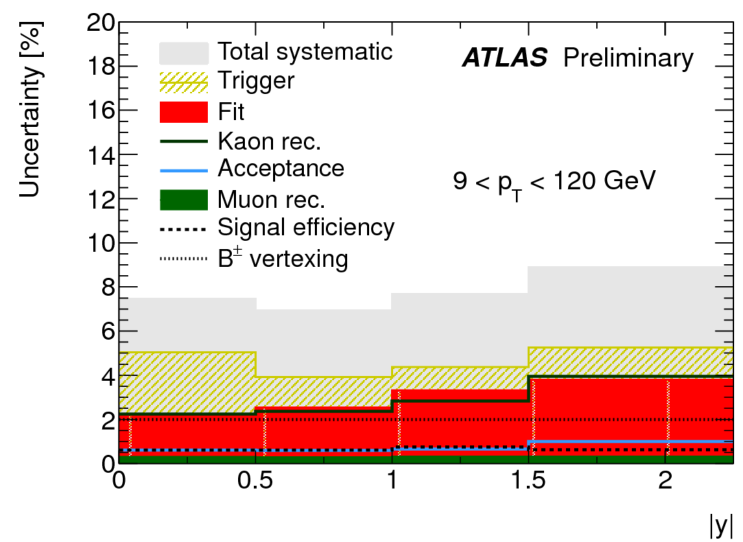
POWHEG+PYTHIA: good agreement in absolute scale and in the dependence of $\mathbf{p_T}$ and **y**

MC@NLO+HERWIG: predicts lower production cross section and softer $\mathbf{p_T}$ spectrum than the one observes in data, which becomes harder for **|y|** > 1.

Systematics on the measurement of the σ(pp→$B^{\pm}$X→ J/ψ$K^{\pm}$X)

- **Muon Trigger and reconstruction**: the trigger and the reconstruction efficiency are obtained from data in bins of p_T and qη of the muon, where q is the charge, using the tag and proble method. The uncertainties on the cross section are derived from a series of pseudo-experiments by allowing the weights to fluctuate randomly under a Gaussian assumption, according to their assigned uncertainty.
- **Fit**: For the fit method, three sources of systematic uncertainty are identified and considered to be uncorrelated. These are the shape of the signal pdf, the reconstructed $B^{\pm}$ mass and the shape of the background pdf.
- **Kaon track reconstruction:** The efficiency of hadron reconstruction is determined from MC, with the uncertainty dominated by the material description, and validated by data driven methods (2% - 4%).
- **Acceptance:** uncertainty from MC statistics (from 1% to 4%) and uncertainty from model-dependent kinematics (~0.1%).
- **$B^{\pm}$ vertex-finding efficiency** (2%).
- **Branching ratio** (3.4%).
- **Luminosity**: The luminosity scales determined by the ATLAS Collaboration for 2011 have been calibrated based on van der Meer scan data (1.8%).
- **Signal efficiency:** The efficiency correction factor for $B^{\pm}$ signal events is obtained from MC and dependes on uncertainty from MC statistics and uncertainty from K^+/K $^-$ efficiency asymmetry.





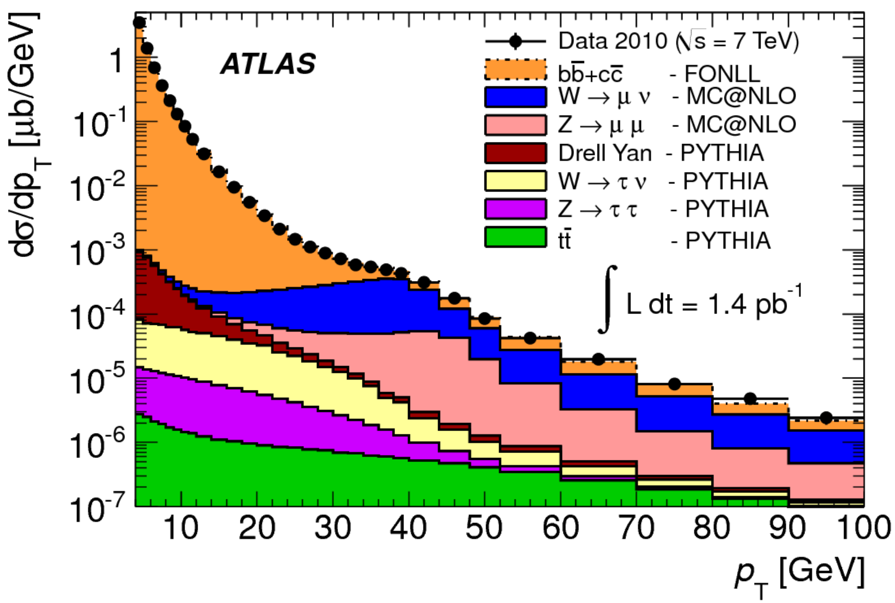
(details in: ATLAS-CONF-2013-008)

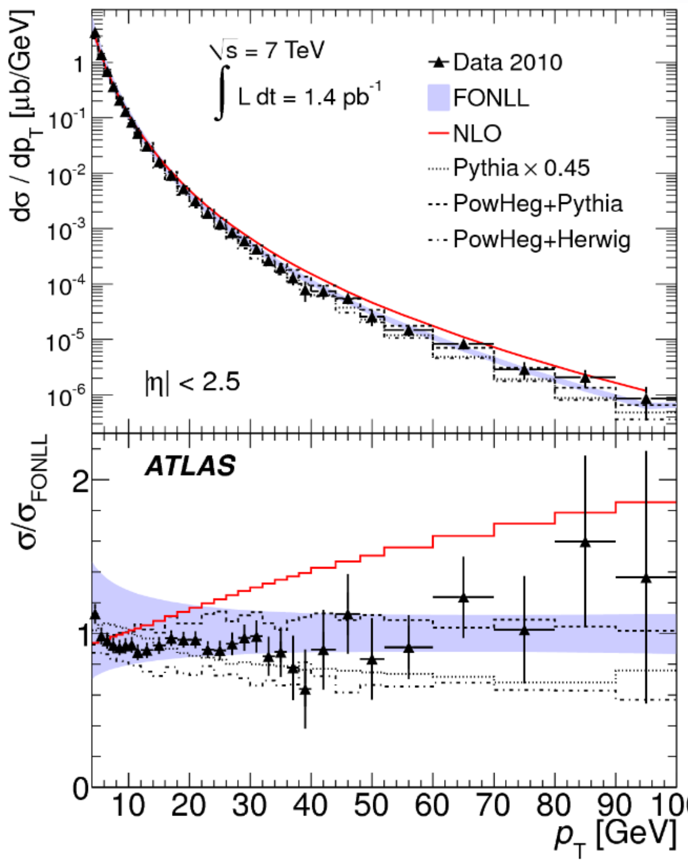
Inclusive muons cross section from heavy flavours in pp

ATLAS pp: $|\eta| < 2.5$, $4 < p_T(\mu) < 100$ GeV

Perturbative calculations in agreement at low p_T but deviate at higher p_T

FONLL doing well in the full range covered

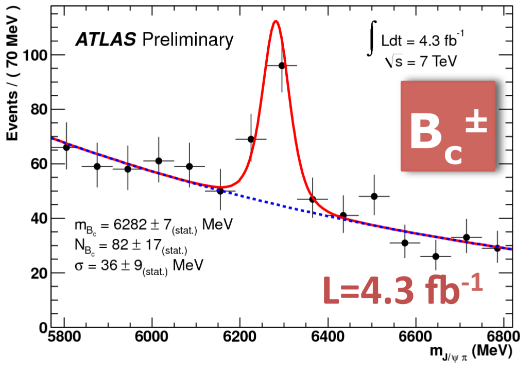




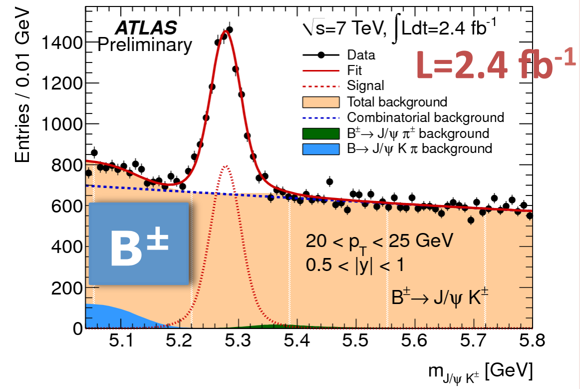
Phys.Lett. B707 (2012) 438-458

ATLAS B Spectroscopy Highlights

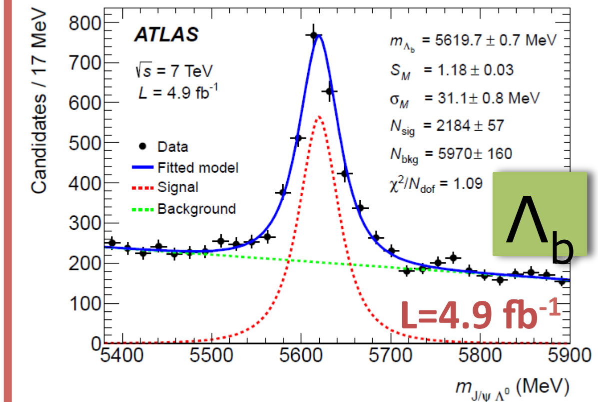
ATLAS-CONF-2012-028



ATLAS-CONF-2013-008

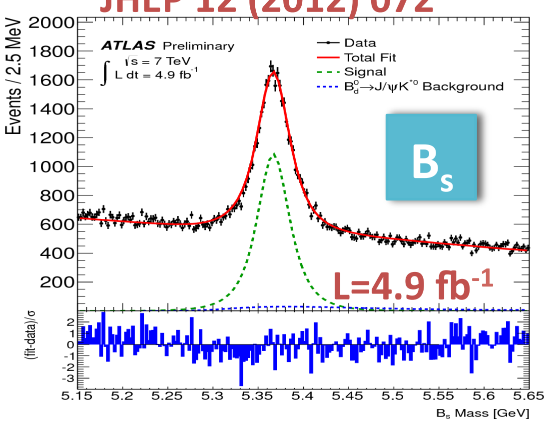


Phys. Rev. Lett. 108 (2012) 152001



Best Λ_b lifetime measurement
Competitive mass measurement

JHEP 12 (2012) 072



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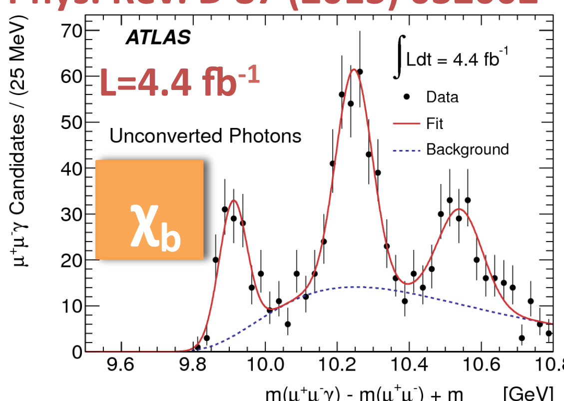
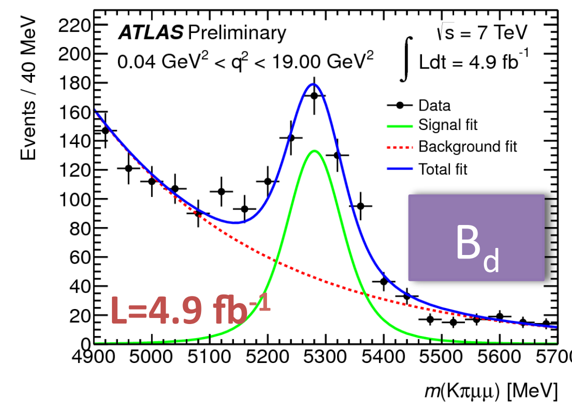


ATLAS-CONF-2013-038



Search for rare decays ($B^o_s \rightarrow \mu\mu$): Phys. Lett. B713 (2012) 180-196