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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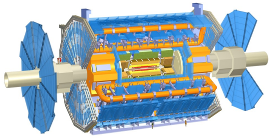
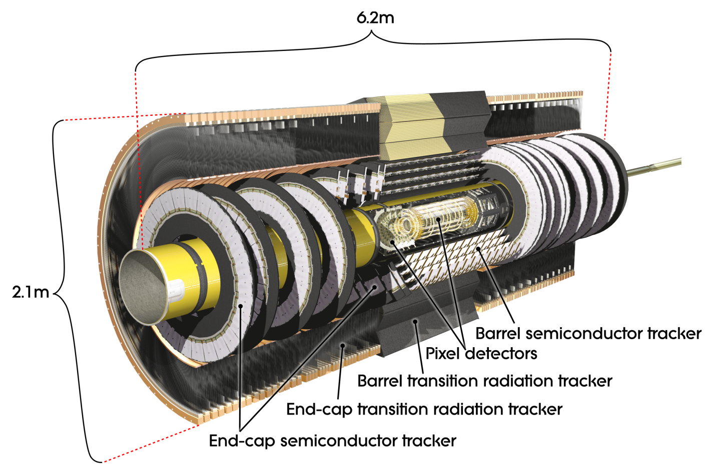
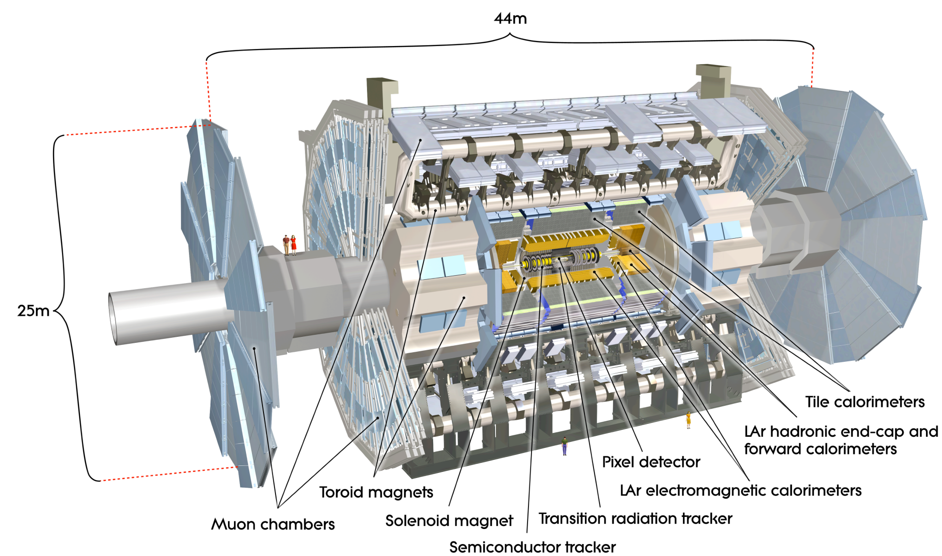
On behalf of ATLAS Collaboration



The ATLAS detector

ATLAS is a general purpose detector, designed to be sensitive to a wide range of physical phenomena: SM rediscovery, 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**
- $\sigma/p_T \sim 3.4\times10^{-4}\, p_T + 0.015$ for ($|\eta|<1.5$)
- Used for Tracking and Vertexing

Precise momentum and lifetime measurements

Muon Spectrometer

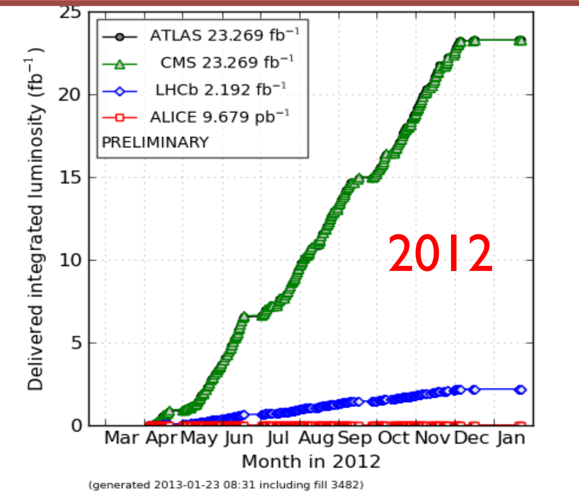
- $|\eta|<2.7$
- Toroid B-Field, average ~0.5 T
- Muon Momentum resolution $\sigma/p < 10\%$ up to ~ 1 TeV

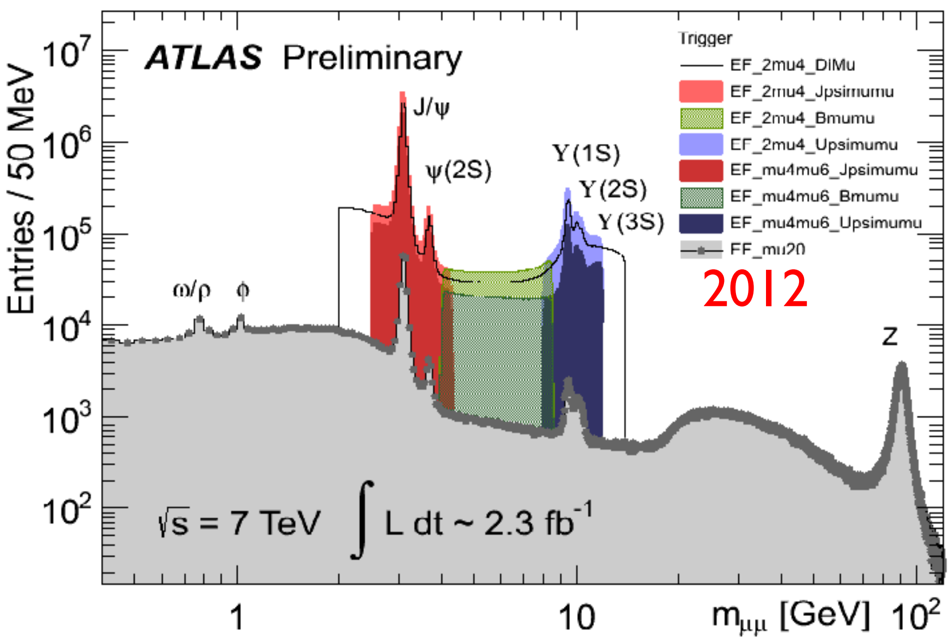
ATLAS Heavy Flavours overview

Wide program:

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

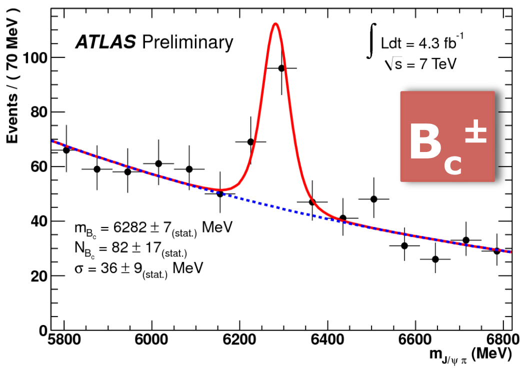
HF sensitive to new physics
ATLAS advantage: high luminosity



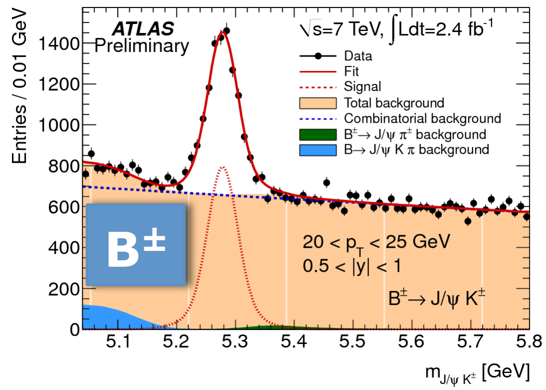


B-physics triggers based on single and di-muons: in 2011 and 2012 lower threshold, on both muons, at 4 GeV.

ATLAS B Spectroscopy Highlights



ATLAS-CONF-2012-028



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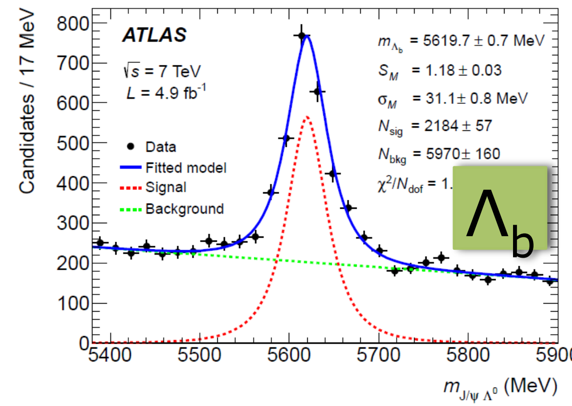
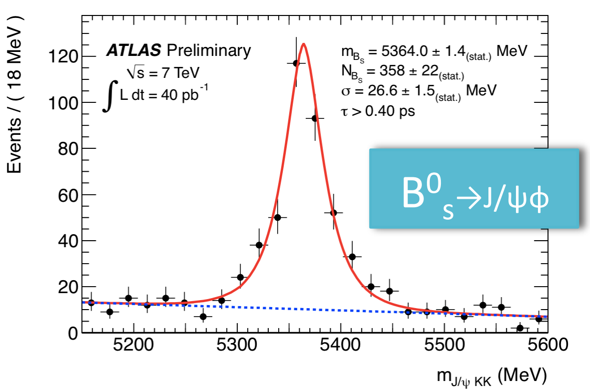
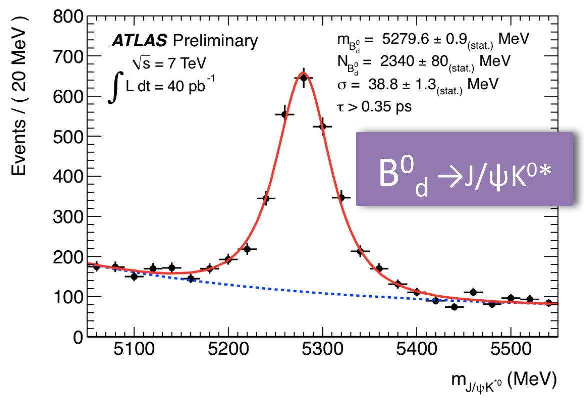


Best Λ_b lifetime measurement
Competitive mass measurement
Phys. Rev. Lett. 108 (2012) 152001

ATLAS-CONF-2011-050





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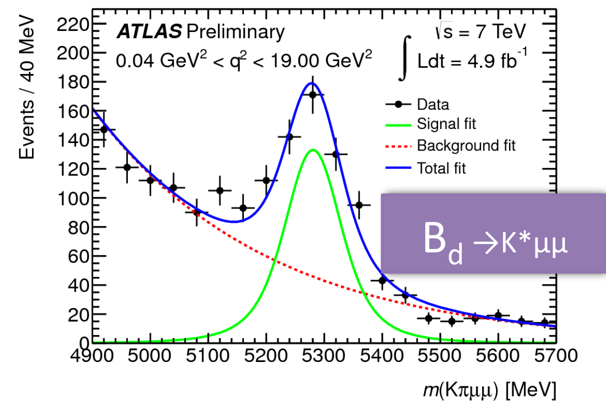


χ_b observation: Phys. Rev. D 87 (2013) 032002
Search for rare decays ($B^o_s \rightarrow \mu\mu$): Phys. Lett. B713 (2012) 180-196

b-hadron production at LHC

- The production of heavy quarks at hadron colliders provides a challenging test of QCD predictions.
- 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.

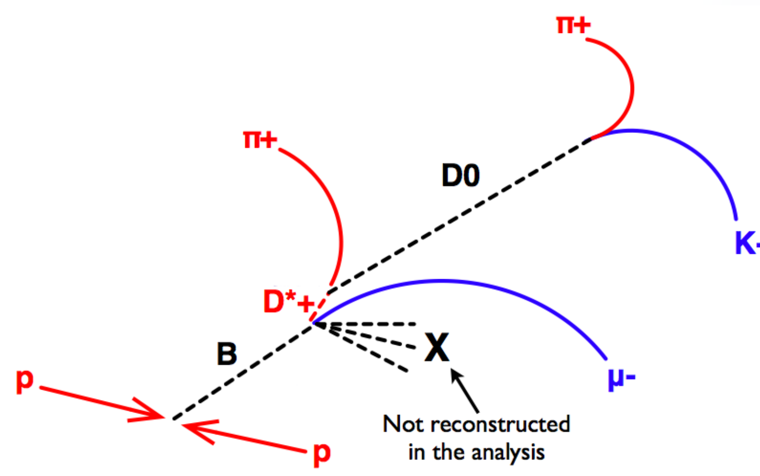
Open beauty production:

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

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

Nucl. Phys. B864 (2012) 341-381

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



Selection:

✧Trigger on muon with $p_T >$ 6 GeV

✧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)

✧**B candidate:** if 2.5GeV < m(D*μ) < 5.4 GeV

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

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

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

- $N^{D^*\mu}$: 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 $B(D^* \rightarrow D^0\pi)B(D^0 \rightarrow K\pi)$ world average value (2.63±0.04)%
- factor 2: $N^{D^*\mu}$ counts both $D^{*+}\mu^-$ and $D^{*-}\mu^+$

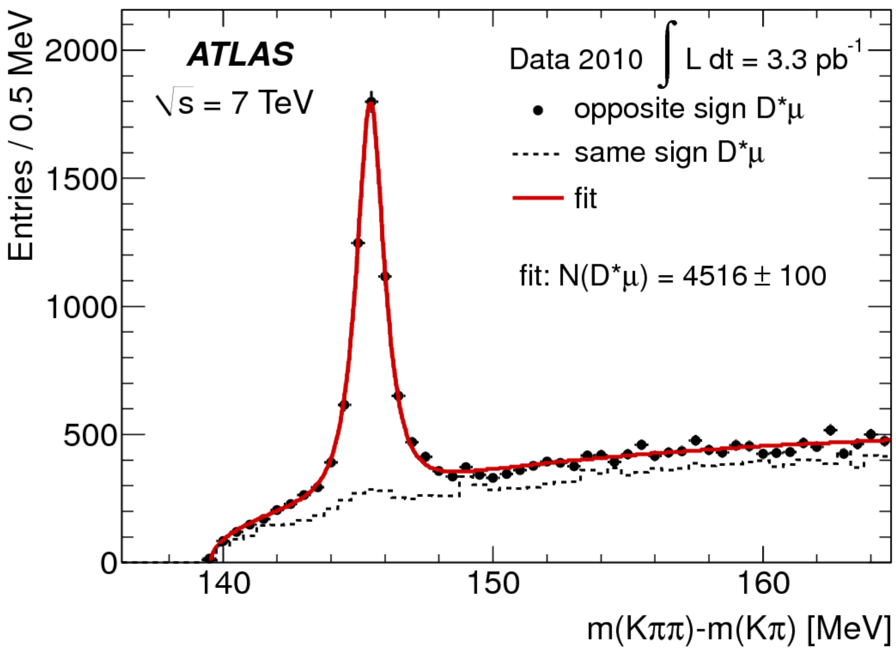
Unfolding is used to account for kinematics of the missing particles →

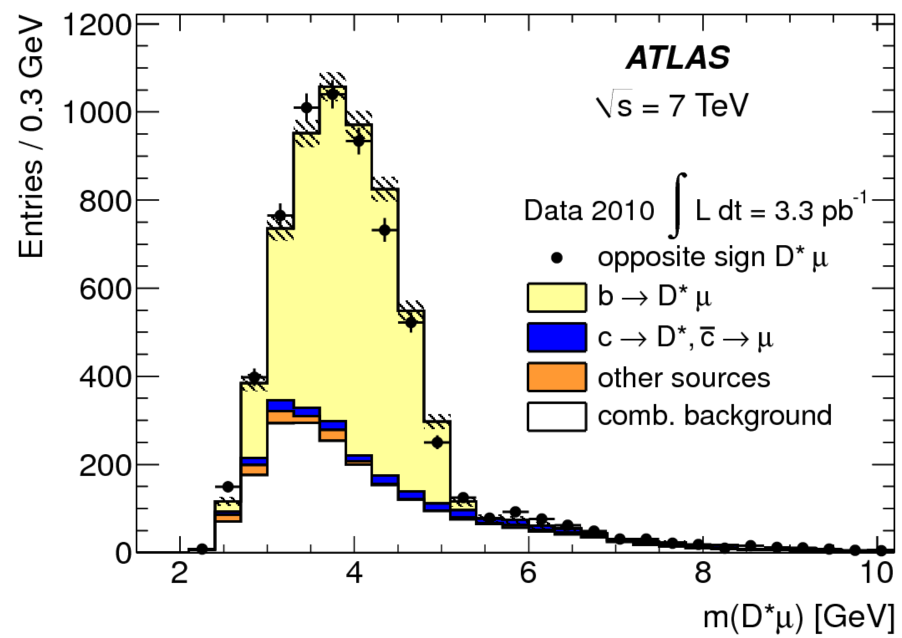
$$\frac{d\sigma(pp \to H_b X \to D^\star \mu X')}{dp_T(dy)}$$

Acceptance corrections and branching ratio $B(b \rightarrow D^*\mu X)$=(2.75±0.19)% are used to obtain the b-hadron production cross section →

$$\frac{d\sigma(pp \to H_b X)}{dp_T(dy)}$$

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





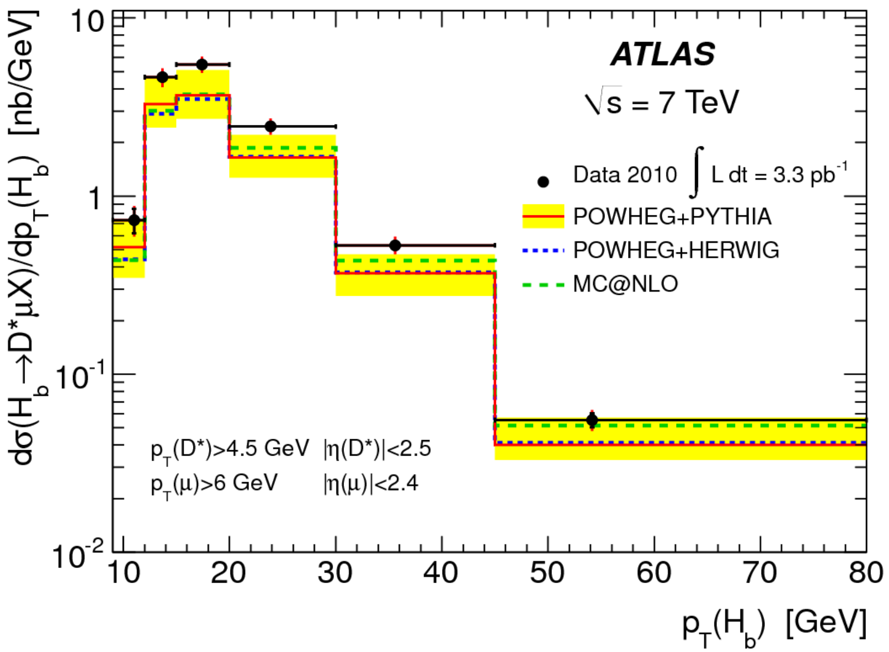
B candidates identied as opposite sign $D^*\mu$ excess in the D^* invariant mass distribution

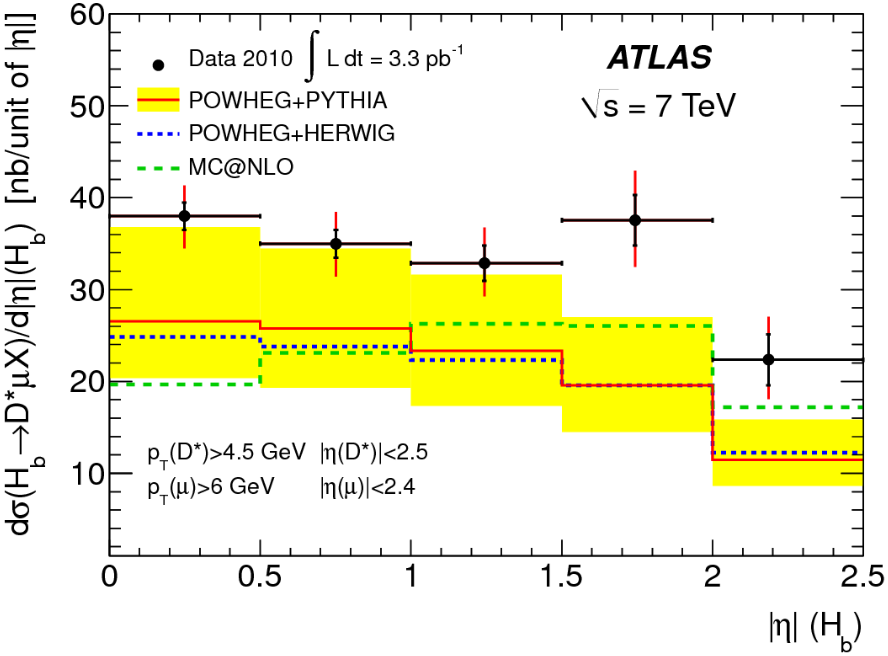
Signal composition shown in the $D^*\mu$ invariant mass distribution

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:

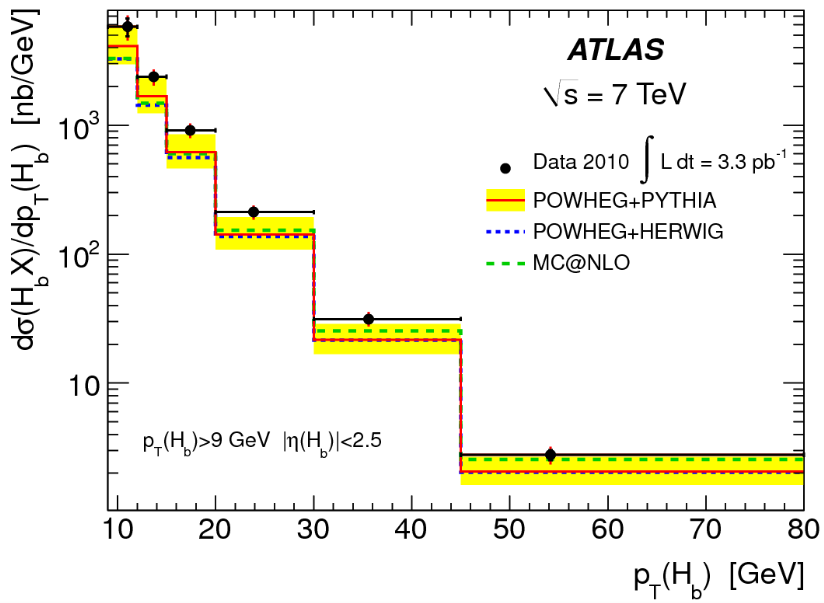
- $p_T\ (D^* \mu) > 4.5$ GeV $|\eta|\ (D^* \mu) < 2.5$
- $p_T\ (\mu) > 6$ GeV $|\eta|\ (\mu) < 2.4$

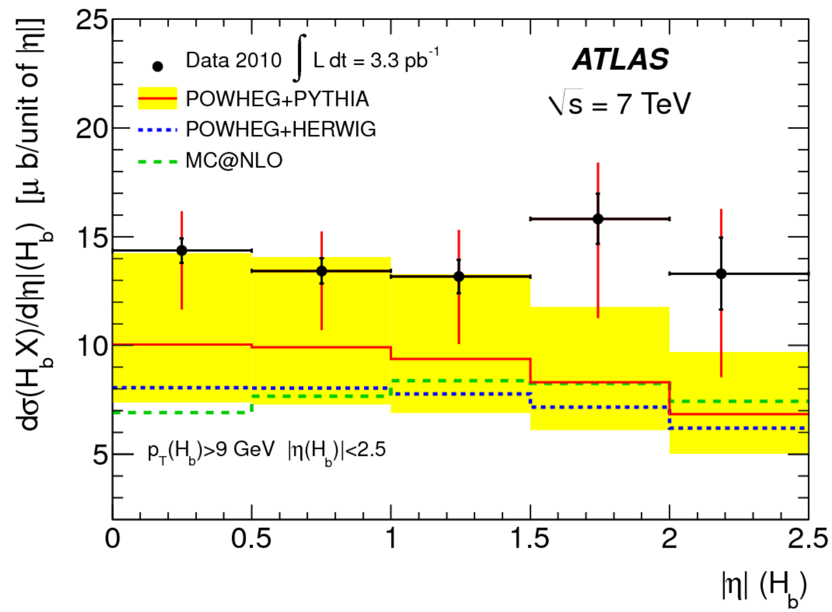




Unfolded cross section σ ($pp \rightarrow H_b X$)

- 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

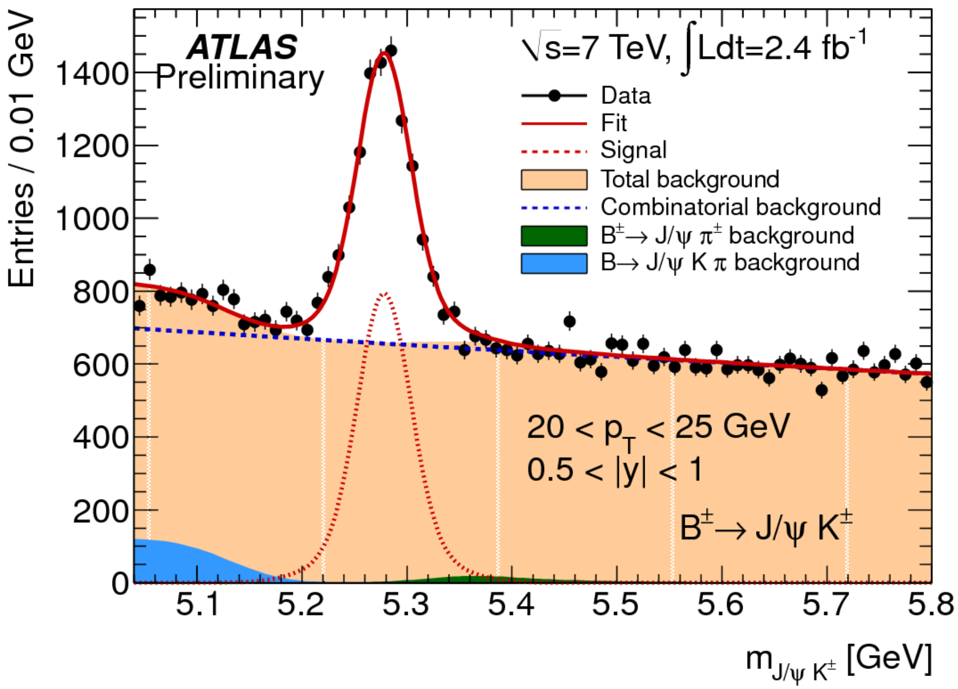
LHCb1 [Phys. Lett. B694 (2010) 209]: σ($pp \rightarrow H_b X$) = 284 ±20(stat) ±49(syst) μb

(LHCb result doesn't include extrapolation uncertainty)

Results are compatible

$B^{\pm} \rightarrow J/\psi\mu^{\pm}$: candidates selection

ATLAS-CONF-2013-008



Selection:

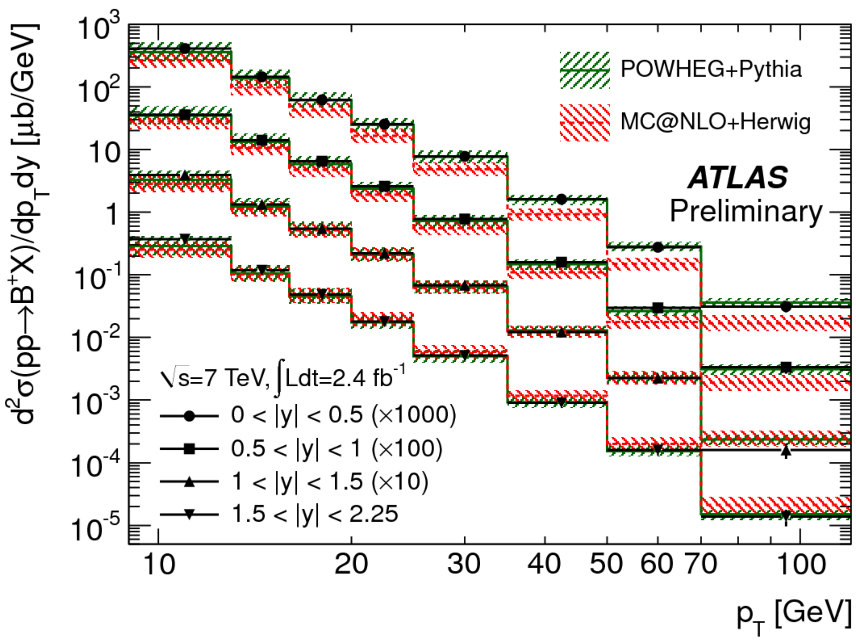
- **$J/\psi \rightarrow \mu^+\mu^-$:** J/ψ candidate with mass in the range [2.7,3.5] GeV
- muon tracks of the selected J/ψ candidate are fitted to a common vertex with an additional charged track of $p_T >$ 1 GeV
- **$B^{\pm}$ candidate:** retain $B^{\pm}$ candidate if $p_T >$ 9 GeV and $|y| <$ 2.3

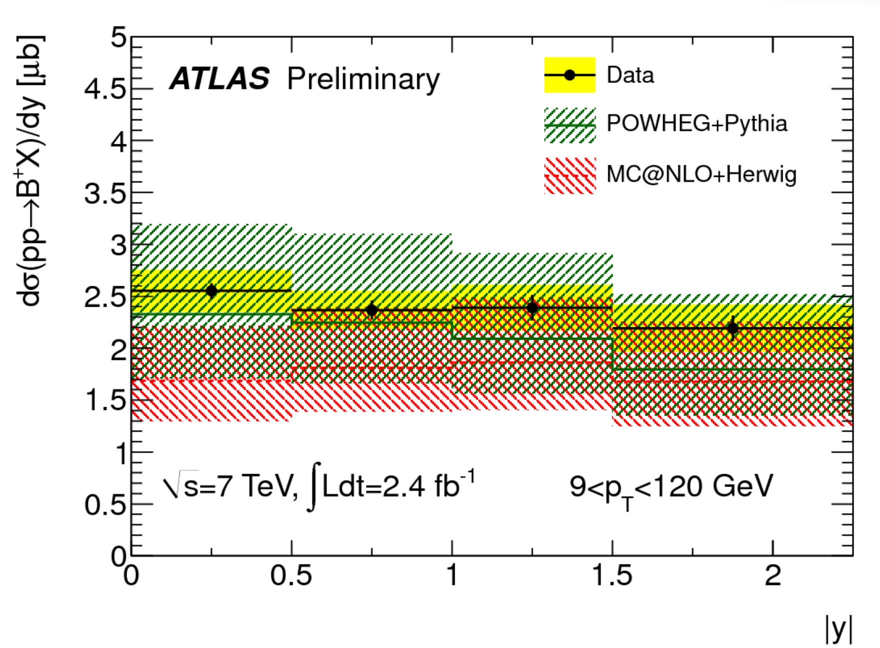
$B^\pm \rightarrow J/\psi\mu^\pm$: cross-section

Differential cross-section

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

- 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

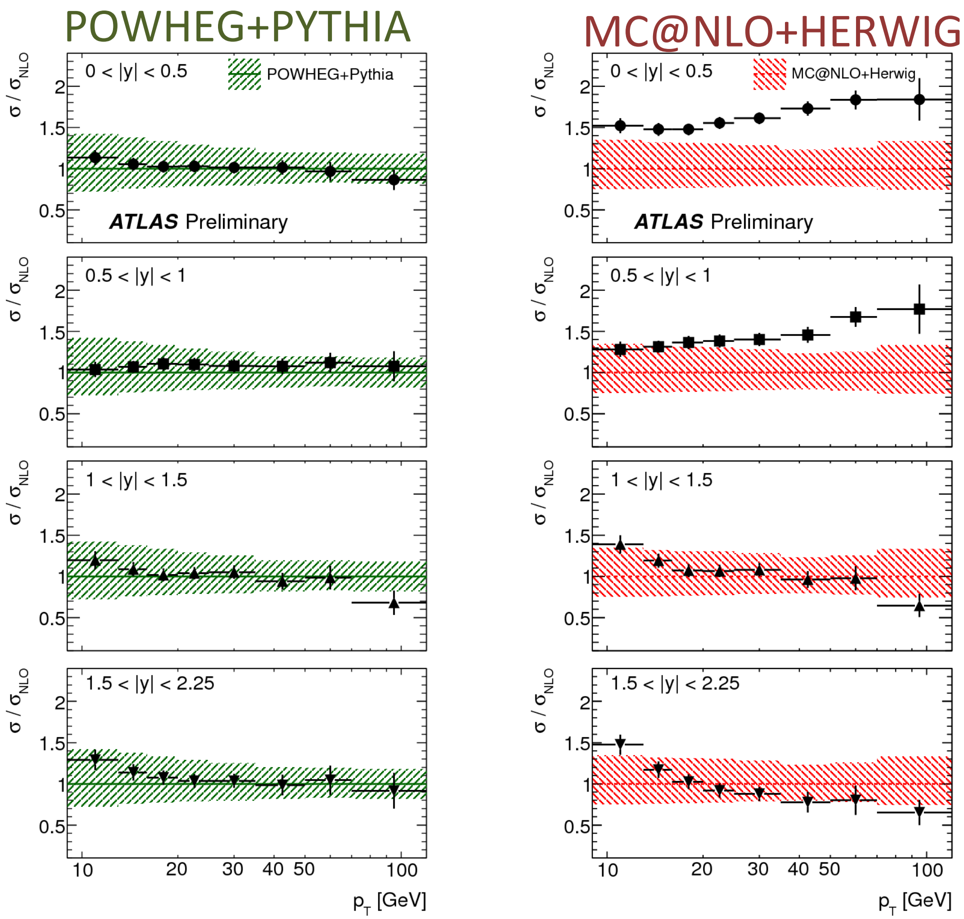




POWHEG+PYTHIA: good agreement in absolute scale and in the dependence of $\mathbf{p_T}$ and **y**

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.

$B^\pm \rightarrow J/\psi\mu^\pm$: cross-section



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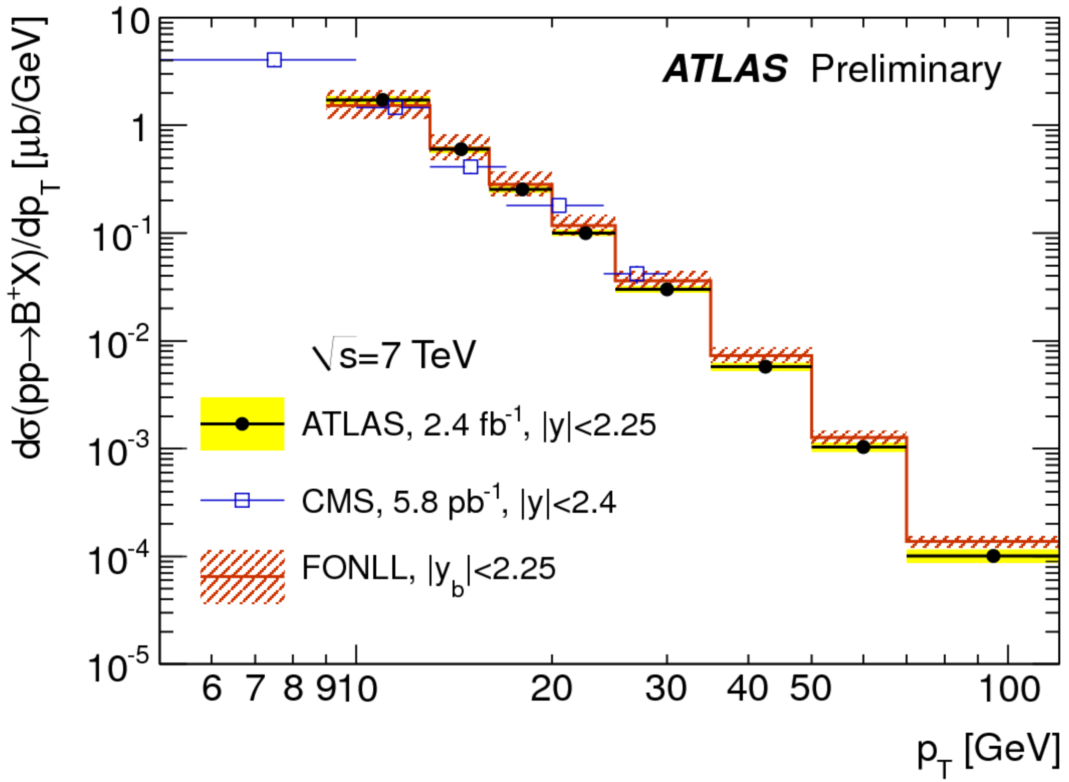
$B^{\pm} \rightarrow J/\psi\mu^{\pm}$: cross-section



Fixed-Order-Next-to-Leading Logarithm (FONLL) (with $\mathbf{f_b \rightarrow B^+}$ = (0.401 ± 0.013)) is in good agreement with the measured $\mathbf{d\sigma/dp_T}$.

Results also in good agreement with CMS.

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 in:
    - b-hadron production cross-section from $D^*\mu X$ final states 3.3 pb^{-1}: **Nucl. Phys. B864 (2012) 341-381**
    - Production cross section of B^+ at $\sqrt{s}$ = 7TeV ($B^\pm \rightarrow J/\psi\mu^\pm$): ATLAS-CONF-2013-008
  - Data/Theory comparison: few production measurements in tension with the corresponding theory predictions, although in agreement within uncertainties.
  - Aim at continuing improving the understanding of heavy flavor and quarkonia hadroproduction and theory-experiment convergence.

  - Other interesting results:
    - QCD production
    - rare decays: $Br(B_s \rightarrow \mu\mu) < 4.2 \times 10^{-9}$ 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

Observation of $B^{\pm}$ mesons: $B^{\pm} \rightarrow J/\psi K^{\pm}$

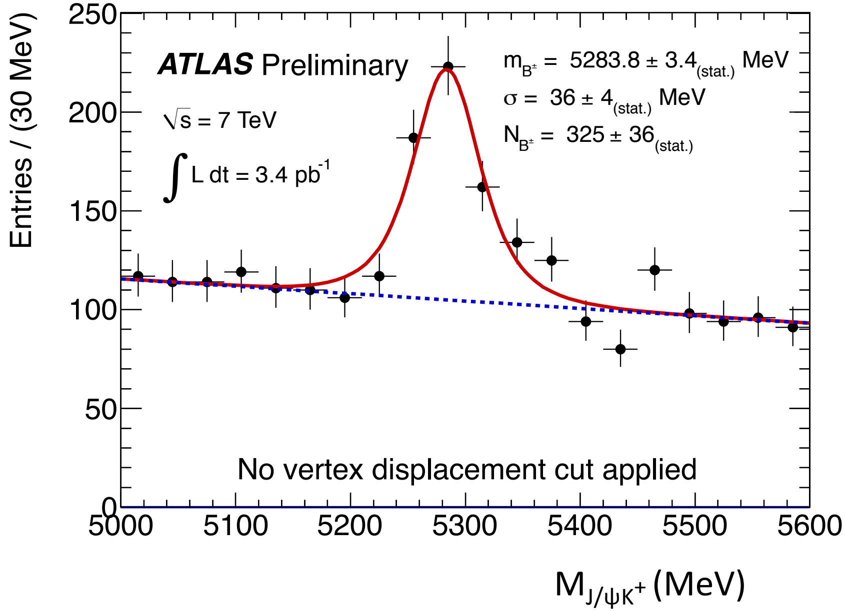
$J/\psi \rightarrow \mu^{+}\mu^{-}$

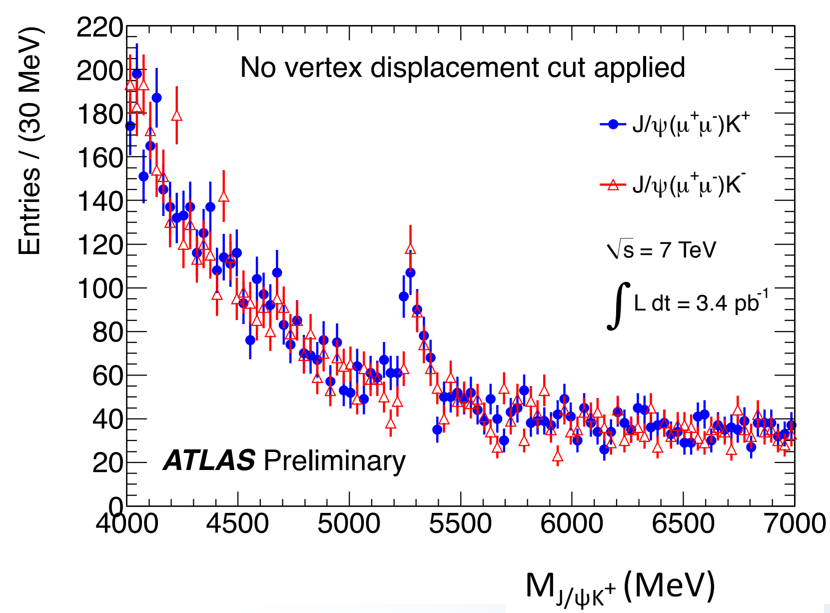
ATLAS-CONF-2010-098

Reference channel for other B decay measurements.
Cross section measurement imminent.

Data taken from June to August 2010, using single- and di-muon triggers:

- ✓ Di-muon in the J/ψ mass range combined with a third track (kaon mass assigned).
- ✓ Fitted 3-track vertex, with J/ψ mass constraint on di-muon
- ✓ Unbinned maximum likelihood: the Gaussian signal description uses per candidate uncertainties; for the background the mass distribution is modelled with a linear function

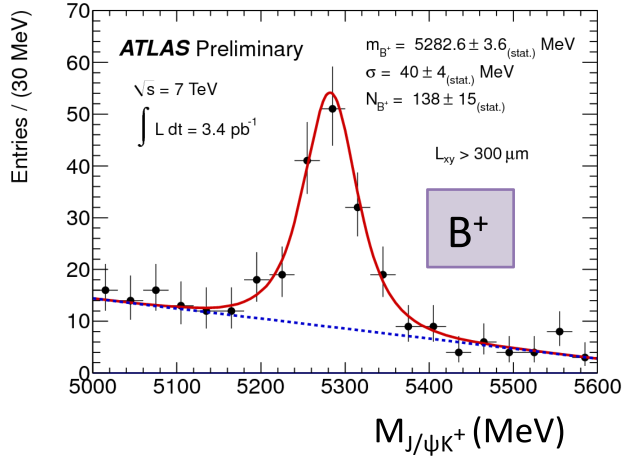


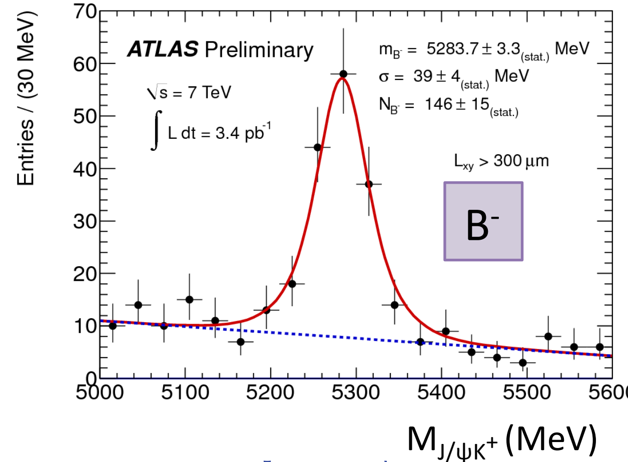


$B^{\pm} \to J/\psi(\mu\mu)K^{\pm}$

ATLAS-CONF-2010-098

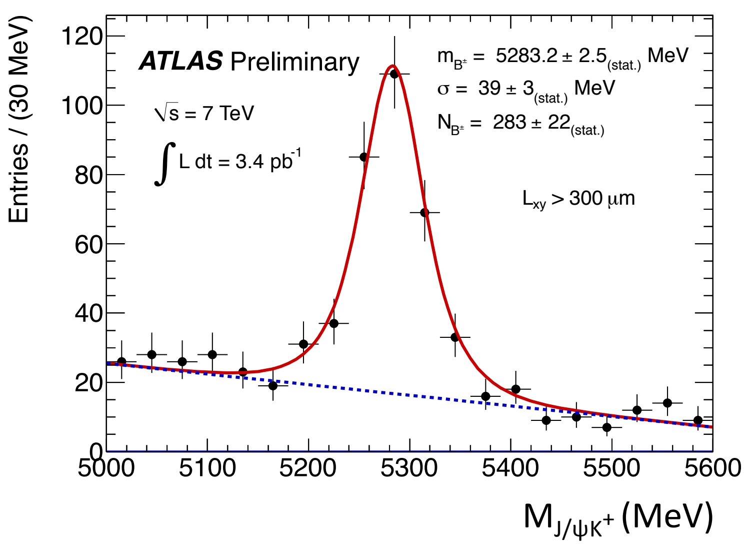
Positive and negative states are observed with consistent fitted parameters

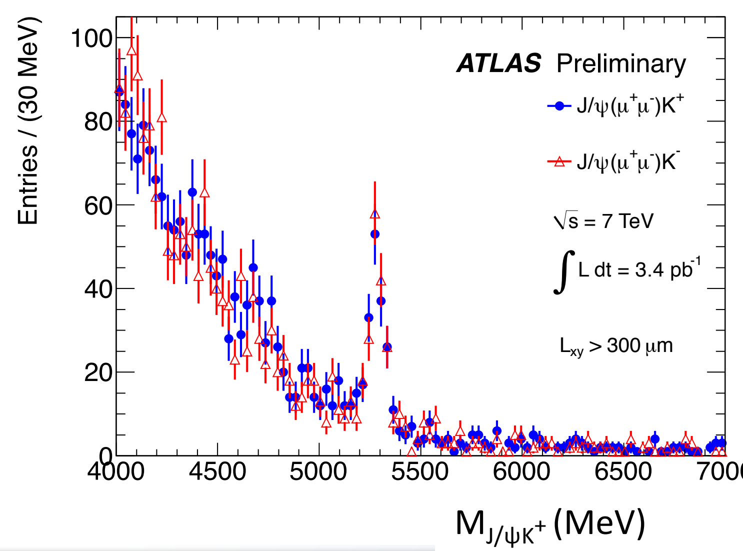




Background suppression by applying a cut on transverse decay length L_{xy} > 0.3 mm

Factor of 6 reduction in background with ~13% loss of signal.





Mass compatible with PDG value:

ATLAS: M(B) = 5283.2 ± 2.5 MeV PDG: M(B) = 5279.17± 0.29MeV

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

f_b: fraction of $D^*\mu$ candidates from a single b decay (MC)

$N^{D^*\mu}$: number of reconstructed $D^*\mu$ pairs

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

factor 2: $N^{D^*\mu}$ counts both $D^{*+}\mu^-$ and $D^{*-}\mu^+$

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

ε: reconstruction, trigger and selection efficiency

$\mathcal{B}$: total branching ratio $B(D^* \rightarrow D^0\pi)B(D^0 \rightarrow K\pi)$ world average value (2.63±0.04)%

Unfolding is used to account for kinematics of the missing particles and obtain: $\frac{d\sigma(pp \to H_b X \to D^*\mu X')}{dp_T(dy)}$

Acceptance corrections and branching ratio B ($b \rightarrow D^*\mu X$) are used to obtain: $\frac{d\sigma(pp \to H_b X)}{dp_T(dy)}$

Systematics on NLO QCD predictions for σ ($pp \rightarrow H_b X \rightarrow D^* \mu X$)

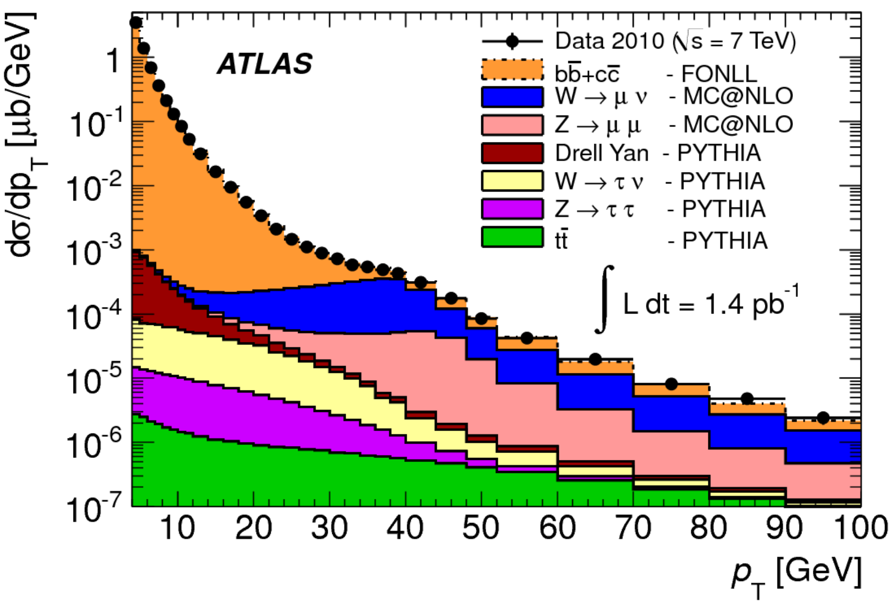
- Scale uncertainty, determined by varying μ_r and μ_f independently to $\mu/2$ and 2μ , with the additional constraint $1/2 < \mu_r/\mu_f < 2\mu$, and selecting the largest positive and negative variations
- m_b uncertainty, determined by varying the b-quark mass (4.75 GeV) by ±0.25 GeV
- PDF uncertainty, determined by using the CTEQ6.6 PDF error eigenvectors; the total uncertainty is obtained by varying each parameter independently within these errors and summing the resulting variations in quadrature
- Hadronisation uncertainty, determined in PYTHIA by using the Peterson fragmentation function instead of the Bowler one, with extreme choices of the b -quark fragmentation parameter: b=0.002 and b=0.01

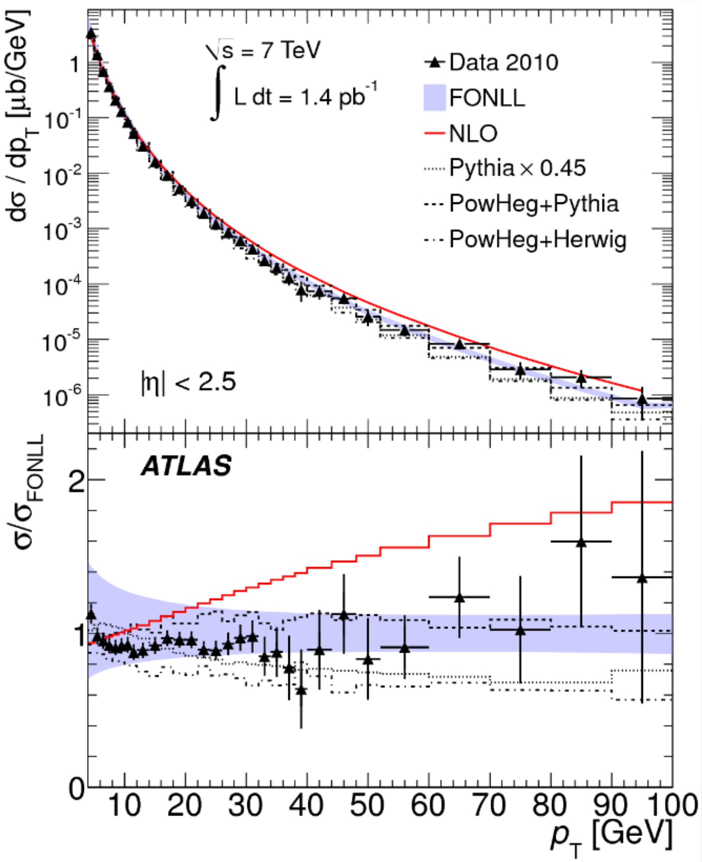
Inclusive muons cross section from heavy flavours in pp

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





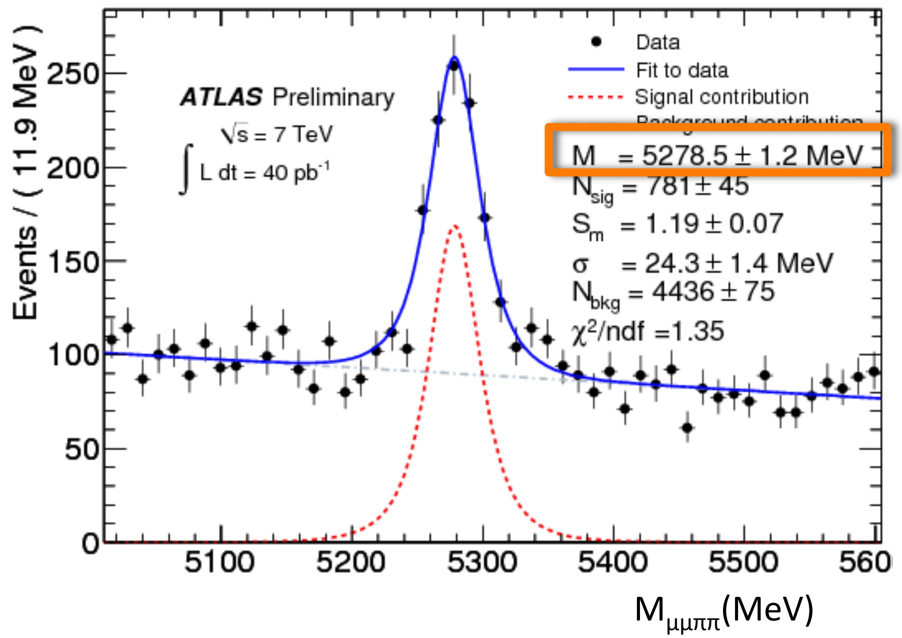
Phys.Lett. B707 (2012) 438-458

$B^0_d \to J/\psi K^0_S$

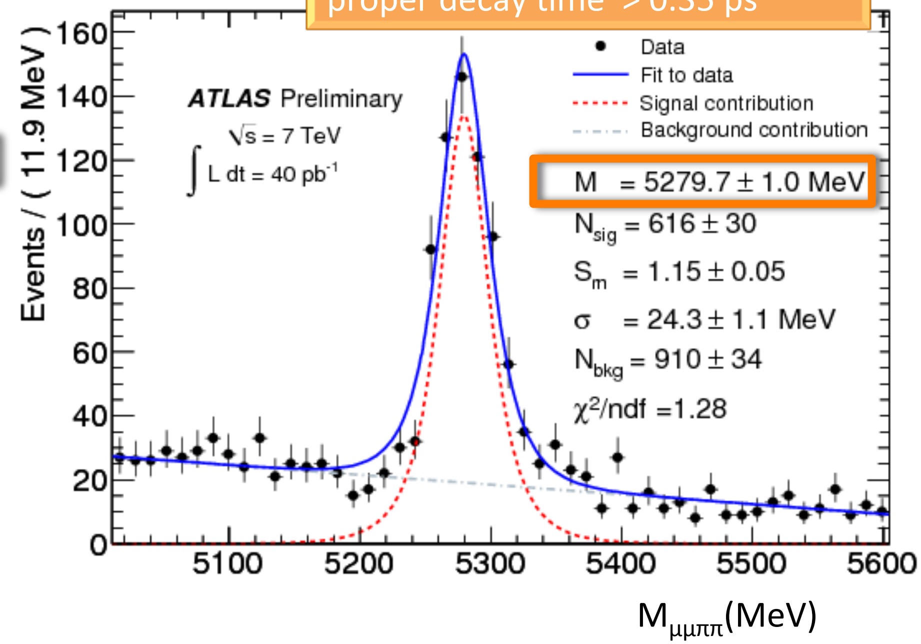
$J/\psi \to \mu^+\mu^-$, $K^0_S \to \pi^+\pi^-$

Decays of neutral *B* mesons into *CP* eigenstates are of particular interest for *B*- physics:

- ✓ *CP* violation studies
- ✓ decay channels have an easily identifiable experimental signature
- ✓ The B^0_d lifetime measurement presents an opportunity for testing the theoretical predictions of the Heavy Quark Effective Theory (HQET) and perturbative QCD (pQCD).



proper decay time > 0.35 ps

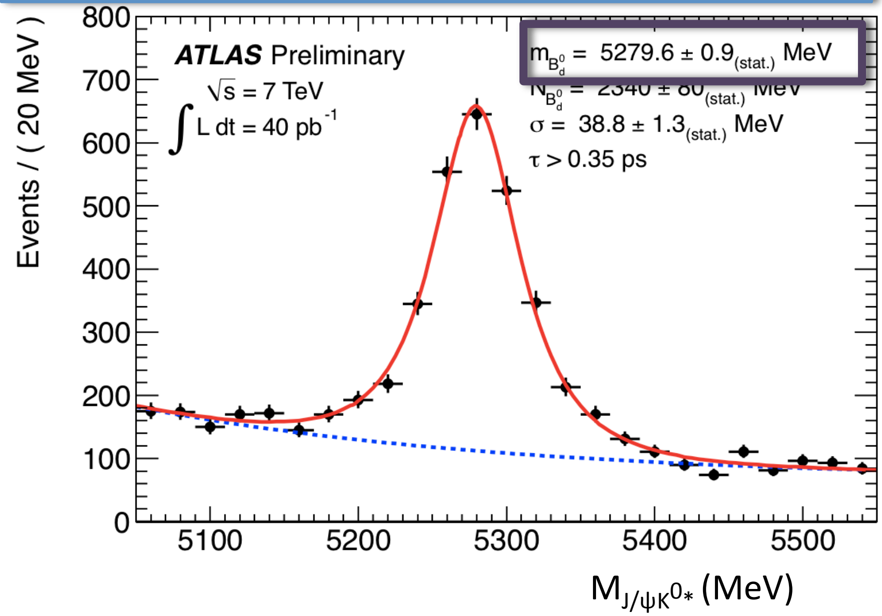


B^0_d measured mass is consistent with the world average 5279.50 ± 0.30 MeV

$B^0_d \to J/\psi K^{0*}$ and $B^0_s \to J/\psi\varphi$

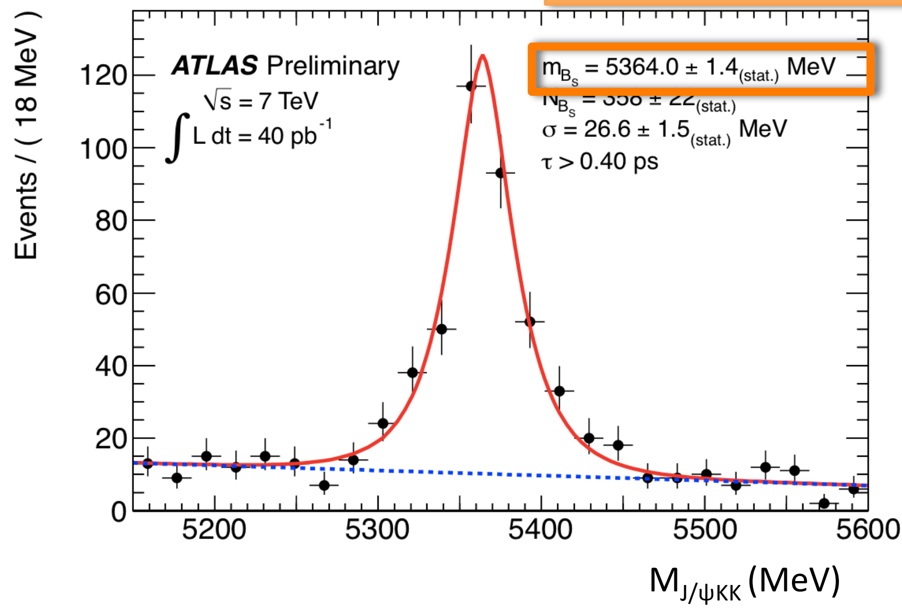
Select 2 muon tracks candidates
Select 2 additional tracks, assume $K^{0*} \to K^+\pi^-$ or $\phi \to K^+K^-$
Fit 4-track vertex; constrain $\mu^+\mu^-$ to $M(J/\psi)$
Apply cuts on $M(\phi)$ or $M(K^{0*})$
Unbinned maximum likelihood fit: Gaussian signal, linear background

$B^0_d \to J/\psi K^{0*}$ and anti-$B^0_d \to J/\psi K^{0*}$



The solid line is the projection of the result of the unbinned maximum likelihood fit to all candidates in the mass range from 5050 MeV to 5550 MeV.

$B^0_s \to J/\psi\phi$



The solid line is the projection of the result of the unbinned maximum likelihood fit to all $J/\psi(\mu^+\mu^-)\phi(KK)$ candidates in the mass range from 5150 MeV to 5600 MeV.

D-mesons production

- ✓ *D-mesons are produced in c and b fragmentation*
- ✓ *c and b quark production are hard processes ($m_Q >> \Lambda_{QCD}$)*
- ✓ *Theoretical calculations available up to NLO+NNLO level*
- ✓ *Still large theoretical uncertainties (scales, multiple interactions)*

Reconstruction of *D-mesons already feasible with first ATLAS data* *due to:*

- ✧ *large cross-section values*
- ✧ *clean D-meson signatures*
- ✧ *precise ATLAS tracking and vertexing*

expected cc and bb cross sections in p-p collisions at $\sqrt{s}$ = 7 TeV:
σ(cc) ~ 4.4 mb σ(bb) ~ 0.24 mb
first charm processes reconstructed in ATLAS:

$D^{*+} \rightarrow D^0\pi^+ \rightarrow (K^-\pi^+)\pi^+$ (+c.c.)

$D^+ \rightarrow K^-\pi^+\pi^+$ (+c.c.)

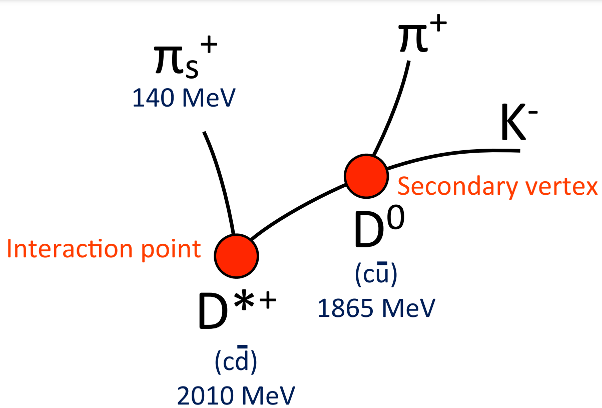
$D_s^+ \rightarrow \Phi\,\pi^+ \rightarrow (K^-K^+)\pi^+$ (+c.c.)

D-mesons production: D*

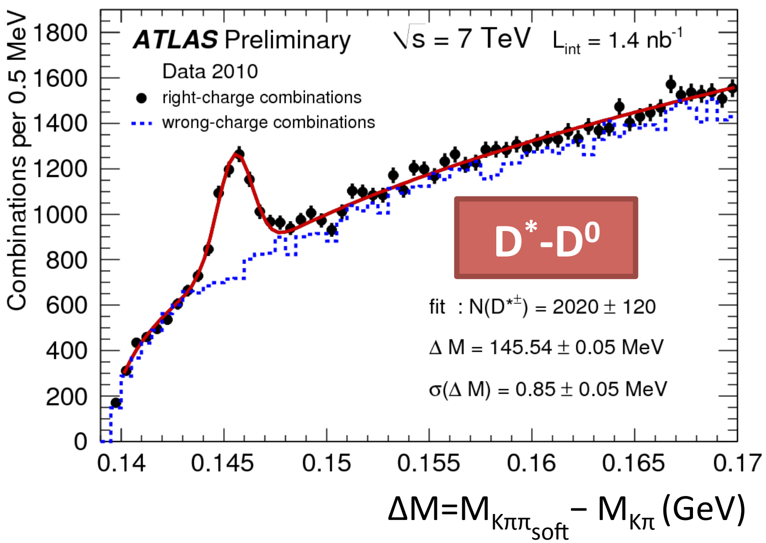
Build D^0 signal from $M(K\pi)$ for $D^{*\pm}$ candidates
Additional discrimination from mass difference
$\Delta M = M(K\pi\pi_s)-M(K\pi)$

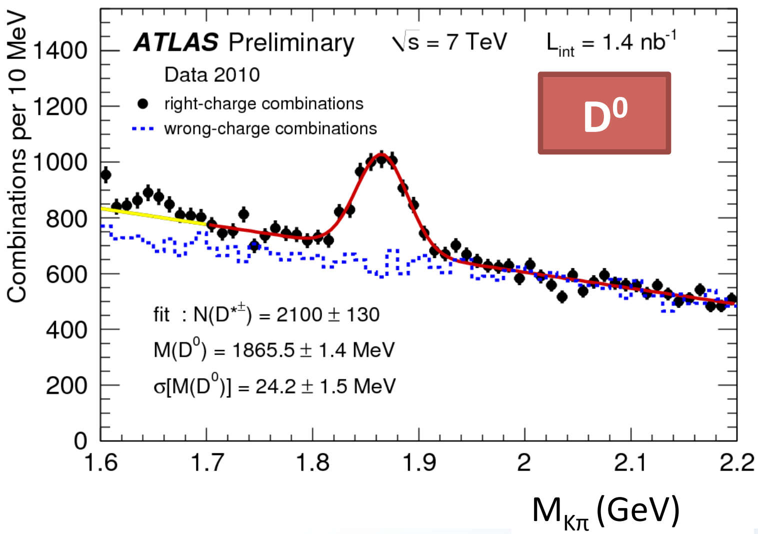
Use presence of secondary vertex and properties of hard process to guide cut selection to enhance signal

$D^{*+} \to D^0\pi^+_{soft} \to (K^-\pi^+)\pi^+_{soft}$ (+c.c.)



- Minimum bias trigger
- Hard production and fragmentation cuts on $p_T(D^*)$, $p_T(K,\pi)$, $p_T(D^*)/\Sigma E_T$
- Charge constraints $q(K)=-q(\pi,\pi_s)$
- Vertex reconstruction $D^{*\pm}$, D^0
- Decay length $L_{XY}(D^0)>0$

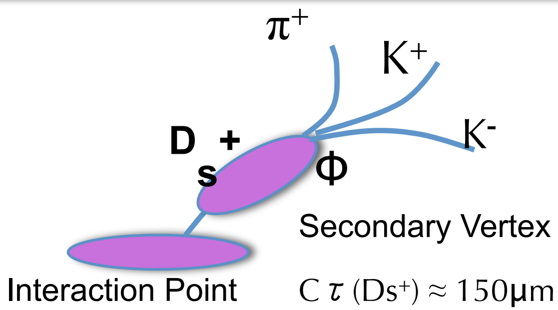


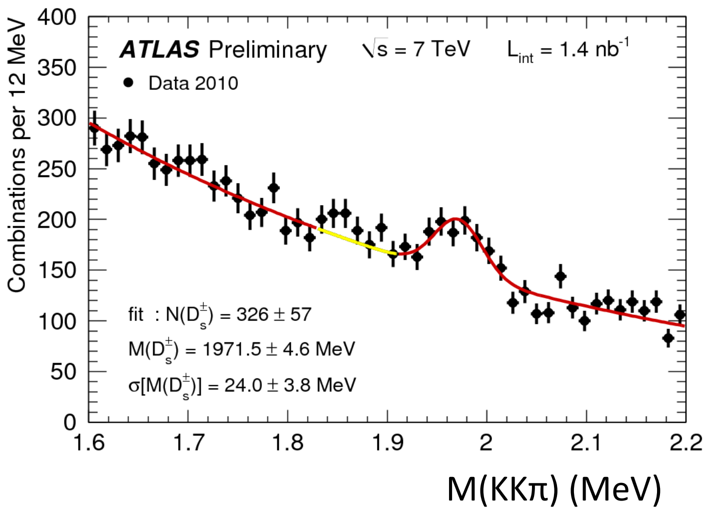


Mesons	PDG Mass (MeV)	ATLAS Mass (MeV)
$D^* - D^0$	145.42 ± 0.01	145.54 ± 0.05(stat.)
D^0	1864.83 ±0.14	1865.5 ± 1.4(stat.)

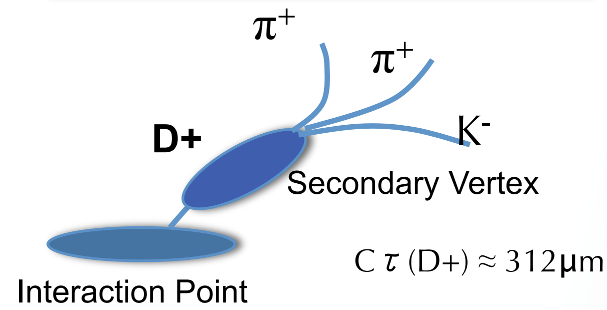
D-mesons production: D_s^+ and D^+

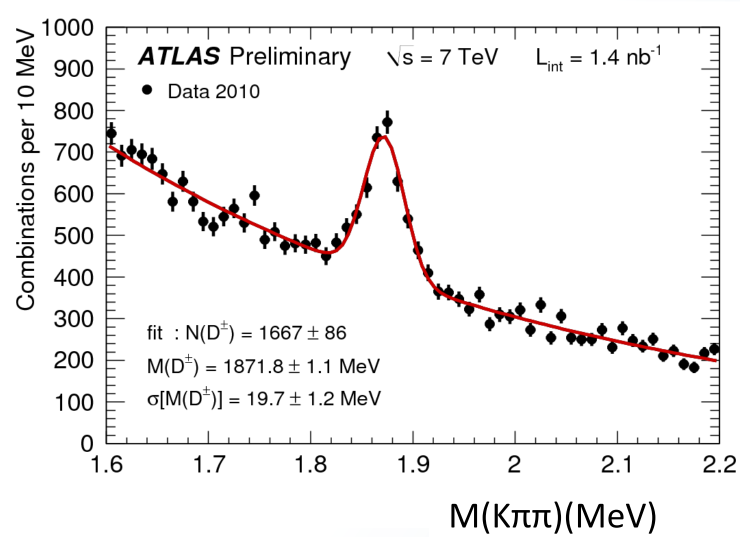
$D_s^+ \rightarrow \Phi \pi^+ \rightarrow (K^- K^+)\pi^+ (+c.c.)$





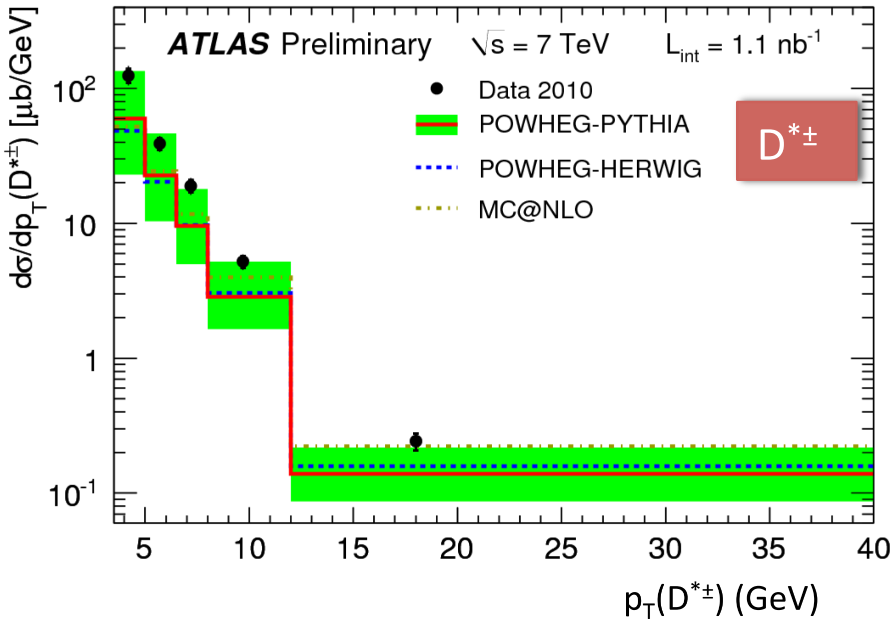
$D^+ \rightarrow K^- \pi^+ \pi^+ (+c.c.)$

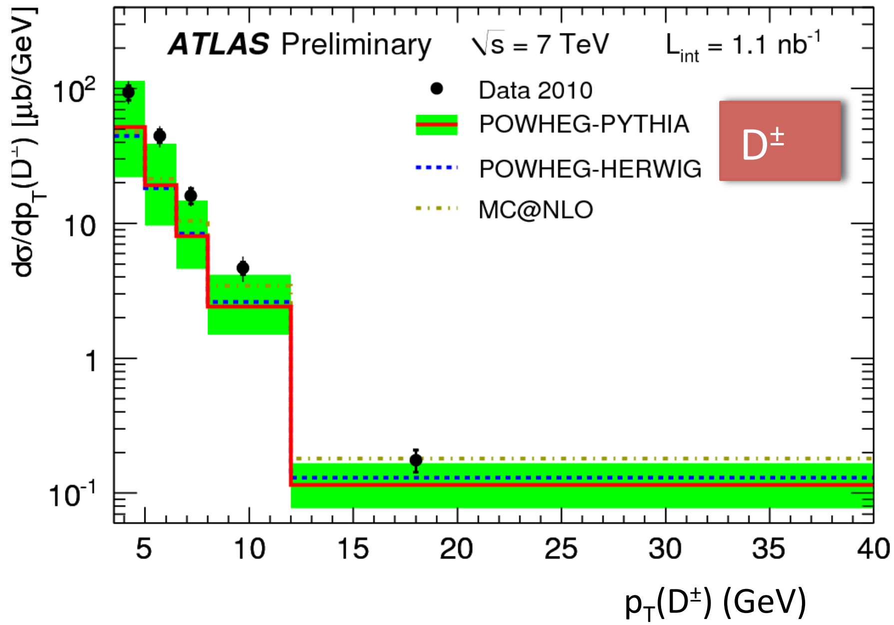




Mesons	PDG Mass (MeV)	ATLAS Mass (MeV)
$D^\pm$	1869.60 ± 0.16	1871.8 ± 1.1(stat.)
$D_s^\pm$	1968.47 ±0.33	1971.5 ± 4.6(stat.)

D meson differential cross sections w.r.t. p_T





Experimental uncertainties dominated by:
- ✓ luminosity
- ✓ tracks reconstruction
- ✓ D selection efficiency

MC Uncertainties due to:
- ✓ renormalization scale
- ✓ factorization scale
- ✓ small: q_{mass} PDF and hadronization

Data higher than NLO predictions, but within large theoretical (scale) uncertainties