Studies of B_c meson with the ATLAS experiment

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Introduction

Studies of B_c^+ meson: motivation

First observed: CDF, 1998, semileptonic mode ($J/\psi\mu^+\nu_\mu$), later hadronic mode ($J/\psi\pi^+$)

- Heavy quark **production dynamics** with a unique system of two different heavy flavours
  - *Cross section* measurements (CDF, CMS, LHCb)
- B_c^+ **decay model**: $\bar{b}$ and c decays compete, weak annihilation can substantially contribute
  - *Lifetime* (CDF, D0, LHCb) and *(relative) decay branching ratios* (LHCb, CMS) measurements
- **Spectroscopy** of $\bar{b}c$ system is well described by numerous models
  - Searches for *new states* (ATLAS)

Outline of this talk

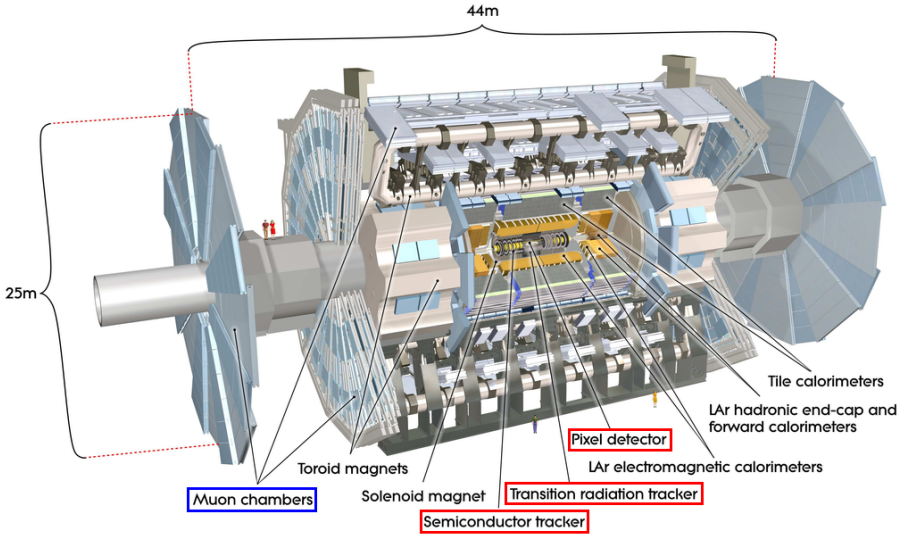
- ATLAS detector
- Observation of B_c^+ meson with 7 TeV data in $B_c^+ \to J/\psi\pi^+$ mode
- First observation of an excited state of B_c^+ consistent with predictions for $B_c^+(2S)$
- Summary

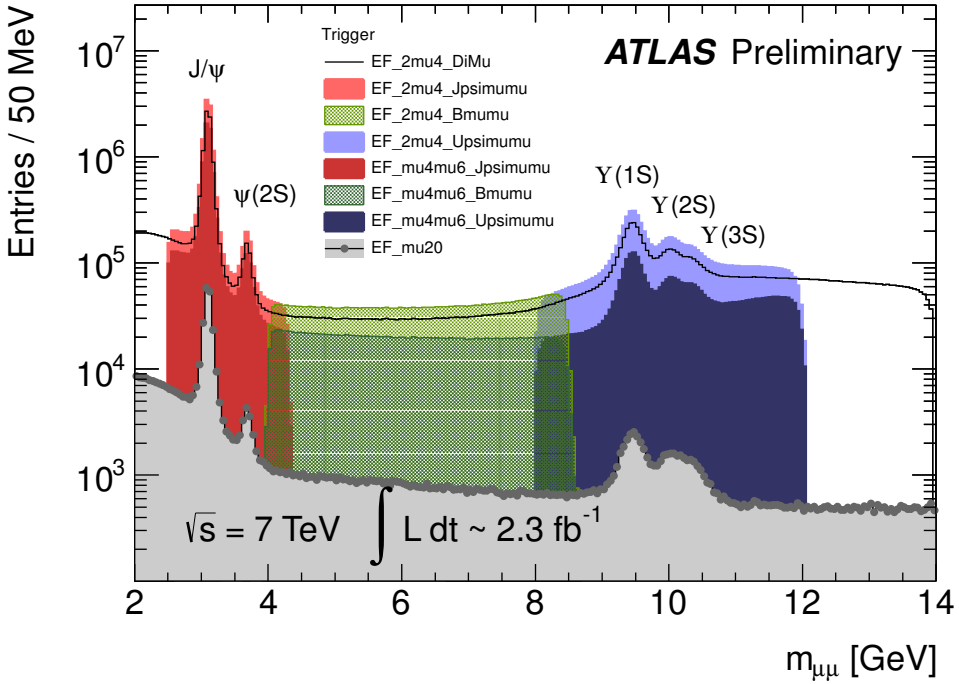
ATLAS detector and trigger system

- Tracking **Inner Detector** in 2 T solenoid field
- **Muon system** put inside a toroid
- ATLAS **trigger system**: hardware *Level-1 trigger* and two-level software *High-Level Trigger*

Trigger selection for heavy flavour studies is mostly based on di-muon signature

- muon p_T threshold (4 or 6 GeV)
- di-muon vertex reconstruction
- invariant mass window





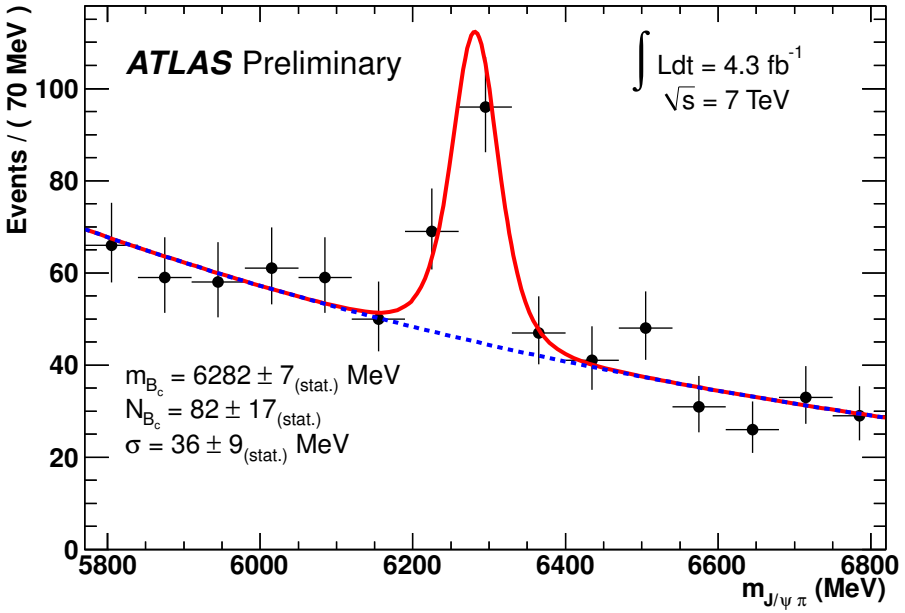
$B_c^+ \to J/\psi\pi^+$ observation

ATLAS-CONF-2012-028

- Full *7 TeV dataset* used
- Muon pairs fitted to a common vertex to form a *J/ψ candidate*
  - $\chi^2/\mathrm{n.d.f.}(J/\psi) < 15$
  - $m(J/\psi)$ within ± 180 MeV around the nominal mass
- Combined with another track, fitted to a *B_c^+ candidate vertex*
  - $\chi^2/\mathrm{n.d.f.}(B_c^+) < 2$
  - $p_T(\mu_1, \mu_2) > 4, 6$ GeV
  - $p_T(\pi^+) > 4$ GeV
  - $p_T(B_c^+) > 15$ GeV
  - transverse impact parameter significance of pion track

$$\frac{d_{xy}^0}{\sigma(d_{xy}^0)} > 5$$

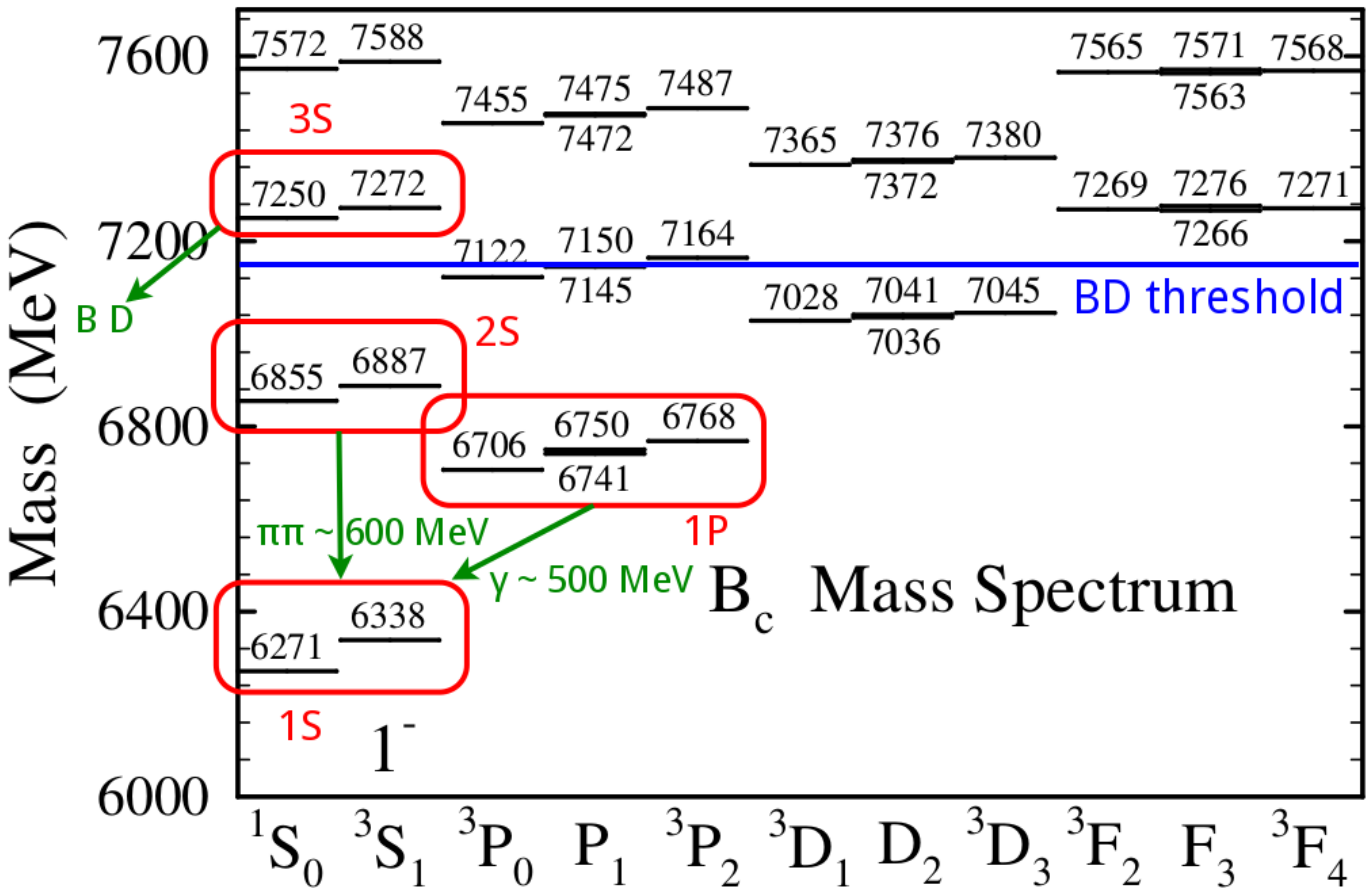
more useful than cutting the decay length (low B_c^+ lifetime)



- Significance of the observed signal exceeds *5 standard deviations*
- No cross-section measurement performed yet – to be done in future with full Run 1 dataset

Search for B_c^+ excited states

- No excited states of B_c^+ reported previously
- The spectrum and properties of B_c^+ family are predicted by non-relativistic potential models, perturbative QCD and lattice calculations
- Measurements of the ground and excited states $\rightarrow$ test of these predictions



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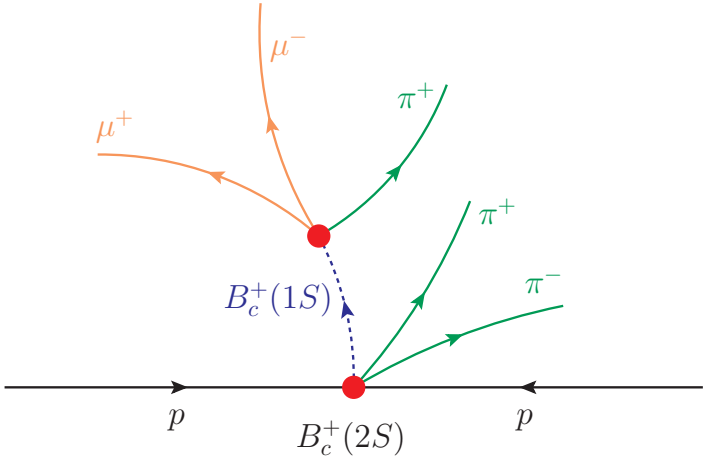
Overview of $B_c^+(2S)$ search arXiv:1407.1032 (accepted by PRL)

- The analysis uses *7 TeV and 8 TeV pp collisions data*
  - 4.9 fb^{-1}and 19.2 fb^{-1}, respectively
- Selection optimized using $S/\sqrt{S+B}$ criterion on Monte Carlo
  - Various exclusive backgrounds and inclusive $b\bar{b} \to J/\psi X$ samples used
  - Optimization performed separately for 7 TeV and 8 TeV data



- *J/ψ candidates* reconstructed by fitting a muon pair to a common vertex
- Combining a J/ψ candidate with another track $\to$ *$B_c^+(1S)$ candidate*
  - Di-muon mass is constrained to the J/ψ world average in 3-prong vertex fit
- *$B_c^+(2S)$ candidates* formed from $B_c^+(1S)$ and two tracks from primary vertex with $\pi^\pm$ masses assigned
  - Cascade fit with $B_c^+(1S)$ combined momentum *constrained to point to $B_c^+(2S)$ vertex*

$B_c^+(1S)$ selection and fit

arXiv:1407.1032 (accepted by PRL)

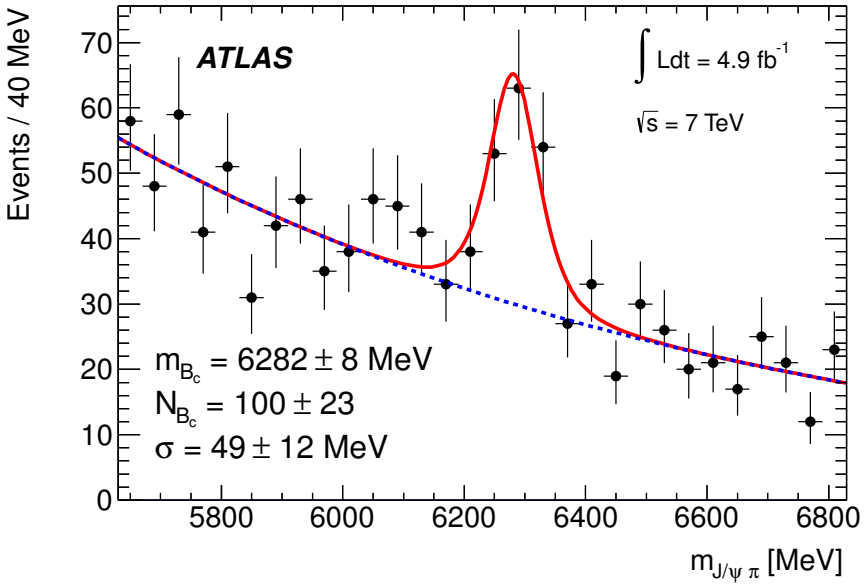
$\mathbf{B_c^+(1S)}$ selection for 2011 (2012) data

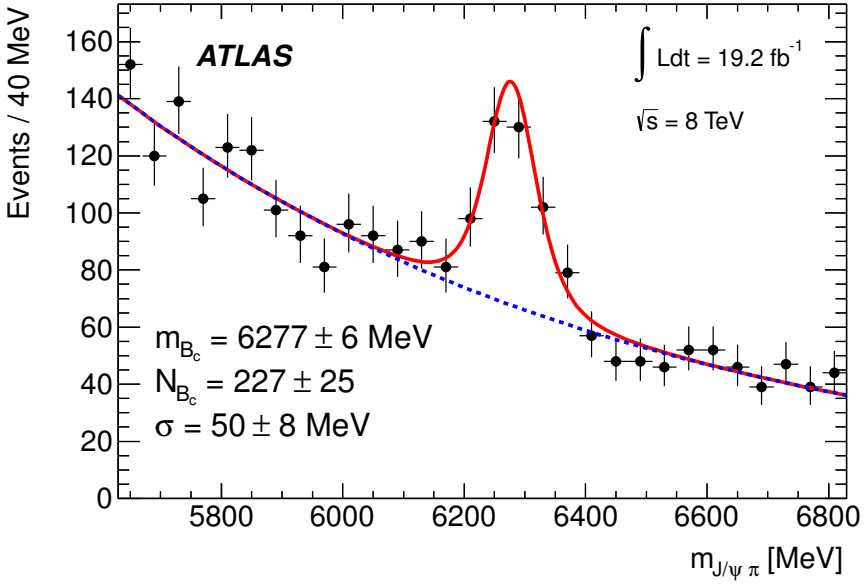
- $p_T(\mu_1, \mu_2) > 4, 6$ GeV
- $\chi^2/\mathrm{n.d.f.}(J/\psi) < 15$
- $m(J/\psi)$ within $\pm 3\sigma$ of the nominal (σ depending on the rapidity range)

- $\chi^2/\mathrm{n.d.f.}(B_c^+) < 2.0\ (1.5)$
- $p_T(B_c^+) > 15$ GeV (18 GeV)
- $\frac{d^0_{xy}}{\sigma(d^0_{xy})}(\pi^+) > 5\ (4.5)$

Extended unbinned fit of the mass distribution

- *Signal*: Gaussian with per-candidate errors
- *Background*: exponential





$B_c^+(2S)$ selection and fit

arXiv:1407.1032 (accepted by PRL)

Selection of $\mathbf{B_c^+(2S) \to B_c^+(1S)\pi^+\pi^-}$ candidates

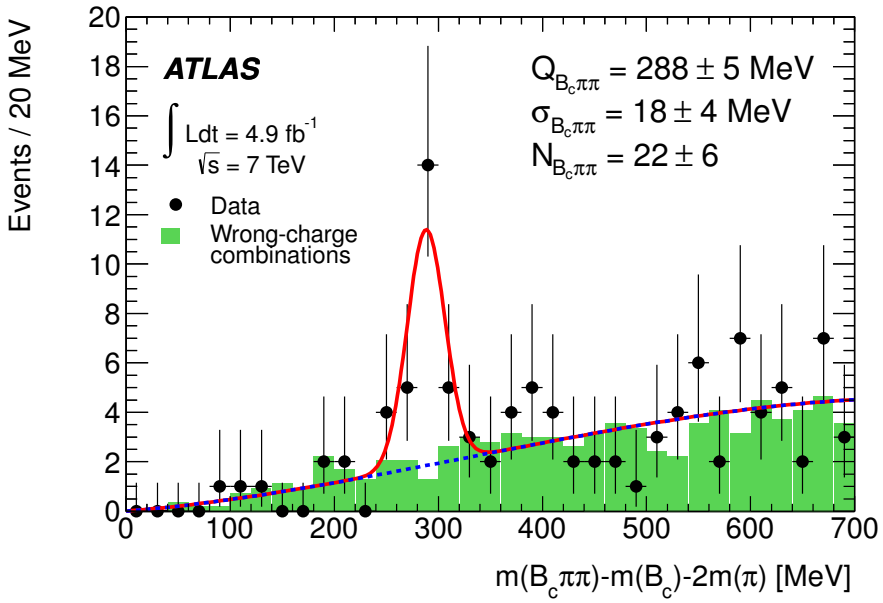
- $B_c^+(1S)$ candidates within $\pm 3\sigma$ of the fitted mass
- $p_T(\pi^+, \pi^-) > 400$ MeV
- for several candidates in event, the one with the best cascade fit χ^2 is kept

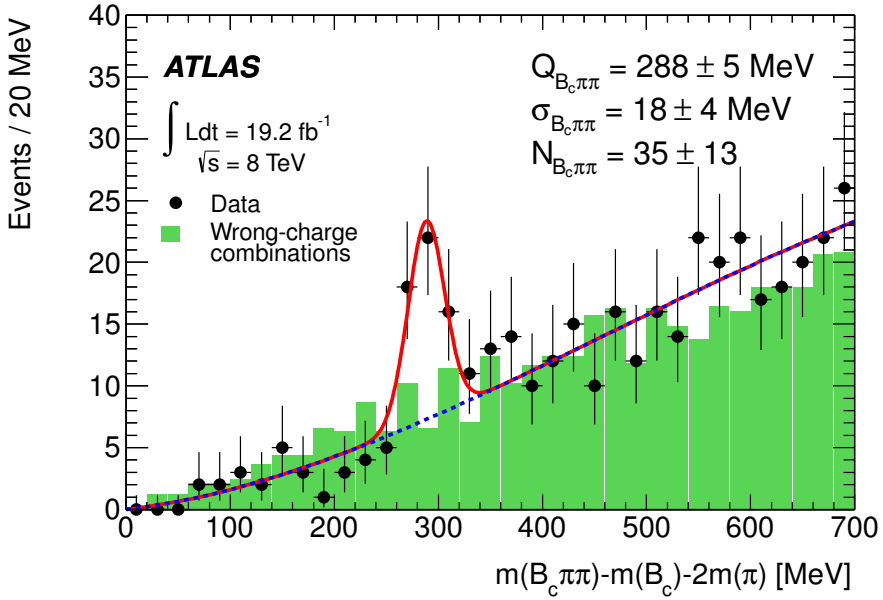
Extended unbinned fit of Q-value distribution

$$Q_{B_c^+\pi\pi} = m(B_c^+\pi^+\pi^-) - m(B_c^+) - 2m(\pi^+)$$

- *Signal*: Gaussian
- *Background*: 3rd order polynomial

Wrong charge combination (same-sign π) used for background control

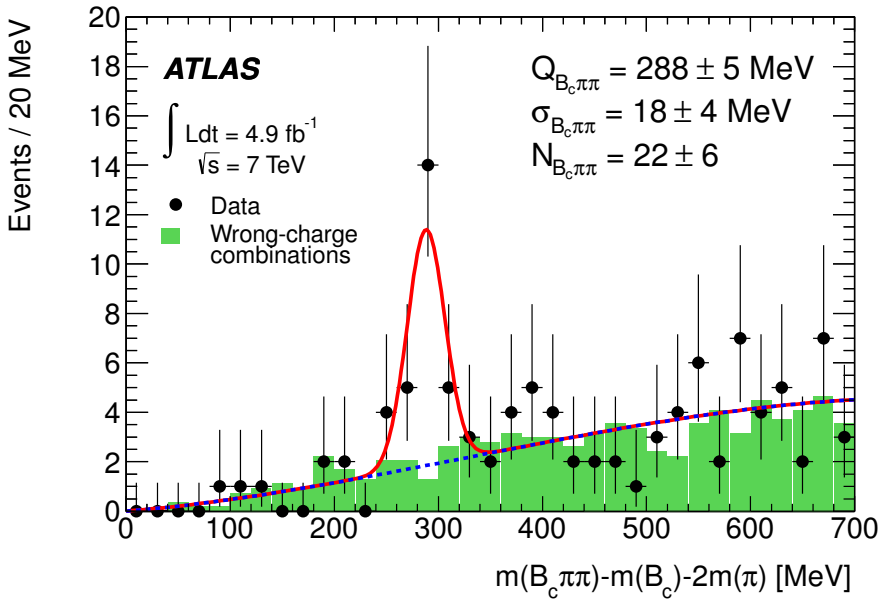


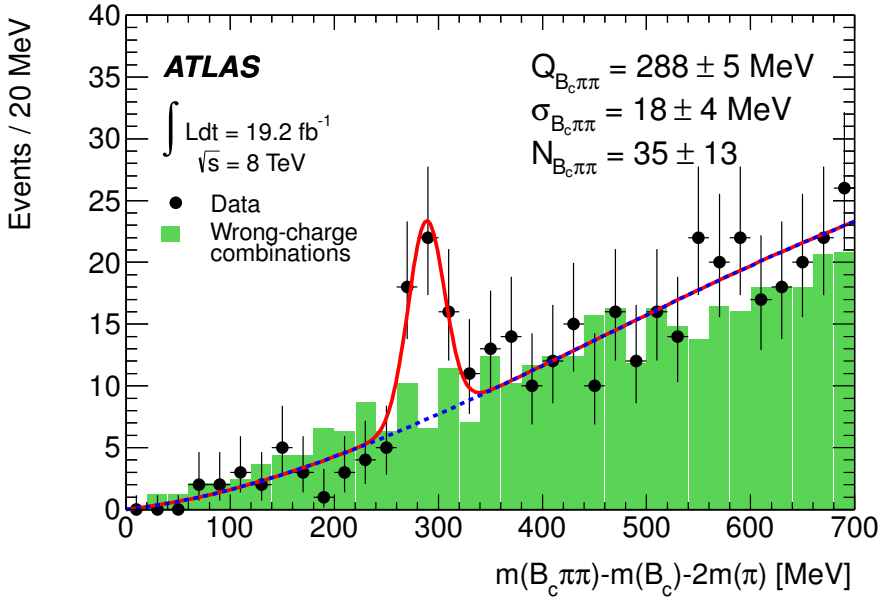


$B_c^+(2S)$ observation

arXiv:1407.1032 (accepted by PRL)

- Significance of the observed signal calculated with toy studies accounting for a *"look elsewhere effect"*
  - 3.7σ in 7 TeV data
  - 4.5σ in 8 TeV data
  - Combined significance is 5.2σ
  - (local significance is 5.4σ)
- Dominant source of systematic of the Q-value is the *fitting procedure*
- A new state observed at $Q = 288.3 \pm 3.5$ (stat.) ± 4.1 (syst.) MeV (error-weighted mean of 7 and 8 TeV values)
- Corresponds to a mass 6842 ± 4 (stat.) ± 5 (syst.) MeV, that is consistent with the predicted mass of $B_c^+(2S)$





Summary

- Two B_c^+-related analysis carried out in ATLAS are reported:
  - Observation of B_c^+ in the decay $B_c^+ \to J/\psi\pi^+$ with 7 TeV data
  - Observation of a *new state decaying into* $B_c^+\pi^+\pi^-$ with a mass consistent with the predictions for the $B_c^+(2S)$ *state* in 7 TeV and 8 TeV data
- Still some potential for B_c^+ physics in the collected Run 1 data
- Looking forward to the new Run 2 data analyses in 2015+!