B-decays and resonances in ATLAS

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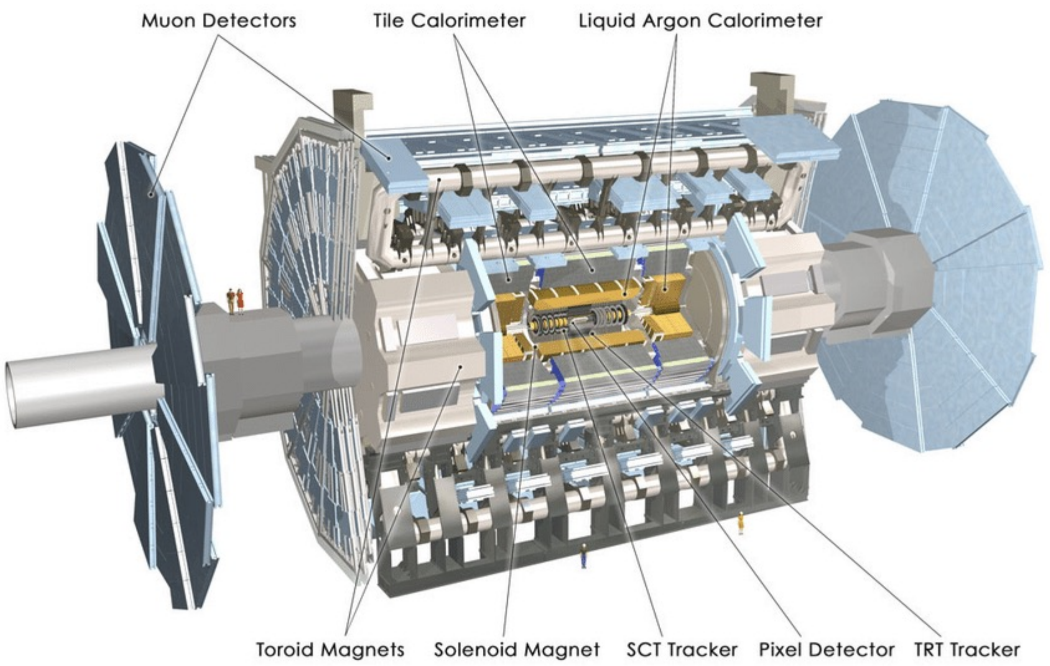
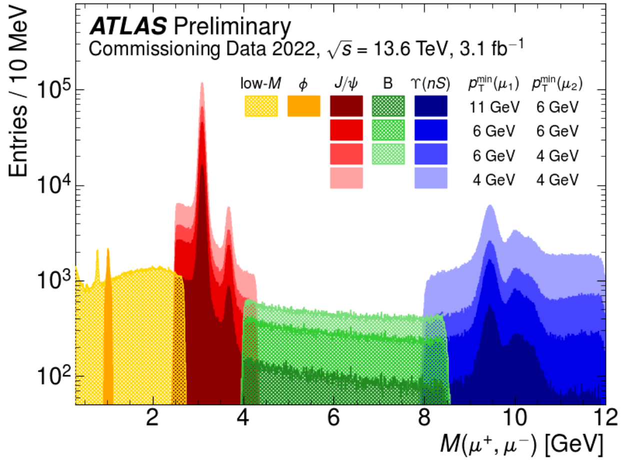
on **behalf on the ATLAS collaboration**

LHCP 2023

Detector & trigger



- High instantaneous luminosity and a lot of trigger bandwidth has been allocated to high-pT physics programs (e.g. Higgs, BSM searches).
- With higher luminosity we have to fit collecting low-pT events within the bandwidth budget.
- ATLAS introduced *topological* triggers to keep lower thresholds and stay within the bandwidth budget.



- Inner Detector: PIX, SCT and TRT, pT > 0.4 GeV, |η| < 2.5
- Run2: new IBL 25% improvement of time resolution with respect to Run1.
- Muon Spectrometer: triggering (|η|< 2.4), precision tracking (|η|< 2.7).
- B-physics: ~100 to 200 Hz trigger budget.

arXiv:2304.08962
BPHY-2022-01

ATLAS EXPERIMENT

Observation of new structures in the di-charmonium mass spectra

- Studies were motivated by LHCb discovery of resonant-like signal X(6900) in di-J/ψ spectrum. See also CMS-PAS-BPH-21-003

Strategy:

- Triggers:
  - 139 fb^{-1} recorded by ATLAS Run 2 at 13TeV
  - 2- or 3-muon triggers with dimuon in mass range 2.5-4.3GeV
  - Trigger combinations with prescaling to increase coverage
  - X(6900) efficiency in trigger 72% relative to offline efficiency

Selection:

- Select events with 2 opposite charge muon pairs
- Select pairs that are J/ψ candidates and fit to common vertex
- Fit with additional 2 muons to a common vertex and impose J/ψ mass to the candidate muons
  - 0.33% $m_{4\mu}$ resolution for X(6900)
- Use ΔR, transverse decay lengths to segment to regions

Signal region	Control region	Non-prompt region
Di-muon or tri-muon triggers, oppositely charged muons from each charmonium, *loose* muons, $p_T^{1,2,3,4} > 4, 4, 3, 3$ GeV and $\lvert\eta_{1,2,3,4}\rvert < 2.5$ for the four muons, $m_{J/\psi} \in [2.94, 3.25]$ GeV, or $m_{\psi(2S)} \in [3.56, 3.80]$ GeV, Loose vertex requirements $\chi^2_{4\mu}/N < 40$ ($N = 5$) and $\chi^2_{\text{di-}\mu}/N < 100$ ($N = 2$),		
Vertex $\chi^2_{4\mu}/N < 3$, $L^{4\mu}_{xy} < 0.2$ mm, $\lvert L^{\text{di-}\mu}_{xy}\rvert < 0.3$ mm, $m_{4\mu} < 11$ GeV,		Vertex $\chi^2_{4\mu}/N > 6$,
$\Delta R < 0.25$ between charmonia	$\Delta R \geq 0.25$ between charmonia	or $\lvert L^{\text{di-}\mu}_{xy}\rvert > 0.4$ mm

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Observation of new structures in the di-charmonium mass spectra

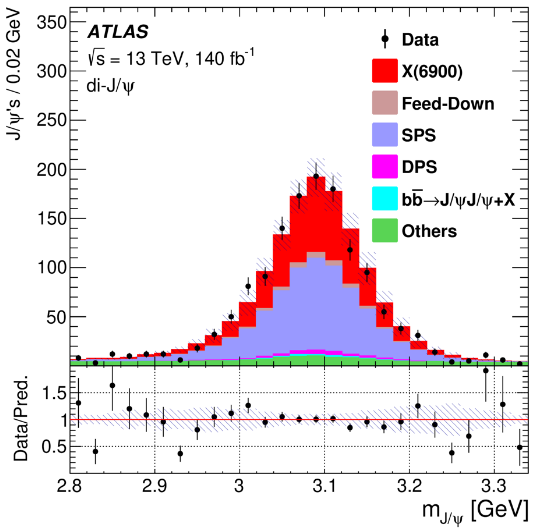
Backgrounds:

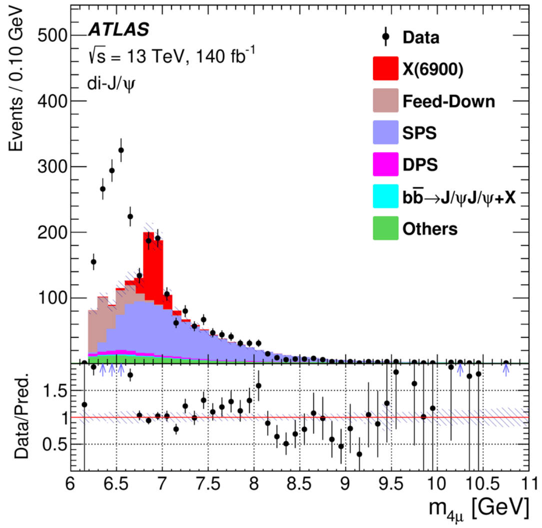
- Prompt J/ψ
    - Single parton scattering
    - Double parton scattering
- Non-prompt J/ψ
    - $b\bar{b}$ →J/ψ J/ψ

(MC but kinematic scaling using data control regions)

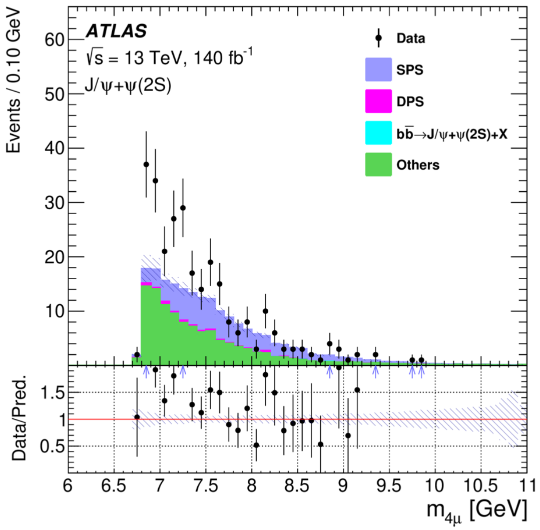
- Single J/ψ background
    - Prompt or non-prompt J/ψ plus fake muons from primary vertex
- Non-peaking background with no real J/ψ

(red samples grouped as 'others' – modelling data-driven)





⇐ di-J/ψ signal region



⇐ J/ψ – ψ(2S) signal region

Observation of new structures in the di-charmonium mass spectra

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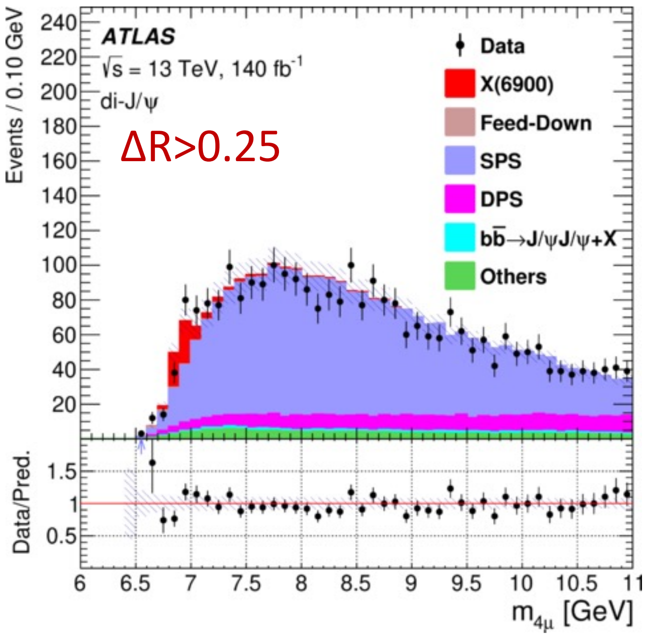
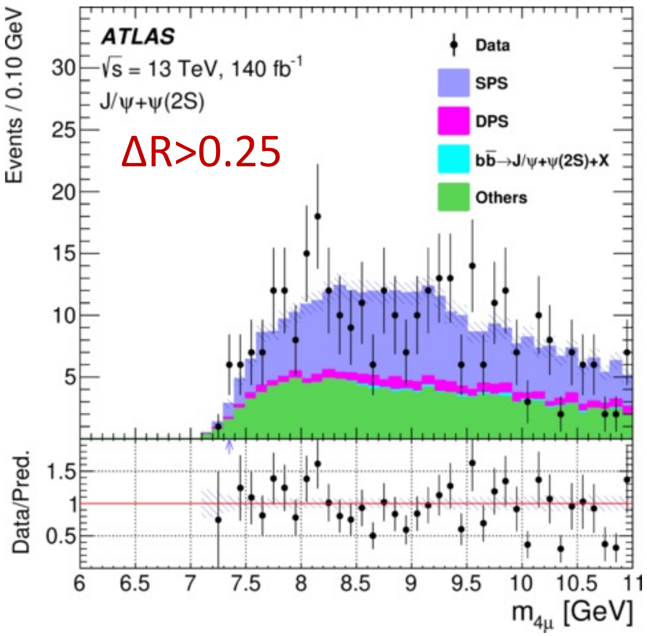
Backgrounds:

- Control regions
- Low & high mass sidebands
- ΔR<0.25 for signal, ΔR>0.25 for background to study SPS mass spectrum
- Reweighting between data and MC in di-J/ψ pT, Δϕ, Δη etc
- Poor 4μ vertex or v long proper lifetime to select non-prompt control region

di-J/ψ control region



J/ψ ψ(2S) control region



Feed-down from J/ψ+ψ(2S) included in diJ/ψ

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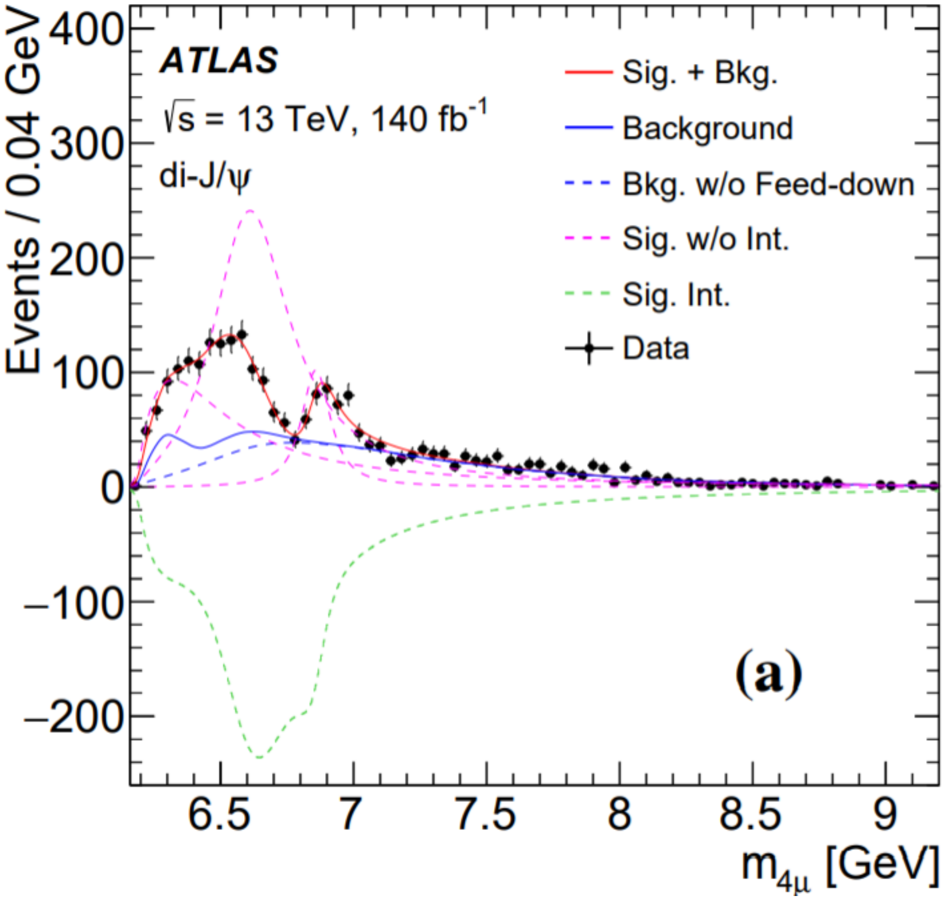
Observation of new structures in the di-charmonium mass spectra

Fit models:

- Di-J/ψ
  - Multiple resonances? – but interference may be important
  - **Model A** has 2 signal resonances that may interfere
  - **Model B** has single signal resonance
    - For comparison, a three-resonance model without interferences was also tried.
    - Excluded >95%

- J/ψ ψ(2S)
  - **Model α** with same 2 resonances as above decaying to J/ψ ψ(2S)
  - **Model β** with a single resonance



139 fb^{-1} recorded by ATLAS

[arXiv:2304.08962](https://arxiv.org/abs/2304.08962)

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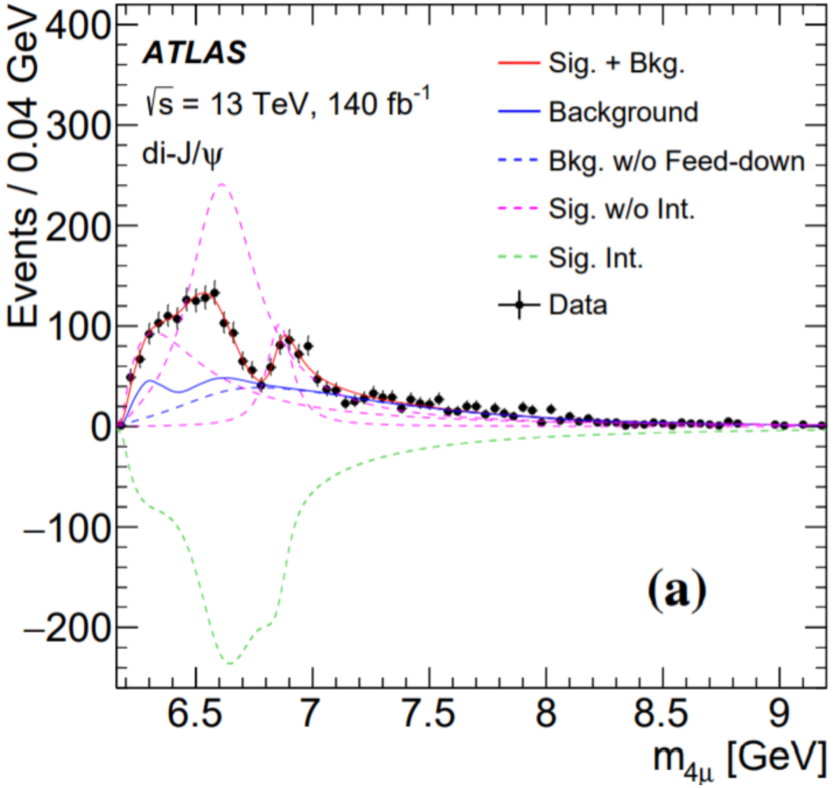
Observation of new structures in the di-charmonium mass spectra

- Observation of the X (6900) structure is confirmed.
- Evidence for a broad lower mass structure



- In both channels, details of the lower-mass structure cannot be discerned directly from the data.
- More data are required to better characterize the excesses observed in both channels.

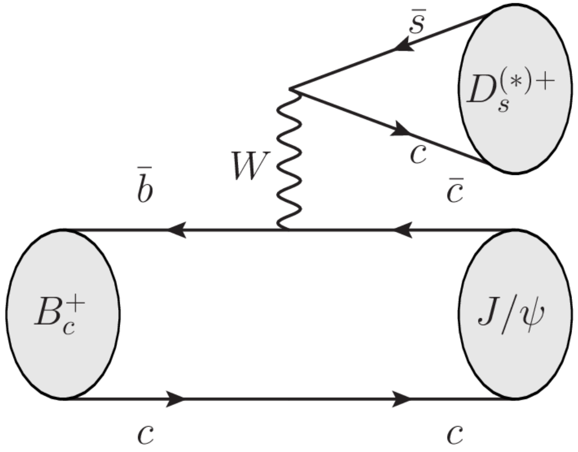
di-J/ψ	model A	model B
m_0	$6.41 \pm 0.08^{+0.08}_{-0.03}$	$6.65 \pm 0.02^{+0.03}_{-0.02}$
Γ_0	$0.59 \pm 0.35^{+0.12}_{-0.20}$	$0.44 \pm 0.05^{+0.06}_{-0.05}$
m_1	$6.63 \pm 0.05^{+0.08}_{-0.01}$	—
Γ_1	$0.35 \pm 0.11^{+0.11}_{-0.04}$	
m_2	$6.86 \pm 0.03^{+0.01}_{-0.02}$	$6.91 \pm 0.01 \pm 0.01$
Γ_2	$0.11 \pm 0.05^{+0.02}_{-0.01}$	$0.15 \pm 0.03 \pm 0.01$
$\Delta s/s$	$\pm 5.1\%^{+8.1\%}_{-8.9\%}$	—
J/ψ+$\psi(2S)$	model α	model β
m_3 or m	$7.22 \pm 0.03^{+0.01}_{-0.03}$	$6.96 \pm 0.05 \pm 0.03$
Γ_3 or Γ	$0.09 \pm 0.06^{+0.06}_{-0.03}$	$0.51 \pm 0.17^{+0.11}_{-0.10}$
$\Delta s/s$	$\pm 21\% \pm 14\%$	$\pm 20\% \pm 12\%$

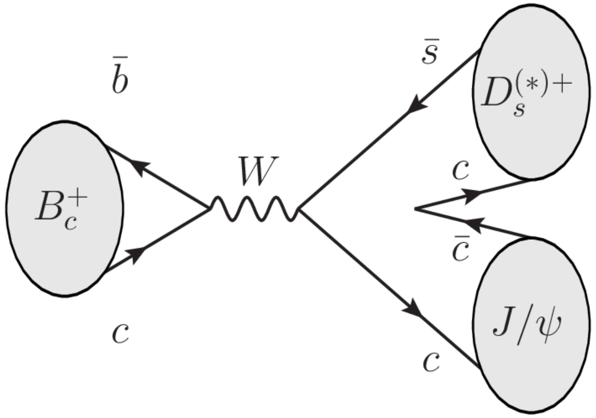
[JHEP 08 (2022) 087](#)

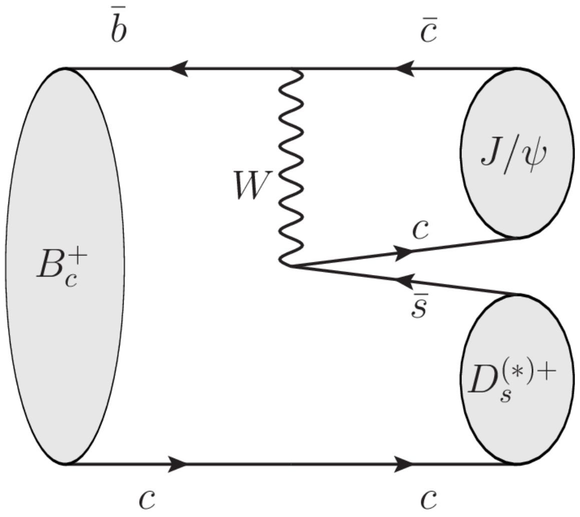
B_c results from ATLAS

Study of $B^+_c \to J/\psi D^+_s$ and $B^+_c \to J/\psi D^{*+}_s$

- High precision measurement of branching fractions and the final state polarization in decays of double HF meson B_c^+
  - Tests predictions of various theory models, e.g. pQCD calculations, relativistic potential models , sum rules calculations .
- Observed earlier by LHCb (PRD 87 (2013) 112012) and ATLAS (EPJC 76 (2016) 4) in Run 1.
- **Now highest precision using total Run2 data.**







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B_c results from ATLAS

Study of $B^+_c \to J/\psi D^+_s$ and $B^+_c \to J/\psi D^{*+}_s$

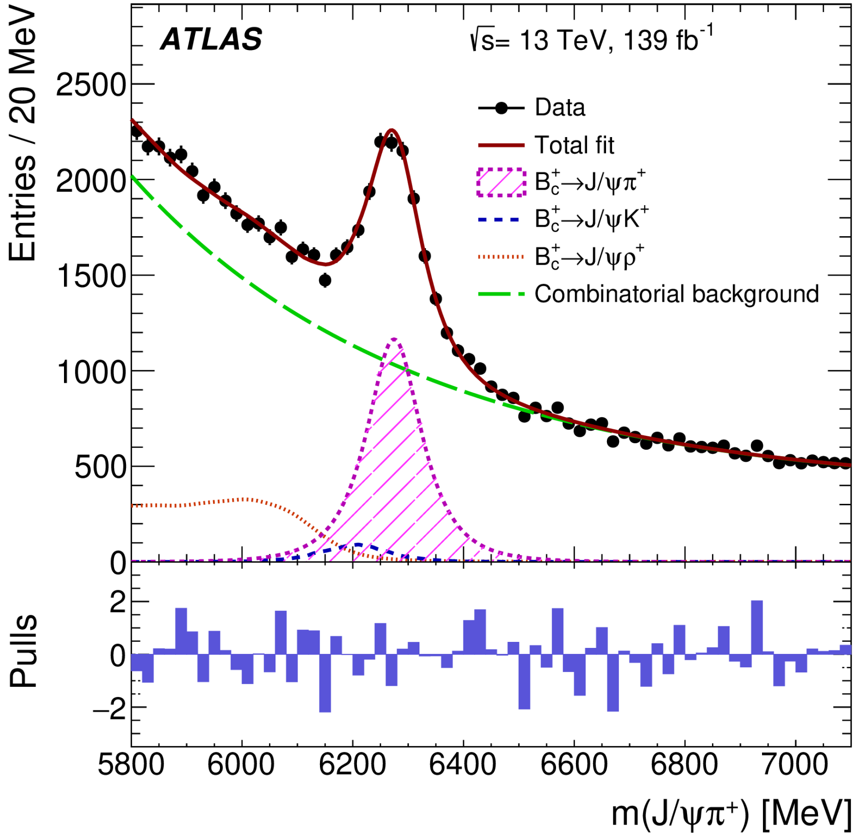
- *Triggers:* Mainly dimuon triggers, pT(μ)>4 or 6 GeV, compatible with J/ψ

- D_s^+ and D_s^{*+} are reconstructed from their decays:
  $D_s^+ \to \varphi(K^+K^-)$ and $D_s^{*+} \to D_s^+\pi^0/\gamma$ with partial reconstruction.

- Sample: 139fb^{-1} at 13TeV

Use $B_c^+ \to J/\psi\pi^+$ reference channel for *Br* measurement

- Fiducial range: $pT(B_c^+) > 15$ GeV, $|\eta(B_c^+)| < 2.0$



Reference channel with signal statistics
$N_{B_c^+ \to J/\psi\pi^+} = 8440^{+500}_{-470}$

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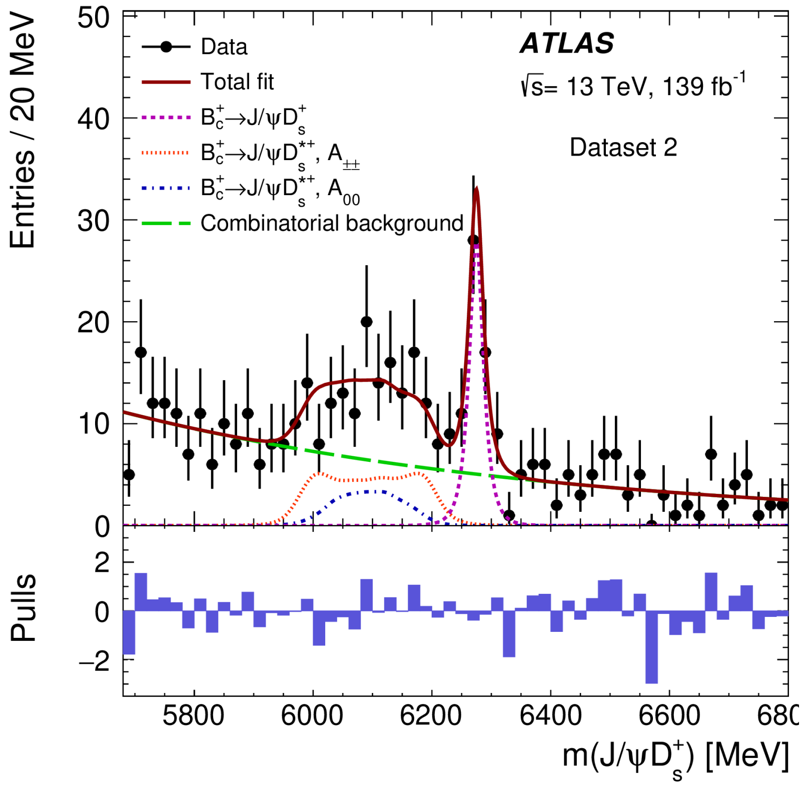
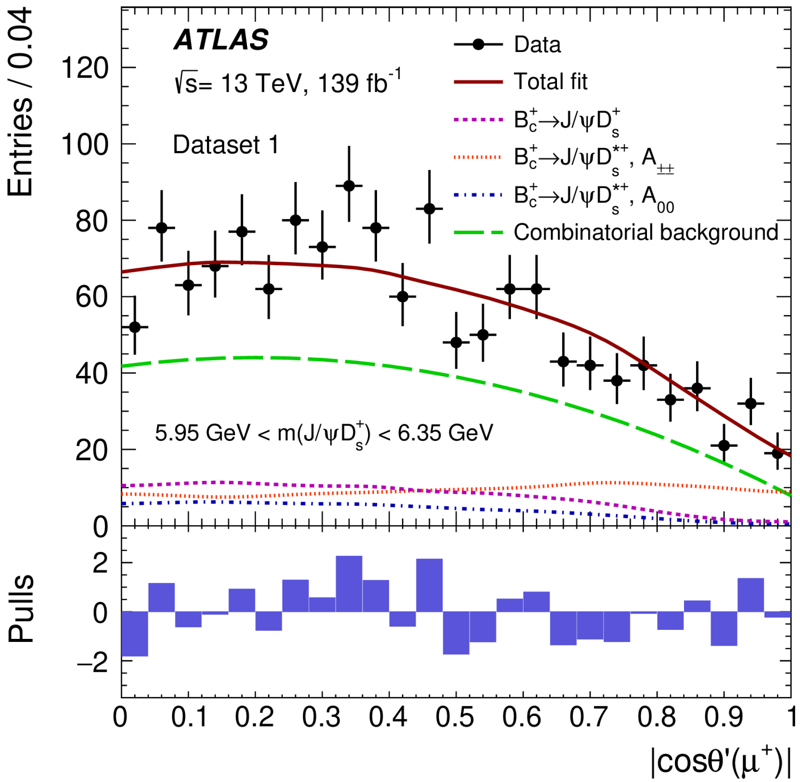
B_c results from ATLAS

Study of $B^+_c \to J/\psi D^+_s$ and $B^+_c \to J/\psi D^{*+}_s$

- 2D ($m(J/\psi D_s^+)$, $|\cos\theta'(\mu^+)|$ J/ψ helicity angle) fit to extract the signal parameters
- Both sensitive to polarization of the final state particles J/ψ and D_s^+ in $B_c^+ \to J/\psi D_s^{*+}$ decay.



Fit to inv. mass $m(J/\psi D_s^+)$



Fit to $|\cos\theta'(\mu^+)|$, where $\cos\theta'(\mu^+)$ is the helicity angle between μ^+ and D_s^+ momenta, in J/ψ rest frame.

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B_c results from ATLAS

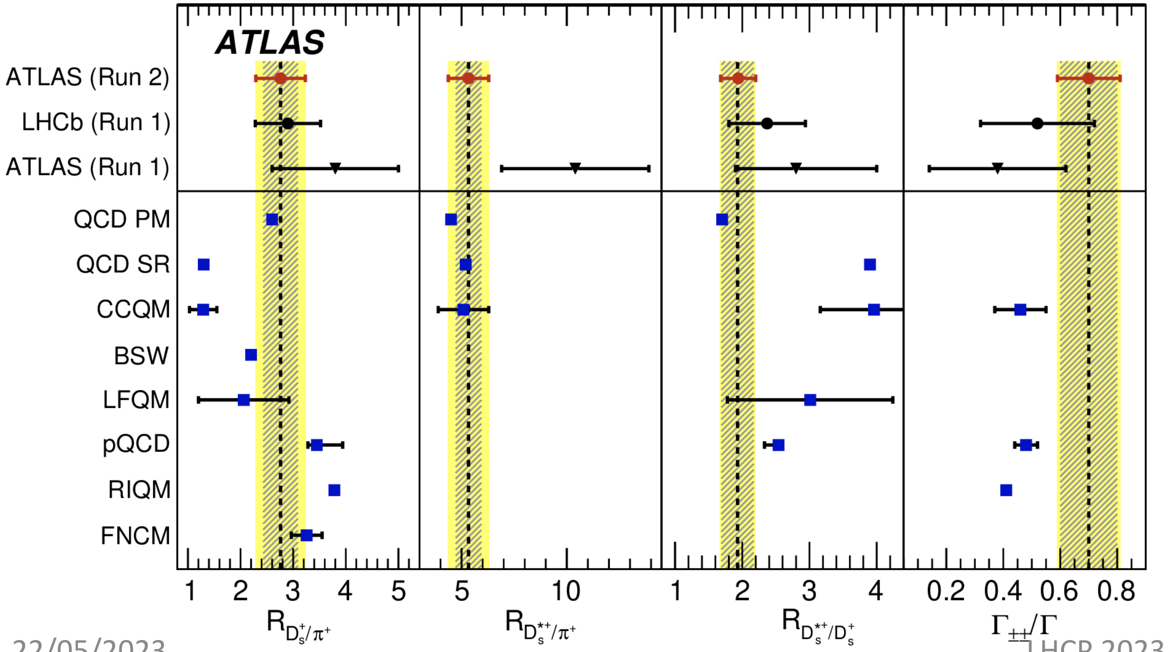
Study of $B^+_c \to J/\psi D^+_s$ and $B^+_c \to J/\psi D^{*+}_s$

$$R(D_s^+/\pi^+) \equiv \frac{Br(B_c^+ \to J/\psi\, D_s^+)}{Br(B_c^+ \to J/\psi\, \pi^+)} = 2.76 \pm 0.33(stat.) \pm 0.30(syst.) \pm 0.16(BF)$$

$$R(D_s^{*+}/\pi^+) \equiv \frac{Br(B_c^+ \to J/\psi\, D_s^{*+})}{Br(B_c^+ \to J/\psi\, \pi^+)} = 5.33 \pm 0.61(stat.) \pm 0.67(syst.) \pm 0.32(BF)$$

$$R(D_s^+/D^{*+}) \equiv \frac{Br(B_c^+ \to J/\psi\, D_s^+)}{Br(B_c^+ \to J/\psi\, D^{*+})} = 1.93 \pm 0.24(stat.) \pm 0.10(syst.)$$

$B_c^+ \to J/\psi\, D_s^{*+}$ transverse polarisation fraction $\Gamma_{++}/\Gamma = 0.70 \pm 0.10(stat.) \pm 0.04(syst.)$



- Hatched areas - statistical uncertainties of this measurement and yellow bands total uncertainties.
- New results consistent with earlier measurements.
- QCD PM (arXiv:hep-ph/9909423) agrees very well while others deviate in some cases or lack precision.
- $\Gamma_{\pm\pm}/\Gamma$ agrees with a naive spin-counting estimate of 2/3 and is larger than the dedicated predictions

Conclusions

- ATLAS continue its B-Physics program, publishing analyses from Run-2 and collecting new data in Run-3.
- I have presented the first observations of some resonances.
- Improved measurements of **$B^{+}_{c} \rightarrow J/\psi D^{+}_{s}$ and $B^{+}_{c} \rightarrow J/\psi D^{*+}_{s}$**

- I have presented a selection of results here, see published results pages for more ATLAS
- All measurements searching for new physics in B-flavour sector - confirmed no violation of SM - within a precision of data used since far.
- Measurements of Charmonia as well as the open-flavour hadron-productions, provide valuable tests to multiple QCD production models.

arXiv:2304.08962
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Observation of new structures in the di-charmonium mass spectra

- Multiple interfering S wave Breit-Wigners, R is mass resolution function

Di- J/ψ)

$$f_s(x) = \left| \sum_{i=0}^{2} \frac{z_i}{m_i^2 - x^2 - i m_i \Gamma_i(x)} \right|^2 \sqrt{1 - \frac{4m_{J/\psi}^2}{x^2}} \otimes R(\alpha),$$

$$BW(x; m_0, \Gamma_0) = \frac{\left(\frac{q}{q_0}\right)^L \frac{F_L(Rq)}{F_L(Rq_0)}}{m_0^2 - x^2 - i m_0 \Gamma(x)}, \qquad \Gamma(x) = \Gamma_0 \left(\frac{q}{q_0}\right)^{2L+1} \frac{m_0}{x} \frac{F_L^2(Rq)}{F_L^2(Rq_0)}.$$

- Simplified B-W for S-wave

$$BW(x; m_0, \Gamma_0) = \frac{1}{m_0^2 - x^2 - i m_0 \Gamma(x)} = \frac{1}{m_0^2 - x^2 - i m_0 \Gamma_0 \frac{m_0}{x} \sqrt{\frac{x^2 - 4m_{J/\psi}^2}{m_0^2 - 4m_{J/\psi}^2}}}.$$

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BPHY-2022-01

Observation of new structures in the di-charmonium mass spectra

- Fit model A – same two peaks as in the di-J/ψ channel, R is resolution function

J/ψ ψ(2S)

$$f_s(x) = \left(\left| \sum_{i=0}^{2} \frac{z_i}{m_i^2 - x^2 - i m_i \Gamma_i(x)} \right|^2 + \left| \frac{z_3}{m_3^2 - x^2 - i m_3 \Gamma_3(x)} \right|^2 \right) \sqrt{1 - \left(\frac{m_{J/\psi} + m_{\psi(2S)}}{x} \right)^2} \otimes R(\alpha),$$

$$\Gamma_3(x) = \Gamma_3 \frac{m_3}{x} \sqrt{\frac{x^2 - (m_{J/\psi} + m_{\psi(2S)})^2}{m_3^2 - (m_{J/\psi} + m_{\psi(2S)})^2}}.$$

- Fit model B – Single peak

Feed down:

- Feed-down normalisation in the di-J/ψ channel

$$N_{\text{fd}} = \frac{\mathcal{B}' \epsilon'_{\text{filter}} \epsilon'_{\text{reco}}}{\mathcal{B}(\psi \to \mu\mu) \epsilon_{\text{filter}} \epsilon_{\text{reco}}} N.$$

- Branching fraction

$$\mathcal{B}' = [\mathcal{B}(\psi \to J/\psi + X) + \mathcal{B}(\psi \to \gamma \chi_{c0}) \mathcal{B}(\chi_{c0} \to \gamma J/\psi) + \mathcal{B}(\psi \to \gamma \chi_{c1}) \mathcal{B}(\chi_{c1} \to \gamma J/\psi) + \mathcal{B}(\psi \to \gamma \chi_{c2}) \mathcal{B}(\chi_{c2} \to \gamma J/\psi)]\, \mathcal{B}(J/\psi \to \mu\mu).$$

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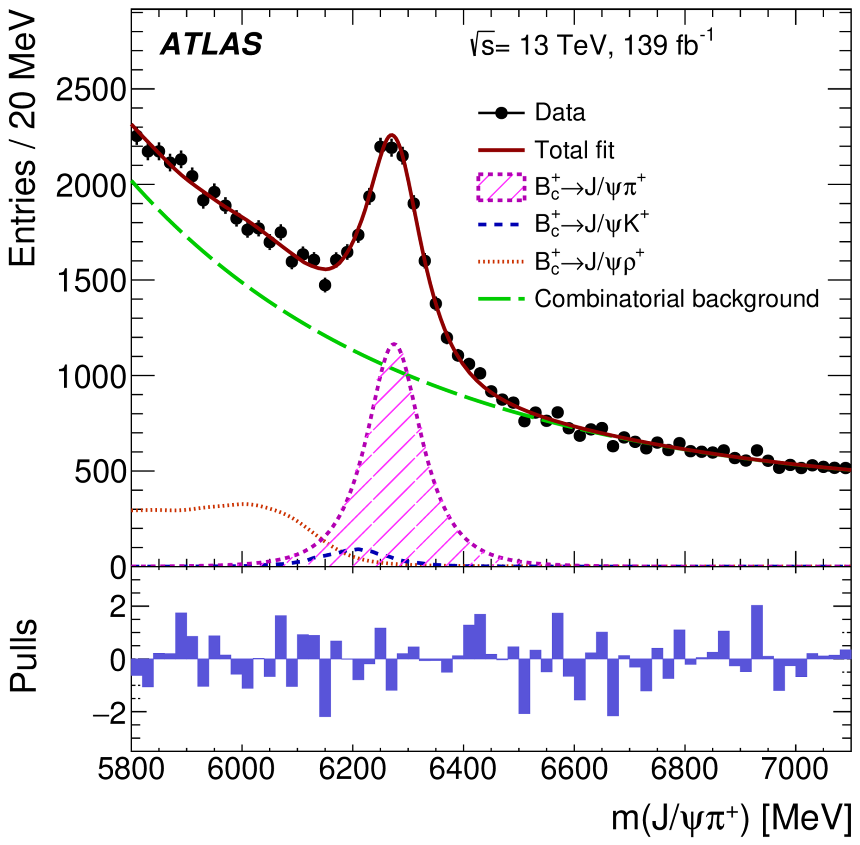
- D_s^+ and D_s^{*+} are reconstructed from their decays:
- $D_s^+ \to \varphi(K^+K^-)$ and $D_s^{*+} \to D_s^+\pi^0/\gamma$ with partial reconstruction.

  Use $B_c^+ \to J/\psi\pi^+$ reference channel for B*r* measurement
- Fiducial range: $pT(B_c^+) > 15$ GeV, $|\eta(B_c^+)| < 2.0$



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