Recent heavy-flavour results from ATLAS

Semen Turchikhin[a,*] **on behalf of the ATLAS Collaboration**

[a] *University and INFN Genova,*
Via Dodecaneso 33, Genova, Italy

E-mail: Semen.Turchikhin@cern.ch

Recent heavy-flavour results from the ATLAS experiment at the LHC are presented. These include studies of charmonium production, searches for exotic states in four-muon final state and measurement of $B_s^0 \to \mu^+\mu^-$ decay effective lifetime. Most of the results are obtained with pp collision data collected at a centre-of-mass energy of 13 TeV.

ATL-PHYS-PROC-2024-053
16 August 2024

31st International Workshop on Deep Inelastic Scattering (DIS2024)
8–12 April 2024
Grenoble, France

*Speaker

1. Introduction

The ATLAS experiment at the LHC [1], while not being a dedicated heavy-flavour physics detector, has a wide program in that field, covering heavy hadron production measurements, conventional and exotic states spectroscopy and various studies of weak decay properties. ATLAS is particularly competitive in the studies exploiting the final states with muons, where it can fully benefit from large available integrated luminosity, using mostly unprescaled (multi-)muon triggers. This contribution to the conference proceedings summarizes the recent results in the specified areas.

2. Exotic states spectroscopy

A search for potential $cc\bar{c}\bar{c}$ tetraquark states decaying into a pair of charmonium states is performed by ATLAS using $\sqrt{s} = 13$ TeV pp collision dataset corresponding to 140 fb^{-1} of integrated luminosity [2]. The search is inspired by the recent LHCb experiment observation of the new $X(6900)$ state [3]. Four-muon final state is used in the search and two channels are considered: $J/\psi + J/\psi$ and $J/\psi + \psi(2S)$.

To describe the four-muon mass spectrum in the di-J/ψ channel, two models are used. Model A assumes presence of three interfering Breit-Wigner resonances, while model B includes just two resonances, one of which interferes with single parton scattering J/ψ pair production background and the other is standalone. Corresponding fits are shown in Figure 1 (top). Both of them yield a resonance near 6.9 GeV mass with a significance well exceeding 5σ. Its parameters are consistent with those of $X(6900)$ state observed by LHCb. Broader structure at lower masses is described well by both models, but could also result from other physical effects, such as feed-down from higher di-charmonium resonances.

Two models are also used for the $J/\psi + \psi(2S)$ channel. Model α assumes that the same three interfering resonances from Model A of the di-J/ψ channel also decay in $J/\psi + \psi(2S)$, along with a fourth standalone resonance. Model β, in contrast, assumes a single $J/\psi + \psi(2S)$ resonance. Both fits are shown in Figure 1 (bottom). Overall signal significance with the two models is 4.7σ and 4.3σ, respectively. With model α, significance of the additional standalone resonance is 3.0σ. Its mass is close to another excess visually seen in LHCb data on di-J/ψ channel, which is, however, not claimed as a signal.

Another search for exotic states is performed in $\Upsilon(1S)\mu^+\mu^-$ channel [4]. The analysis was done separately for $\sqrt{s} = 8$ TeV data collected in 2012, $\sqrt{s} = 13$ TeV data collected in 2015–2017 and in 2018. In the 8 TeV data an excess consistent with a narrow-width particle was observed at the four-muon invariant mass of 18 GeV. The excess survived an extensive validation and its global significance varies between 1.9σ and 5.4σ depending on the selection criteria. A much less significant structure was observed in 2015–2017 data, and no signal was seen in 2018 data. The considered data-taking periods had significant difference in the trigger conditions, with only the most restrictive triggers available in 2018. Monte Carlo and data-driven studies confirm the reduction of the signal sensitivity in 13 TeV data, however, they still exclude the excess seen in 8 TeV data at the level of 2.7σ.

Figure 2 shows the limits set on the hypothetical particle production rate for two different assumptions on its nature, high-efficiency pseudoscalar tetraquark and low-efficiency Higgs-like

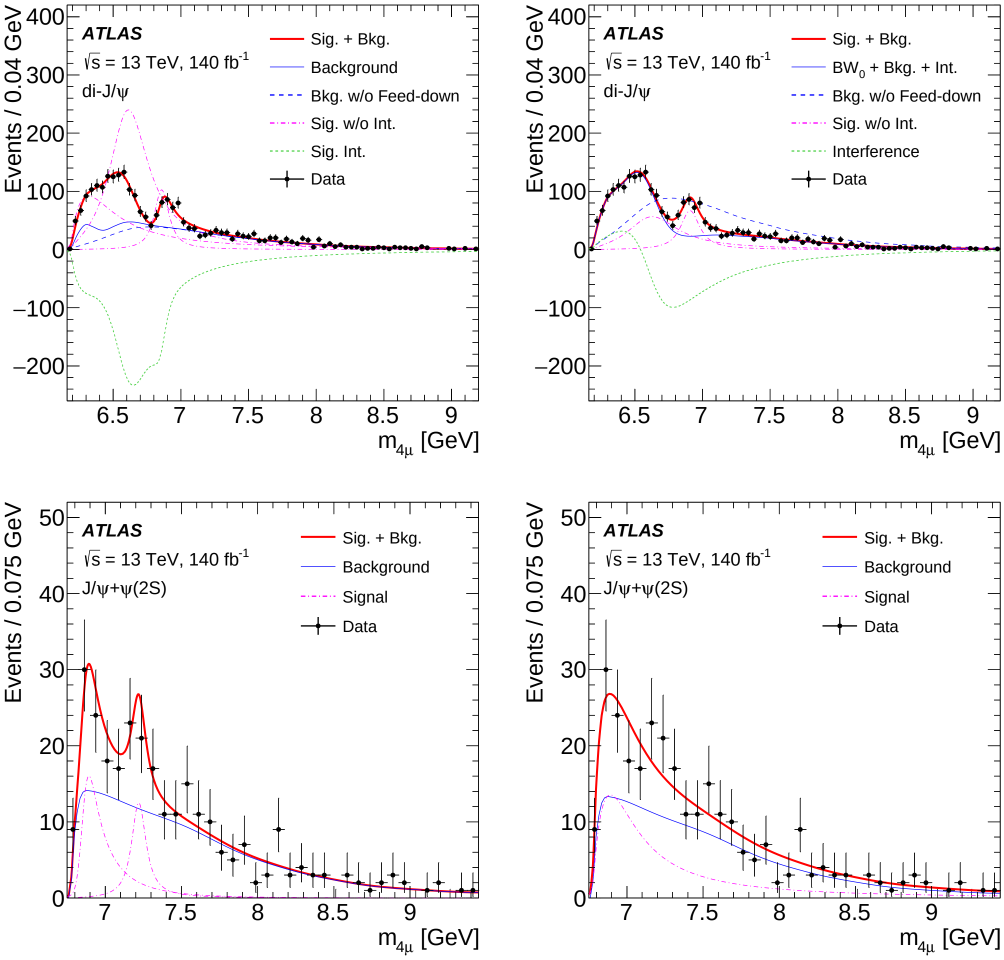

Figure 1: Fits to the 4-muon mass spectrum in the signal regions in the di-J/ψ channel using model (top-left) A and (top-right) B and in the $J/\psi + \psi(2S)$ channel using model (bottom-left) α and (bottom-right) β [2].

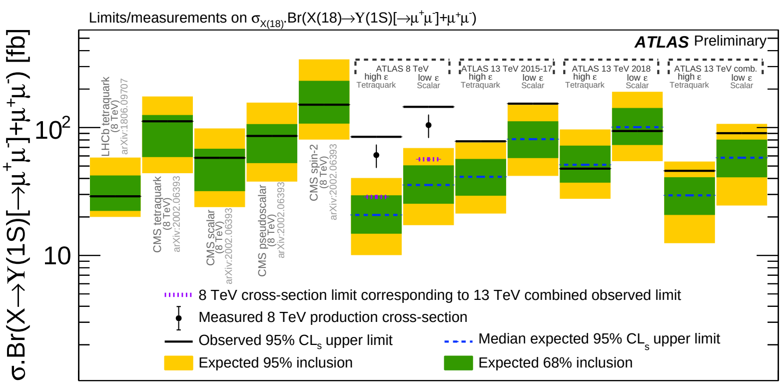

Figure 2: Limits on the production cross-section times branching fraction for a particle with an invariant mass of 18 GeV decaying to a $\Upsilon(1S)\mu^+\mu^-$ final state in the three data-taking periods (as well as the statistical combination of the full 13 TeV dataset) [4].

scalar. Limits set by CMS and LHCb experiments are also shown. Further studies with a larger dataset are necessary for a more conclusive answer on the presence of such states.

3. Charmonium production measurement

Measurements of differential production cross-section of J/ψ and $\psi(2S)$ mesons at $\sqrt{s}$ = 13 TeV were performed by ATLAS with the full Run-2 dataset [5]. Prompt and non-prompt production cross-sections are measured separately in bins of the charmonium p_T and rapidity, as well as non-prompt fraction for both states and ratio between $\psi(2S)$ and J/ψ production cross-sections.

The measurement benefits from using data collected by two types of trigger. Di-muon trigger which have p_T threshold of 4 GeV for both muons is used to cover the range of charmonium p_T between 7 and 60 GeV. These triggers are, however, inefficient for close-by muons. Therefore, to extend the measurement towards higher p_T up to 360 (140) GeV for J/ψ ($\psi(2S)$), single-muon trigger with muon p_T threshold of 50 GeV is used. This strategy allows to cover the kinematic range well beyond what was achieved in previous measurements.

Figure 3 compares the measured prompt and non-prompt J/ψ production with available theory predictions. For prompt production, noticeably harder p_T spectrum is predicted by all models. The spectrum of the non-prompt production is described generally better in the soft part, but the cross-section for high p_T is also overestimated in all calculations. The extended kinematic reach of the measurement thus provides important input for future tuning of these theoretical models.

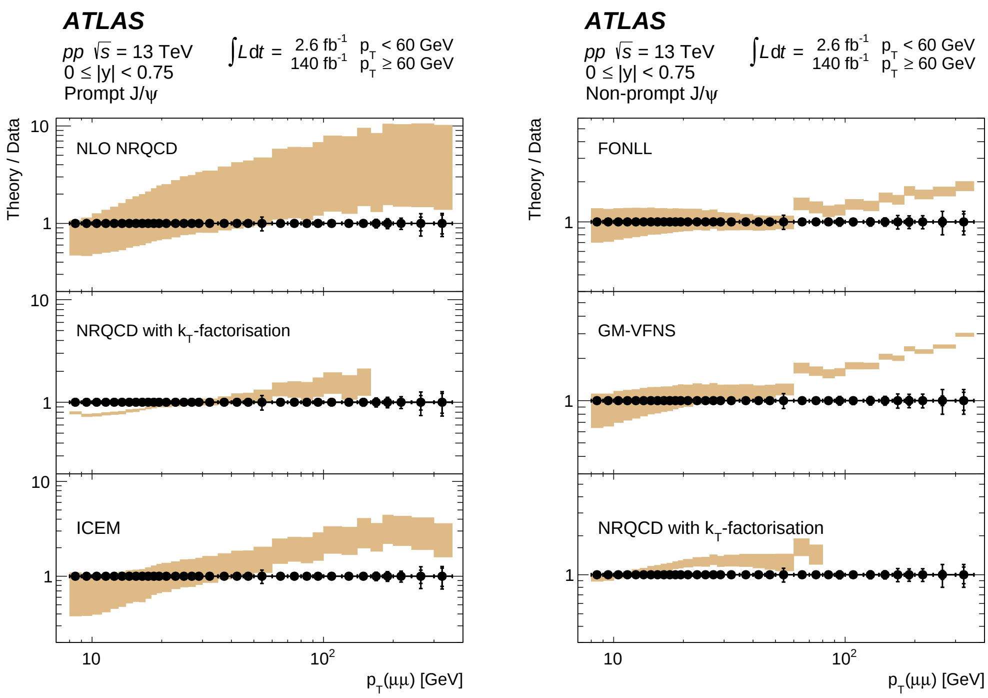

Figure 3: Ratios of various theoretical predictions to data for the (left) prompt and (right) non-prompt production of J/ψ in the central rapidity region [5].

4. $B_s^0 \to \mu^+\mu^-$ effective lifetime measurement

In the Standard Model, only the heavy CP-odd B_s^0 eigenstate, $B_{s,H}^0$, is allowed to decay to a muon pair. Numerous new physic scenarios, however, allow the light eigenstate, $B_{s,L}^0$, to contribute to the rate of the decay as well. Due to the large difference in the lifetimes of the $B_{s,H}^0$ and $B_{s,L}^0$ states, such contribution would manifest itself in the value of the B_s^0 effective lifetime in its dimuon decay. Perturbations of these value can be significant even in absence of a measurable effect on the decay branching fraction.

The first ATLAS measurement of $B_s^0 \to \mu^+\mu^-$ effective lifetime was performed using 26.3 fb^{-1} of data collected in 2015 and 2016 [6]. Figure 4 shows the signal peak in the di-muon mass distribution and the extracted distribution of the signal proper decay time. The latter is fitted with Monte Carlo templates parametrised with varying signal lifetime. The measured effective lifetime is $\tau_{\mu\mu} = 0.99^{+0.42}_{-0.07}$ (stat.) $\pm$ 0.17 (syst.) ps. It is consistent with the SM prediction $\tau_{\mu\mu}^{\mathrm{SM}} = (1.624 \pm 0.009)$ ps and with other available experimental results.

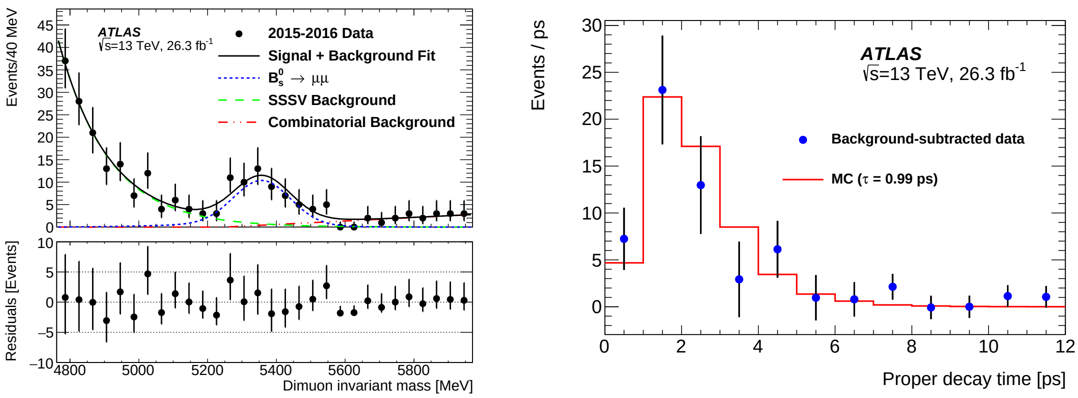

Figure 4: Distribution (left) of the di-muon invariant mass with the fit overlaid and (right) of the signal proper decay time with the signal MC template resulting from the lifetime fit [6].

5. Summary

Recent ATLAS heavy-flavour results using mainly Run-2 data are highlighted in these proceedings. These topics remain relevant and still leave questions to be answered by further studies with more data, including the new ones being collected during Run-3 of the LHC.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[2] ATLAS Collaboration, *Observation of an Excess of Dicharmonium Events in the Four-Muon Final State with the ATLAS Detector*, Phys. Rev. Lett. **131** (2023) 151902, arXiv:2304.08962 [hep-ex].

[3] LHCb Collaboration, *Observation of structure in the J/ψ -pair mass spectrum*, Science Bulletin **65** (2020) 1983, arXiv:2006.16957 [hep-ex].

[4] ATLAS Collaboration, *Search for narrow low-mass resonances in the four-muon final state with the ATLAS detector at the LHC*, ATLAS-CONF-2023-041, 2023, https://cds.cern.ch/record/2869238.

[5] ATLAS Collaboration, *Measurement of the production cross-section of J/ψ and $\psi(2S)$ mesons in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. C **84** (2023) 169, arXiv:2309.17177 [hep-ex].

[6] ATLAS Collaboration, *Measurement of the $B_s^0 \to \mu\mu$ effective lifetime with the ATLAS detector*, JHEP **09** (2023) 199, arXiv:2308.01171 [hep-ex].