Recent B-Physics Results from ATLAS

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ATLAS Experiment

On behalf of the ATLAS collaboration

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Introduction and Outline

Heavy Flavour physics gives us precise predictions of experimentally accessible quantities (lifetimes, branching ratios, …)

Predictions modified in **numerous New Physics scenarios** → great laboratory to look for BSM effects!

Many interesting recent results!

A search for lepton-flavour violating $\tau \to 3\mu$ decays with the ATLAS detector
- Submitted to Phys. Lett. B, arXiv:2603.18099

Precision measurement of the B^0 meson lifetime using $B^0 \to J/\psi K^{*0}$ decays with the ATLAS detector
- Eur. Phys. J. C 85 (2025) 736, arXiv:2411.09962

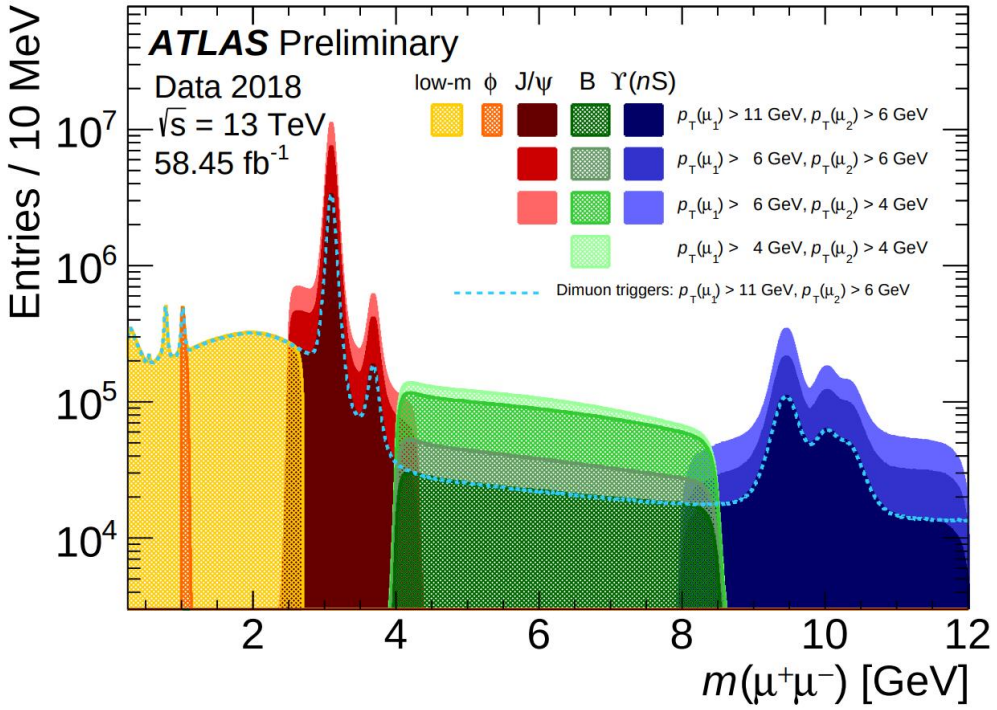
Observation of structures in the $J/\psi + \psi(2S)$ mass spectrum with the ATLAS detector
- Submitted to Phys. Rev. D, arXiv:2509.13101

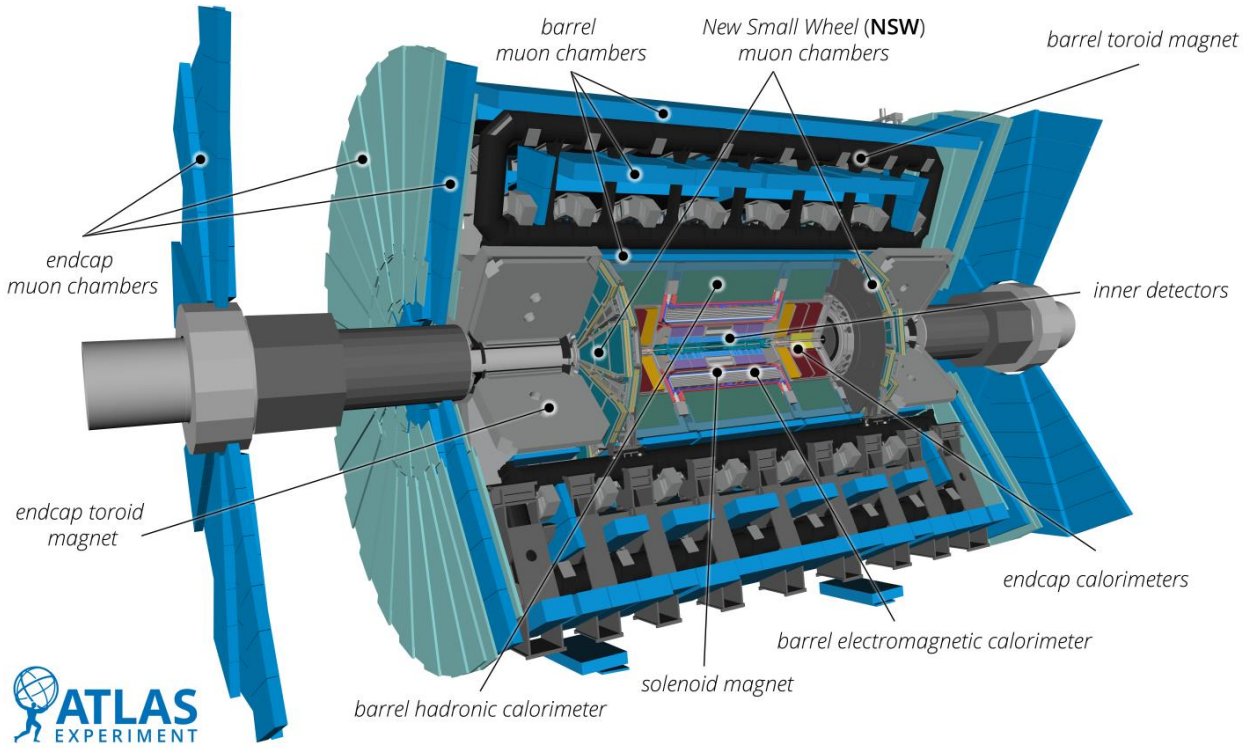
ATLAS Experiment

General purpose detector probing the SM and beyond in 13 TeV (13.6 TeV from 2022) p-p collisions @ LHC

Dedicated flavour physics programme including:

- CP/LFU violation
- Rare decays
- Quarkonium Spectroscopy





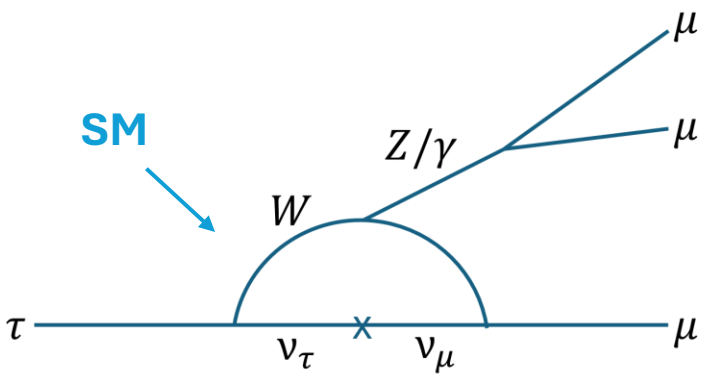
Many measurements **highly competitive** with dedicated B-physics experiments thanks to **excellent muon performance, statistics and kinematic coverage**

A search for lepton-flavour violating $\tau \rightarrow 3\mu$ decays with the ATLAS detector

Dataset: 2016 - 2018 pp data (137 fb^{-1})
Keywords: Lepton Flavour Violation, Rare Decay
Link: arXiv:2603.18099, submitted to Phys. Lett. B

$\tau \rightarrow 3\mu$ search

Flavour is not a fundamental SM symmetry – FV observed in q, ν.
Charged LFV not observed, μ limits ~10^4 × stronger than τ.



$\tau \rightarrow 3\mu$ possible in SM through neutrino oscillation

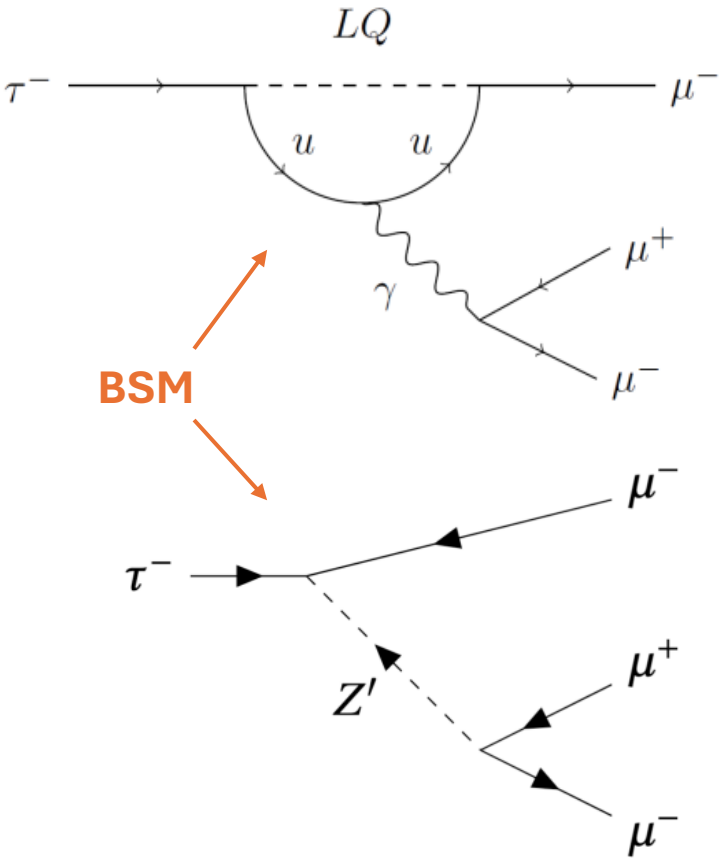
- Vanishing BR ~10^{-55}

Significant contribution in different BSM scenarios

- e. g. LQ, Z' with BR up to ~10^{-9} → observation = NP

Previous results – upper limit on $\tau \rightarrow 3\mu$ BR @ 90% CL

- Belle II, LHCb – BR < 1.9×10^{-8}
- CMS - BR < 2.9×10^{-8}
- ATLAS (Run 1) - BR < 37.6×10^{-8}



$\tau \rightarrow 3\mu$ search - Strategy

$\tau \rightarrow 3\mu$ forms a peak in 3-muon invariant mass spectrum

- Extract signal yield in signal + bkg fit to $m_{3\mu}$

τ production at LHC

- Heavy flavour decays – e. g. $D_s \rightarrow \tau\nu$
  - Dominates, but typically soft → missed by trigger
- EW production - $W \rightarrow \tau\nu$, $Z \rightarrow \tau\tau$, $tt \rightarrow \tau X$
  - Better acceptance → main analysis channel

Triggers, objects & Selections

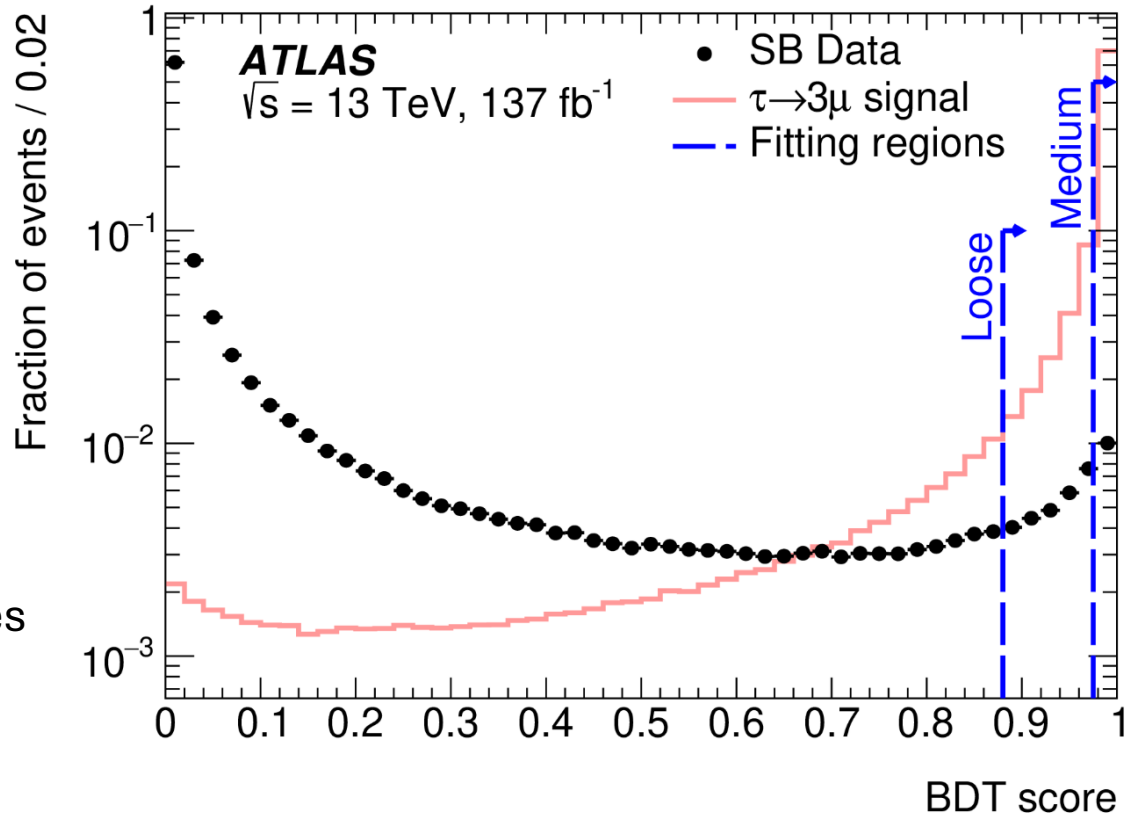
- 2- and 3-μ triggers covering different p_T regimes
- 3μ vertex candidate
  - Muon tracks refit with vertex constraint
  - Cleaning based on fit quality, IP, isolation

MVA Classifier

- BDT using 3μ vertex quality, geometry and isolation variables
- Trained on $m_{3\mu}$ sidebands (bkg) and MC (signal)

Background sources

- random combinations of (misidentified) muons
- $\omega, \varphi \rightarrow \mu\mu$ + another muon

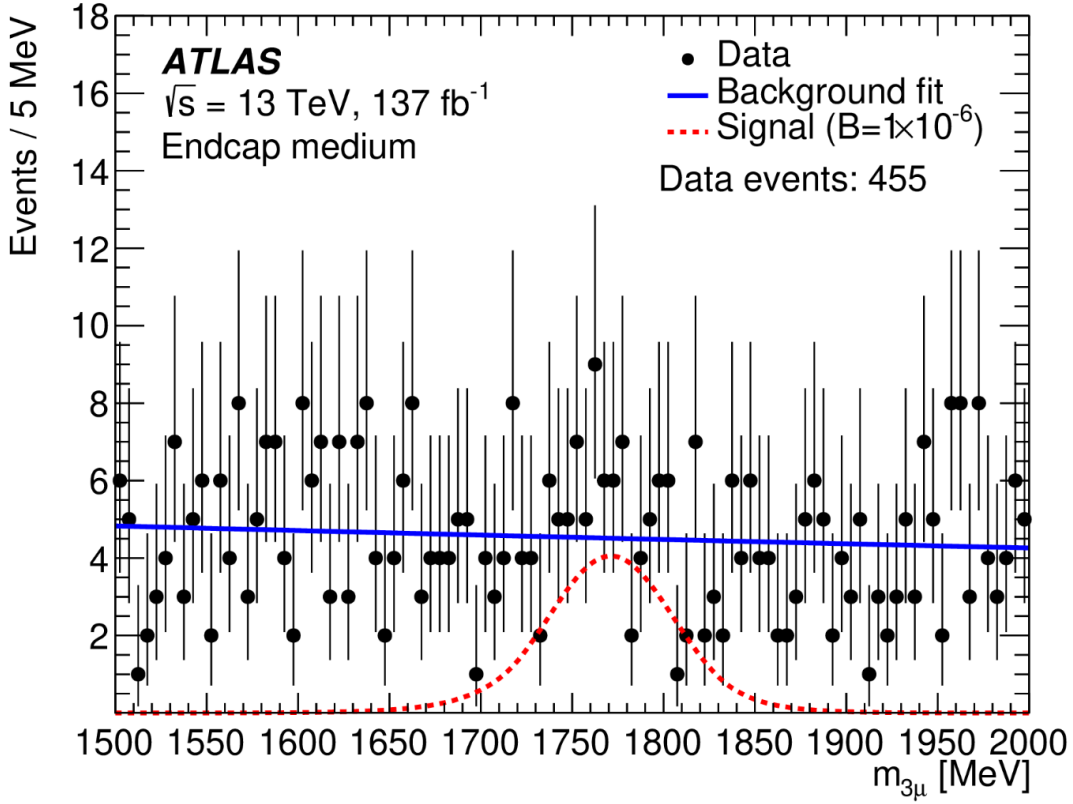


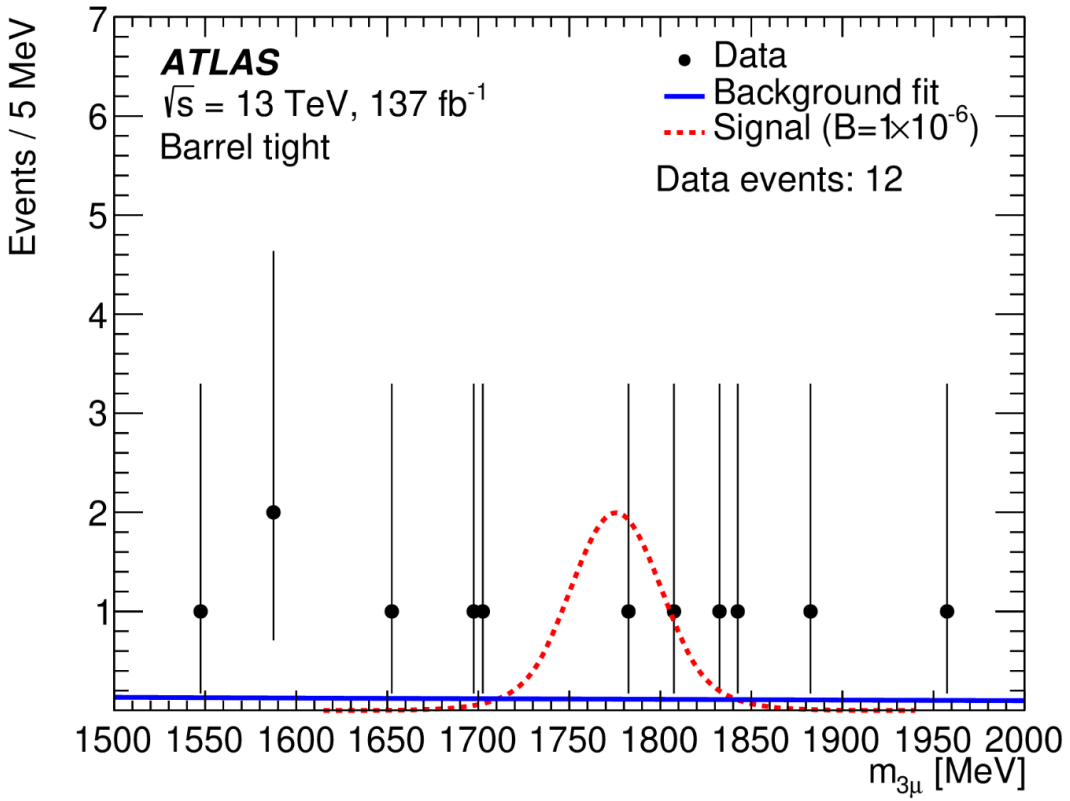
$\tau \to 3\mu$ search - Strategy

3-muon invariant mass fit of Signal + Bkg models

- Simultaneous in BDT and mass resolution (barrel, EC) categories for optimal sensitivity

	Events in fit category					
BDT category	Loose		Medium		Tight	
Source	Barrel	Endcap	Barrel	Endcap	Barrel	Endcap
EW signal	1.0	2.0	3.2	5.8	2.5	5.3
HF signal	1.0	2.4	0.6	1.4	0.1	0.2
Background in signal region	191.9	275.8	88.0	135.6	3.4	6.4
Signal region data	209	291	86	141	5	5





$\tau \to 3\mu$ search - Results

3-muon invariant mass fit of Signal + Bkg models

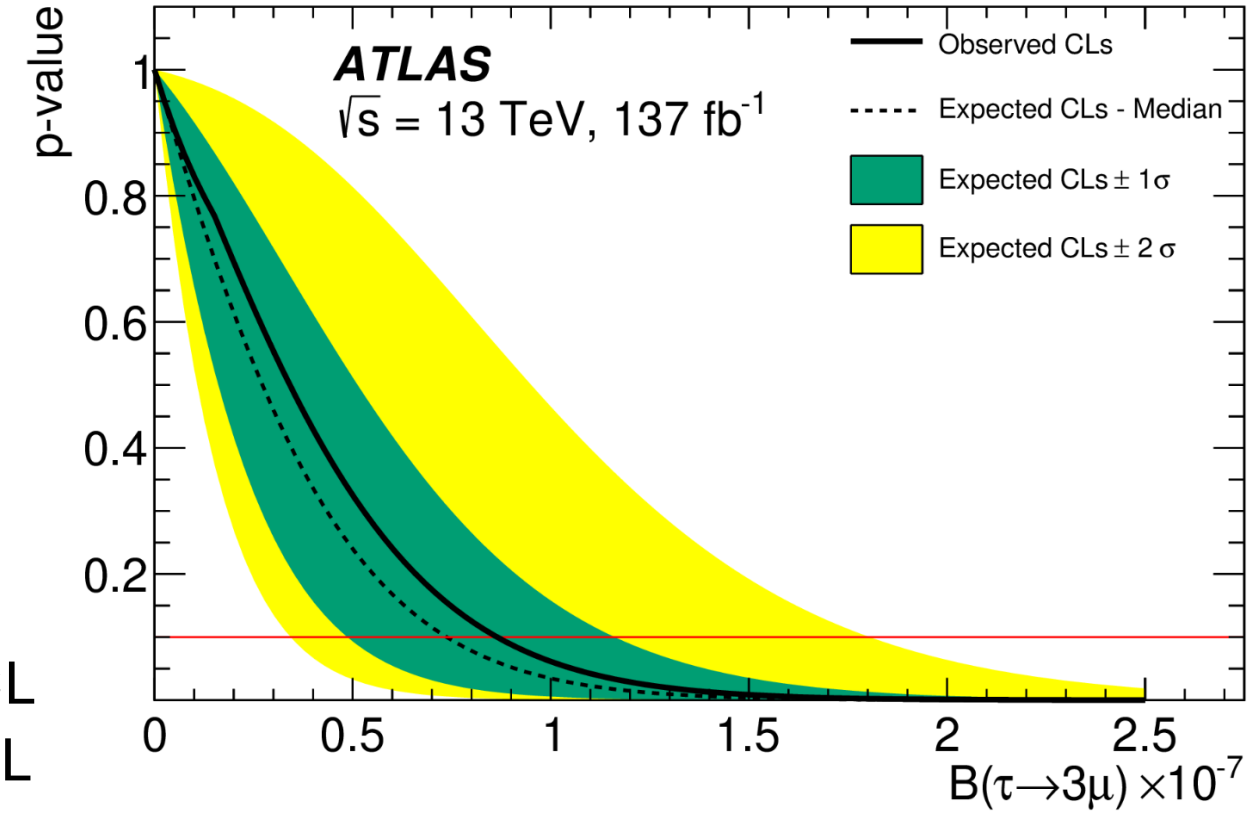
- Systematics implemented as nuisance parameters
- $\tau \to 3\mu$ BR is varied, 90% CL upper limit is found using profile likelihood test statistic

No significant signal excess observed

Observed (expected) limits

- $BR(\tau \to 3\mu) < 8.7\ (7.5) \times 10^{-8}$ @ 90% CL
- $BR(\tau \to 3\mu) < 10.6\ (9.3) \times 10^{-8}$ @ 95% CL

Significant improvement wrt. previous ATLAS result thanks to larger dataset & improved analysis strategy



	Systematic signal uncertainty [%]					
BDT category	Loose		Medium		Tight	
Systematic uncertainty	Barrel	Endcap	Barrel	Endcap	Barrel	Endcap
Trigger efficiency	±26.7	±10.1	±20.9	±9.1	±16.2	±11.4
Muon reconstruction efficiency	±3.7	±3.5	±3.4	±3.2	±2.9	±3.0
$E_{\mathrm{T}}^{\mathrm{miss}}$ track resolution	±1.9	±1.1	±0.8	±1.2	∓2.4	∓2.3
Jet energy scale	±5.0	±3.3	±0.9	±0.4	∓5.1	∓3.2
Pile-up	±1.5	±1.5	< 0.1	< 0.1	∓1.8	∓1.4

Precision measurement of the B^0 meson lifetime using $B^0 \to J/\psi K^{*0}$ decays with the ATLAS detector

Dataset: 2015 - 2018 pp data (140 fb^{-1})
Keywords: CP Violation, Precision SM test
Link: arXiv:2411.09962, Eur. Phys. J. C 85 (2025) 736

$B^0 \to J/\psi K^{*0}$ Lifetime measurement

Measurements of fundamental b-hadron properties provide a stringent SM test

- phenomenological importance
- lifetimes, decay widths & especially ratios **precisely predicted** & sensitive to BSM effects

Effective B^0 lifetime (τ_{B^0}) measured in $B^0 \to J/\psi K^{*0}$ relates to the heavy/light eigenstate decay widths

$$\tau_{B^0} = \frac{1}{\Gamma_d}\frac{1+y^2}{1-y^2} \qquad y = \frac{\Gamma_{d,L} - \Gamma_{d,H}}{2\Gamma_d}$$

external parameter

- τ_{B^0} measurement allows to extract $\Gamma_d = (\Gamma_{d,L} - \Gamma_{d,H})/2$
- together with ATLAS measurement of B_s^0 decay width measured in $B_s^0 \to J/\psi\phi$ (Eur. Phys. J. C 81(2021) 342) yields Γ_d/Γ_s ratio

Model	Γ_d/Γ_s
HQE	1.003 ± 0.006
Lattice QCD	1.00 ± 0.02

$B^0 \to J/\psi K^{*0}$ Lifetime - Strategy

2D unbinned ML fit to invariant mass and proper decay time of B^0 candidates

- Mass provides separation power between signal (peak) and background (continuous)
- Candidates formed by refitting $J/\psi \to \mu\mu$ and $K^{*0} \to K^+\pi^-$ to a common decay vertex
  - J/ψ constrained to PDG mass
- independent mass and decay time PDFs conditional on σ_t

Candidate proper decay time calculated as

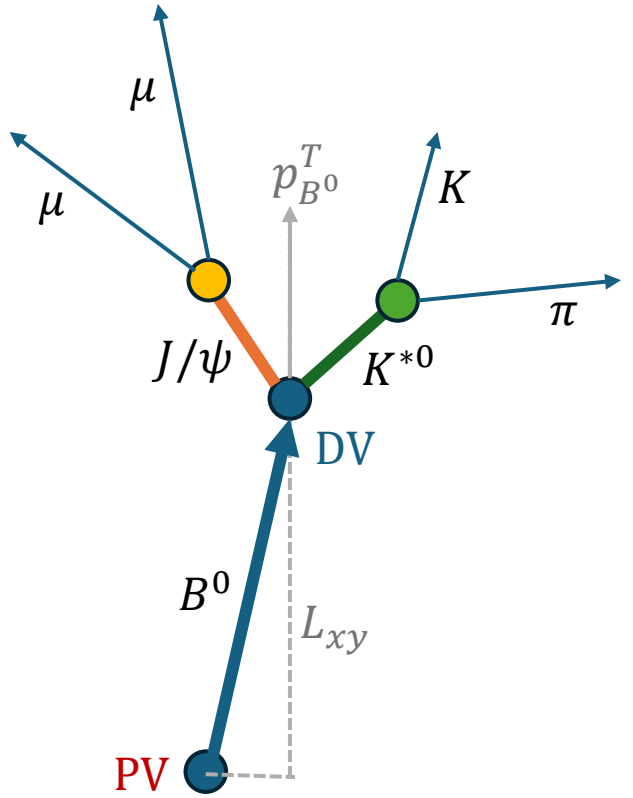
$$t = \frac{L_{xy} m_B}{p^T_{B^0}}$$

Main backgrounds

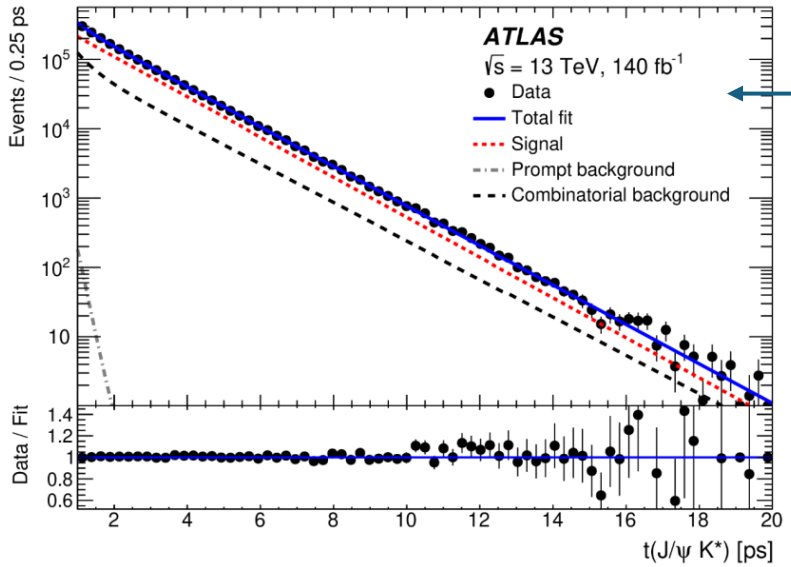
- prompt - pp $\to J/\psi X$ combined with random K^{*0}
- combinatorial - J/ψ from b-hadron decay + K^{*0}

Leading systematics

- mass/decay time correlation – $1.9 \times \sigma_{stat}$
- mass PDF modelling - $1.3 \times \sigma_{stat}$
- decay time efficiency x acceptance modelling – $1.3 \times \sigma_{stat}$



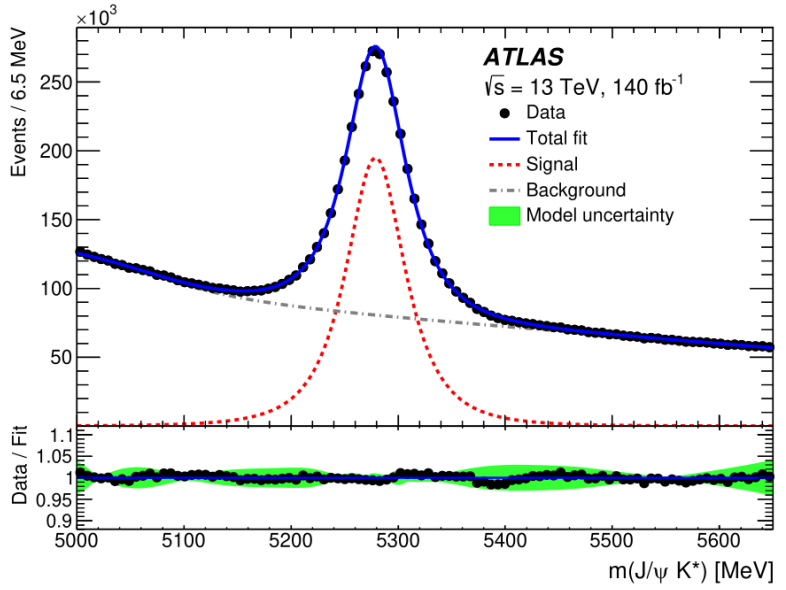
$B^0 \to J/\psi K^{*0}$ Lifetime - Strategy

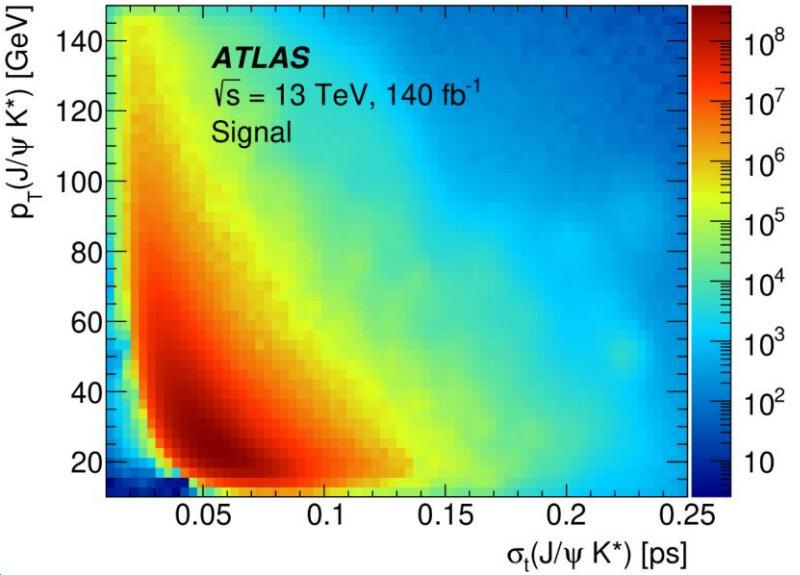


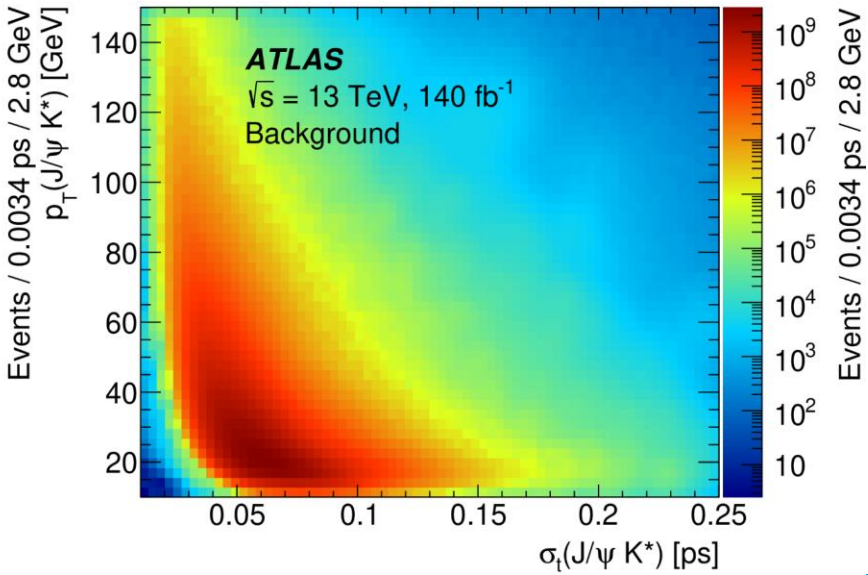
$$\mathcal{T}_j(t_i, \sigma_{t_i}, p_{\mathrm{T}_i}) = P_j(t_i|\sigma_{t_i}, p_{\mathrm{T}_i}) \cdot C_j(\sigma_{t_i}, p_{\mathrm{T}_i})$$

Proper decay time PDF conditional on per-candidate σ_t (obtained in decay vertex fit) and p^T.

- Different (σ_t, p^T) distribution for signal and background → **different constraint terms**







$B^0 \to J/\psi K^{*0}$ Lifetime - Results

Resulting B^0 lifetime

$$\tau_{B^0} = 1.5053 \pm 0.0012\ (stat)\ \pm 0.0035\ (syst)\ ps$$

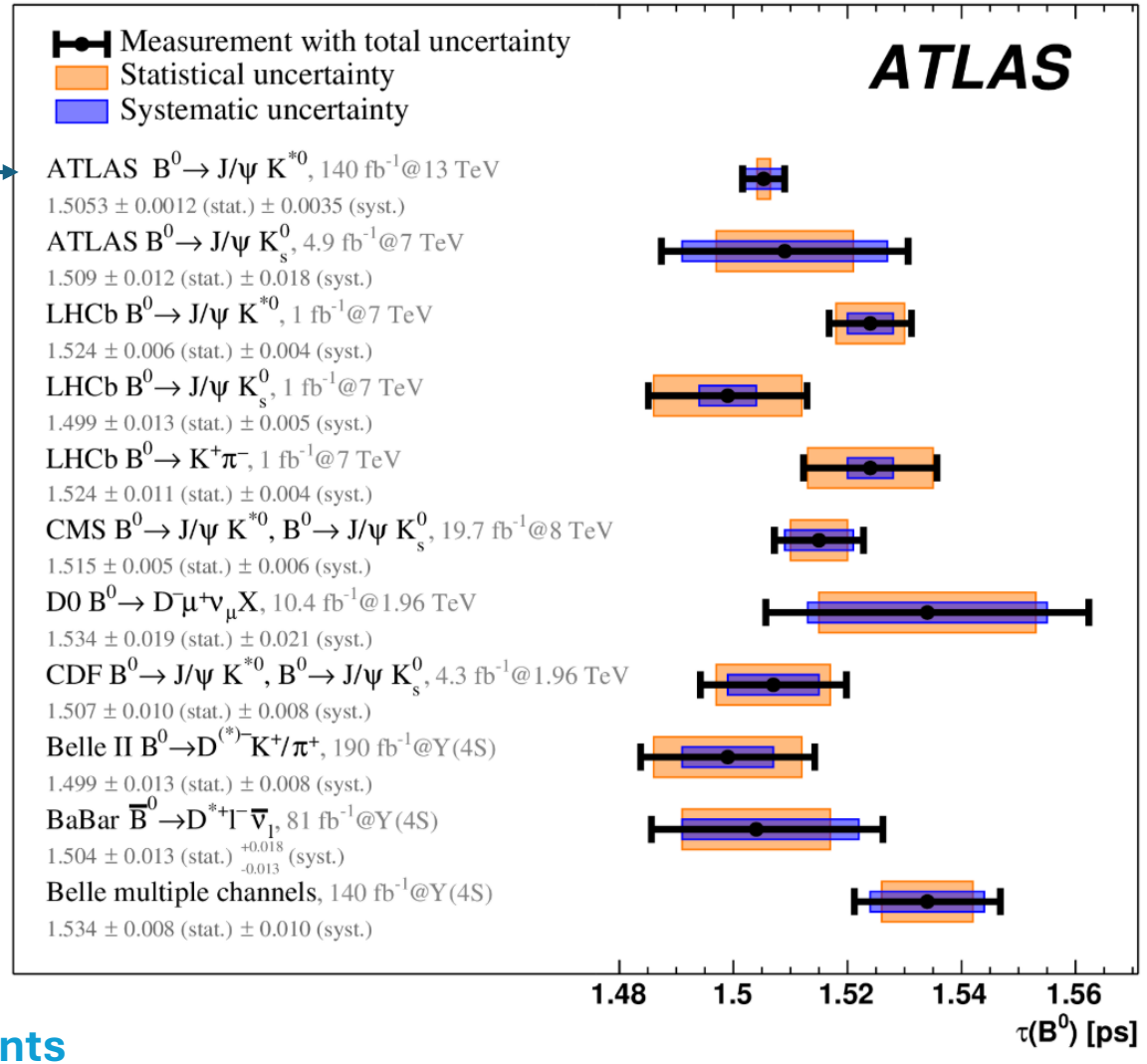
Most precise τ_{B^0} measurement to date!

In combination with y yields the decay width

$$\Gamma_d = 0.6643 \pm 0.0005\ (stat)\ \pm 0.0016\ (syst)\ ps$$

The Γ_d/Γ_s decay width ratio measured as

$$\frac{\Gamma_d}{\Gamma_s} = 0.9910 \pm 0.0022\ (stat)\ \pm 0.0036\ (syst)\ ps$$



Results compatible with predictions and other measurements

Observation of structures in the $J/\psi + \psi(2S)$ mass spectrum with the ATLAS detector

Dataset: 2015 - 2018 pp data (140 fb^{-1})
Keywords: Quarkonium spectroscopy, tetraquarks
Link: arXiv:2509.13101, submitted to Phys. Rev. D

Resonances in $J/\psi + \psi(2S)$ spectrum

Tetraquark states provide a unique insight into QCD

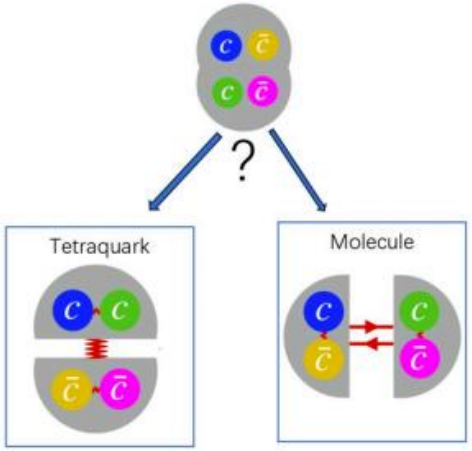
- Many properties remain unknown – e. g. tightly-bound state vs. ‘molecule’?

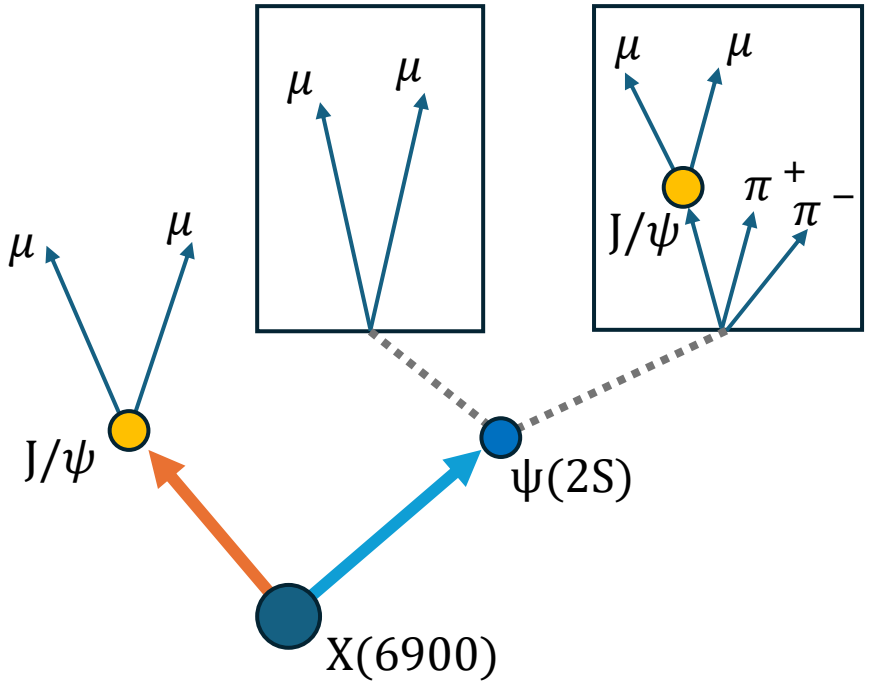
Many recent results on all-charm tetraquarks

- LHCb (2020) – Observation of a narrow resonance in di- J/ψ spectrum near 6.9 GeV – X(6900) arXiv:2006.16957
  - Confirmed by ATLAS (2023) and CMS (2024) arXiv:2304.08962, arXiv:2306.07164
- CMS (2025) – Measurement of tetraquark quantum numbers arXiv:2506.07944

This analysis - First-time inclusion of $\psi(2S) \to J/\psi\pi^+\pi^-$

- >2 x BR of previously used $\psi(2S) \to \mu\mu$





$J/\psi + \psi(2S)$ - Strategy

Event and candidate selections

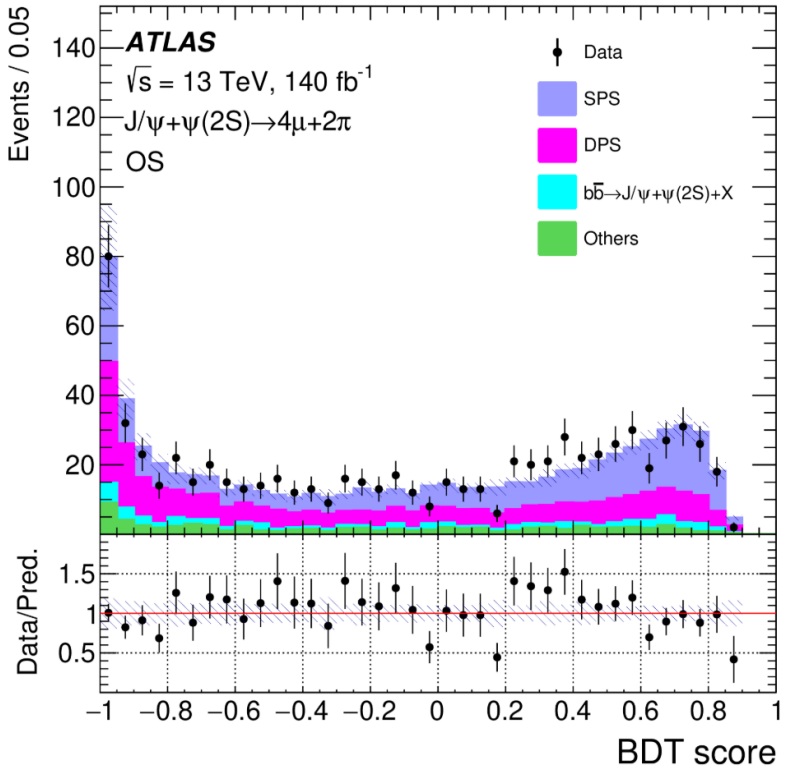
- 2- and 3-μ triggers with at least one pair compatible with J/ψ or $\psi(2S)$ mass
- two pairs of opposite-sign muons (+ 2 OS pions) refitted to a common vertex constrained to the charmonia masses

4μ channel		$4\mu + 2\pi$ channel	
SR	CR	SR	CR
Di-muon or tri-muon triggers, oppositely charged muons from each charmonium, *Loose* muons, $p_{T1,2,3,4} > 4, 4, 3, 3$ GeV and $\lvert\eta_{1,2,3,4}\rvert < 2.5$ for the four muons, $m_{J/\psi} \in [2.94, 3.25]$ GeV, $m_{\psi(2S)} \in [3.56, 3.80]$ GeV			
—		Two *loose* OS ID tracks with $p_T > 0.5$ GeV for pions, BDT requirement	
$\chi^2_{4\mu}/N < 3$, $\lvert L_{xy}^{4\mu}\rvert < 0.2$ mm, $\lvert L_{xy}^{\text{charm}}\rvert < 0.3$ mm, $m_{4\mu} < 11$ GeV		$\chi^2_{4\mu+2\pi}/N < 3$, $\lvert L_{xy}^{4\mu+2\pi}\rvert < 0.2$ mm, $\lvert L_{xy}^{\text{charm}}\rvert < 0.3$ mm, $m_{4\mu+2\pi} < 11$ GeV	
$\Delta R(J/\psi, \psi(2S)) < 0.25$	$\Delta R(J/\psi, \psi(2S)) \geq 0.25$	$\Delta R(J/\psi, \psi(2S)) < 0.25$	$\Delta R(J/\psi, \psi(2S)) \geq 0.25$

Resonance masses, widths and normalizations extracted in an UML fit to $J/\psi + \psi(2S)$ invariant mass spectrum

Backgrounds

- prompt – single/double parton scattering producing a ψ pair
- non-prompt - $b\bar{b} \rightarrow J/\psi\ \psi(2S) + X$
- single real charmonium + combinatorics
- di- J/ψ signal + 2 random pions ("feed-up bkg")
  - suppressed by BDT
  - yield constrained in same-sign-π regions, shape from MC



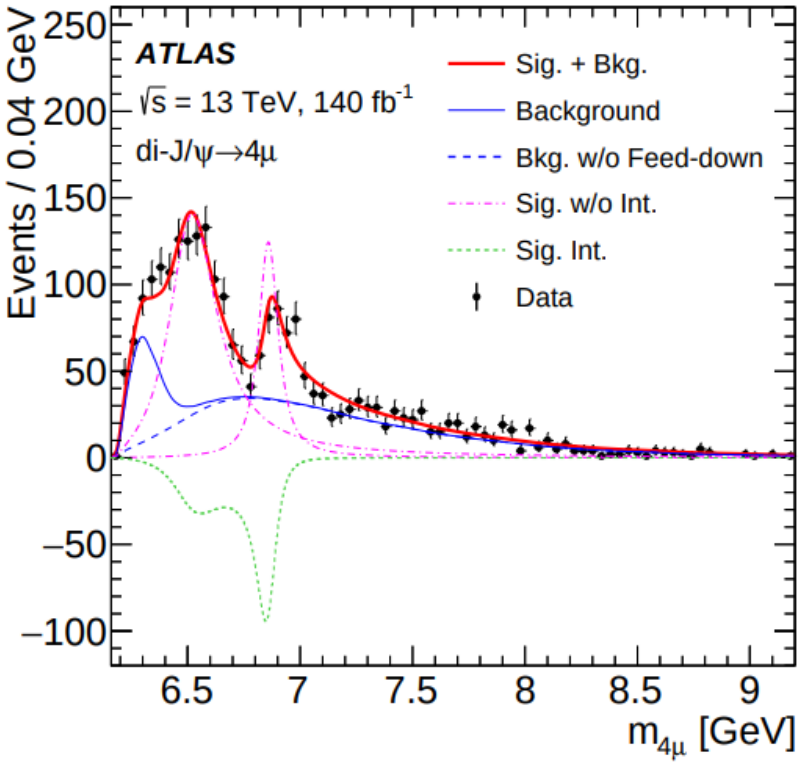
$J/\psi + \psi(2S)$ - Fit

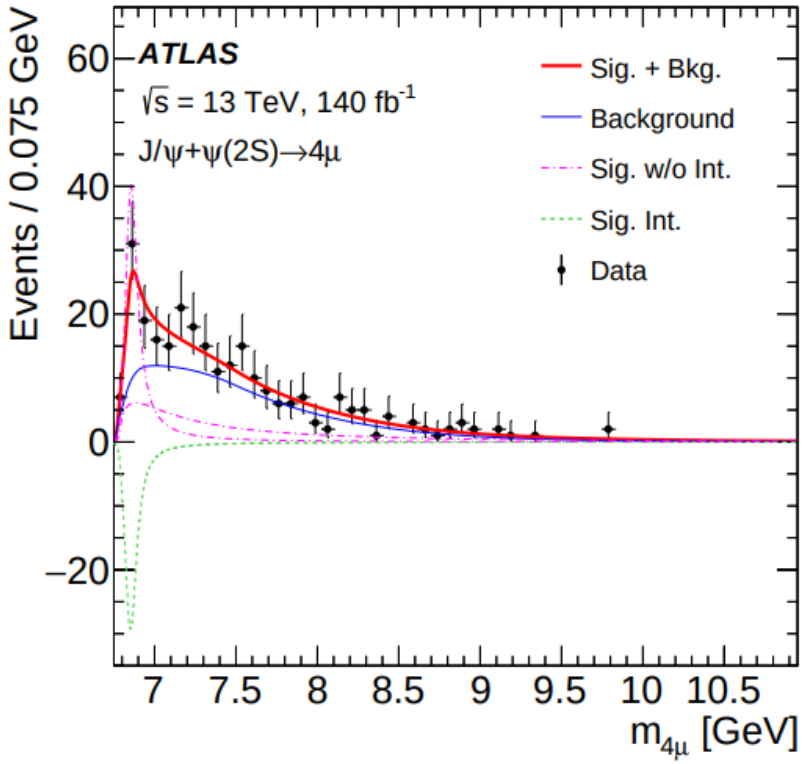
Three signal models tested

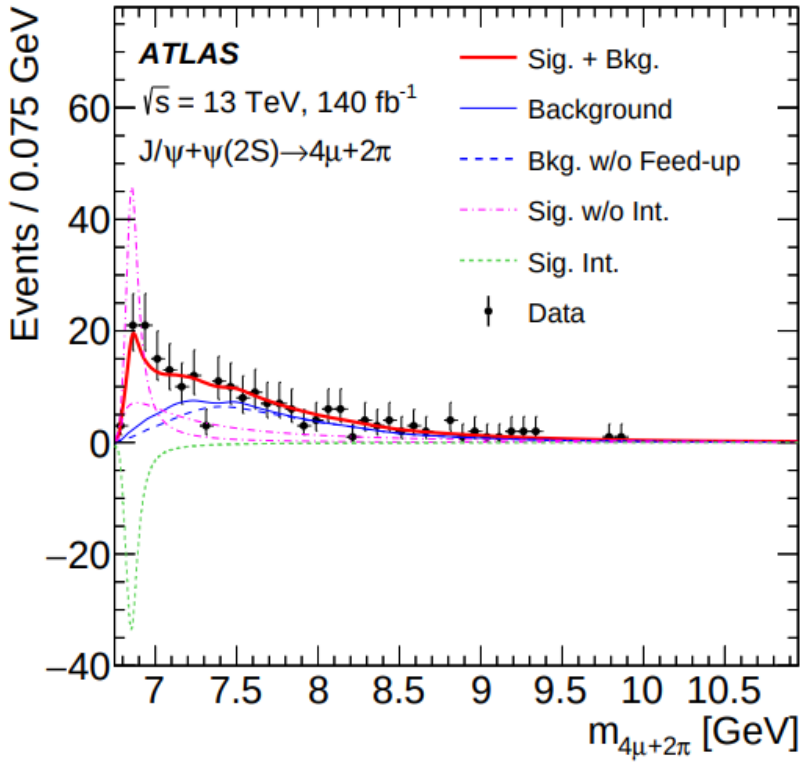
- A – two interfering resonances in di- J/ψ & $J/\psi + \psi(2S)$ channels
- B – one resonance interfereing with SPS + one standalone
- C – standalone resonance in $J/\psi + \psi(2S)$ channel

The di- J/ψ channel is included from previous ATLAS measurement (arXiv:2304.08962)

Model A ⬇







$J/\psi + \psi(2S)$ - Results

X(6900) signal significance 8.9σ

Resonance properties

- mass consistent in all models ~6900 MeV
- decay widths compatible in B and C
- results in agreement with previous measurements

X(7200) existence tested with each model

- no evidence in data, $N_{X(7200)}/N_{X(6900)} < 0.41$ @ 95% CL

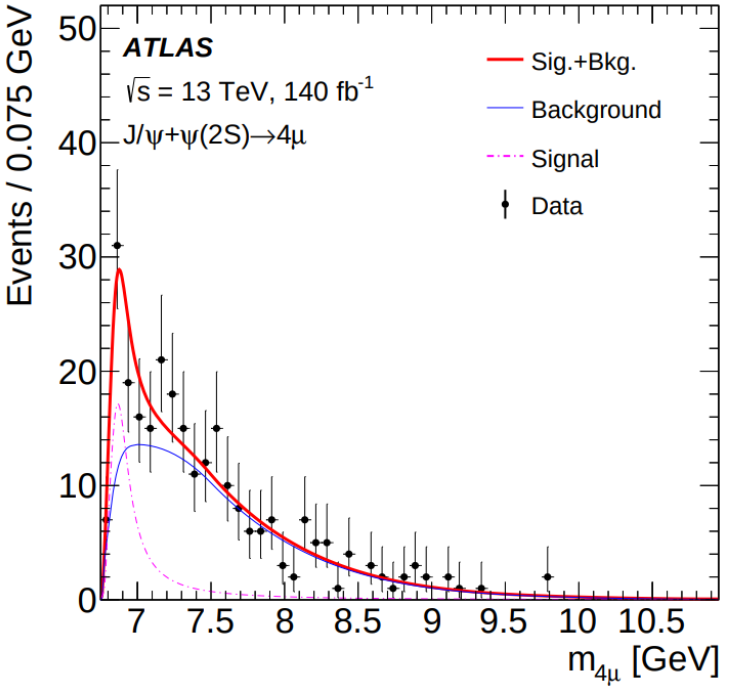
Inclusion of di- J/ψ allows to determine

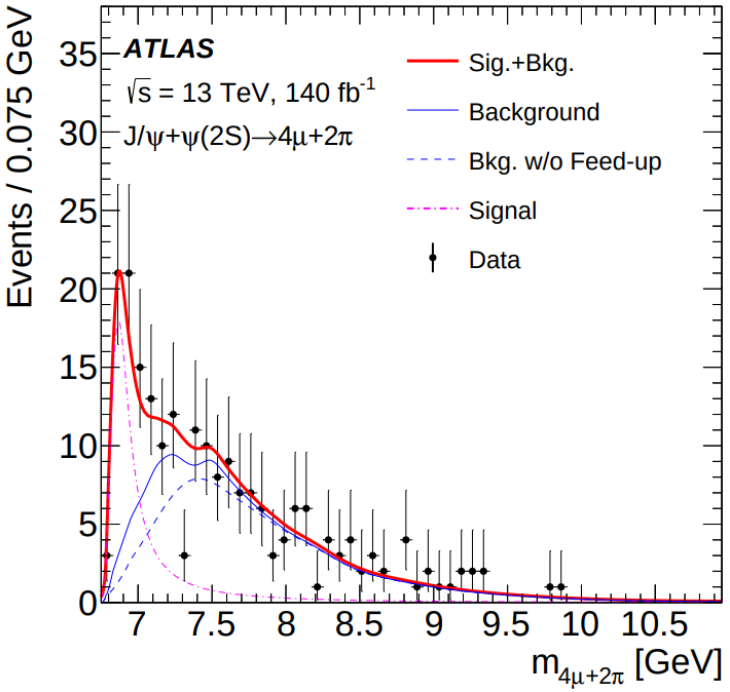
$$R = \frac{\Gamma_{X(6900)\to J/\psi+\psi(2S)}}{\Gamma_{X(6900)\to \mathrm{di}-J/\psi}}$$

	model A	model B	model C
m / GeV	$6.860 \pm 0.023 \pm 0.010$	$6.902 \pm 0.008 \pm 0.010$	$6.884 \pm 0.017^{+0.058}_{-0.005}$
Γ / GeV	$0.082 \pm 0.032 \pm 0.015$	$0.183 \pm 0.025 \pm 0.007$	$0.178 \pm 0.054^{+0.176}_{-0.024}$
R	$1.08 \pm 0.20^{+0.40}_{-0.09}$	$0.93 \pm 0.17 \pm 0.11$	—

first uncertainty stat., second syst.

Model C





Conclusion

Many interesting B-Physics results by ATLAS

A search for lepton-flavour violating $\tau \rightarrow 3\mu$ decays with the ATLAS detector

- 5x stronger limit wrt. previous ATLAS result

Precision measurement of the B^0 meson lifetime using $B^0 \rightarrow J/\psi K^{*0}$ decays with the ATLAS detector

- Most precise B^0 lifetime measurement to date

Observation of structures in the $J/\psi + \psi(2S)$ mass spectrum with the ATLAS detector

- Discovering the properties of a new 4-charm resonance

Stay tuned for more *b*eauty from ATLAS!

Backup

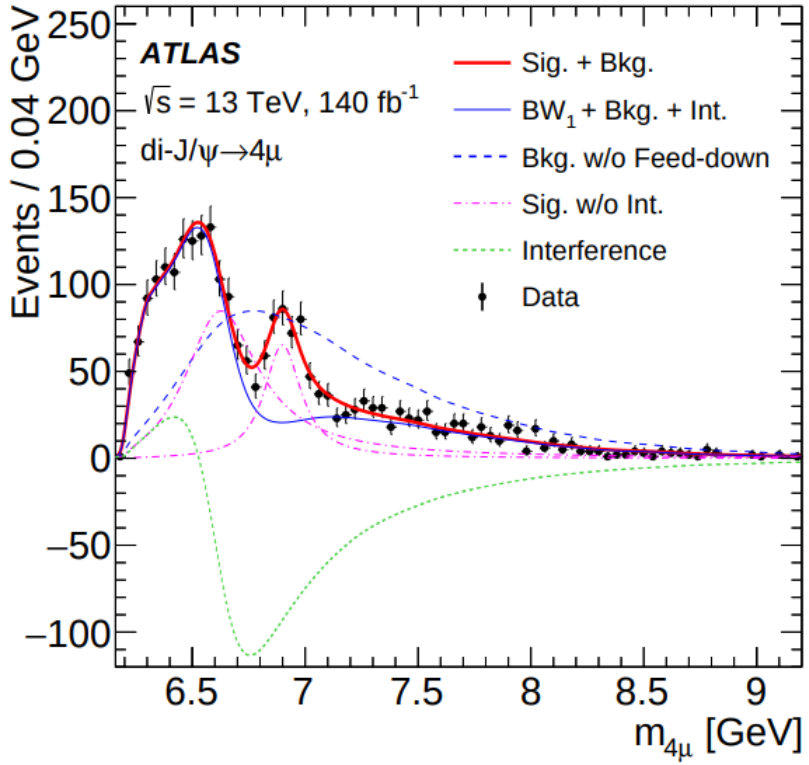
$J/\psi + \psi(2S)$ - Fit

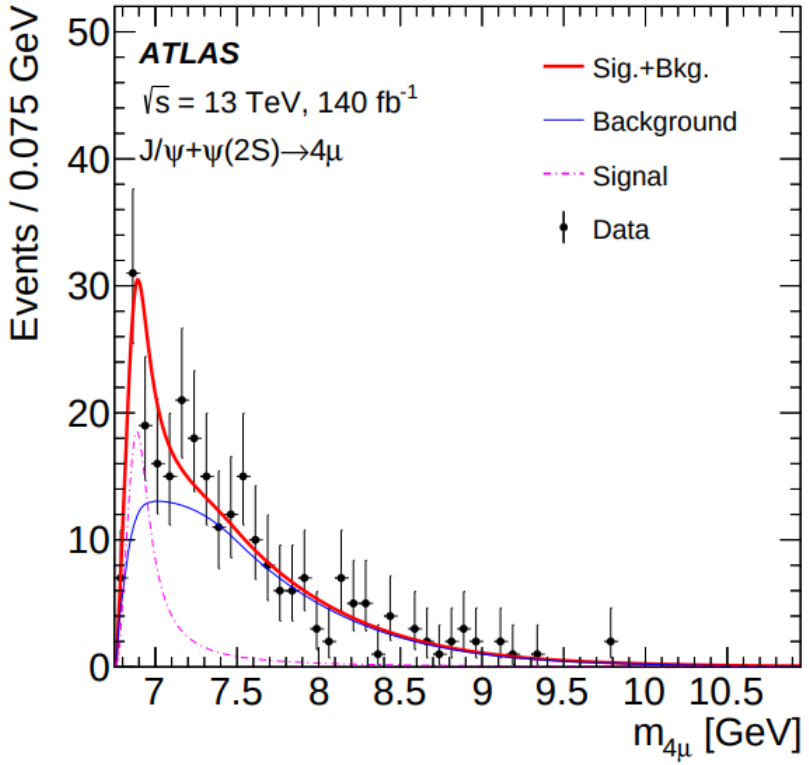
Three signal models tested

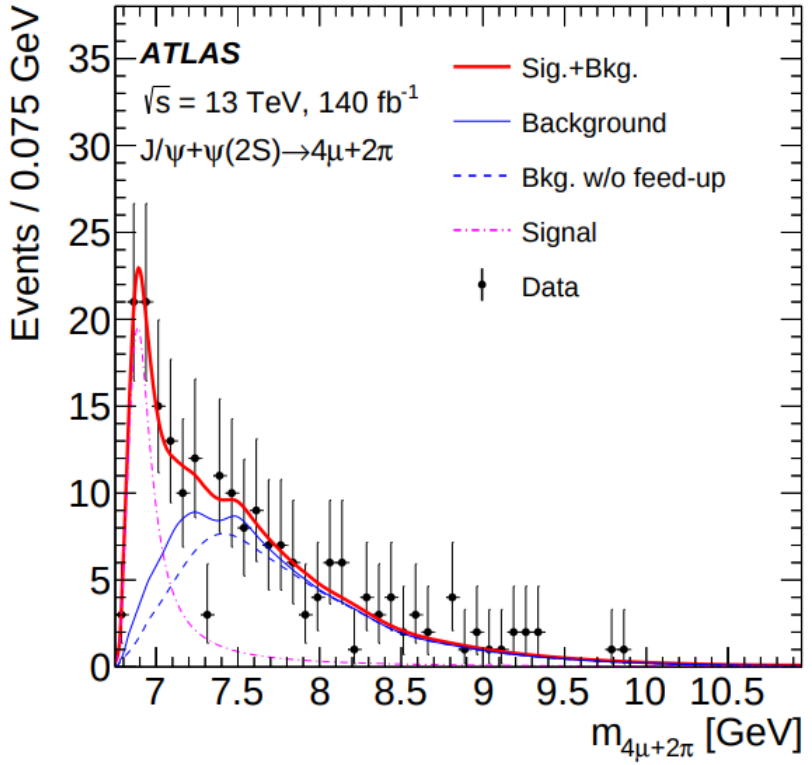
- A – two interfering resonances in di- J/ψ & $J/\psi + \psi(2S)$ channels
- B – one resonance interfereing with SPS + one standalone
- C – standalone resonance in $J/\psi + \psi(2S)$ channel

The di- J/ψ channel is included from previous ATLAS measurement (arXiv:2304.08962)

Model B ⬇

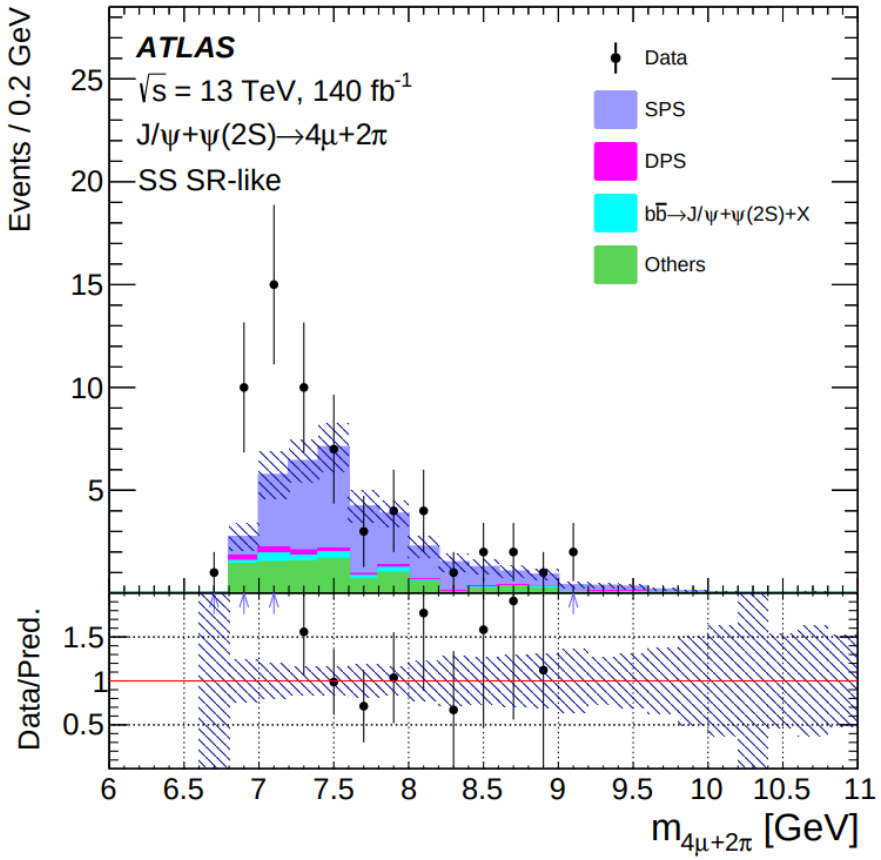


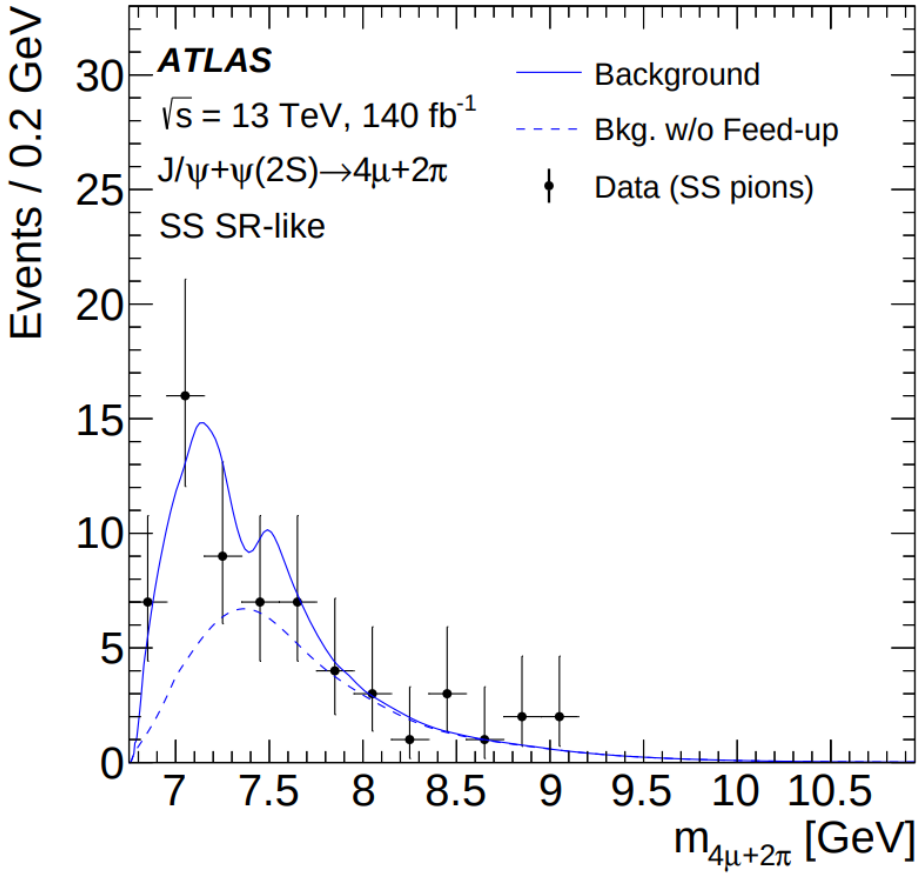




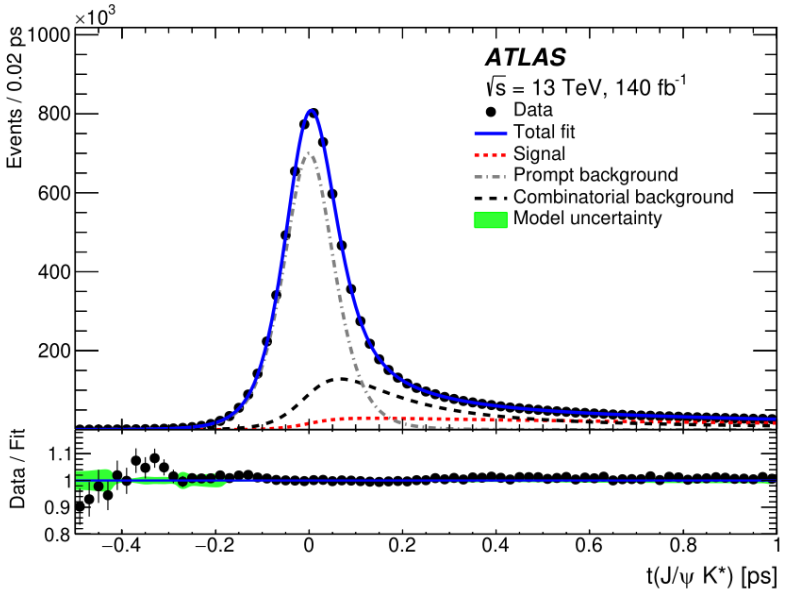
$J/\psi + \psi(2S)$ – Feed-up background

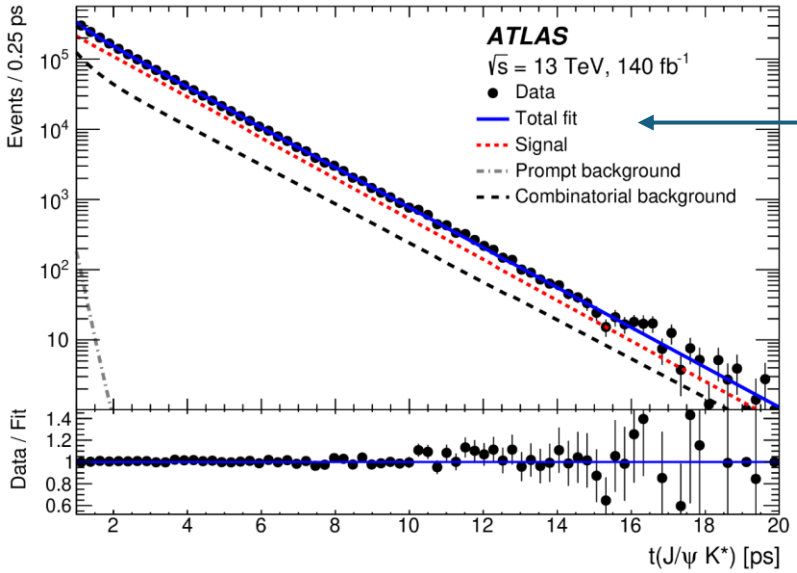
- di-J/ψ signal + 2 random pions (“feed-up bkg”)
  - suppressed by BDT
  - yield constrained in same-sign-π control regions, shape from MC



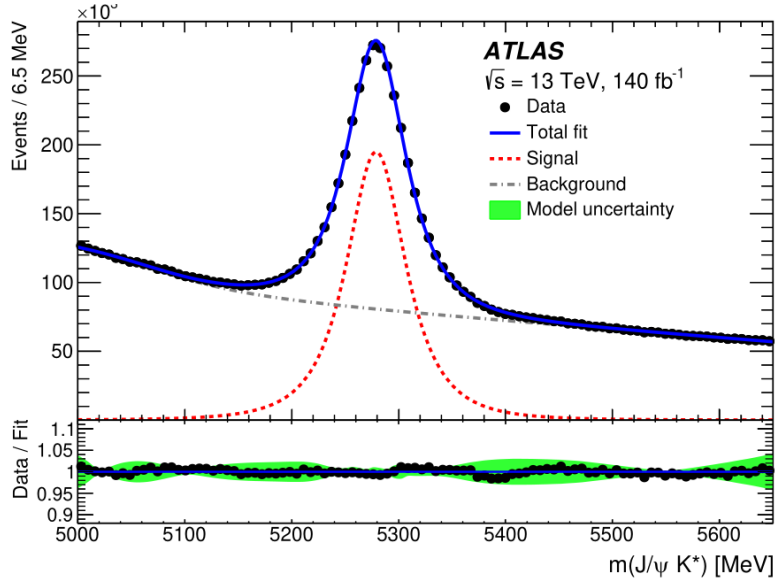


$B^0 \to J/\psi K^{*0}$ Lifetime - Fit





$$\mathcal{T}_j(t_i, \sigma_{t_i}, p_{\mathrm{T}_i}) = P_j(t_i|\sigma_{t_i}, p_{\mathrm{T}_i}) \cdot C_j(\sigma_{t_i}, p_{\mathrm{T}_i})$$



$$\mathcal{M}_{\mathrm{sig}}(m_i) = \frac{\delta}{\lambda\sqrt{2\pi}\sqrt{1+\left(\frac{m_i-\mu}{\lambda}\right)^2}} \exp\left[-\frac{1}{2}\left(\gamma + \delta \sinh^{-1}\left(\frac{m_i-\mu}{\lambda}\right)\right)^2\right]$$

$$\mathcal{M}_{\mathrm{bkg}}(m_i) = f_{\mathrm{poly}}(1 + p_0 \cdot m_i) + (1 - f_{\mathrm{poly}})\left(1 - \frac{s(m_i - m_0)}{\sqrt{1 + (s(m_i - m_0))^2}}\right)$$