B Physics in ATLAS and CMS

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On behalf of the ATLAS and CMS collaborations

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!

ATLAS

- Measurement of the $\boldsymbol{B_s^0 \to \mu^+\mu^-}$ **effective lifetime** with the ATLAS detector — JHEP09(2023)199
- Measurement of the **production cross-section of $\boldsymbol{J/\psi}$ and $\boldsymbol{\psi(2S)}$ mesons** — Eur. Phys. J. C 84 (2024) 169

CMS

- Measurement of the B_s^0 effective lifetime in the decay $B_s^0 \to J/\psi\, K_S^0$ — CMS-PAS-BPH-22-001 — New!
- Observation of the $\boldsymbol{\Xi_b^- \to \psi(2S)\Xi^-}$ **decay** and studies of the $\boldsymbol{\Xi_b^{*0}}$ **baryon** — arXiv:2402.17738 — New!
- Search for CP violation in $D^0 \to K_S^0\, K_S^0$ — CMS-BPH-23-005 — New!
- Observation of the rare decay $J/\psi \to 4\mu$ — arXiv:2403.11352 — New!

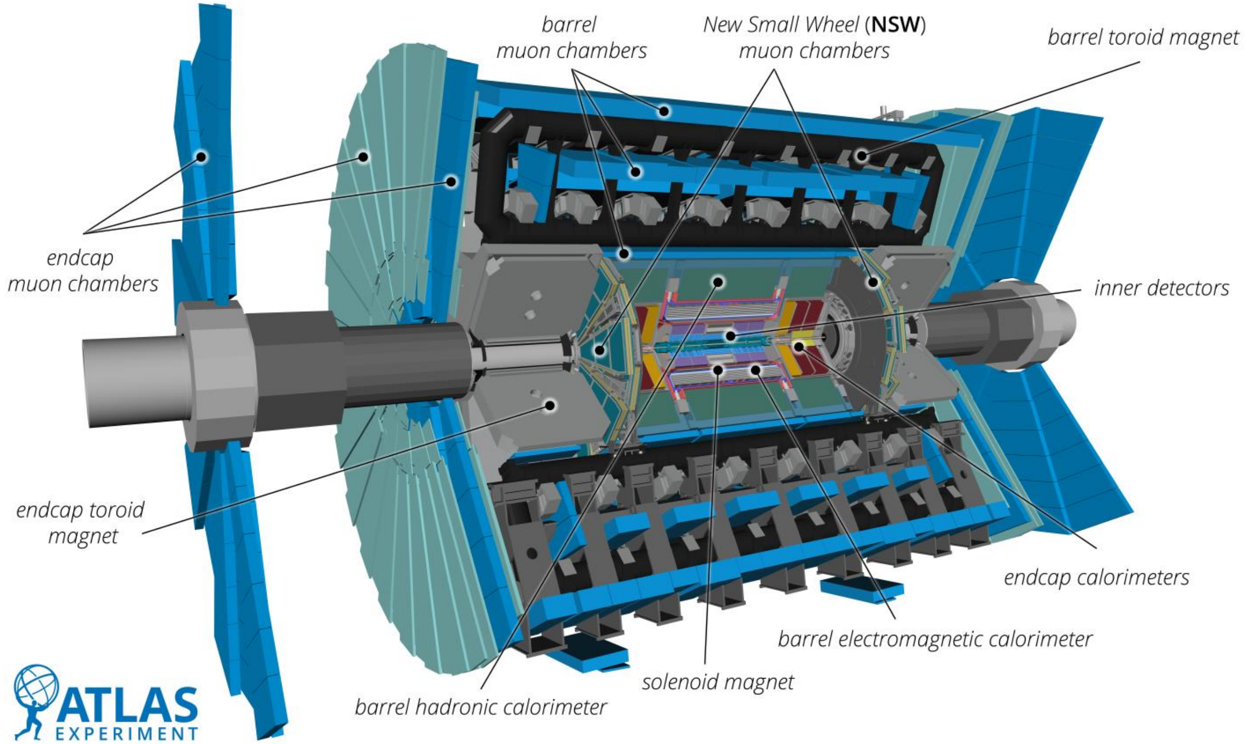
See also the CMS wildcard talk later in this session!

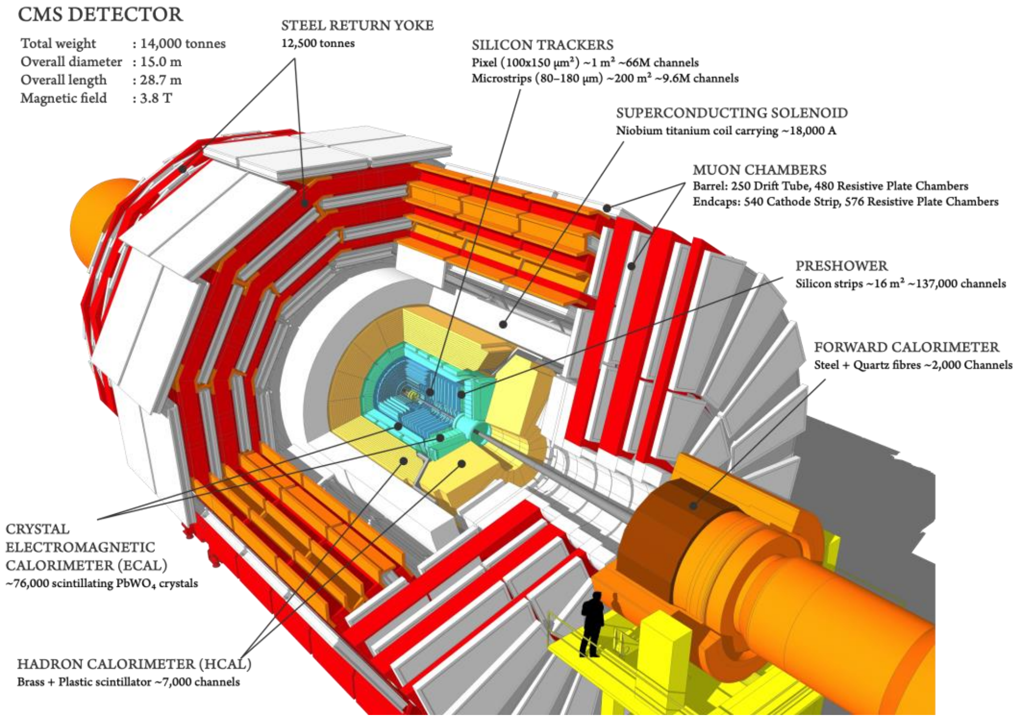
ATLAS and CMS Experiments

General purpose detectors 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**





Measurement of the $B_s^0 \to \mu^+\mu^-$ **effective lifetime** with the ATLAS detector

Experiment: ATLAS
Dataset: 2015 + 2016 pp data (26.3 fb^{-1})
Keywords: CP violation, rare decay
Link: JHEP09(2023)199

$B_s^0 \to \mu^+\mu^-$ effective lifetime

$B_s^0 \to \mu^+\mu^-$ effective lifetime ($\tau_{\mu\mu}$) relates to the "heavy-light rate asymmetry" parameter $A_{\mu\mu}$

$$\tau_{\mu\mu} = \frac{\tau_{B_s^0}}{1-y^2}\left[\frac{1+2yA_{\mu\mu}+y^2}{1+yA_{\mu\mu}}\right], \qquad y = \frac{\Gamma_{s,L}-\Gamma_{s,H}}{2\Gamma_s}, \qquad A_{\mu\mu} = \frac{\Gamma(B_{s,H}^0 \to \mu^+\mu^-) - \Gamma(B_{s,L}^0 \to \mu^+\mu^-)}{\Gamma(B_{s,H}^0 \to \mu^+\mu^-) + \Gamma(B_{s,L}^0 \to \mu^+\mu^-)}$$

SM: Only the CP-odd heavy ($B_{s,H}^0$) eigenstate contributes ($A_{\mu\mu} = +1$)

- CP-even $\boldsymbol{B_{s,L}^0}$ contribution allowed in certain **BSM** scenarios ($A_{\mu\mu} \in [-1,+1]$)
- $B_{s,H}^0$ and $B_{s,L}^0$ have notably different lifetimes ($\tau_{B_{s,H}^0} - \tau_{B_{s,L}^0} = [1.624 - 1.431]\ \mathrm{ps} = \mathbf{0.193\ ps}$)

→ **$\boldsymbol{\tau_{\mu\mu}}$ is sensitive to $\boldsymbol{B_{s,L}^0}$ contribution!**

- Complementary observable to the $B_s^0 \to \mu^+\mu^-$ branching ratio
  - Different combination of effective operators

  → Even if one is measured SM-consistent, the other can still be affected by New Physics

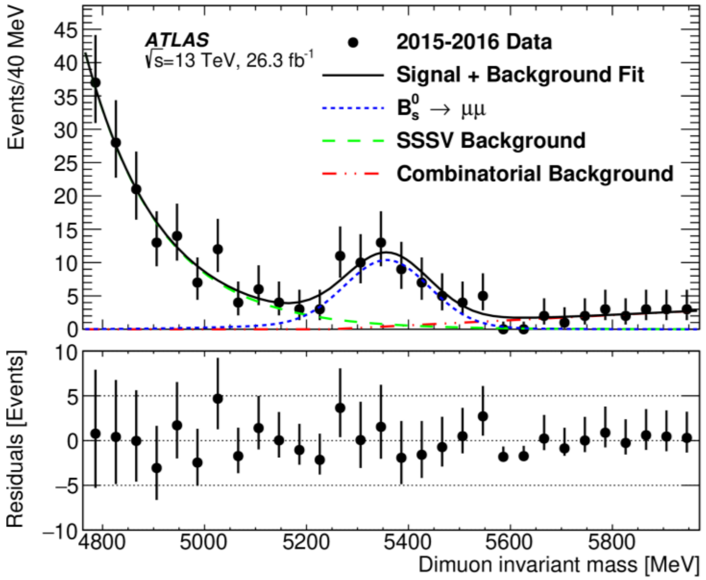
First $\boldsymbol{\tau_{\mu\mu}}$ measurement in ATLAS

- Based on 2015-2016 dataset & the corresponding BR measurement
  - Well understood simulation, signal/background BDT classifier and modelling
- Using $B^+ \to J/\psi\ (\to \mu\mu)K^+$ reference channel for data/MC comparisons

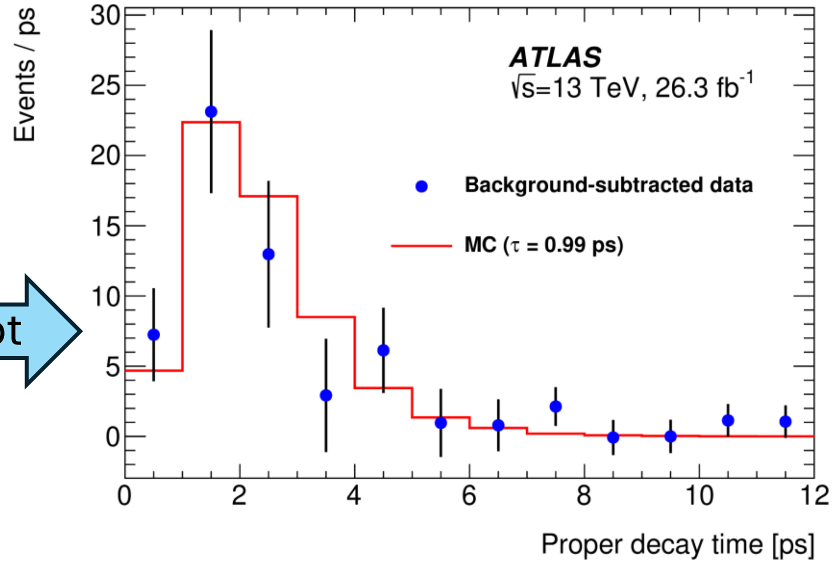
$B_s^0 \to \mu^+\mu^-$ effective lifetime: Strategy

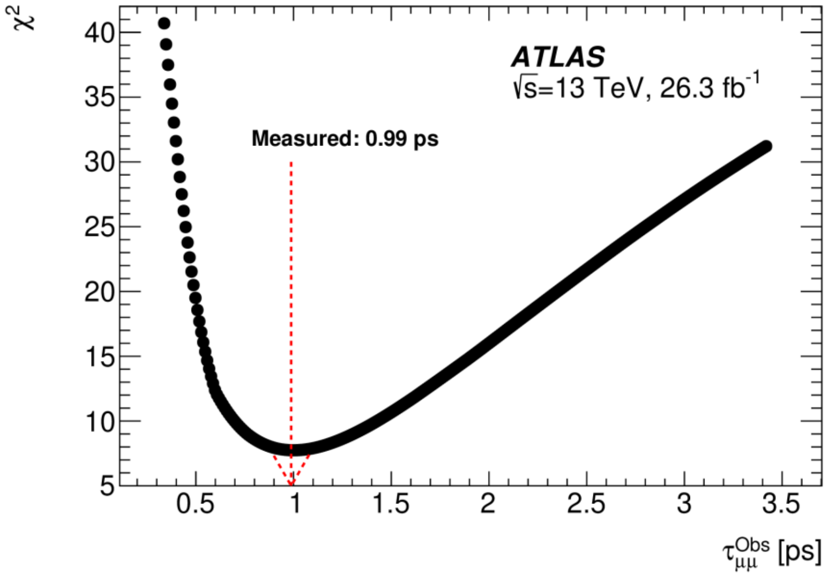
1. ML fit to dimuon invariant mass distribution
    - 3 components: $B_s^0 \to \mu^+\mu^-$, partially reconstructed B-meson decays, random μ combinations
2. sPlot Background subtraction in proper decay time
    - sPlot procedure based on the invariant mass fit
    - Isolation of different fit components in proper decay time
3. χ^2- fit of the proper decay time distribution with $\tau_{\mu\mu}$ MC templates
    - Each template represents different $\tau_{\mu\mu}$ value

sPlot: statistical method allowing to project out the signal/background distributions of a variable (e. g. $\tau_{\mu\mu}$), based on a fit to another, uncorrelated variable (e. g. dimuon mass).



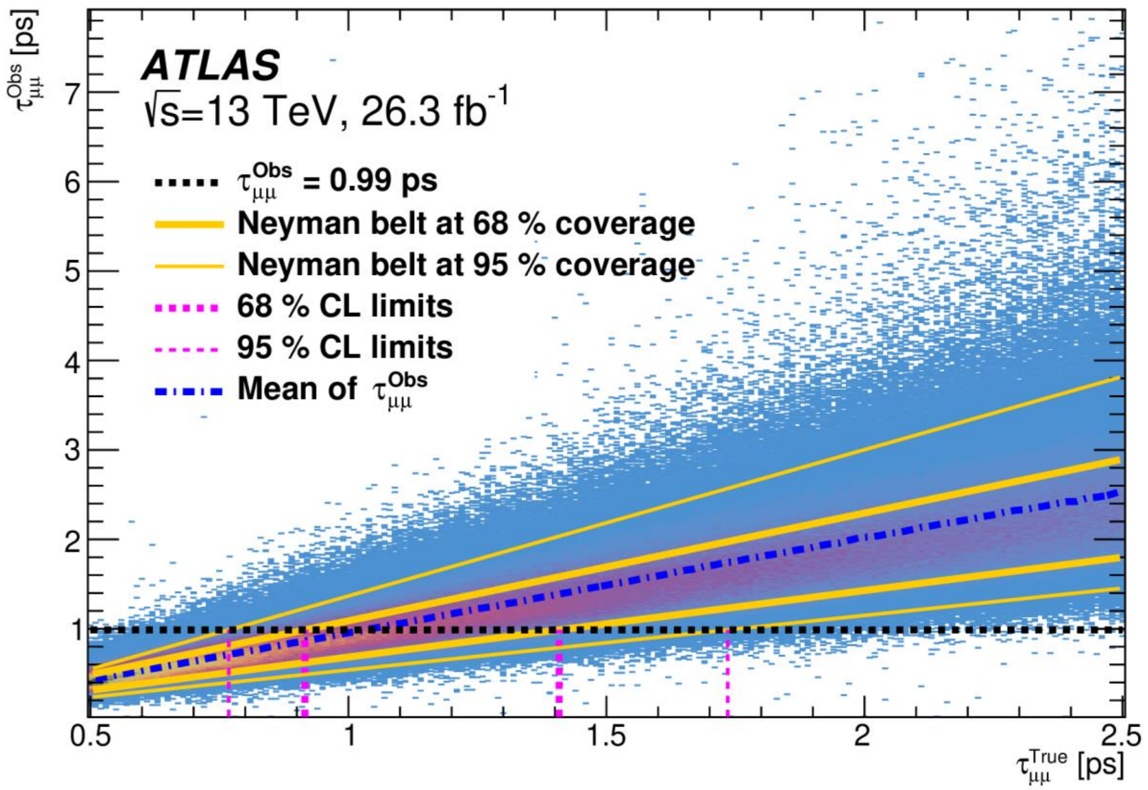
sPlot





$B_s^0 \to \mu^+\mu^-$ effective lifetime: Uncertainties

Statistical
- Evaluated with Neyman construction
- based on fits toy-MC datasets generated at different $\tau_{\mu\mu}$



Systematic
- Estimated in fits to toy-MC & reference channel data
- Three categories: Fit-related, data/MC discrepancies, neglected backgrounds
- Each contribution symmetrized & combined in quadrature

Uncertainty source	$\Delta\tau_{\mu\mu}^{\text{Obs}}$ [fs]
Data - MC discrepancies	134
SSSV lifetime model	60
Combinatorial lifetime model	56
B kinematic reweighting	55
B isolation reweighting	32
SSSV mass model	22
B_d background	16
Fit bias lifetime dependency and B_s^0 eigenstates admixture	15
Combinatorial mass model	14
Pileup reweighting	13
B_c background	10
Muon Δ_η correction	6
$B \to hh'$ background	3
Muon reconstruction SF reweighting	2
Semileptonic background	2
Trigger reweighting	1
Total	174

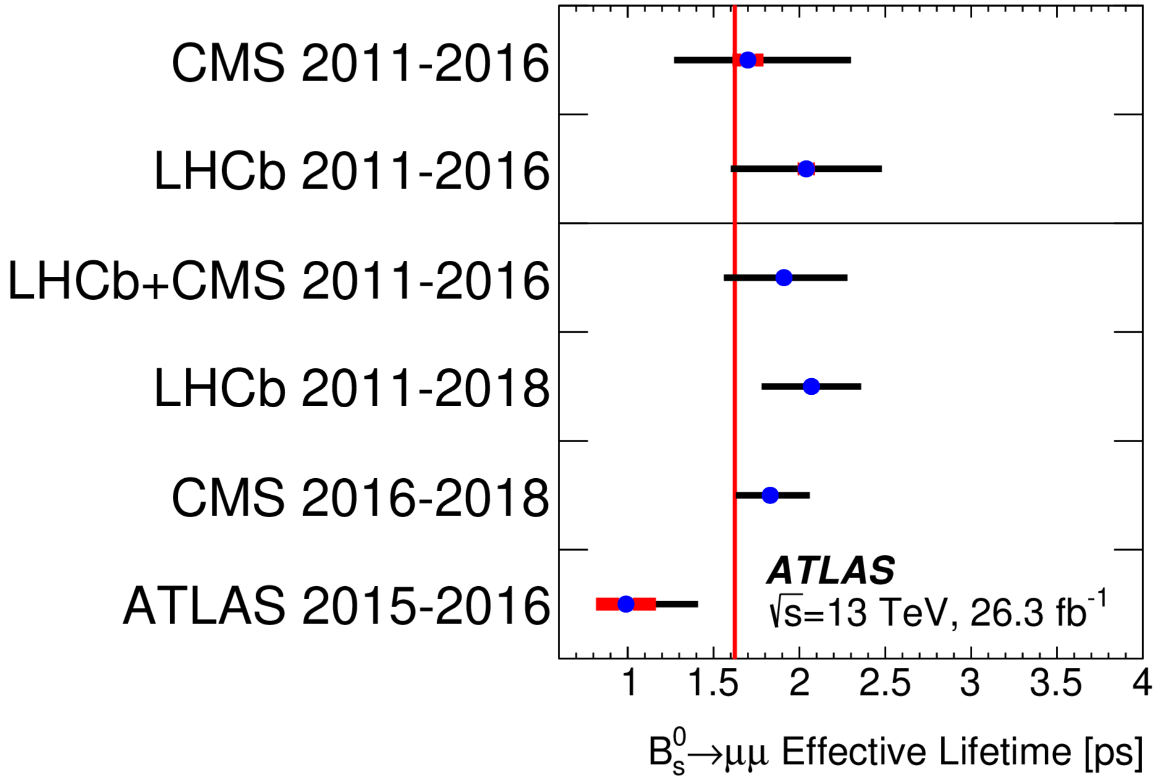
$B_s^0 \to \mu^+\mu^-$ effective lifetime: Result

ATLAS EXPERIMENT

The first ATLAS $\tau_{\mu\mu}$ measurement is

$$\boldsymbol{\tau_{\mu\mu} = \left[0.99^{+0.42}_{-0.07}\,(\mathrm{stat}) \pm 0.17(\mathrm{syst})\right] ps}$$

- In agreement with the **SM prediction** that only $B^0_{s,H}$ contributes:
  $\tau_{B^0_{s,H}} = (1.624 \pm 0.009)\ ps$ (or $A_{\mu\mu} = +1$)
- Consistent with other experimental results
  - Similar precision to other measurements using datasets of comparable size
- Statistics-limited
  - Analysis of the Full-Run 2 (2015-2018) dataset underway



CMS $\tau_{\mu\mu}$ measurements:

2011-2016: $\mathbf{1.70^{+0.61}_{-0.44}\ (stat + syst)\ ps}$

2016-2018: $\mathbf{\left[1.83^{+0.23}_{-0.20}\ (stat) \pm 0.04\ (syst)\right]\ ps}$

Measurement of the **production cross-section of J/ψ and $\psi(2S)$ mesons** in pp collisions at $\sqrt{s} = 13\ \mathrm{TeV}$ with the ATLAS detector

Experiment: ATLAS
Dataset: 2015 - 2018 pp data (Full Run 2, 140 fb^{-1})
Keywords: Charmonium production, QCD model constraints
Link: Eur. Phys. J. C 84 (2024) 169

J/ψ and $\psi(2S)$ production cross-section

An important measurement constraining QCD models

- Charmonium production modes:
  - **Prompt:** QCD sources
  - **Non-prompt:** decays of B-hadrons

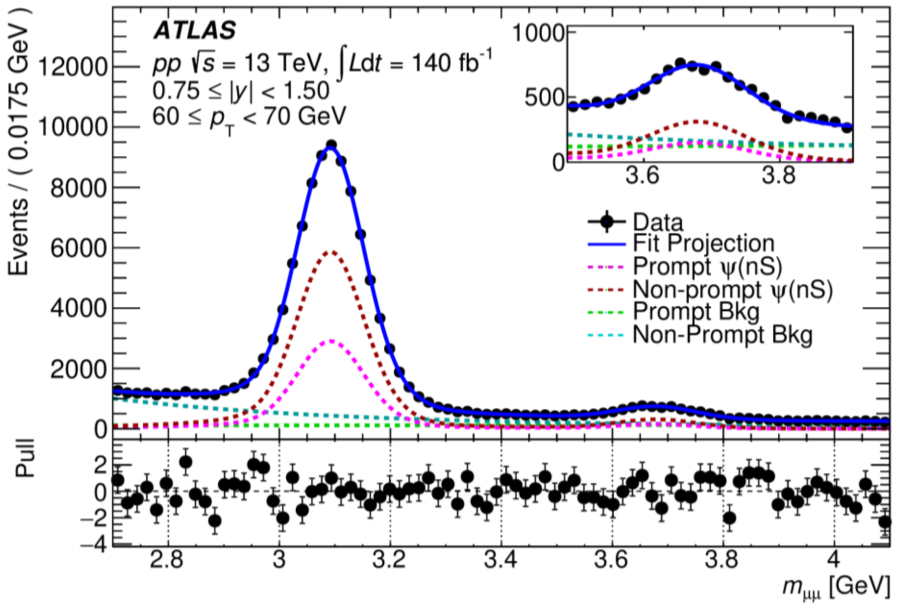
Double-differential cross-section measured in bins of p^T and rapidity (y)

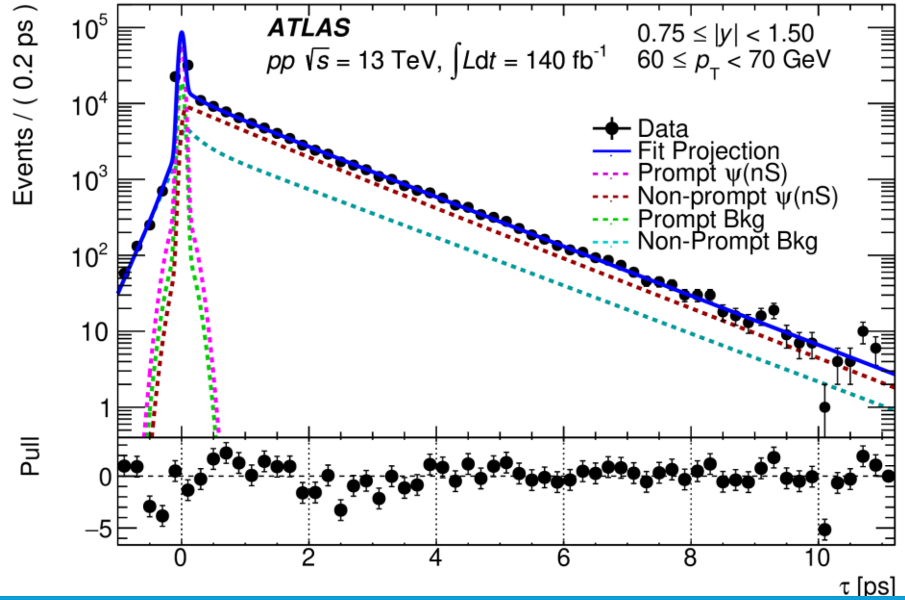
- Significantly improved reach in p^T wrt. existing measurements
  - Use of two trigger strategies:
    - Di-muon for low- p^T regime ($p^T_{\mu\mu} < 60$ GeV)
    - Single-muon for high-pT regime ($60 \text{ GeV} < p^T_{\mu\mu} < 360 \text{ GeV } (J/\psi) \text{ / } 140 \text{ GeV } \psi(2S)$)
- Separate treatment of prompt (P) and non-prompt (NP) components
  - Signal yields extracted in a 2-D fit to the dimuon invariant mass and proper decay time

$$\frac{d\sigma^{P,NP}(pp \to \psi)}{dp^T dy} \times BR(\psi \to \mu\mu) = \frac{1}{A \times \epsilon} \times \frac{N_{\psi}^{P,NP}}{\Delta p^T \Delta y \int \mathcal{L} dt}$$

$\psi = J/\psi$ or $\psi(2S)$ $\epsilon =$ efficiency

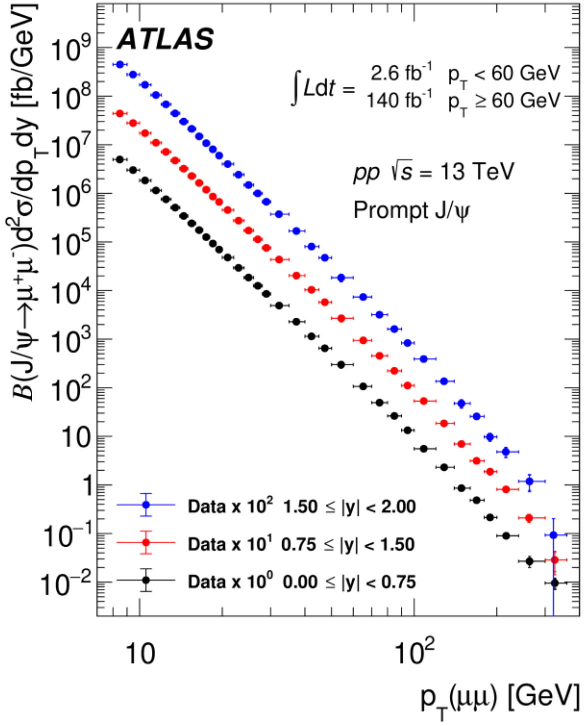
$A =$ acceptance





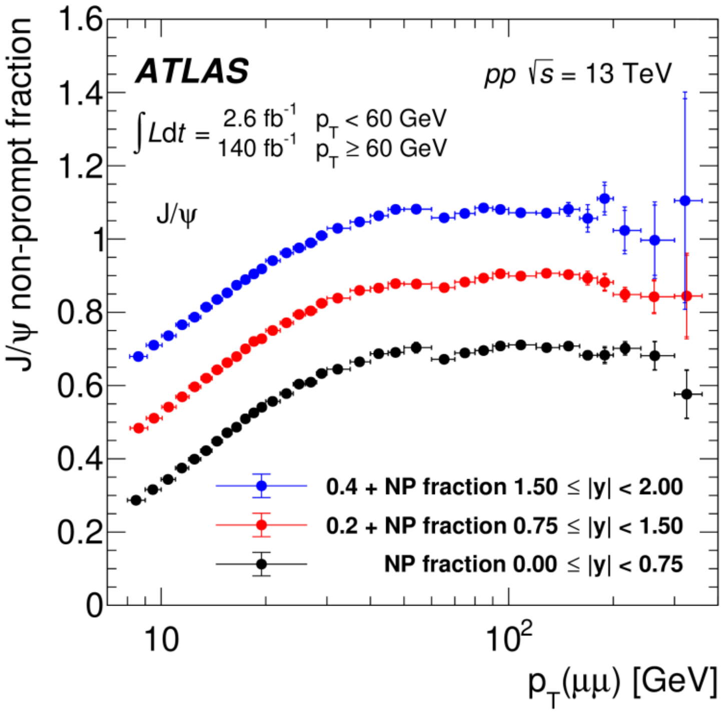
J/ψ and $\psi(2S)$: Results

Cross-sections show similar falling trend with $p_{\mu\mu}^{T}$ for both J/ψ and $\psi(2S)$, in both P and NP production modes



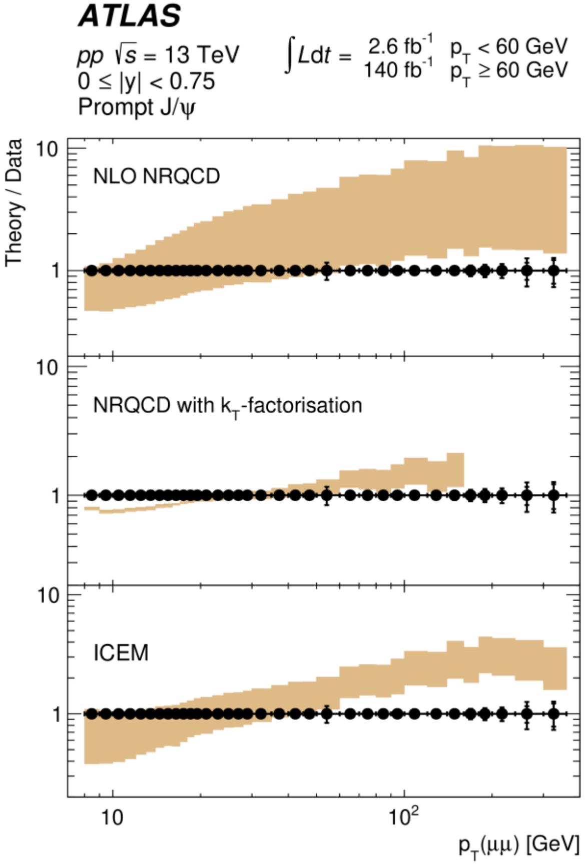
The NP fraction ($\sigma^{NP}/\sigma^{P+NP}$) shows a plateau at $p_{\mu\mu}^{T}$ ~100 GeV

→ **similar σ^{P} and σ^{NP} behaviour at very high $p_{\mu\mu}^{T}$**



Different theory models: large discrepancy at high $p_{\mu\mu}^{T}$

→ highlighting **the importance of this measurement's high $p_{\mu\mu}^{T}$ reach** for tuning these models (see backup for more!)



Measurement of the B_s^0 effective lifetime in the decay $B_s^0 \to J/\psi\, K_S^0$

Experiment: CMS
Dataset: 2016 - 2018 pp data (140 fb^{-1}, Full Run 2)
Keywords: CP violation
Link: CMS-PAS-BPH-22-001

$B_s^0 \to J/\psi\, K_S^0$ effective lifetime

Effective lifetime (τ) can disentangle heavy and light eigenstate contributions

- If CP is conserved, only the heavy (CP-odd) eigenstate will contribute
- Precision B-meson lifetime measurements constrain other SM parameters (CKM elements, ...)

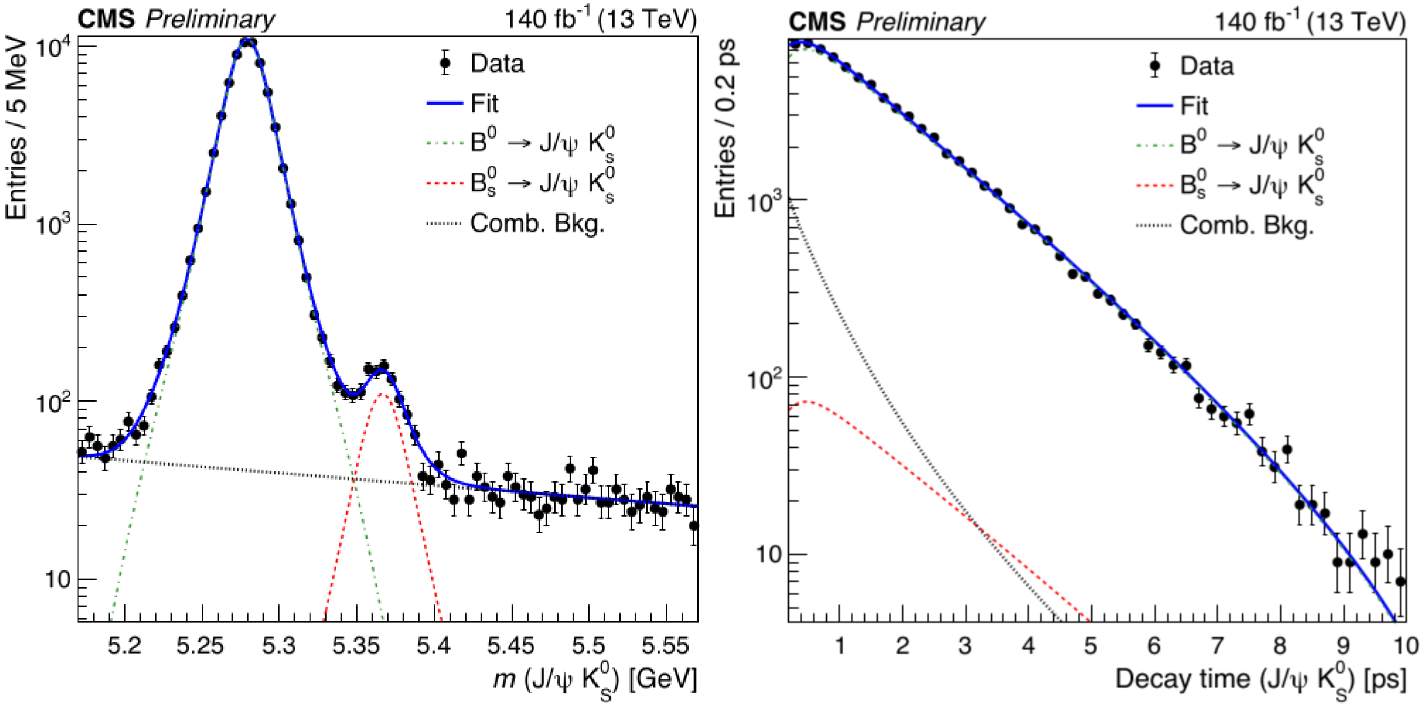
$\tau_{J/\psi K_S^0}$ measurement

- $\tau_{J/\psi K_S^0}$ extracted in a 2D fit to the B_s^0 invariant mass and proper decay time
- Effective lifetime of more abundant $B^0 \to J/\psi\, K_S^0$ decay measured in the same fit
  → Used as a reference for systematic tests & validation
- Using BDT to improve signal/bkg ratio

Results

$$\boldsymbol{\tau_{J/\psi K_S^0} = [1.59 \pm 0.07(\text{stat}) \pm 0.03(\text{syst})]\ \text{ps}}$$

- Consistent with $\tau_{B_{s,H}^0} = (1.624 \pm 0.009)$ ps
- Dominant systematic: invariant mass functional models
- Control channel lifetime also SM-consistent
- Improved precision wrt. earlier LHCb result:
  $\tau_{J/\psi K_S^0}^{LHCb} = [1.75 \pm 0.12(\text{stat}) \pm 0.07(\text{syst})]$ ps



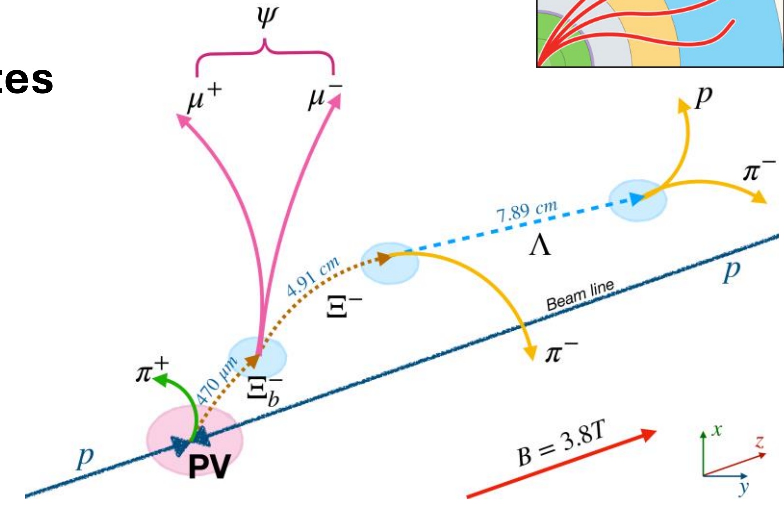
Observation of the $\Xi_b^- \to \psi(2S)\Xi^-$ decay and studies of the Ξ_b^{*0} baryon

Experiment: CMS
Dataset: 2016 - 2018 pp data (Full Run 2, 140 fb^{-1})
Keywords: Ξ_b^* spectroscopy, Ξ_b^- properties
Link: arXiv:2402.17738

$\Xi_b^- \to \psi(2S)\Xi^-$ observation and Ξ_b^{*0} studies

Increasing data statistics @LHC allows **exploration of ground and excited Ξ_b states**

- Weak ground Ξ_b decays: possible intermediate resonances or CP violation
- Measurements of both ground and excited (Ξ_b^*) state properties constrain heavy quark EFT → **better understanding of quark dynamics and hadronization**
- Ξ_b^{*0} is the first particle discovered by CMS

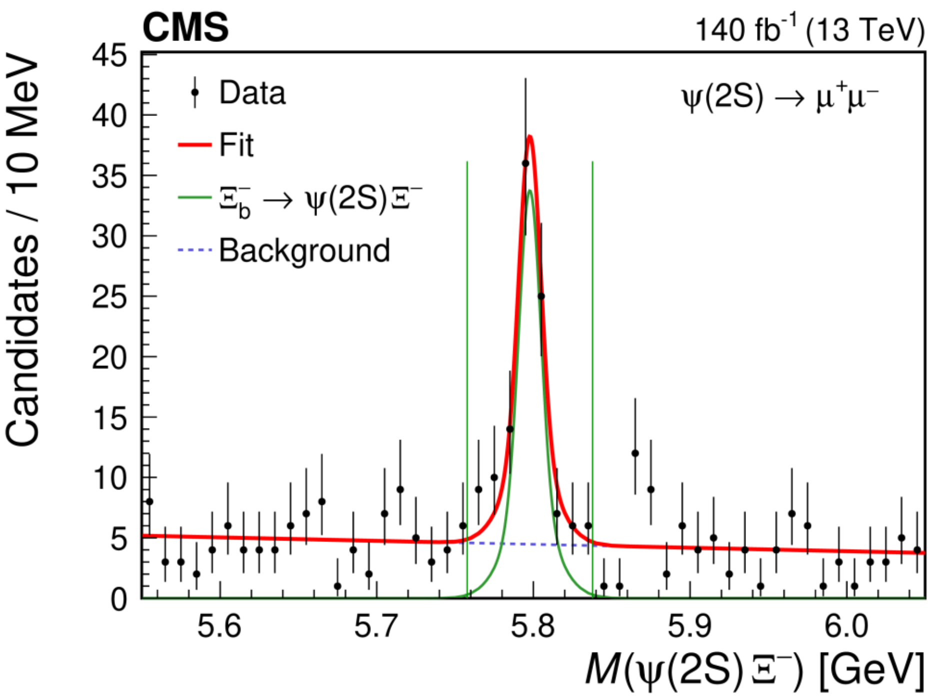


First observation of $\Xi_b^- \to \psi(2S)\Xi^-$

- Using $\psi(2S) \to \mu\mu$, $\Xi^- \to \Lambda(\to p\pi^-)\pi^-$
- Branching ratio measured relative to **reference channel with $\psi(2S) \leftrightarrow J/\psi$**

$$R = \frac{B(\Xi_b^- \to \psi(2S)\Xi^-)}{B(\Xi_b^- \to J/\psi\,\Xi^-)} = 0.84^{+0.21}_{-0.19}(\text{stat}) \pm 0.10(\text{syst}) \pm 0.02(\text{ext. inputs})$$

- Consistent with analogous **$b \to (cc)$ decays of $B_{(s)}$ and Λ_b** (with values of R between $0.5, -0.6$)



$\Xi_b^- \to \psi(2S)\Xi^-$ observation and Ξ_b^{*0} studies

Properties of Ξ_b^{*0}

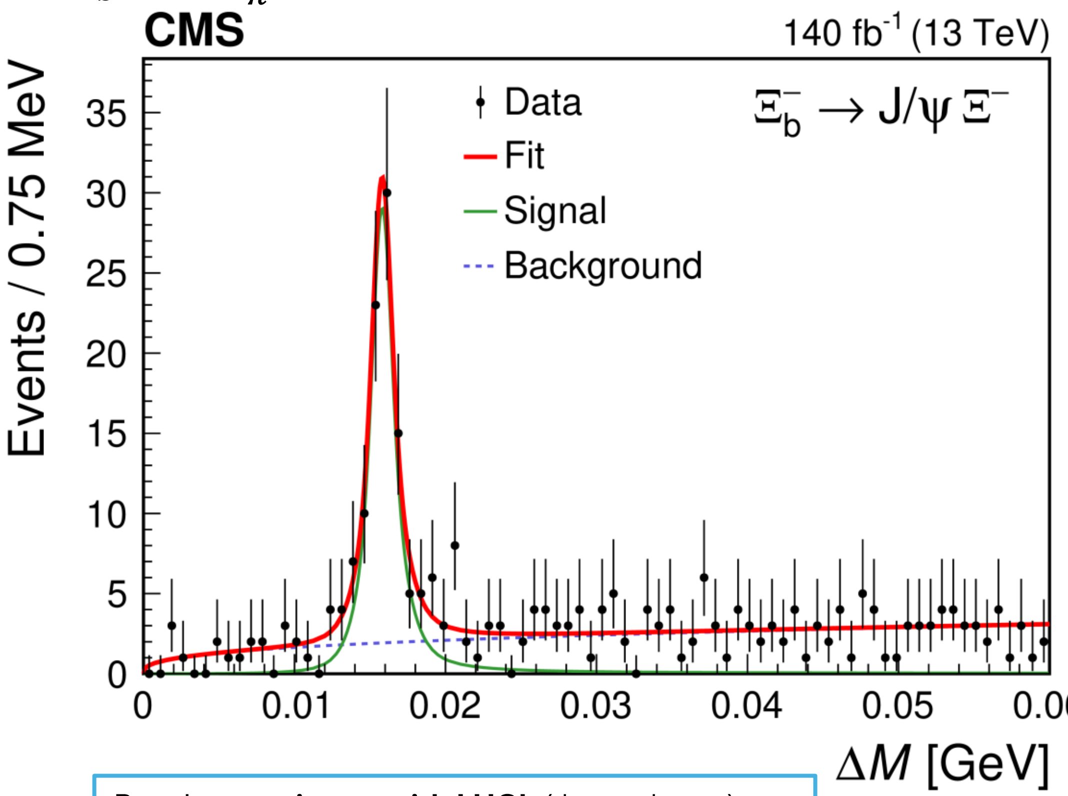
- Using $\Xi_b^{*0} \to \Xi_b^- \pi^+$ with multiple Ξ_b^- decays ($\psi(2S)\Xi^-, J/\psi\,\Xi^-, J/\psi\,\Lambda K^-, J/\psi\,\Sigma^0 K^-$)
- Ξ_b^{*0} mass and decay width extracted in a fit to $\Delta \boldsymbol{M} = M(\Xi_b^- \pi^+) - M(\Xi_b^-) - m_{\pi^+}^{PDG}$
  → **Improved mass resolution** wrt. $M(\Xi_b^- \pi^+)$

$$m_{\Xi_b^{*0}} = 5952.4 \pm 0.1(\text{stat} + \text{syst}) \pm 0.6(m_{\Xi_b^-})\ \text{MeV}$$
$$\Gamma_{\Xi_b^{*0}} = 0.87^{+0.22}_{-0.20}(\text{stat}) \pm 0.16(\text{syst})\ \text{MeV}$$

- Ξ_b^{*0} and Ξ_b^- **production cross-section ratio**

$$\frac{\sigma(pp \to \Xi_b^{*0} X) B(\Xi_b^{*0} \to \Xi_b^- \pi^+)}{\sigma(pp \to \Xi_b^- X)} = 0.23 \pm 0.04\ (\text{stat}) \pm 0.02\ (\text{syst})$$

→ $\sim {}^1/_4$ of Ξ_b^- are produced in $\Xi_b^{*0} \to \Xi_b^- \pi^+$
→ $\sim {}^1/_3$ of Ξ_b^- coming from Ξ_b^{*0} decays



Results **consistent with LHCb** ($\pm$ stat $\pm$ syst):
$m_{\Xi_b^{*0}} = 5953.02 \pm 0.07 \pm 0.02 \pm 0.55(m_{\Xi_b^-})$ MeV
$\Gamma_{\Xi_b^{*0}} = 0.90 \pm 0.16 \pm 0.08$ MeV
Prod. Ratio $= 0.28 \pm 0.03 \pm 0.01$

Search for CP violation in $D^0 \to K_S^0\ K_S^0$

Experiment: CMS
Dataset: 2018 pp data (41.6 fb^{-1})
Keywords: CP violation
Link: CMS-BPH-23-005

Novel trigger strategy employed: “**B parking**”

- b-hadrons mostly produced in pairs
  - → One decay used for triggering (“tag”)
  - → Second decay is unbiased (“probe”)
- Unbiased sample of 10^{10} b-hadron decays obtained in 2018 data

CP violation in $D^0 \to K_S^0 K_S^0$

$$A_{CP} = \frac{\Gamma(D^0 \to K_S^0 K_S^0) - \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}{\Gamma(D^0 \to K_S^0 K_S^0) + \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}$$

Study of CP violation in charm-mesons

- Complementary to and SM-suppressed wrt. b- and s- systems
  - Significant CP asymmetry (A_{CP}) → hint of BSM contribution

First CMS CP measurement in charm sector

- Using D^0s from $D^{*\pm} \to D^0\pi^\pm$ → **pion charge tags $\boldsymbol{D^0}$ vs. $\boldsymbol{\bar{D}^0}$**
- **$\boldsymbol{D^{*+}}$ vs. $\boldsymbol{D^{*-}}$ differences:**
  - Production cross-section (→ different rate of D^0 vs. $\bar{D}^0$)
  - Detection efficiency of low-momentum π^+ vs. π^-

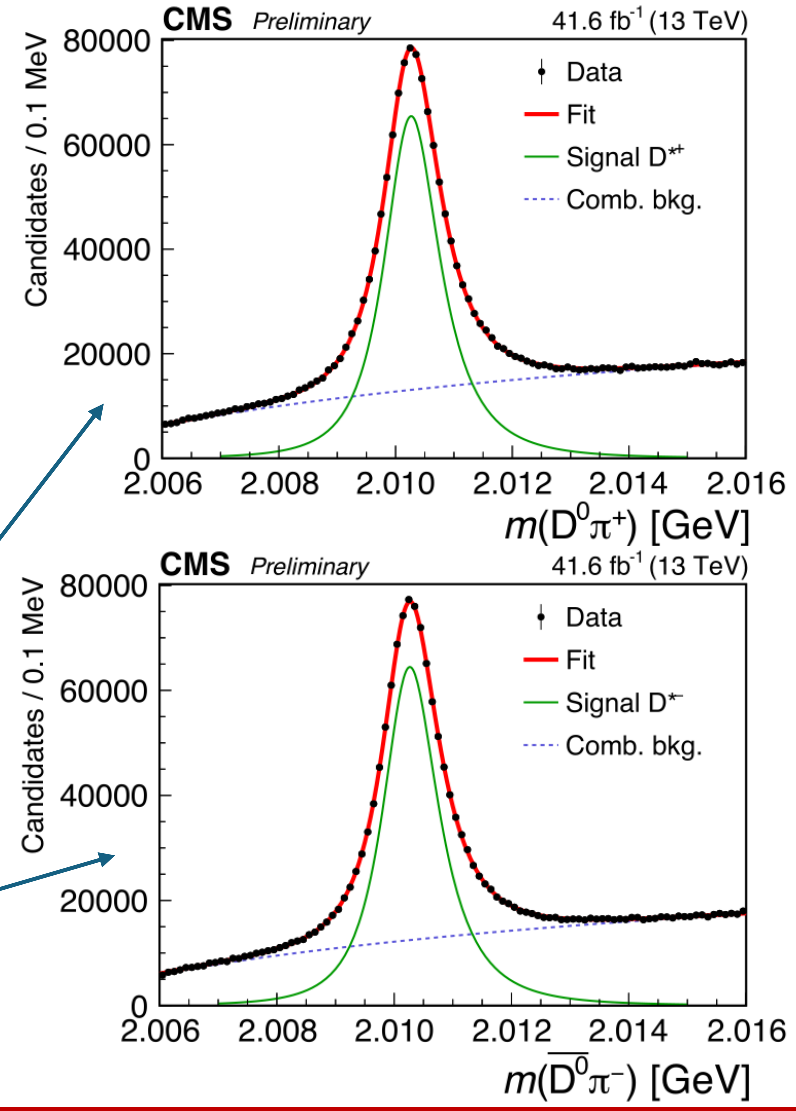
→A_{CP} in signal (S) measured **relative to $\boldsymbol{D^0 \to K_S^0\pi^+\pi^-}$** **reference (R)** channel

$$\Delta A_{CP} = A_{CP}^S - A_{CP}^R = \frac{N_S^{D^0} - N_S^{\bar{D}^0}}{N_S^{D^0} + N_S^{\bar{D}^0}} - \frac{N_R^{D^0} - N_R^{\bar{D}^0}}{N_R^{D^0} + N_R^{\bar{D}^0}}$$

→D^{*+} vs. D^{*-} differences **cancel out in $\boldsymbol{\Delta A_{CP}}$**

Reference channel

- Similar kinematics and topology to signal
- More abundant & well established A_{CP}^R
- Yields $N_R^{D^0}$ and $N_R^{\bar{D}^0}$ obtained in a fit to the D^{*+} and D^{*-} inv. mass



CP violation in $D^0 \to K_S^0\, K_S^0$

$$\Delta A_{CP} = A_{CP}^S - A_{CP}^R = \frac{N_S^{D^0} - N_S^{\bar{D}^0}}{N_S^{D^0} + N_S^{\bar{D}^0}} - \frac{N_R^{D^0} - N_R^{\bar{D}^0}}{N_R^{D^0} + N_R^{\bar{D}^0}}$$

Signal channel

- Rare process – signal statistics dominates the analysis uncertainty

→ Yields $N_S^{D^0}$ and $N_S^{\bar{D}^0}$ obtained in a **2D fit** to the $D^{*\pm}$ and $\bar{D}^0$ inv. mass

Small overall systematics

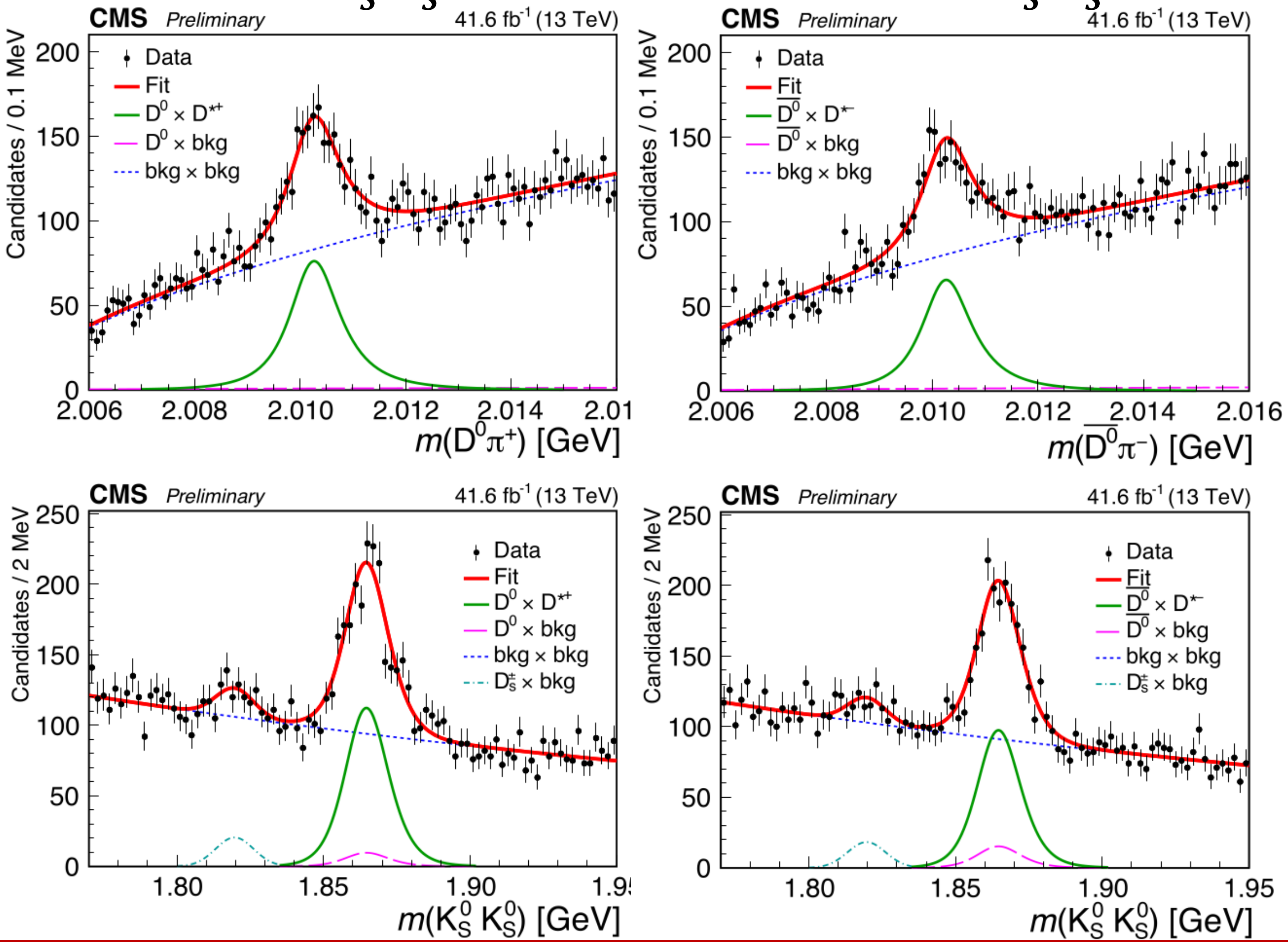
- Signal & background parametrization
- Non-cancellation of terms in ΔA_{CP}

Result ($\pm$stat $\pm$ syst $\pm$ A_{CP}^R):

$$A_{CP}(K_S^0\, K_S^0) = [6.2 \pm 3.0\ \pm 0.2 \pm 0.8\,]\%$$

- Consistent with no CP violation ($A_{CP} = 0$)
- Pilot result paving way to future measurements with more data
- Consistent with LHCb ($[3.1 \pm 1.2 \pm 0.4 \pm 0.2]\%$) and Belle ($[0.02 \pm 1.53 \pm 0.02 \pm 0.17]\%$)

$D^0 \to K_S^0\, K_S^0$ $\qquad$ $\bar{D}^0 \to K_S^0\, K_S^0$

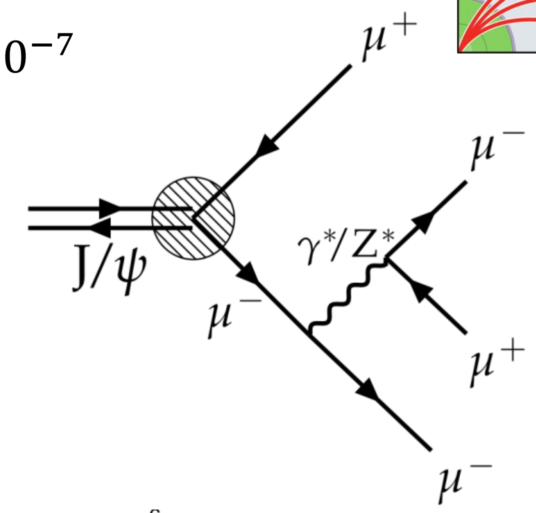


Observation of the rare decay $J/\psi \rightarrow 4\mu$

Experiment: CMS
Dataset: 2018 pp data (33.6 fb^{-1})
Keywords: rare decay
Link: arXiv:2403.11352

Observation of $J/\psi \rightarrow 4\mu$

- **SM:** proceeds via virtual photon or Z with predicted $B(J/\psi \rightarrow 4\mu) = (9.74 \pm 0.05) \times 10^{-7}$
  → **BSM particles can contribute** & affect the rates
- Novel **testing ground for QED** predictions
- Previously: 90% CL upper limit on BR set by **BESIII** at 1.6×10^{-6}

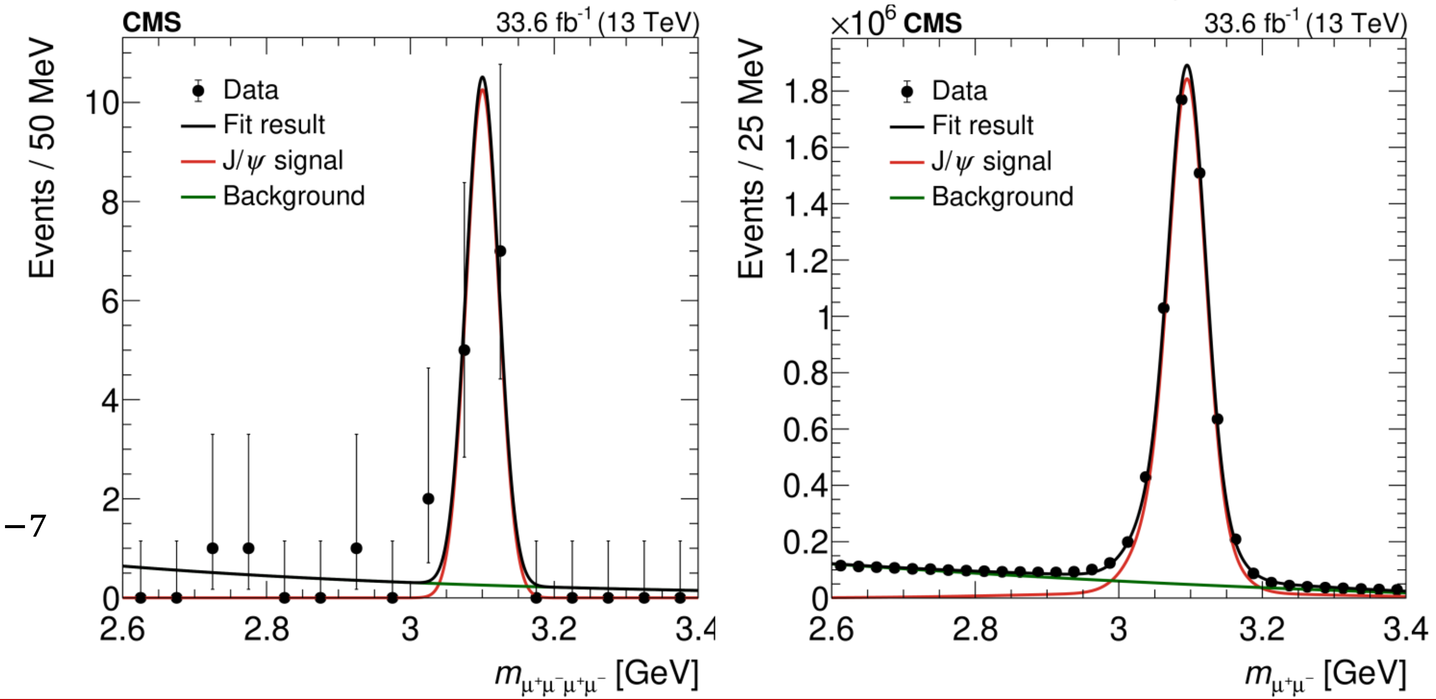


First observation of $J/\psi \rightarrow 4\mu$

- Using the "B-parking" trigger strategy (see slide 17)
- Branching ratio measured relative to abundant $J/\psi \rightarrow \mu\mu$ reference decay

$$B(J/\psi \rightarrow 4\mu) = B(J/\psi \rightarrow \mu\mu) \times \frac{N_{4\mu}}{N_{2\mu}} \times \frac{\epsilon_{2\mu}}{\epsilon_{4\mu}}$$

- Signal and reference yields extracted in a fit to the 4- (2-)μ invariant mass
- Efficiency ratio studied in MC



Result

$$B(J/\psi \rightarrow 4\mu) = [10.1^{+3.3}_{-2.7}(\text{stat}) \pm 0.4(\text{syst})] \times 10^{-7}$$

- Consistent with SM prediction $(9.74 \pm 0.05) \times 10^{-7}$

Summary

Summary

Many exciting new results probing the flavour sector:

- Covering a broad range of observables accessible to LHC's general purpose detectors

Measurement of the $\boldsymbol{B_s^0 \to \mu^+\mu^-}$ **effective lifetime** with the ATLAS detector

→ $\boldsymbol{\tau_{\mu\mu} = \left[0.99^{+0.42}_{-0.07}\,(\mathrm{stat}) \pm 0.17(\mathrm{syst})\right]\,\mathrm{ps}}$ – Consistent with SM prediction of exclusive $B^0_{s,H}$ contribution

Measurement of the $\boldsymbol{B_s^0}$ **effective lifetime in the decay** $\boldsymbol{B_s^0 \to J/\psi\, K_S^0}$

→ $\boldsymbol{\tau_{J/\psi K_S^0} = [1.59 \pm 0.07(\mathrm{stat}) \pm 0.03(\mathrm{syst})]\,\mathrm{ps}}$ - consistent with SM and $B^0_{s,H}$ hypothesis

Measurement of the **production cross-section of Jpsi and psi2S mesons**

→ **New high-$\boldsymbol{p^T}$ constraints for QCD models**

Observation of the $\boldsymbol{\Xi_b^- \to \psi(2S)\Xi^-}$ **decay** and studies of the $\boldsymbol{\Xi_b^{*0}}$ **baryon**

→ Novel measurements of **b-baryon properties**

Search for $\boldsymbol{CP}$ **violation in** $\boldsymbol{D^0 \to K_S^0\, K_S^0}$

→ **No significant $\boldsymbol{CP}$ violation observed** in the pilot CMS CP measurement in the charm sector

Observation of the rare decay $J/\psi \to 4\mu$

→ $\boldsymbol{B(J/\psi \to 4\mu) = [10.1^{+3.3}_{-2.7}(stat) \pm 0.4(syst)] \times 10^{-7}}$ - in agreement with SM

See backup for more results from 2023!

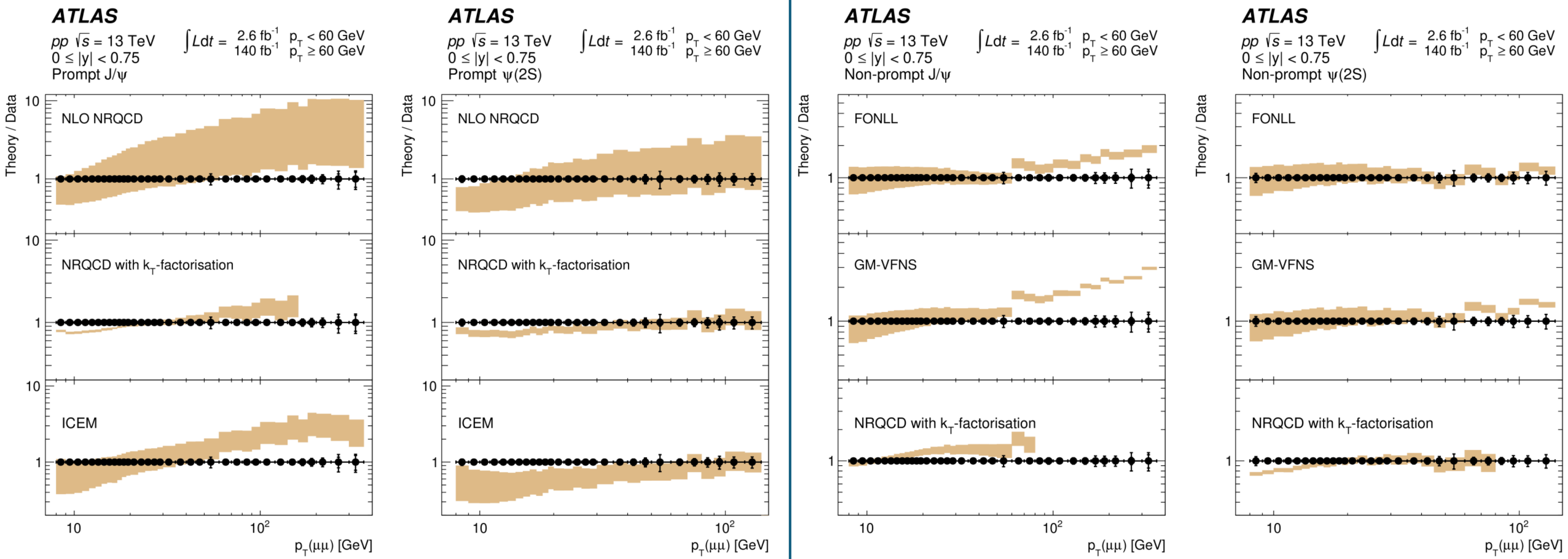
Backup

J/ψ and $\psi(2S)$: Results

All theory – data comparisons

The **high $p_{\mu\mu}^{T}$ reach of this measurement** is important for tuning different models

Prompt | **Non-prompt**

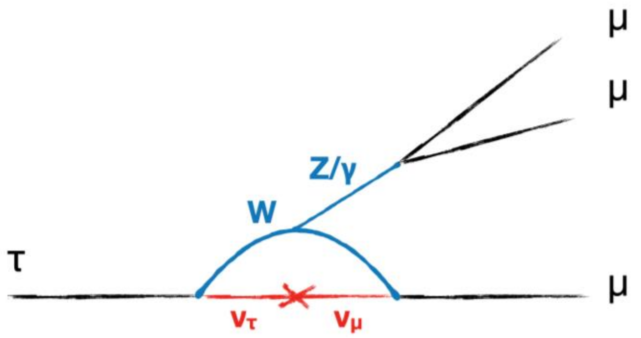


Search for the **lepton flavor violating** $\tau \to 3\mu$ **decay** in proton-proton collisions at $\sqrt{s} = 13$ TeV

Experiment: CMS
Dataset: 2017 + 2018 pp data (97.7 fb^{-1})
Keywords: Lepton flavour violation, rare decay

Search for the $\tau \to 3\mu$ decay

LF-violating decay, can proceed in SM through neutrino oscillations in loops
→ **Extremely** suppressed: $BR(\tau \to 3\mu) \approx O(10^{-55})$
→ Significant contribution in NP scenarios (e. g. SUSY: $BR \approx O(10^{-10} - 10^{-8})$)



Two strategies based on the τ source:

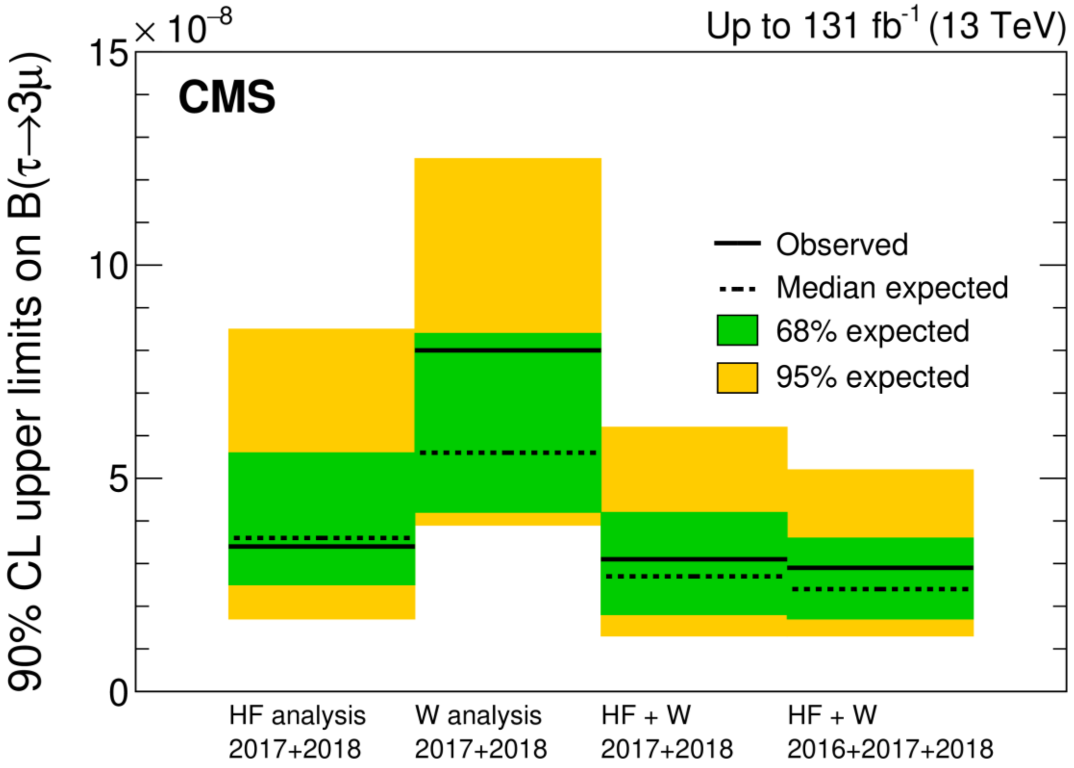
- Heavy flavour decays ($D^+ \to \tau^+\nu_\tau, B^+(B^0) \to \tau^+ + X$)
    - Vast majority of the sample
    - Lower muon p^T
    - BR normalized with $D_s^+ \to \varphi(\to \mu\mu)\pi^+$ yield

- $W^+ \to \tau^+\nu_\tau$ decay
    - Typically high p^T, well-isolated muons
    - Large missing transverse momentum

$BR(\tau \to 3\mu)$ extracted in a simultaneous fit to the tri-muon invariant mass in all data categories

Measurement combined with 2016 result:

$$BR(\tau \to 3\mu) < 2.9 \times 10^{-8} \text{ at } 90\% \text{ CL}$$



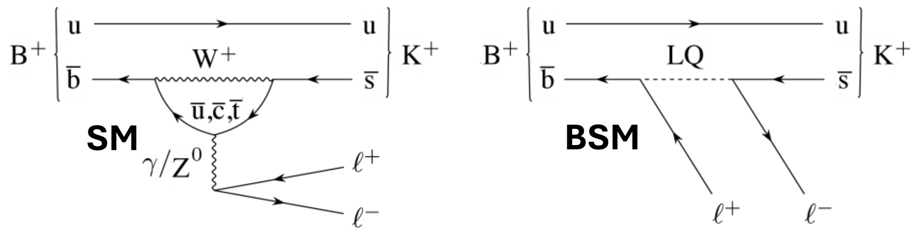
Test of **lepton flavor universality in $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$ decays** in proton-proton collisions at $\sqrt{s} = 13\ \text{TeV}$

Experiment: CMS
Dataset: 2018 pp data (33.6 fb^{-1})
Keywords: Lepton flavour universality violation, branching ratio

$R(K)$ and differential $B(B^+ \to K^+\mu^+\mu^-)$

SM: LFU violated only by lepton mass difference → $R(K^+)$ very close to unity

- Can be significantly affected in BSM (e. g. leptoquarks with non-universal couplings)



Experiment: measuring double ratio wrt. abundant reference channels:

$$R(K)|_{q^2} = \frac{B(B^+ \to K^+\mu^+\mu^-)|_{q^2}}{B(B^+ \to J/\psi\,(\to \mu^+\mu^-)K^+)} \Big/ \frac{B(B^+ \to K^+e^+e^-)|_{q^2}}{B(B^+ \to J/\psi\,(\to e^+e^-)K^+)} \quad (\cong 1 \text{ in SM})$$

- Same final state, proceeding through J/ψ resonance
  → Cancellation of systematics

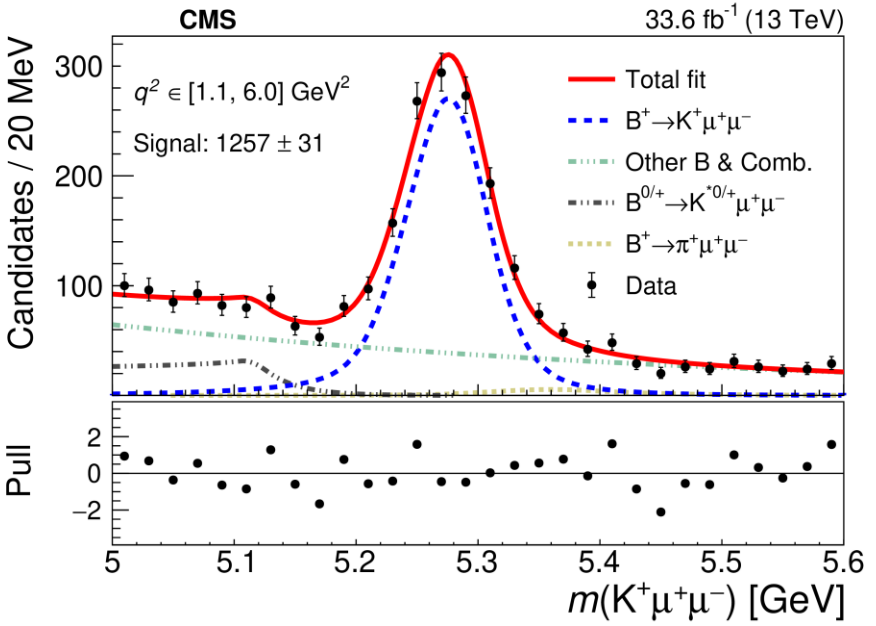
$R(K)$ measurement performed in dimuon invariant mass squared (q^2) region of $1.1\ \mathrm{GeV}^2 < q^2 < 6\ \mathrm{GeV}^2$

- Optimized to avoid contamination by ϕ and J/ψ decays

Measurement of $B(B^+ \to K^+\mu^+\mu^-)$

- Differential in q^2: range extended to $0.1\ \mathrm{GeV}^2 < q^2 < 22.9\ \mathrm{GeV}^2$, avoiding the ϕ, J/ψ and $\psi(2S)$ windows
- Integrated: in the $R(K)$ q^2 range

Signal and reference yields extracted in an invariant mass fit:



$R(K)$ and differential $B(B^+ \to K^+\mu^+\mu^-)$

Novel trigger strategy employed: “B parking”

- b-hadrons mostly produced in pairs
  - → One decay used for triggering (“tag”), source of $B^+ \to K^+\mu^+\mu^-$
  - → Second decay is unbiased (“probe”), source of $B^+ \to K^+e^+e^-$
- Unbiased sample of 10^{10} b-hadron decays obtained in 2018 data

Results:

$R(K) = 0.78^{+0.46}_{-0.23}\,(stat.)^{+0.09}_{-0.05}\,(syst.)$

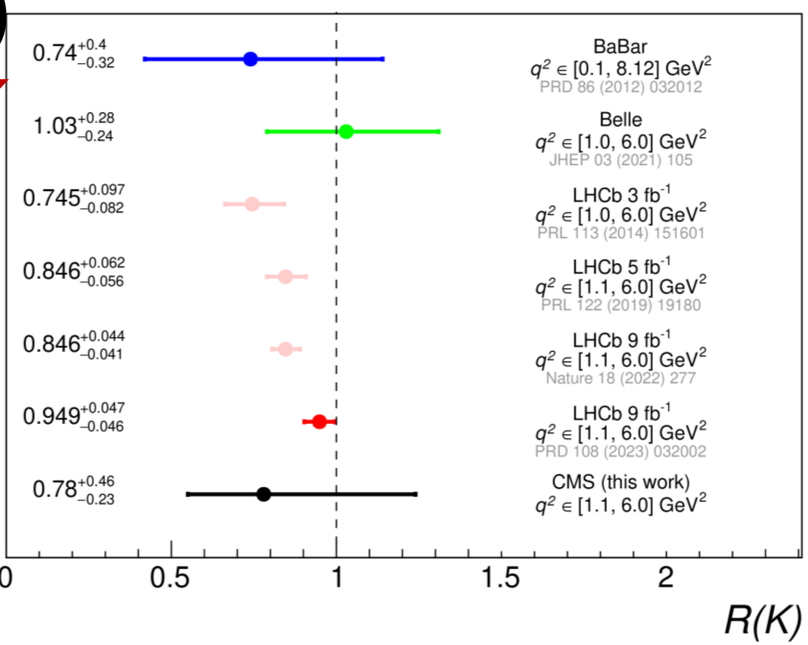
- Consistent with unity
- Largely limited by the electron channel statistics

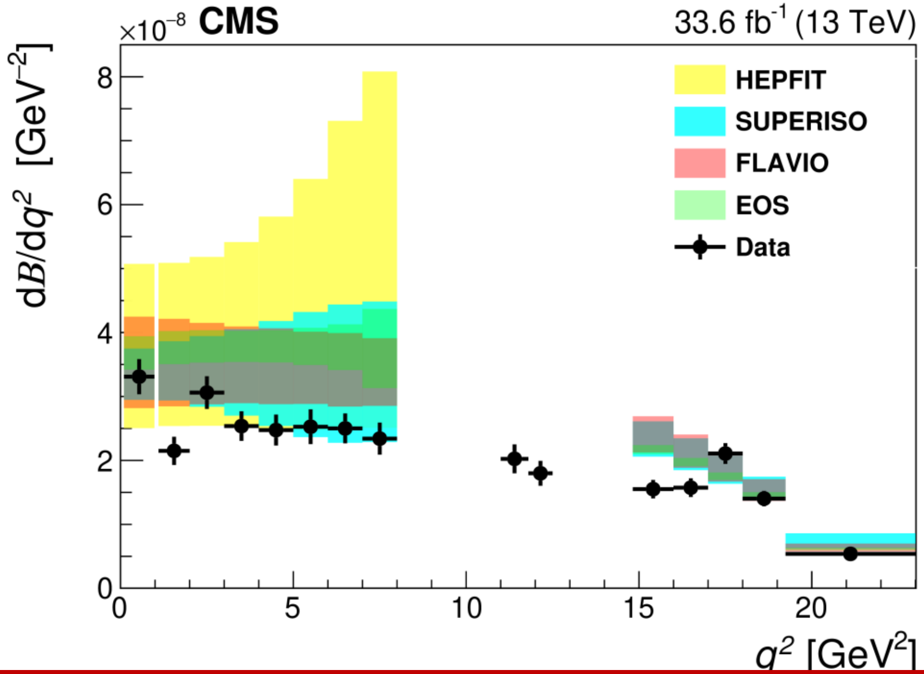
Differential $B(B^+ \to K^+\mu^+\mu^-)$

- Generally lower than theory predictions

Integrated $B(B^+ \to K^+\mu^+\mu^-)|_{q^2\in[1.1,6]} = (12.42 \pm 0.68) \times 10^{-8}$

- In agreement with and of similar precision as the current world average





Observation of the $\Lambda_b \to J/\psi\, \Xi^- K^+$ decay

Experiment: CMS
Dataset: 2015 - 2018 pp data (Full Run 2, 140 fb^{-1})
Keywords: intermediate resonances, pentaquarks, rare decay

Observation of the $\Lambda_b \to J/\psi\, \Xi^- K^+$ decay

Multi-body decays of b-hadrons may proceed through exotic intermediate resonances

- E. g. pentaquark-like $J/\psi\, p$ structure in $\Lambda_b \to J/\psi\, pK^-$ observed by LHCb
- $J/\psi\, \Xi^- K^+$ final state can unveil yet-unobserved (e. g. doubly-strange) pentaquarks

This measurement:

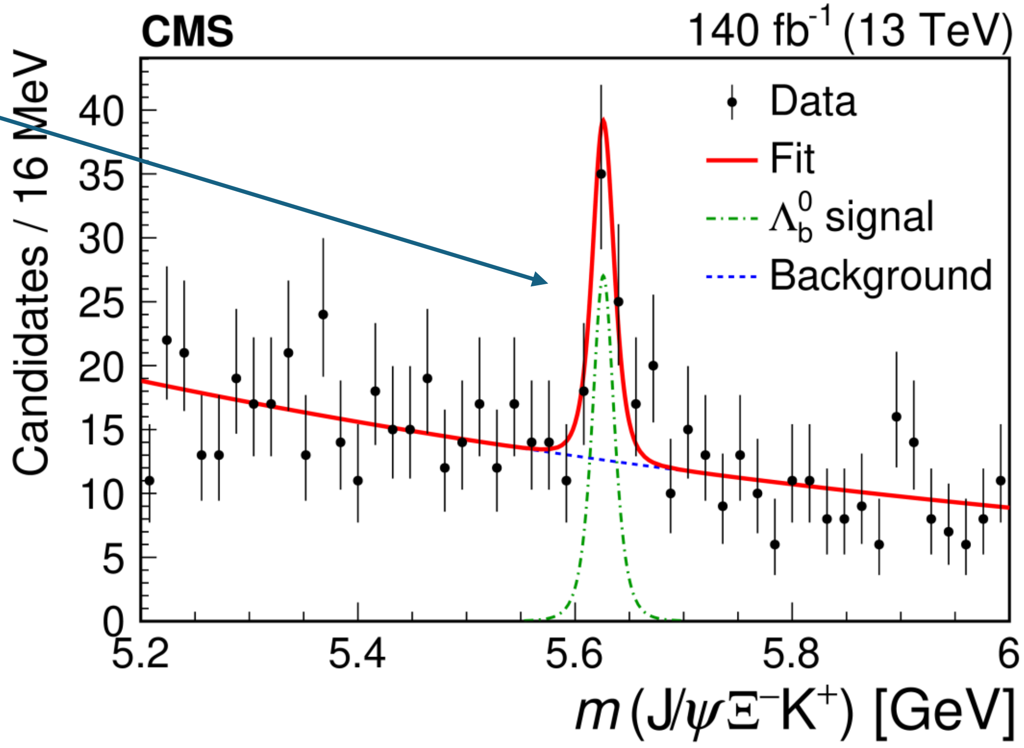
- **First-time observation of $\Lambda_b \to J/\psi\, \Xi^- K^+$**
  - In final states with $J/\psi \to \mu\mu$, $\Xi^- \to \Lambda(\to p\pi^-)\pi^-$

  → **$5.8\,\sigma$ significance**
- **$\Lambda_b \to J/\psi\, \Xi^- K^+$ branching fraction ratio measurement**
  - Determined relative to the topologically similar $\Lambda_b \to \psi(2S)(\to J/\psi\, \pi^-\pi^+)\Lambda$ reference channel:

$$R = \frac{B(\Lambda_b \to J/\psi\, \Xi^- K^+)}{B(\Lambda_b \to \psi(2S)\Lambda)}$$

- **Search for intermediate resonances**
  - Looking for structures in the invariant mass of the decay product pairs

Signal extracted in a fit to the $(J/\psi\, \Xi^- K^+)$ invariant mass:



Observation of the $\Lambda_b \to J/\psi\, \Xi^- K^+$ decay

$\Lambda_b \to J/\psi\, \Xi^- K^+$ branching fraction ratio measurement

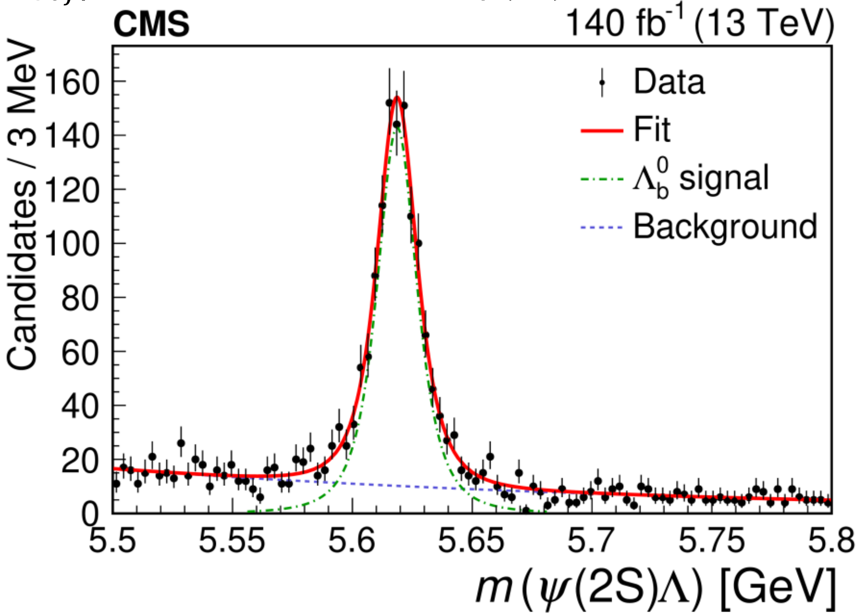
- Large systematics cancellation in the measured ratio R

$$R = \frac{B(\Lambda_b \to J/\psi\, \Xi^- K^+)}{B(\Lambda_b \to \psi(2S)\Lambda)} = \frac{N_{signal}}{N_{ref.}} \times \frac{\epsilon_{signal}}{\epsilon_{ref.}} \times \frac{B(\psi(2S) \to J/\psi\, \pi^-\pi^+)}{B(\Xi^- \to \Lambda\pi^-)}$$

$$= [\mathbf{3.38 \pm 1.02\ (\mathit{stat.}) \pm 0.61(\mathit{syst.}) \pm 0.03\ (\mathit{B})}]\ \%$$

- Result dominated by low signal statistics, last uncertainty is due to the external BRs

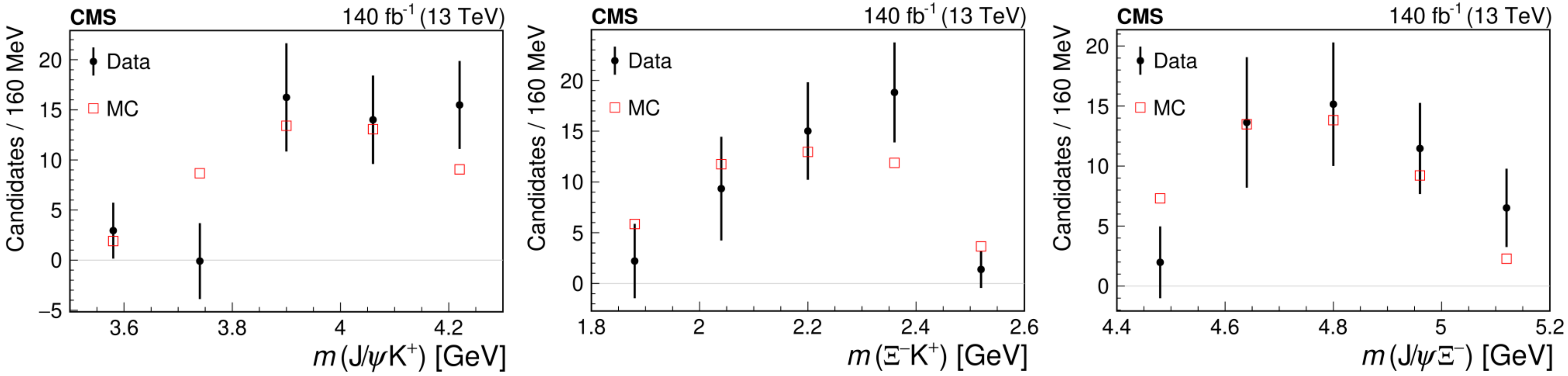
$N_{ref.}$ extracted in a fit to the $(\psi(2S)\Lambda)$ invariant mass:



Search for intermediate resonances

- Invariant mass distributions of the signal decay product pairs isolated with the *sPlot* procedure:

No evidence of resonant structures at this signal statistics



Test of **lepton flavor universality in semileptonic B_c^+ meson decays** at CMS

Experiment: CMS
Dataset: 2018 pp data (59.7 fb^{-1})
Keywords: Lepton flavour universality violation

$R(J/\psi)$ measurement

Test of LFU in B_c^+ decays:

- SM predicts $R(J/\psi) \approx 0.26$

$$R(J/\psi) = \frac{B(B_c^+ \rightarrow J/\psi\, \tau^+ \nu_\tau)}{B(B_c^+ \rightarrow J/\psi\, \mu^+ \nu_\mu)}$$

Experiment: $R(J/\psi)$ ratio measured directly

- Using only $J/\psi \rightarrow \mu^+\mu^-$ and $\tau^+ \rightarrow \mu^+\nu_\mu$ decay channels
  → Always 3 muons in the final state
- Signals best separated in kinematical variables utilizing the large $m_\tau - m_\mu$ difference:
  - $q^2 = \left(p_{B_c^+} - p_{J/\psi}\right)^2$, transverse decay length significance ($\frac{L_{xy}}{\sigma_{L_{xy}}}$)
- Dominant background: hadrons misidentified as muons

Signal and background yields obtained in binned template fits to q^2 and $\frac{L_{xy}}{\sigma_{L_{xy}}}$ in several data categories

Result:
$R(J/\psi) = 0.17 \pm 0.33\ (\text{stat.} + \text{syst.} + \text{theory})$