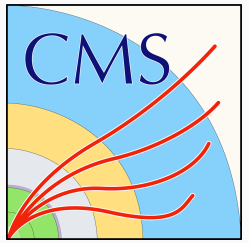


Flavour anomaly updates from ATLAS and CMS

Alberto Bragagnolo[a] on behalf of ATLAS and CMS collaborations

Obergurgl University Centre – ALPS2019
23 April 2019

[a] INFN–Padova & University of Padova

Outline

Search for $\tau \to 3\mu$ decays using τ leptons produced in D and B meson decays with CMS

CMS PAS BPH–17–004

$\tau \to \mu\mu\mu$ state of the art

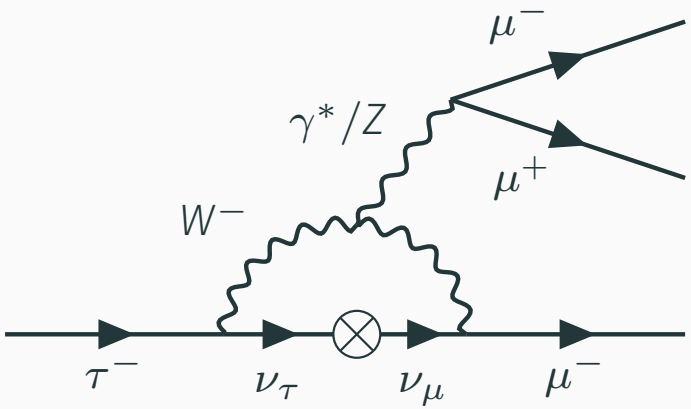
Physics motivations

- Charged Lepton Flavour Violation decay allowed by neutrino oscillation
- Predicted branching fraction smaller than experimentally accessible values [1]
- Many New–Physics scenarios predict branching ratio enhancement [2]

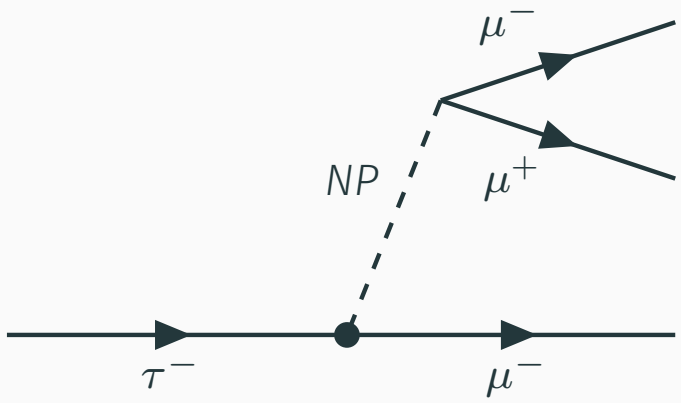
Experimental state of the art

- Experimentally clean three–muon final state
- No signal observed by Belle [3], BaBar [4], LHCb [5] and ATLAS [6]
- Most stringent limit (Belle): $BF < 2.1 \cdot 10^{-8}$ (90% CL)

Standard Model ($BF \sim 10^{-14}$)



New Physics ($BF \sim 10^{-8}$)



[1] Eur. Phys. J. C 8 (1999) 513–516 [2] Ann. Rev. Nucl. Part. Sci. 58 (2008) 315 [3] Phys. Lett. B687 (2010) 139143 [4] Phys. Rev. D81 (2010) 111101 [5] JHEP 02 (2015) 121 [6] Eur. Phys. J. C (2016) 76:232

Search for $\tau \to 3\mu$ with CMS

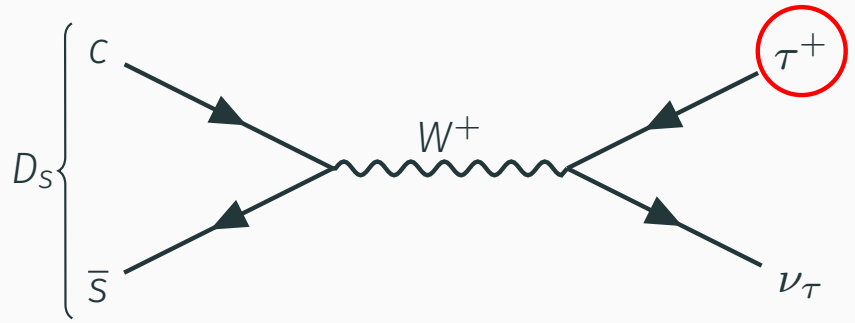
DATASET

τ from D and B decays, using the data collected in 2016, corresponding to 33 fb^{-1}

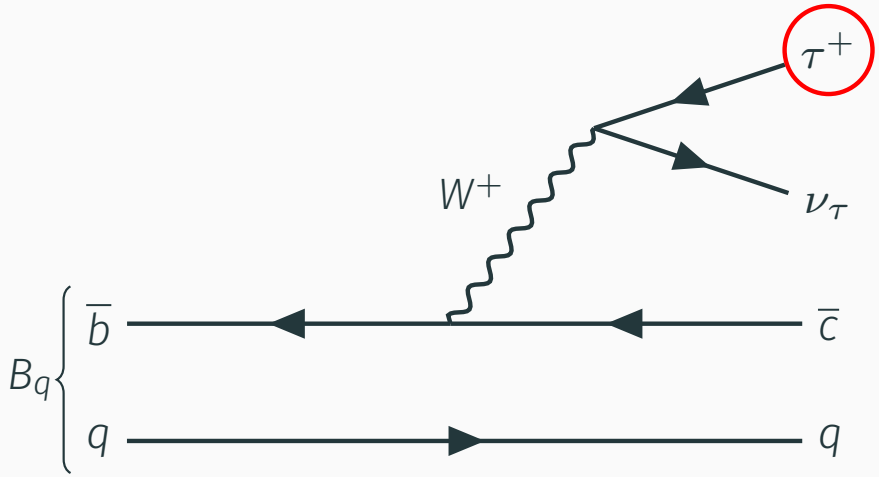
ANALYSIS STRATEGY

1. Select trimuon candidates
2. Train BDT to separate signal from background
3. Define event categories based on per–event trimuon mass resolution and BDT score
4. Normalise with $D_s \to \phi\pi \to (2\mu)\pi$ events
5. Perform combined search for a peak at $m(3\mu) = m(\tau)$

~70%



~30%



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- **Trigger:** two muons plus one track
  - mass and displacement requirements
- **Trimuon candidates:**
  - $p_T^{(\mu_1,\,\mu_2)} > 3$ GeV, $p_T^{(\mu_3)} > 2$ GeV
  - Sum of charge = ± 1
  - $1.62 < m(3\mu) < 2.00$ GeV
  - vertex displaced from beam–spot (2 sigma)

Search for $\tau \to 3\mu$ with CMS

DATASET

τ from D and B decays, using the data collected in 2016, corresponding to 33 fb^{-1}

Signal ← Monte Carlo
Background ← Data Sidebands

ANALYSIS STRATEGY

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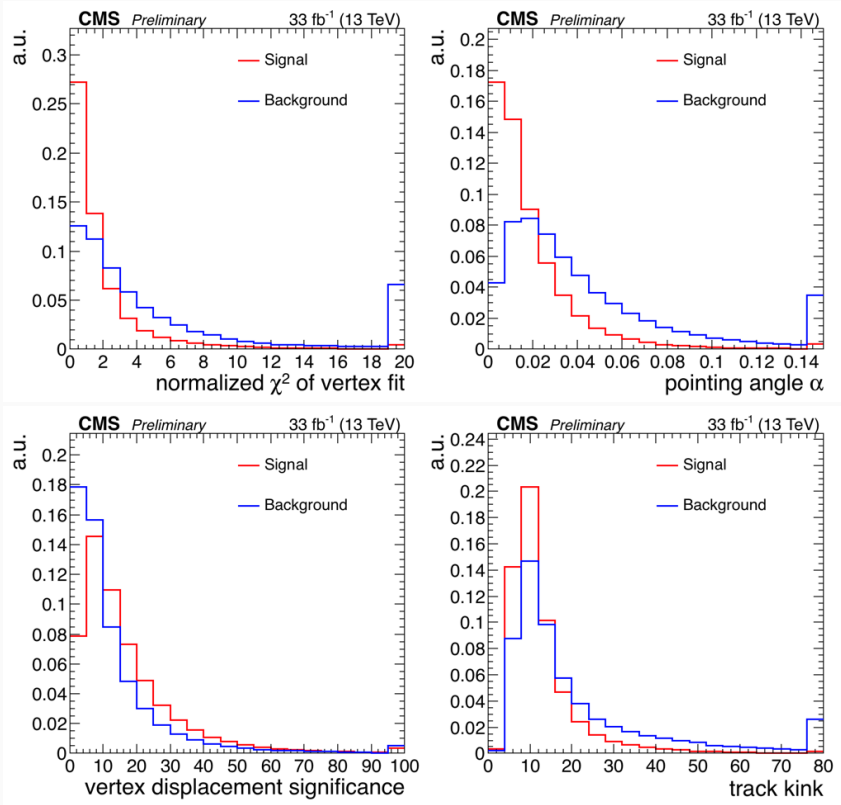

Search for $\tau \to 3\mu$ with CMS

DATASET

τ from D and B decays, using the data collected in 2016, corresponding to 33 fb^{-1}

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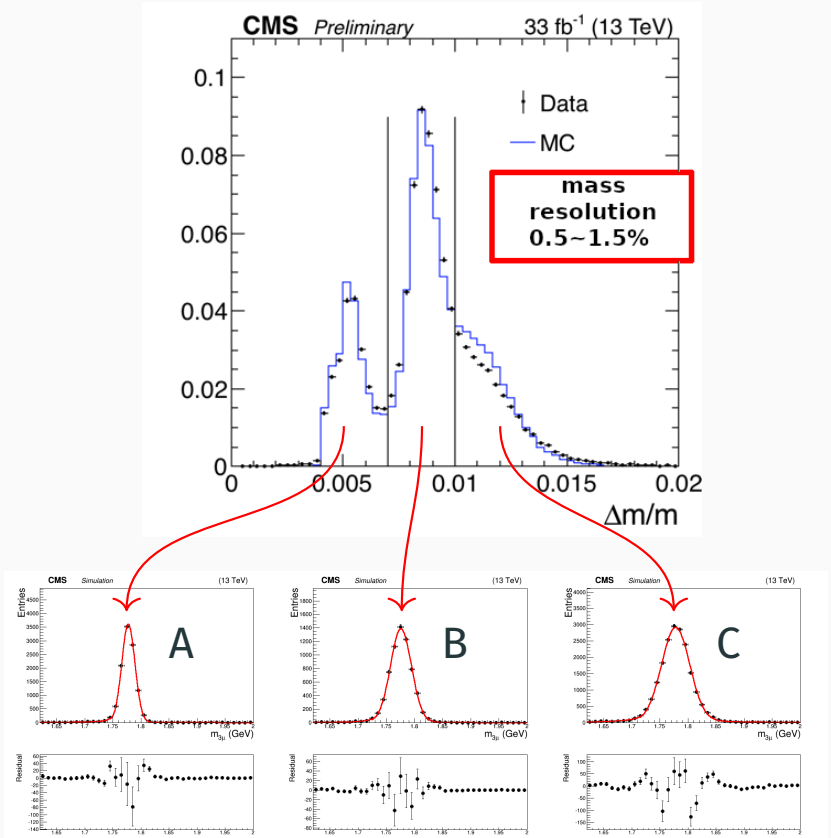
Three per–event mass resolution categories
$\times$
Two BDT score sub–categories



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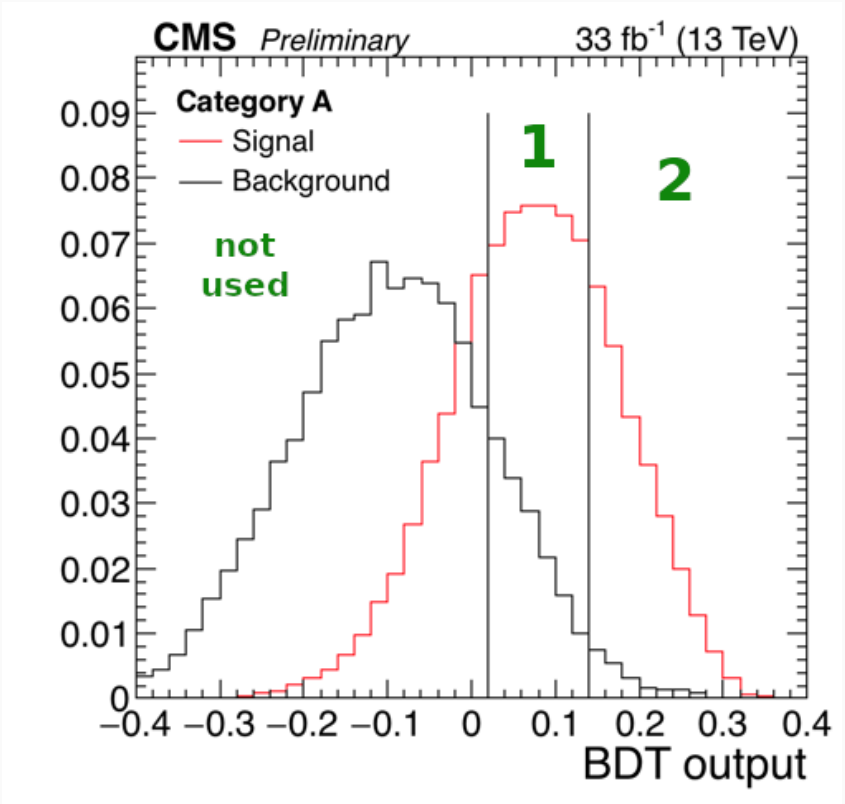

Search for $\tau \to 3\mu$ with CMS

DATASET

τ from D and B decays, using the data collected in 2016, corresponding to 33 fb^{-1}

$$N_{\text{sig}} = N_{\mu\mu\pi} \frac{\mathcal{B}(D_S \to \tau\nu)}{\mathcal{B}(D_S \to \mu\mu\pi)} \frac{\epsilon(\text{signal})}{\epsilon(\mu\mu\pi)} \mathcal{B}(\tau \to 3\mu)$$

ANALYSIS STRATEGY

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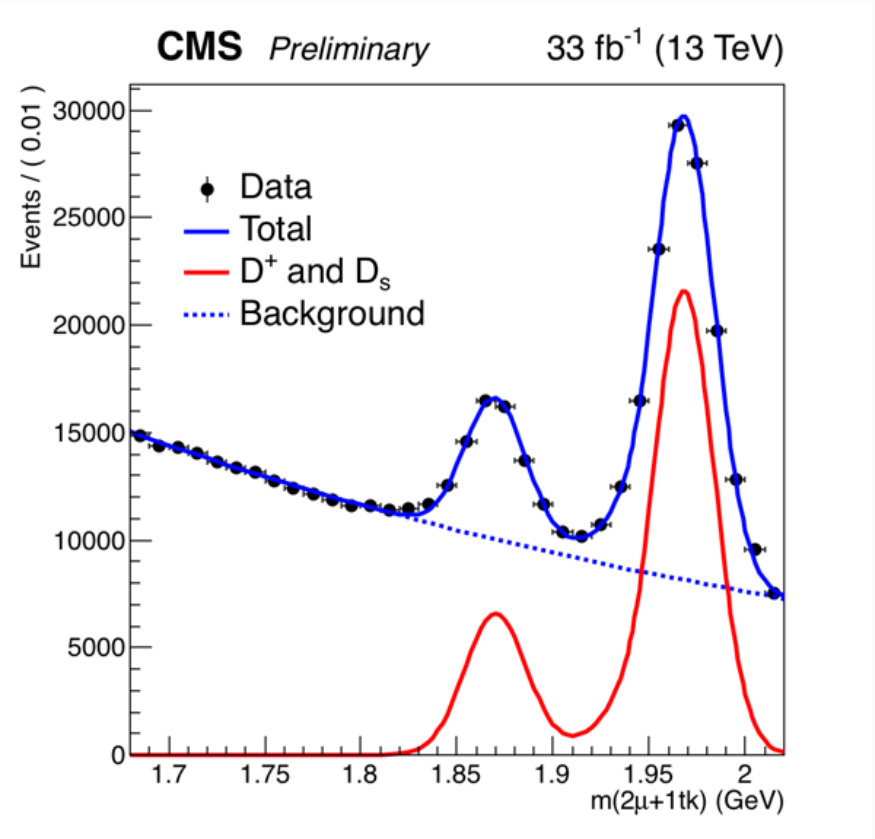

Search for $\tau \to 3\mu$ with CMS

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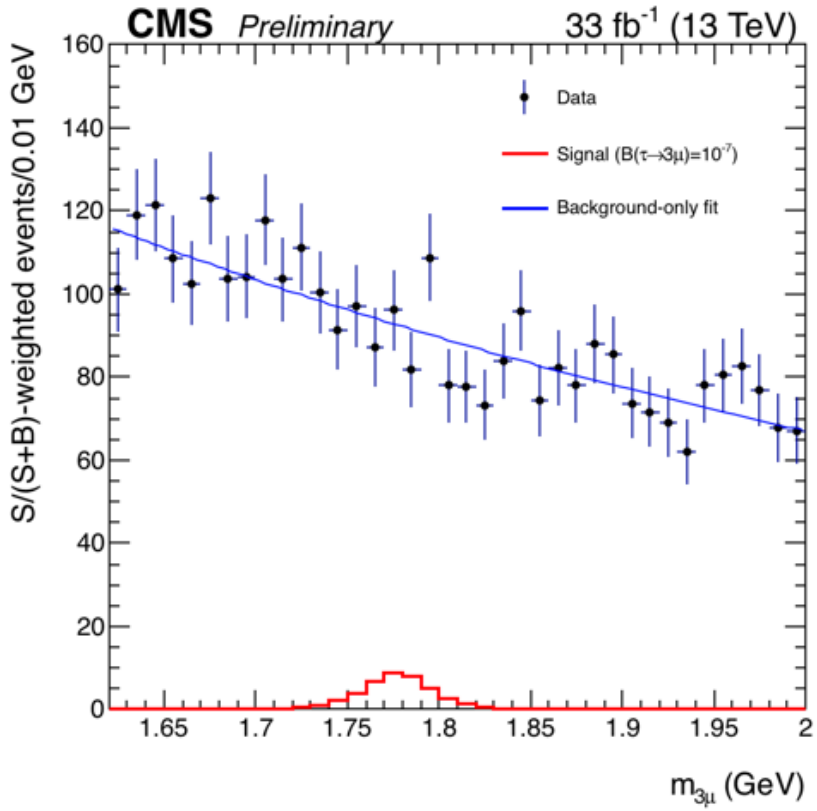

- **Maximum likelihood fit performed simultaneously on the six categories**
- Dominant systematic uncertainty: D_s normalisation (10%)

Search for $\tau \to 3\mu$ with CMS

DATASET

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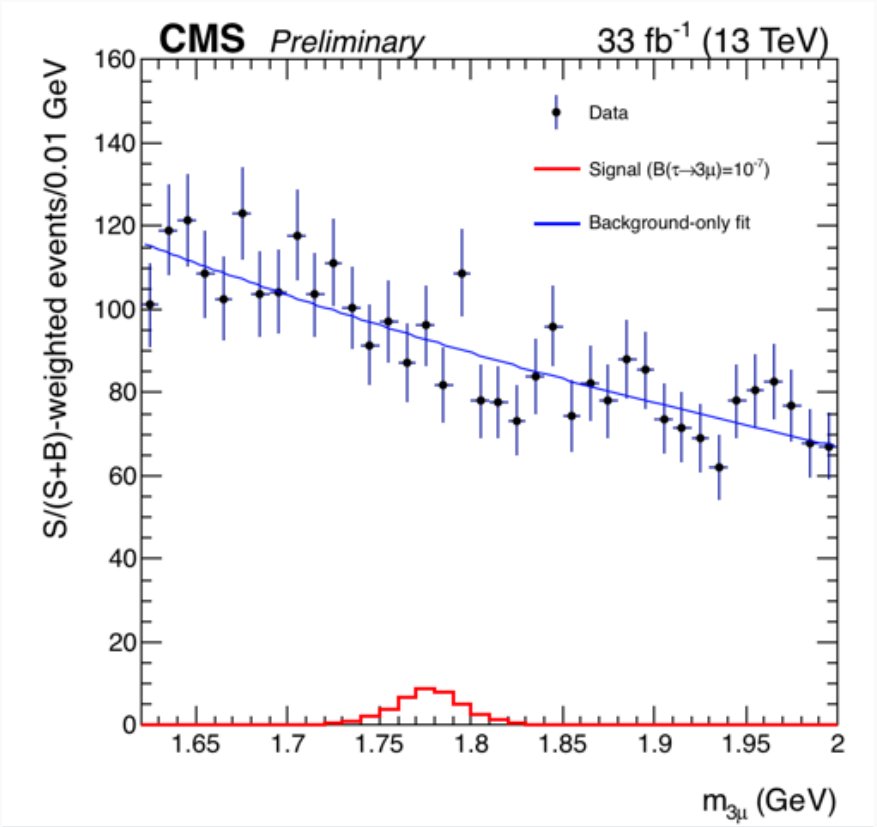


No excess observed

Observed (expected) limits at 90% CL:

$\mathcal{B}(\tau \to 3\mu) < 8.8(9.9) \cdot 10^{-8}$

$B^+ \to K^+\mu^+\mu^-$ angular analysis with CMS

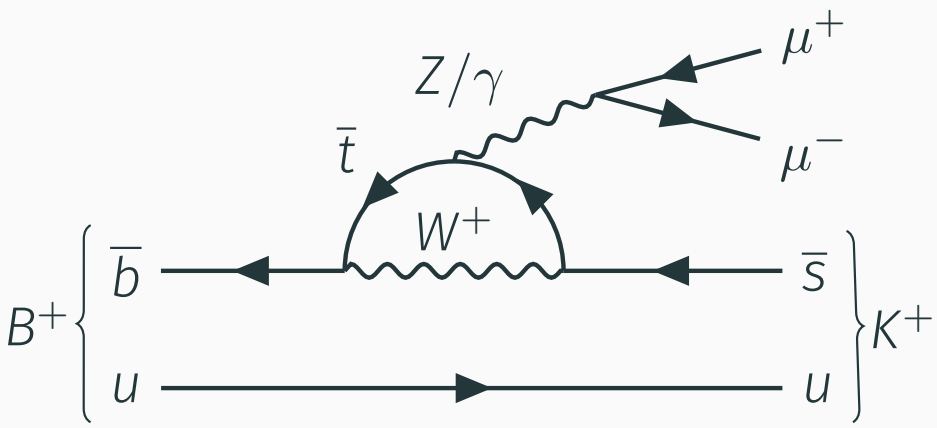
Phys. Rev. D 98, 112011 (2018)

$B^+ \to K^+\mu^+\mu^-$: overview

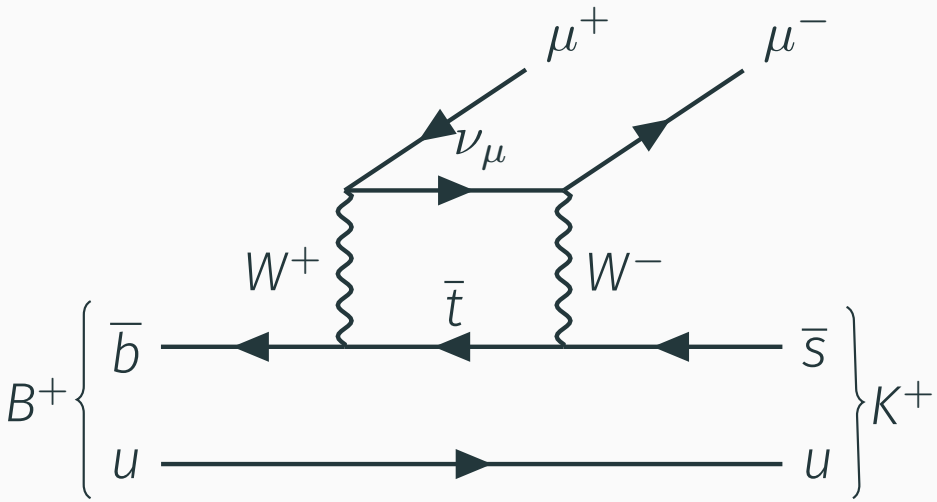
MOTIVATIONS

- $b \to s\ell\ell$ FCNC mediated by electroweak loop and box diagram
  - forbidden at tree level
- Amplitudes may interfere with non–SM contribution
- Previously studied by BABAR [1], Belle [2], CDF [3], and LHCb [4, 5]
  - no hints of beyond SM physics

PENGUIN



BOX



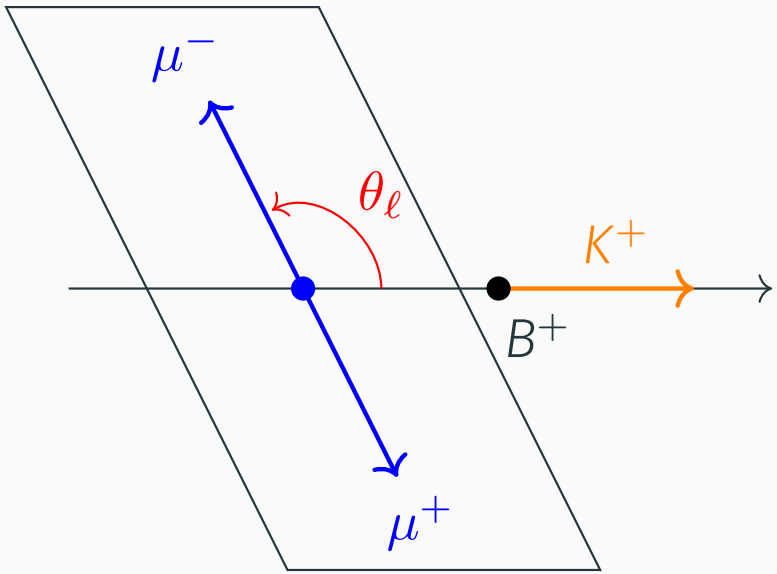
[1] Phys. Rev. D 73 (2006) 092001
[2] Phys. Rev. Lett. 103 (2009) 171801
[3] Phys. Rev. Lett. 108 (2012) 081807
[4] JHEP 02 (2013) 105
[5] JHEP 05 (2014) 082

$B^+ \to K^+\mu^+\mu^-$: angular distribution

The differential decay rate $\mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell$ can be written as:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_\ell)+\frac{1}{2}F_H+A_{FB}\cos\theta_\ell$$

- $\boldsymbol{\theta_\ell}$: the angle between the μ^- and the K^+ in the dimuon rest frame
- A_{FB}: $\mu^+\mu^-$ forward–backward asymmetry
- F_H: measure of the contribution from (pseudo)scalar and tensor amplitude



Dataset and selection

DATASET

$\sqrt{s}$	8 TeV
$\mathcal{L}_{INT}$	20.5 fb^{-1}
$N(B^+ \to K^+\mu^+\mu^-)$	2286 ± 73
parameters measured	F_H, A_{FB}
q^2 range	$[1.0, 22.0]$ GeV^2

SELECTION

- displaced low-mass dimuon HLT
- $p_T(\mu) > 3.5$ GeV
- $|\eta(\mu)| < 2.2$
- $p_T(\mu\mu) > 6.9$ GeV
- $1.0 < m(\mu\mu) < 4.8$ GeV
- $p_T(K^+) > 1.3$ GeV
- $\mathrm{DCA}_{xy}(K^+)/\sigma_{\mathrm{DCA}} > 3.3$
- $L/\sigma_L > 10.6$ (lifetime cut)
- J/ψ and ψ' resonance used as validation

LEADING SYSTEMATICS

1. Background distribution
2. Fitting procedure
3. Efficiency description

$B^+ \to K^+\mu^+\mu^-$ distributions

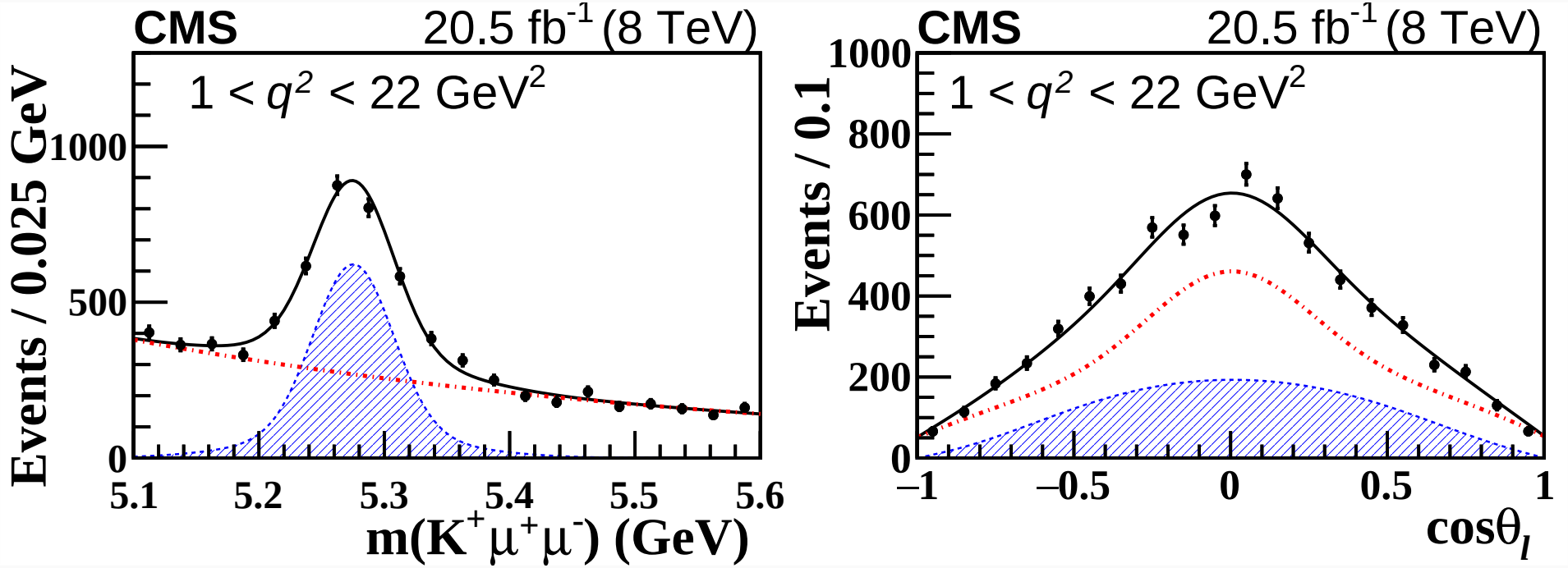
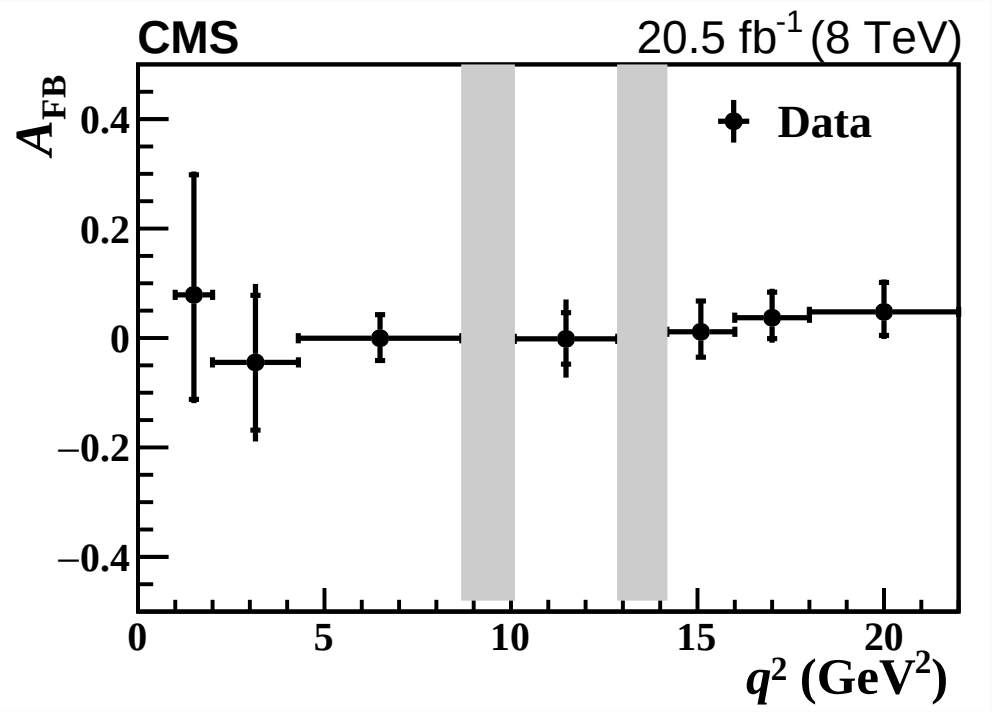
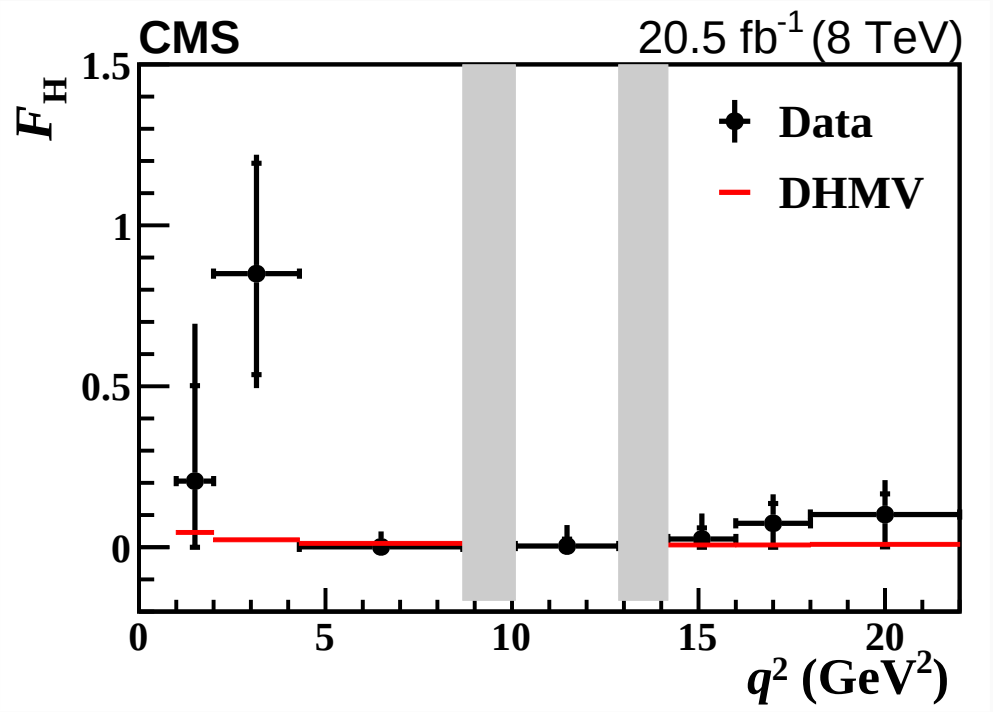


Figure 1: Signal → shaded area, background → dash–dotted line.

$B^+ \to K^+\mu^+\mu^-$ results





Good agreement between the CMS results, Standard Model predictions and previous measurements.

Status and prospective of $B^0 \to K^{*0}\mu^+\mu^-$ angular analysis by ATLAS and CMS

ATLAS RUN–1 JHEP 10 (2018) 047

CMS RUN–1 Phys. Lett. B 781 (2018) 517

$B^0 \to K^{*0}\mu^+\mu^-$: overview

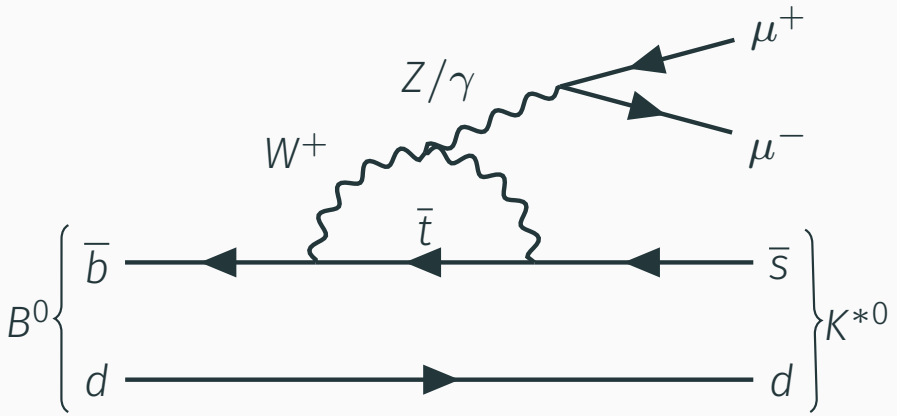
MOTIVATIONS

- $B^0 \to K^{*0}\mu^+\mu^-$ is described within the SM as a **FCNC $b \to s\ell\ell$ process**
- **NP** can change the angular distribution

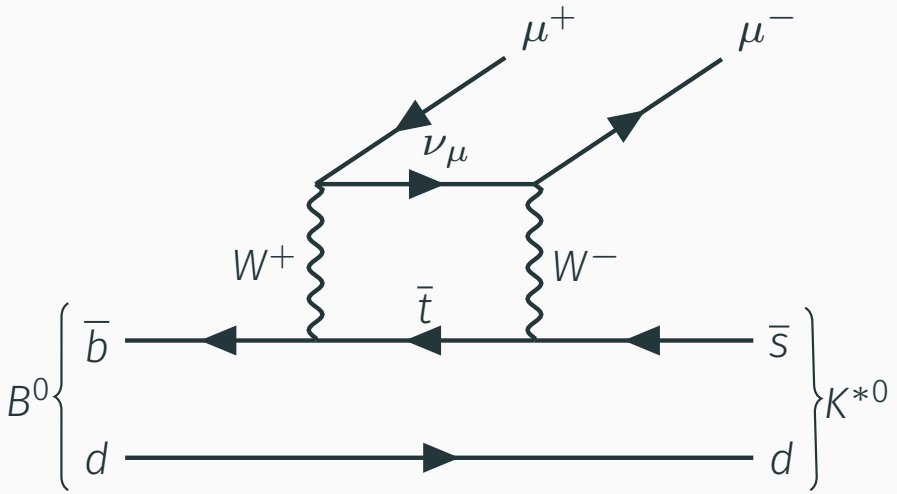
P_5' ANOMALY HISTORY

1. Deviation $> 3\sigma$ from SM seen by LHCb [1] on the P_5' observable at $q^2 \sim 6$ GeV^2
2. Belle saw a similar deviation [2] (preliminary)
3. Both ATLAS and CMS used their 8 TeV dataset to measure (among others) P_5'
   - CMS has extended a previous analysis [3] were it already measured
     - $A_{FB} \to$ FB asymmetry of the muons
     - $F_L \to K^{*0}$ longitudinal polarization fraction
     - A_S, $F_S \to$ S–wave fraction and S/P–wave interference parameters

PENGUIN



BOX



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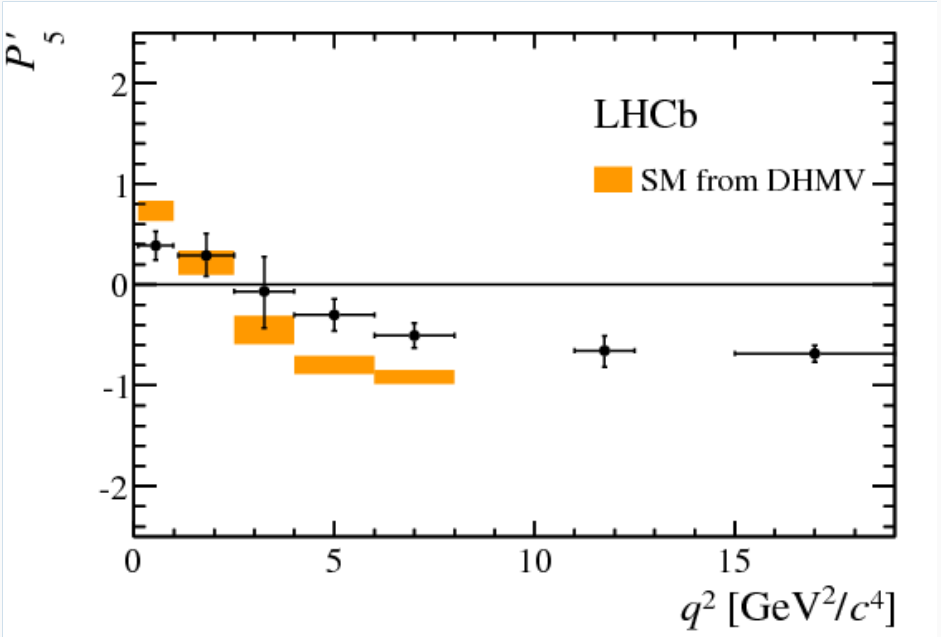
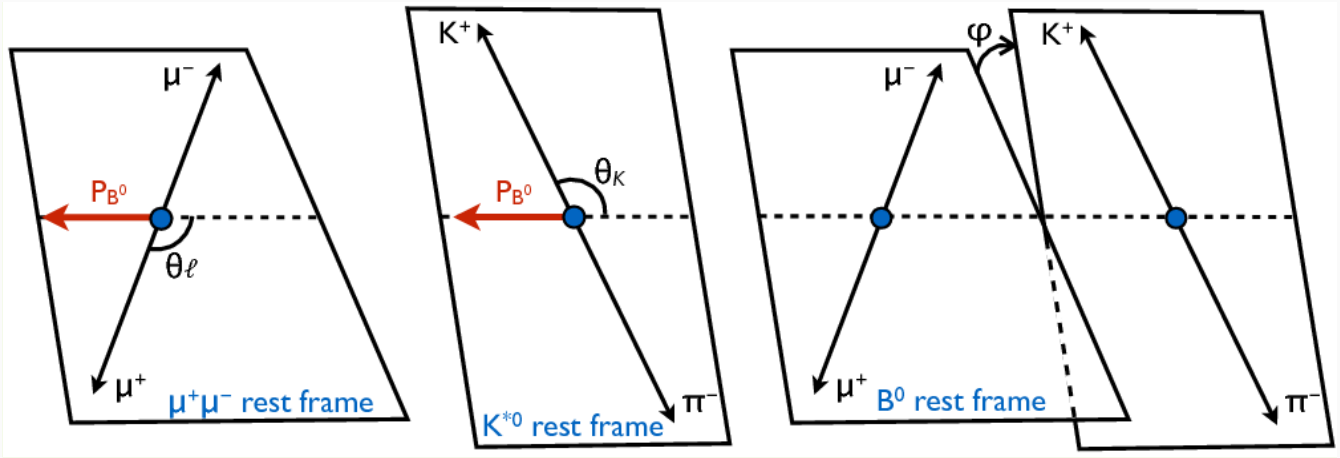


- $q^2 = m^2_{\mu\mu}$
- $P_5' = S_5/\sqrt{F_L(1-F_L)}$ is one of several angular parameters in the LHCb parameterization

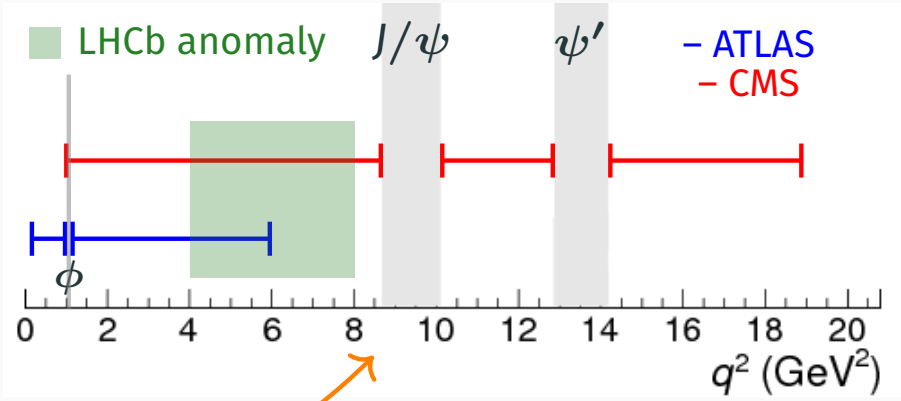
[1] JHEP 1602 (2016) 104
[2] arXiv:1612.05014
[3] Phys. Lett. B 753 (2016) 424

$B^0 \to K^{*0}\mu^+\mu^-$: framing the "picture"

$B^0 \to K^{*0}\mu^+\mu^-$ decay fully described as a function of three angles $(\theta_\ell, \theta_K, \phi)$ and dimuon q^2 (invariant mass squared)



	ATLAS	CMS
$\sqrt{s}$	8 TeV	
$\mathcal{L}_{\text{int}}$	20.3 fb^{-1}	20.5 fb^{-1}
N_{signal}	348	1397
q^2 range [GeV^2]	[0.04, 6.0]	[1.0, 8.68] [10.09, 12.86] [14.18, 19.0]



$B^0 \to K^{*0}\mu^+\mu^-$: selection

ATLAS

- lowmass dimuon trigger
- $p_T(\mu) > 3.5$ GeV^2; $p_T(K,\pi) > 0.5$ GeV^2; $p_T(K^{*0}) > 3.0$ GeV^2
- $L/\sigma_L > 12.5$ (lifetime cut)
- $|m(K\pi) - m^{\text{PDG}}(K^{*0})| < 50$ MeV^2
- $5150 < m(K\pi\mu\mu) < 5700$ MeV^2
  - asymmetric to suppress $B \to \mu^+\mu^- X$
- reject $0.98 < q^2 < 1.1$ GeV^2 (ϕ resonance)
- no PID to distinguish the two CP–states
  - $B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$
  - $\overline{B^0} \to \overline{K^{*0}}(\to K^-\pi^+)\mu^+\mu^-$

  CP–state assignment based on mass hypothesis closer to $m^{\text{PDG}}(K^{*0})$
  - mistag rate $\sim 10\%$

CMS

- dedicated lowmass dimuon trigger
- $p_T(\mu) > 3.5$ GeV^2; $p_T(K,\pi) > 0.8$ GeV^2; $p_T(\mu\mu) > 6.9$ GeV^2
- $L/\sigma_L > 12.0$ (lifetime cut)
- $|m(K\pi) - m^{\text{PDG}}(K^{*0})| < 90$ MeV^2
- $|m(K\pi\mu\mu) - m^{\text{PDG}}(B^0)| < 280$ MeV^2
- DCA$(K^{*0})/\sigma$>2 w.r.t beam–spot
- no PID to distinguish the two CP–states
  - $B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$
  - $\overline{B^0} \to \overline{K^{*0}}(\to K^-\pi^+)\mu^+\mu^-$

  CP–state assignment based on mass hypothesis closer to $m^{\text{PDG}}(K^{*0})$
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$B^0 \to K^{*0}\mu^+\mu^-$: selection

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$B^0 \to K^{*0}\mu^+\mu^-$: measurement

- Not enough events to fit the whole decay rate model in the various bins
- Both experiments exploited the odd symmetry of trigonometric functions and **"fold"** the decay rate
  - folding scheme depends on the parameter to measure, e.g. for P_1 and $P_5' \to$ folding around $\phi = 0$ and $\theta_\ell = \pi/2$
- Parameters measured:
  - ATLAS: F_L, S_3, S_4, S_5, S_7, S_8, $(\to P_1, P_4', P_5', P_6', P_8')$
    - S–wave component neglected (a related systematic was estimated)
  - CMS: P_1, P_5'
    - A_S, F_S, F_L have been measured in [Phys. Lett. B 753 (2016) 424] and here they are fixed (their uncertainty is treated as a systematics)
- Leading systematics:
  - ATLAS: combinatorial $K\pi$ background and partially reconstructed $B \to D^0/D^+/D_s, X$ background
  - CMS: A_S, F_S, F_L uncertainty propagation, finite size of MC samples and fit bias

$B^0 \to K^{*0}\mu^+\mu^-$: measurement

- Not enough events to fit the whole decay rate model in the various bins
- Both experiments exploited the odd symmetry of trigonometric functions and **"fold"** the decay rate
  - folding scheme depends on the parameter to measure, e.g. for P_1 and $P_5' \to$ folding around $\phi = 0$ and $\theta_\ell = \pi/2$
- Parameters measured:
  - **ATLAS**: F_L, S_3, S_4, S_5, S_7, S_8, ($\to P_1$, P_4', P_5', P_6', P_8')
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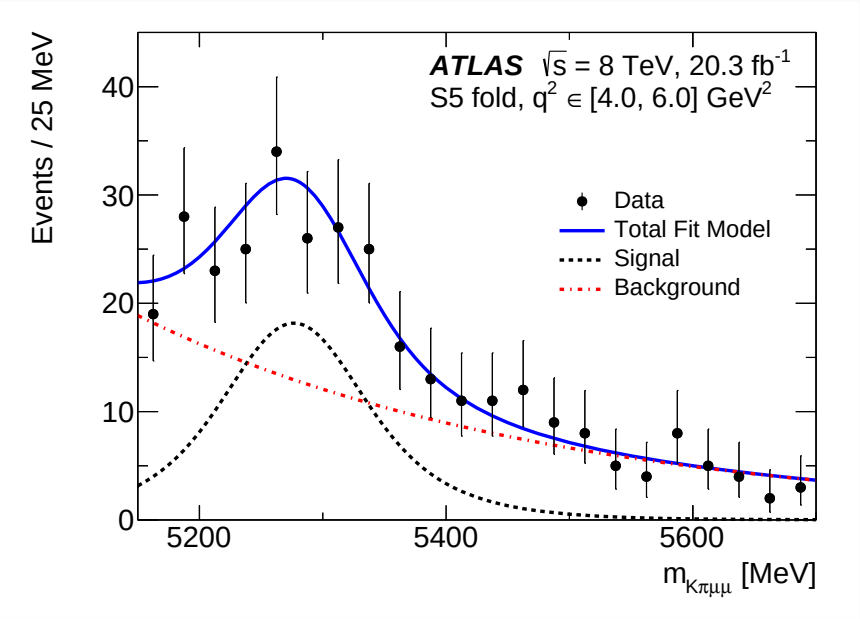
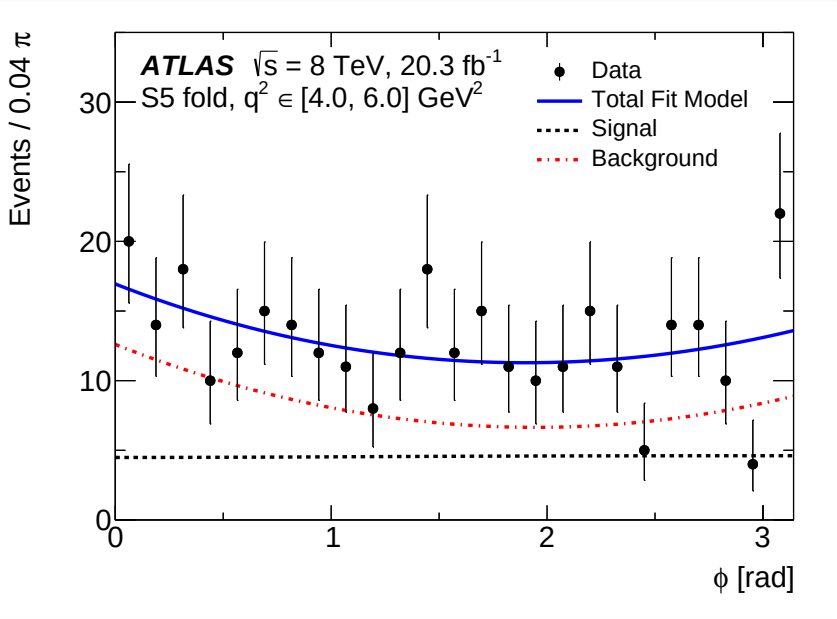
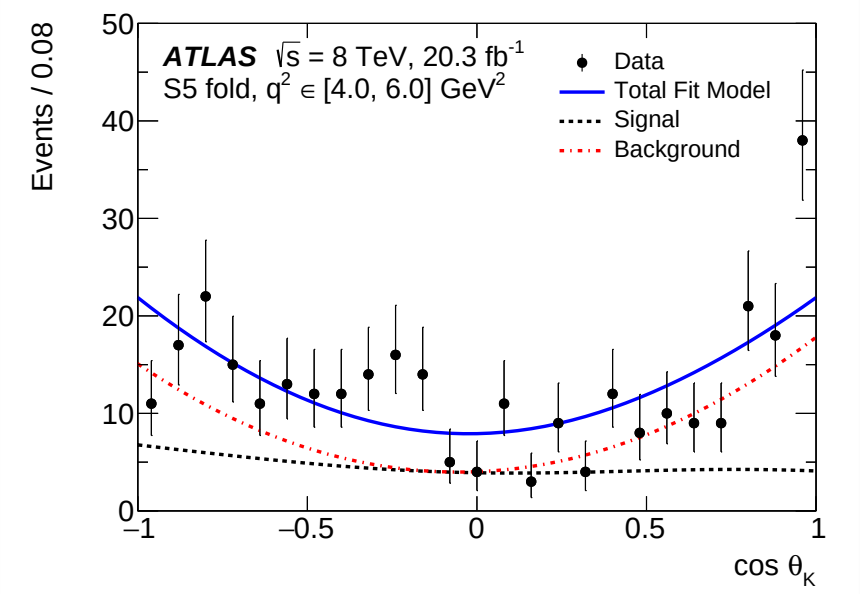
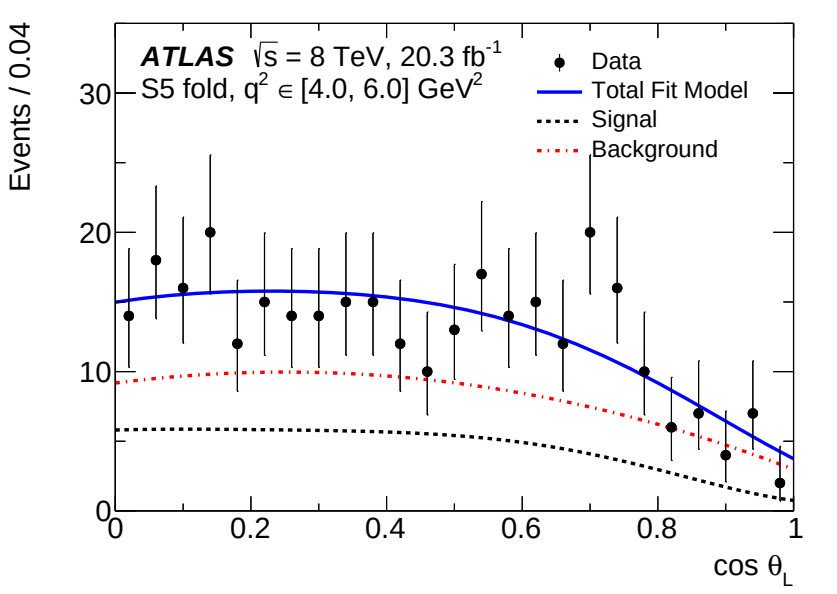
$B^0 \to K^{*0}\mu^+\mu^-$: ATLAS results

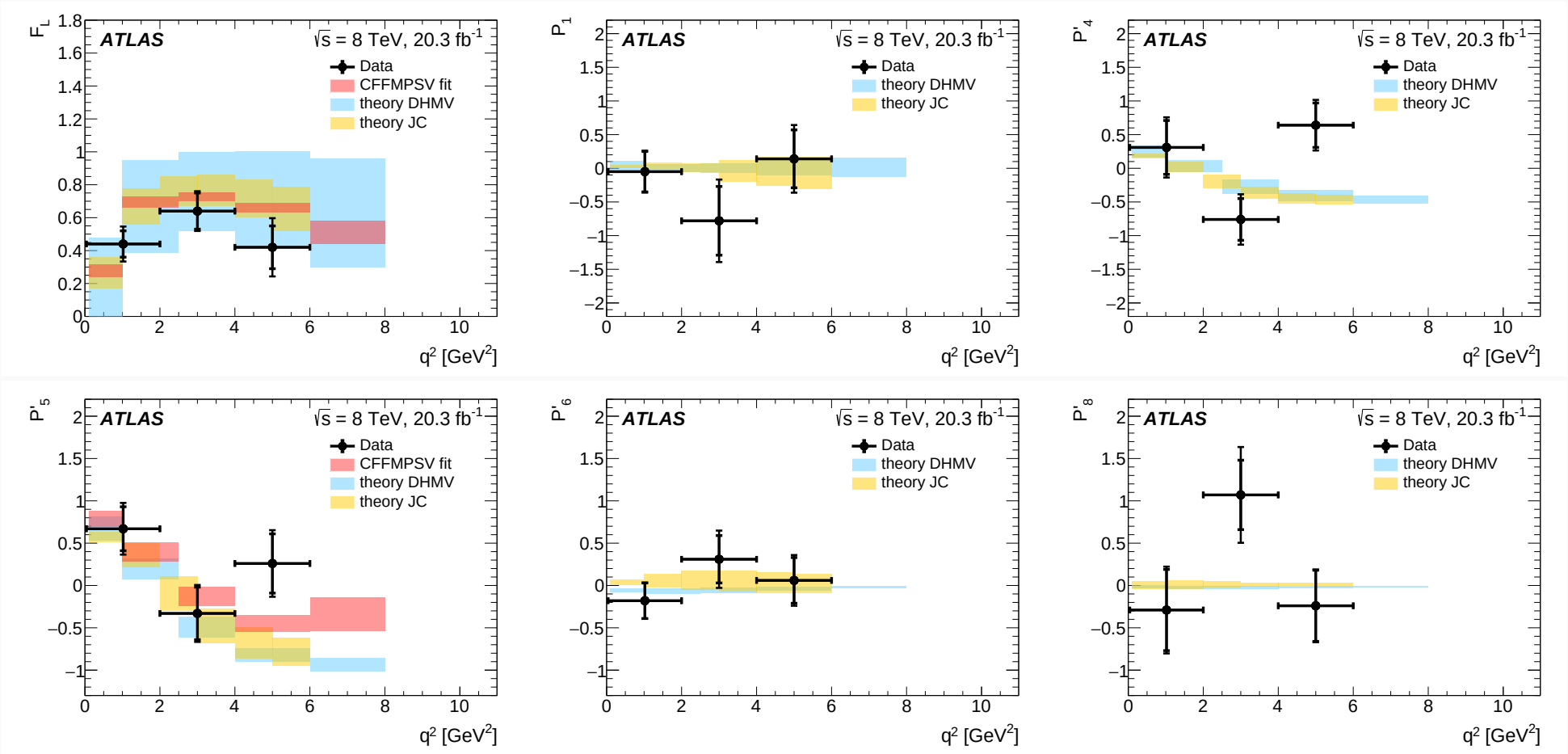




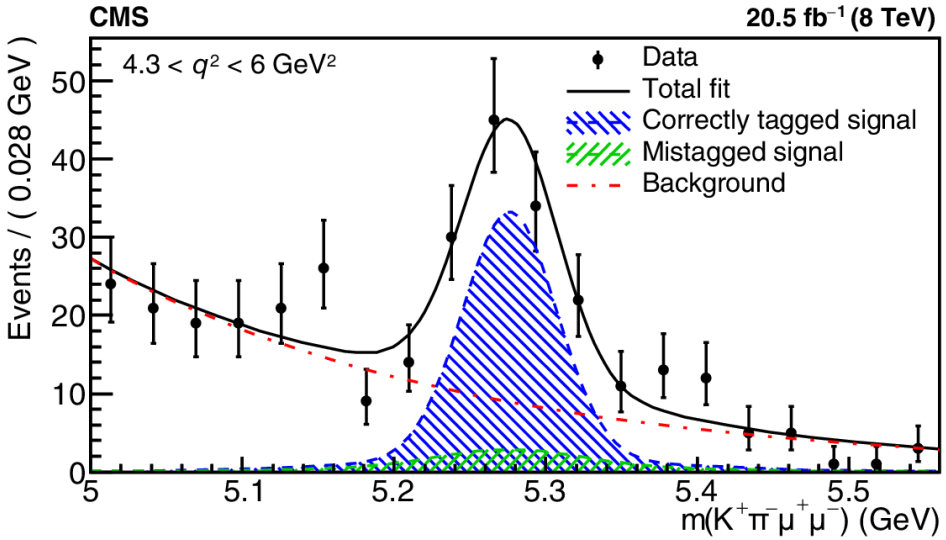


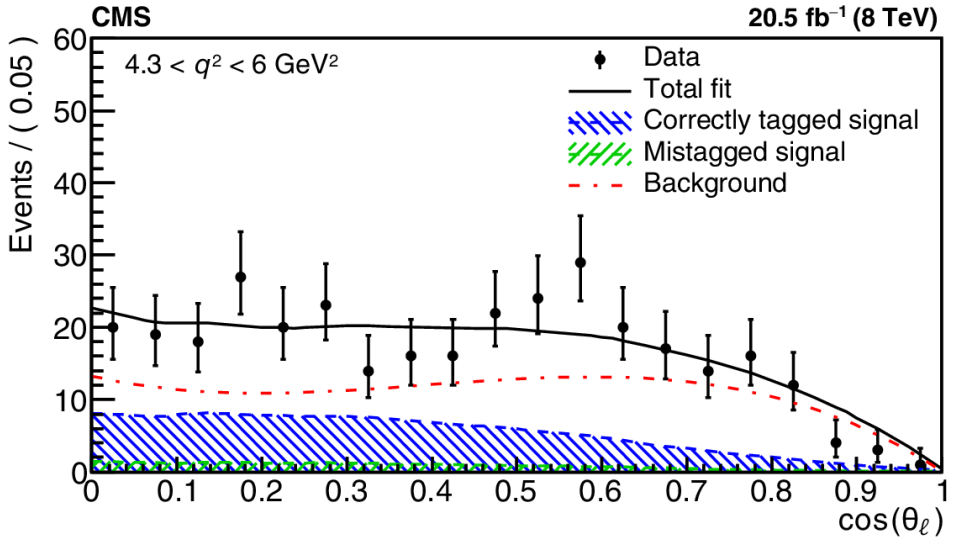


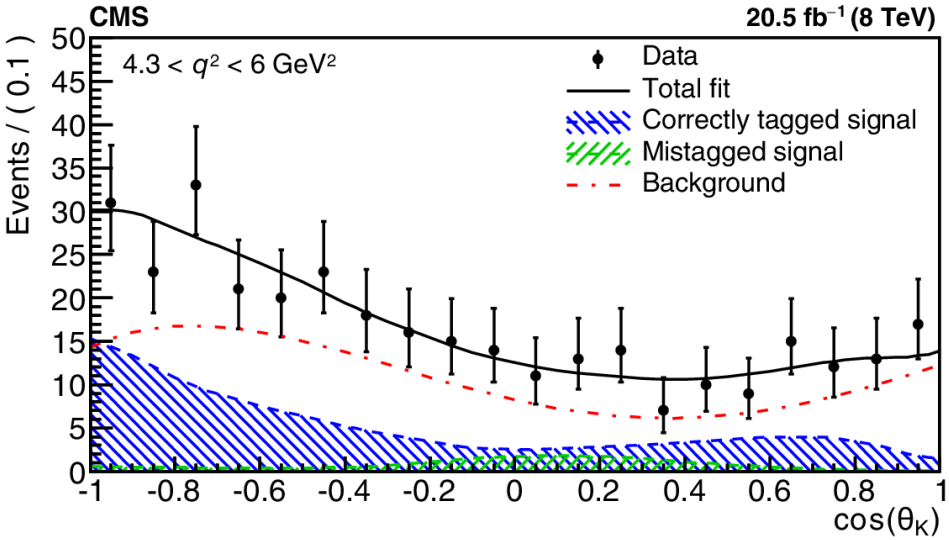
$B^0 \to K^{*0}\mu^+\mu^-$: ATLAS results

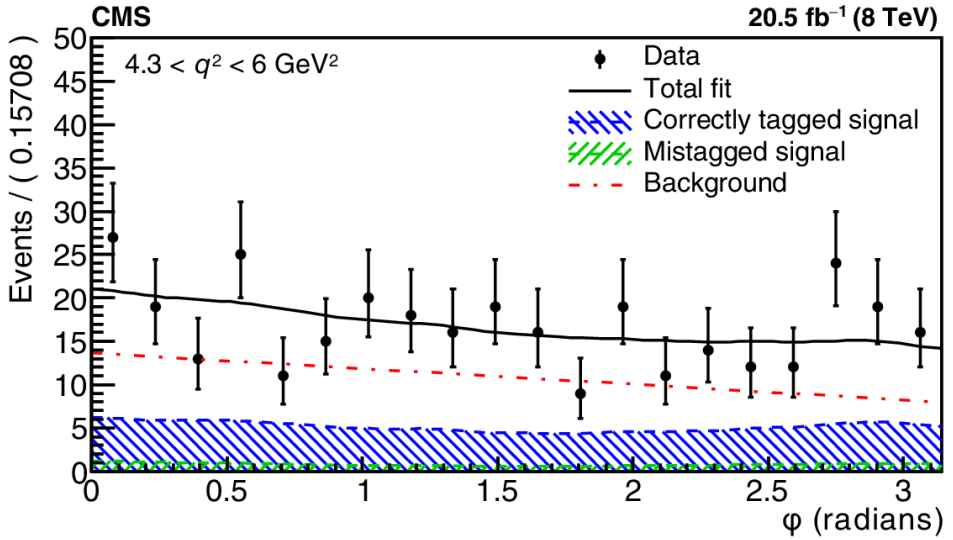


$B^0 \to K^{*0}\mu^+\mu^-$: CMS results

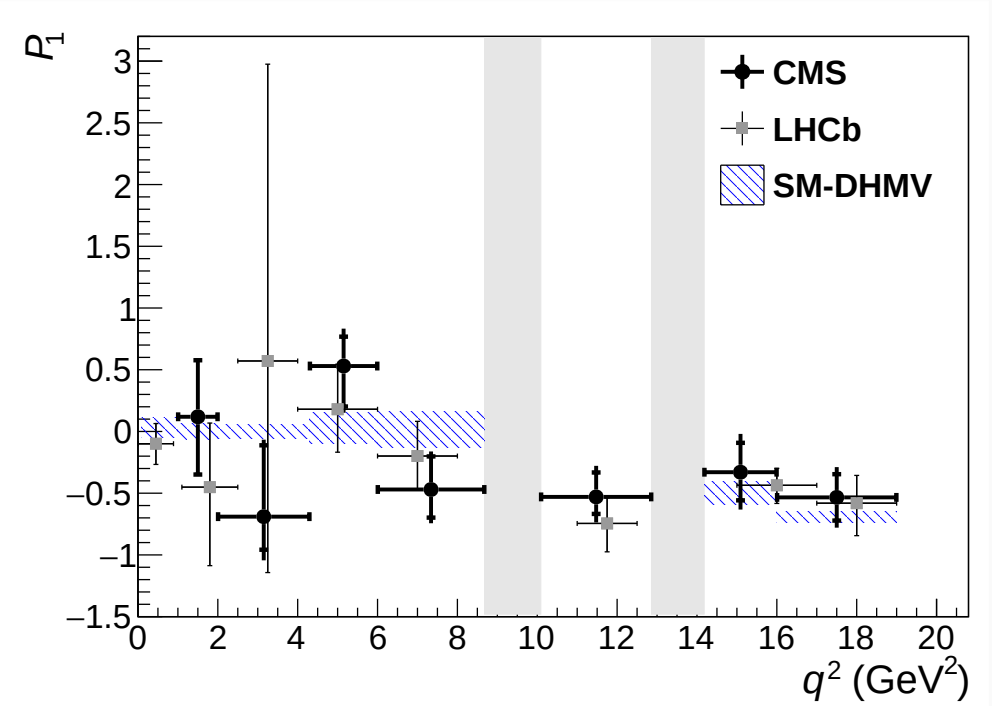


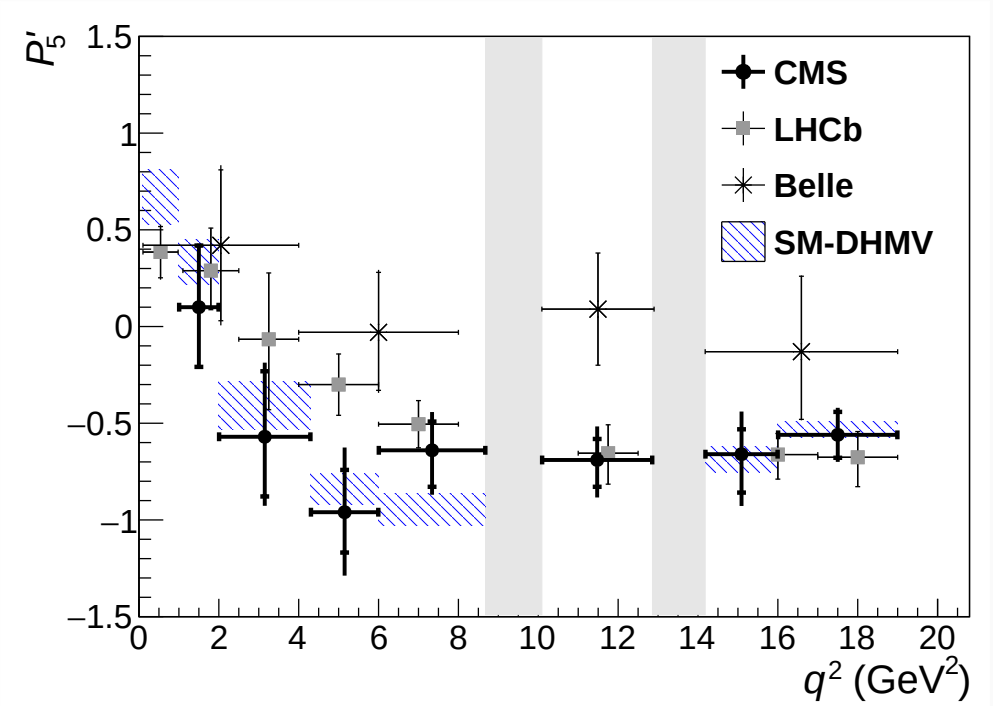




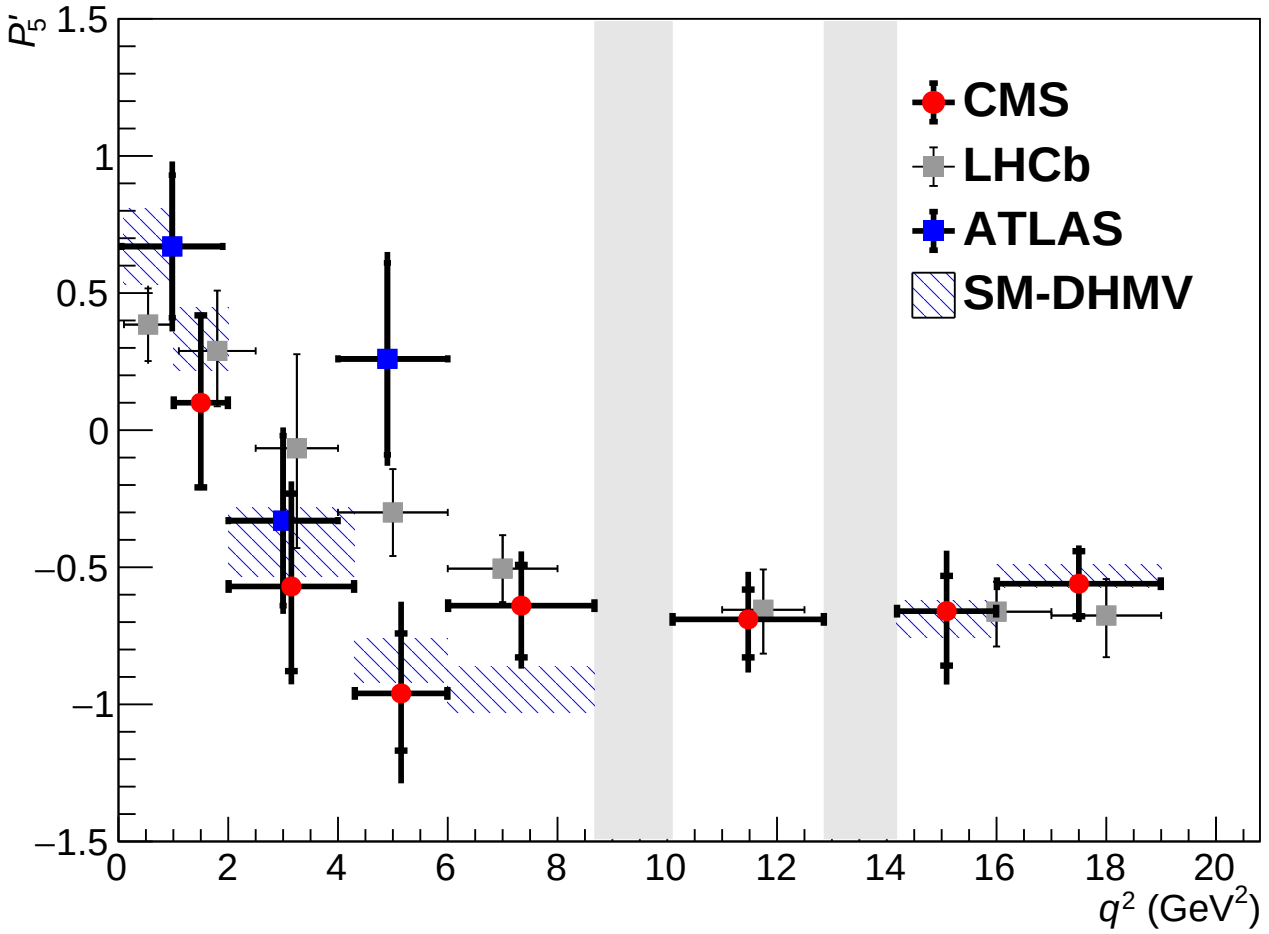


$B^0 \to K^{*0}\mu^+\mu^-$: CMS results





$B^0 \to K^{*0}\mu^+\mu^-$: P_5' state of the art



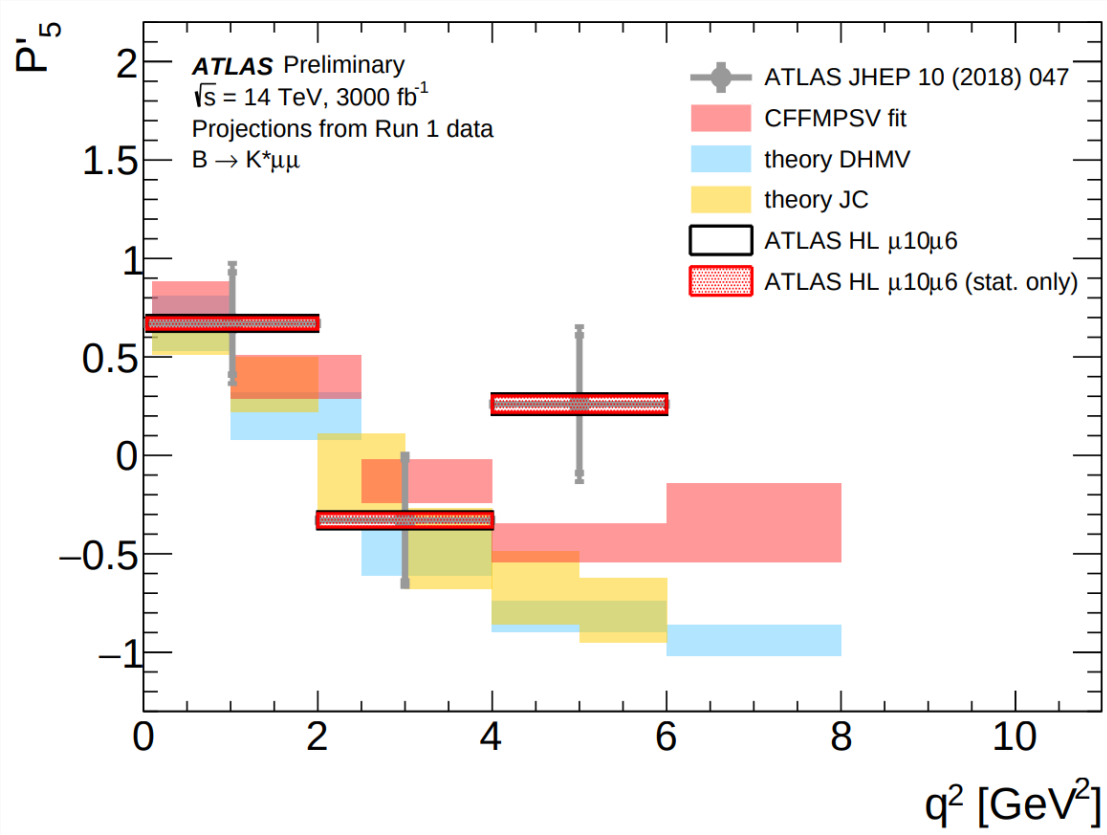
- **CMS** measurement in excellent agreement with SM
- **ATLAS** measurement in agreement with SM, with some discrepancy ($\sim 2\,\sigma$) around the "infamous" $q^2 = 5$ GeV^2 bin
- Still a lot to clarify between 4 and 8 GeV^2
- ATLAS, CMS and LHCb have all planned Run–2 analyses of $B^0 \to K^{*0}\mu^+\mu^-$

Status and prospective of $B^0 \to K^{*0}\mu^+\mu^-$ angular analysis by ATLAS and CMS

HL–LHC projections

YR: arXiv:1812.07638

ATLAS Phase–2 projection



- **ATLAS** provided projections at of F_L, P_1, P_4', P_5', P_6', P_8' for $\mathcal{L}_{\text{INT}} = 3000\ \text{fb}^{-1}$
- Uncertainties are estimated to **improve up to a factor** $5 \sim 9$ w.r.t. Run–1, depending on the trigger

CMS Phase–2 projection

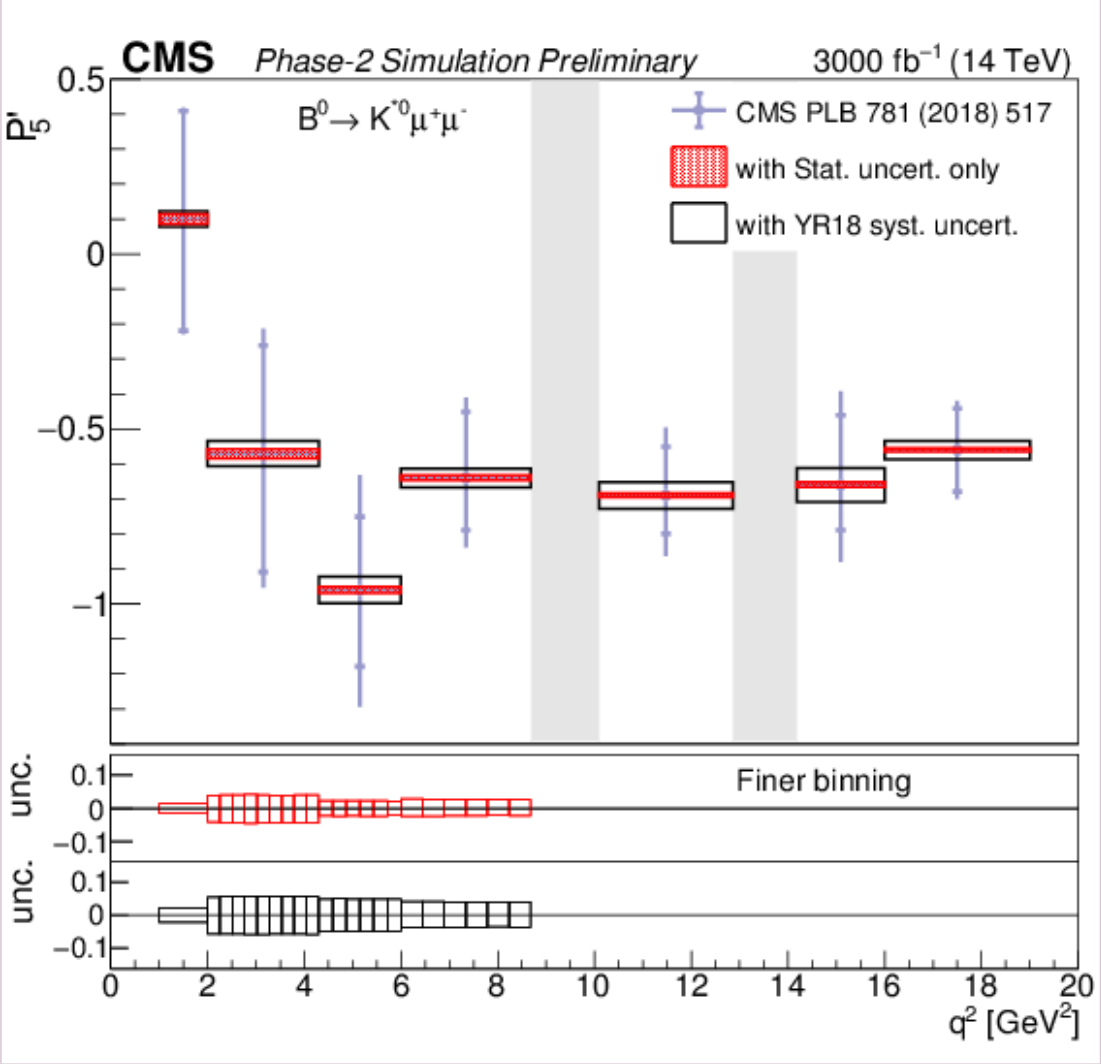


Figure: Lower pads represent the statistical (upper pad) and total (lower pad) uncertainties with the finer binning.

- **CMS** projected the measurement of P'_5 for $\mathcal{L}_{\text{INT}} = 3000\ \text{fb}^{-1}$
- Uncertainties are estimated to **improve up to a factor 15** w.r.t. Run–1
- Opportunity to use **finer q^2 binning**

Summary and outlook

Summary

- **Search for $\tau \to 3\mu$ decay, in sample from B and D meson decays with CMS**
  - No excess observed
  - Upper limit set at 90% CL: $\mathcal{B}(\tau \to 3\mu) < 8.9 \cdot 10^{-8}$
- **Angular analysis of $B^+ \to K^+\mu^+\mu^-$ with CMS**
  - Measured A_{FB} and F_{H} with 20.5 fb^{-1} at $\sqrt{s} = 8$ TeV
  - Good agreement with prediction and previous measurements
- **Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ with ATLAS and CMS**
  - **ATLAS** measured F_L, P_1, P_4', P_5', P_6', P_8' for $q^2 \in [0.04, 6.0]$ GeV^2 ($\phi(1020)$ resonance excluded).
    - All measurements are found to be within three standard deviations from SM, with the largest discrepancy being 2.7σ for P_5' in the $q^2 \in [4, 6.0]$ GeV^2 bin
  - **CMS** measured P_1 and P_5' for $q^2 \in [1.0, 19.0]$ GeV^2 (J/ψ and ψ' resonances excluded) observing no deviations from SM predictions

Many other exciting B–physics results from ATLAS and CMS are in the making. **Stay tuned!**

Thanks for your attention!
Questions?

BACKUP

$$\tau \to 3\mu$$

Number of expected signal events, assuming $\mathcal{B}(\tau \to 3\mu) = 10^{-7}$

Produced in pp collisions	$4.9 \cdot 10^5$
Three muons in fiducial volume	$8.9 \cdot 10^3$
Trigger	328
Three global muons ($p_T > 2$ GeV)	135
Trimuon candidate selection	93

Expected inclusive number of τ leptons

Process	Number of τ leptons (33 fb^{-1})
$D \to \tau\ \nu$	$4.0 \cdot 10^{12}$ (95% D_s, 5% $D^{\pm}$)
$B \to \tau\ \nu$	$1.5 \cdot 10^{12}$ (44% $B^{\pm}$, 45% B^0, 11% B_s)
$B \to D \to \tau\ \nu$	$1.5 \cdot 10^{12}$ (98% D_s, 2% $D^{\pm}$)

D and B meson decay branching fraction

Process	Branching Ratio
$D_s \to \tau\nu$	5.48 ± 0.23 %
$B^+ \to \tau\nu D^{*0}$	2.7 ± 0.3 %
Other $B^+ \to \tau X$	0.7 %
$B^0 \to \tau\nu D^{*+}$	2.7 ± 0.3 %
Other $B^0 \to \tau X$	0.7 %
$B^+ \to D_s X$	9.0 ± 1.5 %
$B^0 \to D_s X$	10.3 ± 2.1 %
$D_s \to \phi(\mu\mu)\pi$	$(1.3 \pm 0.1) \cdot 10^{-5}$ %

Expected signal yield

$$N_{\text{sig(D)}} = \mathcal{L}\,\sigma(pp \to D_s)\,\mathcal{B}(D_s \to \tau\nu)\,\mathcal{B}(\tau \to 3\mu)\mathcal{A}_{3\mu(D)}\epsilon_{\text{reco}}^{3\mu}\epsilon_{\text{trig(sig)}} \tag{1}$$

$$N_{\mu\mu\pi} = \mathcal{L}\,\sigma(pp \to D_s)\,\mathcal{B}(D_s \to \phi\pi \to \mu\mu\pi)\,\mathcal{A}_{2\mu\pi}\epsilon_{\text{reco}}^{2\mu\pi}\epsilon_{\text{trig}(\mu\mu\pi)} \tag{2}$$

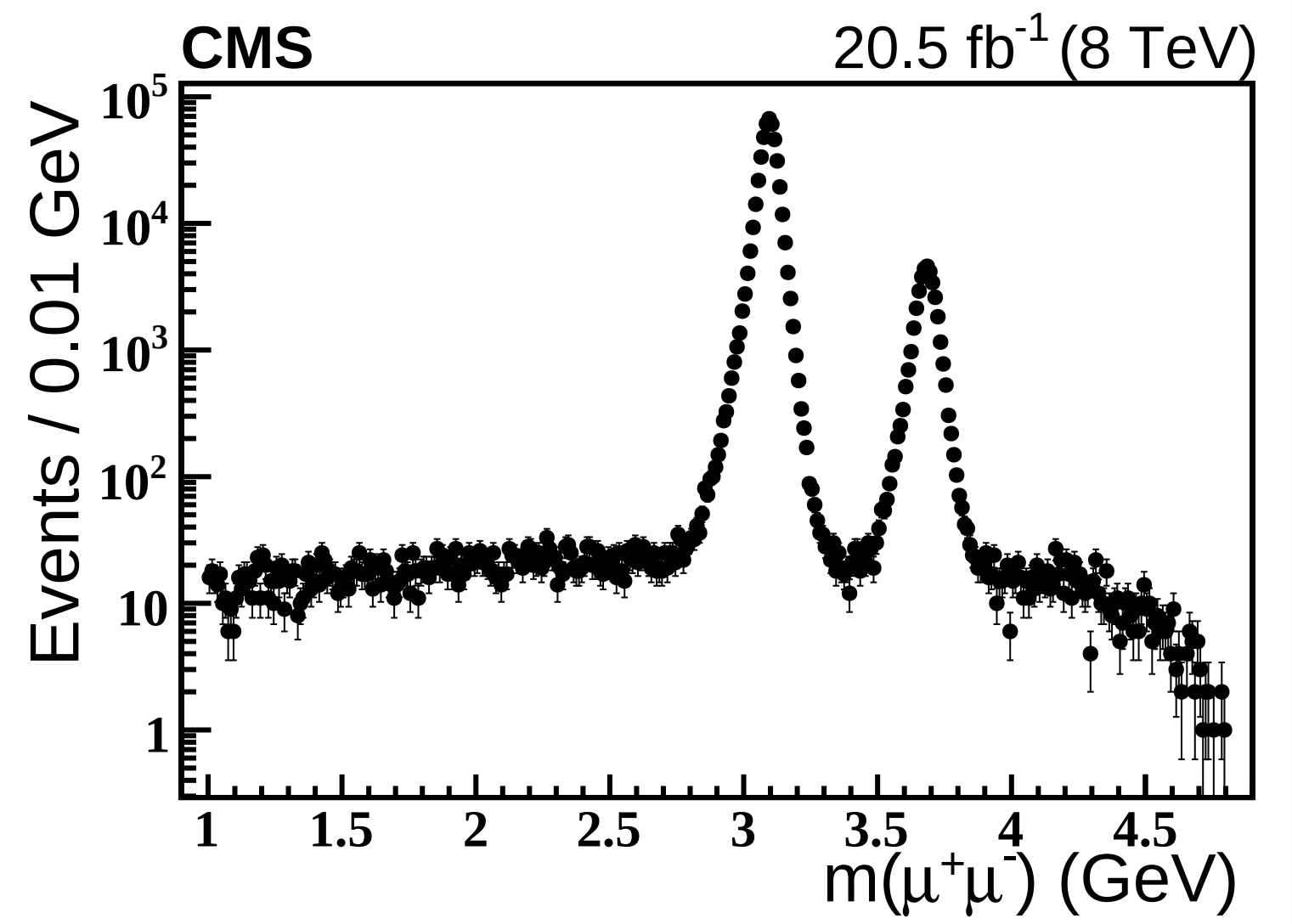
$$\boxed{N_{\text{sig(D)}} = N_{\mu\mu\pi}\frac{\mathcal{B}(D_s \to \tau\nu)}{\mathcal{B}(D_s \to \mu\mu\pi)}\frac{\epsilon_{\text{reco}}^{3\mu}}{\epsilon_{\text{reco}}^{2\mu\pi}}\frac{\epsilon_{\text{trig(sig)}}}{\epsilon_{\text{trig}(\mu\mu\pi)}}\mathcal{B}(\tau \to 3\mu)} \tag{3}$$

Signal modeling systematics uncertainties

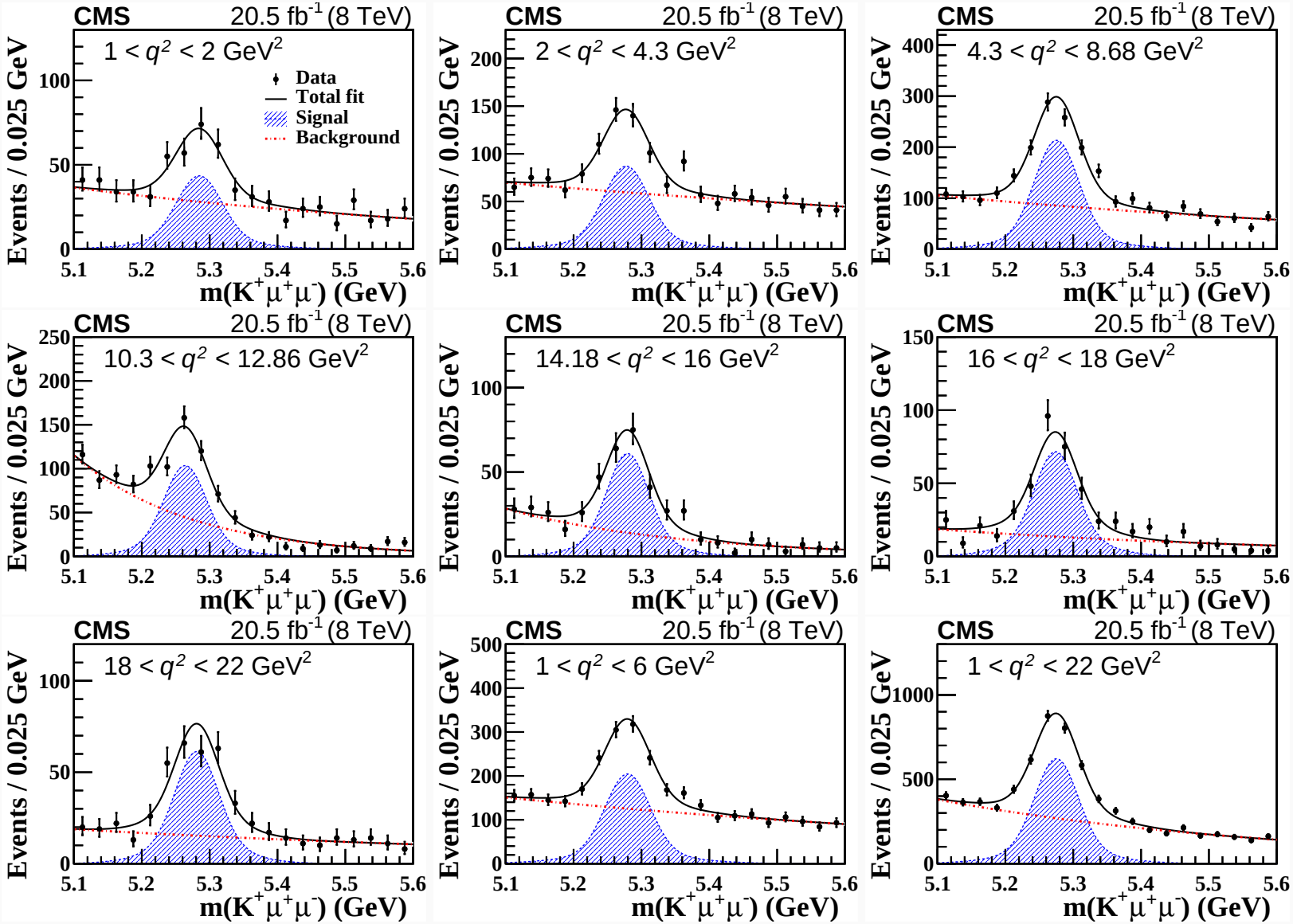
Source of uncertainty	Yield	Shape
Uncertainty on D_s normalization [10%]	10%	
Relative uncertainty in $\mathcal{B}(D_s \to \tau\nu)$ [4%]	3%	
Relative uncertainty in $\mathcal{B}(D_s \to \phi\pi \to \mu\mu\pi)$ [8%]	8%	
Relative uncertainty in $\mathcal{B}(B \to D_s + ...)$ [16%]	5%	
Relative uncertainty in $\mathcal{B}(B \to \tau + ...)$ [11%]	3%	
Uncertainty in f (B/D ratio) [11%]	3%	
Uncertainty on D^+ as a source of τ [100%]	3%	
Uncertainty on B_s as a source of τ [100%]	4%	
Uncertainty in number of events triggered by trimuon trigger [8%]	2%	
Uncertainty in the ratio of acceptances $\mathcal{A}_{sig}/\mathcal{A}_{2\mu\pi}$ [1%]	1%	
Muon reconstruction efficiency [1.5%]	1.5%	
Charged pion reconstruction efficiency [2.3%]	2.3%	
BDT cut efficiency [5%]	5%	
Mass scale uncertainty [0.07%]	–	yes
Mass resolution uncertainty [2.5%]	–	yes

$$\mathrm{B}^{+} \rightarrow \mathrm{K}^{+}\mu^{+}\mu^{-}$$

Dimuon invariant mass spectrum

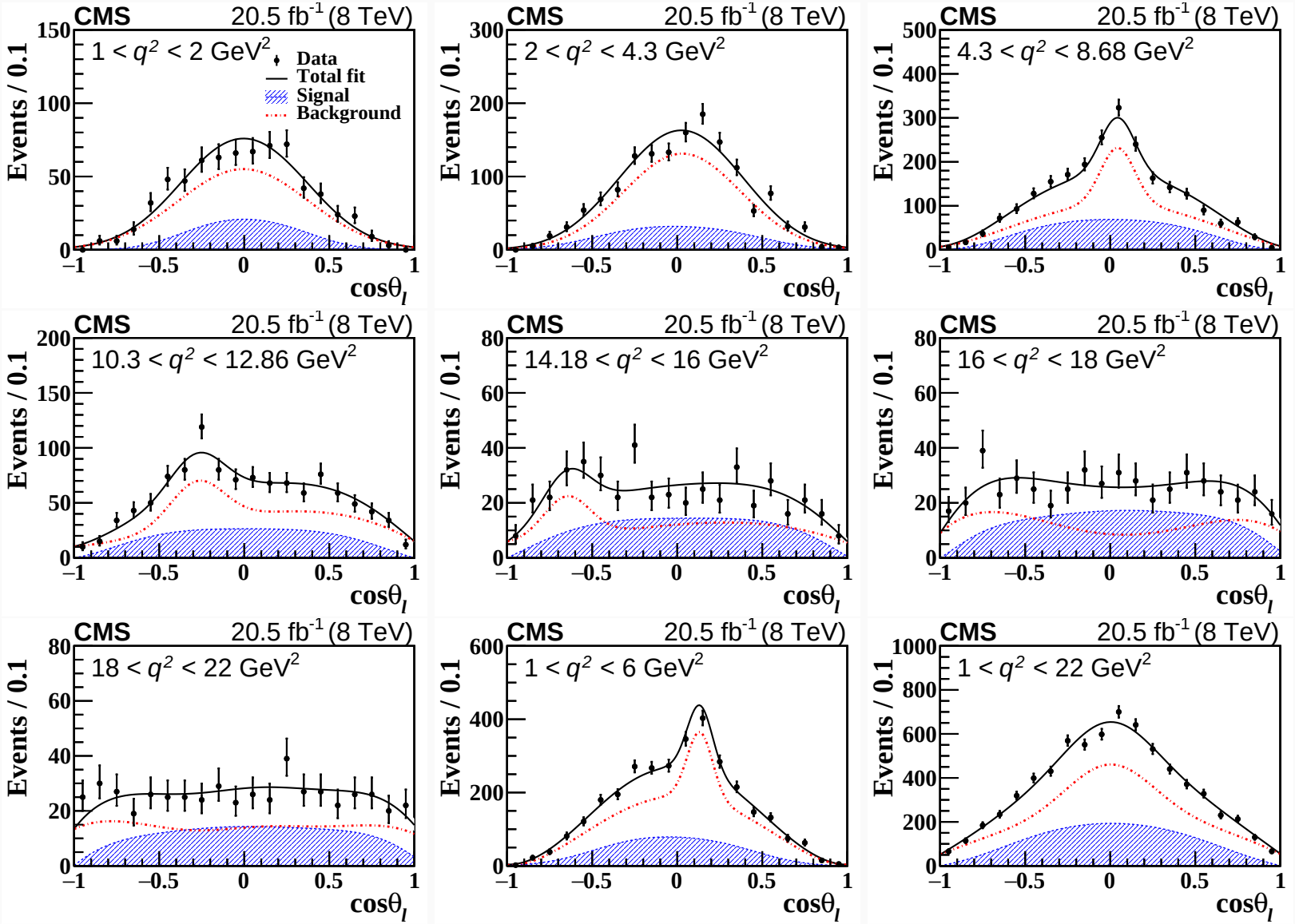


Results: $K^+\mu^+\mu^-$ invariant mass distribution



Signal → shaded area, background → dash–dotted line.

Results: $\cos\theta_\ell$ distribution



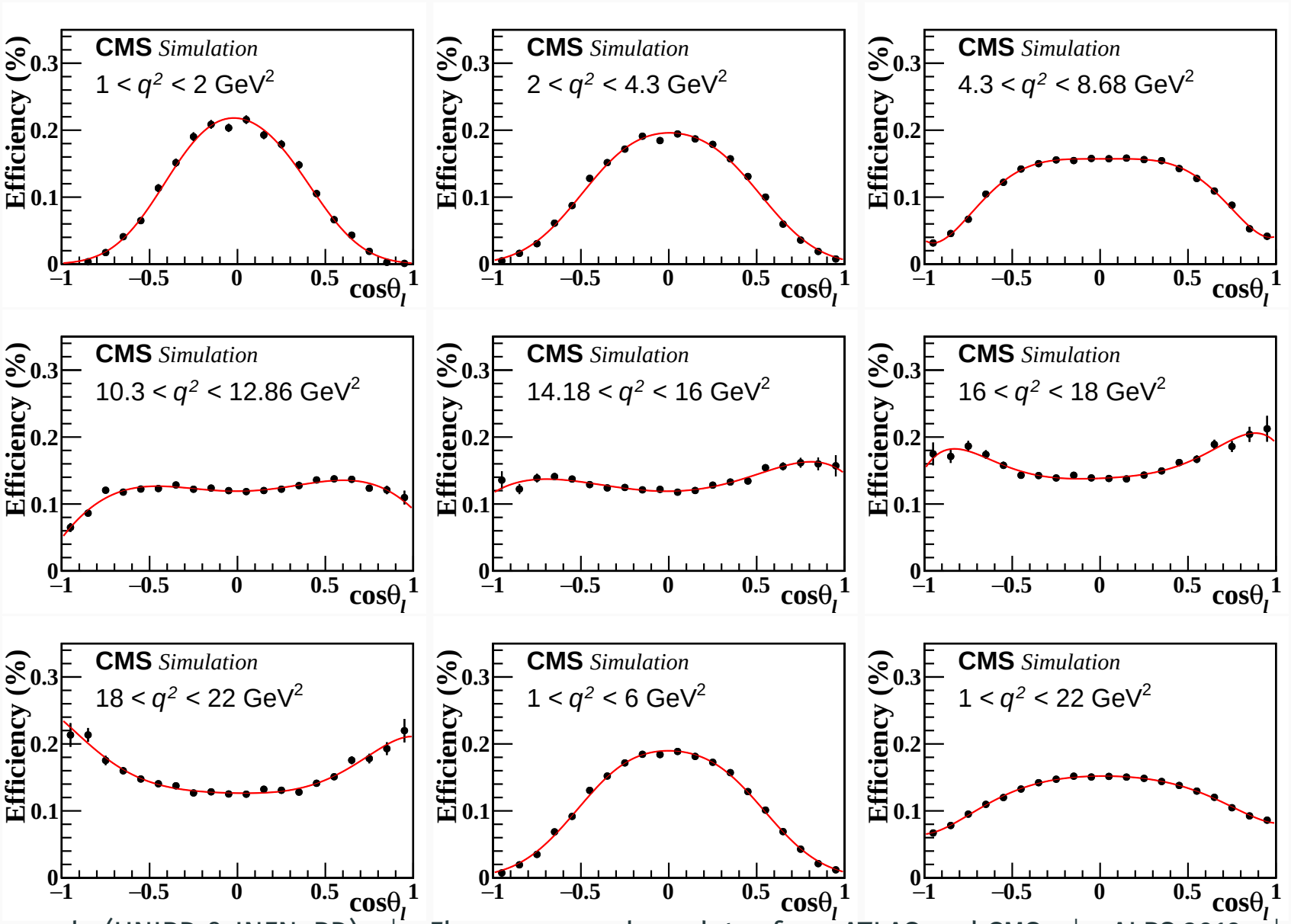
Signal → shaded area, background → dash–dotted line.

Fit pdf

$$\text{pdf}(m, \cos\theta_\ell) = Y_S S_m(m) S_a(\cos\theta_\ell)\epsilon(\cos\theta_\ell) + Y_B B_m(m) B_a(\cos\theta_\ell) \quad (4)$$

- free parameters: Y_S, Y_B, A_{FB}, F_{H}

Efficiency ($\mathcal{A} \sim 2 - 4\%$, reco $\sim 4 - 7\%$)



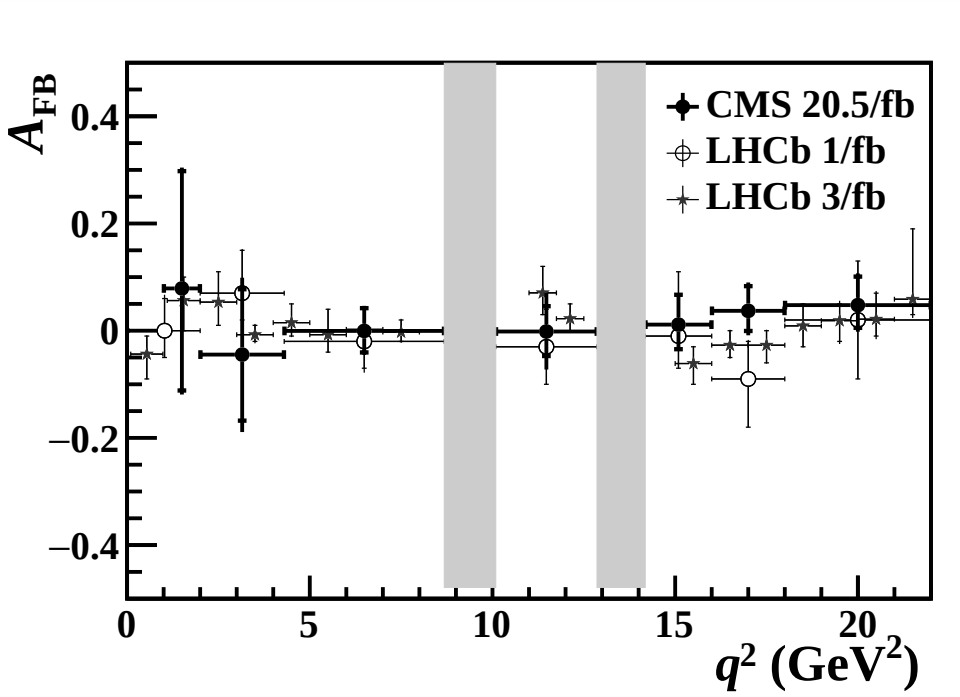
Systematics uncertainties

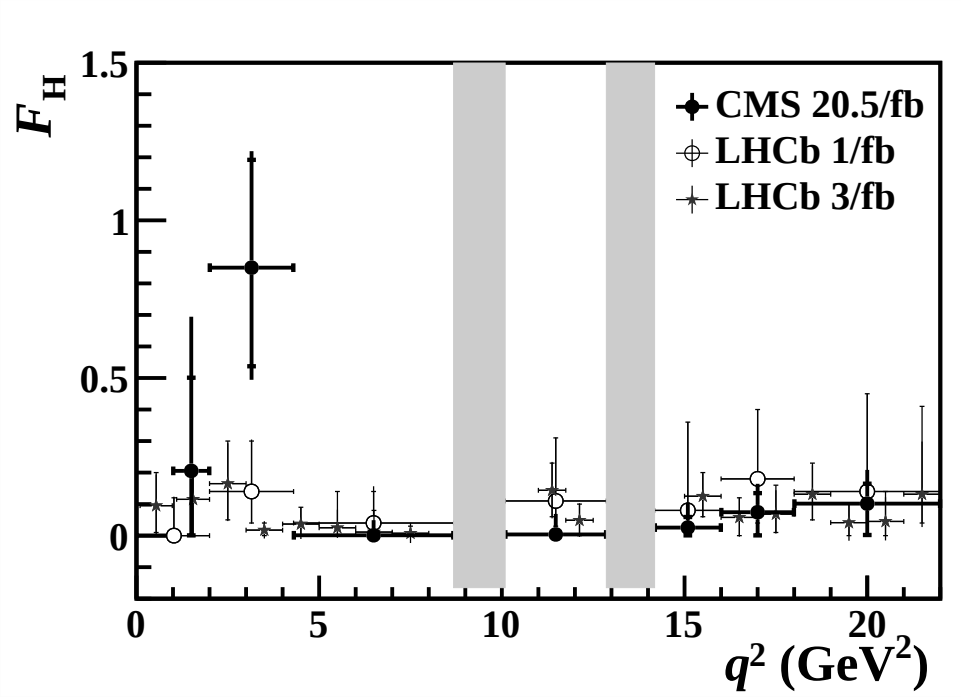
Systematic uncertainty	A_{FB} $(\times 10^{-2})$	F_H $(\times 10^{-2})$
Finite size of MC samples	0.4–1.8	0.9–5.0
Efficiency description	0.1–1.5	0.1–7.8
Simulation mismodeling	0.1–2.8	0.1–1.4
Background parametrization model	0.1–1.0	0.1–5.1
Angular resolution	0.1–1.7	0.1–3.3
Dimuon mass resolution	0.1–1.0	0.1–1.5
Fitting procedure	0.1–3.2	0.4–25
Background distribution	0.1–7.2	0.1–29
Total systematic uncertainty	1.6–7.5	4.4–39

Results

q^2 (GeV^2)	Y_S	A_{FB}	F_H	F_H(EOS)	F_H(DHMV)	F_H(FLAVIO)
1.00–2.00	169 ± 22	$0.08\ ^{+0.22}_{-0.19} \pm 0.05$	$0.21\ ^{+0.29}_{-0.21} \pm 0.39$	0.047	0.046	0.045
2.00–4.30	331 ± 32	$-0.04\ ^{+0.12}_{-0.12} \pm 0.07$	$0.85\ ^{+0.34}_{-0.31} \pm 0.14$	0.024	0.023	0.022
4.30–8.68	785 ± 42	$0.00\ ^{+0.04}_{-0.04} \pm 0.02$	$0.01\ ^{+0.02}_{-0.01} \pm 0.04$	—	0.012	0.011
10.09–12.86	365 ± 29	$0.00\ ^{+0.05}_{-0.05} \pm 0.05$	$0.01\ ^{+0.02}_{-0.01} \pm 0.06$	—	—	—
14.18–16.00	215 ± 19	$0.01\ ^{+0.06}_{-0.05} \pm 0.02$	$0.03\ ^{+0.03}_{-0.03} \pm 0.07$	0.007	0.007	0.006
16.00–18.00	262 ± 21	$0.04\ ^{+0.05}_{-0.04} \pm 0.03$	$0.07\ ^{+0.06}_{-0.07} \pm 0.07$	0.007	0.007	0.006
18.00–22.00	226 ± 20	$0.05\ ^{+0.05}_{-0.04} \pm 0.02$	$0.10\ ^{+0.06}_{-0.10} \pm 0.09$	0.008	0.009	0.008
1.00–6.00	778 ± 47	$-0.14\ ^{+0.07}_{-0.06} \pm 0.03$	$0.38\ ^{+0.17}_{-0.21} \pm 0.09$	0.025	0.025	0.020
1.00–22.00	2286 ± 73	$0.00\ ^{+0.02}_{-0.02} \pm 0.03$	$0.01\ ^{+0.01}_{-0.01} \pm 0.06$	—	—	—

Comparison with LHCb





$$\mathrm{B}^0 \to \mathrm{K}^{*0}\mu^+\mu^-$$

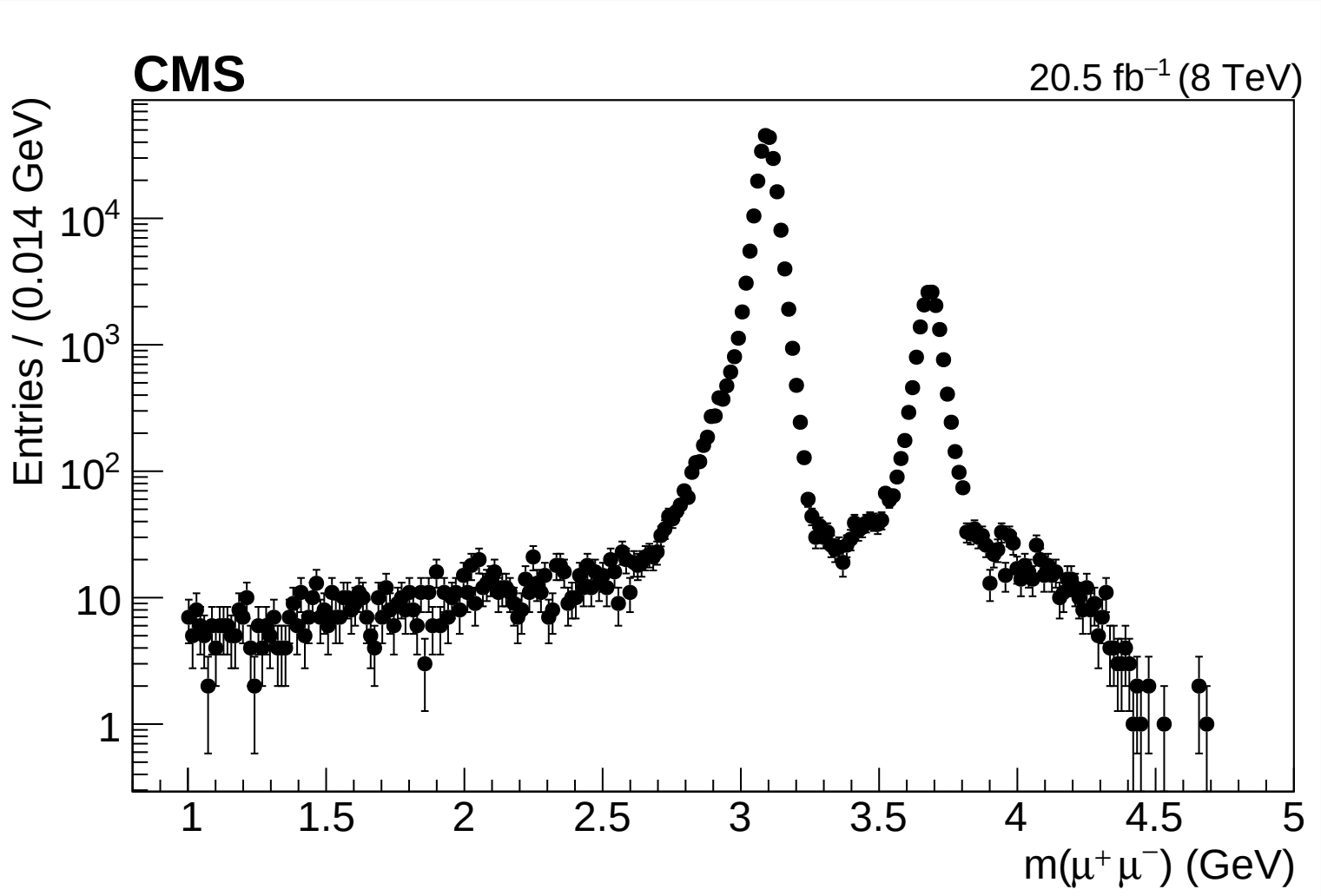
ATLAS: systematics uncertainties

Source	F_L	S_3	S_4	S_5	S_7	S_8
Combinatoric $K\pi$ (fake K^*) background	0.03	0.03	0.05	0.04	0.06	0.16
D and B^+ veto	0.11	0.04	0.05	0.04	0.01	0.06
Background pdf shape	0.04	0.04	0.03	0.03	0.03	0.01
Acceptance function	0.01	0.01	0.07	0.01	0.01	0.01
Partially reconstructed decay background	0.03	0.05	0.02	0.08	0.05	0.06
Alignment and B field calibration	0.02	0.04	0.05	0.04	0.04	0.04
Fit bias	0.01	0.01	0.02	0.03	0.01	0.05
Data/MC differences for p_T	0.02	0.02	0.01	0.01	0.01	0.01
S-wave	0.01	0.01	0.01	0.01	0.01	0.03
Nuisance parameters	0.01	0.01	0.01	0.01	0.01	0.01
Λ_b, B^+ and B_s background	0.01	0.01	0.01	0.01	0.01	0.01
Misreconstructed signal	0.01	0.01	0.01	0.01	0.01	0.01
Dilution	–	–	-	< 0.01	–	< 0.01

ATLAS: complete results

q^2 [GeV^2]	P_1	P'_4	P'_5	P'_6	P'_8
[0.04, 2.0]	$-0.05 \pm 0.30 \pm 0.08$	$0.31 \pm 0.40 \pm 0.20$	$0.67 \pm 0.26 \pm 0.16$	$-0.18 \pm 0.21 \pm 0.04$	$-0.29 \pm 0.48 \pm 0.18$
[2.0, 4.0]	$-0.78 \pm 0.51 \pm 0.34$	$-0.76 \pm 0.31 \pm 0.21$	$-0.33 \pm 0.31 \pm 0.13$	$0.31 \pm 0.28 \pm 0.19$	$1.07 \pm 0.41 \pm 0.39$
[4.0, 6.0]	$0.14 \pm 0.43 \pm 0.26$	$0.64 \pm 0.33 \pm 0.18$	$0.26 \pm 0.35 \pm 0.18$	$0.06 \pm 0.27 \pm 0.13$	$-0.24 \pm 0.42 \pm 0.09$
[0.04, 4.0]	$-0.22 \pm 0.26 \pm 0.16$	$-0.30 \pm 0.24 \pm 0.17$	$0.32 \pm 0.21 \pm 0.11$	$0.01 \pm 0.17 \pm 0.10$	$0.38 \pm 0.33 \pm 0.24$
[1.1, 6.0]	$-0.17 \pm 0.31 \pm 0.13$	$0.05 \pm 0.22 \pm 0.14$	$0.01 \pm 0.21 \pm 0.08$	$0.03 \pm 0.17 \pm 0.12$	$0.23 \pm 0.28 \pm 0.20$
[0.04, 6.0]	$-0.15 \pm 0.23 \pm 0.10$	$0.05 \pm 0.20 \pm 0.14$	$0.27 \pm 0.19 \pm 0.06$	$0.03 \pm 0.15 \pm 0.10$	$0.14 \pm 0.27 \pm 0.17$

CMS: dimuon invariant mass spectrum



CMS: systematics uncertainties

Source	$P_1 (\times 10^{-3})$	$P_5' (\times 10^{-3})$
Simulation mismodeling	1–33	10–23
Fit bias	5–78	10–120
Finite size of simulated samples	29–73	31–110
Efficiency	17–100	5–65
Kπ mistagging	8–110	6–66
Background distribution	12–70	10–51
Mass distribution	12	19
Feed-through background	4–12	3–24
F_L, F_S, A_S uncertainty propagation	0–210	0–210
Angular resolution	2–68	0.1–12
Total	100–230	70–250

CMS: complete results

q^2 (GeV^2)	Signal yield	P_1	P_5'	Correlations
1.00–2.00	80 ± 12	$+0.12\ ^{+0.46}_{-0.47} \pm 0.10$	$+0.10\ ^{+0.32}_{-0.31} \pm 0.07$	-0.0526
2.00–4.30	145 ± 16	$-0.69\ ^{+0.58}_{-0.27} \pm 0.23$	$-0.57\ ^{+0.34}_{-0.31} \pm 0.18$	-0.0452
4.30–6.00	119 ± 14	$+0.53\ ^{+0.24}_{-0.33} \pm 0.19$	$-0.96\ ^{+0.22}_{-0.21} \pm 0.25$	$+0.4715$
6.00–8.68	247 ± 21	$-0.47\ ^{+0.27}_{-0.23} \pm 0.15$	$-0.64\ ^{+0.15}_{-0.19} \pm 0.13$	$+0.0761$
10.09–12.86	354 ± 23	$-0.53\ ^{+0.20}_{-0.14} \pm 0.15$	$-0.69\ ^{+0.11}_{-0.14} \pm 0.13$	$+0.6077$
14.18–16.00	213 ± 17	$-0.33\ ^{+0.24}_{-0.23} \pm 0.20$	$-0.66\ ^{+0.13}_{-0.20} \pm 0.18$	$+0.4188$
16.00–19.00	239 ± 19	$-0.53 \pm 0.19 \pm 0.16$	$-0.56 \pm 0.12 \pm 0.07$	$+0.4621$