Rare B Decays at CMS

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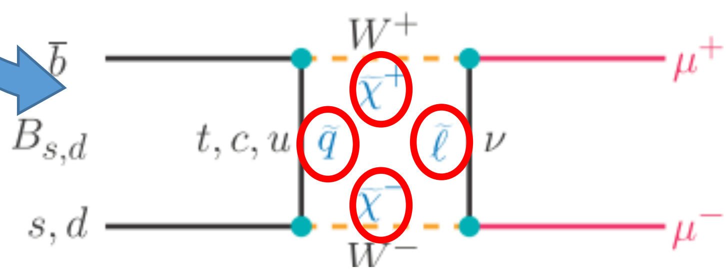
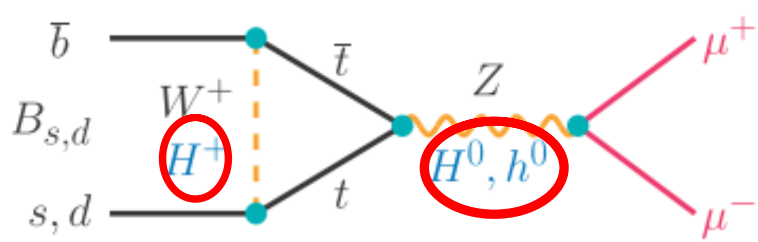
Outline

- Introduction
- Rare B-decay anomalies
- Logical possible BSM models
- CMS rare B-decay analyses
  - Angular analysis of the decay: $B^0 \to K^{*0}\mu^+\mu^-$
  - Rare decay search: $B^0_{(s,d)} \to \mu^+\mu^-$
- Summary

Introduction

- Rare decays are ideal playground for indirect searches for New Physics (NP). FCNC (Flavour-changing neutral current) transitions are forbidden at tree level in the SM, but can be described by box and penguin diagrams. BSM particles can contribute in loops processes.
- If these particles cannot be observed in the direct searches, this is the place one shall still look for!
- **Interestingly, rare B decays do show numerous intriguing anomalies.**





FCNC processes $b \to (X)\mu^+\mu^-$

- Clean experiment signature; robust theory calculation; high sensitivity.

✓ Effective theory: model independent descriptions

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{\text{tb}} V_{\text{tq}}^* \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{\text{Left handed}} + \underbrace{\mathcal{C}_i' \mathcal{O}_i'}_{\text{Right handed, } \frac{m_s}{m_b} \text{ suppressed}} + \sum \frac{c}{\Lambda_{\text{NP}}^2} \mathcal{O}_{\text{NP}}$$

$i = 1, 2$	Tree
$i = 3 - 6, 8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9, 10$	EW penguin
$i = S, P$	(Pseudo)scalar penguin

✓ Different processes have sensitivities to different operators

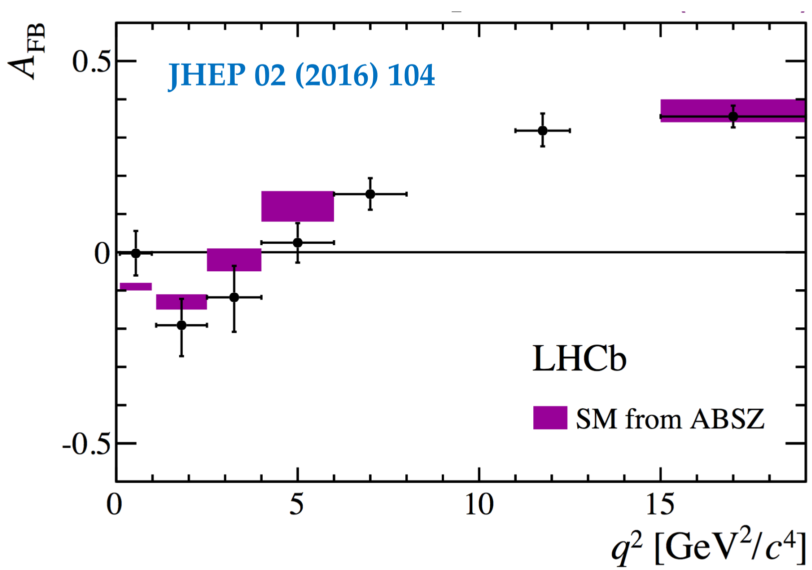
Operator $\mathcal{O}_i$	$B_{s,d} \to X_{s,d}\mu^+\mu^-$	$B_{s,d} \to \mu^+\mu^-$	$B_{s,d} \to X_{s,d}\gamma$
$\mathcal{O}_7 \sim m_b(\bar{s}_L \sigma^{\mu\nu} b_R)F_{\mu\nu}$	✓		✓
$\mathcal{O}_9 \sim (\bar{s}_L \gamma^\mu b_L)(\bar{\ell}\gamma_\mu \ell)$	✓		
$\mathcal{O}_{10} \sim (\bar{s}_L \gamma^\mu b_L)(\bar{\ell}\gamma_5\gamma_\mu \ell)$	✓	✓	
$\mathcal{O}_{S,P} \sim (\bar{s}b)_{S,P}(\bar{\ell}\ell)_{S,P}$	(✓)	✓	

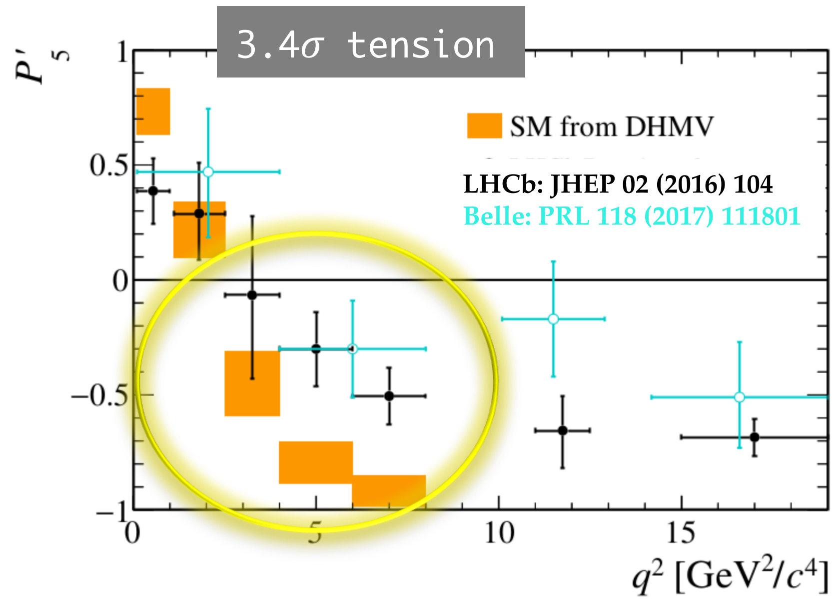
Rare B-decay anomalies : P_5'

➢ $b \to s\, \mu^+ \mu^-$ anomalies

JHEP 01 (2013) 048, JHEP 1204 (2012) 104, JHEP 01 (2009) 019

✓ $B \to K^* \mu^+ \mu^-$ angular observables, in SCET/QCD factorization can reduce to just two form-factors, can then construct ratios of observables which are independent of form-factors at LO.



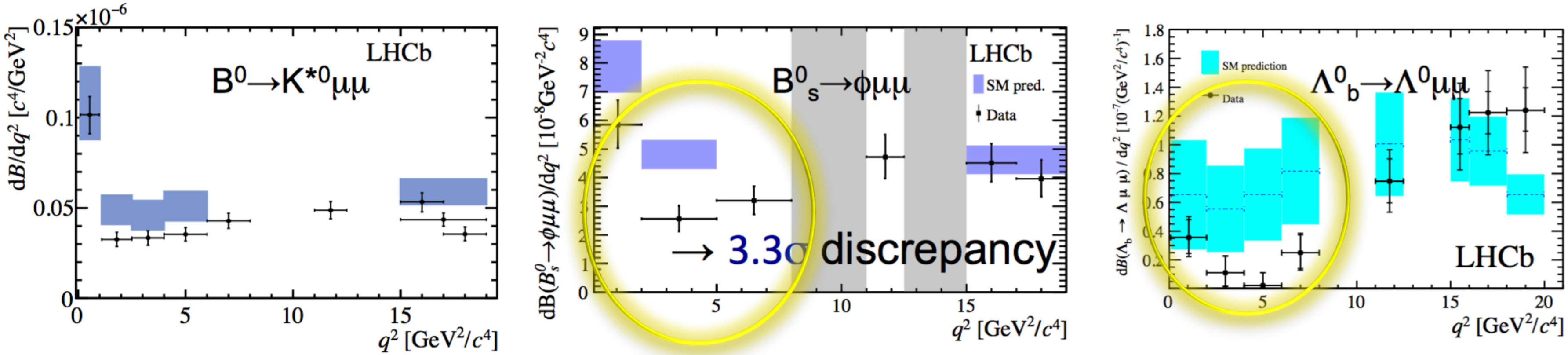


✓Form-factor dependent A_{FB} hints at a trend, but is consistent with SM.
✓Form-factor "independent" P_5' has a local discrepancy in two bins.

→ 3.4σ discrepency with the vector coupling $\Delta C_9 = -1.04 \pm 0.25$.

Rare B-decay anomalies : branching fraction

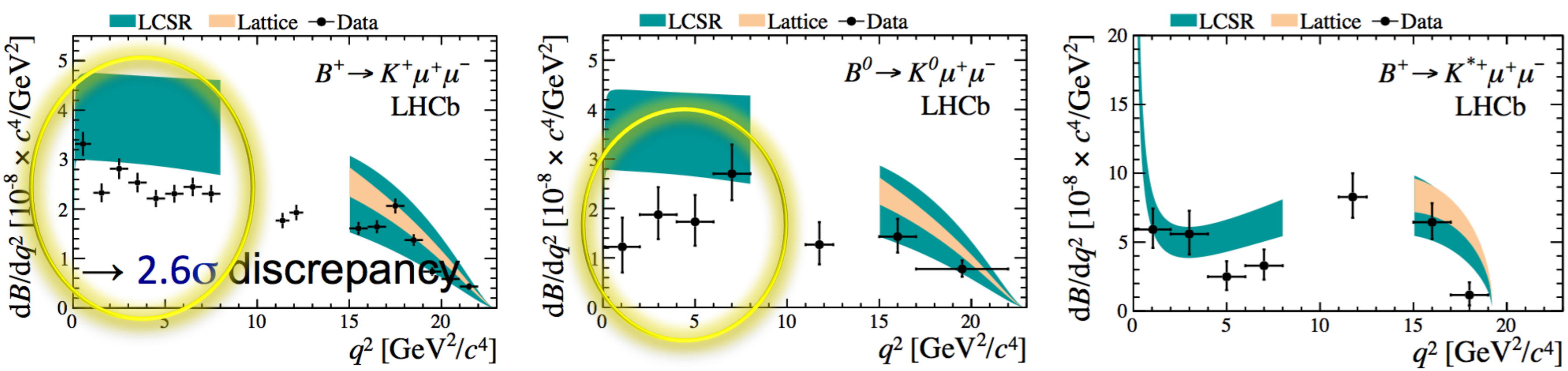
- $b \to s\,\mu^+\mu^-$ anomalies
  - ✓ Several branching fraction measured, show some tension with predictions, particularly at low q^2.



JHEP 11 (2016) 047; JHEP 04 (2017) 142

JHEP 09 (2015) 179

JHEP 06 (2015) 115



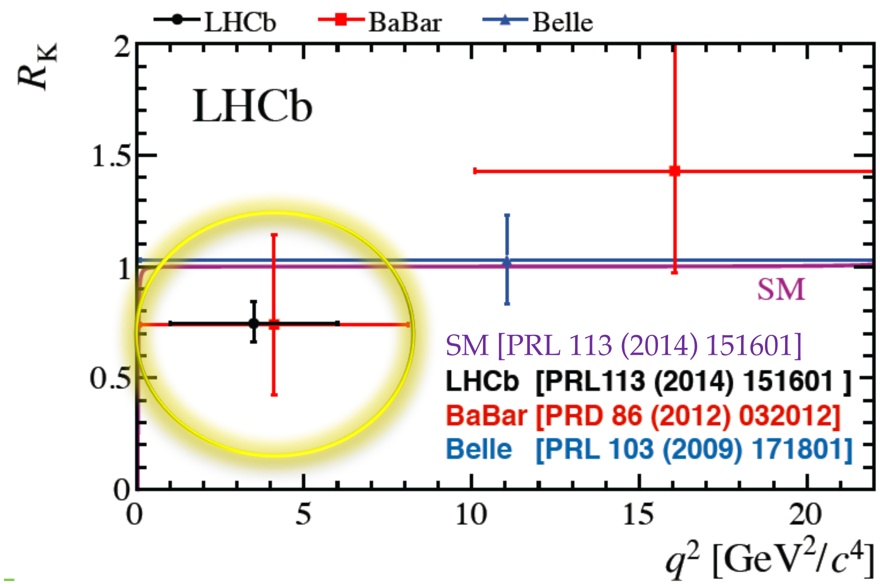
JHEP 06 (2014) 133

Rare B-decay anomalies : $R_{K^{(*0)}}$

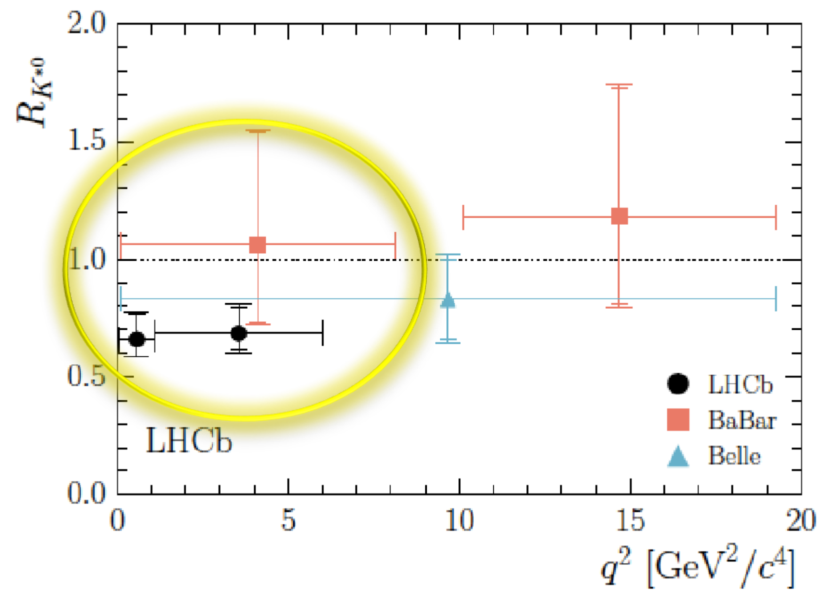
- Lepton universality with loop decays

$$\checkmark\ R_{\mathrm{K}^{(*0)}} = \frac{\mathcal{B}(\mathrm{B}\to\mathrm{K}^{(*0)}\mu^+\mu^-)}{\mathcal{B}(\mathrm{B}\to\mathrm{K}^{(*0)}J/\psi(\to\mu^+\mu^-))} \Big/ \frac{\mathcal{B}(\mathrm{B}\to\mathrm{K}^{(*0)}e^+e^-)}{\mathcal{B}(\mathrm{B}\to\mathrm{K}^{(*0)}J/\psi(\to e^+e^-))}$$

LHCb: 2.6σ tension in [1 – 6] GeV^2 bin



LHCb:
2.1-2.3σ tension in [0.045 – 1.1] GeV^2;
2.4-2.5σ tension in [1.1 – 6] GeV^2 bins.



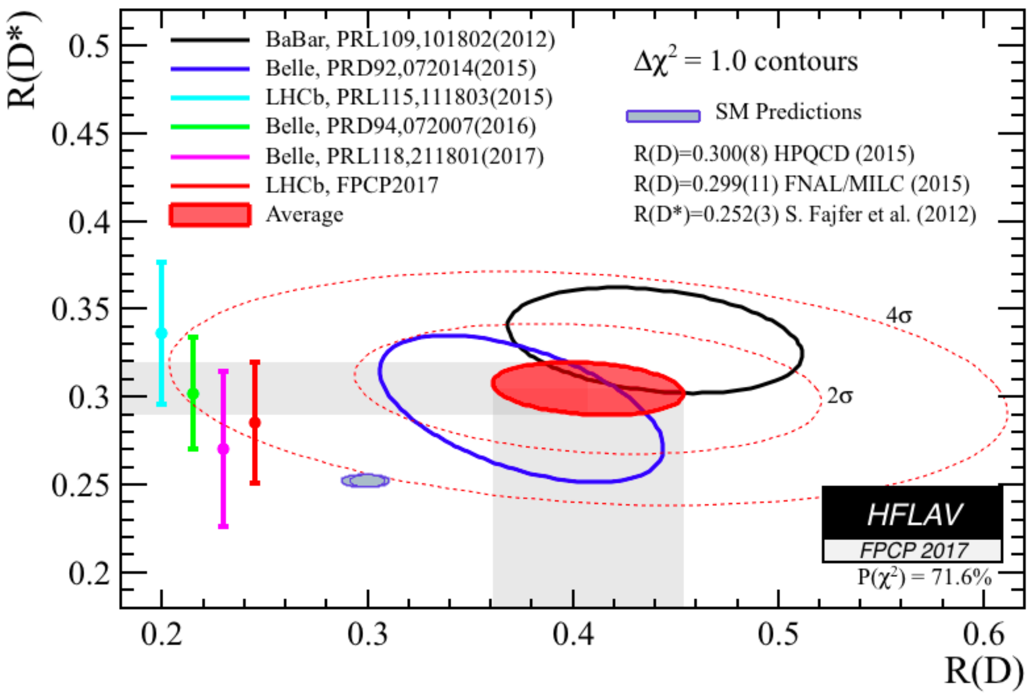
LHCb [JHEP 08 (2017) 055]
BaBar [PRD 86 (2012) 032012]
Belle [PRL 103 (2009) 171801]

Rare B-decay anomalies : $R_{D^{(*)}}$

➢ Lepton universality with tree decays

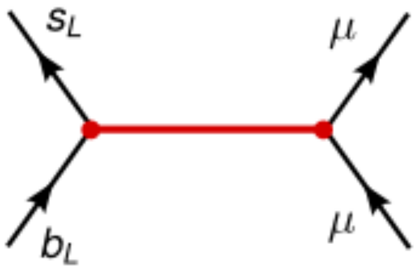
✓ $R_{\mathrm{D}^{(*)}} = \frac{\mathcal{B}(\mathrm{B}\to\mathrm{D}^{(*)}\tau\nu)}{\mathcal{B}(\mathrm{B}\to\mathrm{D}^{(*)}l\nu)}$ (see the talk by Guy Wormser)

HFLAV combined significance: 4.1$\boldsymbol{\sigma}$ from SM expectation.



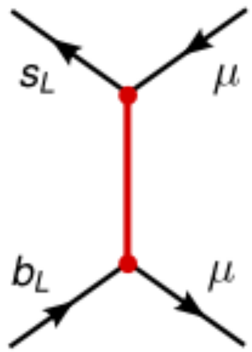
Logical possible BSM models

- Possible models to explain the anomalies:



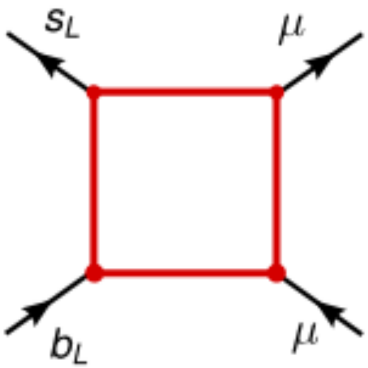
- Heavy Z' model
- $SU(2)_L$ singlet or triplet

arXiv:1403.1269, 1501.00993, 1503.03477, 1611.02703, ...



- Leptoquark model
- Spin 0 or 1

arXiv: 1511.01900, 1503.01084, 1704.05835, 1512.01560, 1511.06024, 1408.1627, ...

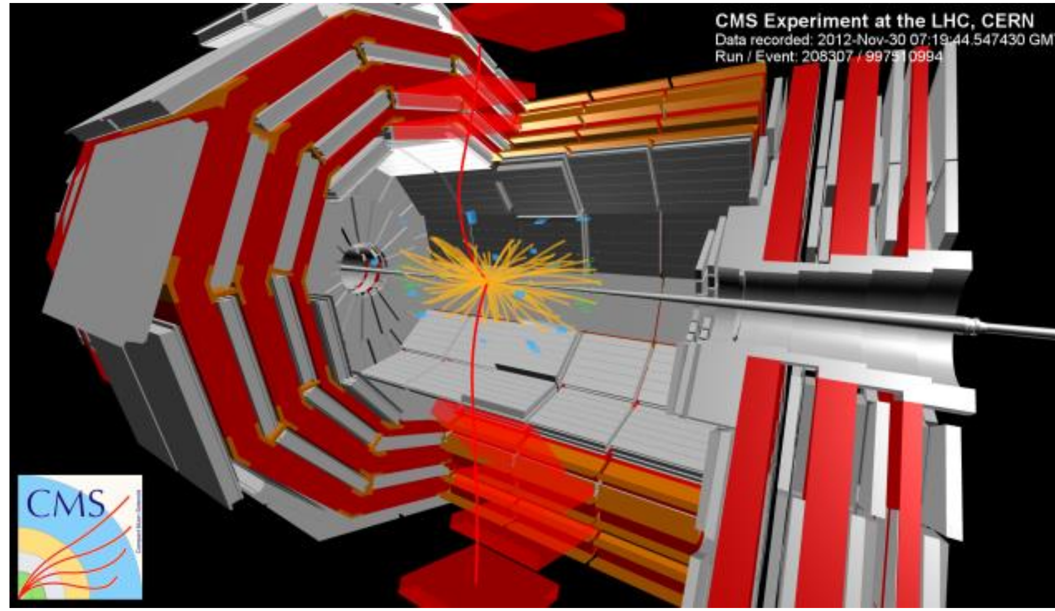


- Other new heavy scalars/vectors also leptoquarks possible

arXiv: 1509.05020, 1608.07832, 1704.05438, 1607.01659, 1704.07845, hep-ph/0610037, ...

CMS is marvelous for HF studies

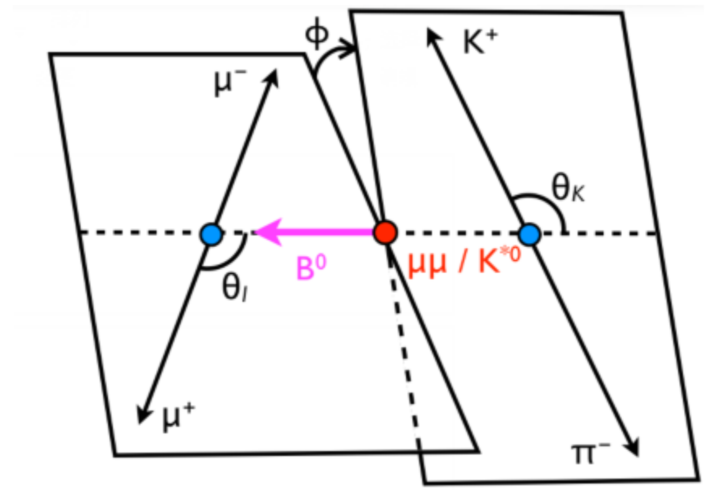
- ✓ Flexible triggers
- ✓ Large silicon tracker
- ✓ Strong magnetic field
- ✓ Broad acceptance
- ✓ Superb muon systems



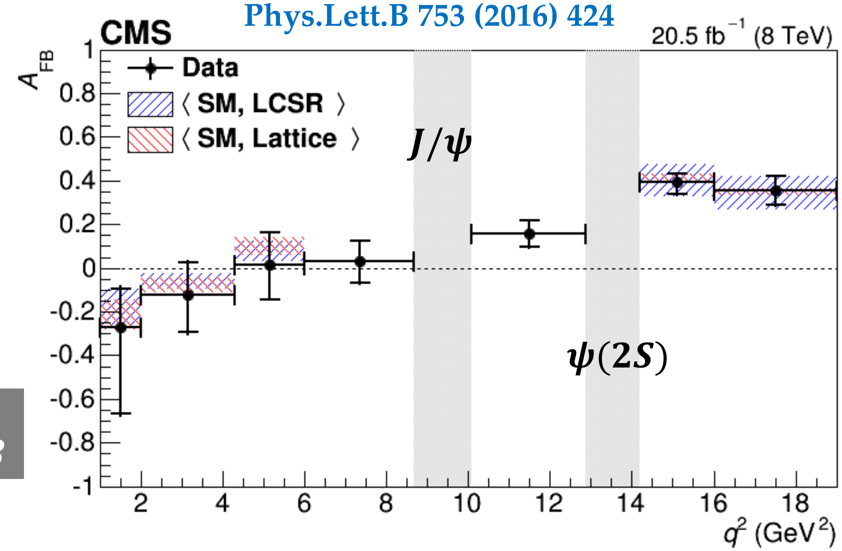
- Three different devices, coverage up to $|\eta|<2.4$
- Dimuon mass resolution ~0.6-1.5% (depending on |y|).
- Fake rate ≤0.1% for π,K; ≤0.05% for proton.

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

- ✓ The process can be fully described by the three angles (θ_l, θ_k, ϕ) and the dimuon invariant mass squared q^2.
- ✓ Robust SM calculation of several angular parameters, e.g. forward-backward asymmetry of the muons, $\mathbf{A_{FB}}$, longitudinal polarization fraction of the K^*, $\mathbf{F_L}$, $\mathbf{F_S}$, $\mathbf{A_S}$, $\mathbf{P_i}$ and $\mathbf{P_i'}$, are available for much of the phase space.
- ✓ Discrepancy of the angular parameters vs q^2 with respect to SM might be hint of NP.



Phys.Lett.B 753 (2016) 424



A_{FB}

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

- **Two channels can contribute to the final state $K^+\pi^-\mu^+\mu^-$:**

  P-wave resonant channel, $K^+\pi^-$ from the meson vector resonance K^{*0} decay;

  S-wave no-resonant channel, $K^+\pi^-$ don't come from any resonance.

- **Folding the p.d.f. around $\phi = 0$ and $\theta_l = \pi/2$.**

S-wave and S&P-wave interference

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{dq^2 d\cos\theta_l d\cos\theta_K d\phi} = \frac{9}{8\pi}\left\{\frac{2}{3}\left[(F_S + A_S\cos\theta_K)\left(1-\cos^2\theta_l\right) + A_S^5\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right] + (1-F_S)\left[2F_L\cos^2\theta_K\left(1-\cos^2\theta_l\right) + \frac{1}{2}(1-F_L)\left(1-\cos^2\theta_K\right)\left(1+\cos^2\theta_l\right) + \frac{1}{2}P_1(1-F_L)\left(1-\cos^2\theta_K\right)\left(1-\cos^2\theta_l\right)\cos 2\phi + 2P_5'\cos\theta_K\sqrt{F_L(1-F_L)}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\}$$

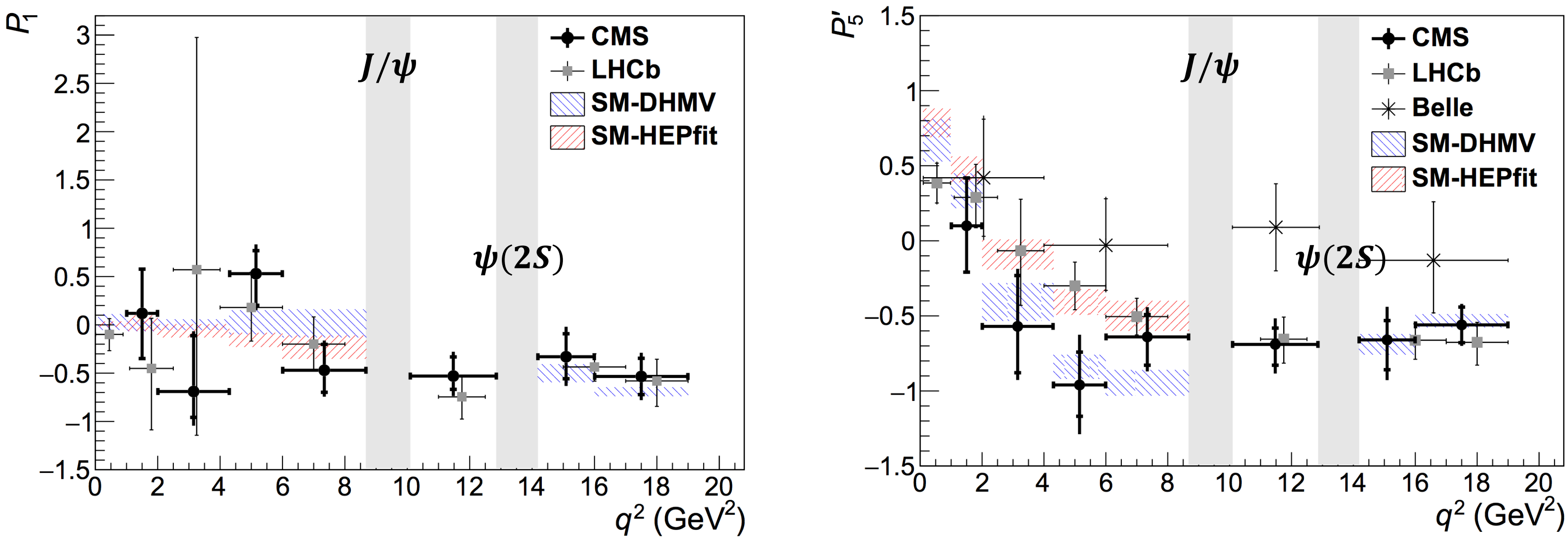
P-wave

- ✓ F_L, F_S, A_S: fixed from previous CMS measurement (Phys.Lett.B 753 (2016) 424)
- ✓ P_1, P_5': recently measured parameters
- ✓ A_S^5: nuisance parameter

Submitted to Phys. Lett. B.
arXiv:1710.02846

P_1 and P'_5 Distributions

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



- ✓ SM-DHMV is computed using soft form factors in addition with parametrised power corrections and with the hadronic charm-loop contribution derived from calculations (JHEP 01 (2013) 048, JHEP 05 (2013) 137)
- ✓ SM-HEPfit uses full QCD computation of the form factors and derives the hadronic contribution from LHCb data (JHEP 06 (2016) 116, arXiv:1611.04338)
- ✓ Both SM predictions are in agreement with the CMS experimental results, albeit CMS data are slightly more compatible with SM-DHMV, while LHCb data with SM-HEPfit.

Belle: PRL 118 (2017) 111801
LHCb: JHEP 02 (2016) 104
ATALS preliminary: ATLAS-CONF-2017-023

Submitted to Phys. Lett. B.
arXiv:1710.02846

Rare decay search: $B^0_{(s,d)} \to \mu^+\mu^-$

✓ $B^0_{(s,d)} \to \mu^+\mu^-$ decays are only proceed through FCNC processes and are highly suppressed in SM:

Loop diagram + Suppressed SM +Theoretically clean =

An excellent place to look for new physics.

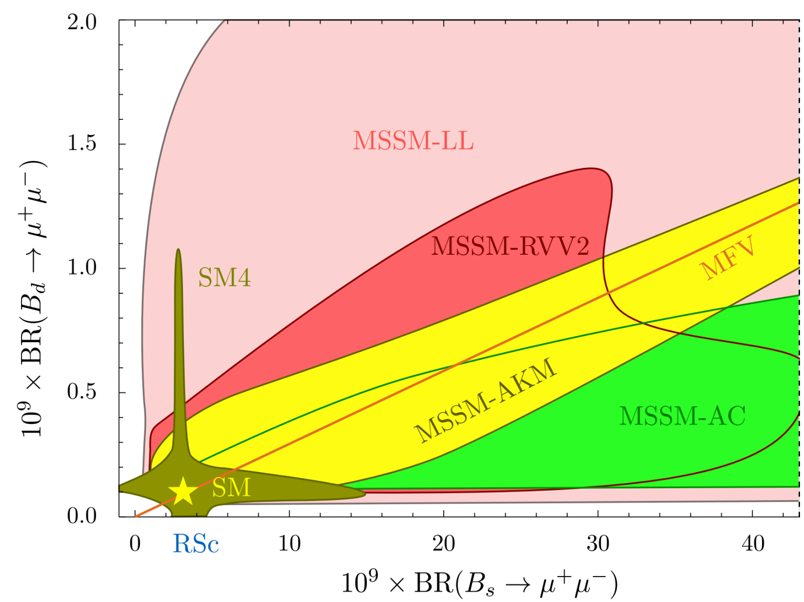
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.65 \pm 0.63)\times 10^{-9}$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) = (1.06 \pm 0.09)\times 10^{-10}$$

Ref: Bobeth et al, PRL 112, 101801 (2014)

✓ Some of the new physics scenarios may boost the $B \to \mu^+\mu^-$ decay rates by 10~20 times easily, for example:

- 2HDM: $\mathcal{B} \propto \tan^4\beta\ \&\ m(H^+)$
- MSSM: $\mathcal{B} \propto \tan^6\beta$

Ref: D. M. Straub, arXiv: 1012.3893



Reference analysis

$B^0_{(s,d)} \to \mu^+\mu^-$

✓Event classification is carried out by Boosted Decision Tree (BDT).

✓Branching fractions were extracted by unbined maximum likelihood fits in 12 categorized BDT bins.

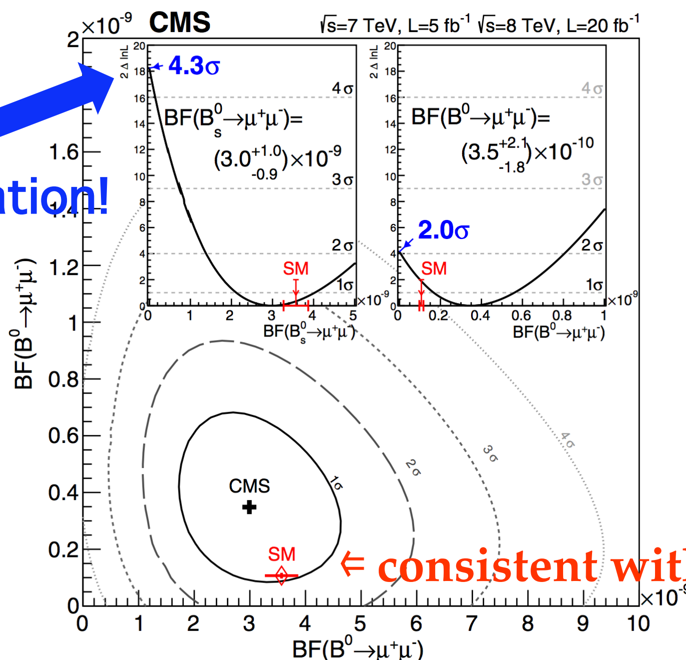
Ref. CMS PRL 111 (2013) 101804

Channel	Branching fraction
$B^0_s \to \mu^+\mu^-$	$(3.0^{+1.0}_{-0.9})\times 10^{-9}$
$B^0_d \to \mu^+\mu^-$	$< 1.1\times 10^{-9}$ @ 95% CL

Simultaneous publication with LHCb, each with > 4σ for $B^0_s \to \mu^+\mu^-$.

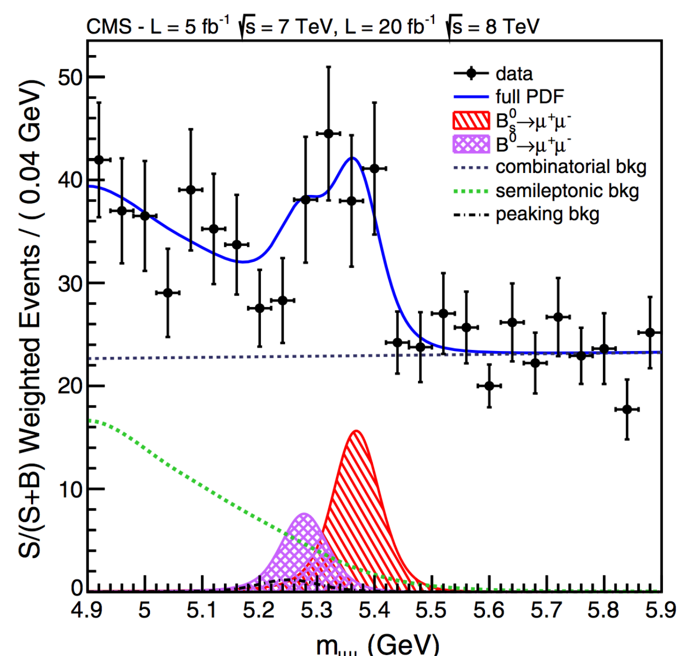
2D contour

4.3σ observation!



⇐ consistent with SM

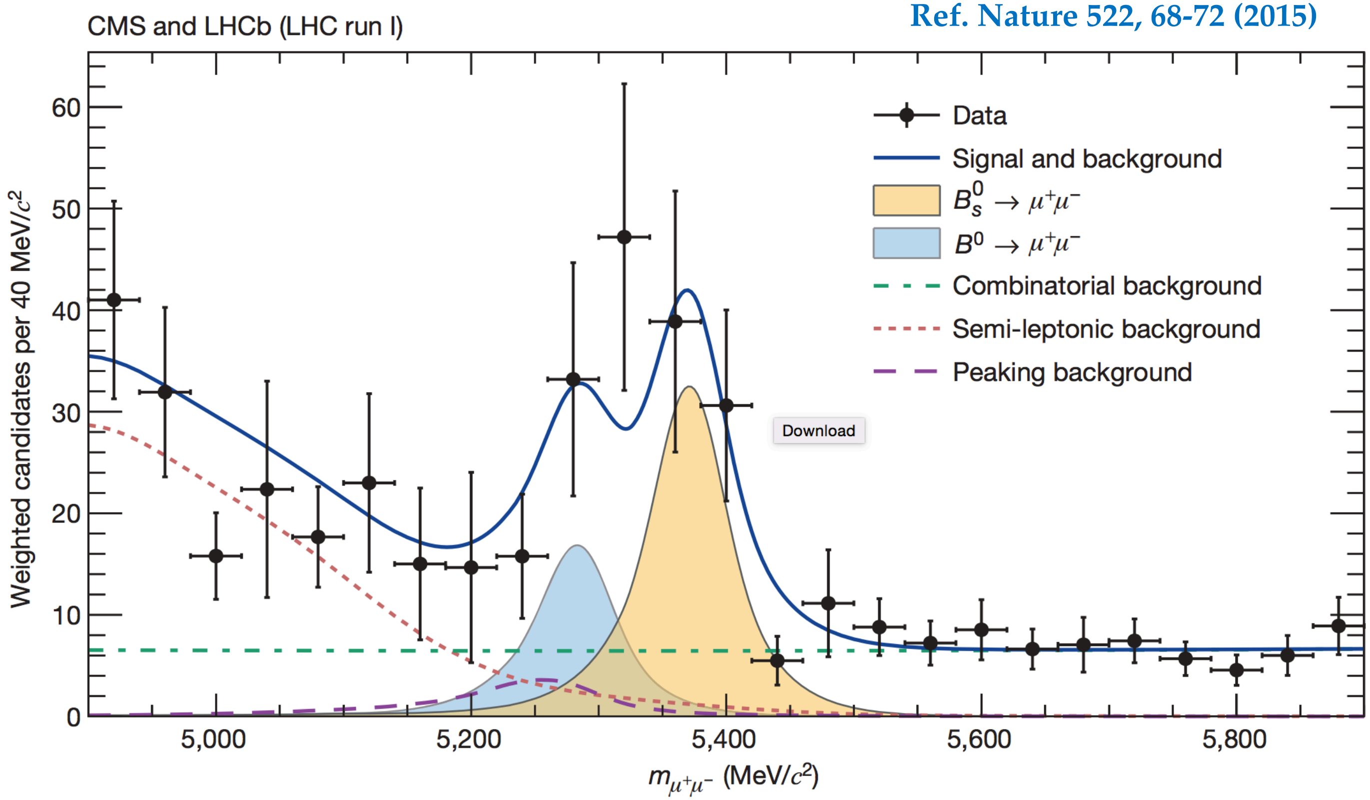
S/(S+B) weighted mass



CMS and LHCb combination

$B^0_{(s,d)} \to \mu^+\mu^-$

Ref. Nature 522, 68-72 (2015)



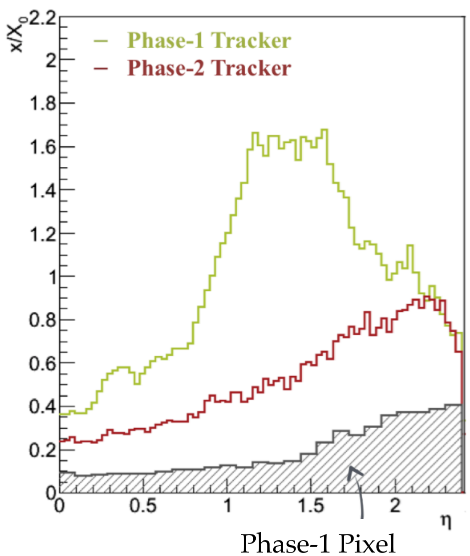
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.8^{+0.7}_{-0.6})\times10^{-9} \quad (6.2\sigma \text{ significance})$$

$$\mathcal{B}(B^0_d \to \mu^+\mu^-) = (3.9^{+1.6}_{-1.4})\times10^{-10} \quad (3.0\sigma \text{ significance})$$

CMS towards the future

$B^0_{(s,d)} \to \mu^+\mu^-$

➢Scope of CMS upgrade

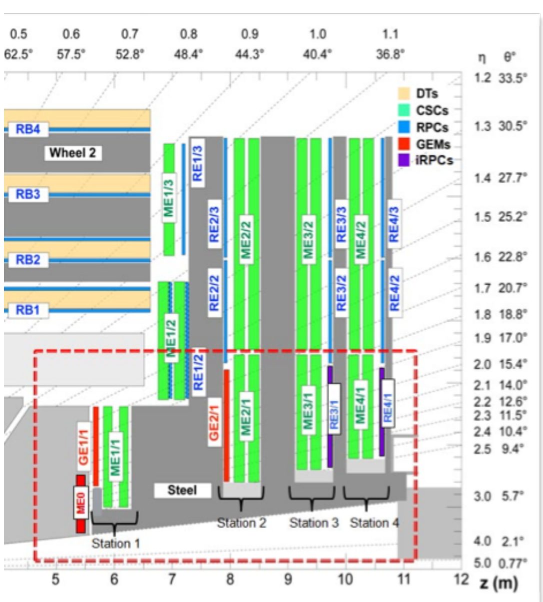


✓New tracker system

- Feature 4 pixel barrel layers and 5 disks on the endcaps with half of the material budget in the central region.
- Combined with a smaller silicon sensors pitch, the momentum resolution will be improved, and help to **separate B^0_d and B^0_s signals**.

✓Forward muon system

- provide coverage up to $\eta = 3$ or more.



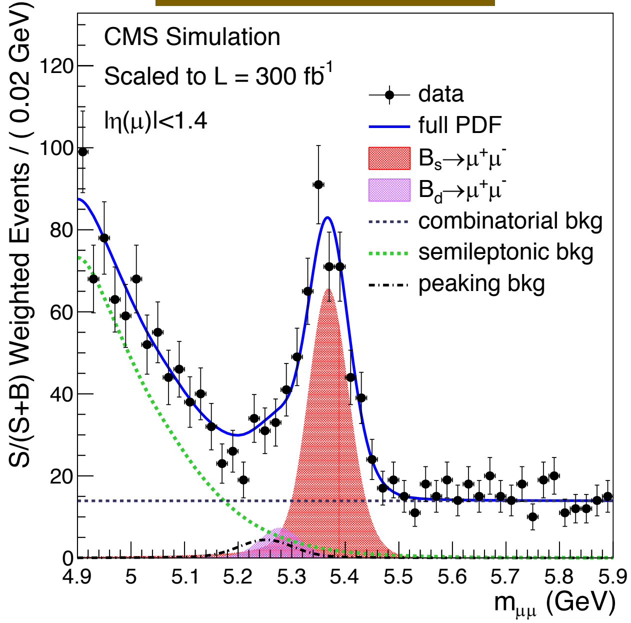
✓Enhanced L1 trigger

- Extended trigger capabilities for the muon system with improved coverage in the forward direction.

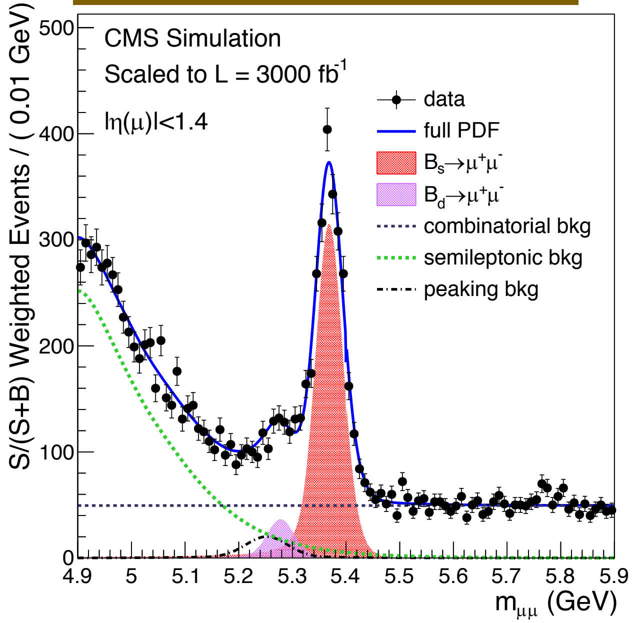
CMS towards the future

➢Results

300 fb^{-1}, barrel only



3000 fb^{-1}, w/ improved tracker



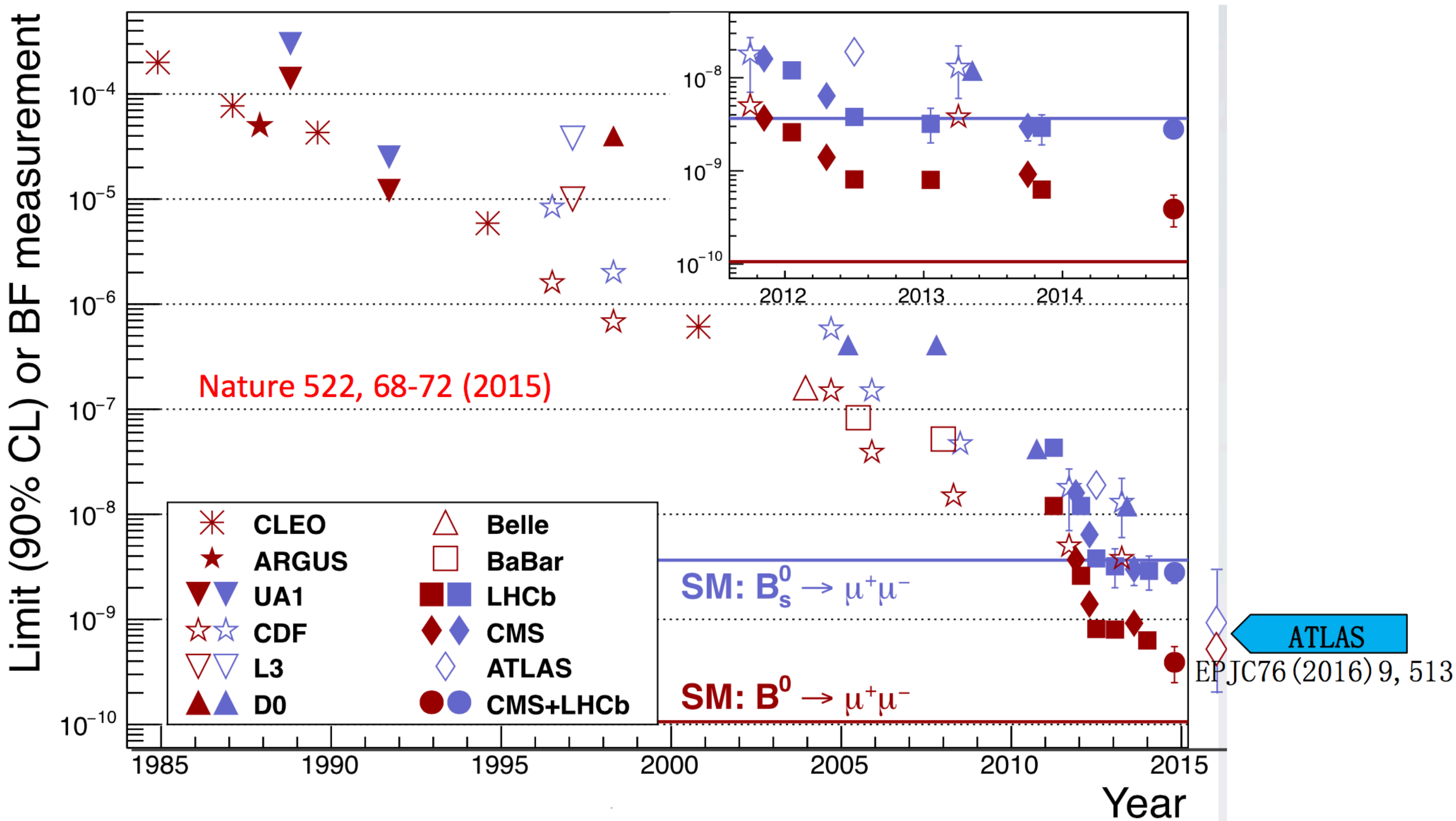
Toy data assumed a strong BDT requirement.

$L(fb^{-1})$	$\delta\mathcal{B}(B^0_s \to \mu^+\mu^-)$	$\delta\mathcal{B}(B^0_d \to \mu^+\mu^-)$	B^0_d significance	$\delta[\mathcal{B}(B^0_d)/\mathcal{B}(B^0_s)]$
100	14%	63%	$0.6 - 2.5\sigma$	66%
300	12%	41%	$1.5 - 3.5\sigma$	43%
300 (barrel)	13%	48%	$1.2 - 3.3\sigma$	50%
3000 (barrel)	11%	18%	$5.6 - 8.0\sigma$	21%

Ref. CMS-PAS-FTR-14-015

30 years of searching

$B^0_{(s,d)} \to \mu^+\mu^-$



Summary

- CMS has carried out angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$, and will keep searching the rare decays: $B^0_{(s,d)} \to \mu^+\mu^-$. The measurement of P_1 and P_5' show no significant deviations from SM.

- CMS is an ideal environment to study rare B-decays, some other rare decays analyses on going: $B^+ \to K^+\mu^+\mu^-$, $B^+ \to K^{*+}\mu^+\mu^-$, $B^0_s \to \phi\mu^+\mu^-$, etc.

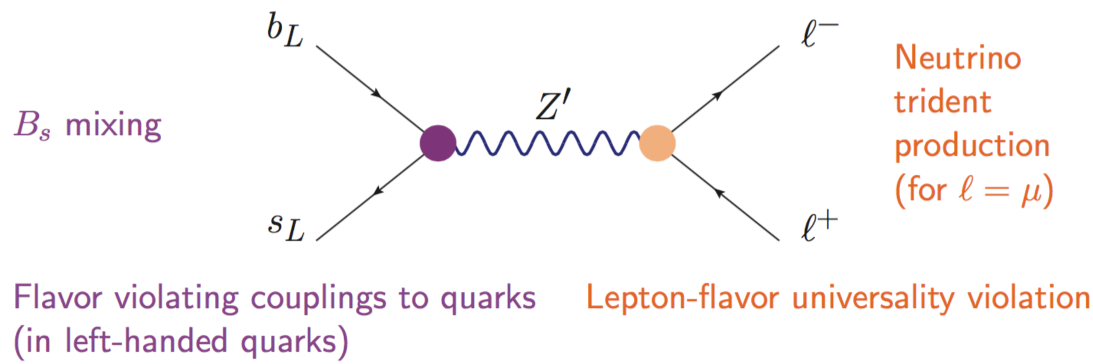
- Interesting set of anomalies observed in B decays – given experimental precision and theoretical uncertainties, none of them are yet compelling IMHO.

- More data and future theoretical developments will clarify these anomalies.

Additional Materials

Z' model

$$G \equiv SU(3)_c \times SU(2)_L \times U(1)_Y \times G_E$$



- $SU(2)_L$ singlet case: $G_E \equiv U(1)', U(1)' \times U(1)''$
- $SU(2)_L$ triplet case: $G_E \equiv SU(2)'$
- Extra requirements: extended scalar sector to give mass to the Z' and/or to accommodate quark masses and mixing angles

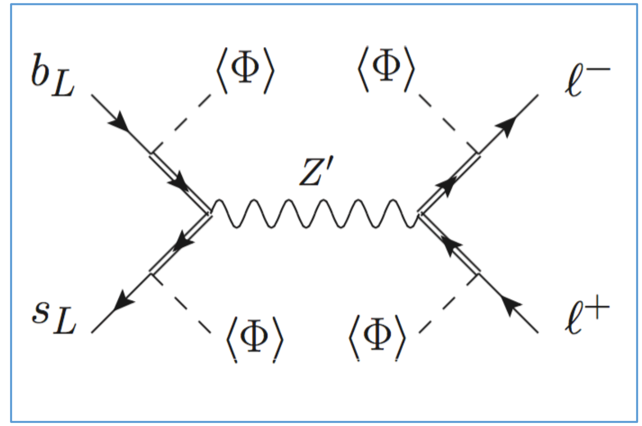
Models with an extra $SU(2)'$

- **The triplet operator $O_{lq}^{(3)}$ can provide a simultaneous explanation to the $b \to s l^+ l^-$ and $R_{D^{(*)}}$ anomalies.** arXiv:1505.05164, 1702.07238
- Dynamical $SU(2)'$ model arXiv:1506.01705
- Ultraviolet complete $SU(2)'$ model arXiv:1604.03088, 1608.01349
    - $SU(2)_1 \times SU(2)_2 \times U(1)_Y$
    - Non-universality induced through mixing with VL fermions

Z' model

$U(1)'$ models with vector-like fermions:

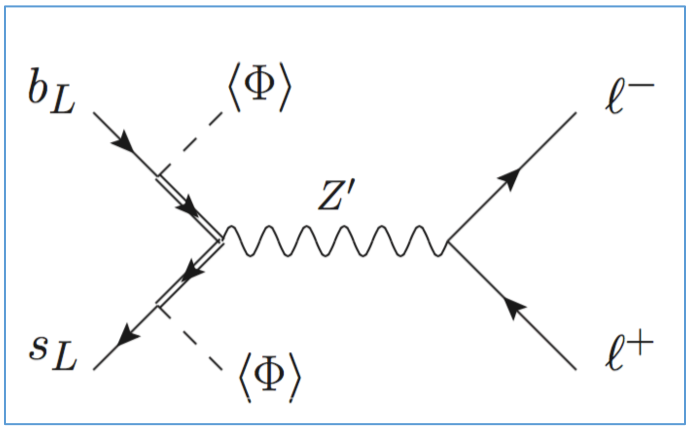
arXiv:1503.06077



- Extended the SM with an extra gauged dark $U(1)_X$
- Add heavy vector-like fermions charged under $U(1)_X$
- SM-VL mixing includes effective SM Z' couplings

✓ Interesting interplay with DM, very general framework;

❑ The mixing parameters are ad hoc, lack of predictability, the SM-VL mixings are unknown.



arXiv:1403.1269, 1501.00993

- Gauge the $U(1)_{L_\mu - L_\tau}$ sysmetry
- Automatically anomaly-free with the SM alone
- Good zeroth order approximation to neutrino mixing with quasi-degenerate masses
- SM-LV mixing includes effective SM Z' couplings with quarks

✓ Prediction in lepton sector, interesting interplay with DM;

❑ The mixing parameters are ad hoc, lack of predictability in the quark sector.

Leptoquark models

Spin	G	Name	Topology	$R_{D^{(*)}}$?	
0	$(\bar{3},1)_{1/3}$	S_1	□	✓	Bauer and Neubert 1511.01900
0	$(\bar{3},3)_{1/3}$	S_3	🌲	✓	Medeiros Varzielas and Hiller 1503.01084
1	$(3,2)_{7/6}$	R_2	□		Bečirević and Sumensari 1704.05835
1	$(3,1)_{2/3}$	U_1	🌲	✓	Barbieri et al. 1512.01560
1	$(3,3)_{2/3}$	U_3	🌲	✓	Fajfer and Košnik 1511.06024

- S_1 & S_3 can have problematic B-violating coupling
- All 5 models predict $C_9^{\mu} = -C_{10}^{\mu}$
- U_1 can additionally generate $C_9^{\prime\mu} = C_{10}^{\prime\mu}$

arXiv: 1511.01900, 1503.01084, 1704.05835, 1512.01560, 1511.06024, 1408.1627, 1412.1791, …

➢LQ models exist that are able to explain $R_{K^{(*0)}}$, $R_{D^{(*)}}$ and $(g-2)_{\mu}$

PRL 116 (2016) 141802

Other loop (box) models

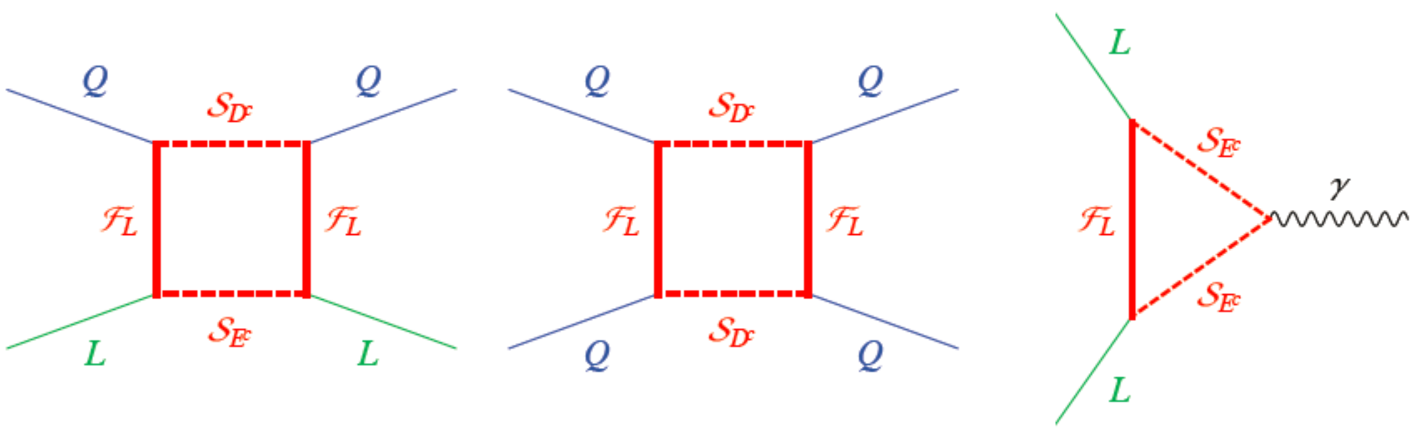
- New scalars and vector-like fermions

  Interesting point: ΔM_s always enhanced except with Majorana fermions

arXiv: 1509.05020, 1608.07832
hep-ph/0610037

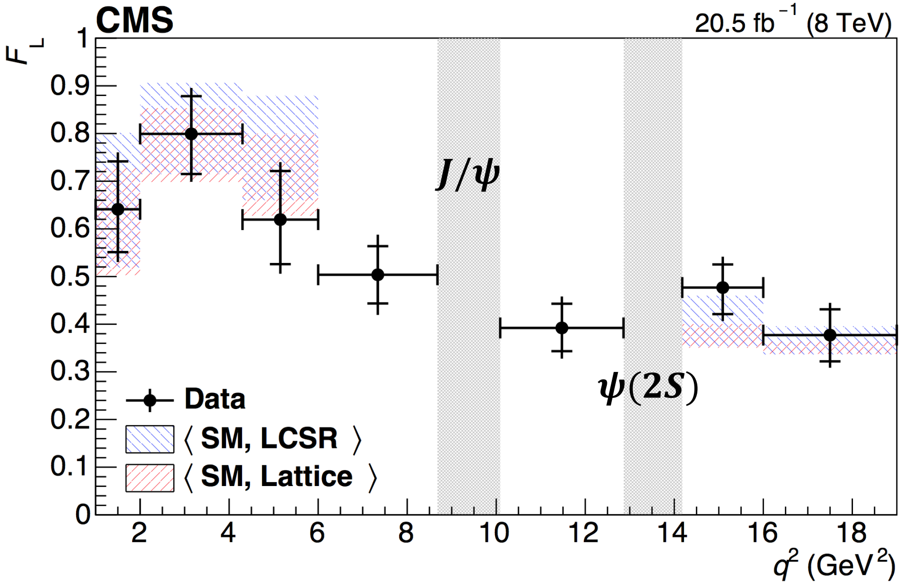
- Fundamental partial compositeness

arXiv: 1704.05438, 1607.01659, 1704.07845

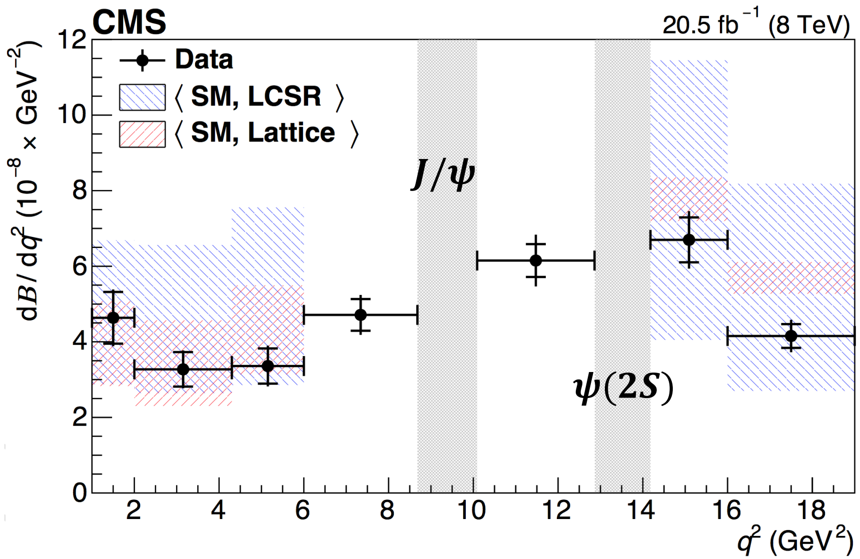


Angular analysis: $B^0 \to K^{*0}\mu^+\mu^-$

F_L



branching fraction



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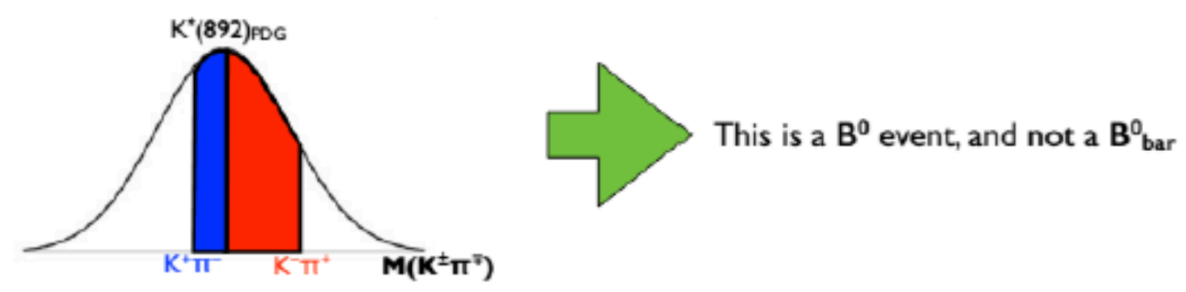
CP tagging

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

- Compute the invariant mass assigning to track-1 the mass of the Kaon and to track-2 the mass of the pion
- Compute the invariant mass assigning to track-1 the mass of the pion and to track-2 the mass of the Kaon
- The closer mass to the K* - PDG mass defines whether it’ s a B0 or a B0_bar

An example:



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p.d.f and Efficiency

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

➢ The probability density function and efficiency

$$\text{p.d.f.}(m,\theta_K,\theta_l,\Phi) = Y_S^C \Big[S^C(m)\, S^a(\theta_K,\theta_l,\phi)\, \epsilon^C(\theta_K,\theta_l,\phi)$$ Correctly tagged events

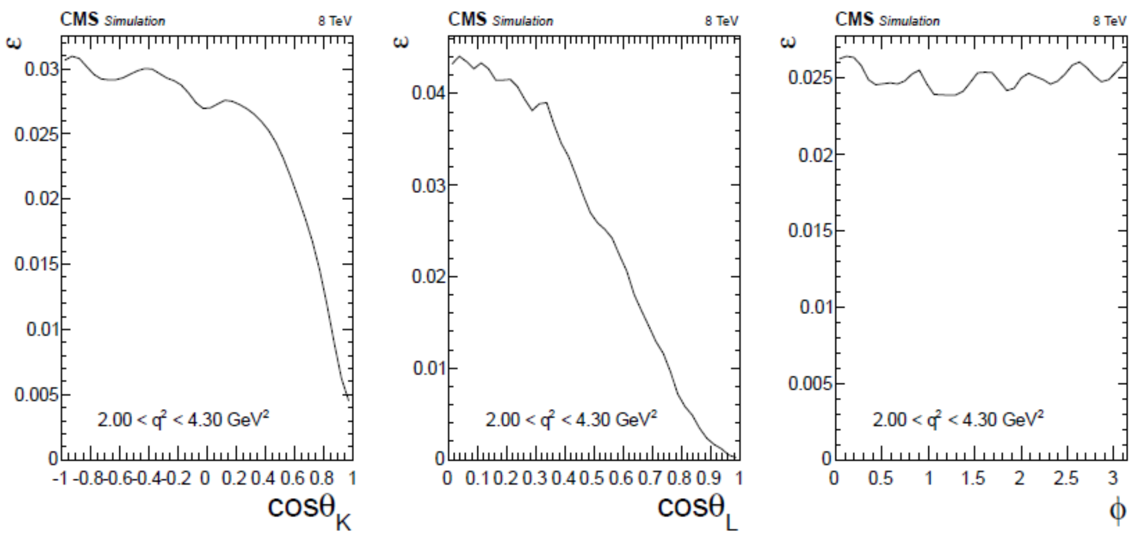
Mistag fraction → f^M

$$+ \frac{f^M}{1-f^M} S^M(m)\, S^a(-\theta_K,-\theta_l,\phi)\, \epsilon^M(\theta_K,\theta_l,\phi) \Big]$$ Mistagged events

$$+ Y_B\, B^m(m)\, B^{\theta_K}(\theta_K)\, B^{\theta_l}(\theta_l)\, B^{\phi}(\phi),$$ Background

- ✓ Signal contribution: mass shape (double Gaussian), decay rate, and 3D efficiency function.
- ✓ Background contribution: mass shape (exponential) and different degrees polynomial functions for each angular variable.

2nd q^2 bin
Correctly tagged events



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Fitting and Validation

➢Fitting strategy:

✓ extracted from un-binned extended maximum likelihood fit in each bin: $m(K^+\pi^-\mu^+\mu^-)$, $cos\theta_l$, $cos\theta_K$, ϕ

✓ Fit performed in two steps:

1) fit sidebands to determined background shape, fixed in the next step;

2) fit whole mass spectrum, 5 free parameters.

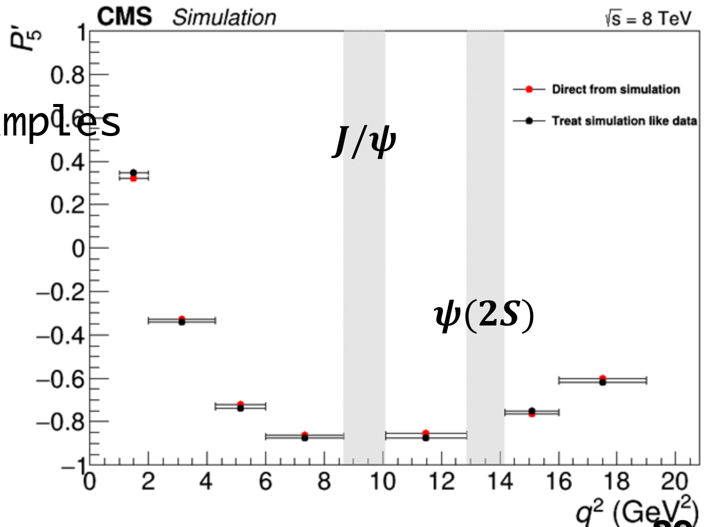
➢Validation with data control channels:

✓ Fit performed with FL free to float;

✓ FL measured agrees with PDG value.

➢Several validation steps are performed with simulation:

- with large data MC signal sample
- with 200 data-like MC signal+background samples
- with pseudo experiments



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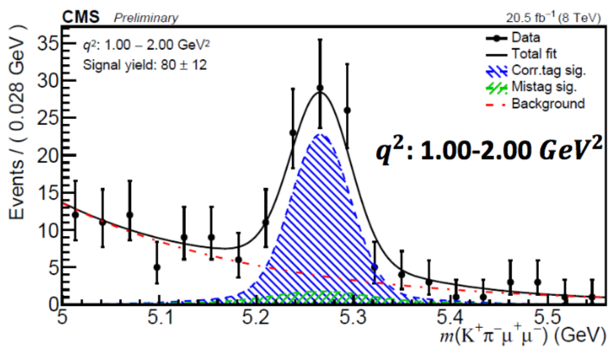
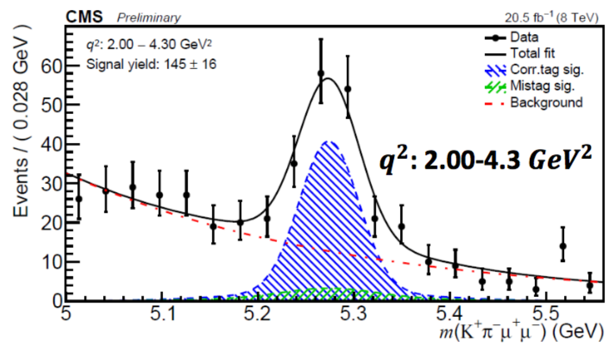
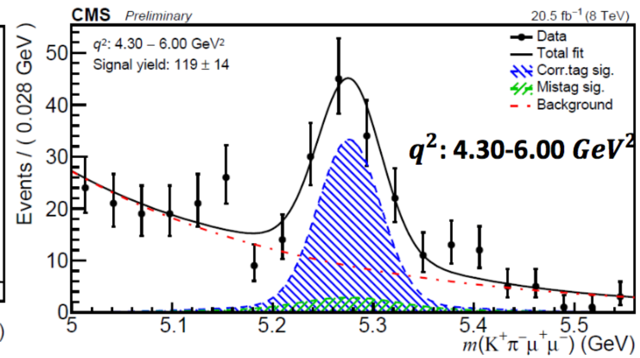
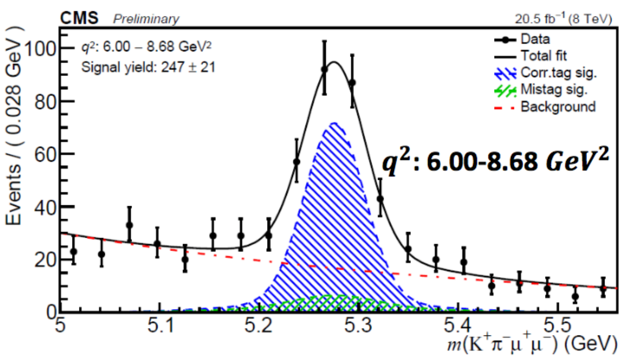
Fitting result projections

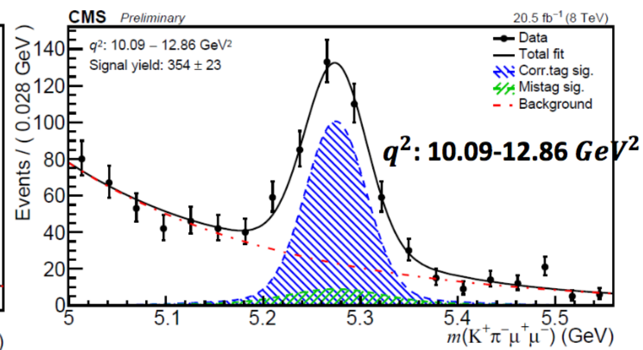
$B^0 \rightarrow K^{*0}\mu^+\mu^-$









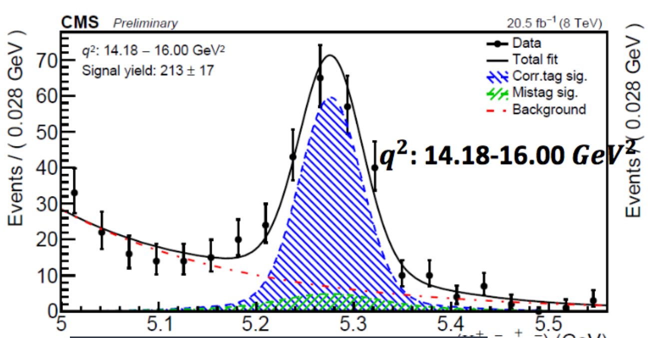


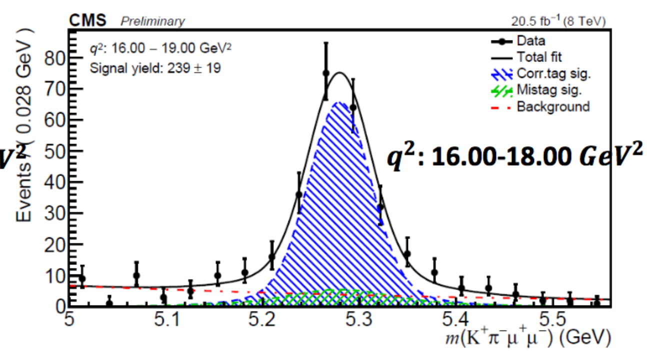
Total fit

Signal (correctly tagged)

Signal (wrongly tagged)

Background





- A total of more than 1400 signal events.
- Clear peaks in all the q^2 bins.

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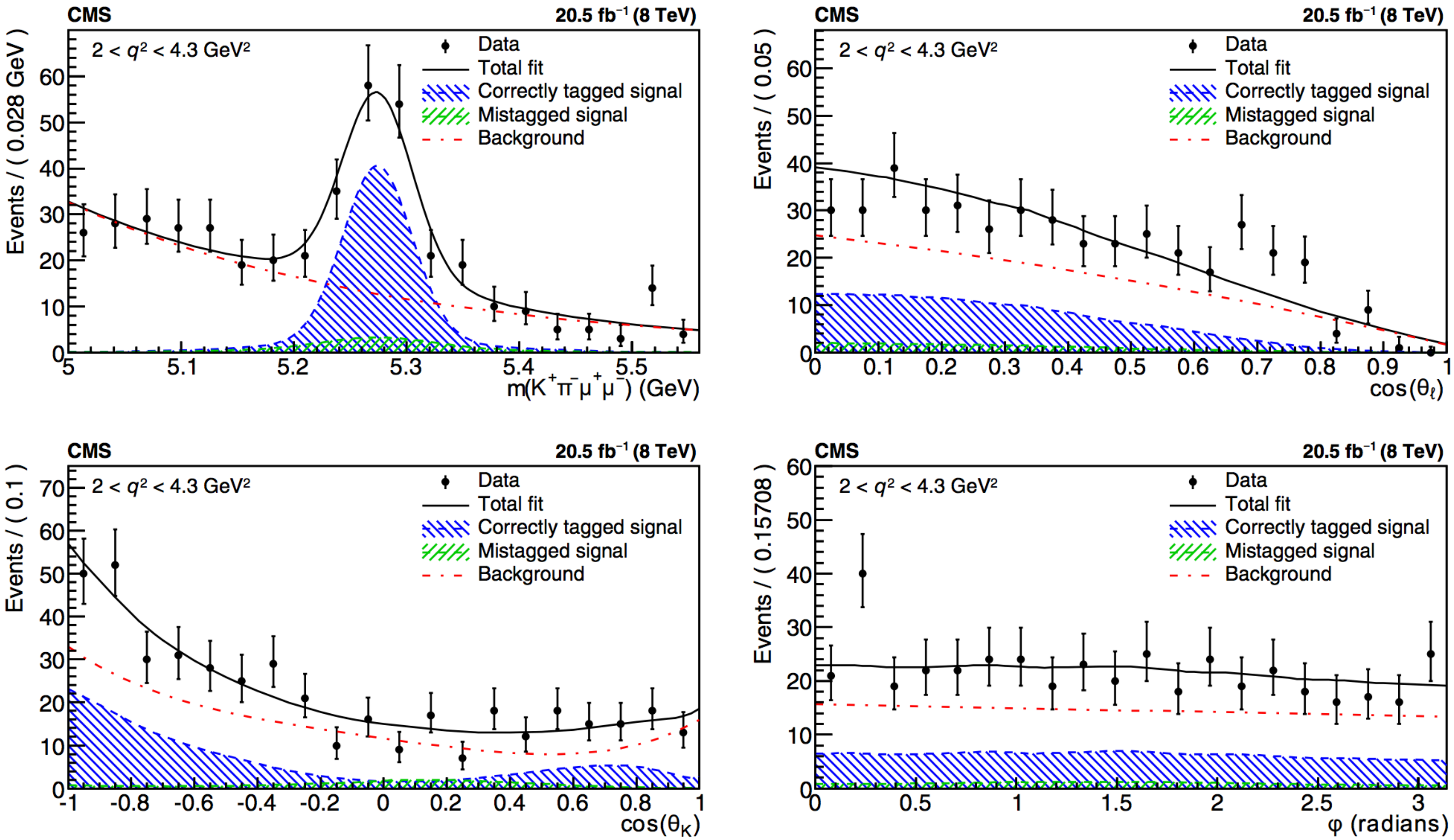
Fitting result projections

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

- 2^{nd} q^2 bin

More than 1400 signal events in total



Total fit
Signal (correctly tagged)
Signal (wrongly tagged)
Background

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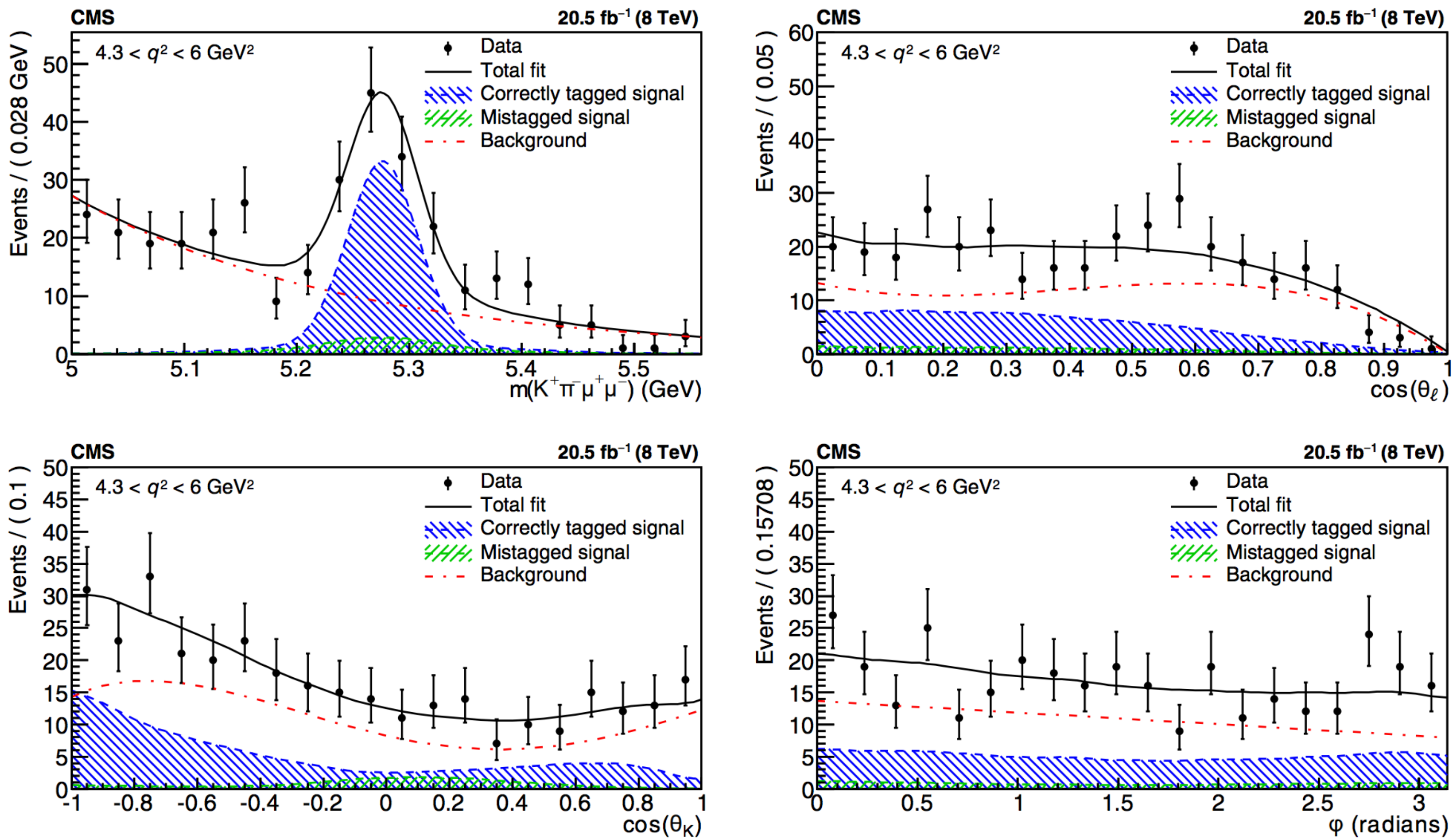
Fitting result projections

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

- 3rd q^2 bin



Total fit
Signal (correctly tagged)

Signal (wrongly tagged)
Background

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Systematic uncertainty

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

Systematic uncertainty	$P_1(10^{-3})$	$P_5'(10^{-3})$
Simulation mismodeling	1 – 33	10 – 23
Fit bias	5 – 78	10 – 119
MC statistical uncertainty	29 – 73	31 – 112
Efficiency	17 – 100	5 – 65
$K\pi$ 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 – 126	0 – 200
Angular resolution	2 – 68	0.1 – 12
Total	**60 – 220**	**70 – 230**

F_L, F_S, A_s uncertainty propagation:

- Generate a large data, $\mathcal{O}(100\times\text{data})$, pseudo experiments (one per q^2);
- Fit with all 6 angular parameters free to float;
- Fit with F_L, F_S, A_s fixed;
- Ratio of uncertainties between free and partially-fixed fit is used to compute the systematic uncertainty.

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Results

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

$q^2 (GeV^2)$	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	$-0.53 \pm 0.19 \pm 0.16$	$-0.56 \pm 0.12 \pm 0.07$	$+0.4621$

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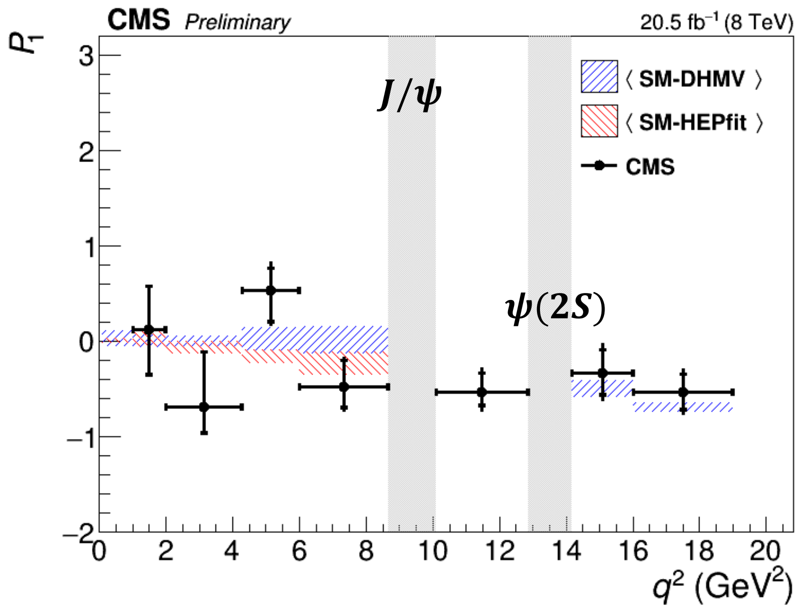
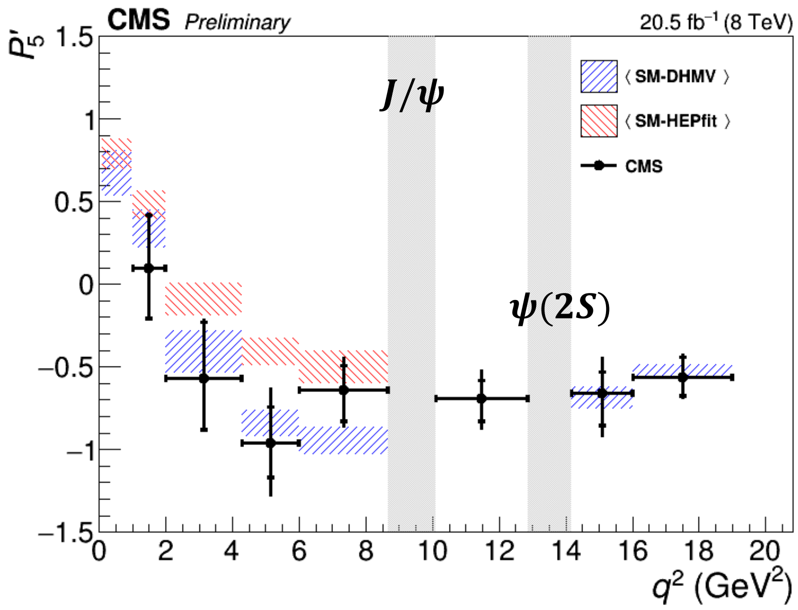
CMS Results

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





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CMS towards the future

$B^0_{(s,d)} \to \mu^+\mu^-$

➢ Analysis Assumptions

- ✓ Pseudo experiments are used to estimate the expected CMS performance in two different scenarios:
  - The Phase-1 scenario: corresponding to the expected performance of the CMS detector including LHC Run-II and Run-III, to an integrated luminosity of $300\ \mathrm{fb}^{-1}$ at 14TeV.
  - The Phase-2 upgrade scenario: corresponding to the expected performance of the CMS detector after the full Phase-2 upgrades and to a luminosity of $3000\ \mathrm{fb}^{-1}$ at 14TeV.
- ✓ GEANT4-based simulated samples are used to estimated the performance of trigger, resolution, and pile-up effect at the phase-2 running condition.
- ✓ Muon efficiency and identification are assumed to be the same as Run-I.
- ✓ Standard Model branching fractions are assumed in the study.