Electroweak penguin decays: $b \to s\, ll$

FPCP 2015, Nagoya

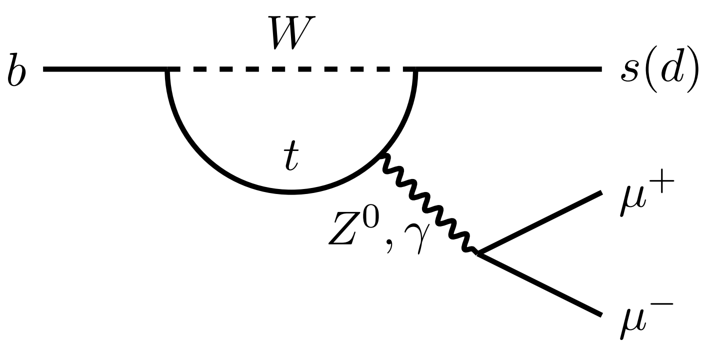
Christian Linn, CERN

on behalf of the LHCb collaboration,
including results from other experiments

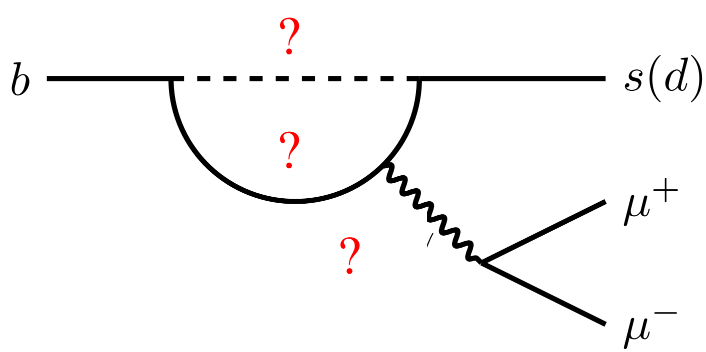
EW penguin decays

FCNC as b → sll transitions in the SM only possible via loop and box diagrams
→ highly suppressed / new particles can enter the loop and modify observables

SM



NP



b → sll decays can theoretically be described by effective hamiltonian:

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_i (C_i\mathcal{O}_i + C_i'\mathcal{O}_i')$$

left-handed part

right-handed part suppressed in SM

i=1,2	Tree
i=3-6,8	Gluon penguin
i=7	Photon penguin
i=9,10	Electroweak penguin
i=S, P	Scalar / Pseudoscalar penguin

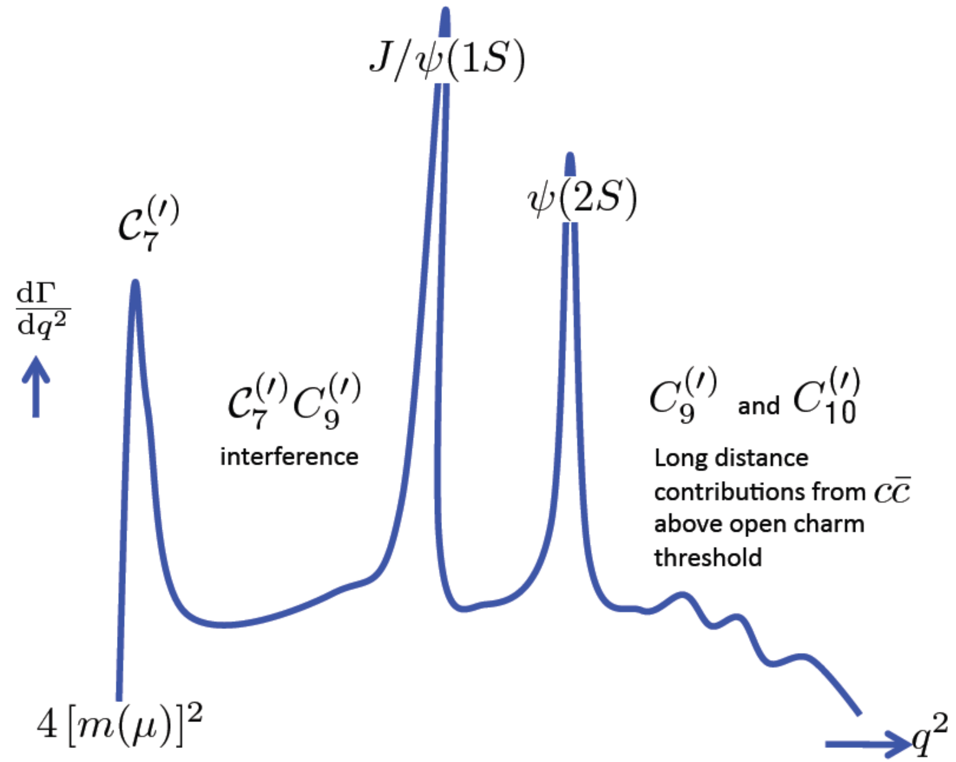
- Operators O_i depend on hadronic form factors (FF) of the decay
  (FF usually dominate theoretical uncertainties)

- Wilson coefficients C_i describe short distance effects – sensitive to NP contributions
  → **observables like branching fraction, CP asymmetries, angular distributions depend on C_i**

EW penguin decays

Wilson coefficients enter many processes:

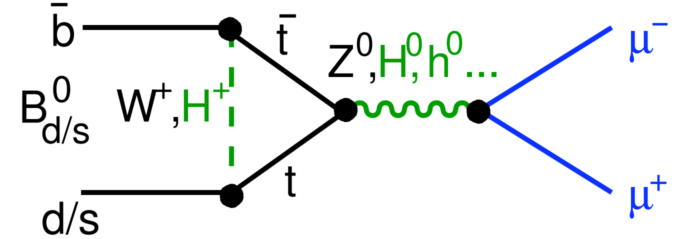
- $B \to X_s \gamma$: C_7
- $B \to (X_s, K^*)\, ll$: C_7, C_9, C_{10}
- $B \to \mu\mu$: C_{10}, C_S, C_P



I will show today:

- Combined measurement of $B_{s/d} \to \mu\mu$ (CMS + LHCb)
- Branching fractions of $b \to s\,\mu\mu$ / Test of lepton universality in $b \to s\, ll$ decays
- Angular analysis of $B \to K^*\,\mu\mu$ and $B \to K^*\, ee$
- Branching fraction and angular analysis of $B_s \to \phi\,\mu\mu$ - NEW

rare B → μμ decays are loop, CKM and helicity suppressed in SM
→ golden channel for C_{10} and pseudo-scalar operators
(probes models like e.g. 2HDM, MSSM, …)



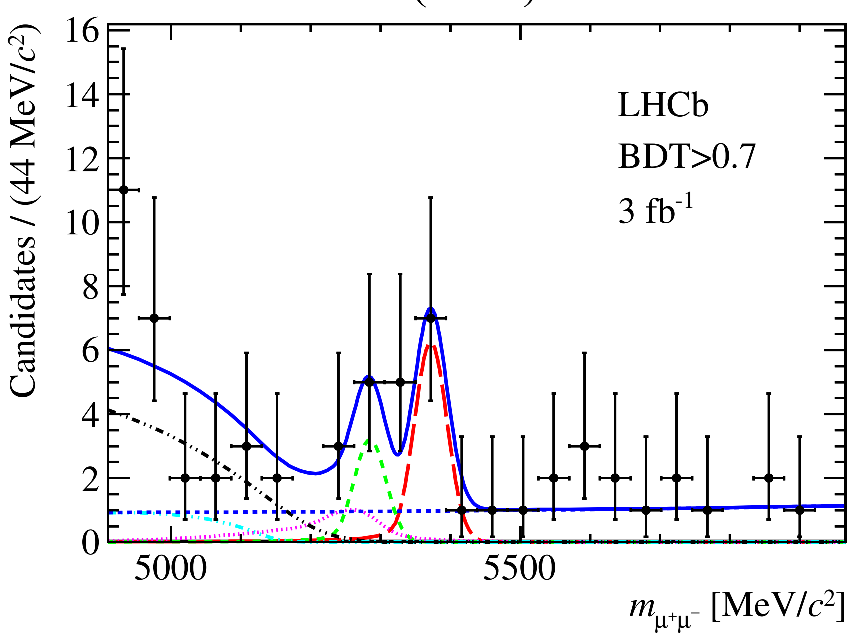
Precise theoretical predictions:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

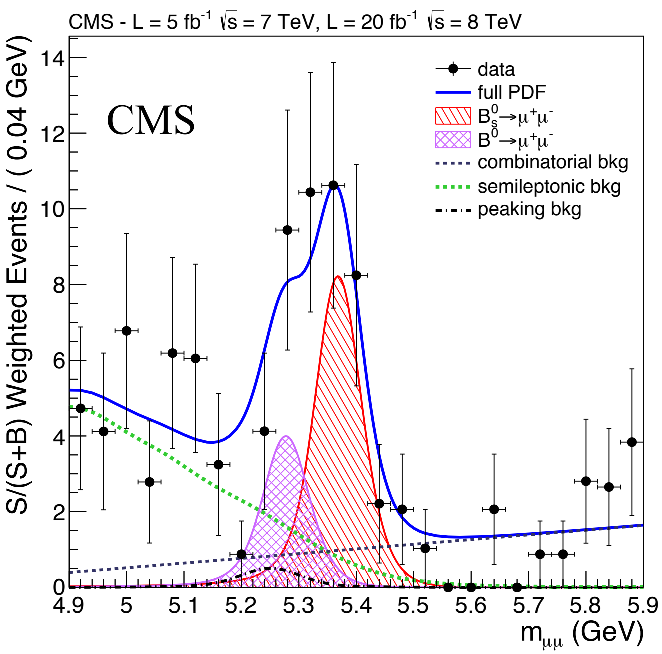
Bobeth et al, PRL 112 (2014) 101801

Measured by both LHCb and CMS with full Run 1 dataset:

PRL 111 (2013) 101805



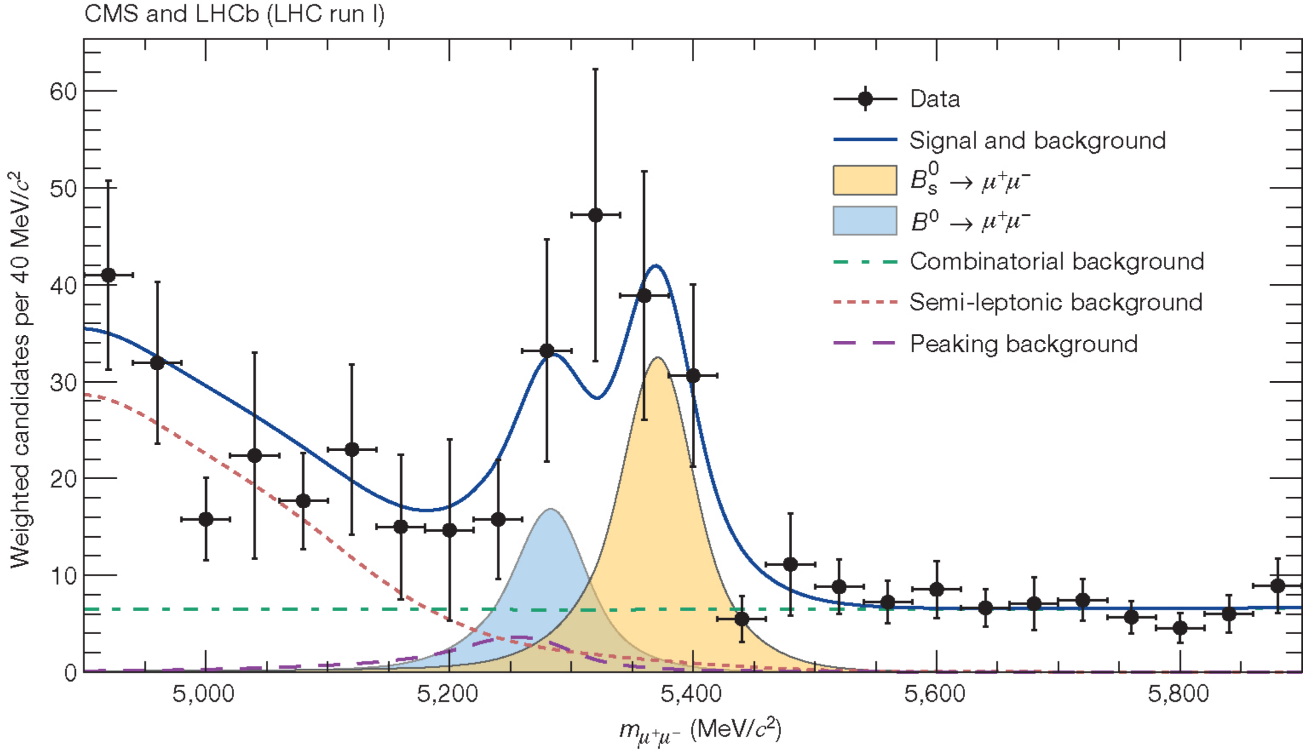
PRL 111 (2013) 101804



$B \to \mu^+\mu^-$ combination

hep-ex/1411.4413
doi:10.1038/nature14474

Simultaneous analysis of the LHCb and CMS datasets, with shared signal parameters and nuisance parameters:

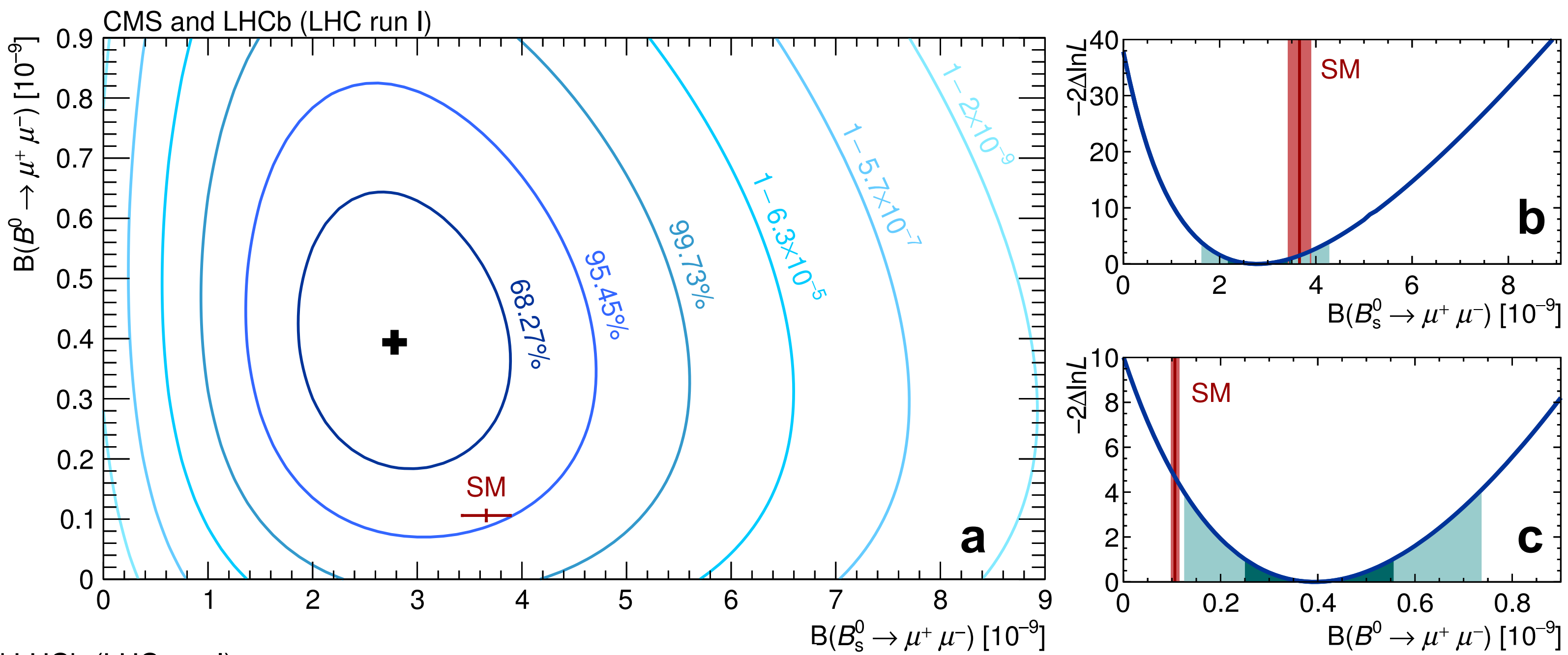


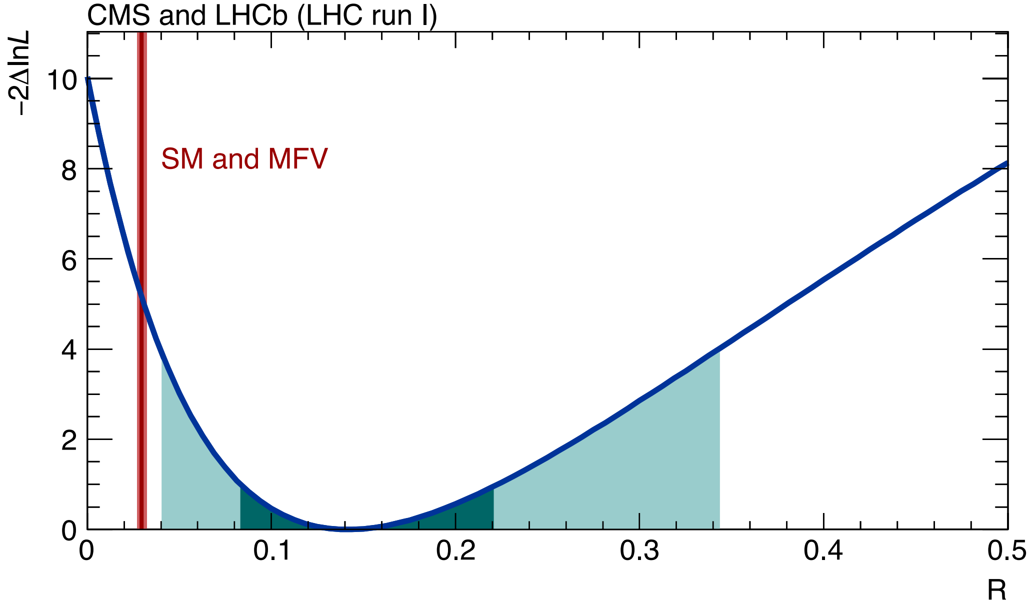
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(2.8\,^{+0.7}_{-0.6}\right) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(3.9\,^{+1.6}_{-1.4}\right) \times 10^{-10}$$

- First observation of $B_s \to \mu\mu$ decay (6.2 σ significance),
- First evidence of $B^0 \to \mu\mu$ decay (3.0 σ significance)

$B \to \mu^+ \mu^-$ combination

hep-ex/1411.4413
doi:10.1038/nature14474





Ratio of branching fractions is probe of MFV hypothesis:

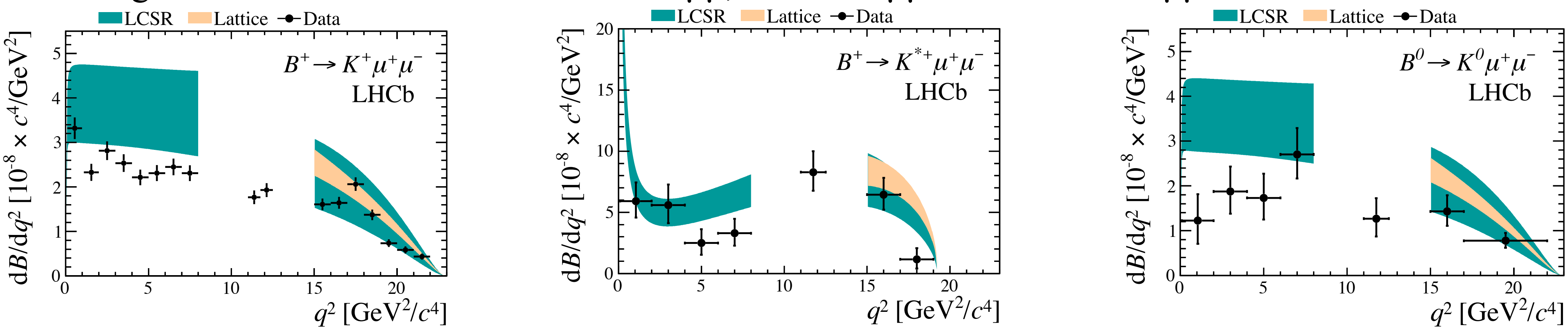
$$R = \frac{\mathcal{B}(B^0 \to \mu\mu)}{\mathcal{B}(B^0_s \to \mu\mu)} = 0.14^{+0.08}_{-0.06}$$

→ measured for the first time

→ compatible with the SM prediction at the 2.3σ level

$b \to s\mu\mu$ branching fractions

Branching fraction measurement for $B^0 \to K^0 \mu\mu$, $B^+ \to K^+ \mu\mu$ and $B^+ \to K^{*+} \mu\mu$: JHEP 06 (2014) 133

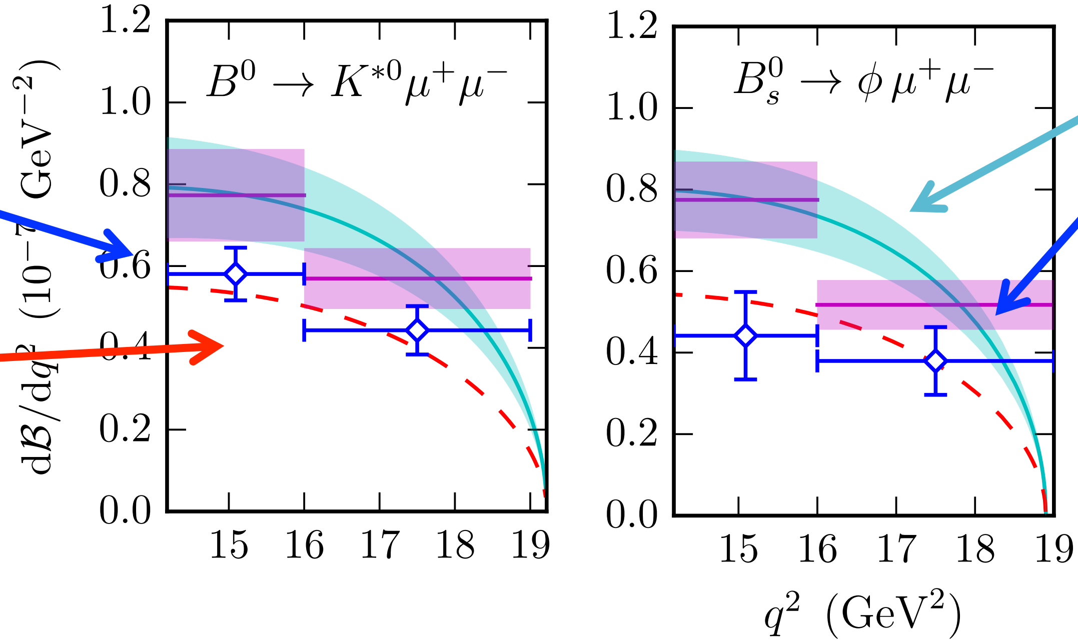


SM predictions: JHEP 07 (2011) 067; JHEP 01 (2012) 107; \Phys. Rev. Lett. 111 (2013) 162002

Average of the $B^0 \to K^*\mu\mu$ and $B_s \to \phi\,\mu\mu$ decay in the high-q2 range: Horgan et al., PRL 112, 212003

Averages from LHCb, CDF, CMS, ATLAS

$C_9 = C_9^{SM} - 1.5$



SM

Averages from LHCb, CDF

LHCb: JHEP 06 (2014) 133, JHEP 08 (2013)131, JHEP 07 (2013) 084
CDF: Public note 10894,
CMS: Phys. Lett. B 727 (2013) 77
ATLAS: ATLAS-CONF-2013-038

→ branching fractions tend to lie below SM predictions

(see also: Altmannshofer et al., arxiv:1411.3161)

Test of lepton universality

Ratio of branching fractions of
$B^+ \to K^+\mu\mu$ and $B^+ \to K^+ee$:

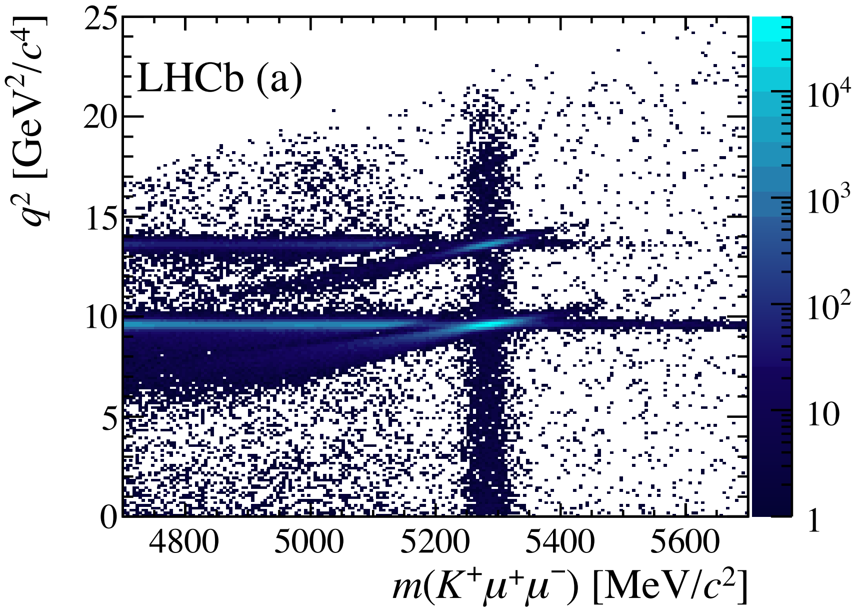
$$R_K = \frac{\Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^+ \to K^+e^+e^-)}$$

- Lepton universality in SM → R_K predicted to be 1 in SM within $O(10^{-3})$
  JHEP 12 (2007) 040, Phys. Rev. Lett. 111 (2013) 162002

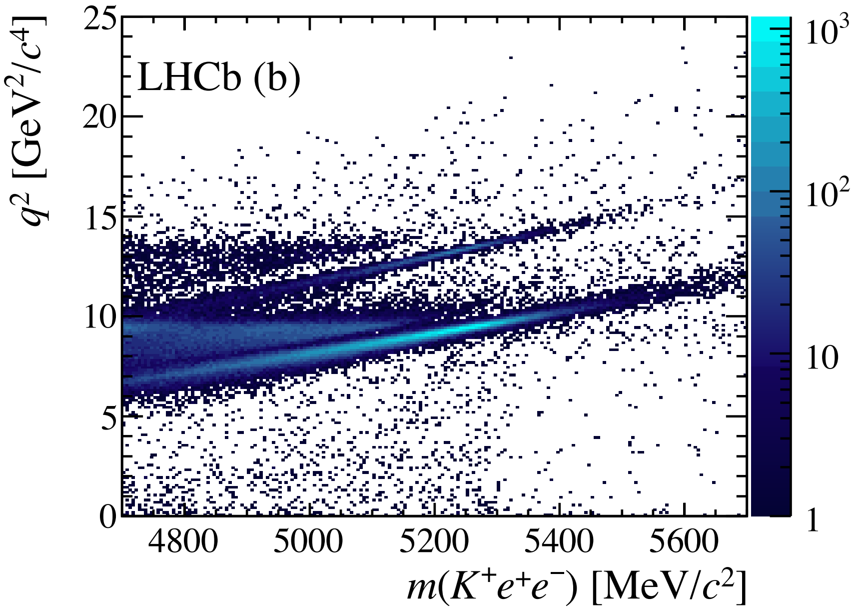
- Measurements from Babar (Phys. Rev. D86 (2012) 032012),
  Belle (Phys. Rev. Lett. 103 (2009) 171801) and LHCb (Phys. Rev. Lett. 113 (2014) 151601)

LHCb measurement uses full 3fb^{-1} dataset in $1 < q^2 < 6$ GeV^2/c^4 :

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

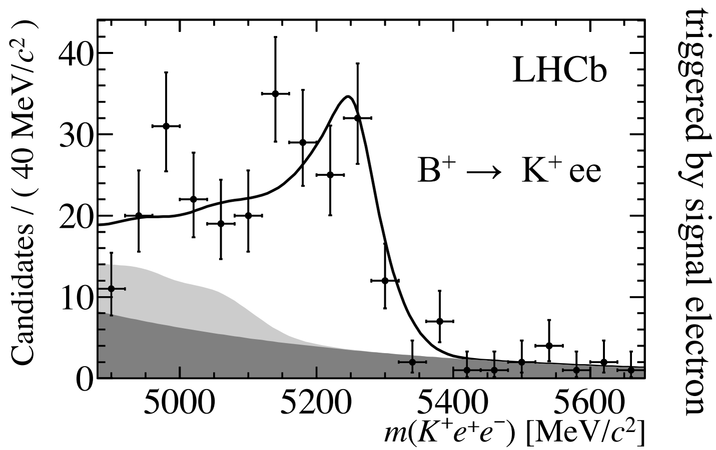


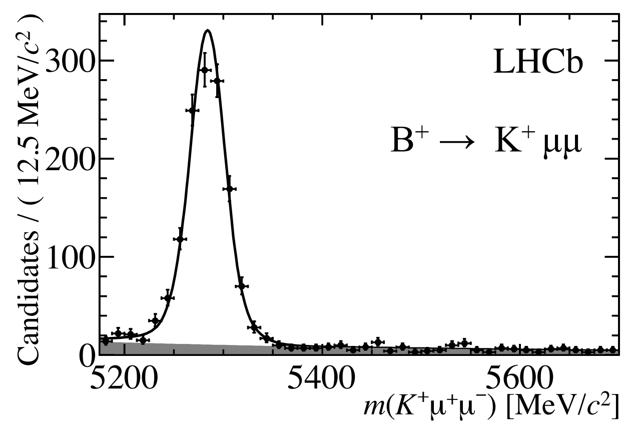
$B^+ \to K^+ee$



Test of lepton universality

- $B^+ \rightarrow K^+ ee$ mass shape affected by bremsstrahlung, transverse momentum of electron and occupancy $\rightarrow$ sample divided in trigger categories / $B^+ \rightarrow J/\Psi K^+$ to investigate shape dependence
- Signal yield corrected for bin migration due to bremsstrahlung





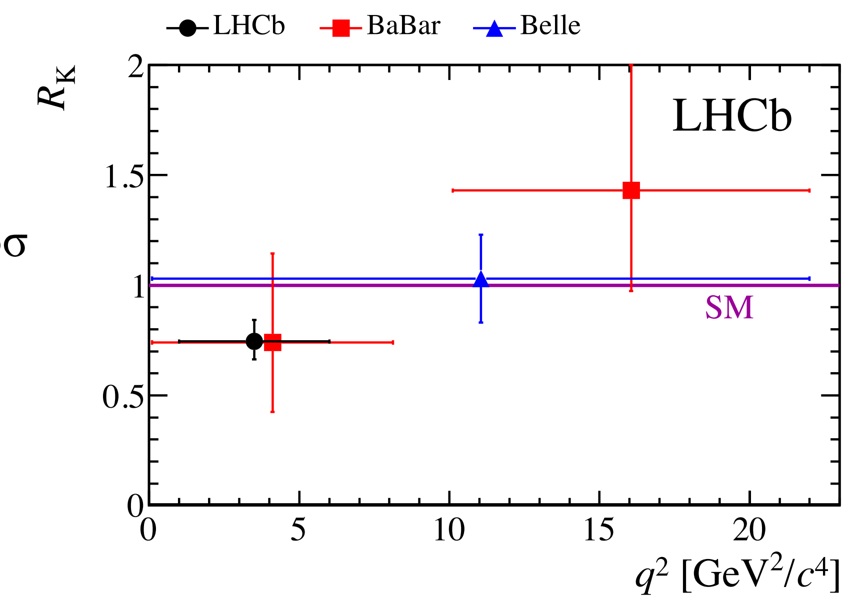
$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

$\rightarrow$ most precise to date, compatible with SM within 2.6σ

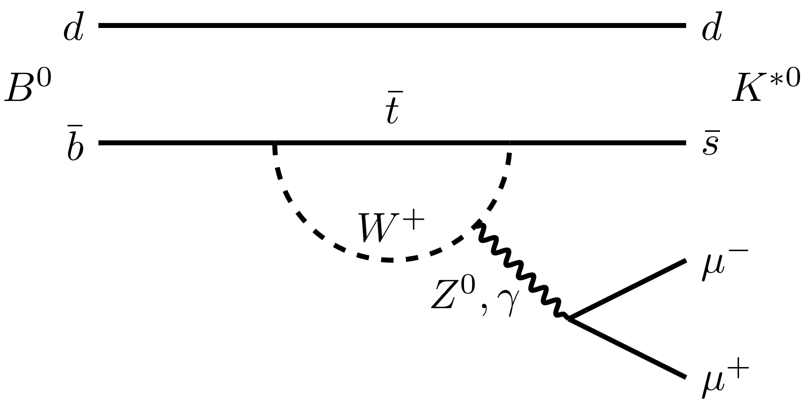
$\rightarrow$ BR ($B^+ \rightarrow K^+ ee$) in agreement with SM

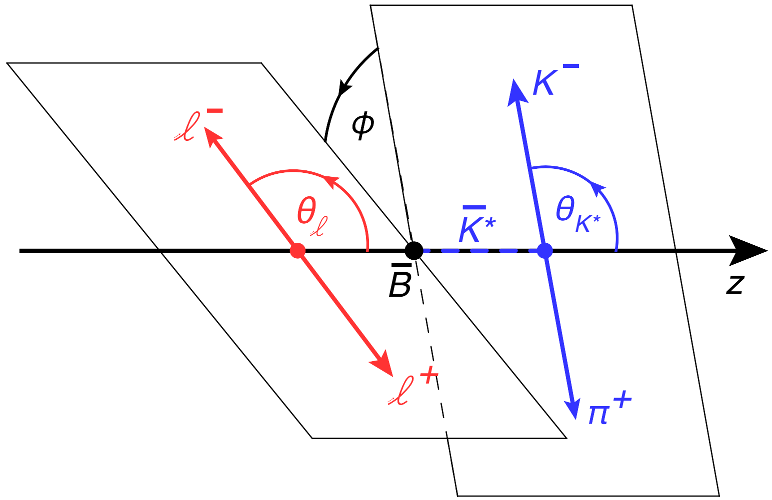
Consistent with branching fractions if possible NP only contributes to $b \rightarrow s\,\mu\mu$ and not to $b \rightarrow s\,ee$

Altmannshofer, Straub, arXiv:1503.06199v2



Angular observables of B → K* l⁺ l⁻





$B^0 \to K^{*0}\ l^+l^-$ described by three angles (θ_K, θ_l, Φ) and di-muon mass squared, q^2:

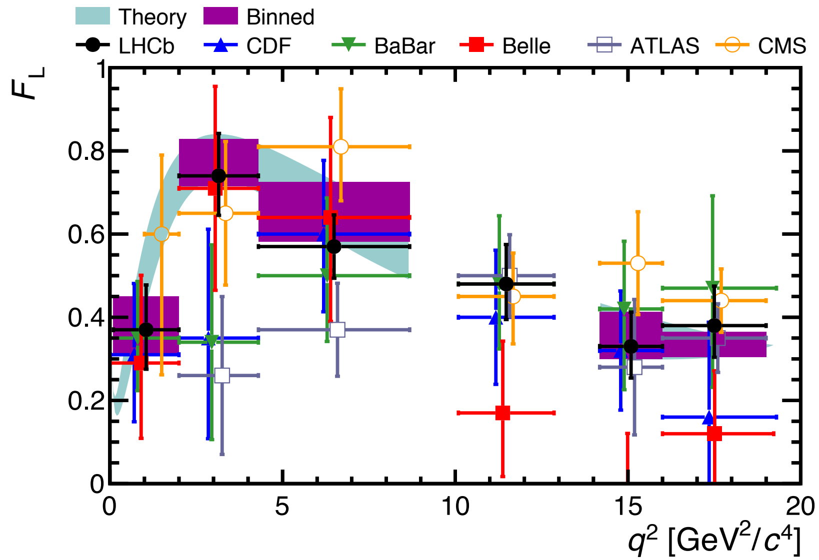
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \tfrac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ \tfrac{4}{3}A_\mathrm{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

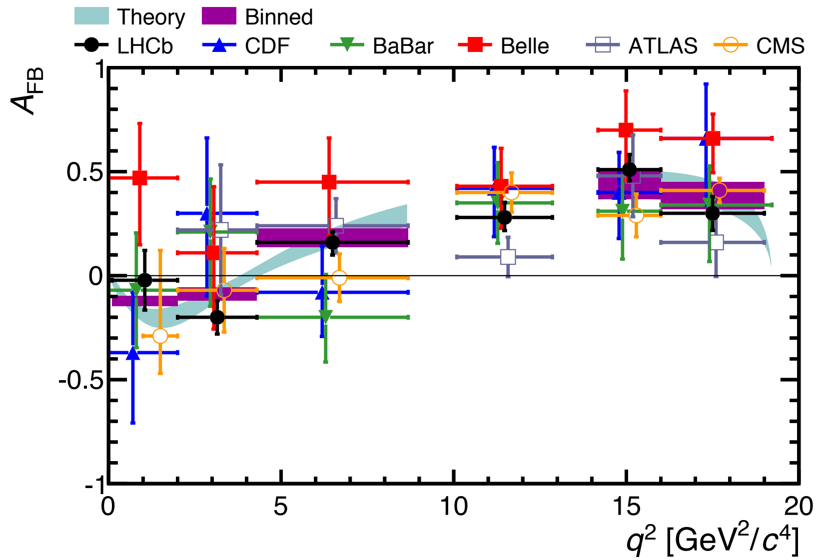
F_L, A_{FB} and S_i are determined in bins of q^2 and depend on Wilson coefficiencs C_7, C_9 and C_{10} and hadronic form factors

Angular analysis of $B^0 \to K^{*0}\ \mu\mu$

Long history of $B^0 \to K^{*0}\ \mu\mu$ measurements:

Belle: Phys. Rev. Lett. 103 (2009) 171801, **Babar**: Phys. Rev. D. 73. 092001, **CDF**: Phys. Rev. Lett. 108 081807, **CMS**: Phys. Lett. B 727 (2013) 77, **ATLAS**: ATLAS-CONF-2013-038, **LHCb** JHEP 08 (2013) 131





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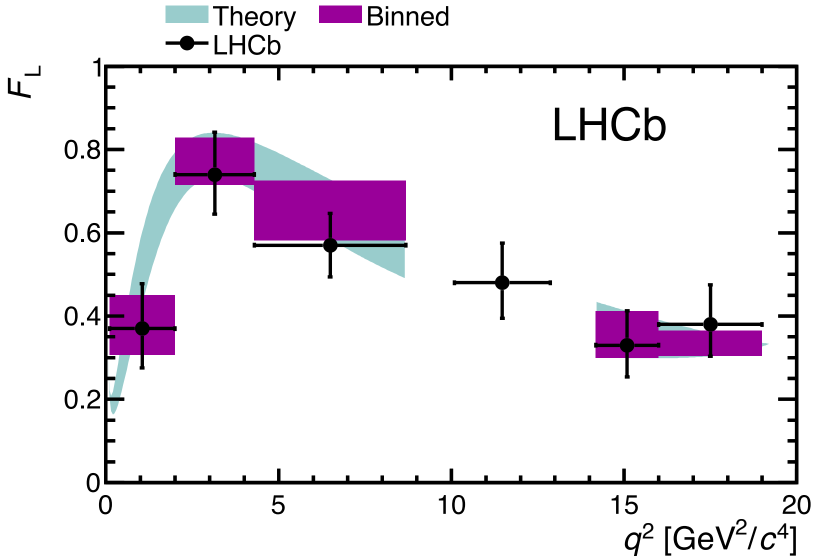
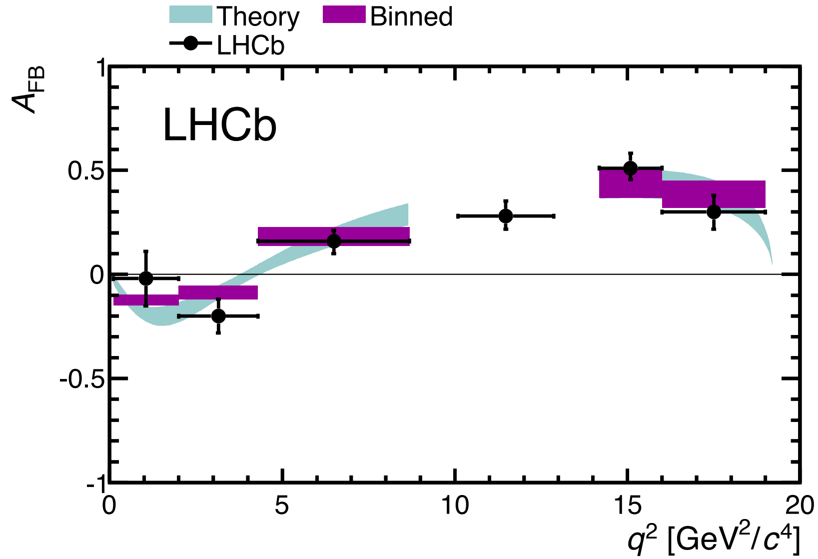
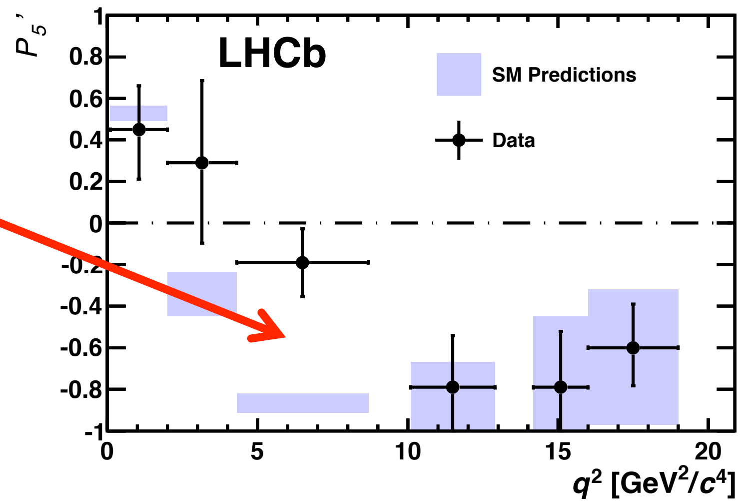




→ mostly compatible with SM, but …

3.7σ local deviation from SM prediction

PRL 111, 191801 (2013)

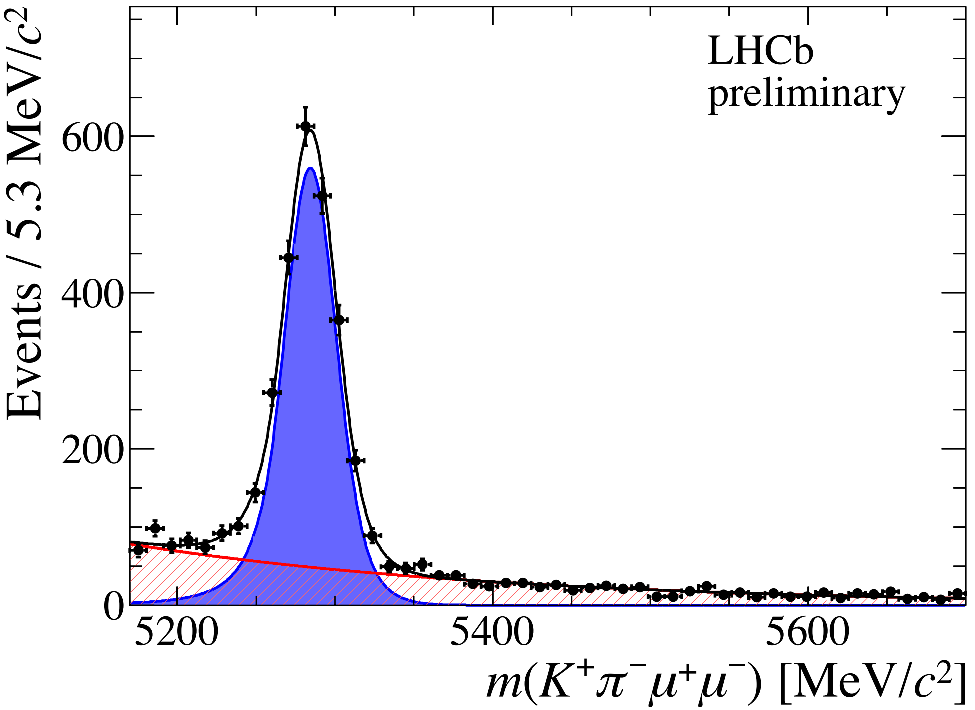


Less form-factor dependent observable:

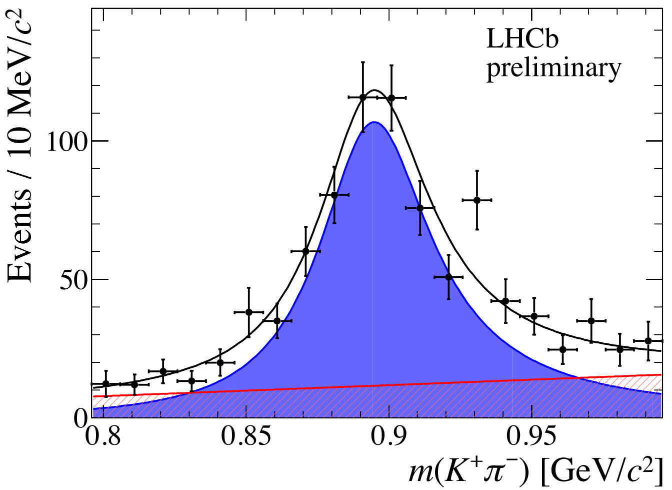
$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

Full Run1 analysis from LHCb (3 fb^{-1}) :

- update of 1 fb^{-1} analysis, first presented at Moriond 2015
- total signal yield: $N_{sig} = 2398 \pm 57$



- first simultaneous determination of all eight CP-averaged observables in a single fit which allows to provide the full correlation matrix extracted from likelihood fit in decay angles, $m_{K\pi\mu\mu}$ and q^2

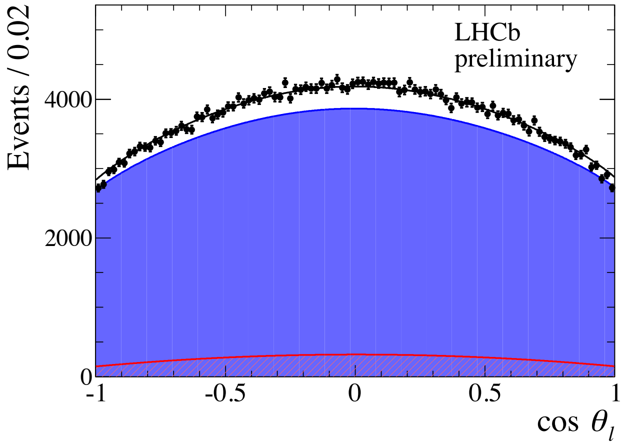


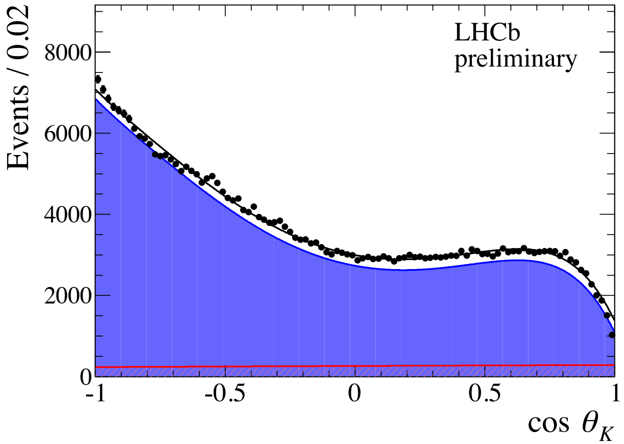
Simultaneously fitting $m_{K\pi}$ to constrain S-wave component F_S

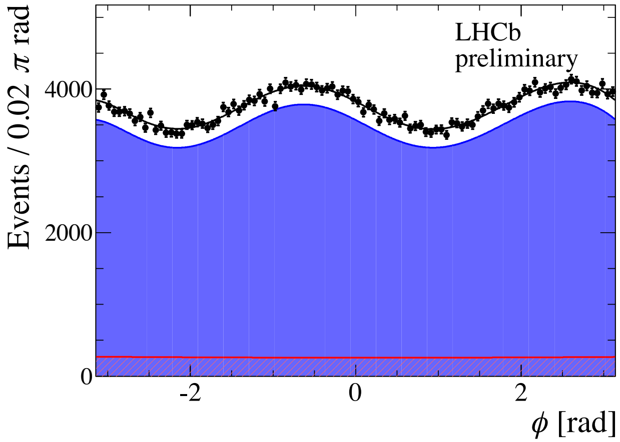
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\bigg|_{\mathrm{S+P}} = (1-F_{\mathrm{S}})\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\bigg|_{\mathrm{P}} + \frac{3}{16\pi}F_{\mathrm{S}}\sin^2\theta_\ell + \text{S-P interference}$$

Angular acceptances from simulation, 4D parameterization using Legendre polynomials

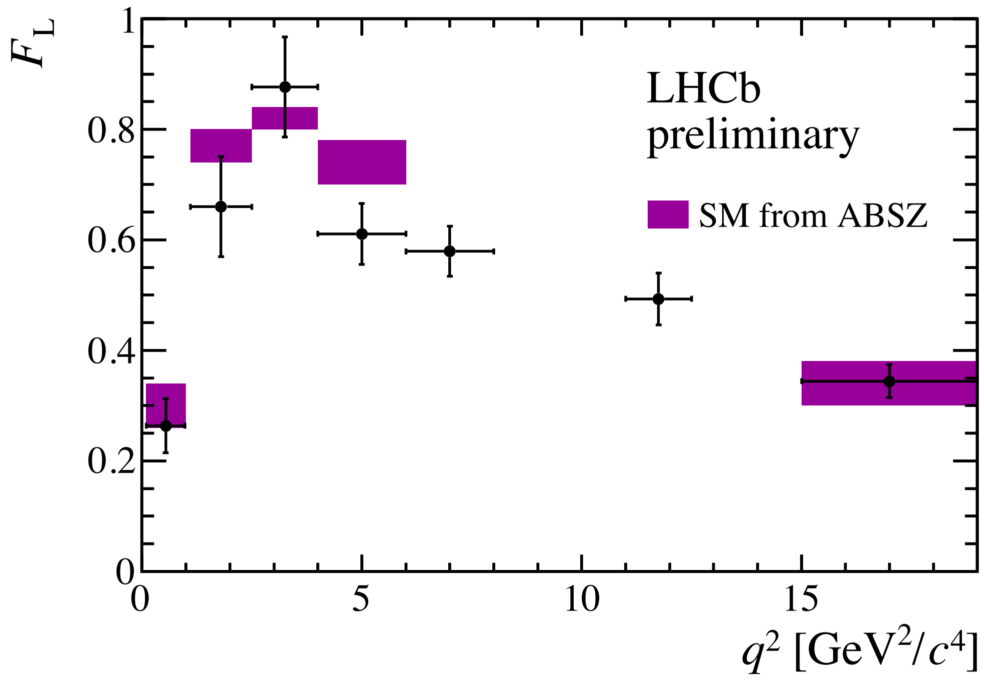
Fit cross-checked with $B^0 \to J/\Psi\ K^{*0}$: consistent with results in PRD 88, 052002 (2013)

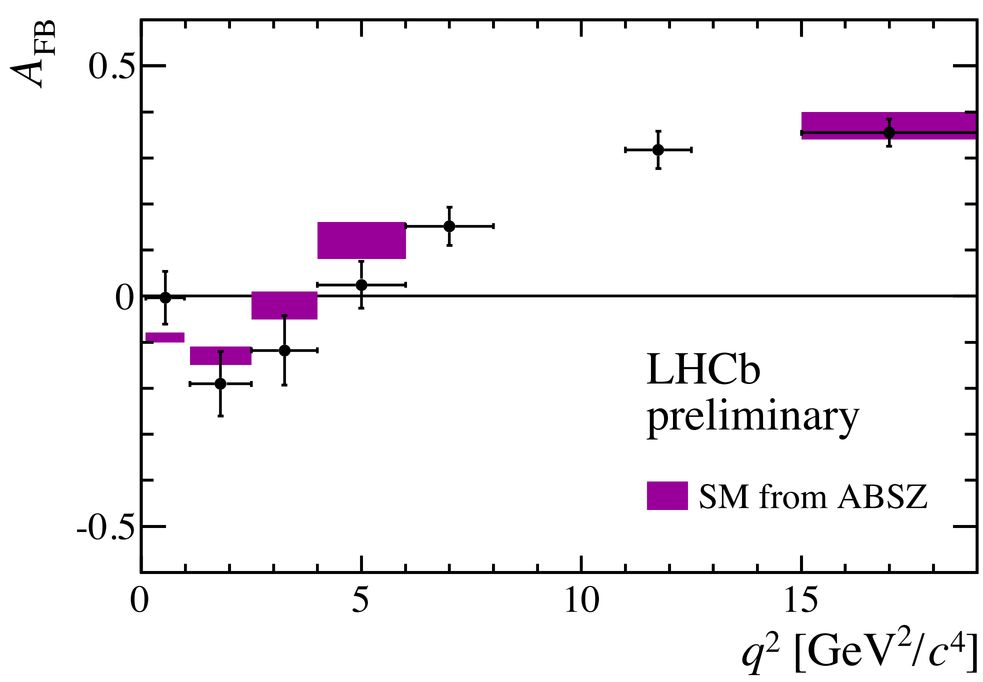






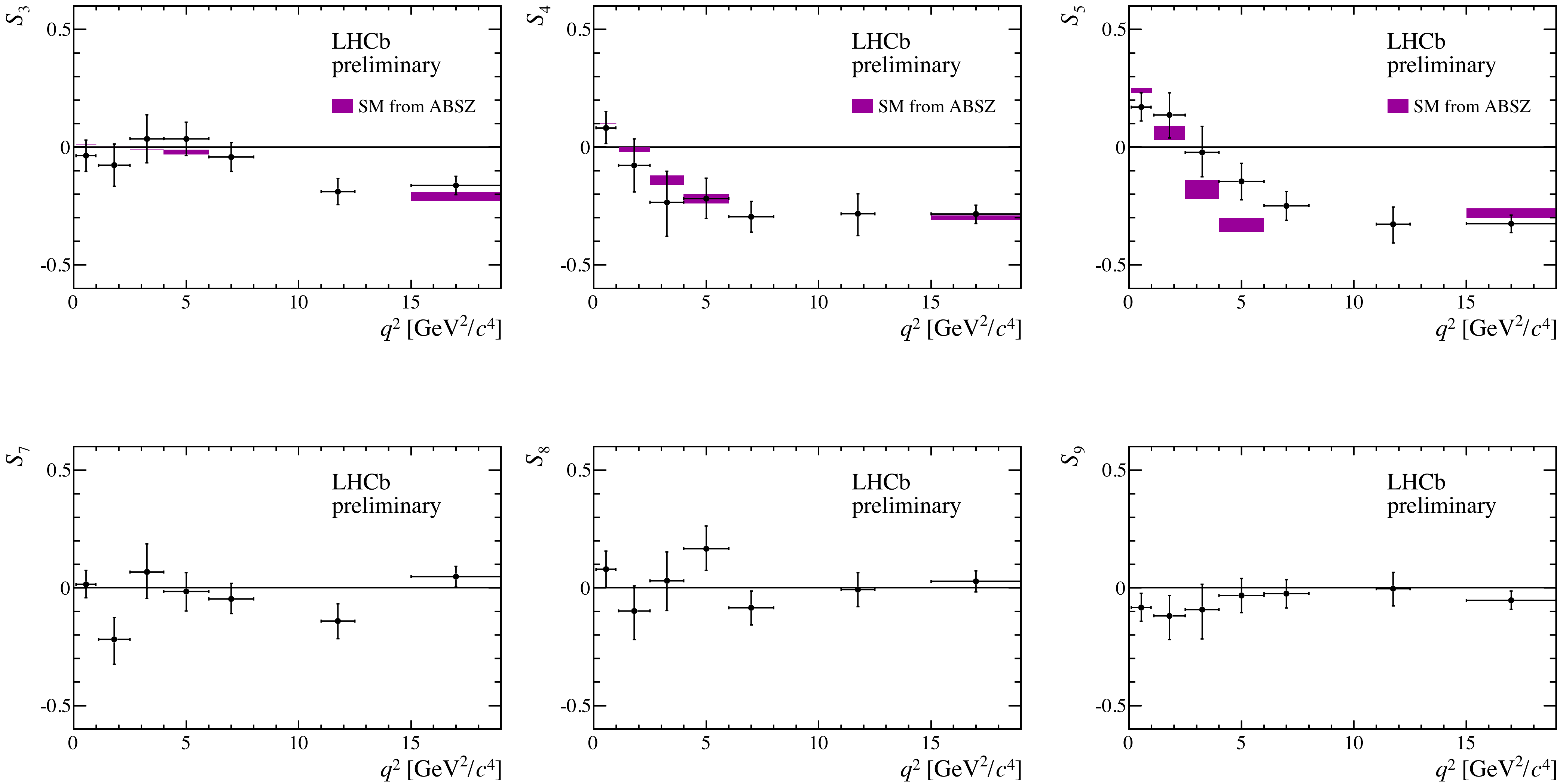
Angular analysis of $B^0 \rightarrow K^{*0}\ \mu\mu$





Theory prediction from arXiv:1503.05534, arXiv:1411.3161

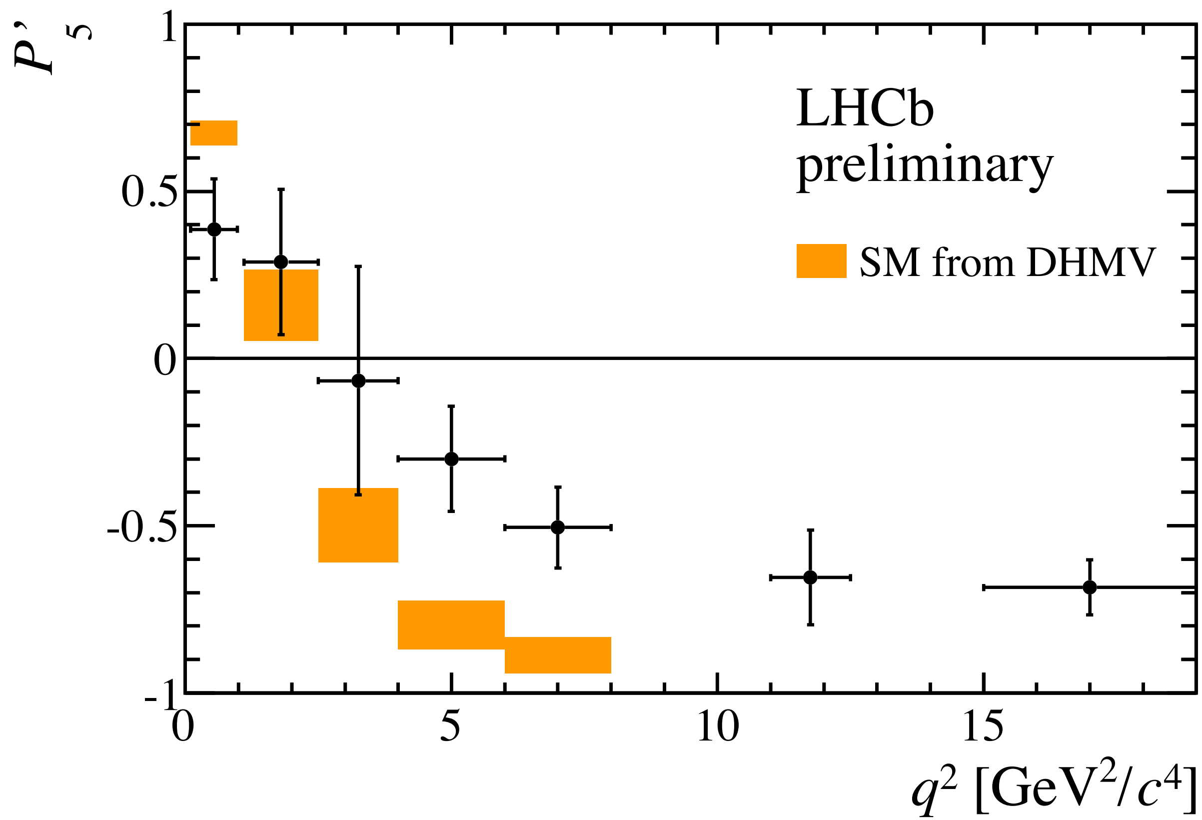
- A_{FB} systematically below SM prediction
- Zero-crossing point evaluated as in JHEP 08 (2013) 131 and consistent with SM: $q^2_0 = 3.7^{+0.8}_{-1.1}$ GeV^2


S_3
S_4
S_5
S_7
S_8
S_9
LHCb
preliminary
SM from ABSZ
0.5
0
-0.5
0
5
10
15
q^2 [GeV^2/c^4]

Angular analysis of $B^0 \rightarrow K^{*0} \mu\mu$

Less form-factor dependent observable: (smaller theoretical uncertainties)

$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$



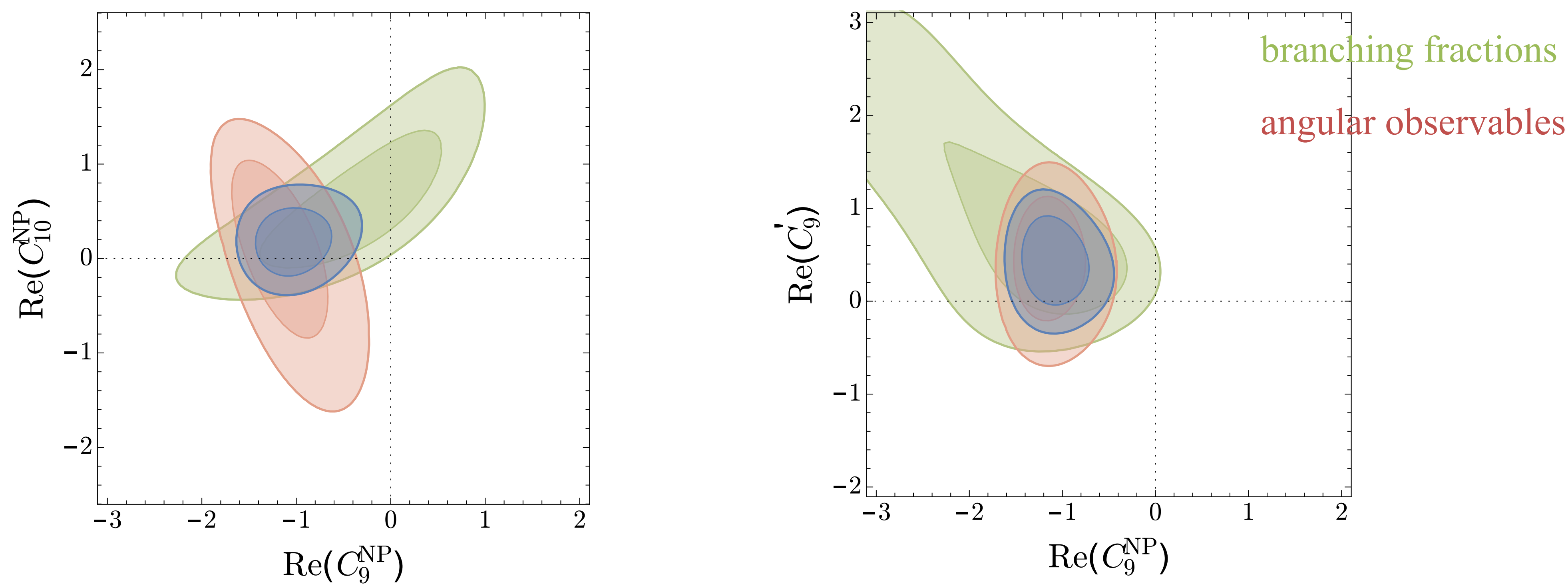
Consistent with 1 fb^{-1} analysis and tension to SM prediction confirmed

Two bins each show local deviation of 2.9 σ, naïve χ^2 combination gives 3.7 σ

Theoretical interpretations

Wilson coefficients from b → s μμ in global fit:
- 88 measurements are used as input for this fit (including results from ATLAS, CMS, LHCb)

Altmannshofer, Straub, arXiv:1503.06199v2 [hep-ph]

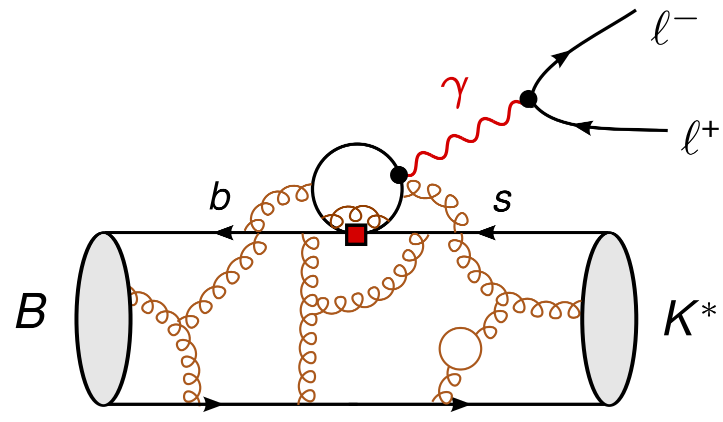


- Fit prefers negative $C_9^{NP} \sim -1.1$ ($C_9 = C_9^{SM} + C_9^{NP}$)
- Constraints from angular observables and branching fractions compatible

Theoretical interpretations

Hadronic effects:

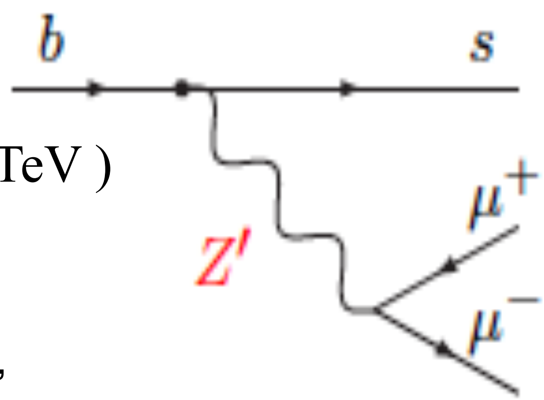
- Unexpectedly huge charm effects can mimic negative C_9^{NP} at intermediate q^2
- But: hadronic effects can not violate LFU
  → important to perform more measurements like R_K



Altmannshofer, Straub, arXiv:1503.06199v2 [hep-ph], Straub, Moriond EW, 2015

Possible New Physics interpretation:

- Data can be described with Z' with FV couplings and mass O(7TeV)
  → can accommodate all present measurements



Gauld et al., JHEP 1401 (2014) 069, Buras et al., JHEP 1402 (2014) 112, Altmannshofer et al. PRD 89 (2014) 095033

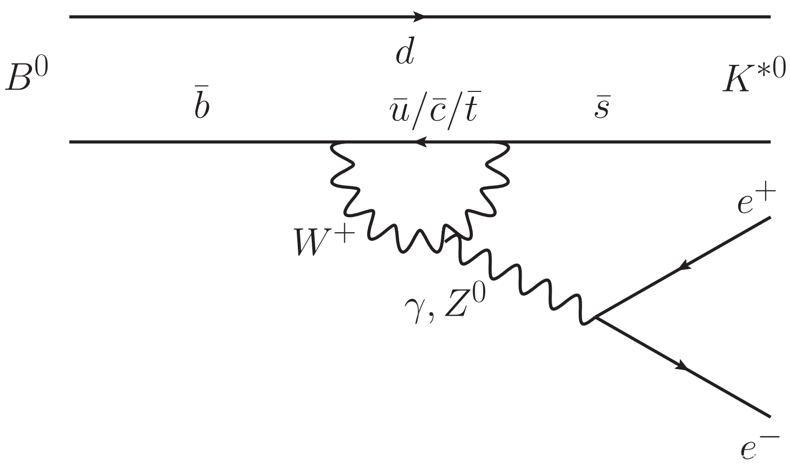
but also other models: Hiller et al., PRD 90, 054014 (2014) , Glashow et al., PRL 114, 091801 (2015) , Crivellin et al., Phys.Rev.Lett. 114 (2015) 151801

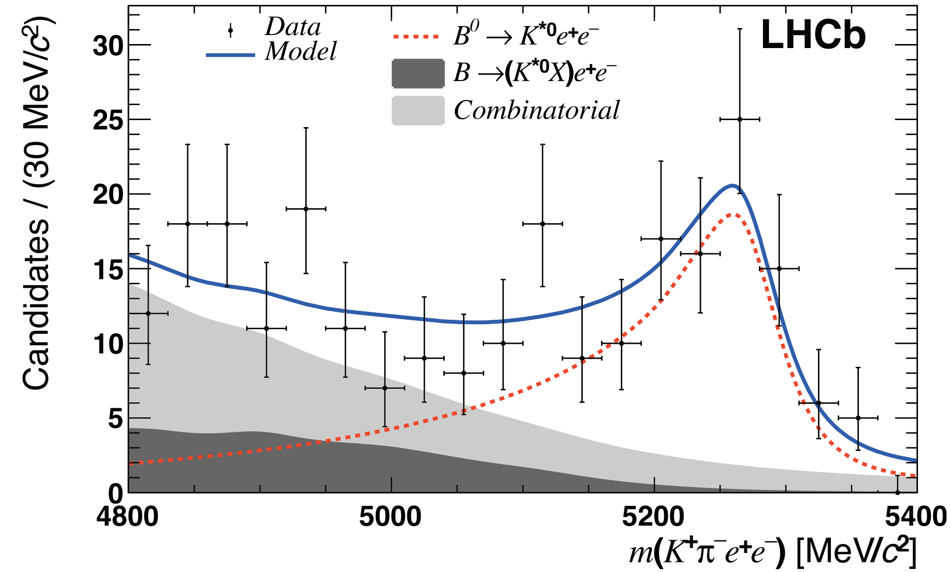
Angular analysis of $B^0 \rightarrow K^{*0} e^+ e^-$

JHEP 1504 (2015) 064

In SM photons from $b \rightarrow s \gamma$ are predominantly left-handed

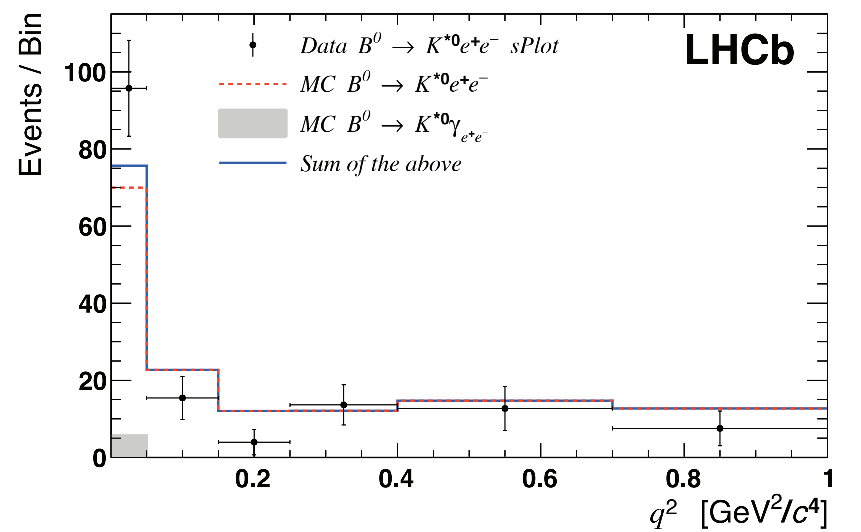
Angular analysis of $B^0 \rightarrow K^{*0}$ e e is at small values of q^2 sensitive to photon polarization and therefore to C_7, C_7'





Virtual photon coupling dominates at low q^2 (photon pole):

Analysis is performed in q^2 [0.004 , 1.0] GeV^2

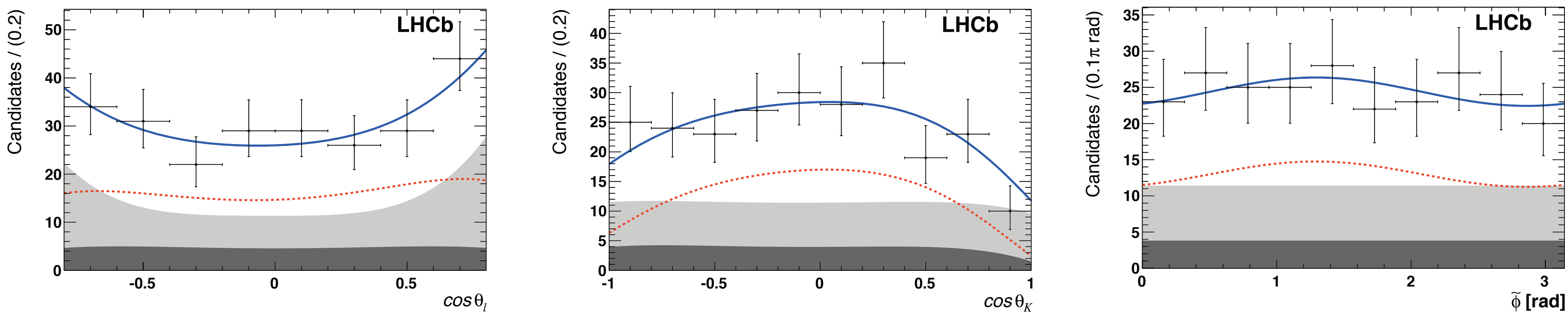


Angular analysis of $B^0 \to K^{*0} e^+ e^-$

JHEP 1504 (2015) 064

Fit to folded decay angle distribution: $\varphi = \varphi + \pi$ if $\varphi < 0$

Measurement of F_L, $A_T^{(2)}$, $A_T^{(Im)}$, $A_T^{(Re)}$ with $A_T^{(2)}(q^2 \to 0) = \dfrac{2\mathcal{R}e(\mathcal{C}_7\mathcal{C}_7'^*)}{|\mathcal{C}_7|^2 + |\mathcal{C}_7'|^2}$ $\quad A_T^{\mathrm{Im}}(q^2 \to 0) = \dfrac{2\mathcal{I}m(\mathcal{C}_7\mathcal{C}_7'^*)}{|\mathcal{C}_7|^2 + |\mathcal{C}_7'|^2}$



Result:

obs.	result
F_L	$+0.16 \pm 0.06 \pm 0.03$
$A_T^{(2)}$	$-0.23 \pm 0.23 \pm 0.05$
A_T^{Re}	$+0.10 \pm 0.18 \pm 0.05$
A_T^{Im}	$+0.14 \pm 0.22 \pm 0.05$

Jaeger et al. JHEP 05 (2013) 043

obs.	SM prediction
F_L	$+0.10^{+0.11}_{-0.05}$
$A_T^{(2)}$	$+0.03^{+0.05}_{-0.04}$
A_T^{Re}	$-0.15^{+0.04}_{-0.03}$
A_T^{Im}	$(-0.2^{+1.2}_{-1.2}) \times 10^{-4}$

Results consistent with SM , sensitivity to C_7’ comparable to sensitivity from $S_{K^*\gamma}$

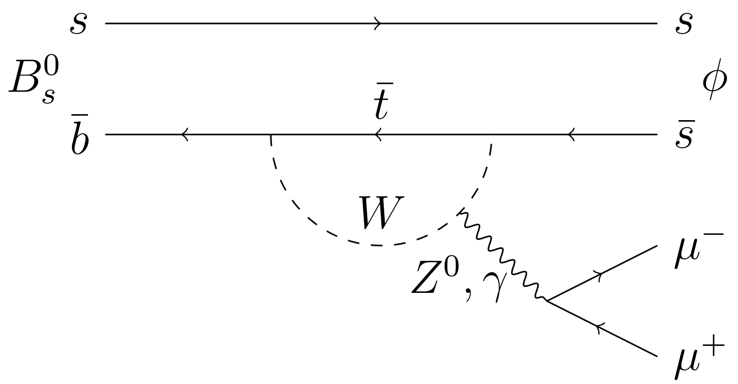
New results

Branching fraction of $B_s \to \phi\,\mu\mu$

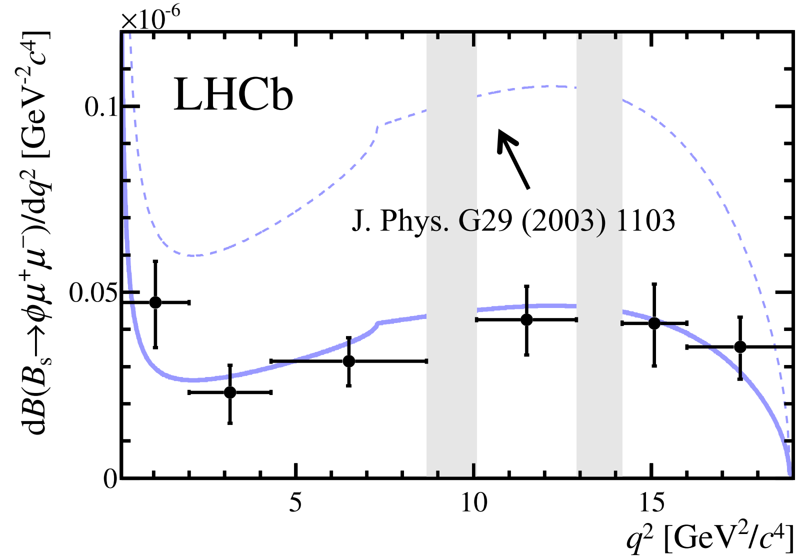
New

LHCb-PAPER-2015-023

Very similar to $B^0 \to K^{*0}\,\mu\mu$:

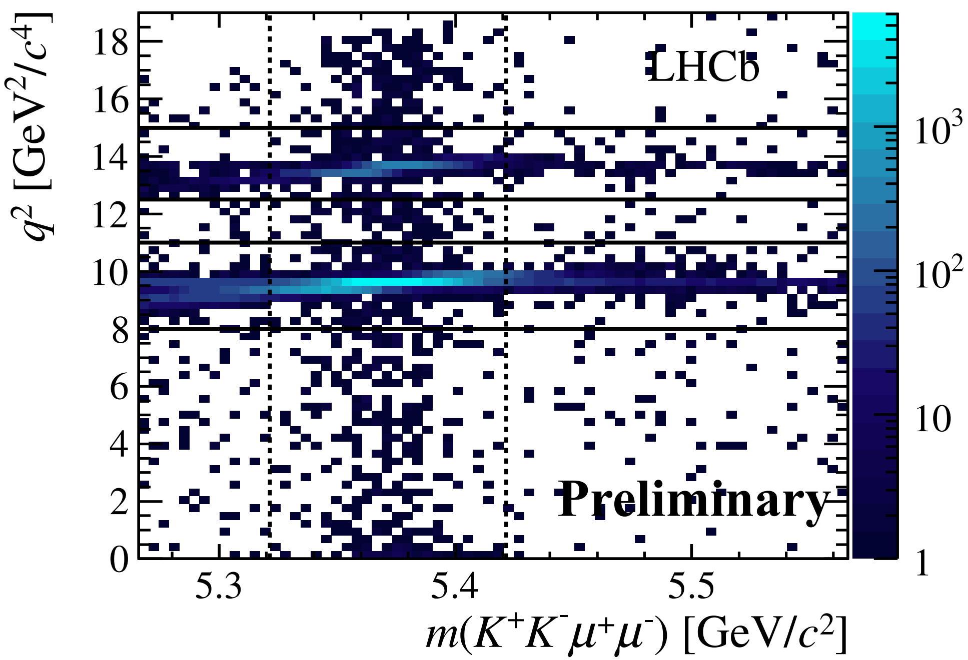


1fb^{-1} analysis showed tension to SM predictions:



JHEP 07 (2013) 084

Today: update with full Run1 dataset (3fb^{-1}):



BDT to suppress combinatorial background

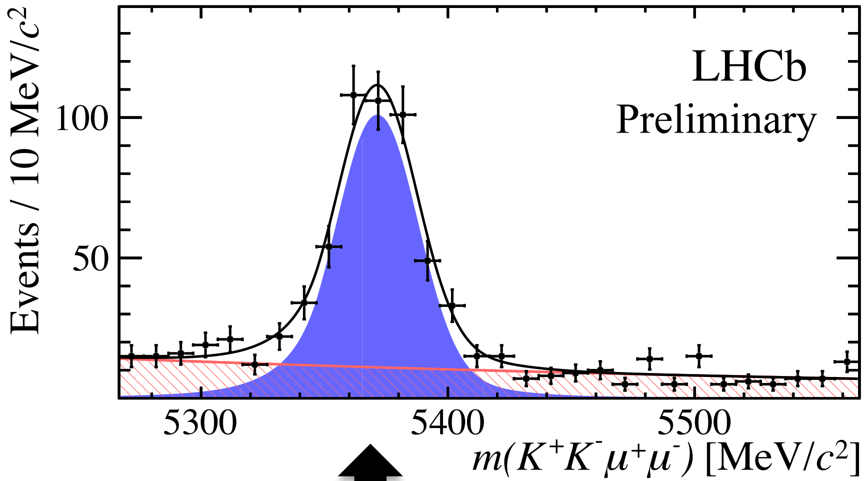
Veto of $B_s \to J/\Psi\,\phi$ and $B_s \to \Psi(2S)\,\phi$

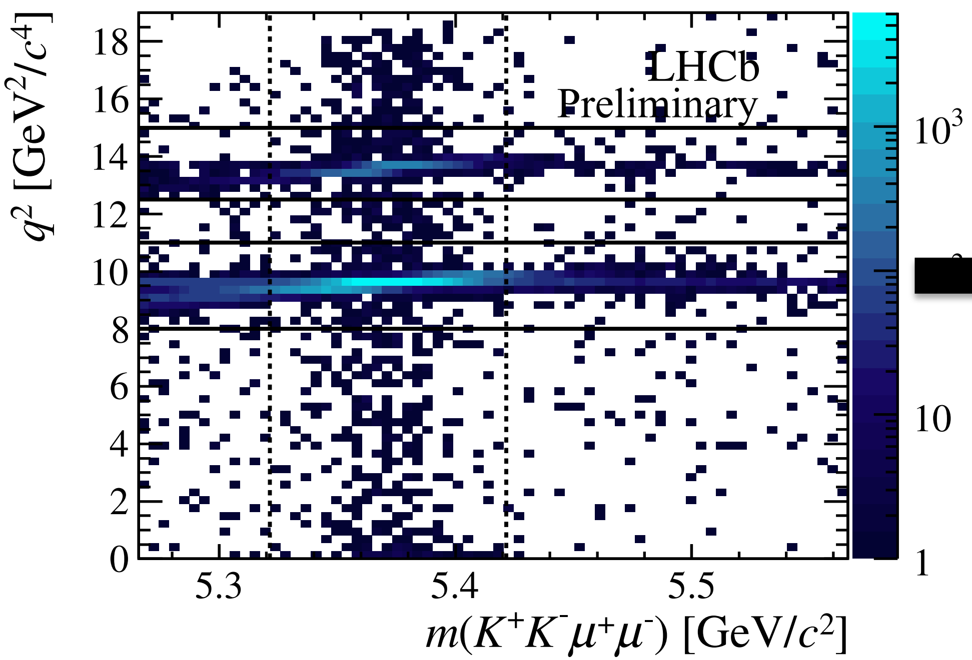
Similar to $B^0 \to K^{*0}\,\mu\mu$ used PID to explicitly veto

- $B_s \to J/\Psi\,\phi$ with K – μ double misidentification
- $\Lambda_b \to \Lambda(1520)\,\mu\mu$ with p – K misidentification

Branching fraction of $B_s \to \phi \mu\mu$

New



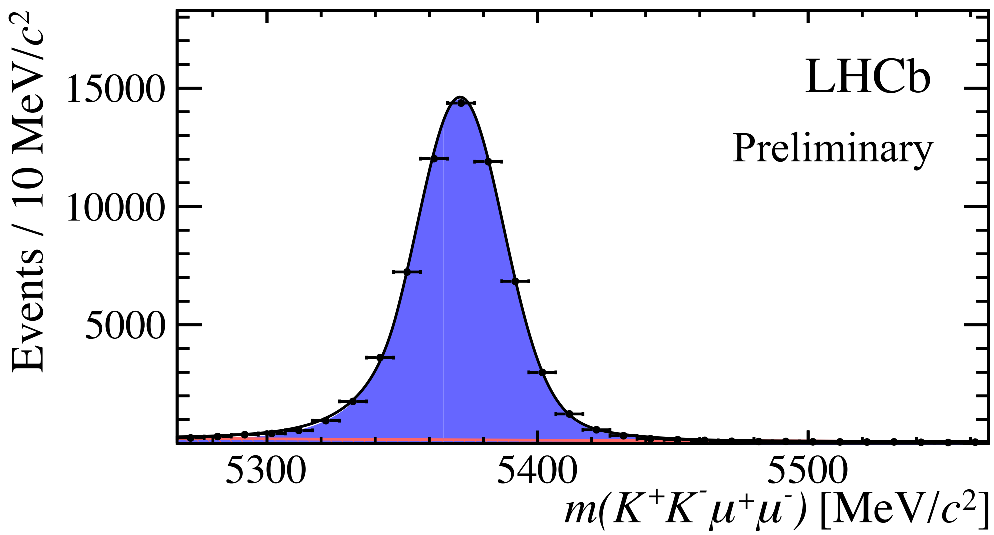


Total signal yield: $N_{sig} = 432 \pm 24$

$B_s \to J/\Psi\ \phi$ as normalisation channel for branching fraction measurement

Efficiencies determined from simulated signal samples

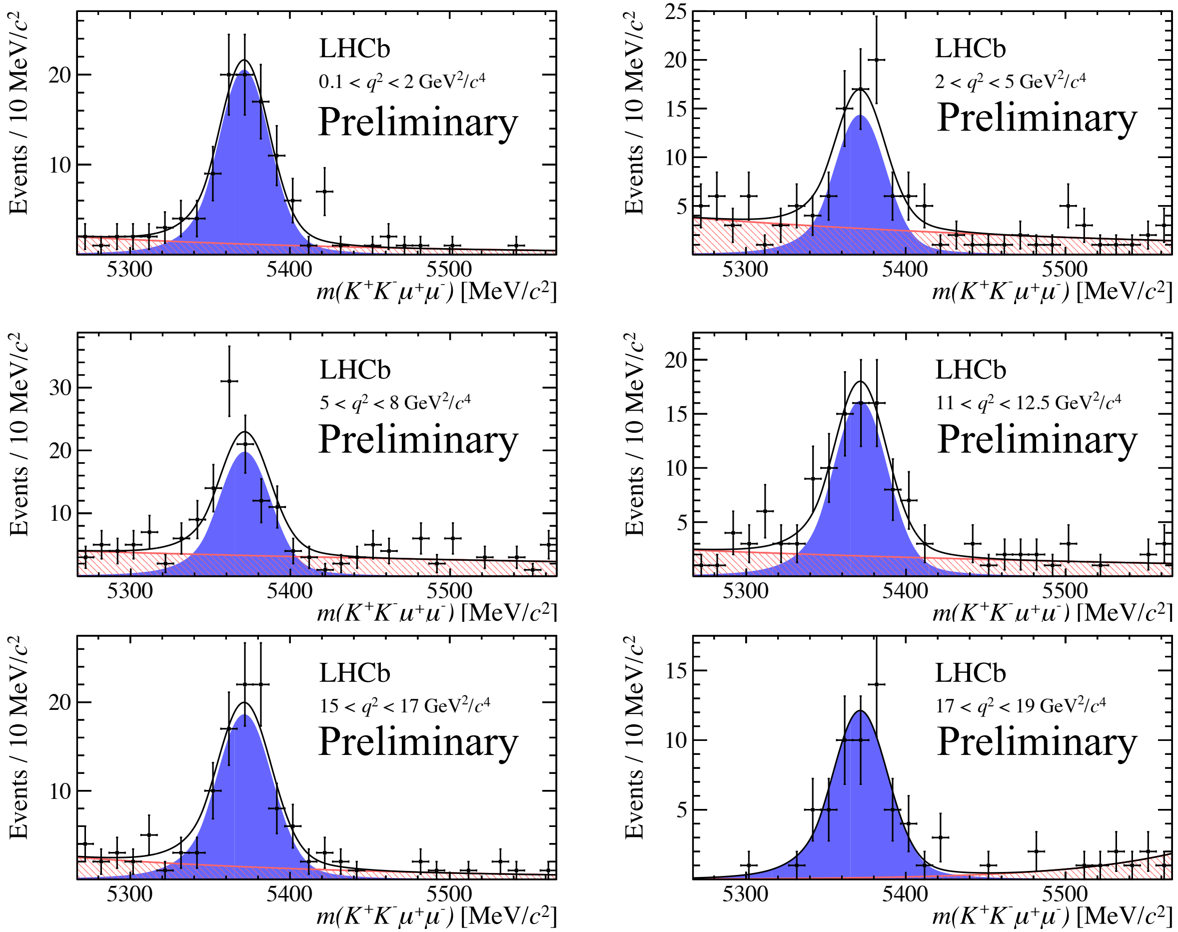
- ➢ corrected for differences to data



Branching fraction of $B_s \to \phi\mu\mu$

New

LHCb-PAPER-2015-023



Branching fraction in bins of q^2:

- Bins chosen such that signal yield is evenly distributed

Signal mass model:

- Determined from $B_s \to J/\Psi\,\phi$ fit
- Allow for q^2 dependent width

Background model:

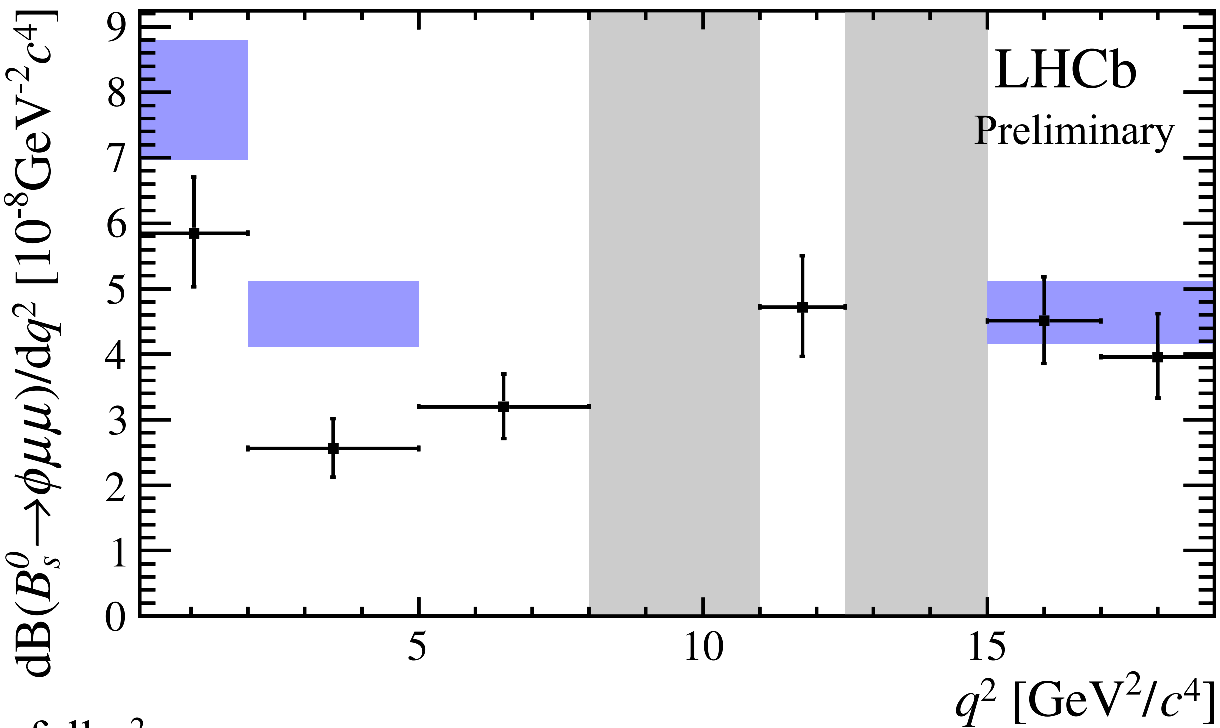
- exponential function

Systematic uncertainties:

- Dominated by the limited size of the simulated signal sample
- Angular acceptance effects estimated by varying Wilson coefficients in generation
- Mass model uncertainties estimated with pseudo-experiments

Branching fraction of $B_s \to \phi \mu\mu$

New



theory prediction:
arXiv:1411.3161,
arXiv:1503.05534

Extrapolation to full q^2 range:
(using WC and FF from Phys. Rev. D66 (2002) 034002, Phys. Rev. D 71 (2005) 014029)

$$\frac{\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = (7.40^{+0.42}_{-0.40} \pm 0.20 \pm 0.21) \times 10^{-4},$$

$$\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-) = (7.97^{+0.45}_{-0.43} \pm 0.22 \pm 0.23 \pm 0.60) \times 10^{-7}$$

Most precise measurement to date, consistent with previous analysis
in $1 < q^2 < 6$ GeV^2 : 3.5 σ tension to prediction based on SM

Angular analysis of $B_s \to \phi\,\mu\mu$

New

Angular observables extracted from 4d unbinned maximum likelihood fit:

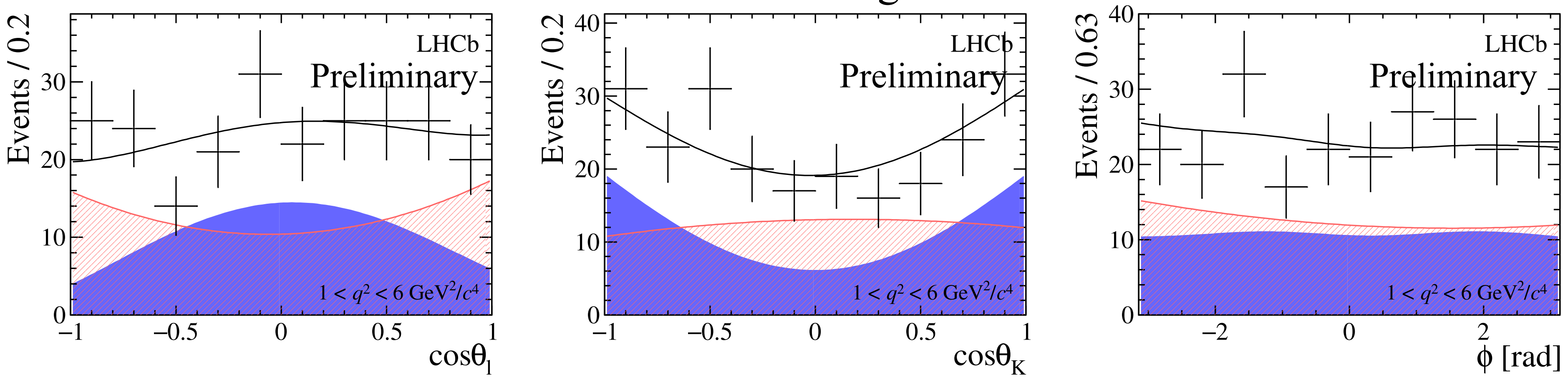
$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_l\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K + \tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_l - F_{\mathrm{L}}\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + A_5\sin 2\theta_K\sin\theta_l\cos\phi + A_6^s\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi + A_8\sin 2\theta_K\sin 2\theta_l\sin\phi + A_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big].$$

KK μμ is not a flavour-specific final state:
→ observables:
CP-averages and CP-asymmetries

angular acceptance parameterized in 4d using using Legendre coefficients:

$$\epsilon(\cos\theta_l, \cos\theta_K, \phi, q^2) = \sum_{klmn} c_{klmn} P_k(\cos\theta_l) P_l(\cos\theta_K) P_m(\phi) P_n(q^2)$$

Feldman-Cousins method to ensure correct coverage with low statistics



Angular analysis of $B_s \to \phi\,\mu\mu$

New

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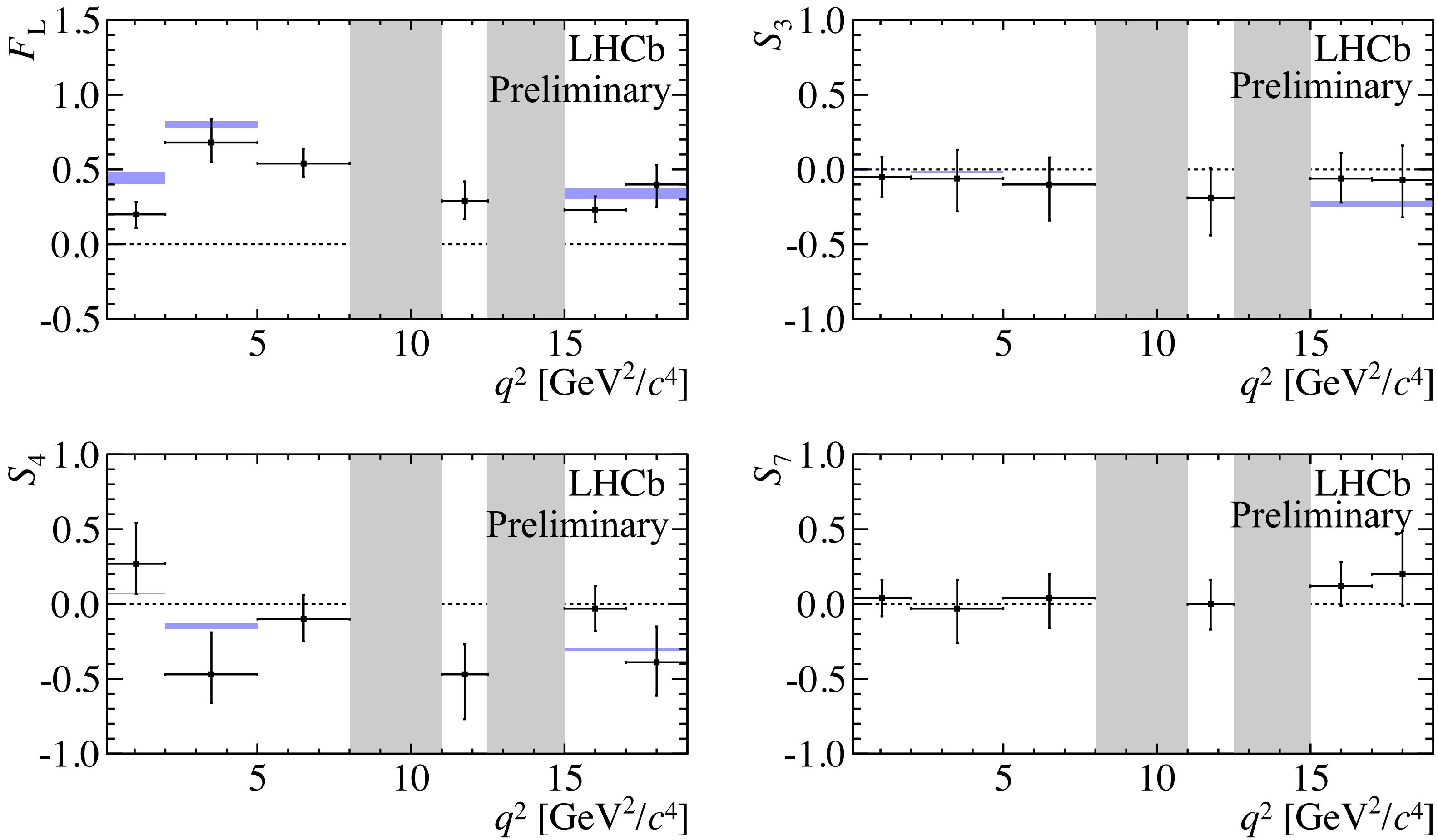


theory prediction: arXiv:1503.05534, S_7 zero in SM

Systematic uncertainties evaluated with pseudo-experiments:

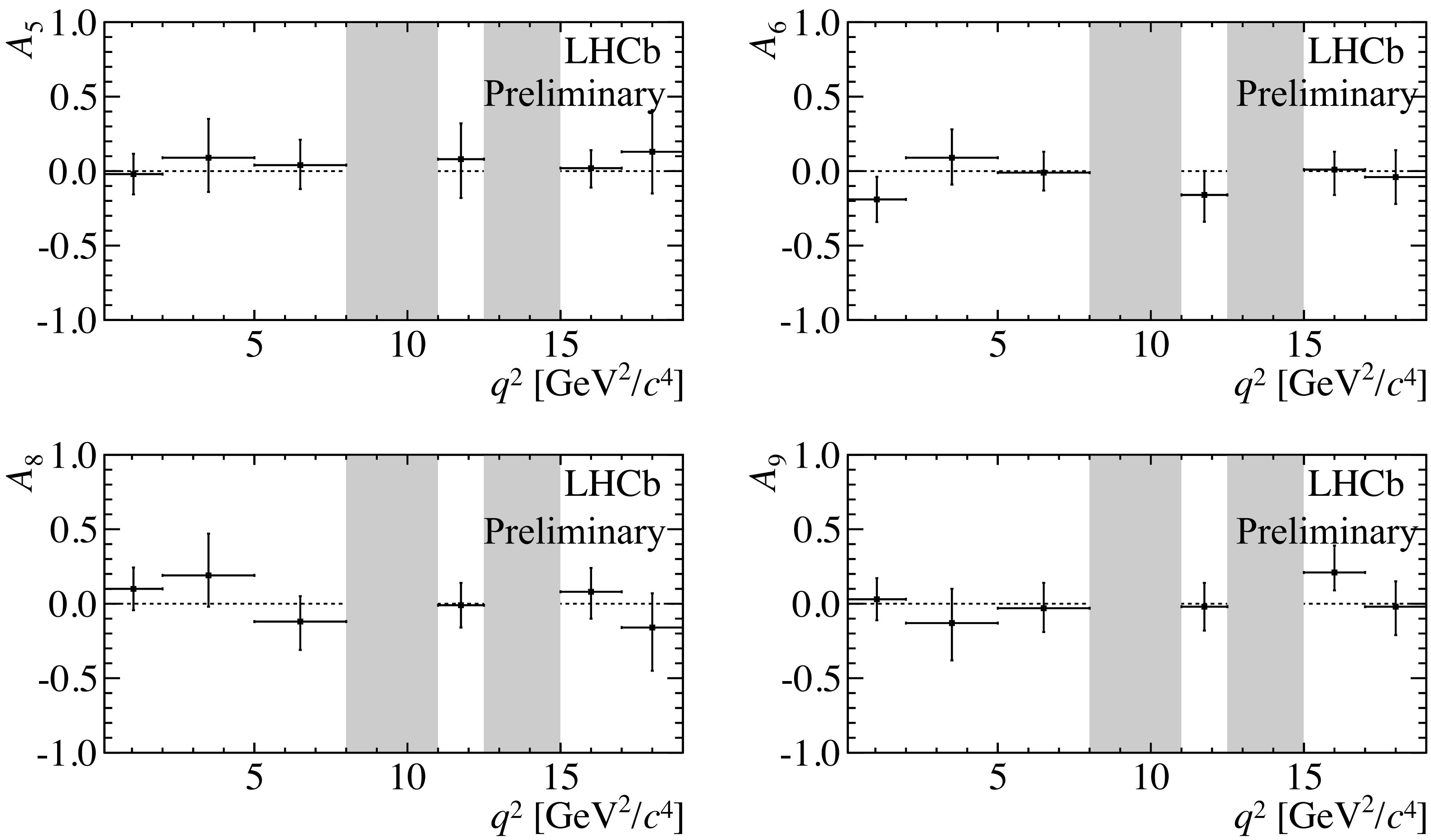
- Dominated by background model choice
- Angular acceptance affected by limited statistics of simulated sample
- S-wave pollution estimated by simulating 1.1% S-wave component

In general measurement is dominated by statistical

Angular analysis of $B_s \to \phi\,\mu\mu$

New

LHCb-PAPER-2015-023



all CP-asymmetries are zero in SM → consistent with measurement

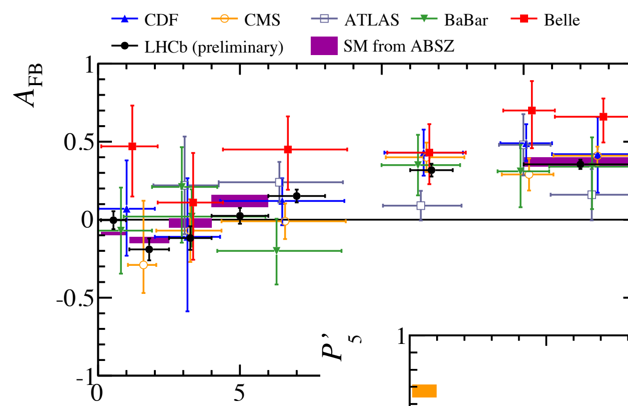
Systematic uncertainties evaluated with pseudo-experiments:

- ➢ Dominated by background model choice
- ➢ Angular acceptance affected by limited statistics of simulated sample
- ➢ S-wave pollution estimated by simulating 1.1% S-wave component

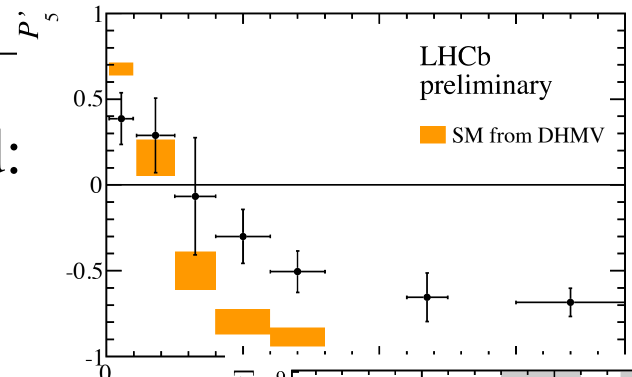
In general measurement is dominated by statistical

Summary and Outlook

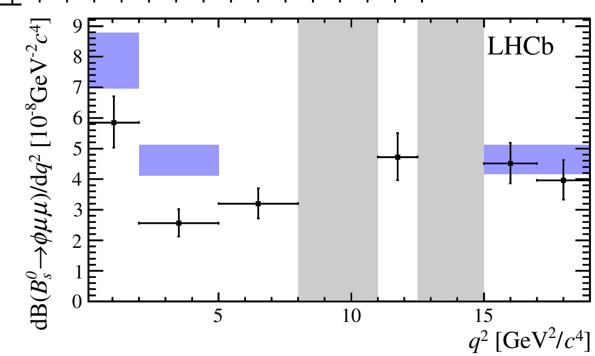
- Electroweak penguin decays are an interesting and promising probe for NP effects



- Results from many experiments, including LHCb, ATLAS, CMS



- Some tensions to the SM have been observed: global fit of WC provides consistent picture throughout all measurements



- Presented new results on $B_s \to \phi\,\mu\mu$ from LHCb

… many more interesting results in the pipeline and promising times ahead with LHC Run2

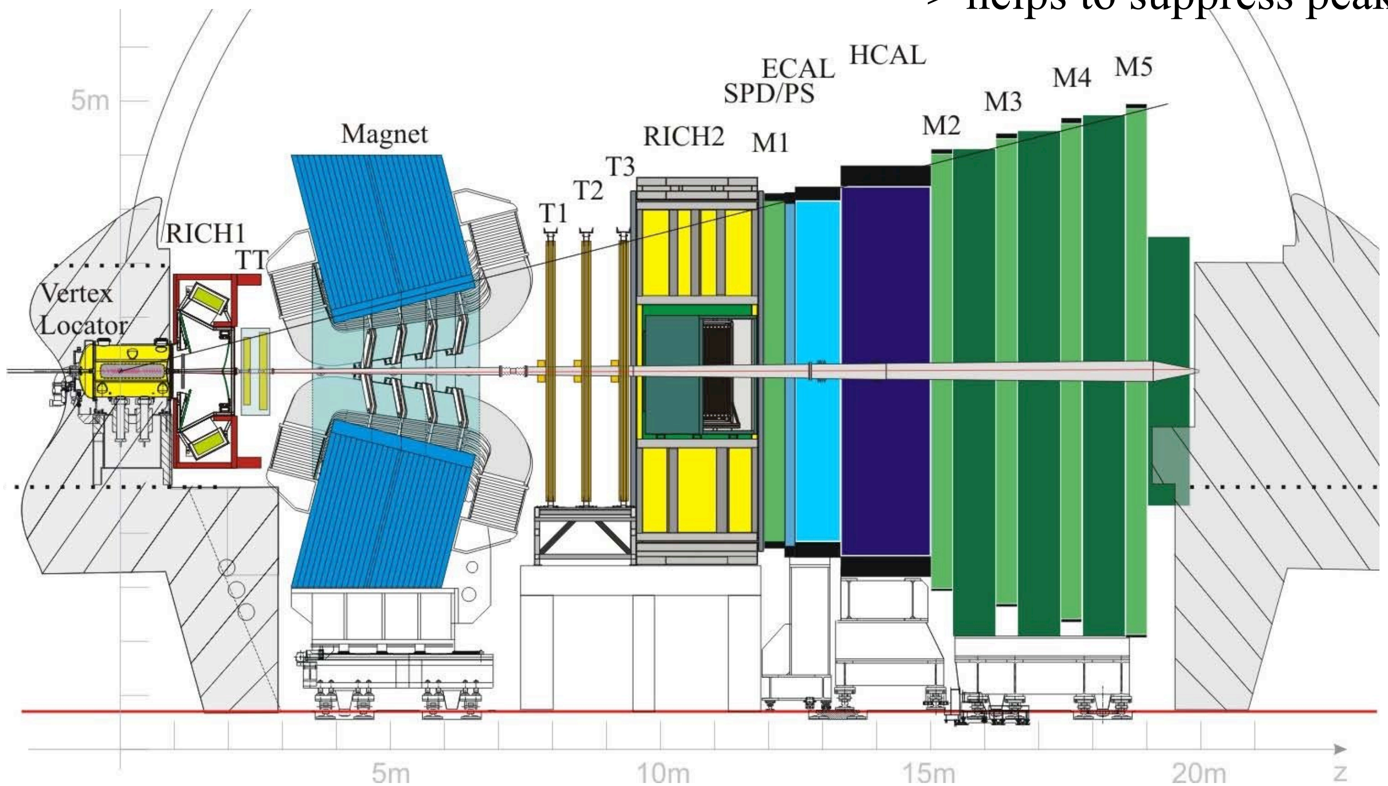
Backup

LHCb detector

Forward spectrometer with acceptance optimized for b-hadrons: $2 < \eta < 5$

decay time resolution ~ 45 fs
–> good separation of B vertices

excellent K - π separation
(~ 95 % for ~ 5 % $\pi \rightarrow K$ mis-id probability)
–> helps to suppress peaking background



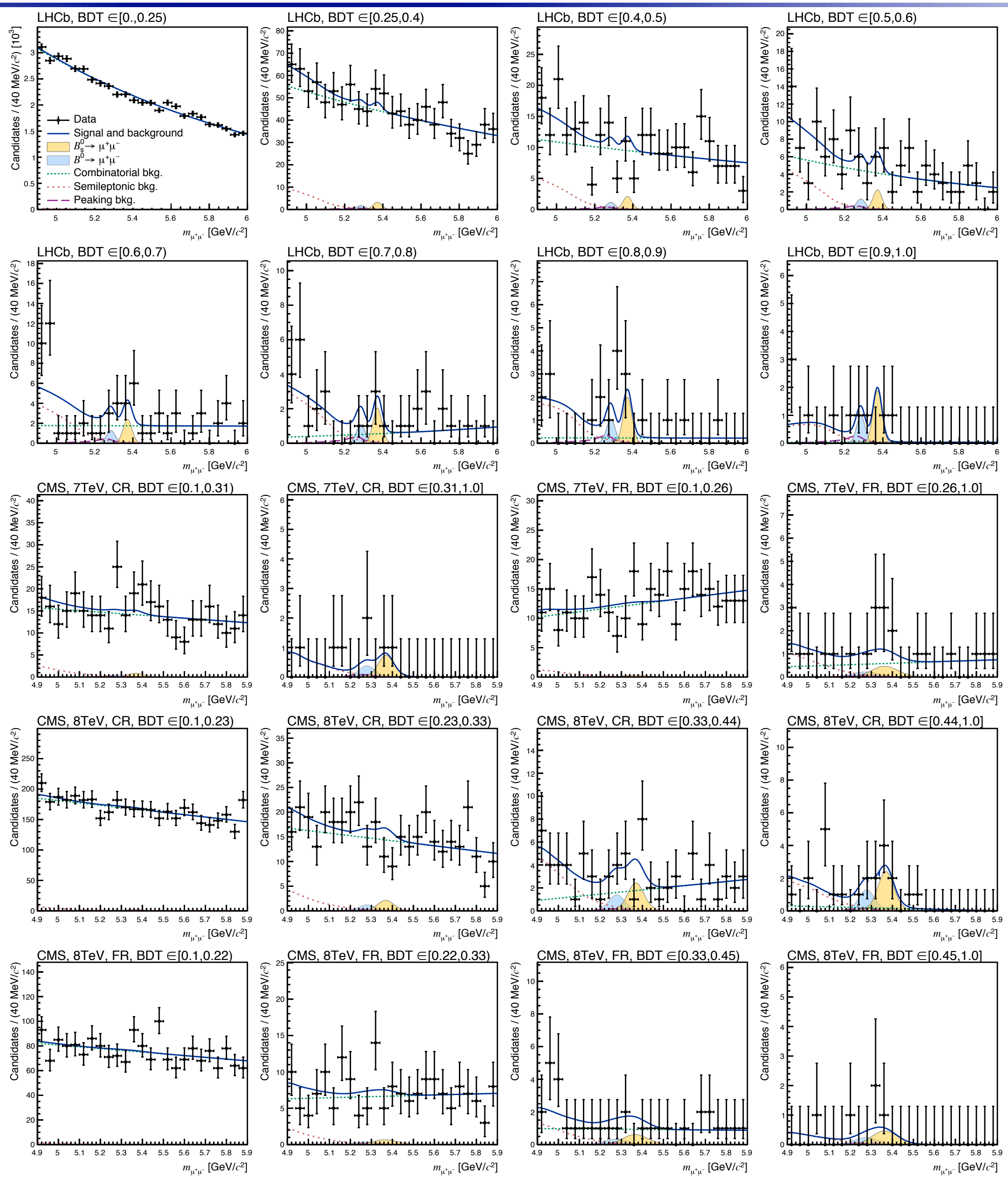
good momentum ($\Delta p / p = 0.4 – 0.6$ %)
and mass resolution

excellent muon identification
(~ 97 % for 1-3 % $\pi \rightarrow \mu$ mis-id probability)

+ very efficient trigger for di-muon channels $\varepsilon \approx 90$ %

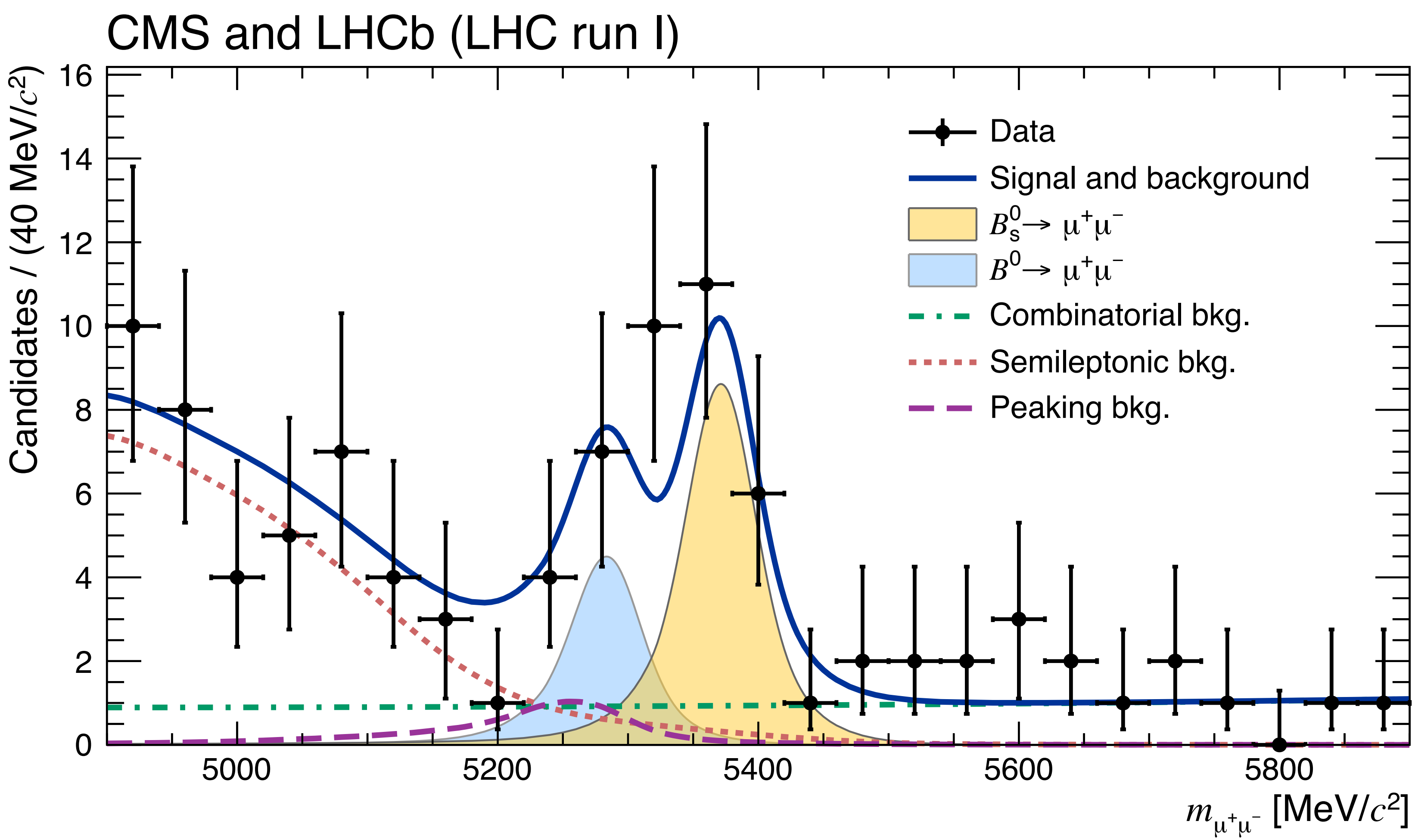
B → $\mu^+ \mu^-$ combination

Invariant di-muon mass in each of the 20 fit categories:



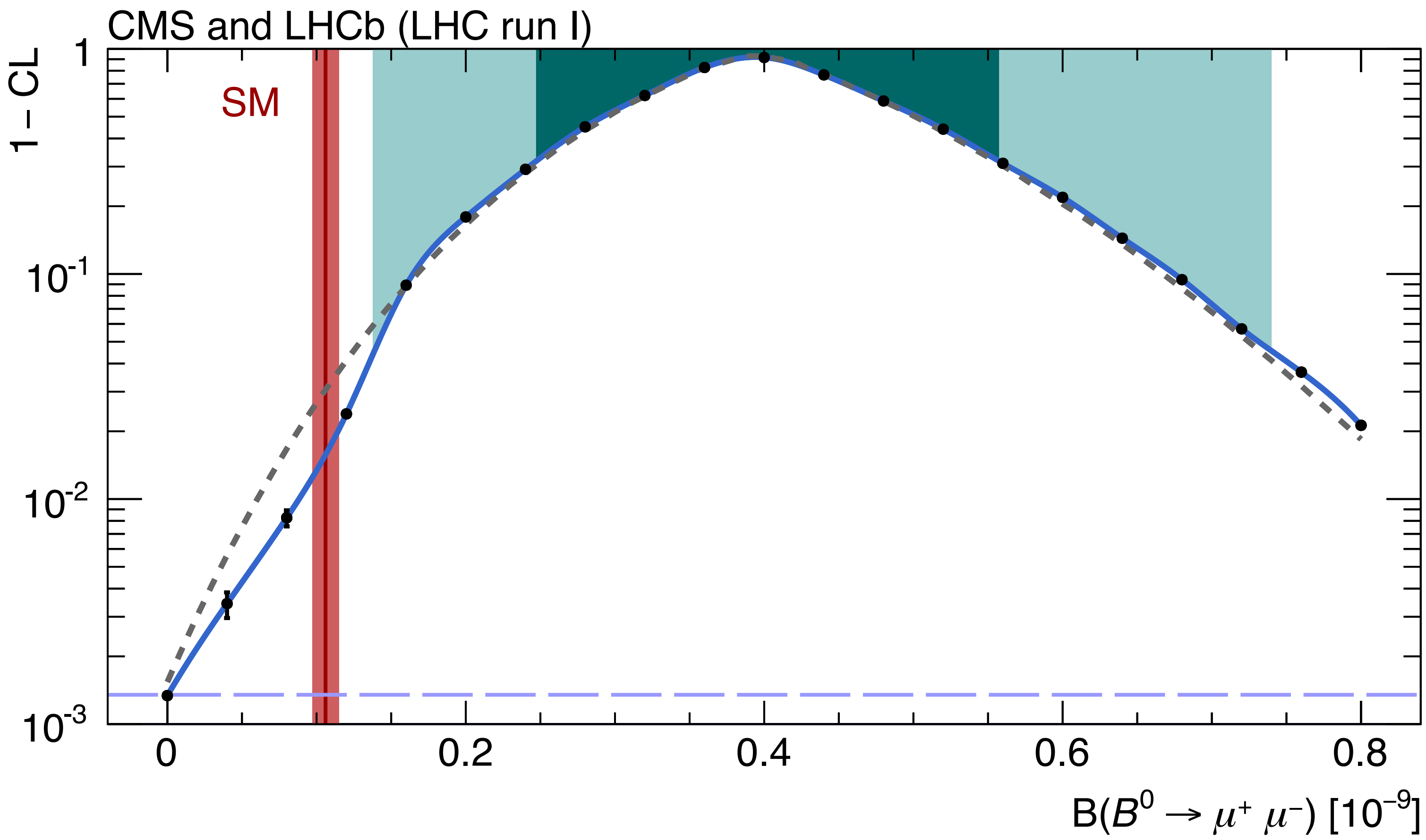
$B \rightarrow \mu^+ \mu^-$ combination

Invariant di-muon mass for the best 6 categories:



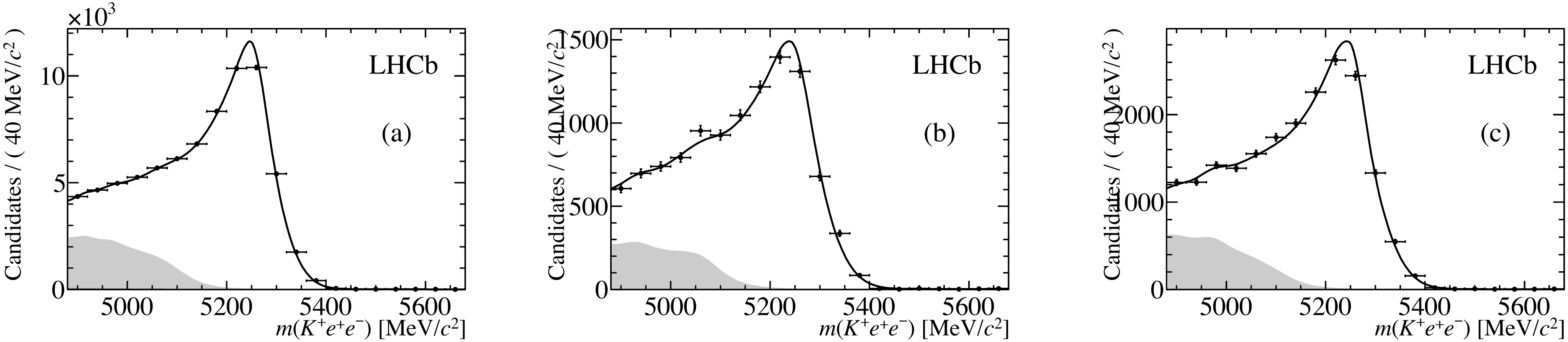
$B \to \mu^+ \mu^-$ combination

Confidence level obtained with the Feldman-Cousins method for $B^0 \to \mu\mu$:

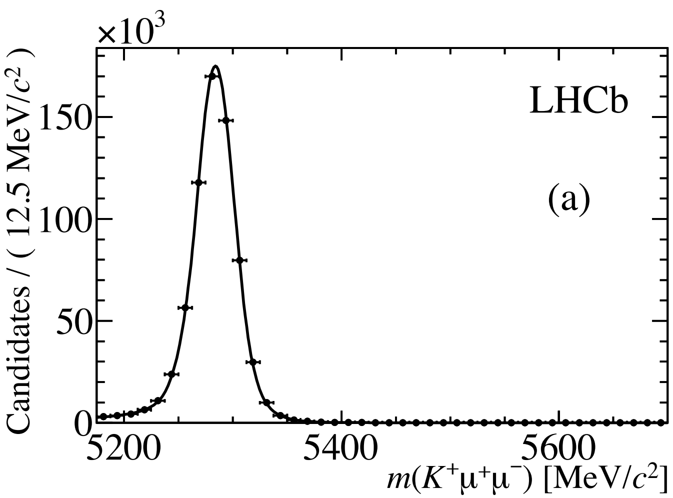


Test of lepton universality

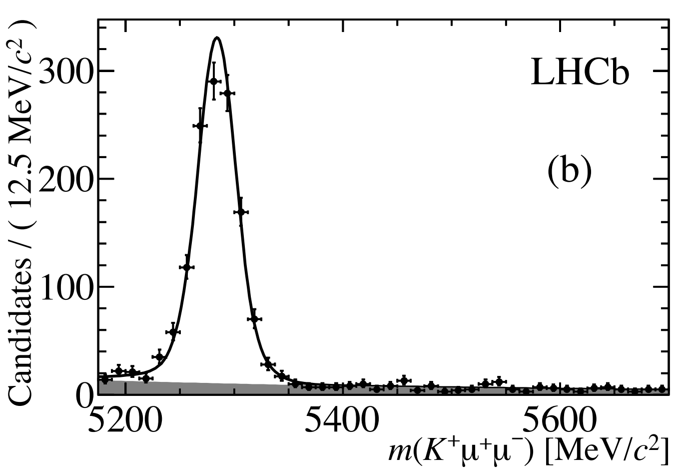
$B^+ \rightarrow J/\Psi\ (\rightarrow e\ e\ )\ K^+$ mass fits:



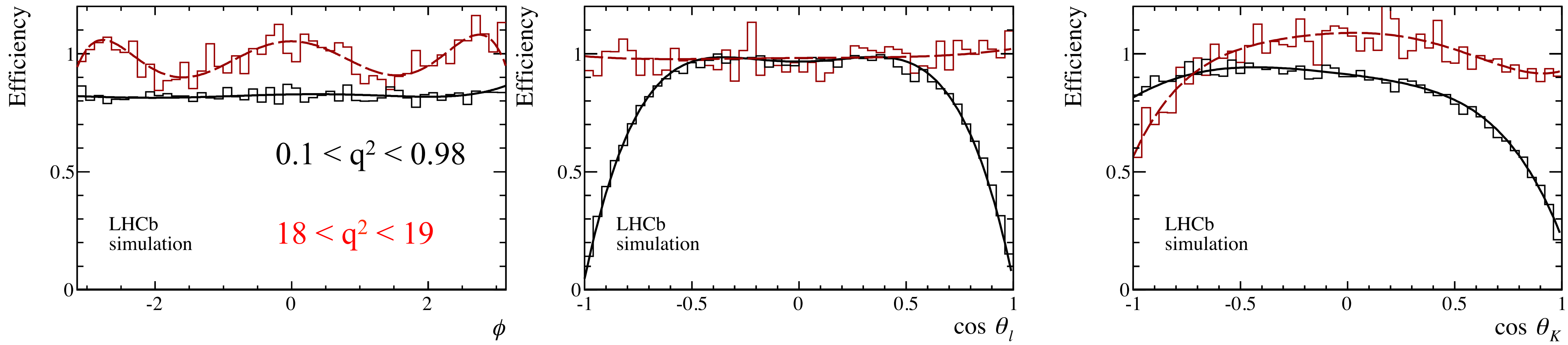
$B^+ \rightarrow J/\Psi\ (\rightarrow \mu\mu\ )\ K^+$:



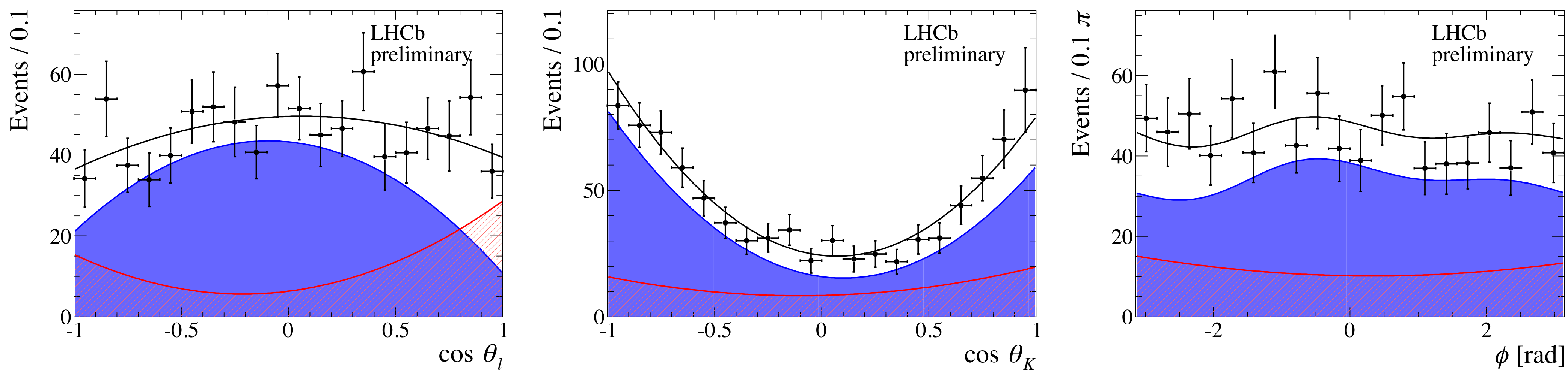
$B^+ \rightarrow K^+\ \mu\ \mu$:



Angular efficiency determined from a principal moment analysis using simulated events:



Fit projections in $1.1 < q^2 < 6.0$:



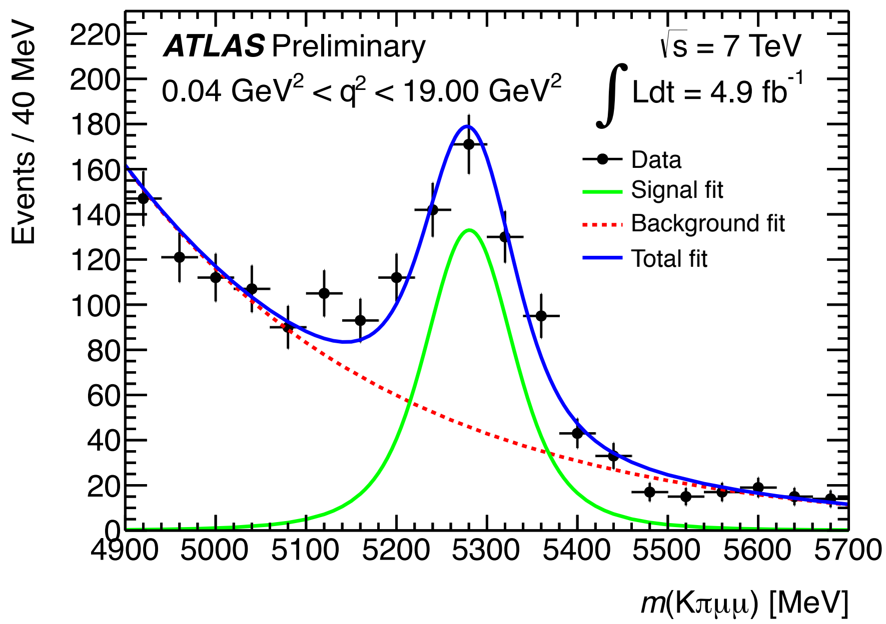
Angular analysis of B → K* μμ - ATLAS

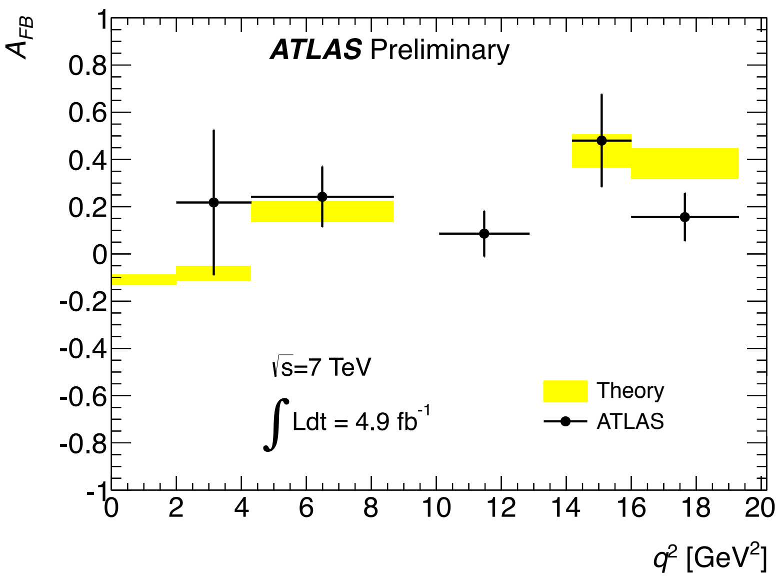
ATLAS-CONF-2013-038

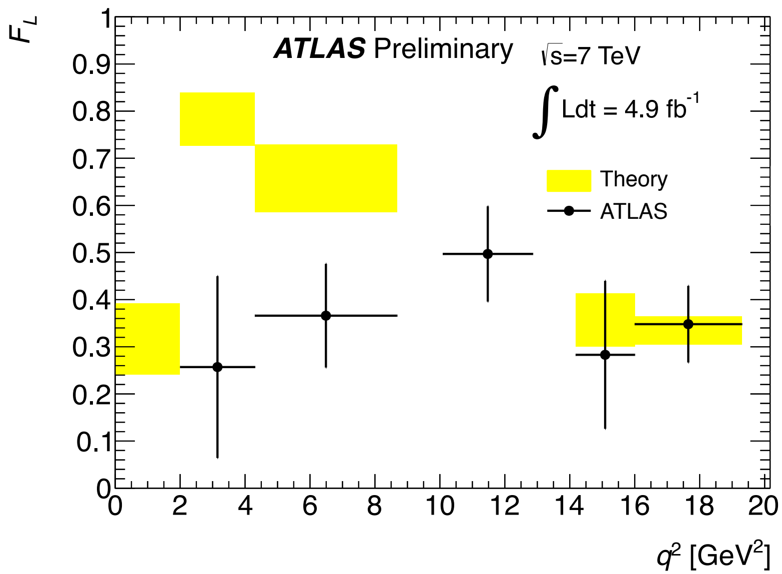
F_L and A_{FB} extracted from product of 1d decay rates:

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_L} = \frac{3}{4}F_L(q^2)\left(1-\cos^2\theta_L\right) + \frac{3}{8}\left(1-F_L(q^2)\right)\left(1+\cos^2\theta_L\right) + A_{FB}(q^2)\cos\theta_L$$

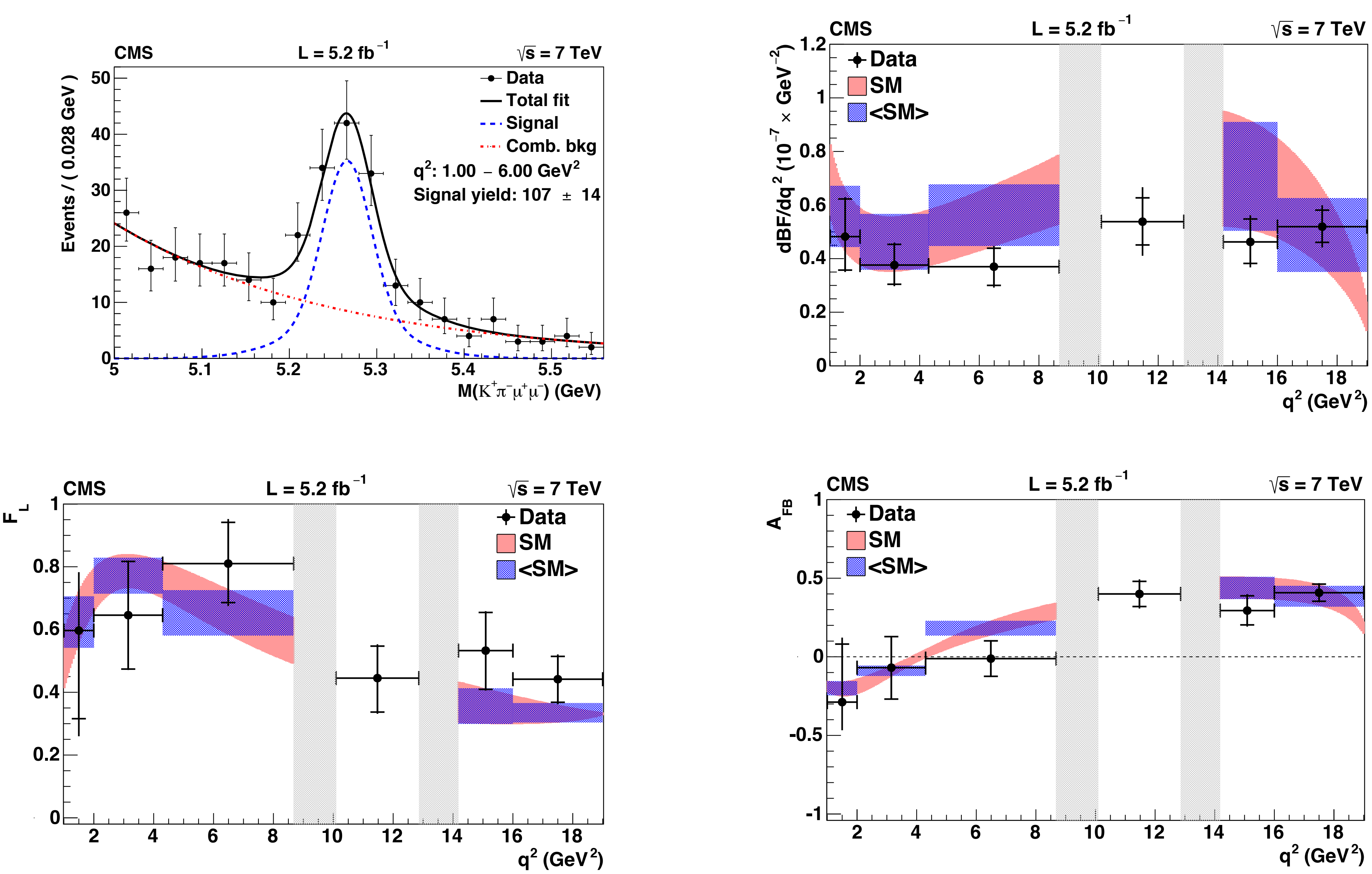
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_K} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}\left(1-F_L(q^2)\right)\left(1-\cos^2\theta_K\right)$$





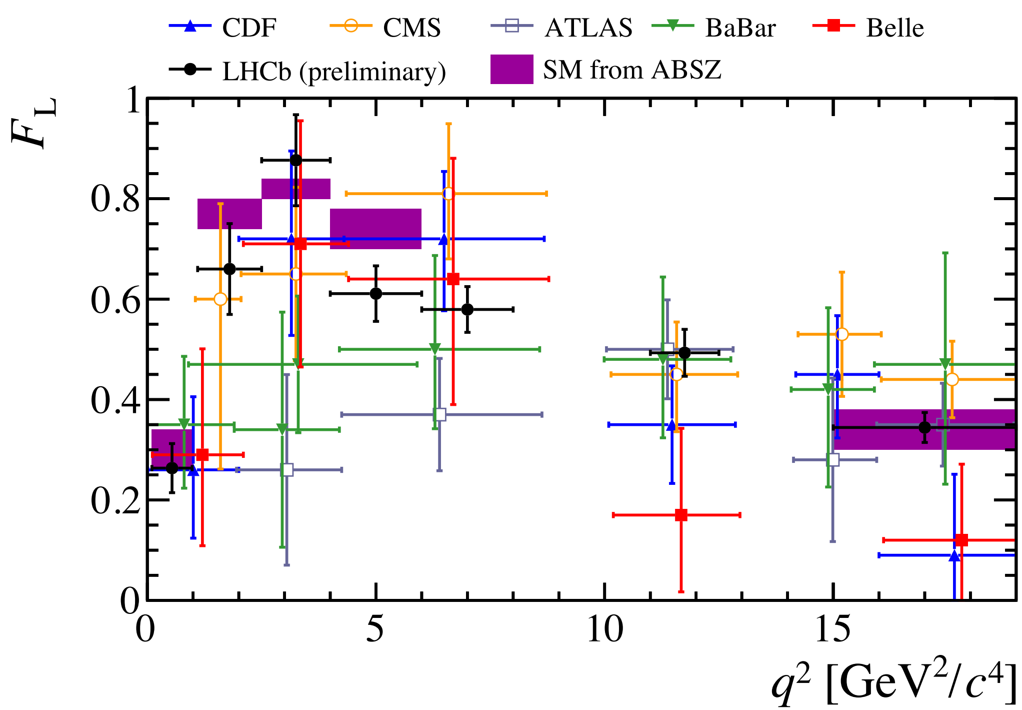


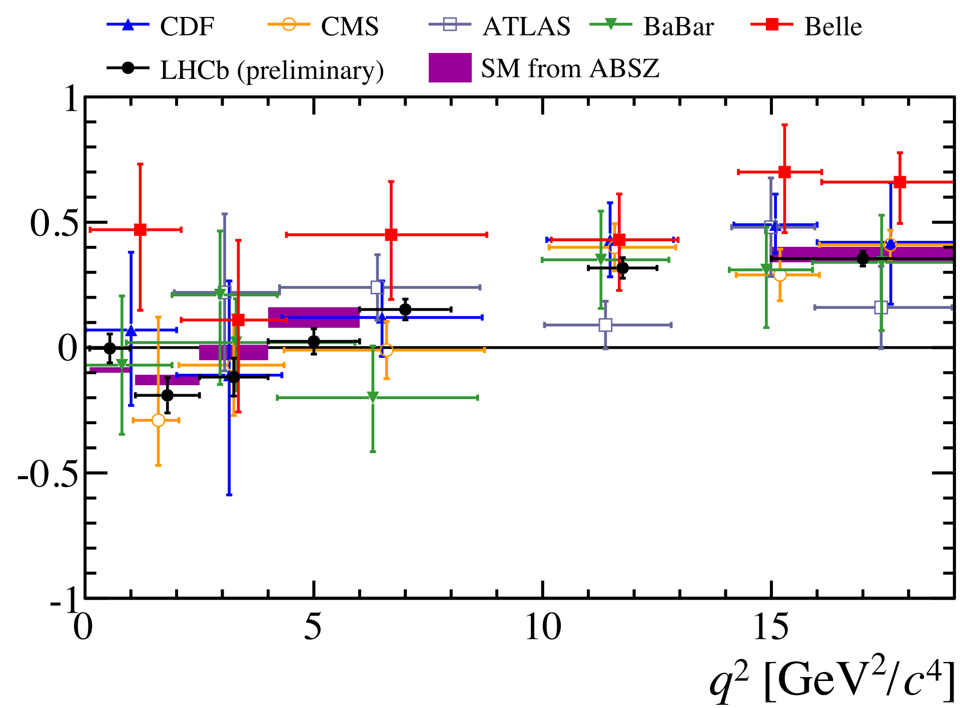
Angular analysis of B → K* μμ - CMS



Angular analysis of $B \rightarrow K^* \mu\mu$

Belle: Phys. Rev. Lett. 103 (2009) 171801, **Babar**: Phys. Rev. D. 73. 092001, **CDF**: Phys. Rev. Lett. 108 081807, **CMS**: Phys. Lett. B 727 (2013) 77, **ATLAS**: ATLAS-CONF-2013-038, **LHCb**: LHCb-CONF-2015-002

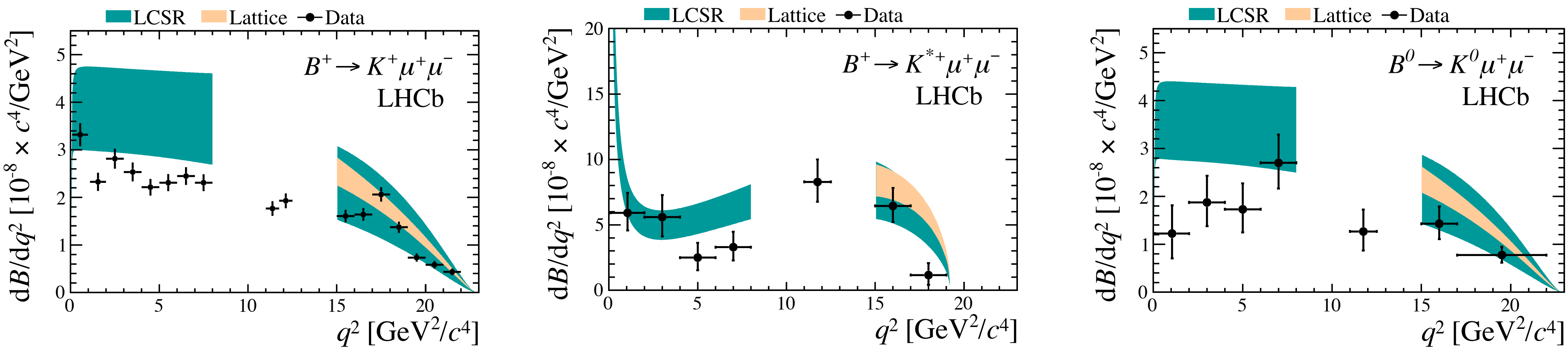




b –> s μμ branching fractions

- Branching fraction measurement for B^0 –> K^0 μμ, B^+ –> K^+ μμ and B^+ –> K^{*+} μμ
  (B^0–> K^{*0} μμ to be updated soon with detailed study of s-wave contribution)
- Full Run-2 dataset ($3fb^{-1}$)
- normalized to resonant B –> J/Ψ K channels

Decay mode	Signal yield
$B^+ \to K^+\mu^+\mu^-$	4746 ± 81
$B^0 \to K^0_S\mu^+\mu^-$	176 ± 17
$B^+ \to K^{*+}(\to K^0_S\pi^+)\mu^+\mu^-$	162 ± 16
$B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$	2361 ± 56



extrapolated to full q2 range:

$$\mathcal{B}(B^+ \to K^+\mu^+\mu^-) = (4.29 \pm 0.07(\text{stat}) \pm 0.21(\text{syst})) \cdot 10^{-7}$$

$$\mathcal{B}(B^0 \to K^0\mu^+\mu^-) = (3.27 \pm 0.34(\text{stat}) \pm 0.17(\text{syst})) \cdot 10^{-7}$$

$$\mathcal{B}(B^+ \to K^{*+}\mu^+\mu^-) = (39.24 \pm 0.93(\text{stat}) \pm 0.67(\text{syst})) \cdot 10^{-7}$$

–> more precise than world average
–> consistent with predictions but favors lower values

main systematic uncertainty: B –> J/Ψ K branching fraction

q^2 bin $[\mathrm{GeV}^2/c^4]$	$N_{\phi\mu\mu}$	$\frac{\mathrm{d}\mathcal{B}(B_s^0\to\phi\mu\mu)}{\mathcal{B}(B_s^0\to J/\psi\,\phi)\mathrm{d}q^2}$ $[10^{-5}\,\mathrm{GeV}^{-2}c^4]$	$\frac{\mathrm{d}\mathcal{B}(B_s^0\to\phi\mu^+\mu^-)}{\mathrm{d}q^2}$ $[10^{-8}\,\mathrm{GeV}^{-2}c^4]$
$0.1 < q^2 < 2.0$	$85.1^{+10.6}_{-10.0}$	$5.43^{+0.68}_{-0.64} \pm 0.13$	$5.85^{+0.73}_{-0.69} \pm 0.14 \pm 0.44$
$2.0 < q^2 < 5.0$	$59.5^{+9.8}_{-9.2}$	$2.38^{+0.39}_{-0.37} \pm 0.06$	$2.56^{+0.42}_{-0.39} \pm 0.06 \pm 0.19$
$5.0 < q^2 < 8.0$	$82.6^{+11.5}_{-10.9}$	$2.98^{+0.41}_{-0.39} \pm 0.07$	$3.20^{+0.44}_{-0.42} \pm 0.08 \pm 0.24$
$11.0 < q^2 < 12.5$	$70.5^{+10.4}_{-9.8}$	$4.38^{+0.64}_{-0.61} \pm 0.14$	$4.72^{+0.69}_{-0.65} \pm 0.15 \pm 0.36$
$15.0 < q^2 < 17.0$	$83.0^{+10.4}_{-9.9}$	$4.19^{+0.53}_{-0.50} \pm 0.11$	$4.51^{+0.57}_{-0.54} \pm 0.12 \pm 0.34$
$17.0 < q^2 < 19.0$	$54.2^{+7.8}_{-7.4}$	$3.68^{+0.53}_{-0.50} \pm 0.13$	$3.96^{+0.57}_{-0.54} \pm 0.14 \pm 0.30$
$1.0 < q^2 < 6.0$	$100.9^{+12.8}_{-12.2}$	$2.40^{+0.30}_{-0.29} \pm 0.07$	$2.58^{+0.33}_{-0.31} \pm 0.08 \pm 0.19$
$15.0 < q^2 < 19.0$	$135.4^{+13.2}_{-12.7}$	$3.75^{+0.37}_{-0.35} \pm 0.12$	$4.04^{+0.39}_{-0.38} \pm 0.13 \pm 0.30$

Branching fraction of $B_s \to \phi \mu\mu$

LHCb-PAPER-2015-023 New

Systematic	Uncertainty $[10^{-5}\,\mathrm{GeV}^{-2}c^4]$ [0.1, 2]	[2, 5]	[5, 8]	[11, 12.5]	[15, 17]	[17, 19]	[1, 6]	[15, 17]
Peaking bkg.	0.03	0.02	0.02	0.10	0.02	0.01	0.02	0.01
Simulation corr.	0.01	0.01	0.01	0.01	0.05	0.04	0.00	0.04
Angular model	0.04	0.00	0.01	0.00	0.01	0.06	0.00	0.01
Efficiency ratio	0.06	0.03	0.03	0.06	0.06	0.07	0.02	0.04
$\mathcal{B}\,(J/\psi \to \mu^+\mu^-)$	0.03	0.01	0.02	0.02	0.02	0.02	0.01	0.02
Signal mass model	0.02	0.01	0.03	0.03	0.03	0.00	0.05	0.05
Bkg. mass model	0.02	0.02	0.02	0.02	0.03	0.05	0.01	0.06
Quadratic sum	0.09	0.04	0.06	0.12	0.09	0.11	0.06	0.10

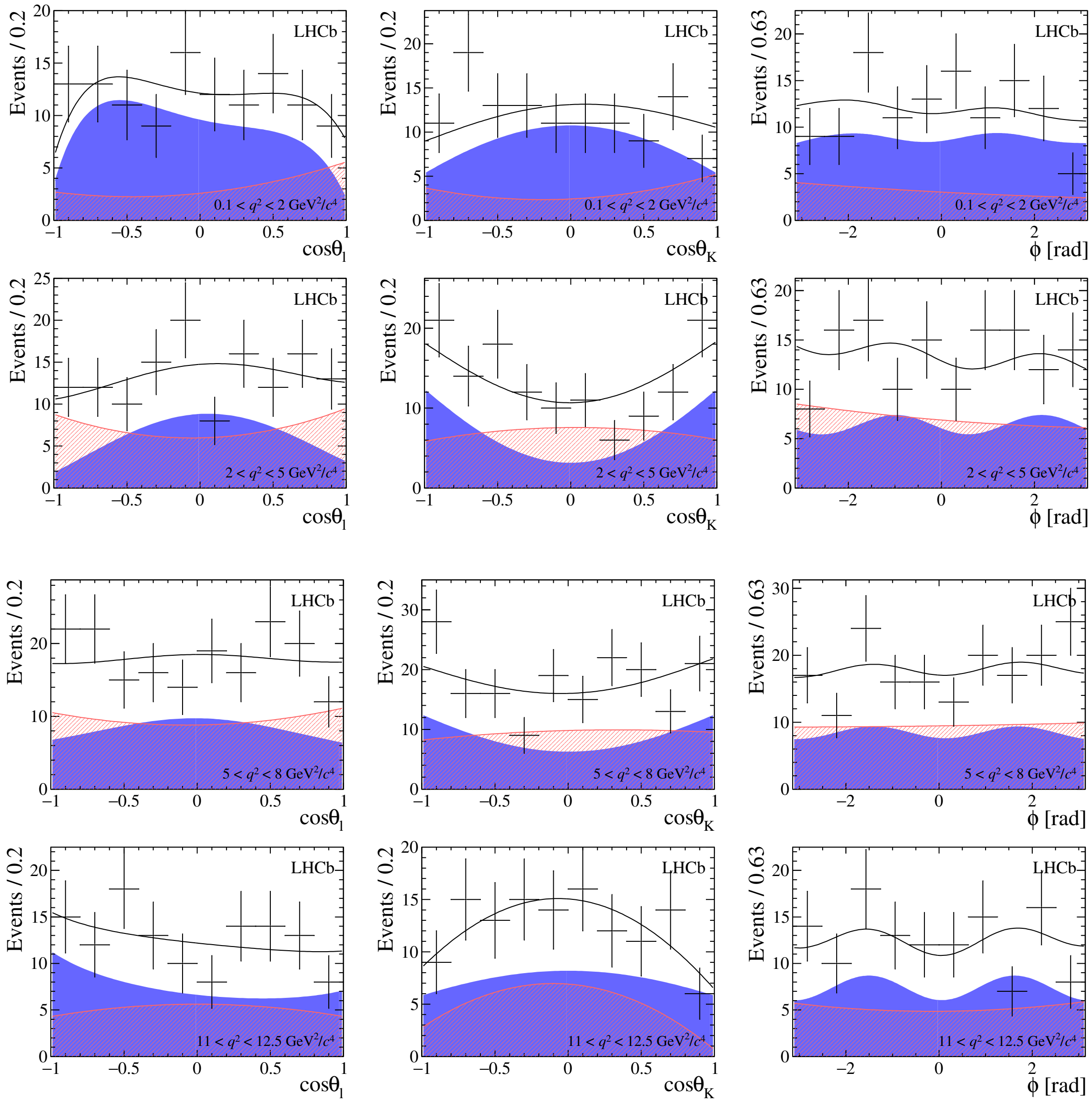
Efficiency related uncertainties:
- Dominated by the limited size of the simulated signal sample
- Angular acceptance effects estimated by varying Wilson coefficients in generation
- Effect of corrections of simulated sample in general small

Mass model uncertainties:
- Estimated with pseudo-experiments

Dominant uncertainty for total branching fraction:
- Branching fraction of $B_s \to J/\Psi\,\phi$ normalization channel: 7.5%

Angular analysis of $B_s \to \phi\, \mu\mu$

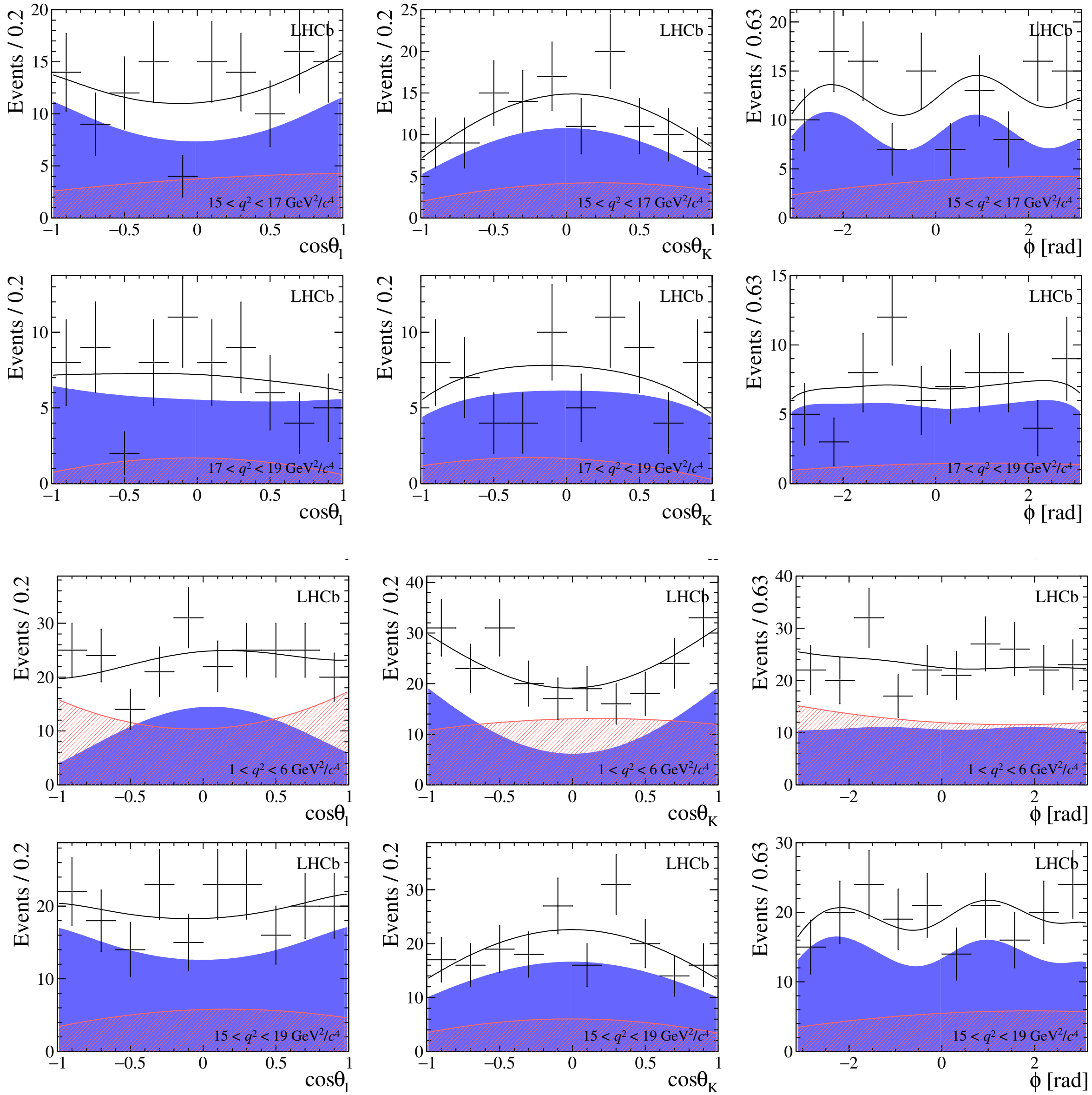
New



Angular analysis of $B_s \to \phi \mu\mu$

New

LHCb-PAPER-2015-023



Systematic uncertainties evaluated with pseudo-experiments:

Mostly related to angular acceptance:

- Data-driven corrections of simulated signal sample: < 0.01
- Limited statistics of simulated sample: < 0.02

Remaining peaking background:

- Estimated by injecting simulated $\Lambda_b \to \Lambda(1520)\, \mu\mu$ and $B \to K^*\, \mu\mu$ events: < 0.01

S-wave pollution:

- Expected to be similar to $B_s \to J/\Psi\, \phi$, estimated by simulating a 1.1% S-wave: < 0.01

Background parameterization:

- Dominant uncertainty from model choice: < 0.04

Angular analysis of $B_s \to \phi \mu\mu$

New

LHCb-PAPER-2015-023

q^2 bin $[\mathrm{GeV}^2/c^4]$	F_{L}	S_3	S_4	S_7
$0.1 < q^2 < 2.0$	$0.20^{+0.08}_{-0.09} \pm 0.02$	$-0.05^{+0.13}_{-0.13} \pm 0.01$	$0.27^{+0.28}_{-0.18} \pm 0.01$	$0.04^{+0.12}_{-0.12} \pm 0.00$
$2.0 < q^2 < 5.0$	$0.68^{+0.16}_{-0.13} \pm 0.03$	$-0.06^{+0.19}_{-0.23} \pm 0.01$	$-0.47^{+0.30}_{-0.44} \pm 0.01$	$-0.03^{+0.18}_{-0.23} \pm 0.01$
$5.0 < q^2 < 8.0$	$0.54^{+0.10}_{-0.09} \pm 0.02$	$-0.10^{+0.20}_{-0.29} \pm 0.01$	$-0.10^{+0.15}_{-0.18} \pm 0.01$	$0.04^{+0.16}_{-0.20} \pm 0.01$
$11.0 < q^2 < 12.5$	$0.29^{+0.11}_{-0.11} \pm 0.04$	$-0.19^{+0.20}_{-0.23} \pm 0.01$	$-0.47^{+0.21}_{-0.29} \pm 0.01$	$0.00^{+0.15}_{-0.17} \pm 0.01$
$15.0 < q^2 < 17.0$	$0.23^{+0.09}_{-0.08} \pm 0.02$	$-0.06^{+0.16}_{-0.19} \pm 0.01$	$-0.03^{+0.15}_{-0.15} \pm 0.01$	$0.12^{+0.16}_{-0.13} \pm 0.01$
$17.0 < q^2 < 19.0$	$0.40^{+0.13}_{-0.15} \pm 0.02$	$-0.07^{+0.23}_{-0.27} \pm 0.02$	$-0.39^{+0.25}_{-0.34} \pm 0.02$	$0.20^{+0.29}_{-0.22} \pm 0.01$
$1.0 < q^2 < 6.0$	$0.63^{+0.09}_{-0.09} \pm 0.03$	$-0.02^{+0.12}_{-0.13} \pm 0.01$	$-0.19^{+0.14}_{-0.13} \pm 0.01$	$-0.03^{+0.14}_{-0.14} \pm 0.00$
$15.0 < q^2 < 19.0$	$0.29^{+0.07}_{-0.06} \pm 0.02$	$-0.09^{+0.11}_{-0.12} \pm 0.01$	$-0.14^{+0.11}_{-0.11} \pm 0.01$	$0.13^{+0.11}_{-0.11} \pm 0.01$

q^2 bin $[\mathrm{GeV}^2/c^4]$	A_5	A_6	A_8	A_9
$0.1 < q^2 < 2.0$	$-0.02^{+0.13}_{-0.13} \pm 0.00$	$-0.19^{+0.15}_{-0.15} \pm 0.01$	$0.10^{+0.14}_{-0.14} \pm 0.00$	$0.03^{+0.14}_{-0.14} \pm 0.01$
$2.0 < q^2 < 5.0$	$0.09^{+0.28}_{-0.22} \pm 0.01$	$0.09^{+0.20}_{-0.19} \pm 0.02$	$0.19^{+0.26}_{-0.21} \pm 0.01$	$-0.13^{+0.24}_{-0.30} \pm 0.01$
$5.0 < q^2 < 8.0$	$0.04^{+0.17}_{-0.17} \pm 0.01$	$-0.01^{+0.14}_{-0.12} \pm 0.01$	$-0.12^{+0.17}_{-0.19} \pm 0.01$	$-0.03^{+0.17}_{-0.16} \pm 0.01$
$11.0 < q^2 < 12.5$	$0.08^{+0.21}_{-0.21} \pm 0.01$	$-0.16^{+0.16}_{-0.18} \pm 0.01$	$-0.01^{+0.15}_{-0.15} \pm 0.01$	$-0.02^{+0.16}_{-0.15} \pm 0.01$
$15.0 < q^2 < 17.0$	$0.02^{+0.13}_{-0.14} \pm 0.01$	$0.01^{+0.12}_{-0.17} \pm 0.01$	$0.08^{+0.16}_{-0.18} \pm 0.01$	$0.21^{+0.18}_{-0.12} \pm 0.01$
$17.0 < q^2 < 19.0$	$0.13^{+0.29}_{-0.27} \pm 0.01$	$-0.04^{+0.18}_{-0.19} \pm 0.01$	$-0.16^{+0.24}_{-0.29} \pm 0.01$	$-0.02^{+0.19}_{-0.19} \pm 0.01$
$1.0 < q^2 < 6.0$	$0.20^{+0.13}_{-0.13} \pm 0.00$	$0.08^{+0.12}_{-0.11} \pm 0.01$	$-0.00^{+0.15}_{-0.17} \pm 0.00$	$-0.01^{+0.13}_{-0.13} \pm 0.01$
$15.0 < q^2 < 19.0$	$0.11^{+0.10}_{-0.10} \pm 0.00$	$0.00^{+0.10}_{-0.11} \pm 0.01$	$0.03^{+0.12}_{-0.12} \pm 0.00$	$0.12^{+0.11}_{-0.09} \pm 0.00$