Electroweak penguin decays to leptons at LHCb

SUSY 2014, Manchester

Christian Linn, CERN

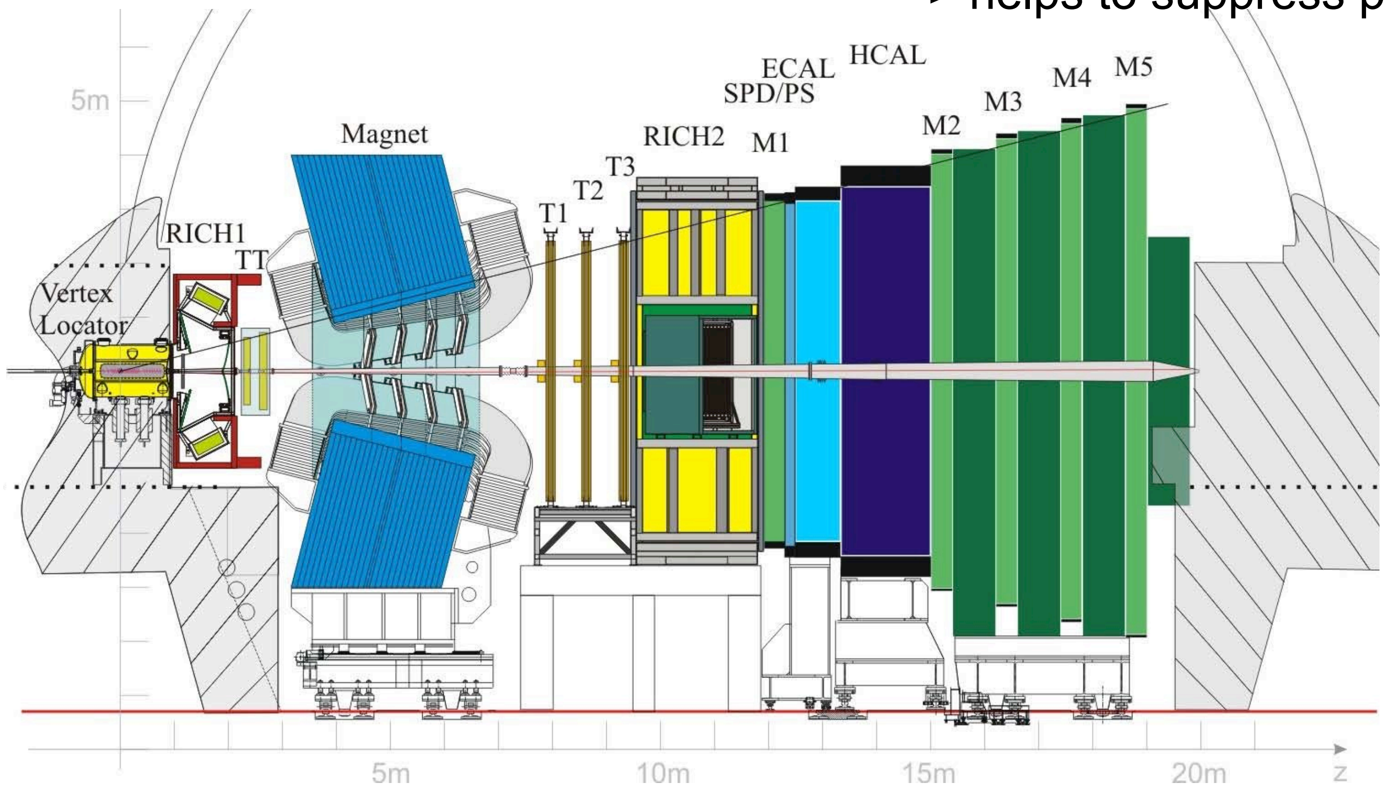
on behalf of the LHCb Collaboration

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



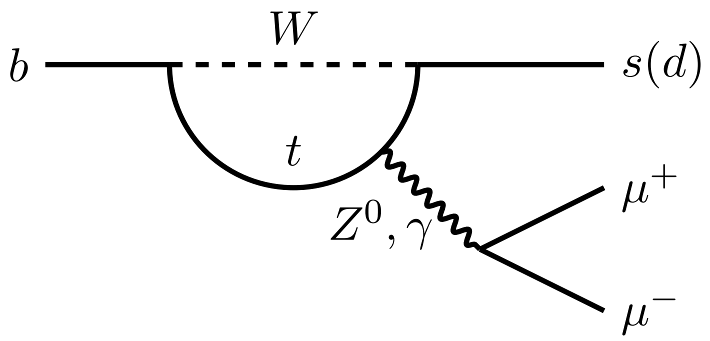
good momentum ($\Delta p / p = 0.4 – 0.6$ %)
and mass resolution

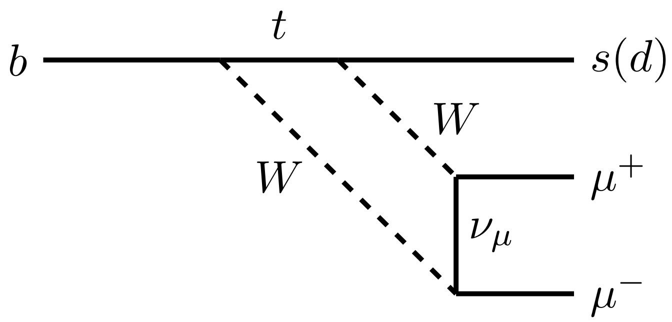
excellent muon identification
(~ 97 % for 1-3 % $\pi \rightarrow \mu$ mis-id probability)

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

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





b −> sll decays can theoretically be described by effective hamiltonian:

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

- 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

What I will show today

- Angular analysis of $B^0 \to K^* \mu\mu$ ($1 fb^{-1}$)
  JHEP 08 (2013) 131, Phys. Rev. Lett. 111 (2013) 191801

  and $B^+ \to K^+ \mu\mu$, $B^0 \to K_s^0 \mu\mu$ ($3 fb^{-1}$)
  arXiv:1403.8045v2

- CP asymmetry of $B^0 \to K^* \mu\mu$, $B^+ \to K^+ \mu\mu$ ($3 fb^{-1}$)
  LHCb-PAPER-2014-032, **PRELIMINARY**

- Branching fractions and isospin asymmetry of $B \to K \mu\mu$ ($3 fb^{-1}$)
  arXiv:1403.8044v3

- Ratio of branching fractions $B^+ \to K^+ \mu\mu$ and $B^+ \to K^+ ee$ ($3 fb^{-1}$)
  arXiv:1406.6482v1

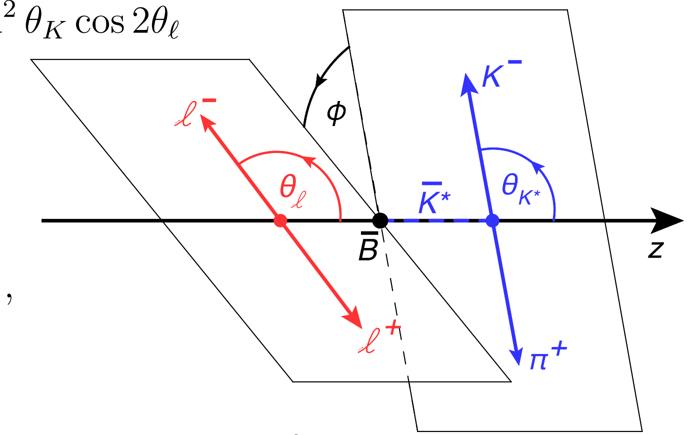
- Branching fractions of $B^+ \to hhh \mu\mu$ ($3 fb^{-1}$)
  LHCb-PAPER-2014-030, **PRELIMINARY**

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

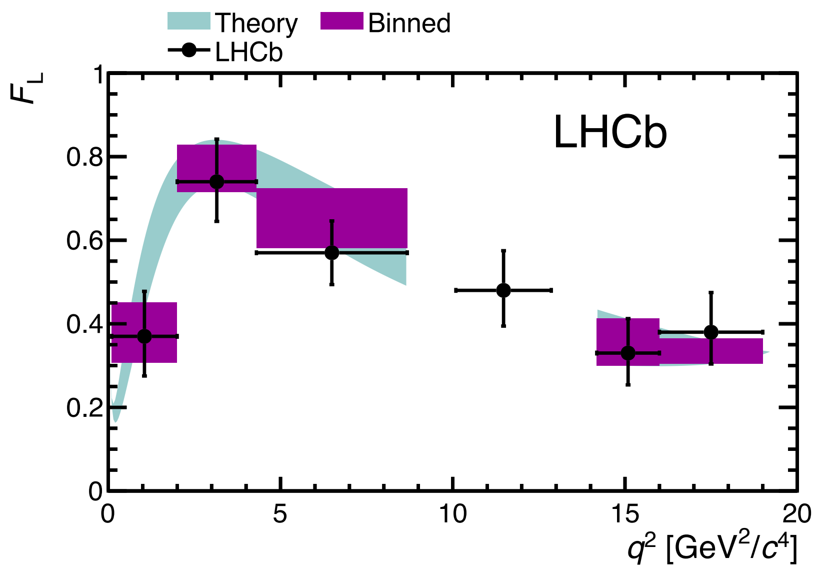
LHCb-PAPER-2013-019
JHEP 08 (2013) 131

B^0 –> K^* μμ described by three angles (θ_K, θ_l, Φ) and di-muon mass squared, q^2:

$$\frac{1}{\mathrm{d}\Gamma/dq^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

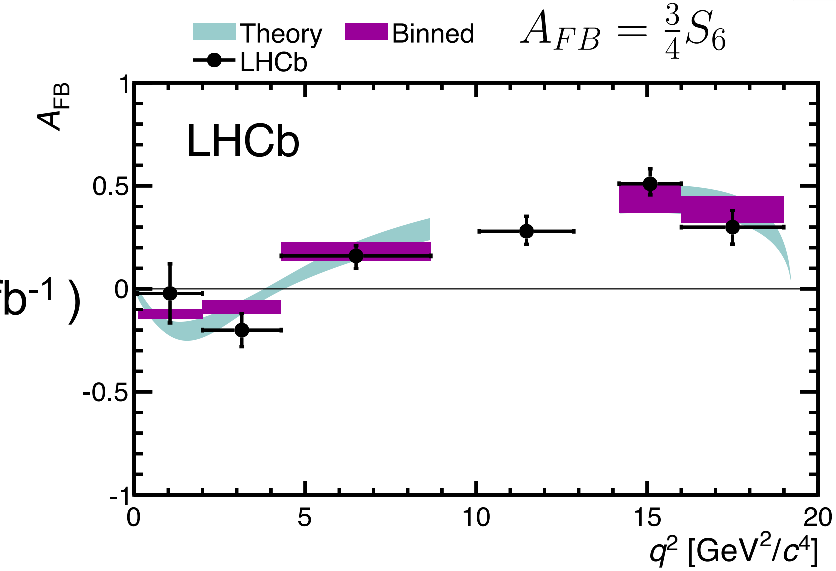


Observables extracted from 4d fit – in bins of q^2



($1\mathrm{fb}^{-1}$)

$A_{FB} = \frac{3}{4}S_6$



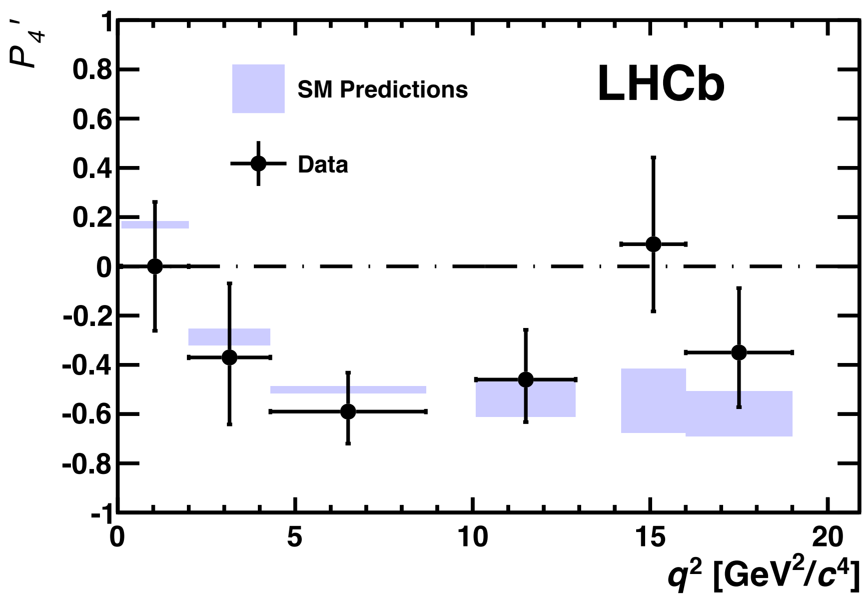
Zero-crossing point of A_{FB} in SM largely free from form-factor uncertainties:

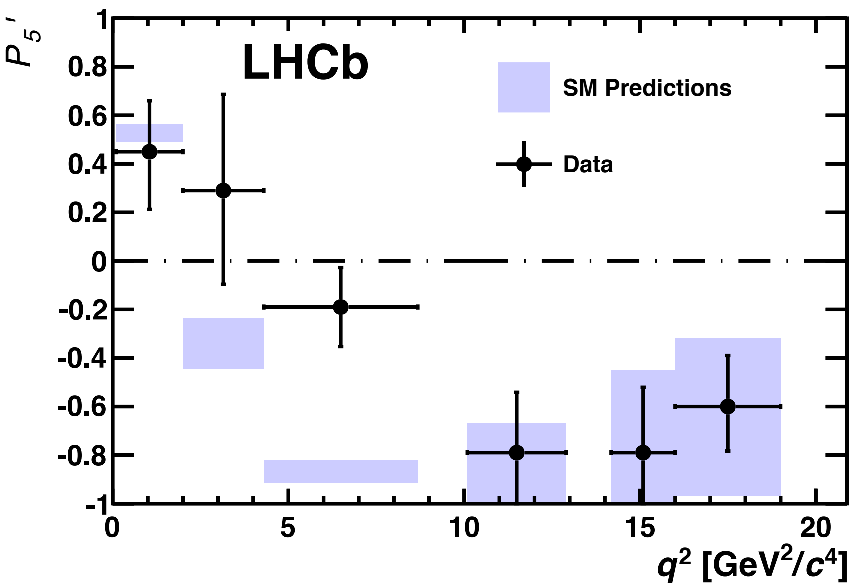
$q_0^2 = 4.9 \pm 0.9\ \mathrm{GeV}^2/\mathrm{c}^4$ –> consistent with SM predictions (3.9 – 4.4 GeV^2/c^4)

FF independent observables

Form-factor independent observables: $P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_{\rm L}(1-F_{\rm L})}}$

Observables extracted separately from different fits to dataset:



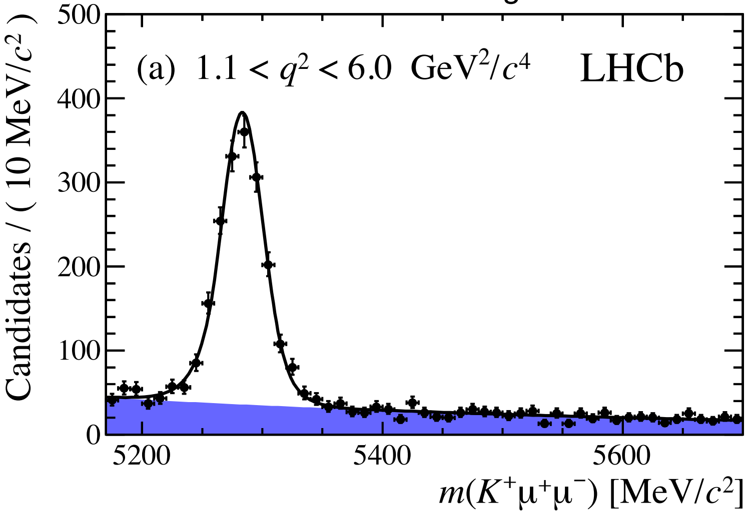


- In general good agreement with SM expectation, discrepancy for P_5' in 3rd q^2 bin
- P-value for observed deviation is 0.02% (3.7σ)

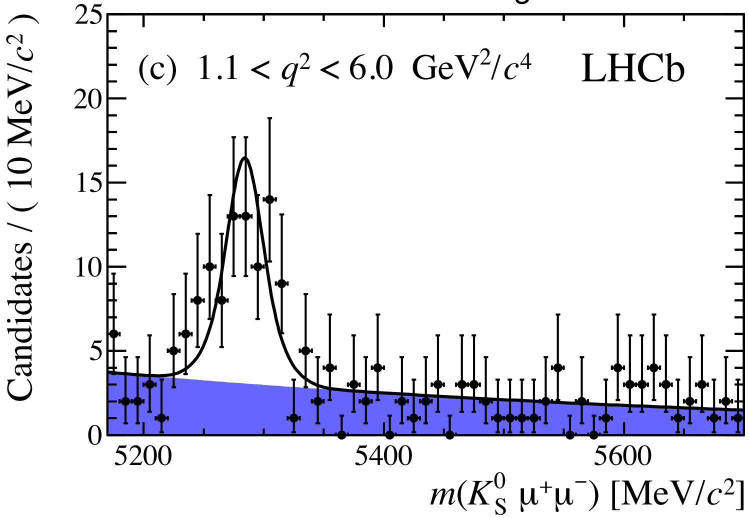
possible reasons: smaller Wilson coefficient C_9 with respect to SM

Angular analysis of

$B^+ \to K^+ \mu\mu$ (total N_{sig}= 4746 ± 81)

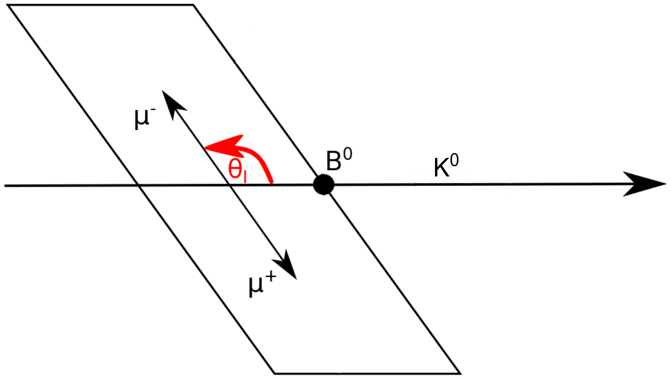


$B^0 \to K_s^0 \mu\mu$ (total N_{sig}= 176 ± 17)



$B^+ \to K^+ \mu\mu$: $$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_l) + \frac{1}{2}F_H + A_{FB}\cos\theta_l$$

$B^0 \to K_s^0 \mu\mu$: $$\frac{1}{\Gamma}\frac{d\Gamma}{d|\cos\theta_l|} = \frac{3}{2}(1-F_H)(1-|\cos\theta_l|^2) + F_H$$



A_{FB}: forward backward asymmetry of di-muon system -> zero in SM

F_H: fractional contribution of (pseudo)scalar + tensor amplitudes -> small in SM

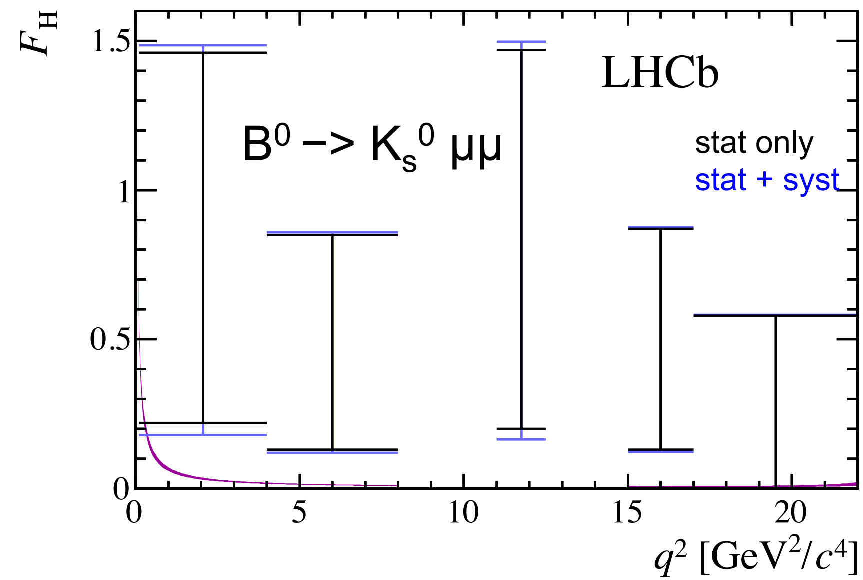
Angular analysis of $B \to K\mu^+\mu^-$

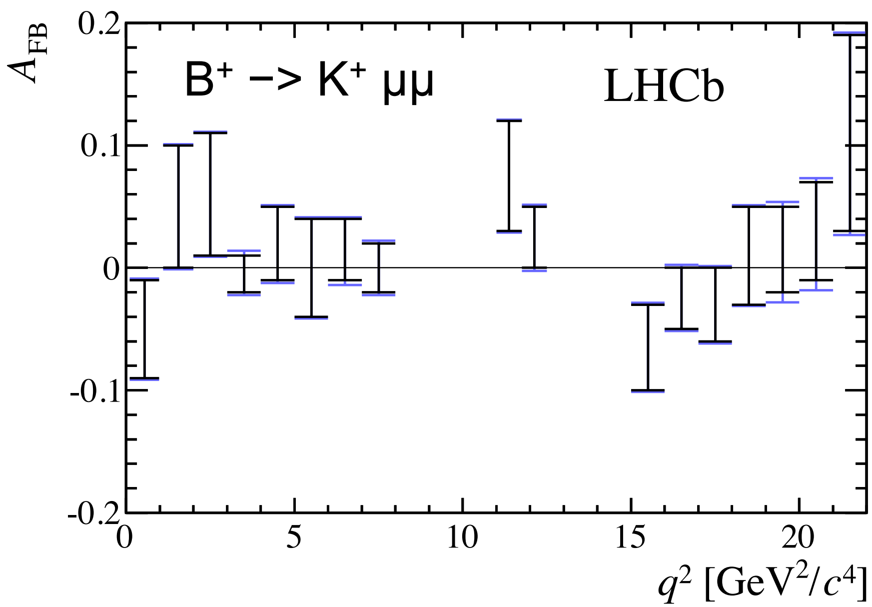
LHCb-PAPER-2014-007
arXiv:1403.8045v2

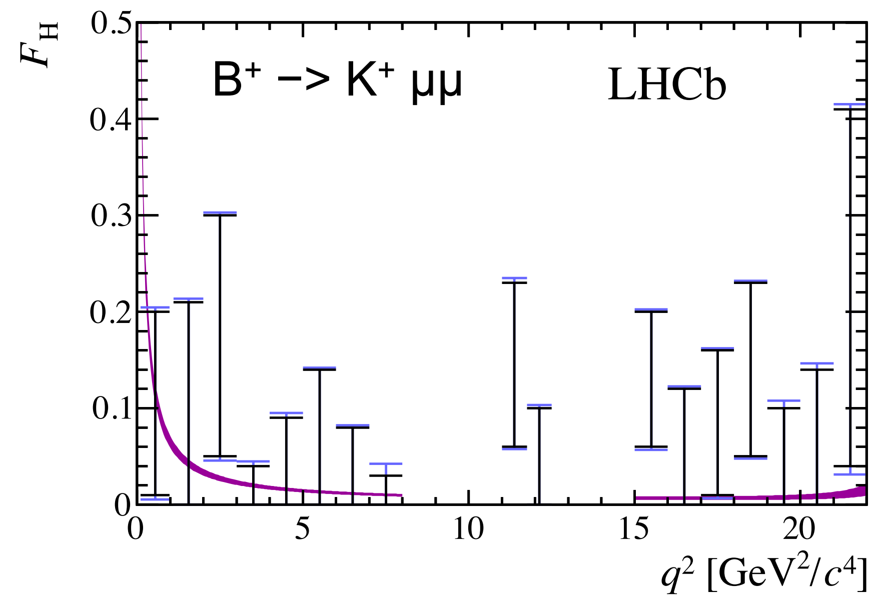
Parameters extracted from 2d fit (mass – angle)

- in bins of q^2

–> most precise to date + consistent with SM





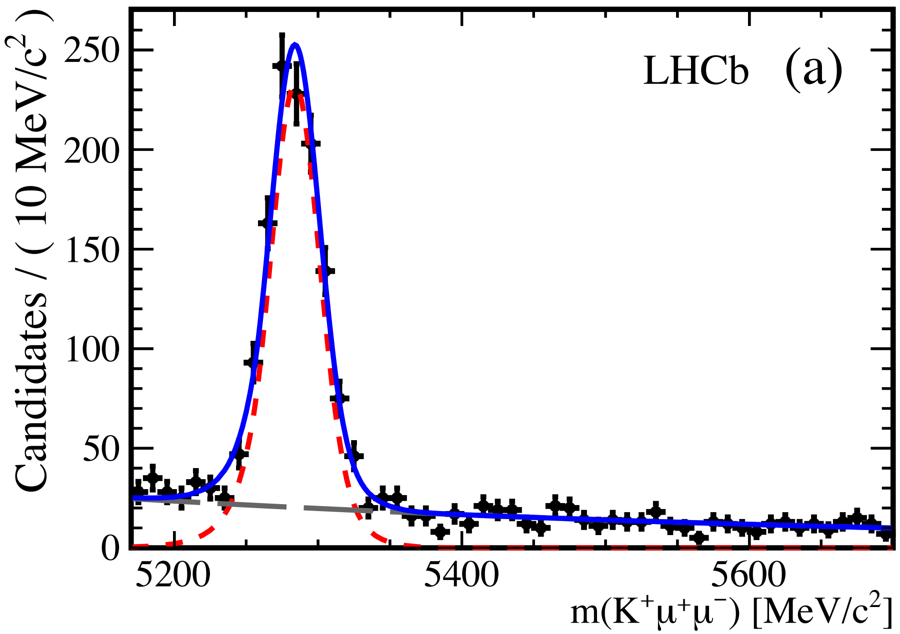


CP asymmetries of $B^+ \to K^+ \mu\mu$ and $B^0 \to K^* \mu\mu$

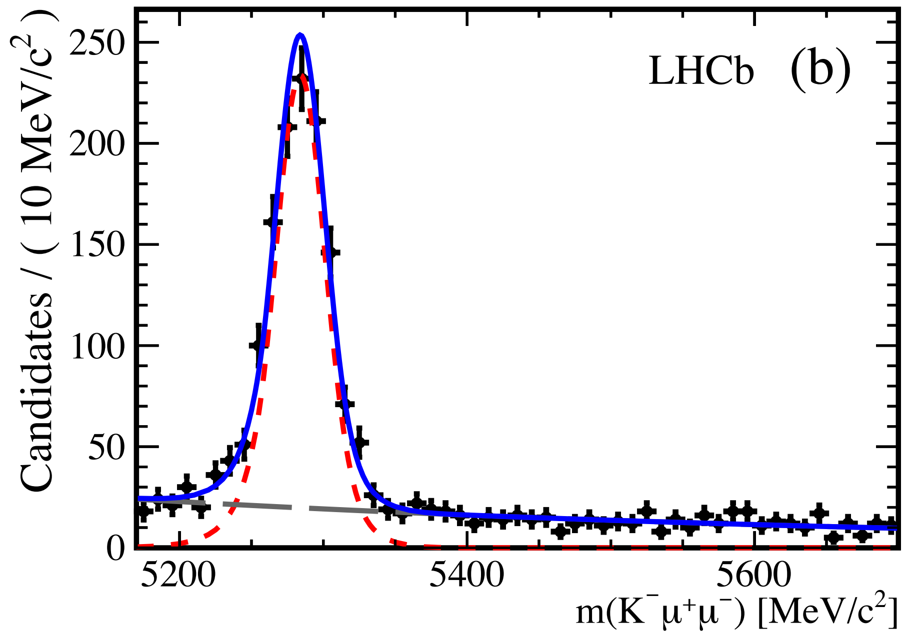
$$\mathcal{A}_{\mathrm{CP}} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-) - \Gamma(B \to K^{(*)}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-) + \Gamma(B \to K^{(*)}\mu^+\mu^-)}$$

- SM prediction is $O(10^{-3})$, JHEP 01 (2009) 019

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



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



CP asymmetries of $B \to K\mu^+\mu^-$

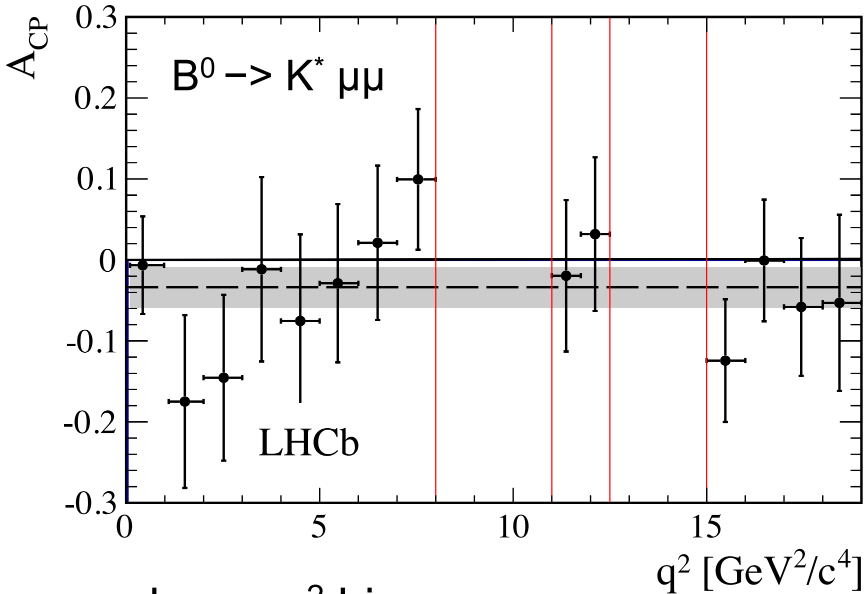
LHCb-PAPER-2014-032
PRELIMINARY

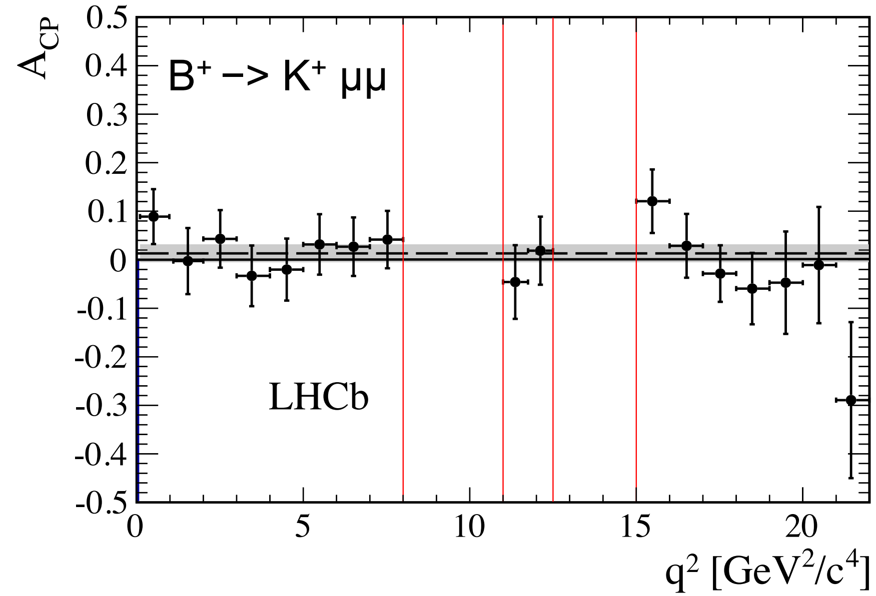
Yields give raw asymmetry A_{RAW} –> contaminated by production and detection asymmetries

$$\mathcal{A}_{\rm CP}(B \to K^{(*)}\mu^+\mu^-) = \mathcal{A}_{\rm RAW}(B \to K^{(*)}\mu^+\mu^-) - \mathcal{A}_{\rm RAW}(B \to J/\Psi K^{(*)})$$

A_{CP} (B –> J/Ψ $K^{(*)}$) assumed to be zero

difference removes production and detection efficiencies





averaged over q^2 bins:

$$\mathcal{A}_{\rm CP}(B^* \to K^*\mu^+\mu^-) = -0.035 \pm 0.024({\rm stat}) \pm 0.003({\rm syst})$$

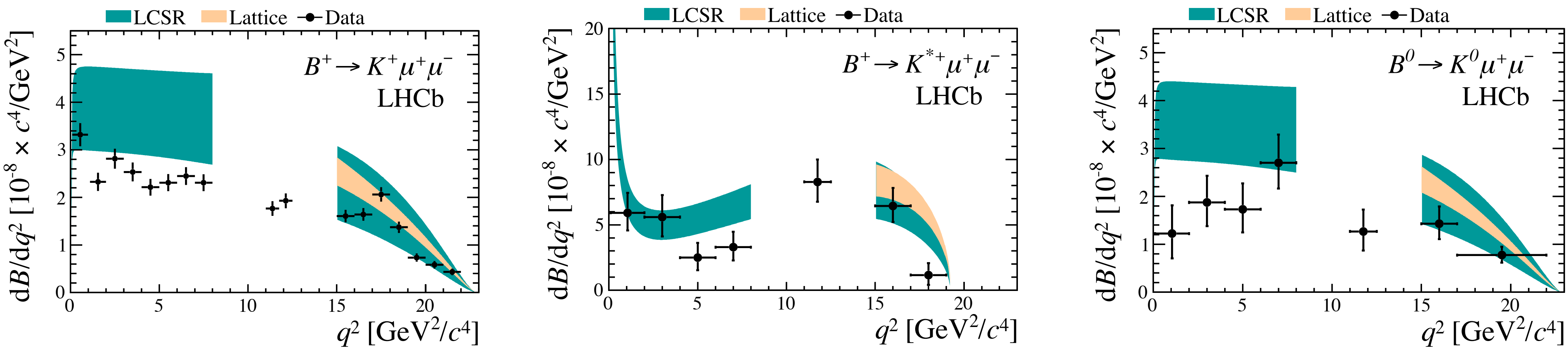
$$\mathcal{A}_{\rm CP}(B^0 \to K^0\mu^+\mu^-) = 0.012 \pm 0.017({\rm stat}) \pm 0.001({\rm syst})$$

–> consistent with SM prediction

$\mathcal{BR}(B \to K\mu^+\mu^-)$

- 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:

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

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

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

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

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

- Isospin asymmetry is determined from measured branching fractions:

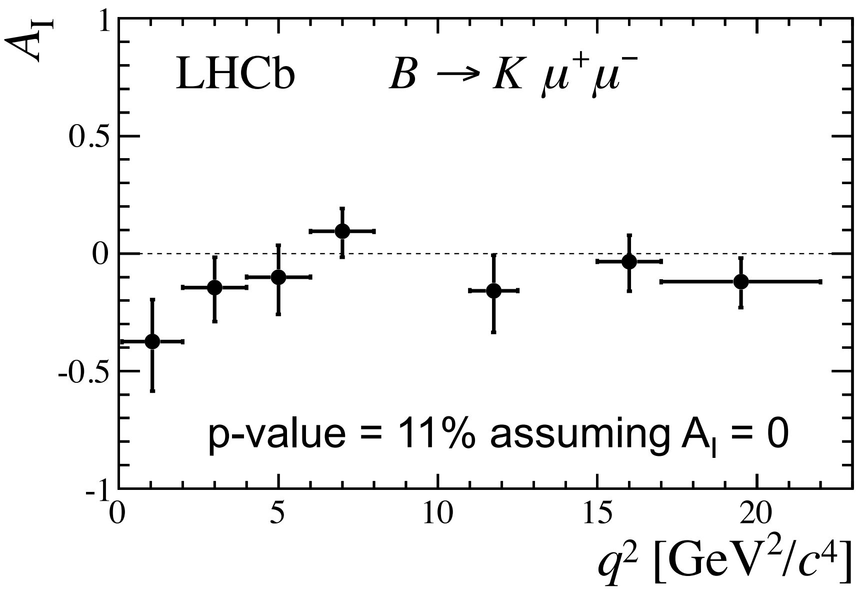
$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - (\tau_0/\tau_+)\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + (\tau_0/\tau_+)\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-))}$$

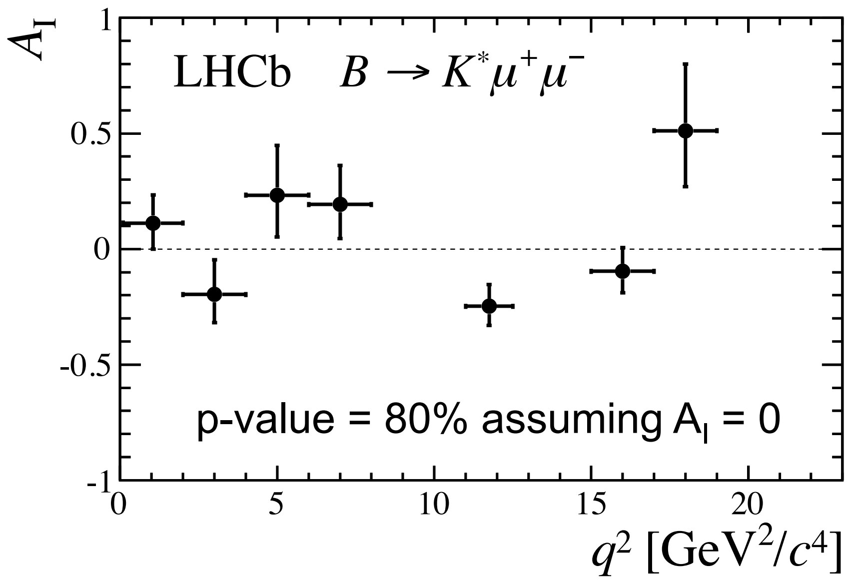
- SM prediction is O(1%) below J/Ψ resonance, even smaller above

JHEP 01 (2003) 074, JHEP 02 (2013) 010, Phys. Rev D88 (2013) 094004

- previous measurements from Babar, Belle, LHCb (1fb^{-1})

Phys. Rev. D86 (2012) 032012, Phys. Rev. Lett. 103 (2009) 171801, JHEP 07 (2012) 133





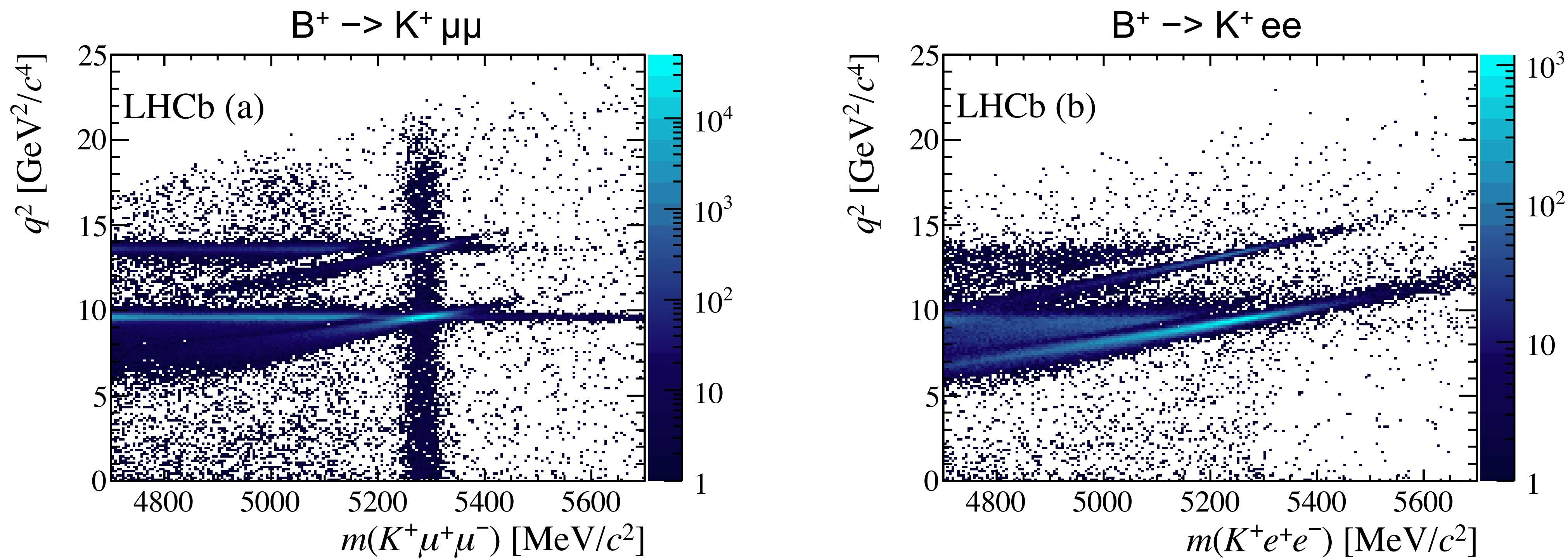
supersedes previous LHCb result (quoted 4.4σ difference to zero)
−>inclusion of 2012 dataset, updated reconstruction and selection, changes in test statistics

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

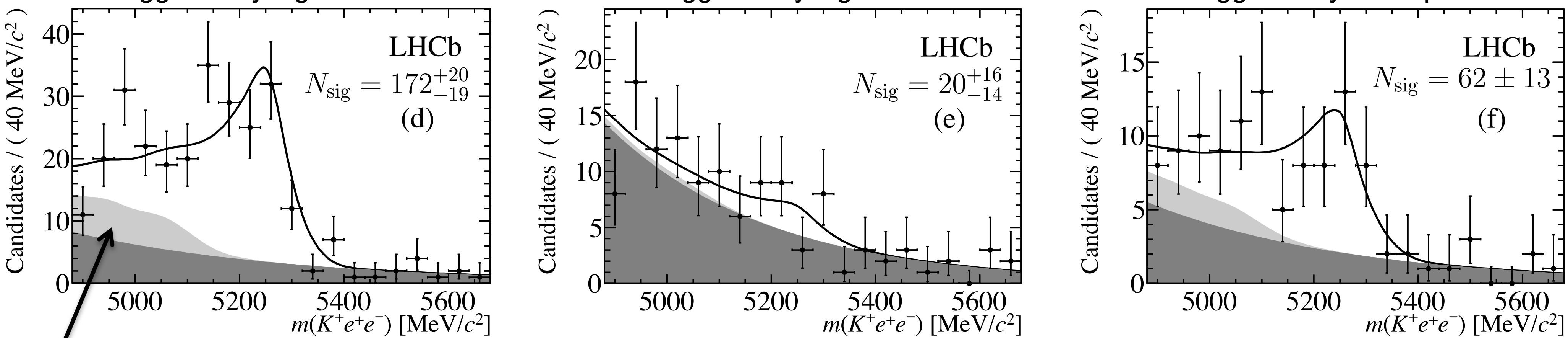


- R_K measured as ratio of relative branching fractions between $B^+ \to K^+ ll$ and $B^+ \to J/\Psi K^+$ –> cancellation of systematic uncertainties

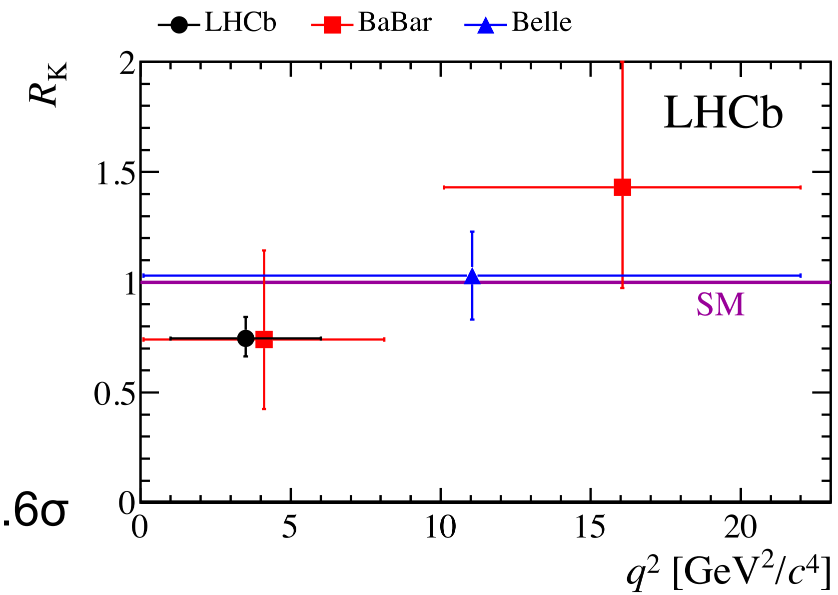
Lepton universality

$B^+ \rightarrow K^+ ee$ mass shape affected by
- number of bremsstrahlung photons, transverse momentum of electron and occupancy
-> sample divided in three trigger categories / $B^+ \rightarrow J/\Psi K^+$ to investigate shape dependence

triggered by signal electron | triggered by signal kaon | triggered by other particles



partially reconstructed background: mainly $B^0 \rightarrow K^* ee$

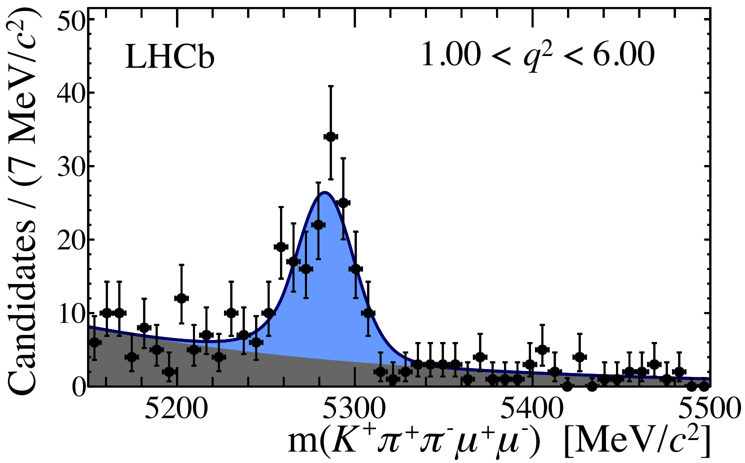


Combined result:

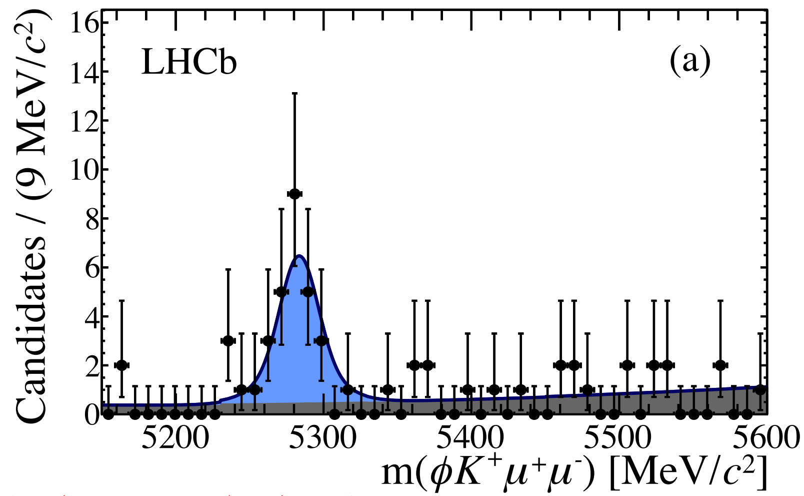
$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

−> most precise to date, compatible with SM within 2.6σ

$B^+ \to K^+ \pi^+ \pi^- \mu^+ \mu^-$ $N_{\rm sig} = 367^{+23}_{-23}$

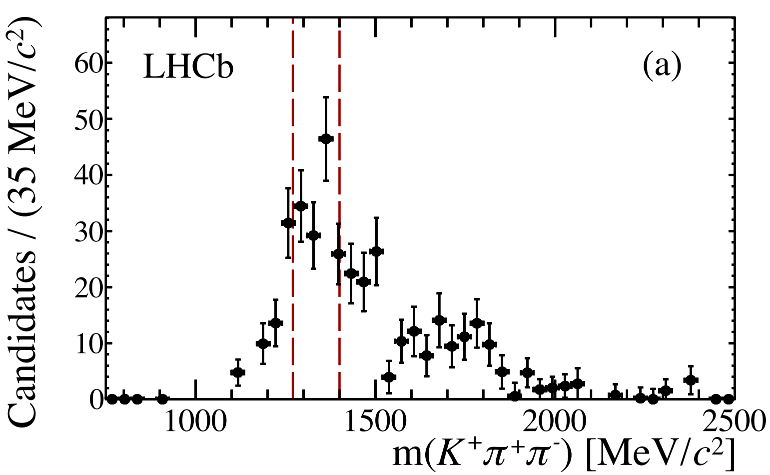


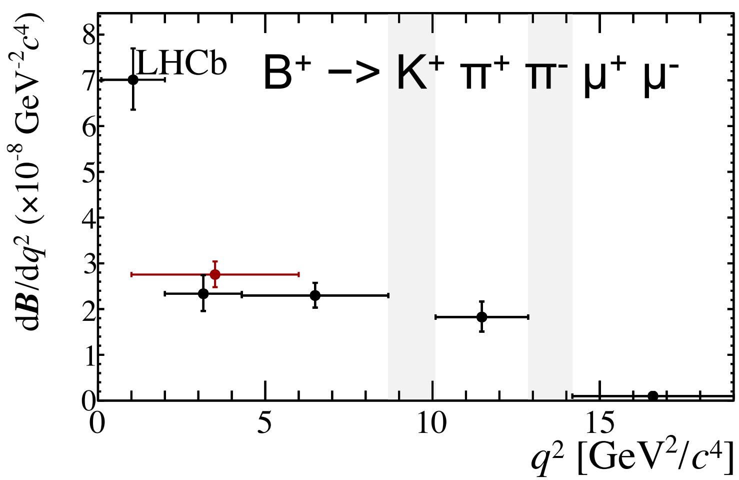
$B^+ \to \Phi K^+ \mu^+ \mu^-$ $N_{\rm sig} = 25.2^{+6.0}_{-5.3}$



unknown resonance structure
largest contribution from $B^+ \to K_1^+(1270)\,\mu^+\mu^-$
Phys. Rev. D83 (2011) 032005

$\mathcal{B}(B^+ \to \phi K^+ \mu^+ \mu^-)$
$= (8.22^{+1.88}_{-1.67}(\text{stat}) \pm 0.35(\text{syst}) \pm 2.47(\text{norm})) \cdot 10^{-8}$





$\mathcal{B}(B^+ \to K^+\pi^+\pi^-\mu^+\mu^-) = (4.36^{+0.29}_{-0.27}(\text{stat}) \pm 0.20(\text{syst}) \pm 0.18(\text{norm})) \cdot 10^{-7}$

Summary and Outlook

Electroweak penguins are an excellent way for indirect NP searches

LHCb is a unique ground to study these decays:

- **a lot of different EW penguin decays have been investigated**
- **plenty of interesting results (not all presented today)**
  angular observables, CP asymmetries, branching fractions, …

−> In general good agreement with SM, but some small tensions:
branching fractions, arXiv:1403.8044v3,
P_5' of $B^0 \to K^* \mu\mu$, Phys. Rev. Lett. 111 (2013) 191801

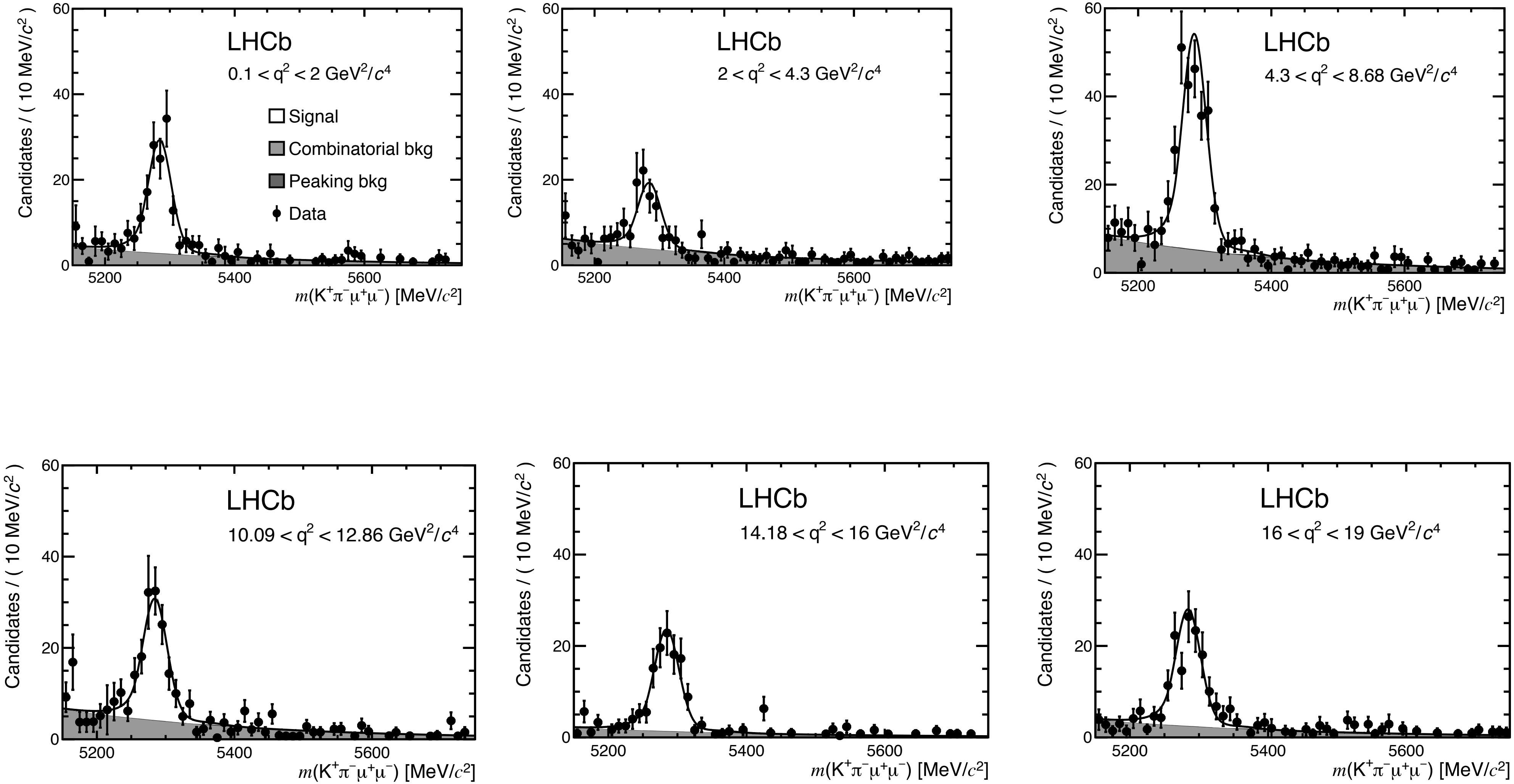
More to come…

- **Angular analysis of $B^0 \to K^* \mu\mu$ with $3fb^{-1}$**
- **…**


Stay tuned…
penguins are always
good for surprises!

Backup

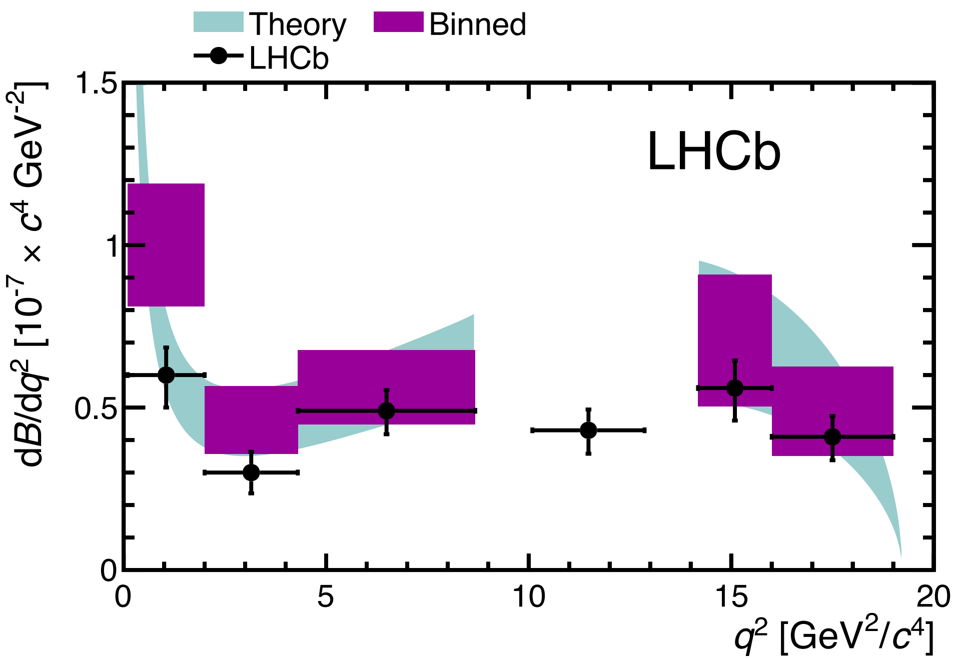
Invariant mass distributions in bins of q^2



Differential branching fraction:

$$\frac{d\mathcal{B}}{dq^2} = \frac{1}{q^2_{\max} - q^2_{\min}} \frac{N_{\rm sig}}{N_{K^{*0}J/\psi}} \frac{\varepsilon_{K^{*0}J/\psi}}{\varepsilon_{K^{*0}\mu^+\mu^-}} \times \mathcal{B}(B^0 \to K^{*0}J/\psi) \times \mathcal{B}(J/\psi \to \mu^+\mu^-)$$

q^2 (GeV$^2/c^4$)	$N_{\rm sig}$	$d\mathcal{B}/dq^2$ (10^{-7} GeV$^{-2}c^4$)
0.10 – 2.00	140 ± 13	$0.60 \pm 0.06 \pm 0.05 \pm 0.04\,^{+0.00}_{-0.05}$
2.00 – 4.30	73 ± 11	$0.30 \pm 0.03 \pm 0.03 \pm 0.02\,^{+0.00}_{-0.02}$
4.30 – 8.68	271 ± 19	$0.49 \pm 0.04 \pm 0.04 \pm 0.03\,^{+0.00}_{-0.04}$
10.09 – 12.86	168 ± 15	$0.43 \pm 0.04 \pm 0.04 \pm 0.03\,^{+0.00}_{-0.03}$
14.18 – 16.00	115 ± 12	$0.56 \pm 0.06 \pm 0.04 \pm 0.04\,^{+0.00}_{-0.05}$
16.00 – 19.00	116 ± 13	$0.41 \pm 0.04 \pm 0.04 \pm 0.03\,^{+0.00}_{-0.03}$
1.00 – 6.00	197 ± 17	$0.34 \pm 0.03 \pm 0.04 \pm 0.02\,^{+0.00}_{-0.03}$



Folding of angular distributions: $\hat{\phi} = \begin{cases} \phi + \pi & \text{if } \phi < 0 \\ \phi & \text{otherwise} \end{cases}$

Differential decay rate with reduced number of observables:

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2} \frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{16\pi}\Big[F_\mathrm{L}\cos^2\theta_K + \frac{3}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K) \; - \\ F_\mathrm{L}\cos^2\theta_K(2\cos^2\theta_\ell - 1) \; + \\ \frac{1}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) \; + \\ S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} \; + \\ \frac{4}{3}A_\mathrm{FB}(1-\cos^2\theta_K)\cos\theta_\ell \; + \\ A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi} \Big] \; .$$

Constraints of observables to keep decay rate positive in allowed phase space:

$$|A_\mathrm{FB}| \leq \frac{3}{4}(1-F_\mathrm{L}) \; , \; |A_9| \leq \frac{1}{2}(1-F_\mathrm{L}) \;\; \text{and} \;\; |S_3| \leq \frac{1}{2}(1-F_\mathrm{L})$$

Analysis of $B^0 \to K^* \mu^+ \mu^-$

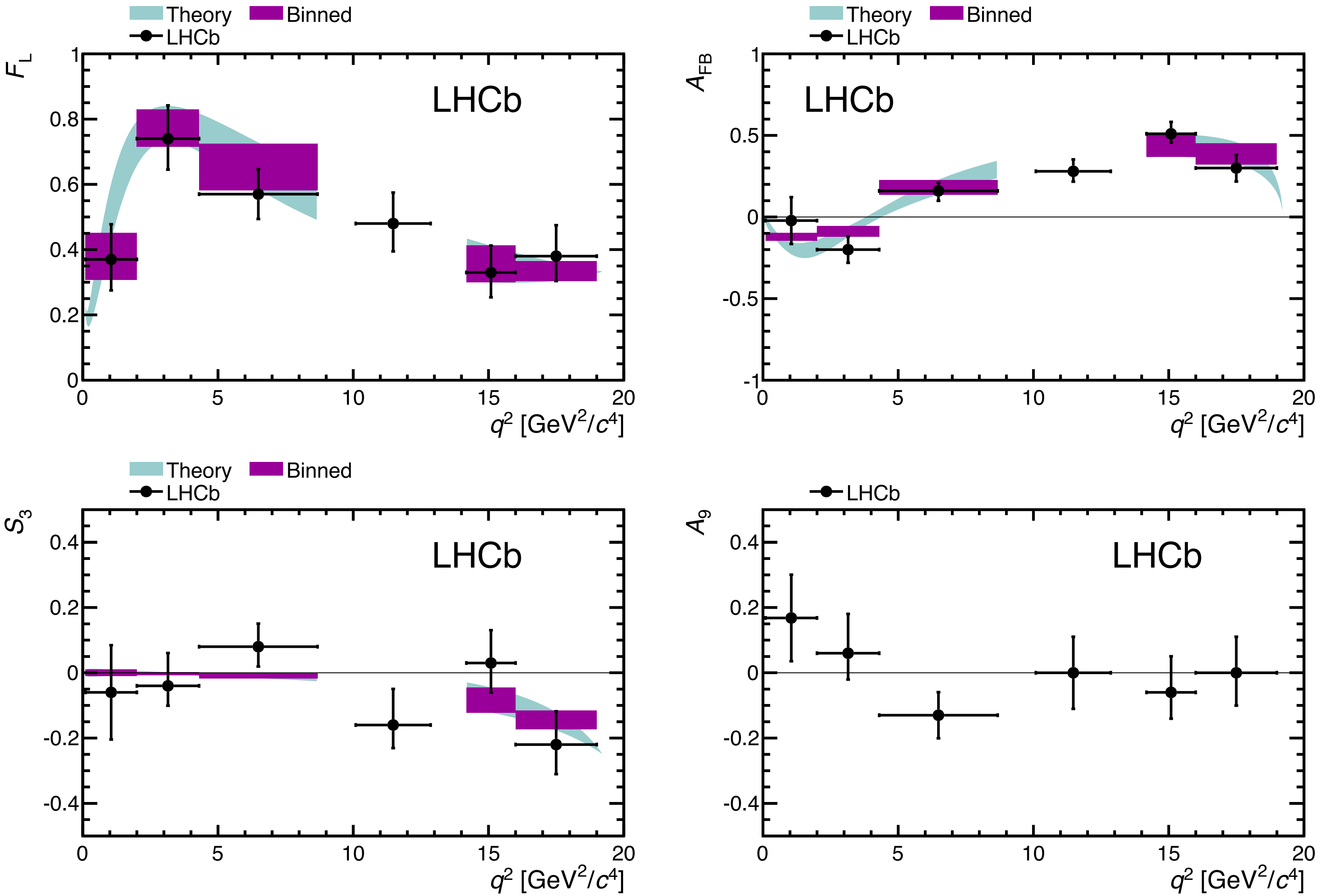
LHCb-PAPER-2013-019
JHEP 08 (2013) 131

Results of angular analysis:

q^2 (GeV^2/c^4)	F_{L}	A_{FB}	S_3	S_9
$0.10 - 2.00$ (uncorrected)	$0.37\,^{+0.10}_{-0.09}\,^{+0.04}_{-0.03}$	$-0.02\,^{+0.12}_{-0.12}\,^{+0.01}_{-0.01}$	$-0.04\,^{+0.10}_{-0.10}\,^{+0.01}_{-0.01}$	$0.05\,^{+0.10}_{-0.09}\,^{+0.01}_{-0.01}$
$0.10 - 2.00$ (corrected)	$0.37\,^{+0.10}_{-0.09}\,^{+0.04}_{-0.03}$	$-0.02\,^{+0.13}_{-0.13}\,^{+0.01}_{-0.01}$	$-0.05\,^{+0.12}_{-0.12}\,^{+0.01}_{-0.01}$	$0.06\,^{+0.12}_{-0.12}\,^{+0.01}_{-0.01}$
$2.00 - 4.30$	$0.74\,^{+0.10}_{-0.09}\,^{+0.02}_{-0.03}$	$-0.20\,^{+0.08}_{-0.08}\,^{+0.01}_{-0.01}$	$-0.04\,^{+0.10}_{-0.06}\,^{+0.01}_{-0.01}$	$-0.03\,^{+0.11}_{-0.04}\,^{+0.01}_{-0.01}$
$4.30 - 8.68$	$0.57\,^{+0.07}_{-0.07}\,^{+0.03}_{-0.03}$	$0.16\,^{+0.06}_{-0.05}\,^{+0.01}_{-0.01}$	$0.08\,^{+0.07}_{-0.06}\,^{+0.01}_{-0.01}$	$0.01\,^{+0.07}_{-0.08}\,^{+0.01}_{-0.01}$
$10.09 - 12.86$	$0.48\,^{+0.08}_{-0.09}\,^{+0.03}_{-0.03}$	$0.28\,^{+0.07}_{-0.06}\,^{+0.02}_{-0.02}$	$-0.16\,^{+0.11}_{-0.07}\,^{+0.01}_{-0.01}$	$-0.01\,^{+0.10}_{-0.11}\,^{+0.01}_{-0.01}$
$14.18 - 16.00$	$0.33\,^{+0.08}_{-0.07}\,^{+0.02}_{-0.03}$	$0.51\,^{+0.07}_{-0.05}\,^{+0.02}_{-0.02}$	$0.03\,^{+0.09}_{-0.10}\,^{+0.01}_{-0.01}$	$0.00\,^{+0.09}_{-0.08}\,^{+0.01}_{-0.01}$
$16.00 - 19.00$	$0.38\,^{+0.09}_{-0.07}\,^{+0.03}_{-0.03}$	$0.30\,^{+0.08}_{-0.08}\,^{+0.01}_{-0.02}$	$-0.22\,^{+0.10}_{-0.09}\,^{+0.02}_{-0.01}$	$0.06\,^{+0.11}_{-0.10}\,^{+0.01}_{-0.01}$
$1.00 - 6.00$	$0.65\,^{+0.08}_{-0.07}\,^{+0.03}_{-0.03}$	$-0.17\,^{+0.06}_{-0.06}\,^{+0.01}_{-0.01}$	$0.03\,^{+0.07}_{-0.07}\,^{+0.01}_{-0.01}$	$0.07\,^{+0.09}_{-0.08}\,^{+0.01}_{-0.01}$

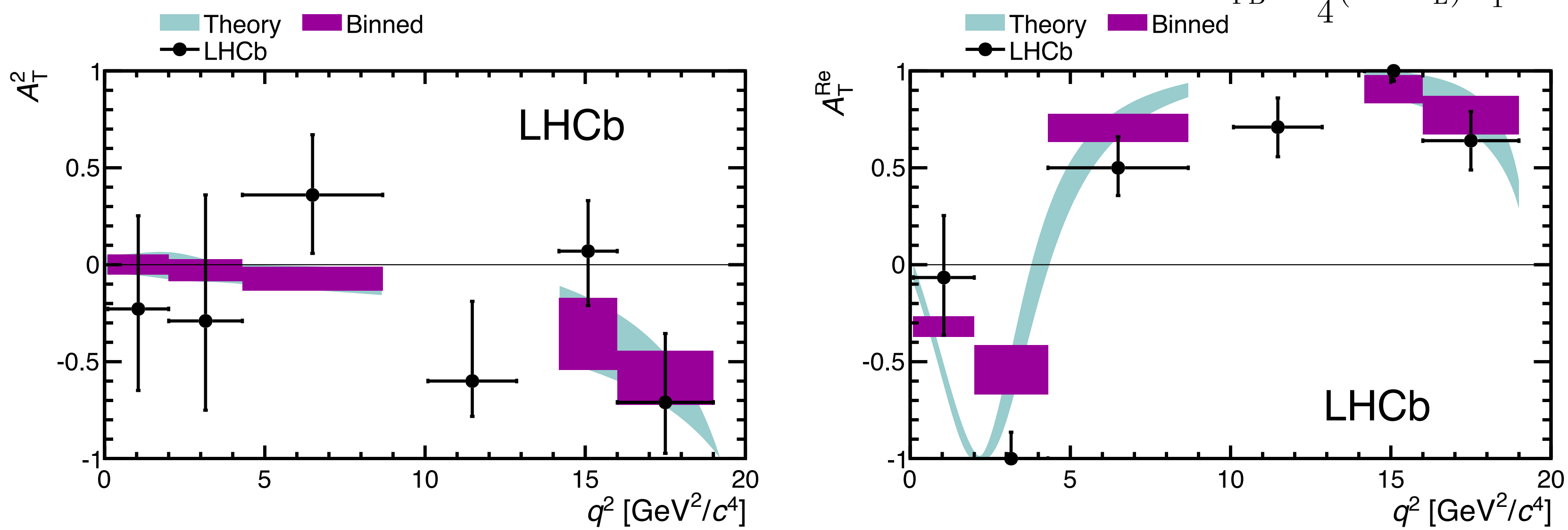
q^2 (GeV^2/c^4)	A_9	A_{T}^2	$A_{\mathrm{T}}^{\mathrm{Re}}$	p-value
$0.10 - 2.00$ (uncorrected)	$0.12\,^{+0.09}_{-0.09}\,^{+0.01}_{-0.01}$	$-0.14\,^{+0.34}_{-0.30}\,^{+0.02}_{-0.02}$	$-0.04\,^{+0.26}_{-0.24}\,^{+0.02}_{-0.01}$	0.18
$0.10 - 2.00$ (corrected)	$0.14\,^{+0.11}_{-0.11}\,^{+0.01}_{-0.01}$	$-0.19\,^{+0.40}_{-0.35}\,^{+0.02}_{-0.02}$	$-0.06\,^{+0.29}_{-0.27}\,^{+0.02}_{-0.01}$	–
$2.00 - 4.30$	$0.06\,^{+0.12}_{-0.08}\,^{+0.01}_{-0.01}$	$-0.29\,^{+0.65}_{-0.46}\,^{+0.02}_{-0.03}$	$-1.00\,^{+0.13}_{-0.00}\,^{+0.04}_{-0.00}$	0.57
$4.30 - 8.68$	$-0.13\,^{+0.07}_{-0.07}\,^{+0.01}_{-0.01}$	$0.36\,^{+0.30}_{-0.31}\,^{+0.03}_{-0.03}$	$0.50\,^{+0.16}_{-0.14}\,^{+0.01}_{-0.03}$	0.71
$10.09 - 12.86$	$0.00\,^{+0.11}_{-0.11}\,^{+0.01}_{-0.01}$	$-0.60\,^{+0.42}_{-0.27}\,^{+0.05}_{-0.02}$	$0.71\,^{+0.15}_{-0.15}\,^{+0.01}_{-0.03}$	–
$14.18 - 16.00$	$-0.06\,^{+0.11}_{-0.08}\,^{+0.01}_{-0.01}$	$0.07\,^{+0.26}_{-0.28}\,^{+0.02}_{-0.02}$	$1.00\,^{+0.00}_{-0.05}\,^{+0.00}_{-0.02}$	0.38
$16.00 - 19.00$	$0.00\,^{+0.11}_{-0.10}\,^{+0.01}_{-0.01}$	$-0.71\,^{+0.35}_{-0.26}\,^{+0.06}_{-0.04}$	$0.64\,^{+0.15}_{-0.15}\,^{+0.01}_{-0.02}$	0.28
$1.00 - 6.00$	$0.03\,^{+0.08}_{-0.08}\,^{+0.01}_{-0.01}$	$0.15\,^{+0.39}_{-0.41}\,^{+0.03}_{-0.03}$	$-0.66\,^{+0.24}_{-0.22}\,^{+0.04}_{-0.01}$	0.72

Results of angular analysis:



Results of angular analysis:

$$A_{\mathrm{FB}} = \frac{3}{4}(1 - F_{\mathrm{L}})A_{\mathrm{T}}^{\mathrm{Re}} \quad \text{and} \quad S_3 = \frac{1}{2}(1 - F_{\mathrm{L}})A_{\mathrm{T}}^2$$

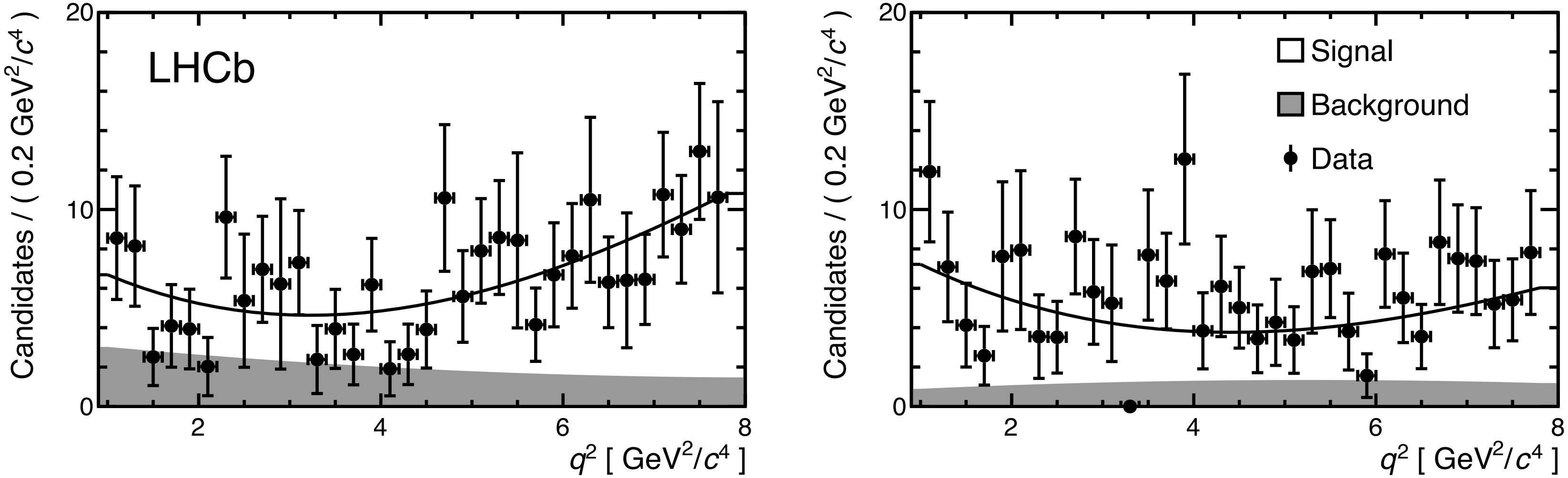


Systematic uncertainties:

Source	A_{FB}	F_{L}	S_3	S_9	A_9	A_{T}^2	$A_{\mathrm{T}}^{\mathrm{Re}}$
Acceptance model	0.02	0.03	0.01	< 0.01	< 0.01	0.02	0.01
Mass model	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
$B^0 \to \overline{B}^0$ mis-id	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01
Data-simulation diff.	0.01	0.03	0.01	< 0.01	< 0.01	0.03	0.01
Kinematic reweighting	< 0.01	0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01
Peaking backgrounds	0.01	0.01	0.01	0.01	0.01	0.01	0.01
S-wave	0.01	0.01	0.02	0.01	< 0.01	0.05	0.04
B^0-$\overline{B}^0$ asymmetries	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Determination of zero-crossing point:

$$A_{\mathrm{FB}}(q^2) = \frac{P_{\mathrm{F}}(q^2) - P_{\mathrm{B}}(q^2)}{P_{\mathrm{F}}(q^2) + P_{\mathrm{B}}(q^2)}$$



FF independent observables

Transformation of angular distributions:

$$P'_4,\ S_4: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases}$$

$$P'_6,\ S_7: \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases}$$

$$P'_5,\ S_5: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases}$$

$$P'_8,\ S_8: \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_K \to \pi - \theta_K & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2. \end{cases}$$

$q^2\,[\mathrm{GeV}^2/c^4]$	P_4'	P_5'	P_6'	P_8'
0.10 – 2.00	$0.00^{+0.26}_{-0.26} \pm 0.03$	$0.45^{+0.19}_{-0.22} \pm 0.09$	$-0.24^{+0.19}_{-0.22} \pm 0.05$	$-0.06^{+0.28}_{-0.28} \pm 0.02$
2.00 – 4.30	$-0.37^{+0.29}_{-0.26} \pm 0.08$	$0.29^{+0.39}_{-0.38} \pm 0.07$	$0.15^{+0.36}_{-0.38} \pm 0.05$	$-0.15^{+0.29}_{-0.28} \pm 0.07$
4.30 – 8.68	$-0.59^{+0.15}_{-0.12} \pm 0.05$	$-0.19^{+0.16}_{-0.16} \pm 0.03$	$-0.04^{+0.15}_{-0.15} \pm 0.05$	$0.29^{+0.17}_{-0.19} \pm 0.03$
10.09 – 12.90	$-0.46^{+0.20}_{-0.17} \pm 0.03$	$-0.79^{+0.16}_{-0.19} \pm 0.19$	$-0.31^{+0.23}_{-0.22} \pm 0.05$	$-0.06^{+0.23}_{-0.22} \pm 0.02$
14.18 – 16.00	$0.09^{+0.35}_{-0.27} \pm 0.04$	$-0.79^{+0.20}_{-0.13} \pm 0.18$	$-0.18^{+0.25}_{-0.24} \pm 0.03$	$-0.20^{+0.30}_{-0.25} \pm 0.03$
16.00 – 19.00	$-0.35^{+0.26}_{-0.22} \pm 0.03$	$-0.60^{+0.19}_{-0.16} \pm 0.09$	$0.31^{+0.38}_{-0.37} \pm 0.10$	$0.06^{+0.26}_{-0.27} \pm 0.03$
1.00 – 6.00	$-0.29^{+0.18}_{-0.16} \pm 0.03$	$0.21^{+0.20}_{-0.21} \pm 0.03$	$-0.18^{+0.21}_{-0.21} \pm 0.03$	$0.23^{+0.18}_{-0.19} \pm 0.02$

$q^2\,[\mathrm{GeV}^2/c^4]$	S_4	S_5	S_7	S_8
0.10 – 2.00	$0.00^{+0.12}_{-0.12} \pm 0.03$	$0.22^{+0.09}_{-0.10} \pm 0.04$	$-0.11^{+0.11}_{-0.11} \pm 0.03$	$-0.03^{+0.13}_{-0.12} \pm 0.01$
2.00 – 4.30	$-0.14^{+0.13}_{-0.12} \pm 0.03$	$0.11^{+0.14}_{-0.13} \pm 0.03$	$0.06^{+0.15}_{-0.15} \pm 0.02$	$-0.06^{+0.12}_{-0.12} \pm 0.02$
4.30 – 8.68	$-0.29^{+0.06}_{-0.06} \pm 0.02$	$-0.09^{+0.08}_{-0.08} \pm 0.01$	$-0.02^{+0.07}_{-0.08} \pm 0.04$	$0.15^{+0.08}_{-0.08} \pm 0.01$
10.09 – 12.90	$-0.23^{+0.09}_{-0.08} \pm 0.02$	$-0.40^{+0.08}_{-0.10} \pm 0.10$	$-0.16^{+0.11}_{-0.12} \pm 0.03$	$-0.03^{+0.10}_{-0.10} \pm 0.01$
14.18 – 16.00	$0.04^{+0.14}_{-0.08} \pm 0.01$	$-0.38^{+0.10}_{-0.09} \pm 0.09$	$-0.09^{+0.13}_{-0.14} \pm 0.01$	$-0.10^{+0.13}_{-0.12} \pm 0.02$
16.00 – 19.00	$-0.17^{+0.11}_{-0.09} \pm 0.01$	$-0.29^{+0.09}_{-0.08} \pm 0.04$	$0.15^{+0.16}_{-0.15} \pm 0.03$	$0.03^{+0.12}_{-0.12} \pm 0.02$

CP asymmetries of $B \to K \mu^+ \mu^-$

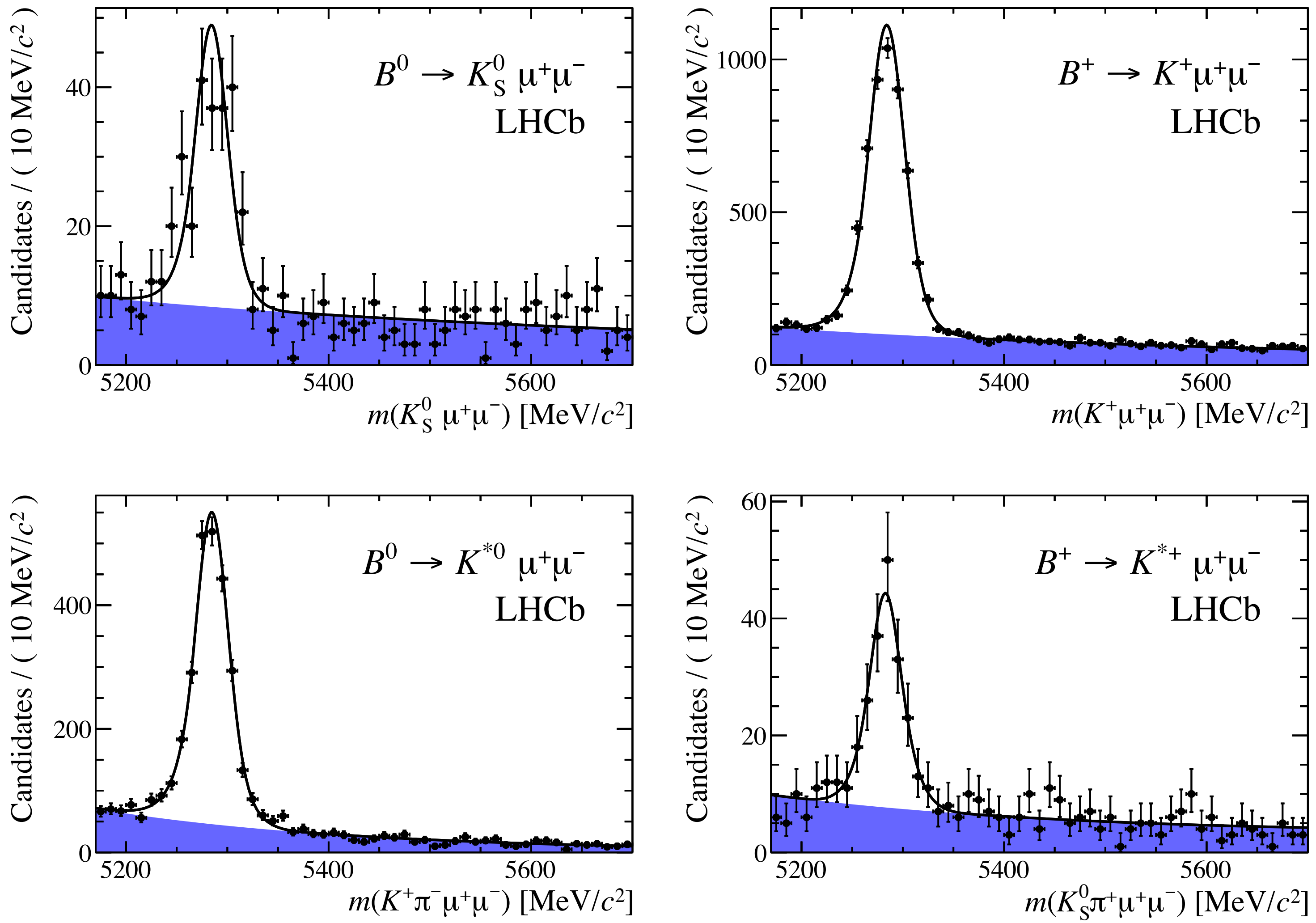
LHCb-PAPER-2014-032
PRELIMINARY

Results for $B^0 \to K^* \mu\mu$

q^2 bin [GeV$^2/c^4$]	yield	$\mathcal{A}_{CP}$	stat. error	syst. error
0.10–0.98	304±18	−0.007	0.060	0.006
1.10–2.00	105±11	−0.175	0.106	0.009
2.00–3.00	120±13	−0.145	0.102	0.008
3.00–4.00	101±12	−0.012	0.113	0.014
4.00–5.00	120±13	−0.075	0.106	0.012
5.00–6.00	143±13	−0.029	0.097	0.009
6.00–7.00	144±14	0.021	0.095	0.008
7.00–8.00	177±15	0.100	0.087	0.006
11.0–11.8	144±14	−0.020	0.093	0.007
11.8–12.5	147±14	0.032	0.093	0.022
15.0–16.0	205±16	−0.124	0.075	0.009
16.0–17.0	216±16	−0.001	0.074	0.010
17.0–18.0	169±14	−0.058	0.085	0.009
18.0–19.0	105±11	−0.053	0.108	0.016
0.10–19.0	2190±52	−0.034	0.024	0.003

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

q^2 bin [GeV^2/c^4]	yield	$\mathcal{A}_{CP}$	stat. error	syst. error
0.10–0.98	387±22	0.089	0.057	0.001
1.10–2.00	277±19	−0.003	0.068	0.002
2.00–3.00	367±22	0.043	0.059	0.001
3.00–4.00	334±21	−0.033	0.063	0.001
4.00–5.00	307±20	−0.020	0.064	0.001
5.00–6.00	332±21	0.032	0.062	0.002
6.00–7.00	355±22	0.027	0.060	0.001
7.00–8.00	371±22	0.042	0.059	0.002
11.0–11.8	232±18	−0.046	0.076	0.002
11.8–12.5	247±17	0.019	0.070	0.002
15.0–16.0	287±19	0.121	0.065	0.004
16.0–17.0	287±19	0.029	0.066	0.001
17.0–18.0	349±21	−0.029	0.058	0.001
18.0–19.0	222±17	−0.060	0.074	0.003
19.0–20.0	121±13	−0.047	0.105	0.003
20.0–21.0	95±12	−0.011	0.120	0.003
21.0–22.0	50±8	−0.289	0.161	0.004
0.10–22.0	4630±78	0.013	0.017	0.001


$B^0 \to K^0_S \mu^+\mu^-$
LHCb
Candidates / (10 MeV/c^2)
$m(K^0_S \mu^+\mu^-)$ [MeV/c^2]
$B^+ \to K^+\mu^+\mu^-$
LHCb
Candidates / (10 MeV/c^2)
$m(K^+\mu^+\mu^-)$ [MeV/c^2]
$B^0 \to K^{*0} \mu^+\mu^-$
LHCb
Candidates / (10 MeV/c^2)
$m(K^+\pi^-\mu^+\mu^-)$ [MeV/c^2]
$B^+ \to K^{*+} \mu^+\mu^-$
LHCb
Candidates / (10 MeV/c^2)
$m(K^0_S\pi^+\mu^+\mu^-)$ [MeV/c^2]

Branching fraction:

$$\frac{d\mathcal{B}}{dq^2} = \frac{N(B\to K^{(*)}\mu^+\mu^-)}{N(B\to J/\psi\, K^{(*)})} \cdot \frac{\varepsilon(B\to J/\psi\, K^{(*)})}{\varepsilon(B\to K^{(*)}\mu^+\mu^-)} \cdot \frac{\mathcal{B}(B\to J/\psi\, K^{(*)})\mathcal{B}(J/\psi \to \mu^+\mu^-)}{(q^2_{\rm max} - q^2_{\rm min})}$$

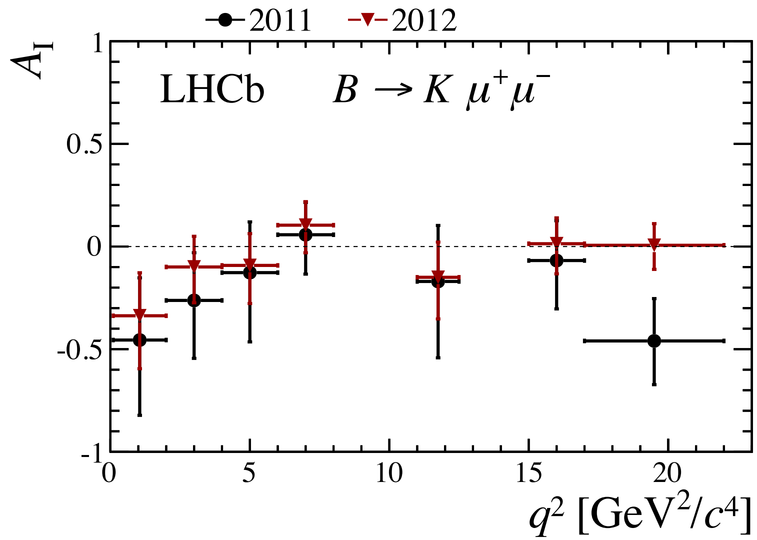
Branching fraction of normalization channels:

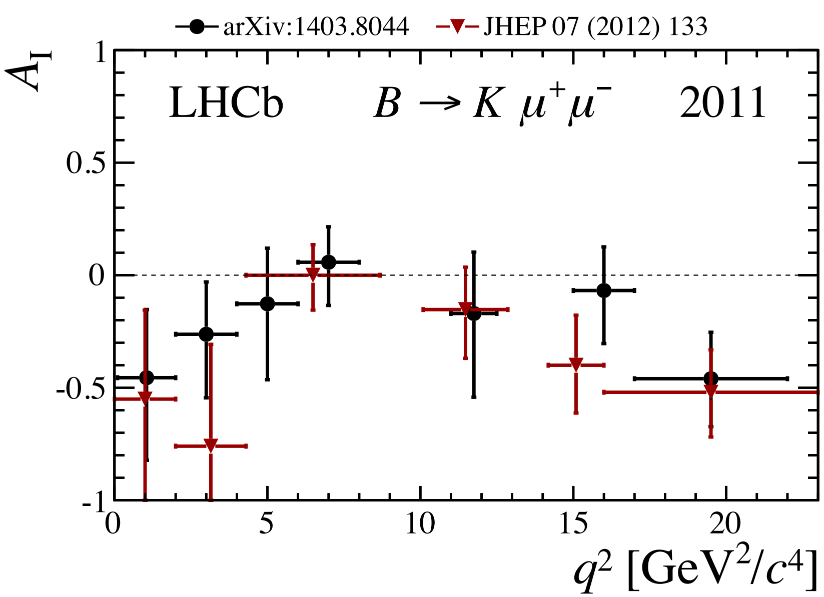
$$\mathcal{B}(B^+\to J/\psi\, K^+) = (0.998 \pm 0.014 \pm 0.040) \times 10^{-3},$$
$$\mathcal{B}(B^0\to J/\psi\, K^0) = (0.928 \pm 0.013 \pm 0.037) \times 10^{-3},$$
$$\mathcal{B}(B^+\to J/\psi\, K^{*+}) = (1.431 \pm 0.027 \pm 0.090) \times 10^{-3},$$
$$\mathcal{B}(B^0\to J/\psi\, K^{*0}) = (1.331 \pm 0.025 \pm 0.084) \times 10^{-3},$$

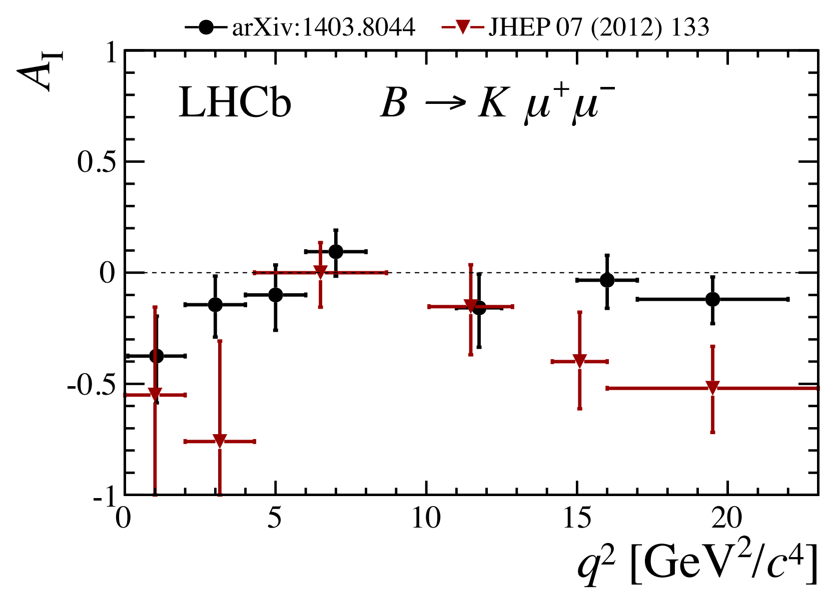
Systematic uncertainties:

Source	Branching fraction	Isospin asymmetry
$B\to J/\psi\, K^{(*)}$ branching fractions	4% – 6%	–
Physics model	1% – 2%	1% – 2%
Simulation mis-modelling	1% – 3%	1% – 3%

Isospsin asymmetry comparison 2011 and 2012 data set:







$\mathcal{BR}(B \to K\mu^+\mu^-)$

LHCb-PAPER-2014-006
arXiv:1403.8044v3

Lepton universality

Definition of R_K:

$$R_K = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\Gamma[B^+ \to K^+\mu^+\mu^-]}{dq^2} dq^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\Gamma[B^+ \to K^+e^+e^-]}{dq^2} dq^2}$$

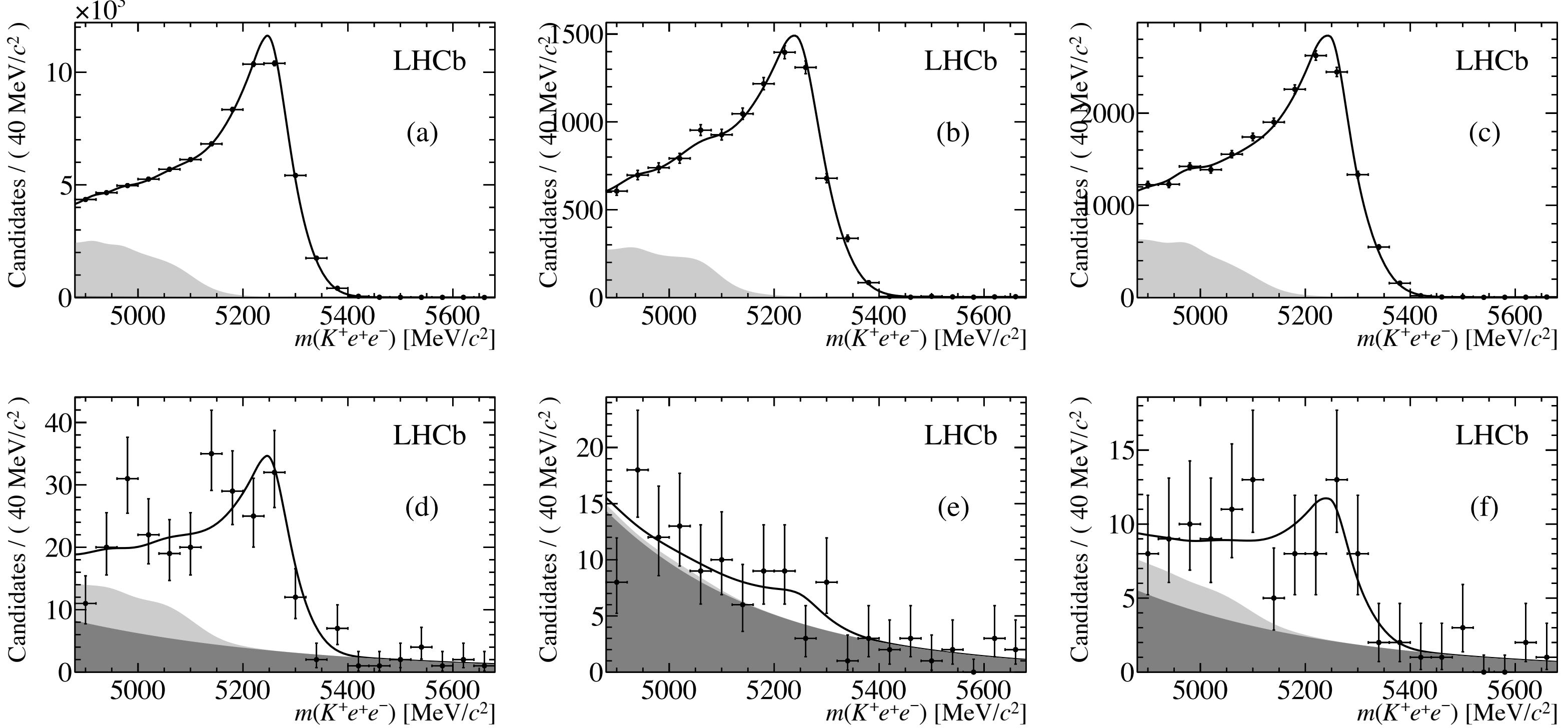
$$R_K = \left(\frac{\mathcal{N}_{K^+\mu^+\mu^-}}{\mathcal{N}_{K^+e^+e^-}}\right)\left(\frac{\mathcal{N}_{J/\psi\,(e^+e^-)K^+}}{\mathcal{N}_{J/\psi\,(\mu^+\mu^-)K^+}}\right)\left(\frac{\epsilon_{K^+e^+e^-}}{\epsilon_{K^+\mu^+\mu^-}}\right)\left(\frac{\epsilon_{J/\psi\,(\mu^+\mu^-)K^+}}{\epsilon_{J/\psi\,(e^+e^-)K^+}}\right)$$

Mass fits of

triggerd by signal electron | triggerd by signal kaon | triggerd by other particles

$B^+ \to J/\Psi\,(ee)\,K^+$

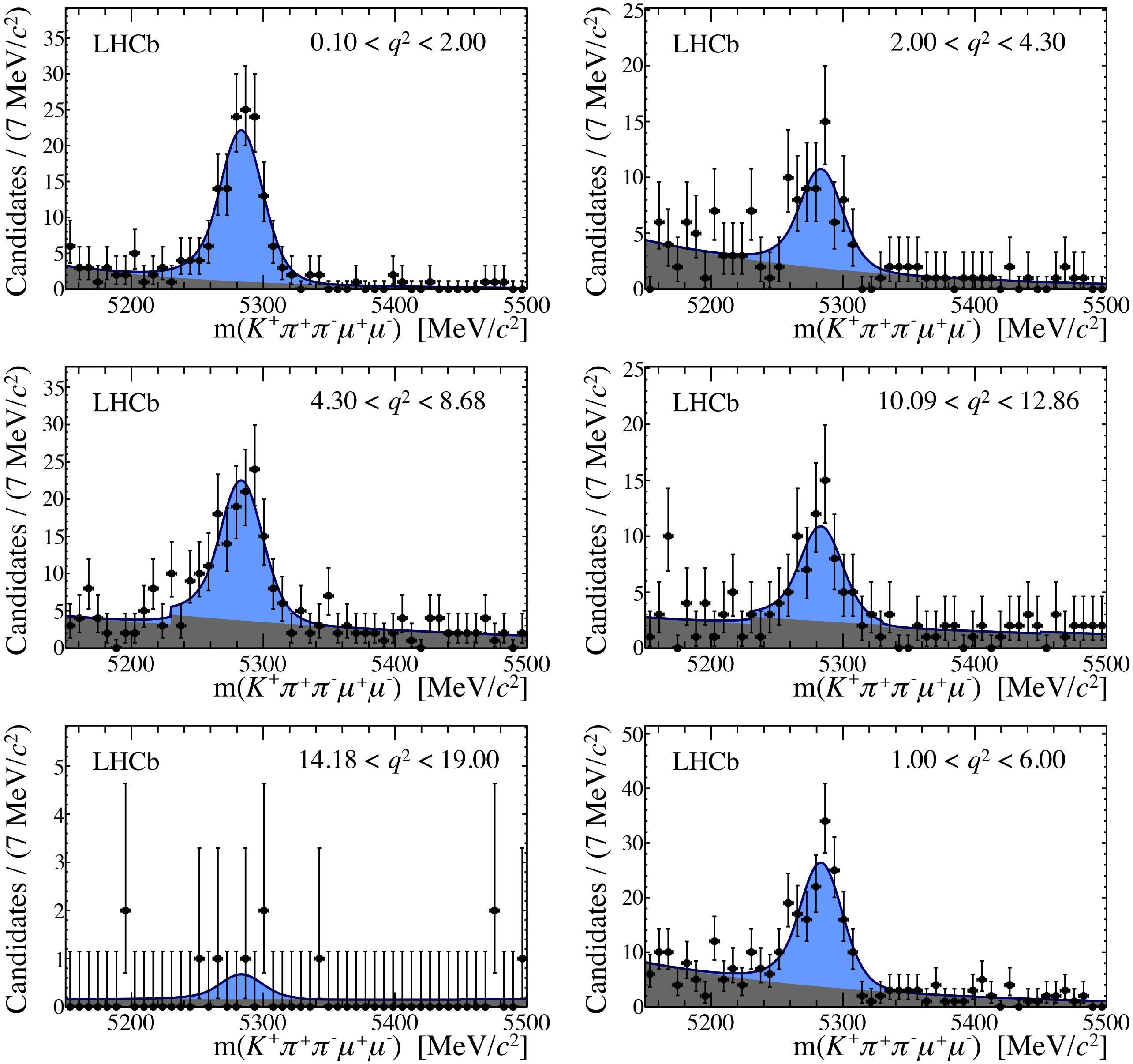
$B^+ \to K^+ ee$



$\mathcal{B}R(B^+ \to hhh\ \mu^+\mu^-)$

LHCb-PAPER-2014-030
PRELIMINARY

Invariant mass fits of $B^+ \to K^+ \pi^+ \pi^- \mu^+ \mu^-$ in bins of q^2



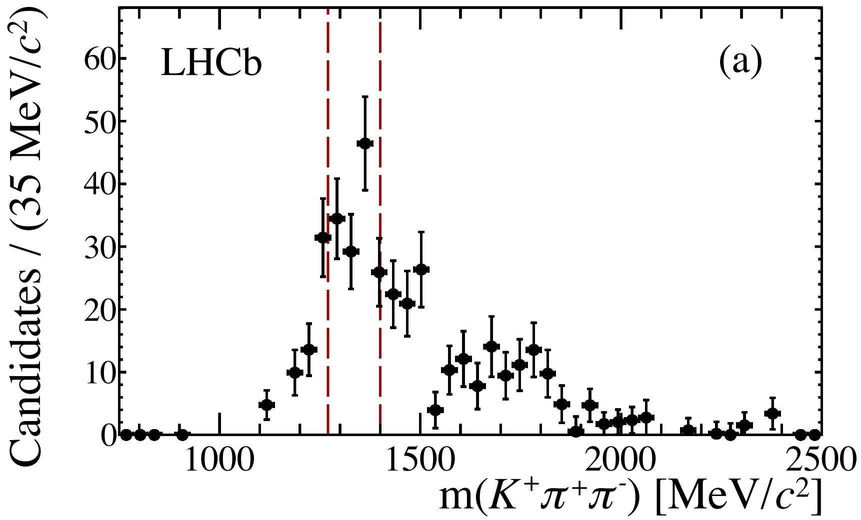
Results branching fraction:

q^2 bin $[\mathrm{GeV}^2/c^4]$	N_{sig}	$\frac{d\mathcal{B}}{dq^2}$ $[\times 10^{-8}\,\mathrm{GeV}^{-2}c^4]$
[0.10, 2.00]	$134.1^{+12.9}_{-12.3}$	$7.01^{+0.69}_{-0.65} \pm 0.47$
[2.00, 4.30]	$56.5^{+\ 9.7}_{-\ 9.1}$	$2.34^{+0.41}_{-0.38} \pm 0.15$
[4.30, 8.68]	$119.9^{+14.6}_{-13.7}$	$2.30^{+0.28}_{-0.26} \pm 0.20$
[10.09, 12.86]	$54.0^{+10.1}_{-\ 9.4}$	$1.83^{+0.34}_{-0.32} \pm 0.17$
[14.18, 19.00]	$3.3^{+\ 2.8}_{-\ 2.1}$	$0.10^{+0.08}_{-0.06} \pm 0.01$
[1.00, 6.00]	$144.8^{+14.9}_{-14.3}$	$2.75^{+0.29}_{-0.28} \pm 0.16$

$\mathcal{B}R(B^+ \to hhh\ \mu^+\mu^-)$

Reconstructed $K^+ \pi^+ \pi$ mass of $B^+ \to K^+ \pi^+ \pi^- \mu^+ \mu^-$ signal decays:

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



$B^+ \to K^+ \Psi(2S)\ [\to \pi^+ \pi^- \mu^+ \mu^-]$