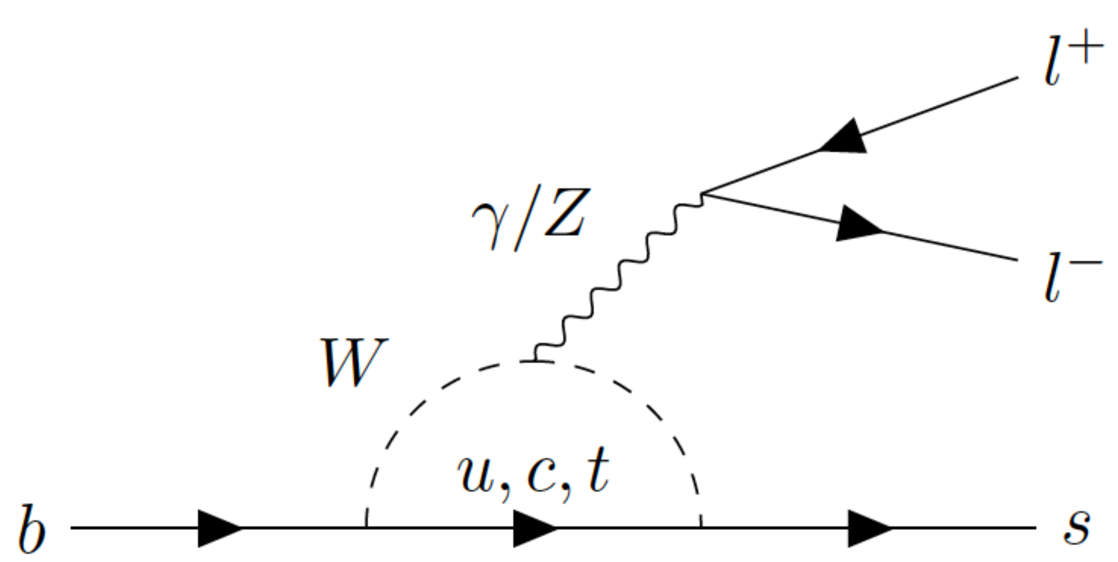
LHCb: $b \to sll$

Da Yu Tou
on behalf of the LHCb Collaboration

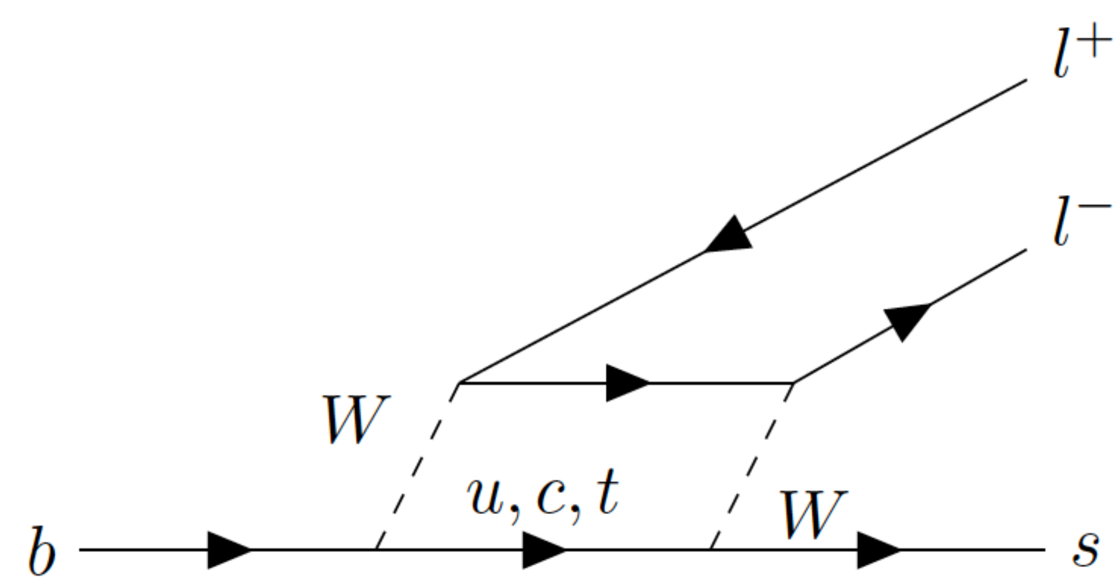
$b \to sll$ Decays

- SM forbids tree-level flavour changing neutral current transitions.

- Lowest-order Feyman diagrams are electroweak penguin or box diagrams.
    - Loops can couple to new physics and access new physics scales beyond direct searches.
    - Small branching fractions makes these decays sensitive to new physics effects.



Electroweak Penguin



Box Diagram

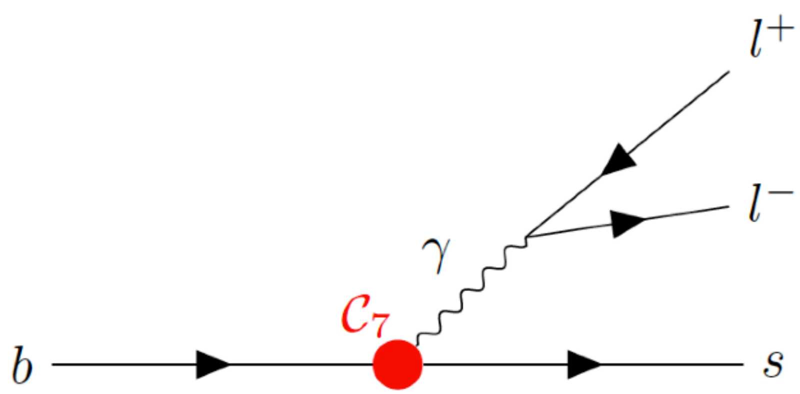
$b \to sll$ Effective Hamiltonian

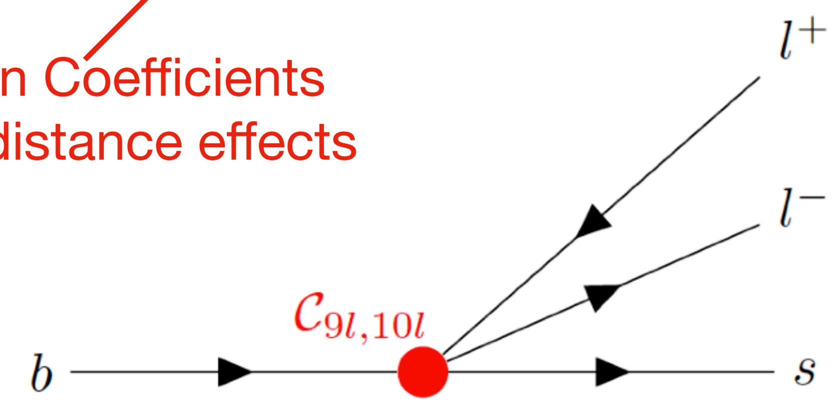
- $b \to sll$ decays can be modelled using a model-independent Effective Field theory approach

Local Operators
Long distance effects

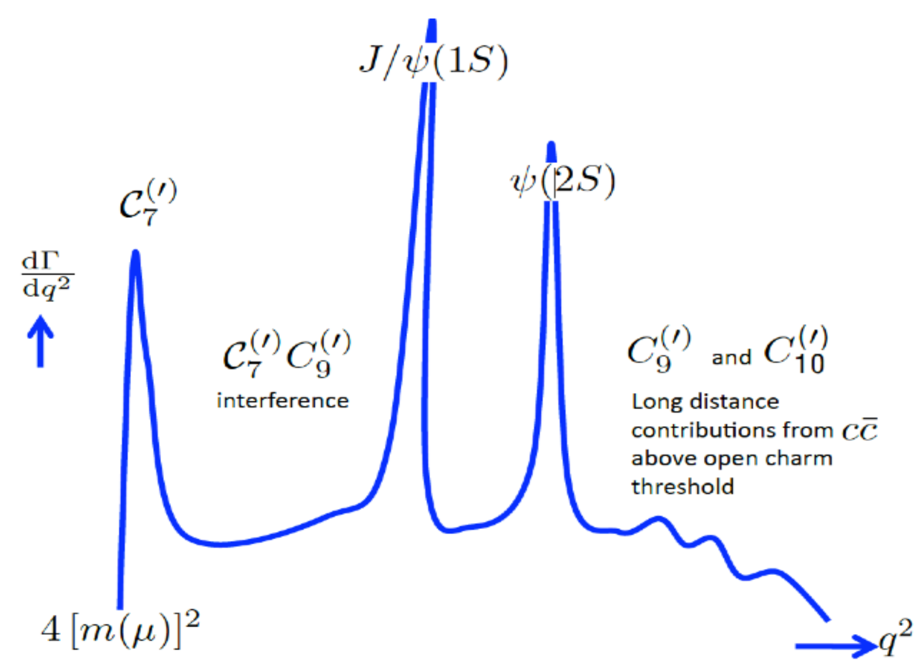
$$\mathcal{H}_{eff} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \boxed{C_i} \boxed{\mathcal{O}_i}$$

Wilson Coefficients
Short distance effects





- Different regions of q^2 (dilepton invariant mass) probes different Wilson Coefficients



Possible Measurements

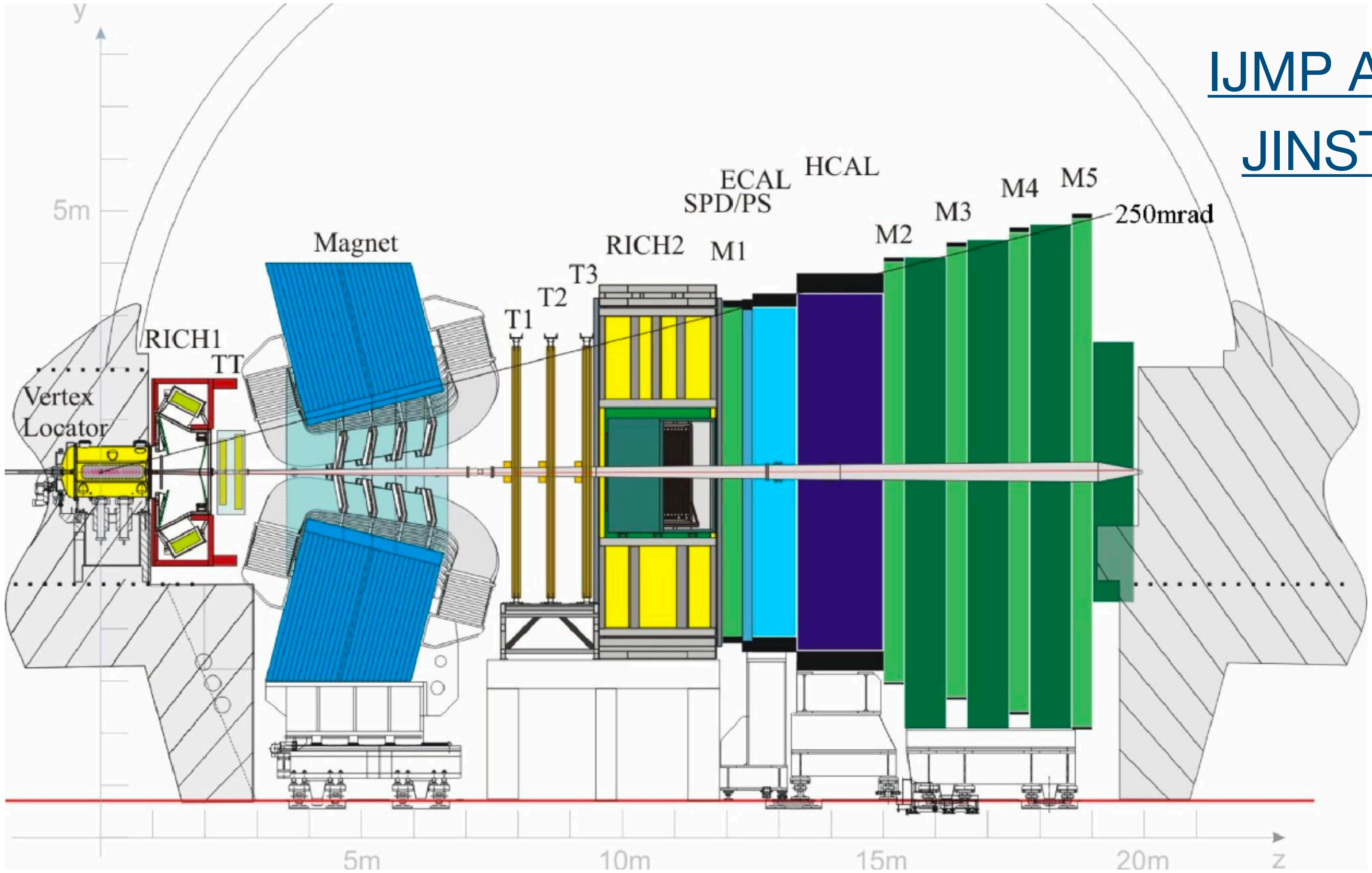
Decreasing hadronic form-factors uncertainty

- Differential branching fractions.
  - Uncertainties dominated by hadronic form-factor uncertainties.

- Angular observables.
  - Hadronic form-factors cancel to first-order.

- Lepton flavour universality ratios.
  - Hadronic form-factors cancel, theoretically clean.
  - SM is lepton flavour universal.

The LHCb Detector

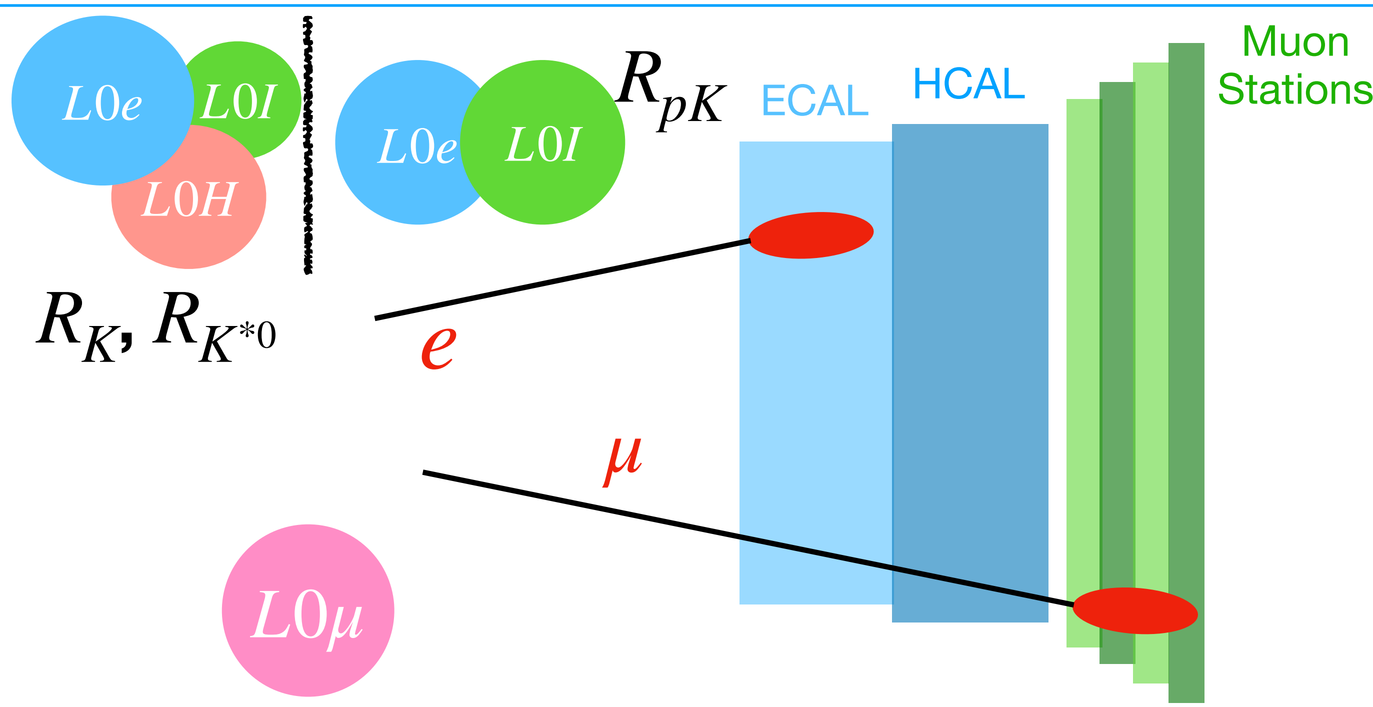


IJMP A 30, 1530022 (2015)

JINST 14 (2019) P04013

- LHCb is a forward spectrometer optimised in the $2 < \eta < 5$ region for b-physics.
- $1\,\%$ momentum resolution, $15 + \dfrac{29}{p_T(\text{GeV})}$ μm impact parameter resolution and good particle identification performance.

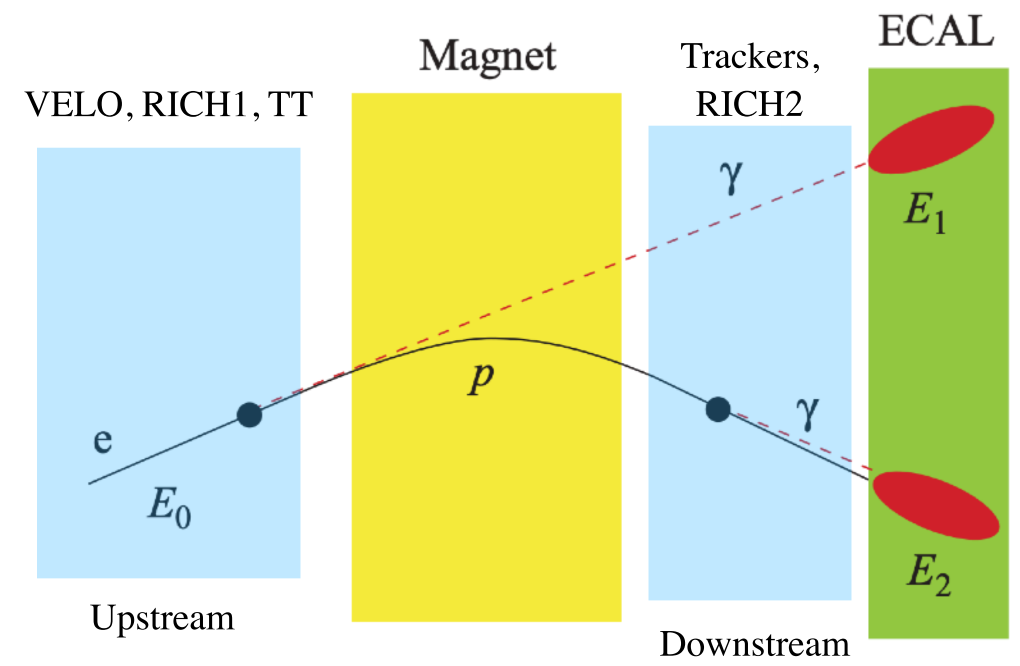
Electrons vs Muons in LHCb



LHCb hardware trigger

$L0\mu$: Triggered by muon
$L0e$: Triggered by electron
$L0H$: Triggered by hadron
$L0I$: Triggered by other particle in event

- Electron triggers are tighter and less efficient.
- Electron modes use hadron and/or exclusive triggers to mitigate efficiency loss.

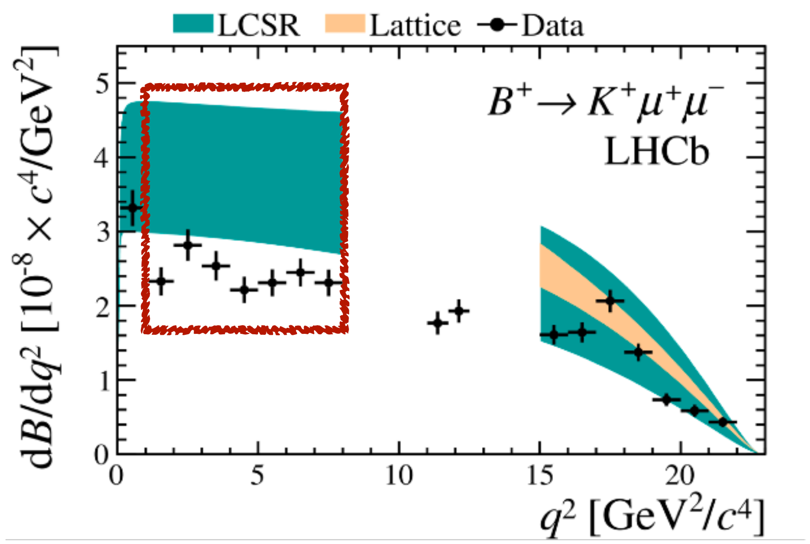


Bremsstrahlung in LHCb

- Electrons emit bremsstrahlung due to material interactions.
- LHCb has recovery procedure but:
  - Photon recovery not 100% efficient.
  - ECAL has worse resolution than trackers.
- Electron modes have worse momentum and mass resolution.

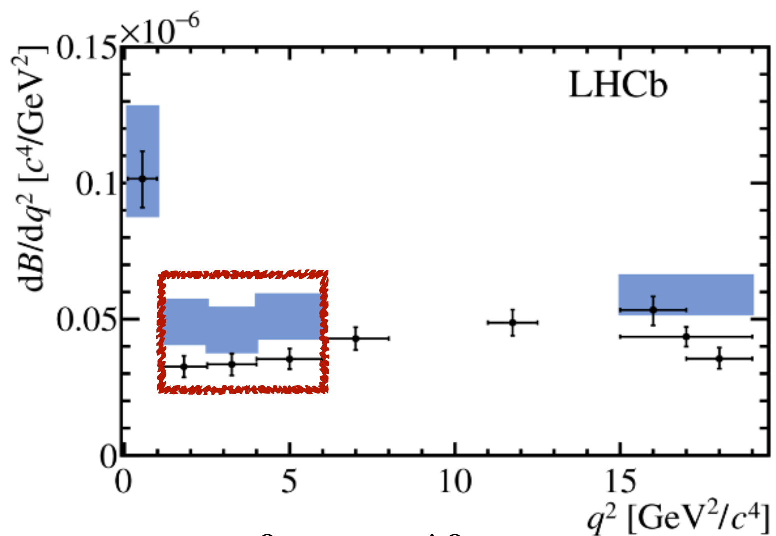
$b \to s\mu^+\mu^-$ BF Measurements

Low q^2 measurements of different decay modes tend to lie consistently below SM predictions but no significant deviations are observed due to large theory uncertainties



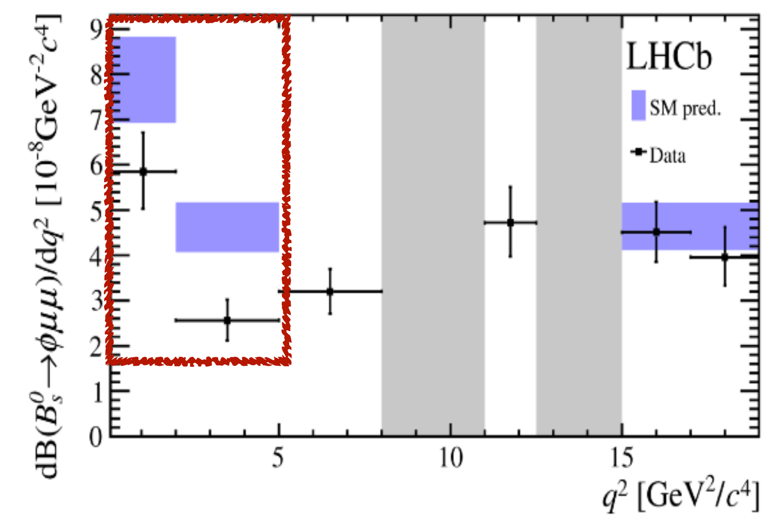
$B^+ \to K^+\mu^+\mu^-$

JHEP 06 (2014) 133



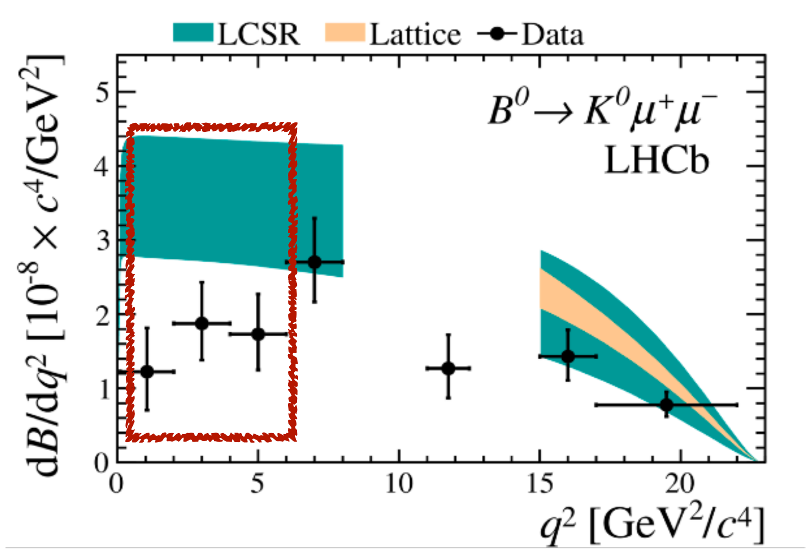
$B^0 \to K^{*0}\mu^+\mu^-$

JHEP 11 (2016) 047



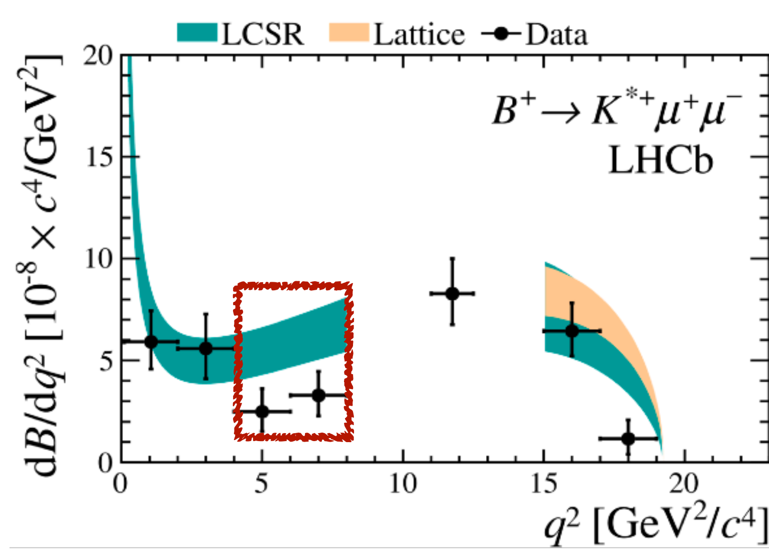
$B_s^0 \to \phi\mu^+\mu^-$

JHEP 09 (2015) 179



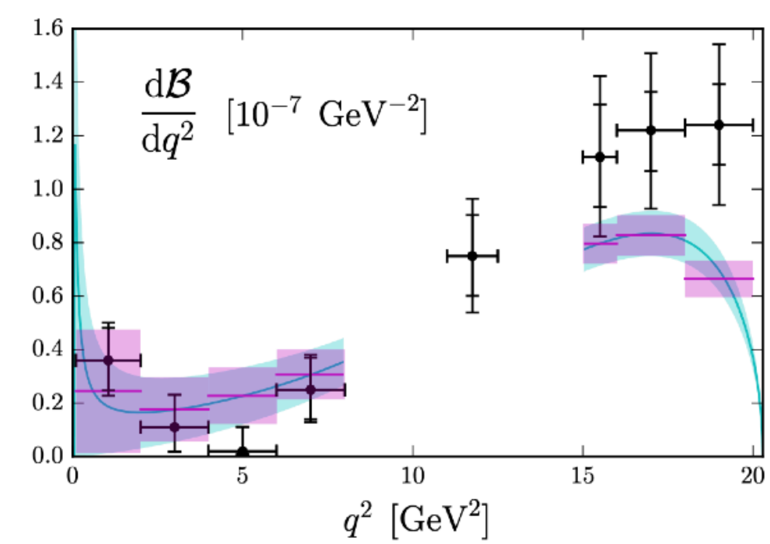
$B^0 \to K^0\mu^+\mu^-$

JHEP 06 (2014) 133



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

JHEP 06 (2014) 133



$\Lambda_b \to \Lambda\mu^+\mu^-$

JHEP 06 (2015) 115

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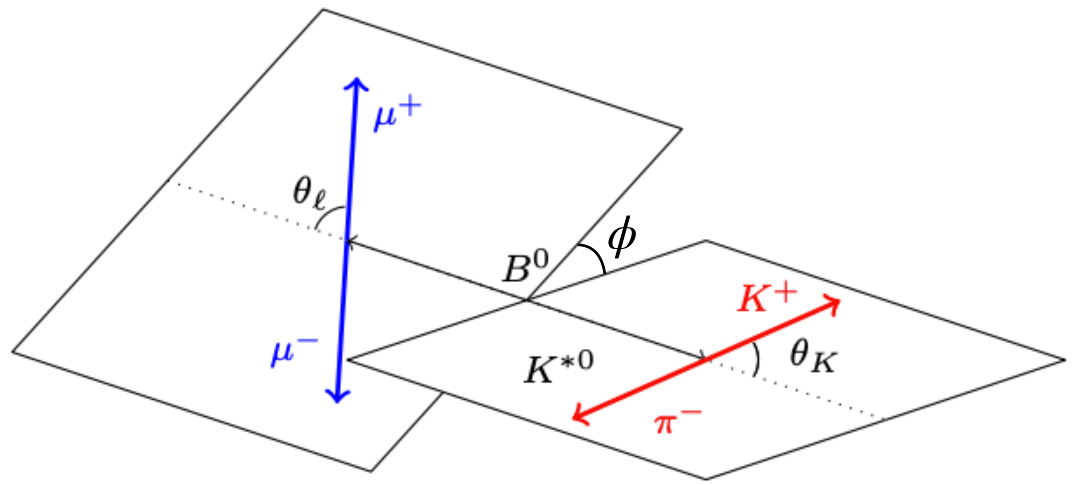
Angular Analysis of $B^0 \to K^{*0}\mu^+\mu^-$

PRL 125, 011802 (2020)



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

- Differential decay rate can be parameterised as a function of q^2, angles $\vec{\Omega} = (\cos\theta_l, \cos\theta_K, \phi)$

q^2 dependent angular observables

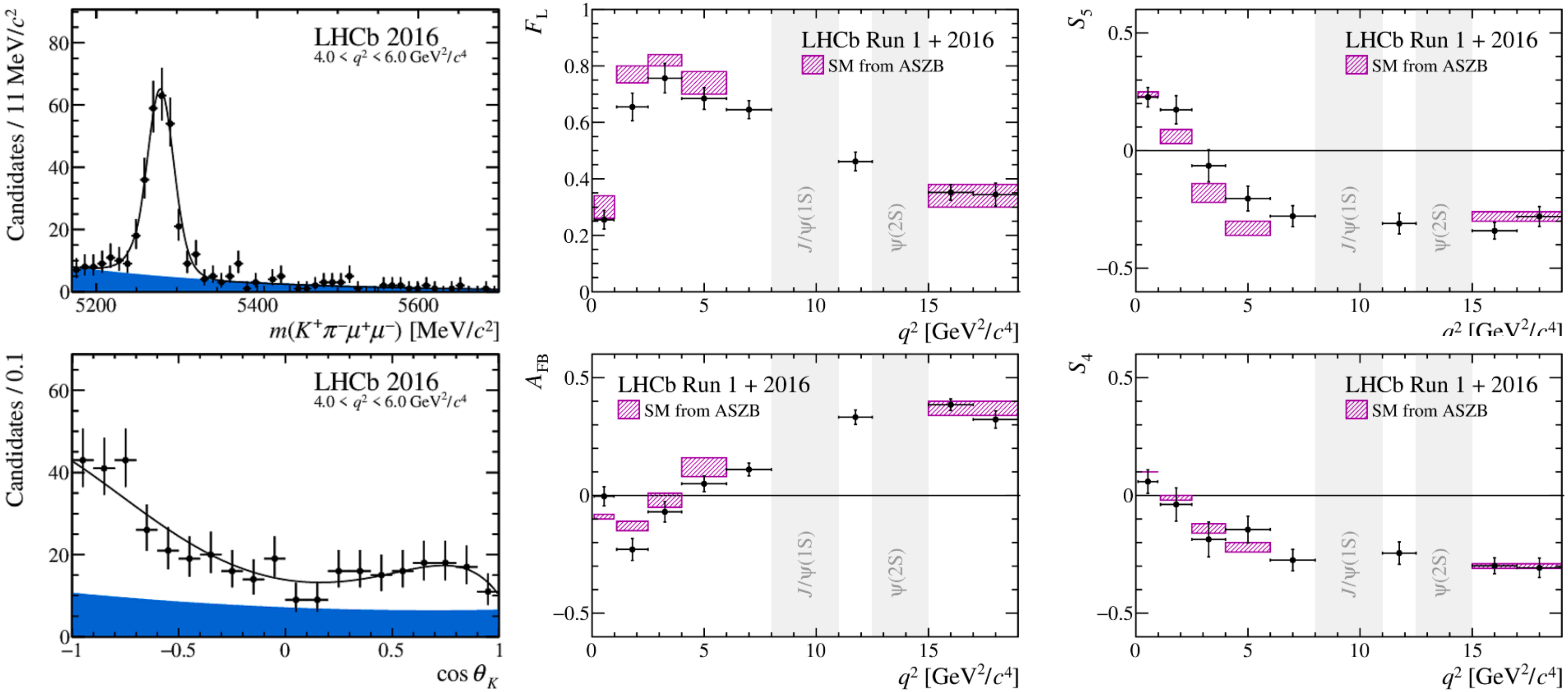
$$\frac{d^4\Gamma\left[B^0 \to K^{*0}\mu^+\mu^-\right]}{dq^2 q\vec{\Omega}} = \frac{9}{32\pi}\sum_i \boxed{I_i(q^2)}\,\boxed{f_i(\vec{\Omega})}$$

$\vec{\Omega}$ dependent angular functions

- Measure angular observables F_L, A_{FB}, S_i with $4.7\ \text{fb}^{-1}$ of data.

Fit Results

PRL 125, 011802 (2020)

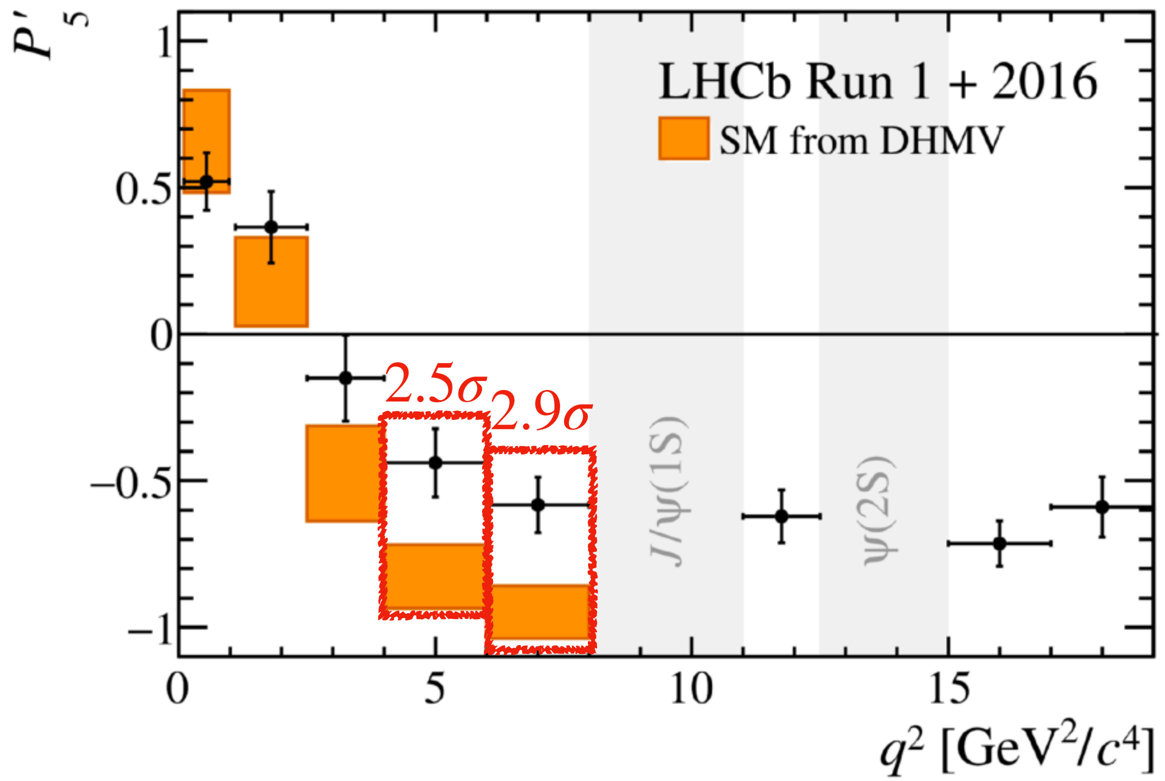


- Efficiencies are evaluated as function of $(q^2, \theta_l, \theta_K, \phi)$ and multiplied into $\dfrac{d^4\Gamma}{dq^2 q\overrightarrow{\Omega}}$ PDF.

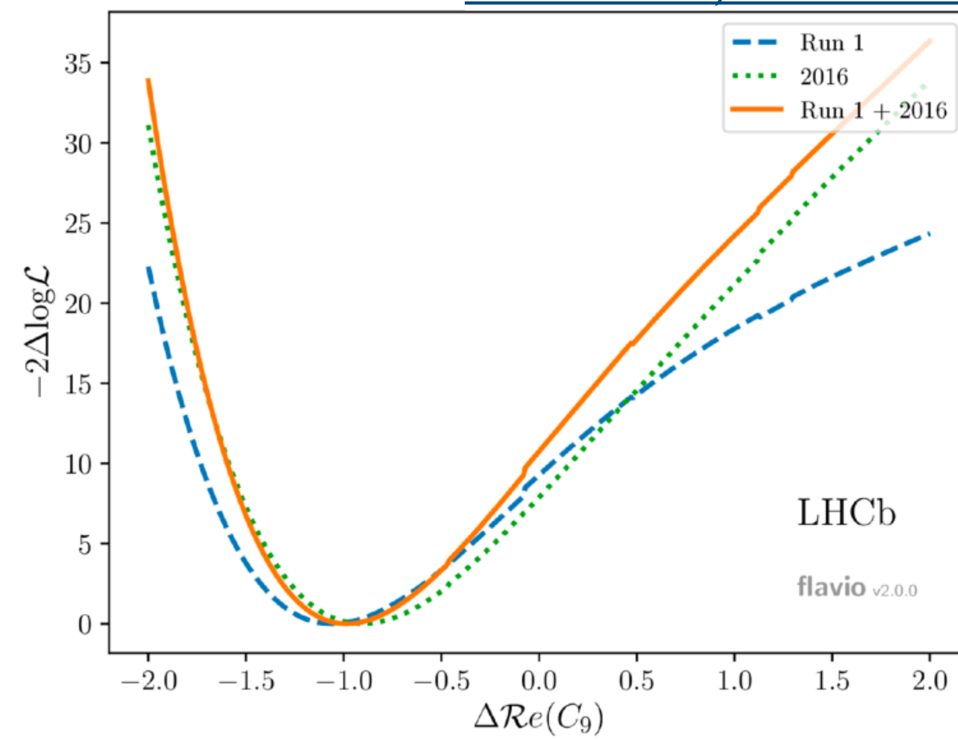
Disentangle K^{*0} from S-Wave

- Fit $(m_{K\pi\mu\mu}, \boxed{m_{K\pi}}, \overrightarrow{\Omega})$ distributions in 8 q^2 bins, excluding $\phi(1020)$, J/ψ, $\psi(2S)$.

Optimised basis: P'_5



PRL 125, 011802 (2020)

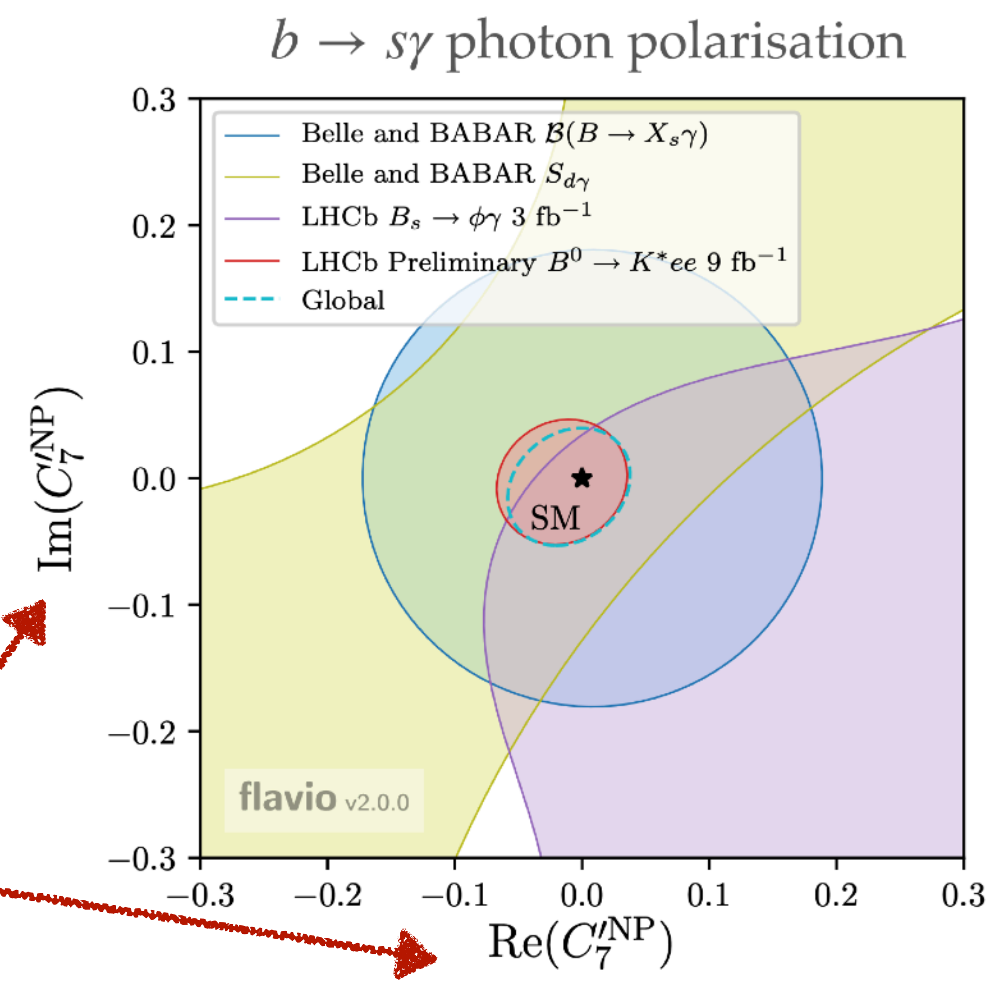


- Transform F_L, A_{FB}, S_i into P'_i basis which is independent, to first-order, of hadronic form-factors.
- Fit in P'_i basis. $P'_5 = \dfrac{S_5}{\sqrt{F_L(1-F_L)}}$, tension with SM at 2.5σ and 2.9σ.
- Fit $\Delta Re(C_9)$ using FLAVIO package and other parameters assuming their SM value: 3.3σ tension with SM.

Angular Analysis of $B^0 \to K^{*0} e^+ e^-$ [preliminary]

$$
\begin{aligned}
F_{\mathrm{L}} &= 0.044 \pm 0.026 \pm 0.014 \\
A_{\mathrm{T}}^{\mathrm{Re}} &= -0.064 \pm 0.077 \pm 0.015 \\
A_{\mathrm{T}}^{(2)} &= +0.106 \pm 0.103^{+0.016}_{-0.017} \\
A_{\mathrm{T}}^{\mathrm{Im}} &= +0.015 \pm 0.102 \pm 0.012,
\end{aligned}
$$

$$
\boxed{
\begin{aligned}
A_T^{(2)}(q^2 \to 0) &= \frac{2\, Re(C_7 C_7'^{*})}{|C_7|^2 + |C_7'|^2} \\
A_T^{Im}(q^2 \to 0) &= \frac{2\, Im(C_7 C_7'^{*})}{|C_7|^2 + |C_7'|^2}
\end{aligned}
}
$$



- Measured with 9 fb^{-1} of data, in the very low q^2 range $[0.0008, 0.256]$ GeV^2/c^4.
- Similar to $B^0 \to K^{*0}\mu^+\mu^-$, 4D fit to $(m_{K\pi ee}, \cos\theta_l, \cos\theta_K, \tilde{\phi})$, $\tilde{\phi} = \phi + \pi$.
- Results agree with SM. Strong constraints on right-handed photon polarisation Wilson coefficient C_7'. (left plot).
- Presented at ICHEP, paper LHCb-PAPER-2020-020 in preparation.

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RECEPT

LHCb

Measurement of short-distance and long-distance interference

Eur. Phys. J. C (2017) 77: 161

- Experimental measurements of $b \to sl^+l^-$ typically avoid the q^2 region around J/ψ and $\psi(2S)$ charmonium resonances

- However, these resonances (and ρ, ω, ϕ) might interfere destructively with $b \to sl^+l^-$ decays and mimic a new physics effect. Argued by:

  arXiv:1406.0566 arXiv:1503.06199 JHEP 06(2016)116

- Analysis selects $K^+\mu^+\mu^-$ final states and fits the $m_{\mu^+\mu^-}$ spectrum using the effective Hamiltonian to study the interference effect, assuming

Magnitude

$$C_9^{eff} = C_9 + \sum_j \boxed{\eta_j} \boxed{e^{i\delta_j}} \boxed{A_j^{res}(q^2)}$$

Phase

Lineshape function, typically relativistic Breit-Wigner

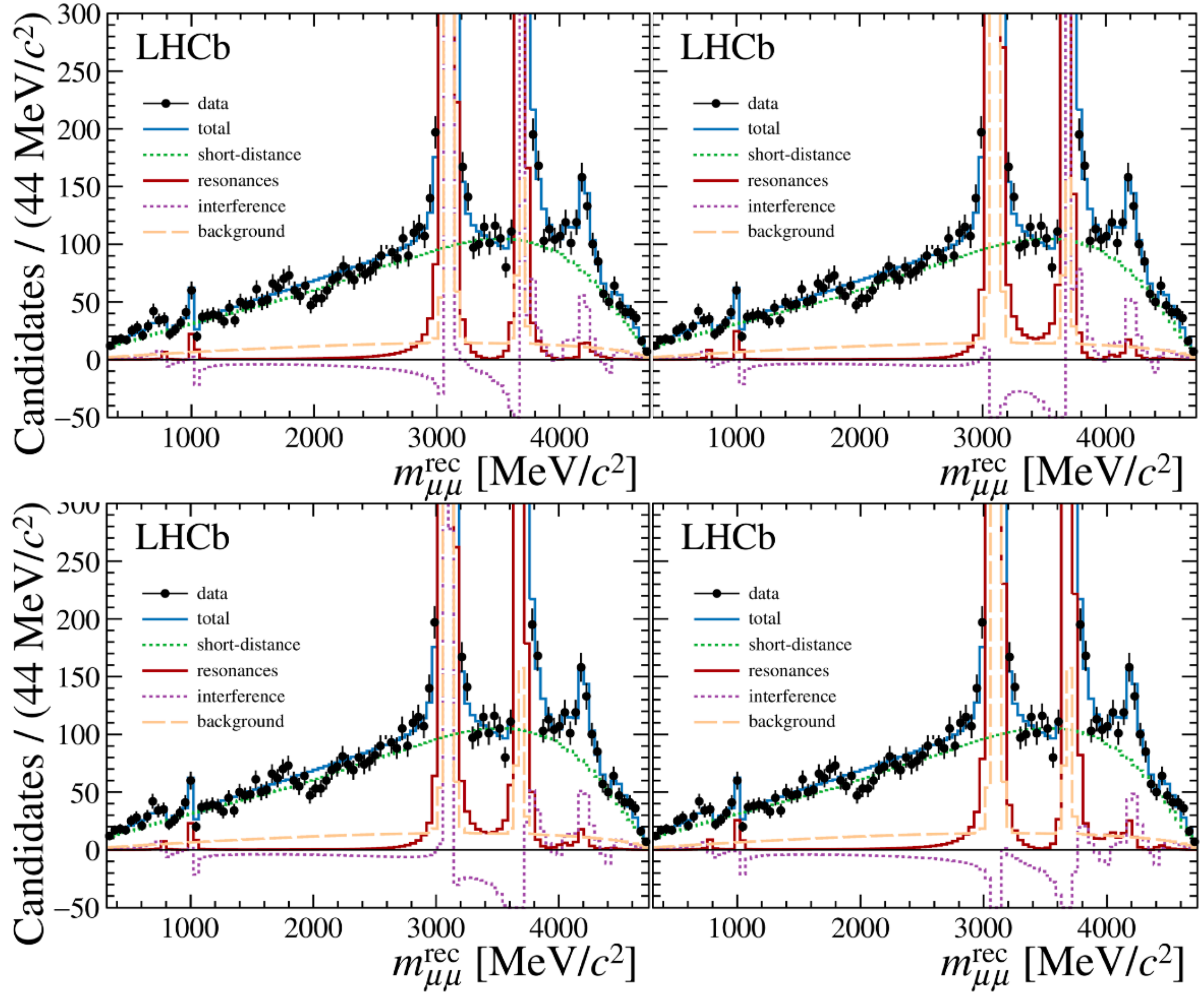
Measurement of short-distance and long-distance interference

[Eur. Phys. J. C (2017) 77: 161]

- Model fits data well, $\chi^2_{ndof} = \dfrac{110}{78}$

- Four-fold ambiguities due to sign on J/ψ and $\psi(2S)$ phases

- The contributions from charmonium resonances are small in the q^2 region far away from the J/ψ mass



Four best-fit solutions to $m_{\mu^+\mu^-}$

Test of Lepton Flavour Universality

- Theoretical calculations predict $R_H = \dfrac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B \to H\mu\mu)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B \to Hee)}{dq^2} dq^2}$.

- LHCb analysis strategy: use tree-level $B \to H\ J/\psi(\to l^+l^-)$ as a control mode. Measure lepton flavour universality as a double ratio.

- $$R_H^{Double} = \frac{R_H}{r_{J/\psi}} = \frac{\mathcal{B}(B \to H\mu\mu)}{\mathcal{B}\big(B \to HJ/\psi(\to \mu\mu)\big)} \Big/ \frac{\mathcal{B}(B \to Hee)}{\mathcal{B}\big(B \to HJ/\psi(\to ee)\big)}$$

Expected to be unity

$$= \frac{N(B \to H\mu\mu)}{N\big(B \to HJ/\psi(\to \mu\mu)\big)} \times \frac{\epsilon\big(B \to HJ/\psi(\to \mu\mu)\big)}{\epsilon(B \to H\mu\mu)}$$

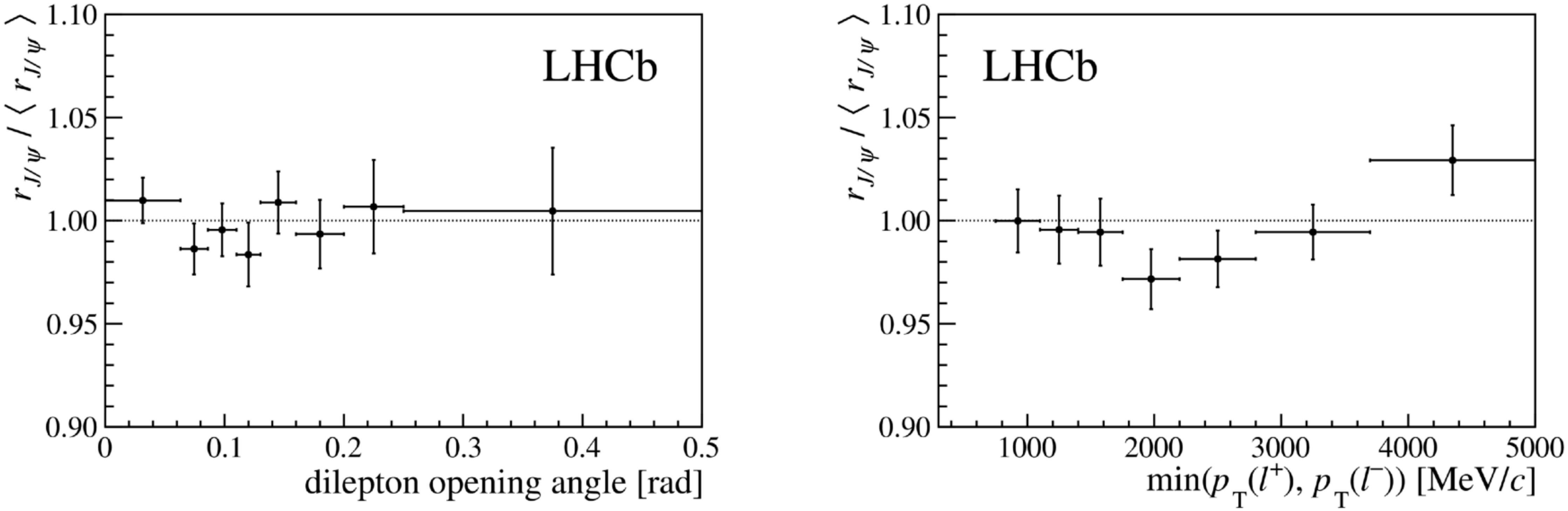
Measure with mass fits to m_{Hll}

Estimate with simulation, corrected using data-driven methods

$$\times \frac{N\big(B \to HJ/\psi(\to ee)\big)}{N(B \to Hee)} \times \frac{\epsilon(B \to Hee)}{\epsilon\big(B \to HJ/\psi(\to ee)\big)}$$

- Systematics cancel in the efficiency ratio.

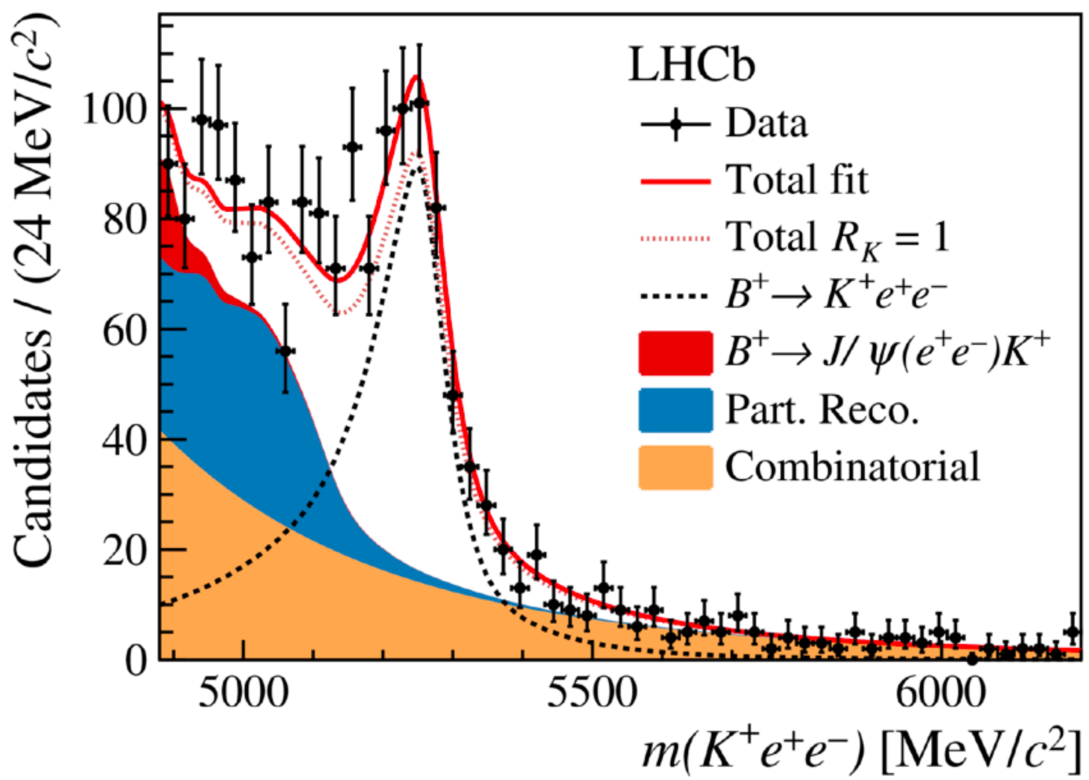
$r_{J/\psi}$ and $R_{\psi(2S)}$ Cross-checks

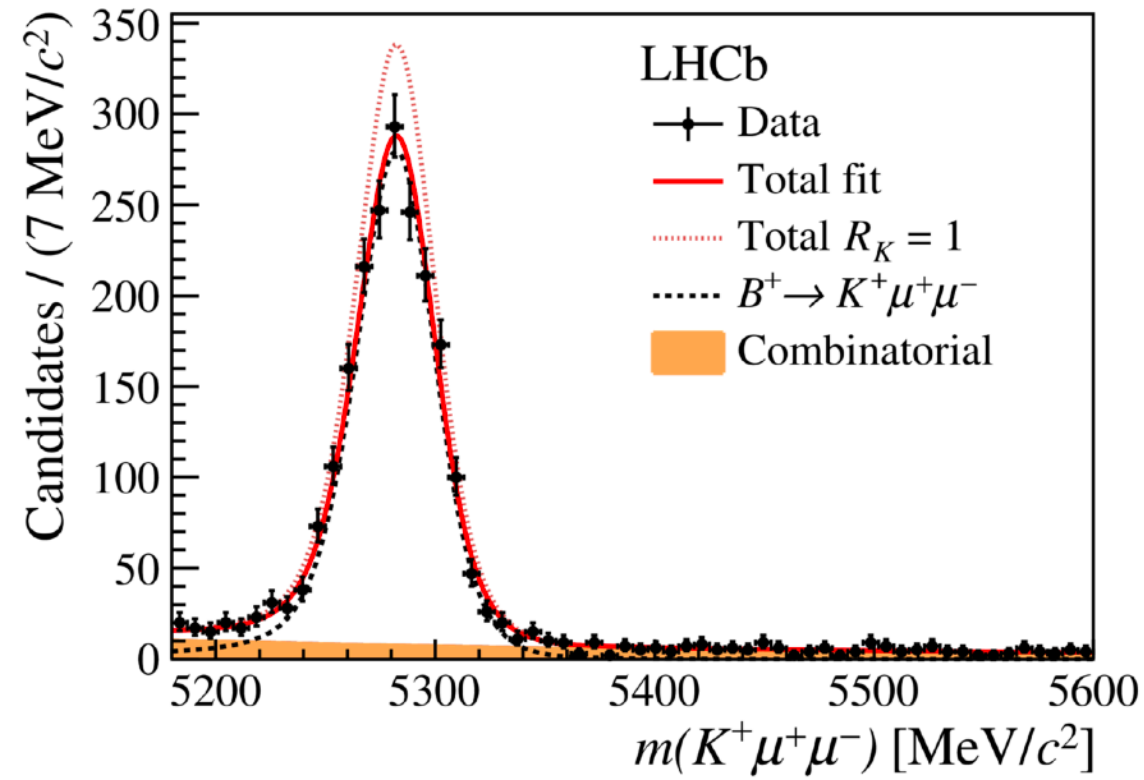


[PRL 122, 191801 (2019)]

- Measure $r_{J/\psi} = \dfrac{\mathcal{B}\left(B \to HJ/\psi(\to \mu\mu)\right)}{\mathcal{B}\left(B \to HJ/\psi(\to ee)\right)}$ as an efficiency cross check. Systematics in μ/e efficiency ratio do not cancel.
- Integrated $r_{J/\psi}$ cross checks total efficiencies.
- Differential $r_{J/\psi}$ flat, independent of kinematics (see plots).
- Check double ratio $R_{\psi(2S)} = \dfrac{\mathcal{B}\left(B \to H\psi(2S)(\to \mu\mu)\right)}{\mathcal{B}\left(B \to H\psi(2S)(\to ee)\right)} \times \dfrac{1}{r_{J/\psi}}$.

R_K [PRL 122, 191801 (2019)]





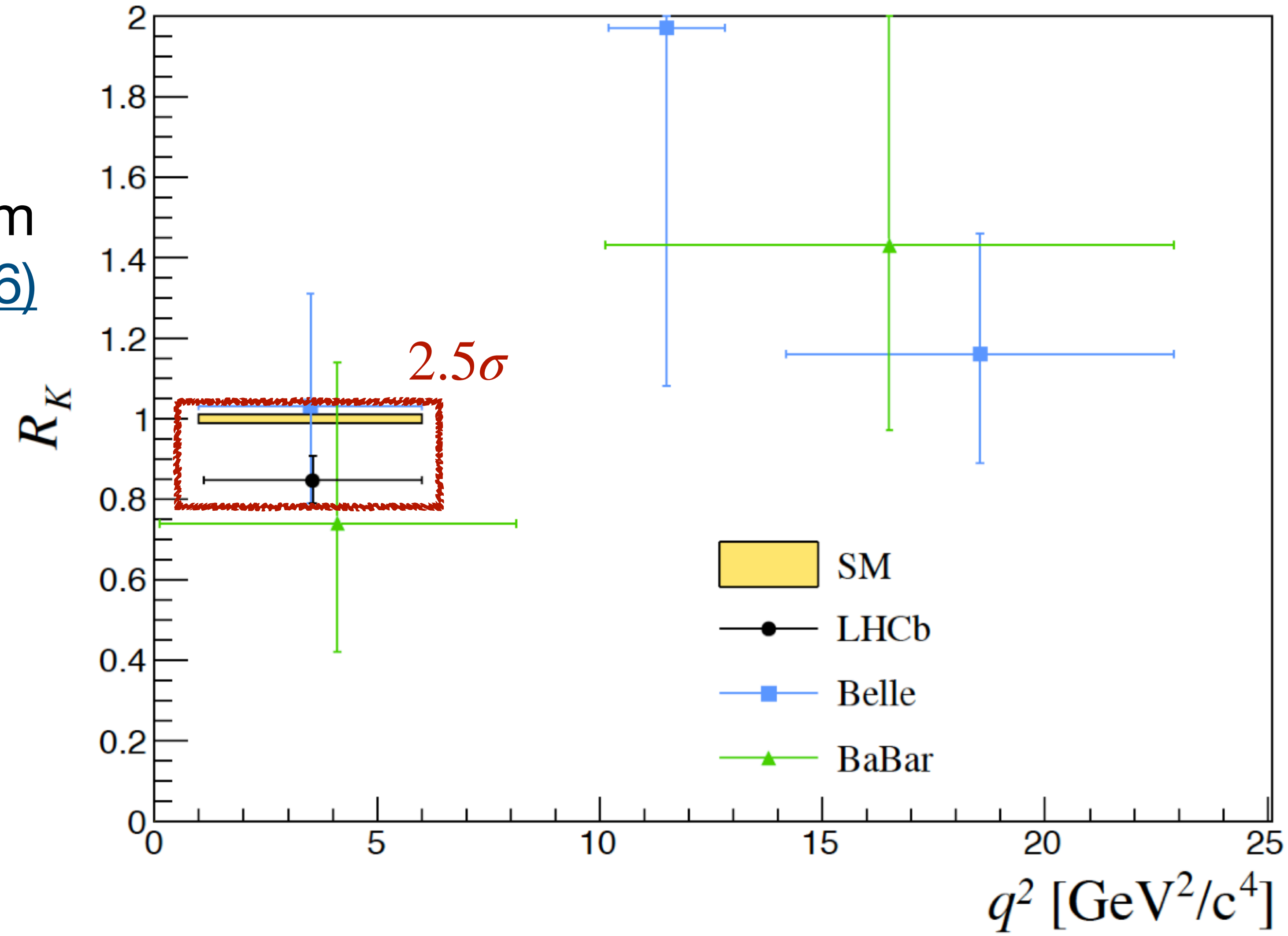
$N(B^+ \to K^+e^+e^-) = 766 \pm 48$

$N(B^+ \to K^+\mu^+\mu^-) = 1943 \pm 49$

- Measure $R_K = \dfrac{\mathscr{B}(B^+ \to K^+\mu^+\mu^-)}{\mathscr{B}(B^+ \to K^+e^+e^-)}$ with 5.0 fb^{-1} of data.
- $1.1 < q^2 < 6.0\ GeV^2/c^4$ dilepton invariant mass.
- Cross-checked $r_{J/\psi} = 0.986 \pm 0.013$.

R_K PRL 122, 191801 (2019)

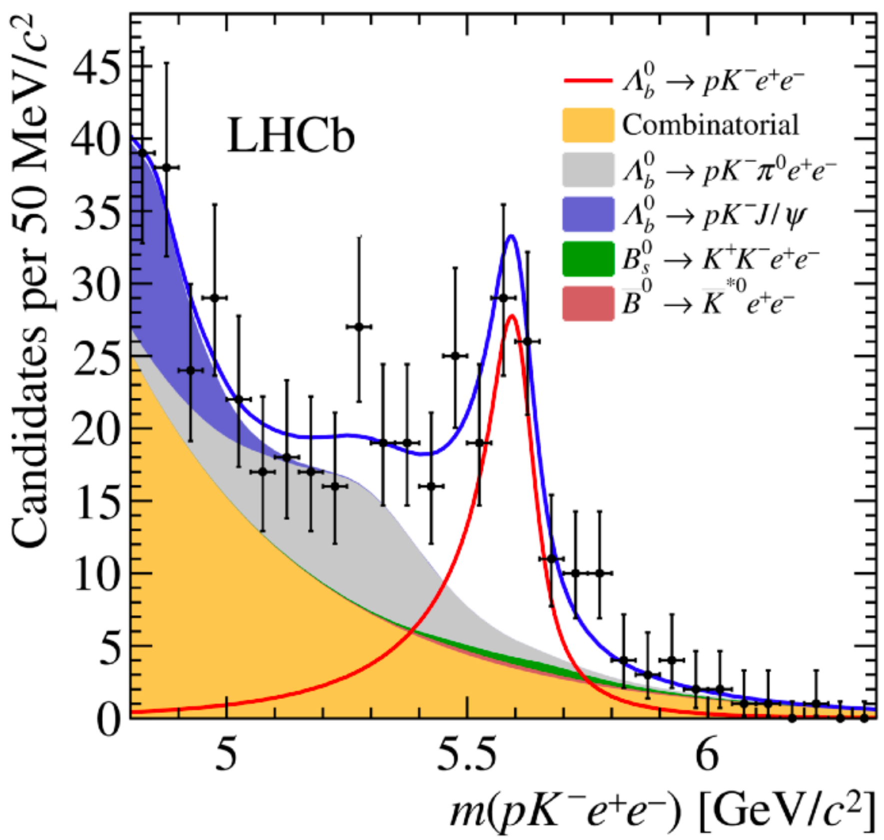
SM predictions from EPJC 76, 440 (2016)

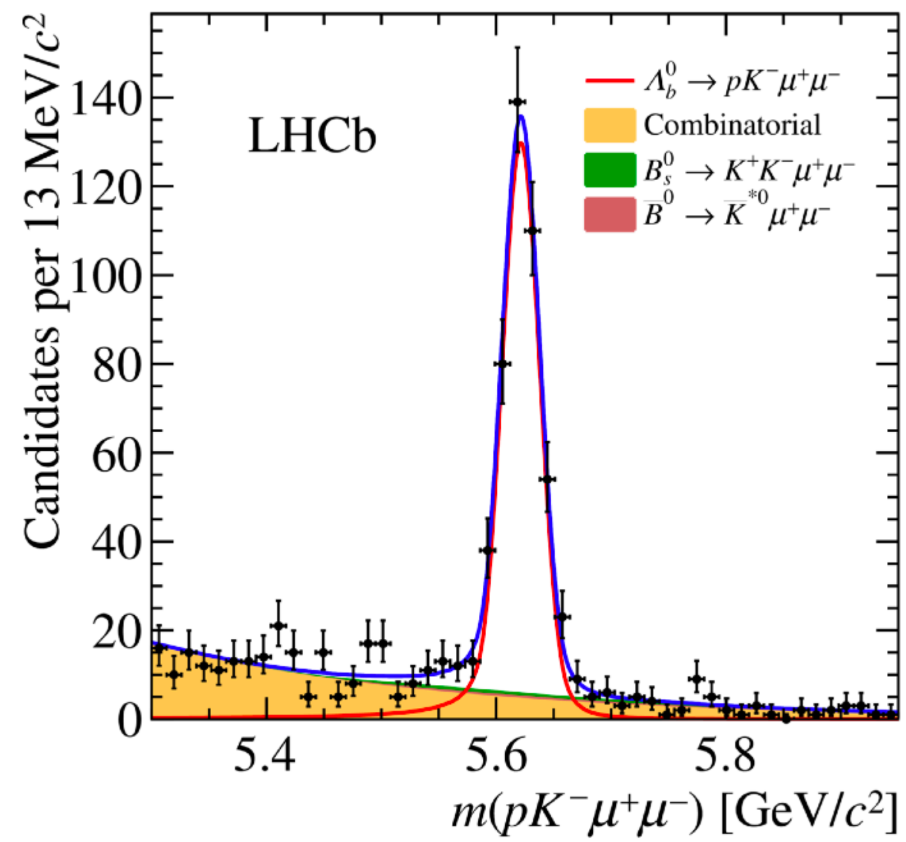


- $R_K = 0.846^{+0.060}_{-0.054}{}^{+0.016}_{-0.014}$ in $1.1 < q^2 < 6.0\ GeV^2/c^4$.
- 2.5σ tension with SM.

Point out datapoint, highlight

R_{pK} JHEP 2020, 40 (2020)





$N(\Lambda_b \to pK^-e^+e^-) = 122 \pm 17$ $N(\Lambda_b \to pK^-\mu^+\mu^-) = 444 \pm 23$

- Measure $R_{pK}^{-1} = \dfrac{\mathscr{B}(\Lambda_b \to pK^-e^+e^-)}{\mathscr{B}(\Lambda_b \to pK^-\mu^+\mu^-)}$ inverted ratio with $4.7\ \text{fb}^{-1}$ of data.
- $0.1 < q^2 < 6.0\ GeV^2/c^4$ dilepton invariant mass and $m_{pK^-} < 2600\ MeV/c^2$.
- First test of lepton universality in b-baryons.
- Cross-checked $r_{J/\psi}^{-1} = 0.96 \pm 0.05$.

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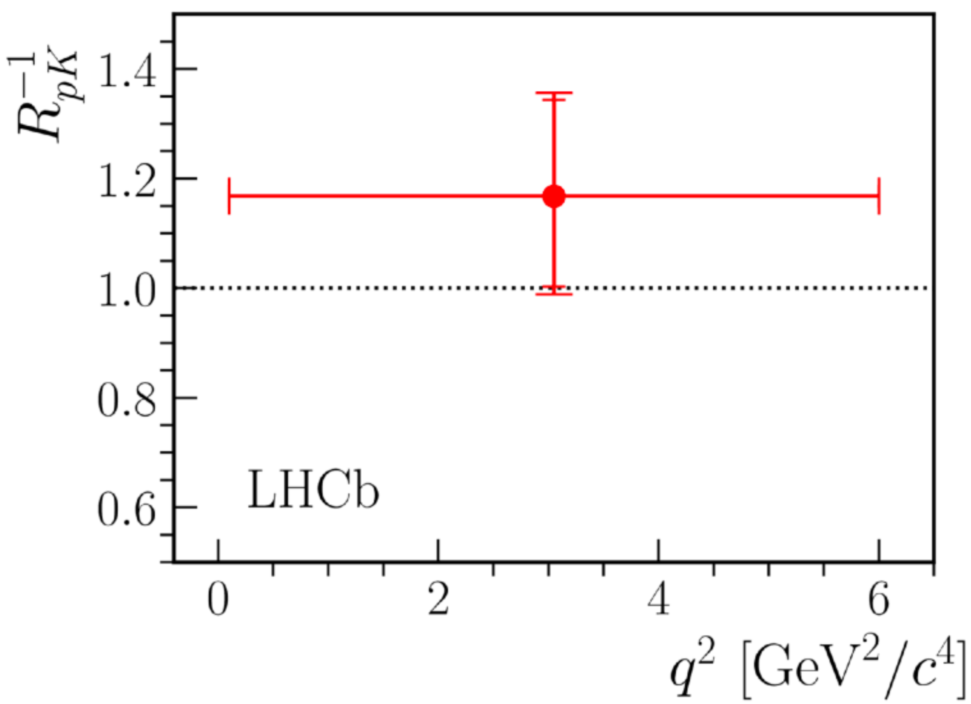
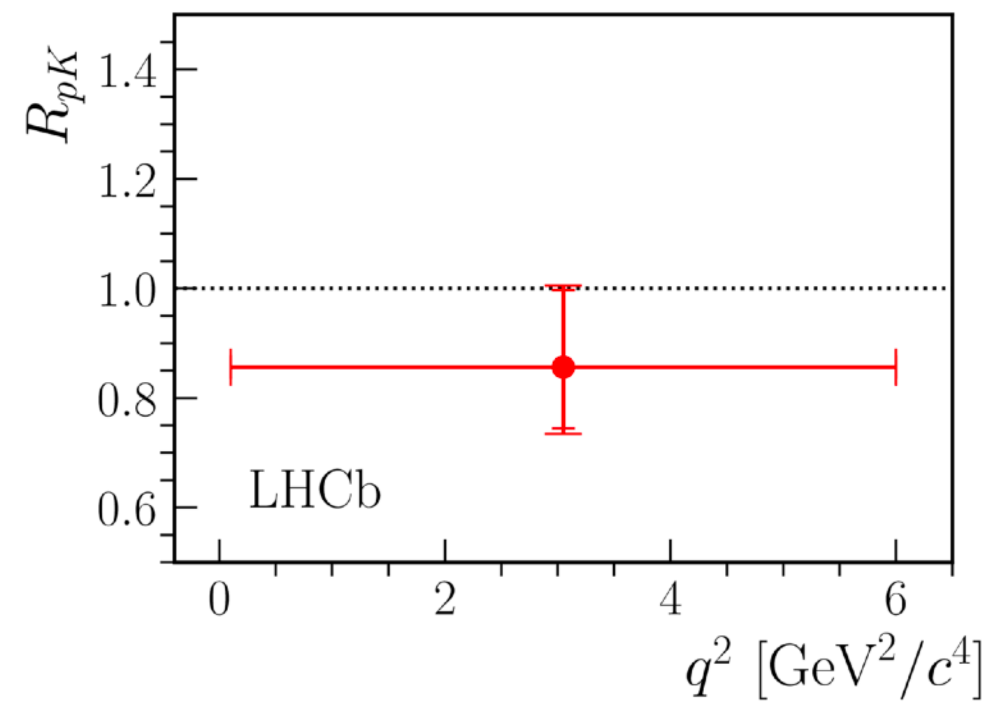
R_{pK} [JHEP 2020, 40 (2020)](#)





- $R_{pK}^{-1} = 1.17^{+0.18}_{-0.16} \pm 0.07$, inverts into $R_{pK} = 0.86^{+0.14}_{-0.11} \pm 0.05$.
- First measurement of $\mathscr{B}(\Lambda_b \to pK^-\mu^+\mu^-)$.

Uncertainty on $\mathscr{B}(\Lambda_b \to pK^- J/\psi)$

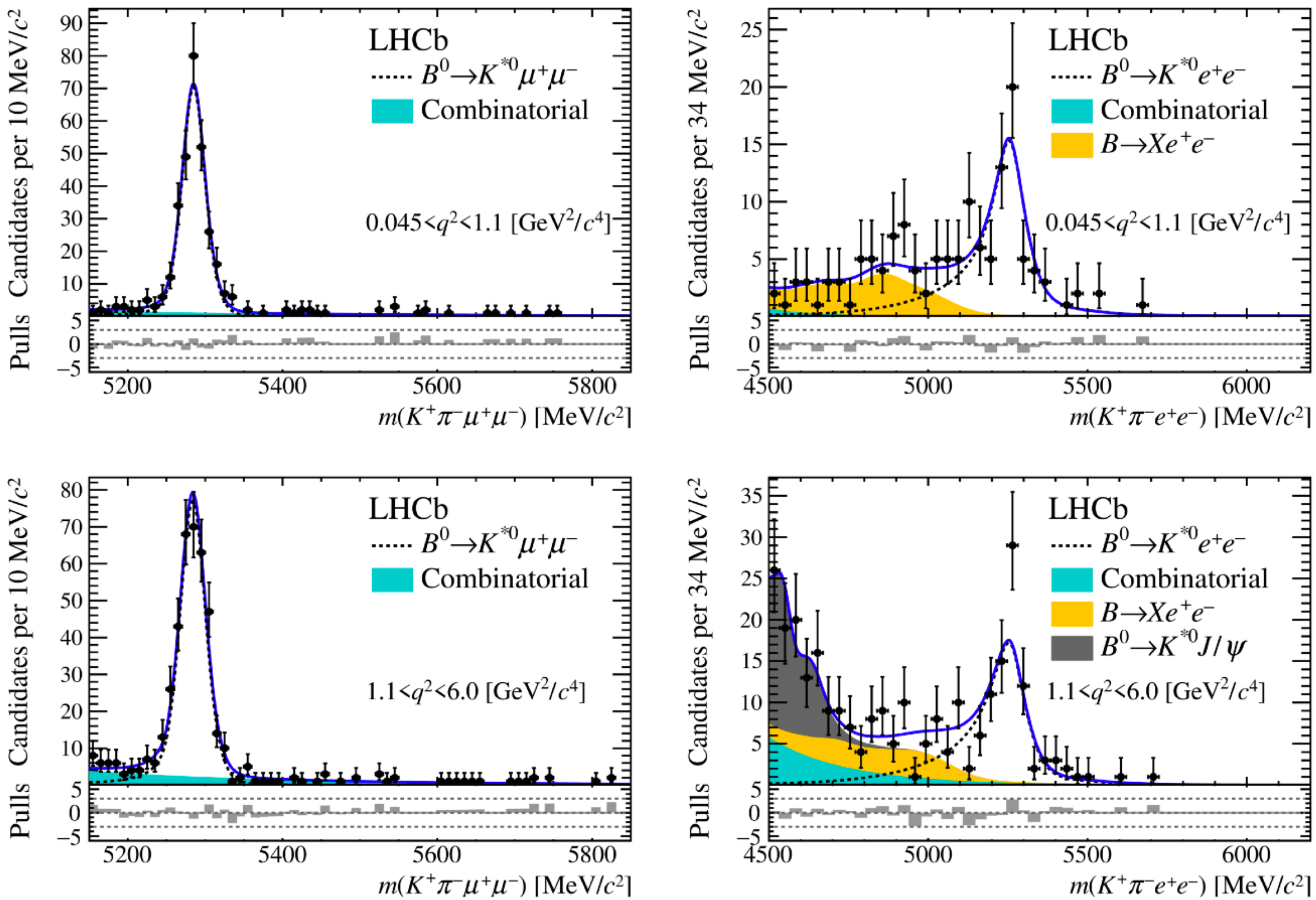
Statistical

- $\mathscr{B}(\Lambda_b \to pK^-\mu^+\mu^-)|_{0.1<q^2<6.0\ GeV^2/c^4} = (2.65 \pm \boxed{0.14} \pm \boxed{0.12} \pm \boxed{0.29^{+0.38}_{-0.23}}) \times 10^{-7}$.

Systematic

- First observation of $\Lambda_b \to pK^-e^+e^-$.

$R_{K^{*0}}$ JHEP 08 (2017) 055



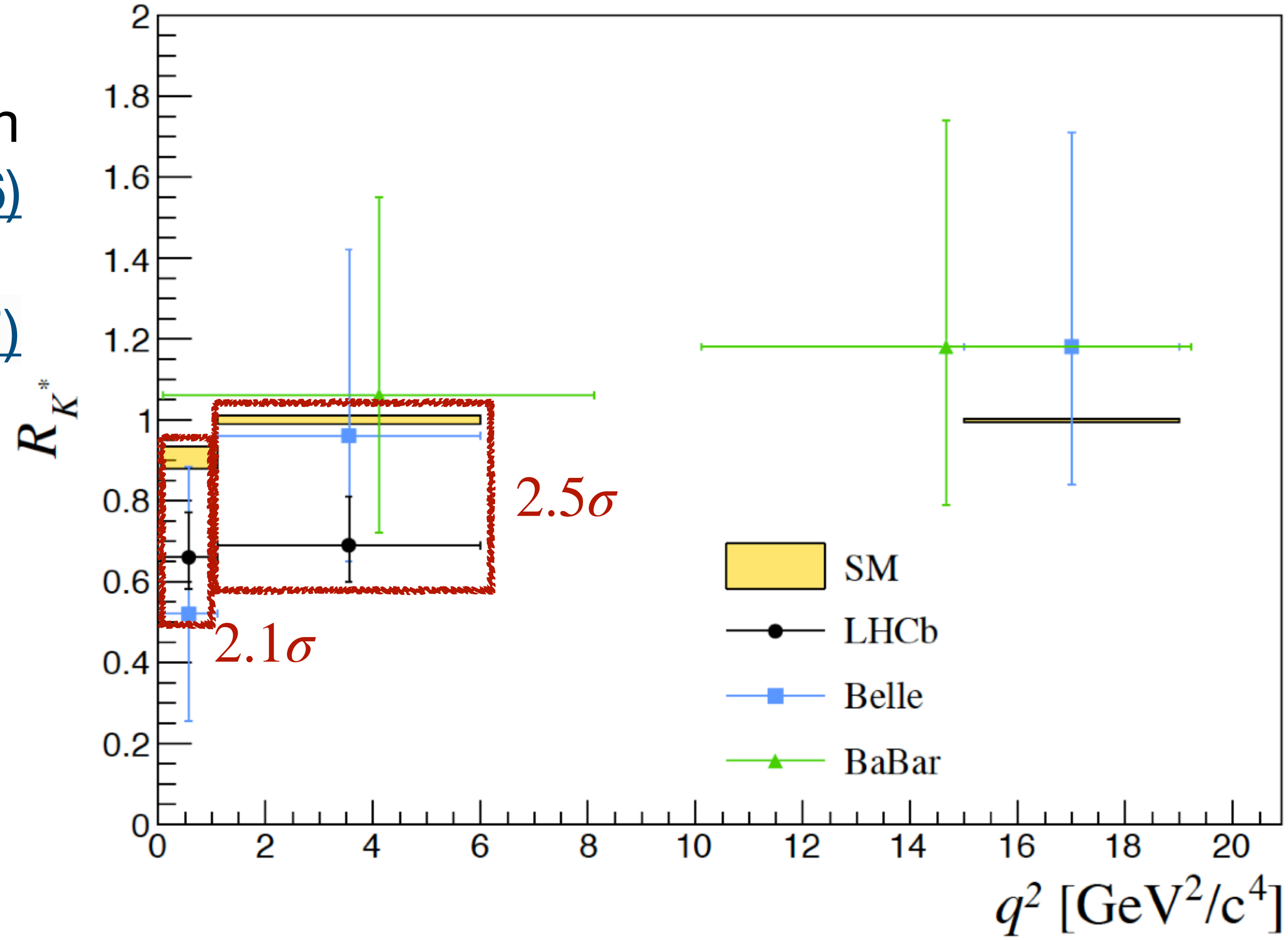
$$0.045 < q^2 < 1.1\ GeV^2/c^4$$
$$N(B^0 \to K^{*0}e^+e^-) = 89^{+11}_{-10}$$
$$N(B^0 \to K^{*0}\mu^+\mu^-) = 285^{+18}_{-18}$$

$$1.1 < q^2 < 6.0\ GeV^2/c^4$$
$$N(B^0 \to K^{*0}e^+e^-) = 111^{+14}_{-13}$$
$$N(B^0 \to K^{*0}\mu^+\mu^-) = 353^{+21}_{-21}$$

- Measure $R_{K^{*0}} = \dfrac{\mathscr{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathscr{B}(B^0 \to K^{*0}e^+e^-)}$ with 3.0 fb^{-1} of data.
- $0.045 < q^2 < 1.1\ GeV^2/c^4$ and $1.1 < q^2 < 6.0\ GeV^2/c^4$ dilepton mass bins.
- $r_{J/\psi} = 1.043 \pm 0.006 \pm 0.045$.

$R_{K^{*0}}$ JHEP 08 (2017) 055

SM predictions from
EPJC 76, 440 (2016)
and
EPJC 77, 377 (2017)

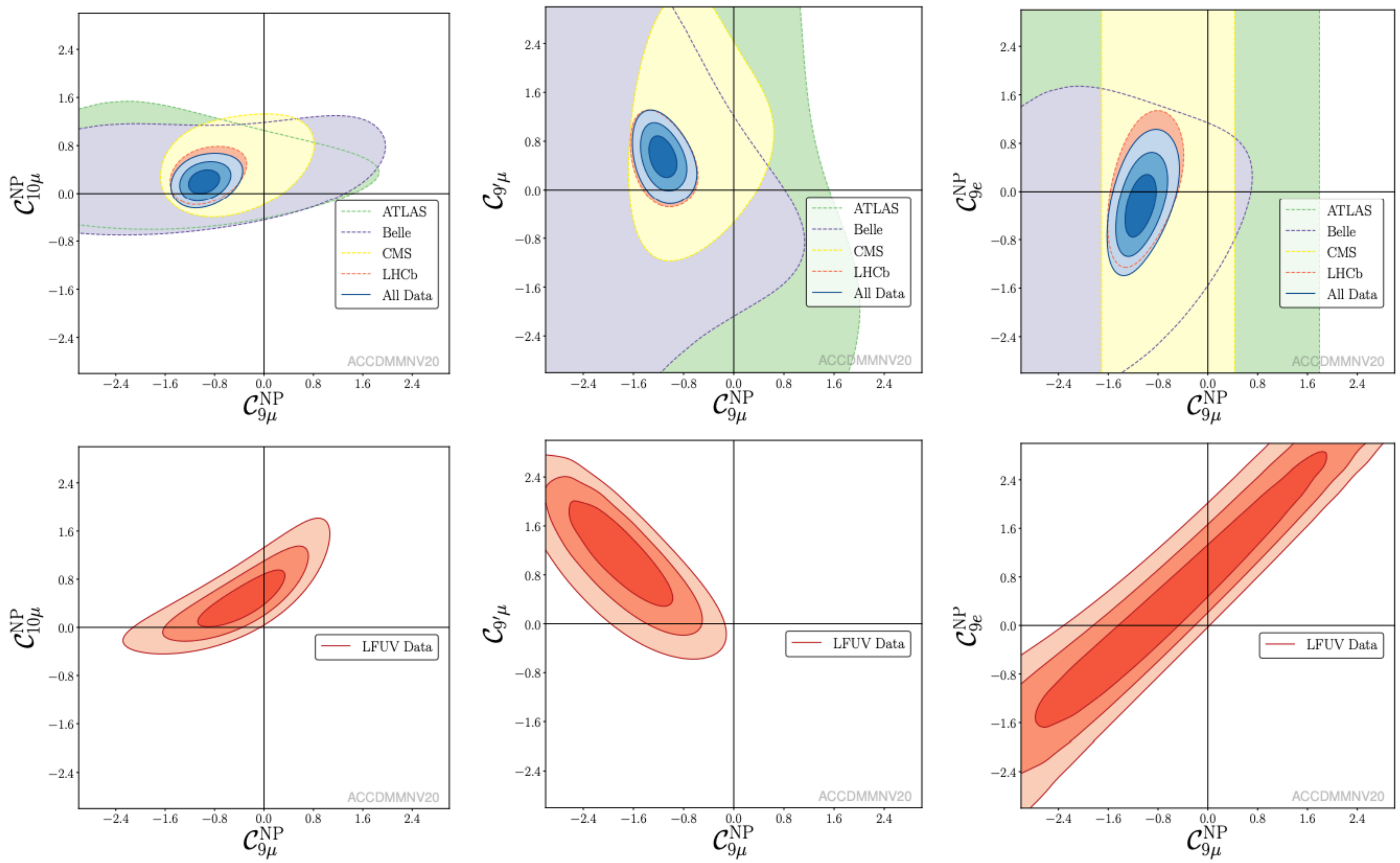


- $$R_{K^{*0}} = \begin{cases} 0.66\,^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.03\,(\text{syst}) & \text{for } 0.045 < q^2 < 1.1\ \text{GeV}^2c^4\,, \\ 0.69\,^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.05\,(\text{syst}) & \text{for } 1.1 \quad < q^2 < 6.0\ \text{GeV}^2c^4\,. \end{cases}$$

- Deviation from SM at 2.1σ and 2.5σ respectively.

Global Fits

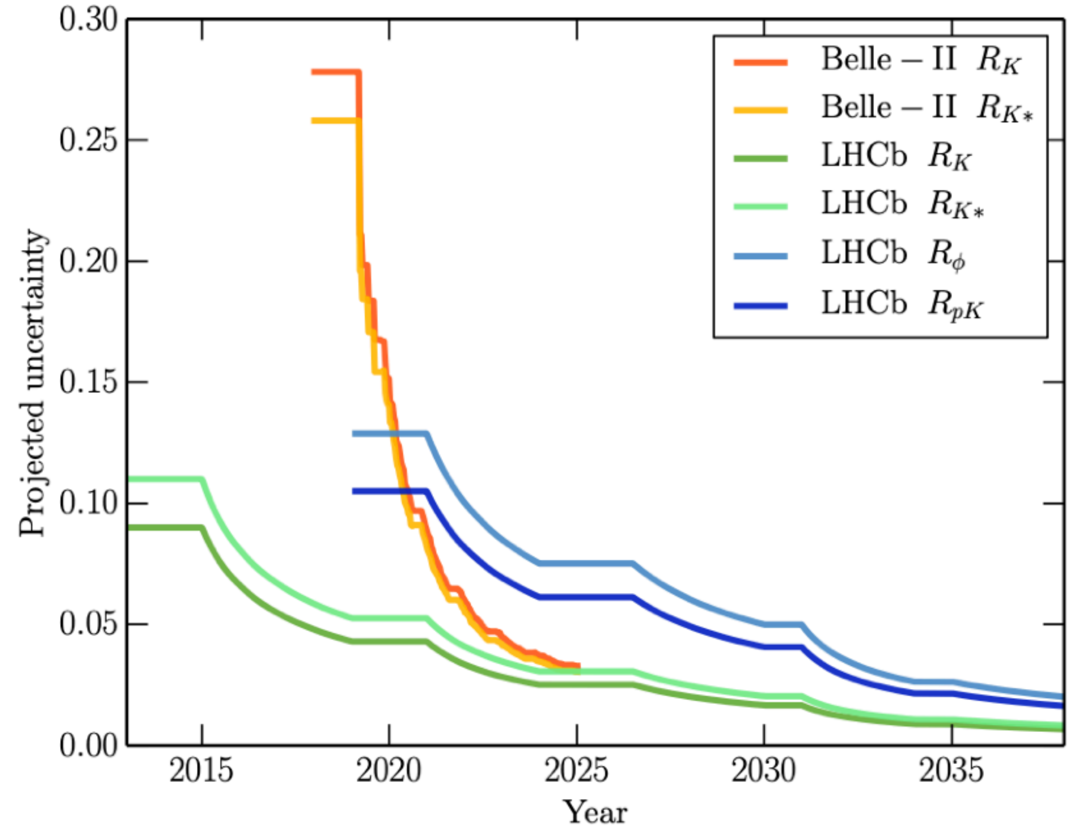
EPJC 79 (2019) 8, 714



- Most recent global fits of $b \to sll$ observables to Wilson coefficients.
  - Top: global fits to ‘All’ $b \to sll$ observables.
  - Bottom: global fits to lepton flavour universality measurements.
- ‘All’ deviates from SM at $6.0 - 6.5\sigma$, ‘LFU’ deviates from SM at $2.9 - 3.5\sigma$.
- Consistent patterns between ‘All’ and ‘LFU’ fits.

Summary and Prospects

Projected uncertainty of Belle 2 and LHCb
lepton flavour universality measurements.



arXiv:1809.06229

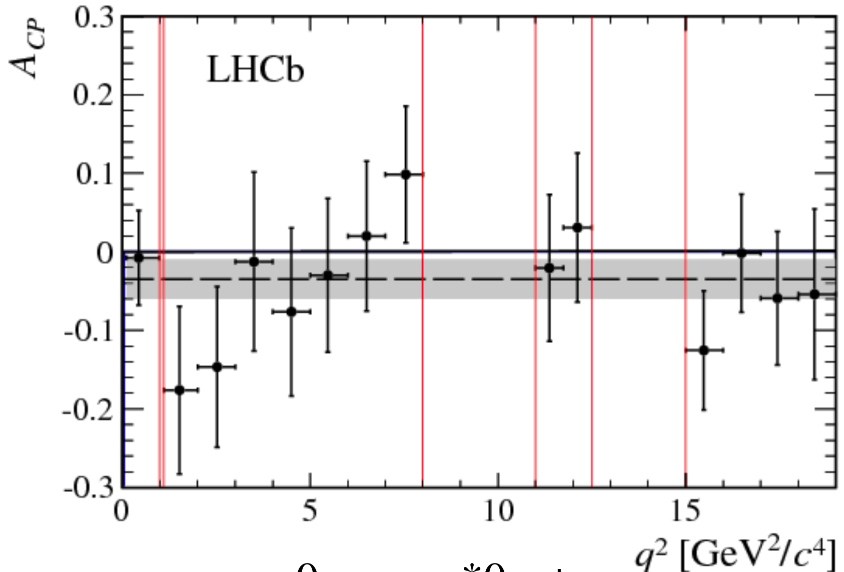
- Measurements:
  - P_5' measured in $B^0 \to K^{*0}\mu^+\mu^-$ angular analysis in tension with SM.
  - Lepton flavour universality measurements deviate from SM in the same direction.

- Prospects:
  - Angular analysis of P_5' and R_K with another $4\ \text{fb}^{-1}$ of data. ($1.45 \times$ published)
  - Updated $R_{K^{*0}}$ with full $9\ \text{fb}^{-1}$ dataset. ($3 \times$ published)
  - R_ϕ analysis in the works.

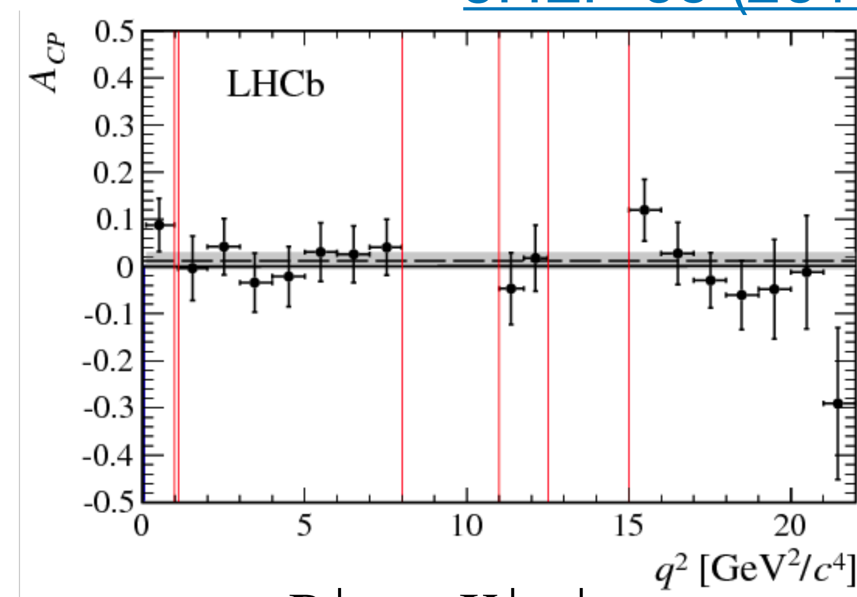
Backup

CP asymmetry in $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^+\mu^+\mu^-$

JHEP 09 (2014) 177



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



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

- Measure

$$\mathscr{A}_{CP} = \boxed{\frac{\Gamma(\overline{B} \to \overline{K}^{(*)}\mu^+\mu^- - \Gamma(B \to K^{(*)}\mu^+\mu^-)}{\Gamma(\overline{B} \to \overline{K}^{(*)}\mu^+\mu^- + \Gamma(B \to K^{(*)}\mu^+\mu^-)}}$$

Hadronic form factors cancel

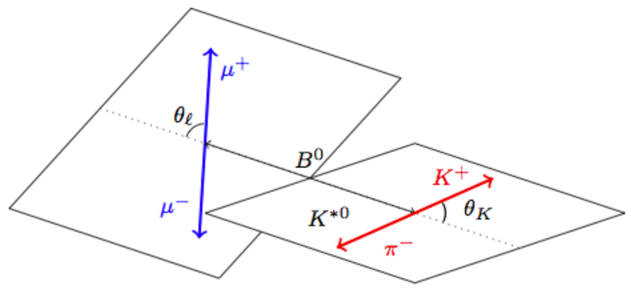
- Results agree with SM:

$$\mathscr{A}_{CP}(B^0 \to K^{*0}\mu^+\mu^-) = -0.035 \pm 0.024 \pm 0.003$$
$$\mathscr{A}_{CP}(B^+ \to K^+\mu^+\mu^-) = 0.012 \pm 0.017 \pm 0.001$$

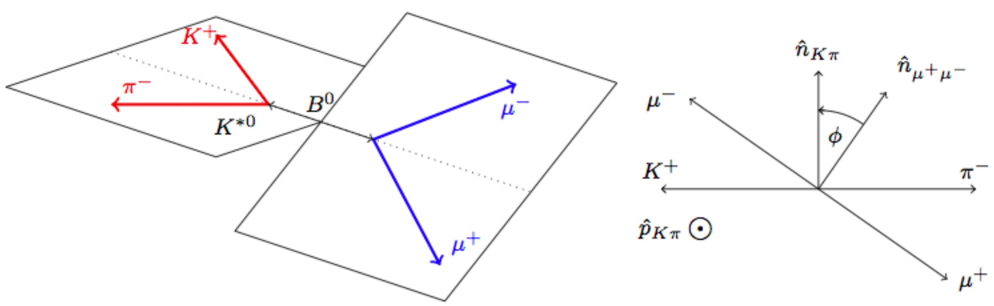
- NP contribution to $b \to sl^+l^-$ has no CP violation or it is negligibly small.

- EFT assumes CP symmetry.

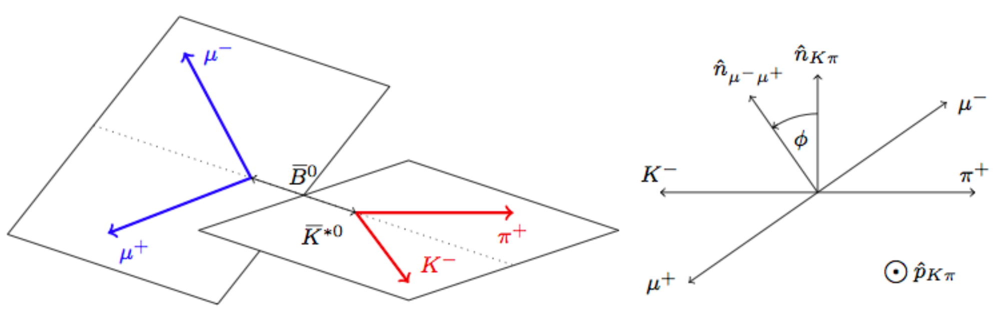
$B^0 \to K^{*0}\mu^+\mu^-$ Angular Analysis PDF



(a) θ_K and θ_ℓ definitions for the B^0 decay



(b) ϕ definition for the B^0 decay

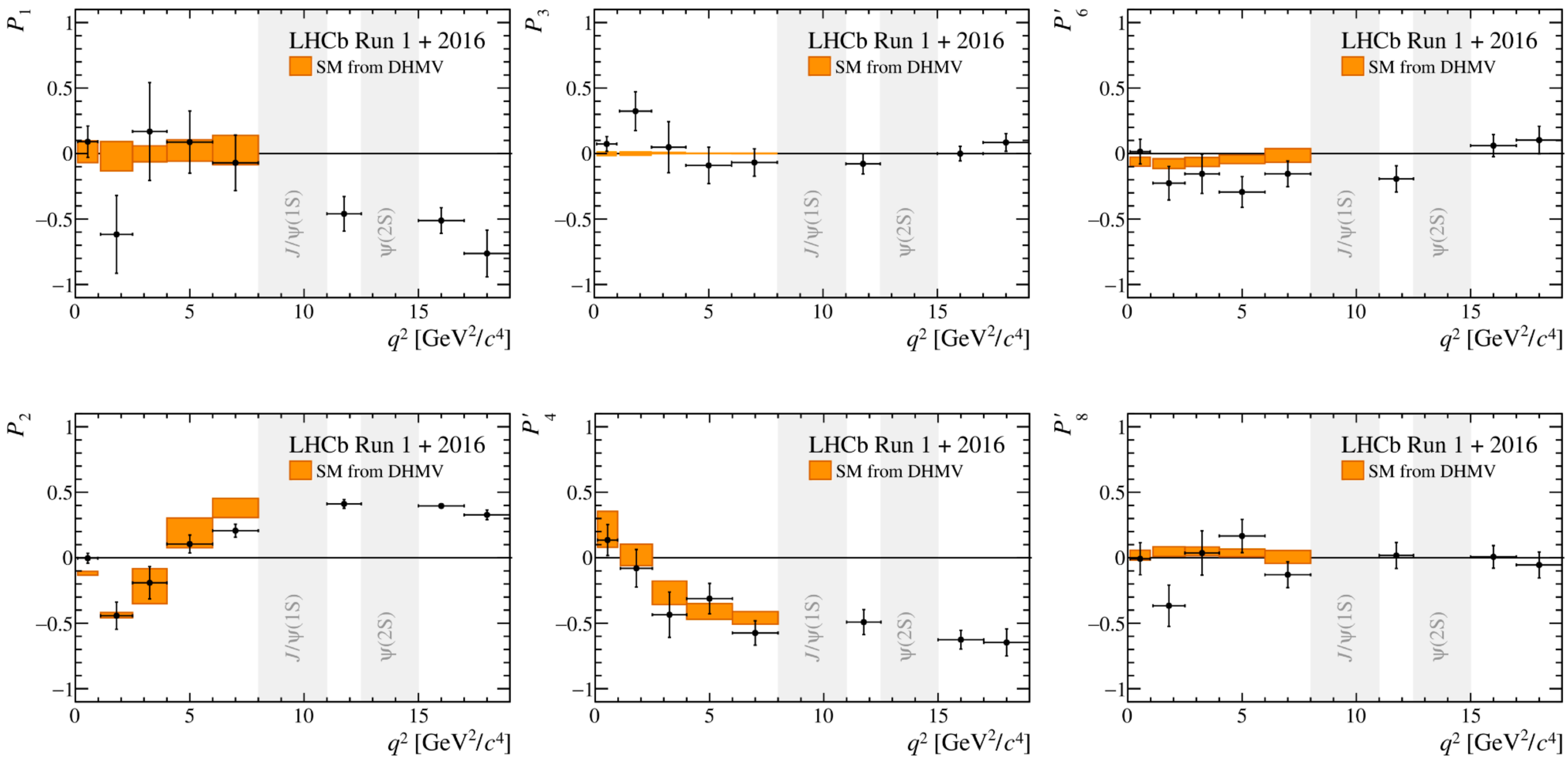


(c) ϕ definition for the $\overline{B}^0$ decay

$$\frac{1}{d(\Gamma+\overline{\Gamma})/dq^2}\frac{d^4(\Gamma+\overline{\Gamma})}{dq^2 d\vec{\Omega}}$$

$$\begin{aligned}
= \frac{9}{32\pi}\Big[& \frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K \\
& + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l \\
& + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi \\
& + S_5\sin 2\theta_K\sin\theta_l\cos\phi + \frac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_l \\
& + S_7\sin 2\theta_K\sin\theta_l\sin\phi + S_8\sin 2\theta_K\sin 2\theta_l\sin\phi \\
& + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big].
\end{aligned}$$

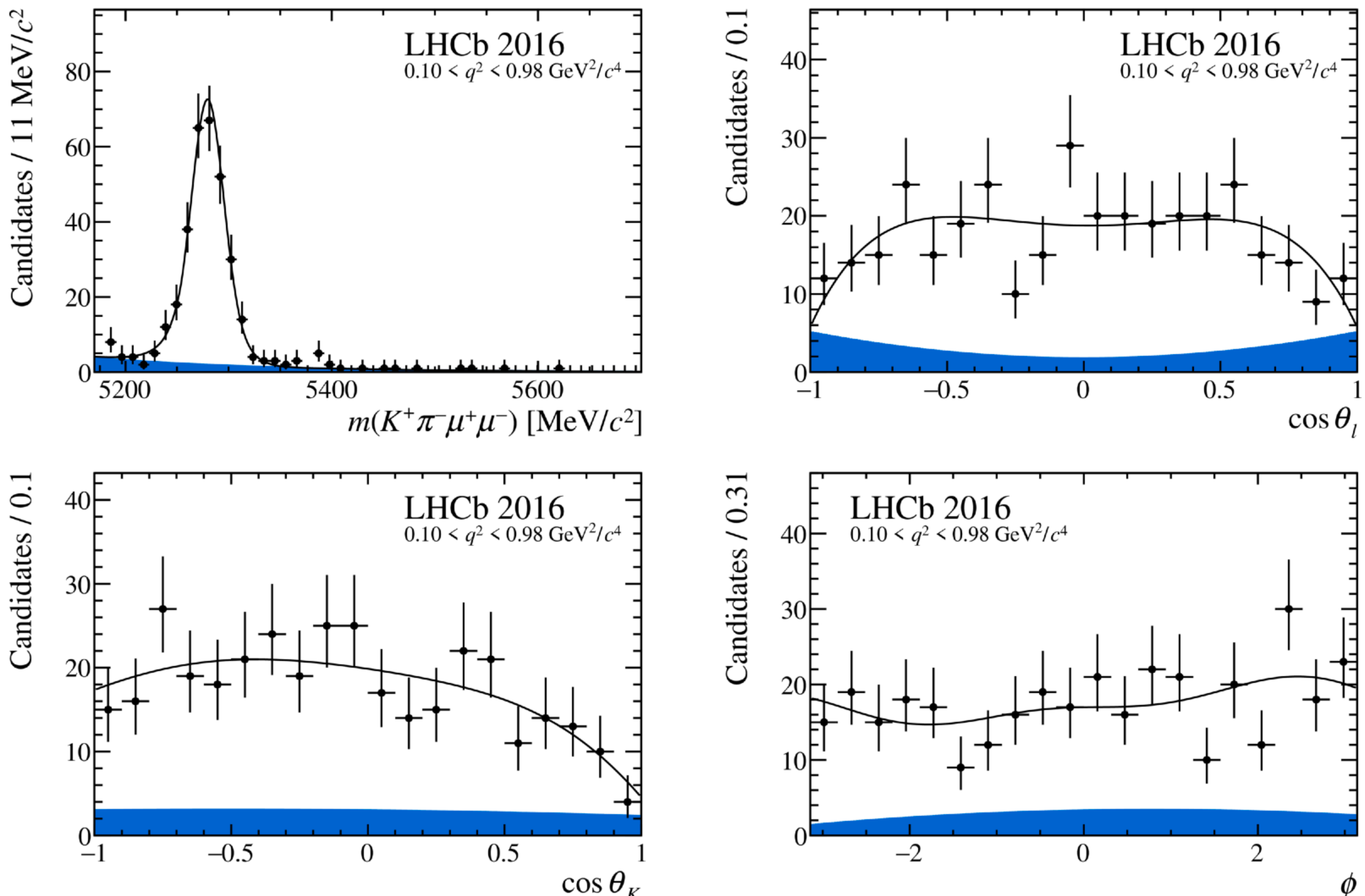
Angular Analysis of $B^0 \to K^{*0}\mu^+\mu^-$: P_i'



Other observables in optimised basis agree with SM

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

[PRL 125, 011802 (2020)](#)



Fitted $B^0 \to K^{*0}\mu^+\mu^-$ distribution in the angular analysis.

Angular Analysis Efficiency

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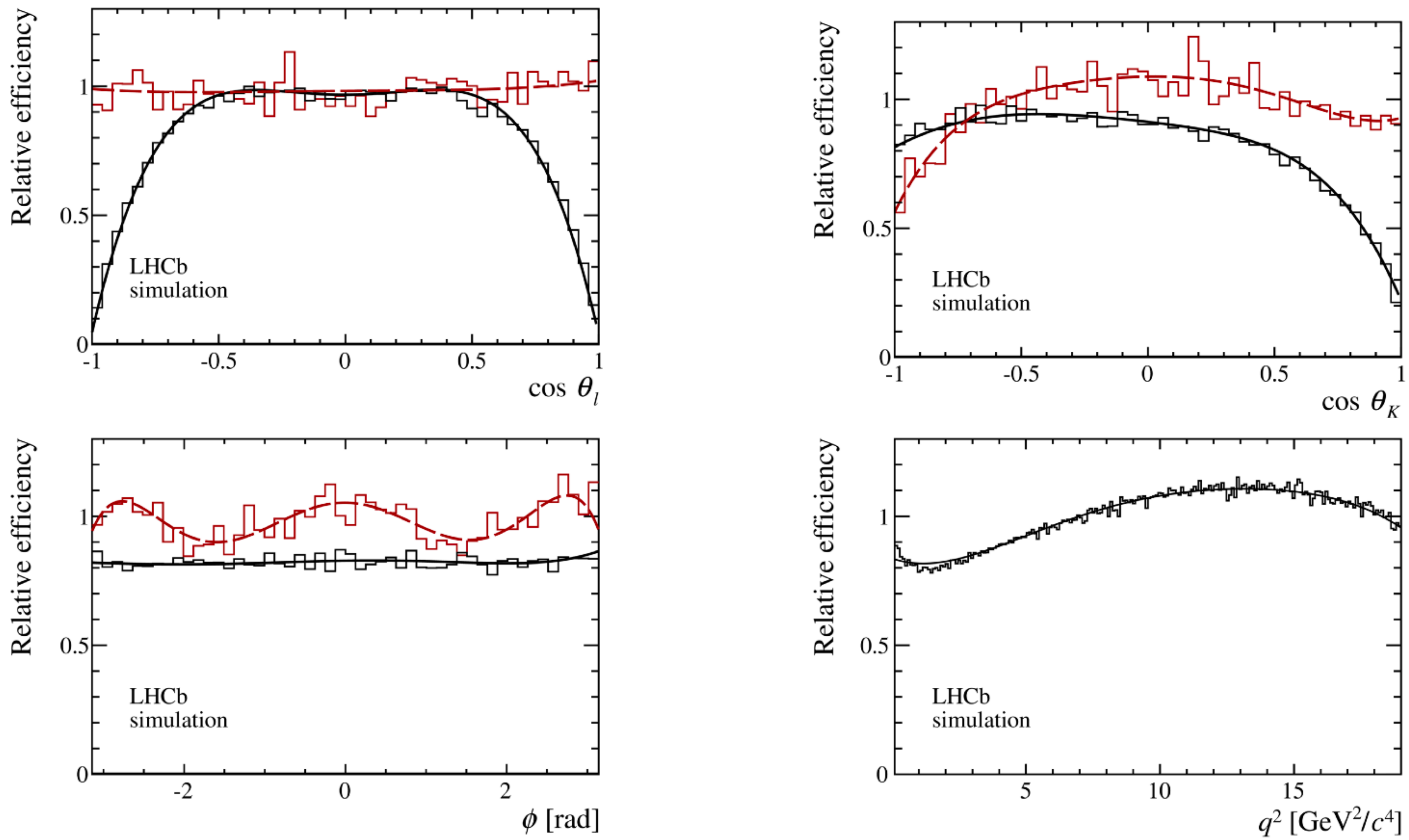
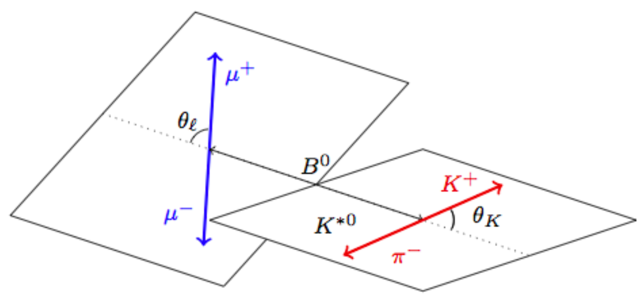


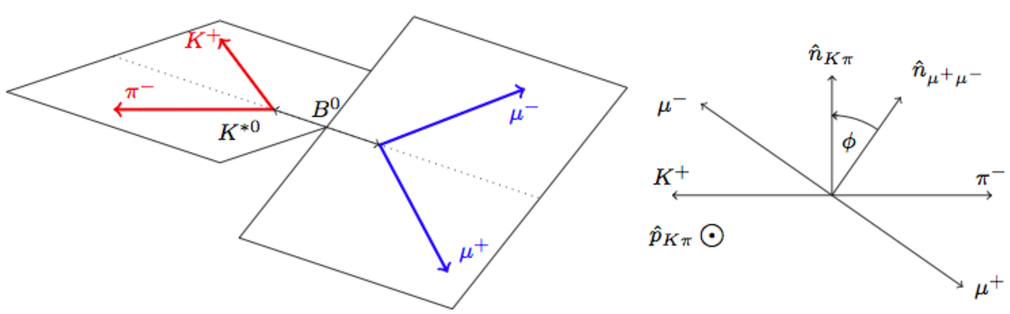
- Efficiencies of $B^0 \to K^{*0}\mu^+\mu^-$ in
  - $0.1 < q^2 < 0.98\ GeV^2/c^4$ (black line)
  - $18 < q^2 < 19\ GeV^2/c^4$ (red dashed)
- The efficiency as a function of q^2 is integrated over the angles.

$B^0 \to K^{*0}e^+e^-$ Angular Analysis PDF

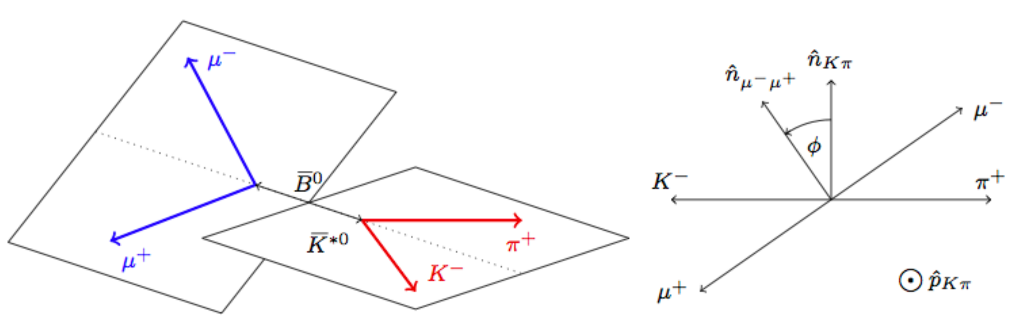
Same angle definition as
$B^0 \to K^{*0}\mu^+\mu^-$ but $\tilde{\phi} \mapsto \phi + \pi$



(a) θ_K and θ_ℓ definitions for the B^0 decay



(b) ϕ definition for the B^0 decay



(c) ϕ definition for the $\overline{B}^0$ decay

$$\frac{1}{d(\Gamma+\overline{\Gamma})/dq^2}\frac{d^4(\Gamma+\overline{\Gamma})}{dq^2 d\vec{\Omega}}$$

$$= \frac{9}{16\pi}\Big[\ \frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+\frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l$$
$$+(1-F_L)A_T^{Re}\sin^2\theta_K\cos\theta_l$$
$$+(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_l\cos 2\tilde{\phi}$$
$$+(1-F_L)A_T^{Im}\sin^2\theta_K\sin^2\theta_l\cos 2\tilde{\phi}\Big].$$

$B^0 \to K^{*0}e^+e^-$ angular observables

- SM predictions

$$F_{\mathrm{L}}(\mathrm{SM}) = 0.051 \pm 0.013, \quad A_{\mathrm{T}}^{\mathrm{Re}}(\mathrm{SM}) = -0.0001 \pm 0.0004\,,$$
$$A_{\mathrm{T}}^{(2)}(\mathrm{SM}) = 0.033 \pm 0.020, \quad A_{\mathrm{T}}^{\mathrm{Im}}(\mathrm{SM}) = -0.00012 \pm 0.00034.$$

- Relation to photon polarisation:
  - $A_{R(L)} = |A_{R(L)}|e^{i\phi_{R(L)}}$, $\tan\chi = |A_R/A_L|$
  - $A_T^{(2)} \simeq \sin(2\chi)\cos(\phi_L - \phi_R)$
  - $A_T^{Im} \simeq \sin(2\chi)\sin(\phi_L - \phi_R)$

Relation to Wilson Coefficients

$$F_{\mathrm{L}} = \frac{|A_0|^2}{|A_0|^2 + |A_{\|}|^2 + |A_{\perp}|^2}$$

$$A_T^{(2)} = \frac{|A_{\perp}|^2 - |A_{\|}|^2}{|A_{\perp}|^2 + |A_{\|}|^2}$$

$$A_T^{Re} = \frac{2\mathcal{R}e\left(A_{\|}^{\mathrm{L}} A_{\perp}^{*\mathrm{L}} + A_{\|}^{\mathrm{R}} A_{\perp}^{*\mathrm{R}}\right)}{|A_{\|}|^2 + |A_{\perp}|^2}$$

$$A_T^{Im} = \frac{2\mathcal{I}m\left(A_{\|}^{\mathrm{L}} A_{\perp}^{*\mathrm{L}} + A_{\|}^{\mathrm{R}} A_{\perp}^{*\mathrm{R}}\right)}{|A_{\|}|^2 + |A_{\perp}|^2}$$

Relation to Wilson Coefficients

$$A_{\perp L,R} = \sqrt{2} N m_B (1-\hat{s}) \left[(C_9^{\text{eff}} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}} (C_7^{\text{eff}} + C_7^{\text{eff}\prime}) \right] \xi_\perp(E_{K^*}),$$

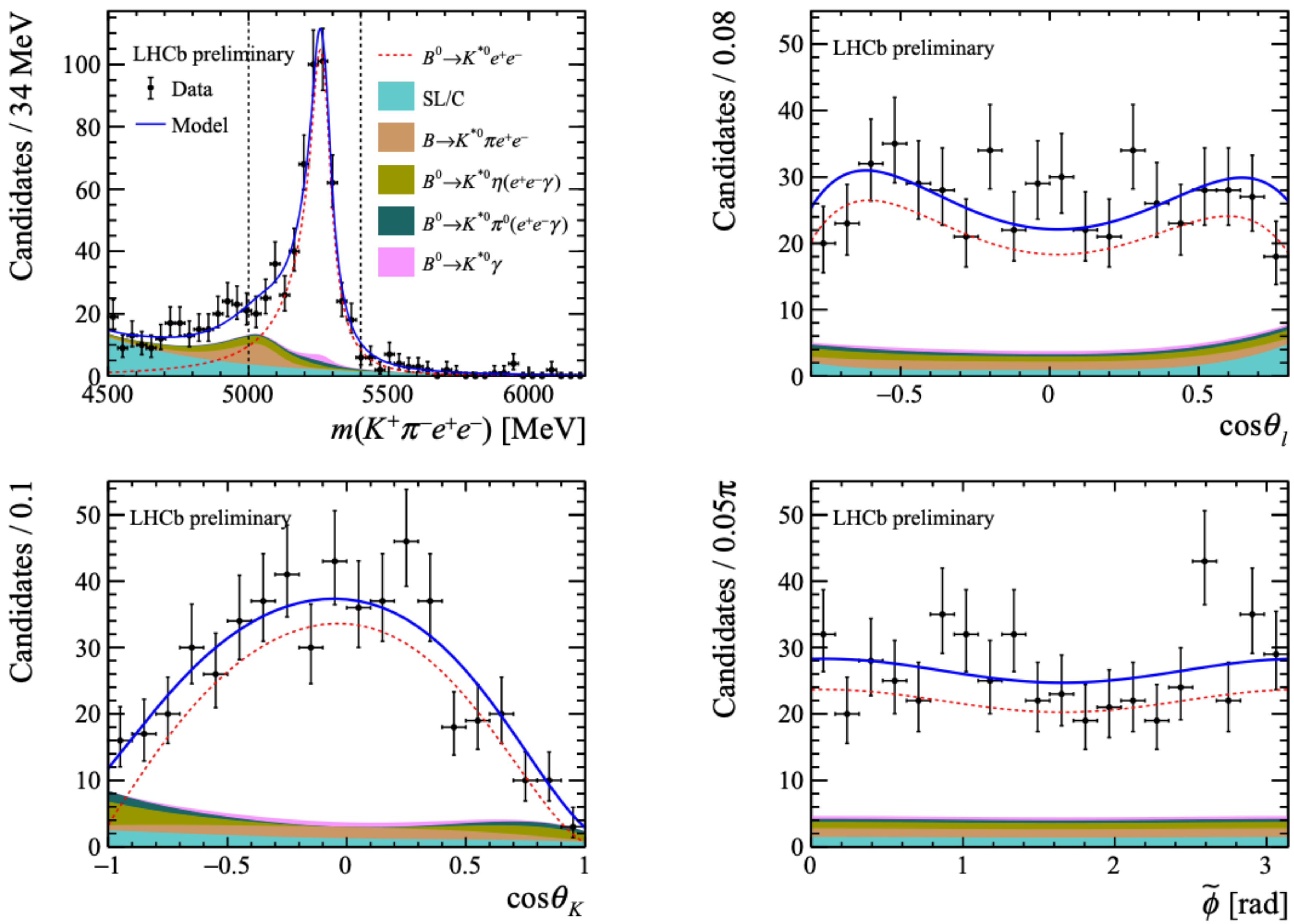
$$A_{\parallel L,R} = -\sqrt{2} N m_B (1-\hat{s}) \left[(C_9^{\text{eff}} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}} (C_7^{\text{eff}} - C_7^{\text{eff}\prime}) \right] \xi_\perp(E_{K^*}),$$

$$A_{0L,R} = -\frac{N m_B}{2\hat{m}_{K^*}\sqrt{\hat{s}}} (1-\hat{s})^2 \left[(C_9^{\text{eff}} \mp C_{10}) + 2\hat{m}_b (C_7^{\text{eff}} - C_7^{\text{eff}\prime}) \right] \xi_\parallel(E_{K^*}),$$

$$A_t = \frac{N m_B}{\hat{m}_{K^*}\sqrt{\hat{s}}} (1-\hat{s})^2 C_{10} \xi_\parallel(E_{K^*}),$$

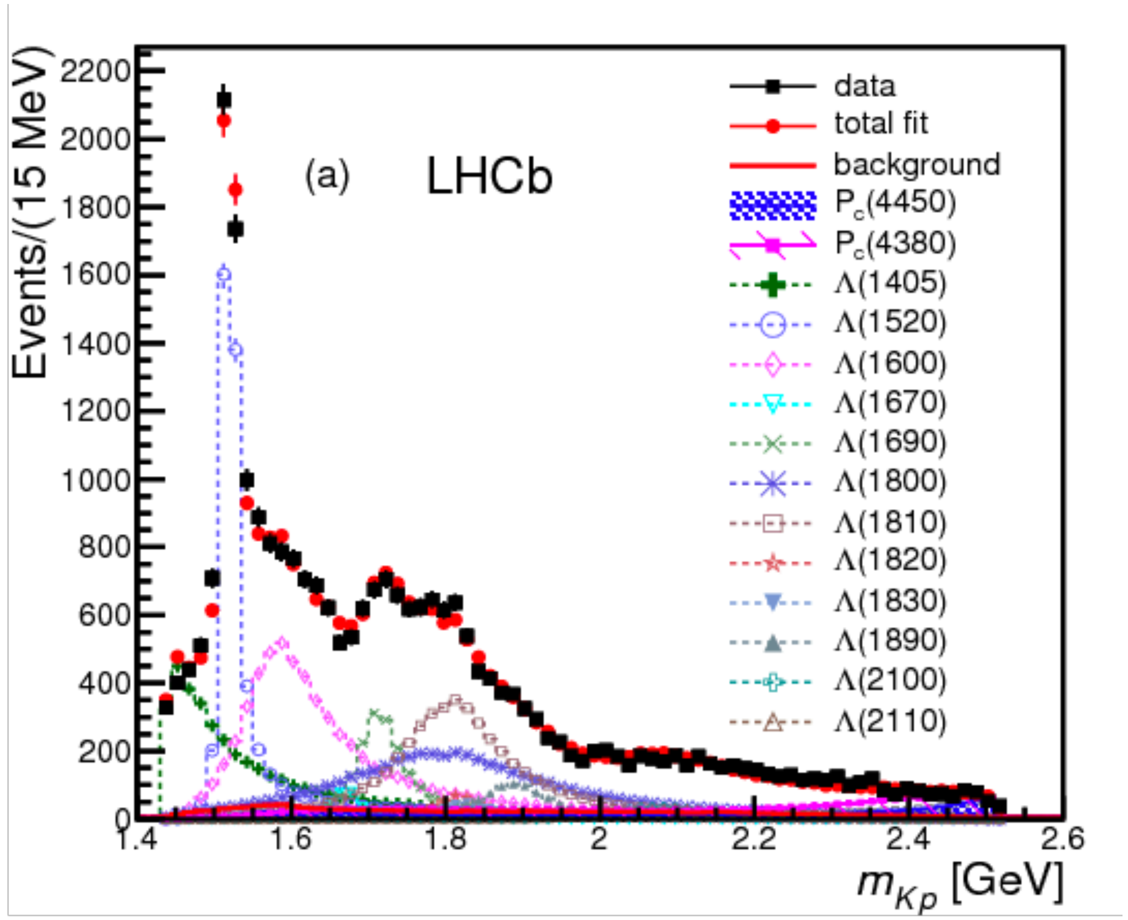
In the low q^2 regime, ξ hadronic form factor. PRD 71.094009

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



- Compared to $B^0 \to K^{*0}\mu^+\mu^-$ analysis, $B^0 \to K^{*0}e^+e^-$ invariant mass spectrum is significantly smeared and the background contamination is higher.
- Some of these background, $B^0 \to K^{*0}\gamma$ for instance, are due to the q^2 bin range.

m_{pK} Spectrum Re-weighting



PRL 115, 072001 (2015)

- Hadronic pK rich in structures.
- Weight m_{pK} according to measurements by $\Lambda_b \to pKJ/\psi$ amplitude analysis

Hardware Trigger Threshold

	p_T or E_T 2011	p_T or E_T 2012	SPD 2011 and 2012
single muon	$1.48\,\text{GeV}/c$	$1.76\,\text{GeV}/c$	600
dimuon $p_{T1} \times p_{T2}$	$(1.30\,\text{GeV}/c)^2$	$(1.60\,\text{GeV}/c)^2$	900
hadron	3.50 GeV	3.70 GeV	600
electron	2.50 GeV	3.00 GeV	600
photon	2.50 GeV	3.00 GeV	600

Int. J. Mod. Phys. A 30, 1530022 (2015)

L0 trigger	E_T/p_T threshold 2015	E_T/p_T threshold 2016	E_T/p_T threshold 2017	SPD threshold
Hadron	> 3.6 GeV	> 3.7 GeV	> 3.46 GeV	< 450
Photon	> 2.7 GeV	> 2.78 GeV	> 2.47 GeV	< 450
Electron	> 2.7 GeV	> 2.4 GeV	> 2.11 GeV	< 450
Muon	> 2.8 GeV	> 1.8 GeV	> 1.35 GeV	< 450
Muon high p_T	> 6.0 GeV	> 6.0 GeV	> 6.0 GeV	none
Dimuon	$> 1.69\ \text{GeV}^2$	$> 2.25\ \text{GeV}^2$	$> 1.69\ \text{GeV}^2$	< 900

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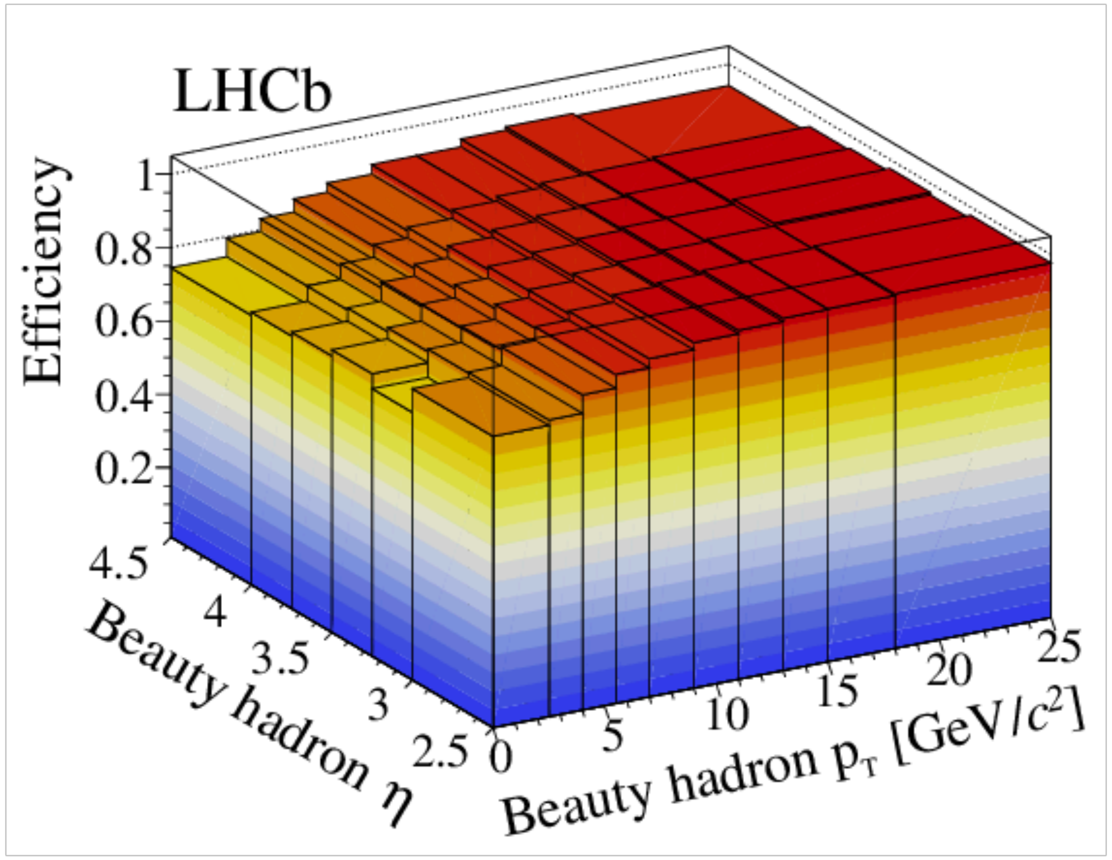
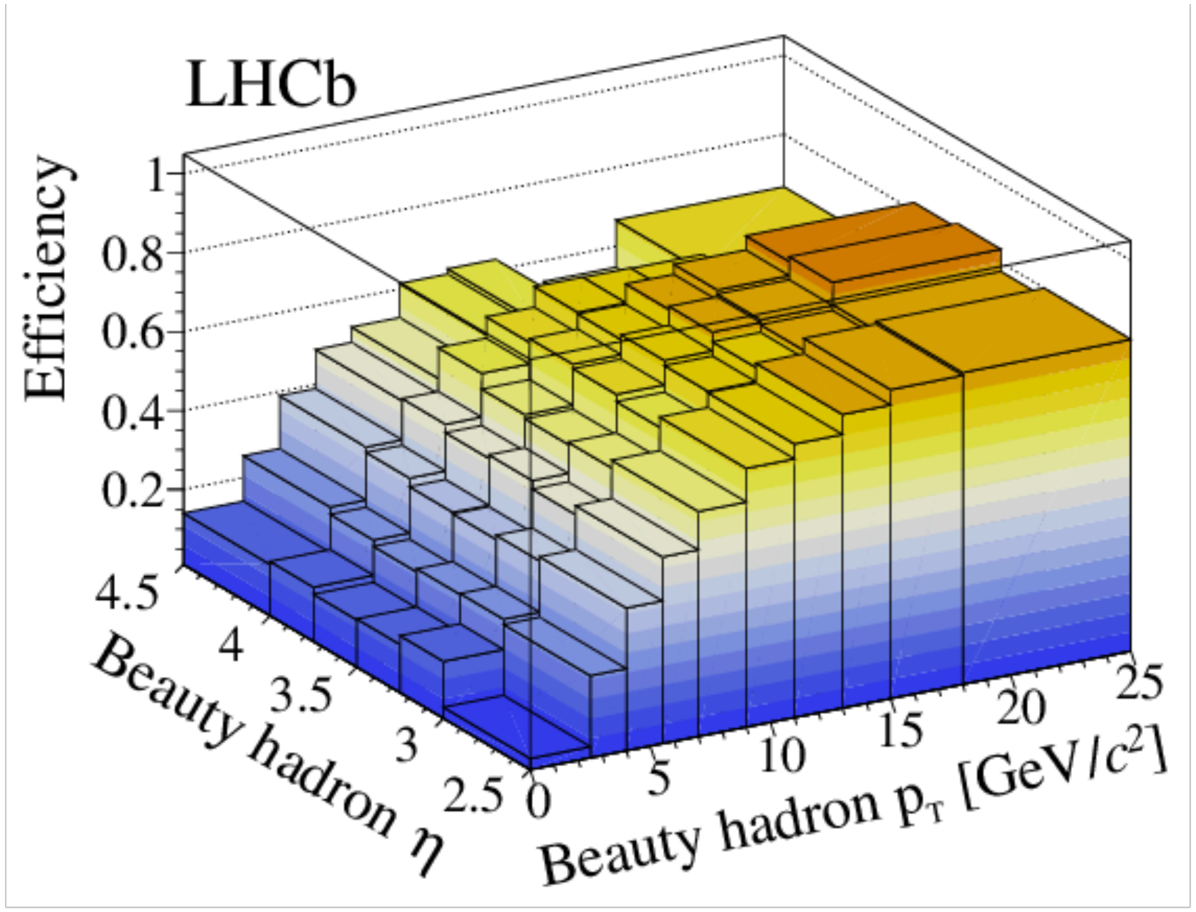
Electron vs Muon L0 Efficiency



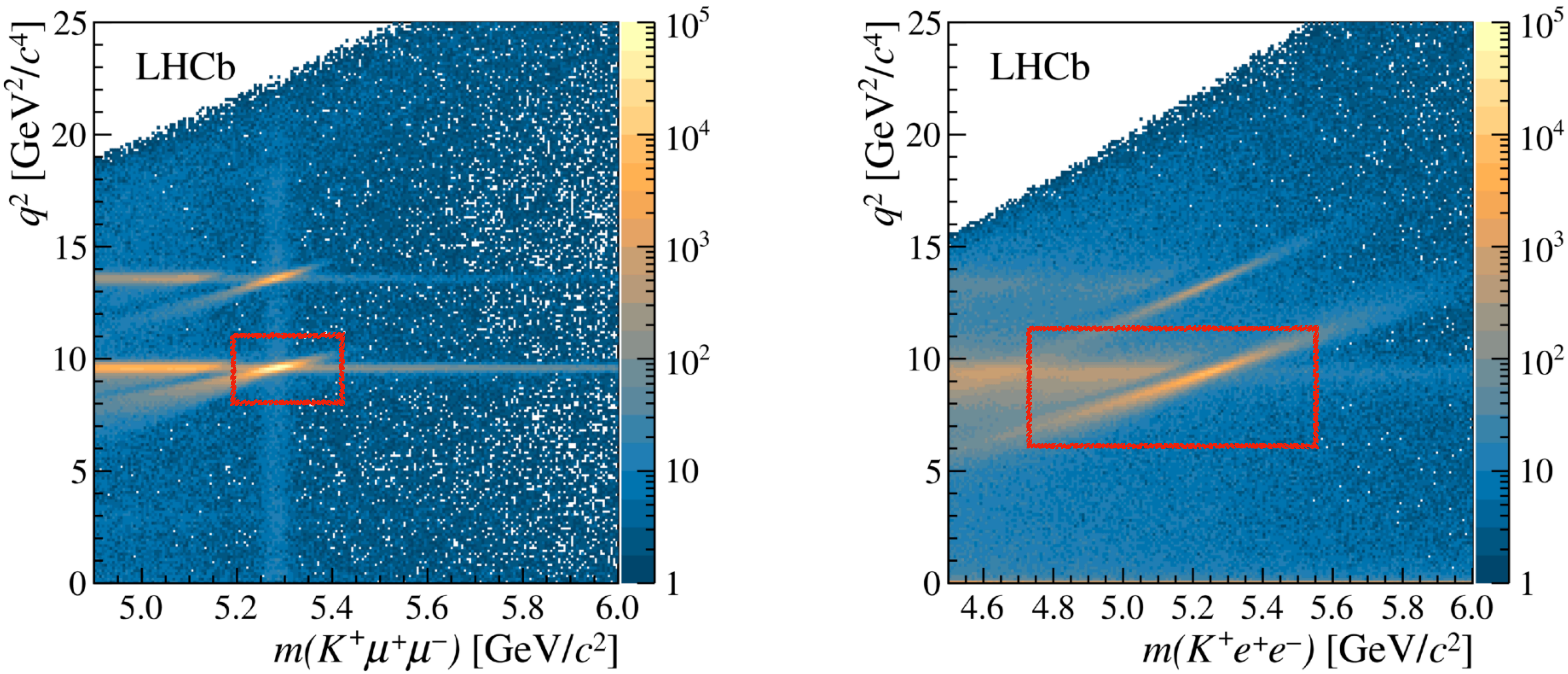


$L0\mu$ efficiency as a function of η and p_T.

$L0e$ efficiency as a function of η and p_T.

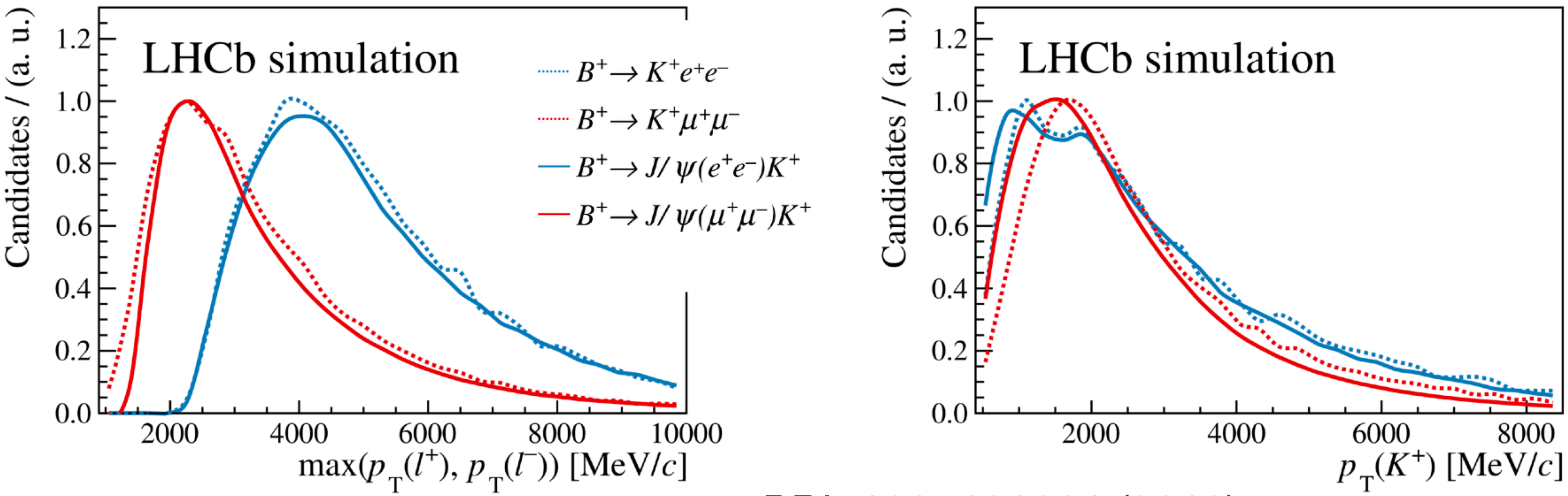
Electron vs Muon Resolution

PRL 122, 191801 (2019)



- The diagonal lines highlighted in the red boxes are $B^+ \to K^+ J/\psi(\to l^+ l^-)$ events.
- Due to Bremsstrahlung radiation, the electron resolution are significantly smeared.

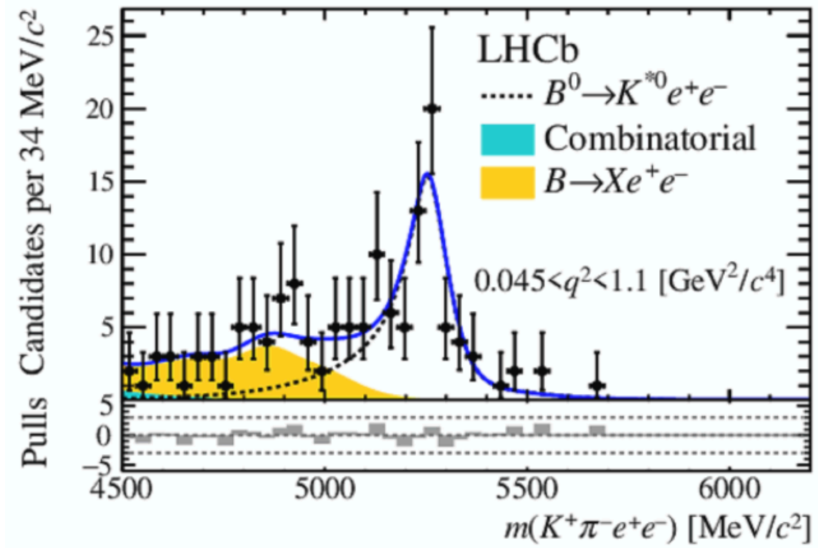
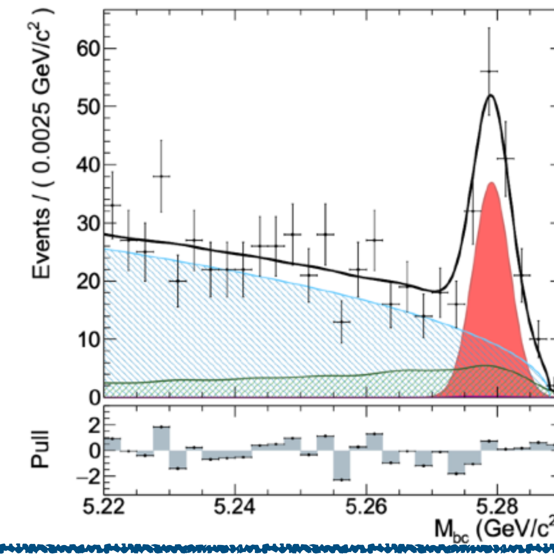
Lepton Flavour Universality Efficiencies



PRL 122, 191801 (2019)

- Data-driven efficiency correction with high statistics sample.
  - J/ψ control mode corrects B kinematics, reconstruction, trigger and multiplicity.
  - Collaboration-wide calibration samples to correct particle identification.
- Since the B daughters have high boost, control and signal modes are kinematically similar (see plots).
- Systematics cancel in efficiency ratio.

Electrons: LHCb vs Belle

<table>
<tr><th></th><th>LHCb</th><th>Belle</th></tr>
<tr><td>e</td><td>
</td><td>
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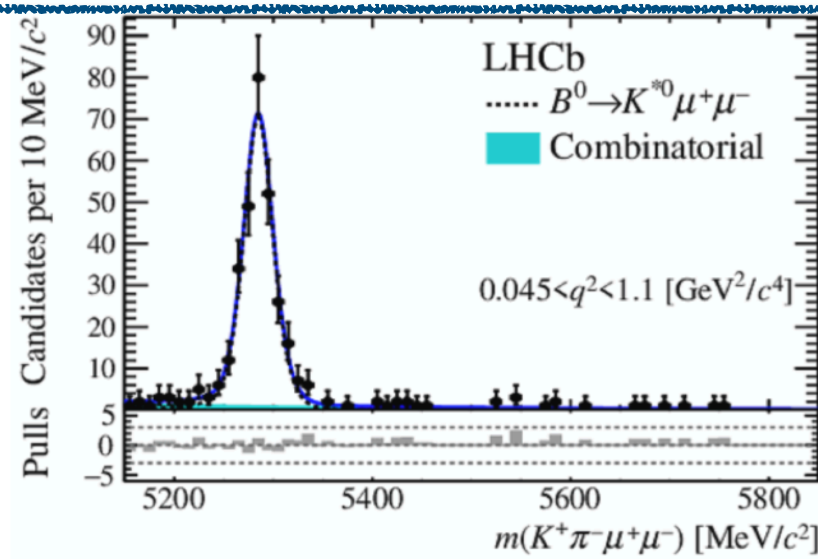
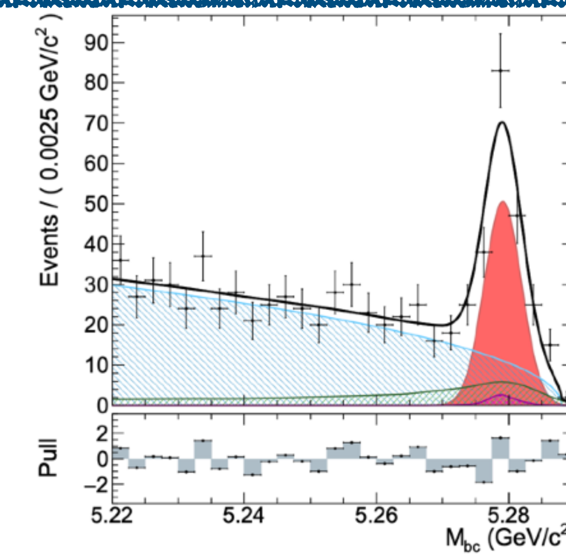
<tr><td>μ</td><td>
</td><td>
</td></tr>
</table>

- Reconstructed $B^0 \to K^{*0} e^+ e^-$
- LHCb has worse electron mass resolution.

Theory Predictions of R_X

Decay	q^2 range	Ref. [38]	Ref. [39]	Ref. [40]	Ref. [41]
$B^+ \to K^+\ell^+\ell^-$	$[1, 6]$	1.0 ± 0.01	$1.0004^{+0.0008}_{-0.0007}$	-	1.00 ± 0.01
$B^0 \to K^{*0}\ell^+\ell^-$	$[0.045, 1.1]$	0.92 ± 0.02	$0.920^{+0.007}_{-0.006}$	0.9259 ± 0.0041	0.906 ± 0.028
	$[0.1, 1.1]$	–	–	–	0.983 ± 0.014
	$[1.1, 6]$	1.00 ± 0.01	$0.996^{+0.002}_{-0.002}$	0.9965 ± 0.0006	1.00 ± 0.01
	$[15, 19]$	–	$0.998^{+0.001}_{-0.001}$	0.9981 ± 0.0001	–
$B^0_s \to \phi\ell^+\ell^-$	$[0.045, 1.1]$	–	–	0.9299 ± 0.0028	–
	$[1.1, 6.0]$	–	–	0.9970 ± 0.0002	–
	$[15, 19]$	–	–	0.9981 ± 0.0001	–

- 38: JHEP 1801 (2018) 093
- 39: PRD 96, 093006 (2017)
- 40: EPJC 77, 377 (2017)
- 41: EPJC 76, 440 (2016)