

Experimental status of the flavour anomalies

Eluned Smith



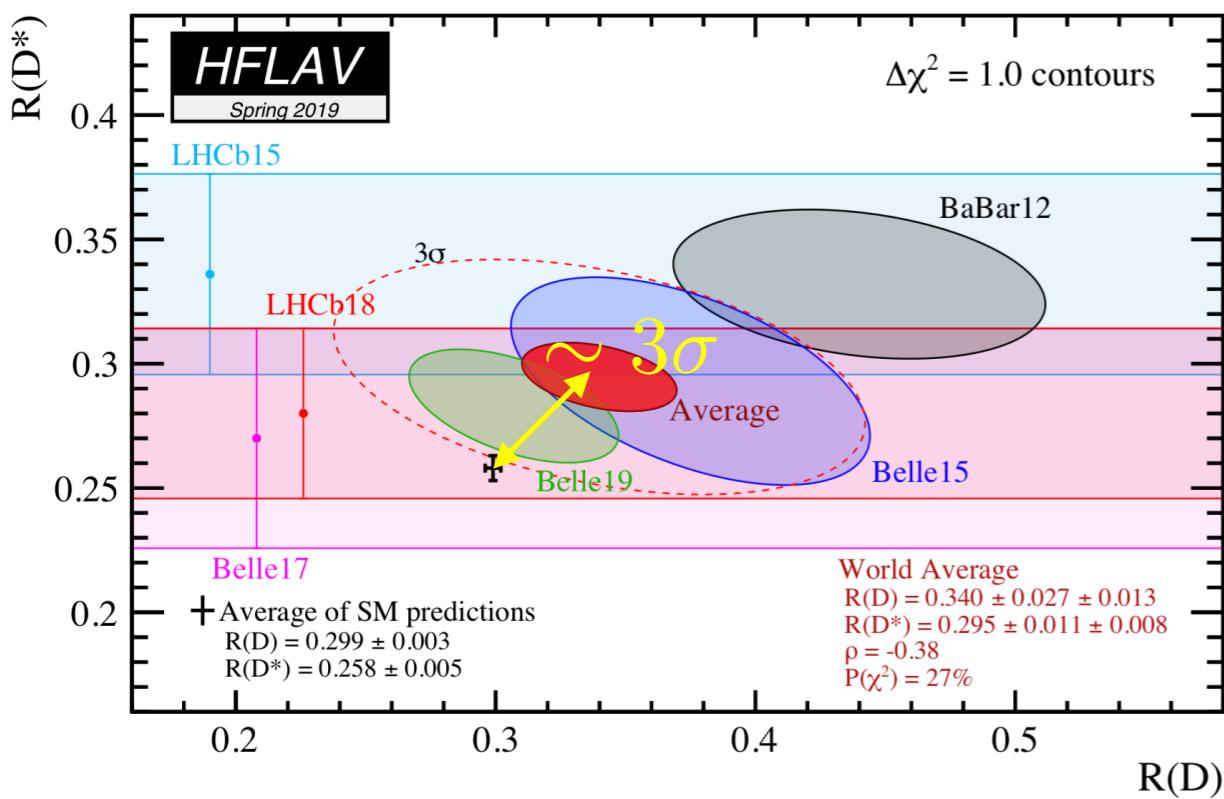
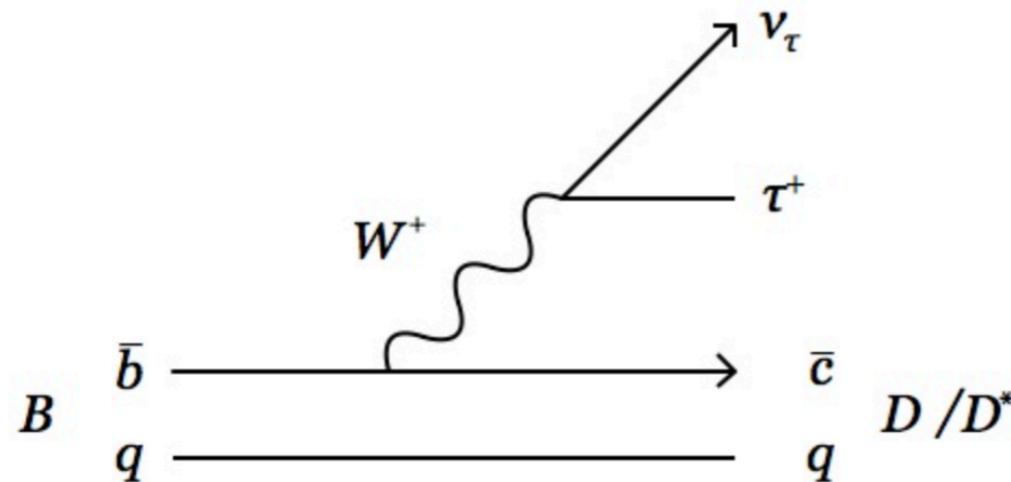
University of
Zurich^{UZH}

14/07/2021

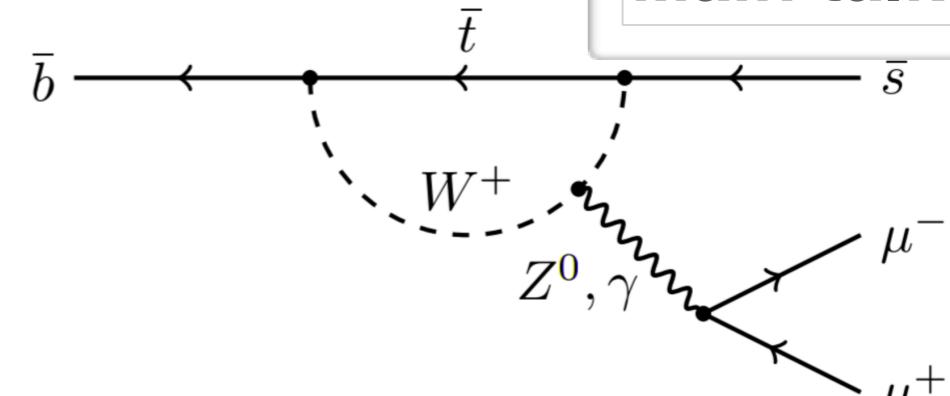
FNSNF
SWISS NATIONAL SCIENCE FOUNDATION

The flavour anomalies

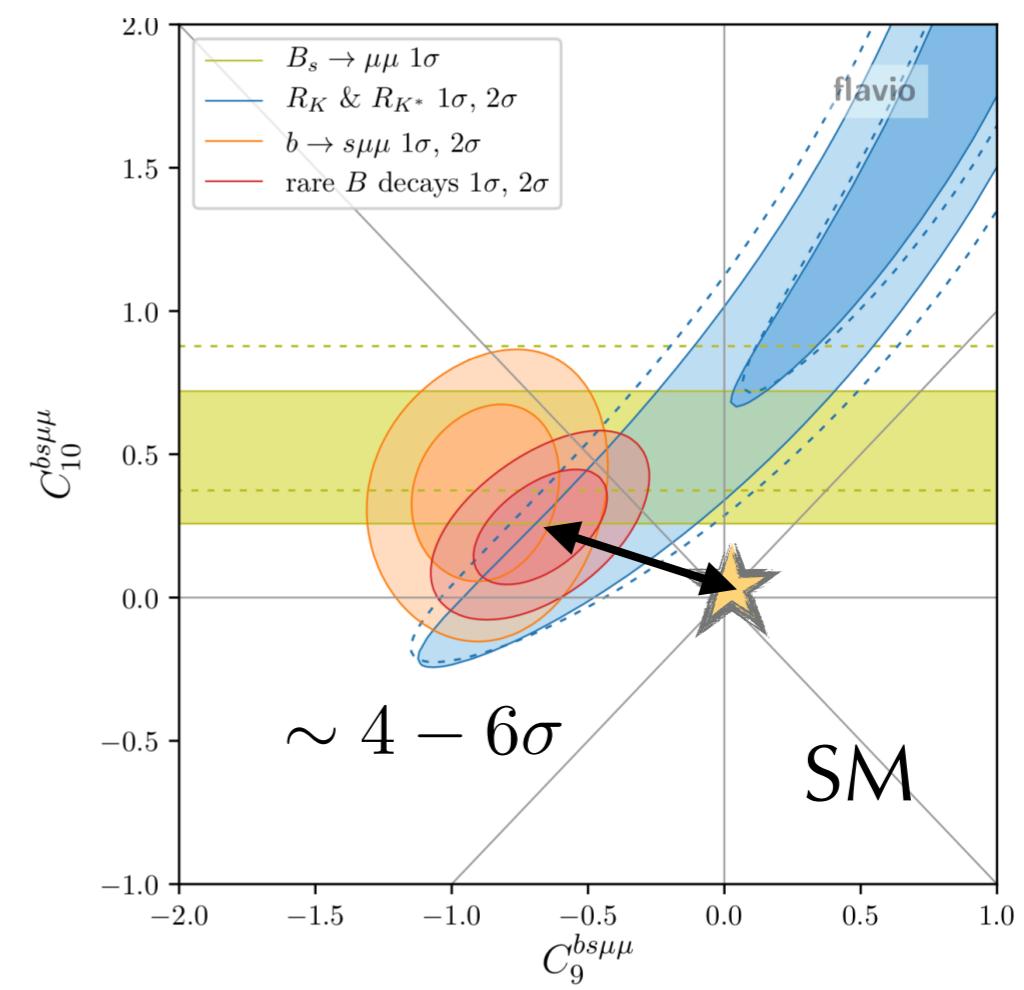
$b \rightarrow c l \bar{\nu}$



$b \rightarrow s \ell^+ \ell^-$



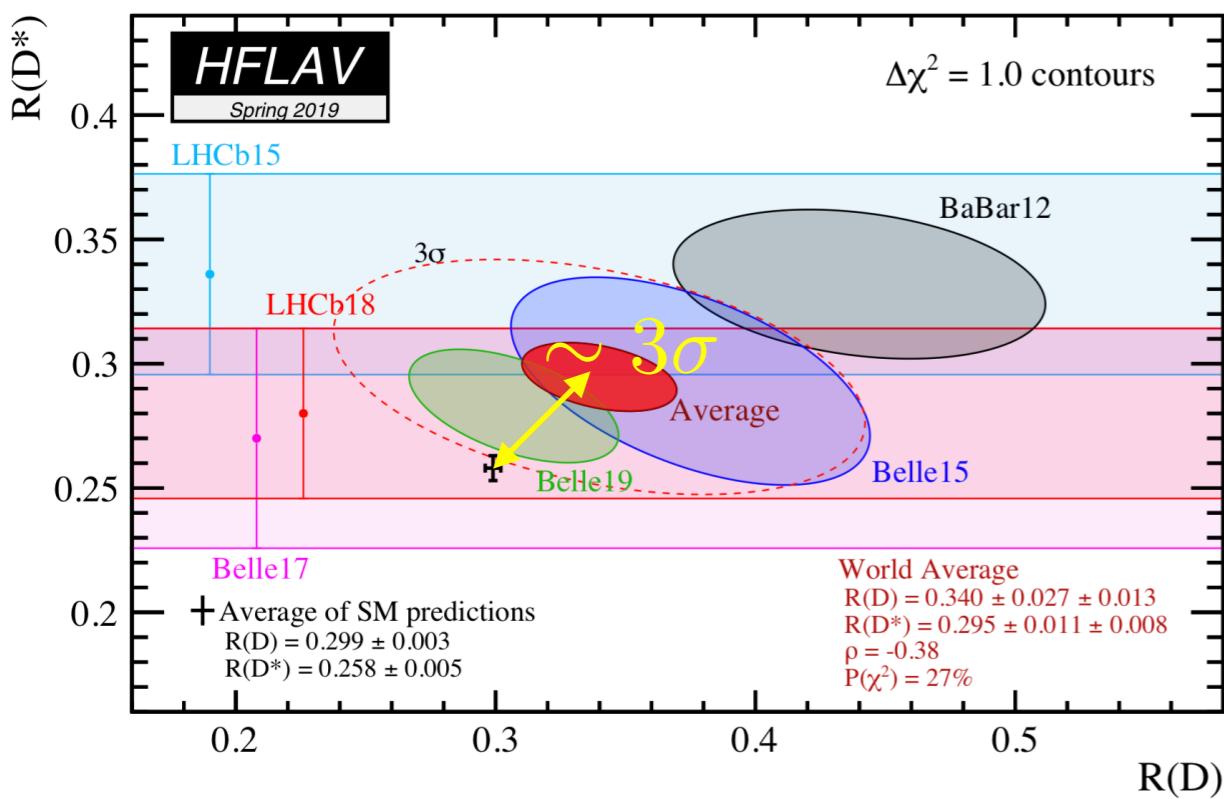
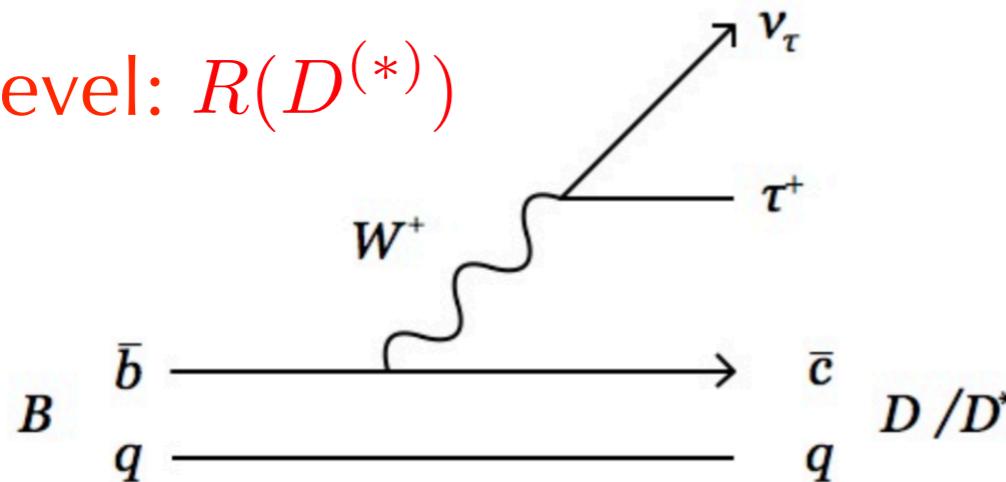
Main talk focus



The flavour anomalies

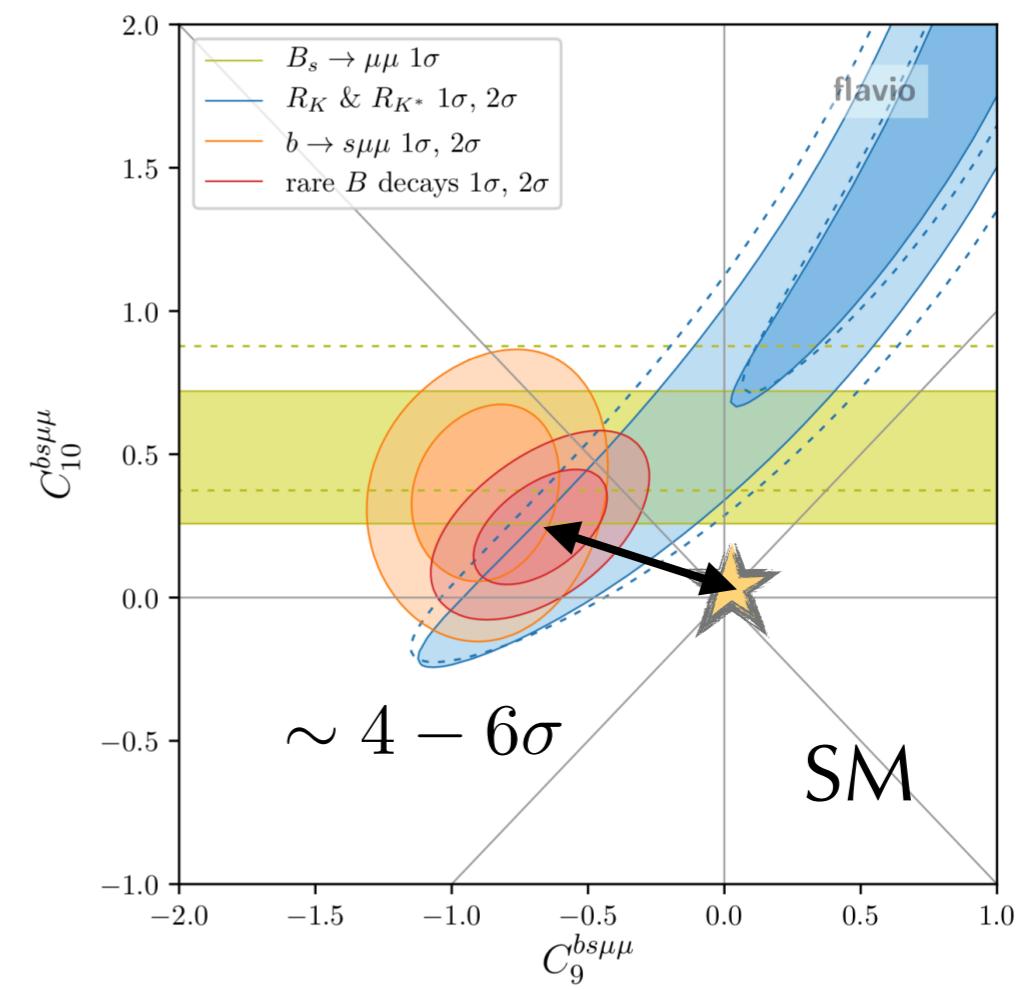
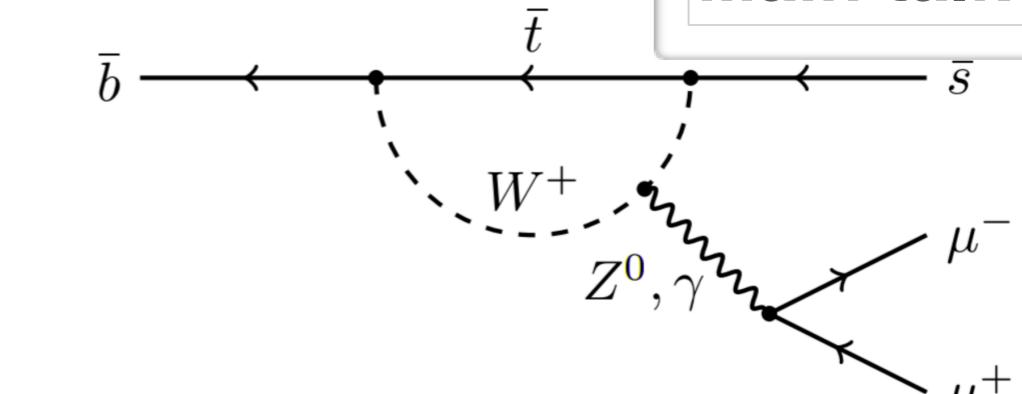
$b \rightarrow c \ell \nu$

Tree-level: $R(D^{(*)})$



$b \rightarrow s \ell^+ \ell^-$

Main talk focus

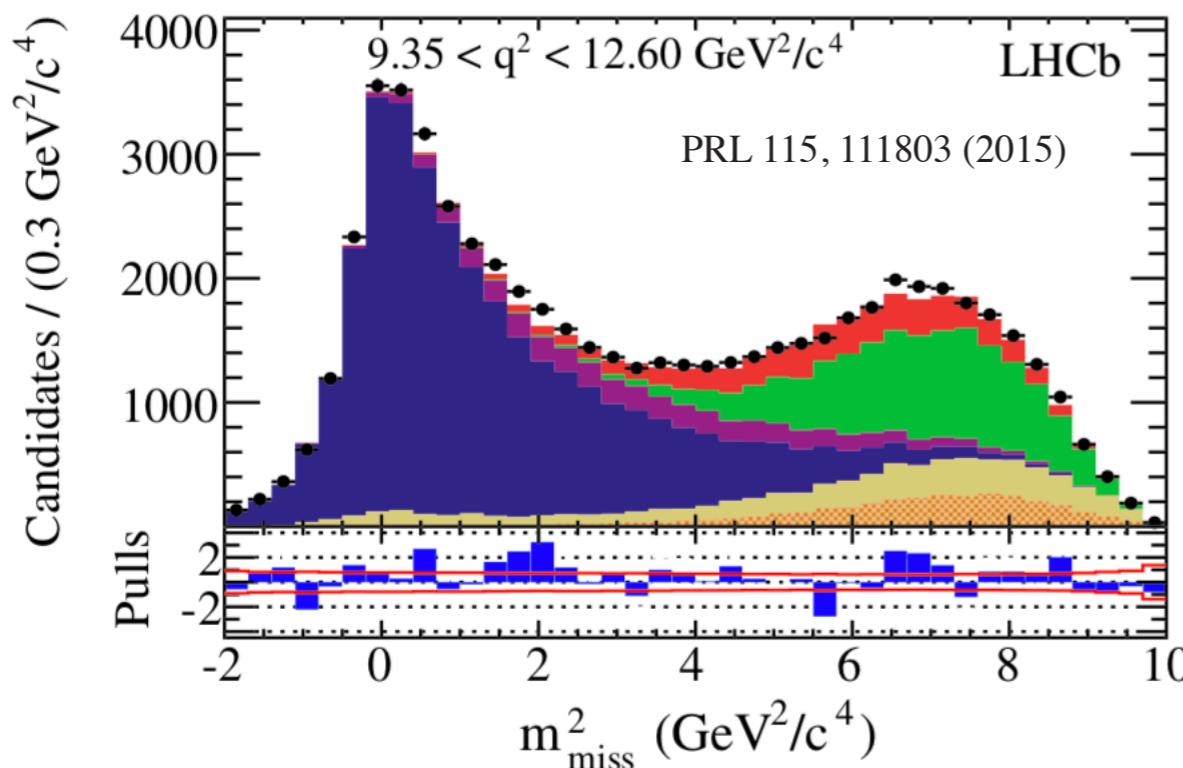


Tree-level $b \rightarrow c \ell \nu$ decays

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell)}$$

$\ell = e, \mu$ [Belle]

$\ell = \mu$ [LHCb]



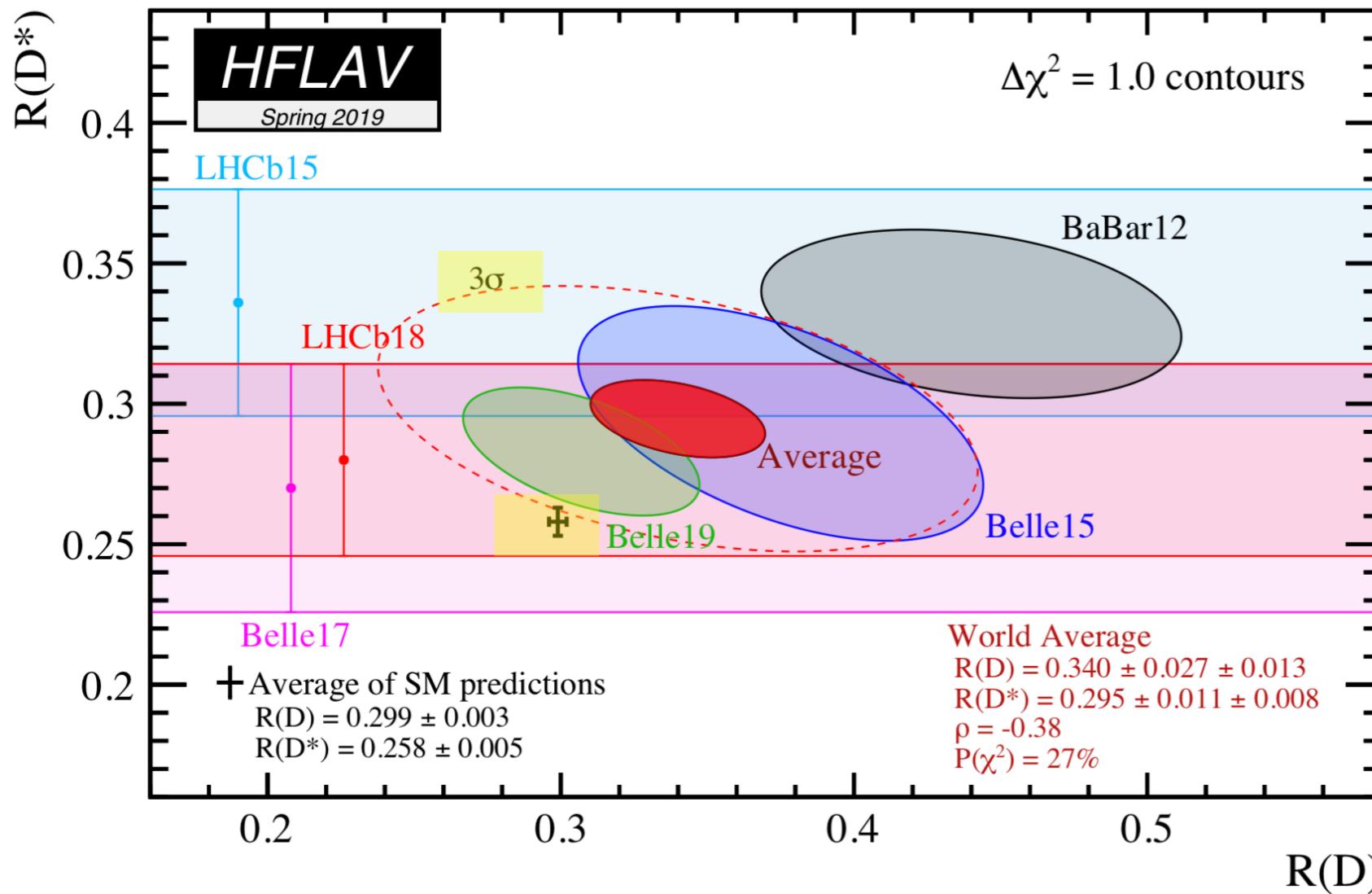
$$m_{\text{miss}}^2 = (p_B^\mu - p_D^\mu - p_\mu^\mu)^2$$

Muon energy

Tree-level $b \rightarrow c\ell\nu$ decays

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell)}$$

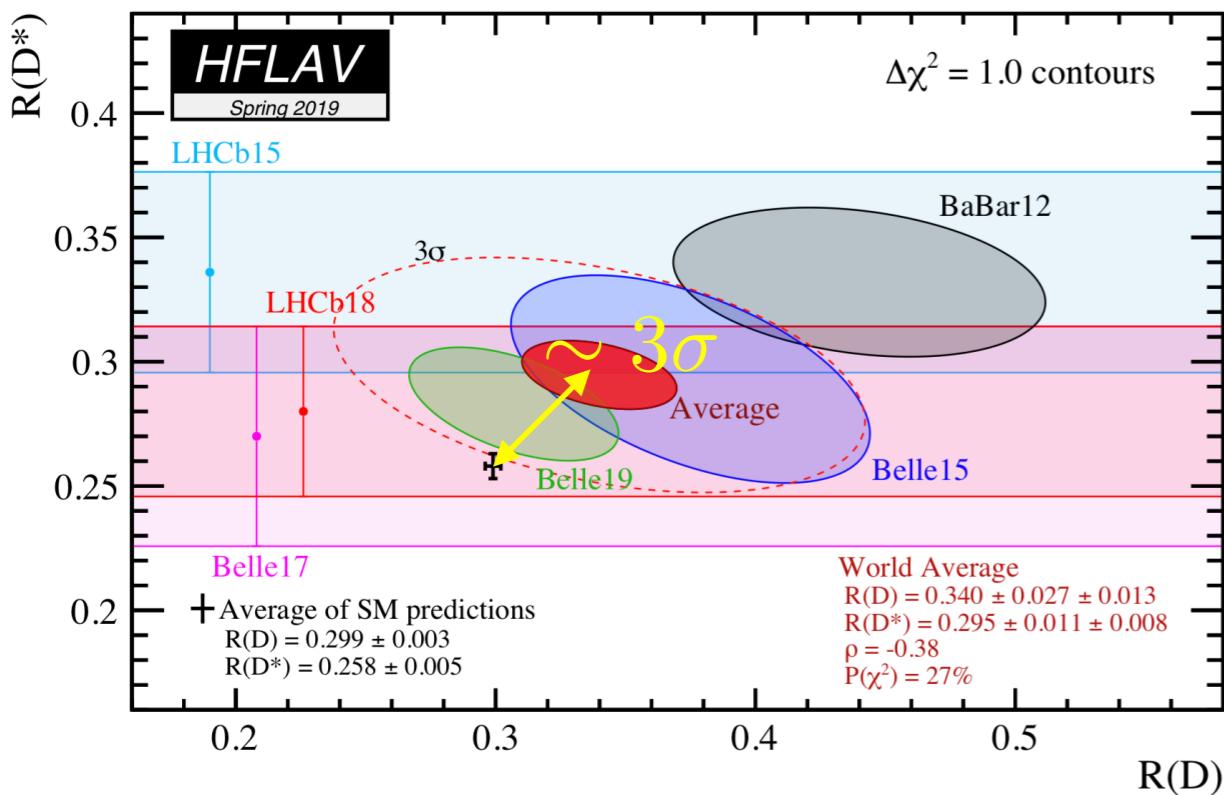
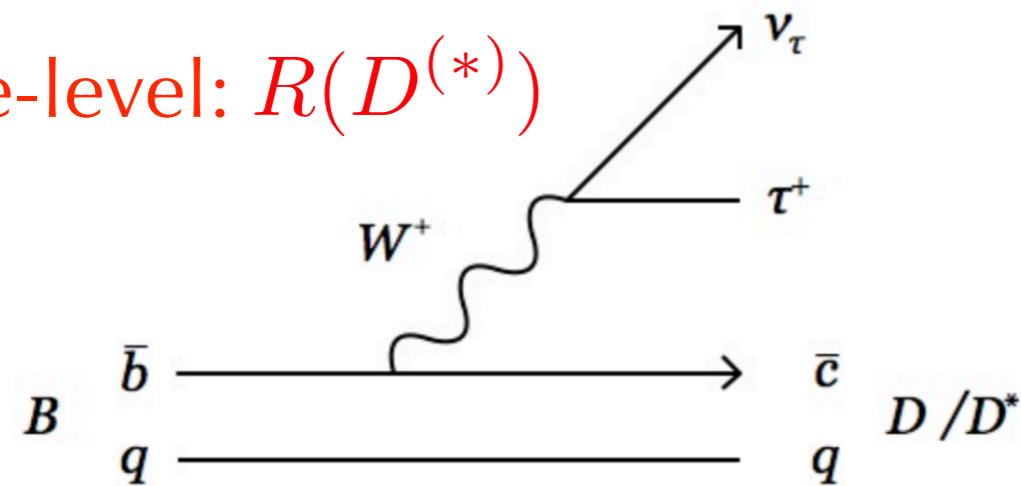
$\ell = e, \mu$ [Belle]
 $\ell = \mu$ [LHCb]



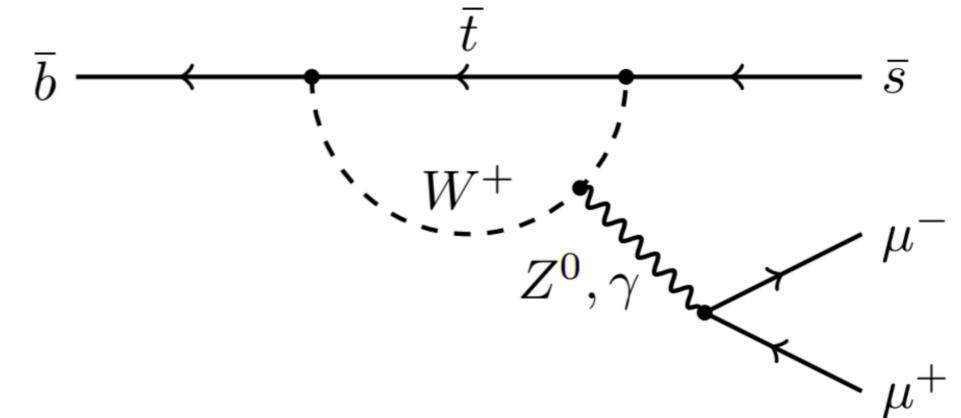
The flavour anomalies

$b \rightarrow c l \bar{\nu}$

Tree-level: $R(D^{(*)})$

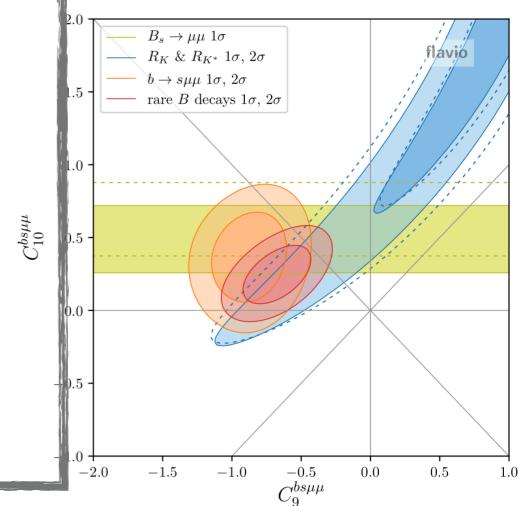


$b \rightarrow s \ell^+ \ell^-$



Flavour Changing Neutral Current (loop-suppressed):

- Branching fractions
- Angular analysis
- Lepton Flavour Universality tests

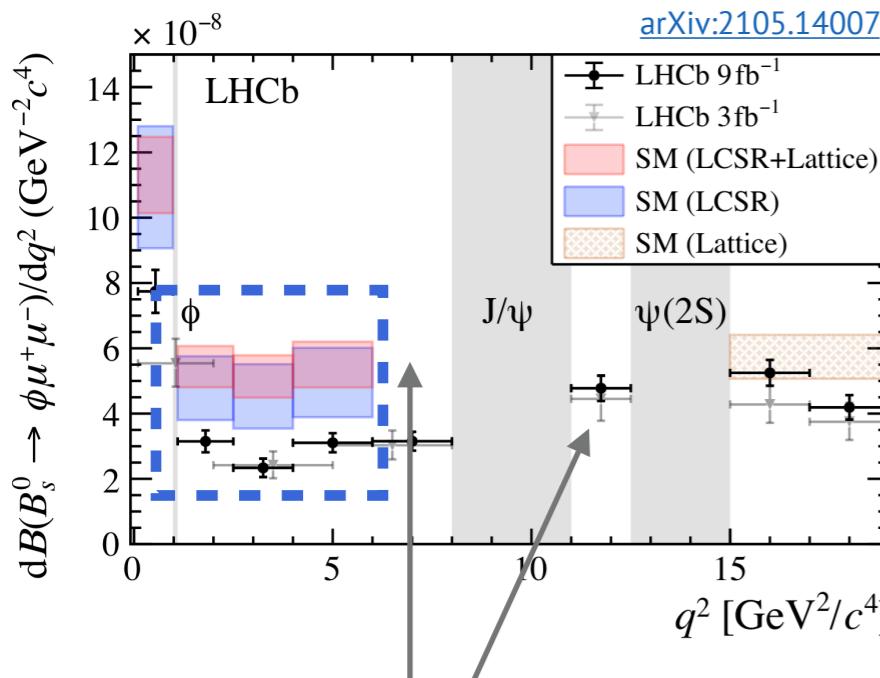


Loop-mediated $b \rightarrow s\ell\ell$ decays

- Deviations from Standard Model predictions observed in a range of experimental observables for $b \rightarrow s\ell\ell$

Branching fractions

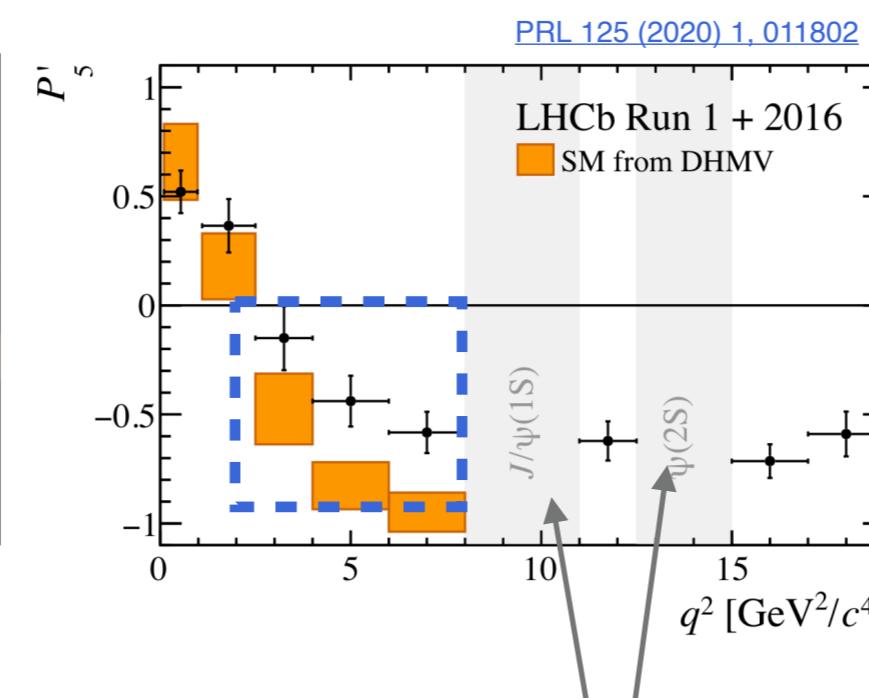
$(1.1 < q^2 < 6.0) \text{ GeV}^2 \sim 3\sigma$



Predictions omitted due to non-local hadronic contributions

Angular analysis

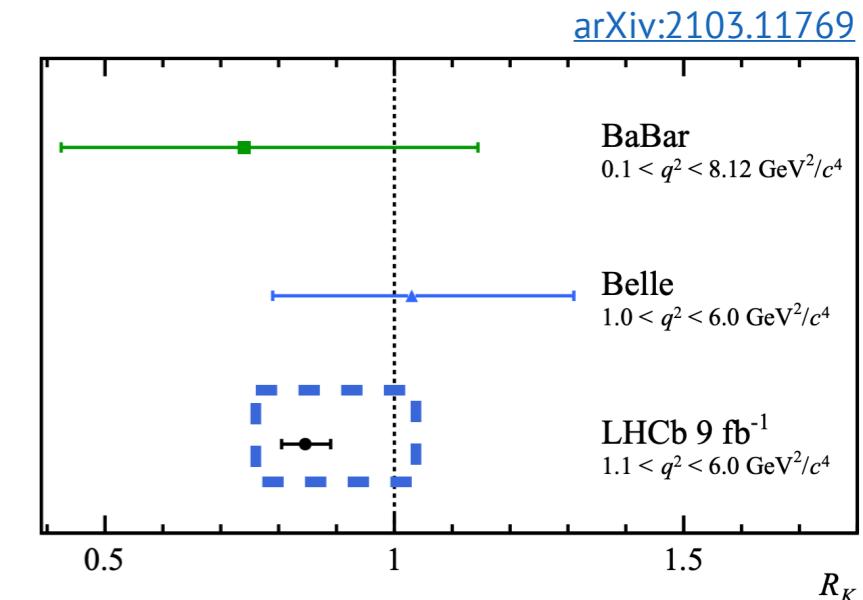
Fit to all observables $\sim 3\sigma$



Regions dominated by tree-level $b \rightarrow s[c\bar{c} \rightarrow \ell^+\ell^-]$ decays

$$R(X) = \frac{\mathcal{B}(B \rightarrow X \mu\mu)}{\mathcal{B}(B \rightarrow X ee)}$$

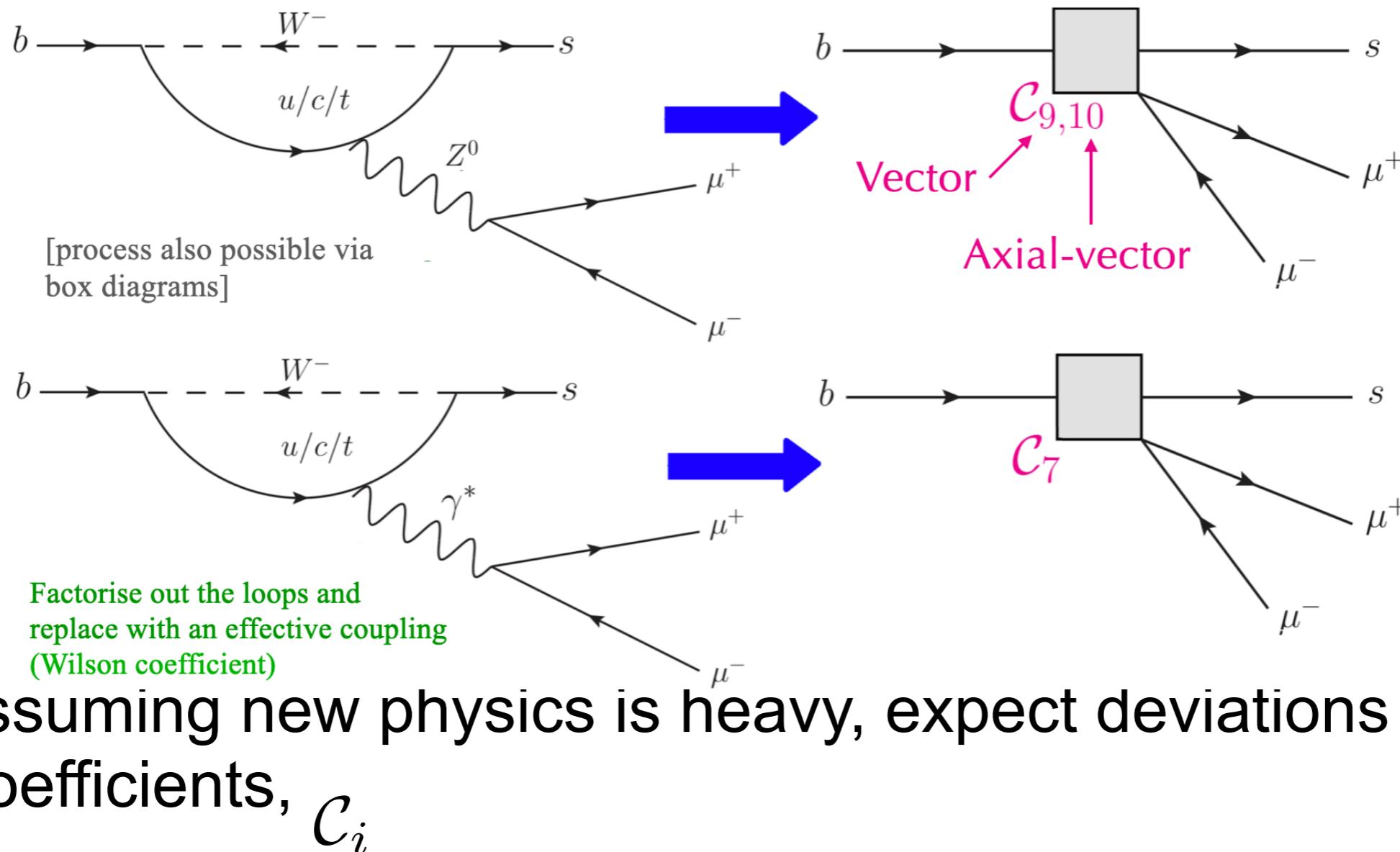
$(1.1 < q^2 < 6.0) \text{ GeV}^2 \sim 3\sigma$



$$q^2 = m^2(\ell^+ \ell^-)$$

Describing $b \rightarrow sll$ decays in the SM

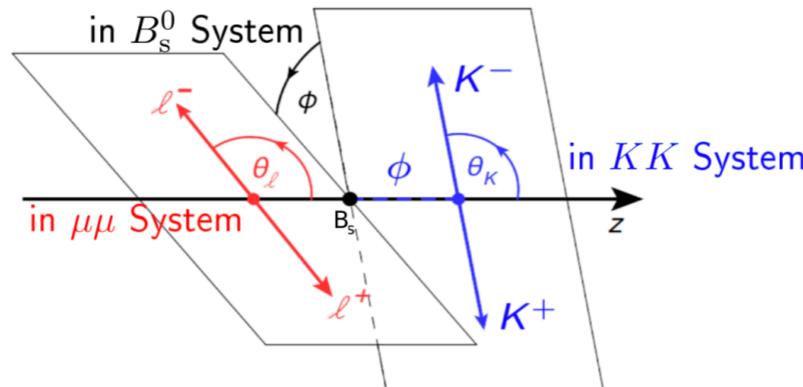
- Effective field theory: heavy part of the diagram integrated out \implies effective couplings, analogous to Fermi's constant



- Assuming new physics is heavy, expect deviations in Wilson Coefficients, C_i

Some highlights of recent results

- June 2021: Angular analysis of $B_s^0 \rightarrow \phi\mu^+\mu^-$ decays with 8.4fb^{-1}



$$\Rightarrow \text{Measure untagged } \frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \left[\frac{d^3\Gamma(B_s^0 \rightarrow \phi\mu^+\mu^-)}{dcos\theta_l dcos\theta_K d\phi} + \frac{d^3\bar{\Gamma}(\bar{B}_s^0 \rightarrow \phi\mu^+\mu^-)}{dcos\theta_l dcos\theta_K d\phi} \right]$$

$$\begin{aligned} &= \frac{9}{32\pi} \left[\frac{3}{4}(1 - F_L) \sin^2 \theta_K (1 + \frac{1}{3} \cos 2\theta_l) + F_L \cos^2 \theta_K (1 - \cos 2\theta_l) + S_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi \right. \\ &\quad + S_4 \sin 2\theta_K \sin 2\theta_l \cos \phi + A_5 \sin 2\theta_K \sin \theta_l \cos \phi + \frac{4}{3} A_{FB}^{CP} \sin^2 \theta_K \cos \theta_l \\ &\quad \left. + S_7 \sin 2\theta_K \sin \theta_l \sin \phi + A_8 \sin 2\theta_K \sin 2\theta_l \sin \phi + A_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi \right] \end{aligned}$$

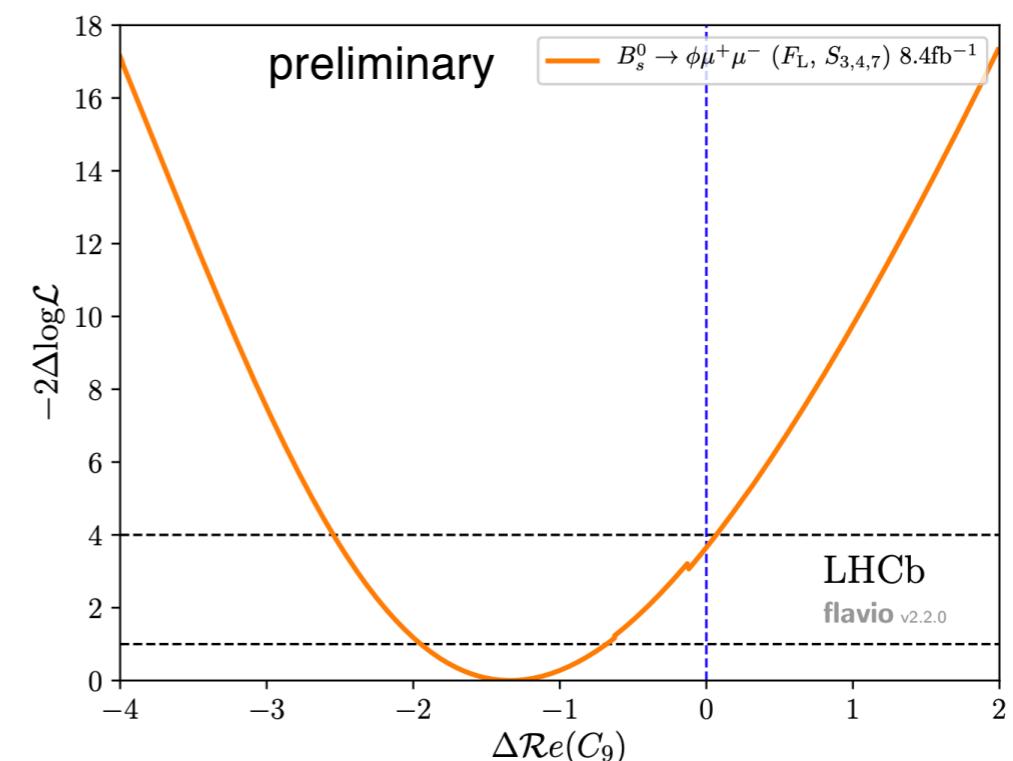
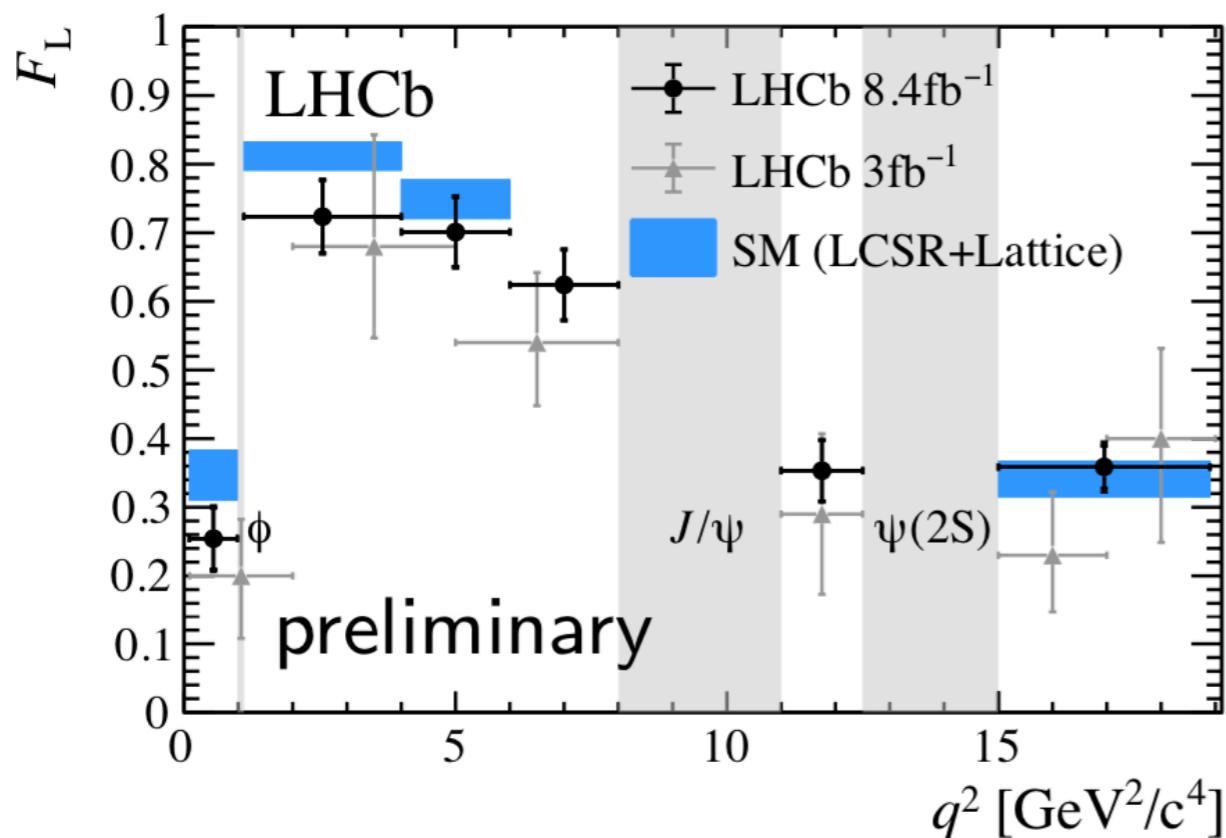
S_i CP-averages

A_i CP-asymmetries

[LHCb-PAPER-2021-022] (in prep.)

Some highlights of recent results

- June 2021: Angular analysis of $B_s^0 \rightarrow \phi\mu^+\mu^-$ decays with 8.4fb^{-1}

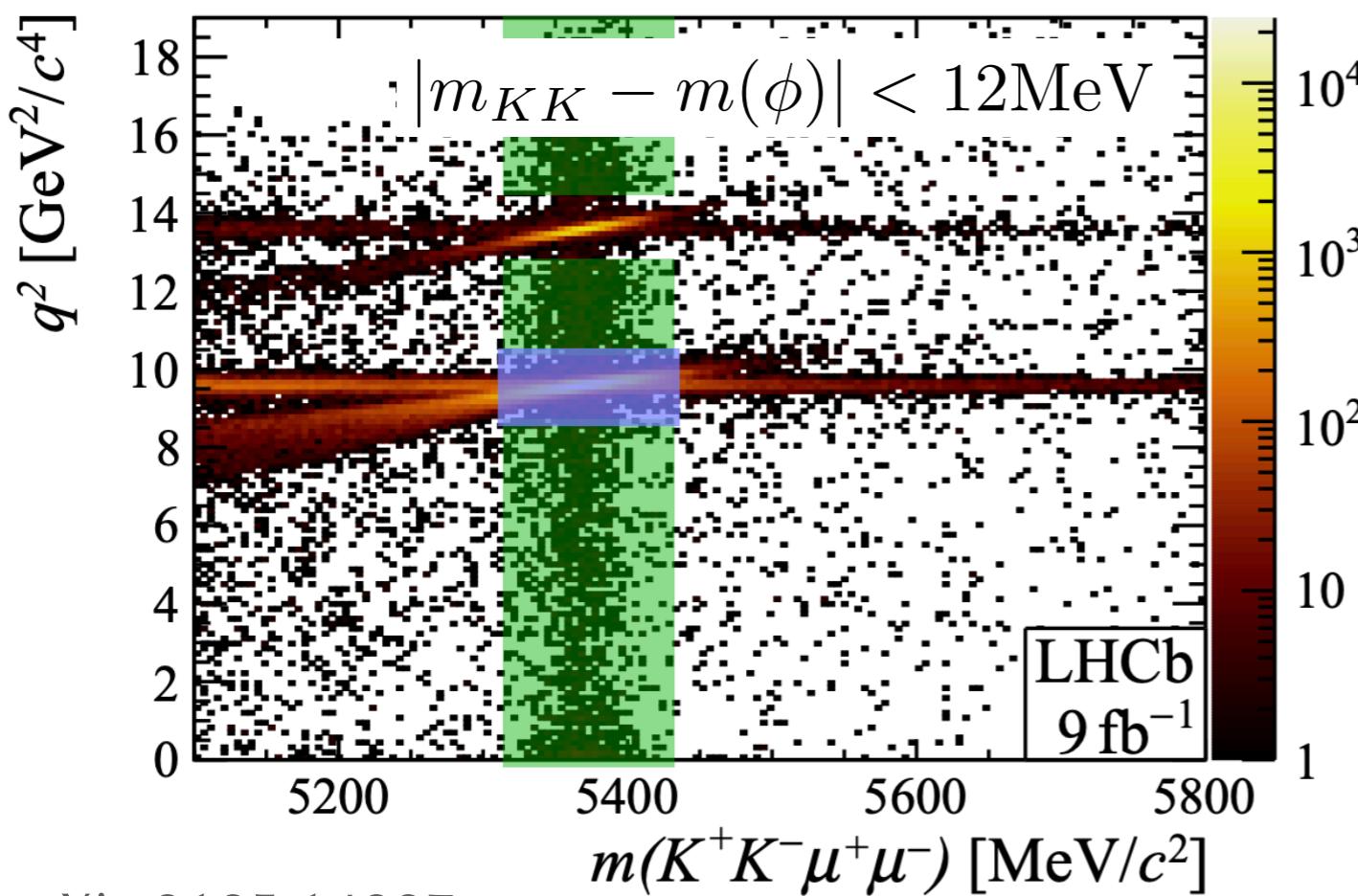


[LHCb-PAPER-2021-022] (in prep.)

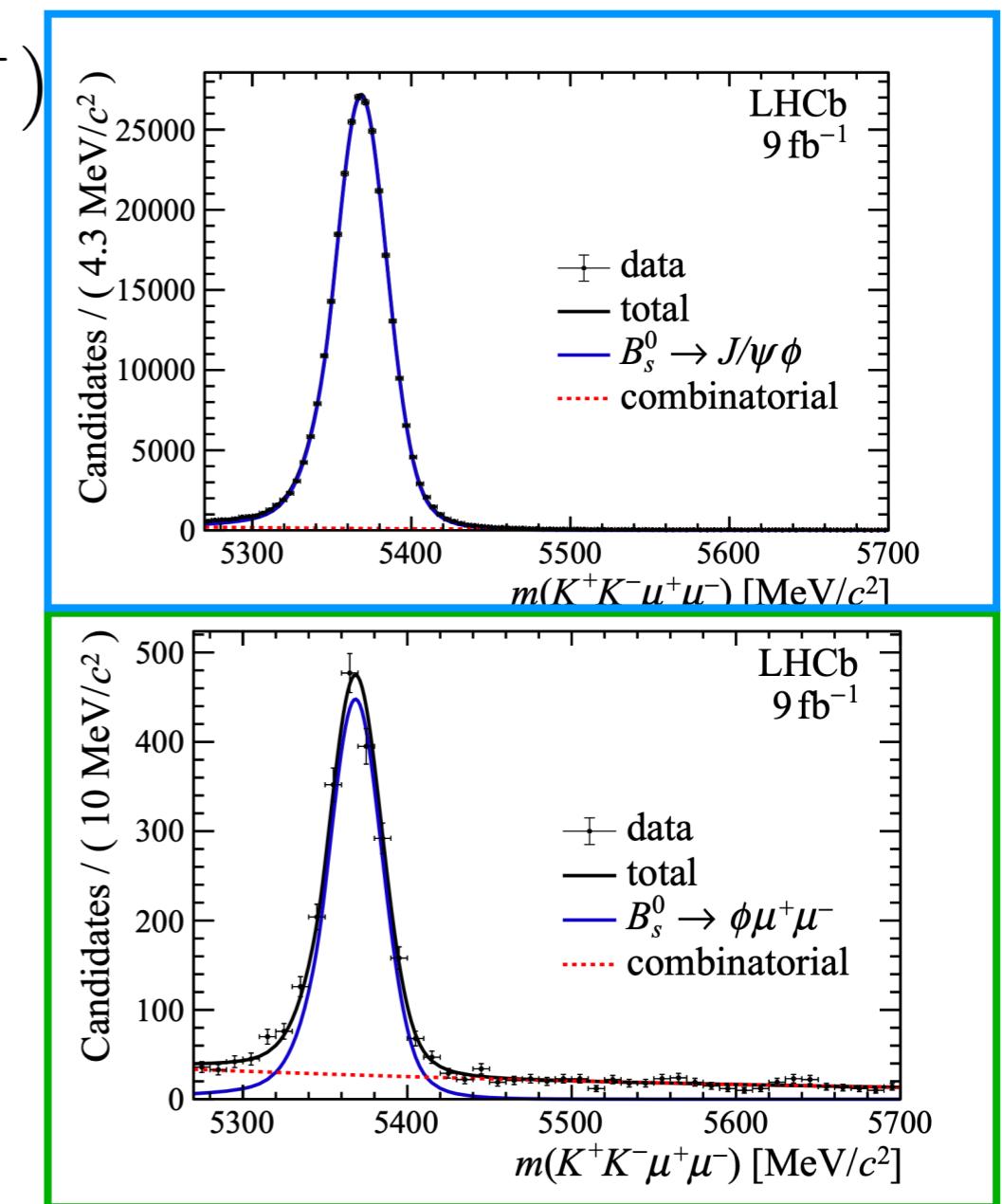
Some highlights of recent results

- **April 2021:** Branching fraction measurement of $B_s^0 \rightarrow \phi\mu^+\mu^-$ decays with 9fb^{-1} and first observation of $B_s^0 \rightarrow f'_2(1525)\mu^+\mu^-$

Measure relative to $B_s^0 \rightarrow \phi J/\psi(\rightarrow \mu^+\mu^-)$



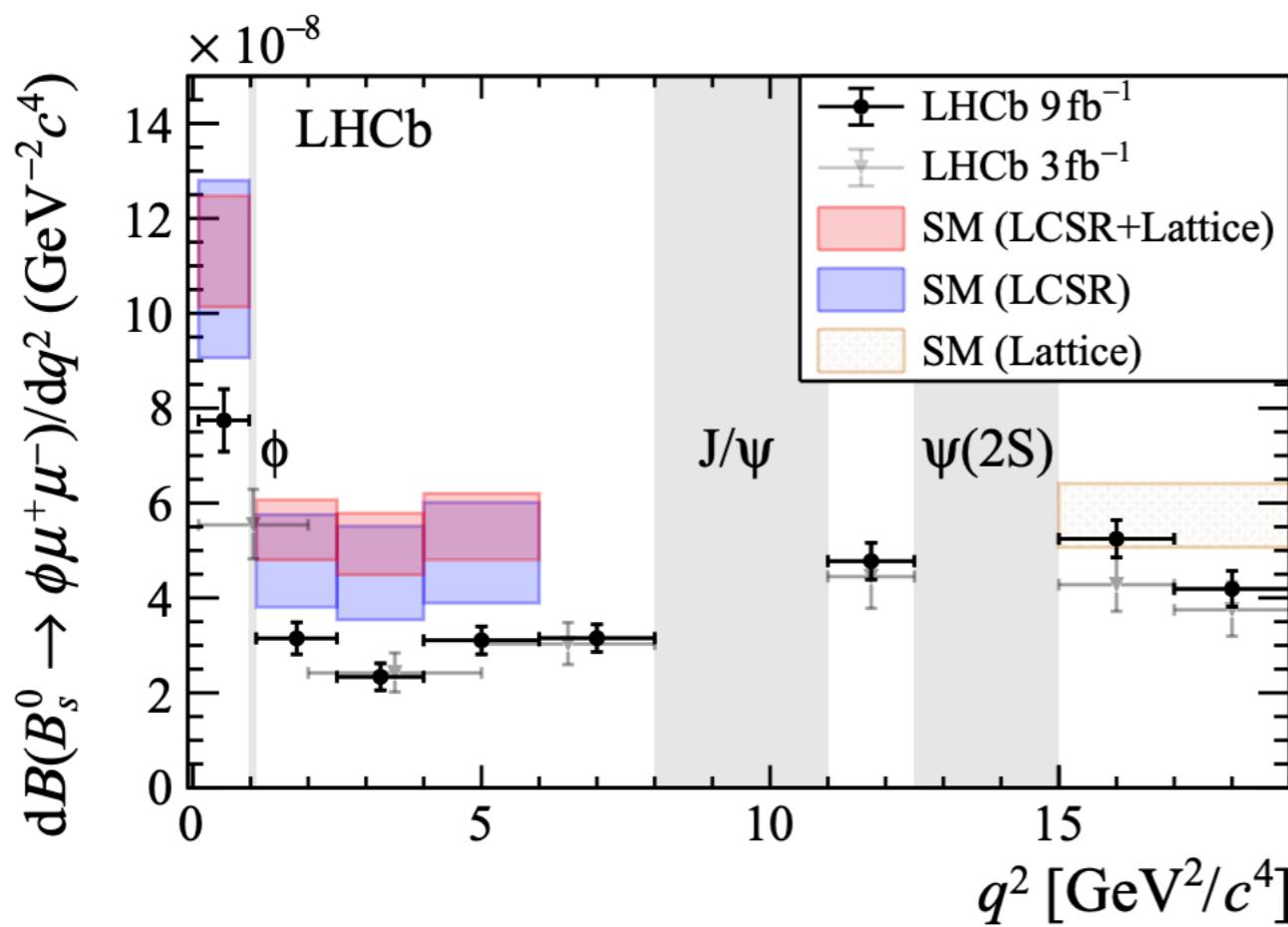
arXiv:2105.14007



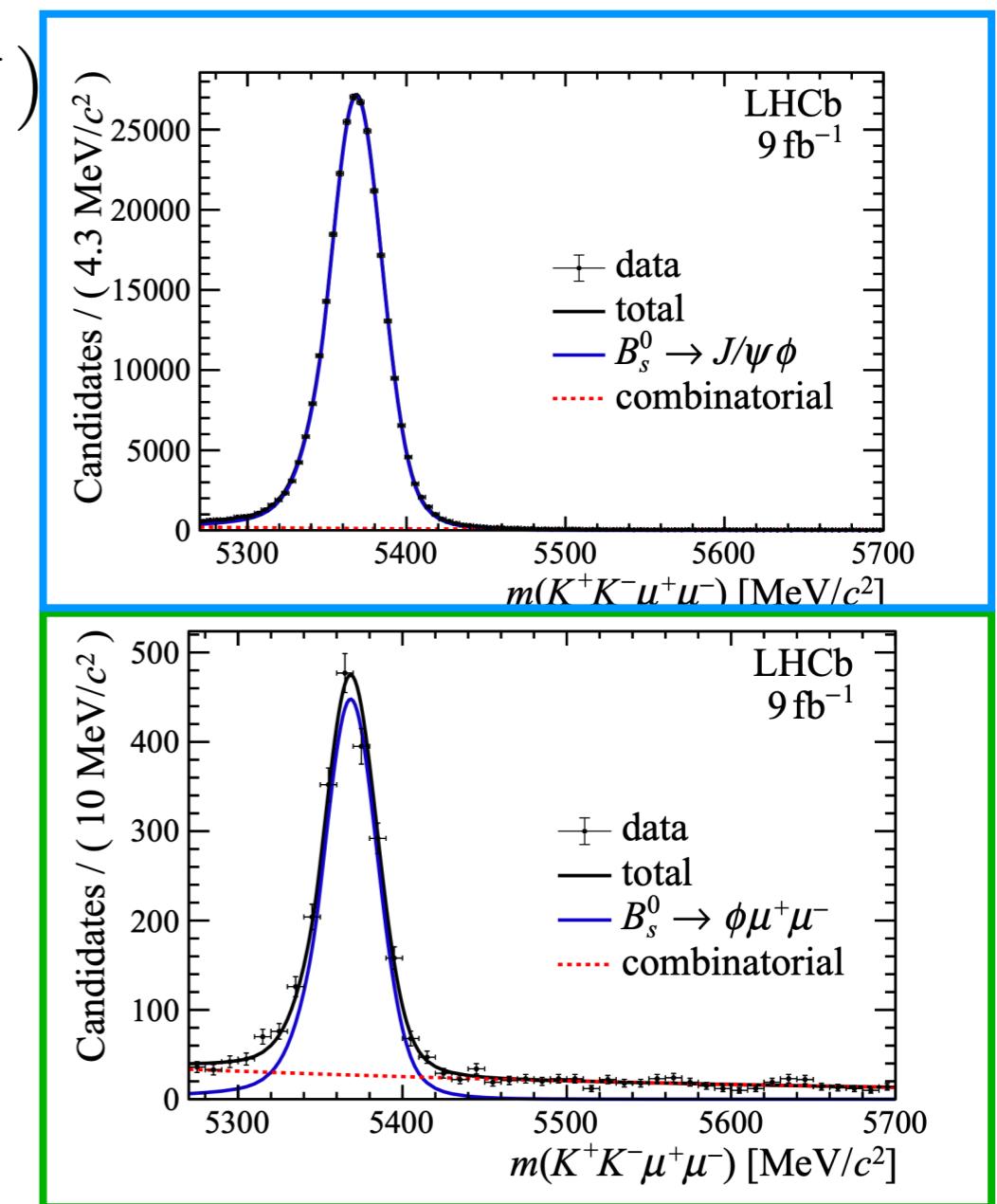
Some highlights of recent results

- **April 2021:** Branching fraction measurement of $B_s^0 \rightarrow \phi \mu^+ \mu^-$ decays with 9fb^{-1} and first observation of $B_s^0 \rightarrow f'_2(1525) \mu^+ \mu^-$

Measure relative to $B_s^0 \rightarrow \phi J/\psi (\rightarrow \mu^+ \mu^-)$



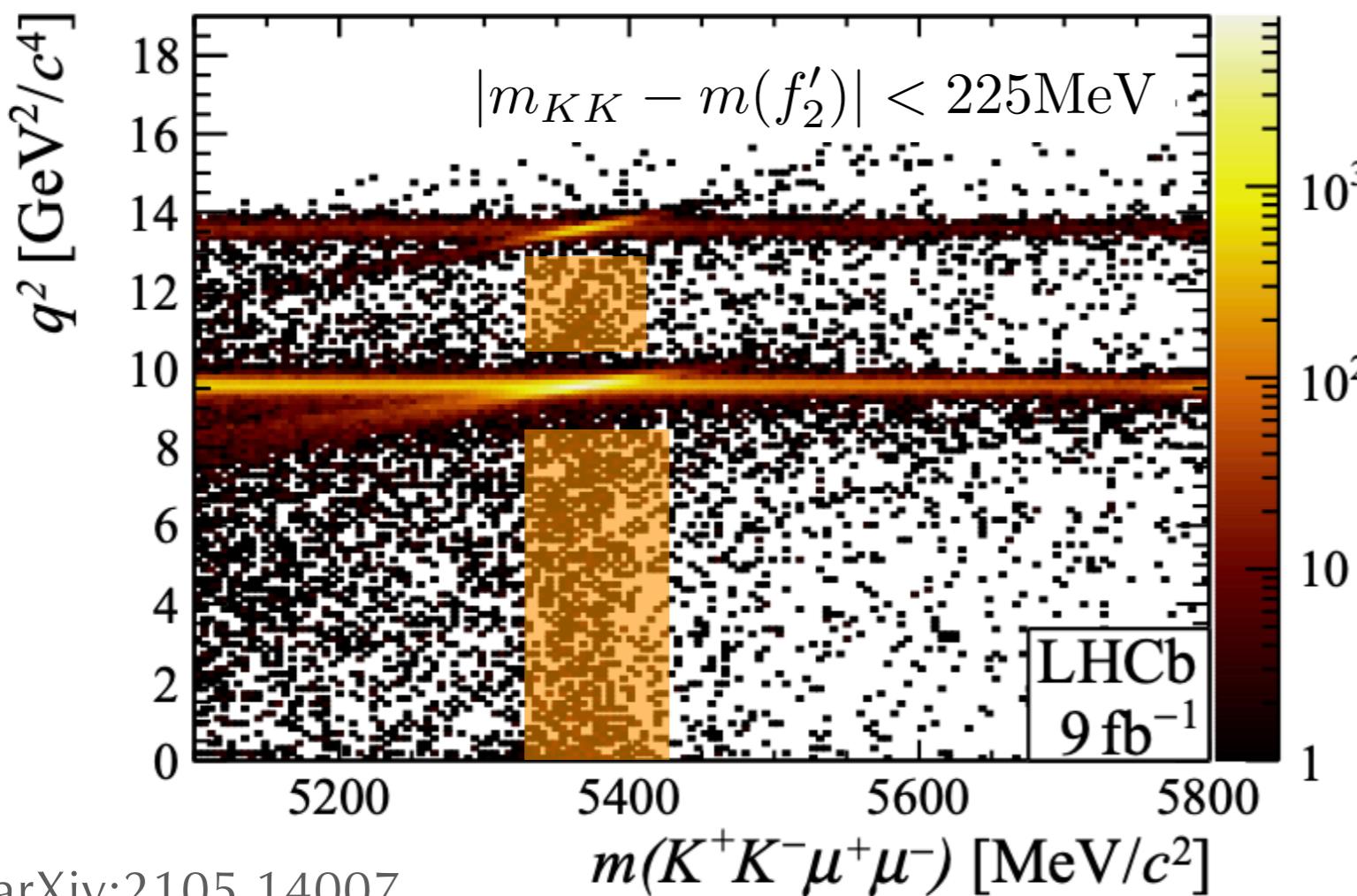
arXiv:2105.14007



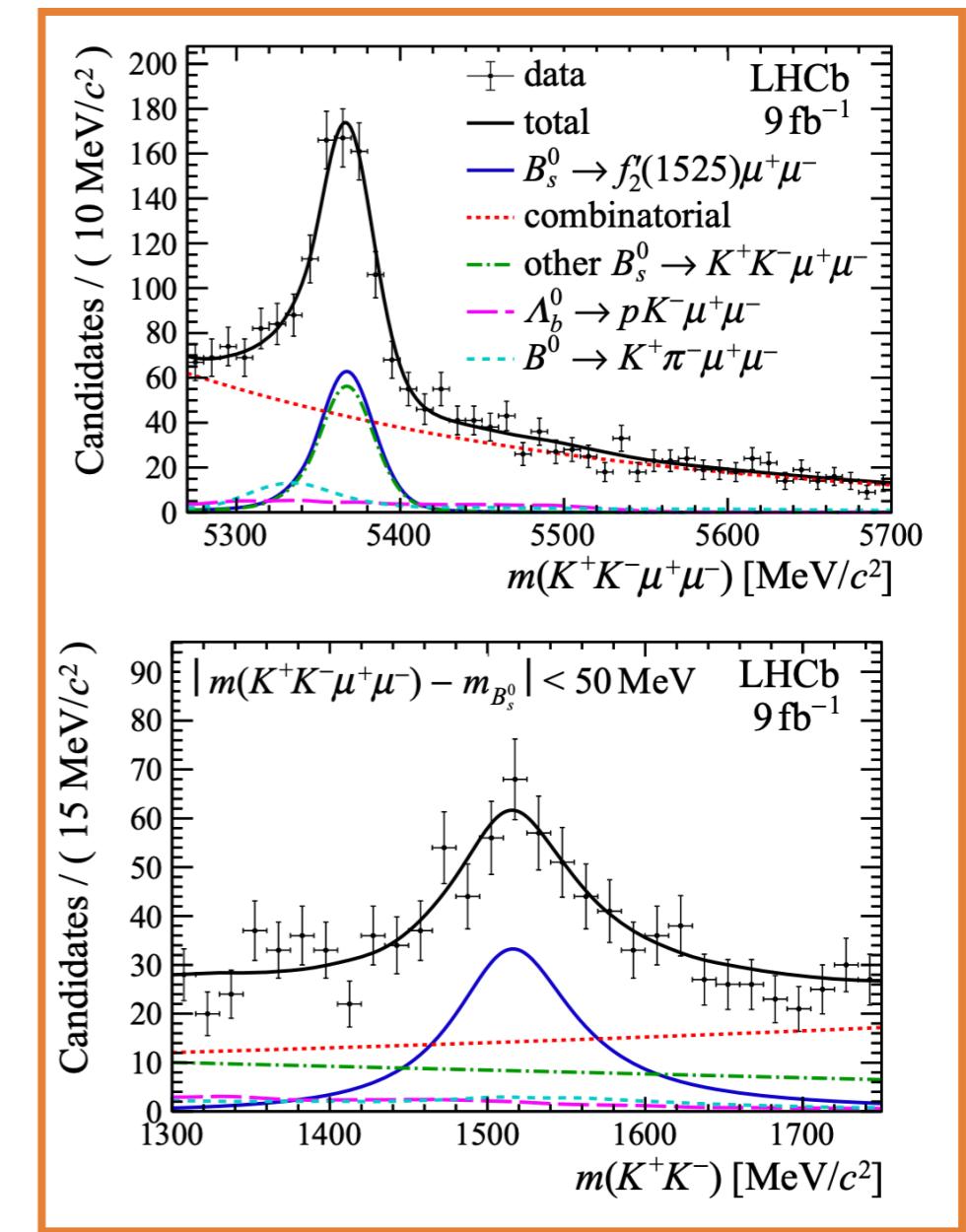
Some highlights of recent results

- **April 2021:** Branching fraction measurement of $B_s^0 \rightarrow \phi\mu^+\mu^-$ decays with 9fb^{-1} and first observation of $B_s^0 \rightarrow f'_2(1525)\mu^+\mu^-$

Measure relative to $B_s^0 \rightarrow \phi J/\psi(\rightarrow \mu^+\mu^-)$

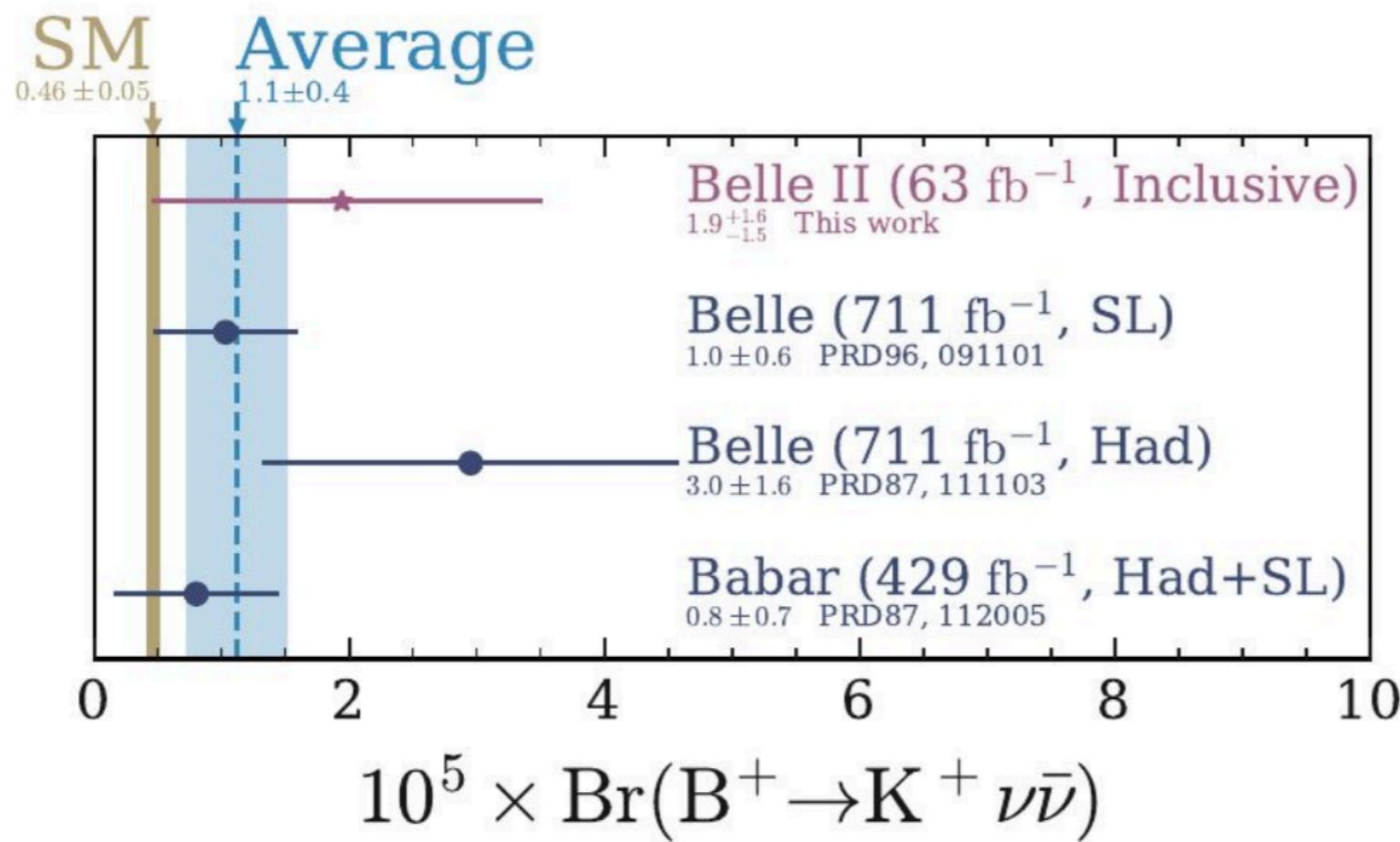


arXiv:2105.14007



Some highlights of recent results

- April 2021: First physics results from current Belle II data, limit on $\mathcal{B}(B^+ \rightarrow K^+ \nu \bar{\nu})$ (leave details to later Belle II talk) [[arXiv:2104.12624](https://arxiv.org/abs/2104.12624)]



Taken from [slide from S. Glazov](#)

Some highlights of recent results

► March 2021: Measurement of RK with 9fb⁻¹

arXiv:2105.11769

Lepton Flavour Universality tests defined as

$$R(X) = \frac{\mathcal{B}(B \rightarrow X\mu\mu)}{\mathcal{B}(B \rightarrow Xee)}$$

In practice measure double-ratio:

$$R(X) = \frac{\mathcal{B}(B \rightarrow X\mu\mu)}{\mathcal{B}(B \rightarrow Xee)} / \frac{\mathcal{B}(B \rightarrow XJ/\psi[\rightarrow \mu\mu])}{\mathcal{B}(B \rightarrow XJ/\psi[\rightarrow ee])}$$

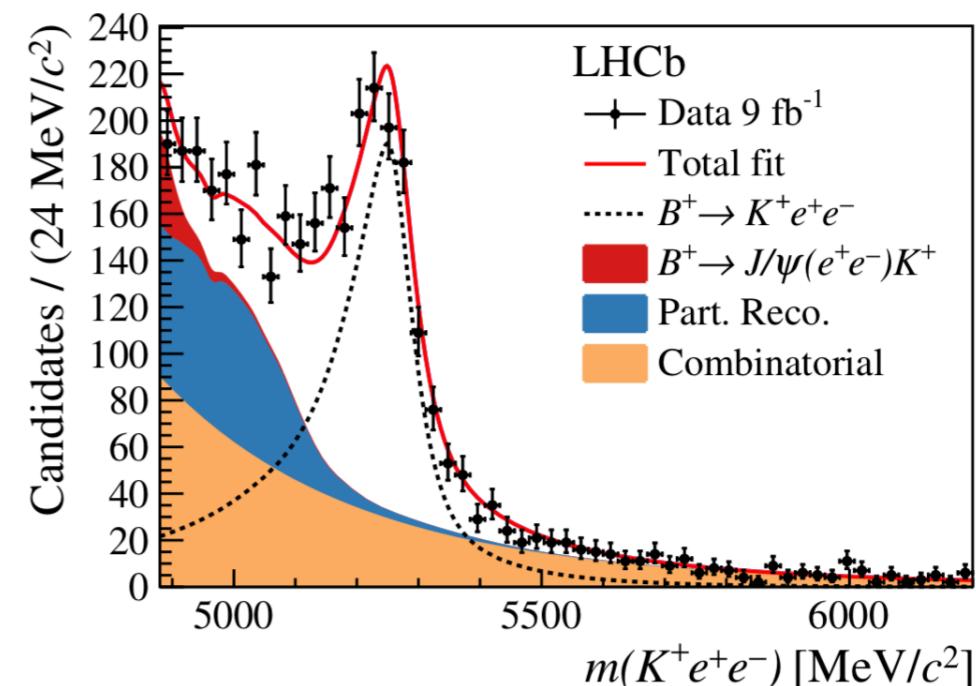
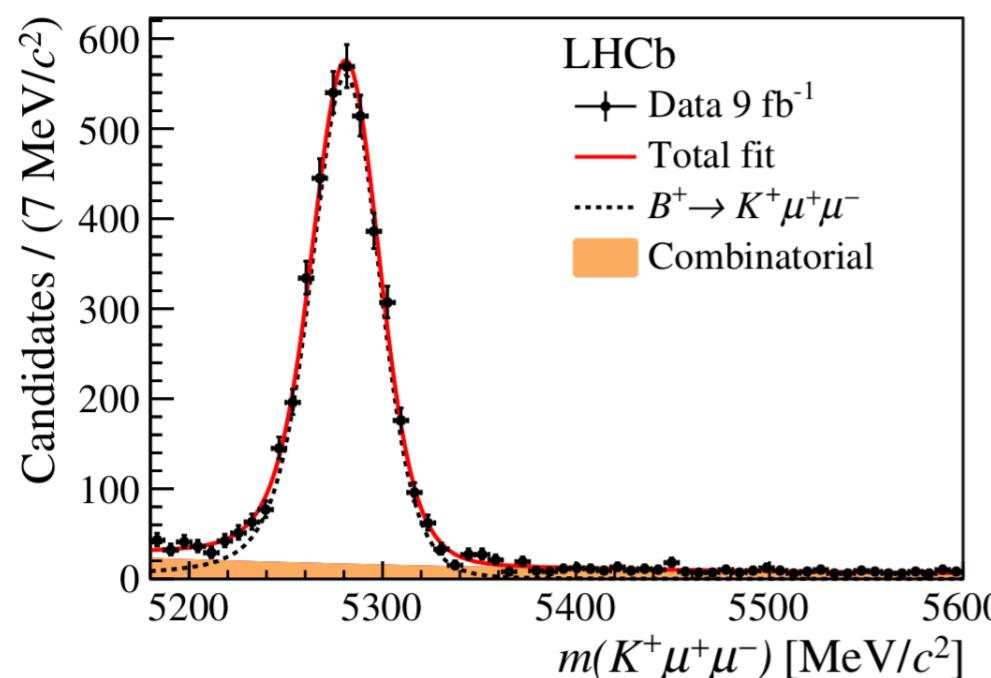
Many systematic effects cancel in double ratio

Measurement of $r(J/\psi)$ gives stringent test of efficiencies

Some highlights of recent results

- March 2021: Measurement of RK with 9fb⁻¹

arXiv:2105.11769



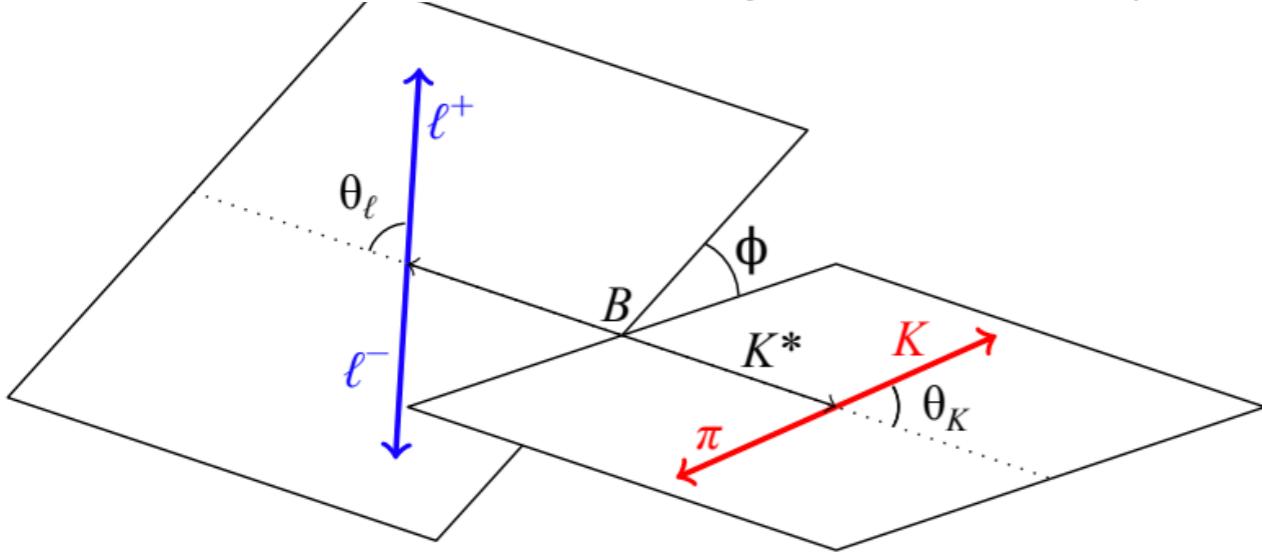
$$R_K(1.1 < q^2 < 6.0 \text{ GeV}^2/c^4) = 0.846^{+0.042}_{-0.039}{}^{+0.013}_{-0.012}$$

SM expectation, 1.00 ± 0.01

Consistent with SM at level of 3.1 standard deviations

Some highlights of recent results

- Dec 2020: Angular analysis of $B^+ \rightarrow K^{*+} (\rightarrow K_S^0 \pi^+) \mu^+ \mu^-$



PRL. 126, 161802 (2021)

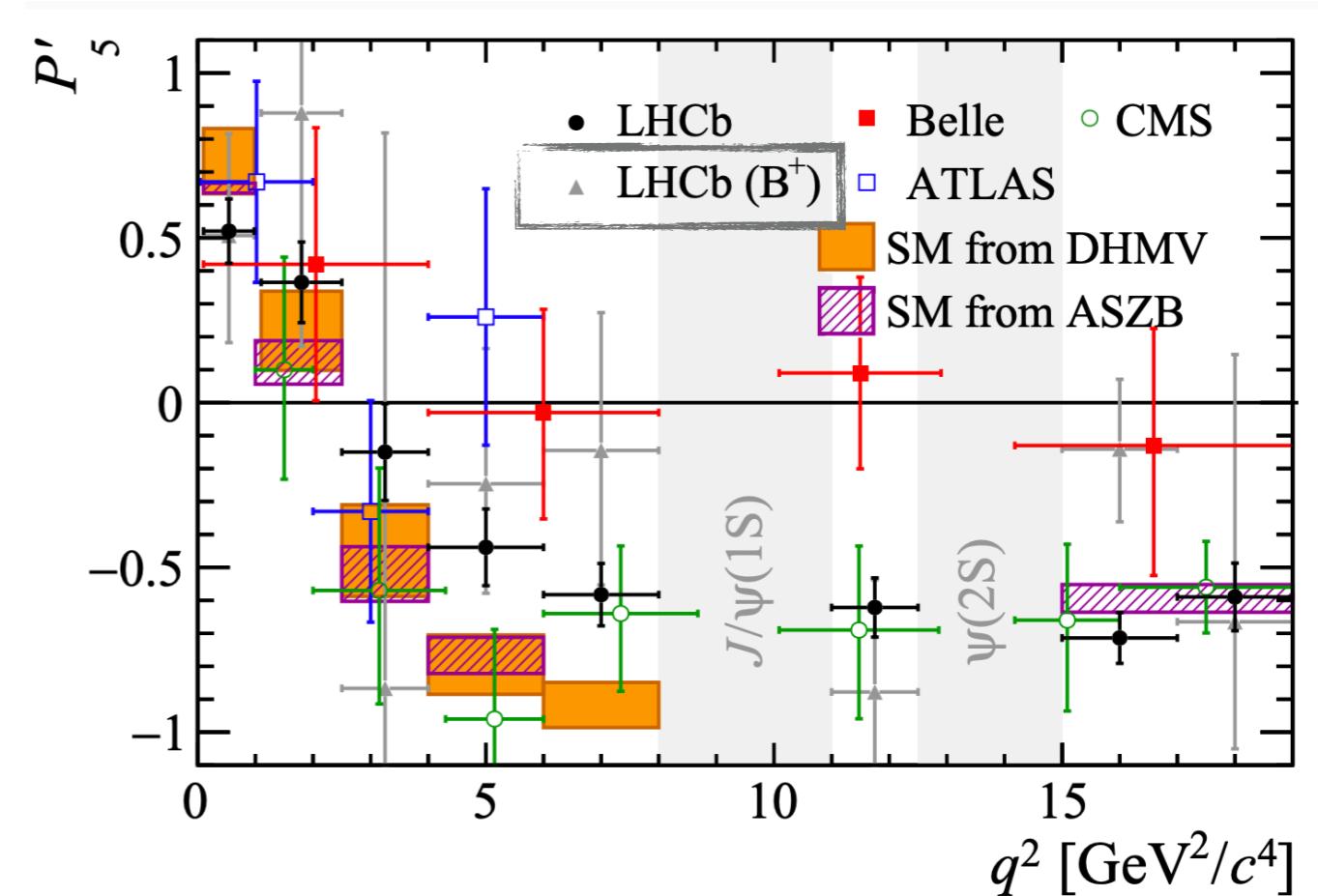
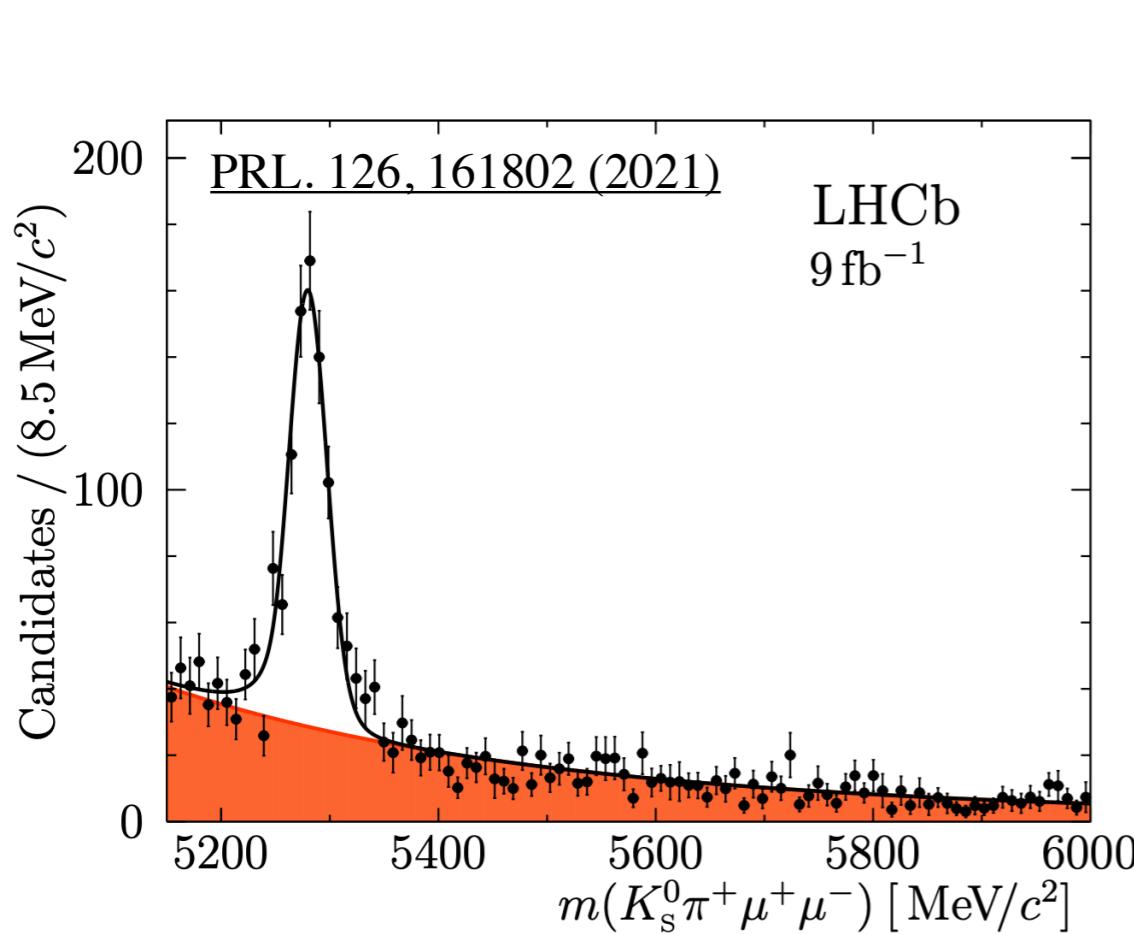
- Perform fit in two bases
- S_i basis
- $P_i^{(\prime)}$ basis (reduced theory uncert.)

$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \left. \frac{d(\Gamma + \bar{\Gamma})}{dcos\theta_l \, dcos\theta_K \, d\phi} \right|_P = \frac{9}{32\pi} \left[\frac{3}{4}(1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K + \frac{1}{4}(1 - F_L) \sin^2 \theta_K \cos 2\theta_l - F_L \cos^2 \theta_K \cos 2\theta_l + S_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi + S_4 \sin 2\theta_K \sin 2\theta_l \cos \phi + S_5 \sin 2\theta_K \sin \theta_l \cos \phi + \frac{4}{3}A_{FB} \sin^2 \theta_K \cos \theta_l + S_7 \sin 2\theta_K \sin \theta_l \sin \phi + S_8 \sin 2\theta_K \sin 2\theta_l \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi \right]. \quad (29)$$

$$\begin{aligned} P_1 &= \frac{2S_3}{(1 - F_L)} = A_T^{(2)} & P'_{4,5,8} &= \frac{S_{4,5,8}}{\sqrt{F_L(1 - F_L)}}, \\ P_2 &= \frac{2}{3} \frac{A_{FB}}{(1 - F_L)}, & P'_6 &= \frac{S_7}{\sqrt{F_L(1 - F_L)}}. \end{aligned}$$

Some highlights of recent results

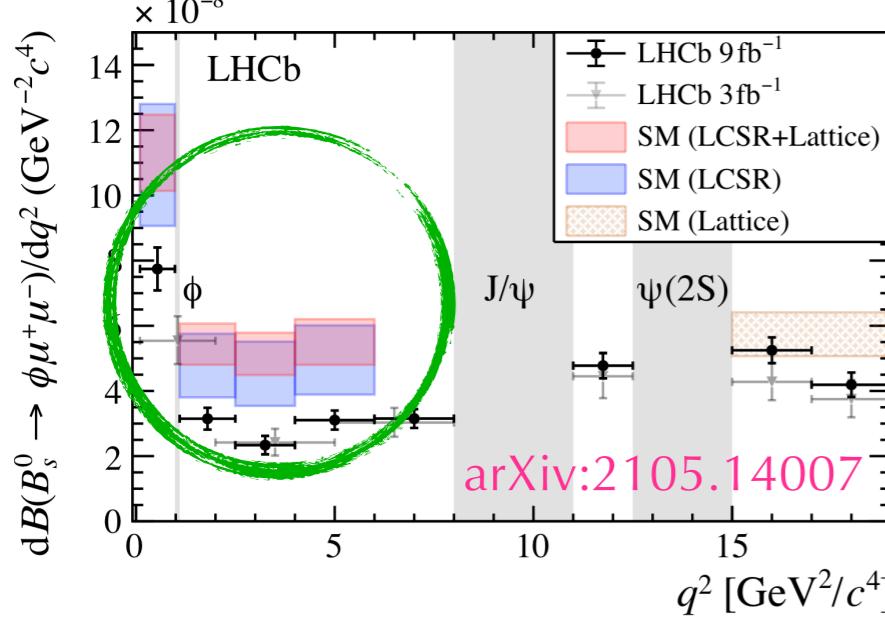
- Dec 2020: Angular analysis of $B^+ \rightarrow K^{*+} (\rightarrow K_S^0 \pi^+) \mu^+ \mu^-$



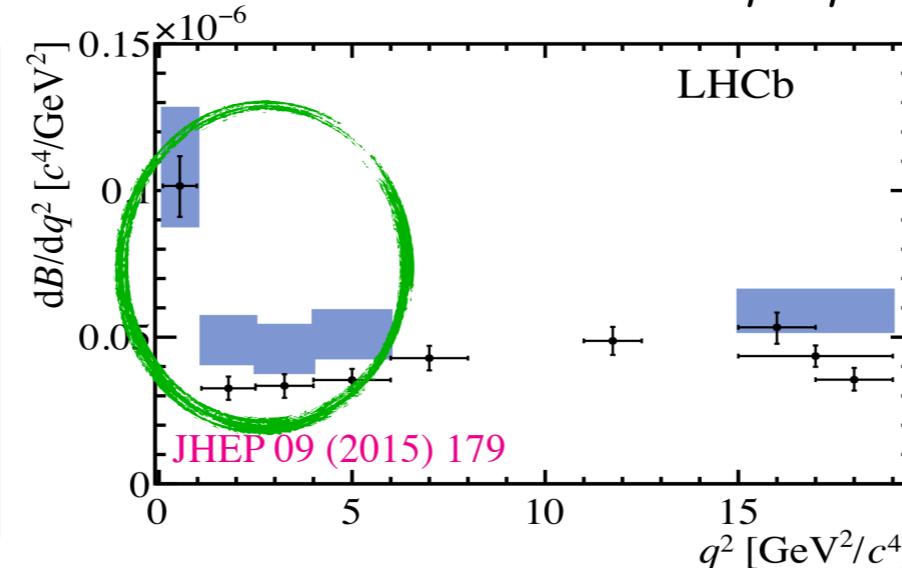
- Tension in P'_5 and $\text{Re}(C_9)$ (next slide) consistent with same trends seen in $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ decays

Overview of branching fractions

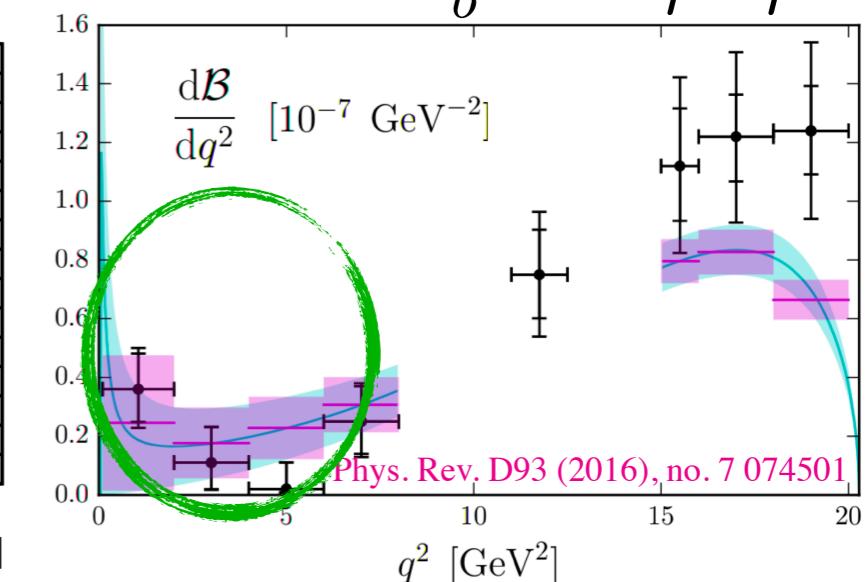
$B_s^0 \rightarrow \phi \mu^+ \mu^-$



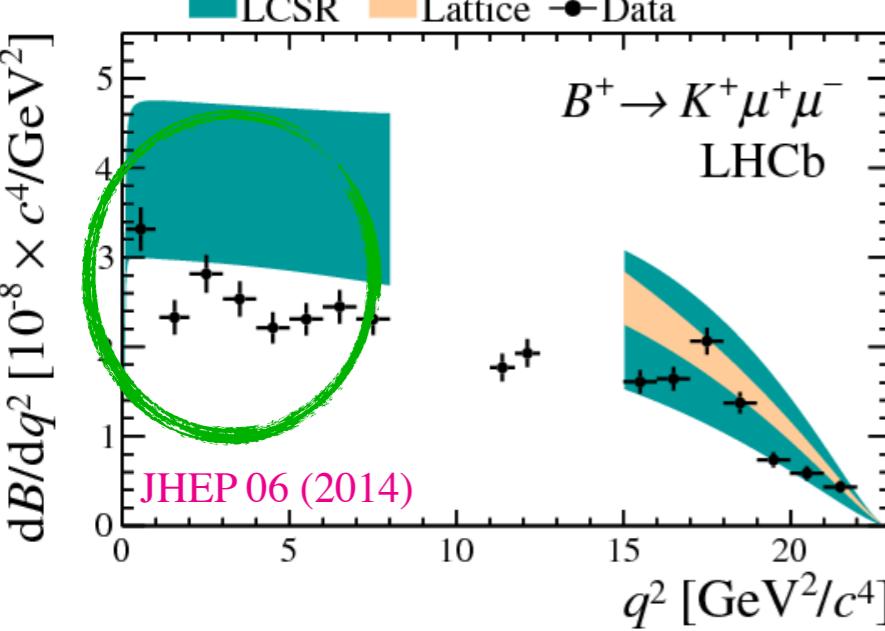
$B^0 \rightarrow K^{*0} \mu^+ \mu^-$



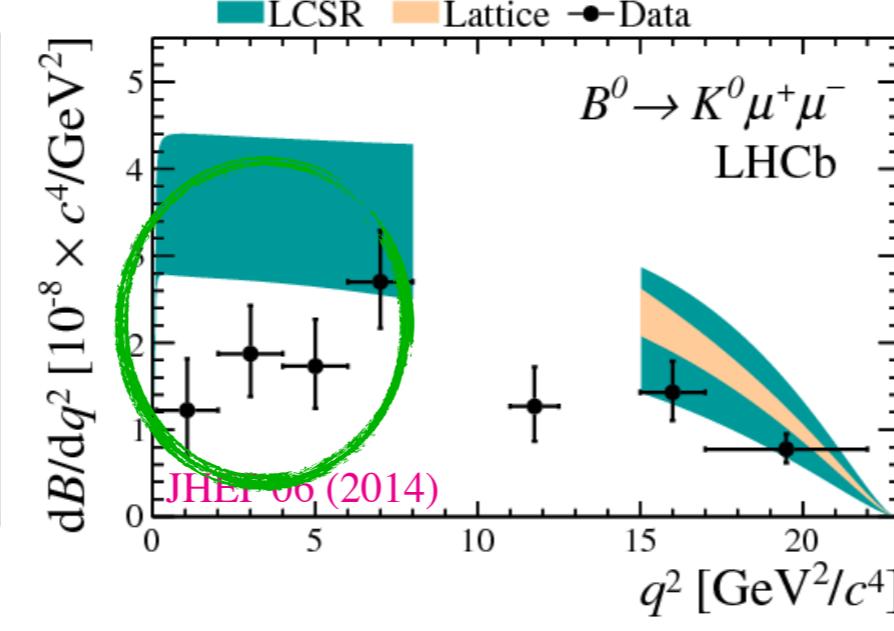
$\Lambda_b^0 \rightarrow \Lambda \mu^+ \mu^-$



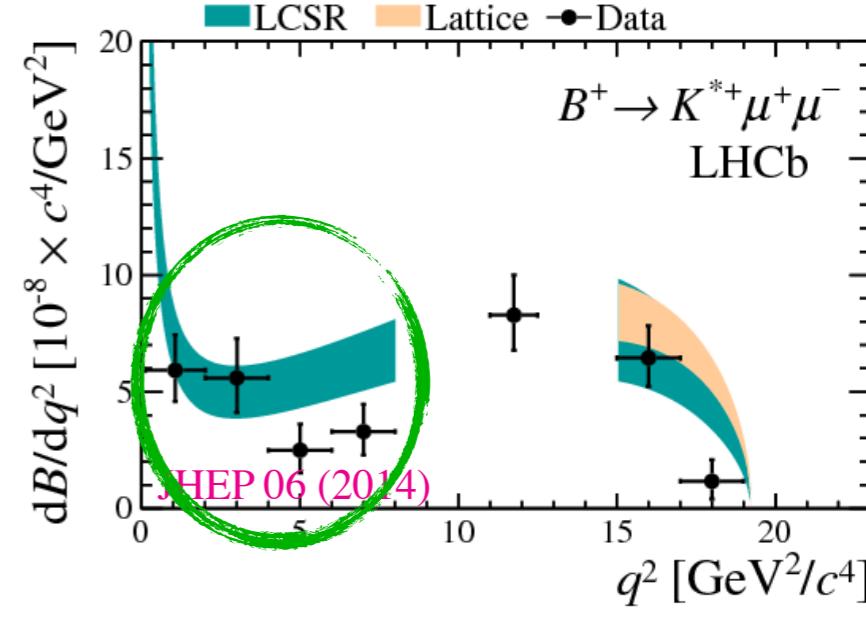
LCSR Lattice Data



LCSR Lattice Data



LCSR Lattice Data

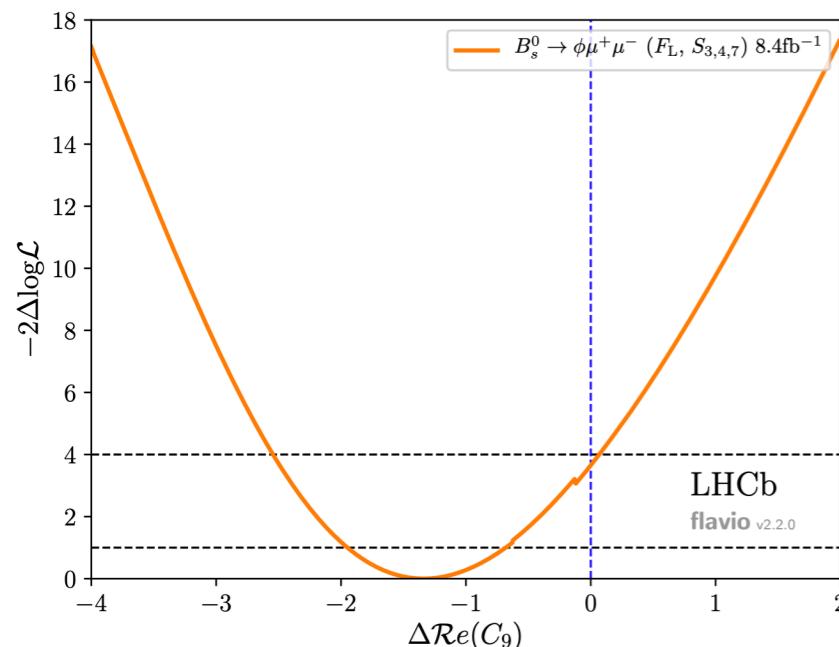


Overview of angular analyses

- Angular analysis of $B \rightarrow V\mu^+\mu^-$ decays, consistent shift in $Re(C_9)$ across different decay modes

$\sim 2\sigma$

[LHCb-PAPER-2021-022] (in prep.)



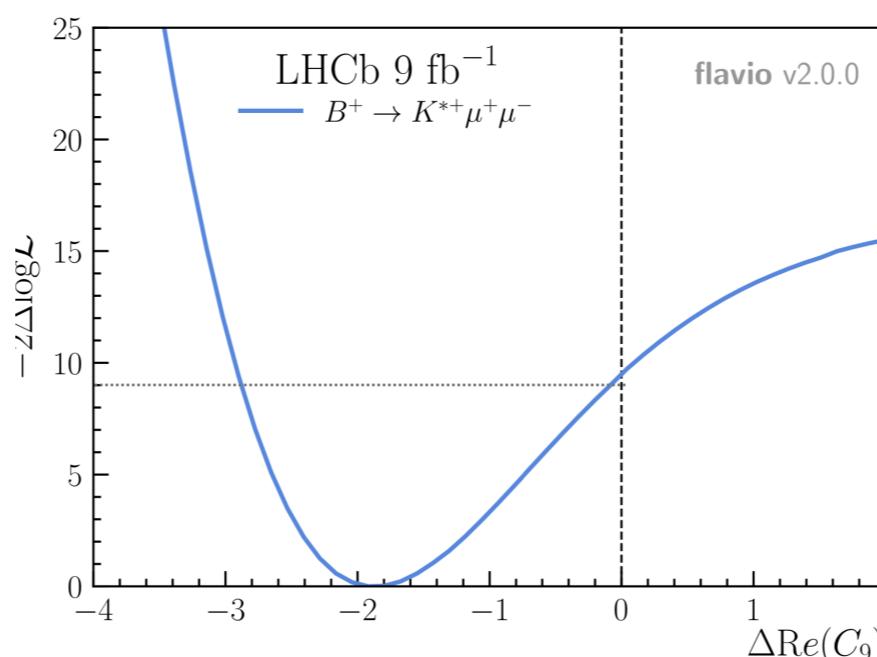
$$B_s^0 \rightarrow \phi \mu^+ \mu^-$$

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

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

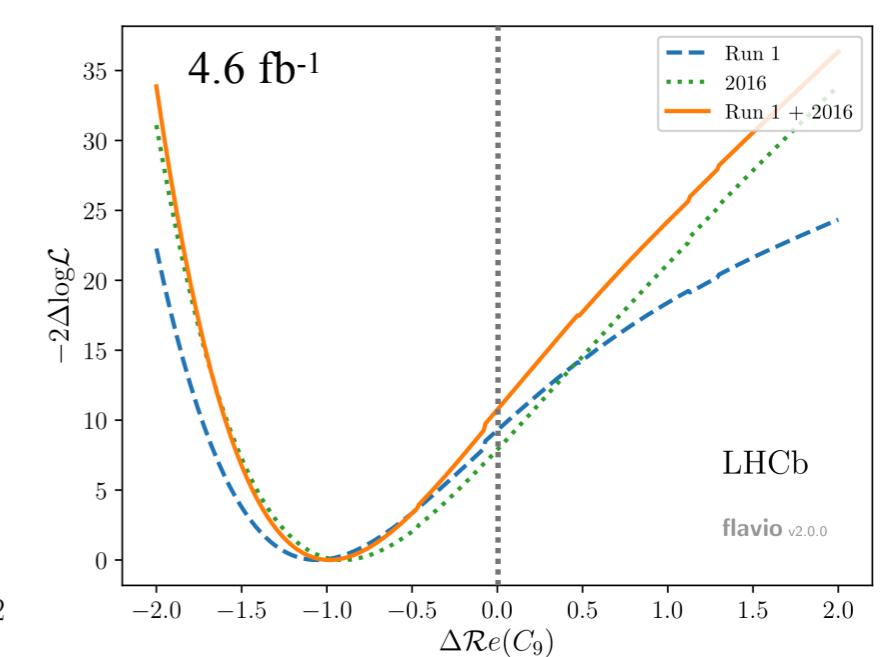
$\sim 3\sigma$

Phys. Rev. Lett. **126**, 161802

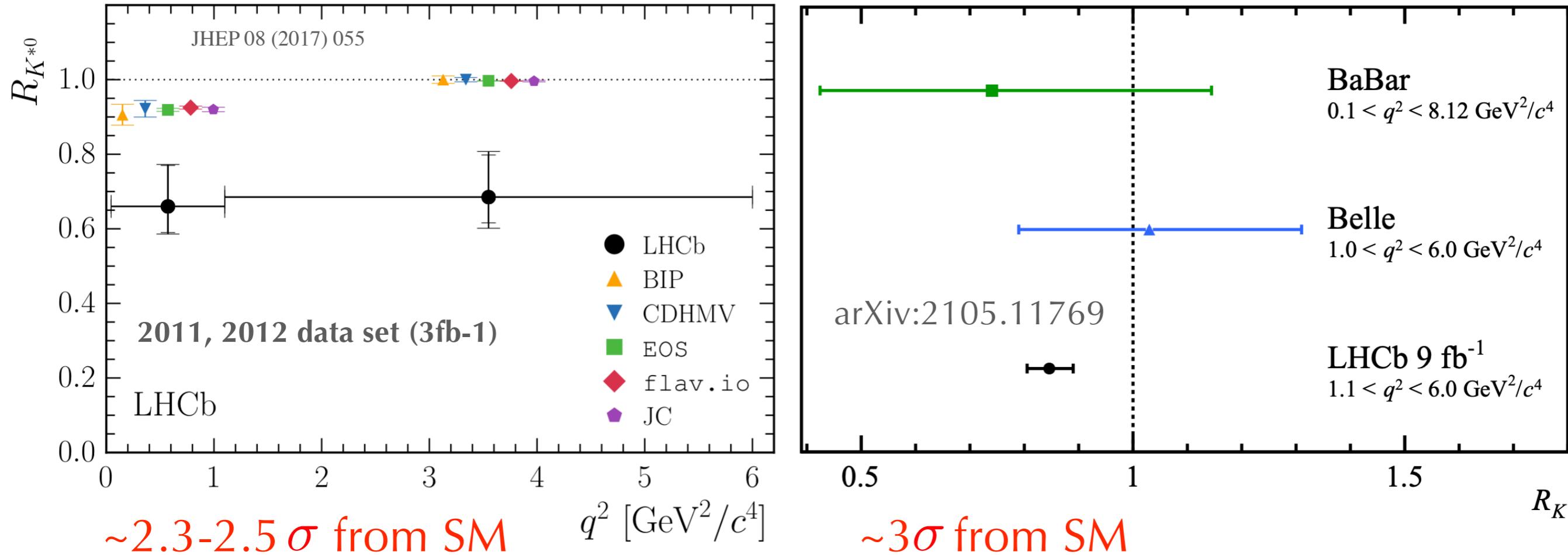


$\sim 3\sigma$

Phys. Rev. Lett. **125**, 011802

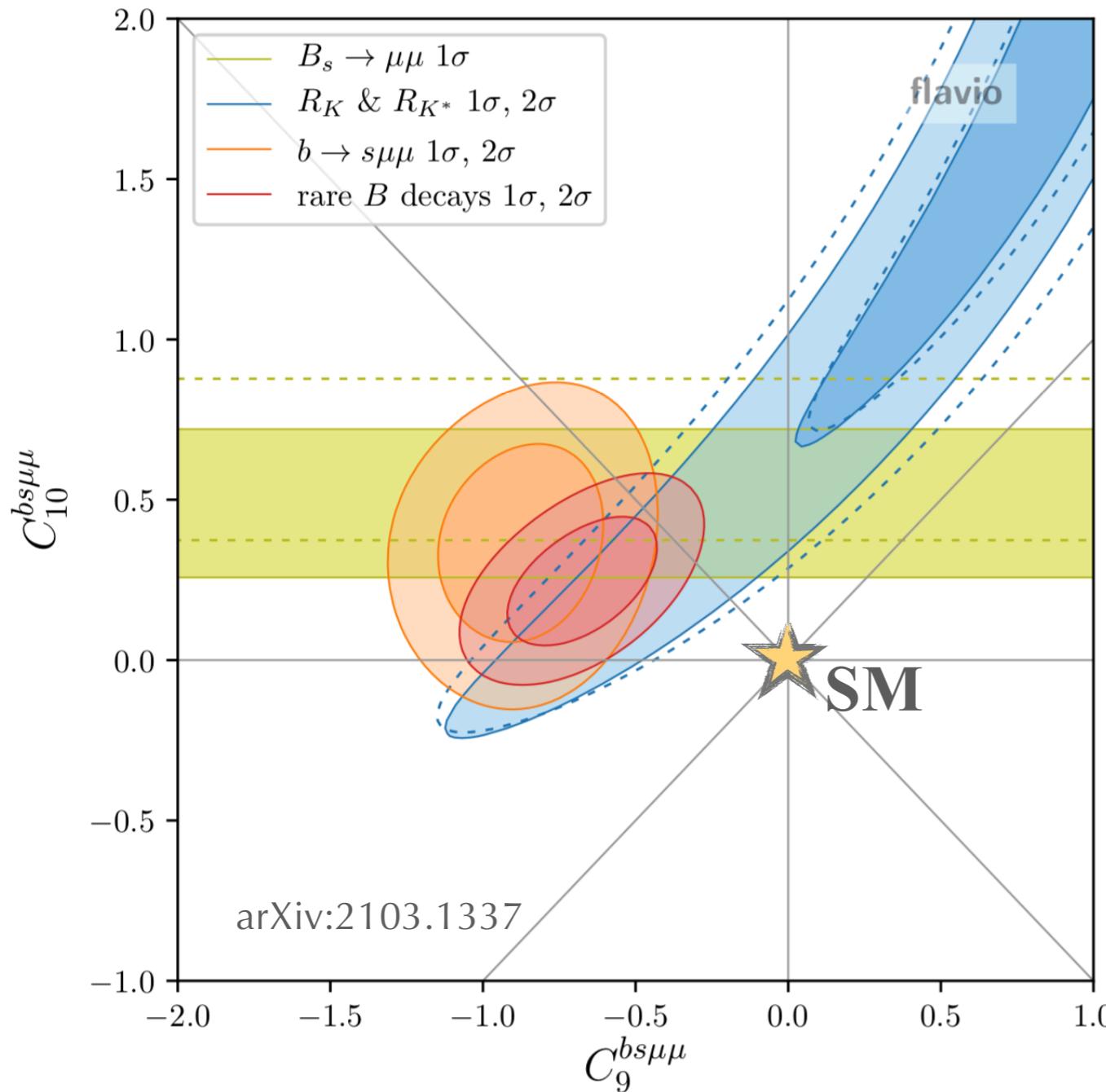


Overview of LFU tests



- $+R(pK)$ ($\sim 1\sigma$ below SM) J. High Energ. Phys. 2020, 40 (2020)
- Other tests in pipeline from LHCb ($R(\phi)$, $R(K\pi\pi)$, $R(K^{*0})$ update)

Global fits to experimental observables

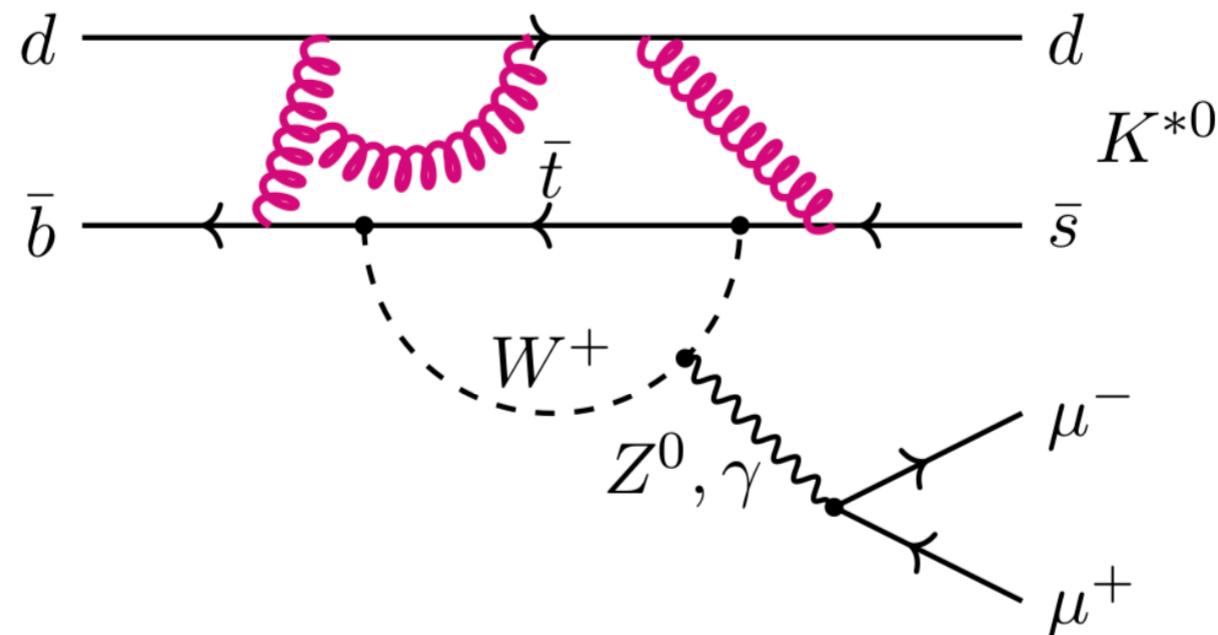


Combine across different types of $b \rightarrow s\ell\ell$ experimental observables and fitting to underlying Wilson Coefficients

Significance with SM depends on WC fit, between 4-6 σ

Challenges for $b \rightarrow s\ell\ell$ decays: QCD effects

- Branching fractions + angular analyses
- Theory predictions affected by **non-perturbative QCD uncertainties**

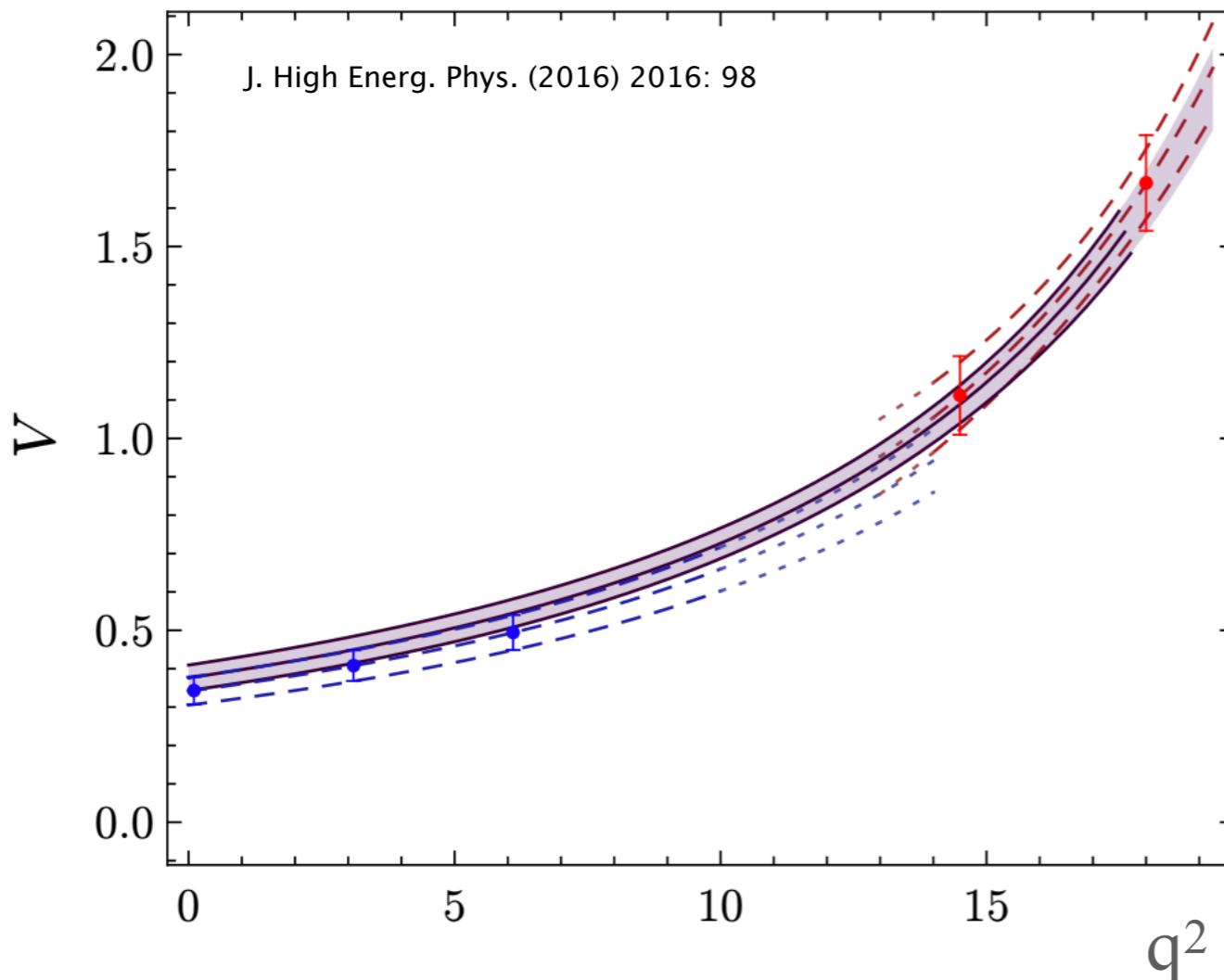


- LFU tests: not effected by QCD uncertainties
-

Challenges for $b \rightarrow s\ell\ell$ decays: QCD effects

► Branching fractions + angular analyses

$$A_{\perp L,R} = N\sqrt{2}\lambda^{1/2} \left[[(C_9^{\text{eff}} + C_9^{\text{eff}'}) \mp (C_{10}^{\text{eff}} + C_{10}^{\text{eff}'})] \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2} (C_7^{\text{eff}} + C_7^{\text{eff}'}) T_1(q^2) \right]$$



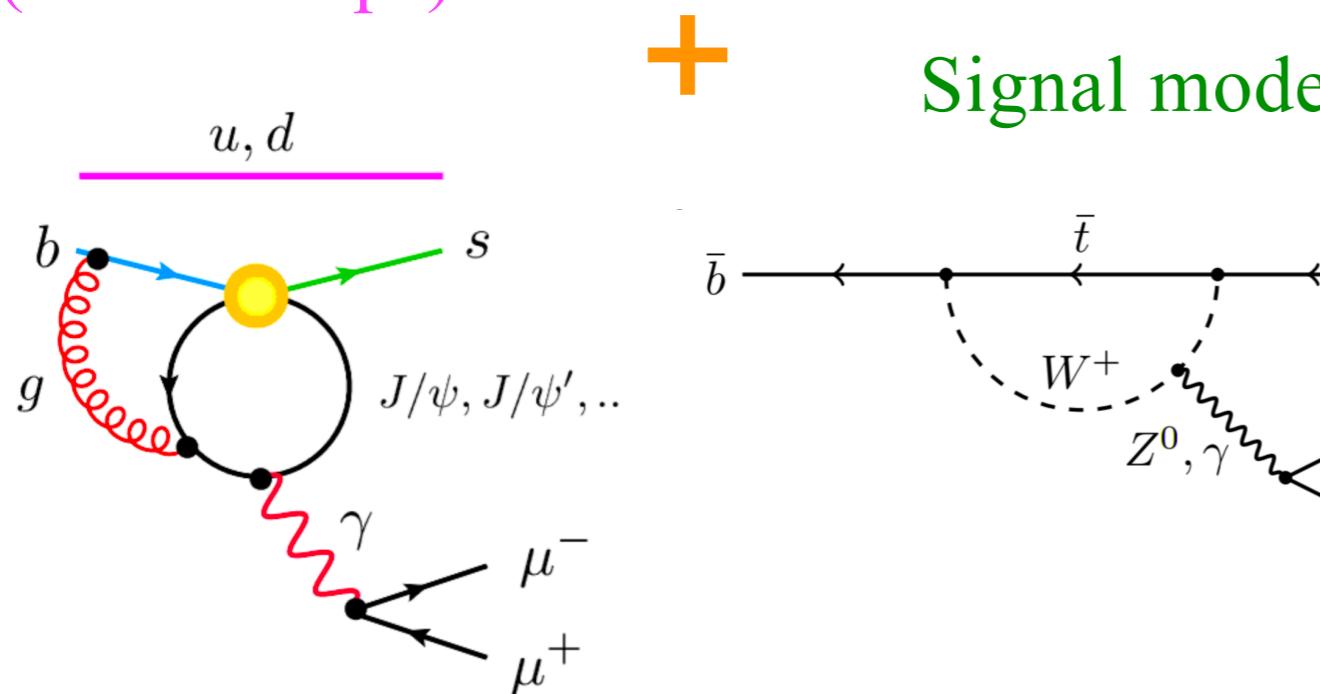
Form factors

- High q^2 , lattice QCD
- Low q^2 , Light Cone Sum Rules
- Generally well-understood with well parameterised errors

Challenges for $b \rightarrow s\ell\ell$ decays: QCD effects

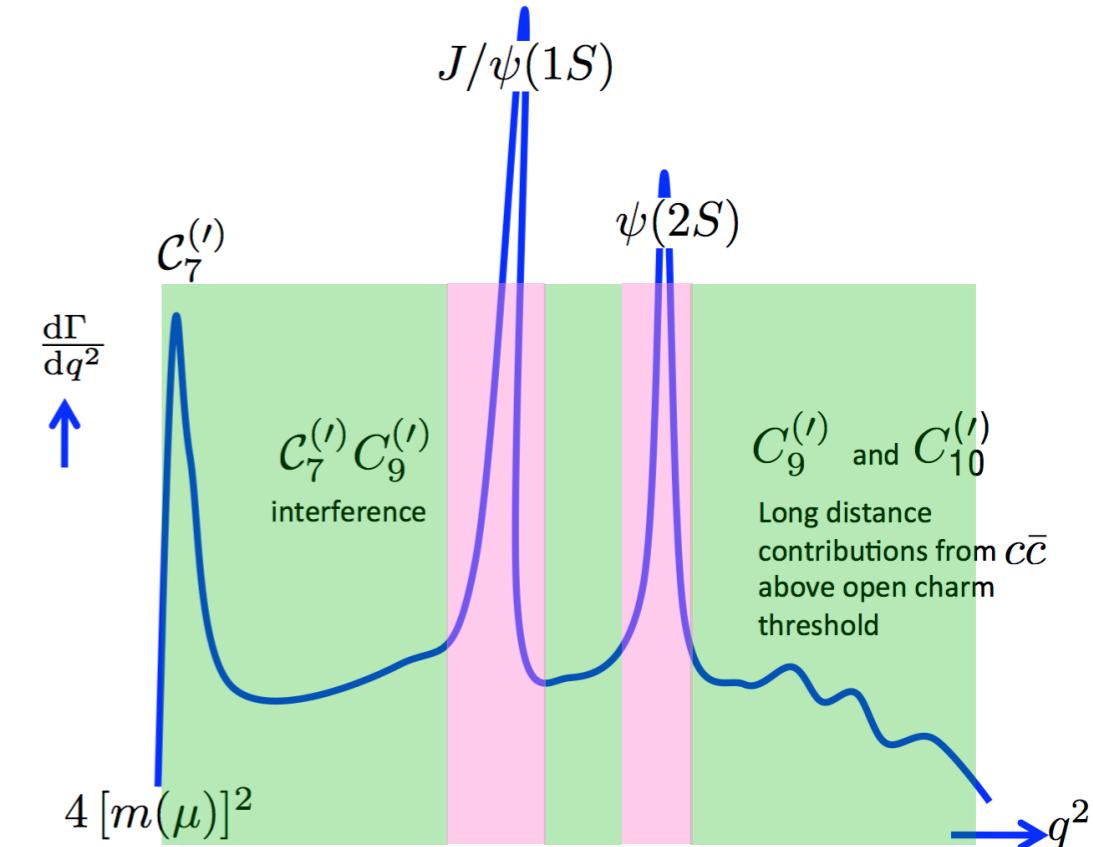
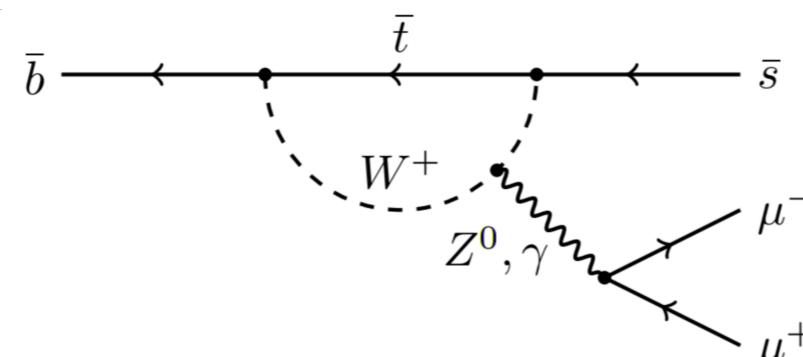
► Branching fractions + angular analyses

Non-local hadronic effects
(charm loops)



+

Signal mode



=
Long-distance effects that could affect signal mode even when outside the vetoed J/ψ region

Charm loops cannot be parameterised from first principle,
key problem for interpretation of non-LFU flavour anomalies

Extracting magnitude of charm-loops from data

- Directly fit for the under-lying Wilson Coefficients
- Two current approaches to parameterising non-local effects

$$\mathcal{A}_\perp^{\text{L,R}}(q^2) = N\sqrt{2\lambda} \left\{ (C_9 \mp C_{10}) \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2} C_l T_1(q^2) + \mathcal{G}_\perp(q^2) \right\}$$

1) “Isobar” model - fit $J/\psi, \psi(2S)$ (all q^2)

$$\mathcal{G}_p = \left[\sum_{i \in J/\psi, \psi(2S), \dots} \eta_p^i \mathcal{L}^i \right] \times FF_p$$

Form factors

\mathcal{L} = Rel. Breit Wigner or Dispersion relation

η_p = Mag. of resonance + **phase. rel. to penguin**

2) “Analyticity” fit up to $q^2 = 8 \text{ GeV}$

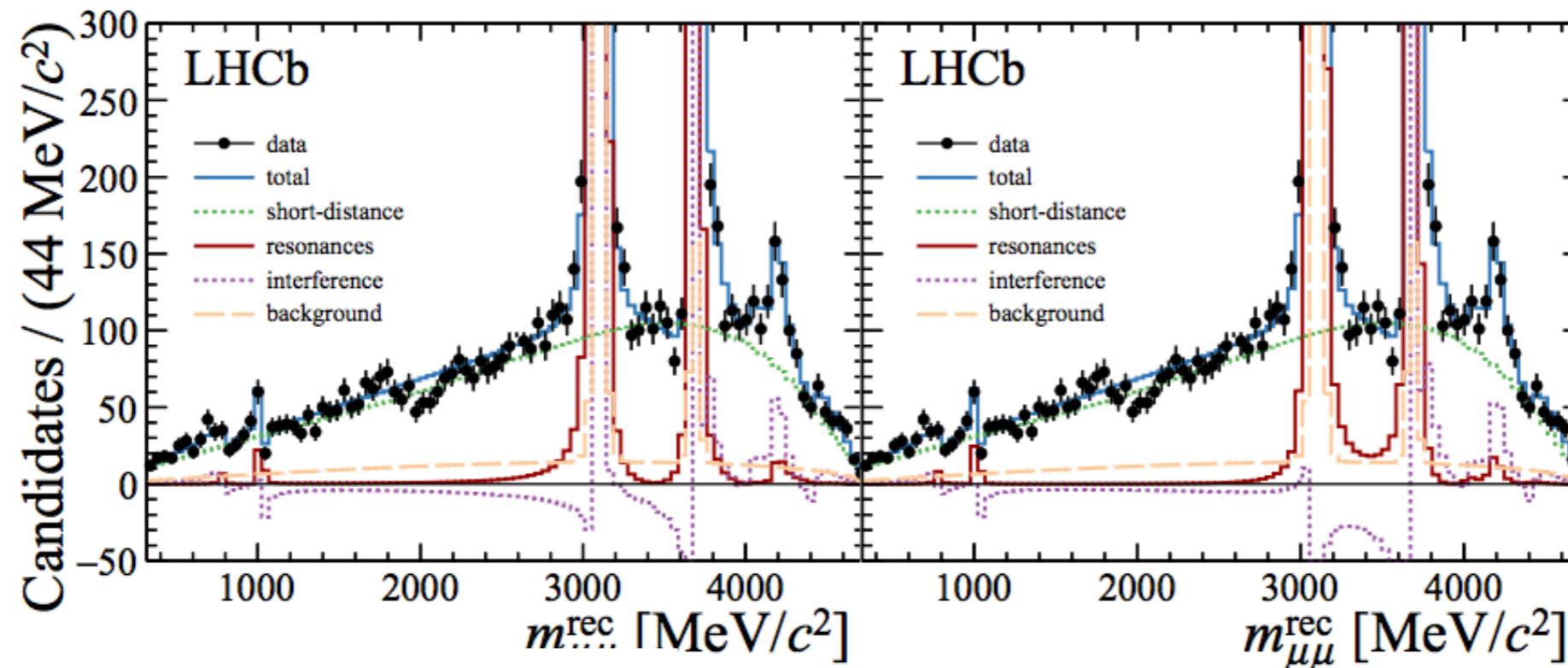
$$z = \text{re-parameterisation of } q^2$$
$$\mathcal{G}_p = \left[\sum_k \alpha_p^k z^k \right] \times FF_p$$

Fit (complex) polynomial terms α_p
+ constrain using theory info from
 $q^2 < 0$. Truncation = model dep.

Extracting magnitude of charm-loops from data $B^+ \rightarrow K^+ \mu^+ \mu^-$

Isobar approach

(EJPC 77 (2017) 161)



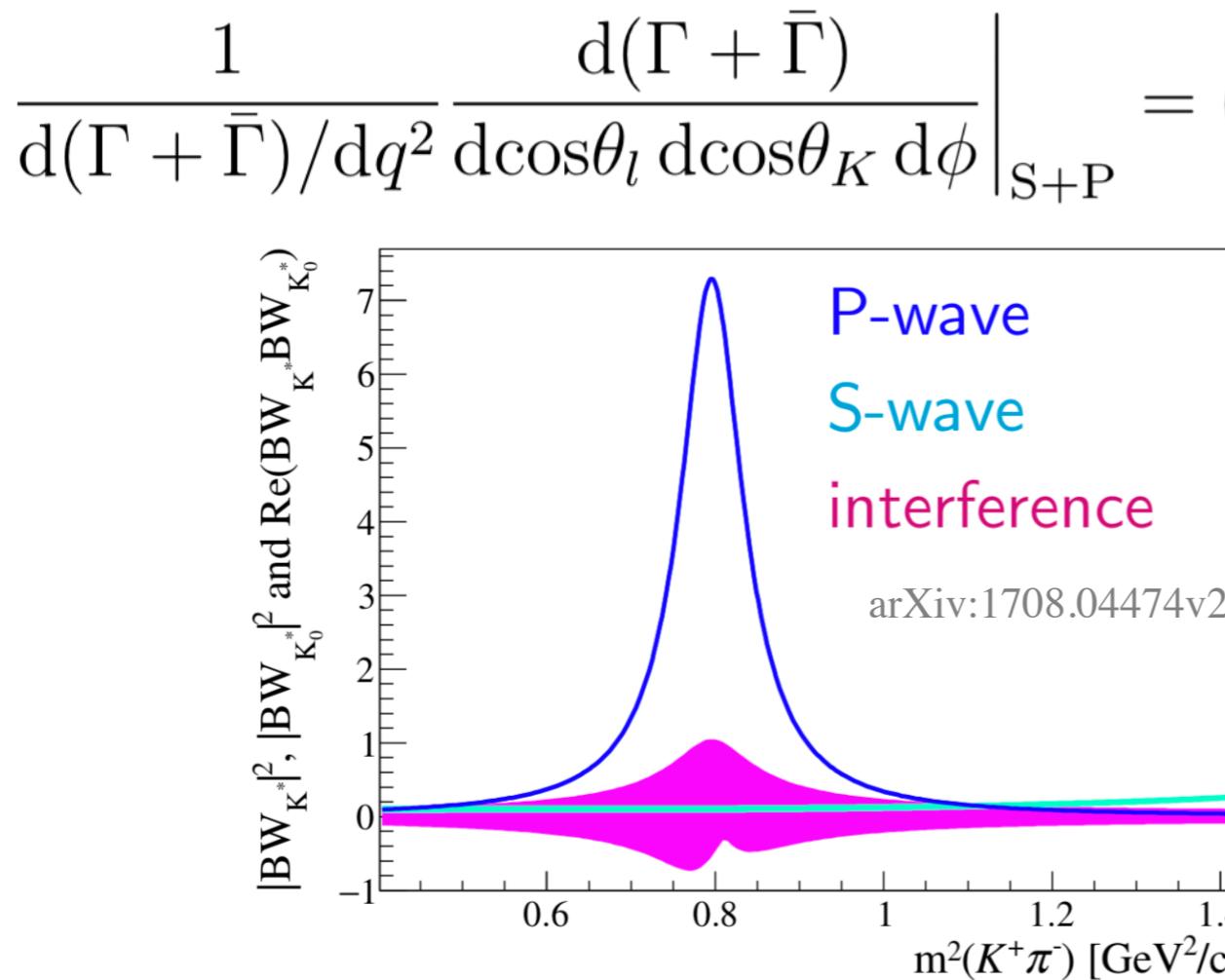
Resonance	J/ψ negative/ $\psi(2S)$ negative	
	Phase [rad]	Branching fraction
$\rho(770)$	-0.35 ± 0.54	$(1.71 \pm 0.25) \times 10^{-10}$
$\omega(782)$	0.26 ± 0.39	$(4.93 \pm 0.59) \times 10^{-10}$
$\phi(1020)$	0.47 ± 0.39	$(2.53 \pm 0.26) \times 10^{-9}$
J/ψ	-1.66 ± 0.05	-
$\psi(2S)$	-1.93 ± 0.10	$(4.64 \pm 0.20) \times 10^{-6}$
$\psi(3770)$	-2.13 ± 0.42	$(1.38 \pm 0.54) \times 10^{-9}$
$\psi(4040)$	-2.52 ± 0.66	$(4.17 \pm 2.72) \times 10^{-10}$
$\psi(4160)$	-1.90 ± 0.64	$(2.61 \pm 0.84) \times 10^{-9}$
$\psi(4415)$	-2.52 ± 0.36	$(6.04 \pm 3.93) \times 10^{-10}$

Four results from ambiguity in sign of $J/\psi, \psi(2S)$ phase

J/ψ phase relative to penguin found to be close to $\pm\pi/2$, minimal interference

Challenges for $b \rightarrow s\ell\ell$ analyses: S-wave contributions

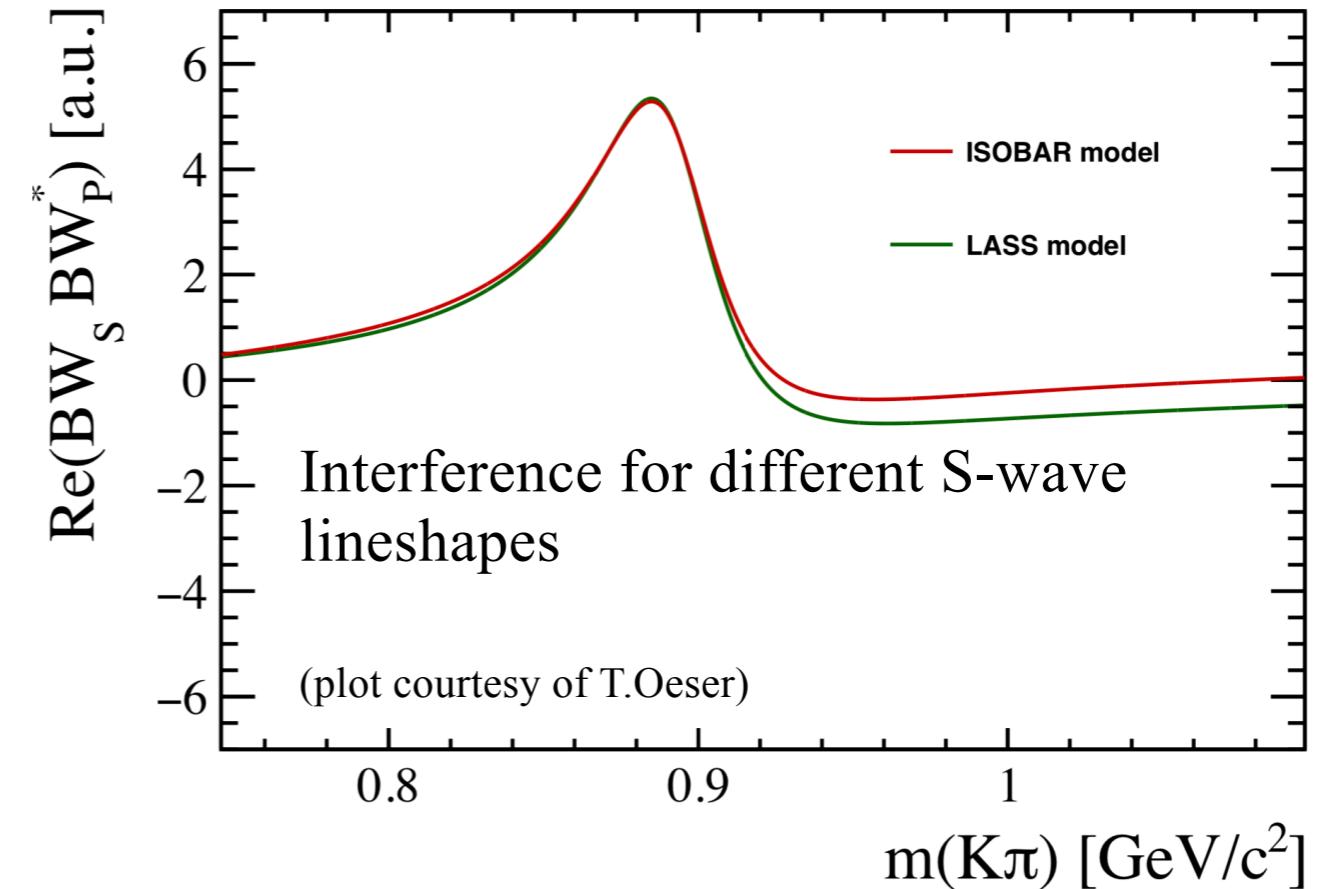
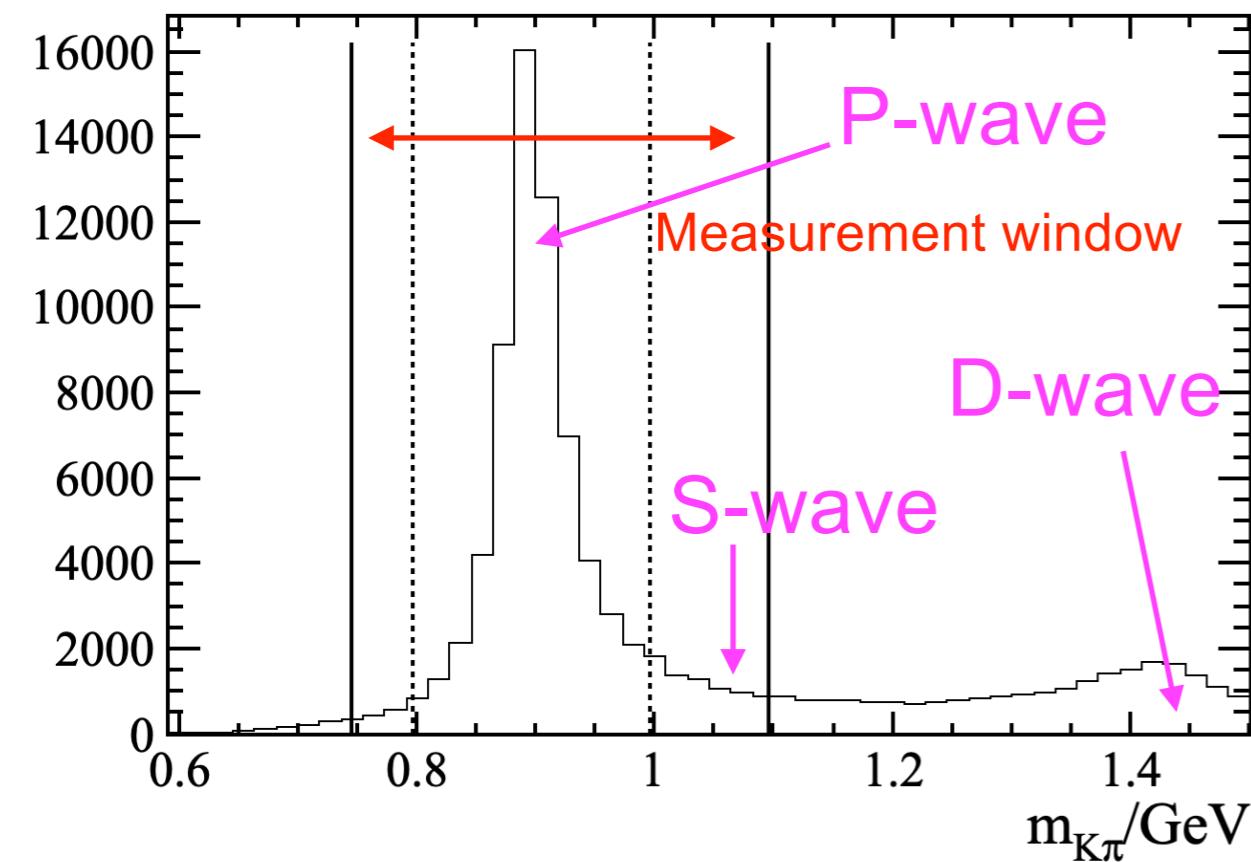
- Analyses involving intermediate vector mesons, such as $B^0 \rightarrow K^{*0}(\rightarrow K^+ \pi^-) \mu^+ \mu^-$, also have to deal with spin-0 (S-wave) $K\pi$ resonances



$$\begin{aligned} & \left. \frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d(\Gamma + \bar{\Gamma})}{dcos\theta_l \, dcos\theta_K \, d\phi} \right|_P \\ & + \frac{3}{16\pi} [F_S \sin^2 \theta_l + S_{S1} \sin^2 \theta_l \cos \theta_K \\ & + S_{S2} \sin 2\theta_l \sin \theta_K \cos \phi \\ & + S_{S3} \sin \theta_l \sin \theta_K \cos \phi \\ & + S_{S4} \sin \theta_l \sin \theta_K \sin \phi \\ & + S_{S5} \sin 2\theta_l \sin \theta_K \sin \phi]. \end{aligned}$$

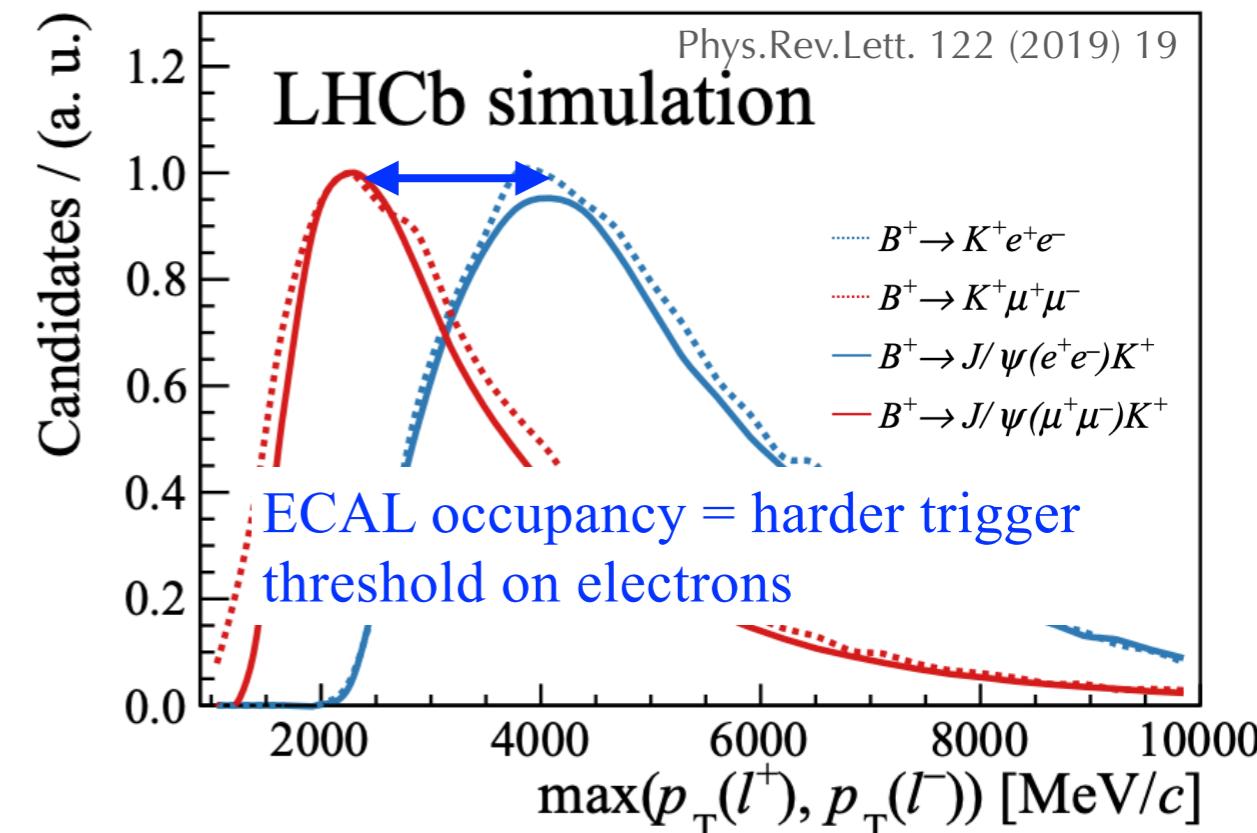
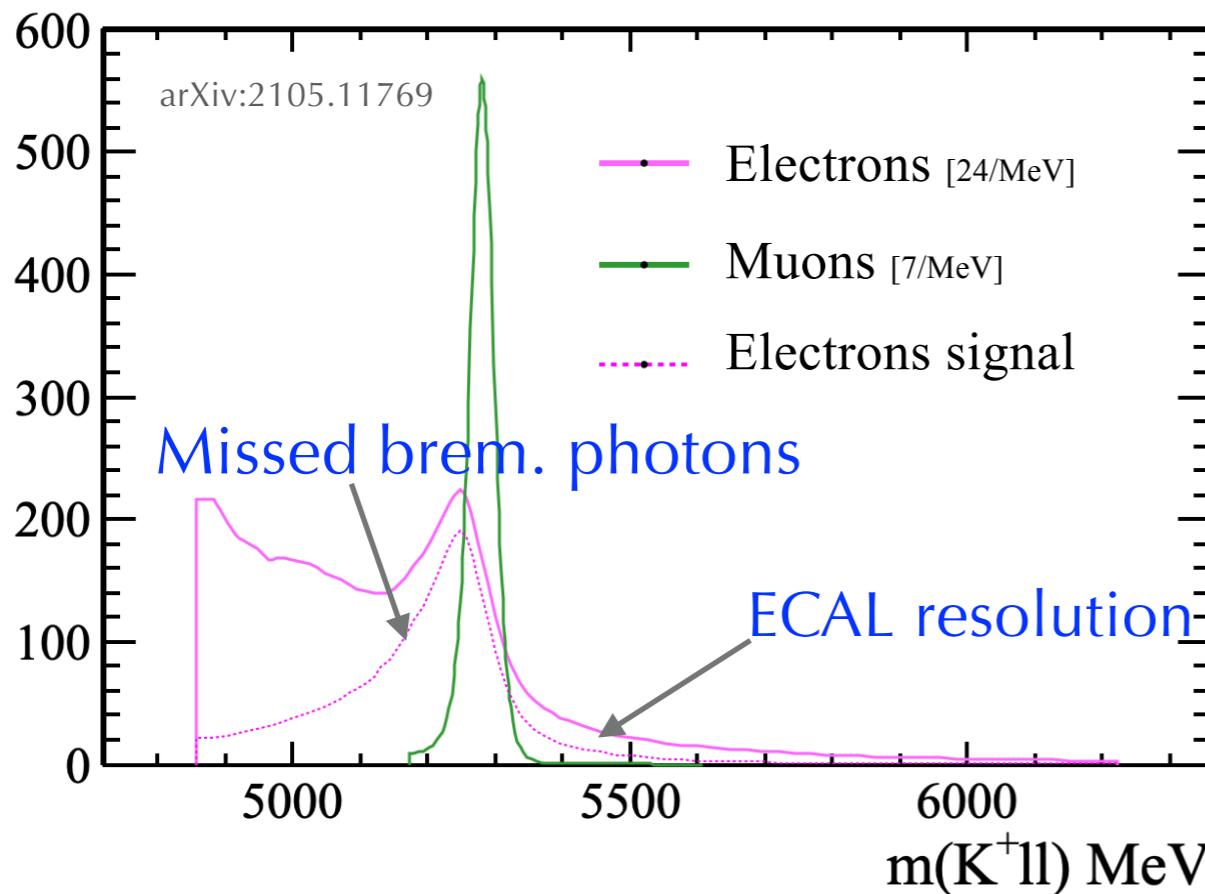
Challenges for $b \rightarrow s\ell\ell$ analyses: S-wave contributions

- Can fit for S-wave and S-P wave interference, better separation from $m(K\pi)$ line shape
- However, lack of precise knowledge of S-wave lineshape dominates uncertainty on interference observables



Challenges for $b \rightarrow s\ell\ell$ analyses: electrons

- Lighter electron mass = more Bremsstrahlung emitted + ECAL occupancy is high, particular challenge for LHCb



- Belle II, similar resolution between muons and electrons
- LHCb, Run 3 should see improve trigger performance for electrons

Conclusions

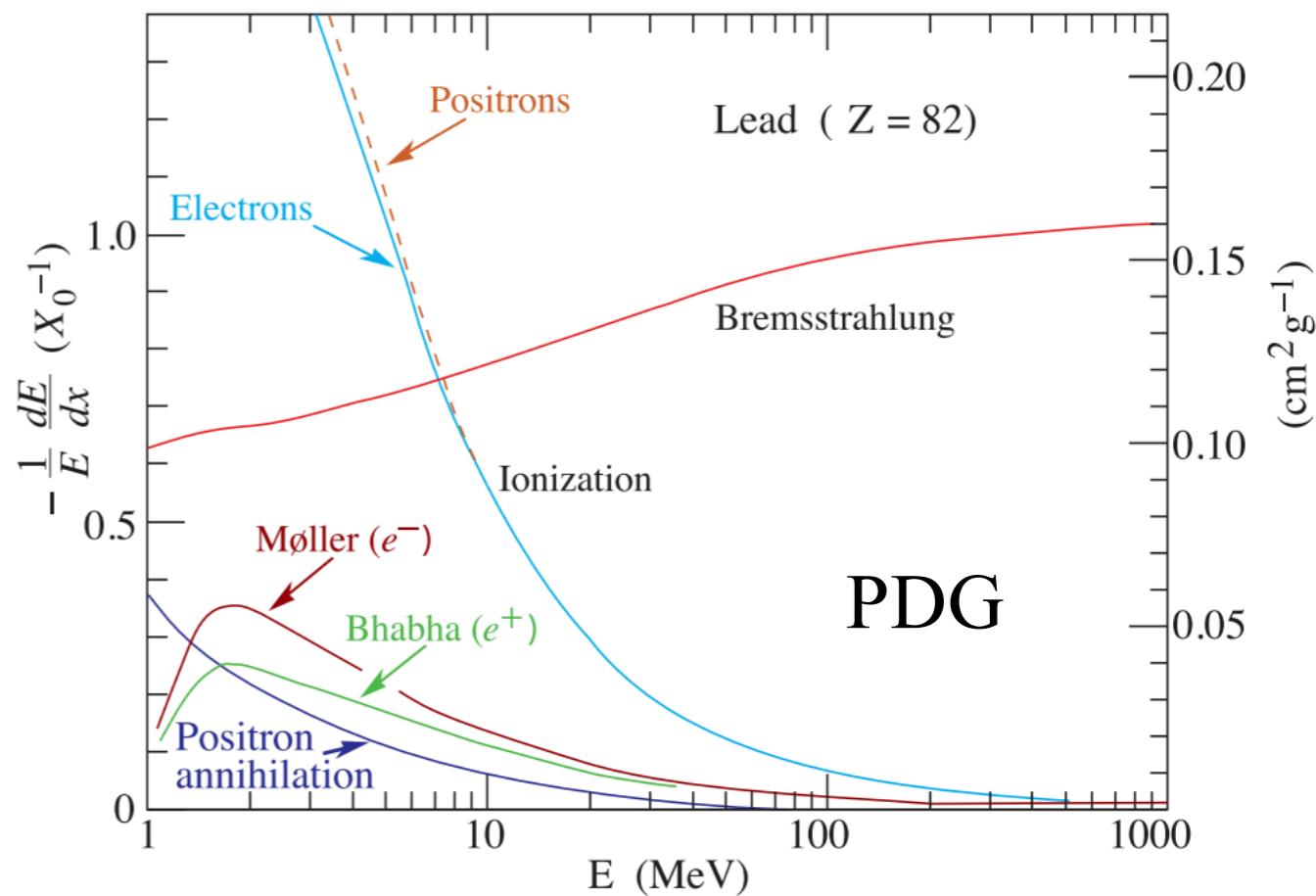
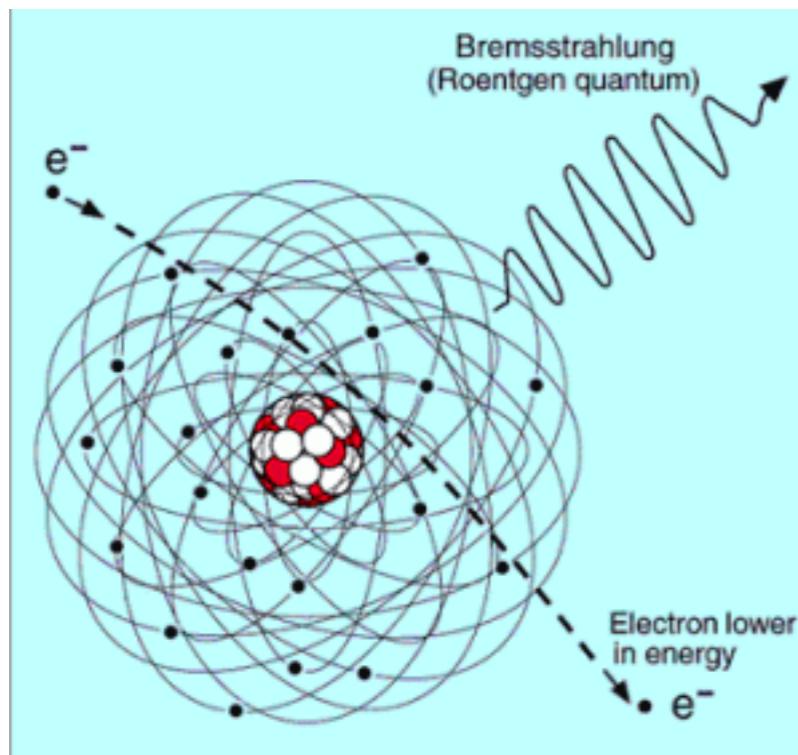
- Coherent pattern of tensions observed between SM predictions and measured observables
- Interpretation of angular analyses and branching fraction measurements for $b \rightarrow s\ell\ell$ modes requires better understanding of non-local hadronic effects
- State-of-the-art methods use data-driven approaches to measured non-local effects
- Complete analysis of Run 1 + 2 data for all observables, + Run 3 data, will help clarify picture
- More results from Belle II will also be central going forward

66

Back-up slides

Worse resolution: bremsstrahlung radiation

- Particles interact with the detector material, losing energy via different types of radiation
- $E(e) \gtrsim 10\text{GeV}$ within LHCb environment
- Radiation loss overwhelming due to Bremsstrahlung

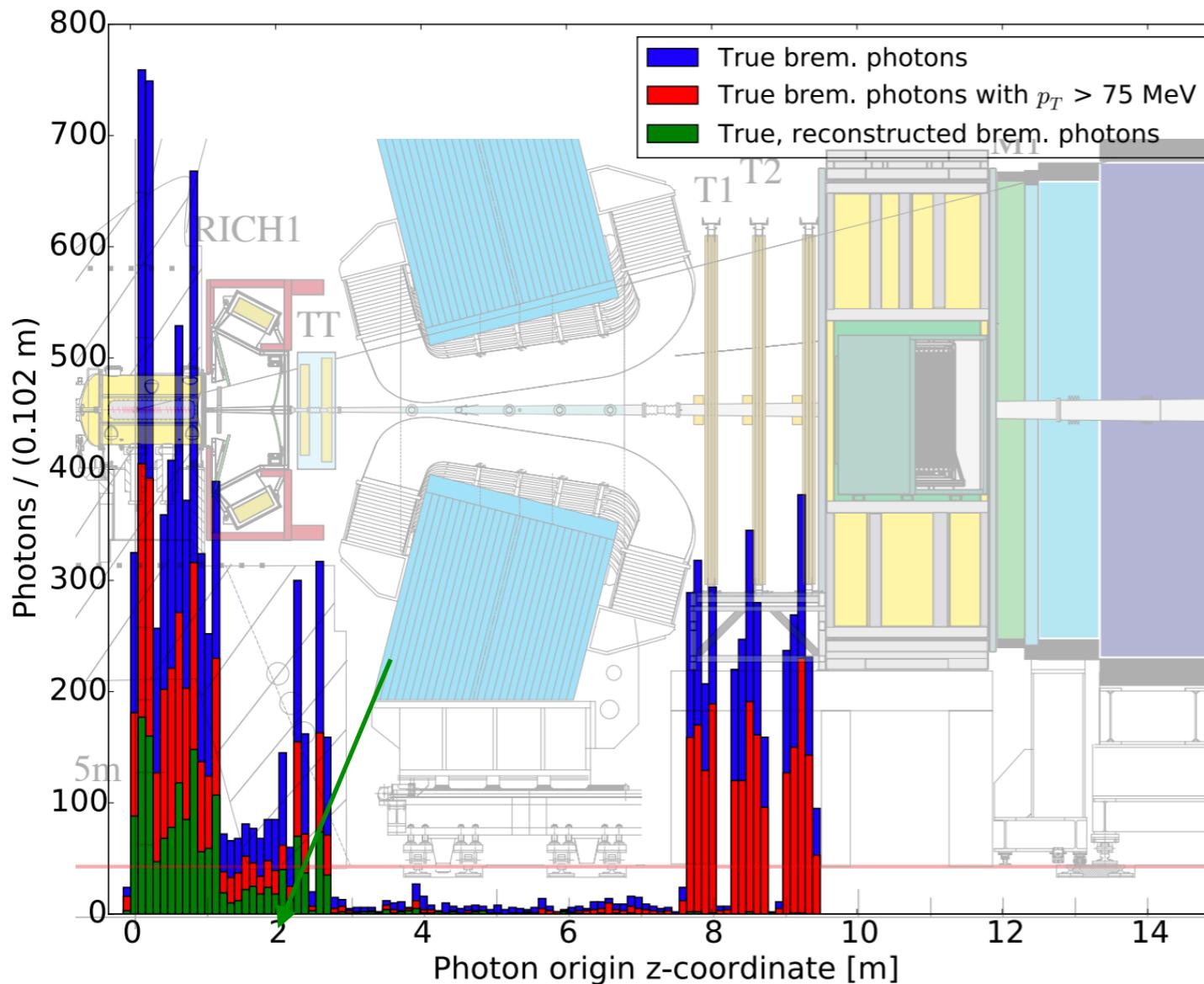


Probability of brem. emission $\propto 1/m^2$
 $m^{-2}(\mu)/m^{-2}(e) \sim 0.00002$

Mainly just issue for electrons due to light mass

Bremsstrahlung radiation

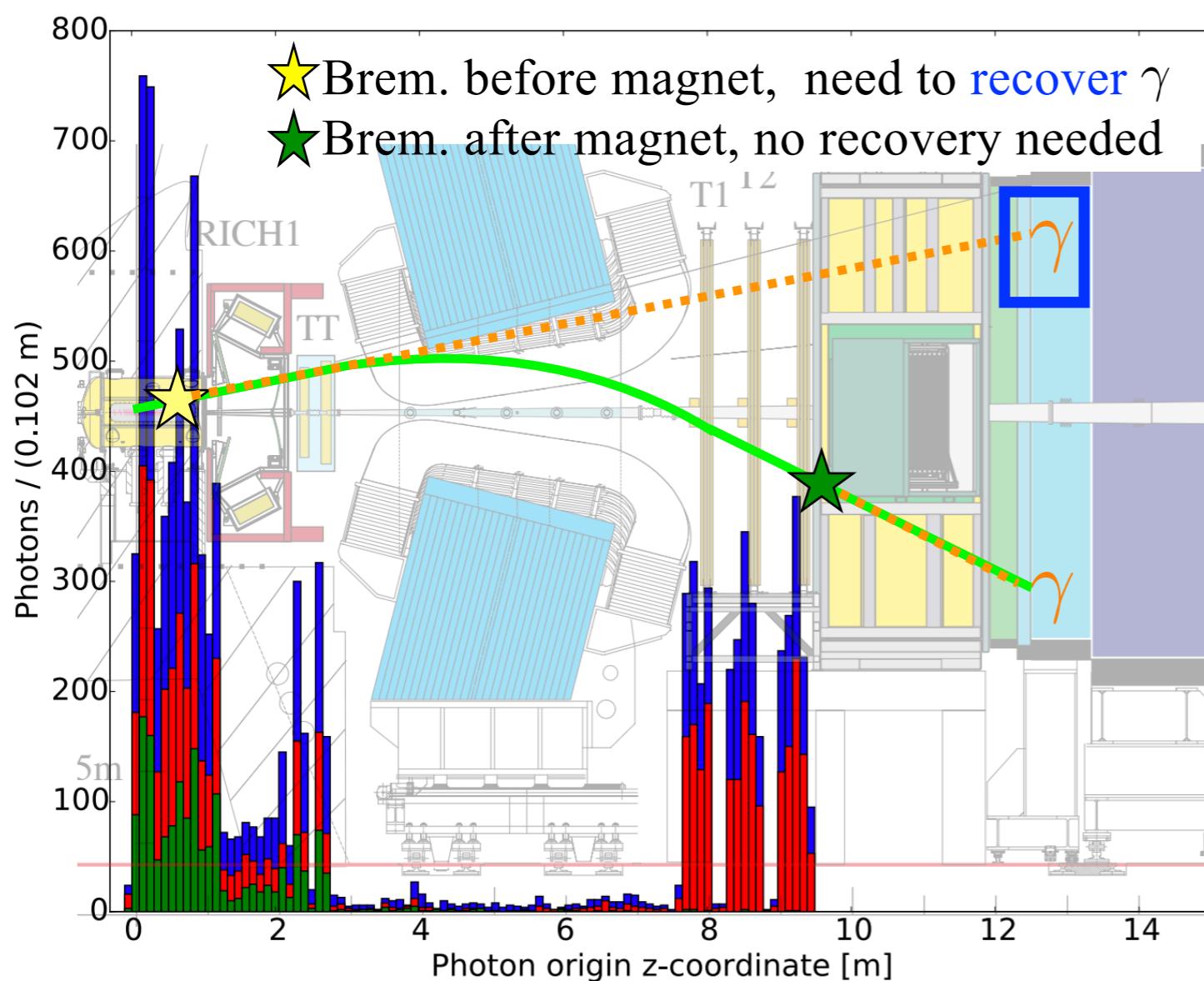
Daniel Berninghoff masters thesis, U. Dortmund



- Tracks only brem. where there is material
- In LHCb this means mainly before and after the magnet
- Note radiation due to bending in magnetic field (synchrotron radiation) is negligible

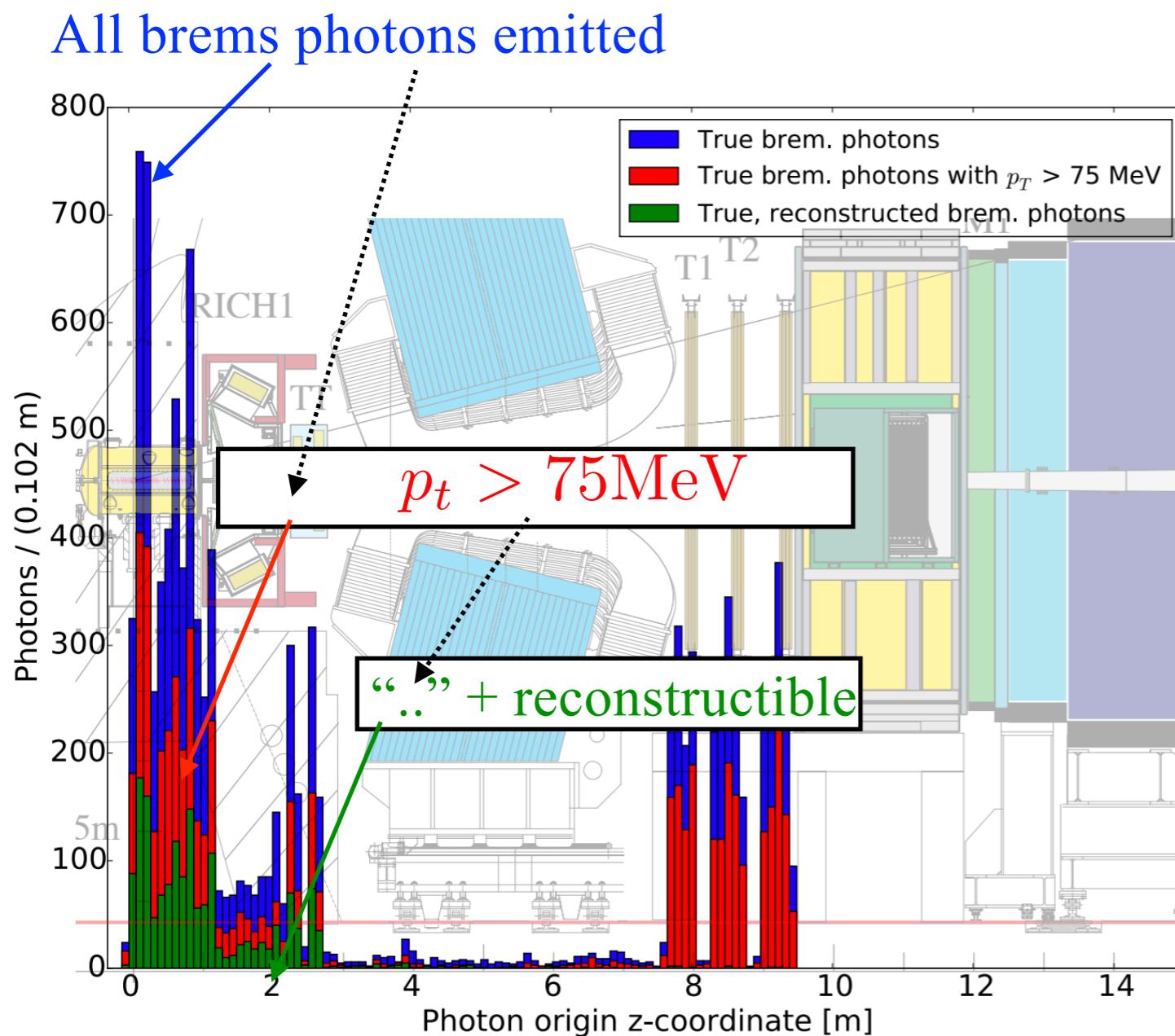
Bremsstrahlung recovery

Daniel Berninghoff masters thesis, U. Dortmund



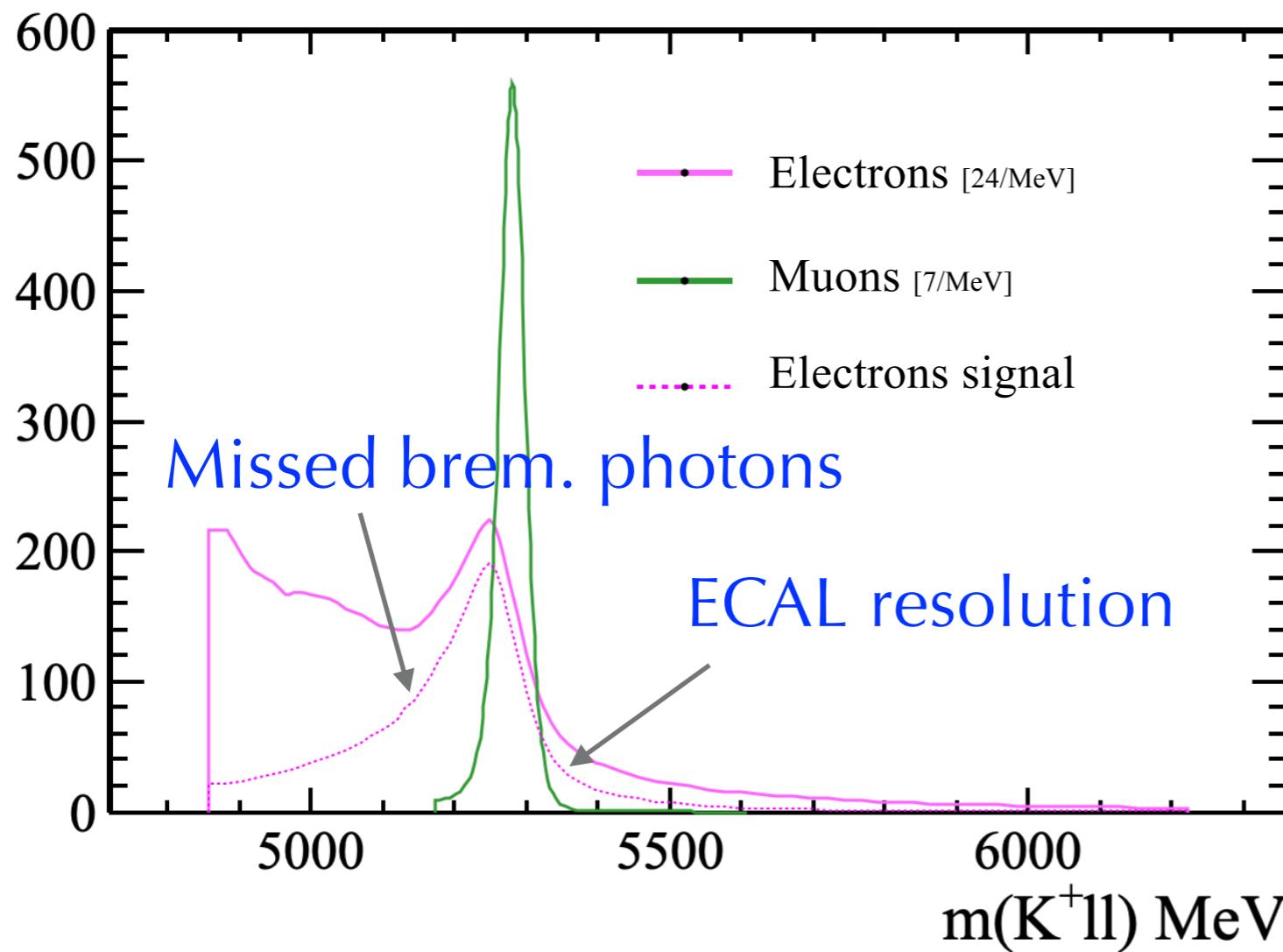
- Add ECAL clusters in **window** with energy deposits
 $E_t > 75 \text{ MeV}$ not associated with a charged track
- Issues:
 - Resolution of ECAL worse than that of tracker
 - Many photons are missed as too soft or not in ECAL acceptance
 - Some clusters incorrectly assigned to track

Bremsstrahlung recovery



- Add ECAL clusters in **window** with energy deposits
 $E_t > 75 \text{ MeV}$ not associated with a charged track
 - Issues:
 - Resolution of ECAL worse than that of tracker
 - Many photons are missed as too soft or not in ECAL acceptance
 - Some clusters incorrectly assigned to track

Bremsstrahlung recovery

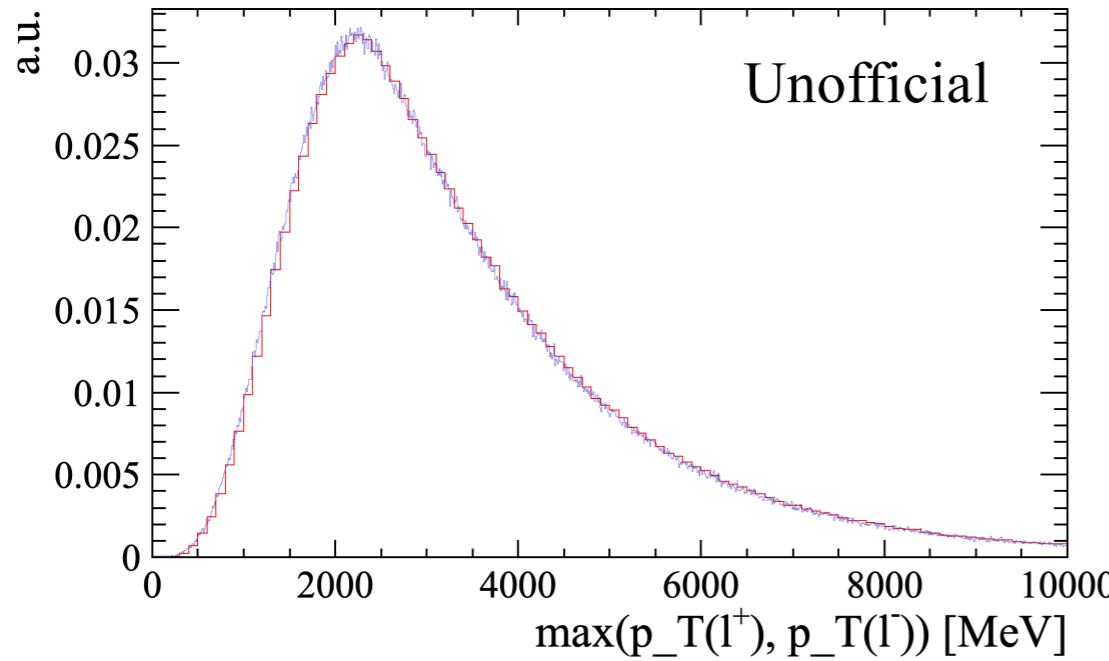


- Add ECAL clusters in [window](#) with energy deposits $E_t > 75 \text{ MeV}$ not associated with a charged track
- Issues:
 - [Resolution of ECAL worse than that of tracker](#)
 - [Many photons are missed as too soft or not in ECAL acceptance](#)
 - Some clusters incorrectly assigned to track

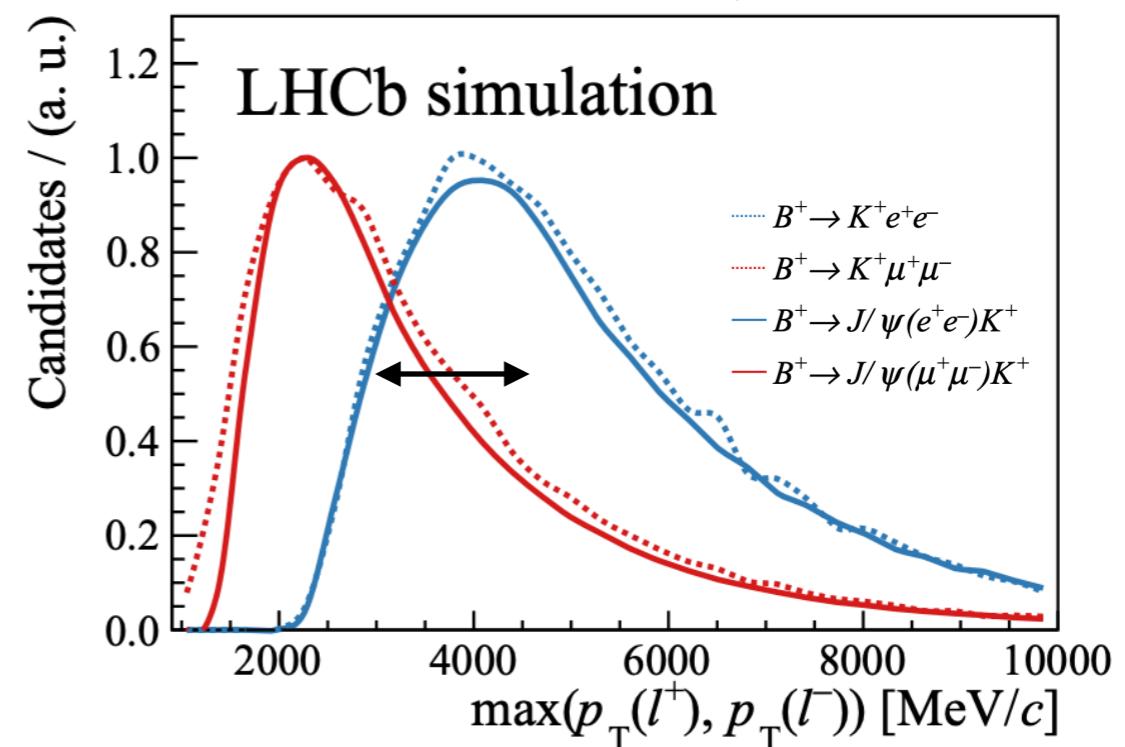
Lower yields: trigger+acceptance

- Electrons are triggered via the signatures they leave in the ECAL
- High occupancy in the ECAL-> need higher trigger threshold to reduce throughput to acceptable level, **~40% of muon efficiency**

Phys.Rev.Lett. 122 (2019) 19



Before passing through detector

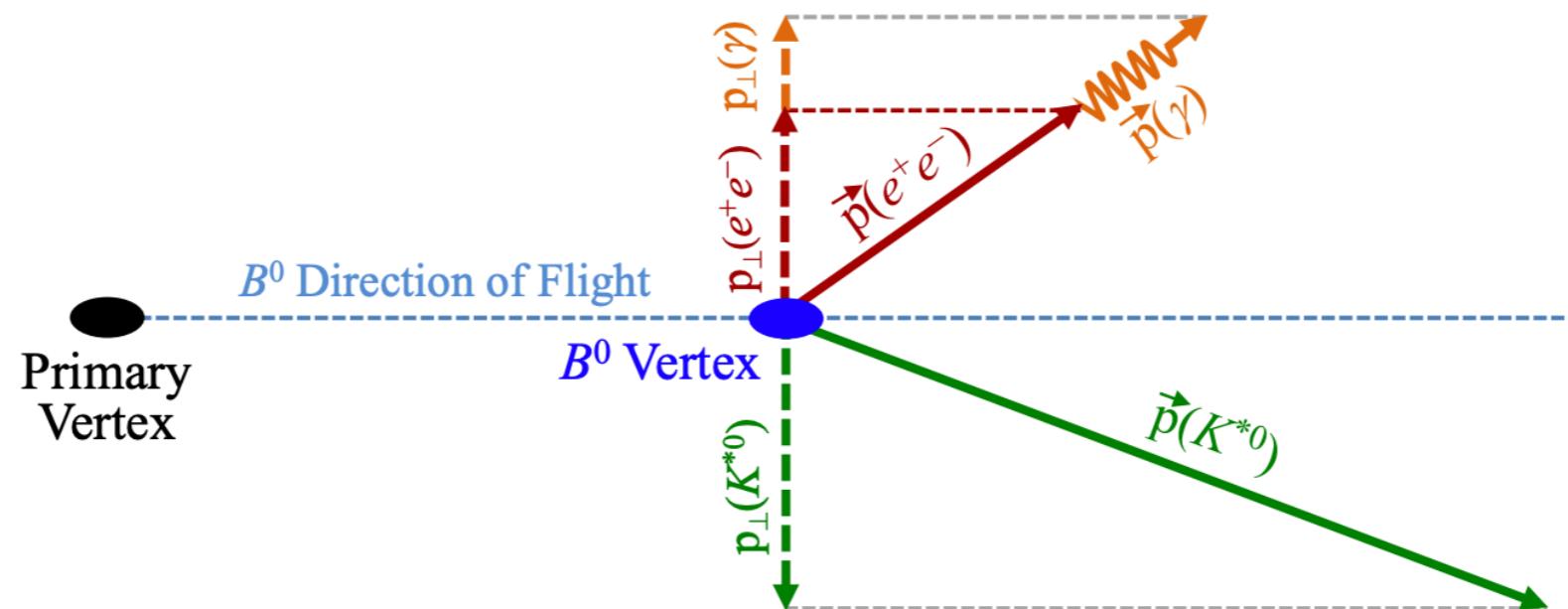


After trigger + selection

- Additionally, electrons loose energy through brem., increasing chance off being bent of acceptance by magnet

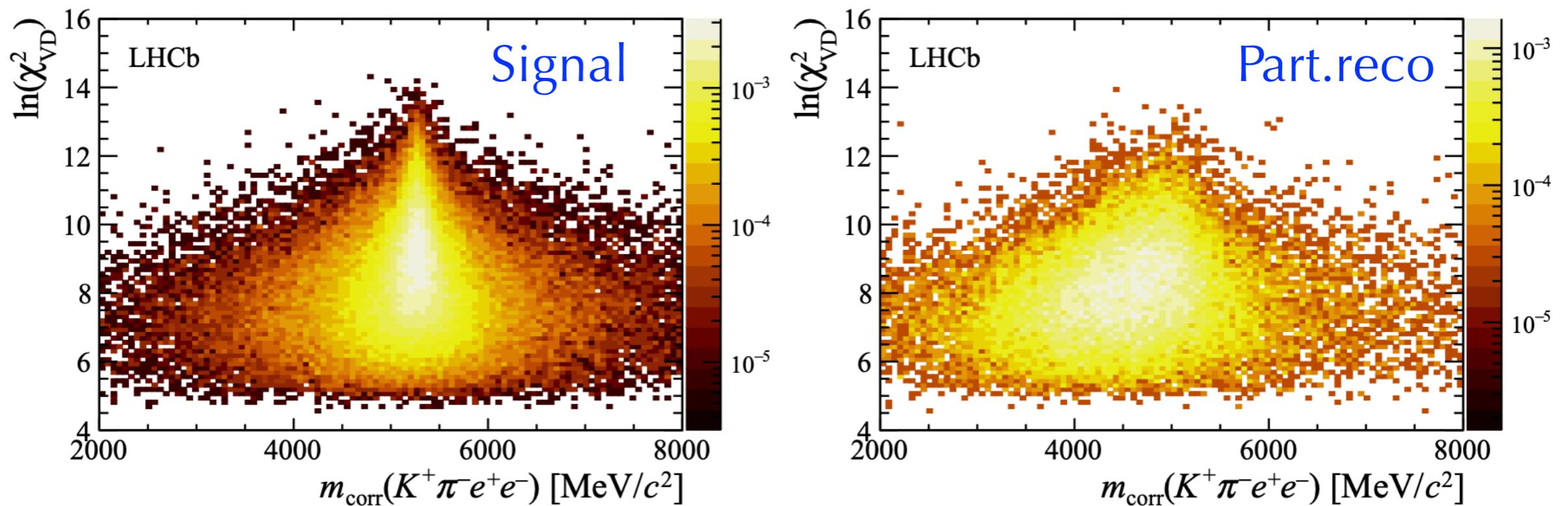
Dealing with electrons in analysis: resolution

- Use additional kinematic decay info. to reduce background
- For $B \rightarrow X J/\psi(\rightarrow ee)$ control channels can use fact that we know $m(ee)$ has to be consistent with $m(J/\psi)$
- For b->see modes, assume any imbalance in pt between hadron and electron system due to missing pt in electron system (i.e. missed brem.)



Dealing with electrons in analysis: resolution

- Since backgrounds where a final state track has been missed (partially reconstructed backgrounds) are generally missing energy from the hadronic system, distinctive distributions between signal and background

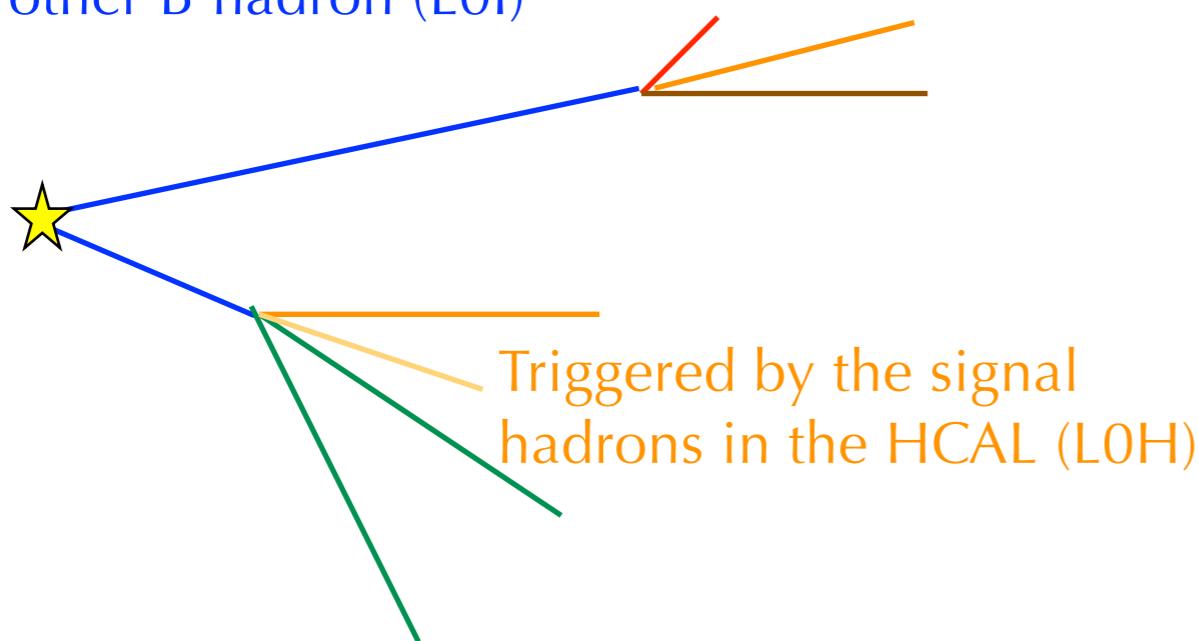


[JHEP 08 \(2017\) 055](#)

Dealing with electrons in analysis: trigger

- As electrons have poor trigger efficiency, generally consider 3 trigger categories for electron candidates
-

Triggered by any track from the other B hadron (L0I)



Triggered by the signal electrons in the ECAL (LOE)

Most events still selected via ECAL trigger

[JHEP 08 \(2017\) 055](#)

	$B^0 \rightarrow K^{*0} \ell^+ \ell^-$	
	low- q^2	central- q^2
$\mu^+ \mu^-$	285 ± 18	353 ± 21
$e^+ e^-$ (L0E)	55 ± 9	67 ± 10
$e^+ e^-$ (L0H)	13 ± 5	19 ± 6
$e^+ e^-$ (L0I)	21 ± 5	25 ± 7

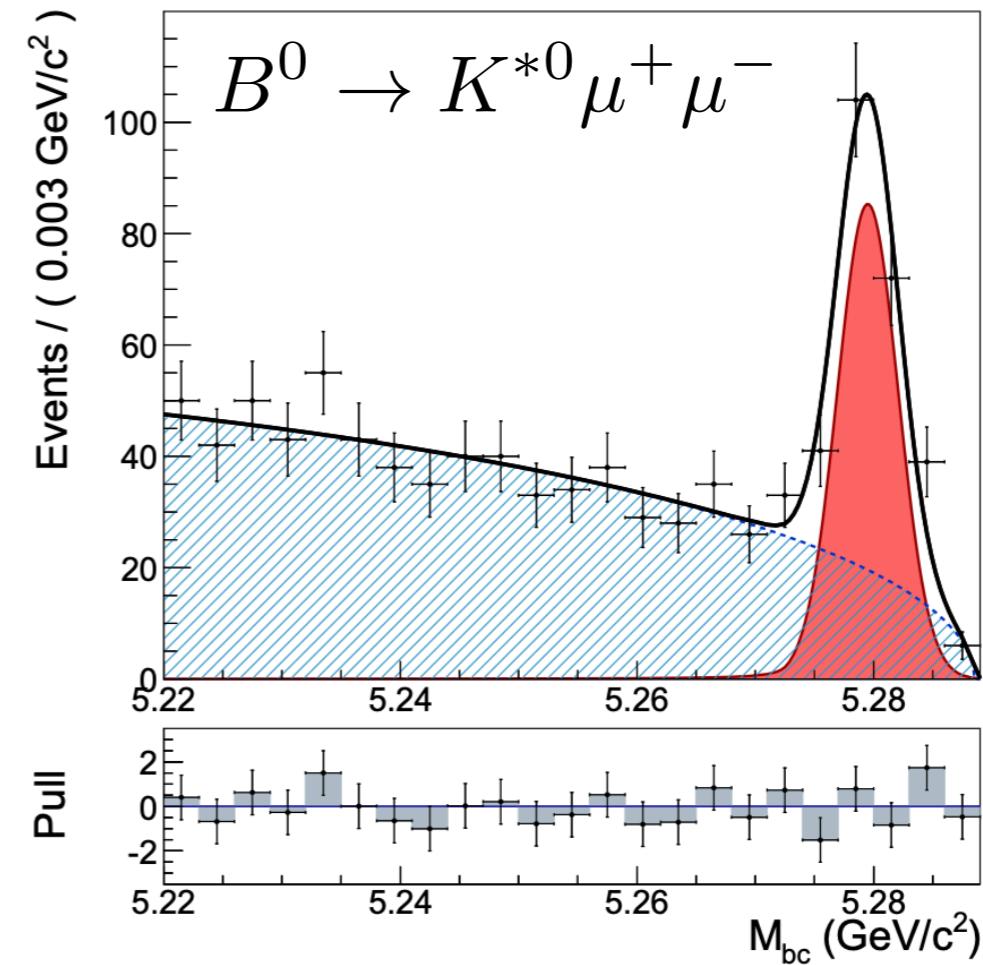
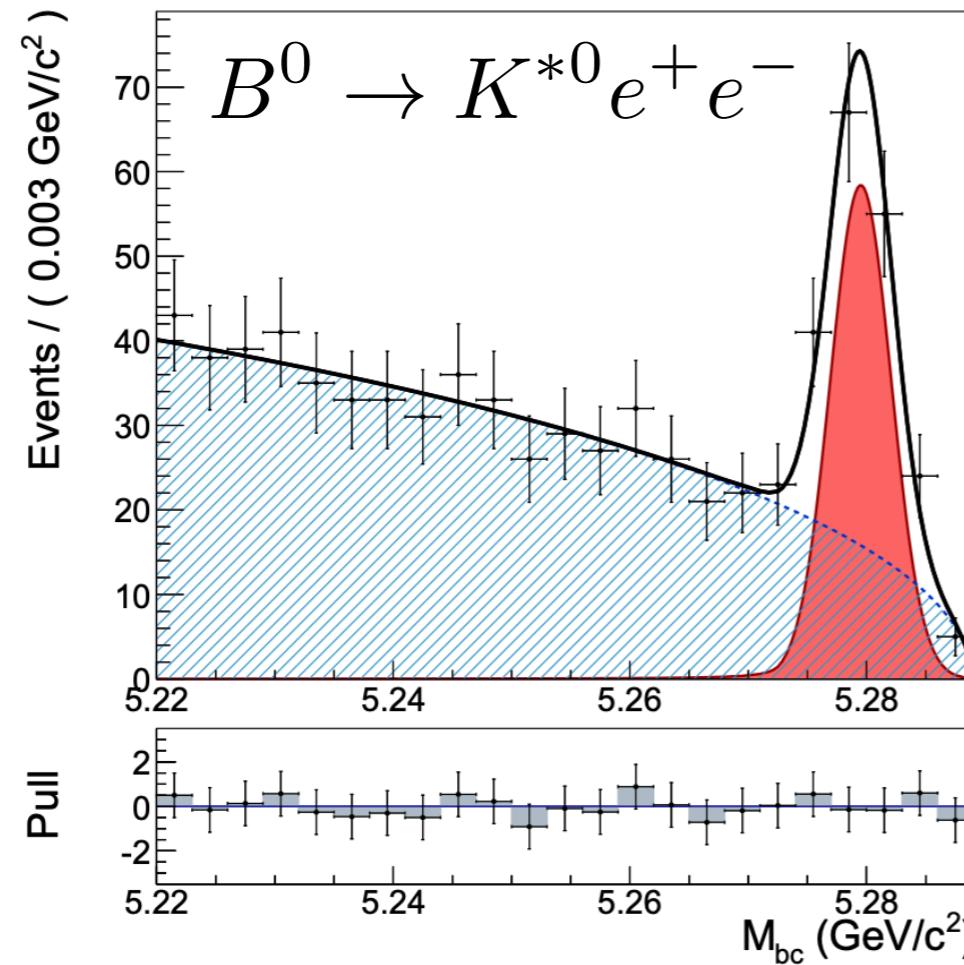
How well does Belle/Belle II perform for electrons?

- Belle has the advantage of knowing the beam energy, can construct the beam-energy constrained mass

$$M_{bc} = \sqrt{E_{beam}^{\star 2} - p_B^{\star 2}}$$

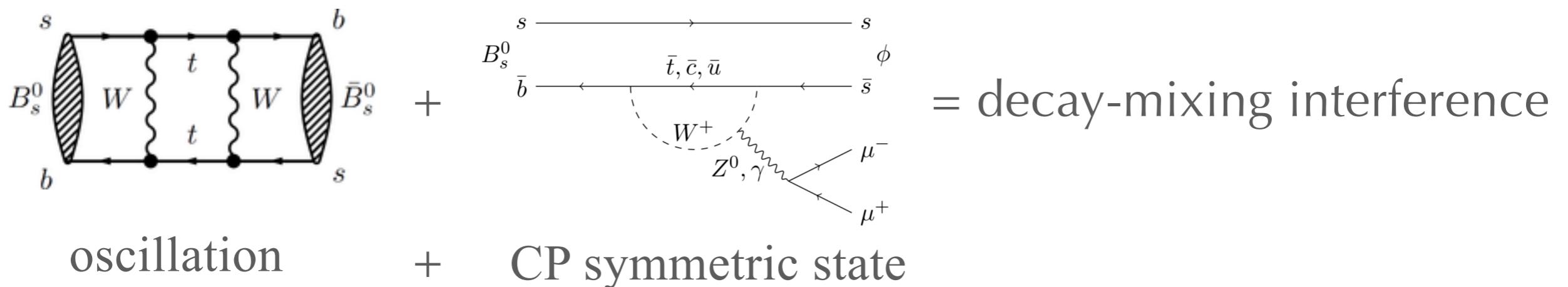
PRL 118,111801

Resolution very similar



Is there any other decay information we need?

- LFU and angular analyses can be performed as long as one has the four-momentum of each final-state candidate
- Additional information in the effective lifetime of the B meson also
- Doing a time-dependent analysis is fairly trivial
- However often want time-dependence to access decay-mixing interference **which requires flavour-tagging**



Flavour tagging $b \rightarrow s\mu^+\mu^-$ decays

Yields, $\epsilon_{tag} \equiv 5\%$	Run 1 observed		Run 3 expected	
	Full q^2	$1.1 < q^2 < 6.0$	Full q^2	$1.1 < q^2 < 6.0$
$B_s^0 \rightarrow \phi(1020)\mu^+\mu^-$	untagged 432	101	5230	1220
	tagged 22	5	262	60
$B_d^0 \rightarrow K_s\mu^+\mu^-$	untagged 176	70	2200	850
	tagged 9	4	110	43

- Observables dependent on interference between mixing and decay can only be accessed using flavour-tagging
- Tagged angular analysis possible by end of Run 3 (2025) in wider q^2 bins at LHCb, full lifetime + angular analysis still somewhat limited
- Effective tagging power at Belle II $\sim 30\%$ -> better sensitivity to CP-eigenstates, particularly from B^0 decays

What else can we expect from Run 3?

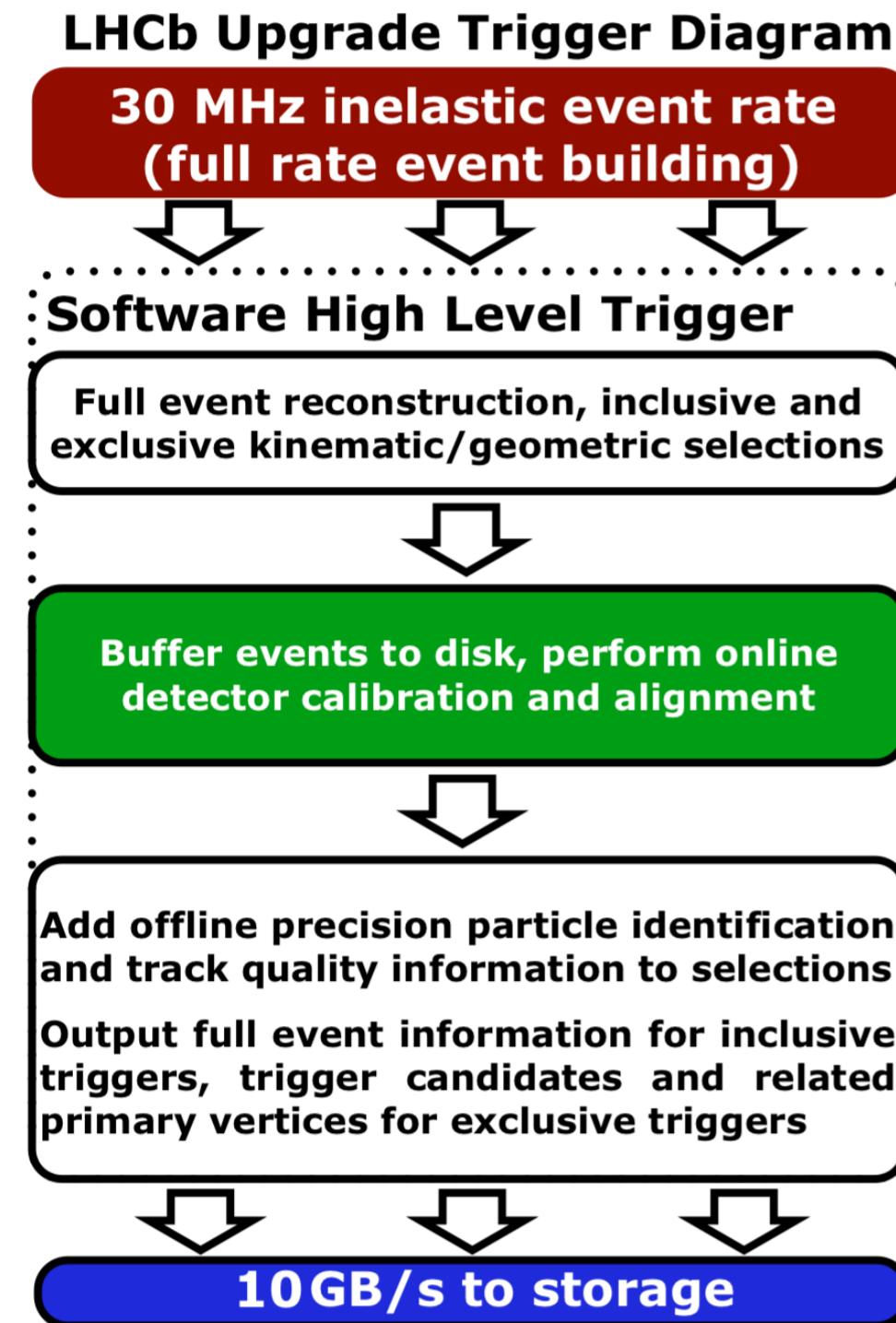
- We expect around 5 times the number of bb pairs by end of Run 3 compared to end of Run 2

Run 1 - Run 2	Long shutdown 2	Run 3	Long shutdown 3
$\mathcal{L} = 4 \times 10^{32} / cm^2 s$ $\int \mathcal{L} dt \approx 10 fb^{-1}$	LHCb Upgrade I	$\mathcal{L} = 2 \times 10^{33} / cm^2 s$	Incremental improvements to LHCb Upgrade I
2010 → 2018	2019	2020	2021

2022	2023	2024	2025	2026	2027
------	------	------	------	------	------

- Significant increase in the number of pp collisions per second -> different problems compared to Run 1+2
- The increase in luminosity in Run 3 means that 24% of all events with have a reconstructable $c\bar{c}$ pair and 2% have a reconstructable $b\bar{b}$ pair (!)

New trigger for Run 3



- Remove hardware trigger!
- Make decision with more event info, better efficiencies
- Implement the trigger entirely in software
- First-level software trigger (HLT1)
MVA based on inclusive one and two track selections
- Except output to first level trigger to be reduced to ~0.1 - 1 MHz

What does this mean for $b \rightarrow sll$ decays?

- The ECAL hardware trigger is currently the major issue for electron analyses
- Removing this bottleneck should increase trigger efficiency relative to the muon mode

Comput. Softw. Big Sci. 4 (2020) 1, 7

Signal	GEC	TIS -OR- TOS	TOS	GEC × TOS
$B^0 \rightarrow K^{*0} \mu^+ \mu^-$	88.9 ± 2.0	90.6 ± 2.0	88.8 ± 2.1	79.0 ± 2.6
$B^0 \rightarrow K^{*0} e^+ e^-$	84.2 ± 2.7	69.1 ± 3.8	61.7 ± 4.0	52.0 ± 3.8

GEC: Global Event Cut, TIS: Trigger Independent of Signal, TOS: Trigger on Signal

- From ~40% of muon mode currently to ~60% of muon mode

Some outlook plots for Run 3

- Expect around 2.5% statistical uncertainty on RK by end of Run 3
- Angular muon modes will also significantly increase precision

