Rare decays in LHCb

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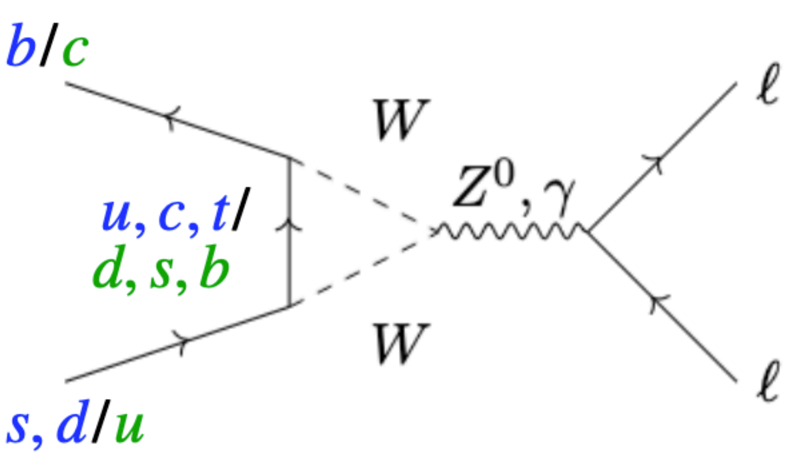
Roma

Flavour Changing Neutral Currents

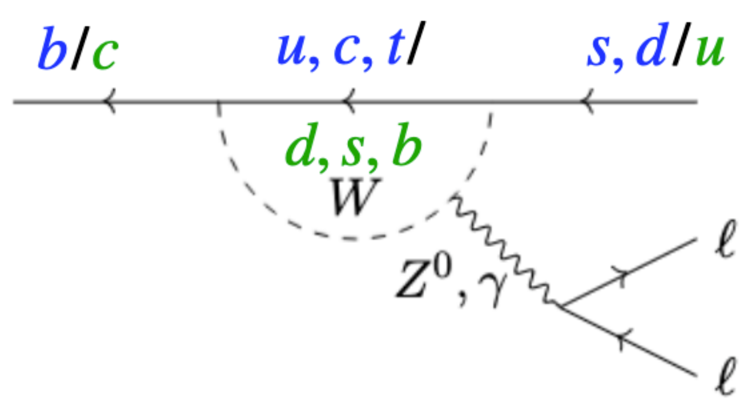
See talks from S. Maccolini and D. Moise
@ImplicationsWorkshop

- **FCNC** processes ($b \to s, d$ and $c \to u$) are forbidden at tree level in the SM
- In the SM they are allowed at loop level (penguin and box diagrams)
  - **Charm** decays further *suppressed* (GIM mechanism)

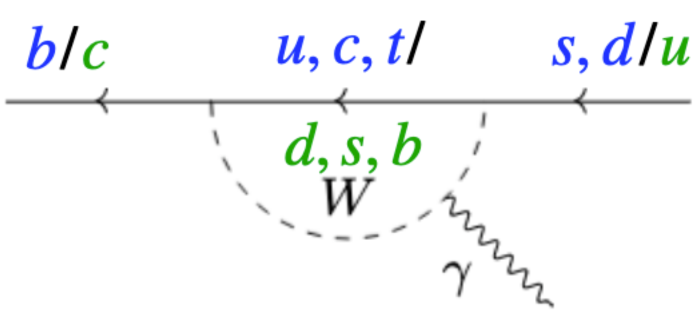
- **Sensitive to New Physics**: new heavy particles can significantly contribute and affect decay rates, angular distributions, and rate asymmetries



Leptonic



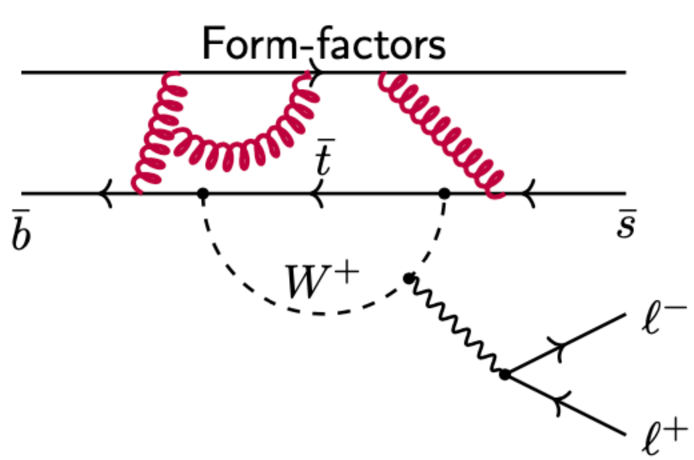
Semileptonic

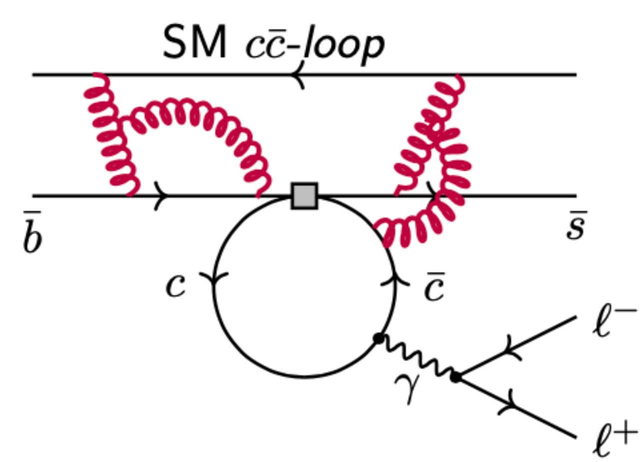


Radiative

QCD challenges

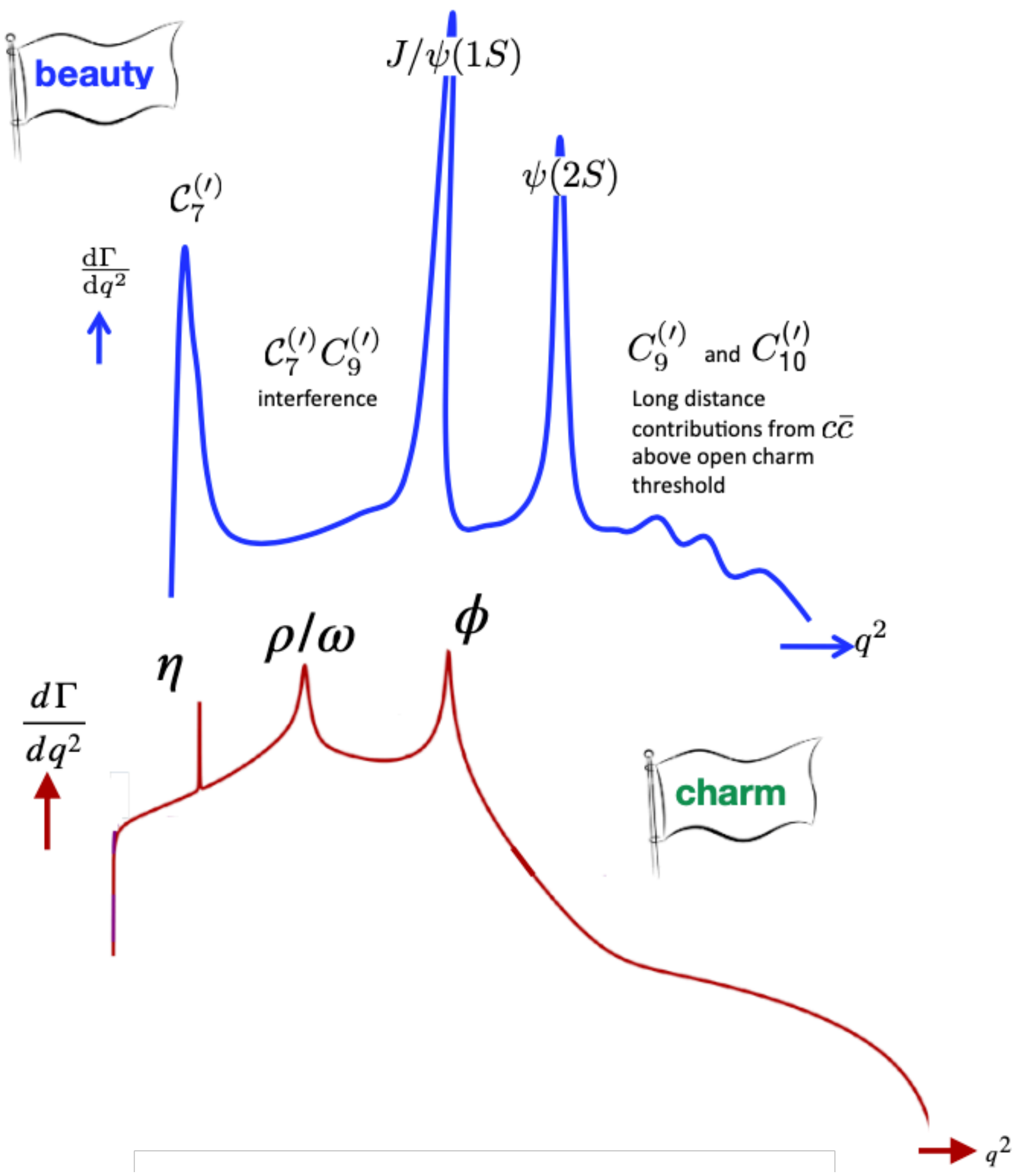
- Local form-factors
- Non-local form factors ($q\bar{q}$ loops)
- Non-factorizable soft gluon corrections





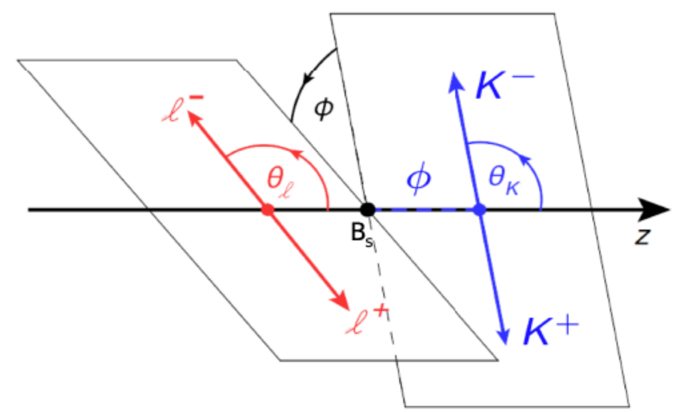
Observables

Branching fractions



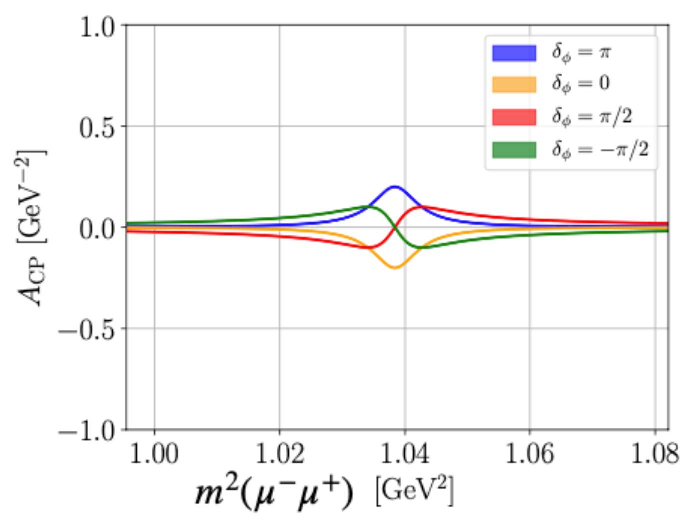
- Experimentally simple
- Affected by form-factors and $c\bar{c}$ loops

Angular observables



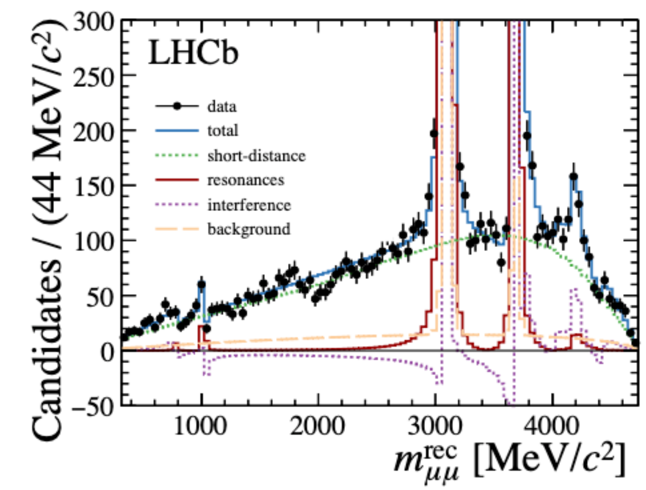
- Affected by $c\bar{c}$ loops

CP violation



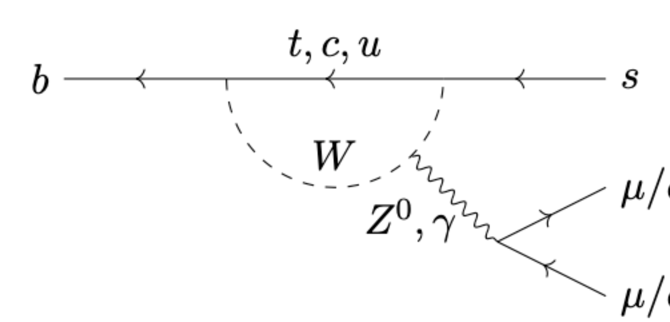
- Theoretically cleaner
- Probe structures of potential NP

Amplitude analysis



- Information about the composition of the decay

LFU test



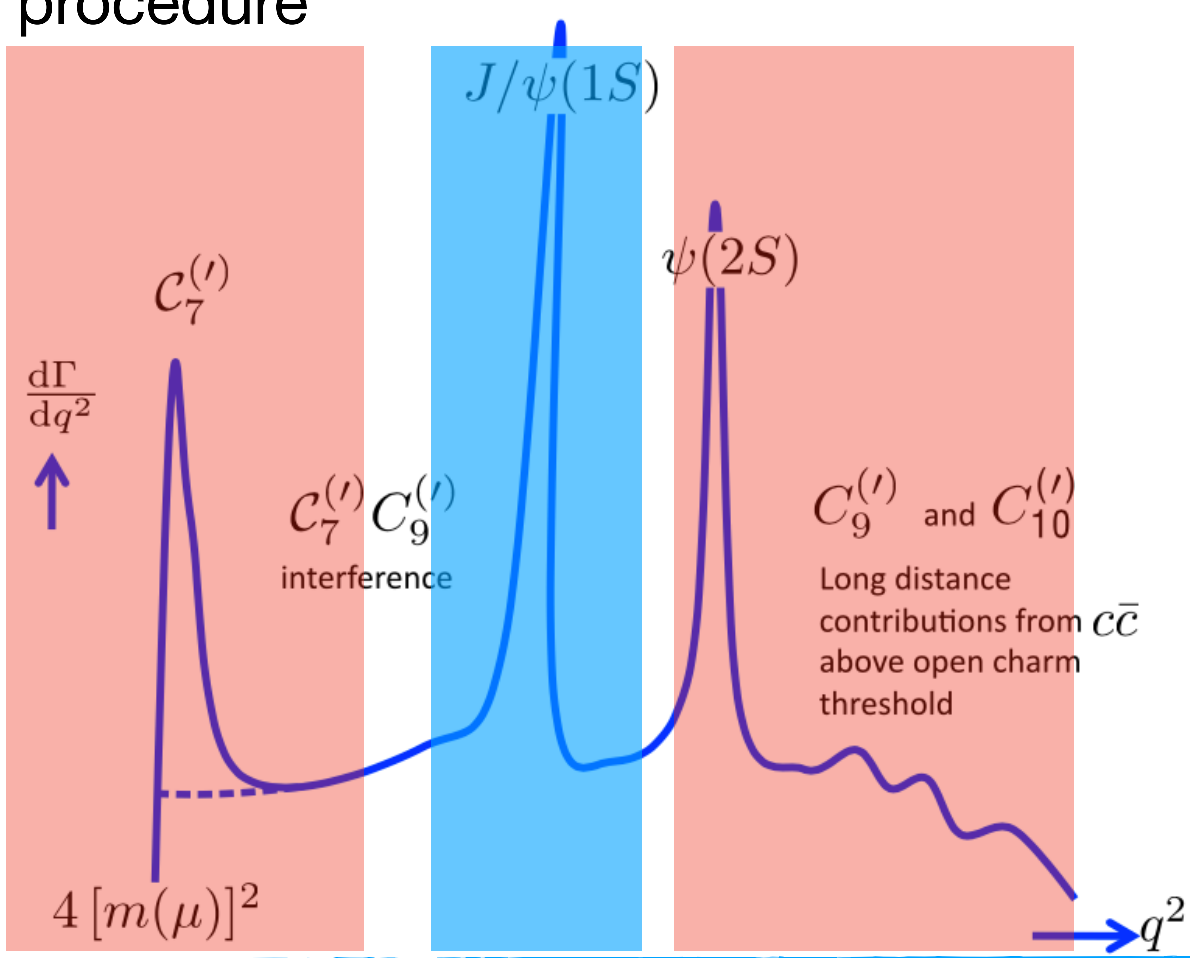
- Clean

Branching fractions

- Measurement in q^2 bins

$$\frac{d\mathscr{B}}{dq^2} = \frac{\mathscr{B}(norm)}{q^2_{max} - q^2_{min}} \cdot \frac{N_{sig}}{N_{norm}} \cdot \frac{\epsilon_{norm}}{\epsilon_{sig}}$$

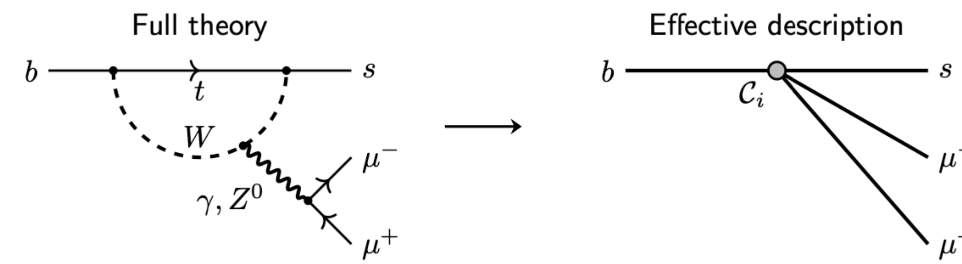
- **Beauty**: remove J/ψ region and use it as normalisation channel $\longrightarrow$ cancellation of systematic uncertainties
- Exploit $\psi(2S)$ as control mode to check procedure



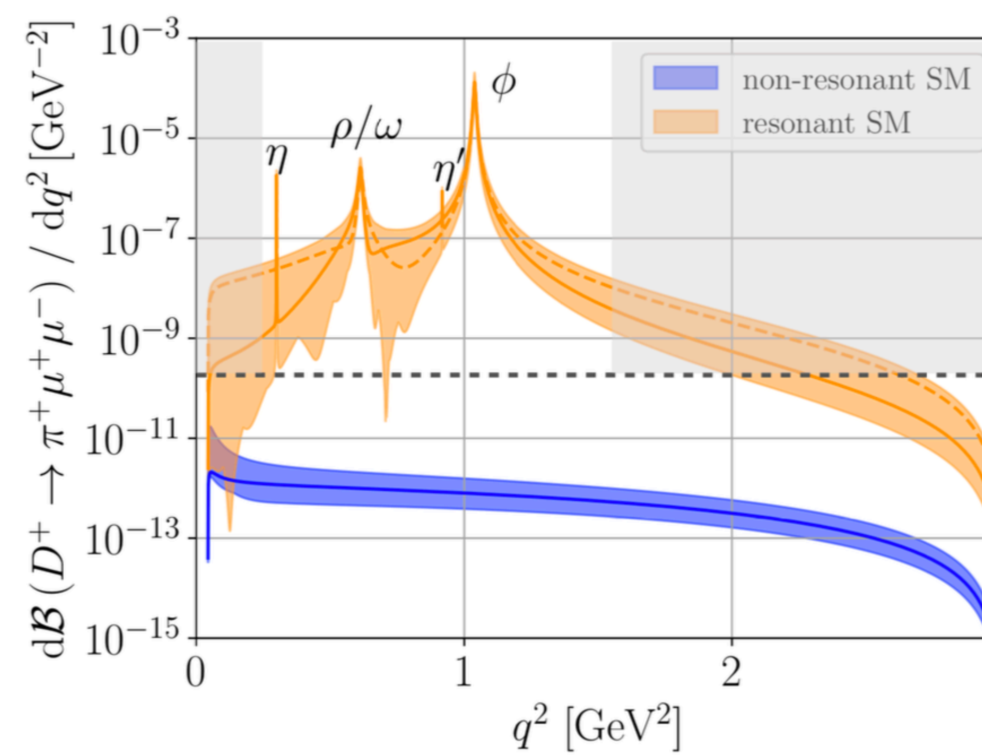
$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{\text{tb}} V^*_{\text{ts}} \frac{e^2}{16\pi^2} \sum_i \boxed{\mathcal{C}_i} \boxed{\mathcal{O}_i}$$

Local operator

Wilson coefficient ("effective coupling")



- **Charm**: conceptually similar approach in $D^+ \to h\ell^+\ell^-$, exploiting the ϕ resonance

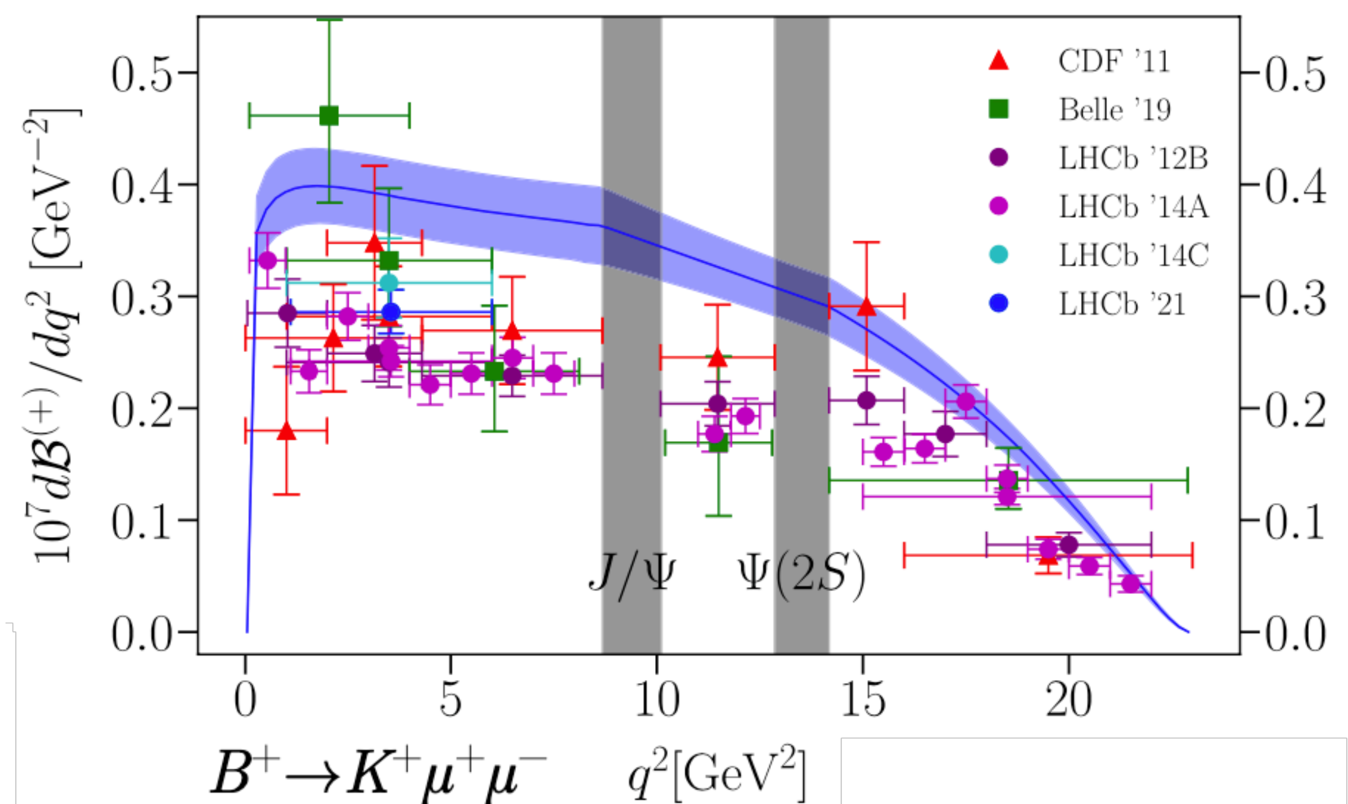


[Mod. Phys. Lett. A 36 (2021) 2130002]

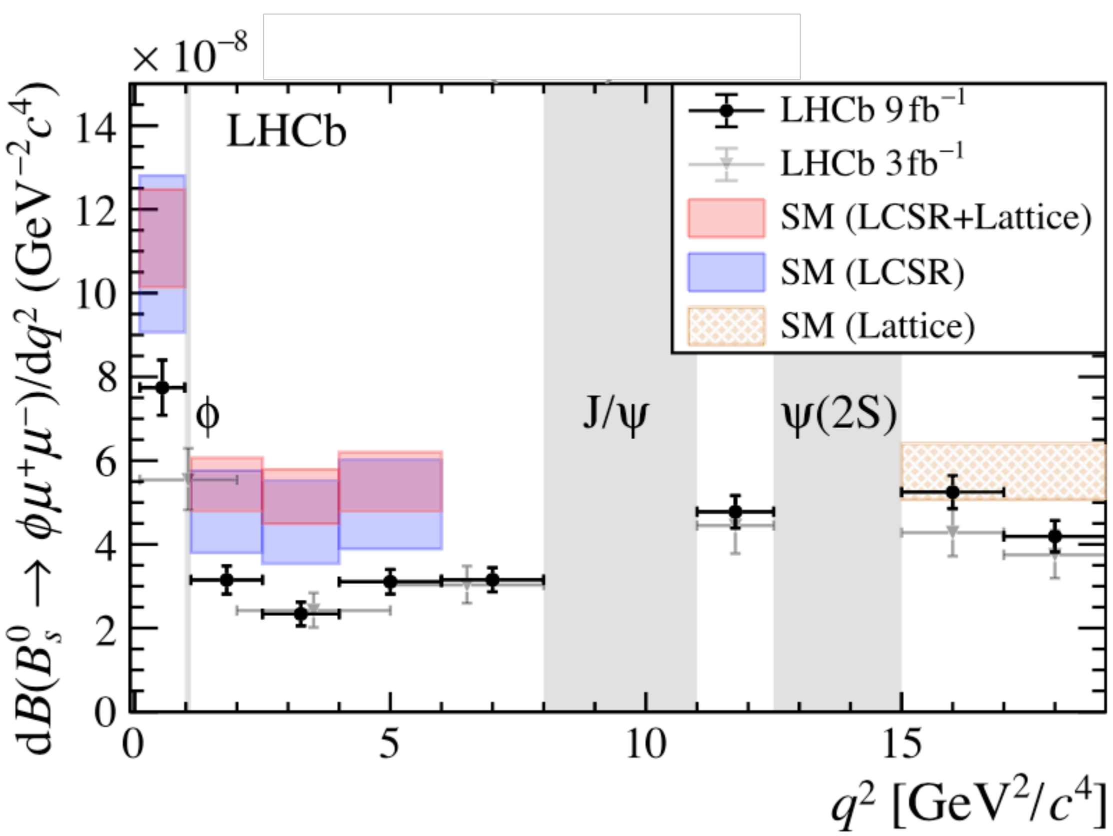
$b \to s\ell\ell$ branching fractions

- Since Run 1 branching fractions are systematically below SM predictions, particularly at low q^2 (tensions at $1-3\sigma$ level)
- SM predictions exhibit sizeable hadronic uncertainties
- Work on updates with full data sample

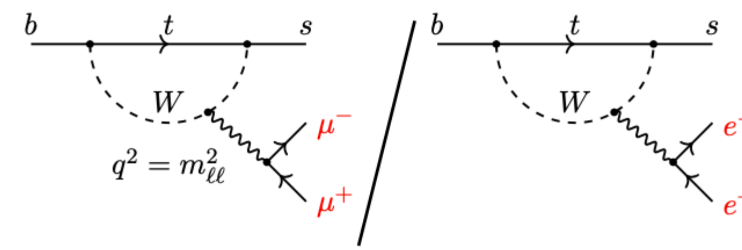
[PRD 107 (2023) 119903]



[PRL 127 (2021) 151801]



Lepton Flavour Universality

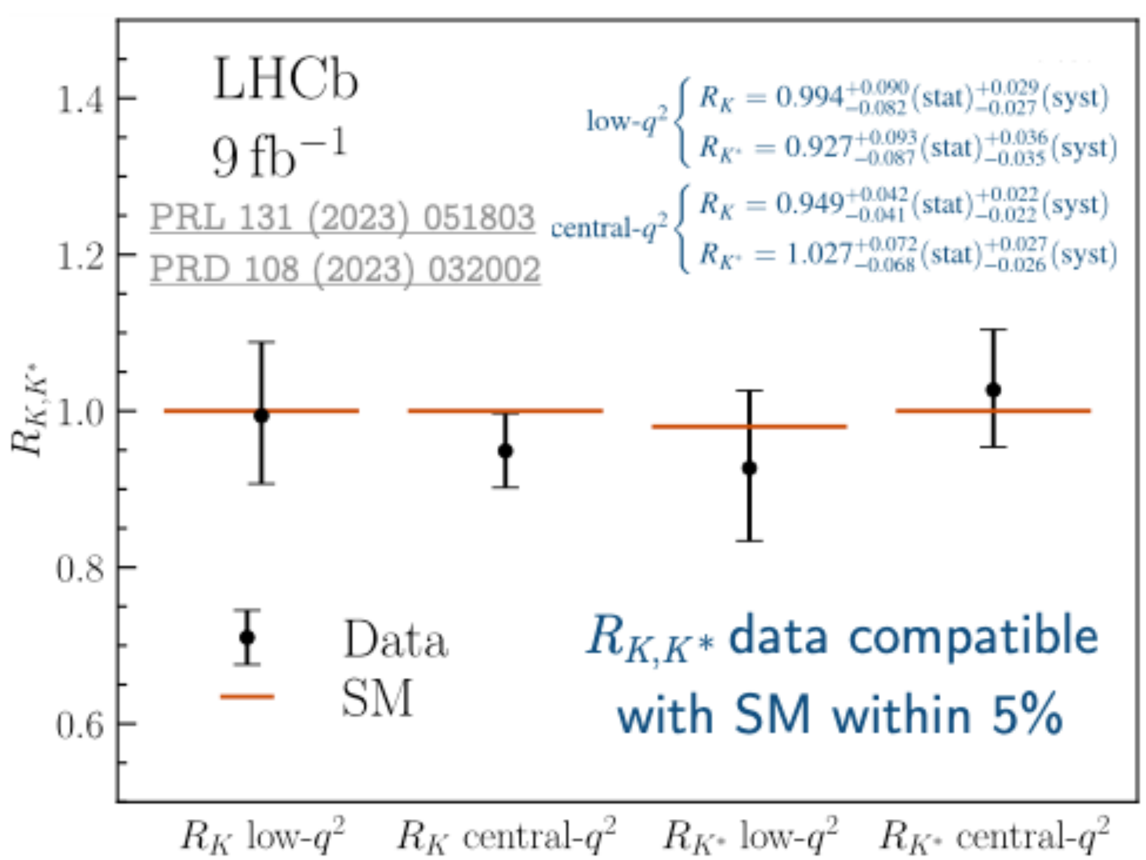


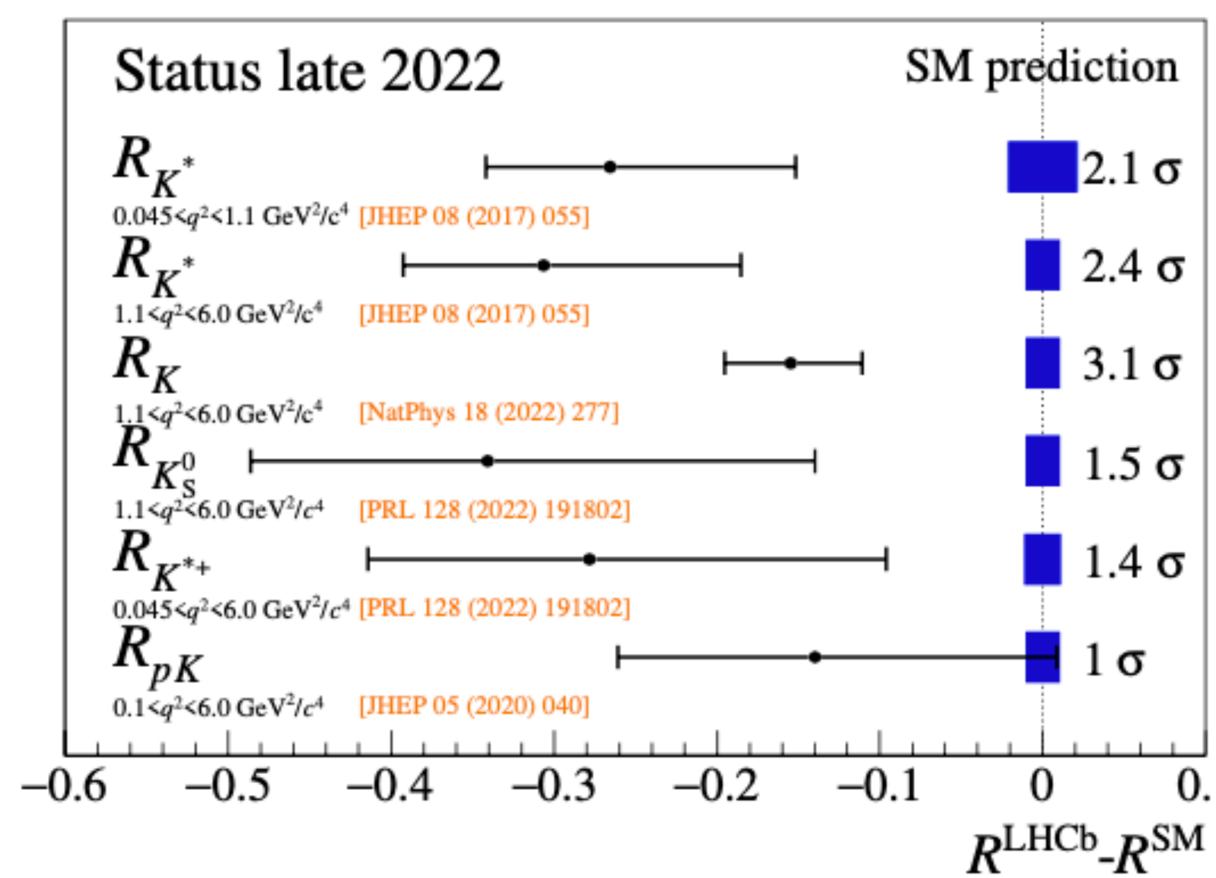
- LFU exactly unity in the SM, differences due to lepton mass difference
- QED corrections ~1%
- Testable using ratios of branching fractions, where hadronic uncertainties cancel
- <u>Data in excellent agreement with lepton flavour universality</u>

$$R_{K,K^*} = \frac{\mathcal{B}(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\mathcal{B}(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}$$

Electrons wrt muons have:

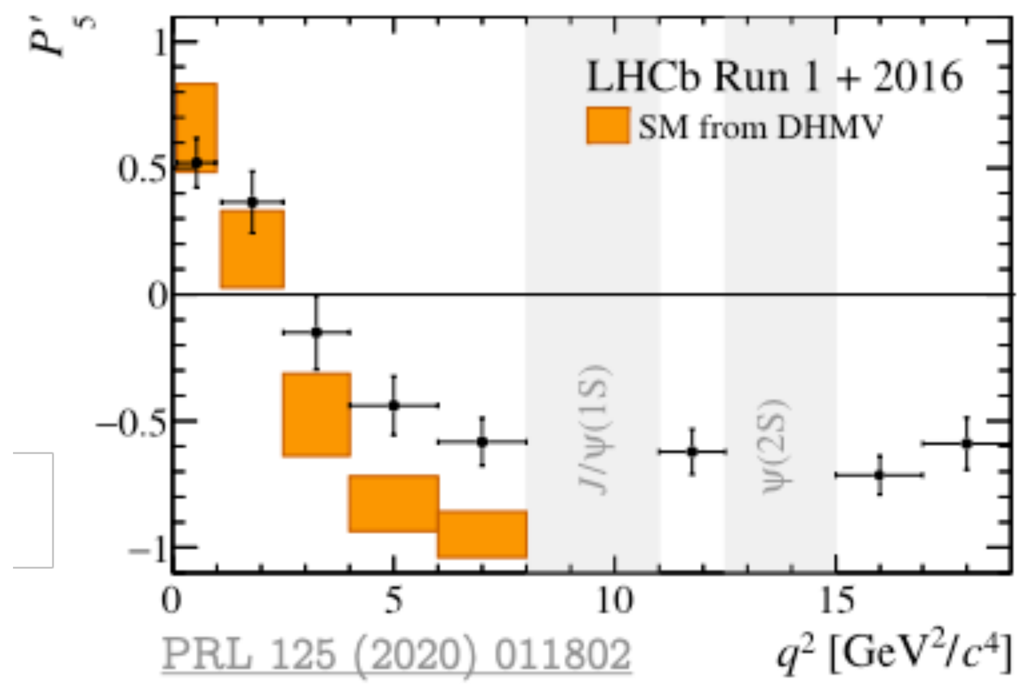
- Lower trigger efficiency (ECAL)
- Worse resolution (bremsstrahlung)
- More challenging bkg sources

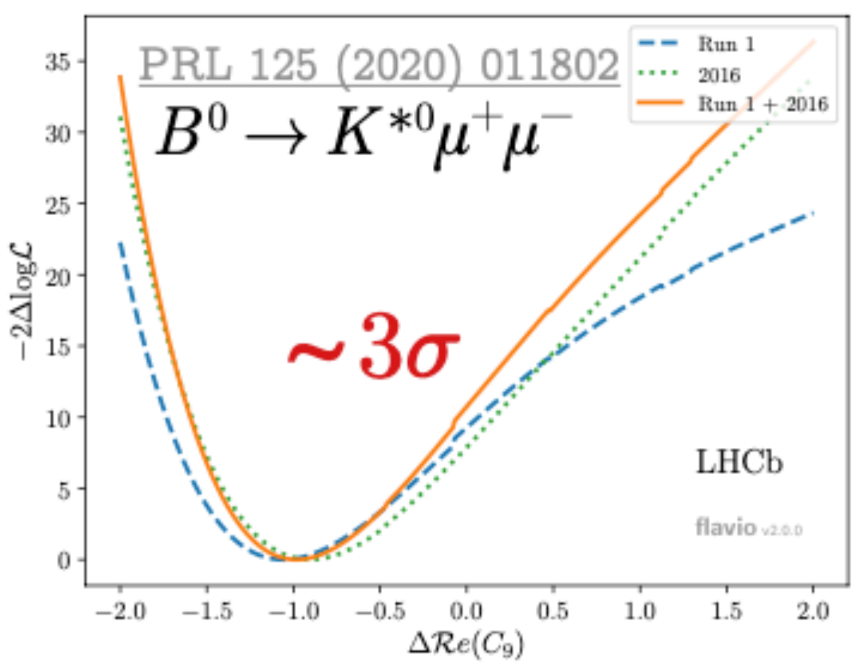


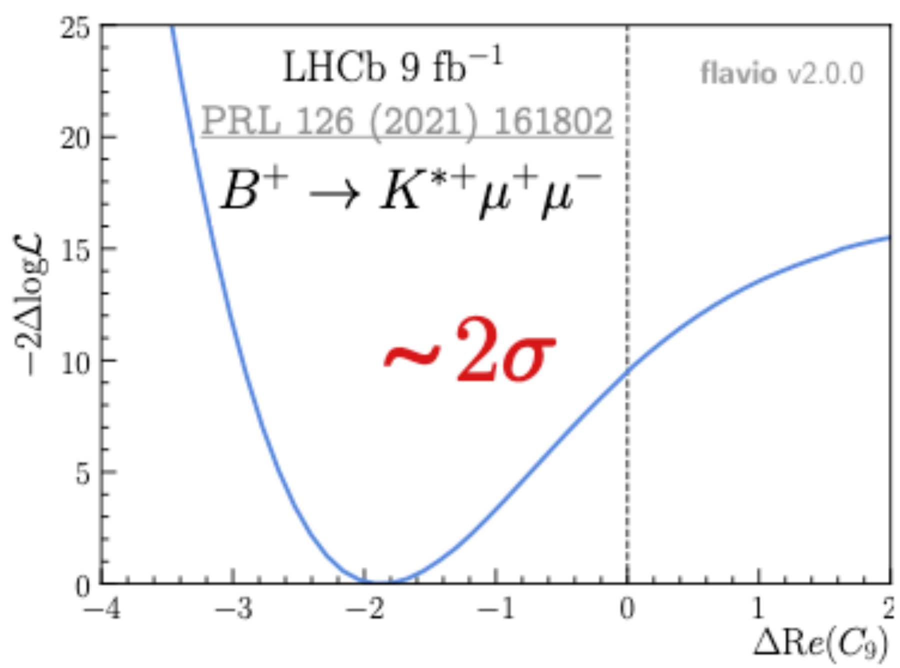


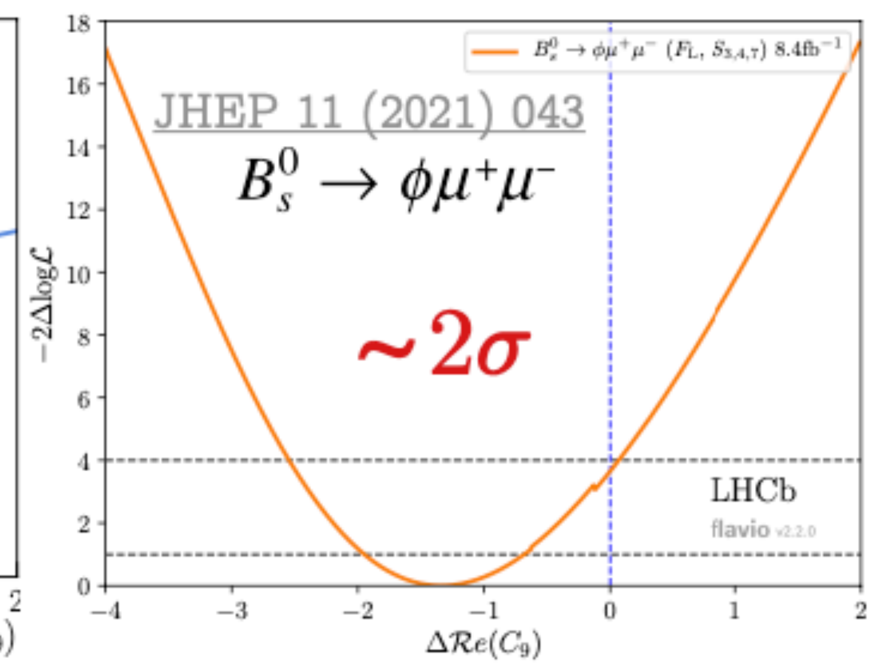
Angular binned analysis

- Tensions in angular analyses
- Coherent pattern seen in exclusive $b \to s\mu^+\mu^-$
- Prefer shifts of effective couplings
- Dedicated branching fraction measurements and angular analyses of *di-electron* modes ongoing







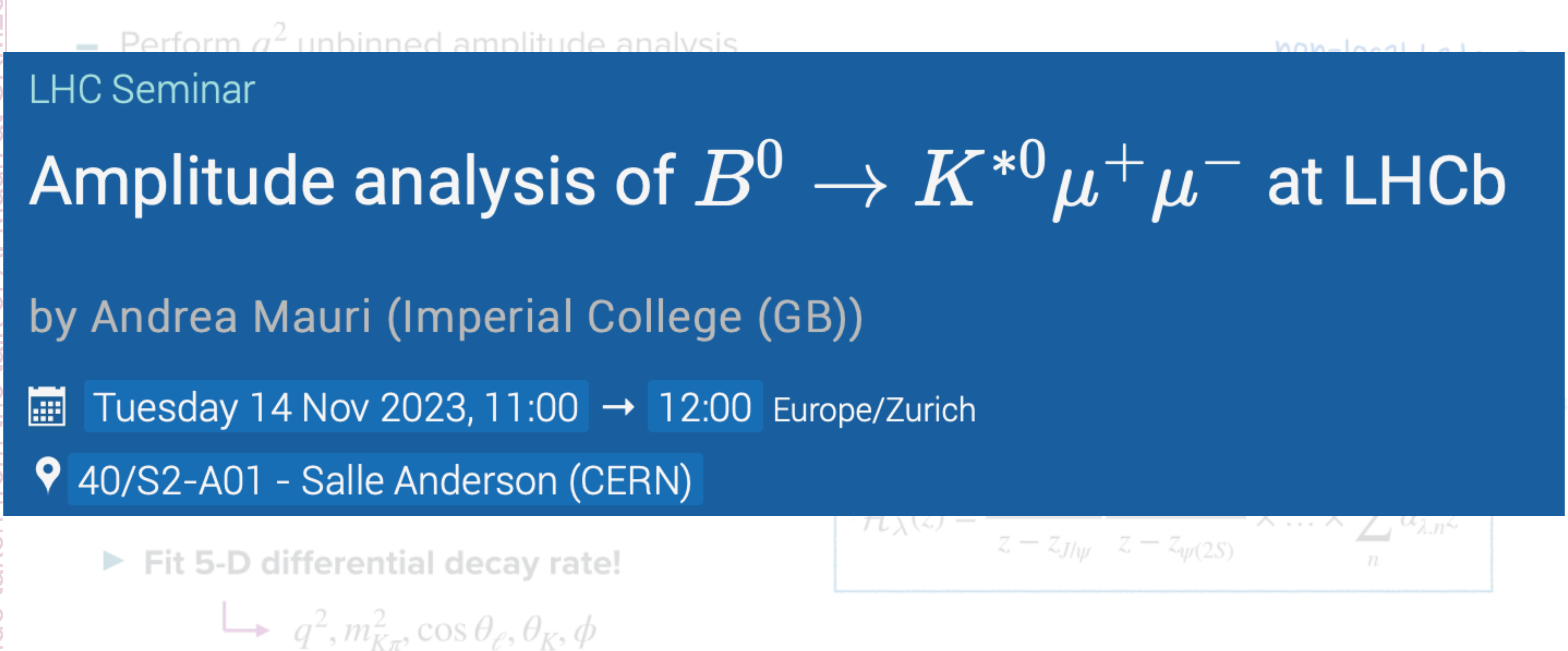


See also talk of A. Smolkovic on *Global analysis of rare $b \to d$ and $b \to s$ decays @ImplicationsWorkshop*

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

- Disentangling hadronic contributions requires work from theory and experiment
- Difficult to calculate reliably from first principles, but progress from theory:
  - Form-factors are systematically improved on the lattice [PRD 107 (2023) 1]
  - More precise estimation of charm-loop effect [JHEP 09 (2022) 133]
- **Can we access the non-local hadronic contribution ("charm-loop") from data?**

Slide taken from the talk of A. Mauri at CKM23



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- Perform q^2 unbinned amplitude analysis
    - model *local* vs *non-local* contributions

non-local hadronic matrix elements "charm-loop"

$$\mathcal{A}_\lambda^{L,R} = \mathcal{N}_\lambda \left\{ \left[(\mathcal{C}_9 \pm \mathcal{C}_9') \mp (\mathcal{C}_{10} \pm \mathcal{C}_{10}') \right] \mathcal{F}_\lambda(q^2) + \frac{2 m_b M_B}{q^2} \left[(\mathcal{C}_7 \pm \mathcal{C}_7') \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b} \overline{\mathcal{H}_\lambda(q^2)} \right] \right\}$$

$\lambda = \perp, \parallel, 0$

Wilson coeff.

Form Factors

polynomial expansion

JHEP 09 (2022) 133

$$\boxed{\mathcal{H}_\lambda(z) = \frac{1 - z z_{J/\psi}^*}{z - z_{J/\psi}} \frac{1 - z z_{\psi(2S)}^*}{z - z_{\psi(2S)}} \times \ldots \times \sum_n \alpha_{\lambda,n} z^n}$$

- **Fit 5-D differential decay rate!**

↳ $q^2, m_{K\pi}^2, \cos\theta_\ell, \theta_K, \phi$

Non-local contributions

[LHCb-PAPER-2023-032]
[LHCb-PAPER-2023-033]
in preparation

Slide taken from the talk of A. Mauri at CKM23

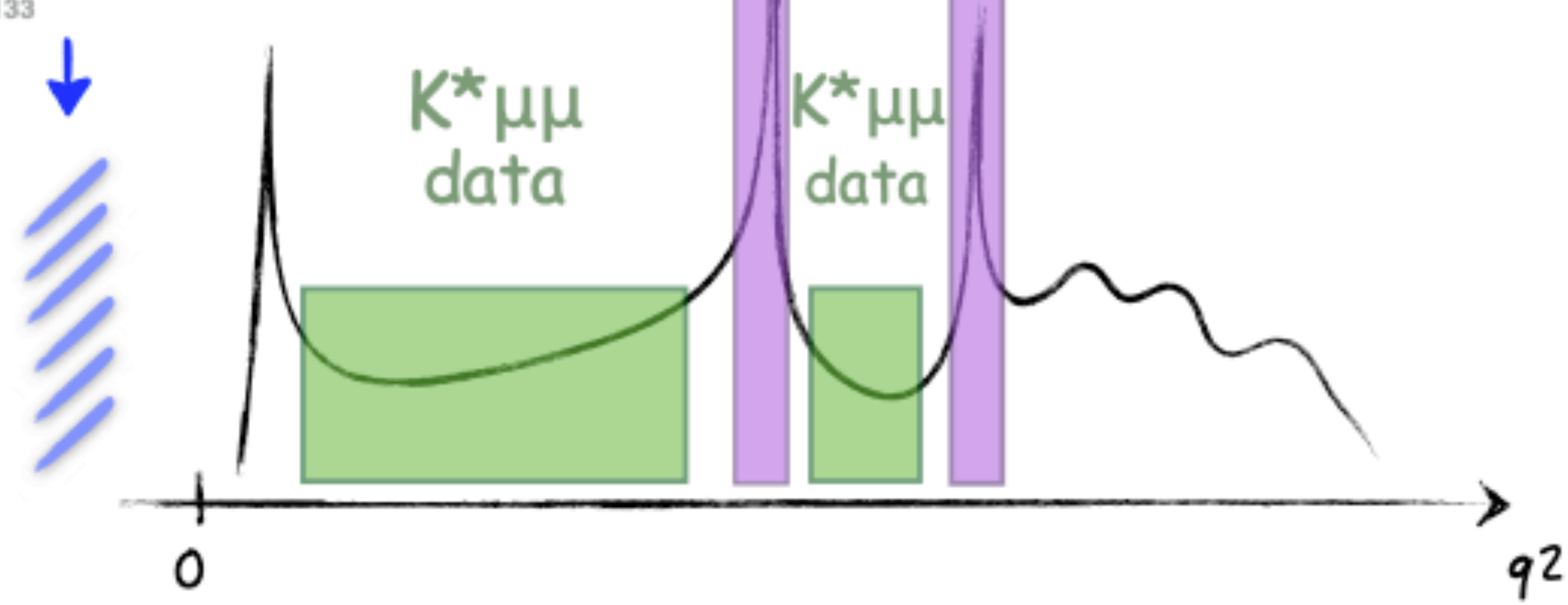
– Combining theory & experimental information to constrain charm-loop parameters

Theory information
Value of charm-loop at $q^2 < 0$
▸ reliable for $q^2 \ll 4m_c^2$

JHEP 09 (2022) 133

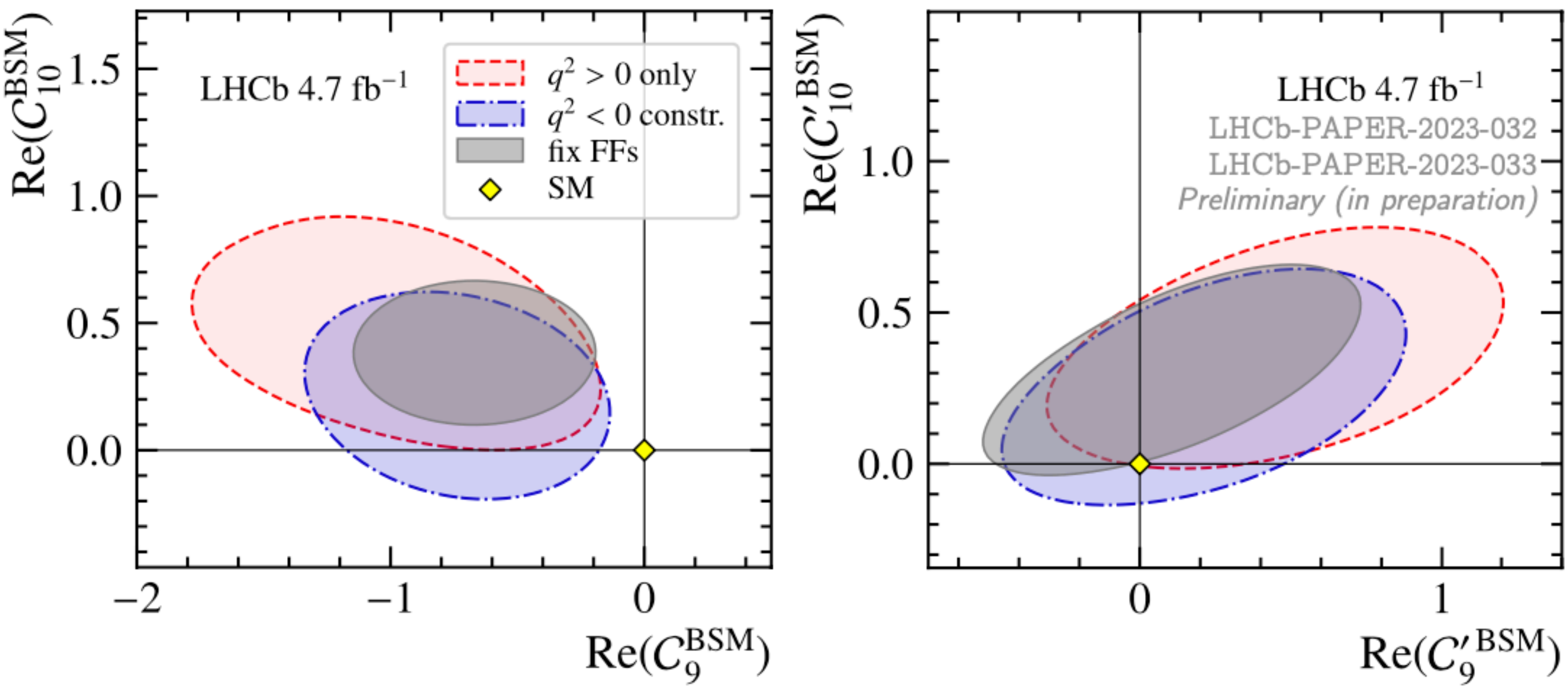
Experimental measurements
Branching ratio, polarization fraction and phase difference from $B^0 \to \psi_n K^{*0}$

PRD 76 031102(R) (2007)
PRD 88 052002 (2013)
PRD 88 074026 (2013)
PRD 90 112009 (2014)



Results: Wilson coefficients

[LHCb-PAPER-2023-032]
[LHCb-PAPER-2023-033]
in preparation



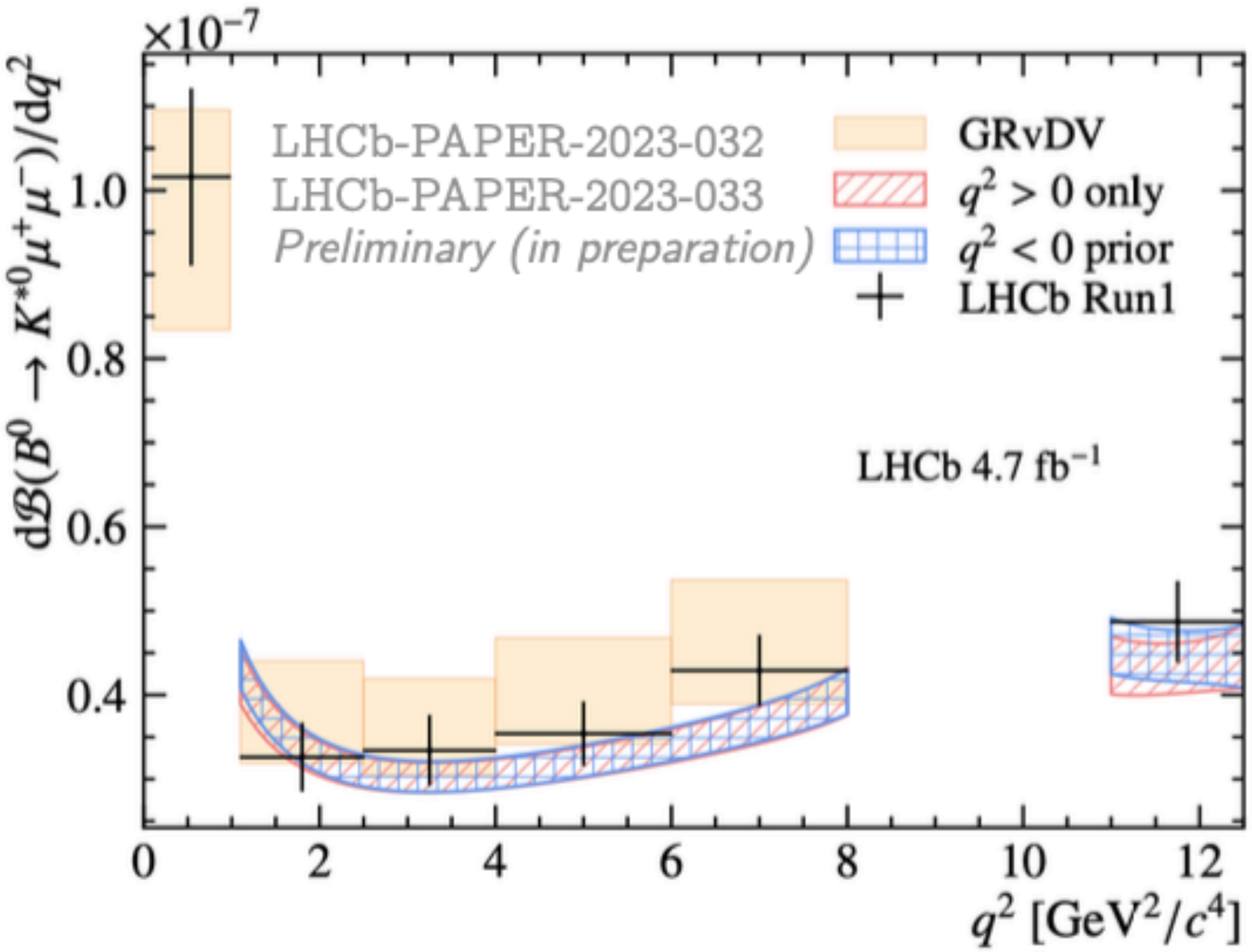
- Results consistent with the pattern suggested by global analyses
- ..but non-local contributions are found to dilute the tension with the SM observed

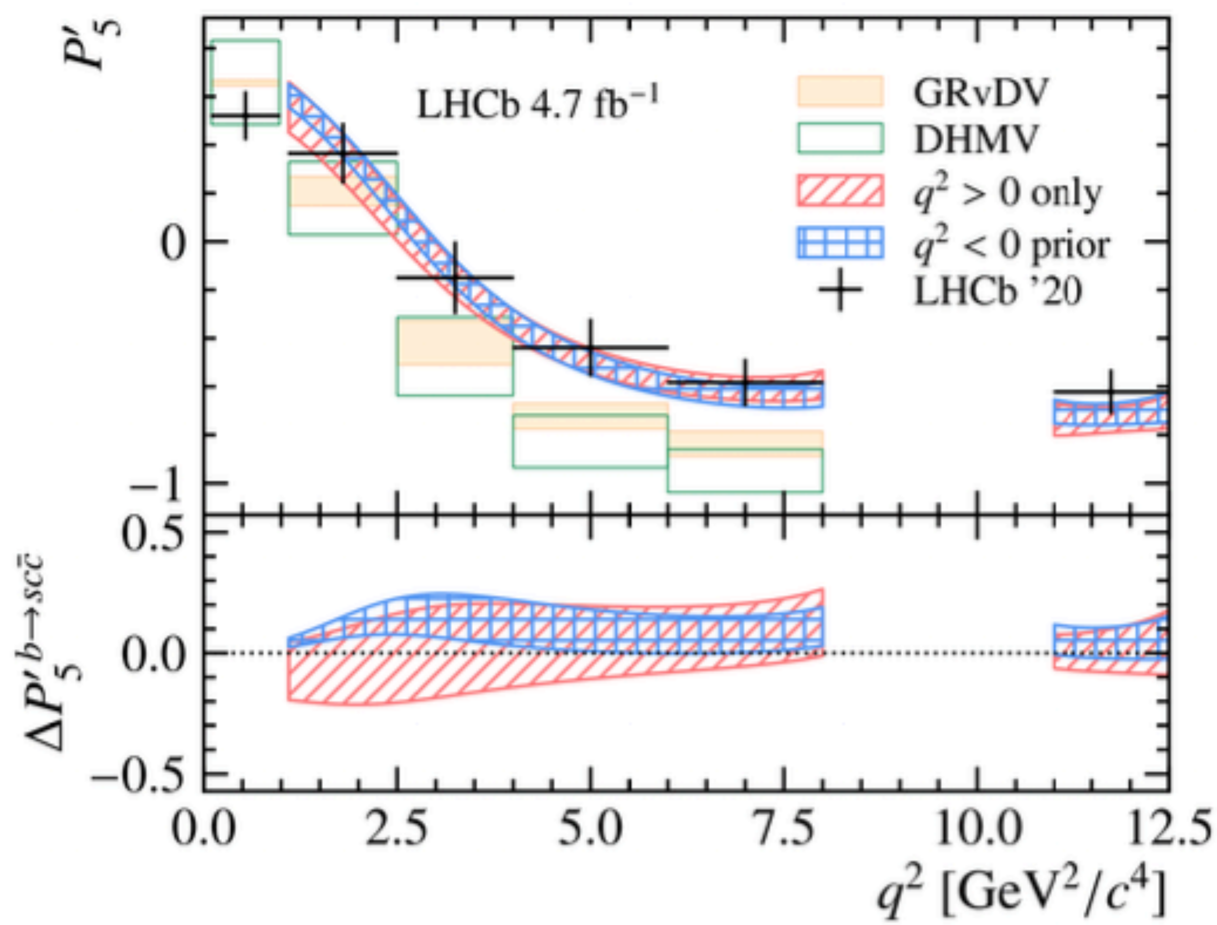
Data-SM tension $\sim 1.9\ \sigma$ in C_9, up to $1.5\ \sigma$ in C_{10}

Combined tension $\sim 1.4\sigma$

Results: differential BF and P_5'

[LHCb-PAPER-2023-032]
[LHCb-PAPER-2023-033]
in preparation





- Lower BF compared to LHCb Run 1 results, due to updated normalisation

- Very good agreement with binned results
- Impact of $c\bar{c}$ up to 20%

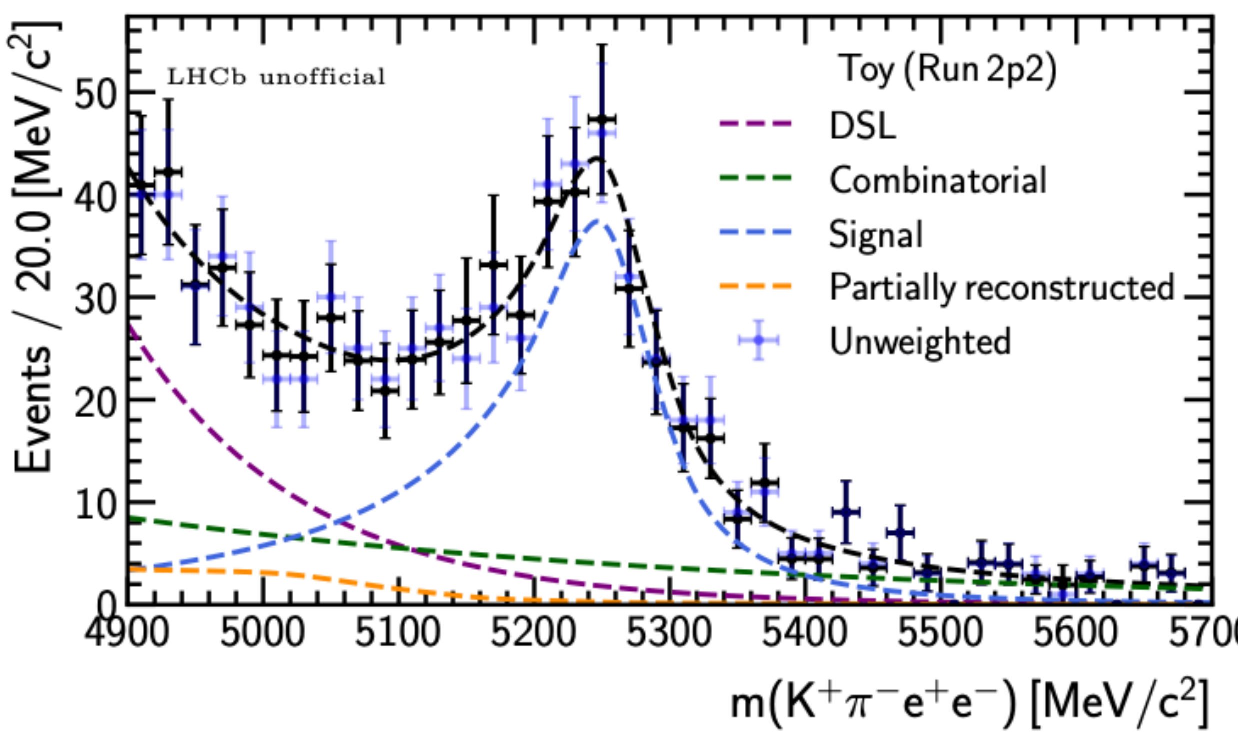
Prospects for Run1+2

LFU tests

- **Exclusive**
  - R_ϕ with $B_s \to \phi\ell\ell$
  - R_Λ with $\Lambda_b \to \Lambda\ell\ell$: first measurement
  - R_{pK} with $\Lambda_b \to pK\ell\ell$: update with 2017+2018 data
- **Non-exclusive** multi-body decays
  - $R_{K\pi\pi}$ with $B^+ \to K\pi\pi\ell\ell$
  - $B^0 \to K\pi\ell\ell$ (outside K^* resonance)
- **High** q^2 region in $R_{K^{(*)}}$ and R_ϕ
  - Difficult background to control: $\psi(2S)$ + part. reconstructed + misID

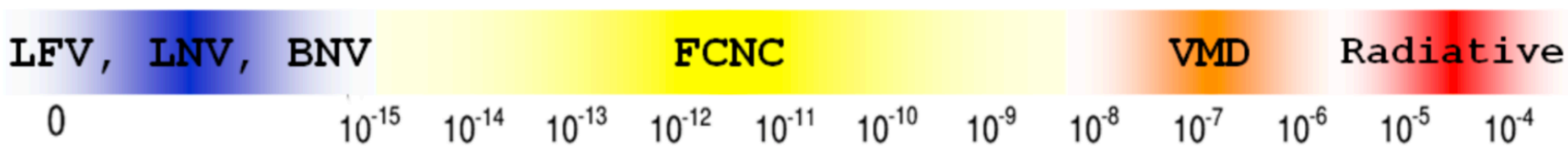
Angular observables

- $B \to K^* e^+e^-$: challenging due to bin migration and bkg modelling



- $B \to K^*\mu^+\mu^-$ extra fit parameters: massive leptons and scalar amplitudes
- Binned (more bins and full dataset) vs Unbinned (study different models)

Rare charm decays

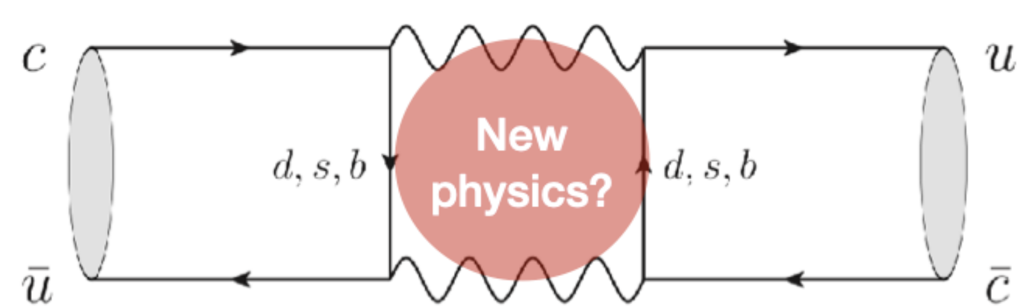


Charm systems offer a unique opportunity to search for NP

- Only bound system made of up-type quarks, complementary sensitivity to BSM couplings wrt *K* and *B* decays
- All processes involving loops are highly suppressed in the SM:
  - Charm meson oscillation probability very low
  - CPV effect tiny ($\leq \mathcal{O}(10^{-3})$)
  - Extremely rare decays ($\leq \mathcal{O}(10^{-9})$)

Story of rare charm decays in LHCb

- 2015: First observation of the decay $D^0 \to K^-\pi^+\mu^+\mu^-$ in the $\rho^0 - \omega$ region of the dimuon mass spectrum
  Phys. Lett. B 757 (2016) 558
- 2015: Search for the lepton-flavour violating decay $D^0 \to e^\pm\mu^\mp$
  Phys. Lett. B 754 (2016) 167
- 2017: Rarest observed charm meson decays $D^0 \to KK\mu\mu$ and $D^0 \to \pi\pi\mu\mu$ with branching fraction ~10^{-7}
  Phys. Rev. Lett. **119**, 181805 (2017)
- 2018: Search for the rare decay $\Lambda_c^+ \to p\mu^+\mu^-$
  Phys. Rev. D 97, 091101 (2018)
- 2021: Searches for 25 rare and forbidden decays of D^+ and D_s^+ mesons
  JHEP 06 (2021) 044
- 2021: Angular analysis of $D^0 \to \pi\pi\mu\mu$ and $D^0 \to KK\mu\mu$ decays and search for CP violation
  Phys. Rev. Lett. **128**, 221801 (2022)
- 2022: Search for rare decays of D^0 mesons into two muons
  arXiv:2212.11203v1 [hep-ex] 21 Dec 2022
- 2023: Search for $D^*(2007)^0 \to \mu^+\mu^-$ in $B^- \to \pi^-\mu^+\mu^-$decays
  arXiv:2304.01981v2 [hep-ex] 5 Apr 2023

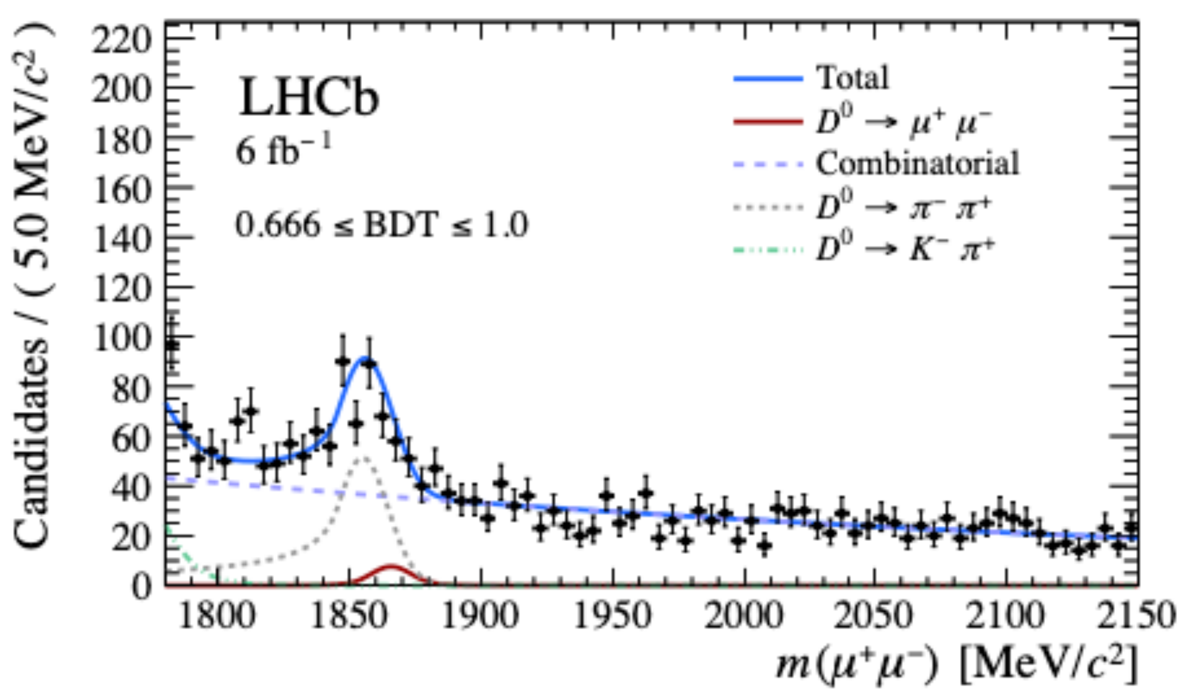


Search for leptonic rare charm decays

$D^0 \to \mu^+\mu^-$ [PRL 131 (2023) 041804]

- Very rare decay: FCNC + helicity suppression
- Very clean experimental signature
- Minimal hadronic uncertainties
- Intermediate two-photon state: $\mathscr{B} \sim 10^{-13}$ in the SM → $\mathscr{B} < 10^{-11}$ (Belle constraint from $D^0 \to \gamma\gamma$) [PRD 93, 051102(R)]
- Using $D^{*+} \to D^0\pi^+$ decays with $D^0 \to \pi^+\pi^-$ and $D^0 \to K^-\pi^+$ as normalisation
- No significant signal observed:

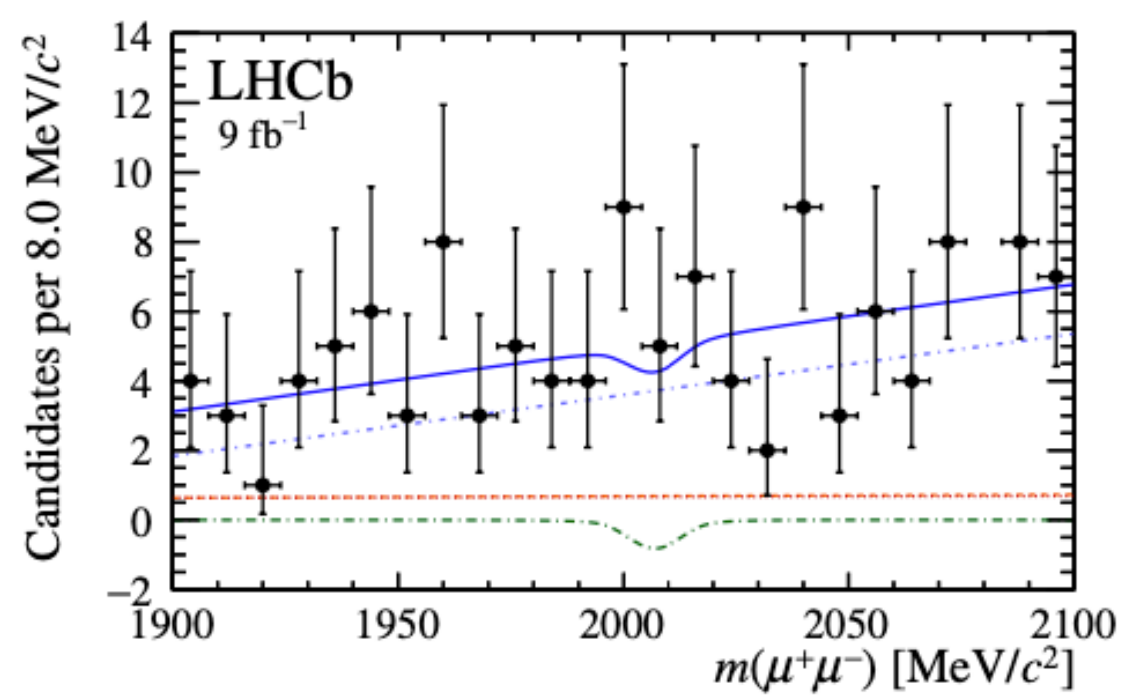
$$\mathscr{B}(D^0 \to \mu^+\mu^-) < 3.1 \times 10^{-9} \text{ at } 90\,\% \text{ CL}$$



$D^{*0} \to \mu^+\mu^-$ [EPJC 83, 666 (2023)]

- $\mathscr{B} \sim 10^{-19}$ in the SM [JHEP 11 (2015) 142]
- Using $B^- \to D^{*0}\pi^-$ decays and $B^- \to J/\psi K^-$ as normalisation
- Simultaneous fit to $m(\mu^+\mu^-)$ and $m(\pi^+\mu^+\mu^-)$
- No significant signal observed:

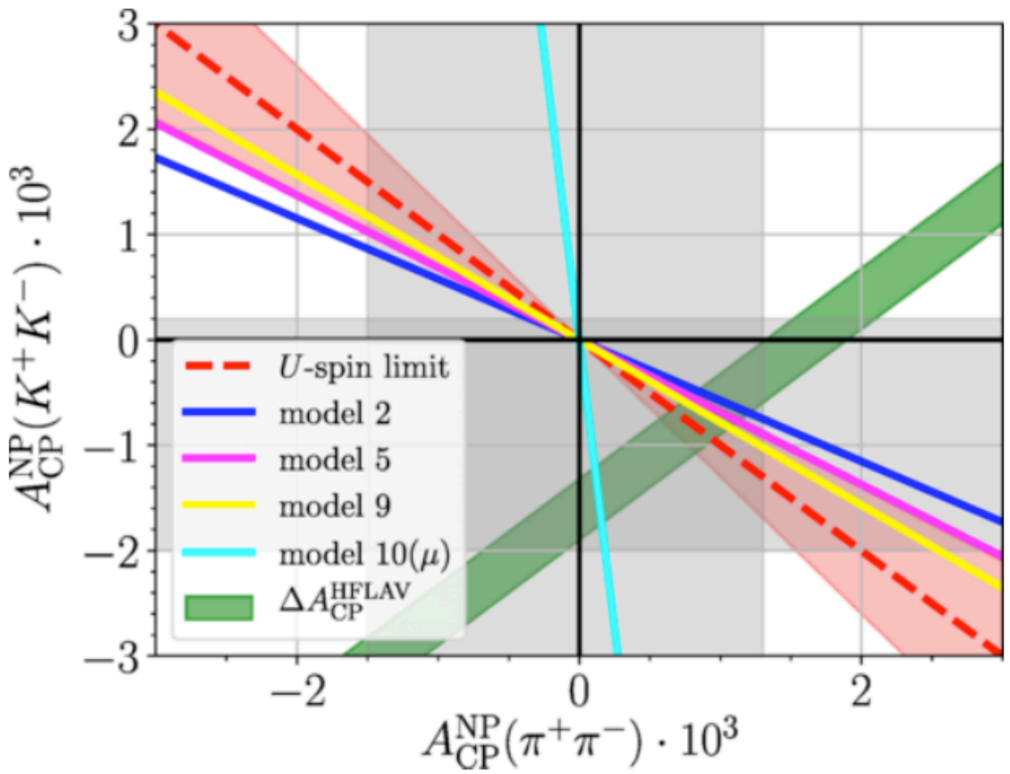
$$\mathscr{B}(D^{*0} \to \mu^+\mu^-) < 2.6 \times 10^{-8} \text{ at } 90\,\% \text{ CL}$$

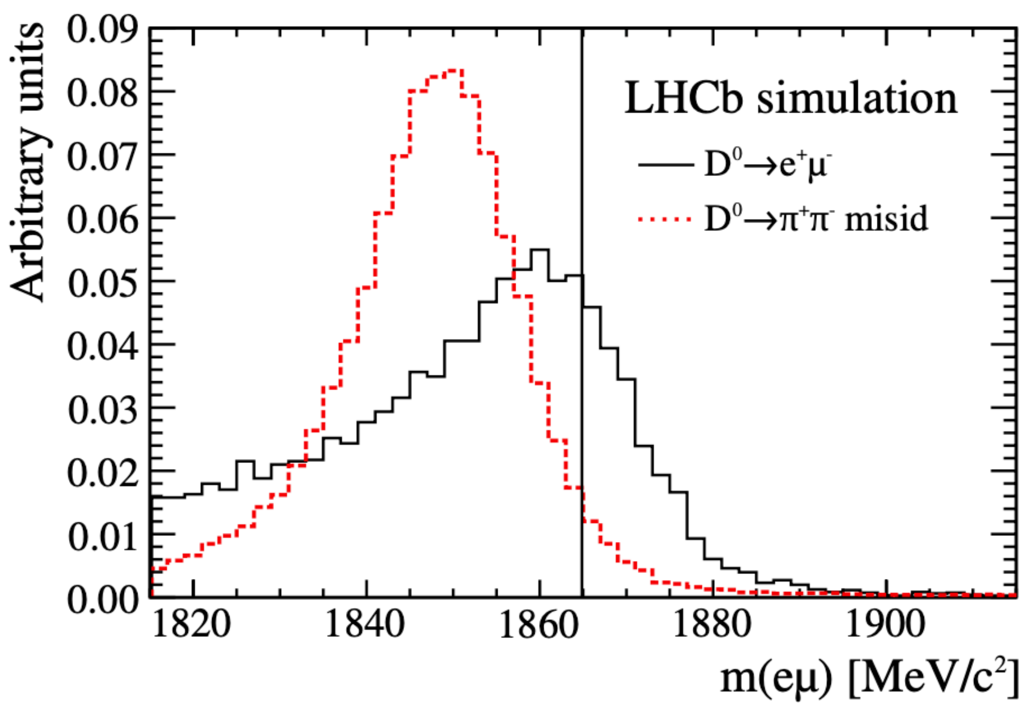


Prospects for Run1+2

- **Semileptonic decays**: ongoing analysis in $D^+_{(s)} \to h\ell\ell$ and $\Lambda_c \to p\ell\ell$
- First analyses looked for signal only in the non-resonant regions [PRD 97, 091101 (2018)] [JHEP 06 (2021) 044]
- Another method exploited for $D^0 \to$ 4body decays studies the resonant region with clean null tests:
  - CP asymmetry
  - Angular observables

[PRD 101, 115006]





[Phys. Lett. B754 (2016) 167]

- More challenging: measure branching fraction and A_{CP} in **radiative decays** $D^0 \to V\gamma$ $(V = \phi, \rho, K^*)$
  - Complement Belle measurements [JHEP 08 (2017) 091]
  - Room for NP with A_{CP} up to 10% with BF SM-like [PRL 118, 051801 (2017)]
- Final states with **electrons**:
  - Search for $D^0 \to hhe^+e^-$
  - First LFU test with $D^+_{(s)} \to \phi(\to \ell\ell)\pi^+$

A word on kaon rare decays

Almost infinite strangeness production
at LHC (kaon xs ~ 1.2 barn)

$K_S^0 \to \mu^+\mu^-$ [PRL 125, 231801 (2020)]

- SM prediction $\mathscr{B} \sim 10^{-12}$
- Sensitive to different physics than $K_L \to \mu^+\mu^-$
- Full Run 1+2 dataset analysed
- No significant signal observed:

$\mathscr{B}(K_S^0 \to \mu^+\mu^-) < 2.1 \times 10^{-10}$ at $90\,\%$ CL

$K_{S,L}^0 \to \mu^+\mu^-\mu^+\mu^-$ [PRD 108 (2023) L031102]

- SM prediction $K_S^0 \sim 10^{-14}$, $K_L^0 \sim 10^{-13}$
- Full dataset analysed
- No significant signal observed:

$\mathscr{B}(K_S^0 \to \mu^+\mu^-\mu^+\mu^-) < 5.1 \times 10^{-12}$

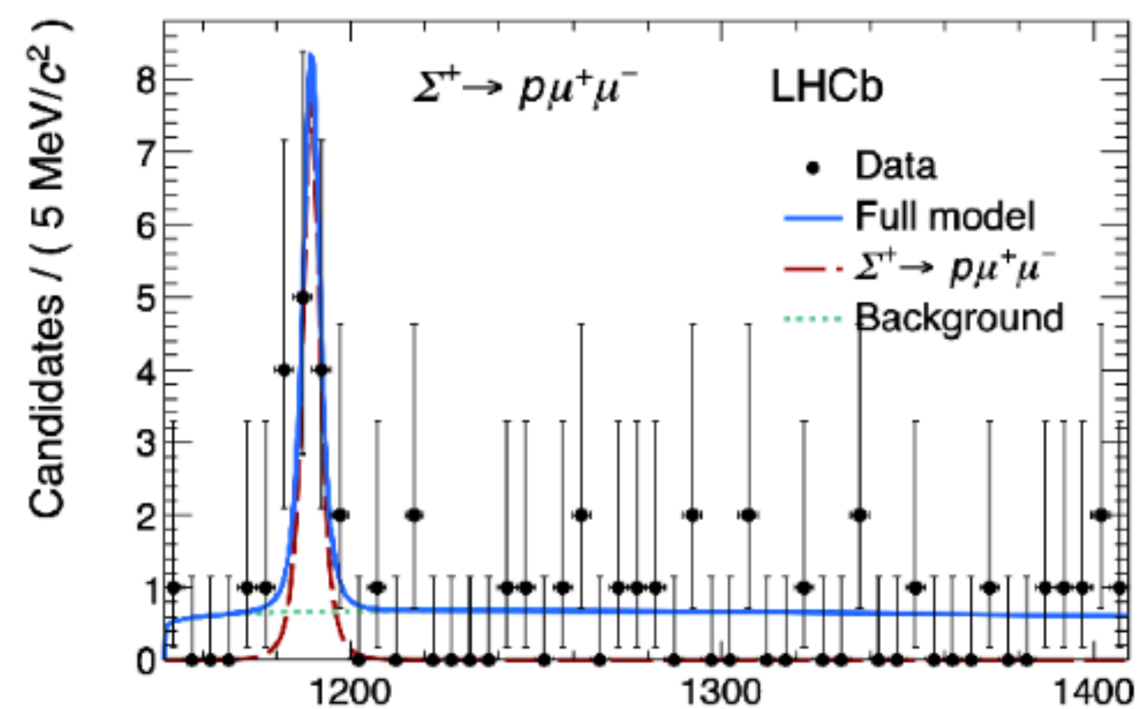
$\mathscr{B}(K_L^0 \to \mu^+\mu^-\mu^+\mu^-) < 2.3 \times 10^{-9}$

$\Sigma^+ \to p\mu^+\mu^-$ [PRL 120, 221803 (2018)]

- $4.1\ \sigma$ evidence with Run 1 data

$\mathscr{B}(\Sigma^+ \to p\mu^+\mu^-) = (2.1^{1.8}_{1.3}) \times 10^{-8}$

- Run 2: possible observation and investigation of the full differential decay rate



Run 2 (2016-2018) data analysis ongoing: $\Sigma^+ \to p\mu^+\mu^-$, $K_S \to (\gamma, \pi^0)\mu\mu$, ...

Prospects for Run 3

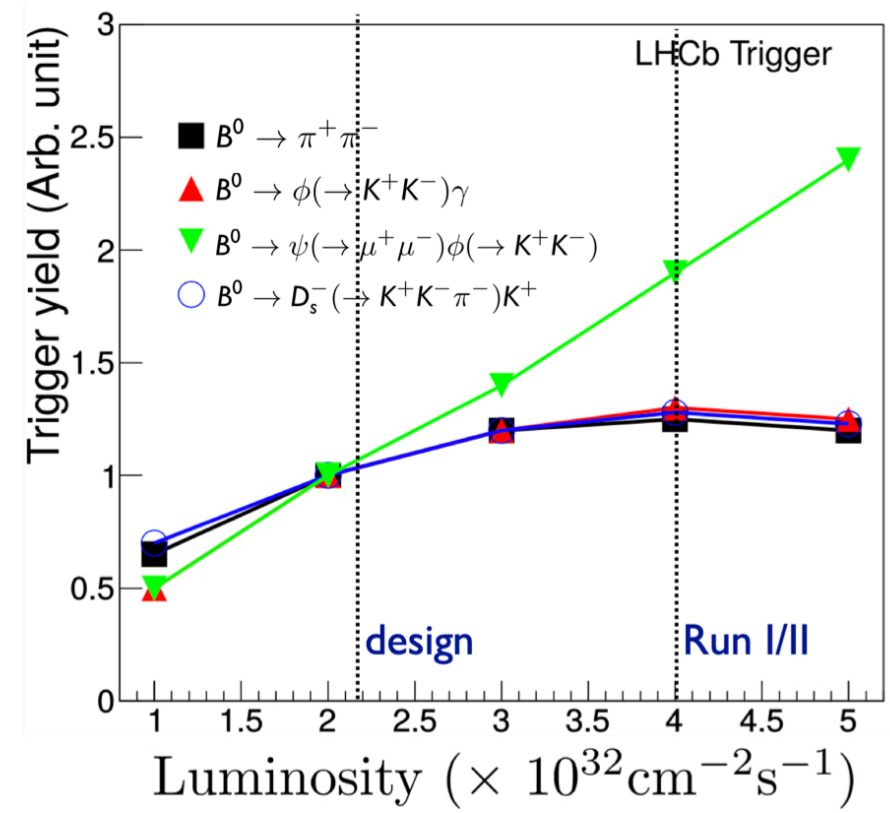
The upgraded LHCb experiment

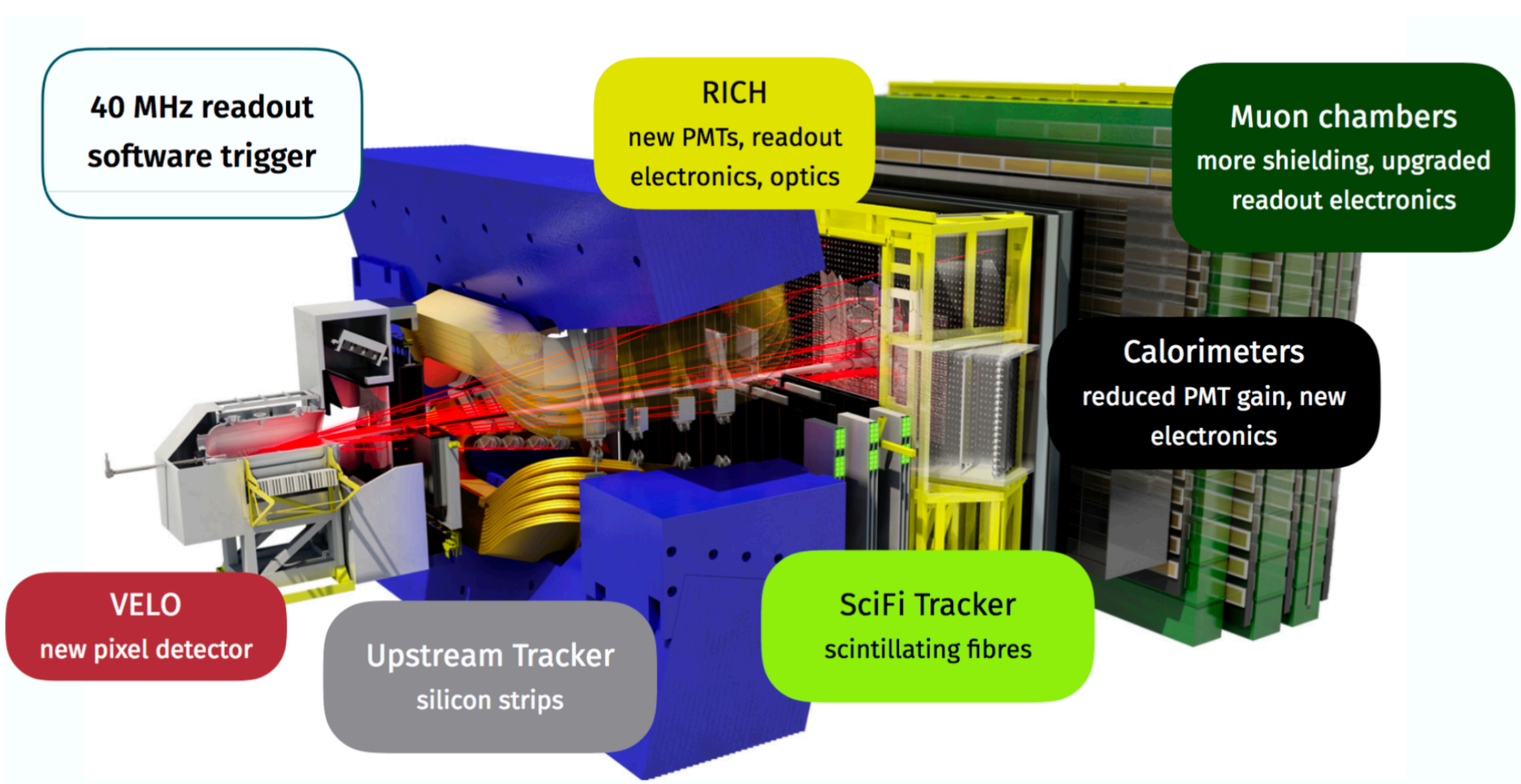
See talk from M. Vieites Diaz @ImplicationsWorkshop

- **Most of the studies presented are limited by statistics**
- Major upgrade of all subdetectors
- Higher instantaneous luminosity

  $$\mathscr{L} = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$$

  → more collisions per bunch crossing (from 1 to 5 visible interaction), while keeping the same performance
- 100% of the readout electronics replaced
- New data acquisition system and data center





CERN-LHCC-2012-007

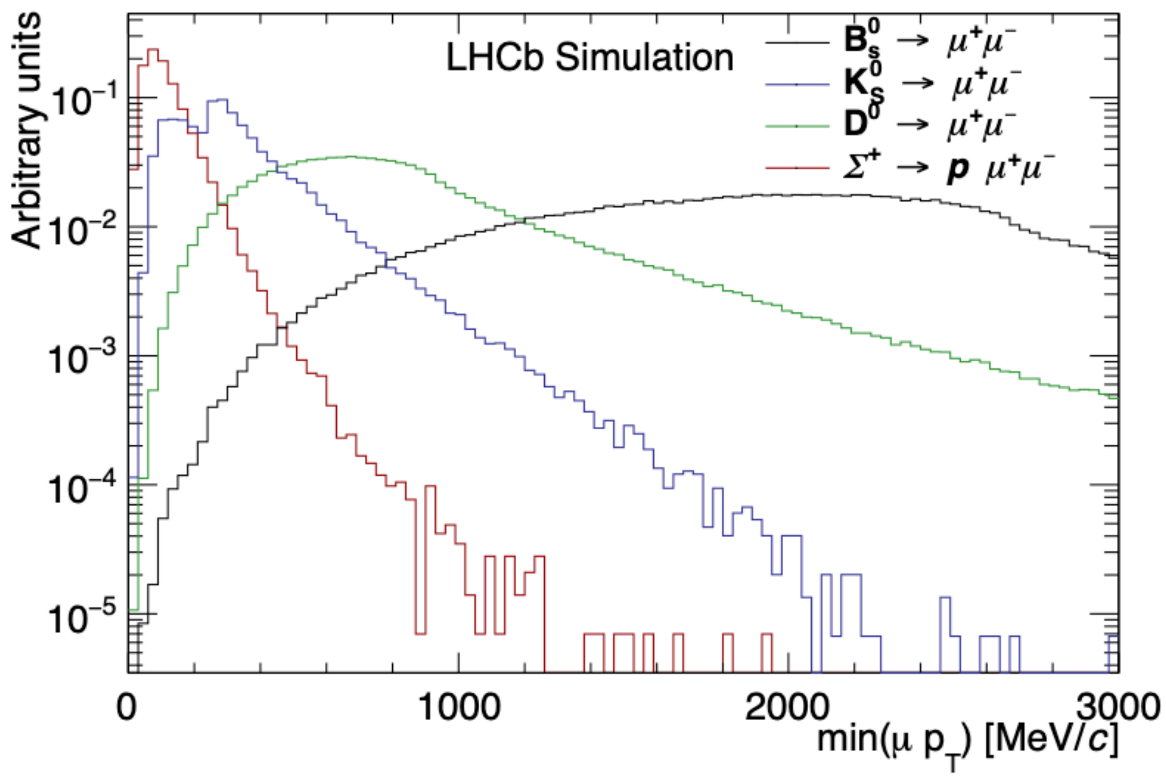
- Cannot effectively trigger on heavy flavour using hardware signatures
- Trigger for many decays with hadrons and electrons saturated already at Run 1-2 luminosity
- **Solution:** fully software trigger with event reconstruction in real time at 40MHz

Expected improvements relevant for FCNC

Muons

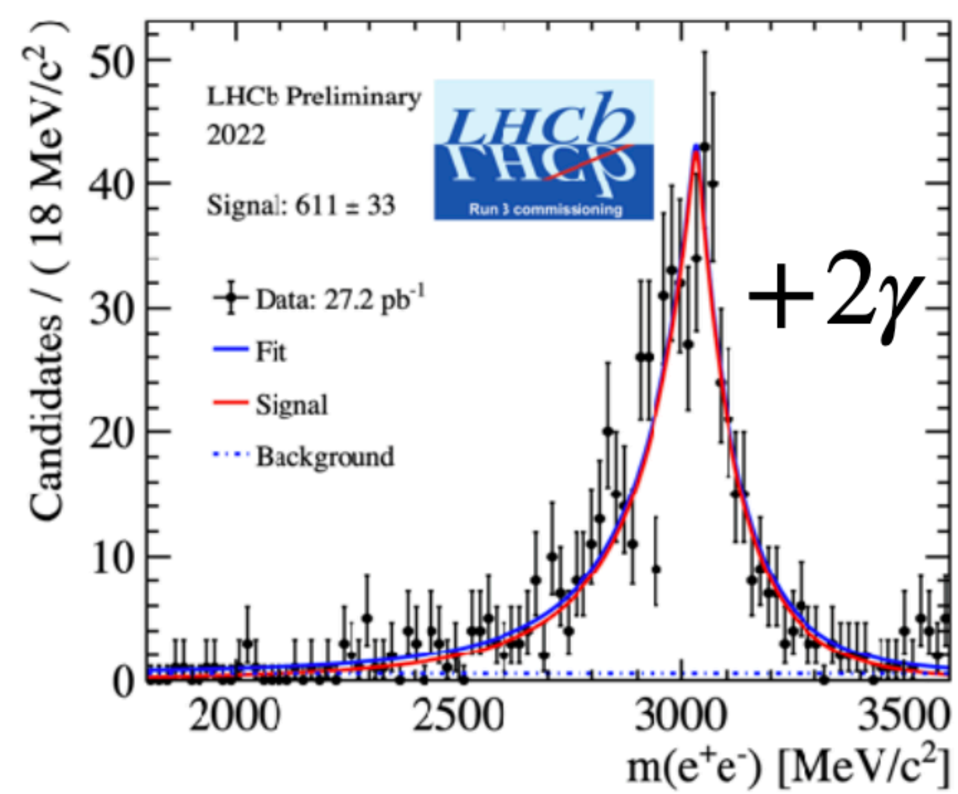
- Removal of the L0 trigger → softer p_T requirements: recover soft muons for strange, charm and tau physics

LHCb-PUB-2017-023



Electrons

- Removal of the L0 trigger → large efficiency increase and better kinematic overlap with the muon samples
- Calorimeter reconstruction and electronID algorithms heavily improved compared to Run1/2



LHCb-FIGURE-2023-010

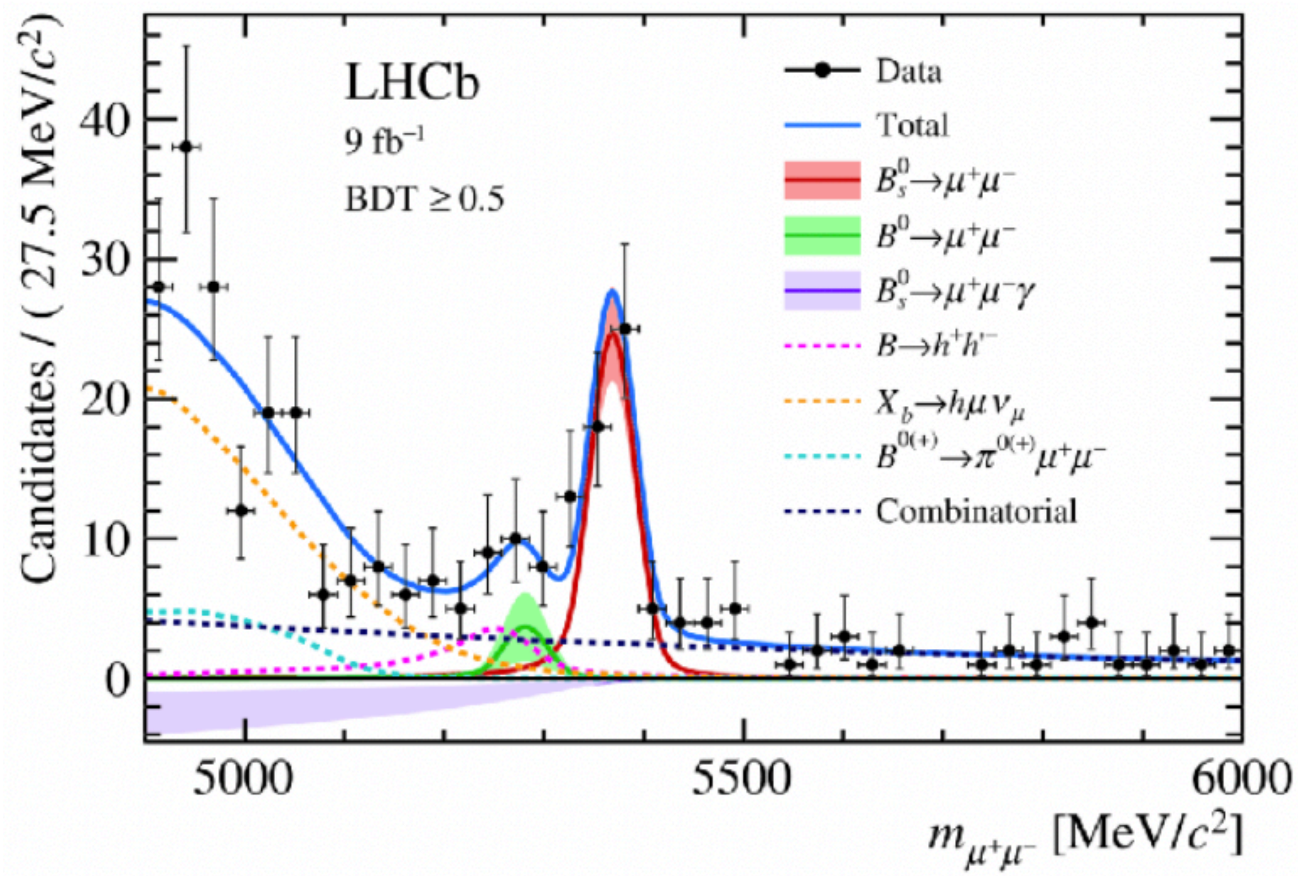
Vertexing

- Expected to improve the decay time resolution by 10% wrt Run1-2
- Better track/vertex association
  - → lower combinatorial background

The golden channel: $B_{(s)} \to \mu^+\mu^-$

- B_s mode well established, hint for B^0
- Plans for next measurements:
  - $\mathscr{B}(B^0 \to \mu\mu)/\mathscr{B}(B_s^0 \to \mu\mu)$
  - $\mathscr{B}(B_s^0) \to \mu\mu\gamma$
  - Effective lifetime and time-dependent CP asymmetry
- The improved vertexing and momentum resolution will help in keeping the combinatorial background under control
- f_s/f_d will probably be the dominant uncertainty with the Upgrade II detector ($300\ \mathrm{fb}^{-1}$)

[PRL128, (2022) 041801]



Observable	Current LHCb (up to $9\,\mathrm{fb}^{-1}$)	Upgrade I ($23\,\mathrm{fb}^{-1}$)	Upgrade I ($50\,\mathrm{fb}^{-1}$)	Upgrade II ($300\,\mathrm{fb}^{-1}$)
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69% [40, 41]	41%	27%	11%
$S_{\mu\mu}$ $(B_s^0 \to \mu^+\mu^-)$	—	—	—	0.2

Impact on rare charm

- General gain from L0 removal
- Better kinematic overlap of different modes
- Dedicated new trigger lines for better misID control

- Potential new limits on branching ratios* Upgrade 1, 2022-2030, and Upgrade 2, 2030+:

Mode	Run1-2 ($1\text{-}9\ \mathrm{fb}^{-1}$)	Upgrade1 ($50\,\mathrm{fb}^{-1}$)	Upgrade2 ($300\,\mathrm{fb}^{-1}$)
$D^0 \to \mu^+\mu^-$	$\cancel{6.2 \times 10^{-9}}$ 3.1×10^{-9}	4.2×10^{-10}	1.3×10^{-10}
$D^+ \to \pi^+\mu^+\mu^-$	6.7×10^{-8}	10^{-8}	3×10^{-9}
$D_s^+ \to K^+\mu^+\mu^-$	2.6×10^{-8}	10^{-8}	3×10^{-9}
$\Lambda_c^+ \to p\mu^+\mu^-$	9.6×10^{-8}	1.1×10^{-8}	4.4×10^{-9}
$D^0 \to e^\pm\mu^\mp$	1.3×10^{-8}	10^{-9}	4.1×10^{-9}

A.Contu - Towards ultimate precision in Flavour Physics, Durham (2-4 April 2019)

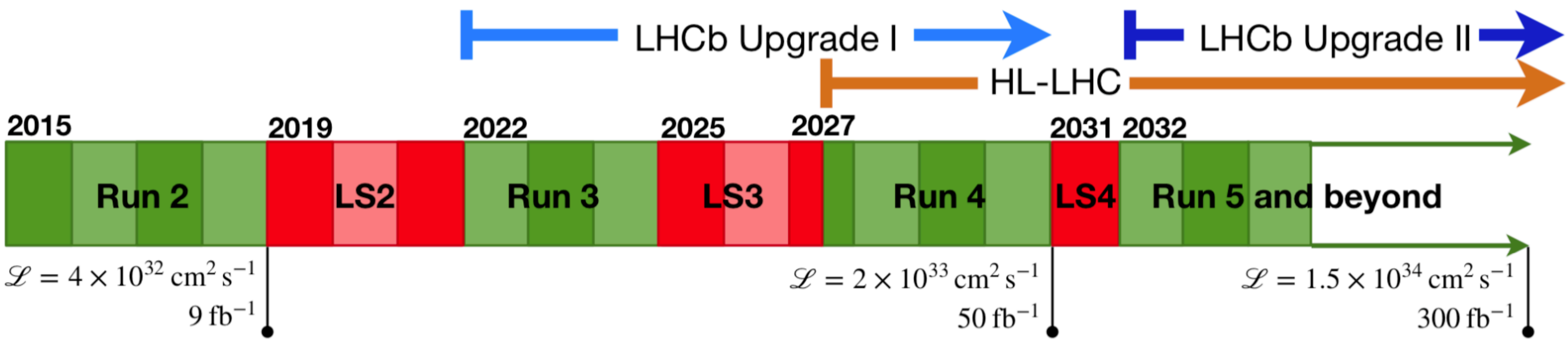
- Statistical precision* on asymmetries:

Mode	Run1-2 ($1\text{-}9\ \mathrm{fb}^{-1}$)	Upgrade1 ($50\,\mathrm{fb}^{-1}$)	Upgrade2 ($300\,\mathrm{fb}^{-1}$)
$D^+ \to \pi^+\mu^+\mu^-$		0.2 %	0.08 %
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	~~3.8 %~~ 2%	1 %	0.4 %
$D^0 \to K^-\pi^+\mu^+\mu^-$		0.3 %	0.13 %
$D^0 \to K^+\pi^-\mu^+\mu^-$		12 %	5 %
$D^0 \to K^+K^-\mu^+\mu^-$	~~11 %~~ 6%	4 %	1.7 %

A.Contu - Towards ultimate precision in Flavour Physics, Durham (2-4 April 2019)

Towards the ultimate precision

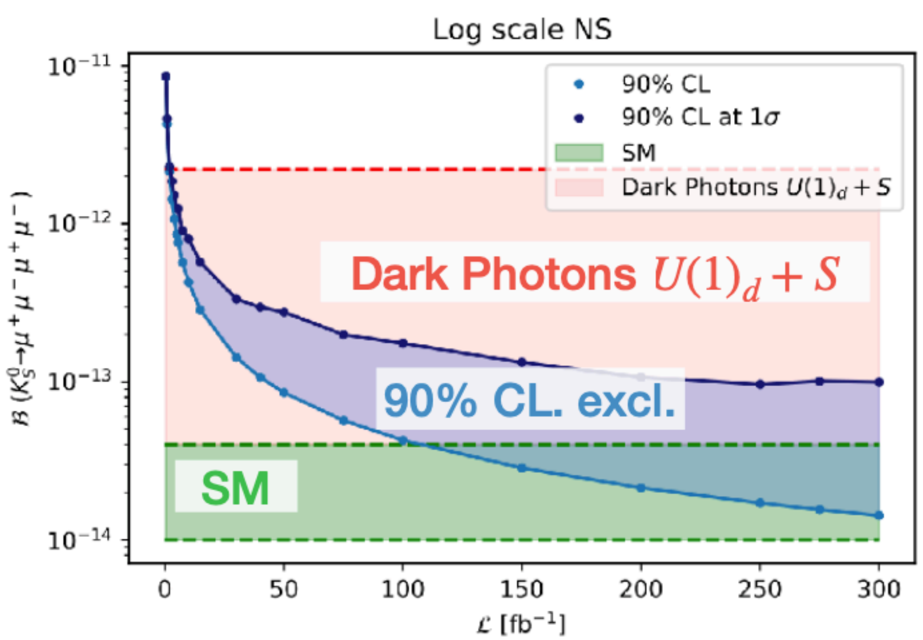
LHC schedule



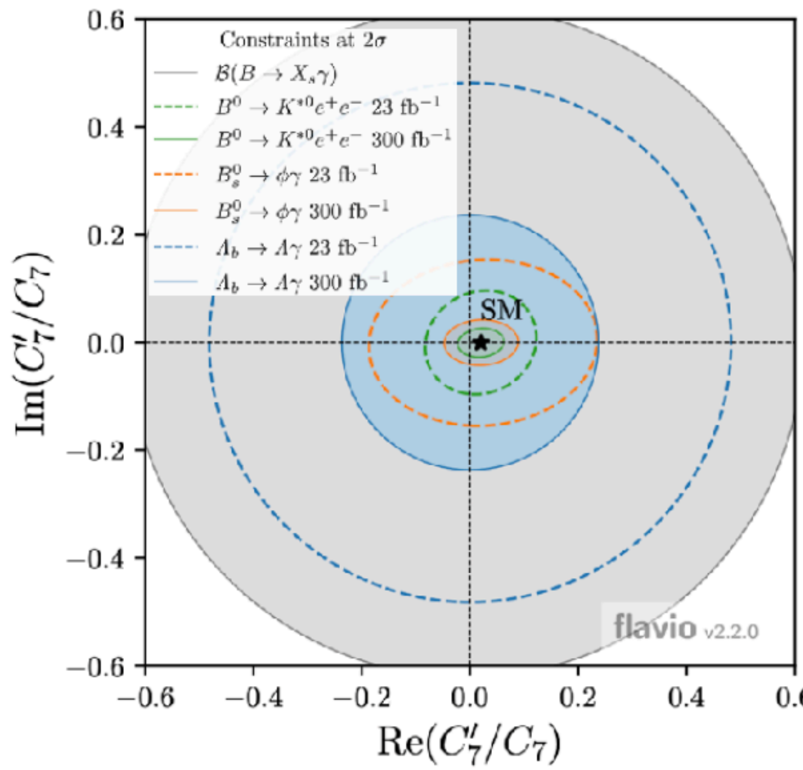
- **Very challenging goal**:
  - Operate at an instantaneous luminosity x7 larger than Run 3 conditions → PU~40
  - Retain the same performance and the flexibility provided by the software trigger
  - Accumulate $300\ \mathrm{fb}^{-1}$ by the end of Run 6
- Detector features:
  - Very similar layout as current spectrometer with major changes to all detectors
  - Remove HCAL, add TORCH (for low momentum PID), magnet stations and muon shields
  - Use of timing information to resolve primary vertices in the same bunch crossings
  - New ECAL with improved energy, position resolution and improved sensitivity at low E_T

What we can achieve with $300\ \mathrm{fb}^{-1}$

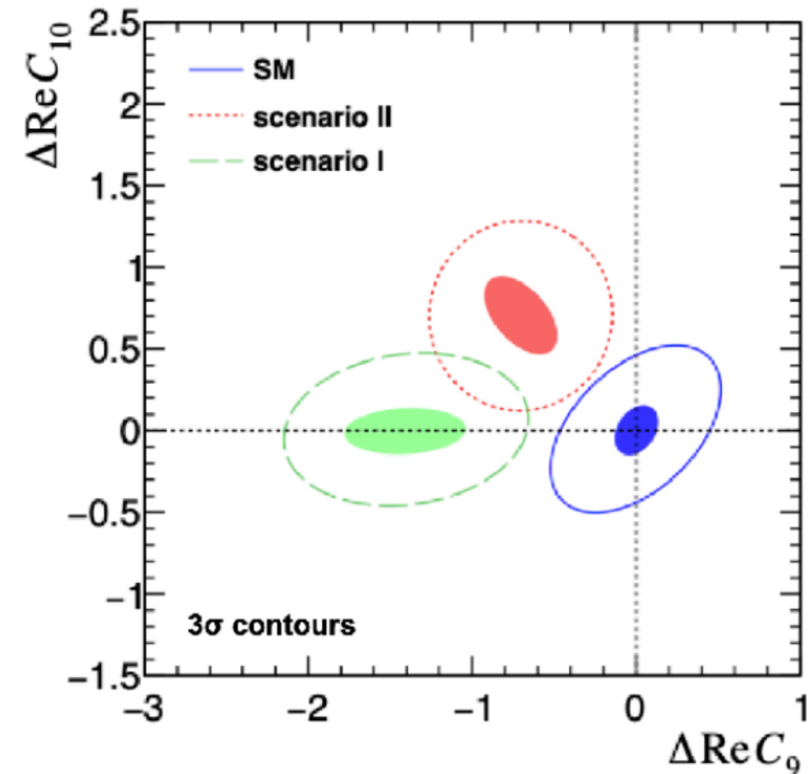
[D. Martinez Santos @Kaon22](#)



[FTDR-LHCbUII, LHCC 2021-012](#)



[LHCB-PUB-2018-009](#)



Lines: Run3
Shaded areas: Upgrade II

Strange decays

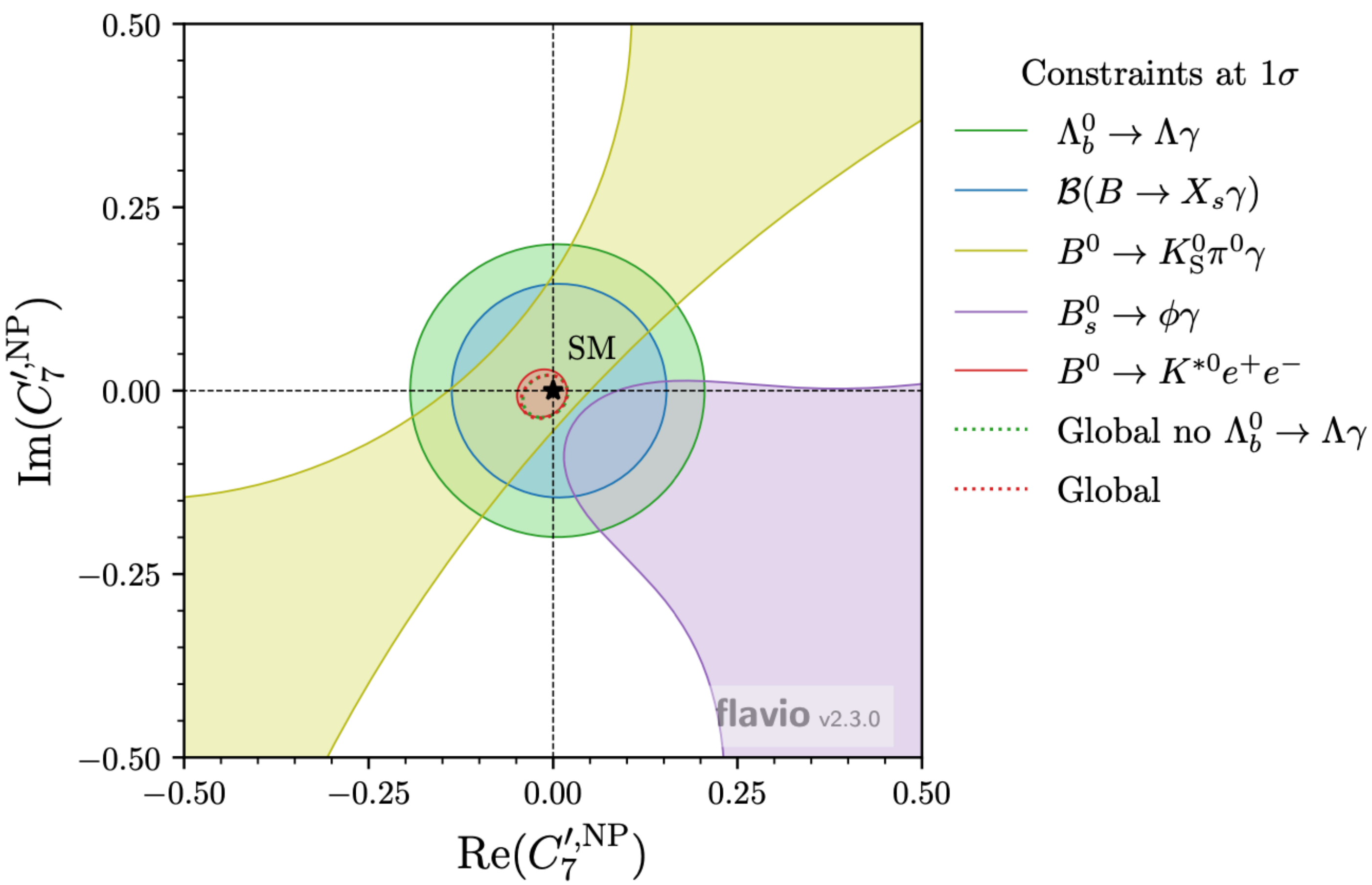
- K_s^0 decays unique to LHCb
- Sensitivity on K_L^0 decays might still compete with dedicated kaon experiments

High precision SM test thanks to gains on electrons and better neutral PID

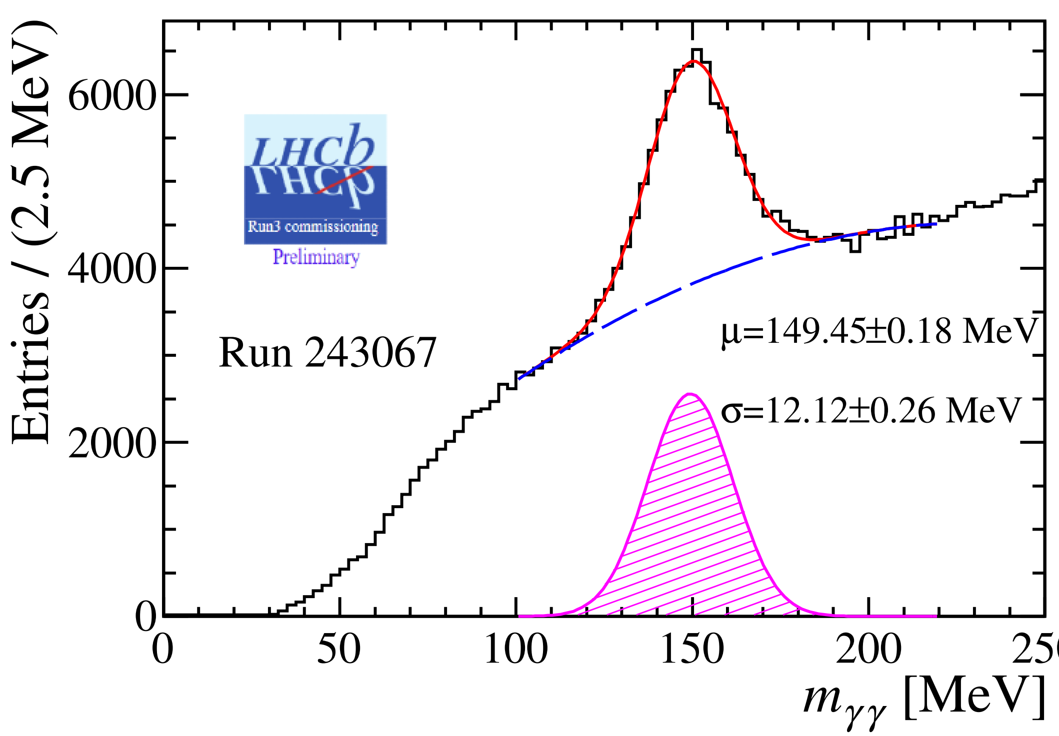
Discriminate between different NP models through the comparison of the angular distribution of dielectron and dimuon final-states

What about radiative decays?

- Similar prons and cons as electrons → higher level quantities to be optimised to recover efficiencies
- Benefits from higher statistics and potential for large impact:
- **ImC_7^{eff}**: time integrated CP asymmetry, $A_{CP}(B^0 \to K^*\gamma) \sim 2\text{Im}C_7^{eff}\text{Im}\Delta C_7$
- C_7': currently dominated by $B^0 \to K^* e^+ e^-$ but nice complementarity with other modes and the direct determination of the photon polarisation



[Phys. Rev. D105 (2022) L051104]



LHCb-FIGURE-2022-019

Conclusion

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- Rare decays constitutes a unique environment to look for NP
- LHCb is giving major contributions in the beauty, but also charm and strange sectors
- Many LHCb measurements are world's best, but there is still space for improvement with respect to SM predictions and to reach NP sensitivity
- New studies or update of some measurements are still expected with Run 1+2 data
- LHCb Upgrade I (Run 3-4) is currently taking data and will allow to push some boundaries, but rarer modes and differential BR measurements still expected to be statistically limited by the end of Run 4
- The full potential of the detector in flavour physics will be exploited with the Upgrade II (Run 5 and beyond)

Thanks for you attention!

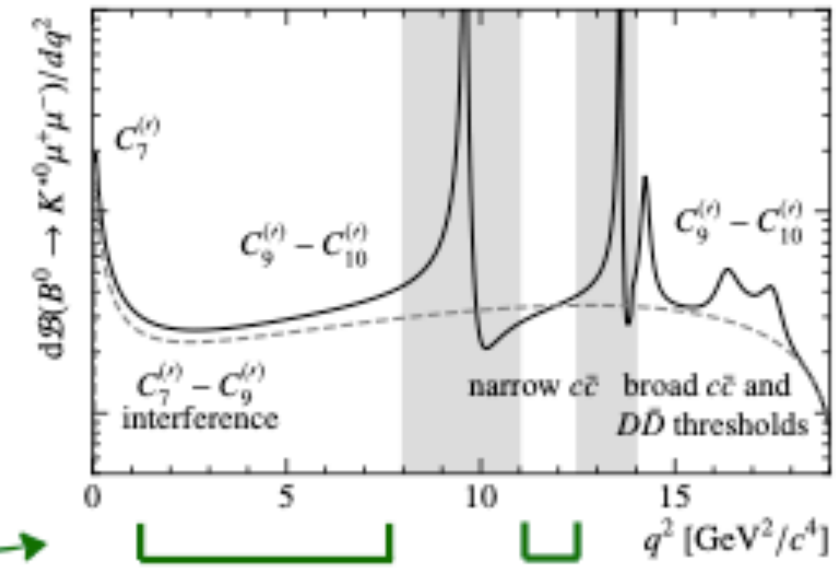
Backup

Analysis overview

[LHCb-PAPER-2023-032]
[LHCb-PAPER-2023-033]
in preparation

Slide taken from the talk of A. Mauri at CKM23

- Same dataset of previous LHCb $B^0 \to K^{*0}\mu^+\mu^-$ binned angular analysis (Run-I + 2016) $4.7\ \mathrm{fb}^{-1}$
  - two q^2 regions: $[1.1, 8.0]$ & $[11, 12.5]$ GeV



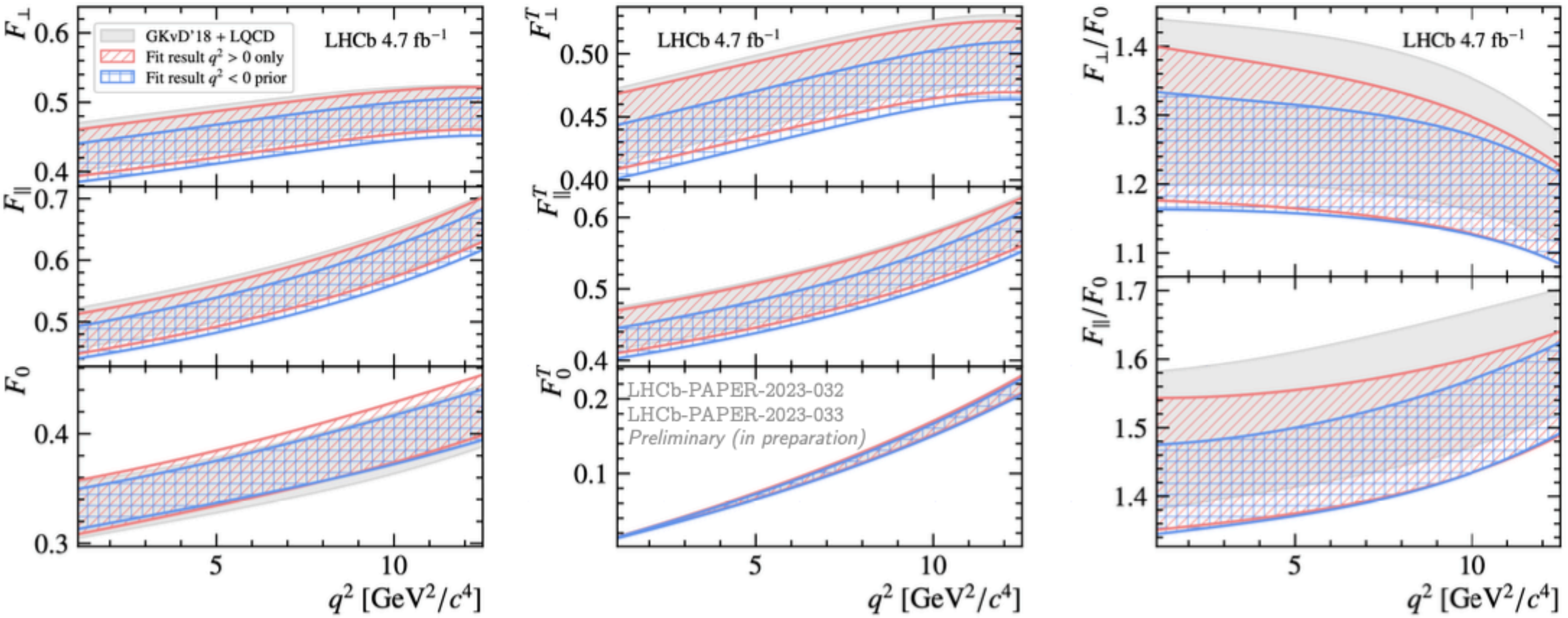
- Six-dimensional fit
  - `differential decay rate + invariant B mass to separate signal from combinatorial background

- Large number of signal parameters
  - Wilson coefficients: $\mathcal{C}_9, \mathcal{C}_{10}, \mathcal{C}'_9, \mathcal{C}'_{10}$ [floated] + $\mathcal{C}_7, \mathcal{C}'_7$ [fixed to SM]
  - local FF : [constrained to LCSR + latticeQCD] JHEP 01 (2019) 150, *PoS* LATTICE2014 (2015) 372
  - non-local hadronic parameters $\mathcal{H}_\lambda(q^2)$ (see next slides)
  - S-wave (FFs + relative magnitude&phase)

Results: form-factors

LHCb-PAPER-2023-032
LHCb-PAPER-2023-033
in preparation

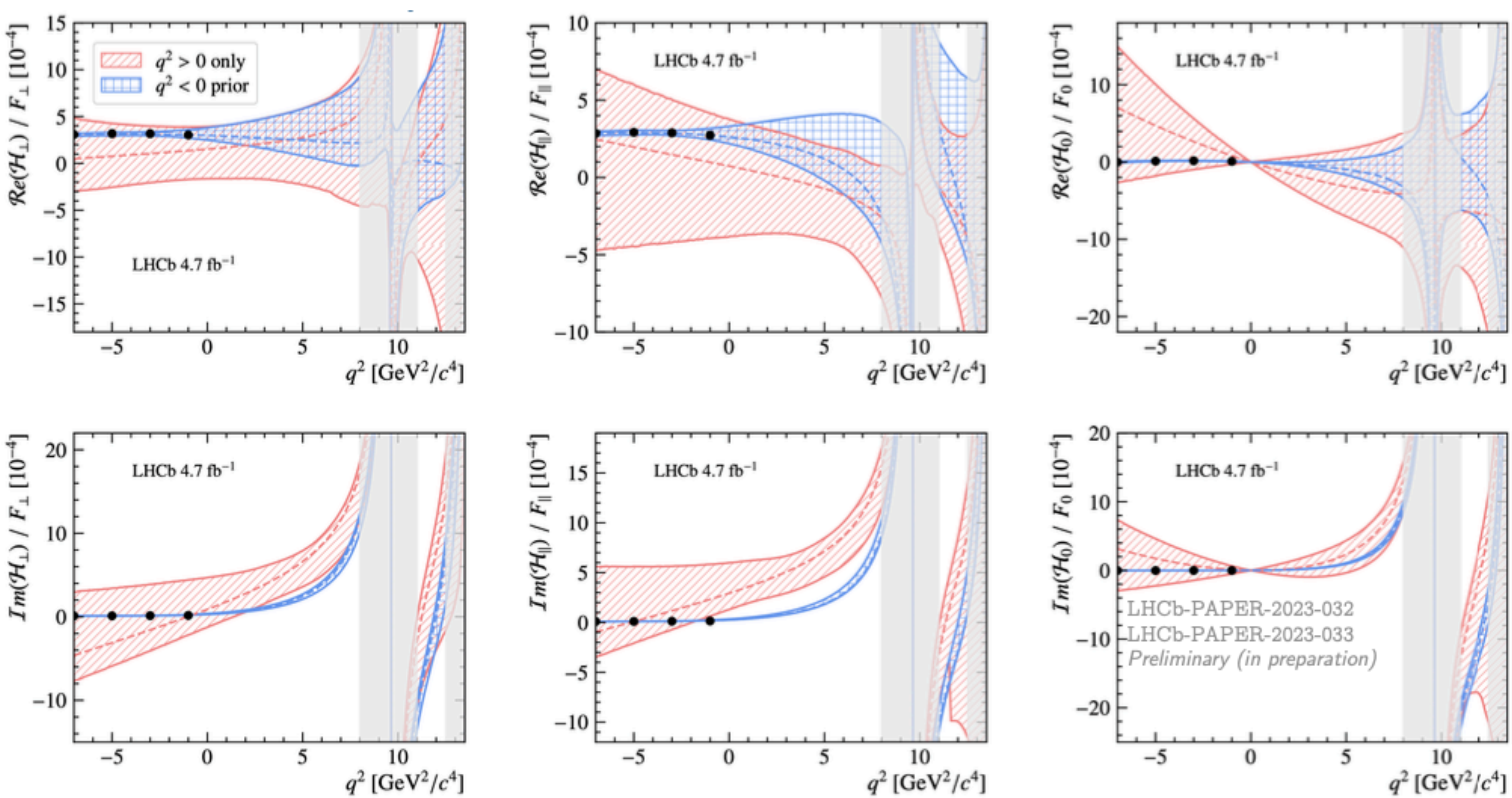
- Overall good agreement with theory, mild preference for lower $F_{\perp,\parallel}/F_0$



Results: charm-loop matrix elements

[LHCb-PAPER-2023-032]
[LHCb-PAPER-2023-033]
in preparation

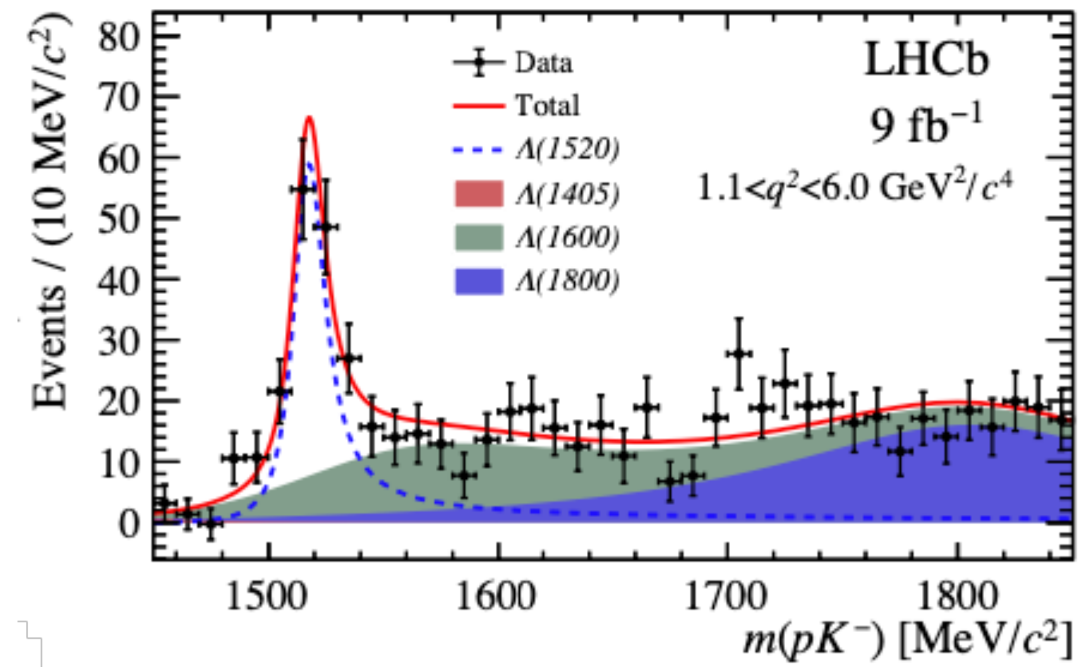
- Fit results compatible, some discrepancies in the imaginary parts

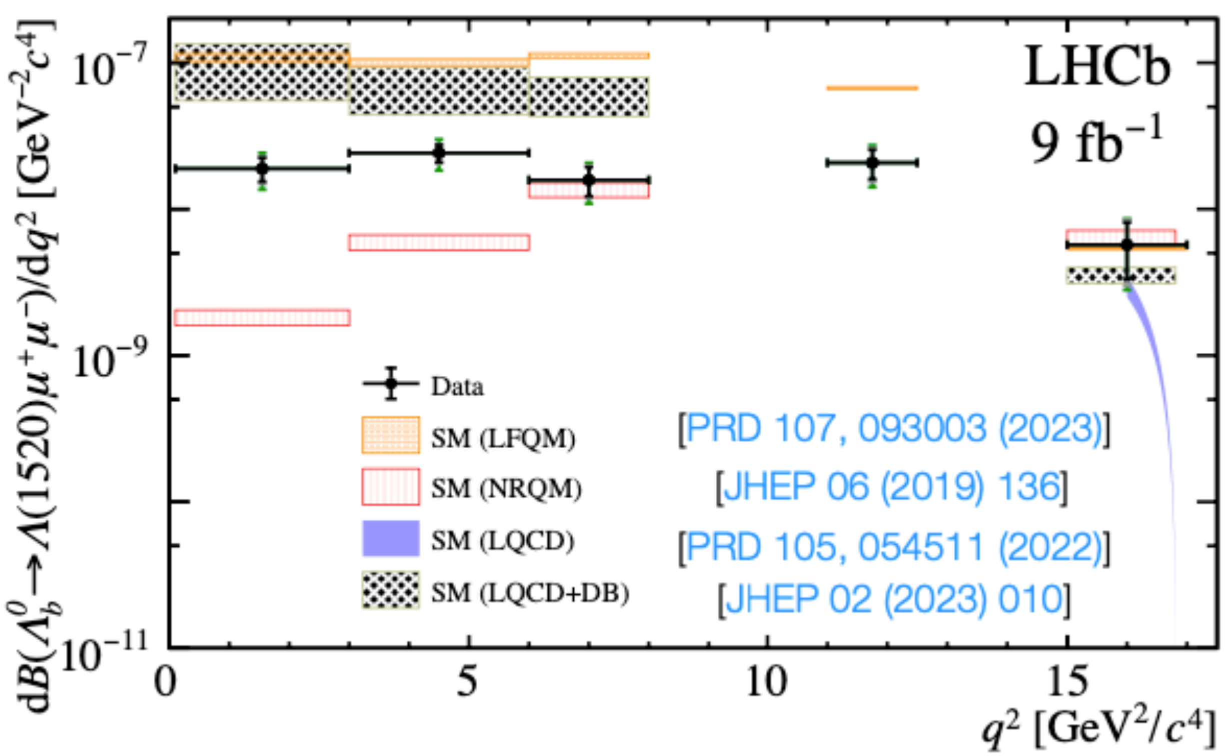


$\Lambda_b \to \Lambda(1520)\mu^+\mu^-$

[PRL 131 (2023) 151801]

- Previous measurement of the branching fraction of the ground state [JHEP 06 (2015) 115]
- New measurement of the $\Lambda(1520)$ in the pK spectrum
- Agreement with theory in high q^2 region
- Significant disagreement in the low q^2 region





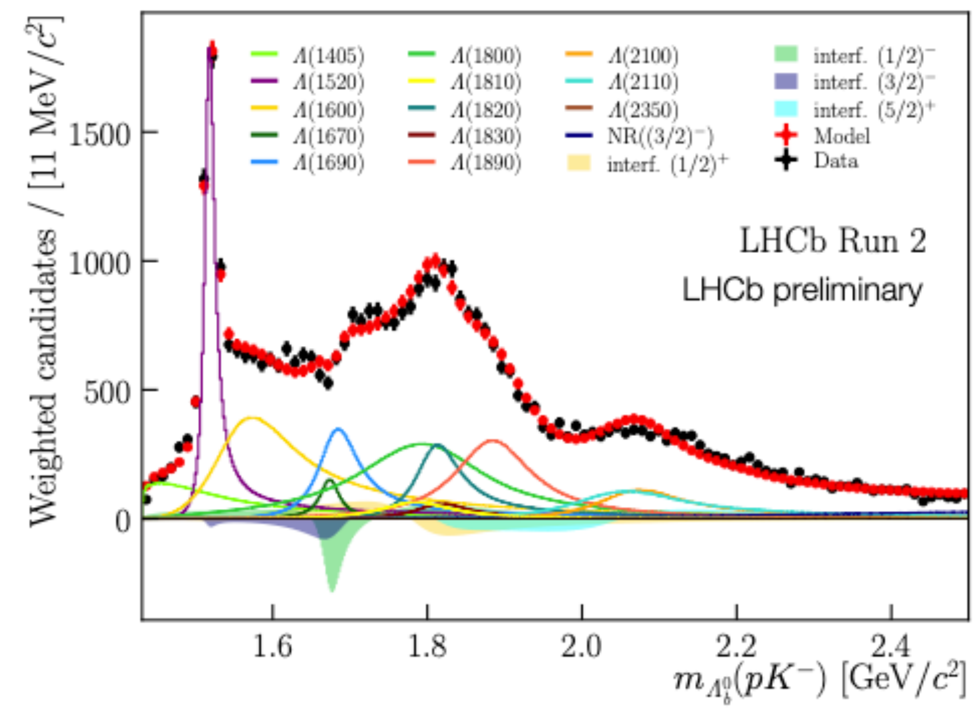
stat. ± syst. ± $\Lambda_b \to pK^- J/\psi$ and $J/\psi \to \mu^+\mu^-$

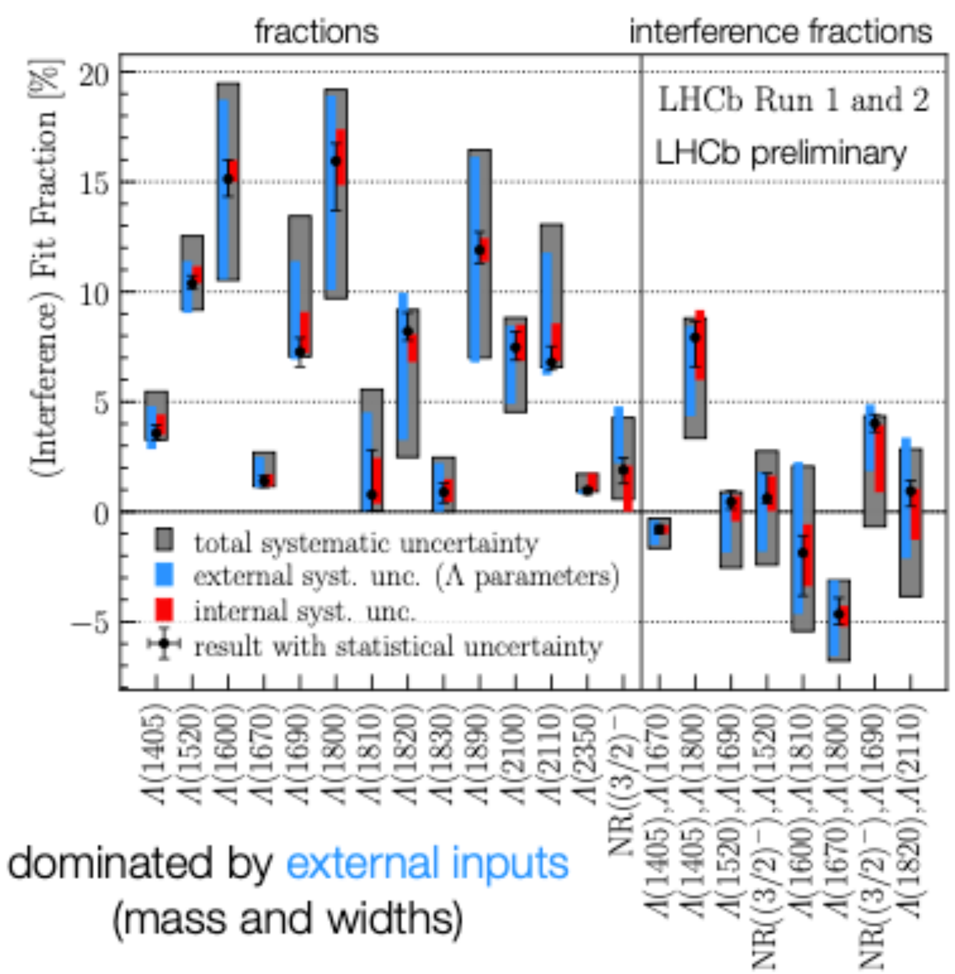
q^2 interval [GeV$^2/c^4$]	$N_{\Lambda(1520)\mu^+\mu^-}$	$\frac{d\mathcal{B}(\Lambda_b^0\to\Lambda(1520)\mu^+\mu^-)}{dq^2}$ [10^{-8} GeV$^{-2}c^4$]
0.1–3.0	96 ± 18	$1.89 \pm 0.35 \pm 0.19 \pm 0.36$
3.0–6.0	138 ± 18	$2.42 \pm 0.32 \pm 0.17 \pm 0.45$
6.0–8.0	65 ± 14	$1.58 \pm 0.36 \pm 0.16 \pm 0.30$
11.0–12.5	59 ± 14	$2.07 \pm 0.47 \pm 0.26 \pm 0.39$
15.0–17.0	12 ± 5	$0.57 \pm 0.24 \pm 0.13 \pm 0.11$
1.1–6.0	175 ± 21	$1.95 \pm 0.23 \pm 0.16 \pm 0.37$

Amplitude analysis of $\Lambda_b \to pK\gamma$

LHCb-PAPER-2023-036
in preparation

- $\Lambda_b \to pK\ell\ell$ deeply investigated in LHCb:
  - LFU measurement R_{pK} [JHEP 05 (2020) 040]
  - Branching fractions [PRL 131 (2023) 151801]
  - CP violation measurement [JHEP 06 (2017) 108]
- Hard to interpret due to poor knowledge of the pK spectrum
- We can gain information in terms of resonance structure:
  - Measurement with $\Lambda_b \to pKJ/\psi$ with the discovery of a new state $P_c(4450)$
  - $\Lambda_b \to pK\gamma$ gives access to heavier states with $m(pK) > 2$ GeV/c^2
- Amplitude analysis: final decay rate is the sum over Λ resonances and possible helicities
- Best model containing the Λ states with $L \leq 3$ plus a non-resonant component with $J^P = 3/2$

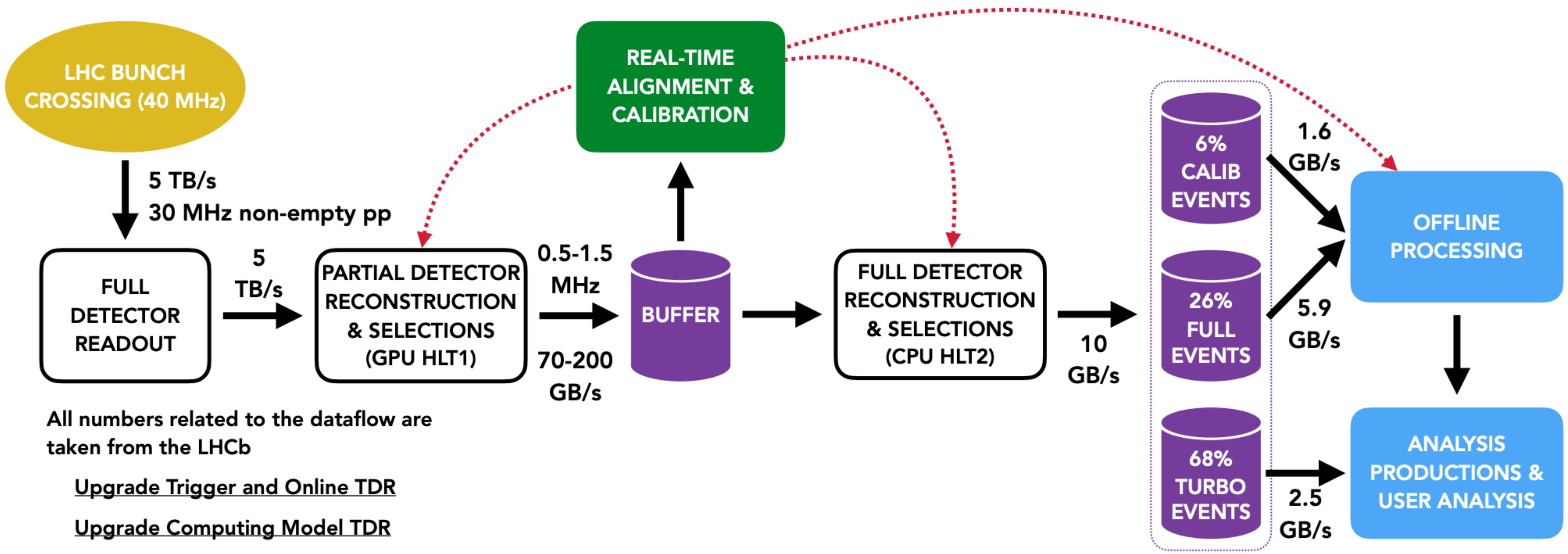




dominated by external inputs
(mass and widths)

The LHCb data flow

LHCB-FIGURE-2020-016



- Detector data @30 MHz received by O(500) FPGAs
- 2-stage software trigger, HLT1 & HLT2
- Real-time alignment & calibration
- After HLT2, 10 GB/s of data for offline processing