Rare decays

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on behalf of LHCb and Belle/Belle-II collaborations

Setting up the scene

New results : LFU tests, angular analyses and time-dependent CP violation

Why rare decays ?

- Change of paradigm: not any more theory driven
- Which are the sources of flavour symmetry breaking we observed ?
- History is telling us that rare decays (FCNC) are powerful tools

Rule of the game

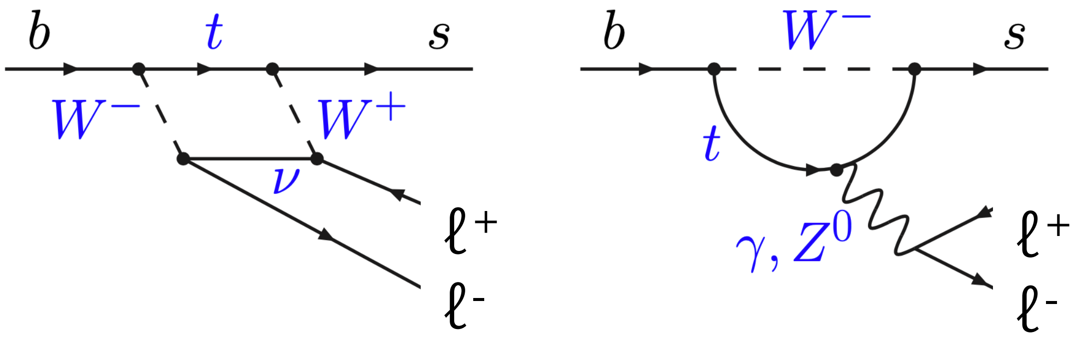
- Precisely predicted
- Precise measurements (as much as possible !)

What is rare ?

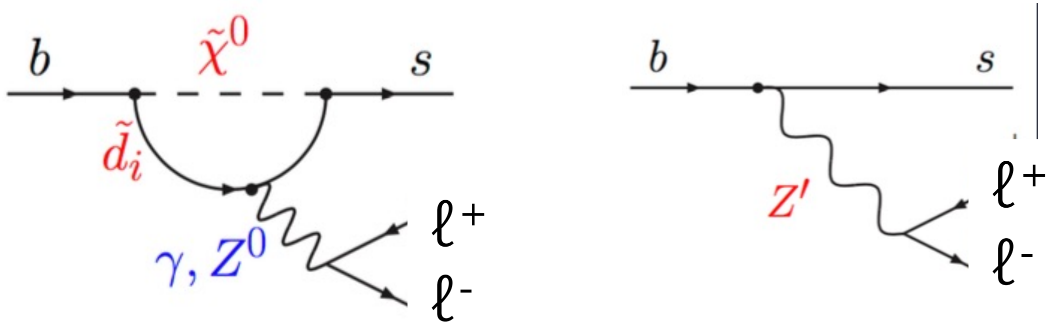
$BR_{eff} < 10^{-6}$

Flavour Changing Neutral Currents

SM



New Physics (examples)



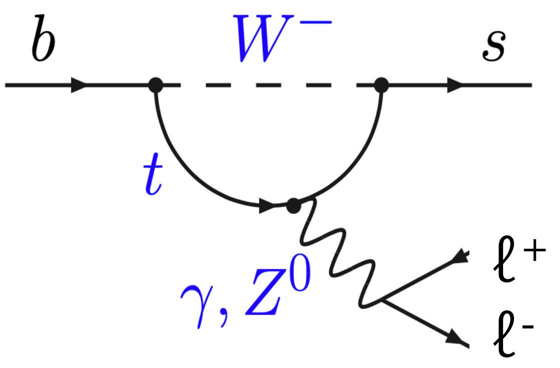
Relative importance of the different diagrams varies with $q^2 = M^2(\ell^+\ell^-)$. Eg : photon pole dominates when $q^2 \rightarrow 0$

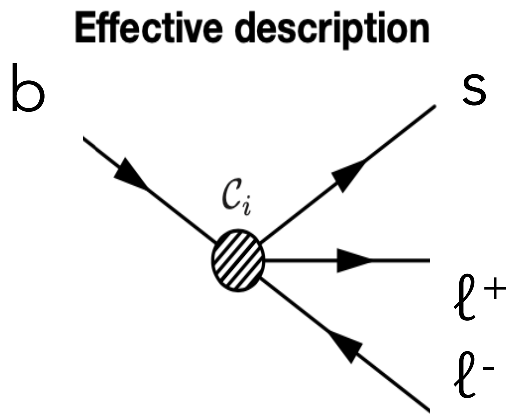
How NP would manifest ?

- Modification of the decay rates (↑ or ↓)
- Modification of the angular distributions
- New sources of CP violation

Potentially different for $b \rightarrow s\mu^+\mu^-$ and $b \rightarrow se^+e^-$

Description using an effective field theory



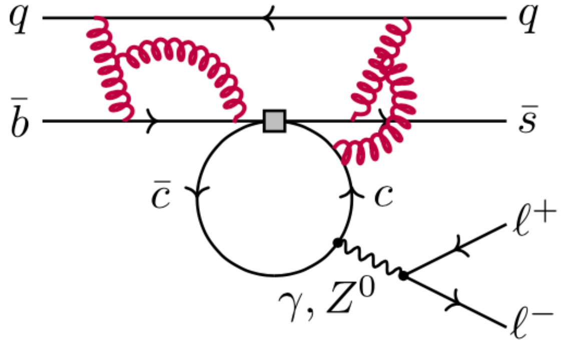


$C_7^{(\prime)}, C_{9,10}^{(\prime)}$

$$H_{\text{eff}} \propto V_{tb} V_{ts}^* \sum_i (C_i \mathcal{O}_i + C_i' \mathcal{O}_i')$$

$O_i^{(\prime)}$ operator encoding Lorentz structure

$$C_i^{(\prime)} = C_i^{SM\,(\prime)} + C_i^{NP\,(\prime)}$$



QCD challenges:

- working with hadrons ⇒ local form factors
- qq loops ⇒ non-local form factors + non factorizable soft gluon corrections

$$C_i^{(\prime)} = C_i^{SM\,(\prime)} + C_i^{NP\,(\prime)} + C_i^{had\,(\prime)}$$

What to measure ?

In general BR are $\mathcal{O}(10^{-7})$
→LHC large production is clearly a plus
→comes with the cost of a very challenging experimental environment

- b→s μμ channels :
  - clean experimental signature
  - precise experimental results on a large number of BR and angular observables in a fine q^2 binning
- b→s ee channels :
  - low p_T electrons in the harsh LHC context
  - limited number of results
  - A corner of the phase space provides powerful constraints on C_7'

Branching Ratios

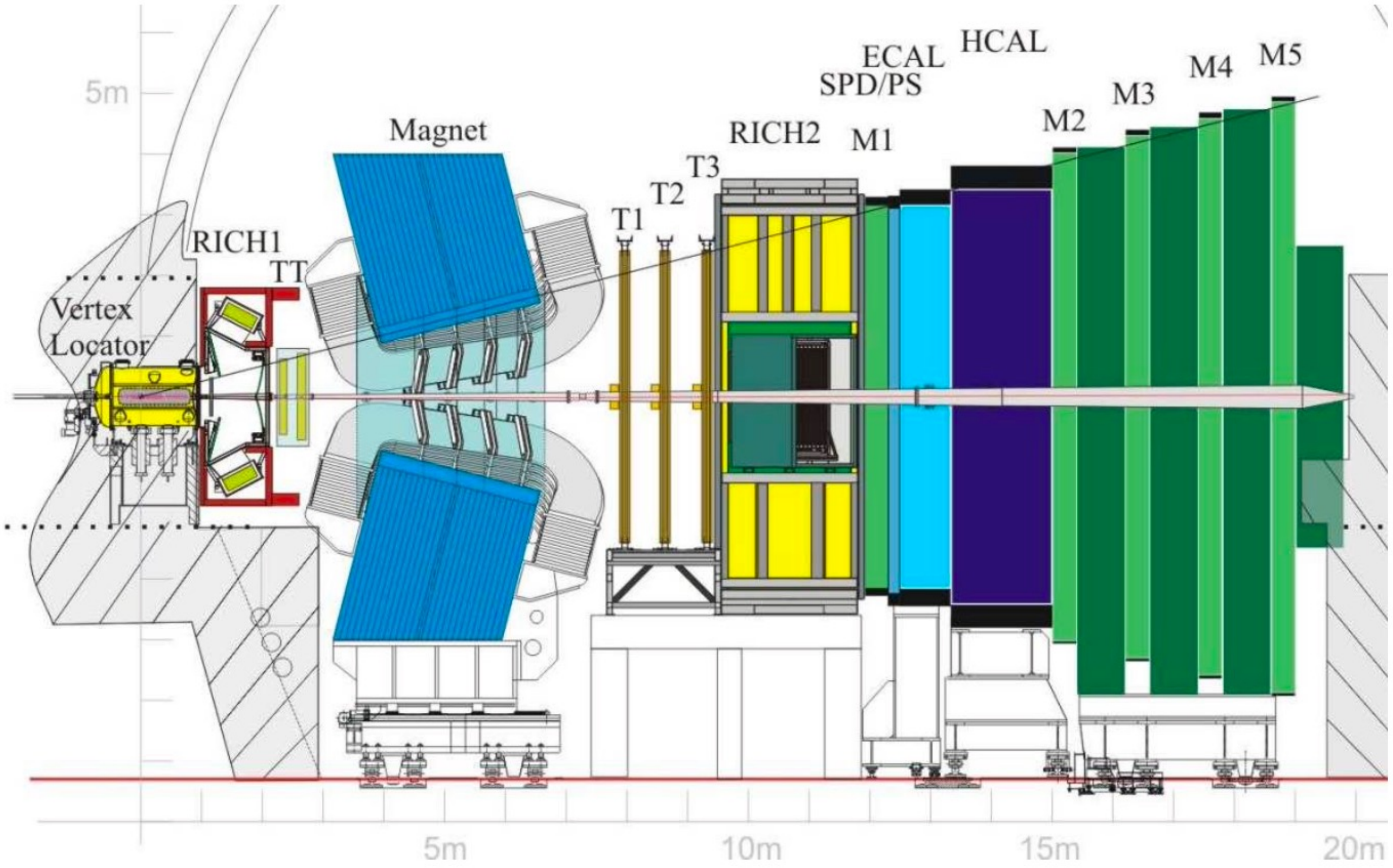
Angular observables

LFU observables :
R-ratios
angular observables differences

↓ theoretical cleanness

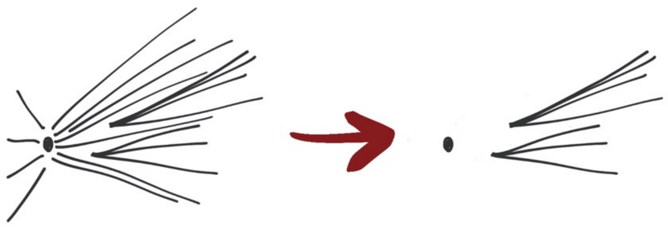
Most of the rare decays results are obtained by LHCb

Results obtained using 2011-2018 datasets (9 fb^{-1})



$\Delta p / p = 0.5 - 1.0\%$

$\Delta IP = (15 + 29/p_T[GeV])\ \mu m$



$\Delta E/E_{ECAL} = 1\% + 10\% / \sqrt{(E[GeV])}$

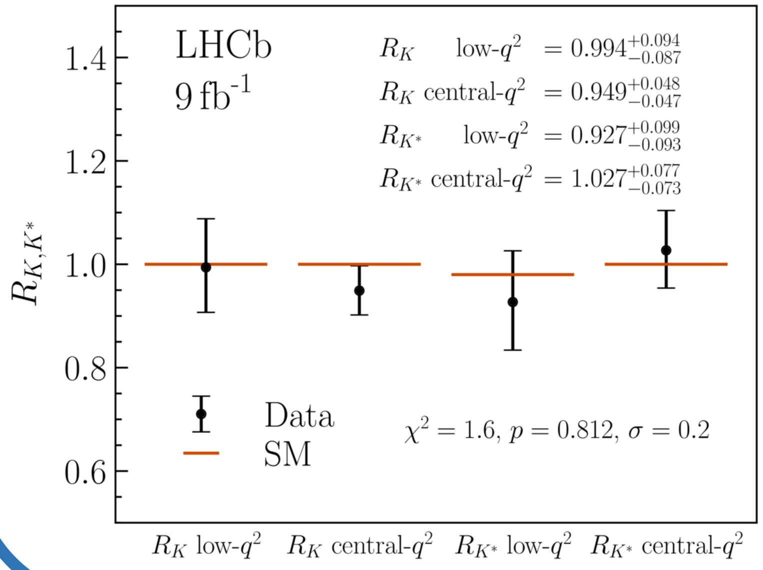
Electron ID ~90% for ~5% $h \rightarrow e^{\pm}$ mis-id probability

Muon ID ~ 97% for 1-3% $\pi \rightarrow \mu$ mis-id probability

Current situation

Test of LFU on Branching Ratios in agreement with SM

Phys. Rev. D 108 (2023) 032002
Phys. Rev. Lett. 131 (2023) 051803



- 5 to 10 % precision
- dominated by statistical uncertainty

$B^{+,0}$, B_S, Λ_b — K, K^*, ϕ, pK …

$$R_{H_s} = \frac{\int \frac{d\Gamma(B \to H_s\, \mu^+\mu^-)}{dq^2}\, dq^2}{\int \frac{d\Gamma(B \to H_s\, e^+ e^-)}{dq^2}\, dq^2} \overset{SM}{\cong} 1$$

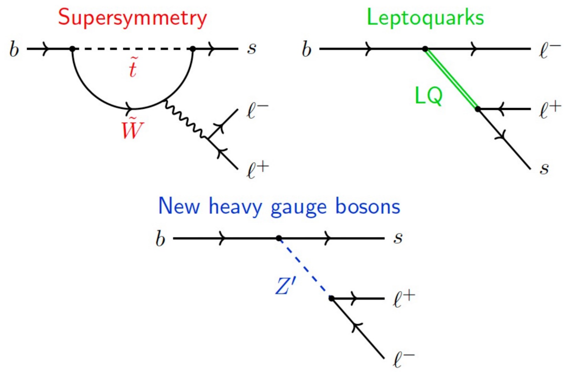
Recent CMS result [CMS-PAS-BPH-22-005]
less precise but in agreement

$R(K) = 0.78^{+0.47}_{-0.23}$

Persistent tensions:

- BR measurements (a lot of modes)
- angular analyses : precise measurements in $K^*\mu\mu$

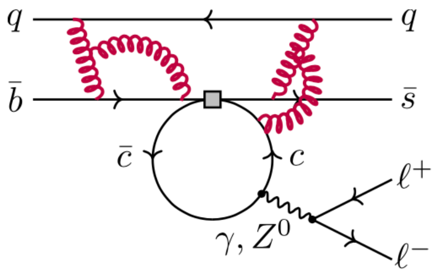
New Physics showing up

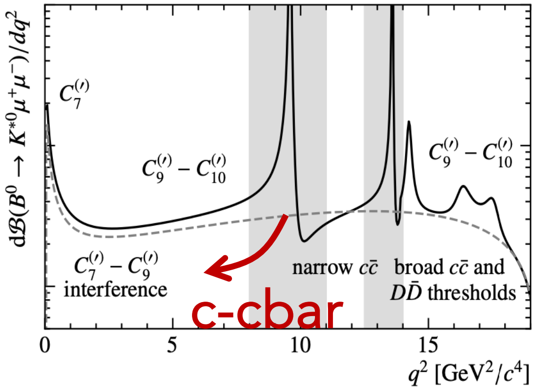


or

?

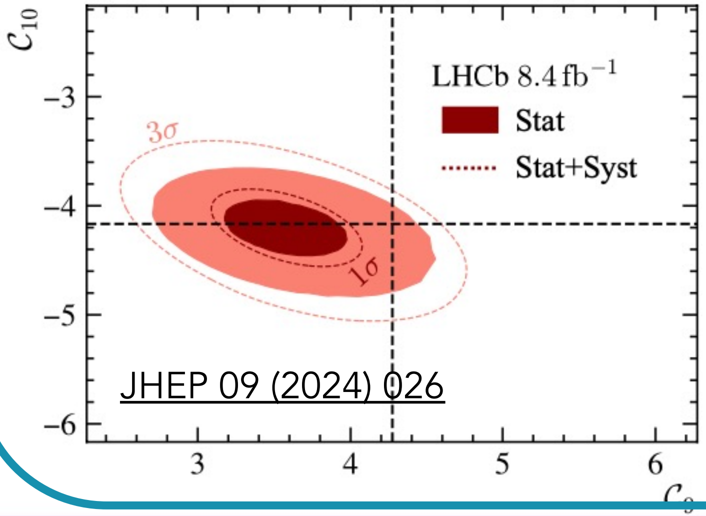
Mismodelling of SM (non perturbative QCD) predictions





Use of data to also extract non-local contributions

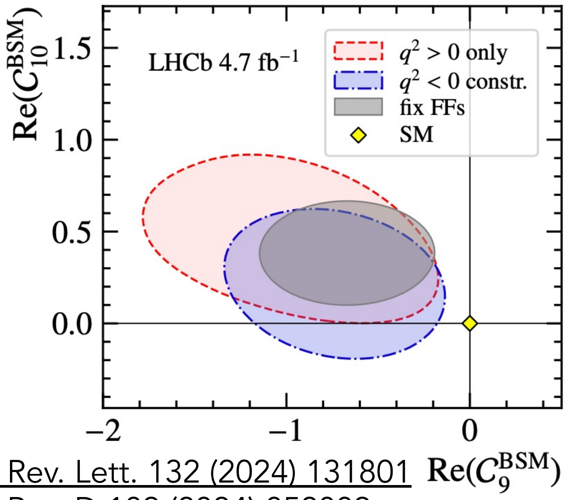
q^2 - unbinned fit with parametrisation of the decay in terms of Wilson coefficients, Form Factors, and non-local contributions



JHEP 09 (2024) 026

- Non-local contributions seem larger than what has been assumed so far
- C_9 still shifted from SM
- More data is needed

q^2 unbinned amplitude analysis



Phys. Rev. Lett. 132 (2024) 131801

Phys. Rev. D 109 (2024) 052009

Cherry picked results

Tests of LFU:

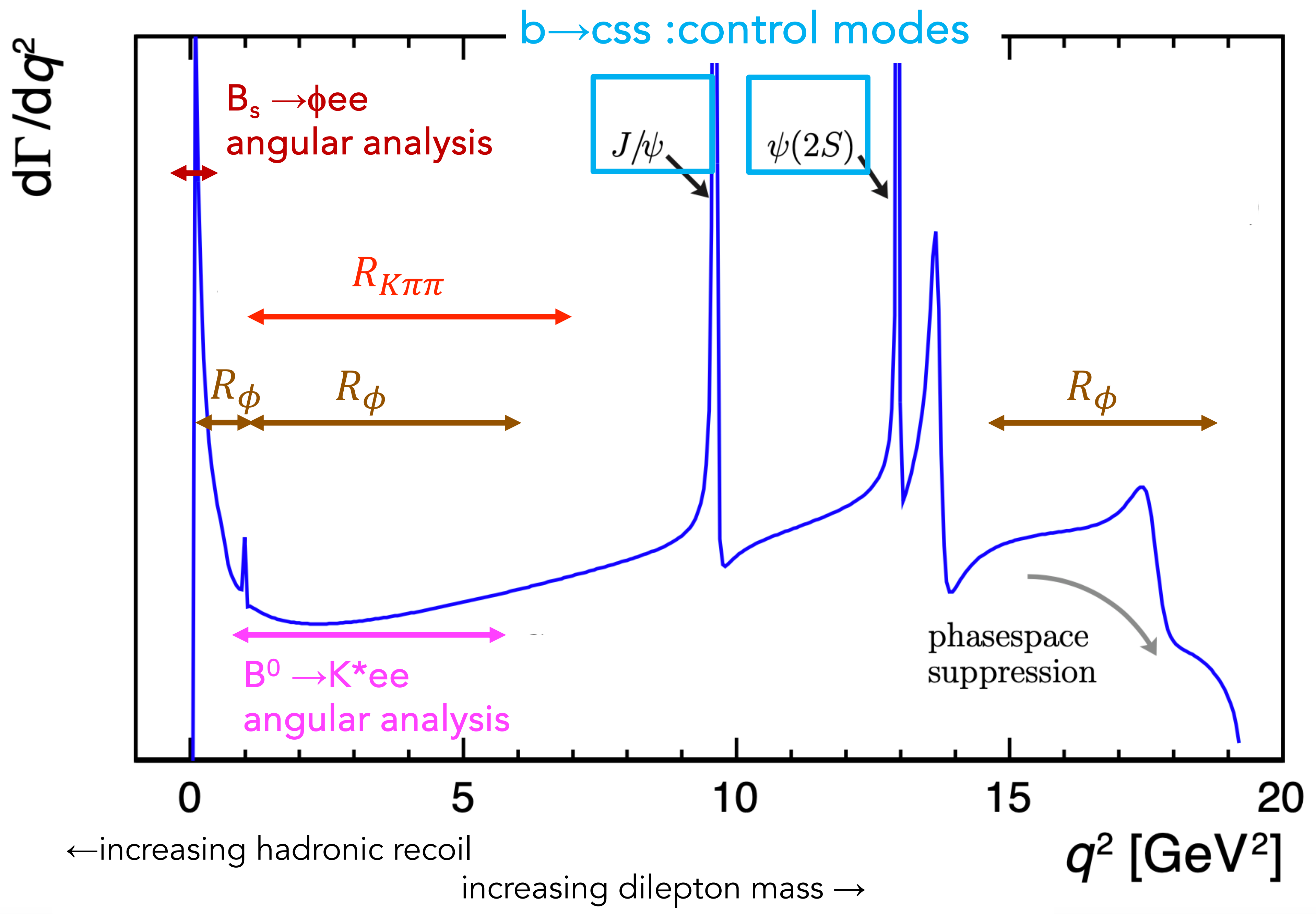
1. $R_{\phi} = \frac{BR(B_s \to \phi\mu\mu)}{BR(B_s \to \phi ee)}$
2. $R_{K\pi\pi} = \frac{BR(B^{\pm} \to K\pi\pi\,\mu\mu)}{BR(B^{\pm} \to K\pi\pi\,ee)}$
3. $B^0 \to K^*ee$ angular analysis

Measurement of the photon polarization in $b \to s\gamma$:

1. $B_s \to \phi ee$ angular analysis
2. Time dependent CP violation (Belle II)

Some common features for the 4 LHCb analyses

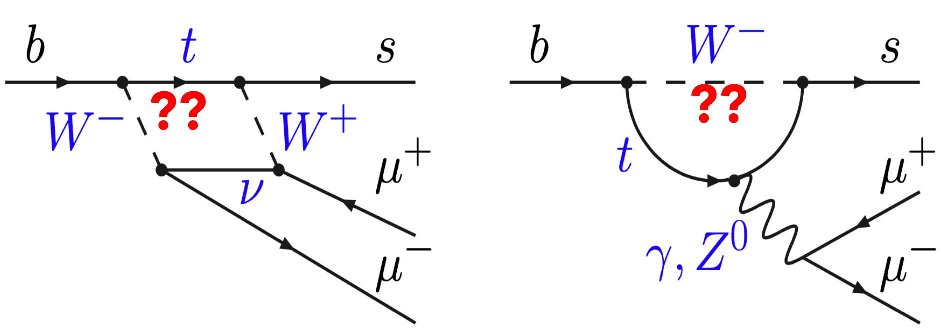
- Full Run1 + Run2 statistics (9 fb^{-1})
- e+e- in the final state
- Electron and charged hadrons identification very similar to R_X (Phys. Rev. D 108 (2023) 032002) in most of the case *h*→e residual contamination extracted from data
- Dominating background is of combinatorial nature: removed using multivariate techniques relying on kinematical and vertexing variables

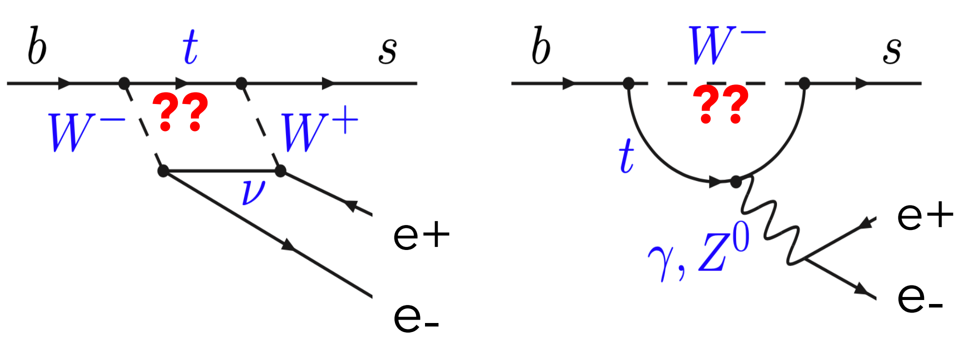

b→css :control modes
$d\Gamma/dq^2$
$B_s \to \phi ee$
angular analysis
J/ψ
$\psi(2S)$
$R_{K\pi\pi}$
R_ϕ
R_ϕ
R_ϕ
$B^0 \to K^*ee$
angular analysis
phasespace
suppression
0
5
10
15
20
q^2 [GeV^2]
←increasing hadronic recoil
increasing dilepton mass →

Tests of Lepton Flavour Universality : $B_s \to \phi \ell \ell$ and $B^{\pm} \to K \pi \pi \ell \ell$

[LHCb-PAPER-2024-032, in preparation]

[LHCb-PAPER-2024-046, in preparation]





Tests of LFU using $B_s \to \phi\ell\ell$: general strategy

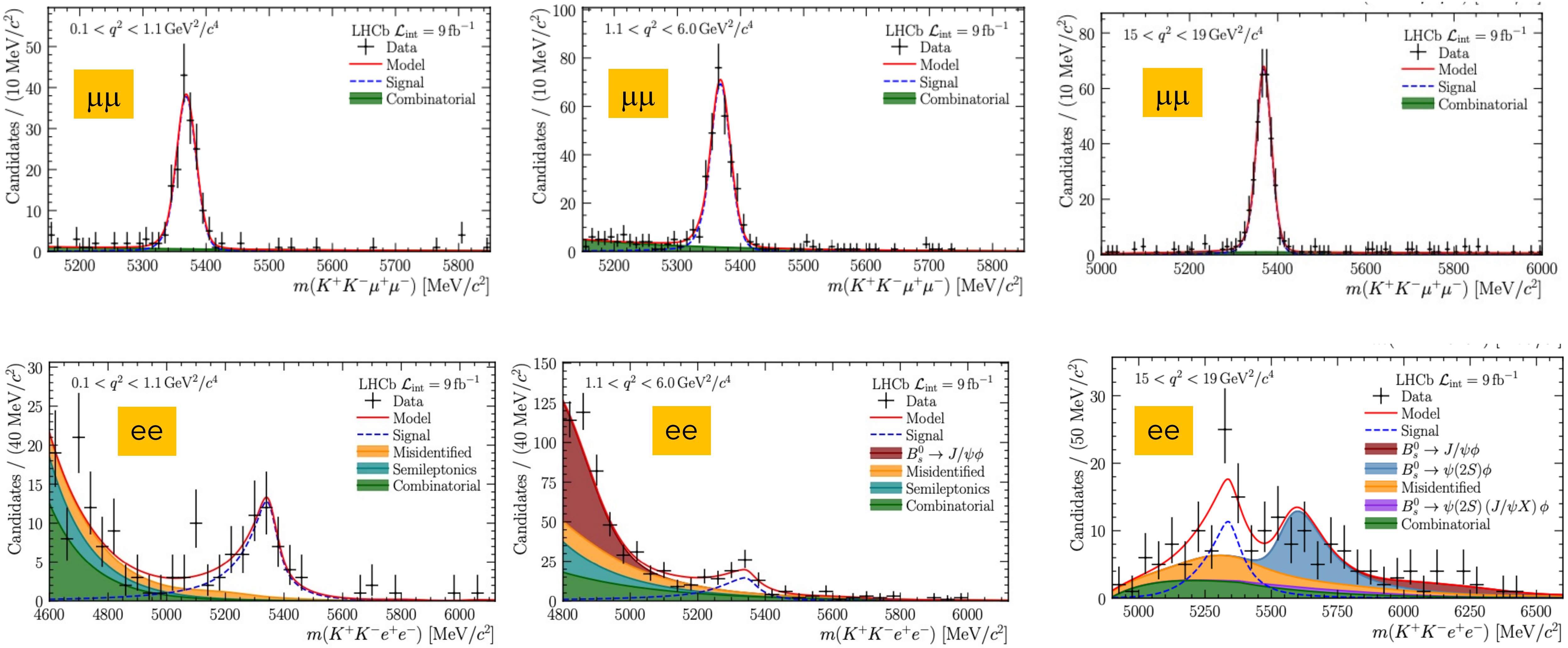
$$R_\phi^{-1} = \frac{\frac{\mathcal{N}}{\mathcal{E}} B(B_s \to \phi ee)}{\frac{\mathcal{N}}{\mathcal{E}} B\big(B_s \to \phi J/\psi(ee)\big)} \Bigg/ \frac{\frac{\mathcal{N}}{\mathcal{E}} B(B_s \to \phi\mu\mu)}{\frac{\mathcal{N}}{\mathcal{E}} B\big(B_s \to \phi J/\psi(\mu\mu)\big)}$$

$$\frac{\Gamma(J/\psi \to e^+e^-)}{\Gamma(J/\psi \to \mu^+\mu^-)} = 1 \text{ [PDG]}$$

- Double ratio using the resonant channels ⇒ cancel out most of the systematics due to e/μ differences
- Yields obtained from mass fits
- Efficiencies obtained from corrected MC using data-driven techniques

- Blind analysis in 3 q^2 ($=M^2(\ell\ell)$) regions
- Narrow ϕ resonance, no partially reconstructed hadronic background ("ϕ^{**} ")
- Combinatorial & double semi-leptonic backgrounds suppressed using multivariate classifiers
- Residual hadron→e mids-ID background measured from data

Low-q^2 | Central-q^2 | High-q^2



$$R_\phi^{-1}(\mathrm{low}-q^2) = 1.57\,^{+0.28}_{-0.25} \pm 0.05$$
$$R_\phi^{-1}(\mathrm{central}-q^2) = 0.91\,^{+0.20}_{-0.19} \pm 0.05$$
$$R_\phi^{-1}(\mathrm{high}-q^2) = 0.85\,^{+0.24}_{-0.23} \pm 0.09$$

In agreement with SM

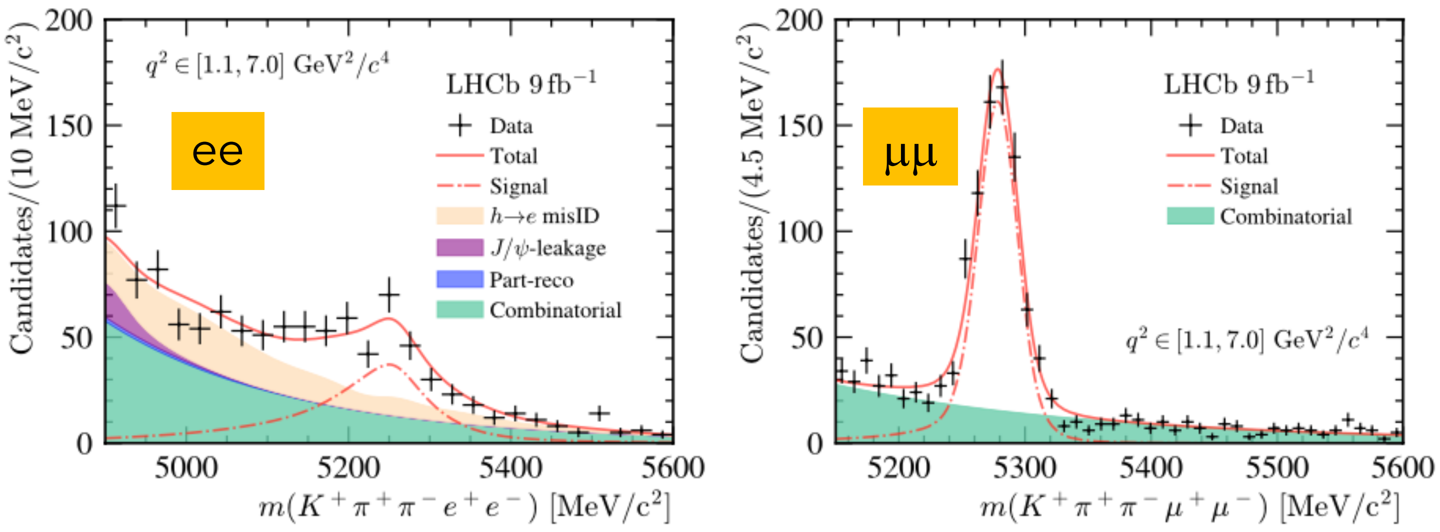
$\psi(2S)$ leakage due to improper bremsstrahlung reconstruction

LHCb-PAPER-2024-032 in preparation

Similar analysis but using $B^{\pm} \to K\pi\pi\,\ell\ell$

LHCb-PAPER-2024-046
in preparation

One kinematic region $1.1<q^2<7$ GeV^2/c^4



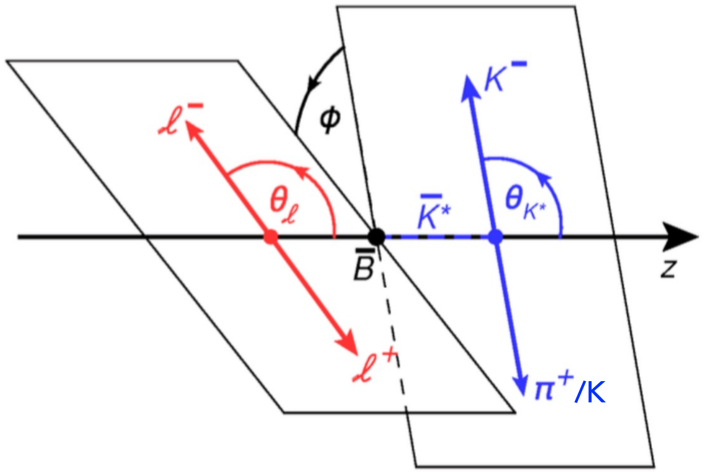
$$R^{-1}_{K\pi\pi} = 1.31^{+0.18}_{-0.17}(\text{stat})^{+0.12}_{-0.09}(\text{syst})$$

Systematic uncertainty dominated by the modelling of mass distribution of the hadron→e mids-ID background

In agreement with SM

Angular analyses

Decay described by 3 angles and 8 q^2-dependent parameters



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

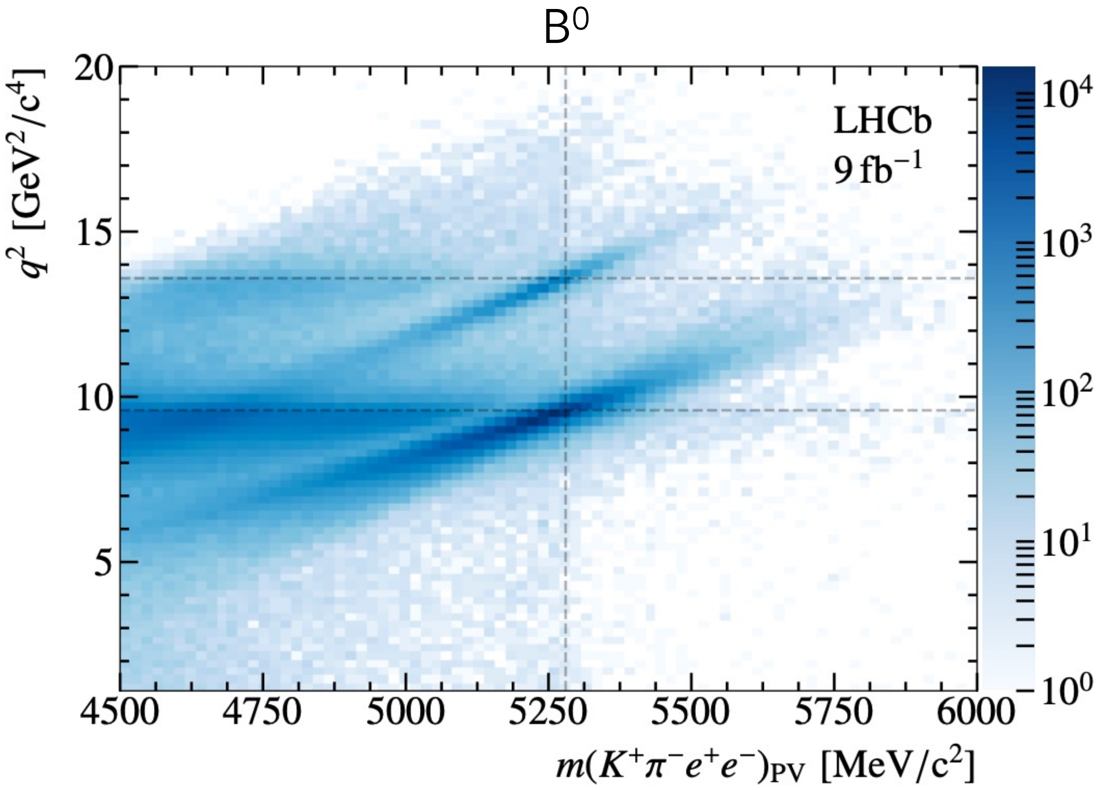
F_L : fraction of K* with longitudinal polarisation

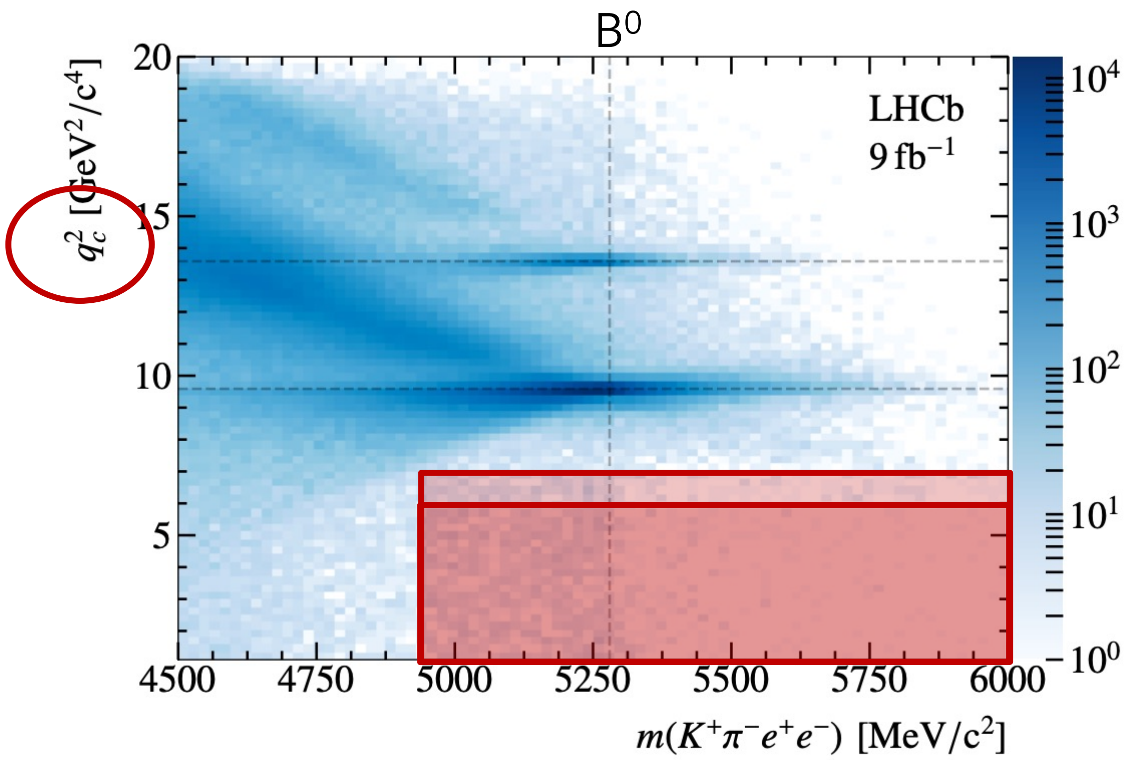
Forward-backward asymmetry of the di-lepton system

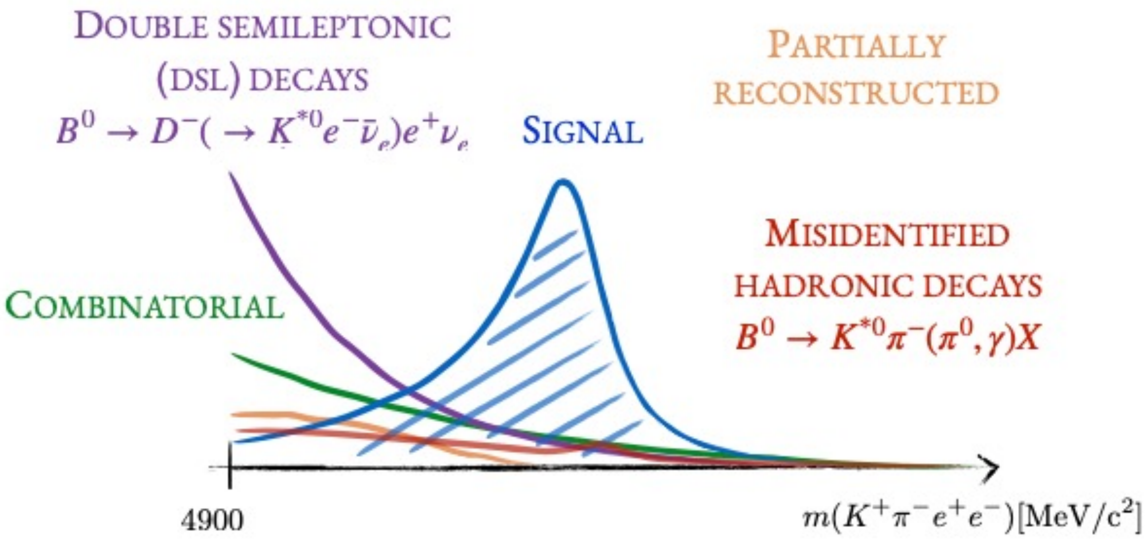
F_L , A_{FB} and the other six parameters are sensitive to $C^{(\prime)}_{7,9,10}$ and Form Factors

Angular analysis of $B^0 \rightarrow K^{*}ee$ in the central q^2 region

[LHCb-PAPER-2024-022, in preparation]



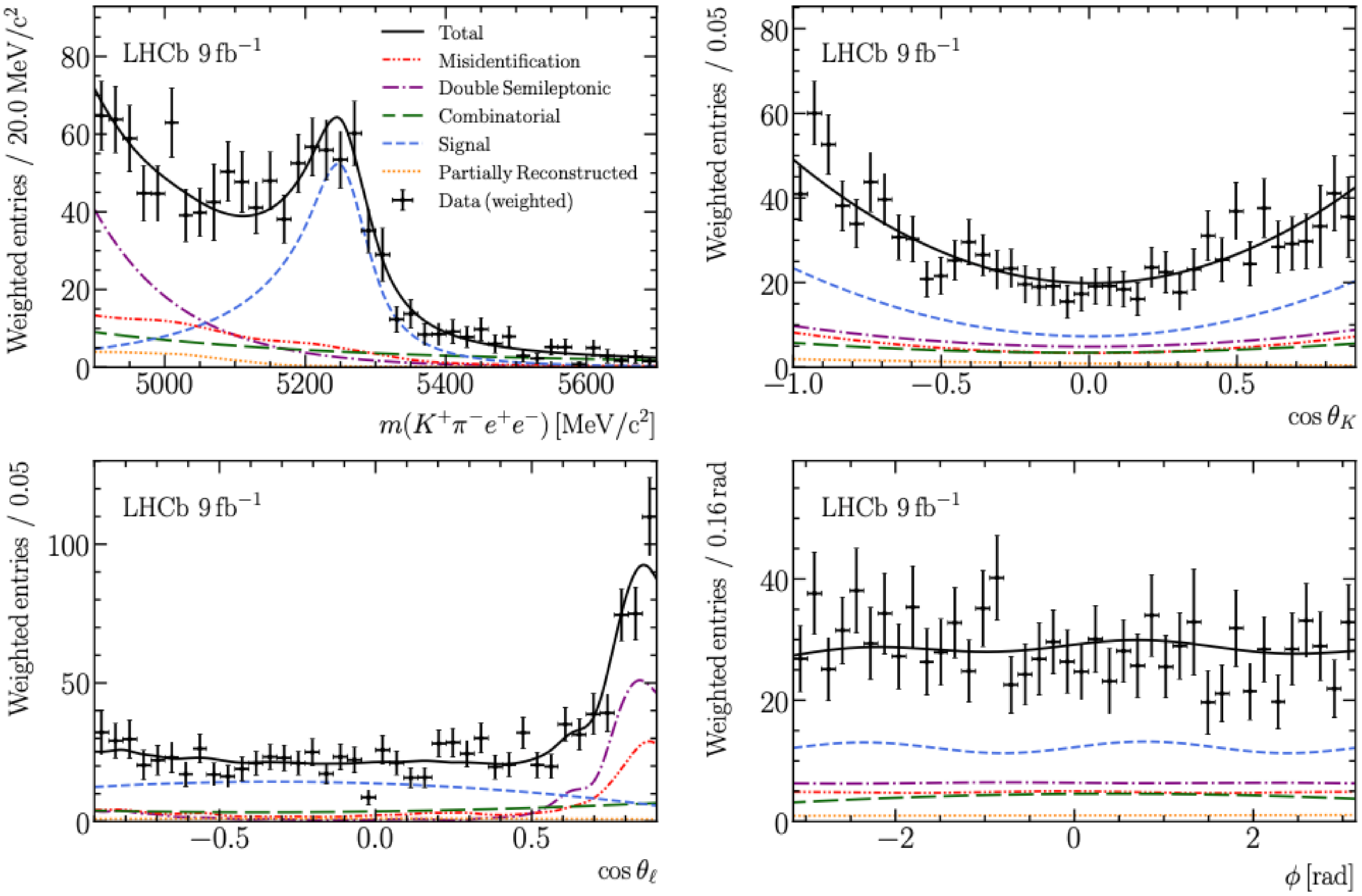




Modelling of the mass and angular distributions of all the components

⇒ Data-driven methods

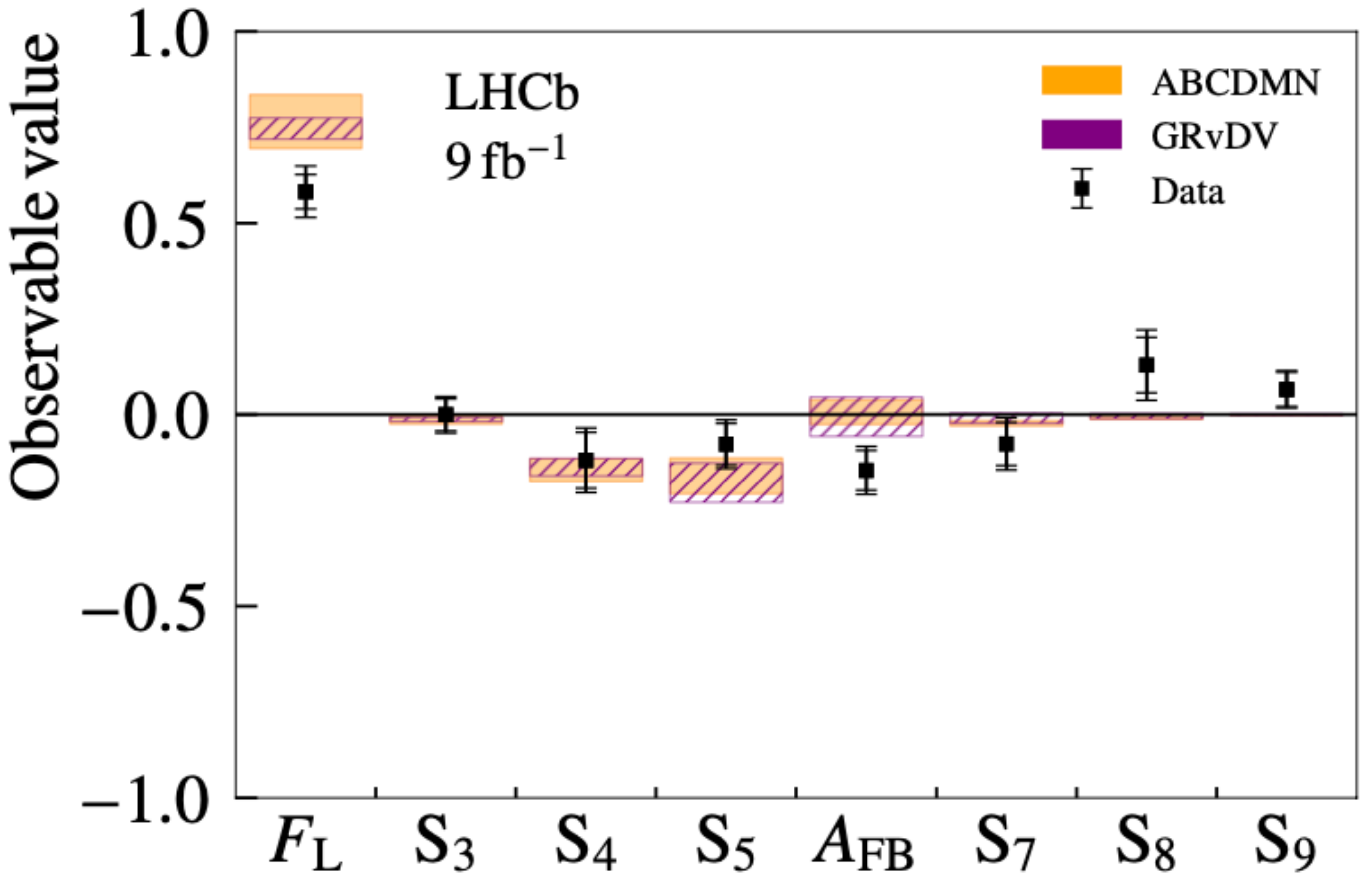
the fit result:



F_L	$0.582 \pm 0.045 \pm 0.050$
S_3	$-0.000 \pm 0.042 \pm 0.023$
S_4	$-0.119 \pm 0.073 \pm 0.042$
S_5	$-0.077 \pm 0.054 \pm 0.033$
A_{FB}	$-0.146 \pm 0.052 \pm 0.035$
S_7	$-0.077 \pm 0.056 \pm 0.038$
S_8	$0.129 \pm 0.072 \pm 0.056$
S_9	$0.066 \pm 0.045 \pm 0.020$

[N. Gubernari, M. Reboud, D. Van Dyk, J. Virto, JHEP 09 (2022) 133

[M. Algueró, A. Biswas, B.Capdevila, S. Descotes-Genon, J. Matias, EPJC 83 (2023) 7, 648



In agreement with SM prediction

LFU test

- Use the set of observables which are less sensitive to Form Factors
- Compare with the results from the muon fit (as in PRL 132 (2024) 131801 but without S-wave for overall coherence)

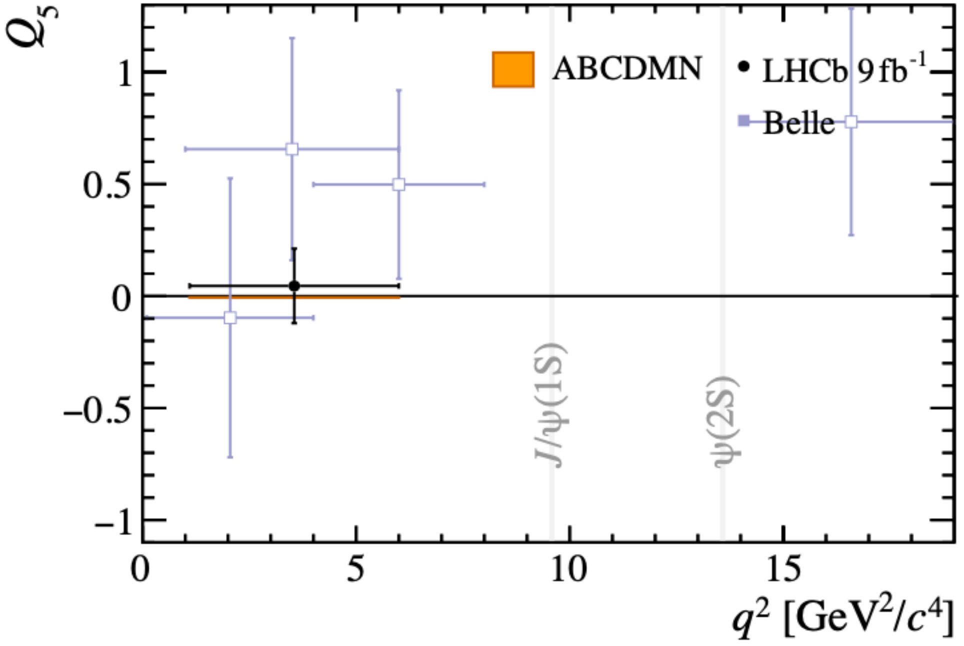
$$P_1 = \frac{2S_3}{(1-F_L)}\,,$$

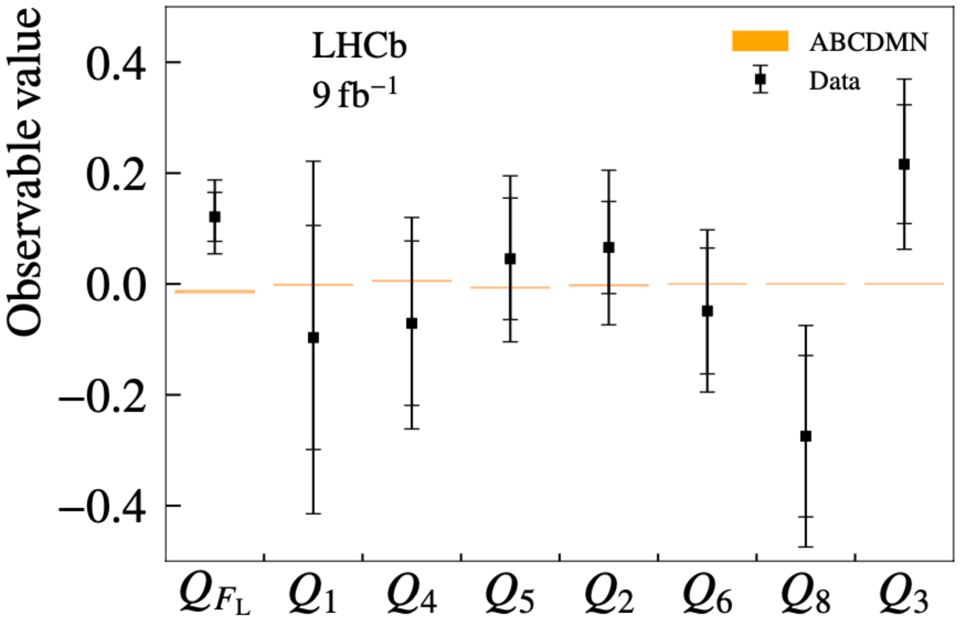
$$P_2 = \frac{2}{3}\frac{A_{FB}}{(1-F_L)}\,,$$

$$P_3 = \frac{-S_9}{(1-F_L)}\,,$$

$$P'_{4,5,6,8} = \frac{S_{4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

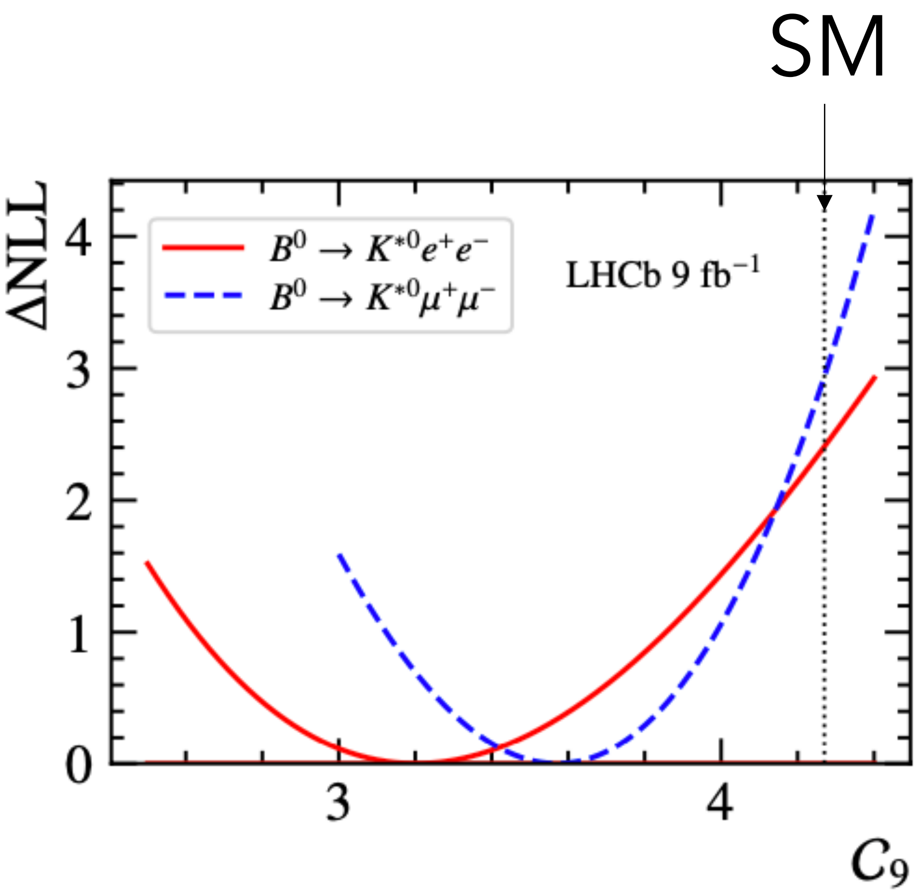
$$Q_i = P_i^{(\mu)} - P_i^{(e)}$$

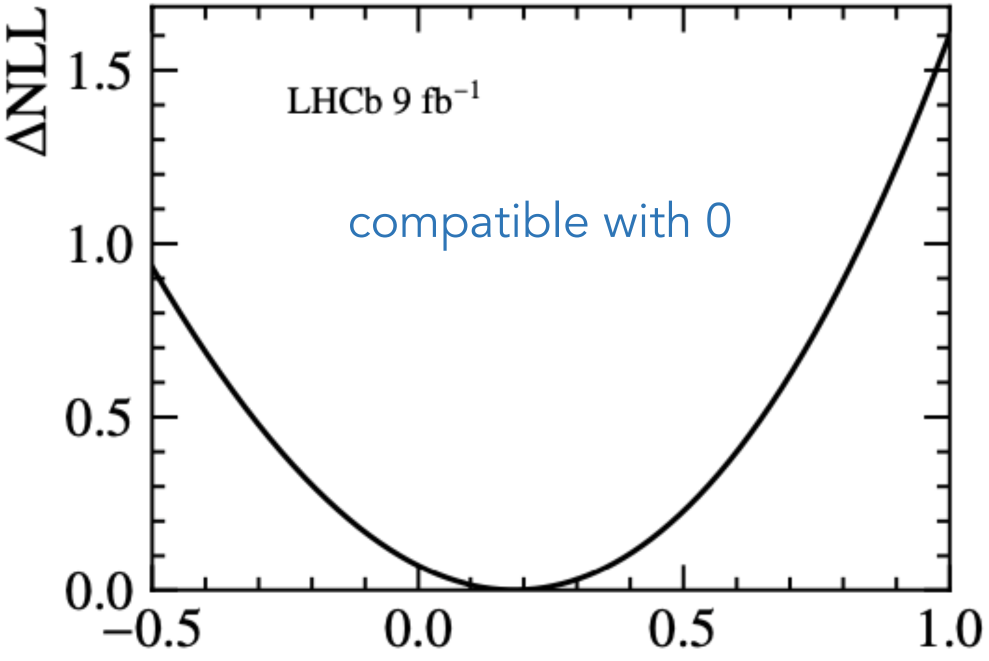




- more precise than previous Belle measurement
- consistent with LFU conservation

in agreement with the SM but also with the K*μ μ results.





$$\Delta C_9 = C_9^{(\mu)} - C_9^{(e)}$$

Similar shift in K*μμ and K*ee

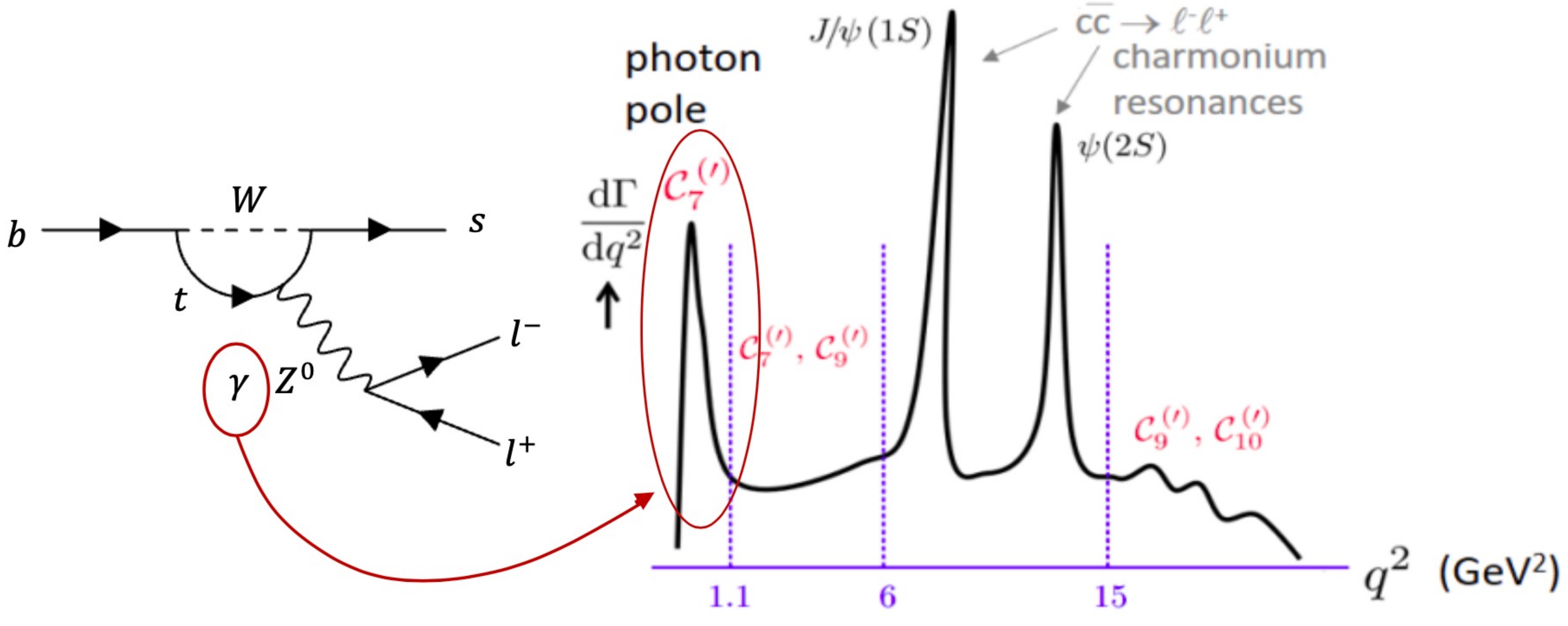
Form factors constrained from [JHEP 12 (2023) 153] and non-local QCD terms from [JHEP 02 (2021) 088, JHEP 09 (2022) 133]
Hadronic contributions shared between K*μμ and K*ee

Measurement of the photon polarisation in $b \to s\gamma$ transitions

[LHCb-PAPER-2024-030, in preparation]

Belle II [arXiv:2407.09139]

Angular analysis of $B_s \to \phi(\to KK)ee$

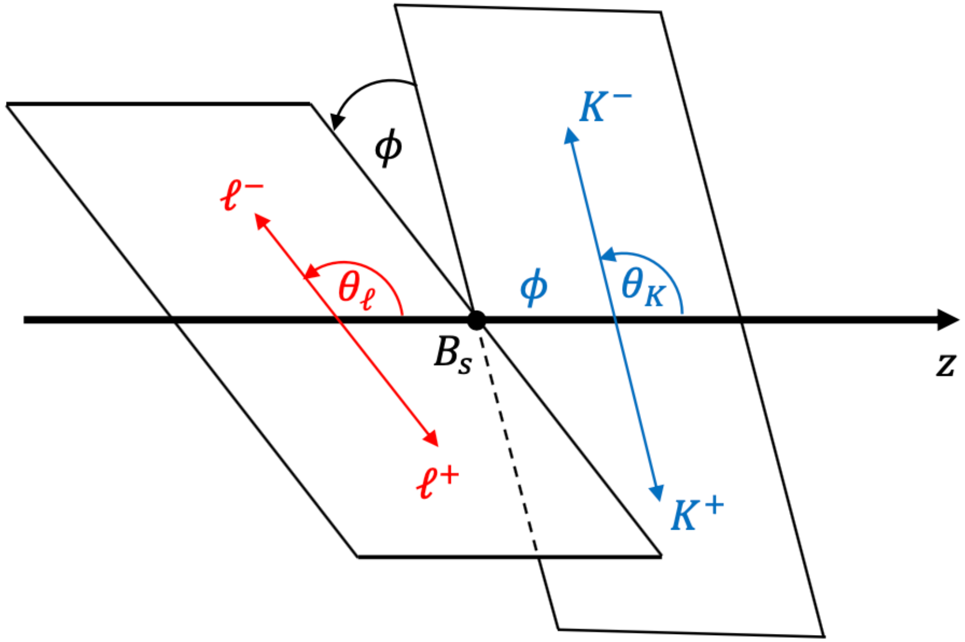


⇒ virtual photon: go for q^2 as low as possible

⇒ use electrons

[LHCb-PAPER-2024-030, in preparation]

3 angles to describe the decay (valid for all q^2) :



+ some folding:

$$\tilde{\phi} = \phi \text{ if } \phi > 0, \text{ and } \tilde{\phi} = \phi + \pi \text{ if } \phi < 0$$

$$\frac{1}{\frac{d(\Gamma+\bar{\Gamma})}{dq^2}} \frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_l \, d\cos\theta_k \, d\tilde{\phi}^1}$$

$$= \frac{9}{32\pi} \left\{ \frac{3}{4}(1-F_L)\sin^2\theta_k + F_L\cos^2\theta_k \right.$$

$$+ \left[\frac{1}{4}(1-F_L)\sin^2\theta_k - F_L\cos^2\theta_k\right]\cos 2\theta_l$$

$$+ \frac{1}{2}(1-F_L)\,A_T^{(2)}\sin^2\theta_k\sin^2\theta_l\cos 2\tilde{\phi}$$

$$+ (1-F_L)\,A_T^{ReCP}\sin^2\theta_k\cos\theta_l$$

$$\left. + \frac{1}{2}(1-F_L)\,A_T^{ImCP}\sin^2\theta_k\sin^2\theta_l\sin 2\tilde{\phi} \right\}$$

$$A_T^{(2)}(q^2\to 0) = \frac{2Re(C_7 C_7'^*)}{|C_7|^2+|C_7'|^2} + \Delta_1{}^2$$

$$A_T^{ImCP}(q^2\to 0) = \frac{2Im(C_7 C_7'^*)}{|C_7|^2+|C_7'|^2} + \Delta_2{}^2$$

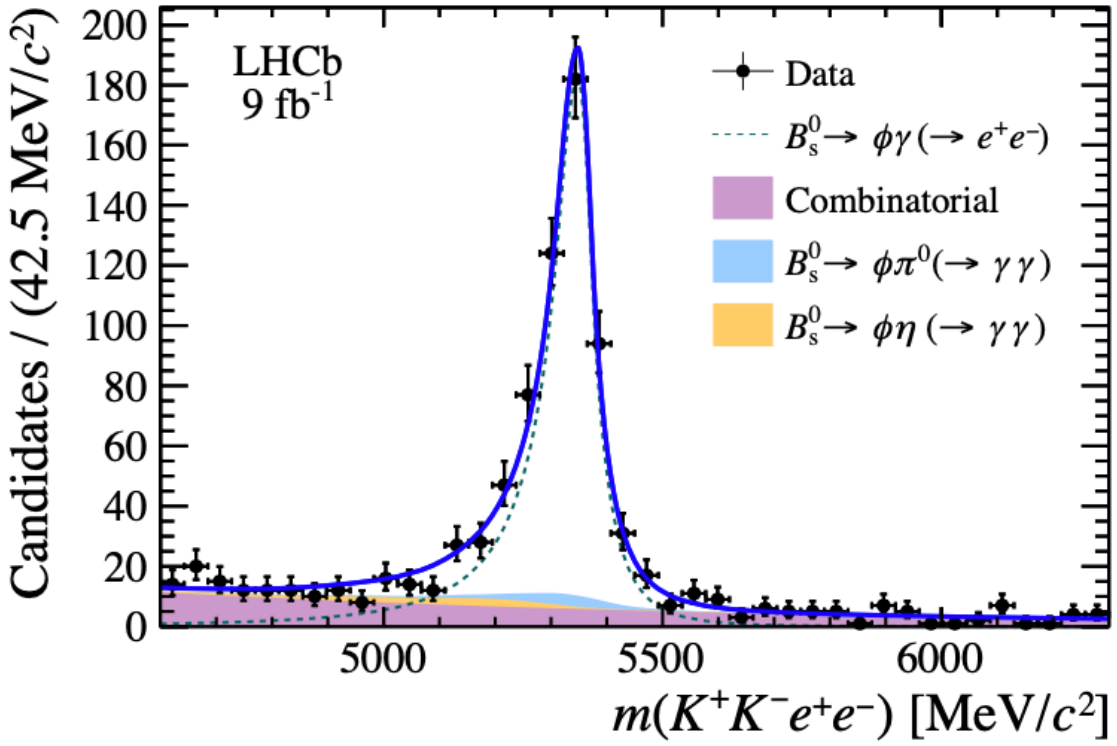
Δ_i due to Δm_s and $d\Gamma_s$

q^2 bin choice similar to previous $B_d \to K^{*0}(\to K^+\pi^-)ee$: 10 MeV< m_{ee} <500 MeV

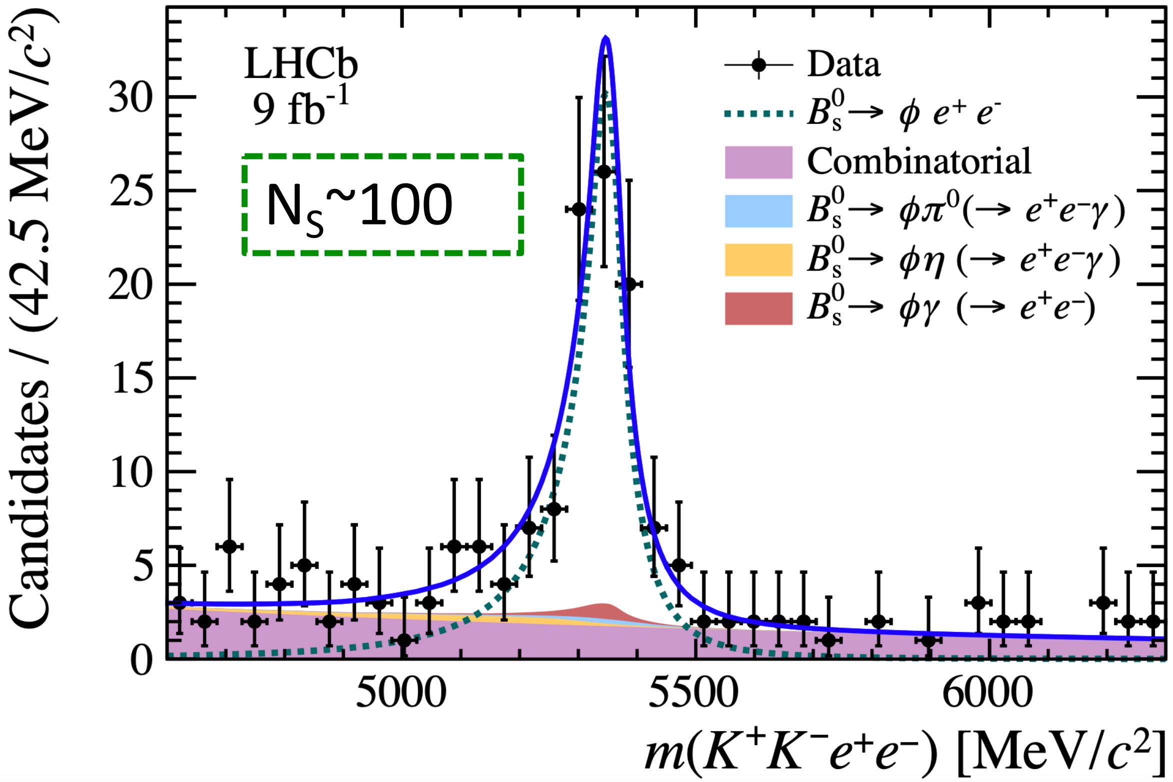
Background mostly of combinatorial nature due to the very specific kinematical region

The radiative decay with a converted photon is a nice control channel : $B_s \to \phi(\to K^+K^-)\gamma_e$

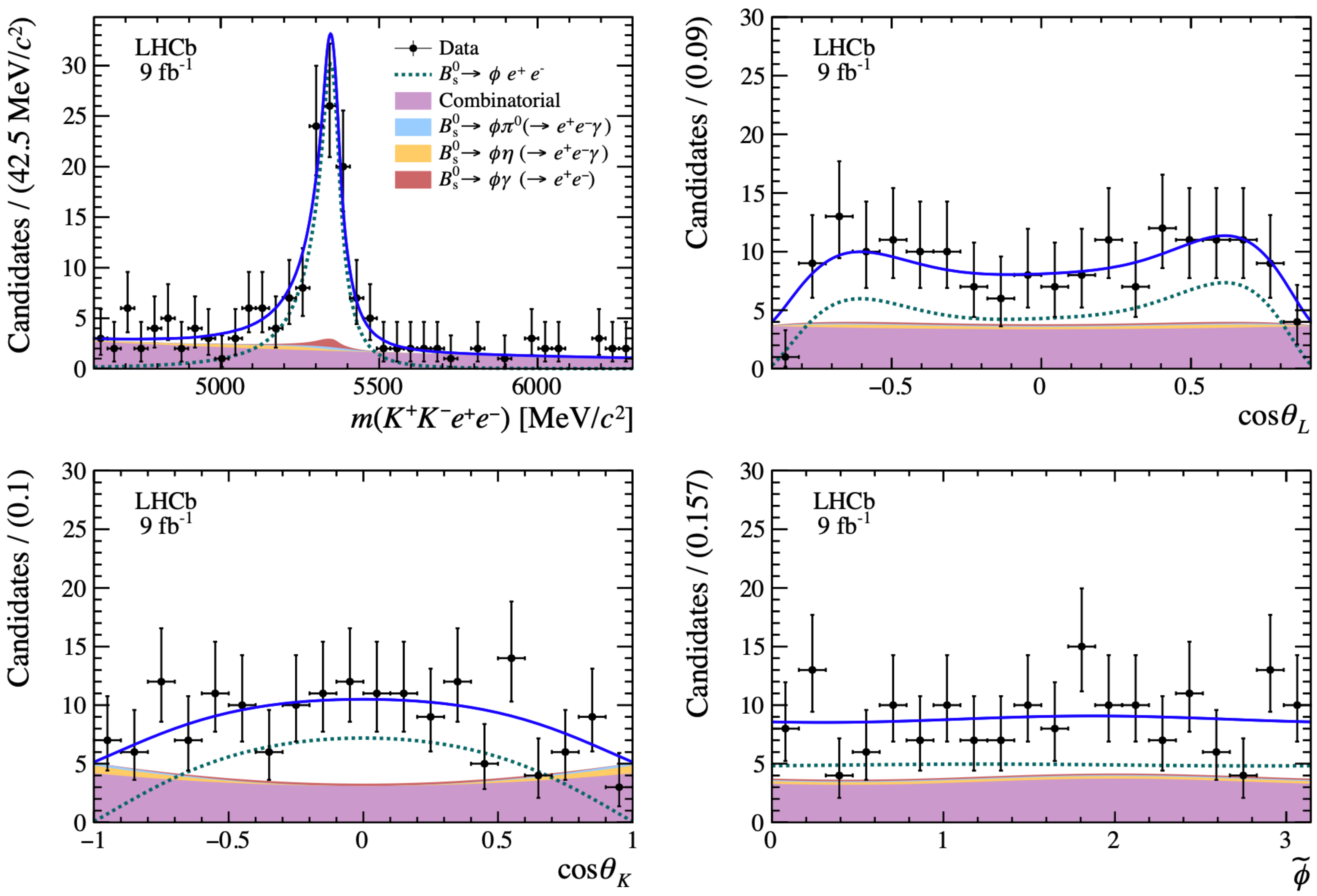
$B_s \to \phi(\to K^+K^-)\gamma_{ee}$ control channel



$B_s \to \phi(\to K^+K^-)ee$ signal



4D fit : m(KKee), $\cos\theta_K$, $\cos\theta_\ell$ $\tilde{\phi}$



$$A_{\mathrm{T}}^{(2)} = -0.045 \pm 0.235 \pm 0.014\,,$$
$$A_{\mathrm{T}}^{ImCP} = 0.002 \pm 0.247 \pm 0.016\,,$$
$$A_{\mathrm{T}}^{ReCP} = 0.116 \pm 0.155 \pm 0.006\,,$$
$$F_{\mathrm{L}} < 11.5\% \text{ @ } 90\% \text{ CL}\,.$$

effective region:
$0.0009 < q^2 < 0.2615$ GeV^2/c^4

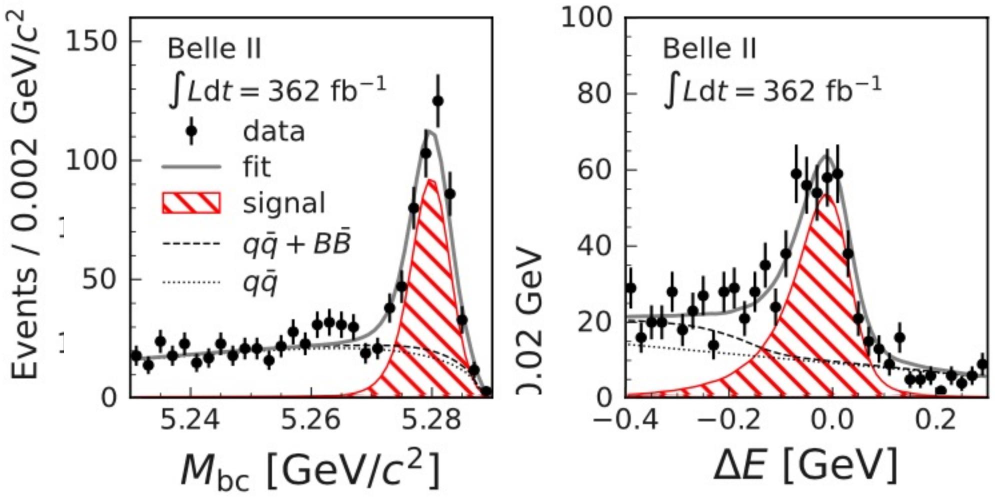
in good agreement with the SM

Mixing-induced CP asymmetries in $B^0 \to K^{*0} (\to K^0 \pi^0) \gamma$

Belle II (362 fb^{-1}) arXiv:2407.09139

$$\mathcal{P}_{\rm TD}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 + q\cdot[S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)]\},$$

q=+1 (-1) B^0 ($\bar{B}^0$)



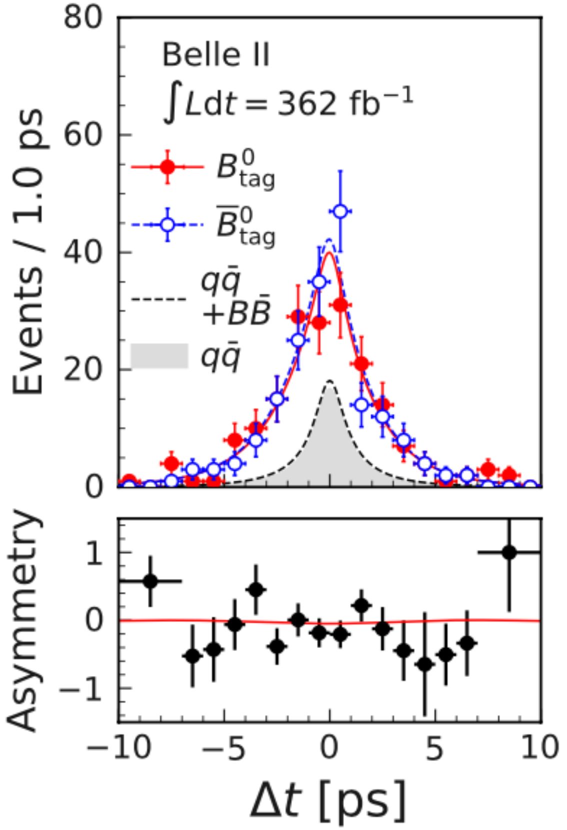
$$S = 0.00^{+0.27}_{-0.26} \pm 0.03,$$

$$C = 0.10 \pm 0.13 \pm 0.04$$

$$\mathcal{S} \approx \xi \frac{2\mathcal{I}m[e^{-i\phi_q}\,\mathcal{C}_7 \mathcal{C}_7'|}{|\mathcal{C}_7|^2 + |\mathcal{C}_7'|^2}$$

$\varepsilon_{eff} = (31.69 \pm 0.35)\%$

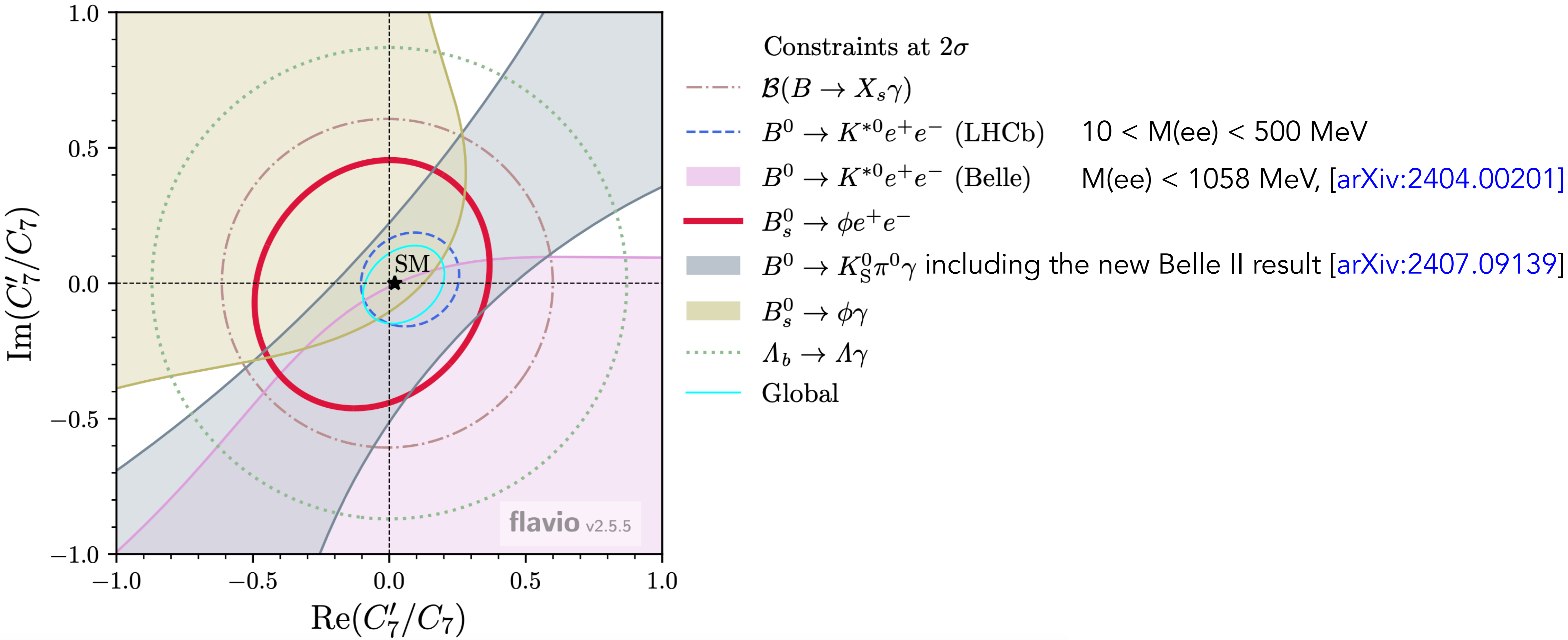
HFLAV average was :
-0.16 ± 0.22



The photon polarisation in b → $s\gamma$ transitions is known with a precision of ~ 4%

All measurements are in good agreement

[LHCb-PAPER-2024-030, in preparation]



Summary: a lot of ‘for the first time‘

- Branching ratio measurements :
  - tensions still present in $b \to s\ \mu\ \mu$
  - similar BR values for ℓ = e or $\ell = \mu$: new modes being added : R_ϕ and $R_{K\pi\pi}$.

LFU holds at the few % level

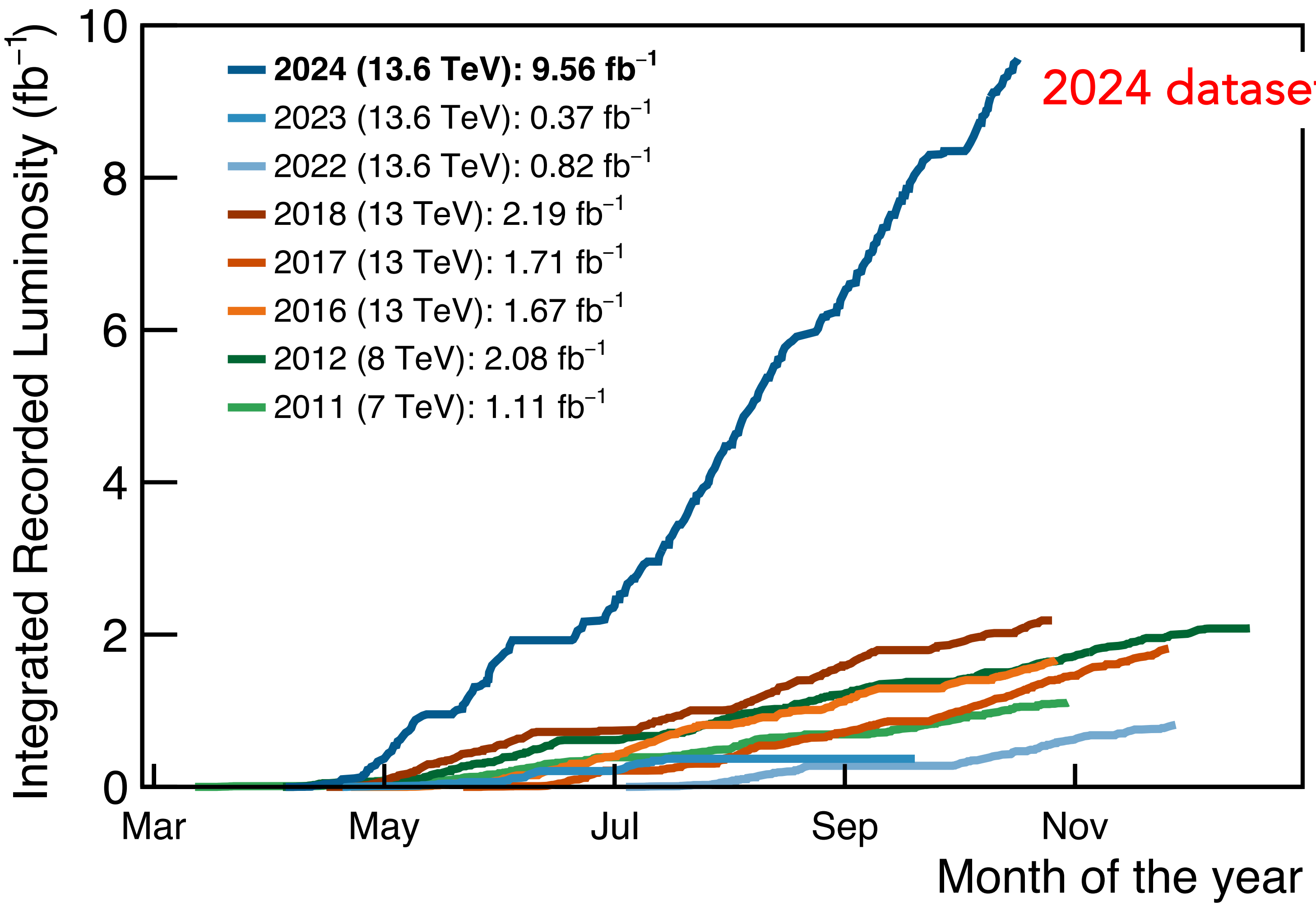
- $B^0 \to K^{*0}$ ee angular analysis in the central q^2 region for the first time

In agreement both with the SM and $B^0 \to K^{*0}\ \mu\ \mu$

- measurement of the photon polarisation in $b \to s\gamma$:
  - $B_s \to \phi ee$ in the very low-q2 region (~12% precision)
  - $B^0 \to K^{*0}\ (\to K^0\ \pi^0)\ \gamma$ CP violation time dependent analysis from Belle-II

A set of very different analyses.
~4% precision. In agreement with SM.

Stay tuned !



2024 dataset ~ (Run1 + Run2)

Thank you for your attention

back-up slides

A game of couplings and scale

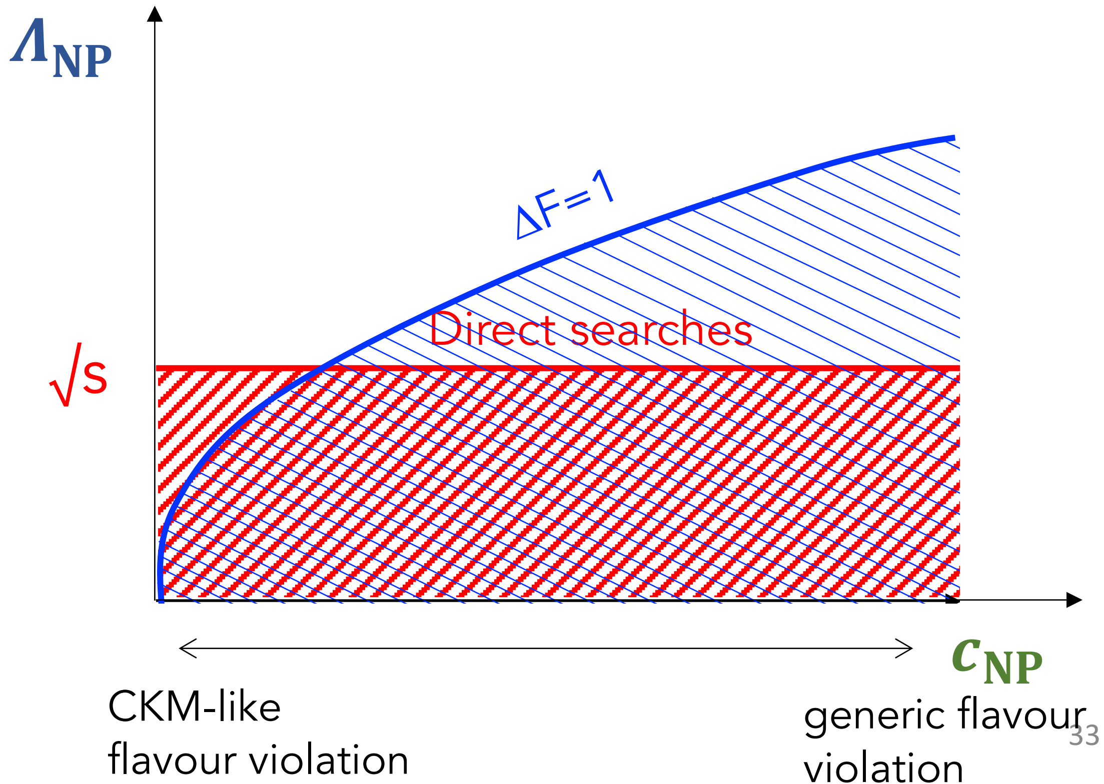
- Flavour Changing Neutral Currents: mediated by box and loop diagrams (strongly suppressed in the SM): New Physics can compete and modify the properties of the decays

- Access to larger scales than direct searches

$$\mathcal{H}_{NP} \propto \frac{c_{\mathrm{NP}}}{\Lambda^2_{\mathrm{NP}}}$$

NP coupling

NP scale



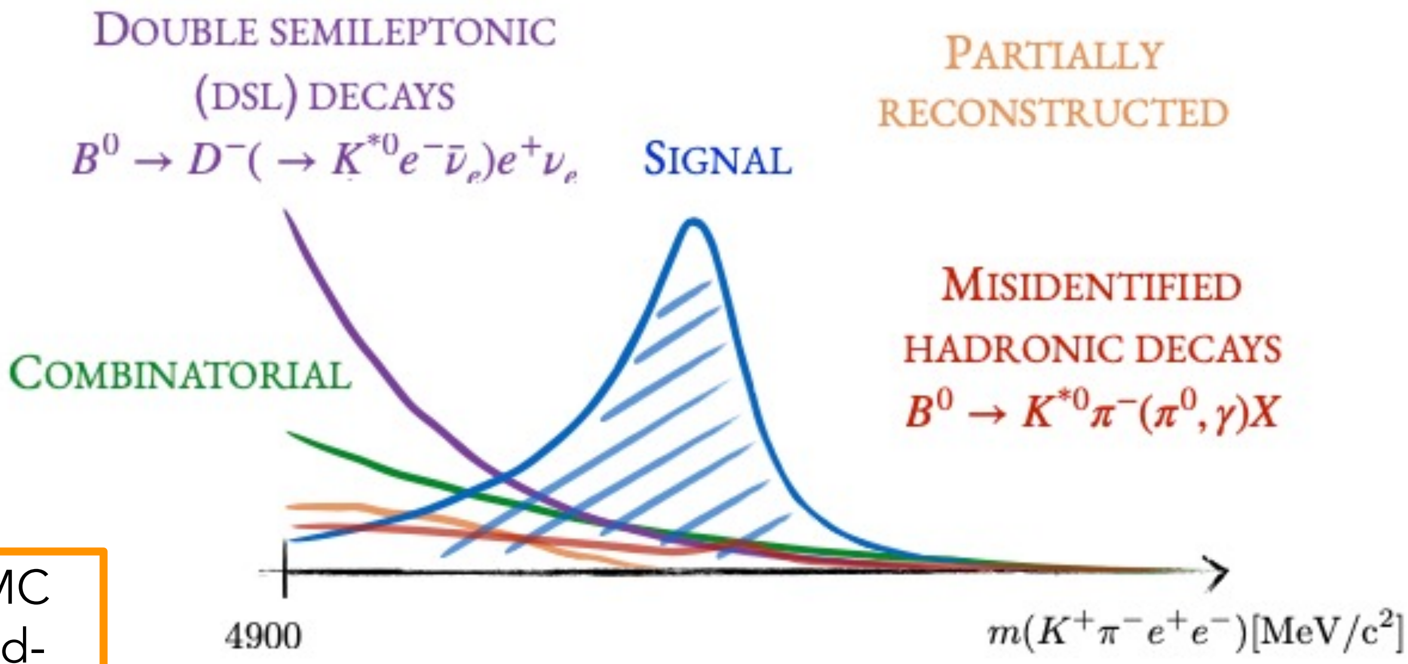
B0 → K*ee Fit set-up

Double Semileptonic and combinatorial backgrounds:
Use of $B^0 \to K^* e\mu$ data sample, wider mass range and BDT

Signal : from simulation for the mass distribution, the angular and q_c^2 acceptance

Misidentified hadronic decays :
Use the "Pass-Fail" method of R_X
([PRL 131 (2023) 051803, PRD 108 (2023) 032002])

partially reconstructed background: Phase Space MC reweighted using $B \to K \pi \pi J/\psi (\to \mu \mu)$ background-substracted data



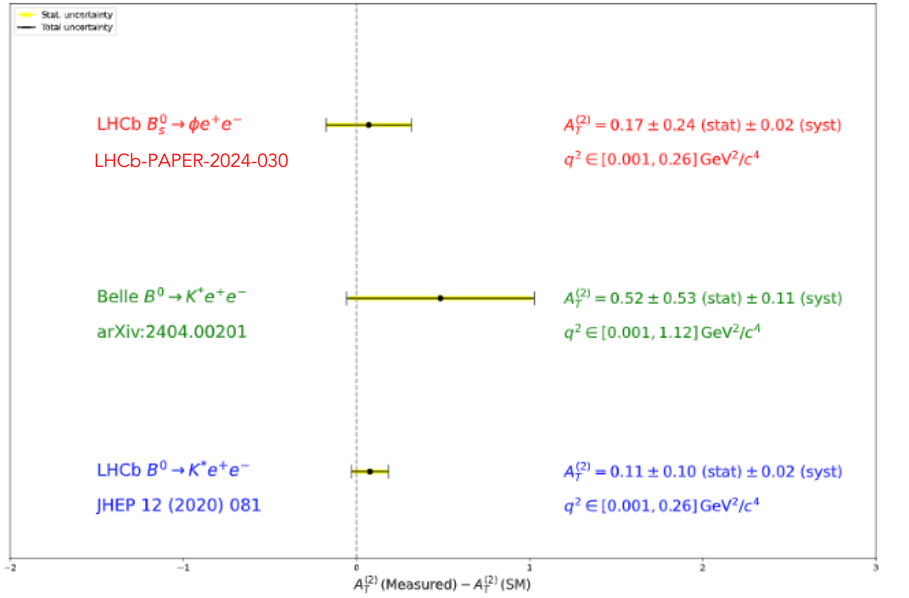
Bs → Phiee systematics

Source of systematic	$A_T^{(2)}$	A_T^{ImCP}	A_T^{ReCP}	F_L
$\Delta\Gamma_s/\Gamma_s$	0.008	< 0.001	< 0.001	< 0.001
Corrections to simulation	0.002	<0.001	<0.001	0.010
Acceptance function modelling	<0.001	<0.001	0.001	0.002
Simulation sample size for acceptance	0.006	0.008	0.005	0.002
Background contamination	0.009	0.014	0.004	0.006
Angles resolution	-0.005	< 0.001	-	-
Total systematic uncertainty	0.014	0.016	0.006	0.012
Statistical uncertainty	0.235	0.247	0.155	+0.056

Results dominated by statistical uncertainty

Add a precise information in the overall measurement of the photon polarisation in $b \rightarrow s\gamma$ transitions

- Mixing-induced CP asymmetries in $B^0 \rightarrow K^{*0} (\rightarrow K^0 \pi^0) \gamma$
- Mixing-induced CP asymmetries in $B_s \rightarrow \Phi\gamma$
- $B \rightarrow K^{*0}(\rightarrow K^+ \pi^-)ee$ angular analysis in the very-low q^2 region
- $B_s \rightarrow \Phi ee$ angular analysis in the very-low q^2 region
- via the angle ϕ
- $\Lambda_b \rightarrow \Lambda\gamma$ decay + Λ weak decay

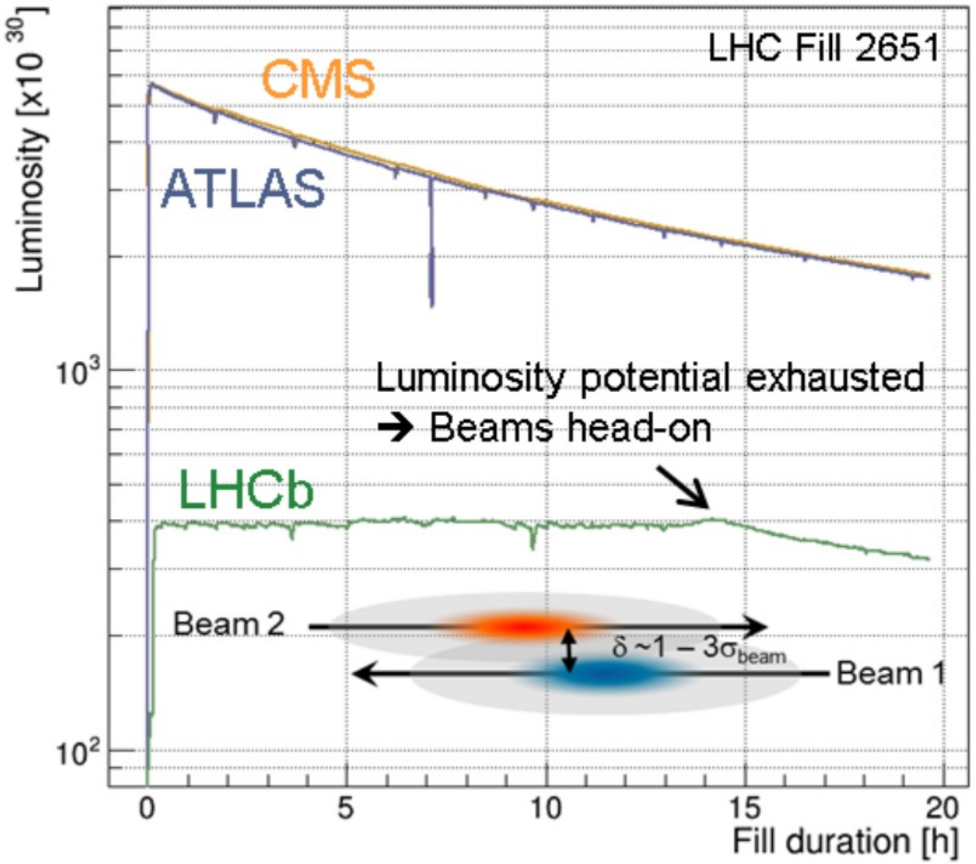


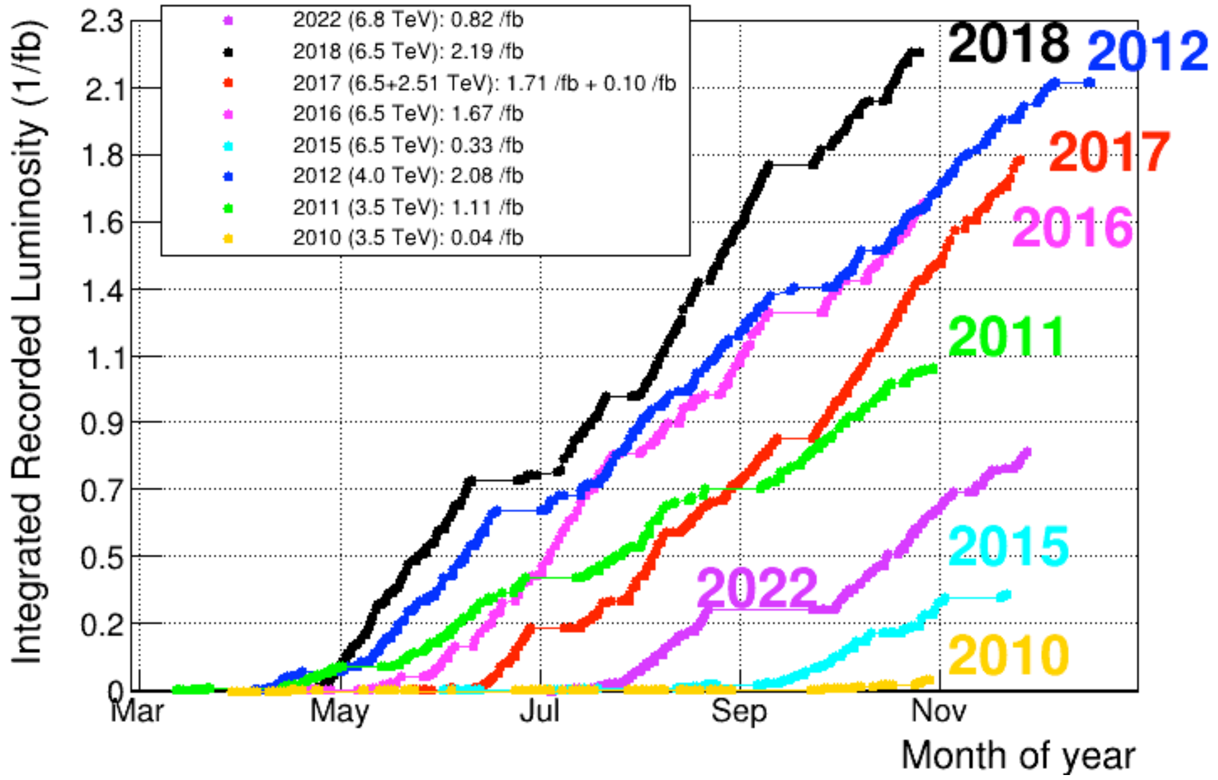
B0->K*ee : Systematic uncertainties (given as % of statistical uncertainties)

Source	F_L	S_3	S_4	S_5	A_{FB}	S_7	S_8	S_9
DSL and comb.	0.687	0.372	0.297	0.321	0.449	0.177	0.668	0.294
Part. reco.	0.091	0.039	0.039	0.049	0.051	0.021	0.034	0.037
Had. misid.	0.376	0.254	0.107	0.178	0.155	0.336	0.129	0.141
Effective acceptance	0.399	0.249	0.419	0.410	0.331	0.508	0.393	0.214
Signal mass modelling	0.254	0.057	0.071	0.111	0.122	0.044	0.045	0.062
Charmonium backgrounds	0.179	0.039	0.045	0.062	0.137	0.032	0.032	0.047
S-wave component	0.351	0.050	0.129	0.084	0.105	0.159	0.008	0.103
B^+ veto	0.499	0.133	0.152	0.179	0.242	0.159	0.154	0.117
Fit bias	0.007	0.008	0.030	0.038	0.042	0.007	0.019	0.031
Total	1.118	0.540	0.570	0.601	0.665	0.676	0.804	0.430

Run1 and Run2 data taking

- Running with luminosity levelling at 4. 10^{32} $cm^{-2}s^{-1}$ (x2 design luminosity)
- About 1.5 interaction per bunch crossing
- 9 fb^{-1} collected

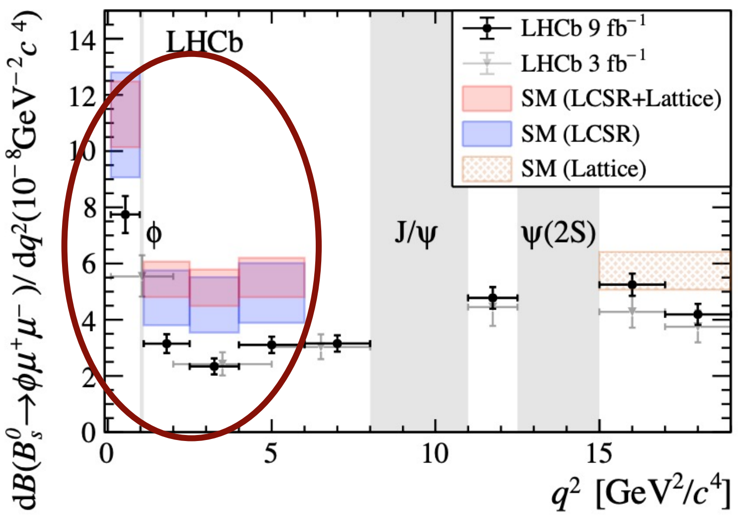




Branching fractions for b→s $\mu\mu$ transitions

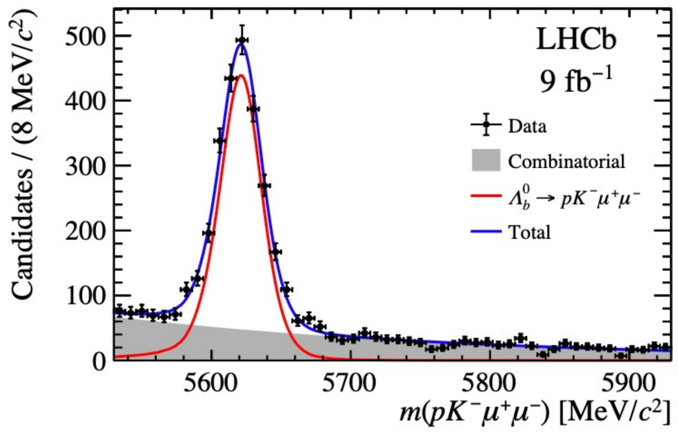
$B_s \to \phi\, \mu\mu$

PRL 127 (2021) 151801

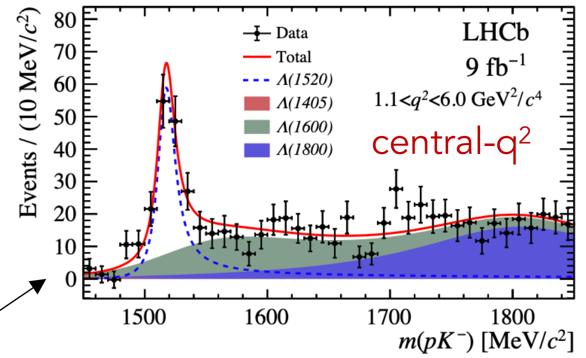


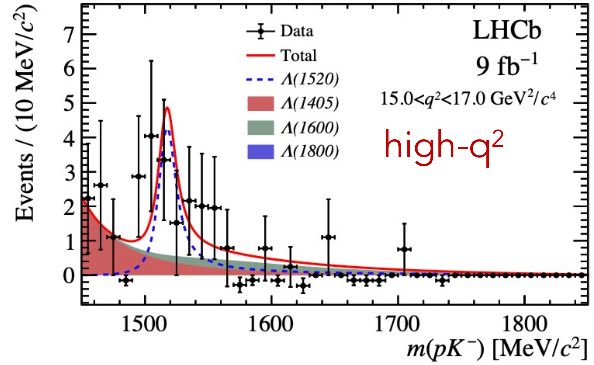
$\Lambda_b \to \Lambda(1520)\, \mu\mu$

arXiv:2302.08262



$N(\Lambda_b \to pK^-\mu^+\mu^-)$ =2250±57(stat)

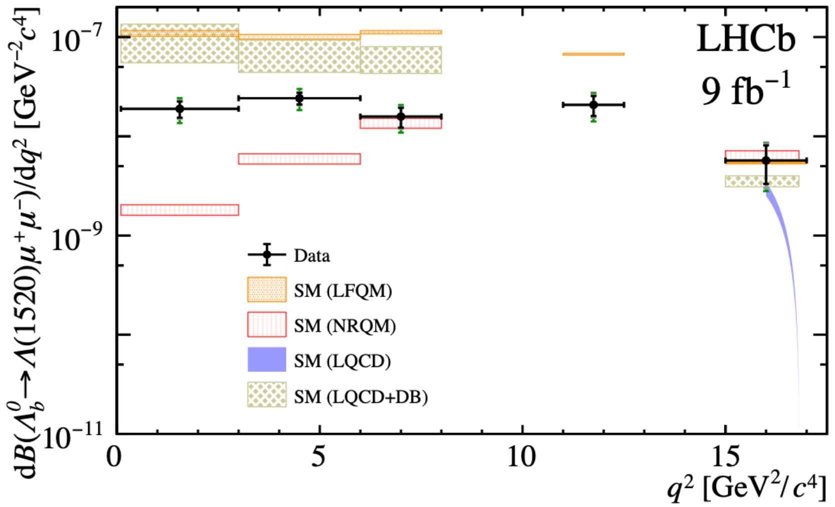




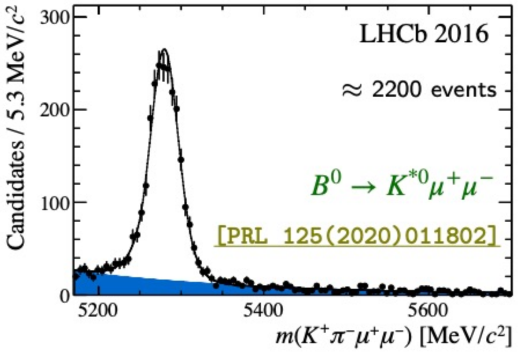
b-mesons: a tendency to measure BF lower than predictions (low and central q^2).

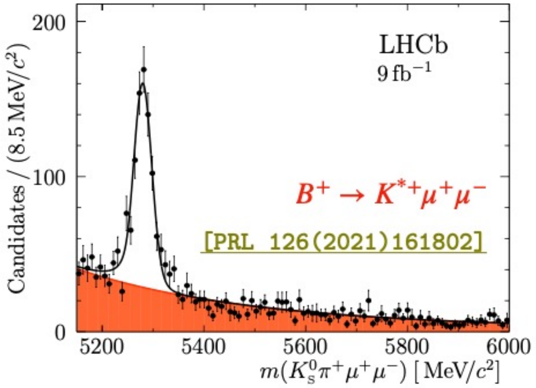
b-baryons: BF in agreement with LQCD (high-q^2). Lack of precise predictions in the rest of phase space.

Predictions uncertainties correlated between bins

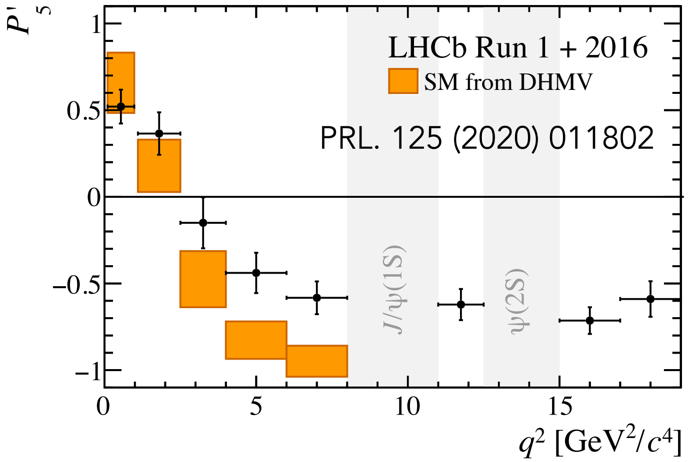


Angular analyses for b→s $\mu\mu$ transitions

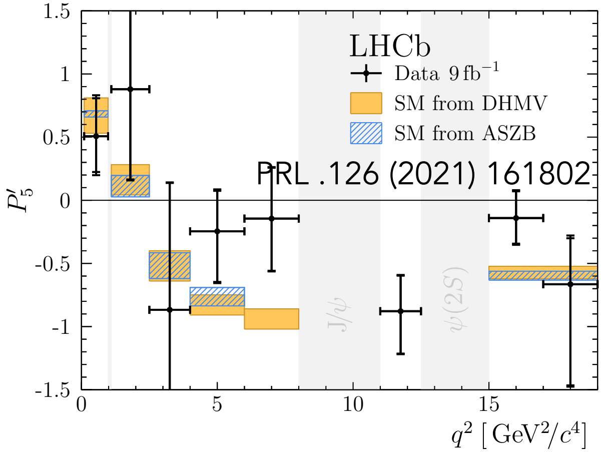




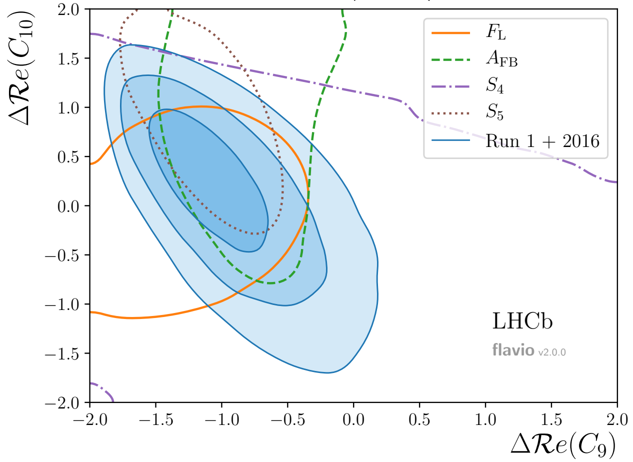
$B^0 \to K^{*0}\ \mu\mu$



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



PRL. 125 (2020) 011802

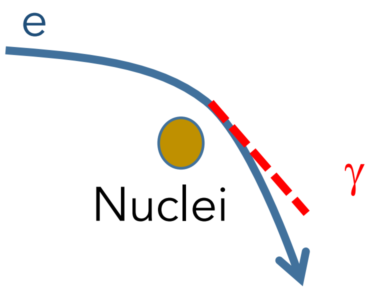


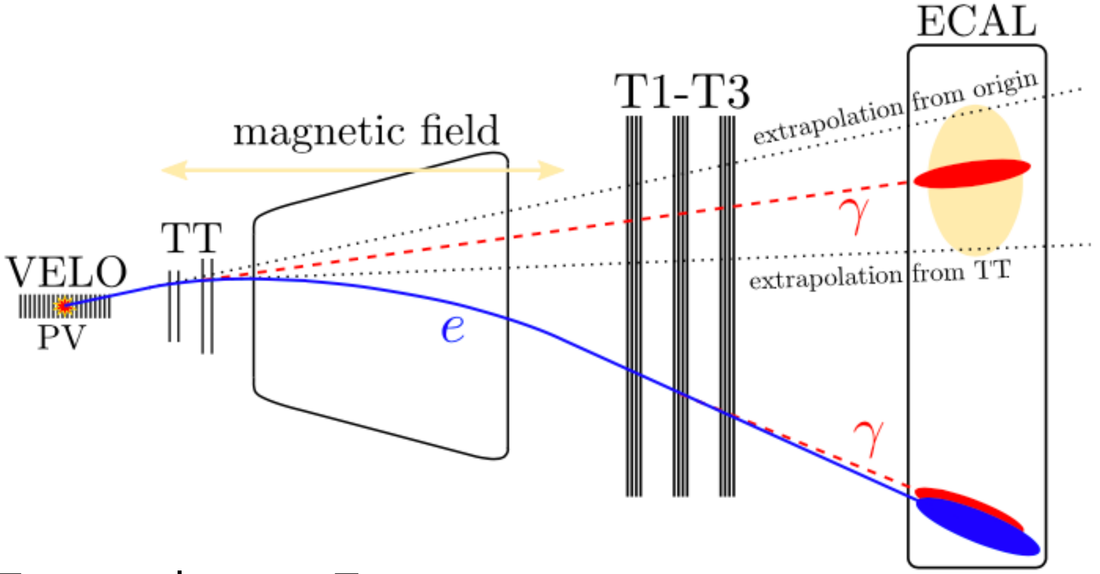
Very clean signal peaks.

Still round for improvements on the experimental side:

- whole Run1 + Run2 dataset for all the modes
- Add more modes (eg $\Lambda_b \to \Lambda(1520)\ \mu\mu$)

Bremsstrahlung emission is significant for electrons





Before the magnet

- electron can be swept out (=lost !)
- kinematics are "wrong"

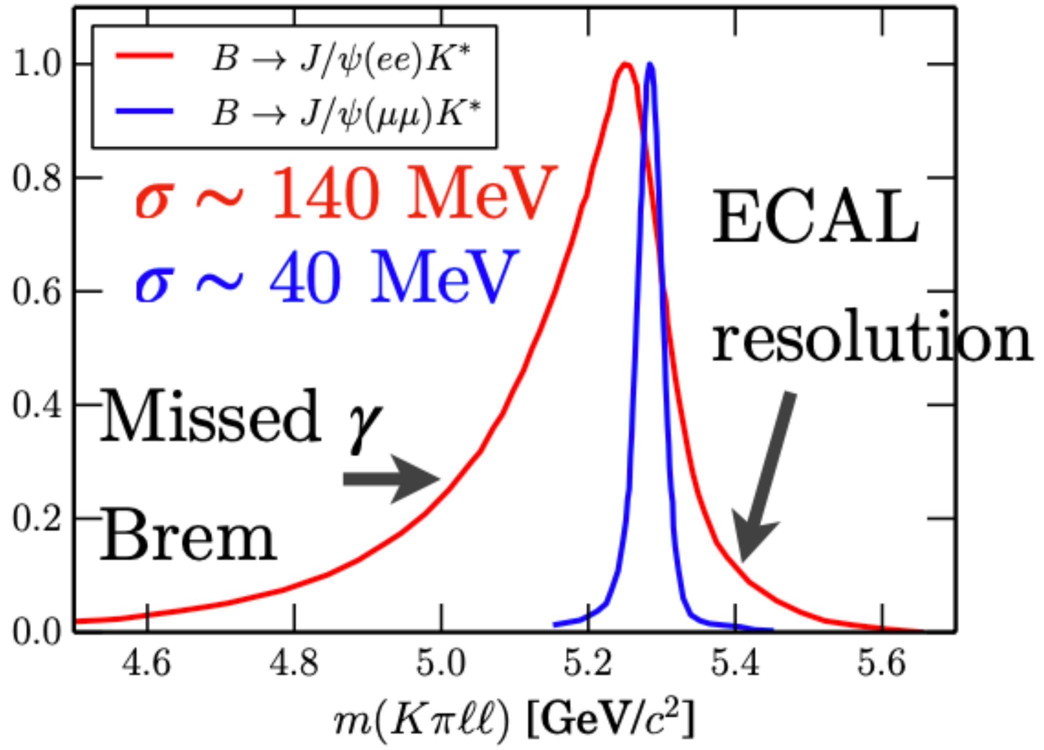
After the magnet

- not an issue

In both cases E/p is correct

Energy loss ∝ E_e
Energy loss ∝ material

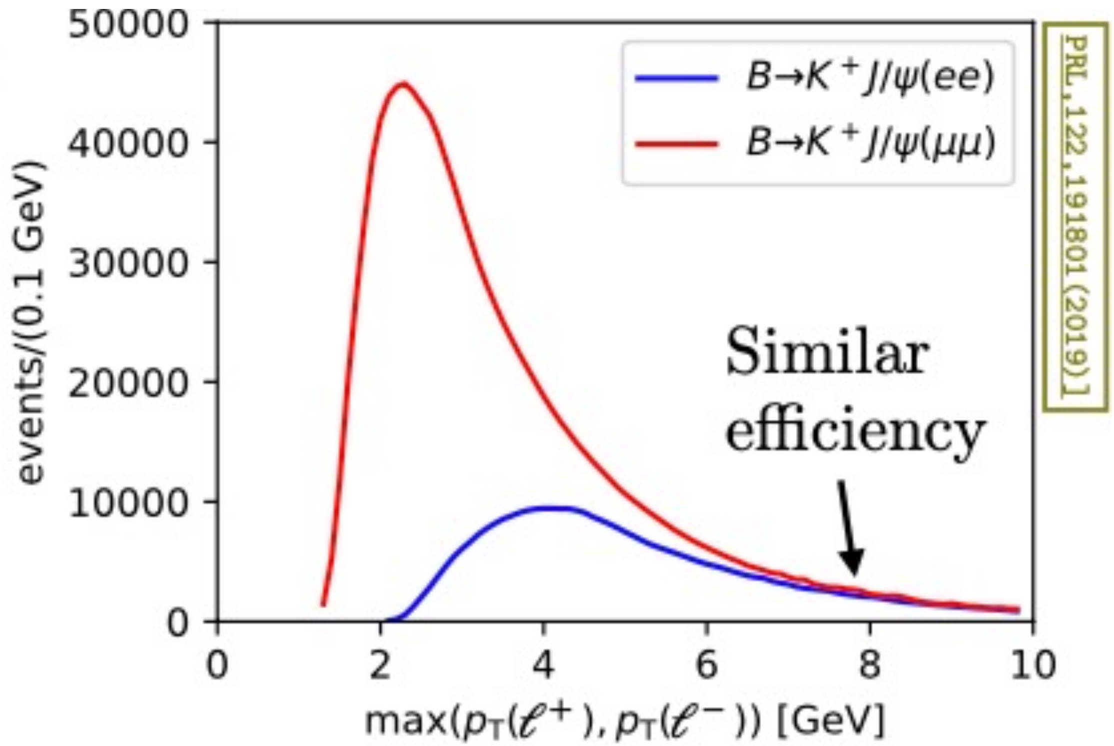
⇒ Use of a recovery algorithm



Hardware trigger is very different for electrons and muons

Larger ECAL occupancy → tighter thresholds for electrons than for muons:

- e pT > 2700/2400 MeV
- μ pT > 1700/1800 MeV



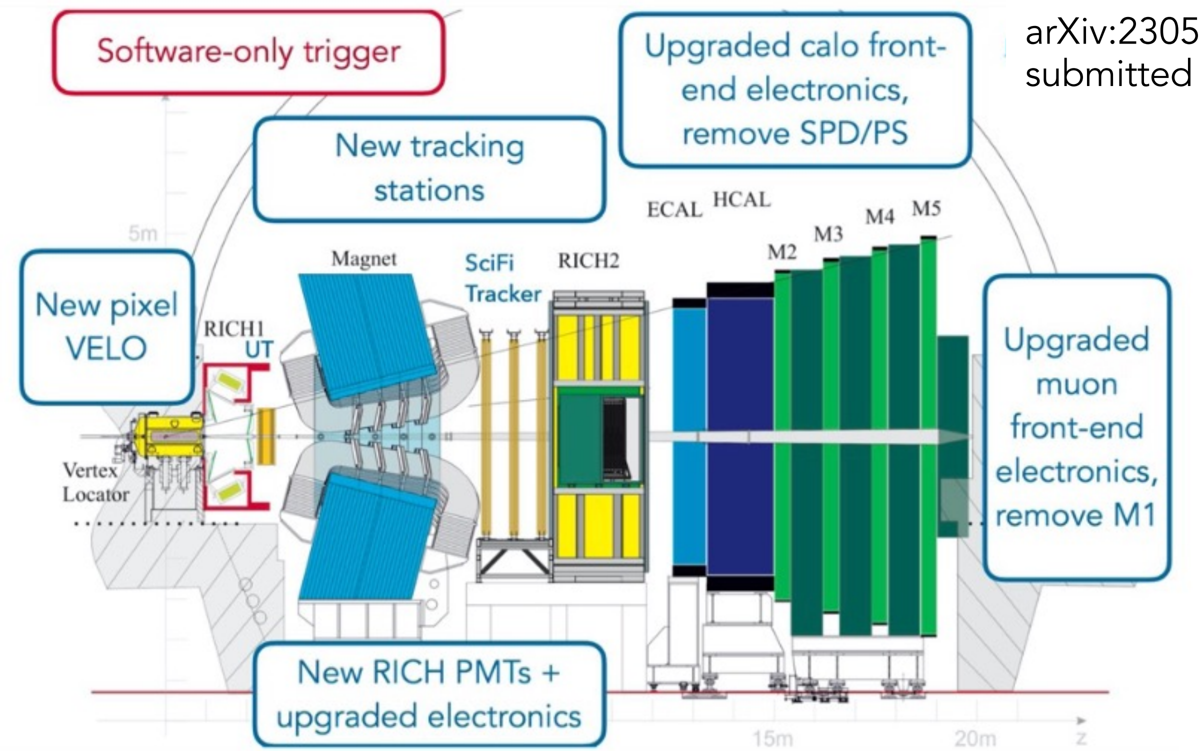
$$\varepsilon(e) \sim \frac{\varepsilon(\mu)}{3}$$

Effect mitigated triggering Independently of Signal

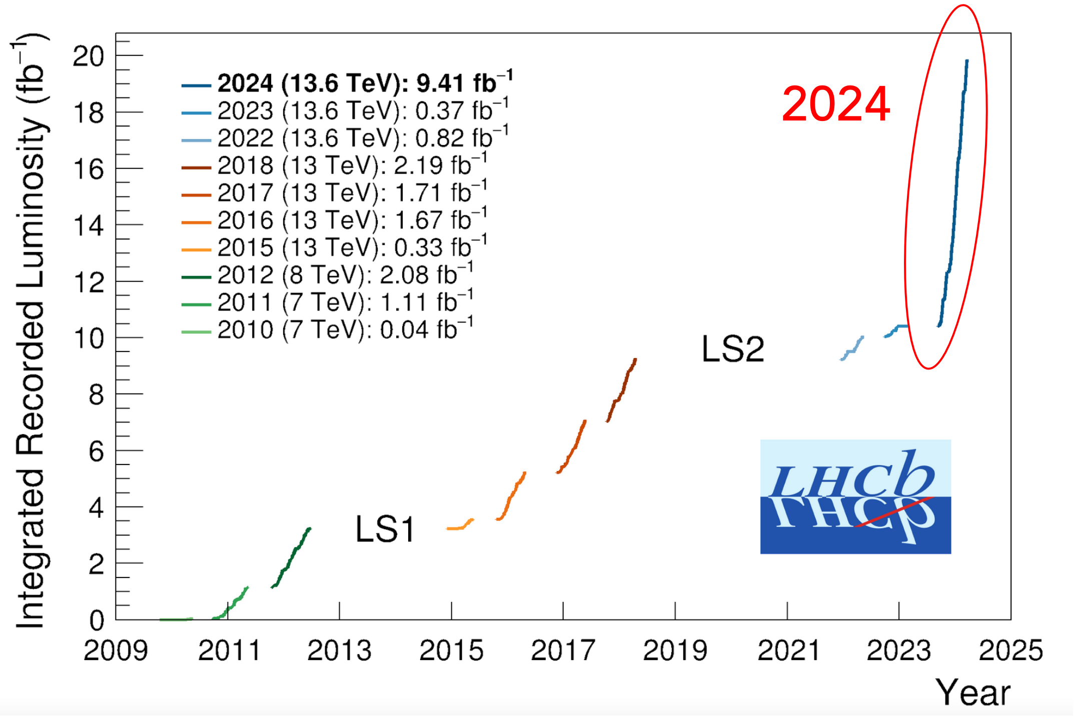
LHCb-Upgrade I

Luminosity x5 wrt Run2
5.5 visible interactions/crossing
Higher track multiplicity from ~<70> to ~<180>)

No more hardware trigger (full detector readout at 40 MHz)
Tracking & PID detectors modified/replaced
Higher granularity



arXiv:2305.10515, submitted to JINST



In January 2023, a loss of control of the LHC primary vacuum system
⇒ plastic deformation of the RF foil separating VELO from LHC.
⇒ significant impact on 2023 physics programme

2022 – 2023 : commissioning and understanding the new detector

2024 : a lot of data !