INTENSITY frontier

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Prospects for NP searches with $\Lambda_b \to \Lambda(1520)ll$ decays

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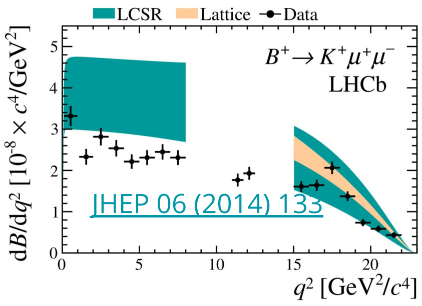
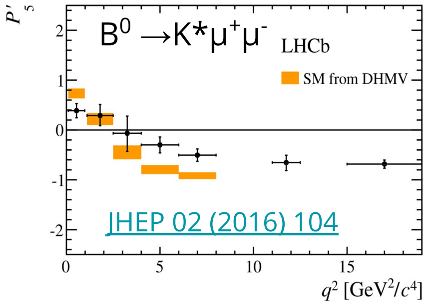
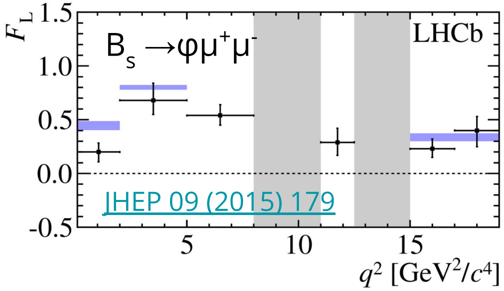
cnrs dépasser les frontières

Intriguing deviations in rare B decays

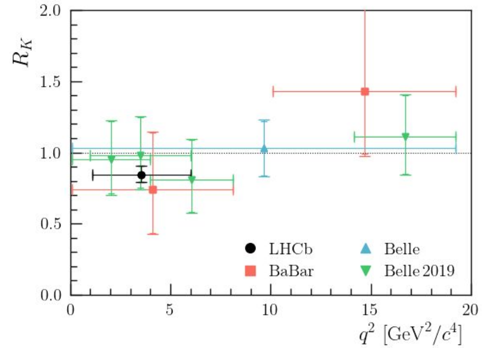
Differential BR and angular distributions

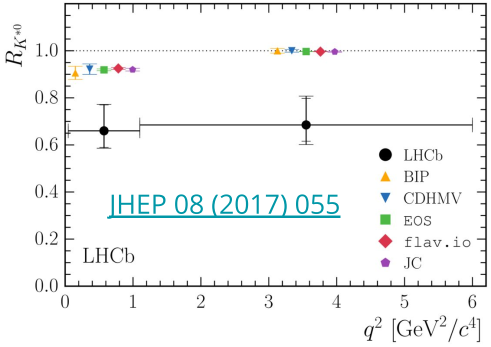






Lepton Flavour Universality (LFU) tests





Effective Hamiltonian (b → sll)

Effective theory for b → sll transitions. Separation of short and long distance at a scale $\mu = \mathcal{O}(m_b)$

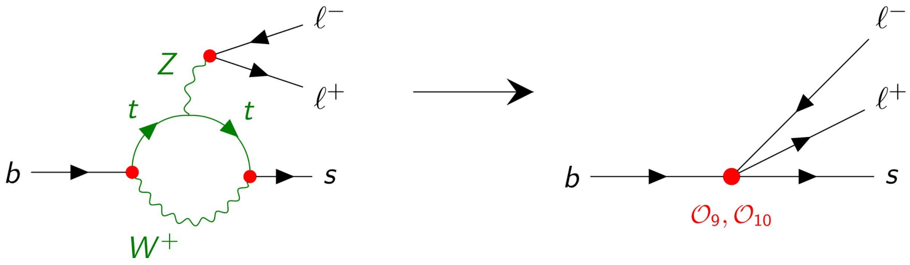
- Non-local high energy processes are reduce to local operators as in Fermi Theory.

$$\mathcal{H}_{\text{eff}}(b \to s\ell^+\ell^-) = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i \mathcal{O}_i$$

- With the SM operators relevant for this analysis

$$\mathcal{O}_7 = \frac{e}{g^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu} \qquad \mathcal{O}_9 = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \qquad \mathcal{O}_{10} = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

- Wilson coefficients (Ci) contain short distance dynamics.
- They are accurately computed in SM and would deviate in presence of NP. Operators absent or suppressed in the SM, can be introduced by NP.



Attention!
Not all contributions become local within the effective Hamiltonian approach. One is particularly relevant phenomenological ($c\bar{c}$ contributions).

Global Fits to b ⟶ sll

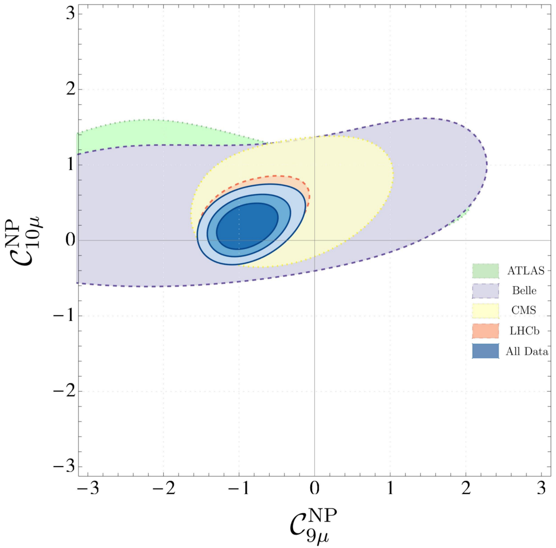
- (LFU) NP hints in rare semileptonic B decays indicate significant non-standard effects in muonic final states.
- Smaller effect in electrons is not excluded but not required to fit data.
- b⟶sττ transitions are at present only poorly constrained

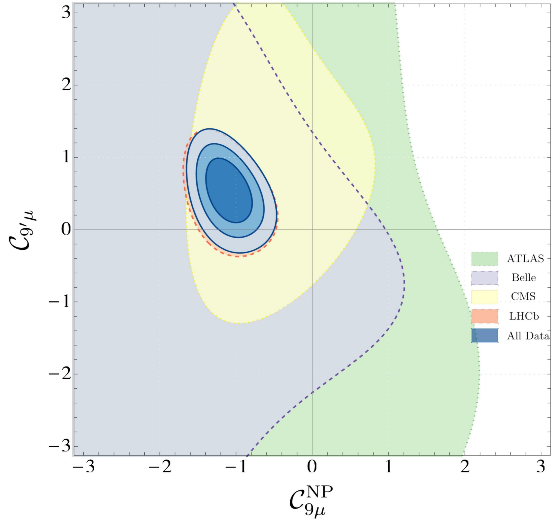
Main 1D scenarios for b⟶sμμ

These prefered scenarios show pulls from the SM of around 6σ

$$\mathcal{C}_{9\mu}^{\rm NP} \qquad \mathcal{C}_{9\mu}^{\rm NP} = -\mathcal{C}_{10\mu}^{\rm NP}$$

$$\mathcal{C}_{9\mu}^{\rm NP} = -\mathcal{C}_{9'\mu}^{\rm NP}$$

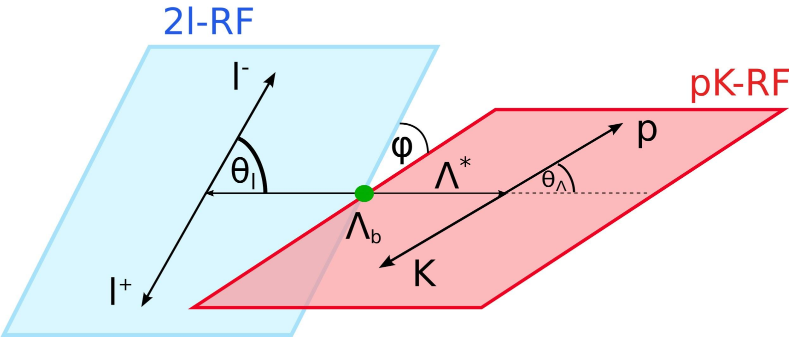




Angular Analysis of $\Lambda_b \to \Lambda^*(\to Kp)ll$ [1903.00448]

We focus on **Λ(1520)**, a **spin 3/2** which decays mainly through **strong** interaction.

$$\frac{d^4\Gamma(\Lambda_b \to \Lambda^*(\to Kp)\ell^+\ell^-)}{dq^2 d\cos\theta_\ell d\cos\theta_\Lambda d\phi} = \frac{3}{8\pi} L(q^2,\theta_\ell,\theta_\Lambda,\phi)$$



$$\begin{aligned} L(q^2,\theta_\ell,\theta_\Lambda,\phi) = &\cos^2\theta_\Lambda \left(L_{1c}\cos\theta_\ell + L_{1cc}\cos^2\theta_\ell + L_{1ss}\sin^2\theta_\ell\right) \\ &+ \sin^2\theta_\Lambda \left(L_{2c}\cos\theta_\ell + L_{2cc}\cos^2\theta_\ell + L_{2ss}\sin^2\theta_\ell\right) \\ &+ \sin^2\theta_\Lambda \left(L_{3ss}\sin^2\theta_\ell\cos^2\phi + L_{4ss}\sin^2\theta_\ell\sin\phi\cos\phi\right) \\ &+ \sin\theta_\Lambda\cos\theta_\Lambda\cos\phi(L_{5s}\sin\theta_\ell + L_{5sc}\sin\theta_\ell\cos\theta_\ell) \\ &+ \sin\theta_\Lambda\cos\theta_\Lambda\sin\phi(L_{6s}\sin\theta_\ell + L_{6sc}\sin\theta_\ell\cos\theta_\ell) \end{aligned}$$

$$L_{1c} \propto \left(\mathrm{Re}(A^L_{\perp 1} A^{L*}_{\parallel 1}) - (L \leftrightarrow R)\right)$$

$$L_{3ss} \propto \left(\mathrm{Re}(B^L_{\parallel 1} A^{L*}_{\parallel 1}) - \mathrm{Re}(B^L_{\perp 1} A^{L*}_{\perp 1}) + (L \leftrightarrow R)\right)$$

$$\vdots$$

- Angular structure is dictated by the spin of the particles and the nature of the decays (P-conserving).
- L_i are interferences of the transversity amplitudes

Transversity Amplitudes

$$\mathcal{C}_{9,10,-}^{L(R)} = (\mathcal{C}_9 \mp \mathcal{C}_{10}) - (\mathcal{C}_{9'} \mp \mathcal{C}_{10'})$$
$$\mathcal{C}_{9,10,+}^{L(R)} = (\mathcal{C}_9 \mp \mathcal{C}_{10}) + (\mathcal{C}_{9'} \mp \mathcal{C}_{10'})$$

The $\Lambda_b \to \Lambda^* ll$ decay is described by 12 transversity amplitudes.

$$TA = \left\{ B_{\perp 1}^{L(R)}, B_{\parallel 1}^{L(R)}, A_{\perp 1}^{L(R)}, A_{\parallel 1}^{L(R)}, A_{\perp 0}^{L(R)}\ A_{\parallel 0}^{L(R)} \right\}$$

$$B_{\perp 1}^{L(R)} \propto \left(\mathcal{C}_{9,10,+}^{L(R)} H_+^V(-1/2,-3/2) - \frac{2m_b(\mathcal{C}_7+\mathcal{C}_{7'})}{q^2} H_+^T(-1/2,-3/2) \right)$$

$$\vdots$$

$$A_{\parallel 0}^{L(R)} \propto \left(\mathcal{C}_{9,10,-}^{L(R)} H_0^A(+1/2,+1/2) + \frac{2m_b(\mathcal{C}_7-\mathcal{C}_{7'})}{q^2} H_0^{T5}(+1/2,+1/2) \right)$$

Wilson Coefficients
(short distance)

Form factors
(long distance)

s_{Λ_b}	s_{Λ^*}	Amplitudes
$\pm\frac{1}{2}$	$\pm\frac{1}{2}$	$A_{\perp 0}^{L(R)}, A_{\parallel 0}^{L(R)}$
$\pm\frac{1}{2}$	$\mp\frac{1}{2}$	$A_{\perp 1}^{L(R)}, A_{\parallel 1}^{L(R)}$
$\pm\frac{1}{2}$	$\pm\frac{3}{2}$	$B_{\perp 1}^{L(R)}, B_{\parallel 1}^{L(R)}$

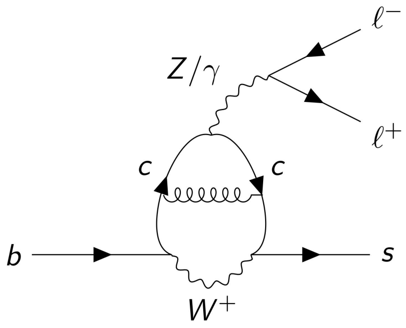
$\Lambda_b \to \Lambda^*$ form factors

- **14** form factors in total
- New lattice results at high q^2 [2009.09313]
- Quark model from [1108.6129] used for numerical illustration on the full q^2 range

Two sources of hadronic uncertainties

Form factors (local)

We assume an uncorrelated uncertainty of 10% (5%) for each form factor (educated guess).

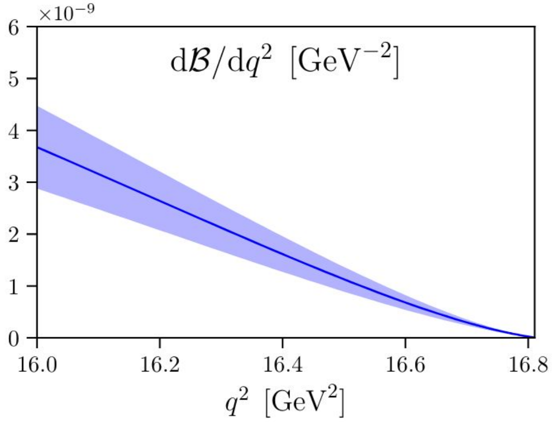


$c\bar{c}$ contributions (non-local)

- These contributions appear as a correction to C9, they are q^2 dependent and depend on external states.
- LCSR could be used to determine corrections near the $q^2 = 0$ region.
- Parametrize $c\bar{c}$ contributions and obtain these parameters from experiment at J/Ψ and $\Psi(2S)$ poles.
- For now we consider contributions (as an error) of the order to the estimations for $B \to K^{(*)} ll$ (i.e. $C_{9cc} \approx 10\%\ C_9$)

New Lattice Results! [2009.09313]

- Form factors coming from the lattice are recently available
- Lattice calculation done in the Λ(1520) RF which restricts the results to high q^2 region
- Lower values of q^2 could be reached in the future using moving-NRQCD



Lattice vs quark model

- Excellent agreement with the results from the quark model [1108.6129]
- Similar uncertainties (10% per FF) for branching but reduced uncertainties for angular observables thanks to correlations

Low- and large-recoil limits (HQET and SCET)

HQET and SCET limits simplify the form factors. Both limits correspond to $m_b \to \infty$ in different kinematical domains.

Low Recoil (HQET)
- Two independent form factors

Large recoil (SCET)
- One independent form factor

Helicity 3/2 amplitudes vanish

Only 3 independent observables

In simple words

In the HQ limit the angular momentum of the heavy-quark and the light quarks are good quantum numbers to describe the Λ_b.

Since the light quarks are in a spin-0 diquark state and the heavy quark carries a spin 1/2, the b→sll transition cannot yield a helicity 3/2 Λ^* in this limit.

Only a trivial dependence on the angle describing the hadronic final state is left!

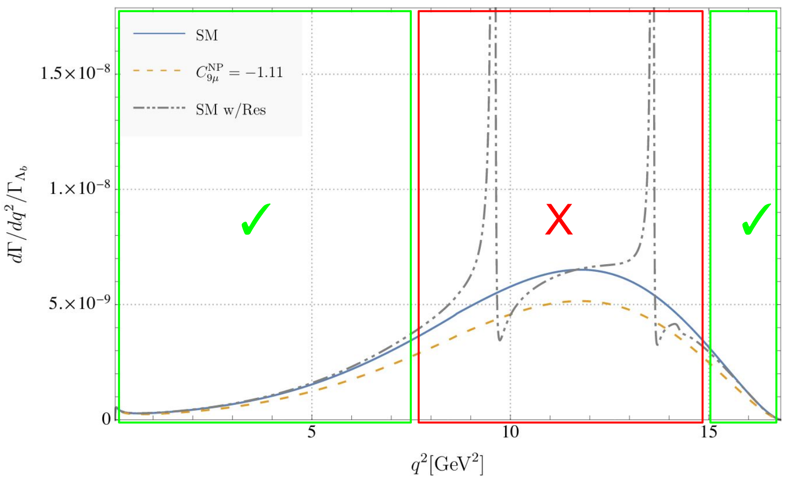
$$L(q^2, \theta_\ell, \theta_\Lambda, \phi) \simeq \frac{1}{4}(1 + 3\cos^2\theta_\Lambda)\left(L_{1c}\cos\theta_\ell + L_{1cc}\cos^2\theta_\ell + L_{1ss}\sin^2\theta_\ell\right)$$

$$A^\ell_{\mathrm{FB}} \simeq \frac{3L_{1c}}{2(L_{1cc}+2L_{1ss})}$$

Prospects for $\Lambda_b \to \Lambda^*(\to pK)\mu^+\mu^-$

We studied the viability of a $\Lambda_b \to \Lambda^*(\to pK)\mu^+\mu^-$ angular analysis by LHCb

- We focus on the muon mode but the results can be directly extrapolated to the electron case by scaling the yields accordingly.
- We work with the simplified (SCET/HQET) angular distribution.



4 different q^2 bins are considered without any high q^2 bin because of the reduced phase space

$$S_i = \frac{L_i + \bar{L}_i}{d(\Gamma + \bar{\Gamma})/dq^2}$$

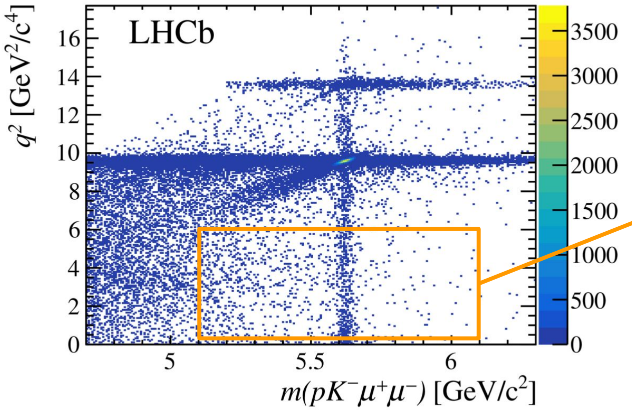
$$\langle S_i \rangle_{bin} = \frac{\int_{bin} dq^2 (L_i + \bar{L}_i)}{\int_{bin} dq^2 d(\Gamma + \bar{\Gamma})/dq^2}$$

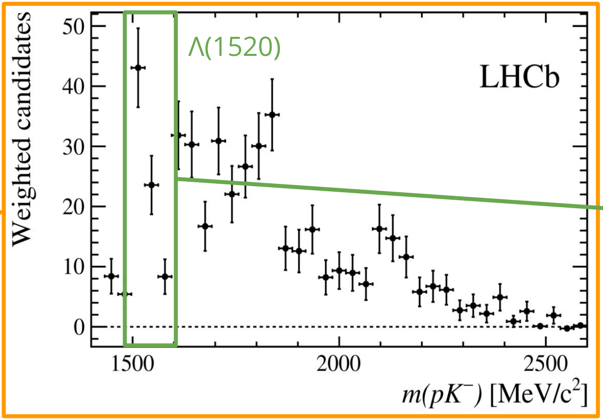
$$bins = \{[0.1, 3], [3, 6], [6, 8.86], [1, 6]\}$$

Experimental setup

LHCb has measured CPV observables in $\Lambda_b \to pK\mu^+\mu^-$ and recently LU test R_{pK}

Λ(1520) dominates the pK spectrum → focus on this for an angular analysis





Run 1 + 2016 data,
$0.1 < q^2 < 6$ GeV^2:

90 $\Lambda_b \to \Lambda(1520)\mu\mu$ events

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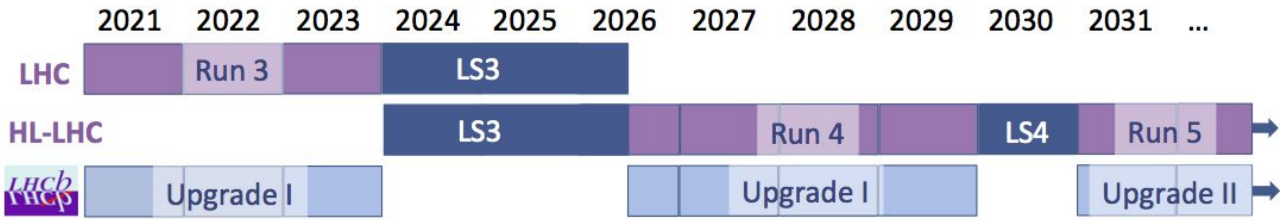
Expected yields

Consider recorded data + upcoming LHCb upgrades



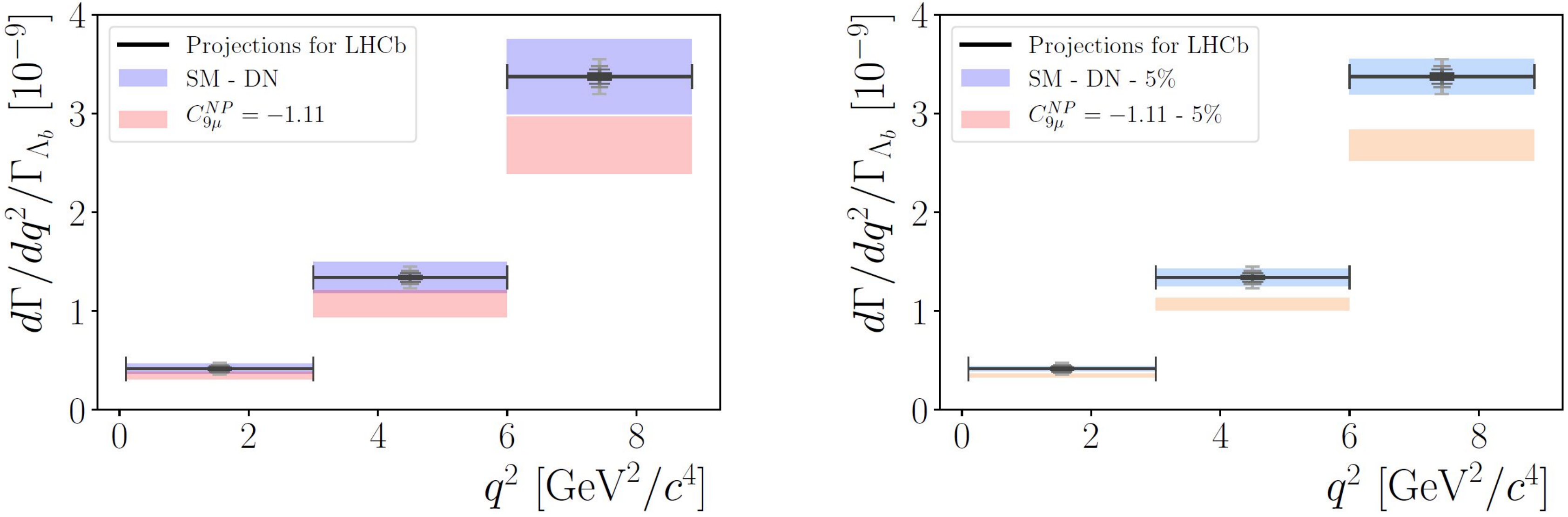
extrapolate yields from R_{pK} analysis and theoretical q^2 dependence:

	Run 1+2	Run 3	Run 4	Run 5+
Dataset $[\mathrm{fb}^{-1}]$ / q^2 bin $[\mathrm{GeV}^2/c^4]$	9	23	50	300
$[0.1, 3]$	50	140	300	1750
$[3, 6]$	150	400	900	5250
$[6, 8.86]$	400	1100	2400	14000
$[1, 6]$	190	510	1140	6650

NP sensitivity from decay width

arXiv:2005.09602

Experimental sensitivity to dΓ/dq^2 extracted from estimated yields, assuming poissonian uncertainties and neglecting the background (observed small)

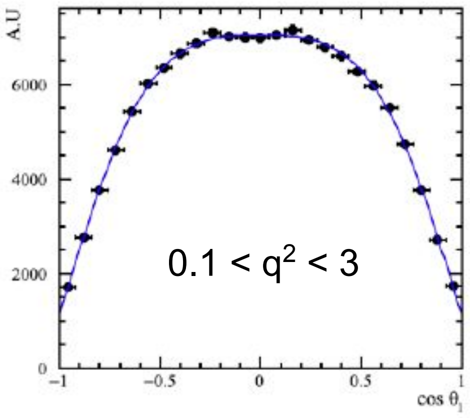


Sensitivity studies: angular analysis

arXiv:2005.09602

Studied with pseudoexperiments:

- generate pdf = theory x acceptance
  - theory: SM and NP with $C_9^{NP} = -1.11$
  - acceptance from RapidSim, including acceptance and p_T cuts, modelled with Legendre polynomials
- fit same pdf with free A_{FB} and S_{1cc}
- repeat 10k times for each q^2 bin and run period



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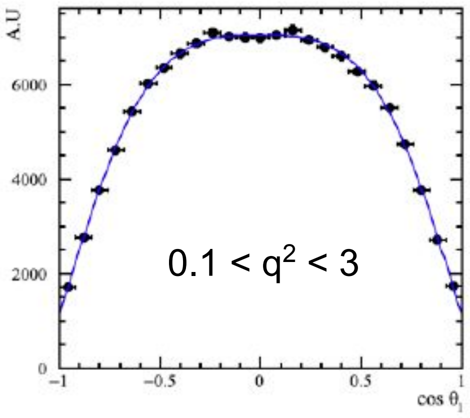


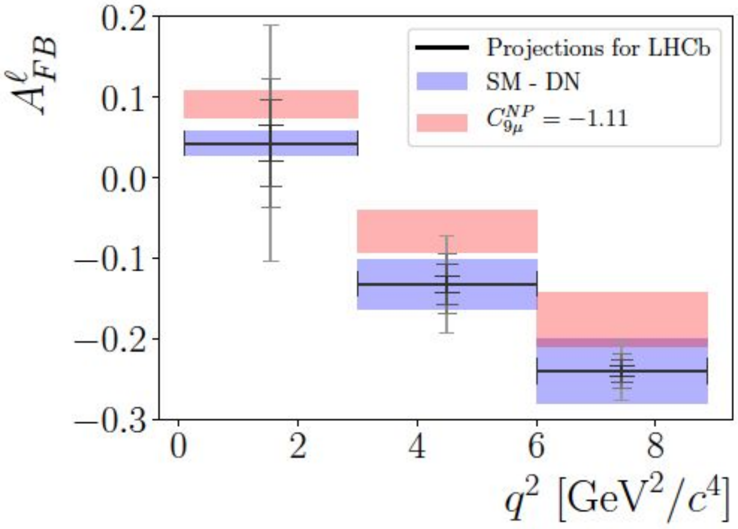
Small biases observed in low and central q^2 bins with small stats (Run 2 and 3)

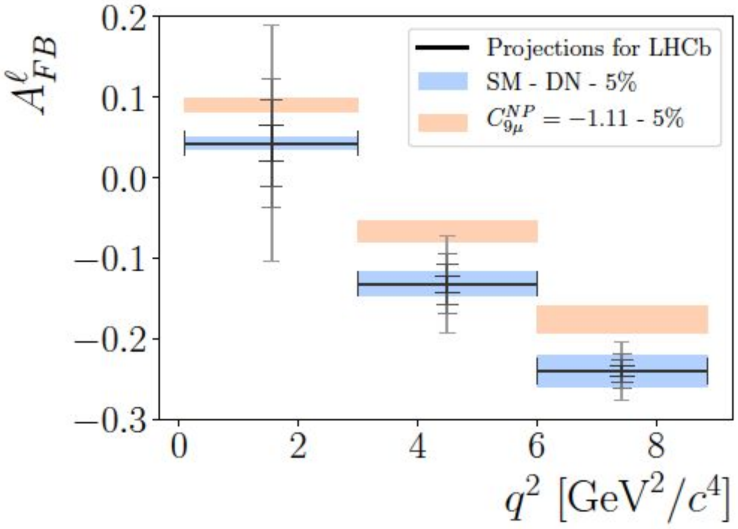
- always below 20% statistical uncertainty → can be added as systematic
- Good coverage in all cases → fit uncertainty as experimental sensitivity

NP sensitivity from angular analysis

arXiv:2005.09602

A_{FB} gives good sensitivity in Run 3/4 with reduced theory uncertainties



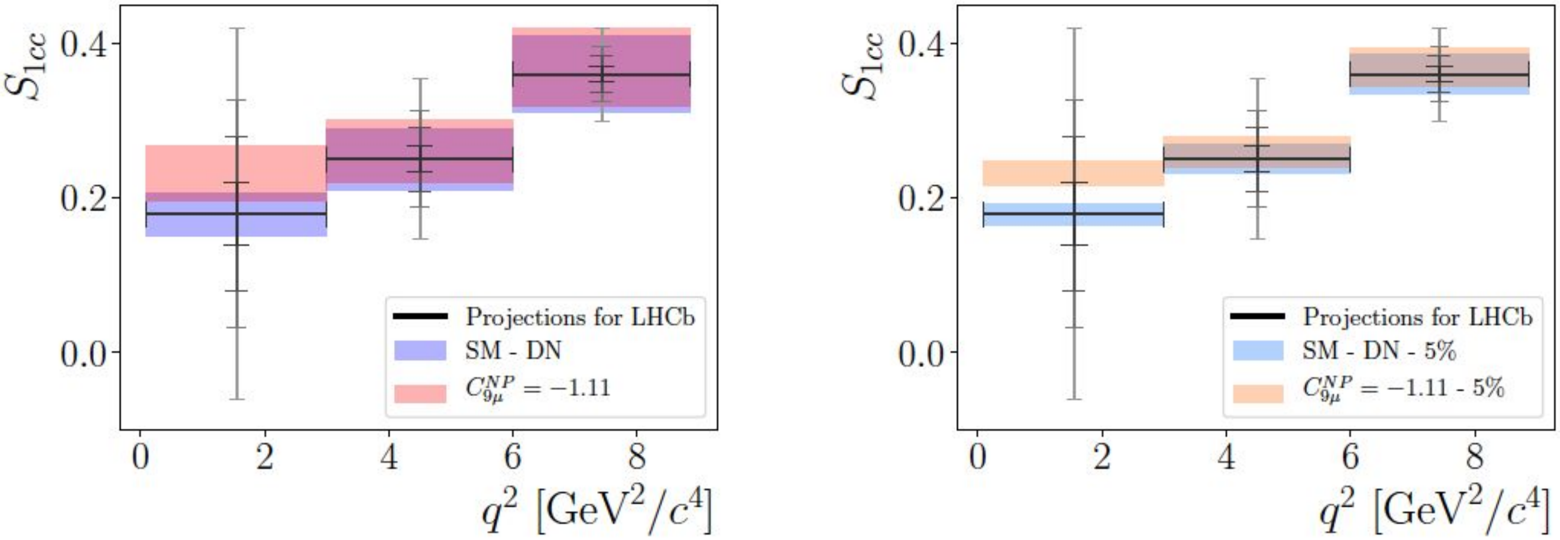


Need to wait for Upgrade 2 stats if theory doesn't improve

NP sensitivity from angular analysis

arXiv:2005.09602

S_{1cc} gives poor sensitivity, but comes for free



Simplified PDF cross-check

arXiv:2005.09602

Can the usage of the simplified PDF introduce any bias?

- generate pseudoexperiments with full PDF (slide 5)
- fit A_{FB} and S_{1cc} with simplified model (slide 9)

Results:

- No effect observed at small yields
- bias ~10% of statistical uncertainty with Upgrade 2 stats

→ Simplified PDF is a good approximation until 300 fb^{-1} are recorded

Summary & conclusions

Test $b \to s\mu\mu$ and LFU anomalies in other modes: $\Lambda_b \to \Lambda(1520)ll$

- theoretical framework: complicated decay rate with 12 angular observables + 14 form factors
- heavy quark limit provides large simplification: 3 observables with sensitivity to NP effects

Experimental precision evaluated from expected $\Lambda_b \to \Lambda(1520)\mu\mu$ yields

- A_{FB} and $d\Gamma/dq^2$ provide sensitivity to NP
- Run 3 or Upgrade 2 stats needed depending on theory progress
  - new lattice results recently available compatible with quark model used!!

Back-up

Acceptance shapes in all bins