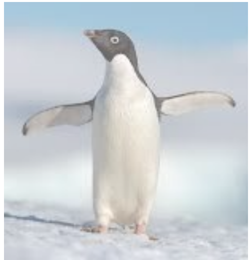
Sensitivity study of $\Lambda_b \to \Lambda(1520)\mu^+\mu^-$



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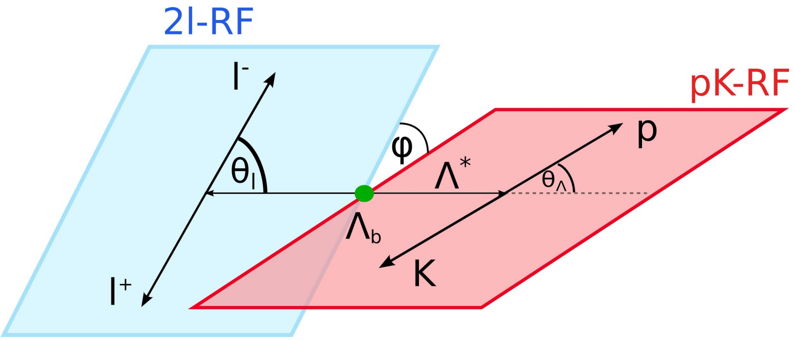
Angular Analysis of $\Lambda_b \to \Lambda^*(\to Kp)ll$ [1903.00448]

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

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

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

$$TA = \left\{ B^{L(R)}_{\perp 1}, B^{L(R)}_{\| 1}, A^{L(R)}_{\perp 1}, A^{L(R)}_{\| 1}, A^{L(R)}_{\perp 0}\ A^{L(R)}_{\| 0} \right\}$$

$$B^{L(R)}_{\perp 1} \propto \left(\mathcal{C}^{L(R)}_{9,10,+} H^V_+(-1/2,-3/2) - \frac{2m_b(\mathcal{C}_7+\mathcal{C}_{7'})}{q^2} H^T_+(-1/2,-3/2) \right)$$

$$\vdots$$

$$A^{L(R)}_{\| 0} \propto \left(\mathcal{C}^{L(R)}_{9,10,-} H^A_0(+1/2,+1/2) + \frac{2m_b(\mathcal{C}_7-\mathcal{C}_{7'})}{q^2} H^{T5}_0(+1/2,+1/2) \right)$$

Wilson Coefficients (short distance)

Form factors (long distance)

s_{Λ_b}	s_{Λ^*}	Amplitudes
$\pm\frac{1}{2}$	$\pm\frac{1}{2}$	$A^{L(R)}_{\perp 0}, A^{L(R)}_{\| 0}$
$\pm\frac{1}{2}$	$\mp\frac{1}{2}$	$A^{L(R)}_{\perp 1}, A^{L(R)}_{\| 1}$
$\pm\frac{1}{2}$	$\pm\frac{3}{2}$	$B^{L(R)}_{\perp 1}, B^{L(R)}_{\| 1}$

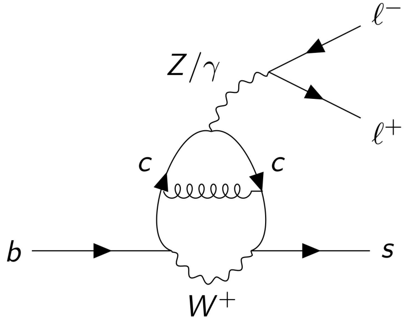
$\Lambda_b \to \Lambda^*$ form factors

- **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)

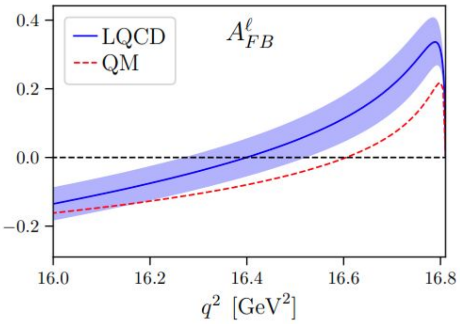
We assume an uncorrelated uncertainty of 10% (5%) for each form factor (educated guess).

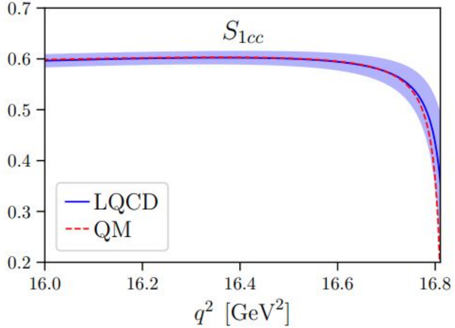


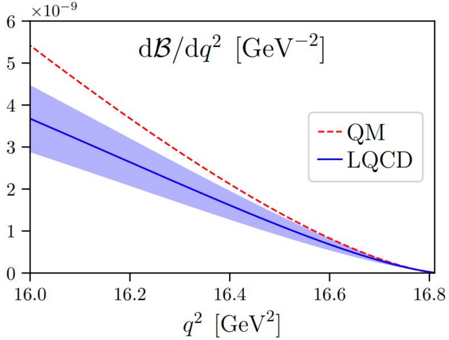
cc̄ contributions (non-local)

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

See Dany’s Talk!







New Lattice Results! [2009.09313]

(Talk by Stefan Meinel)

- 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

- Good agreement with the results from the quark model [1108.6129]
- Similar uncertainties (only at high q^2) 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.

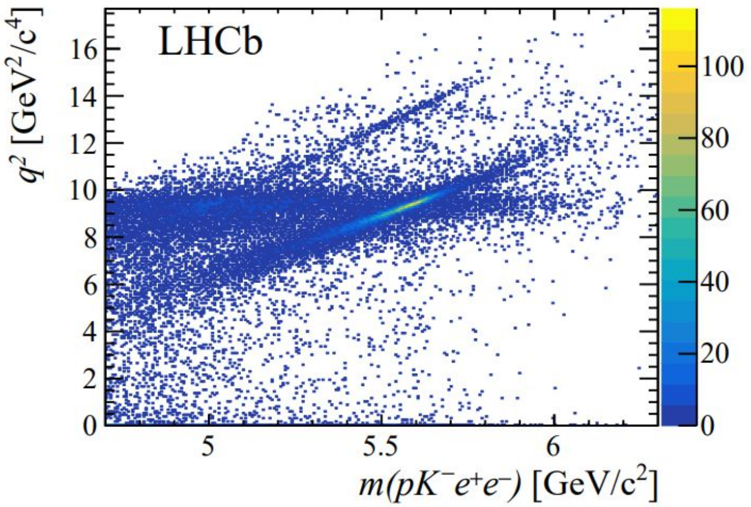
Only a trivial dependence on the angle describing the hadronic final state is left!

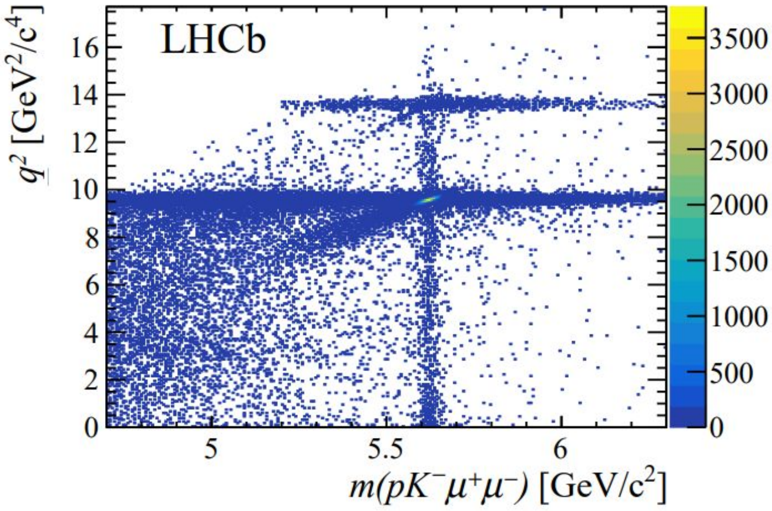
$$L(q^2, \theta_\ell, \theta_\Lambda, \phi) \simeq \frac{1}{4}(1 + 3\cos^2\theta_\Lambda)\left(L_{1c}\cos\theta_\ell + L_{1cc}\cos^2\theta_\ell + L_{1ss}\sin^2\theta_\ell\right)$$

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

Experimental status of $\Lambda_b \to pK^- l^+ l^-$

- Observation, CPV measurement in $\Lambda_b \to pK^-\mu^+\mu^-$ by LHCb JHEP 06 2017 (108)
- Electron mode observed but experimentally difficult JHEP 05 2020 (040)
- LU test R_{pK} by LHCb JHEP 05 2020 (040)





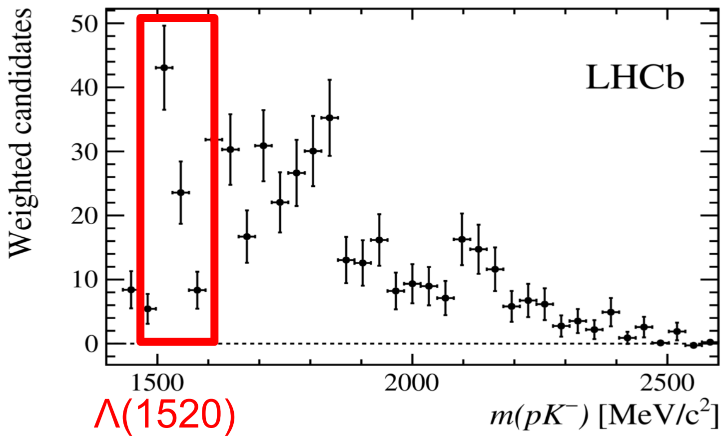
Disentangling the components

Rich Λ* spectrum

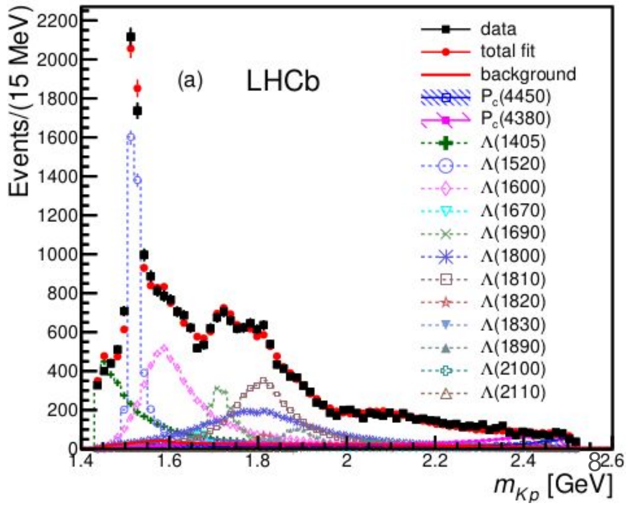
Amplitude analysis at *J/ψ*-pole
[Phys. Rev. Lett. 115, 072001 (2015)](#)
γ-pole analysis ongoing

Problems of amplitude analyses
- many fit parameters (fit stability)
- assumptions and mismodelling

Supl. material to RpK publication



Λ(1520)
dominates



Phys. Rev. D 91, 114012 (2015)

Analysis of the angular moments

Angular structure in terms of an angular basis $f_i(\Omega)$: $\frac{d\Gamma}{d\Omega} = \sum_i K_i f_i(\Omega)$

Idea: find weighting functions $w_i(\Omega)$ to extract the coefficients K_i :

$$\int w_i(\Omega) f_j(\Omega) d\Omega = \delta_{ij}$$

Advantages:

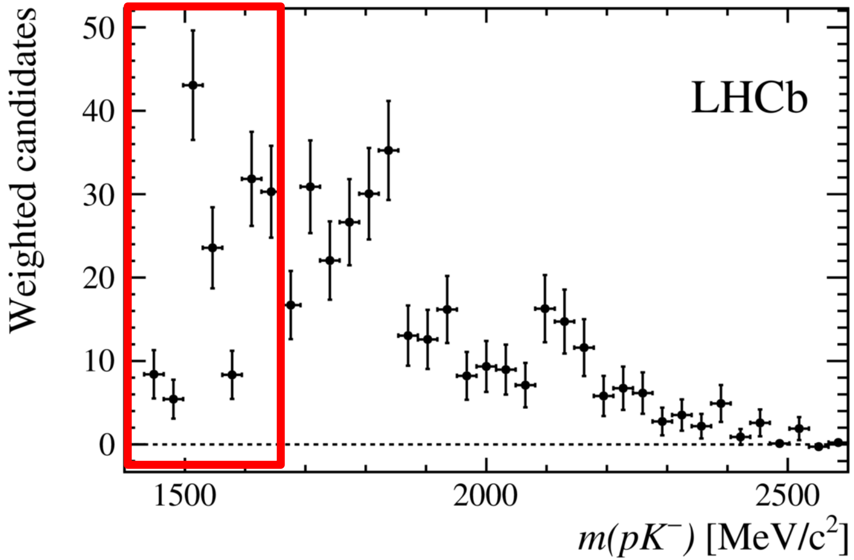
- No fit (no convergence problems, no instabilities, big advantage for small number of events)
- No mismodelling (resonance peaks, cut-offs, …)
- Independent extraction of any observable + well-defined statistical properties

But 10-30% larger uncertainties compared to a fit.

Strategy: combine moment and angular analysis

1) Understand the present spin-parity states using the method of moments.
   - Hope that the Λ(1520) is in fact dominating

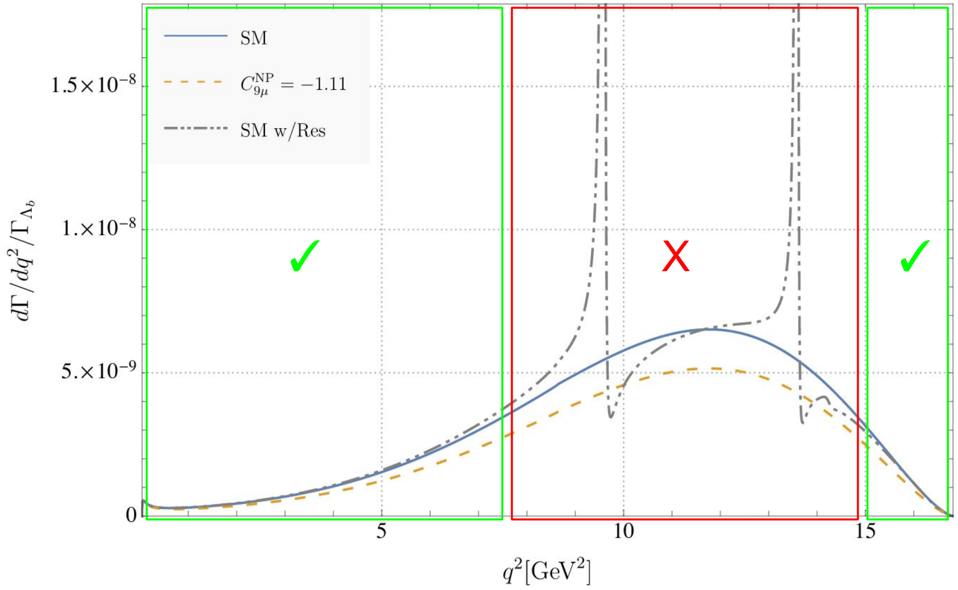
2) Angular analysis in a window around Λ(1520)



Strategy of angular analysis in $\Lambda_b \to \Lambda^*(\to pK)\mu^+\mu^-$

- Focus on **muon mode** but extrapolable to electron case
- Simplified (SCET/HQET) angular distribution used

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, 8.68], [1, 6]}

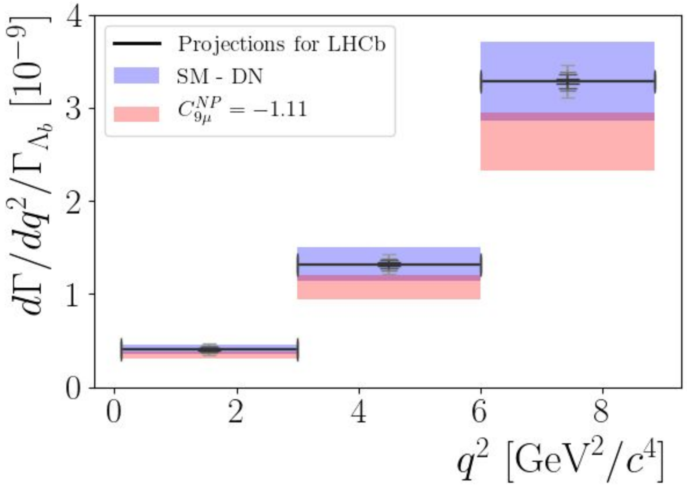
New Physics sensitivity to $d\Gamma/dq^2$

arXiv:2005.09602

1) Extrapolated yields from m(pK) spectrum of LU analysis and theoretical q^2 dependance

Run	1 + 2	3	4	5+
Dataset $[fb^{-1}]$ / q^2 bin $[GeV^2/c^4]$	9	23	50	300
$[0.1, 3]$	50	140	300	1750
$[3, 6]$	150	400	900	5250
$[6, 8.68]$	400	1100	2400	14000
$[1, 6]$	190	510	1140	6650

2) Assuming poissonian uncertainties and neglecting background (observed small)

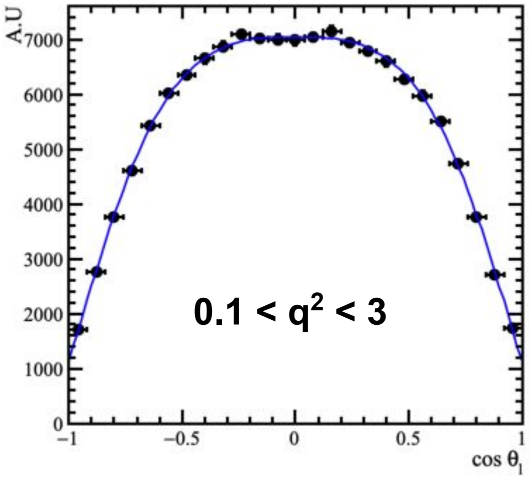


Sensitivity studies for angular observables

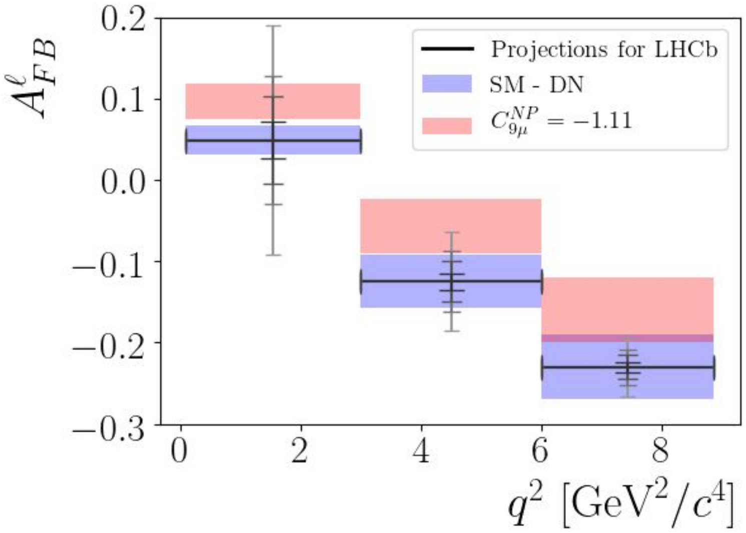
arXiv:2005.09602

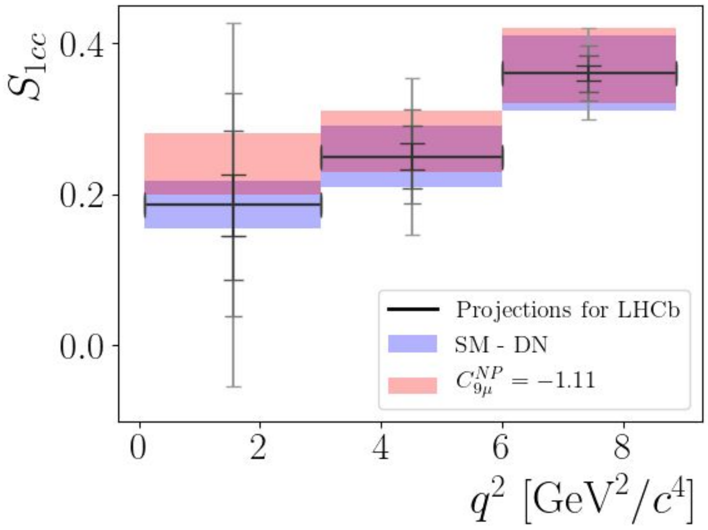
Studies with pseudo-experiments:

- 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^{ℓ}_{FB} and S_{1cc}
- Repeat 10 000 times per q^2 bin and run period



NP sensitivity to A^{ℓ}_{FB} and S_{1cc}





Sensitivity of A^{ℓ}_{FB} after Upgrade 2

Poor sensitivity.

New physics sensitivity could be reached earlier with reduced theory uncertainties

Implementation of angular observables in flavio

Merge request

Implemented angular observables in flavio :

- $d\Gamma/dq2$
- A_{FB}, F_L
- CP averaged angular observables and CP-asymmetries

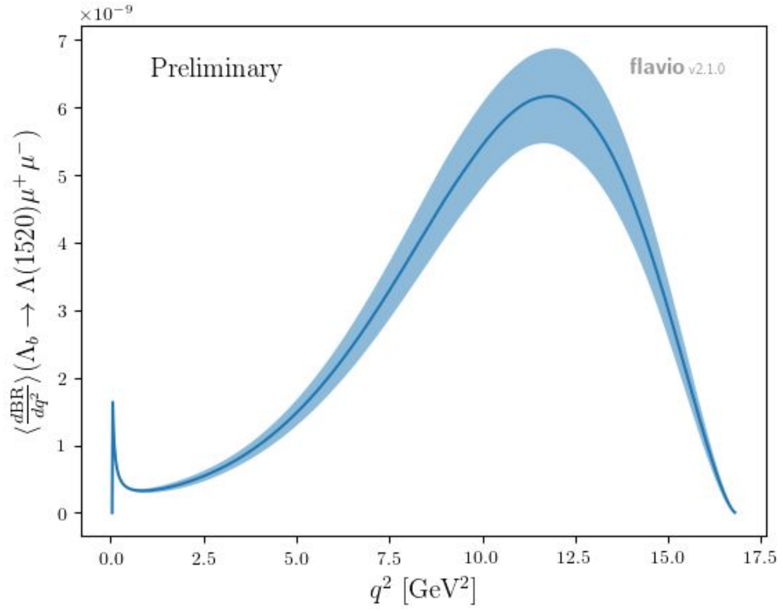
Form factors from the full quark model wave function from arXiv:1108.6129

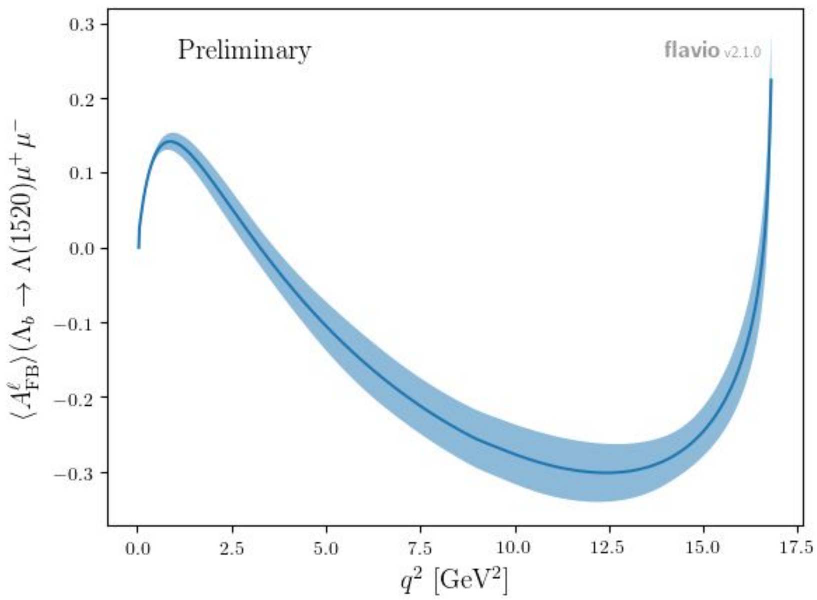
Using 10% uncertainty on $f_{0,\perp,t}$ form factors and 30% on f_g

➔ Allows evaluation of the impact on C_9 and C_{10}

Predictions implemented in Flavio now

Thanks to Peter Stangl





Similar to results achieved by Martín and Sébastien

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
- Measurement only possible in the muon mode at the moment
- Difficult extraction of individual Λ^*
- Experimentally A^{ℓ}_{FB} and $d\Gamma/dq^2$ provide sensitivity to New Physics
- Implementation of angular observables in Flavio → impact on C_9 and C_{10} can be visualized in the future
- Next step: angular analysis with LHCb data

Thank you for your attention !

Back-up: reduced theory uncertainties