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Search for New Physics in baryons decay at LHCb

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New Physics in Baryons decay: Overview

- Why?
  - Motivation from a **theoretical** and **experimental** perspective
- What?
  - **Angular** analysis of $\Lambda_b \to \Lambda_c \mu \nu$
  - **LFU** test: $R(\Lambda_c)$
- How?
  - Analyses **strategy**

Why?

The Flavour Puzzle in Semileptonic decays

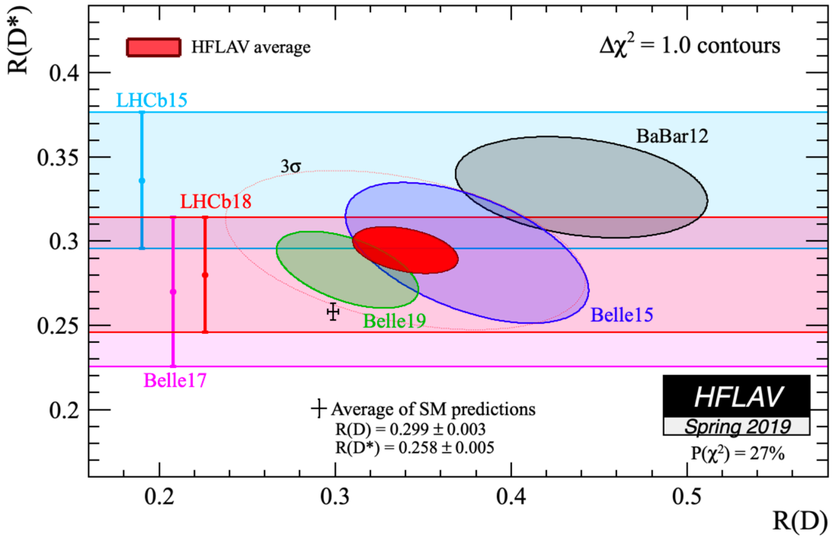
What are the *Flavour anomalies* ?

The assumption

- **Lepton Flavour Universality (LFU)**: the electroweak coupling of bosons $(W^{\pm}, Z^0)$ to leptons is identical.

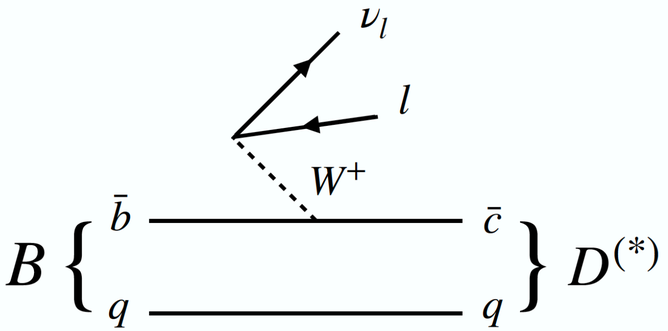
The observation

- Hints for lepton flavour universality **violation** in a variety of semileptonic measurements, deviating $\sim 3.1\,\sigma$ from the Standard Model. ⇒ *Flavour Anomalies* ☞ More in A. Buonaura's talk [302]



Test of LFU involving the 3rd generation of quarks and leptons ($\underline{b \to c\ell\nu}$)

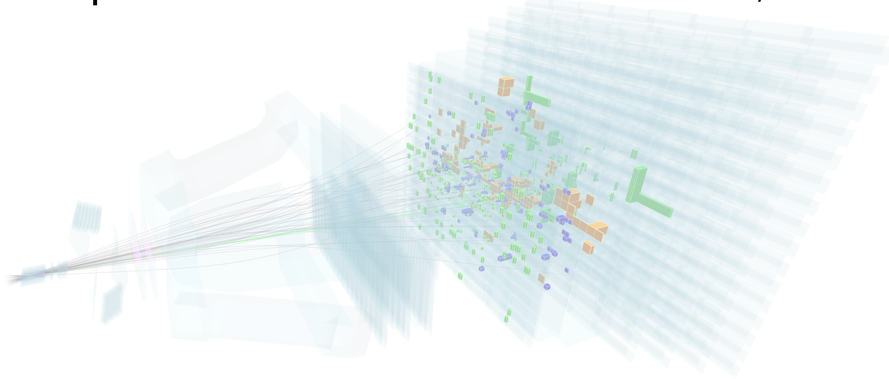
$$R(H_c) = \frac{\mathrm{BR}(B \to H_c \tau \nu)}{\mathrm{BR}(B \to H_c \ell \nu)} \quad \begin{matrix} \longrightarrow & \textit{signal} \\ \longrightarrow & \textit{normalisation} \end{matrix} \qquad \text{where } \ell = \mu, e$$



New Physics with Λ_b baryons at LHCb

Why so interesting? Experimentally convenient!

- Λ_b^0 baryons are **spin** $1/2$ particles, which complement the NP searches performed in the mesonic sector, *e.g.* $B \to D^{(*)}\mu\nu$ decays
  - Different spin-dynamics can be probed
  - **Reduced backgrounds** due to baryon nr conservation



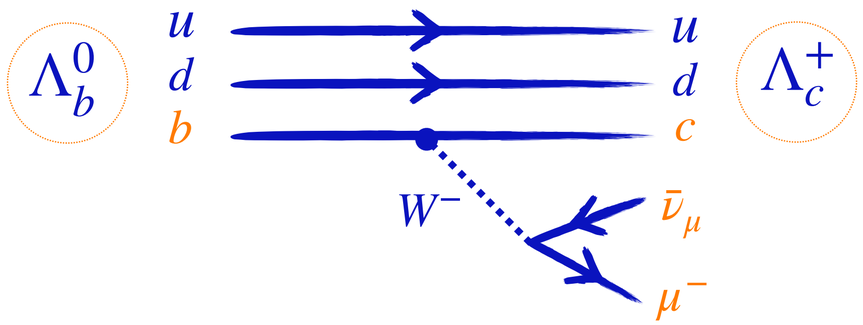
- **Unique feature** to hadron colliders, not possible in leptonic beauty factories

- **High statistics** of Λ_b^0 baryons produced at LHCb ($\sim 20\,\%$ of the produced hadrons) [PRD.85.032008] with large signal yields (~ 6M events for Run2)

What?

What looking for? New Physics (NP) in semi-leptonic $b \to c\ell\nu$ tree-level transitions

$$\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$$



- Probe the *high-energy dynamics* of the Standard Model Lagrangian, by measuring the **Wilson Coefficients**

$$\mathscr{L}_{\mathrm{SM}} = \mathscr{L}^{d\leq 4} + \sum_{i,d} \frac{c_i^{[d]}}{\Lambda_{\mathrm{NP}}^{d-4}} O_i^{d\geq 5}(\psi_{\mathrm{SM}})$$

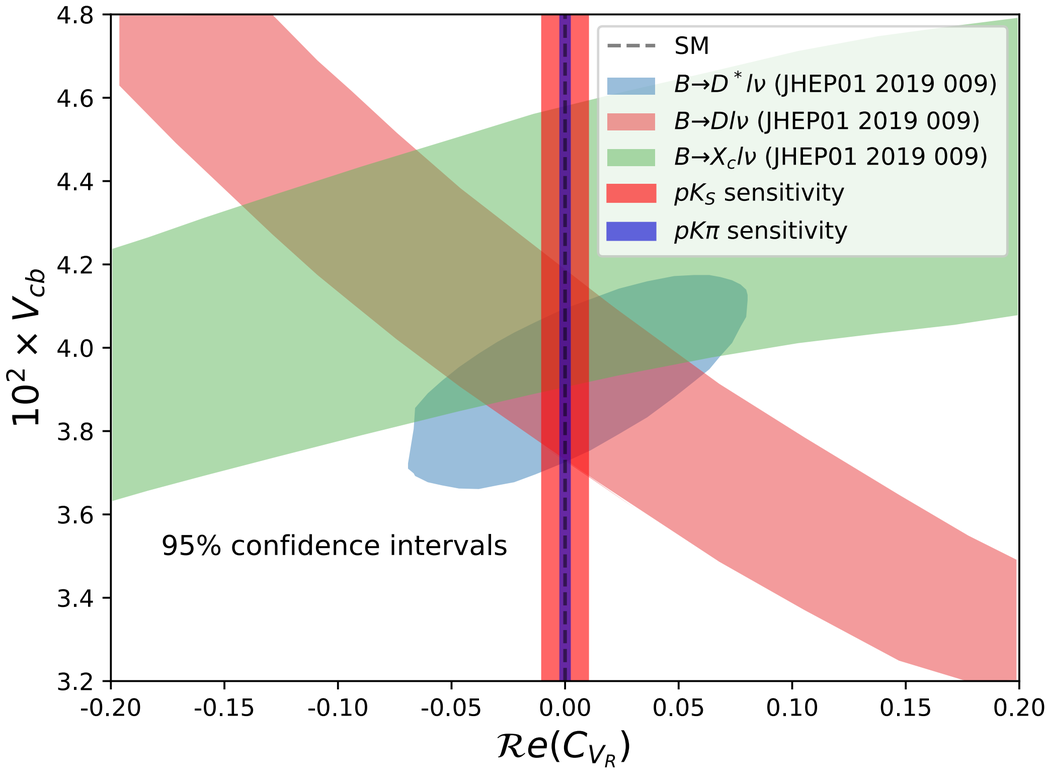
low-energy limit:
Lepton Flavour Universality

high-energy:
NP Operators (scalar, vector, tensor ..)
$C_{V_R}, C_{S_L}, C_{S_R}, C_T$

Non-null measured values of Wilson Coefficients would be a clear **sign** of **New Physics**.

What looking for? New Physics (NP) in semi-leptonic $b \to c\ell\nu$ tree-level transitions

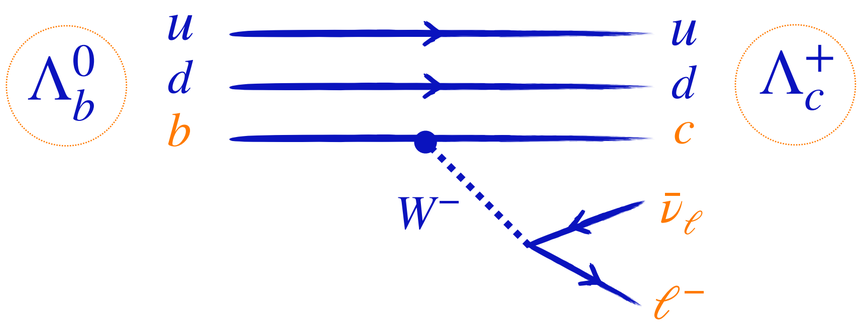
- Enhanced **sensitivity** to NP contributions through the study of **angular observables** of $\Lambda_b \to \Lambda_c \mu\nu$ decay products (MF, A. Mathad, P. Owen, N. Serra [JHEP12(2019)148])



- Study of **mesonic decays** exhibits good sensitivity to the Wilson Coefficients, from **global fits** to $b \to c\mu\nu$ and $b \to ce\nu$ [JHEP01 2019 009]

- In our study we show that the **baryonic counterpart** $\Lambda_b \to \Lambda_c \mu\nu$ can complement and **better constrain** some muonic parameters, *e.g.* C_{V_R}

$R(\Lambda_c)$: A LFU Test with Baryons



Lepton Flavour Universality can be tested in the ratio:

$$R(\Lambda_c) = \frac{\mathrm{BR}(\Lambda_b \to \Lambda_c \tau \nu)}{\mathrm{BR}(\Lambda_b \to \Lambda_c \mu \nu)} \qquad \text{where} \quad \tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$$

✔ This measurement can potentially **validate** or discard the other existing **anomalies** [PRD 100, 035035]

$$\frac{R(\Lambda_c)}{R_{\mathrm{SM}}(\Lambda_c)} \simeq 0.262 \frac{R(D)}{R_{\mathrm{SM}}(D)} + 0.738 \frac{R(D^*)}{R_{\mathrm{SM}}(D^*)}$$

✔ **Theoretically clean** measurement: tree-level transition in the SM

✔ **No dependence** on **CKM** elements, *i.e.* V_{cb}

✔ **Reduced** theoretical and experimental **uncertainties** in the ratio

✘ **Challenging** measurement: 3 missing particles in the final state

How?

$\Lambda_b \to \Lambda_c \mu\nu$ Angular Analysis

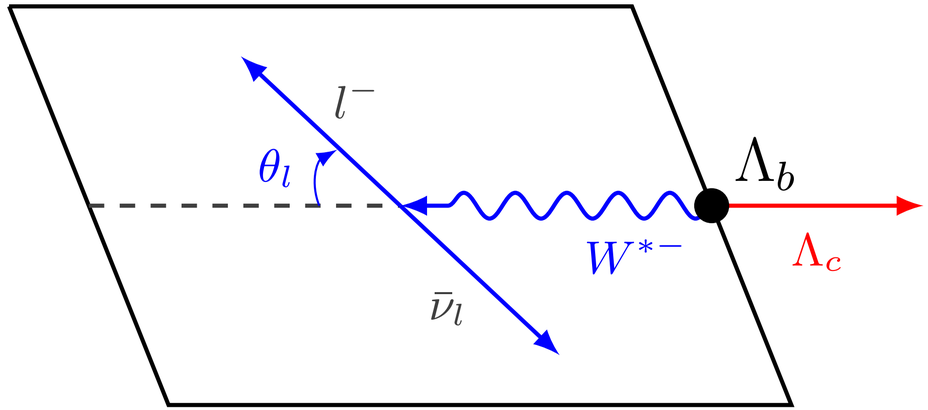
$\Lambda_b \to \Lambda_c \mu\nu$ ANGULAR[*] ANALYSIS

[*] Measurement of New Physics operators **Wilson Coefficients for muons**

- Our aim is to analyse the **Run2** (2016-2018) dataset
- We assume Λ_b decays to be **unpolarised** [JHEP06(2020)110], where $\Lambda_c^+ \to p\, K^+ \pi^-$

  Sensitivity in the 2D phase space q^2, $\cos\theta_\mu$
- **CP violation** effects have **not** been considered

  i.e. Wilson Coefficients are **real** variables



$$q^2 = (\hat{P}_{\Lambda_b} - \hat{P}_{\Lambda_c})^2$$

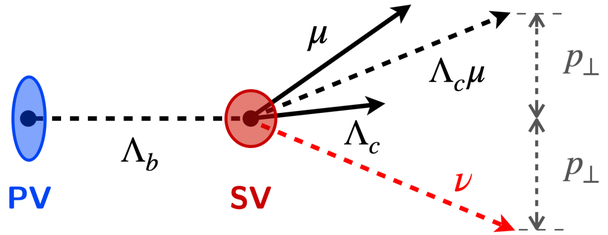
$$\cos\theta_\ell = \overrightarrow{P}^{\{W^*\}}_{\Lambda_b} \cdot \overrightarrow{P}^{\{W^*\}}_{\ell}$$

$\Lambda_b \to \Lambda_c \mu\nu$: Analysis Strategy - Signal Fits

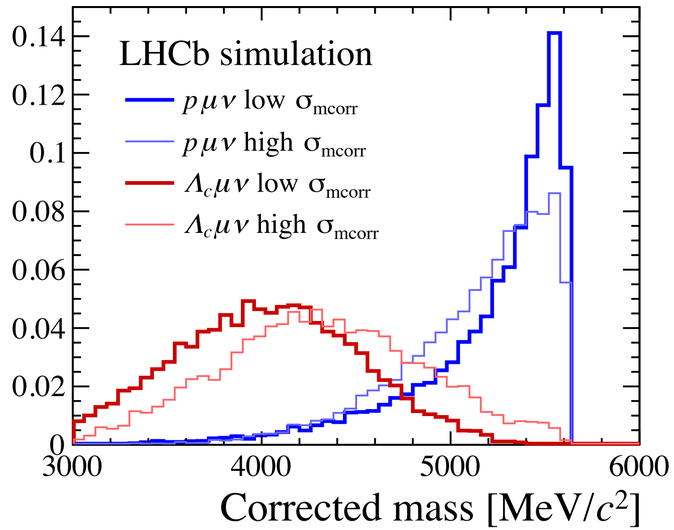
- **Signal extraction**: fit to the corrected mass M_{corr} **binned** in the **phase space** variables q^2, $\cos\theta_\mu$

$$M_{\text{corr}}(\Lambda_b) := \sqrt{m_{\text{vis}}^2 + p_\perp^2} + p_\perp$$ with m_{vis} invariant mass of the visible decay products

- Retrieve $p_\perp$, the **unreconstructed** momentum perp. to the Λ_b flight direction
- M_{corr} ≡ **minimum mass** in the hp of one missing massless particle (neutrino)
- Powerful **discriminating** variable btw signal and backgrounds



Nature Phys 11, 743–747 (2015)



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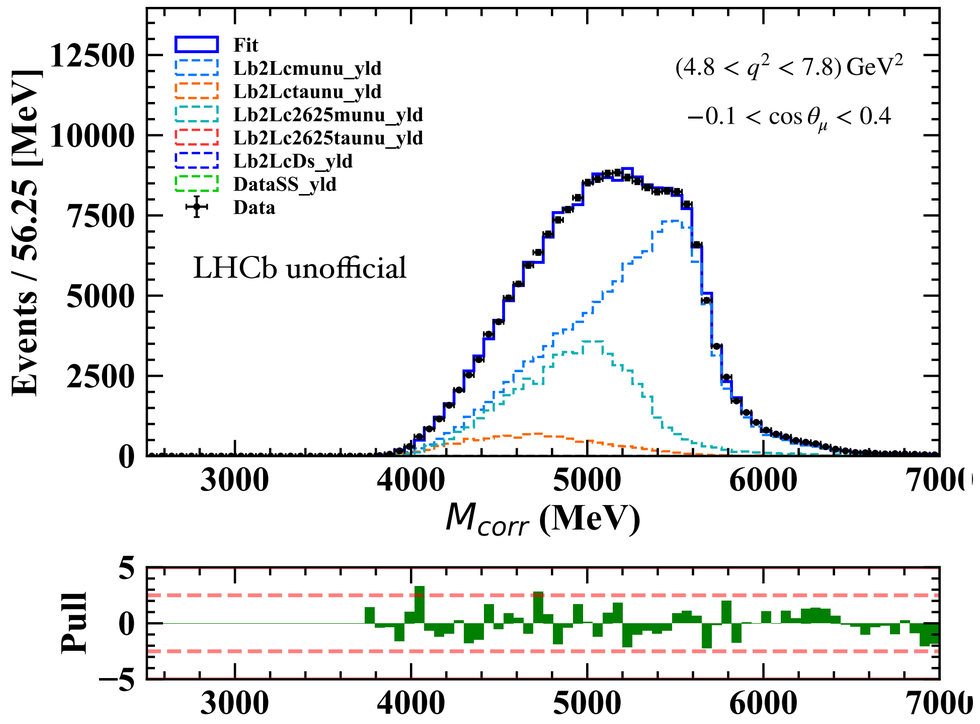
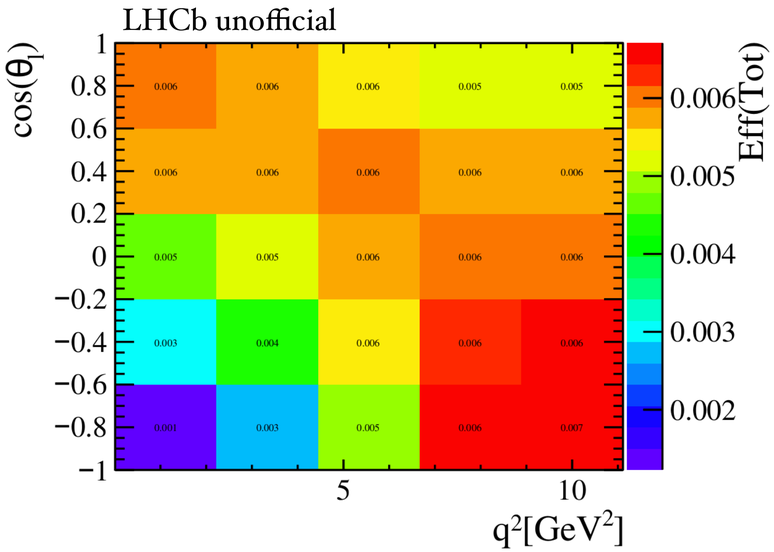


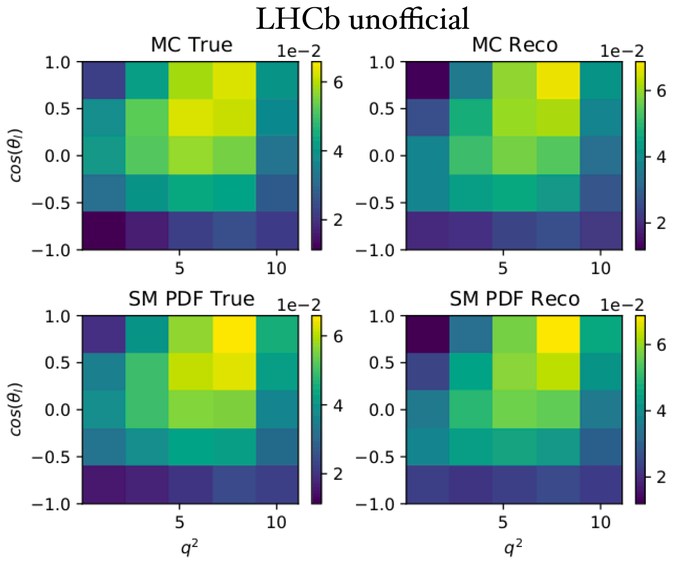
$\Lambda_b \to \Lambda_c \mu \nu$: Analysis Strategy - NP Fits

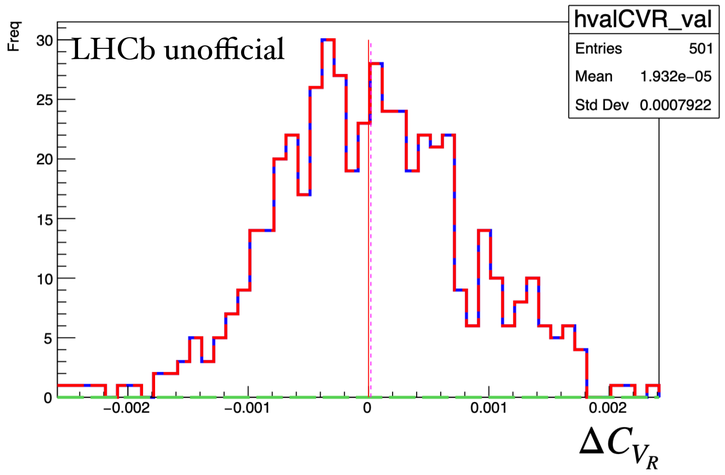
- **Fit model**: *efficiency* and *resolution* maps folded into our **model** $\dfrac{\partial^2\Gamma}{\partial q^2 \partial \cos\theta_\mu}$ to extract the **Wilson Coefficients**

  Form Factors parameters from latest Lattice QCD calculations

(Max. Likelihood binned): $$\mathrm{PDF}\,(\vec{x}^{\,i}_{\mathrm{reco}}, \vec{\theta}) = \kappa \sum_{j=\mathrm{bins}} R(\vec{x}^{\,i}_{\mathrm{reco}}, \vec{x}^{\,j}_{\mathrm{true}})\, \epsilon(\vec{x}^{\,j}_{\mathrm{true}})\, F(\vec{x}^{\,j}_{\mathrm{true}}, \vec{\theta})$$







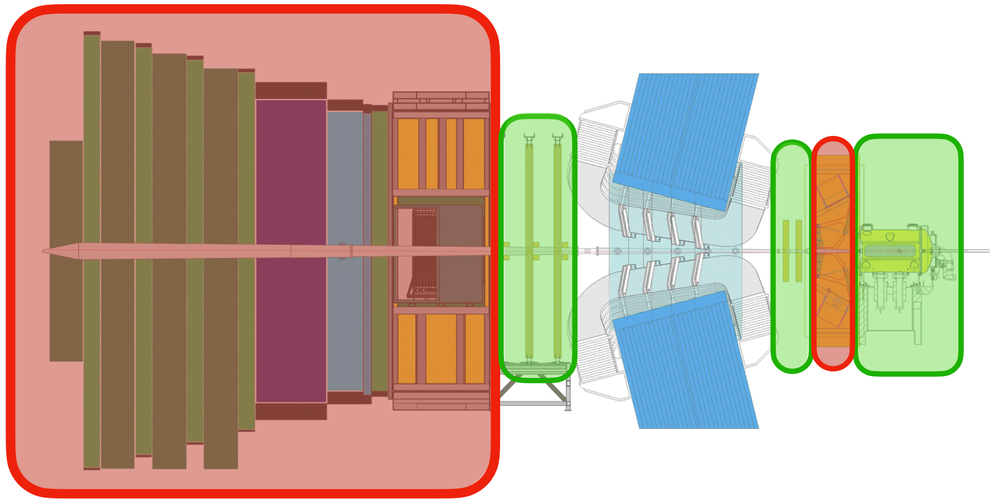
How?

$R(\Lambda_c)$ Analysis

$R(\Lambda_c)^{[*]}$ Analysis: Strategy

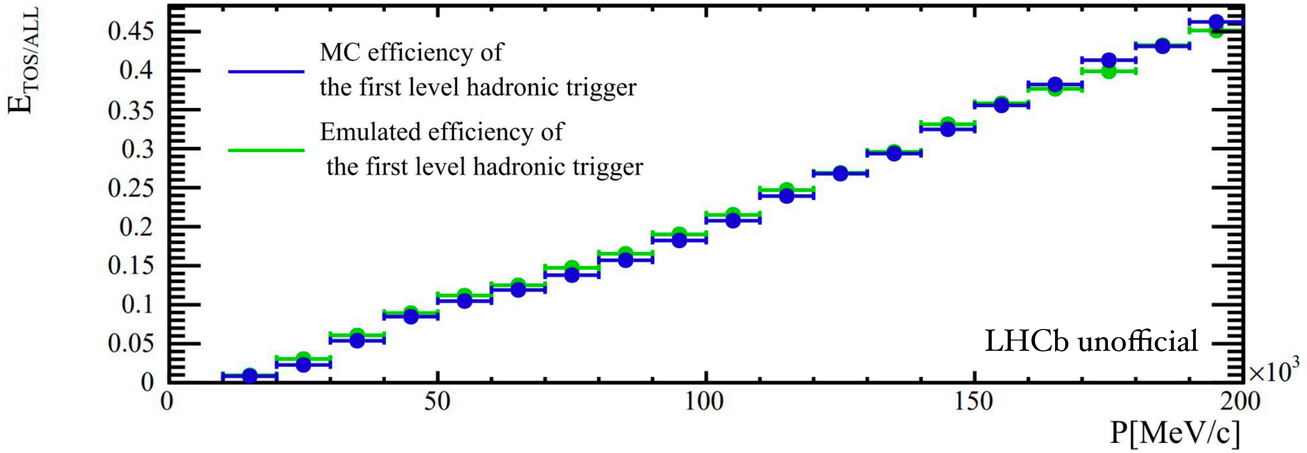
[*] Lepton Flavour Universality test $R(\Lambda_c) = \frac{\mathrm{BR}(\Lambda_b \to \Lambda_c \tau \nu)}{\mathrm{BR}(\Lambda_b \to \Lambda_c \mu \nu)}$

- Measurement in progress on **Run2 - 2016** data
- **Use of Fast Simulation** to reduce the uncertainty due to the MC limited statistics



included
excluded

- Include **only Tracker** information, gaining a factor 8 in processing times and saving 40% disk space
- Need to **emulate** the response of High Level **Trigger** stages in bins of hadrons momentum



$R(\Lambda_c)$ Analysis: Strategy

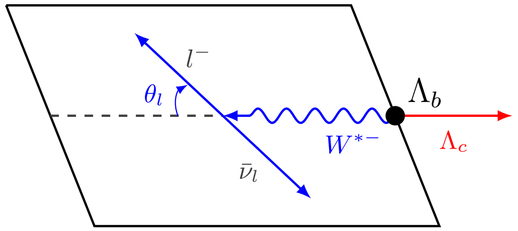
➤ Signal extraction

given the complication of **3 missing neutrinos** in the final state, a **3D simultaneous template fit** is performed

$q^2 = (\hat{P}_{\Lambda_b} - \hat{P}_{\Lambda_c})^2$

$M^2_{\text{miss}} = (\hat{P}_{\Lambda_b} - \hat{P}_{\Lambda_c} - \hat{P}_{\mu})^2$

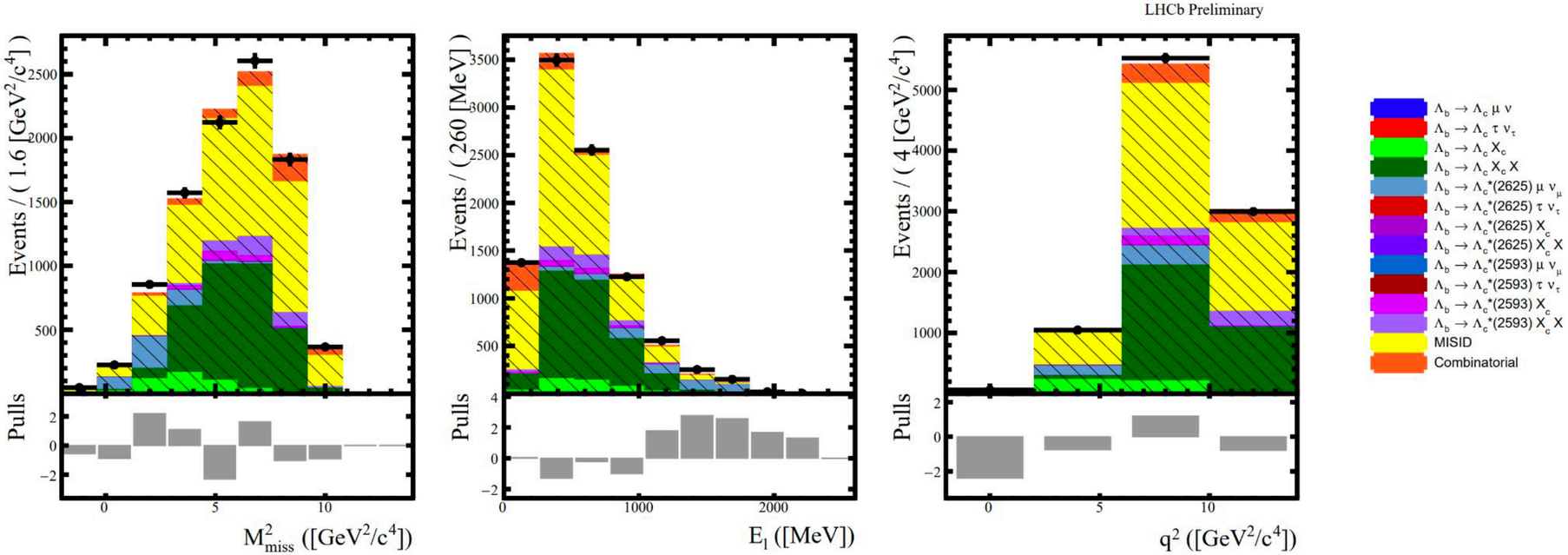
E^*_{μ}



Blind fit to $R(\Lambda_c)$ in the signal region

Fit to the Double charm control region

$\Lambda_b \to \Lambda_c K \mu X$



Summary and Conclusions

- **Exciting times** in the Flavour sector: current semileptonic decays measurements deviate $\sim 3.1\sigma$ from the SM. Hints for **LFU violation?**
  - **More measurements essential to validate or discard the current observations**

- **Semileptonic Λ_b** baryon decays provide a **theoretically** and **experimentally** appealing alternative to investigate **New Physics** scenarios
  - $\Lambda_b \to \Lambda_c \mu\nu$ **angular analysis** to measure Wilson Coefficients
  - $R(\Lambda_c)$ **muonic as a LFU test**

- **Both measurements** are being performed in the **LHCb group at UZH**. They are well advanced and close to review. **Stay tuned!**

Thanks for listening!

Backup

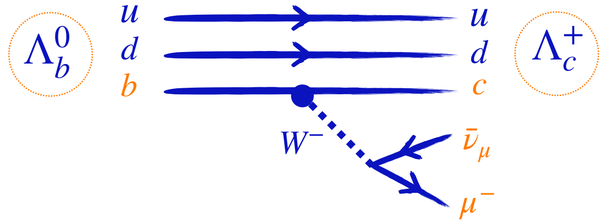
Angular Analysis to Search for New Physics

What looking for? New Physics (NP) in semi-leptonic $b \to c\ell\nu$ tree-level transitions

- Enhanced **sensitivity** to NP contributions through the study of **angular observables** of $\Lambda_b \to \Lambda_c \mu\nu$ decay products (MF, A. Mathad, P. Owen, N. Serra [JHEP12(2019)148])

Sensitive to the spin of the tree-level NP mediator: heavy vector W', heavy scalar $H^{\pm}$, vector/scalar Leptoquark ...

EFT generic Lagrangian of the process (point-like interaction):



$$\mathscr{L}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{cb} \Big\{ (1+V_L)\, \bar{l}_L \gamma_\mu \nu_L \bar{c}_L \gamma^\mu b_L + V_R\, \bar{l}_L \gamma_\mu \nu_L \bar{c}_R \gamma^\mu b_R + S_L\, \bar{l}_R \nu_L \bar{c}_R b_L + S_R\, \bar{l}_R \nu_L \bar{c}_L b_R + T_L\, \bar{l}_R \sigma_{\mu\nu} \nu_L \bar{c}_R \sigma^{\mu\nu} b_L \Big\} + \text{h.c.}$$

They **change the shape** of the phase space distribution

$\Lambda_b \to \Lambda_c \mu\nu$: Analysis Strategy - NP Fits

- **Fit model**: *efficiency* and *resolution* maps folded into our **model** $\dfrac{\partial^2\Gamma}{\partial q^2 \partial \cos\theta_\mu}$ to extract the **Wilson Coefficients**

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- $\vec{\theta}$ **parameter of interest** (PoI), *i.e.* Wilson Coefficients
- $\vec{x}^{\,i} = (q^{2\,i},\, \cos\theta^i_\mu)$ **phase space** vars
- κ normalisation
- R, ϵ **resolution** and **efficiency** matrices, respectively
- F description of the **decay dynamics**