Workshop summary: Heavy flavour aspects in EFT
- semileptonic decays -

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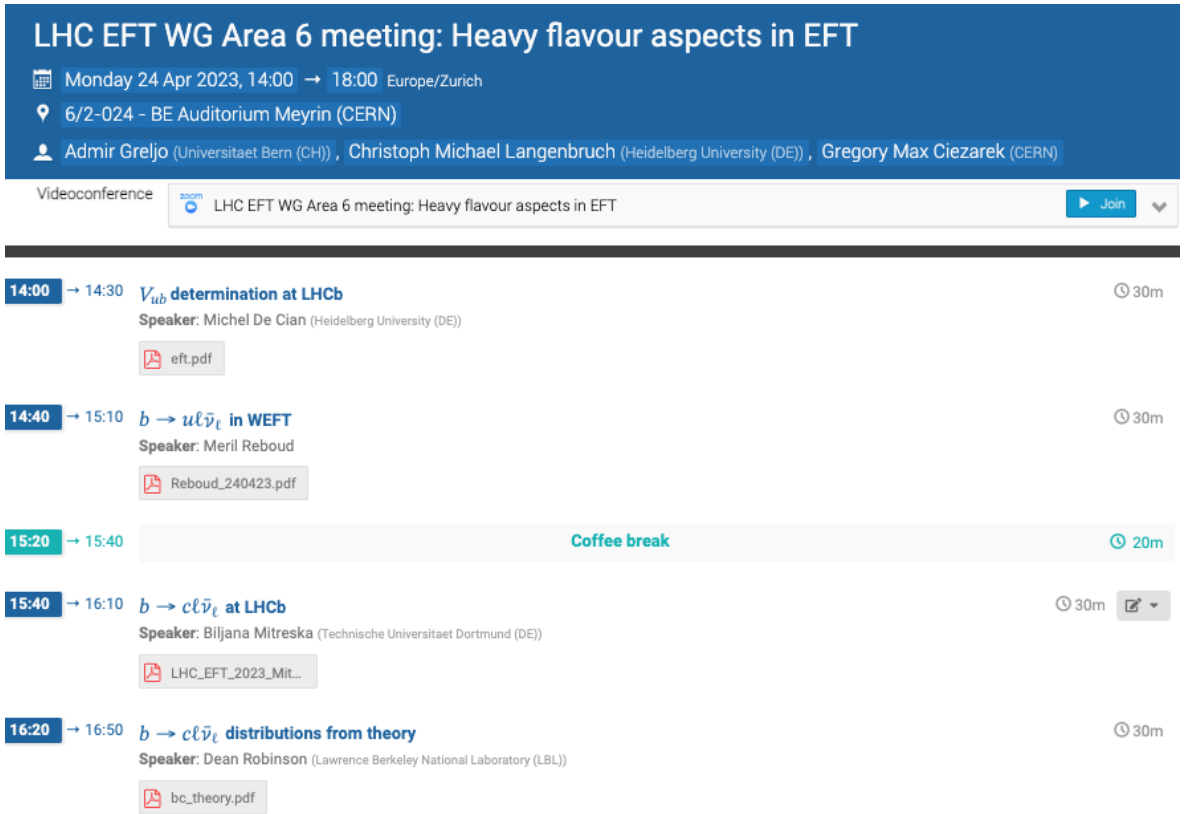
1 Outline

LHC EFT WG Area 6: Heavy flavour aspects in EFT

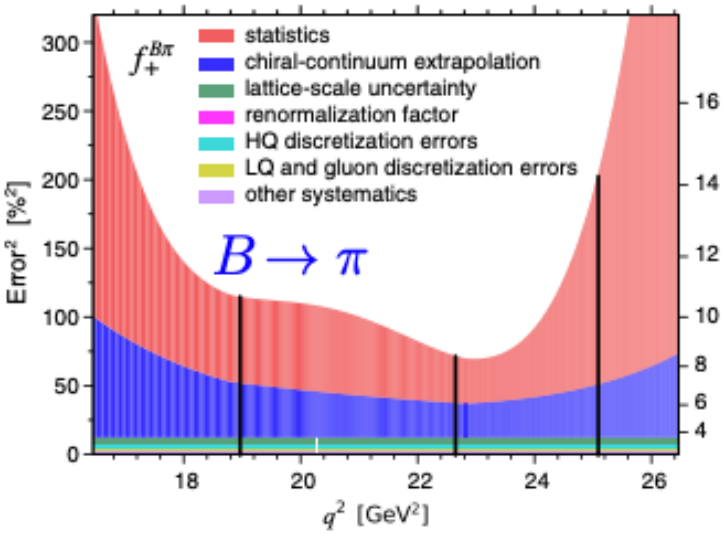
- Dedicated meeting on **Heavy flavour aspects in EFT in semileptonic decays** on 24.04.2023 : ▸ indico
- Theory and experimental(LHCb) contributions on $b \to u\ell\nu$ and $b \to c\ell\nu$ transitions
- Discussion on current/ongoing measurements and prospects

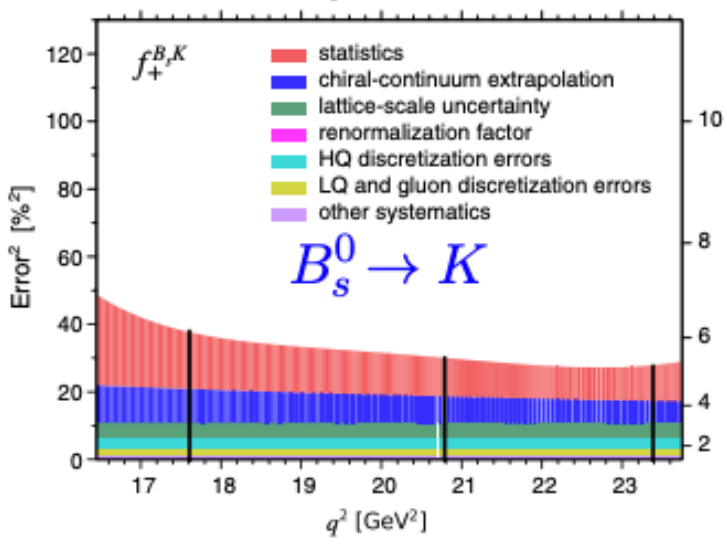


2 Outline

2 $b \to u\ell\nu$

- V_{ub} measurements at LHCb: ▸ talk by Michel de Cian
- Two main ways to measure $|V_{ub}|$
- **Exclusive**: using $B^+ \to \pi^+\mu^-\nu_\mu$, possibly small signal yields
- **Inclusive**: $B^{0/+} \to X_u\mu^{+/-}\nu_\mu$, large background contamination
- Different form factor uncertainties in every $b \to u$ transition





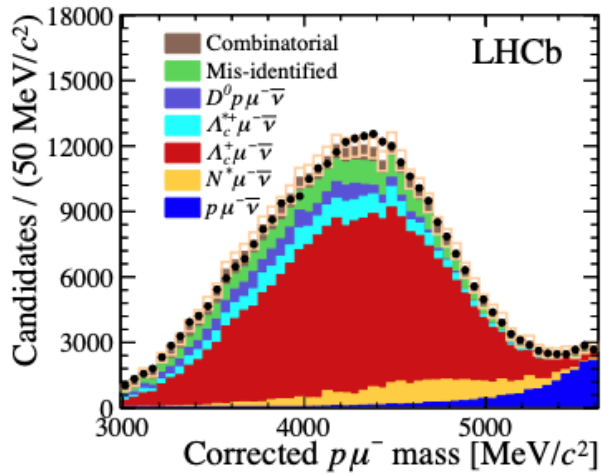
2 V_{ub} from Λ_b^0 at LHCb

- V_{ub} probed using $\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu$ $(q^2 > 15GeV^2)$

$$|V_{ub}| = R_{FF}\frac{B(\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu)}{B(\Lambda_b^0 \to \Lambda_c^+\mu^-\bar{\nu}_\mu)}|V_{cb}|$$

- Exclusive $|V_{cb}|$ world average used as input, R_{FF} from PRD 92(2015)034503]
- Main systematic uncertainties coming from the choice of normalisation channel

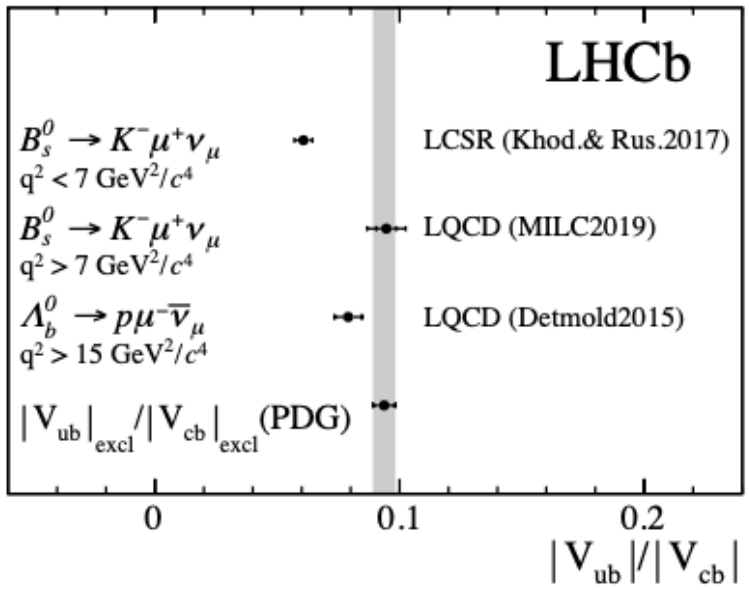
Source	Relative uncertainty (%)
$\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$	$^{+4.7}_{-5.3}$
Trigger	3.2
Tracking	3.0
Λ_c^+ selection efficiency	3.0
$\Lambda_b^0 \to N^*\mu^-\overline{\nu}_\mu$ shapes	2.3
Λ_b^0 lifetime	1.5
Isolation	1.4
Form factor	1.0
Λ_b^0 kinematics	0.5
q^2 migration	0.4
PID	0.2
Total	$^{+7.8}_{-8.2}$



- Possibility of using non semileptonic decay ($\Lambda_b \to p\pi$), depending on external measurements on BFs

2 V_{ub} from B mesons

- Measure $\frac{V_{ub}}{V_{cb}}$ from $B_s^0 \to K^- \mu^+ \nu_\mu$ with $B_s^0 \to D_s^- \mu^+ \nu_\mu$ as normalisation



- Two values of V_{ub} measured depending on the FF predictions: for low q^2 (LCSR) and high q^2 (LQCD)
- Need to perform differential measurements to understand shape better
- Ongoing work on V_{ub} with $B^+ \to \rho^0 \mu^+ \nu$ and $B^+ \to D^0 \mu \nu$: same final state for signal and normalisation

2 V_{ub} from B mesons

- Determine consistency of exclusive data and quality of V_{ub} extraction:
  - talk by Méril Reboud

Goodness of fit				
Data set	χ^2	d.o.f.	p value [%]	$\lvert V_{ub}\rvert \times 10^3$
$\bar{B} \to \pi \ell \nu$	27.83	31	62.98	$3.79^{+0.15}_{-0.15}$
$\bar{B} \to \rho \ell \nu$	5.08	10	88.60	$2.63^{+0.25}_{-0.22}$
$\bar{B} \to \omega \ell \nu$	3.19	4	52.66	$2.74^{+0.33}_{-0.28}$
all data	52.31	47	27.53	$3.50^{+0.13}_{-0.12}$

- **State-of-the-art determinations:**
  - **Inclusive** [HFLAV, PDG, ... '22]
    $|V_{ub}| = 4.13(12)(13)(18)\ 10^{-3}$
  - **Exclusive** [HFLAV, PDG, ... '20]
    $|V_{ub}| = 3.70(10)(12)\ 10^{-3}$

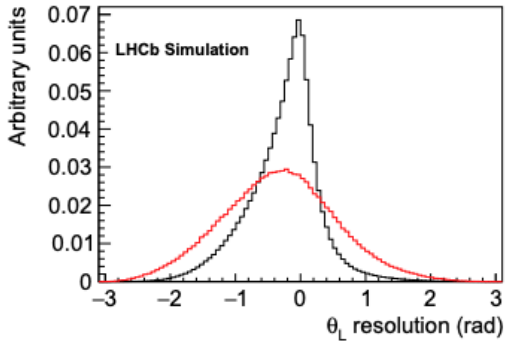
- Tension present in the inclusive vs exclusive V_{ub} extraction
- Floating Wilson coefficients in the fit yields better $b \to u\ell\nu$ fit (from Bayesian model comparison)
- Performing full angular analysis with floating New Physics operators will bring more insights

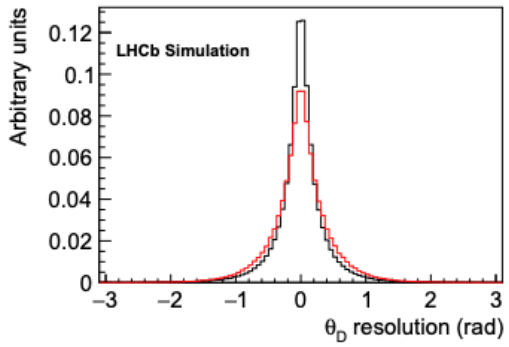
- Discussion between theory and experiment on how to exchange the non-gaussian likelihoods, observables and hadronic inputs from these measurements

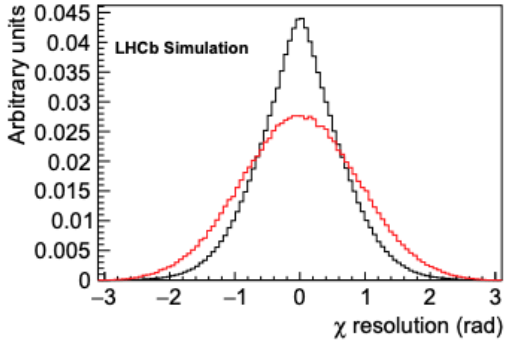
3 Outline

1. LHC EFT workshop: SL decays
2. $b \to u$ transitions
3. $b \to c$ transitions

- Overview of differential measurements at LHCb ▸ talk by Biljana Mitreska
- LHCb has an ongoing effort in angular analyses in each channels measuring: angular coefficients, CP observables, Wilson coefficients and form factor parameters (BGL, BLPR, CLN)







- Theory community welcomes the range of differential measurements at LHCb (particularly direct measurement of angular coefficients and Wilson coefficients)
- Need to find a common solution with theorists on publishing the data together with the results ($B \to D^* \mu(\tau)\nu$)

3 $b \to c\ell\nu$: comments on using BGL

SM fit with BGL

- Belle and BaBar measure 5 BGL parameters
- Current LHCb analysis aims for 9 BGL parameters

▸ PRD 100, 052007 (2019)
▸ PRD 103, 079901 (2019)
▸ CERN-THESIS-2022-105

Parameters	Stat. uncertainty LHCb Run I
a_0	6.0e-05
a_1	5.0e-03
a_2	9.0e-02
b_1	6.0e-04
b_2	1.5e-02
c_1	8.0e-05
c_2	1.2e-03
d_0	1.4e-02
d_1	2.5e-01

- Evaluate uncertainty due to series truncation in BGL
- Evaluate if the fitted coefficients saturate unitarity bounds
- When measuring New Physics contributions BGL is preffered over BLPR and CLN (model dependent)

3 $b \to c\ell\nu$: discussion on New Physics

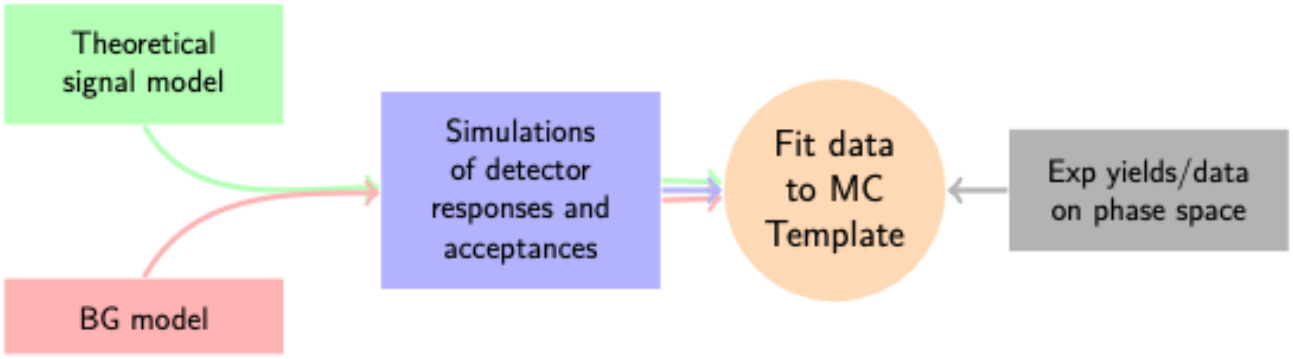
- LFU interpretation in $b \to c\ell\nu$ ▸ talk by Dean Robinson

$$
\begin{aligned}
H_{eff} &= \frac{4G_F}{\sqrt{2}} V_{cb} \sum_i C_i O_i \\
&= \frac{4G_F}{\sqrt{2}} V_{cb} [(1 + C_{V_{LL}}) O_{C_{V_{LL}}} + C_{V_{RL}} O_{C_{V_{RL}}} \\
&+ C_{V_{LR}} O_{C_{V_{LR}}} + C_{V_{RR}} O_{C_{V_{RR}}} + C_{S_{LL}} O_{C_{S_{LL}}} \\
&+ C_{S_{RL}} O_{C_{S_{RL}}} + C_{S_{LR}} O_{C_{S_{LR}}} + C_{S_{RR}} O_{C_{S_{RR}}} \\
&+ C_{T_{LL}} O_{C_{T_{LL}}} + C_{T_{RR}} O_{C_{T_{RR}}}] + h.c.,
\end{aligned}
$$

- 5 complex WCs to consider (assuming left-handed neutrino)
- Simplified models with a single heavy mediators

EW doublet (H_2)	S_L, S_R
W'	V_L
Scalar/Vector LQ ($U_{1,3}$, $S_{1,3}$, R_2, V_2)	V_L, S_R, $S_L \pm 4T$

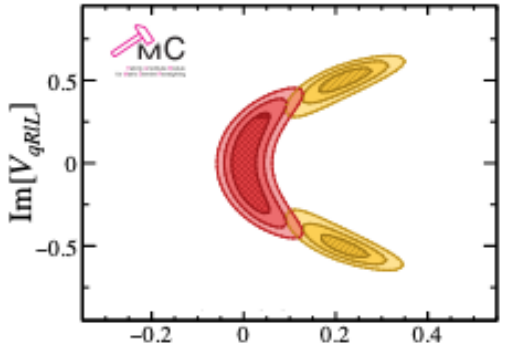
- Standard analysis workflow



3 $b \to c\ell\nu$: discussion on New Physics

- Mismatch in WC subspace

Fit each NP Template to SM truth: Closure with zero NP as expected!



Hammer 2002.00020

Fit each NP Template to 2HDM $S_{qLIR} = -2.^*$ Mismatched templates might obfuscate or wrongly identify NP!

- SM null test could be limited by possible NP biases
- Suggestion to 'redo' the measurements using NP templates to account the NP model
- Impractical to have 20 dimensional space of NP Wilson coefficients
- Quantify the fit templates biases with a fixed NP model
- To be discussed with theorists which is the optimal model to use

3 Summary

- Inclusive vs exclusive determination of V_{ub} and V_{cb} subject to constraints if New Physics is accounted in the fit
- Clear effect of the choice on the normalisation channel (in systematic uncertainties)
- When fitting for LFU observables estimate biases due to New Physics in the fit templates
- Need to decide on a common solution between theory and experiment on how to publish the data + results of the many analyses in $b \to c\ell\nu$ transitions

Thank you!