Rare decays with polarised *Λ^b* Michal Kreps

CEPC 2024 workshop, Hangzhou, 23-27. Oct. 2024

Introduction

- ➡ Decays governed by *b*➝*sll* transitions are sensitive probes for new physics
- ➡ Well studied for meson decays
- ➡ Baryon decays provide complementary information
	- ❖ Different spin structure
	- ❖ Differences in hadronic structure
- \rightarrow Decays *Λ_b*→*Λμμ* well studied (JHEP 01 [\(2015\)](https://doi.org/10.1007/JHEP01(2015)155) 155, JHEP 11 [\(2017\)](https://doi.org/10.1007/JHEP11(2017)138) 138 and many others)
- \rightarrow Decays $\Lambda_b\rightarrow\Lambda^*\mu\mu$ with spin 1/2 and 3/2 Λ^* studied previously [\(1903.10553,](https://arxiv.org/abs/1903.10553) [JHEP 07 \(2020\) 002,](https://link.springer.com/article/10.1007/JHEP07(2020)002) [JHEP 06 \(2019\) 136](https://link.springer.com/article/10.1007/JHEP06(2019)136), [Eur. Phys. J. Plus 136 \(2021\)](https://link.springer.com/article/10.1140/epjp/s13360-021-01194-5) [614](https://link.springer.com/article/10.1140/epjp/s13360-021-01194-5))

in $0.1 < q^2 < 6.0$ GeV²

Angular distributions

- \rightarrow With polarised production, 5 angles to describe kinematics
- \rightarrow Without polarisation, one is sensitive only to ϕ ^{μ} ϕ *b*
- ➡ Angle *θ* should correspond to production polarisation axis
	- ❖ Figure shows case for *pp* collisions with transverse polarisation
	- ❖ For *Z* decays one has to take relevant polarisation axis

p

➡ The full angular distribution with several interfering spin states can be easily written in the helicity formalism *^V ,Oⁱ ^V ,*1² (`*,* ✓`*,* `) no fun angular ulumuallon, will roovoral intonoming ophi olatoo oan bo oachy *V J LLEE I II I II LI I*

Angular distribution lepton. After the rotation of the rotation of the $\setminus / \setminus /$ `⁺ helicity frame, the amplitude is

everal *s* → Several terms will have same angular term, so want to group them *b*, by the spin-density matrix

- unpolarised terms s proporti and P 1*/*2 *b* COS θ W
- $\overline{ }$ $\overline{}$ to P_b sin θ when

Angular distribution structure *H* $\overline{10}$ Combining equations 14–16, with the results of Section 2,

 \blacktriangleright Set of terms proportional to P_b sin θ where amplitude structure is different $\overline{}$ sin ✓*^b* 1 *P*⇤⁰ cos ✓*^b* !
!
! *,*

MV!`+` *^V ,Oⁱ*

= *h*˜*Oi,^V*

1*,*² (*q*2)*DJ^V*

 $d^7\Gamma$ $\mathrm{d} q^2\,\mathrm{d} m_{pK}\mathrm{d}\vec{\Omega}$ = 1 $m_\mathcal{\mathcal{A}}^2$ A_b N_1^2 $2^6(2\pi)^7$ *|* \overline{k} *k||* \overline{k} k_1 || \vec{q}_1 | $\sqrt{q^2}$ \sum λ_b P_{λ_b} \times $\mathcal{H}^{\Lambda,\mathcal{O}_i}_{\lambda_\Lambda,\lambda_V}(q^2,m_{pK}) d_{\lambda_b}^{1/2}$ $\times \tilde{h}_{\lambda_1,\lambda_2}^{\mathcal{O}_i,\lambda_V}(q^2)D^J_{\lambda_V,\lambda_1-\lambda_2}(\phi_{\ell},\theta_{\ell},-\phi_{\ell})^*$ $\times h_{\lambda_\Lambda,\lambda_p}^{\Lambda}(m_{pK})D_{\lambda_\Lambda,\lambda_p}^{J_{\Lambda}}(\phi_p,\theta_p,-\phi_p)^*$ $k_1 ||\vec{q}_1||$ $\boldsymbol{\varsigma}$ $\sqrt{q^2}$ $\left\{\begin{array}{c} \lambda_b \end{array}\right\}$

→ Set of terms without any dependence on polarisation

⇤ *.* (16)

1*/*2

 \rightarrow Set of terms proportional to P_b cos θ with same amplitude structure as 1*/*2 $\overline{}$ ገe

➡ No unique option how to group terms, pick one based on associated Legendre option bow to aroun torme, pick one based on associated Logondre option how to group terms, pick one based on associated Legendre
Leafth parts by

Angular basis ~) with an index ranging from *i* =1–46. In the polarised case, there are 46 additional terms that are proportional to cos ✓*^b* but *h*˜*V,*⁰ +1*/*2*,*+1*/*² = 0 *, ^h*˜*A,*⁰ +1*/*2*,*+1*/*² = 2*m*` *, h*˜*V,*¹ +1*/*2*,*+1*/*² = 2*m*` *, ^h*˜*A,*¹ +1*/*2*,*+1*/*² = 0 *,*

Inserting the Lorentz structures yields the amplitudes yields and the amplitudes yields yields yields yields y
Inserting the amplitudes yields y

polynomials (*Λb*➝*pKμμ*) 1*,*² ⁼ *h*˜*V,J^V* ⁺1*,*+² *, ^h*˜*A,J^V* additional 86 terms also arise proportional to sin ✓*b*. The dependence on ✓*^b* is evident from the \rightarrow ¹/₂ $\ddot{ }$ *, h*˜*A,*¹ +1*/*2*,*1*/*2 ⁼ ^p2*q*2` *, h*˜*V,J^V* = *h*˜*A,J^V* ⁺1*,*+² *,*

* Related to angular momentum and makes it easy to keep track of terms **[◆]** Resulting functions are orthogonal (own weights for the method of moments) $♦$ For $\Lambda_b \rightarrow \Lambda \mu\mu$ bases we chose was slightly suboptimal, but relates to Legendre polynomials III hase $\bar{\bar{\Omega}}$ $; l_{\rm lep}, l_{\rm had}, m_{\rm lep}, m_{\rm had})=2n$ *m*lep *l*lep *n m*had $l_{\rm had}$ $P^{|m_{\text{lep}}|}_{l_{\text{lep}}}(\cos\theta_{\ell})P^{|m_{\text{had}}|}_{l_{\text{had}}}(\cos\theta_{p})$ ⇥ $\sqrt{ }$ $\sin(|m_{\text{lep}}|\phi_{\ell} + |m_{\text{had}}|\phi_p)$ *m*_{lep} ≤ 0 and $m_{\text{had}} \leq 0$ $\times \begin{cases} \frac{\sin(\frac{1}{2}m + \frac{1}{2}m)}{\cos(\frac{1}{2}m + \frac{1}{2}m)} & \text{if } \frac{\sin(\frac{1}{2}m + \frac{1}{2}m)}{\cos(\frac{1}{2}m + \frac{1}{2}m)} & \text{if } \frac{\sin(\frac{1}{2}m + \frac{1}{2}m)}{\cos(\frac{1}{2}m + \frac{1}{2}m)} \end{cases}$ $\Lambda \mu \mu$ \overline{b} $\overline{}$ $\ddot{\theta}$ s d 1 **4** Chans nose was slightly suboptimal, but re

-
-
- \rightarrow Final basis: $f(\vec{\Omega})$

■ The angular distribution takes form

 $\frac{1}{\sqrt{16}} = \sum K_i(q^2, m_{pK}) f_i(\mathcal{S})$ $32\pi^2$ d⁷ Γ 3 d q^2 d m_{pK} d $\vec{\Omega}$ = $\sqrt{ }$ 178 *i*=1 $K_i(q^2,m_{pK})f_i(\vec{\Omega})$

The K i are bilinear combinations of the amplitudes for the amplitude

 $K_i(q^2, m_{pK})$ are bilinear terms proportional terms in $K_i(q^2, m_{pK})$ are bilinear κ _i(q ², κ ill_p κ) are pillitedic the square κ ¹⁷⁸ $T_{i=1}^{(1)Z_{i}}$ are function sindependent of each of each other and can generally independent of each generality of and can general $T_{i=1}^{(1)}$)*.* (47) combinations of

- ➡ There are 178 terms when polarisation is allowed to be nonzero
	- ❖ 46 of these present also with zero polarisation and have no *θ^b* dependence (*m*lep=*m*had)
	-
	- ❖ For polarised case, 46 terms have cos *θb* dependence while rest of the angles are same as unpolarised case
	- ❖ Remaining terms have sin *θ^b* dependence with basis functions where *m*lep≠*m*had

Anatomy of angular distribution Table 3: Amplitude combinations appearing in the coefficient *Ki*. The parity combination and allowed spins indicate which states interfere. Checkmarks in the three columns labelled *single states* indicate whether the coefficient appears in the single resonance case for spin *J*⇤ = take the real part (Re) others the imaginary part (Im) of the amplitude products. A checkmark in the column V/A shows that a coefficient arises from vector-axialvector interference. The right-most column

 $\bigwedge_{k\rightarrow k} \bigwedge_{l\in k} I$

29 opposite 1 Image 1 Image
2001 - De ferste de fers de f

Sensitivity to physics \mathcal{P} from both the polarised observables. Interestingly, interestingly, \mathcal{P} eith*u*ity to nhycing are favoured by global fits to *^b* ! *^s*`+` processes: where *^C*NP and where *C*NP ⁹ ⁼ *C*NP 10 THE UNIVERSITY OF **CANPE THE LOW-RECOVERENT RECOVERENT**

\rightarrow For $\Lambda_b\rightarrow$ *Λμμ* we investigated in greater details what can be extracted $\overline{}$ I The WO THOUGHT CHAT THE STREET OUT THE OUT THE ORIGINAL CHAT THE ORIGINAL PLACE λ β \rightarrow μ μ we investigated in greater detail

➡ Im(*ρ*2) only accessible with non-zero polarisation • One can construct relationships which depend only on short distance where *C*^V contains contributions from *C*⁷ and *C*9. The primed coecients correspond ¹ , ⇢*[±]* $\frac{1}{2}$ and $\frac{1}{2}$ is provided for completeness in $\frac{1}{2}$ is provided for completeness in $\frac{1}{2}$ is provided for complete $\frac{1}{2}$ is provided for complete $\frac{1}{2}$ is provided for complete $\frac{1}{2}$ is provi (2) only accessible with non-zero polarisation $\frac{c}{t}$ being decoded to see ³ and ⇢ ³ using *K*²⁴ and *K*8. It is also possible to form new e can construct relationships which depend only on short distan

physics

At low-hadronic recoil amplitudes depend on combinations of Wilson coefficients $\rho_1^{\pm} = |C_V \pm C_V'|^2 + |C_{10} \pm C_{10}'|$ 2 V ²)
′ 1 $\begin{bmatrix} C'_{10} |^2 \\ \end{bmatrix}$ $\begin{bmatrix} C & C' \end{bmatrix}^*$ ¹ *,*

1 and *N* almarmy in the short-distance contribution of the section of 10 with be separated with 10 and 10

- $-$ *i*Im $($ $C_V C_V^{\prime *} + C_{10} C_{10}^{\prime *}$ $\sum_{i=1}^{n}$
- $\ket{*}$ $\left(\frac{1}{2} + C'_{10}\right)^{*}$

$$
\rho_4 = |C_V|^2 - |C_V'|^2 + |C_{10}|^2
$$

$$
\rho_2 = \text{Re}\left(C_V C_{10}^* - C_V' C_{10}'^*\right) - i \text{Im}\n\n\rho_3^{\pm} = 2\text{Re}\left((C_V \pm C_V')(C_{10} \pm C_{10}')\right)\n\n\rho_2 = |C_{12}|^2 - |C_{12}|^2 + |C_{12}|^2 - |C_{12}|^2
$$

factor dependencies. This permits a new set of checks of the OPE and the form-factors.

 $^{2}-|C'_{10}|^{2}-i \mathrm{Im}\left($ $C_V C_{10}^* - C_V' C_{10}'^*$

 $=-\frac{\text{Im}(\rho_2)}{\text{Im}(\rho_4)}$ $\frac{\text{Im}(\rho_2)}{\text{Im}(\rho_4)}$, *K*²³ K_{10} $=-\frac{\text{Re}(\rho_4)}{\text{Im}(\rho_4)}$ ${\rm Im}(\rho_4)$ P_{Λ_b}

CS
$$
\frac{K_{16}}{K_{34}} = 2 \frac{\text{Re}(\rho_2)}{\text{Im}(\rho_2)} , \quad \frac{K_{25}}{K_{22}} = -\frac{\text{Im}(\rho_2)}{\text{Im}(\rho_4)} , \quad \frac{K_{23}}{K_{10}} = -\frac{\text{Re}(\rho_4)}{\text{Im}(\rho_4)} P_{A_b}
$$

Table 2: Predictions from EOS for the angular observables of the ⇤*^b* ! ⇤*µ*+*µ* decay

SM prediction mass. Observables that depend on the imaginary part of the product of two transversity amplitudes also tend to be vanishingly small, due to the small strong phase di↵erence between pairs of amplitudes in the SM. The SM.

Table 3: Predictions from EOS for the angular observables of the ⇤*^b* ! ⇤*µ*+*µ* decay

 $1 < q^2 < 6$ GeV² *P^Λ* = 1 For polarisation *PΛ*≠1, scale *M*11 — *M*34 by *PΛ*

with *P*⇤*^b* = 1 in the range 15 *< q*² *<* 20 GeV2*/c*4. The SM calculation is described

 $15 < q^2 < 20$ GeV² P_Λ = 1

Latest measurement

■ Well compatible with the SM ➡ Remaining observables compatible with zero $\frac{1}{2}$ all ill ig obsel vabies corripatible with zero

thickness of the light-blue band represents the uncertainty on the SM predictions.

Global fit

➡ Interestingly it constrains production polarisation and *Λ* decay asymmetry tained in rare semileptonic *B* meson decays [32] at *†* smeinel@email.arizona.edu \mathbf{r} 1*.*2, and compatibility with the SM point at '1. Polandarion and the decay asy $mith \wedge_b \rightarrow$ $1/lh \wedge$ \mathcal{M} 1*.*5, and compatibility with the SM point at less \cdot \cdot \cdot $\mathbf{F}_{\mathbf{B}}$ for a rigorous calculation of $\mathbf{F}_{\mathbf{B}}$ is a rigorous calculation of $\mathbf{F}_{\mathbf{B}}$, $\mathbf{F}_{\mathbf{B}}$ ⇤ thomas.blake@cern.ch \overline{u} due to the \overline{u} **K** III **bronching** front

factor $\frac{33}{3}$, we find the degree to which the scenario

- \rightarrow Uses just $\Lambda_b \rightarrow \Lambda \mu \mu$ observables and $B_s \rightarrow \mu \mu$ branching fraction *K* UNSEIVANIES ALIU D culturation of the finite study of the finite study of the finite study of the finite study of the finite study
- as well as dedicated measurement with *Λ^b* ➝ *J/ψΛ* 4 -quark mass, *b* electromagnetic coupling at the scale of the cients as . We write the short-distance (Wilson) coe *^b ^m* , and long- *^b ^m* '*^µ*), taken at ^a renormalization scale *^µ*(*ⁱ C* distance physics is expressed through matrix elements of

at LHCb.

Production polarisation

- ➡ Measure angular moments in Λ_b \rightarrow $J/\psi\Lambda$ and then perform Bayesian analysis
- ➡ Uses same dataset as rare decays
- ➡ Polarisation consistent with zero without visible energy dependence

[JHEP06\(2020\)110](https://doi.org/10.1007/JHEP06(2020)110)

Table 1: Expected experimental precision on the angular moments of the ⇤*b*! ⇤*µ*+*µ*

In this paper we have derived an expression for the angular distribution of the ⇤*^b* ! about 50k reconstructed events

- \rightarrow 1D distribution in *θ*_{*l*} has usual form, K_2 generates lepton A_{FB} instead yields
	- ❖ Usual contributions, just adds *Λ** helicity 3/2 in addition to 1/2 \int The observable *K*² generates the lepton-side forward-backward asymmetry that is a feature of
- ➡ 1D distribution in *θ^p* gets larger number of terms
	- ❖ Includes odd terms in cos *θ^p* which vanish for single resonance
	- ❖ With interference, *A*FB generated also on hadron side with *K*4, *K*10 and *K*¹⁶ contributing

¹⁰⁹ ^q³

² sin ✓*bP*⁰

⁰ (cos ✓*p*)*P*¹

Λb➝*pKμμ* details ¹¹⁰ ^q⁵ 11 S \blacksquare interference can contribute to powers up-to *J*⇤ + *J*⁰

$$
\frac{\mathrm{d}^3 \Gamma}{\mathrm{d}q^2 \mathrm{d}m_{pK} \mathrm{d}\!\cos\theta_\ell} = \frac{\sqrt{3}}{2} K_1 + \frac{3}{2} K_2 \cos\theta_\ell + \frac{\sqrt{15}}{4} K_3 (3\cos^2\theta_\ell - 1)
$$

 $\overline{}$ (cos) cos($\overline{}$ (cos($\overline{}$) cos($\$

$$
\frac{d^3 \Gamma}{dq^2 dm_{pK} d\cos \theta_p} = \frac{\sqrt{3}}{2} K_1 - \frac{\sqrt{15}}{4} K_7 + 9 \frac{\sqrt{3}}{16} K_{13}
$$
\n
$$
+ \left(\frac{3}{2} K_4 - 3 \frac{\sqrt{21}}{4} K_{10} + 15 \frac{\sqrt{33}}{16} K_{16} \right) \cos \theta_p
$$
\nwhich\n
$$
+ \left(3 \frac{\sqrt{15}}{4} K_7 - 45 \frac{\sqrt{3}}{8} K_{13} \right) \cos^2 \theta_p
$$
\n
$$
+ \left(5 \frac{\sqrt{21}}{4} K_{10} - 35 \frac{\sqrt{33}}{8} K_{16} \right) \cos^3 \theta_p
$$
\n
$$
+ \frac{105\sqrt{3}}{16} K_{13} \cos^4 \theta_p + \frac{63\sqrt{33}}{16} K_{16} \cos^5 \theta_p.
$$

Numerical studies

➡ Use all well established states for which prediction for form-factors exists ◆ Form-factors based on quark-model from [Int. J. Mod. Phys. A 30 \(2015\) 1550172](https://doi.org/10.1142/S0217751X15501729) es for which prediction tor torm-tactors exists resonances are taken from Ref. [65]. The branching fraction of the ⇤ resonance to *pK* is calculated -model trom Int. J. Mod. Phys. A $30\,(2015)\,1550172$ ⇤(1405) ! *NK* assumes equal partial widths for ⇤(1405) ! *NK* and ⇤(1405) ! ⌃⇡.

- Use SM Wilson coefficients used in [JHEP 05 \(2013\) 137](https://doi.org/10.1007/JHEP05(2013)137)
- -
- ➡ Most of the resonances modelled by relativistic Breit-Wigner
- ➡ *Λ*(1405) uses Flattè model
- ➡ Investigated scenarios:
	- Flip *C*⁹/*C*¹⁰ or add right *C*⁹/*C*¹⁰
	- Global fit in Eur. Phys. J. C 82 [\(2022\) 326](http://Eur.%20Phys.%20J.%20C%2082%20(2022)%20326)

C_K JNIVERSITY OF WARWICK

Ensemble of resonances

➡ Investigate sensitivity of observables with ensemble of different *Λ* resonances \rightarrow Additional uncertainty from strong phases by varying them between -π and π

-
- ➡ Strong phases of all Λ resonances set to 0 (*π*/2 at the pole)
-

- ➡ Some cases give good sensitivity to new physics without effects from strong phases
- ➡ Some observables like *K*4 has little sensitivity to new physics, but large effect from strong phases

➡ Several observables like *K*³² sensitive to new physics but require knowledge of strong phases

Ensemble of resonances WARWICK $nnno$ **bundi ices** WARWICK resonances.

 $q^2 \ [\text{GeV}^2/c^4]$

- ➡ Particular example of effect of strong phases
- ➡ Set strong phase of spin-3/2 resonances to *π* while keeping rest to 0
- ➡ Very large effects on *K*4 and *K*³²
	- ❖ *K*32 shows significantly different behaviour
- ➡ We have all ingredients but as polarisation at LHCb is small, we never looked into details

Ensemble of resonances 0*.*4 0*.*2 *J/* (1*S*) (2*S*)

4(*q* $\widehat{\mathfrak{g}}$

 -0.4 $\frac{1}{2}$

0*.*0

0*.*2

0*.*4

K

0*.*0

0*.*2 0*.*4 *K*4(*q*

 $\widehat{\mathfrak{g}}$

Λb➝*pKμμ* measurement

- ➡ Unpolarised observables measured at LHCb with Runs 1 and 2 data
- \rightarrow Interpretation is not trivial without detailed understanding of hadronic contributions
- ➡ But interference of various resonances introduces more observables

Summary

- ➡ There is interesting physics to be extracted from rare *Λb* decays
- ➡ With 1012 *Z* bosons we expect about 15k decays for BF 10-6
- \blacktriangleright Size of the sample will likely be smaller than ultimate LHCb sample
- \rightarrow But with polarisation possibly being about 0.5 (10 times of that at LHCb), there is possibility to complement LHCb measurements
	- ❖ Larger uncertainty, but also on 10 times larger effect
	- ❖ Assumes that the polarisation axis does not align to make relevant terms zero
- ➡ There might be other interesting options with higher BF decays, but generally there are not many studies done
	- ❖ People interested will likely need to do work to understand whether polarisation brings benefits

Summary

- ➡ Tom Blake and myself would be interested to look into question what can be gained by 1012 *Z* decays, but currently do not have enough bandwidth to do study on our own
	- \triangle Anja Beck who did lot on $\Lambda_b \rightarrow pK\mu\mu$ is still in physics and she might do some work on this, but again, not as a main work
- ➡ One should work out how well one can do measurement at *Z* pole and also look what impact such measurement would have
- \blacktriangleright If somebody is interested, get in touch we can discuss some collaboration to look into these questions

Backup

Why *Λ^b* ➝ *Λμμ*

- ➡ Provides rich angular structure thanks to non-zero spin of initial state ➡ Λ baryon is very long lived and can be easily treated as stable particle in
- calculations
- ➡ Both experimentally and theoretically very clean from any interference and backgrounds
- \blacktriangleright If produced polarised, it offers access to information not available with mesons
- ➡ Con: Long Λ lifetime decreases detection efficiency, so statistics is usually smaller than similar meson decays

Differential branching fraction

- Measured at LHCb with Run 1 data h
ha
- ➡ Theory prediction is currently more precise than experiment _c t. $\overline{}$ $\sqrt{ }$ \overline{C} $\frac{1}{\sqrt{2}}$ the contract of the contract o
The contract of the contract o r
I
- ➡ Experimentally measured relative *B* to *Λ_b* → *J/ψΛ* for which we do not have good BF ! $\frac{1}{\sqrt{2}}$ numerical thedistributionat \int |
|
| *p* ⇡ \overline{a} pl
)
- ➡ No significant signal below *J/ψ* yet *B* $\bm{\mathsf{Y}}$ $\frac{1}{\sqrt{2}}$ L

Technology,

USA 2*Department of Physics, University of Arizona, Tucson, AZ 85721, USA*

Laboratory,

2

available.

!

this

the

consistent

Experimental normalisation

- ➡ Measurements for *Λ^b* ➝ *J/ψΛ* come from Tevatron which measured *f* Λ f_d
- ➡ Best number comes from D0
- → One needs also fragmentation fraction, in past one would average LEP and Tevatron
- ➡ But there is pT dependence, which means that averaging LEP and Tevatron is not good
- Needs measurement of both ingredients from same experiment \Rightarrow ongoing at LHCb

and conclusions, is *data set 2*. EOS-2019-03, INT-PUB-19-042, TUM-HEP 1242/19 Bayesian analysis of

alongside our relationship of α relationship our relationship of α result. The central curve and α

distribution

measurement

end,

contrast

partial

on

polarization

—

9 compared

reinterpreted

II.

standard

flavour-changing

mass-dimension

i
I

O

are

coupling

short-distance

renormalization

stable, \overline{a} LCSRs.

- ➡ Up to some constants, angular distribution in unpolarised case is \blacksquare l ln to came constante angular distribution in unnalarised a $K(q^2, \cos\theta_\ell, \cos\theta_\Lambda, \phi) = (K_{1ss}\sin^2\theta_\ell + K_{1cc}\cos^2\theta_\ell + K_{1c}\cos\theta_\ell)$ $+ (K_{2ss}\sin^2\theta_\ell + K_{2cc}\cos^2\theta_\ell + K_{2c}\cos\theta_\ell)$ $\cos\theta_\Lambda$ $+$ $(K_{3sc} \sin \theta_\ell \cos \theta_\ell + K_{3s} \sin \theta_\ell)$ $\bigg)$ $\theta_\ell \cos \theta_\ell + K_{3s} \sin \theta_\ell \big) \sin \theta_\Lambda \sin \phi$ $+ \left(K_{4sc} \sin \theta_\ell \cos \theta_\ell + K_{4s} \sin \theta_\ell \right)$ \setminus $\sin \theta_{\Lambda} \cos \phi$. ϵ Theory. Our estimates for large hadronic relations in Heavy ϵ factor relations in Heavy Quark Eq. (θ_{ℓ} cos $\theta_{\ell} + K_{\ell}$ sin θ_{ℓ} sin θ_{Λ} cos ϕ ϵ ects have not been worked out systematically λ `) ⇡ *^N* !(⇤ !*^b* ⇤ for ⁺` reveals that this decay mode can provide new and complementransitions *^s* !*b* cients in radiative and semileptonic tary constraints on the Wilson coe K_2 cos H_0 cos H_1 $\ell \tau$ Theory, $\ell \tau$ Pansion, ℓ and ℓ and ℓ and ℓ ℓ and ℓ ℓ and ℓ ℓ and ℓ ℓ and ℓ and
	- ➡ Specific features :
- ❖ We can still define fraction of longitudinally polarised dilepton system ❖ There is non-zero hadron side forward-backward asymmetry thanks to weak decay of *Λ* with significant differences between two amplitudes $α_\Lambda = ...$ Here the first line corresponds to a relative angular momentum (*L, M*) between the *N*⇡ system and the dilepton system of (*L, M*) = (0*,* 0). The lines two to four correspond $\sqrt{2}$ water *Nachward doymmncuy* and the to wear t baryons. On the basis of ^a properly chosen parametrization of the various helicity am- *^b* ⇤ p

The angular distribution for the 4-body decay can be written as a 4-body decay can be written as a 4-fold died

-
-
- ❖ One can also construct combined forward-backward asymmetry \clubsuit One can also construct combined forward-backward asymmetry of associated Legendre polynomials *P|M[|] l (cos ∠i), where 0* α *is* α), where α is α and disperse of the d *Walter-Flex-Straße 3, D-57068 Siegen, Germany* μ

Angular distributions *K*(*q*² $\sf ISUIIOUIIO$ 8⇡ 3

Philipp B¨oer, Thorstein Börja B
Danny van Dyka Börja Börja

Angular distributions $F_{\rm{max}}$ of the SM against NP, and to extract information on form-factor ratios. In the presence of both SM-like and chirality-flipped operators, we find one ratio of angular observables FB = 24 *|N|* ² Re *{*⇢2*}* ^p*s*+*s ^f^V* ? *^f^A* ? *,* ² ↵ Re *{*⇢4*}* ^p*s*+*s* $\overline{}$ 2 *f^V* ? *^f^A m*² ⇤*^b ^m*² ⇤ *^q*² *^f^V* ⁰ *f^A* $\overline{}$

order are sensitive only to: 250 *KITO TULIOU OF UNJULI VUNIUU LO UUI IULI UUL
Angitiva ank<i>i* ta: s ₂n ⁼ Re *{*⇢2*} ve* only to: \overline{O} rice search to: \overline{a} ansitive onl

➡ One can take ratios of observables to construct quantities which in first

We will present numerical estimates for these observables in the SM (integrated over *q*² in

◆ Form factors We will present numerical estimates for these observables in the SM (integrated over *q*² in

★ Short-scale physics

\n
$$
X_1 \equiv \frac{K_{1c}}{K_{2cc}} = -\frac{\text{Re}\left\{\rho_2\right\}}{\alpha \text{Re}\left\{\rho_4\right\}},
$$

*m*²

⇤*^b ^m*²

Predictions

quarks

our

and

Ξ

lattice

!!

Ī

Predictions

-
- ➡ Predictions are generally reasonably precise ➡ Measurements on these plots come from very early analysis when we were figuring out what we should be actually doing
- ➡ With Tom Blake we extended work to polarised case, which adds another 24 observables
	- ❖ 10 have same structure as unpolarised case, just being multiplied by production polarisation
	- ❖ 14 are proportional to production polarisation and give access to more information
-

Decays

physics

developed

hadronic

Wilson

secondary

smeinel@email.arizona.edu

Latest measurement

- ➡ Uses Run 1 and part of Run 2 data from LHCb
- ➡ Measured only 15 < *q2* < 20 GeV2 bin as this is the only one having significant yield
- ➡ About 610 signal decays
- ➡ Used method of moments
	- ❖ Luckily, otherwise would run to troubles with value of *αΛ*

 \curvearrowright 2 *c*

Candidates / (20 MeV/

) 2 *c*

Candidates / (20 MeV/

0

20

40

Figure 1: Distribution of *p*⇡*µ*+*µ* invariant mass for (left) long- and (right) downstream-track

31

 31

How to get polarised sample

- \blacktriangleright If there is enough interest in observables accessible only with polarisation, we can try to play some tricks
	- ❖ We measured polarisation only integrated over large *η*-*pT* region, but it does not have to be constant
	- ❖ One can look for *Λb* coming from decays which itself could introduce polarisation ✦ Obvious choice for LHCb would be *Σ^b ** but my intuition is that it will not help
		-
		- ✦ Top quark decays might be interesting, *W* in such case is polarised and so would be b-quark, this would be more suitable for ATLAS and CMS
- ➡ Each idea would need dedicated study whether it would work
- ➡ Each idea would mean lower statistics, on the other hand, one does not need to do all observables

What to expect

- data
- ➡ Good chance to see signal in more *q2* bins, we have about 4 times more data in Run 2
- ➡ Not yet clear what we can do with angular observables below *J/ψ*
- ➡ Want to look back to polarisation measurement to see whether there is at least some indication of non-zero polarisation somewhere

\rightarrow LHCb is working on update of $Λ$ _{*b*} → $Λ$ μμ</sub> branching fraction with Run 1+2

for small *^q*2, where *^C*9–*C*⁷ interference is important. Finally, due to the very similar structures of

 q^2 [GeV²/ c^4]

Isolated spin 5/2 resonance *K*1*,*7*,*13, as discussed Section 6, the values of *K*7*,*¹³ are almost identical for the different scenarios considered in this section. In the single resonance case, these observables serve as a useful check of the form-factor description. In general, as the order of the ✓*^p* basis function increases (0*,* 2*,* 4 for the top, mid, and bottom row of Fig. 3) the magnitude of the corresponding observable материалы жана башка ж
Мара жана башка жана $F(0)$ room none \blacksquare UTE TUULIUM IU

- ➡ Only isolated *Λ*(1820)
- ➡ Grey band shows uncertainty from:
	- ❖ Form-factor
	- ❖ Widths etc.
	- ❖ Non-factorisable corrections
- **Often need rather large** $\frac{J/\psi(1S)}{2.5}$ $\frac{J/\psi(1S)}{5.0}$ $\frac{J/\psi(1S)}{7.5}$ $\frac{J/\psi(1S)}{10.0}$ $\frac{J/\psi(1S)}{2.5}$ $\frac{J/\psi(1S)}{7.5}$ $\frac{J/\psi(1S)}{10.0}$ $\frac{J/\psi(1S)}{12.5}$ change in Wilson coefficients for effects larger than uncertainties \overline{C} $\overline{}$ l
L d *m*(*pK*) [10 9 GeV*/c*2]

 $\mathbf{1}_{\{1,2\}}$ is a set of $\mathbf{1}_{\{1,3\}}$. The contract of $\mathbf{1}_{\{1,2\}}$ is a set of $\mathbf{1}_{\{1,3\}}$

differ from the SM for changes in the SM for changes in the left-handed vector currents. The differences here are largest in the differences here are largest in the differences here are largest in the differences here are

THE UNIVERSITY OF WARWICK

-0.4 -0.2 0*.*0 0*.*2 0*.*4 $\overline{K}_3(q^2)$

corresponds to ⇢+1*/*2*,*+1*/*2(⇢1*/*2*,*1*/*2) and the off-diagonal elements correspond to ⇢*±*1*/*2*,*⌥1*/*2.

⇤, arises from QCD separately for each ⇤ resonance. The amplitudes, *^H*⇤*,^µ* **H**
→ *β* (a^2) \mathbf{V} ₁ \mathbf{V} ₁₂ $(\alpha^2)_3$ ^{*y*} | \mathbf{V} ₁₂ $\Delta |\bar{\epsilon} \Gamma^\mu h| A^0 = \bar{u}$. Note, the polarization vectors for the vector-boson used in this paper are defined in the opposite $\mu_{\mathbf{1}}\sigma_{\mathbf{2}}$ of $\sigma_{\mathbf{3}}\sigma_{\mathbf{4}}$ $\lambda |\bar{s}\Gamma^{\mu}b|A_b^0\rangle = \bar{u}_{\alpha}(k,\lambda_{\Lambda}) \left[v_{n}^{\alpha}(X_{\Gamma1}(q^2)\gamma^{\mu} + X_{\Gamma2}(q^2)v_{n}^{\mu} + X_{\Gamma3}(q^2)v_{k}^{\mu}\right] + X_{\Gamma4}(q^2)q^{\alpha\mu}\right]u(p,\lambda_b)$ $\sum_{i=1}^{\infty} \sum_{j=1}^{\infty} \sum_{j$ Γ ^h⇤*|s*¯*µb|*⇤⁰ *^b* i = ¯*u*(*k,* ⇤) $\langle \Lambda | \bar{s} \Gamma^{\mu} b | \Lambda_b^0 \rangle = \bar{u}(k, \lambda_{\Lambda})$ $\langle \Lambda | \bar{s} \Gamma^\mu b | \Lambda_b^0 \rangle = \bar{u}(k, \lambda_\Lambda) \left[X_{\Gamma 1}(q^2) \gamma^\mu + X_{\Gamma 2}(q^2) v_p^\mu \right]$ $\langle \Lambda | \bar{s} \Gamma^\mu b | \Lambda^0_b \rangle = \bar{u}_\alpha(k,\lambda_\Lambda)$ $\langle \Lambda | \bar{\epsilon} \Gamma^\mu b | \Lambda^0 \rangle =$ ⇥ *v*↵ *p* α [[] β (**y**_{α}²)*µ* $\left[v_{p}^{\alpha}\right]$ $(X_{\Gamma1}(q^2)\gamma^{\mu} + X_{\Gamma2}(q^2)v^{\mu}_{p} + X_{\Gamma3}(q^2)v^{\mu}_{k}$ and for *J*⇤ = $\lfloor 51 \rfloor$ $\overline{f}(k) = \sum_{i=1}^{n} (k_i - 1)$ $\overline{f}(k_i - 2) \cdot k + \overline{V}$ $\langle \Lambda | s 1^{\mu} b | \Lambda_b^{\nu} \rangle = u_{\nu}$ $\langle \Lambda | \bar{s} \Gamma^{\mu} b | \Lambda_b^0 \rangle = \bar{u}_{\alpha\beta}(k, \lambda_{\Lambda}) v_p^{\alpha}$ $\sqrt{ }$ v_{p}^{β}

Separate amplitudes need to be considered for hadronic operators with different Lorentz structures,

H⇤*,T*

*C*eff

for *J*⇤ =

2 are
2 are

 $\langle \Psi b | A_b^0 \rangle$ $\binom{0}{b}$ $\langle \hat{I}_b \rangle$

$$
H^{\Lambda,\Gamma^\mu}_{\lambda_\Lambda,\lambda_V}=\varepsilon^*_\mu(\lambda_V)\langle\Lambda|\bar{s}\Gamma^\mu b| \varLambda_b^0\rangle
$$

Helicity amplitudes 3.1 Helicity amplitudes for the ⇤⁰ *^b* ! ⇤*V* decay Separate amplitudes need to be considered for hadronic operators with different Lorentz structures, *Oµ* had*.,i* = ¯*s^µ ⁱ PL,Rb*. The relevant amplitudes for this paper are *H*⇤*,*7(0) ⇤*,^V* (*q*2*, mpK*) = 2*m^b q*2 Γ **2020** *ei*⇤ ⇣ $\sqrt{2}$ 2 $\overline{}$ The labels *V* , *A*, *T* and *T*5 refer to vector, axialvector, tensor and axialtensor currents with the The labels *V* , *A*, *T* and *T*5 refer to vector, axialvector, tensor and axialtensor currents with the Lorentz structures *^µ* = *^µ* , *µ*5, *iµ*⌫*q*⌫ and *iµ*⌫5*q*⌫, respectively. A common complex phase, ⇤, arises from QCD separately for each ⇤ resonance. The amplitudes, *^H*⇤*,^µ* ⇤, arises from QCD separately for each ⇤ resonance. The amplitudes, *^H*⇤*,^µ H*⇤*,^µ* ⇤*,^V* = "⇤ *^µ*(*^V*)h⇤*|s*¯*µb|*⇤⁰

H⇤*,*9(0)

⇤*,^V* (*q*2*, mpK*) =

*C*eff 9(0)

ei⇤

⇣

H⇤*,V*

⇤*,^V* ⌥ *^H*⇤*,A*

, (19)

H⇤*,V*

$$
\mathcal{H}^{\Lambda,7^{(\prime)}}_{\lambda_{\Lambda},\lambda_{V}}(q^{2},m_{pK})=-\frac{2m_{b}}{q^{2}}\frac{\mathcal{C}_{7^{(\prime)}}^{\text{eff}}}{2}\ e^{i\delta_{\Lambda}}\left(H^{\Lambda,T}_{\lambda_{\Lambda},\lambda_{V}}\mp H^{\Lambda,T5}_{\lambda_{\Lambda},\lambda_{V}}\right)\\ \mathcal{H}^{\Lambda,9^{(\prime)}}_{\lambda_{\Lambda},\lambda_{V}}(q^{2},m_{pK})=\qquad \qquad \frac{\mathcal{C}_{9^{(\prime)}}^{\text{eff}}}{2}\ e^{i\delta_{\Lambda}}\left(H^{\Lambda,V}_{\lambda_{\Lambda},\lambda_{V}}\mp H^{\Lambda,A}_{\lambda_{\Lambda},\lambda_{V}}\right)\\ \mathcal{H}^{\Lambda,10^{(\prime)}}_{\lambda_{\Lambda},\lambda_{V}}(q^{2},m_{pK})=\qquad \qquad \frac{\mathcal{C}_{10^{(\prime)}}^{\Omega}}{2}e^{i\delta_{\Lambda}}\left(H^{\Lambda,V}_{\lambda_{\Lambda},\lambda_{V}}\mp H^{\Lambda,A}_{\lambda_{\Lambda},\lambda_{V}}\right)
$$

$$
\langle \Lambda | \bar{s} \Gamma^{\mu} b | \Lambda_b^0 \rangle = \bar{u}(k, \lambda_{\Lambda}) \left[X_{\Gamma 1}(q^2) \gamma^{\mu} + X_{\Gamma 2}(q^2) v_p^{\mu} + X_{\Gamma 3}(q^2) v_k^{\mu} \right] u(p, \lambda_b)
$$
 Spin 1/2
\n
$$
\langle \Lambda | \bar{s} \Gamma^{\mu} b | \Lambda_b^0 \rangle = \bar{u}_{\alpha}(k, \lambda_{\Lambda}) \left[v_p^{\alpha} \left(X_{\Gamma 1}(q^2) \gamma^{\mu} + X_{\Gamma 2}(q^2) v_p^{\mu} + X_{\Gamma 3}(q^2) v_k^{\mu} \right) + X_{\Gamma 4}(q^2) g^{\alpha \mu} \right] u(p, \lambda_b)
$$
 Spin 3/2
\n
$$
\langle \Lambda | \bar{s} \Gamma^{\mu} b | \Lambda_b^0 \rangle = \bar{u}_{\alpha \beta}(k, \lambda_{\Lambda}) v_p^{\alpha} \left[v_p^{\beta} \left(X_{\Gamma 1}(q^2) \gamma^{\mu} + X_{\Gamma 2}(q^2) v_p^{\mu} + X_{\Gamma 3}(q^2) v_k^{\mu} \right) + X_{\Gamma 4}(q^2) g^{\beta \mu} \right] u(p, \lambda_b).
$$
 Spin 5/2

H⇤*,*10(0)

⇤*,^V* (*q*2*, mpK*) = *^C*10(0)

ei⇤

⇣

H⇤*,V*

⇤*,^V* ⌥ *^H*⇤*,A*

l,

.

l,

(23)

The labels *V* , *A*, *T* and *T*5 refer to vector, axialvector, tensor and axialtensor currents with the

Table 2: Amplitude combinations appearing in the coefficient *Ki*. The parity combination and allowed

Amplitude combinations whether the coefficient appears in the single resonance case for spin *J*⇤ = atitude combinations v column V/A shows that a coefficient arises from vector-axialvector interference. The right-most column

19 opposite in de grootste kommen van de grootste kommen van de grootste kommen van de grootste kommen van de
19 opposite in de grootste kommen van de grootste kommen van de grootste kommen van de grootste kommen van de

(131)

Amplitude combinations WARW same 4 X Re X *^V* 6= 0, (⇤*, ^V*)=(⇤*, ^V*)⁰ (126) same 4 X Re (⇤*, ^V*)=(⇤*, ^V*)⁰ (127) opposite 5 Re (⇤*, ^V*)=(⇤*, ^V*)⁰ (128)

37 opposite it de staat de st
37 opposite en de staat de st

Amplitude combinations α **10 IIIUUUU COMMUNICILIONS** AMPANGE 27 Opposite 5 Re (139) op

Explicit expressions for observables combination of amplitudes. In order to the compact of the compact \sim 1*,*² , are inserted under the assumption that ⁴*m*² ` ⌧ *^q*2. The hadron-side helicity amplitudes with negative proton helicity, helicity, helicity, helicity, helicity, helicity, helicity, helicity, helicity, h ⇤*,*1*/*2, are replaced using the parity conservation requirement ⇤ *i*=10(0) where the sum runs over resonances with the quantum numbers *Q*. The reader is reminded that the indices need to satisfy *|*

∴

2 to conserve helicity. The normalisation of the normalisation of the normalisation of the normalisation of th $f \sim r \sim h$

combinations contribute to the coefficient. When a basis function is independent of , the two

AQ,V

⇤*,^V*

= *N* X

^H⇤*,Oⁱ* ⇤*,^V*

h⇤

⇤*,*1*/*² *,*

$$
\mathcal{A}_{\lambda_{\Lambda},\lambda_{V}}^{Q,V}=N\sum_{\Lambda}\sum_{i=7^{(\prime)},9^{(\prime)}}\mathcal{H}_{\lambda_{\Lambda},\lambda_{V}}^{\Lambda,\mathcal{O}_{i}}h_{\lambda_{\Lambda},1/2}^{\Lambda}\ , \nonumber\\ K_{2}=\mathcal{A}_{\lambda_{\Lambda},\lambda_{V}}^{Q,A}=N\sum_{\Lambda}\sum_{i=10^{(\prime)}}\mathcal{H}_{\lambda_{\Lambda},\lambda_{V}}^{\Lambda,\mathcal{O}_{i}}h_{\lambda_{\Lambda},1/2}^{\Lambda}\ ,
$$

$$
K_1 = \frac{1}{\sqrt{3}} \sum_{Q} \sum_{\lambda_{\Lambda}, \lambda_{V}} \left(\left| \mathcal{A}^{Q, V}_{\lambda_{\Lambda}, \lambda_{V}} \right|^2 + V \longleftrightarrow A \right)
$$

contains the phase-space factors, the normalisation of the weak *b* ! *s* transition and a common

*K*¹ =

 $\sqrt{2}$

$$
K_{4} = \frac{1}{105} \sum_{\lambda= \pm 1} \text{Re}\Big[+\lambda \left(+35 \mathcal{A}_{\frac{1}{2}\lambda,0}^{\frac{1}{2}^+,V} \mathcal{A}_{\frac{1}{2}\lambda,0}^{\frac{1}{2}^+,V} \mathcal{A}_{\frac{1}{2}\lambda,0}^{\frac{1}{2}^+,V} \mathcal{A}_{\frac{1}{2}\lambda,0}^{\frac{1}{2}^+,V} \mathcal{A}_{\frac{1}{2}\lambda,0}^{\frac{1}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{3}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{5}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{5}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{5}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{5}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{5}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{5}{2}^+,V} \mathcal{A}_{\frac{3}{2}\lambda,0}^{\frac{5
$$

!!
!!
!!

factor of 2*q*² stemming from the lepton-side amplitudes, *h*˜*J^V*

1*,*² .

1

The coefficient *K*¹ is proportional to the total decay rate and equals the sum of all helicity apic *AQ,V* ⇤*,^V* \blacksquare WARWIC.K The coefficient *K*¹ is proportional to the total decay rate and equals the sum of all helicity \bigcap $\mathcal{L}% _{0}\left(t\right) \equiv\mathcal{L}_{0}\left(t\right) \equiv\mathcal{L}_{1}\left(t\right) \equiv\mathcal{L}_{1}\left(t\right) \equiv0$ *AQ,V* ⇤*,^V* + *V* ! *A* $\overline{}$ \overline{A} 1 ²*,*⁰ *A* \blacktriangle *,V* 1 ²*,* 3 + **+** 2 *,V* ²*,*⁰ *A* 3 2 *,V* 1 ²*,*⁰ + 7*^A* Z, $'$ V \blacksquare ²*, A* ²*,*

$$
K_2 = -\sum_{Q}\sum_{\lambda=\pm 1}\lambda\cdot {\rm Re}\left[{\cal A}_{\frac{3}{2}\lambda,\lambda}^{Q,A*}{\cal A}_{\frac{3}{2}\lambda,\lambda}^{Q,V} + {\cal A}_{\frac{1}{2}\lambda,\lambda}^{Q,A*}{\cal A}_{\frac{1}{2}\lambda,\lambda}^{Q,V}\right]
$$

$$
K_3 = \frac{1}{2\sqrt{15}} \sum_{Q} \sum_{\lambda=\pm 1} \left(\left| \mathcal{A}_{\frac{3}{2}\lambda,\lambda}^{Q,V} \right|^2 + \left| \mathcal{A}_{\frac{1}{2}\lambda,\lambda}^{Q,V} \right|^2 - 2 \left| \mathcal{A}_{\frac{1}{2}\lambda,0}^{Q,V} \right|^2 \right) + V \longleftrightarrow A
$$

 $\ddot{}$

 $\overline{}$ **1**

*K*⁴ =

 \mathcal{F}

=*±*1

 \bigvee

Re

 \mathbf{a}

 \pm

 \bigvee (

⁺*,V* ⇤

- ➡ SM Wilson coefficients used in [JHEP 05](https://doi.org/10.1007/JHEP05(2013)137) [\(2013\) 137](https://doi.org/10.1007/JHEP05(2013)137)
- ➡ Global fit from [Eur. Phys. J. C 82 \(2022\) 326](http://Eur.%20Phys.%20J.%20C%2082%20(2022)%20326)
	- **❖ Consistent with existing measurements in** *b***→***sll*

Wilson coefficients *^b*! *^s*`⁺` measurements [20].

