|Vub| at LHCb: measurements and future prospects

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Implications workshop 5 04/11/15

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|Vub| is important

- Measuring $|V_{ub}|$ is useful because:
	- It's the SM benchmark for sin(2β).
	- Predicting $\mathcal{B}(B^+ \to \tau \nu)$
	- Tests of non-perturbative QCD.

• Processes involving V_{ub} might also be sensitive to NP themselves.

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 $\mathcal{M}_{\pi} = f + \alpha^2 \mathcal{M}$ easuring $|\mathcal{M}_{\pi}$ $\mu = \frac{1}{\sqrt{2}} \left[\frac{1}{\sqrt{2}} \frac{1$ \mathcal{A}_{re} (\mathcal{A}_{re}) semi-leptonic decays $= f^4(\frac{1}{4})^{\frac{1}{2}}$ | $\left[\frac{1}{4}\frac{1}{2}\right]$ | $\left[\frac{1}{4}\frac{1}{2}\right]$ | $\left[\frac{1}{4}\frac{1}{2}\right]$ $\left[\frac{1}{4}\frac{1}{2}\right]$ $\left[\frac{1}{4}\frac{1}{2}\right]$ $\frac{1}{2}$ / $\frac{1}{\sqrt{2}} \int f^{-1}(q^2) \frac{d^2H}{dr^2} q^2 \int d^2\pi$ d^u. JMeasure rate exclusive $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $\bar{B}_{\rm e}$ $f = (\partial \hat{\partial})^2 \frac{M_B^2 \bar{d} - m_\pi^2}{2} g^2$ decay, such as $B \to \pi \ell \nu$ rely on LQCD (LGSR). \overrightarrow{a} $\begin{array}{ccc} \bigcirc & \overline{d} & q^2 \\ \nabla & \overline{d} & \pi^+ \end{array}$ *d* ng the anneavimetic π^+ MAGERENLE RELATIONSHICHA^{NA}F solia as politike drotte i pro *Vub b i* in *ulu l* deg and deg d d d d d d d e f g f $m \sigma$ the grave λ the 44 in be simplified by making the approximation, μ_{ci} erms phomartham + quark-hadron duality. *W l* control theoretical uncertainties. The control term is the control to the control term in the control term in
The control term is the control term in the control term in the control term is the control term in the control $m_l \rightarrow \oint_{\mathcal{V}^{\tau}} q^{\mu} \mathcal{L}_{\mu}$ Th $\bar{\bar{\nu}}_l$ Measure purely deptonic **a**
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l $\det^2 B^+ \to \tau \nu$ rely on \overline{b} $\mathop{\mathrm{en}}\nolimits \; \mathfrak{l}^b \sim \mathcal{W}^+/H^+ \qquad \nearrow \; \tau^+ \qquad \qquad \qquad \mathop{\mathrm{decay}}\nolimits^{B^+} \to \tau \nu$ rely c $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ W^+/H^+ $\qquad \qquad$ τ^+ QCD, but uncertainty is • Factorise electroweak and strong parts of the decay: 0*.*¹⁷) ⇥ ¹⁰³ *[|]Vub[|]* = (3*.*²³ *[±]* ⁰*.*31) ⇥ ¹⁰³ small. $\mathcal{L}_\mathcal{D}$ part encompassed by form-dimensional part encompassed by form-dimensional part encompassed by form- $\frac{dL}{d\sigma^2}u \sim$ ν_{τ} \overline{u} ν_τ $\overline{\overline{d}}$ $\left(1\right)$ 3 $\overline{\nu}_{\tau}$

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• Leptonic measurement not precise enough to tell which one is which, but tends to prefer inclusive. to prefer inclusive. ^I Leptonic B decays (*B*⁺ ! ⌧ ⁺⌫⌧): (1.53) $\overline{}$ 4

Semi-leptonics at LHCb

Best signature fully charged final state, apart from a single neutrino.

The decay Λ_b^0 $\frac{0}{b} \rightarrow p \mu \nu$

- The decay $\Lambda_b^0 \rightarrow p \mu \nu$ is the baryonic version of $B \to \pi \ell \nu$.
- Cleaner at LHCb as protons are rarer than kaons/pions.
- \bullet Λ_b baryons not produced at BaBar or Belle experiments but at the LHC produced half as often as B mesons.

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the semi-line semi-l associated with the hadronic measurement. The dashed red lines indicate the uncertainty on the

Analysis strategy

- Normalise signal yield to V_{cb} decay, $\Lambda_b^0 \rightarrow \Lambda_c \mu \nu$
	- Cancel many systematic uncertainties, including the production rate of Λ_b baryons.
- Calculate the branching fraction ratio at high q², only use data in the region with lattice points.

Results

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- Confirms tension inclusive/exclusive tension.
- Precision split between lattice/experimental data.
	- From experimental side need to improve $\mathcal{B}(\Lambda_c \to pK\pi)$

Differential measurement?

- Should we do a differential measurement of $\Lambda_b^0 \rightarrow p \mu \nu$?
	- Resolution is pretty wide compared to B-factories.
	- Do not rely heavily on z-expansion as we are not extrapolating.

We would probably need more $\frac{88}{80}$ and the UHCb simulation
data to understand migration
between different bins. data to understand migration between different bins.

Beyond $\Lambda_b^0 \rightarrow p$ $\frac{0}{b} \rightarrow p \mu \nu$

- There are several decays to consider.
	- Golden modes: $B \to \pi \ell \nu$, $B^0_s \to K^+ \mu^- \nu$
	- Excited modes: $B \to \rho \mu \nu$, $\Lambda_b^0 \to N^* \mu \nu$, $B \to p \bar{p} \mu \nu$...
- Adding extra tracks to final state reduces background and improves signal resolution.

B_s^0 $\frac{0}{s} \rightarrow K^+ \mu^- \nu^-$

• The decay $B_s^0 \to K^+ \mu^- \nu$ has the potential to produce the most precise result there is.

plots from RBC/UKQCD group, arXiv:1501.05373

11 • The same lattice data produces twice as good budgets for *f*? are on the left and of *f*^k are on the right. The curves from bottom-to-top show the increase in the total port $\beta \rightarrow \pi l \nu$ error, which y-axis label shows the error in the form factor. For readability, we have combined all of the sources o $\text{precision for } B_s^0 \to K^+ \mu^- \nu \text{ w.r.t. } B \to \pi \ell \nu$

 $B_s^0 \to K^+ \mu^- \nu \text{ vs } \Lambda_b^0 \to p \mu \nu$

- $B_s^0 \rightarrow K^+ \mu^- \nu$ is clearly more difficult than $\Lambda_b^0 \rightarrow p \mu \nu$ but has better ultimate precision.
- We are working hard on this, stay tuned for next year.

|Vub| with Bc mesons

- B_c mesons can also decay via V_{ub} .
- \bar{b} • Signature is $B_c^+ \to D^0 \mu^+ \nu X$ and $B_c^+ \to D^+ \mu^+ \nu X$

 $\mathcal{C}_{0}^{(n)}$

 \mathcal{C}_{0}

- We have around $10,000 B_c^+ \rightarrow J/\psi \mu^+ \nu X$ candidates from LHCb-PAPER-2013-063.
	- $B_c^+ \to D^0 \mu^+ \nu X$ • Expect about 100 $B_c^+ \to D^0 \mu^+ \nu X$ candidates.
- Could we get theoretical control to determine $|V_{ub}|/|V_{cb}|$ ratio?

Leptonic decays

- Purely leptonic V_{ub} decays are difficult, if not impossible to find at LHCb.
	- $B^+ \to \tau \nu$ is clearly a waste of time. *^B*⁺ ! *^µ*+*µµ*+⌫*^µ* EvtGen $B^+ \to \tau \nu$
- $B^+ \to \mu \nu$ better, however helicity suppression makes the SM BF too rare to be useful for $|V_{ub}|$. U' μv botton, now over nonony dupp bothas space to the useful for $|V_{ub}|$.
	- Radiate off initial leg to remove helicity suppression.

Analysis on-going. We plan to remove events with q2 above 1GeV/c2 - is this ok?

Vub τ decays

- If there is NP in V_{cb} τ decays, what about V_{ub} ?
	- Less SM background. • Less SM background.

• Excited states can be used here. $R(N^*) = \frac{\mathcal{B}(\Lambda_b \to N^* \tau \nu)}{P(\Lambda_b \to N^* \tau \nu)}$ $D(N^*) = \frac{D(11b)}{2}$

$$
R(p\bar{p}) = \frac{\mathcal{B}(\Lambda_b \to N^* \mu\nu)}{\mathcal{B}(B \to p\bar{p}\tau\nu)}
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R(p\bar{p}) = \frac{\mathcal{B}(B \to p\bar{p}\tau\nu)}{\mathcal{B}(B \to p\bar{p}\mu\nu)}
$$

What kind of limits would be interesting, given constraints on $B(B\to \pi\tau\nu)$ from Belle (arXiv: 1509.06521)?

Other ideas

- Kaon veto applied in inclusive measurement to suppress V_{cb} background.
- Can the decays $B \to KK\pi\mu\nu$ and $B \to KK\mu\nu$ help control the efficiency of this (I. Bigi, arXiv:1507.01842)?
- Another distinctive signature is $B \to p\bar{p}\mu\nu$. Could we learn anything about |Vub| or the hadronic structure?
- What about angular analyses of e.g. $B \to \rho \mu \nu$, is there room left for significant deviations from the SM predictions?

Summary

- LHCb has measured $|V_{ub}|$ using $\Lambda_b^0 \to p \mu \nu$ decays.
- The $|V_{ub}|$ field is relatively new to LHCb, but is expanding rapidly.
- We will obviously try to do everything we can. However, input to what is particularly interesting or new ideas are very welcome.

RH currents

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