

The V_{xb} puzzle, or Uli and the semileptonic decays ...



Thomas Mannel, University of Siegen



CPPS Center for Particle
Physics Siegen

TP1 Theoretical
Particle Physics

Uli - Fest: Exploring New Physics with Flavor, July 2nd, 2026

Opening Remarks ...

- In 1994, the TTP decided to hire a flavor physicist ...
- ... and they chose me!
- I joined TTP at Karlsruhe University (TH) in November 1993
- In 2003 I moved on to the University of Siegen
- ... and in 2005 Karlsruhe hired Uli:
- A Perfect choice to carry on Flavor Physics!
- Not only that: Karlsruhe became Excellent!
- ... and turned in to KIT!

Contents

1 V_{xb} Puzzle

2 Semitauonic Anomaly

Introduction

Why is flavor physics interesting?

- Exploration of weak interactions
- Precision methods for heavy quarks
- High sensitivity to indirect hints at “New Physics”
- Since recently: A lot of fun with B anomalies

What are the B Anomalies?

- Small deviations from the SM expectations
- not significant enough to count as evidence
- ... but persistent enough to be scrutinized

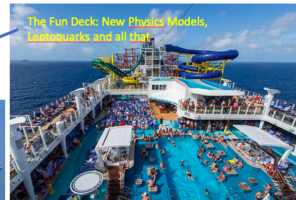
Introduction

Why is flavor physics interesting?

- Exploration of weak interactions
- Precision methods for heavy quarks
- High sensitivity to indirect hints at “New Physics”
- Since recently: A lot of fun with B anomalies

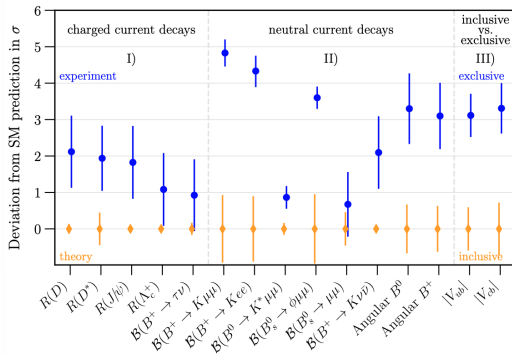
What are the B Anomalies?

- Small deviations from the SM expectations
- not significant enough to count as evidence
- ... but persistent enough to be scrutinized
- On the fun deck: This as New Physics!
- On the machine deck: Check the SM!



The current list of B anomalies

- The angular distribution in FCNC $B \rightarrow K^* \ell^+ \ell^-$ decays
- The total & partial rates in FCNC $B \rightarrow K^* \ell^+ \ell^-$ decays
- The rate of exclusive semi-tauonic decays
- Exclusive vs. inclusive determinations of V_{xb}

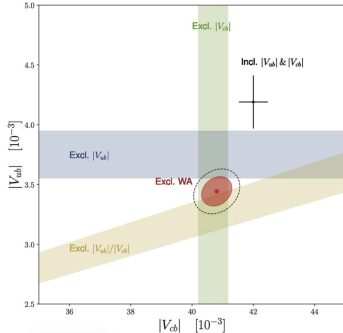


(Plot taken from the CmF proposal)

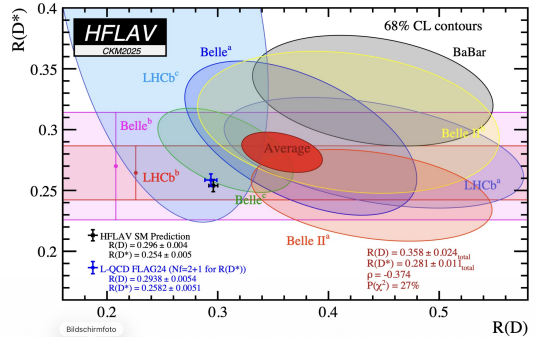
Charged Current Semileptonic Anomalies

- $b \rightarrow c/\ell\bar{\nu}$ is a tree level process
- People believe that it is unlikely to be “New Physics”
- ... Except maybe the semitauonic anomaly
- Go back to the machine deck and scrutinize the Standard model

Current status



Bernlochner, Prim, Vos
[Eur. Phys. J. Spec. Top. (2024)]



The V_{xb} -Puzzle I: Inclusive V_{cb}

First thing: Go back and read the relevant literature:



ELSEVIER

Nuclear Physics B (Proc. Suppl.) 39B, C (1995) 393–395

NUCLEAR PHYSICS
PROCEEDINGS
SUPPLEMENT

Mass definition in heavy quark effective theory and a new determination of V_{cb}

Patricia Ball and Ulrich Nierste

Physik Department/T30, TU München, D-85747 Garching, Germany

(Received 31 March 1994; revised manuscript received 22 April 1994)

Positive powers of the mass parameter in a physical quantity calculated with the help of heavy quark effective theory (HQET) originate from a Wilson coefficient in the matching of a QCD and a HQET Green function. We show that this mass parameter enters the calculation as a well-defined running current mass. We further argue that the recently found ill definition of the pole mass, which is the natural expansion parameter of HQET, does not affect a phenomenological analysis which uses a truncated perturbative series. We reanalyze inclusive semileptonic decays of heavy mesons and obtain the c quark mass $m_c^{\overline{MS}}(m_c) = (1.35 \pm 0.20)$ GeV where the error is almost entirely due to scale, uncertainties. We also obtain $m_b^{\overline{MS}}(m_b) = (4.6 \pm 0.3)$ GeV and $|V_{cb}|(\tau_B/1.49 \text{ ps})^{1/2} = 0.036 \pm 0.005$ where the errors come from the uncertainty in the kinetic energy of the heavy quark inside the meson, in the experimental branching ratios, in QCD input parameters, and scale uncertainties.

The determination of $|V_{cb}|$ from semileptonic inclusive decay rates

Ulrich Nierste^{a*}^aPhysik-Department T31, Technische Universität München, 85747 Garching, Germany

We report on the determination of $|V_{cb}|$ from the comparison of the semileptonic inclusive decay rates and D-mesons using the heavy quark symmetry of QCD. While the renormalization scale ambiguity do allow for a reliable estimate of the quark masses, it almost cancels in the prediction for $|V_{cb}|$, which reads

$$|V_{cb}|(\tau_B/1.49 \text{ ps})^{1/2} = 0.036 \pm 0.005,$$

where the error stems from the ^{Bildschirmfoto} in the kinetic energy of the heavy quark inside the meson, experimental branching ratios, in QCD input parameters, and from scale uncertainties.

... a lot has happend since then!

Theoretical machinery: Heavy Quark Expansion

HQE of inclusive rates and moments

- Use the HQE for the total rate and the moments
- The total rate is $\propto |V_{cb}|^2$
- Use kinematic moments to extract the HQE parameters
- Structure of the differential rate

$$d\Gamma = d\Gamma_0 + \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right)^2 d\Gamma_2 + \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right)^3 d\Gamma_3 + \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right)^4 d\Gamma_4 \\ + d\Gamma_5 \left(a_0 \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right)^5 + a_2 \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right)^3 \left(\frac{\Lambda_{\text{QCD}}}{m_c}\right)^2 \right) + \dots + d\Gamma_7 \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right)^3 \left(\frac{\Lambda_{\text{QCD}}}{m_c}\right)^4$$

- Total rate as well as kinematic moments have a HQE
- ... more details from Keri's presentation.

Status of the HQE Calculation in $B \rightarrow X_c \ell \bar{\nu}$

- Tree level terms up to and **including $1/m_b^5$** known
Bigi, Zwicky, Uraltsev, Grimm, Kapustin, Turczyk, Vos, Milutin, ThM, ...
- $\mathcal{O}(\alpha_s)$, $\mathcal{O}(\alpha_s^2)$, $\mathcal{O}(\alpha_s^3)$ for the partonic rate and spectral moments are known
Biswas, Melnikov, Czarnecki, Pak, Fael, Schönwald, Steinhauser ...
- $\mathcal{O}(\alpha_s)$ for $1/m_b^2$ is known for rates and spectra
Becher, Boos, Lunghi, Gambino, Pivovarov, Rosenthal, Alberti
- $\mathcal{O}(\alpha_s)$ for $1/m_b^3$ is known for rates and spectra Pivovarov, Moreno, ThM

$$V_{cb, incl} = (41.83 \pm 0.47) \times 10^{-3} \quad (\text{Finauri, Gambino: 2310.20324})$$

We are moving towards a TH-uncertainty of 1% in $V_{cb, incl}$!

Details start to matter:

How well do we know the quark mass? and **What about Duality Violations?**

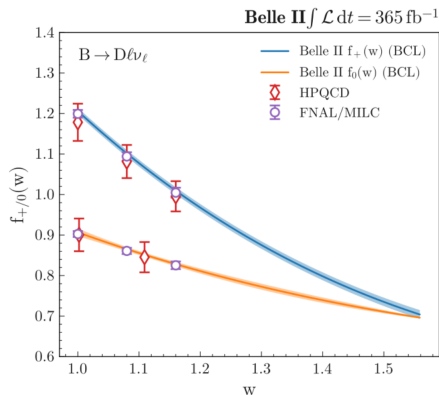
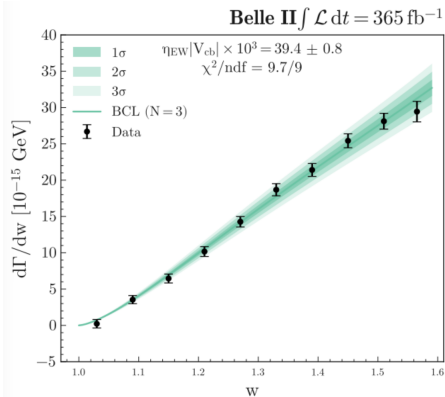
Exclusive V_{cb}

Need the form factors for $B \rightarrow D^{(*)} \ell \bar{\nu}$ transitions

$$\frac{\langle D(p') | V^\mu | B(p) \rangle}{\sqrt{m_B m_D}} = h_+(v + v')^\mu + h_-(v - v')^\mu \quad \frac{\langle D^*(p') | V^\mu | B(p) \rangle}{\sqrt{m_B m_{D^*}}} = h_V \epsilon^{\mu\nu\alpha\beta} \epsilon_\nu^* v'_\alpha v_\beta$$

$$\frac{\langle D^*(p') | A^\mu | B(p) \rangle}{\sqrt{m_B m_{D^*}}} = h_{A_1}(w + 1)\epsilon^{*\mu} - h_{A_2}(\epsilon^* \cdot v)v^\mu - h_{A_3}(\epsilon^* \cdot v)v'^\mu$$

- Reliable and precise Lattice Calculations, not only at $v = v'$
- Extrapolations based on parametrizations based on unitarity and analyticity
- Constraints from the heavy-quark limit



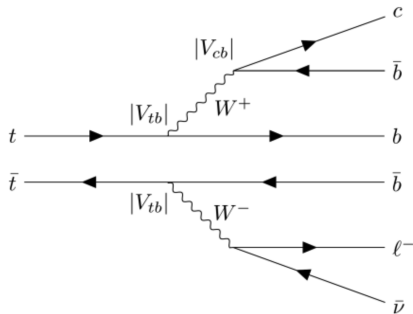
$$|V_{cb}| = (39.2 \pm 0.4_{\text{stat}} \pm 0.6_{\text{sys}} \pm 0.5_{\text{th}}) \times 10^{-3} \text{ from } B \rightarrow D\ell\bar{\nu}$$

$$|V_{cb}| = (40.7 \pm 0.7) \times 10^{-3} \text{ from } B \rightarrow D\ell\bar{\nu} \text{ from } B \rightarrow D^*\ell\bar{\nu}$$

(M. Prim at FPCP2026)

Still some inconsistencies between the different lattice groups ...

New Ideas: V_{cb} from on-shell W decays



$$|V_{cb}|^2 = \frac{\text{Br}(W \rightarrow \bar{b}c)}{\text{Br}(W \rightarrow \bar{b}q)} = \frac{\text{Br}(t\bar{t} \rightarrow b\bar{b}c, \bar{b}\ell\bar{\nu})}{\text{Br}(t\bar{t} \rightarrow b\bar{b}q, \bar{b}\ell\bar{\nu})}$$

$$|V_{cb}| = (50_{-9}^{+7}(\text{stat.})_{-10}^{+9}(\text{sys.})) \times 10^{-3}$$

Not yet competitive, but at the end mainly statistically limited

(P. Harrison at FPCP2026)

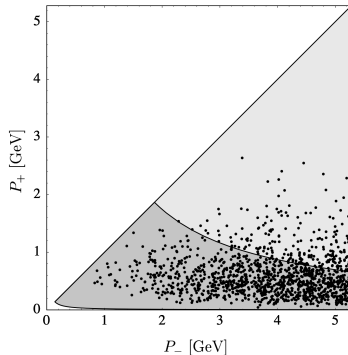
Inclusive V_{ub}

Key ingredient: Fighting the background from $b \rightarrow c\ell\bar{\nu}$:

- Cut on the charged lepton energy, or on $P_\ell = M_B - 2E_\ell$
- Cut on the hadronic mass
- Cut on the hadronic energy and hadronic momentum:

$$P_\pm = E_{had} \mp |\vec{P}_{had}|$$

$$\frac{M_\pi^2}{P_-} \leq P_+ \leq P_\ell \leq P_- \leq M_B$$



(Bosch, Lange, Neubert, Paz 2005)

The region of small P_+ does not have a (local) OPE,
Local OPE gets replaced by a light-cone OPE similar to DIS

Shape Functions

Non-perturbative input are now “shape functions”:

- leading order $S(\omega) = \langle B(v) | \bar{h}_v \delta(\omega - inD) h_v | B(v) \rangle$
- Decay rate at leading order is $\frac{d\Gamma}{dP_+} \propto S(P_+)$
- Several shape functions at subleading order

This has several consequences

- The nonperturbative input is much more complicated
- The shape functions induce a model dependence
- Inclusive V_{ub} is (currently?) much less reliable and precise

There are two approaches of this kind on the market:

GGOU Gambino, Giordano, Ossala, Uraltsev (2007)

- Subleading shape functions are treated by a model function
- Includes NLO and NNLO QCD corrections

$$|V_{ub}| = \left(4.19 \pm 0.12^{+0.11}_{-0.12}\right) \times 10^{-3}$$

BLNP Bosch, Lange, Neubert, Paz (2004)

- Subleading shape functions are included systematically and related to the leading-order shape function
- Includes NLO QCD corrections, NNLO is known, but not (yet) implemented
- Work in progress on a major update

$$|V_{ub}| = \left(4.28 \pm 0.13^{+0.20}_{-0.21}\right) \times 10^{-3}$$

Some new ideas to use the local OPE instead ...

Exclusive V_{ub}

The relevant channels are $B \rightarrow \pi \ell \bar{\nu}$ and $B \rightarrow \rho \ell \bar{\nu}$:

$B \rightarrow \pi \ell \bar{\nu}$:

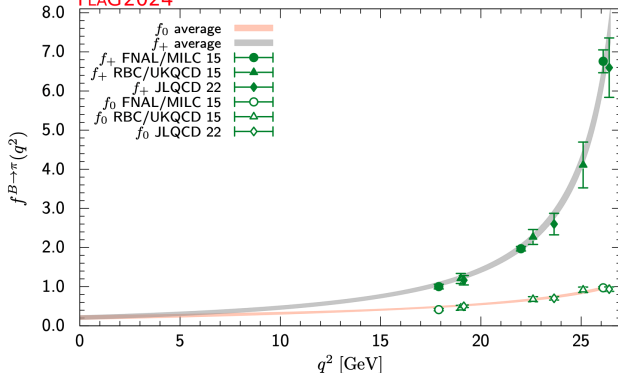
- Only a single form factor (for massless leptons)
- Reliable Lattice simulations in the region close to $q_{max}^2 = (M_B - M_\pi)^2$
- Reasonably good light-cone sum-rule estimates in the region close to $q_{min}^2 = 0$
- Interpolation with form factor parametrizations using unitarity and analyticity

$B \rightarrow \rho \ell \bar{\nu}$:

- Four form factors (for massless leptons)
- The ρ is unstable and quite broad
- $B \rightarrow \rho \ell \bar{\nu}$ is actually $B \rightarrow \pi \pi \ell \bar{\nu}$
- ... this is way more complicated!

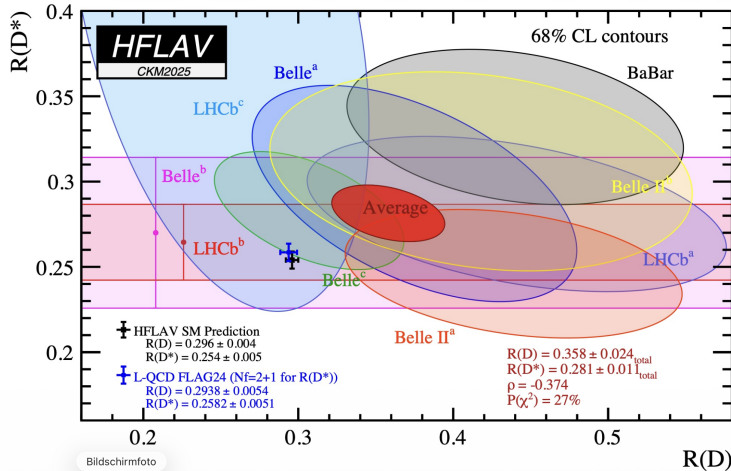
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} |\vec{p}_\pi|^3 |f_+(q^2)|^2$$

FLAG2024



$$|V_{ub}| = (3.70 \pm 0.10 \pm 0.12) \times 10^{-3}$$

Semitaucic Anomaly: $B \rightarrow D\tau\nu$ and $B \rightarrow D^*\tau\nu$





PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: August 14, 2023

REVISED: October 3, 2023

ACCEPTED: November 10, 2023

PUBLISHED: November 21, 2023

Renormalisation group analysis of scalar Leptoquark couplings addressing flavour anomalies: emergence of lepton-flavour universality

Marco Fedele, Ulrich Nierste and Felix Wuest

*Institute for Theoretical Particle Physics, Karlsruhe Institute of Technology (KIT),
Wolfgang-Gaede-Str. 1, 76131 Karlsruhe, Germany*

PHYSICAL REVIEW D **99**, 075006 (2019)

Impact of polarization observables and $B_c \rightarrow \tau \nu$ on new physics explanations of the $b \rightarrow c \tau \nu$ anomaly

Monika Blanke*

*Institut für Kernphysik (IKP), Karlsruher Institut für Technologie (KIT), 76021 Karlsruhe, Germany
Institut für Theoretische Teilchenphysik (TTP), Karlsruher Institut für Technologie (KIT),
76131 Karlsruhe, Germany*

Andreas Crivellin†

Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Stefan de Boer,[‡] Marta Moscati,[§] Ulrich Nierste,^{||} and Ivan Nišandžić[¶]

*Institut für Theoretische Teilchenphysik (TTP), Karlsruher Institut für Technologie (KIT),
76131 Karlsruhe, Germany*

Teppei Kitahara**

*Institute for Advanced Research, Nagoya University, Furo-cho Chikusa-ku, Nagoya 464-8602, Japan;
Kobayashi-Maskawa Institute for the Origin of Particles and the Universe,
Nagoya University, Nagoya 464-8602, Japan
and Physics Department, Technion-Israel Institute of Technology, Haifa 3200003, Israel*

(Received 4 December 2018; published 5 April 2019)

PHYSICAL REVIEW D **78**, 015006 (2008)

Charged-Higgs-boson effects in the $B \rightarrow D \tau \nu_\tau$ differential decay distribution

Ulrich Nierste, Stéphanie Trine, and Susanne Westhoff

*Institut für Theoretische Teilchenphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany
(Received 31 January 2008; published 11 July 2008)*

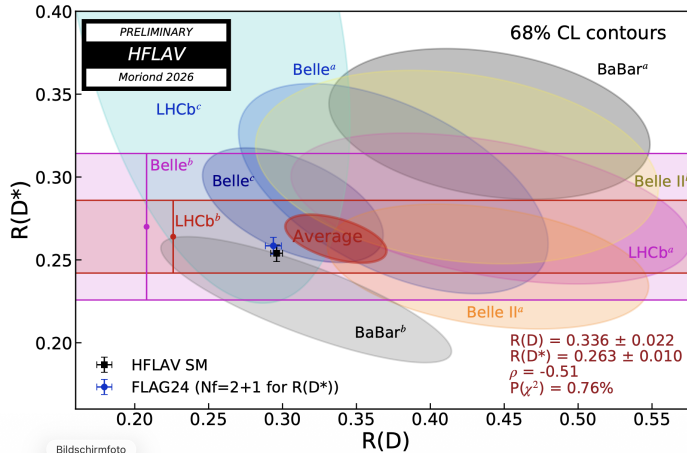
We show that the decay mode $B \rightarrow D \tau \nu_\tau$ is competitive with and complementary to $B \rightarrow \tau \nu_\tau$ in the search for charged-Higgs effects. Updating the relevant form factors, we find that the differential distribution in the decay chain $\bar{B} \rightarrow D \bar{\nu}_\tau \tau^- [\rightarrow \pi^- \nu_\tau]$ excellently discriminates between standard model and charged-Higgs contributions. By measuring the D and π^- energies and the angle between the D and π^- three-momenta, one can determine the effective charged-Higgs coupling including a possible CP -violating phase.

DOI: [10.1103/PhysRevD.78.015006](https://doi.org/10.1103/PhysRevD.78.015006)

PACS numbers: 12.60.Fr, 13.20.He

Uli definitively also spends some time on the fun deck!

However ... a new re-analysis of BaBar data:



(G. Eigen at FPCP 2026)

At the end:

Let have some more fun with flavor and see, where the ship of flavor theory goes.

