Leptonic and semileptonic decays of *b*-hadrons

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LPT Orsay

Leptonic and semileptonic decays of *b*-hadrons

- Metrology of the SM
  - Help understanding weak interaction and CKM matrix
  - Discrepancies to be solved in $b \to c\ell\nu$ and $b \to u\ell\nu$
- Probe of NP
  - Lepton Flavour Universality Violation in $b \to c\tau\nu$ vs $b \to c\ell\nu$
  - More processes and angular analysis to improve understanding
- Status
  - Well studied from the theory and experimental point of view
  - Perspectives in general and within CEPC ?

Chapter 2 of CEPC Flavour report: $b \to c$ and $b \to u$ transitions

Conveners: J. Charles, SDG [th.];

F. Bernlochner, L. Cao, R. Kowaleski, A. Soffer [exp.].

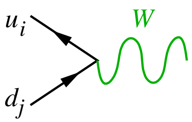
Current status

The CKM matrix

- In SM, W bosons couple to charged currents J_W^μ for left-handed quarks, connecting quarks of the same generation in weak basis
- After electroweak symmetry breaking, Yukawa couplings to Higgs yield "mass" matrices to be diagonalised in flavour space V_{UL}, V_{DL}

$$J_W^\mu = \bar{u}_L^i \gamma^\mu d_L^i \to \bar{u}'_L V_{UL}^\dagger \gamma^\mu V_{DL} d'_L = \bar{u}'_L V \gamma^\mu d'_L$$

- Potential misalignement between (unitary) rotations: $V_{UL} \neq V_{DL}$, so matrix $V = V_{UL}^\dagger V_{DL}$ is unitary but not identity in flavour space



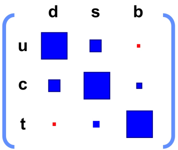
$$\frac{g}{\sqrt{2}} [\bar{u}_L^i V_{ij} \gamma^\mu d_L^j W_\mu^+ + \bar{d}_L^j V_{ij}^* \gamma^\mu u_L^i W_\mu^-]$$

unitary Cabibbo-Kobayashi-Maskawa matrix
connecting quarks of different generations

- V and V^* for CP-conjugates,
  so CP-violation for weak quark decays if V with imaginary part

Structure of CKM matrix

$$V = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$



- 3 generations, unitary, only 4 physically relevant parameters
  - 3 moduli
  - 1 phase, only source of *CP*-violation in SM
- Wolfenstein parametrisation, exploiting the hierarchical structure, defined to hold to all orders in λ and rephasing invariant

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

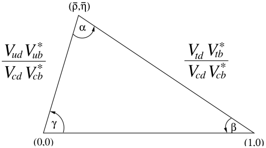
$$V = \begin{bmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho} - i\bar{\eta}) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \bar{\rho} - i\bar{\eta}) & -A\lambda^2 & 1 \end{bmatrix} + O(\lambda^4)$$

Unitarity triangles

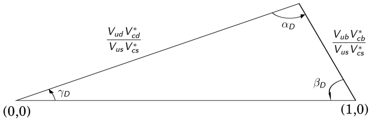
Many unitarity relations, e.g., related to 4 neutral mesons (no top)

- B_d meson (bd) : $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$ $(\lambda^3, \lambda^3, \lambda^3)$
- B_s meson (bs) : $V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$ $(\lambda^4, \lambda^2, \lambda^2)$
- K meson (sd) : $V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0$ $(\lambda, \lambda, \lambda^5)$
- D meson (cu) : $V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub}V_{cb}^* = 0$ $(\lambda, \lambda, \lambda^5)$

Representation of (ρ, η) through rescaled triangles



(small but non squashed)
B_D-meson triangle (bd)

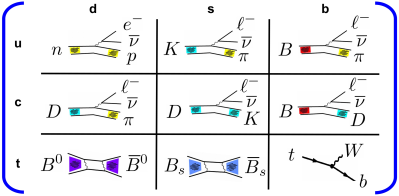


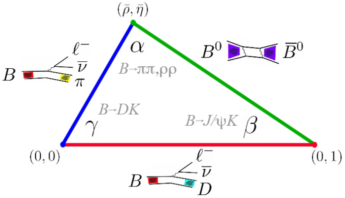
(large but squashed)
D-meson triangle (cu)

In practice, always B_d unitarity triangle (but only 2 parameters out of 4)

Extracting the CKM parameters

V =

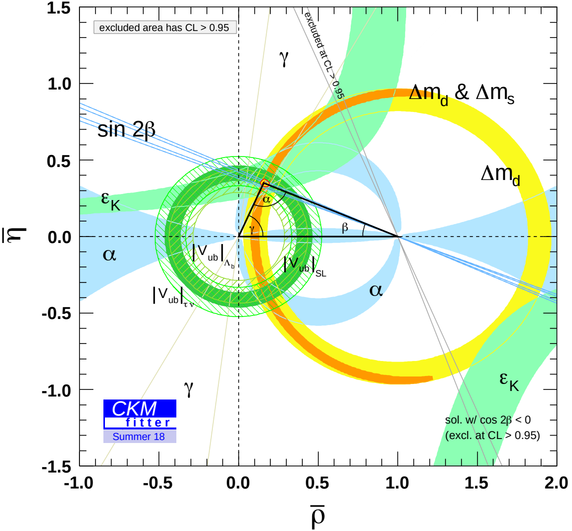




	Exp. uncert.		Theoretical uncertainties	
Tree	$B \to DK$	γ	$B(b) \to D(c)\ell\nu$	$\lvert V_{cb}\rvert$ vs form factor $F^{B\to D}$ (OP
			$B(b) \to \pi(u)\ell\nu$	$\lvert V_{ub}\rvert$ vs form factor $F^{B\to\pi}$ (OP
			$M \to \ell\nu$, $M \to N\ell\nu$	$\lvert V_{UD}\rvert$ vs f_M (decay cst), $F^{M\to N}$
Loop	$B \to (c\bar c)_{\rm res}K$	β	ϵ_K (K mix)	$(\bar\rho,\bar\eta)$ vs B_K (bag parameter)
	$B \to \pi\pi, \rho\pi, \rho\rho$	α	$\Delta m_d, \Delta m_s$ (B_d, B_s mix)	$\lvert V_{tb}V_{tq}\rvert$ vs $f_B^2 B_B$ (bag param)

Leptonic and semileptonic modes
important to fix the CKM moduli
but requires some QCD/hadronic inputs
mainly from lattice QCD simulations

The current status of CKM



$|V_{ud}|, |V_{us}|, |V_{cb}|, |V_{ub}|_{SL}$

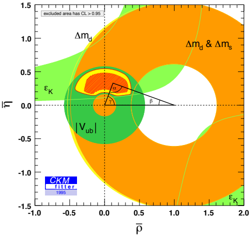
$B \to \tau\nu$

$\Delta m_d, \Delta m_s, \epsilon_K$

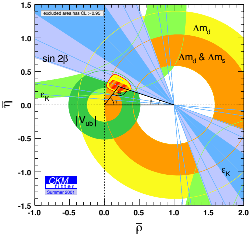
$\alpha, \sin 2\beta, \gamma$

$$A = 0.840^{+0.005}_{-0.020}$$
$$\lambda = 0.2247^{+0.0003}_{-0.0001}$$
$$\bar\rho = 0.158^{+0.010}_{-0.007}$$
$$\bar\eta = 0.349^{+0.010}_{-0.007}$$
(68% CL)

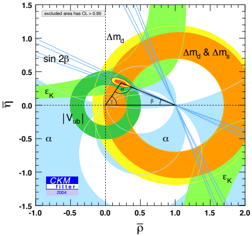
Two decades of CKM



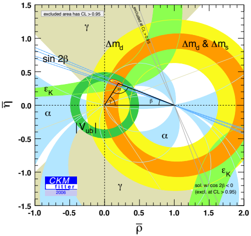
1995



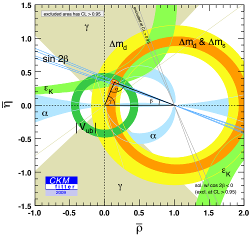
2001



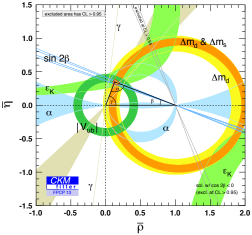
2004



2006



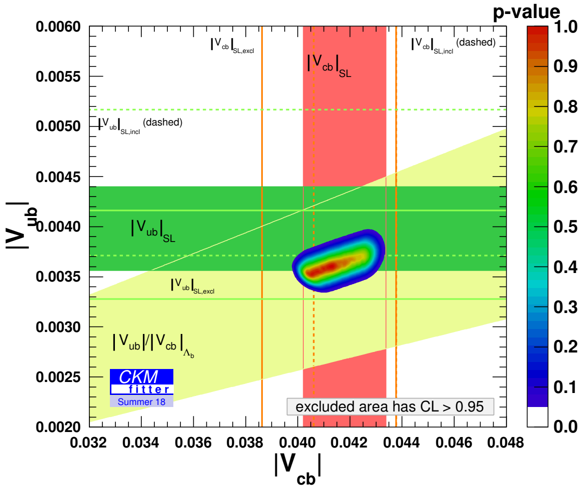
2009



2013

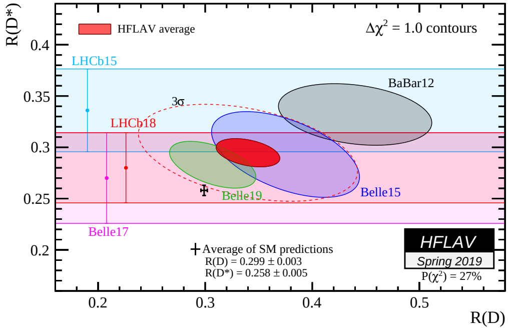
$b \to c\ell\nu$: $|V_{cb}|$ and $|V_{ub}|$

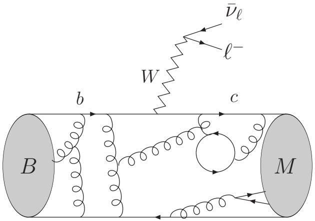
A rather confusing situation concerning $b \to c\ell\nu$ and $b \to u\ell\nu$
(recent hopes to solve $b \to c\ell\nu$ case have not been successful)



- $|V_{cb}|$ and $|V_{ub}|$ from exclusive and inclusive measurements $b \to c\ell\nu$ and $b \to u\ell\nu$ ($\ell = e, \mu$)
- Global fit of CKM favours excl. $|V_{ub}|_{SL}$ but incl. $|V_{cb}|_{SL}$
- $|V_{ub}|$ from $Br(B \to \tau\nu)$
- $|V_{ub}/V_{cb}|$ from $\Gamma(\Lambda_b \to p\mu\nu)/\Gamma(\Lambda_b \to \Lambda_c\mu\nu)$ (large uncertainties)

$b \to c\ell\nu$ vs $b \to c\tau\nu$: R_D and R_{D^*}

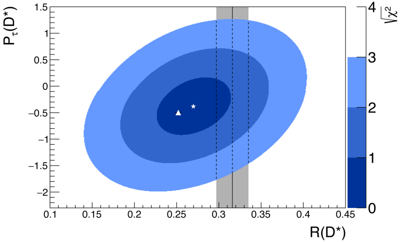




$$R_{D(*)} = \frac{Br(B \to D(^*)\tau\nu)}{Br(B \to D(^*)\ell\bar{\nu}_\ell)}$$

- different identification techniques of the τ for LHCb and B-factories
- $R(D)$ and $R(D^*)$ exceed SM predictions by 1.4 σ and 2.5 σ, leading to combined deviation from SM preds around 3.1σ level
- consistent with 10% enhancement for BRs in $b \to c\tau\bar{\nu}_\tau$
- several NP explanations, easiest by modifying normalisation of SM operator $\mathcal{O}_{V_L\ell} = (\bar{c}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\tau)$ (different G_F for $b \to c\tau\nu$)

$b \to c\tau\nu$: Other observables



τ polarisation in $B \to D^*\tau\nu$

- Belle with $\tau \to X\nu$, $X = \rho$ (or π)

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = \frac{1}{2}[1 + \alpha_X P_\tau \cos\theta_\tau]$$

θ_τ angle $(\vec{p}_X, -\vec{p}_{\tau\nu})$

- Large stat unc, SM compatible, $P_\tau > 0.5$ excluded at 90% CL

D^* polarisation in $B \to D^*\tau\nu$

- Angular analysis: $\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = \frac{3}{4}\left[2F_L\cos^2\theta_{D^*} + (1-F_L)\sin^2\theta_{D^*}\right]$
- Belle: $F_L = 0.60 \pm 0.08 \pm 0.04$, agree with SM at 1.7 σ

$R_{J/\psi}$ ($B_c \to J/\psi\ell\nu$ vs $B_c \to J/\psi\tau\nu$)

- LHCb: $R_{J/\psi} = 0.71 \pm 0.17 \pm 0.18$ whereas SM around 0.2-0.3
- Too large deviation from SM for NP models explaining $R_{D^{(*)}}$

Broad agreement with minimal NP hyp of contrib to G_F for $b \to c\tau\nu$

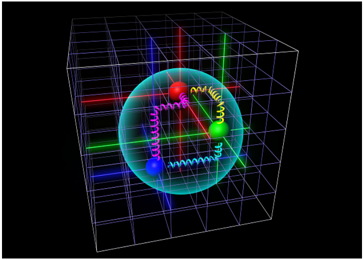
Prospective exercise

Prospective exercise for HL LHC

A prospective exercise performed for HL-LHC report arXiv:1812.97638

- Central values chosen to be all consistent within SM
- Extrapolation of experimental and theory (mostly lattice) inputs
- LHC-centered analysis
  but additional inputs from Belle II physics book arXiv:1808.10567
- Two phases
  - Phase 1 ($\simeq$ 2025)
    LHCb 27 fb^{-1}, CMS/ATLAS 300 fb^{-1}, Belle II 50 ab^{-1}
  - Phase 2 ($\simeq$ 2035)
    LHCb 300 fb^{-1}, CMS/ATLAS 3000 fb^{-1}, Belle II 50 ab^{-1}

Lattice predictions



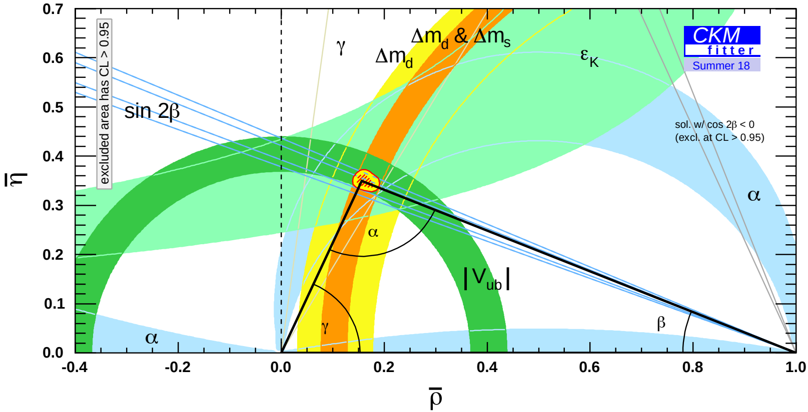
- QCD with discretised space-time (spacing a) in a box (length L)
- All relevant scales Λ must satisfy $1/L \ll \Lambda \ll 1/a$: very heavy (B) and very light (π) harder to reach
- Hadronic quantities by Monte-Carlo sampling of gluon configurations

Uncertainties

- Statistic: size of the sampling (very large)
- Systematic: $a \to 0$, $L \to \infty$, $m_q \to m_q^{\rm phys}$, effective theories...
- Often 1% accuracy, need to include more effects (QED, isospin...)
- Delicate to extrapolate as generally syst dominated already now

	Current	Phase 1	Phase 2
$\lvert V_{ub}\rvert \times 10^3$ ($b \to u\ell\bar\nu$)	± 0.23	± 0.04	± 0.04
$\lvert V_{cb}\rvert \times 10^3$ ($b \to c\ell\bar\nu$)	± 0.7	± 0.5	± 0.5
$\lvert V_{ub}/V_{cb}\rvert$ (Λ_b)	± 0.0050	± 0.0025	± 0.0008
f_{B_s} [GeV]	± 0.0025 (1.1%)	± 0.0011 (0.5%)	± 0.0011 (0.5%)
f_{B_s}/f_{B_d}	± 0.007 (0.6%)	± 0.005 (0.4%)	± 0.005 (0.4%)

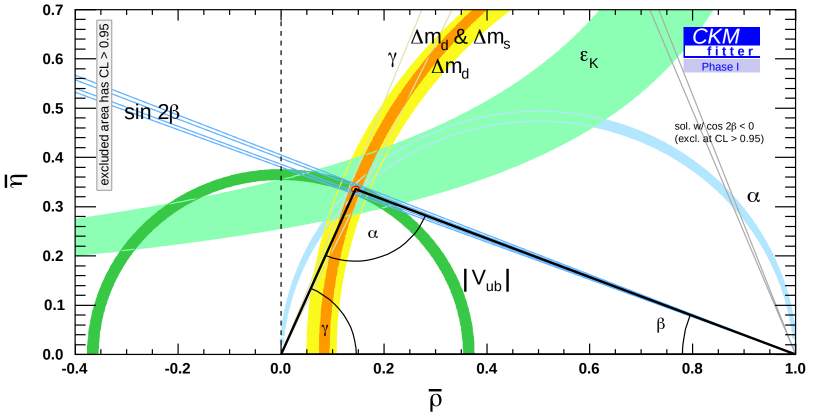
Currently



Summer 2018

(current fit, obs in good but not perfect agreement)

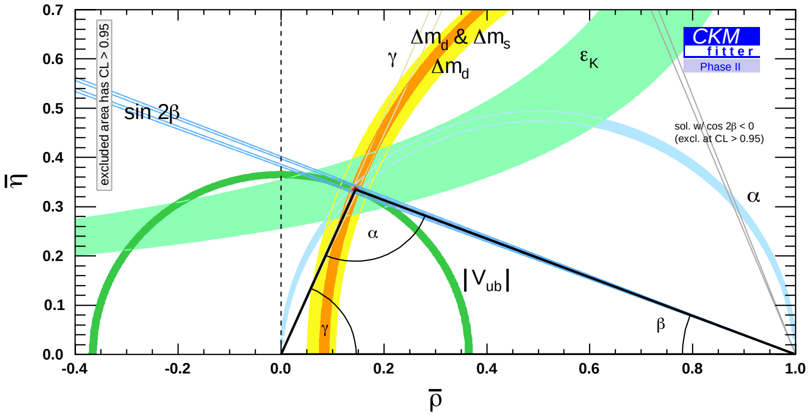
Phase 1



Phase 1 ($\simeq$ 2025)

LHCb 27 fb^{-1}, CMS/ATLAS 300 fb^{-1}, Belle II 50 ab^{-1}

Phase 2



Phase 2 ($\simeq$ 2035)

LHCb 300 fb^{-1}, CMS/ATLAS 3000 fb^{-1}, Belle II 50 ab^{-1}

Improvement on CKM matrix

	Summer 18	Current	Phase I	Phase II
A	0.0129	0.0120	0.0058	0.0057
λ	0.0002	0.0007	0.0004	0.0004
$\bar{\rho}$	0.0085	0.0085	0.0027	0.0018
$\bar{\eta}$	0.0083	0.0087	0.0024	0.0015
$\|V_{ub}\|$	0.000076	0.000096	0.000027	0.000023
$\|V_{cb}\|$	0.00073	0.00070	0.00026	0.00025
$\|V_{td}\|$	0.00017	0.00014	0.00006	0.00006
$\|V_{ts}\|$	0.00068	0.00054	0.00026	0.00025
$\sin 2\beta$	0.012	0.015	0.004	0.003
α (°)	1.4	1.4	0.4	0.3
γ (°)	1.3	1.3	0.4	0.3
β_s (rad)	0.00042	0.00042	0.00012	0.00010

Current = Summer 18 with perfect agreement of inputs with SM

Thoughts about CEPC

CEPC and other flavour factories

Machine	CEPC (10^{12} Z)	Belle II (50 ab^{-1} + 5 ab^{-1} at $\Upsilon(5S)$)	LHCb (50 fb^{-1})	FCC-ee (150 ab^{-1})
Data taking	2030-2040	$\to$ 2025	$\to$ 2030	2035-2045
B^+	6×10^{10}	3×10^{10}	3×10^{13}	3×10^{11}
B^0	6×10^{10}	3×10^{10}	3×10^{13}	3×10^{11}
B_s	2×10^{10}	3×10^{8}	8×10^{12}	1×10^{11}
B_c	6×10^{7}	–	6×10^{10}	6×10^{8}
b baryons	10^{10}	–	10^{13}	10^{11}

- Approximate numbers (not indicated: LHCb 300 fb^{-1} for 2035 ?)
- Similar number of $B_{u,d}$ as Belle II, allowing similar programme (rare decays, CKM determination...)

Phase 1: Belle II + LHCb 23 fb^{-1} $\to$ Belle II + LHCb 50 fb^{-1} + CEPC

- roughly 2 $\times$ more data $\Longrightarrow$30% improvement in CKM prospectives
- neglecting any issue with the scaling of syst...

Beyond the accumulation of dta

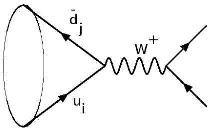
Try to focus on differences/complementarities wrt other machines

- cleaner environment (e^+e^- vs pp) compared to LHCb
- $b\bar{b}$ production incoherent and boosted compared to Belle II
- access to B_c and baryons like LHCb, but different environment
- boosted production $\Longrightarrow$useful for τ and $D_{(s)}$?

CEPC

- Particular focus on B_s, B_c,b-baryon and τ modes ?
- Identify interesting semileptonic and leptonic decays of b-hadrons

Leptonic decays



$$\mathrm{Br}(M \to \ell\nu_\ell)_{\mathrm{SM}} = \frac{G_F^2 m_M m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_M^2}\right)^2 |V_{q_u q_d}|^2 f_M^2 \tau_M (1+\delta_{em}^{M\ell 2})$$

- f_M decay constant main QCD input: $\langle 0|\bar{q}_u\gamma_\mu\gamma_5 q_d|M\rangle = if_M(p_M)_\mu$
- Small QED corrections $\delta_{em}^{M\ell 2}$ (hard to estimate)
- Helicity suppression for light leptons, larger for tau leptons
- In the presence of NP, receives a contribution from axial and (enhanced) pseudoscalar contributions

$$\mathrm{Br}(M \to \ell\nu_\ell) = \mathrm{Br}(M \to \ell\nu_\ell)_{SM} \times \left|1+\epsilon_L+\frac{m_M^2}{m_\ell(m_{q_u}+m_{q_d})}\epsilon_P\right|^2$$

$B_c \to \tau\nu$

Current theoretical knowledge

- $Br(B_c \to \tau^- \bar{\nu}_\ell) = O(2\%)$ in SM
- Two lattice determinations
  - $f_{B_c} = 427 \pm 6$ MeV (McNeile et al. 2012)
  - $f_{B_c} = 434 \pm 15$ MeV (Colquhoun et al. 2015)

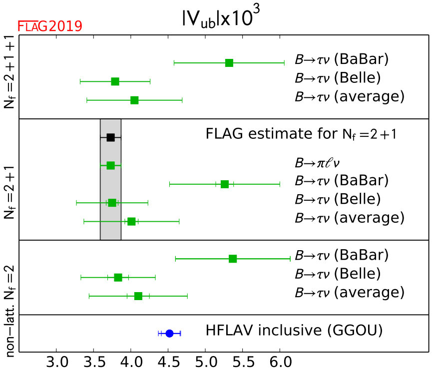
Interest of this decay

- Hard for LHCb, not reachable for Belle II
- New constraint for $|V_{cb}|$ (helping $b \to c\ell\nu$ discrepancy)
- Sensitive to axial and pseudoscalar NP in $b \to c\tau\nu$
- Provide important constraints for NP explanations of R_D, R_{D^*}
  (would replace a weak bound from B_c total width)

A golden channel for CEPC ?
More in S. Prell's talk

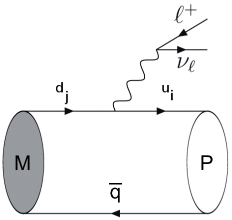
$B^- \to \tau\nu$

- Already studied (but difficult, many semileptonic backgrounds) at Babar and Belle: $Br(B \to \tau\nu) = (1.09 \pm 0.24) \times 10^{-4}$
- Many lattice determinations with FLAG average (2+1 flavours): $f_B = 192 \pm 4.3$ MeV



- Interesting constraint for $|V_{ub}|$ (helping $b \to u\ell\nu$ discrepancy)
- Naturally related to the extraction of $B_c \to \tau\nu$ (same final state)

Semileptonic decays



$0^- \to 0^-$ decays

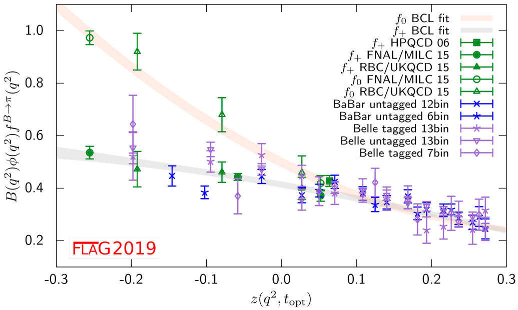
- simple expression, depending on dilepton invariant mass q^2
- hadronic vector f_+ and scalar f_0 form factors from $\langle P|\bar{q}_u\gamma_\mu q_d|M\rangle$, from lattice QCD
- scalar contributions suppressed by m_ℓ^2/q^2

$$\left.\frac{d\Gamma(M\to P\ell\nu)}{dq^2}\right|_{\rm SM} = \frac{G_F^2|V_{q_uq_d}|^2}{24\pi^3}\frac{(q^2-m_\ell^2)^2\sqrt{E_P^2-m_P^2}}{q^4 m_H^2}$$
$$\times\left[\left(1+\frac{m_\ell^2}{2q^2}\right)m_M^2(E_P^2-m_P^2)|f_+(q^2)|^2+\frac{3m_\ell^2}{8q^2}(m_M^2-m_P^2)^2|f_0(q^2)|^2\right]$$

Other semileptonic decays (spin 0 $\to$ spin 1, baryons)

- More form factors (7 for $0\to 1$ for instance)
- Angular distribution of the decay products interesting

The example of $B \to \pi\tau\nu$



- $d\Gamma(B \to \pi\tau\nu)/dq^2$: Determination of $|V_{ub}|$ [Br$= O(10^{-4})$]
  $\Longrightarrow$ also background for leptonic decays (common extraction ?)
- $\frac{d\Gamma(B\to\pi\tau\nu)/dq^2}{\Gamma(B\to\tau\nu)}$: interesting test of QCD (no CKM matrix elements) and constraint on NP (vector and scalar versus axial)
- $\frac{d\Gamma(B\to\pi\tau\nu)/dq^2}{d\Gamma(B\to\pi\ell\nu)/dq^2}$: test of lepton flavour universality, determination of f_0/f_+, comparison with lattice QCD
  $\Longrightarrow f_+$ has already been tested successfully from $B \to \pi\ell\nu$

Other semileptonic decays of interest

Other channels of potential interest (with Br from 10^{-2} to 10^{-5})

	$b \to c\ell\nu$	$b \to u\ell\nu$
B	$B \to D^{(*)}\ell\nu$ ✓	$B \to \pi\ell\nu$ ✓, $B \to \rho\ell\nu$
B_s	$B_s \to D_s\ell\nu$ ✓, $B_s \to D_s^*\ell\nu$	$B_s \to K\ell\nu$ ✓, $B_s \to K^*\ell\nu$
B_c	$B_c \to \eta_c\ell\nu$ ✓, $B_c \to J/\psi\ell\nu$ ✓	$B_c \to D^{(*)}\ell\nu$
Λ_b	$\Lambda_b \to \Lambda_c\ell\nu$ ✓, $\Lambda_b \to \Lambda_c^*\ell\nu$	$\Lambda_b \to p\ell\nu$ ✓

- lattice estimate available ✓ for most of these decays
- $\ell = e, \mu$ or τ sensitive to different NP contributions/form factors
- CEPC seems interesting for last 3 lines compared to Belle II
- Which advantages compared to LHCb (τ, $D_{(s)}$, neutral...) ?

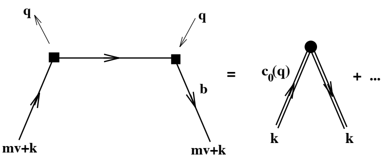
In addition

- theory available for differential decay rate and angular analysis
- $c \to s\ell\nu$ and $c \to d\ell\nu$ accessible through $B_c \to B_s\ell\nu$, $B_c \to B_d\ell\nu$

Inclusive $b \to X\tau\nu$

- Dominated by charm-hadron final states: inclusive test of $b \to c\tau\nu$
- Similar to $\Gamma(b \to X_c\ell\nu)$ with $\ell = e, \mu$, analysed by relating it to imaginary part of a two-point function expanded in $1/m_b$

$$\Gamma(B \to X_c\ell\nu) = \frac{G_F|V_{cb}|^2}{192\pi^2}\left[z_0\left(1-\frac{\mu_\pi^2-\mu_G^2}{2m_b^2}\right)-2\left(1-\frac{m_c^2}{m_b^2}\right)^4\frac{\mu_G^2}{m_b^2}+\ldots\right]$$



- z_0 function of $\frac{m_c^2}{m_b^2}$, ellipsis: higher orders in α_s and $1/m_b$
- μ_π^2 linked to movement of heavy quark inside meson
- μ_G^2 linked to b-spin (B, B^* splitting)

- Separation according to initial hadron ? Baryon veto ?
- Otherwise, more difficult theo and need production fractions (useful in any case: should be measured !)
- Partial cancellation of theo unc in $\Gamma(B \to X_c\tau\nu)/\Gamma(B \to X_c\ell\nu)$

Outlook

Leptonic and semileptonic decays of b-hadrons

- Interesting to probe SM (CKM)
- As well as new physics (Lepton Flavour Universality violation)

CKM determination

- Prospective studies available within HL-LHC and Belle II
- CEPC potential similar to Belle II for $B_{u,d,s}$
- CEPC increase in stat could improve up to 30% on CKM params

CEPC specificities

- B_c and b-baryons accessible, in cleaner environment than LHC
- Boost may helps study final states with τ and $D_{(s)}$
- Study of $b \to X\tau\nu$ to study $B_c \to \tau\nu$, $B \to \tau\nu$, $B \to \pi\tau\nu$, $B \to D\tau\nu$
- Other semileptonic modes of interest: $B_c \to (c\bar{c})\ell\nu$, $b \to X\tau\nu\ldots$

Experimental studies needed
to estimate the CEPC potential on these modes

Back-up

HL-LHC prosp: uncertainties on inputs

	Current	Phase 1	Phase 2
$\lvert V_{ud}\rvert$	± 0.00021	± 0.00021	± 0.00021
$\lvert V_{us}\rvert f_+^{K\to\pi}(0)$	± 0.0004	± 0.0004	± 0.0004
$\lvert\epsilon_K\rvert \times 10^3$	± 0.011	± 0.011	± 0.011
Δm_d [ps^{-1}]	± 0.0019	± 0.0019	± 0.0019
Δm_s [ps^{-1}]	± 0.021	± 0.021	± 0.021
$\lvert V_{ub}\rvert \times 10^3$ $(b \to u\ell\bar{\nu})$	± 0.23	± 0.04	± 0.04
$\lvert V_{cb}\rvert \times 10^3$ $(b \to c\ell\bar{\nu})$	± 0.7	± 0.5	± 0.5
$\lvert V_{ub}/V_{cb}\rvert$ (Λ_b)	± 0.0050	± 0.0025	± 0.0008
$\sin 2\beta$	± 0.017	± 0.005	± 0.003
α [°]	± 4.4	± 0.6	± 0.6
γ [°]	± 5.6	± 1	± 0.35
β_s [rad]	± 0.031	± 0.014	± 0.004
$\mathcal{B}(B \to \tau\nu) \times 10^4$	± 0.21	± 0.04	± 0.04
$\bar{m}_c$ [GeV]	± 0.012 (0.9%)	± 0.005 (0.4%)	± 0.005 (0.4%)
$\bar{m}_t$ [GeV]	± 0.73 (0.4%)	± 0.35 (0.2%)	± 0.35 (0.2%)
$\alpha_s(m_Z)$	± 0.0011 (0.9%)	± 0.0011 (0.9%)	± 0.0011 (0.9%)
$f_+^{K\to\pi}(0)$	± 0.0026 (0.3%)	± 0.0012 (0.12%)	± 0.0012 (0.12%)
f_K	± 0.0006 (0.5%)	± 0.0005 (0.4%)	± 0.0005 (0.4%)
B_K	± 0.012 (1.6%)	± 0.005 (0.7%)	± 0.004 (0.5%)
f_{B_s} [GeV]	± 0.0025 (1.1%)	± 0.0011 (0.5%)	± 0.0011 (0.5%)
B_{B_s}	± 0.034 (2.8%)	± 0.010 (0.8%)	± 0.007 (0.5%)
f_{B_s}/f_{B_d}	± 0.007 (0.6%)	± 0.005 (0.4%)	± 0.005 (0.4%)
B_{B_s}/B_{B_d}	± 0.020 (1.9%)	± 0.005 (0.5%)	± 0.003 (0.3%)