The $B \to D^* \ell \nu$ semileptonic decay at non-zero recoil from lattice QCD

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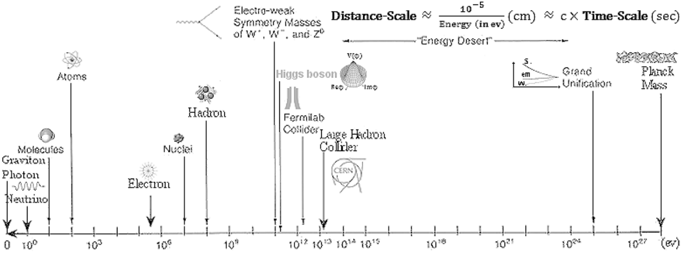
The Standard Model (SM)

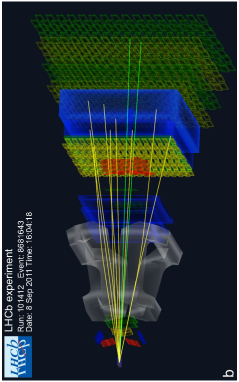
- The Standard Model is (arguably) the most successful theory describing nature we have ever had
- The theory is not completely satisfactory
  - Situation similar to that at the end of the XIX century
- The SM can explain phenomena in a large range of scales



- Yet there is a region where we expect the SM to fail
- The SM is regarded as an effective theory at low energies (low means $E \lesssim v_{EW} \approx 0.1 - 1$ TeV)

Where to look for new physics?

Energy frontier



Intensity frontier

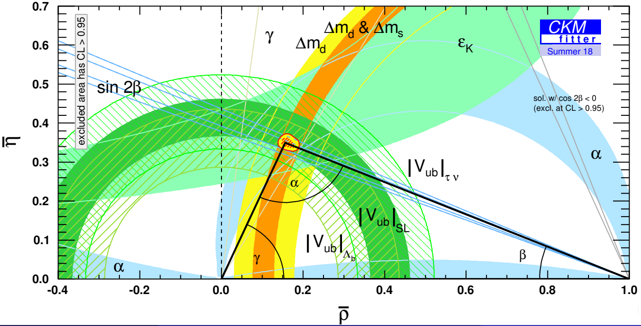
Cosmology frontier

The V_{cb} matrix element: Tensions

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

$\lvert V_{cb}\rvert\,(\cdot 10^{-3})$	PDG 2016	PDG 2018	PDG 2020
Exclusive	39.2 ± 0.7	41.9 ± 2.0	39.5 ± 0.9
Inclusive	42.2 ± 0.8	42.2 ± 0.8	42.2 ± 0.8

- Matrix must be unitary (preserve the norm)
- **Current tensions (2020) stand at** $\approx 3\sigma$



The V_{cb} matrix element: Measurement from exclusive processes

$$\underbrace{\frac{d\Gamma}{dw}\left(\bar{B}\to D^*\ell\bar{\nu}_\ell\right)}_{\text{Experiment}} = \underbrace{\frac{G_F^2 m_B^5}{48\pi^2}(w^2-1)^{\frac{1}{2}}P(w)\left|\eta_{ew}\right|^2}_{\text{Known factors}}\underbrace{\left|\mathcal{F}(w)\right|^2}_{\text{Theory}}\left|V_{cb}\right|^2$$

- The amplitude $\mathcal{F}$ must be calculated in the theory
  - Extremely difficult task, QCD is non-perturbative
- Can use effective theories (HQET) to say something about $\mathcal{F}$
  - Separate light (non-perturbative) and heavy degrees of freedom as $m_Q \to \infty$
  - $\lim_{m_Q\to\infty}\mathcal{F}(w) = \xi(w)$, which is the Isgur-Wise function
  - **We don't know what $\xi(w)$ looks like, but we know $\xi(1) = 1$**
  - At large (but finite) mass $\mathcal{F}(w)$ receives corrections $O\left(\alpha_s, \frac{\Lambda_{QCD}}{m_Q}\right)$
- Reduction in the phase space $(w^2-1)^{\frac{1}{2}}$ limits experimental results at $w \approx 1$
  - Need to extrapolate $\left|V_{cb}\right|^2\left|\eta_{ew}\mathcal{F}(w)\right|^2$ to $w = 1$
  - This extrapolation is done using well established parametrizations

The V_{cb} matrix element: The parametrization issue

All the parametrizations perform an expansion in the z parameter

$$z = \frac{\sqrt{w+1} - \sqrt{2N}}{\sqrt{w+1} + \sqrt{2N}}$$

- Boyd-Grinstein-Lebed (BGL)

Phys. Rev. Lett. 74 (1995) 4603-4606

Phys.Rev. D56 (1997) 6895-6911

Nucl.Phys. B461 (1996) 493-511

$$f_X(w) = \frac{1}{B_{f_X}(z)\phi_{f_X}(z)} \sum_{n=0}^{\infty} a_n z^n$$

  - B_{f_X} Blaschke factors, includes contributions from the poles
  - ϕ_{f_X} is called *outer function* and must be computed for each form factor
  - Weak unitarity constraints $\sum_n |a_n|^2 \leq 1$

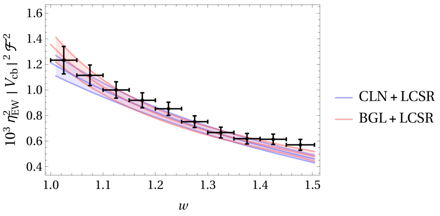
- Caprini-Lellouch-Neubert (CLN)

Nucl. Phys. B530 (1998) 153-181

$$\mathcal{F}(w) \propto 1 - \rho^2 z + c z^2 - d z^3, \quad \text{with } c = f_c(\rho),\, d = f_d(\rho)$$

  - Relies strongly on HQET, spin symmetry and (old) inputs
  - Tightly constrains $\mathcal{F}(w)$: four independent parameters, one relevant at $w = 1$

The V_{cb} matrix element: The parametrization issue



From *Phys. Lett. B769 (2017) 441-445* using Belle data from arXiv:1702.01521 and the Fermilab/MILC'14 value at zero recoil

- CLN seems to underestimate the slope at low recoil
- The BGL value of $|V_{cb}|$ is compatible with the inclusive one

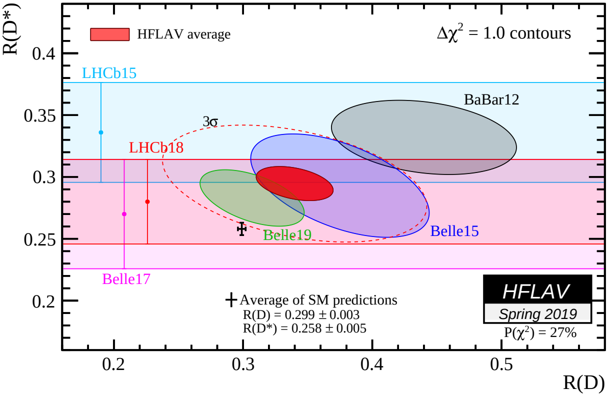
$$|V_{cb}| = 41.7 \pm 2.0(\times 10^{-3})$$

- Latest Belle dataset and Babar analysis seem to contradict this picture
  - From Babar's paper arXiv:1903.10002 **BGL is compatible with CLN and far from the inclusive value**
  - Belle's paper arXiv:1809.03290v3 finds **similar results in its last revision**
- The discrepancy inclusive-exclusive is not well understood
- Data at $w \gtrsim 1$ is **urgently needed** to settle the issue
- Experimental measurements perform badly at low recoil

We would benefit enormously from a high precision lattice calculation at $w \gtrsim 1$

The V_{cb} matrix element: Tensions in lepton universality

$$R\left(D^{(*)}\right) = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu_\ell\right)}$$



- Current $\approx 3\sigma$ tension with the SM

Calculating V_{cb} on the lattice: Formalism

- Form factors

$$\frac{\langle D^*(p_{D^*},\epsilon^\nu)|\,\mathcal{V}^\mu\,|\bar{B}(p_B)\rangle}{2\sqrt{m_B\,m_{D^*}}} = \frac{1}{2}\epsilon^{\nu*}\varepsilon^{\mu\nu}_{\rho\sigma}v_B^\rho v_{D^*}^\sigma \boldsymbol{h_V}(w)$$

$$\frac{\langle D^*(p_{D^*},\epsilon^\nu)|\,\mathcal{A}^\mu\,|\bar{B}(p_B)\rangle}{2\sqrt{m_B\,m_{D^*}}} =$$

$$\frac{i}{2}\epsilon^{\nu*}\left[g^{\mu\nu}\left(1+w\right)\boldsymbol{h_{A_1}}(w) - v_B^\nu\left(v_B^\mu \boldsymbol{h_{A_2}}(w) + v_{D^*}^\mu \boldsymbol{h_{A_3}}(w)\right)\right]$$

- $\mathcal{V}$ and $\mathcal{A}$ are the vector/axial currents in the continuum
- The h_X enter in the definition of $\mathcal{F}$
- We can calculate $h_{A_{1,2,3},V}$ directly from the lattice

Calculating V_{cb} on the lattice: Formalism

- Helicity amplitudes

$$H_{\pm} = \sqrt{m_B\, m_{D^*}}(w+1)\left(\boldsymbol{h_{A_1}}(w) \mp \sqrt{\frac{w-1}{w+1}}\boldsymbol{h_V}(w)\right)$$

$$H_0 = \sqrt{m_B\, m_{D^*}}(w{+}1)m_B\left[(w-r)\boldsymbol{h_{A_1}}(w) - (w-1)\left(r\,\boldsymbol{h_{A_2}}(w) + \boldsymbol{h_{A_3}}(w)\right)\right]/\sqrt{q^2}$$

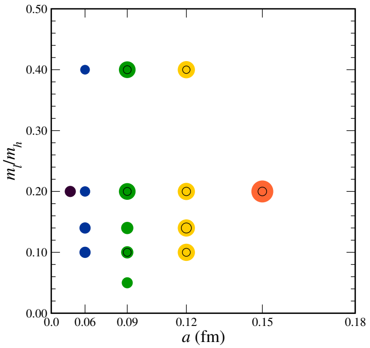
$$H_S = \sqrt{\frac{w^2-1}{r(1+r^2-2wr)}}\left[(1+w)\boldsymbol{h_{A_1}}(w) + (wr-1)\boldsymbol{h_{A_2}}(w) + (r-w)\boldsymbol{h_{A_3}}(w)\right]$$

- Form factor in terms of the helicity amplitudes

$$\chi(w)\left|\mathcal{F}\right|^2 = \frac{1-2wr+r^2}{12m_B\, m_{D^*}\,(1-r)^2}\left(H_0^2(w) + H_+^2(w) + H_-^2(w)\right)$$

Introduction: Available data and simulations

- Using 15 $N_f = 2+1$ MILC ensembles of sea asqtad quarks
- The heavy quarks are treated using the Fermilab action



Calculated ratios

$$\frac{\langle D^*(p)|\,\mathbf{V}\,|D^*(0)\rangle}{\langle D^*(p)|\,V_4\,|D^*(0)\rangle} \to x_f, \qquad w = \frac{1+x_f^2}{1-x_f^2}$$

$$\frac{\left\langle D^*(p_\perp,\varepsilon_\parallel)\right|\mathbf{A}\left|\bar{B}(0)\right\rangle \left\langle \bar{B}(0)\right|\mathbf{A}\left|D^*(p_\perp,\varepsilon_\parallel)\right\rangle}{\langle D^*(0)|\,V_4\,|D^*(0)\rangle \left\langle \bar{B}(0)\right|V_4\left|\bar{B}(0)\right\rangle}^{*} \to R_{A_1}^2, \qquad h_{A_1} = \left(1-x_f^2\right) R_{A_1}$$

$$\frac{\left\langle D^*(p_\perp,\varepsilon_\perp)\right|\mathbf{V}\left|\bar{B}(0)\right\rangle}{\left\langle D^*(p_\perp,\varepsilon_\parallel)\right|\mathbf{A}\left|\bar{B}(0)\right\rangle} \to X_V, \qquad h_V = \frac{2}{\sqrt{w^2-1}} R_{A_1} X_V$$

$$\frac{\left\langle D^*(p_\parallel,\varepsilon_\parallel)\right|\mathbf{A}\left|\bar{B}(0)\right\rangle}{\left\langle D^*(p_\perp,\varepsilon_\parallel)\right|\mathbf{A}\left|\bar{B}(0)\right\rangle} \to R_1, \qquad h_{A_3} = \frac{2}{w^2-1} R_{A_1}\left(w-R_1\right)$$

$$\frac{\left\langle D^*(p_\perp,\varepsilon_\parallel)\right|A_4\left|\bar{B}(0)\right\rangle}{\left\langle D^*(p_\perp,\varepsilon_\parallel)\right|\mathbf{A}\left|\bar{B}(0)\right\rangle} \to R_0,$$

$$h_{A_2} = \frac{2}{w^2-1} R_{A_1}\left(wR_1 - \sqrt{w^2-1}R_0 - 1\right)$$

* Phys.Rev. **D**66, 01503 (2002)

Analysis: Workflow

- Fit meson two-point functions to extract E, M and Z
  - Several smearings to fit properly the ground and excited states
  - For the D^* meson, fit a batch of **unpolarized** correlators to calculate the dispersion relation. Use the result to extract priors for the **polarized** fits
  - Two polarized momenta per ensemble $p = (1, 0, 0)$ and $p = (2, 0, 0)$ in lattice units
  - Explicitly fit wrong parity states
- Fit ratios of three-point functions to extract the form factors
  - Use the result of the two-point function fits to remove the prefactors and set priors
  - Smooth out the wrong parity states
- Renormalize the ratios with the matching factors
- Correct for HQ mistuning
- Perform the chiral-continuum extrapolation

Analysis: Systematics in the two-point function fits

- Try $2+2$ and $3+3$ fits (non-oscillating and oscillating states)
  - Look for agreement in the non-oscillating ground state and ground overlap factors
- Set the **same** t_{Min} **in physical units** for all the ensembles and all the momenta
- Set t_{Max} so the last point of the correlator has an error ≈ 20% - 30%
- Look for a flat distribution of p-values across ensembles and momenta

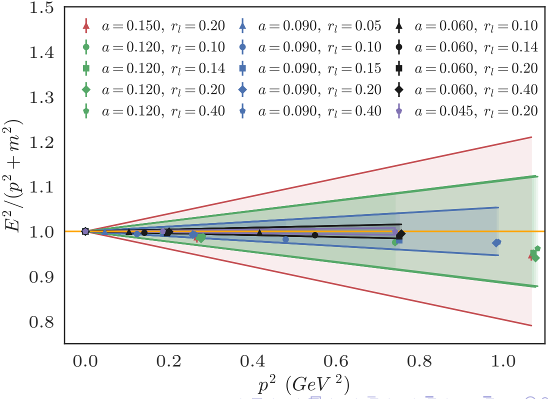
When all conditions all fulfilled, systematic errors coming from the fit procedure should be negligible

Analysis: Systematics in the two-point function fits

- Heavy quark discretization effects break the dispersion relation
- The Fermilab action uses tree-level matching, discretization errors $O(\alpha\, m)$

$$a^2E^2(p_\mu) = (am_1)^2 + \frac{m_1}{m_2}(\mathbf{p}a)^2 + \frac{1}{4}\left[\frac{1}{(am_2)^2} - \frac{am_1}{(am_4)^3}\right](a^2\mathbf{p}^2)^2 - \frac{am_1 w_4}{3}\sum_{i=1}^{3}(ap_i)^4 + O(p_i^6)$$

- Deviations from the continuum experssion measure the size of the discretization errors
- As long as the discretization errors are within expected bounds, this is all right



Analysis: Systematics in the three-point function fits

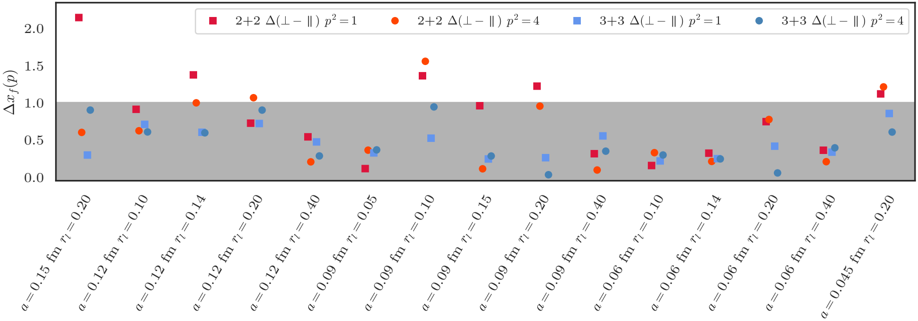
- Use two-point fit results input to remove prefactors and set priors
  - Energy priors are widen to account for different fit ranges
- Set the **same fit ranges in physical units** for all the ensembles and all the momenta
  - Normally on our ratios the D^* meson lives at the source and the B at the sink
  - The double ratio is an exception due to its inherent symmetry, assume D^* at both ends
- Look for a flat distribution of p-values across ensembles and momenta
- The oscillating states are heavily suppressed in our ratios
  - Only the doubly oscillating state is expected to survive
  - This state induces an overall shift in the ratio with sign $(-1)^T$
  - Smooth the doubly oscillating state out

$$\bar{R}(t,T) = \frac{P(t,T)}{2} R(t,T) + \frac{P(t,T+1)}{4} R(t,T+1) + \frac{P(t+1,T+1)}{4} R(t+1,T+1)$$

Analysis: Systematics in the three-point function fits

- Differences in x_f computed using different polarizations inform us about the systematics of the excited states
  - The extra excited states are necessary to handle those systematics

$$R(t,T) = R_0\left(1 + A_0 e^{-E_0 t} + A_1 e^{-E_1 t} + B_0 e^{-M_0(T-t)} + B_1 e^{-M_1(T-t)} + C_0 e^{-(E_0-M_0)t}\right)$$



Measuring V_{cb} on the lattice: Current renormalization

- In the coefficients of the terms of our effective theory a dependence arises with the scale (i.e. a)
- The renormalization tries to account for the right dependence
- The scheme we employ is called *Mostly non-perturbative renormalization* of results

$$Z_{V^{1,4},A^{1,4}} = \underbrace{\rho_{V^{1,4},A^{1,4}}}_{\text{Perturbative factor}} \times \underbrace{\sqrt{Z_{V_{bb}} Z_{V_{cc}}}}_{\text{Non-perturbative piece}}$$

- The (relatively large) non-perturbative piece cancels in our ratios
- The (close to one) perturbative piece (matching factor ρ) is calculated at one-loop level for $w = 1$ and $m_c = 0$
- The errors for $w \neq 1$ and $m_c \neq 0$ are estimated and added to the factor

This analysis is **blinded** and the blinding happens at the level of the matching factors

Analysis: The recoil parameter w

- The recoil parameter is measured dynamically
- In the lab frame (B meson at rest)

$$w^2 = 1 + v_{D^*}^2$$

- Ratio of three point functions

$$X_f(p) = \frac{\langle D^*(p)| \mathbf{V} |D^*(0)\rangle}{\langle D^*(p)| V_4 |D^*(0)\rangle} = \frac{\mathbf{v}_{D^*}}{w+1}$$

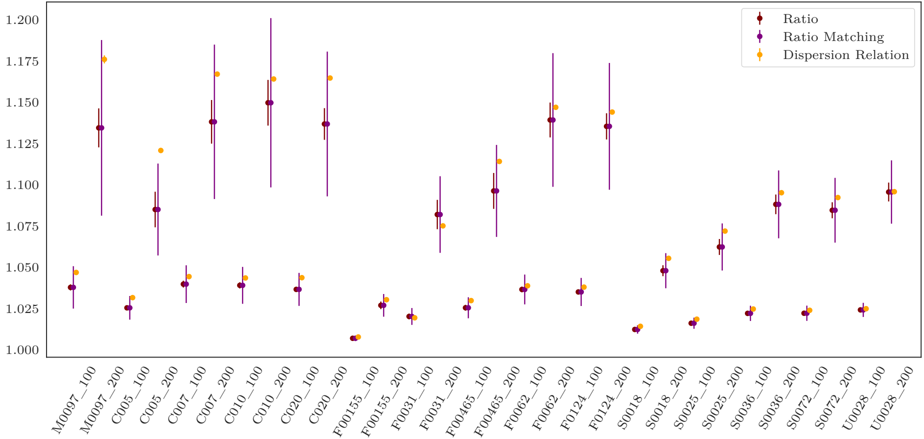
- From here

$$w(p) = \frac{1 + \mathbf{x}_f^2}{1 - \mathbf{x}_f^2}$$

- Alternatively one can use the dispersion relation

Analysis: The recoil parameter

- The recoil parameter suffers heavily from matching errors



Measuring V_{cb} on the lattice: Heavy quark mistuning corrections

- The simulations are run at approximate physical values of m_c, m_b
- After the runs the differences between the calculated and the physical masses is corrected non-perturbatively
  - The Fermilab action uses the kinetic mass m_2 to compute these corrections
  - $m_1 \to m_2$ as $a \to 0$

Correction process

1. For a particular ensemble correlators are computed at different m_c, m_b
2. All the ratios are calculated for the new values of the heavy quark masses, and the form factors are extracted
3. The derivative of combinations of the form factors with respect to the heavy quark masses is fitted to a suitable function
4. All the form factors are corrected using these results

Shifts are small in most cases, but add a small correlation among all data points

Analysis: Chiral-continuum fits

- Our data represents the form factors at non-zero a and unphysical m_π
- Extrapolation to the physical pion mass described by EFTs
  - The EFT describe the a and the m_π dependence
- Functional form explicitly known

$$h_{A_1}(w) = \underbrace{\left[1 + \frac{X_{A_1}(\Lambda_\chi)}{m_c^2} + \frac{g^2_{D^*D\pi}}{48\pi^2 f_\pi^2 r_1^2}\text{logs}_{\text{SU3}}(a, m_l, m_s, \Lambda_{QCD})\right.}_{\text{NLO }\chi\text{PT} + \text{HQET}}$$

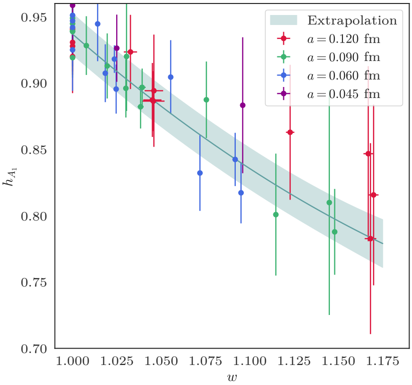
$$\underbrace{\rho^2(w-1) + k(w-1)^2}_{w\text{ dependence}} \underbrace{\left. + c_1 x_l + c_2 x_l^2 + c_{a1} x_{a^2} + c_{a2} x_{a^2}^2 + c_{a,m} x_l x_{a^2}\right]}_{\text{NNLO }\chi\text{PT}} \times$$

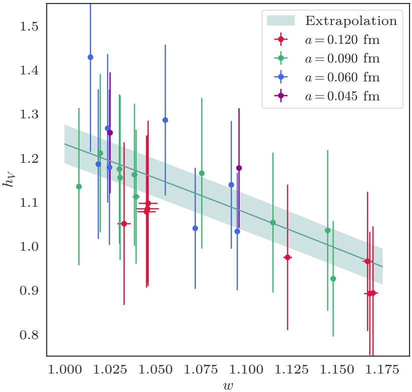
$$\underbrace{\left(1 + \beta_{11}^{A_1}\alpha_s a + \beta_{02}^{A_1} a^2 + \beta_{03}^{A_1} a^3\right)}_{\text{HQ discretization errors}}$$

with

$$x_l = B_0 \frac{m_l}{(2\pi f_\pi)^2}, \qquad x_{a^2} = \left(\frac{a}{4\pi f_\pi r_1^2}\right)^2$$

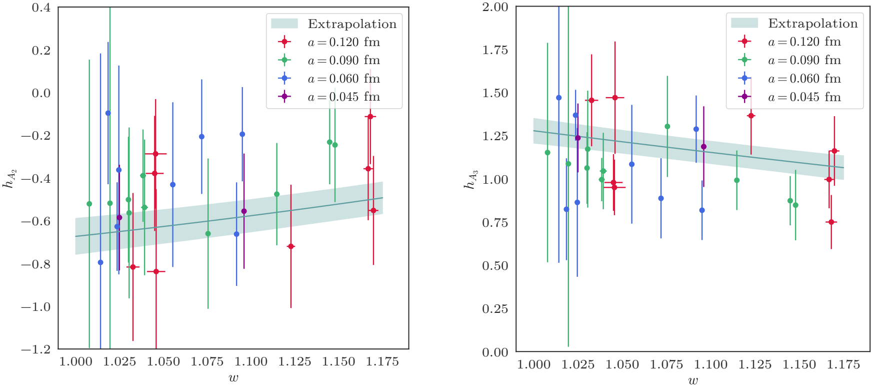
Results: Chiral-continuum fits





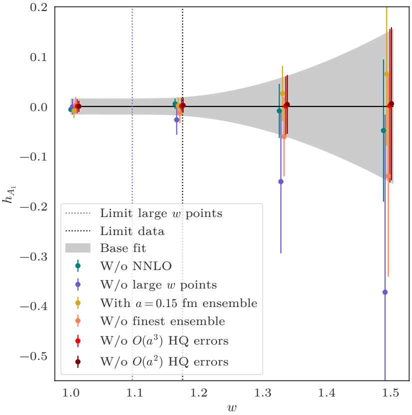
- Preliminary **blinded** results. **Left**: h_{A_1} **Right**: h_V

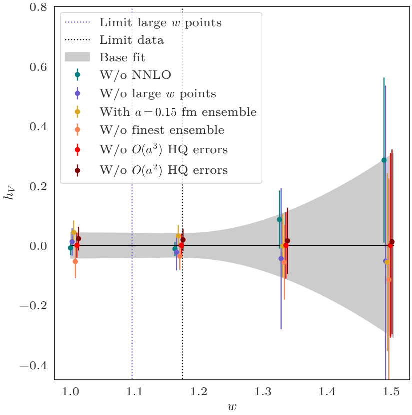
Results: Chiral-continuum fits



- Preliminary **blinded** results. **Left**: h_{A_2} **Right**: h_{A_3}

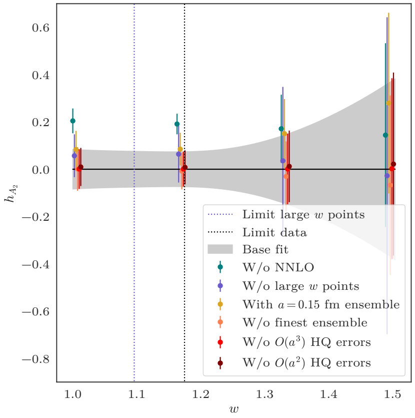
Results: Stability of chiral-continuum fits

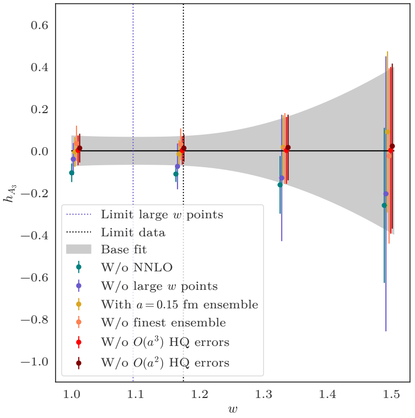




	Base	W/o NNLO	W/o large w	W $a = 0.15$ fm
χ^2/dof	**85.2/102**	132.8/114	62.1/77	102.8/110
		W/o $a = 0.045$ fm	W/o HQ $O(a^3)$	W/o HQ $O(a^2)$
χ^2/dof		76.9/93	85.2/103	85.6/106

Results: Stability of chiral-continuum fits





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χ^2/dof		76.9/93	85.2/103	85.6/106

Analysis: Systematic errors

- Error contributions considered:
  - Correlator fits and excited states
    - Use the same fit ranges for all the correlators
    - Make sure the fits are stable under small variations
    - Add extra excited states

      We assume no extra errors
  - Lattice scale dependence
    - Redo the chiral-continuum extrapolation with $r_1 \pm \sigma$ and compare

      The difference is negligible
  - Heavy quark mistuning
    - The errors are already taken into account in the chiral-continuum extrapolation
    - Try the chiral-continuum extrapolation with and without mistuning corrections to estimate their size
  - Light quark mistuning
    - Try the chiral-continuum extrapolation with $m_{ud} \pm \sigma$ and compare

      The difference is negligible
  - Chiral extrapolation and light quark discretization errors
    - The errors are already taken into account in the chiral-continuum extrapolation
    - Try the chiral-continuum extrapolation with and without the NNLO and NNNLO terms to estimate their size

Analysis: Systematic errors

- Error contributions considered:
  - Matching
    - The errors are already taken into account in the chiral-continuum extrapolation
    - Try the chiral-continuum extrapolation with and without the matching errors to estimate their size
  - Heavy quark discretization errors
    - These errors are already taken into account in the chiral-continuum extrapolation via generic terms
    - We employ generic discretization terms $\beta_X \alpha_s^p a^q$, instead of the universal functions
    - Try the chiral-continuum extrapolation with and without the HQ terms to estimate the size of the correction
  - Isospin effects
    - Try the chiral-continuum extrapolation with $m_{ud} = m_{u,d}$ and compare
    - The difference is added as an extra error to the final result
  - Finite volume errors
    - Following Arndt and Lin we estimate the size of the finite volume errors

Phys. Rev. D70, 014503 (2004)

The errors are negligible

Analysis: Preliminary error budget

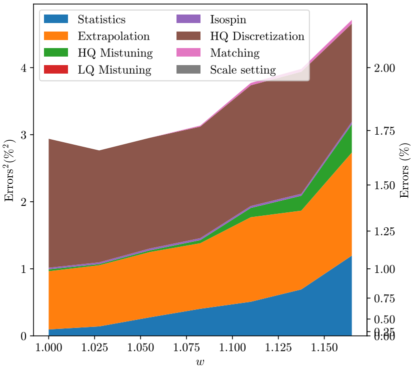
Source	$h_V(\%)$	$h_{A_1}(\%)$	$h_{A_2}(\%)$	$h_{A_3}(\%)$
Statistics + Matching + χPT + HQ	3.8	1.9	13.2	5.7
(Statistics)	(1.1)	(0.7)	(6.0)	(2.8)
(χPT/cont. extrapolation)	**(1.8)**	**(1.1)**	**(8.0)**	**(3.9)**
(Matching)	*(1.8)*	*(0.2)*	*(4.3)*	*(0.9)*
(HQ discretization) *	*(2.6)*	*(1.3)*	*(7.2)*	*(2.8)*
(HQ mistuning correction)	(0.1)	(0.3)	(1.4)	(0.7)
Isospin effects	0.1	0.2	0.1	0.1
Total error	3.8	1.9	13.2	5.7

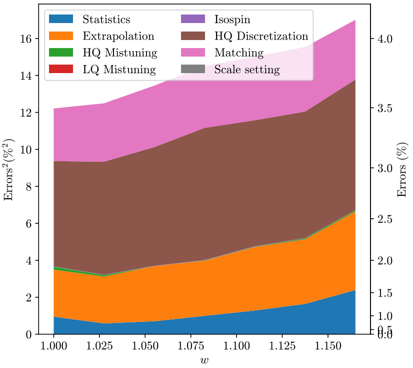
Errors at $w = 1.10$

* **Preliminary estimate, analysis in progress**

- The inclusion of the discretization errors in the chiral-continuum extrapolation puts in evidence that **the discretization errors are one of the most important contribution to the final error**
- Our discretization errors **are not final** and must be crosschecked carefully
- **Bold** marks errors to be reduced/removed when using HISQ for light quarks
- *Italic* marks errors to be reduced/removed when using HISQ for heavy quarks

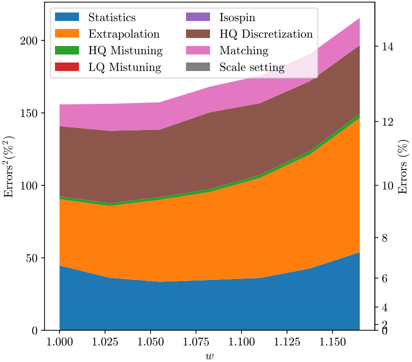
Analysis: Preliminary error budget

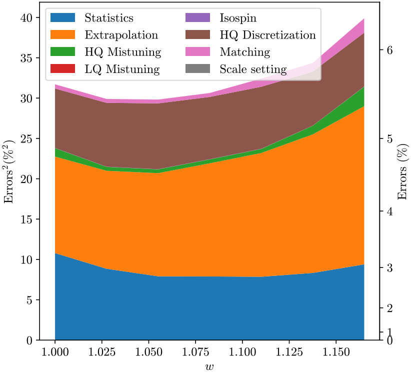




- **Left:** h_{A_1}, **right:** h_V

Analysis: Preliminary error budget





- **Left:** h_{A_2}, **right:** h_{A_3}

Analysis: z-Expansion

- The BGL expansion is performed on different (more convenient) form factors

Phys.Lett. **B**769, 441 (2017), Phys.Lett. **B**771, 359 (2017)

$$g = \frac{h_V(w)}{\sqrt{m_B\, m_{D^*}}} = \frac{1}{\phi_g(z)B_g(z)}\sum_j a_j z^j$$

$$f = \sqrt{m_B\, m_{D^*}}(1+w)h_{A_1}(w) = \frac{1}{\phi_f(z)B_f(z)}\sum_j b_j z^j$$

$$\mathcal{F}_1 = \sqrt{q^2}H_0 = \frac{1}{\phi_{\mathcal{F}_1}(z)B_{\mathcal{F}_1}(z)}\sum_j c_j z^j$$

$$\mathcal{F}_2 = \frac{\sqrt{q^2}}{m_{D^*}\sqrt{w^2-1}}H_S = \frac{1}{\phi_{\mathcal{F}_2}(z)B_{\mathcal{F}_2}(z)}\sum_j d_j z^j$$

- Constraint $\mathcal{F}_1(z=0) = (m_B - m_{D^*})f(z=0)$
- Constraint $(1+w)m_B^2(1-r)\mathcal{F}_1(z=z_{\mathrm{Max}}) = (1+r)\mathcal{F}_2(z=z_{\mathrm{Max}})$
- BGL (weak) unitarity constraints

$$\sum_j a_j^2 \leq 1, \qquad \sum_j b_j^2 + c_j^2 \leq 1, \qquad \sum_j d_j^2 \leq 1$$

Analysis: z expansion fit procedure

- Several different datasets
  - Our lattice data
  - BaBar BGL fit arXiv:1903.10002
  - Belle untagged dataset arXiv:1809.03290
- Several different fits
  - Lattice form factors only
  - Experimental data only (one fit per dataset)
  - Joint fit lattice + experimental data
- Each dataset is given in a different format, and requires a different amount of processing
- Different fitting strategy per dataset

All the experimental and theoretical **correlations are included** in all fits

Analysis: Fit procedure

Constraints

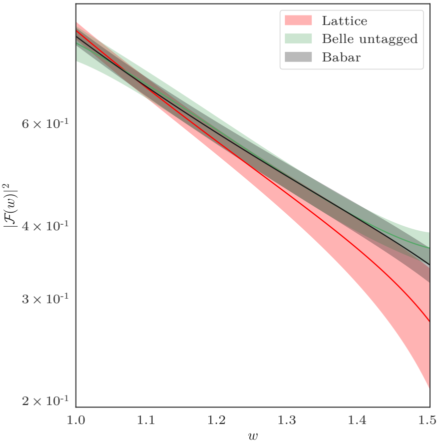
- The constraint at zero recoil is used to remove a coefficient of the BGL expansion
- The constraint at maximum recoil is **not** imposed, but checked for compliance
- The unitarity constraints are **not** imposed, but checked for compliance

How many coefficients in the expansion?

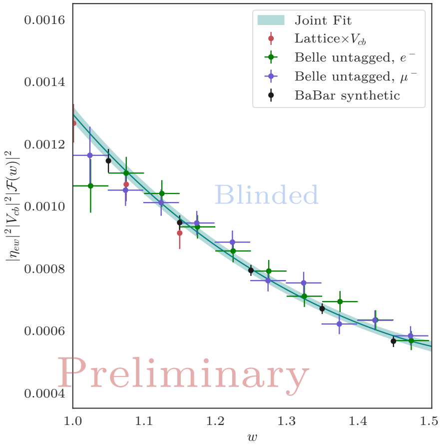
- Add coefficients until
  - We exhaust the degrees of freedom
  - The error is saturated
- In this analysis
  - The lattice only fit uses 3 coefficients per form factor
  - The joint fit uses 4 coefficients for $\mathcal{F}_1$ and 3 for the other form factors

Results: Pure-lattice prediction and joint fit

Separate fits

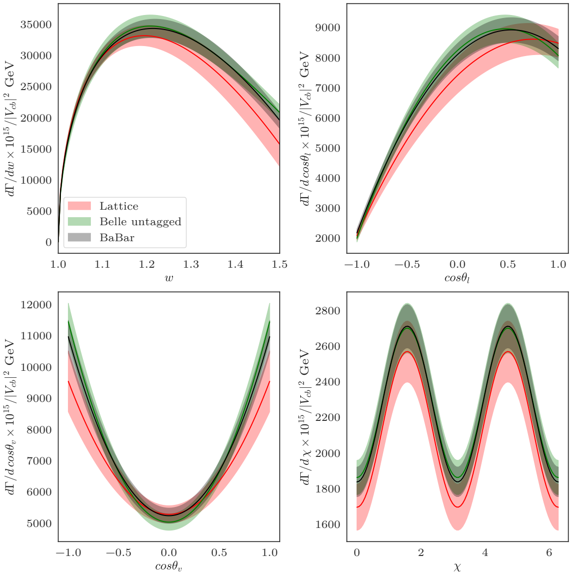


Joint fit

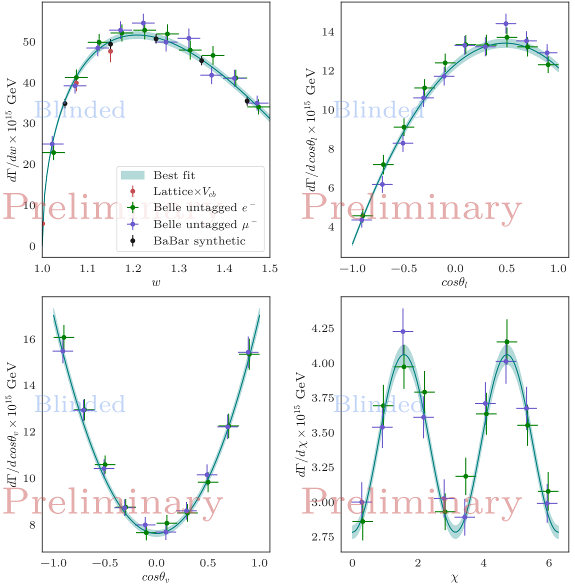


Fit	Lattice	Exp	Lat + Belle	Lat + BaBar	Lat + Exp
p-Value	0.22	0.09	0.07	0.55	0.03

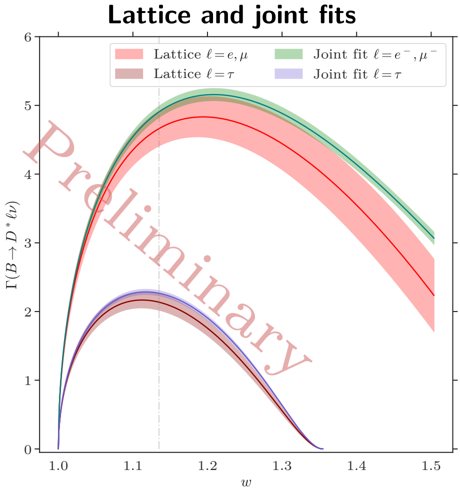
Results: Separate fits, angular bins



Results: Joint fit, angular bins

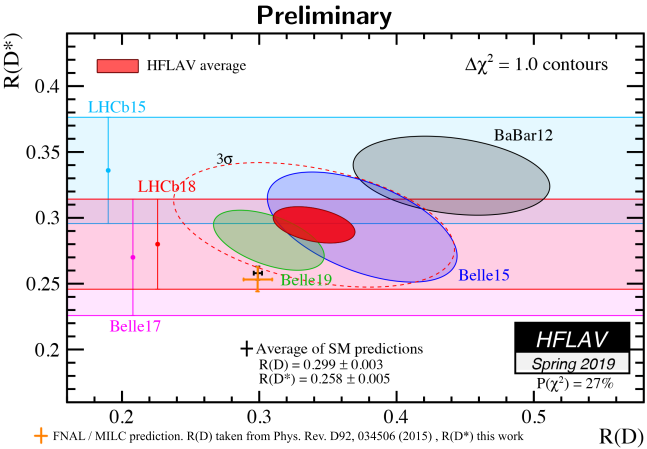


Results: $R(D^*)$



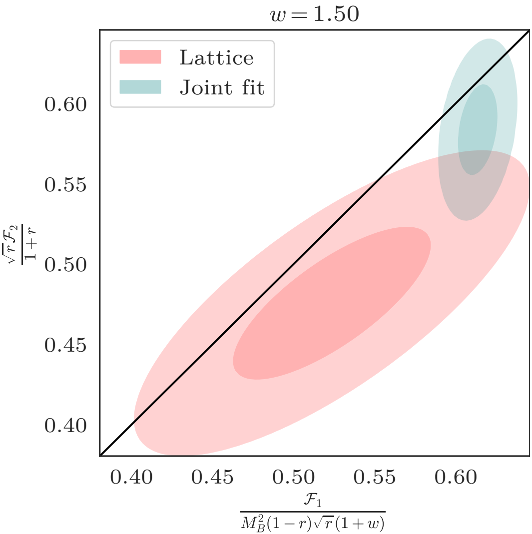
Lattice and joint fits
Lattice $\ell = e, \mu$
Lattice $\ell = \tau$
Joint fit $\ell = e^-, \mu^-$
Joint fit $\ell = \tau$
Preliminary
$\Gamma(B \to D^* \ell \nu)$
w
0
1
2
3
4
5
6
1.0
1.1
1.2
1.3
1.4
1.5

Results: $R(D^*)$


Preliminary
HFLAV average
$\Delta\chi^2 = 1.0$ contours
R(D*)
0.4
0.35
0.3
0.25
0.2
LHCb15
BaBar12
3σ
LHCb18
Belle19
Belle15
Belle17
Average of SM predictions
R(D) = 0.299 ± 0.003
R(D*) = 0.258 ± 0.005
HFLAV
Spring 2019
P(χ²) = 27%
0.2
0.3
0.4
0.5
R(D)
FNAL / MILC prediction. R(D) taken from Phys. Rev. D92, 034506 (2015) , R(D*) this work

Results: Verification of the constraints

$$A_5(w_{\text{Max}}) = P_1(w_{\text{Max}})$$



Conclusions

What to expect

- The preliminary error on V_{cb} from this analysis is of similar size than the error obtained from the $B \to D\ell\nu$ analysis at non-zero recoil
- The **main new information of this analysis** comes from the behavior at small recoil of the form factors
- Main sources of errors of our form factors are
  - χPT-continuum extrapolation
  - HQ discretization
  - Matching
- We have a short-term plan to reduce the χPT-continuum extrapolation errors
- Preliminary results show $R(D^*)$ very close to the **theoretical prediction**
- **Must unblind** to see the impact in the V_{cb} inclusive vs exclusive problem
  - If the blinding factor is small, the tension will persist

Conclusions

Please, do not use our preliminary results in any calculation

Thank you for your attention