Determination of V_{cb} from Semi-leptonic decays of $B \to D^{(*)}\ell\nu$ using the Oktay-Kronfeld action

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Introduction

Standard Model CKM Paradigm

$$\begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\rm WI} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar\rho - i\bar\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar\rho-i\bar\eta) & -A\lambda^2 & 1 \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\rm mass}$$

$$\approx \begin{pmatrix} 0.97245(22) & 0.2253(8) & 0.00359(9)\ e^{-1.17(3)\,i} \\ -0.225(8) & 0.986(16) & 0.03978(42) \\ 0.0084(6)\ e^{0.291(7)\,i} & -0.0400(27) & 1.021(32) \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\rm mass}$$

$$A = 0.810^{+0.018}_{-0.024} \quad \lambda = 0.22548^{+0.00068}_{-0.00034} \quad \bar\rho = 0.145^{+0.013}_{-0.007} \quad \bar\eta = 0.343^{+0.011}_{-0.012}$$

Standard model implies unitarity of the CKM matrix.

Six unitarity triangles defined by scalar products of rows or columns.

Area of unitarity triangle gives CP violation.

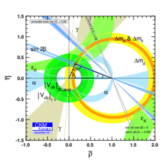
Introduction

Unitarity Triangle

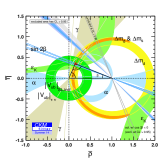
Usually consider normalized product of first and last column: the sides of the triangle are

$$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| \qquad \text{and} \qquad \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$$

and the vertex is approximately at $\bar\rho, \bar\eta$.



Exclusive



Inclusive

Introduction
$B \to D^{(*)}\ell\nu$

Need a better determination of matrix elements of exclusive processes.

$$\frac{d\Gamma(B \to D^*\ell\nu)}{dw} = \frac{G_F^2 M_{D^*}^3}{4\pi^3}(M_B - M_{D^*})^2(w^2-1)^{1/2} \left|\eta_{\mathrm{EW}}\right|^2 \eta_{\mathrm{C}} \left|V_{cb}\right|^2 \chi(w) \left|\mathcal{F}(w)\right|^2$$

$$\frac{d\Gamma(B \to D\ell\nu)}{dw} = \frac{G_F^2 M_B^5}{48\pi^3}(w^2-1)^{3/2} r^3 (1+r)^2 \left|\eta_{\mathrm{EW}}\right|^2 \eta_{\mathrm{C}} \left|V_{cb}\right|^2 \left|\mathcal{G}(w)\right|^2 .$$

Zero recoil point highly suppressed in $B \to D\ell\nu$ decay.

Lattice

Previous calculations

Calculation closest to ours is from MILC/Fermilab

$$B \to D\ell\nu \qquad |V_{cb}| = (39.6 \pm 1.7_{\rm QCD+exp} \pm 0.2_{\rm QED}) \times 10^{-3}$$
$$B \to D^*\ell\nu \qquad |V_{cb}| = (39.04 \pm 0.49_{\rm exp} \pm 0.53_{\rm QCD} \pm 0.19_{\rm QED}) \times 10^{-3}$$

Used

- MILC asqtad configurations
- Fermilab heavy quark actions

Similar results from HPQCD

$$B \to D\ell\nu \qquad |V_{cb}| = (40.2 \pm 1.7_{\rm latt+stat} \pm 1.3_{\rm syst}) \times 10^{-3}$$

Current combined analysis from BaBar+Belle combined with FNAL/MILC+HPQCD: $|V_{cb}| = 40.7(1.0) \times 10^{-3}$.

Lattice
Our proposal

Take the next step:

- Improve the heavy quark action (Oktay Kronfeld)
- Improve the light quark action (2+1+1 HISQ)
- Reduce excited state contamination
  - smear and momentum boost
  - two-state fit
- Increase statistics (AMA)

We, like others, will use the ensembles generated by MILC.

Codes exist and are being optimized.

Lattice
Flow chart

- Tune B_s and D_s.
- Calculate CG HISQ propagators
- Multiple t_f coherent sequential propagators
- Calculate BiCGStab OK propagators
  - From coherent sequential sources
  - From coherent initial sources
- Matrix elements of all terms of improved currents
- Caculate up to lattice momentum 10
- Repeat with low precision inversions

$a = 0.15$ fm and $a = 0.12$ fm ensembles with local resources.
$a = 0.09$ fm, $M_\pi = 312.7(6), 220.3(2), 128.2(1)$ MeV here.

Lattice
Timing

Step	$16^3 \times 48$	$32^3 \times 96$	$48^3 \times 96$	$64^3 \times 96$
Gauge Fixing	0.36	5.8	20	46
HISQ Inversion	5	80	560	3478
Extended Source	3.2	51	179	412
OK Inversion	60	960	3360	7728
Sink Operation	23	368	1288	2962
Contraction	12.4	198	693	1594
Total (Wolf hours)	104	1664	6100	16220
Total (J/ψ hours)	312	4992	18300	48660

128 core-hours for $N_{\mathrm{meas}} = 2$.

Questions

Machines

With the new resources at JLab being as yet unspecified, we would like to know if you are in a position to use them efficiently if they are a) cpu, b) GPU, c) KNL. If you are not, that is fine, but it will help in our allocation decisions to know this information from every proposal.

Our codes are optimized for CPU and GPU accelerated machines.

While our codes will run on Intel KNL, they would need optimization.

Will happen anyway! LANL is getting KNL.

Questions

Tasks

What is the breakdown of tasks within your collaboration in terms of production, tuning and analysis?

- Tuning will be complete before allocation.
- Analysis code is similar to other projects.
- Production codes and runs: Yong-Chull Jang.
- Cross-checks, data, statistical analysis, physics:
  - LANL: Tanmoy Bhattacharya, Rajan Gupta, Boram Yoon
  - SNU: Weonjong Lee, Jon Bailey, Sungwoo Park

Questions
Cost

What is the relative cost of a single OK heavy quark propagator relative to a FNAL heavy propagator after all turnings have been performed? Further, what level of improvement in the final predictions do you expect from using the OK action?

- FLOP count: OK/Fermilab Dslash is 3.8
- Larger memory requiremnt and next-nearest-neighbor
- Code being optimized.

Questions
Improvements

Can you please discuss how the other modifications in your analysis relative to the FNAL/MILC published calculations will modify the uncertainty of Vcb? It does not seem realistic to base uncertainty estimates of this work alone when many other aspects of your calculation beyond the change in HQ action will be different.

Described before

Questions
Precision

How was your statistical precision set? What will you do if you need increased statistics (it does not seem easy to moderately increase statistics given the coherent sources you plan to use)?

Based on plans to analyze 24–64 measurements on O(1000) HISQ configurations.

Can add extra sources on each configurations.

Questions

Error

What is your best estimate for the ultimate cost to get to the 1% measurement and what are your future plans towards this goal?

Next logical step. Can we reduce from 1.5% to 1%?

Questions

Blinding

Since you are planning to calculate quantities for which there already exist results with similar precision, have you considered performing a blind analysis to prevent any inadvertent bias? To blind your analysis, you could add an overall off-set factor to the B -¿ D three-point functions that would be kept unknown to the people doing the analysis until the systematic error analysis is finalized.

Trust inscrutability of random numbers!