

Charm physics with Moebius Domain Wall Fermions

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June 25, 2014



Outline

1 Motivation

2 Ensembles and Analysis setup

3 Results

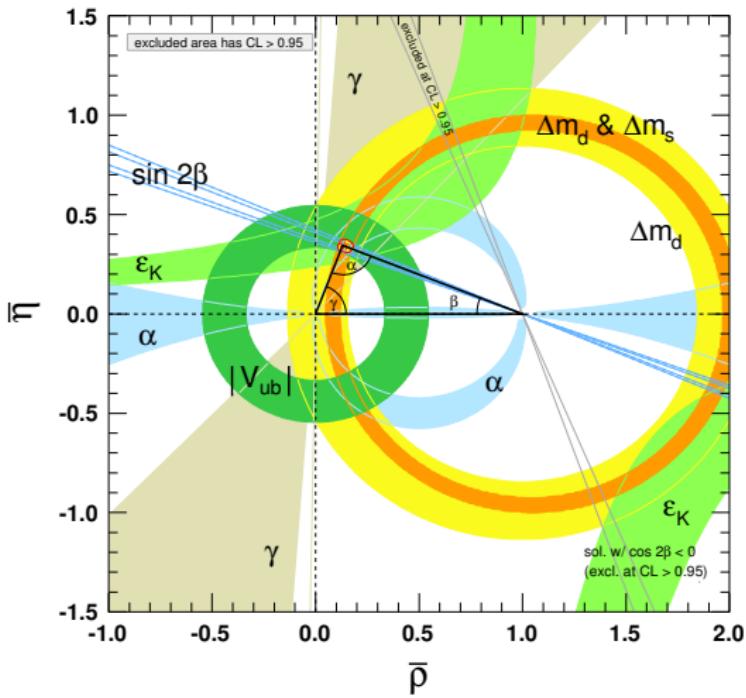
4 Summary and Outlook

Motivation - Where to find New Physics?

- Flavour Sector?!
- Place tight bounds on SM predictions:

$\Rightarrow K, D$ and B physics to test unitarity of the CKM matrix.

J. Beringer et al. (Particle Data Group),
 Phys. Rev. D86, 010001 (2012) and
 2013 partial update for the 2014 edition.



Experimental efforts in B physics: B-factories

Two B-factories recently completed data collection:



BaBar experiment at PEP-II at SLAC in California, USA



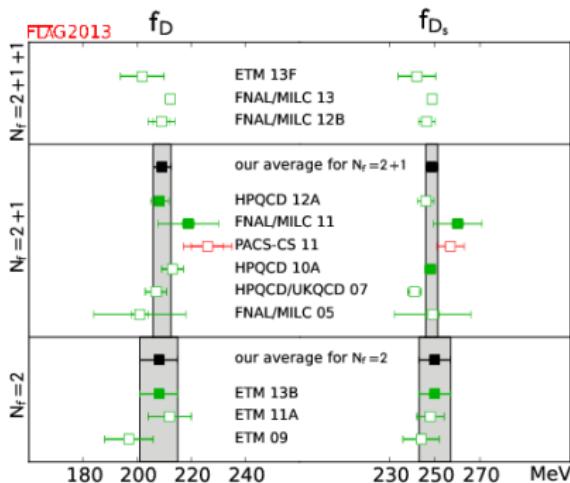
Belle experiment at KEKB collider in Tsukuba, Japan.
Belle2 to come (~ 2017).

And of course there is **LHCb!**

⇒ Need theoretical predictions to test for New Physics

Why focus on D and B physics?

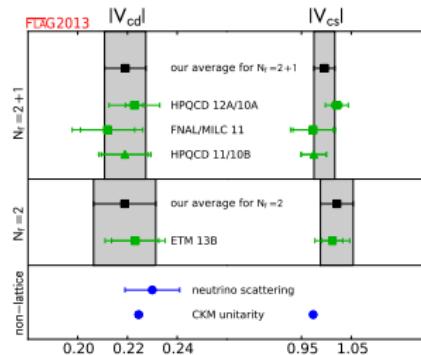
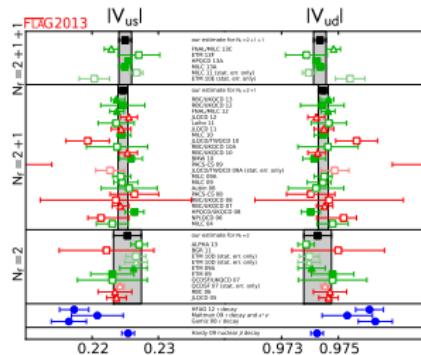
Review of lattice calculations of leptonic decay constants:



- Few published results
 - Place tighter bounds
 - Reduce systematical errors by direct computation

arXiv:1310.8555

Review of lattice calculations of CKM matrix elements



- Light quark sector well explored
- Few polished results in the heavy quark sector

Goal: B and D pheno: masses, decay constants, semi-leptonics

⇒ **Quenched study as proof of concept**

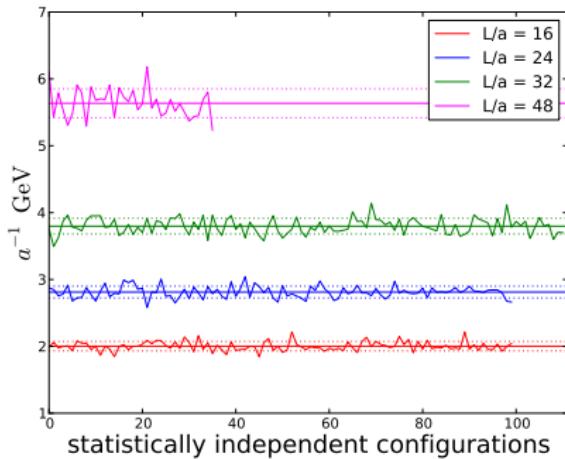
arXiv:1310.8555

Why quenched

- Cheap!
 - ⇒ Topology freezing under control
- Allows for a large cut-off:
 - ⇒ Lattice spacings of up to $a^{-1} \approx 5.6\text{GeV}$
- Pilot study for dynamical studies with Moebius Fermions:
 - ⇒ RBC-UKQCD 2+1f efforts
 - ⇒ Talk by **Andreas Jüttner**
 - ⇒ RBC-UKQCD 2+1+1f efforts
 - ⇒ Talk by **Robert Mawhinney**
 - ⇒ KEK 2+1f efforts
- Part of collaborate efforts with KEK to compare different actions
 - ⇒ Talk by **Cho Yong-Gwi**

Ensembles

- 4 Ensembles
- tree-level Symanzik improved gauge configurations
- $a^{-1} = 2.0 - 5.6 \text{ GeV}$ from Wilson Flow. arXiv:1203.4469
- $\mathcal{O}(a)$ -improved action
- roughly constant volume



L/a	$a(\text{fm})$	$a^{-1}(\text{GeV})$	$L(\text{fm})$	β
16	0.0987(34)	2.00(07)	1.579(55)	4.41
24	0.0702(22)	2.81(09)	1.686(52)	4.66
32	0.0520(16)	3.80(12)	1.664(51)	4.89
48	0.0351(13)	5.64(22)	1.683(64)	4.94

Topology

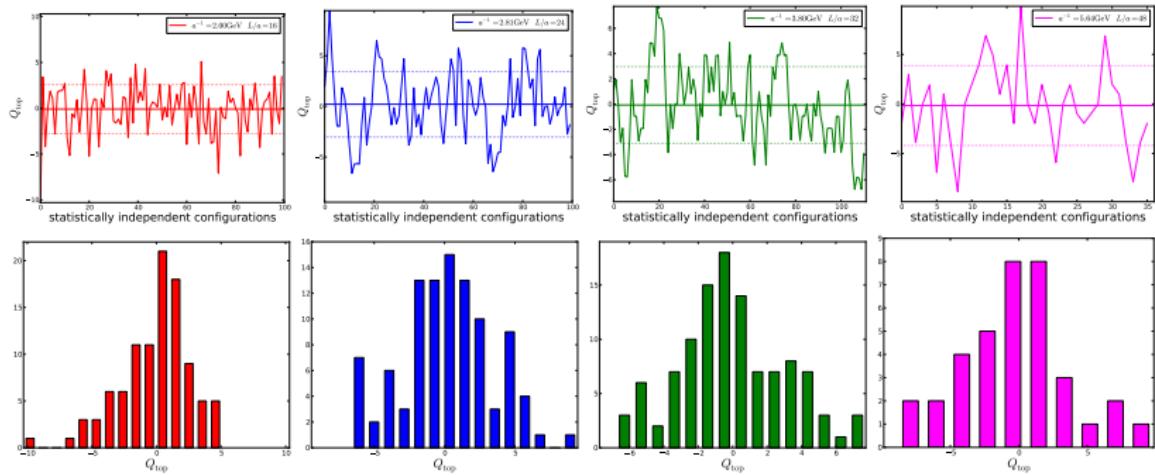


Figure: Topological charge evolution and histograms of the different ensembles.

Heat Bath algorithm is parity even \Rightarrow Interested in Q_{top}^2 . arXiv:1009:5228

Analysis Recipe

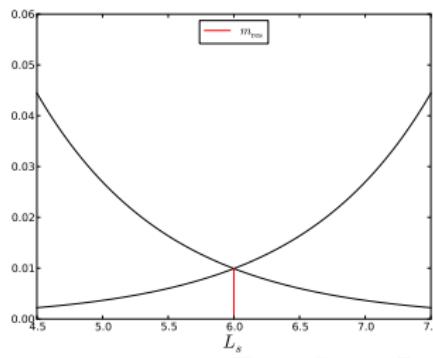
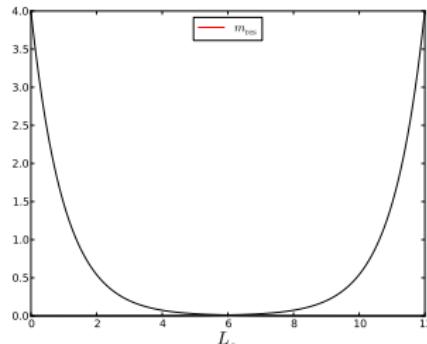
- ① Choose measurement parameters
- ② Fit Correlators to find Masses m_{PS} and Matrix elements (\mathcal{Z}_A and \mathcal{Z}_P) and deduce decay constants f_{PS} .
- ③ Interpolate data to common Pseudoscalar masses on each ensemble.
- ④ Normalise the data at a given reference mass to avoid renormalisation ($f_{\text{PS}}^{\text{lat}} = Z_A f_{\text{PS}}^{\text{ren}}$).

$$R \equiv \frac{f_{\text{PS}} \sqrt{m_{\text{PS}}}}{f_{\text{PS}}^{\text{ref}} \sqrt{m_{\text{PS}}^{\text{ref}}}} \quad \text{where} \quad m_{\text{PS}}^{\text{ref}} = 1.0 \text{GeV}$$

- ⑤ Take the continuum limit.

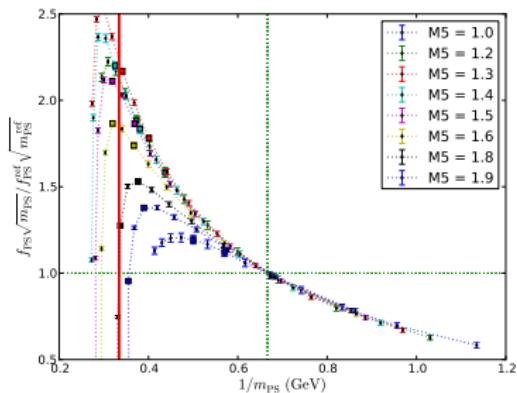
Domain Wall Fermions

- 5th Dimension
 \Rightarrow More costly
- BUT: Exponentially localised chiral modes
 \Rightarrow Approximate χ -Symmetry
 $\Rightarrow \mathcal{O}(a)$ improved
 \Rightarrow Residual Mass m_{res}
- Separated massive bulk modes.
- Parameters: L_s, M_5 .
- Require $m_{\text{res}} \ll m_{\text{quark}}$

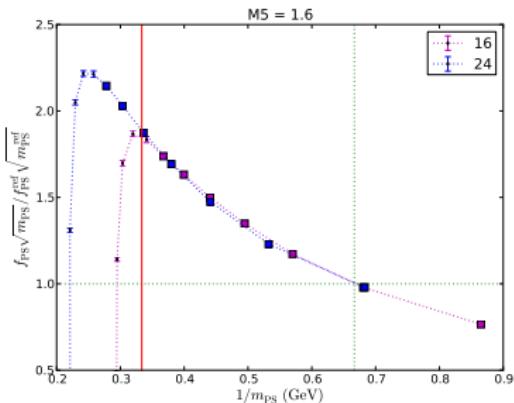


Choice of M_5 from $f_{\text{PS}}\sqrt{m_{\text{PS}}}$ vs $1/m_{\text{PS}}$

$L/a = 16$



$M_5 = 1.6$



- Artefacts for large am_q
- Normalised at $m_{\text{PS}} = 1.5\text{GeV}$
- up to charm and beyond

- ⇒ Choose $M_5 = 1.6$ for good continuum limit scaling
- ⇒ Restrict $am_q \lesssim 0.4$

The Ward Identity: m_{res}

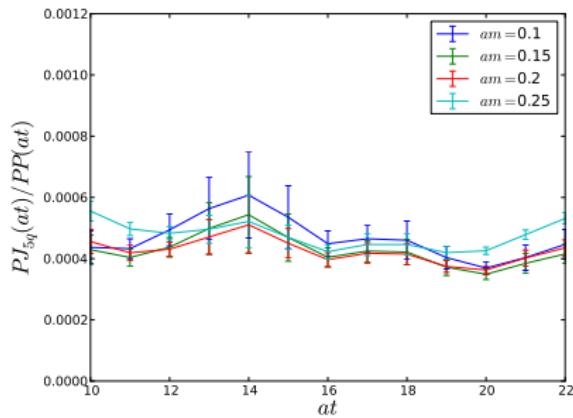
Ward Identity for Moebius Domain Wall Fermions:

$$\left\langle \sum_{\mathbf{x}} \Delta_{\mu} A_{\mu}(x) P(0) \right\rangle = 2m \left\langle \sum_{\mathbf{x}} J_5^a(x) P(0) \right\rangle + 2 \left\langle \sum_{\mathbf{x}} J_{5q}^a(x) P(0) \right\rangle$$

Define m_{res} as

$$m_{\text{res}} \equiv \frac{\left\langle \sum_{\mathbf{x}} J_{5q}^a(\mathbf{x}, t) P(0) \right\rangle}{\left\langle \sum_{\mathbf{x}} J_5^a(\mathbf{x}, t) P(0) \right\rangle}$$

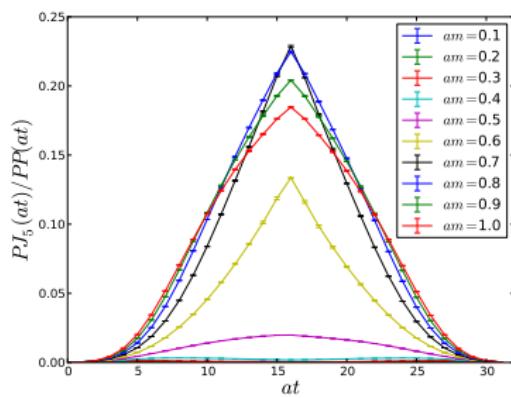
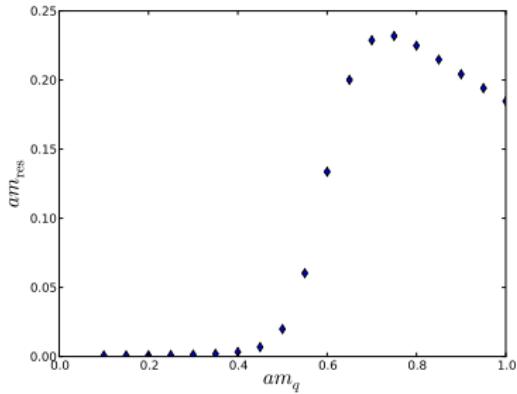
⇒ should be time independent.



Limitations of the Domain Wall Mechanism: m_{res}

$$\max \left(\frac{PJ_{5q}^a(t)}{PJ_5^a(t)} \right)$$

$$\frac{PJ_{5q}^a(t)}{PJ_5^a(t)} = \text{constant}??$$



\Rightarrow restrict simulated quark masses to $am_q \lesssim 0.4$

Simulation Parameters

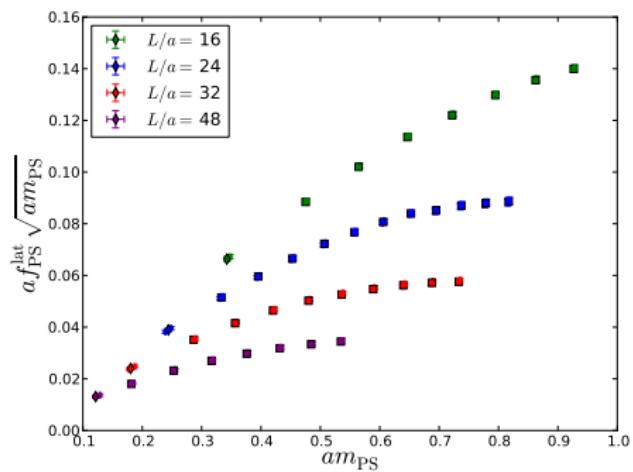
- Chosen Domain Wall Parameters: $L_s = 12$, $M_5 = 1.6$.
- Solver precision and convergence monitored to check breakdown is not due to numerical precision effects
- Restrict to $am_q \lesssim 0.4$
- Gaussian Smearing to increase overlap with the ground state.

L/a	# m_s	# m_h	Statistics
16	2	7	100
24	2	11	100
32	2	9	111
48	2	7	36

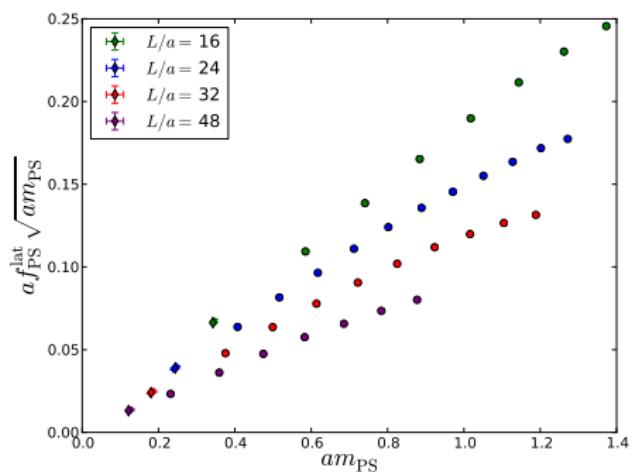
Table: Measurement Statistics

Dimensionless results from correlator fits - $f_{\text{PS}} \sqrt{am_{\text{PS}}}$

D_s

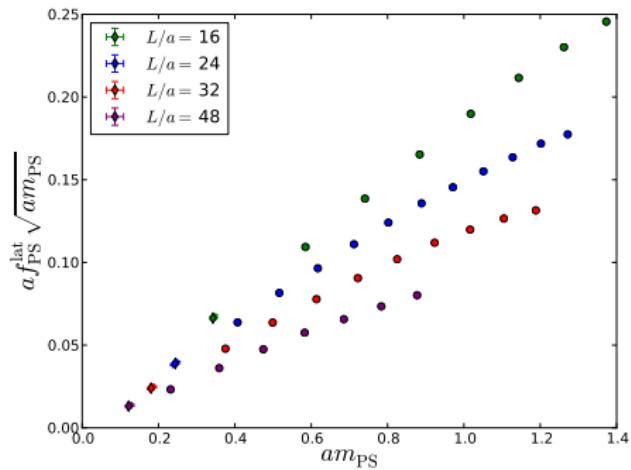


η_c



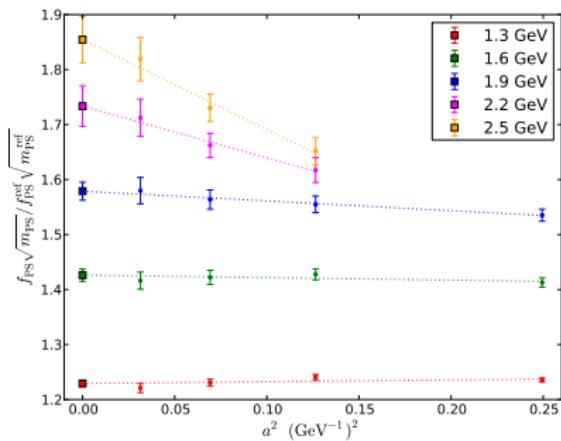
Interpolation to Reference Masses

- Ansatz of interpolation?
⇒ Systematic Error.
- Data seems well behaved
⇒ Polynomial.
- Simplest choice:
⇒ Connect two datapoints
by a line



Continuum Limit for strange - heavy data (D_s)

$$R(a) = c_0 + c_1 a^2$$



tuned strange quark using

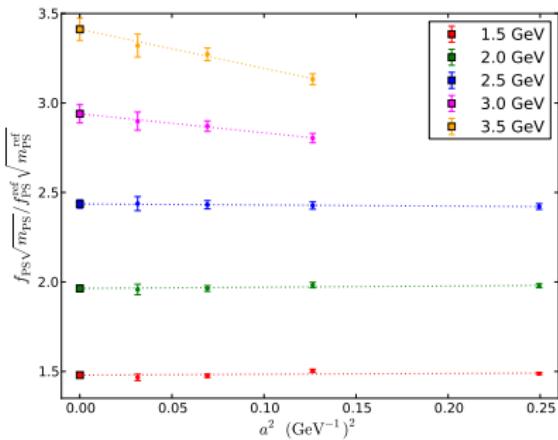
$$m_{\eta_s} = 0.6858(40)\text{GeV}$$

C. Davies et al. Phys.Rev., D81:034506, 2010.

m_{PS}	c_0	c_1
1.3	1.229(06)	0.03(03)
1.6	1.426(11)	-0.05(06)
1.9	1.579(16)	-0.18(09)
2.2	1.670(22)	-0.94(39)
2.5	1.718(25)	-1.64(45)

For comparison: $m_{D_s} = 1.9685(3)\text{GeV}$
[http://www.slac.stanford.edu/xorg/hfag/
 charm/CHARM10/f_ds/results_20jan11.html](http://www.slac.stanford.edu/xorg/hfag/charm/CHARM10/f_ds/results_20jan11.html)

Continuum Limit for heavy-heavy data (η_c)



m_{PS}	c_0	c_1
1.5	1.480(10)	0.04(05)
2.0	1.964(17)	0.07(09)
2.5	2.436(23)	-0.06(13)
3.0	2.940(51)	-1.06(52)
3.5	3.412(63)	-2.18(63)

$$R(a) = c_0 + c_1 a^2$$

For comparison: $m_{\eta_c} = 2.981 \text{ GeV}$

J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012) and 2013 partial update for the 2014 edition.

Summary and Outlook

Summary

- Flat continuum limit for D_s and η_c from 4 lattice spacings compatible with $\mathcal{O}(a^2)$ -scaling.
- Mapped out the parameter space for dynamical simulations
- qualitative check to track applicability of dynamical DWFs.

Outlook

- Dynamical study ($2 + 1f$) under way with first results
⇒ Talk by **Andreas Jüttner**
- Semileptonics for D and D_s
- Plans to make predictions for B physics.

Acknowledgements



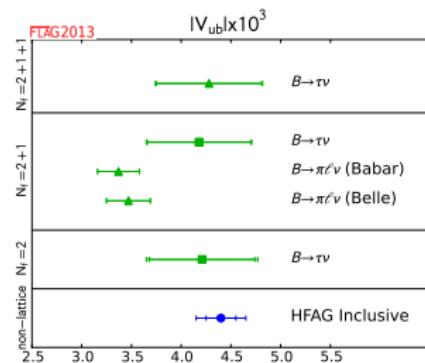
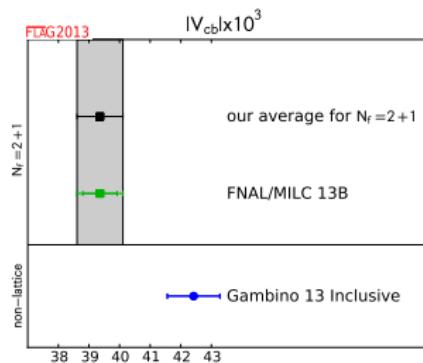
The research leading to these results has received funding from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013) ERC grant agreement No 27975.7



THANK YOU!

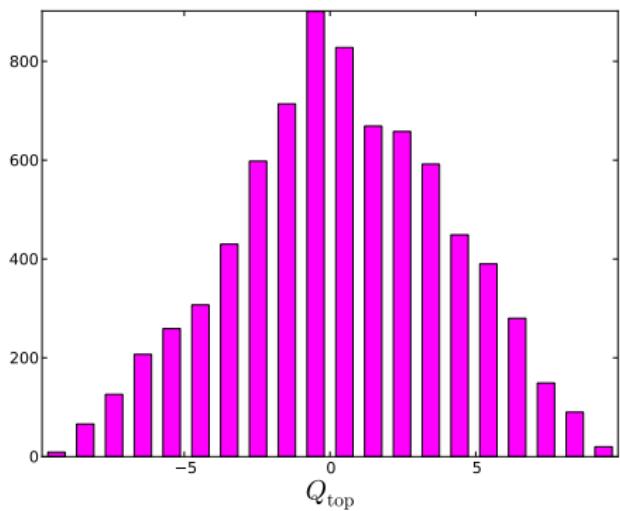
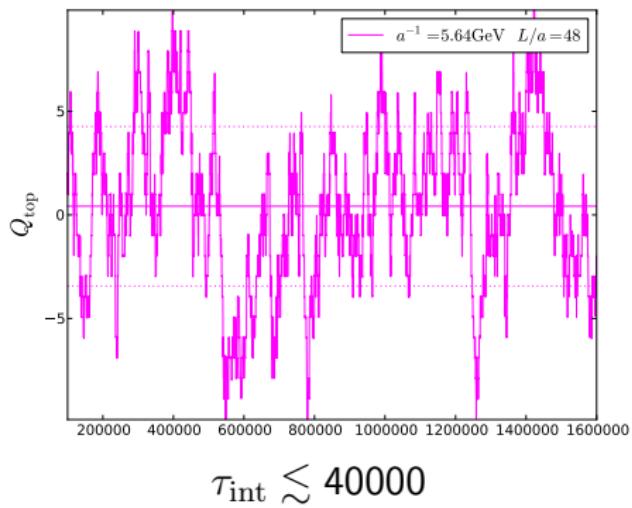
ANY QUESTIONS?

Backup: V_{cb} and V_{ub}

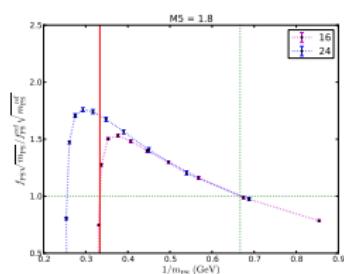
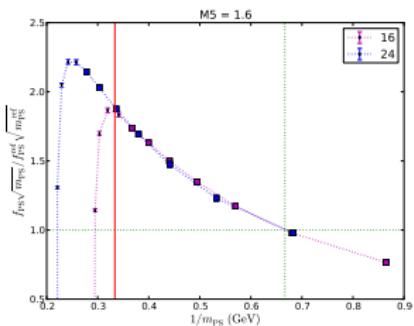
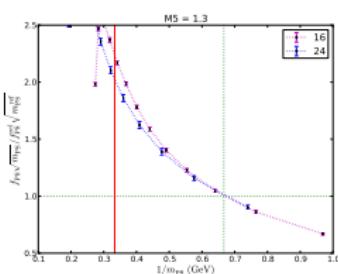
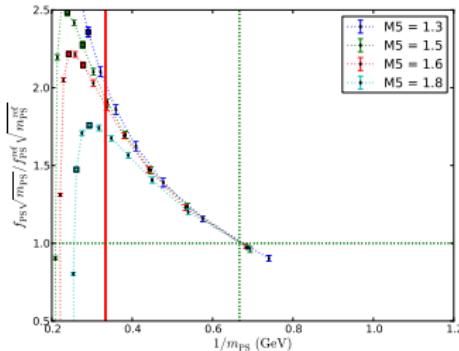
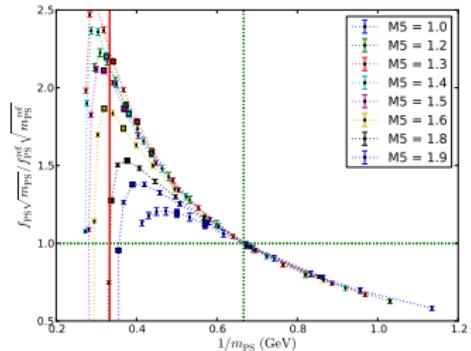


arXiv:1310.8555

Backup: Topology

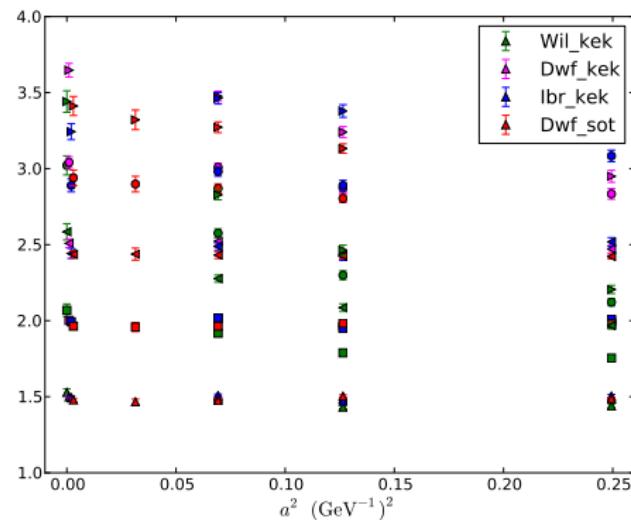


Backup: Choice of M_5



Backup: Comparison of Different Actions

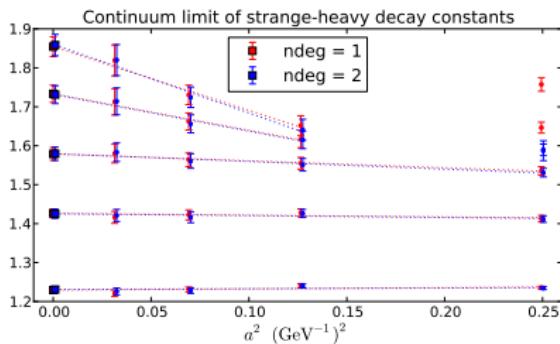
- Moebius Domain Wall
- Brilloin Zone Improved Fermions
- Stout Smeared Moebius Domain Wall Fermions
- Wilson Fermions



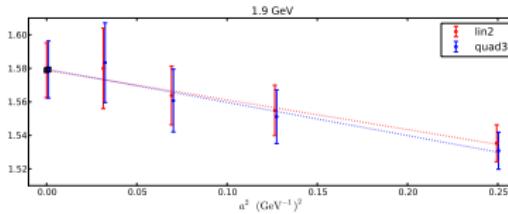
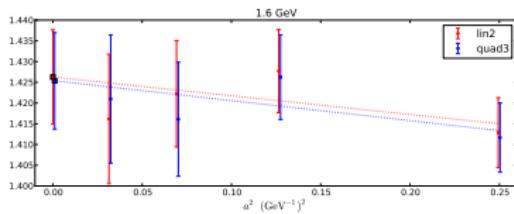
⇒ Talk by **Cho Yong-Gwi**

Backup: Systematical errors from interpolations - D_s

Compare different polynomial approaches.

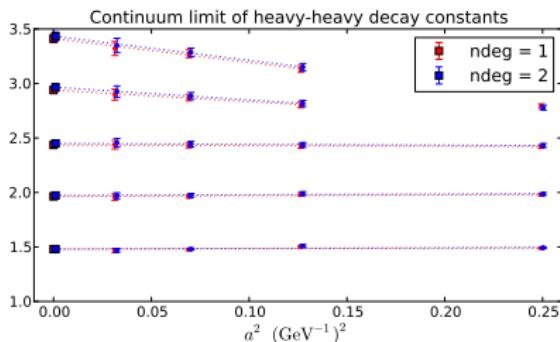


m_{PS}	ndeg = 1	ndeg = 2
1.3	1.229(06)	1.231(06)
1.6	1.426(11)	1.425(12)
1.9	1.579(16)	1.579(17)
2.2	1.670(22)	1.731(38)
2.5	1.718(25)	1.858(43)



Backup: Systematical errors from interpolations - η_c

Compare different polynomial approaches.



m_{PS}	ndeg = 1	ndeg = 2
1.5	1.480(10)	1.481(10)
2.0	1.964(17)	1.973(18)
2.5	2.436(23)	2.450(25)
3.0	2.940(51)	2.965(54)
3.5	3.412(63)	3.432(66)

