Charm Physics at the Physical Point

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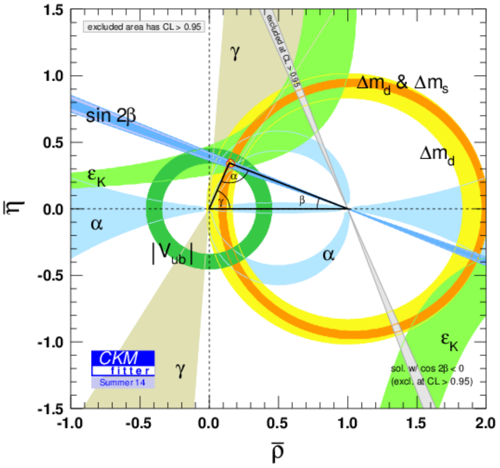
Outline

Motivation - Where to find New Physics?

- Flavour Sector
- Place tight bounds on SM predictions:

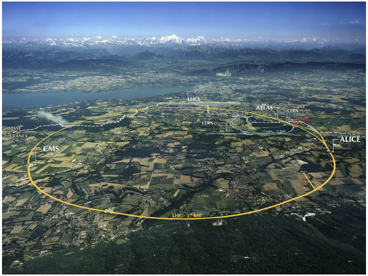
$\Rightarrow$ K, D and B physics to test unitarity of the CKM matrix.



CKMfitter Group (J. Charles et al.), Eur. Phys. J. C41, 1-131 (2005) [hep-ph/0406184], updated results and plots available at: http://ckmfitter.in2p3.fr

Experimental efforts in D and B physics: B-factories

Belle and **BaBar** recently completed data collection.



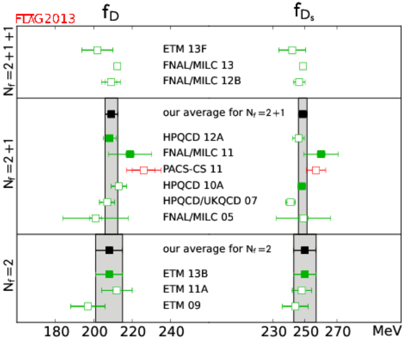
LHCb experiment at the LHC.

Belle2 experiment at KEKB collider in Tsukuba, Japan to come in $\sim$ 2017.

$\Rightarrow$ We need to sharpen the theoretical predicitions too.

Why focus on D and B physics?

Review of lattice calculations of leptonic decay constants:



arXiv:1310.8555

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

Goal: B and D pheno:

- masses
- decay constants
- semi-leptonics

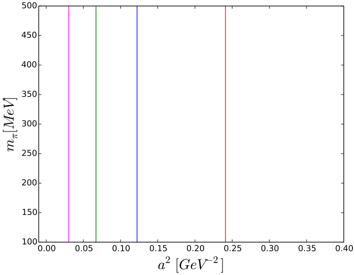
Our Action: Domain Wall Fermions

- Chiral fermions
- Automatically $\mathcal{O}(a)$-improved

- **Physical Pion Mass ensembles**: Moebius Domain Wall Fermions
- Tiny Chiral extrapolation is done with Shamir DWFs

- Tested with quenched **PILOT STUDY**.
  $\Rightarrow$ **Quenched study as proof of concept:** *arXiv:1504.01630*

Quenched ensembles

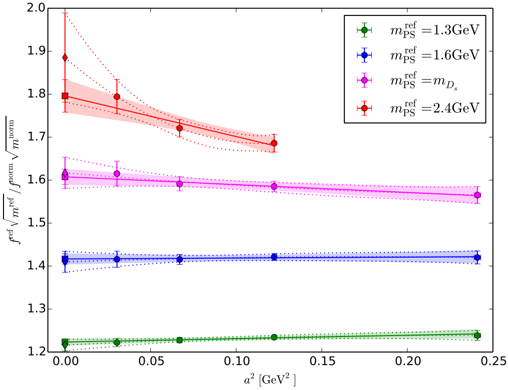


L/a	$a^{-1}(\mathrm{GeV})$	$L(\mathrm{fm})$	β
16	2.037(08)	1.5496(62)	4.41
24	2.861(09)	1.6552(53)	4.66
32	3.864(12)	1.6341(51)	4.89
48	5.740(22)	1.6498(64)	5.20

(w_0 from **arXiv:1411.7017**)

- tree-level Symanzik improved gauge configurations
- $a^{-1} = 2.0 - 5.7\,\mathrm{GeV}$
- $\mathcal{O}(a)$-improved action

Outcome of the Quenched Pilot Study - decay constants



arXiv:1501.00660

- D_s is within reach even for the coarsest ensemble.
- Mapped out parameter space for M_5 and L_s.
- $\mathcal{O}(a)$-improvement holds
- Gained experience for the dynamical runs.

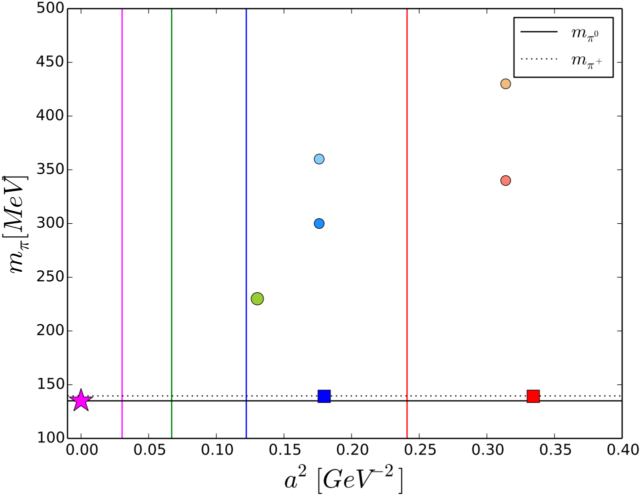
Outcome of the Quenched Pilot Study: How to set up the Dynamical Simulation?

- restrict input quark mass in lattice units to

$$am_h \leq 0.4$$

- $M_5 = 1.6$, $L_s = 12$ gives a flat approach to the continuum.
  $\Rightarrow$ **Mixed action** between the (light+strange) and the heavy quark sector.

Dynamical Ensembles



Dynamical Ensembles - Statistics

$L^3 \times T/a^4$	a^{-1}(GeV)	m_π(MeV)	configs	# t_{src}
$48^3 \times 96$	**1.73**	**139**	88	48
$24^3 \times 64$	1.78	340	87	32
$24^3 \times 64$	1.78	430	52	32
$64^3 \times 128$	**2.36**	**139**	80	32
$32^3 \times 64$	2.38	300	83	16
$32^3 \times 64$	2.38	360	75	16
$48^3 \times 96$	2.77(3)	230	19	48

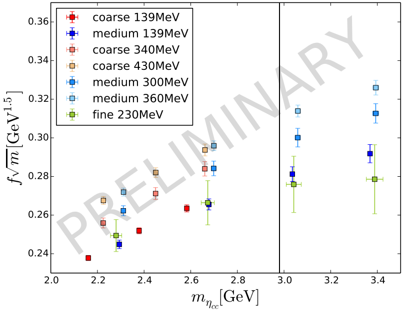
(**arXiv:1411.7017**)

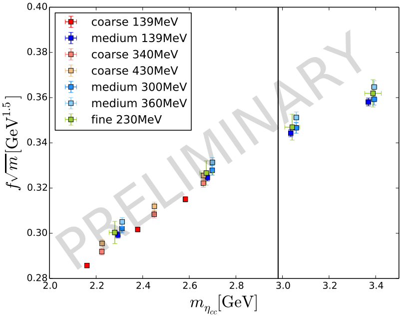
$\Rightarrow$ Volume averaging by using $\mathbb{Z}_2$-Wall sources.

Analysis Recipe

1. Combined fit to $\langle AA \rangle$, $\langle AP \rangle$, $\langle PA \rangle$ and $\langle PP \rangle$ including 1st excited states
2. Extrapolate to physical strange quark masses.
3. Interpolate decay constants to reference masses.
4. Extrapolation to physical pion masses:
   $\Rightarrow$ extrapolate D and D_s to the physical light quark mass.
5. Continuum extrapolation
6. Extrapolate to the D/D_s mass.

Collected Data





Strange Quark Mass Correction

- Slight mistuning between unitary and physical strange quark mass.

ensemble	am_s^{unitary}	am_s^{physical}	mismatch
coarse	0.03620	0.03580	1.1%
medium	0.02661	0.02539	4.8%
fine	0.02144	?	?.?%

- Parameterise mistuning in terms of dimensionless α:

$$\mathcal{O}^{\text{phys}} = \mathcal{O}^{\text{uni}} \left(1 + \alpha \frac{m_s^{\text{phys}} - m_s^{\text{uni}}}{m_s^{\text{phys}}} \right)$$

- Find α from one ensemble and apply to other ensembles.

Strange Quark Mass Correction

$$\mathcal{O}^{\mathrm{phys}} = \mathcal{O}^{\mathrm{uni}} \left(1 + \alpha \frac{m_s^{\mathrm{phys}} - m_s^{\mathrm{uni}}}{m_s^{\mathrm{phys}}}\right)$$

- Based on 87 configurations of the coarse ensemble with $m_\pi = 340\mathrm{MeV}$, with unitary and physical strange quark mass:

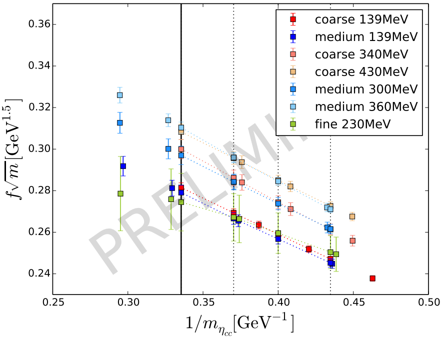
$$\alpha_{f\sqrt{m}} = 0.129(4)$$

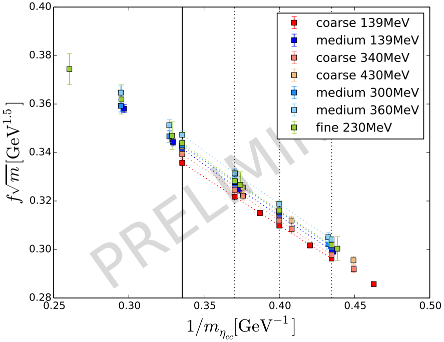
- Effect on physical pion mass data

$$\text{coarse}: \qquad \alpha \frac{m_s^{\mathrm{phys}} - m_s^{\mathrm{uni}}}{m_s^{\mathrm{phys}}} \approx -0.15\%$$

$$\text{medium}: \qquad \alpha \frac{m_s^{\mathrm{phys}} - m_s^{\mathrm{uni}}}{m_s^{\mathrm{phys}}} \approx -0.62\%$$

Reference Mass Interpolation



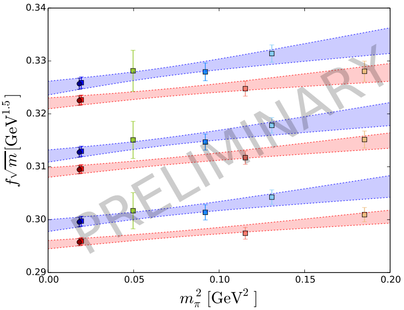


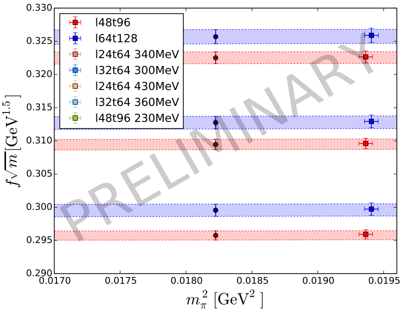
⇒ Use $m_{\eta_{cc}}$ to remain independent of light quark masses.

⇒ Fit ansatz:

$$f_{\mathrm{PS}}\sqrt{m_{\mathrm{PS}}} \propto C_0 + C_1 \frac{1}{m_{\eta_{cc}}}$$

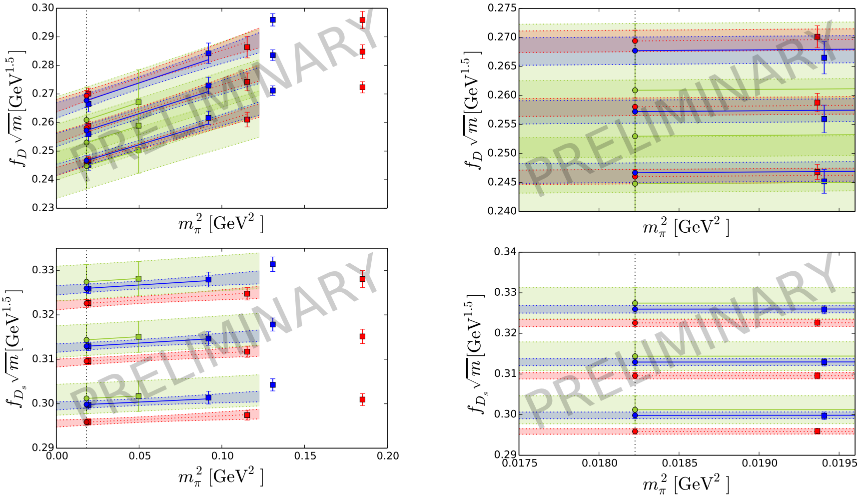
Extrapolation to Physical Pion Masses



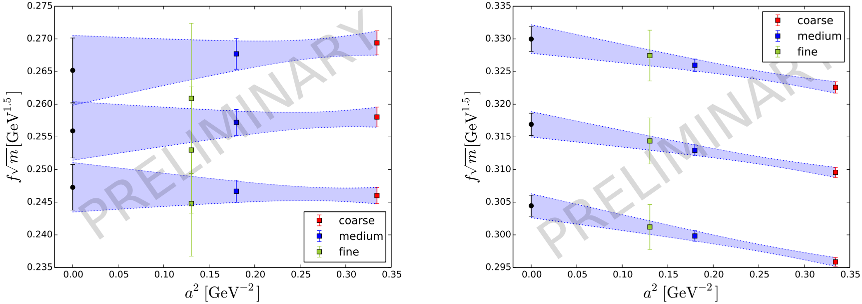


$\Rightarrow$ Tiny correction to physcial point data: $\ll 1\sigma$

TINY Chiral Extrapolation alternative: single slope

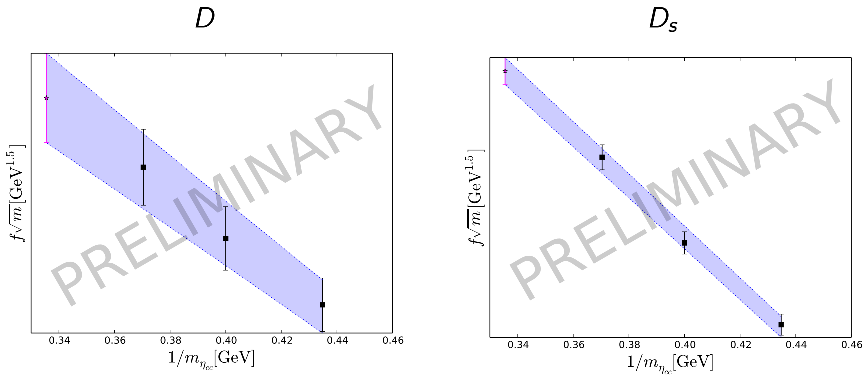


Continuum Limit



$$\mathcal{O}(a^2) = \mathcal{O}_{\mathrm{CL}} + Ca^2$$

Extrapolation to charm



(Stat only) $\dfrac{\Delta(f_D\sqrt{m})}{f_D\sqrt{m}} \approx 2.1\%$

(Stat only) $\dfrac{\Delta(f_{D_s}\sqrt{m})}{f_{D_s}\sqrt{m}} \approx 0.6\%$

From D to B: The ratio method

arXiv:0909.3187

- Define $\phi \equiv f_{\mathrm{PS}}\sqrt{M}$
- HQET predicts:

$$\lim_{m_h \to \infty} \phi = \mathrm{const.}$$

- Define n reference masses M_i^{ref} and $\lambda > 1$ with $\lambda M_i = M_{i+1}$. Then

$$R(M_i) \equiv \frac{\phi(M_i)}{\phi(M_{i+1})} \to 1$$

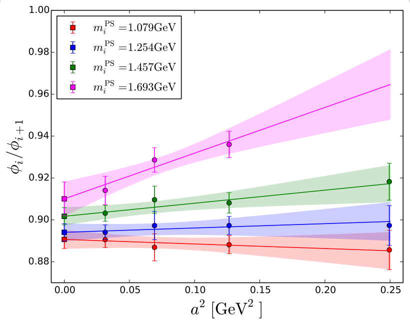
- Expansion around the static limit (HQET):

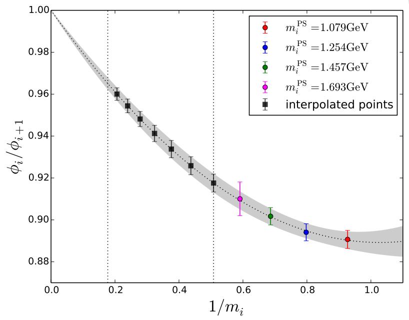
$$R(M_i) = 1 + \frac{C_1}{M_i} + \frac{C_2}{M_i^2} + \mathcal{O}\left(\frac{1}{M_i^3}\right)$$

The Ratio Method

1. Define n geometrically spaced reference masses M_i and build $\phi(M_i)$.
2. Interpolate between static limit and $R(M_i)$, to find $C_1, C_2, \ldots$
3. Reconstruct R_i for $M_i >$simulated data.
4. $$\frac{\phi(M_0)}{\phi(M_m)} = \prod_{i=0}^{m-1} R_i$$

Test the Ratio Method: Quenched Pilot Study





Published (ETMC, $N_f = 2$, arXiv:1308.1851): $f_{B_s}/f_{D_s} = 1.096(49)$

We get: 1.098(31) (quenched) (without heaviest: 1.096(36))

Summary

What we have done:

- Calculated the D and D_s decay constants
- at **Physical Pion Masses** ($2+1f$ simulation) in an automatically $\mathcal{O}(a)$-improved setting.
- Continuum Limit with 3 lattice spacings.

To do list:

- Increase statistic and do autocorrelation analysis for fine ensemble.
- Renormalisation
- Systematic error analysis:
  $\Rightarrow$ Various inter- and extrapolations.
  $\Rightarrow$ Compare different fit ansätze.
- Global Fit

Outlook

What we would like to do:

- Semi-leptonic D and D_s decays
  $\Rightarrow$ BUT: very noisy due to physical light quarks
- B-physics via Ratio Method
  $\Rightarrow$ Tested with quenched data: **Promising**
  $\Rightarrow$ Dynamical data is on disk, so we are ready to start!

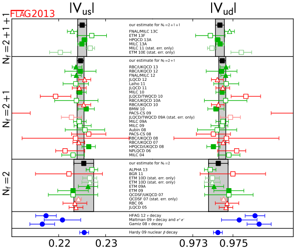
Next: Talk by Ava Khamseh

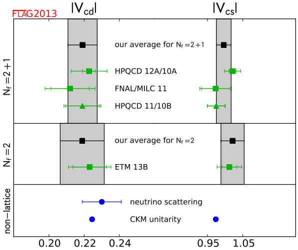
"Neutral D-Meson Mixing near the Charm Mass."

BACKUP

Review of lattice calculations of CKM matrix elements

arXiv:1310.8555

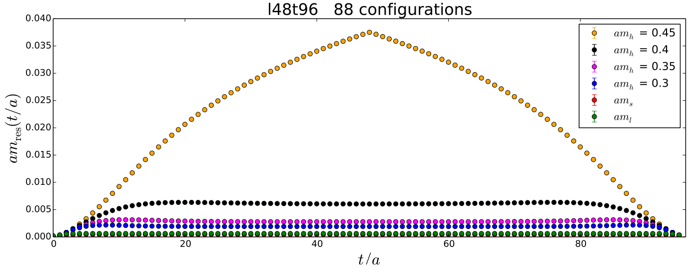




- Light quark sector well explored
- Few pulished results in the heavy quark sector

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

Behaviour of the residual mass for $am_q \gtrsim 0.4$



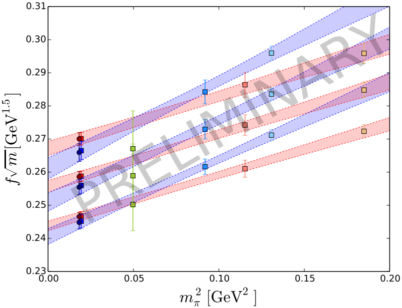
The parameter α used to correct for the strange quark mass mistuning

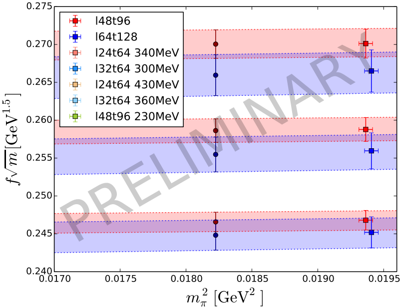
$$\mathcal{O}^{\mathrm{phys}} = \mathcal{O}^{\mathrm{uni}} \left(1 + \alpha \frac{m_s^{\mathrm{phys}} - m_s^{\mathrm{uni}}}{m_s^{\mathrm{phys}}}\right)$$

am_h	α_m	α_f	$\alpha_{f\sqrt{m}}$
0.3	0.06086(42)	0.1023(31)	0.1321(32)
0.35	0.05375(40)	0.1018(32)	0.1281(33)
0.4	0.04838(47)	0.1035(42)	0.1271(44)
avg	0.05476(42)	0.1024(33)	0.1295(35)

Table : $\alpha_{\mathcal{O}}$ determined from 87 configurations on the coarse ensemble with $m_\pi \approx 340\mathrm{MeV}$. The strange quark masses were $am_s^{\mathrm{uni}} = 0.04$ and $am_s^{\mathrm{phys}} = 0.3224$

Extrapolation to Physical Pion Masses





$\Rightarrow$ Tiny correction to physcial point data: $\ll 1\sigma$