Preliminary results from maximally twisted mass lattice QCD at the physical point

A. Abdel-Rehim, P. Boucaud, N. Carrasco, A. Deuzeman, P. Dimopoulos, R. Frezzotti, G. Herdoiza, K. Jansen, B. Kostrzewa, M. Mangin-Brinet, I. Montvay, D. Palao, G.C. Rossi, F. Sanfilippo, L. Scorzatto, A. Shindler, C. Urbach, U. Wenger

Humboldt-Universität zu Berlin
DESY, Zeuthen Site
Supported in full by FNR AFR PhD grant 2773315

Lattice 2013, Mainz – 2nd August 2013

Overview

Introduction

Action

Requirements

- Physical point with $a \sim 0.1\text{fm} \leftrightarrow$ reasonable computing resources
- Stable simulation and controlled $O(a^2)$ cutoff effects $\leftrightarrow$ pion splitting
- Maintain all nice properties of tmLQCD

Twisted mass action: [Frezzotti, Grassi, Sint, Weisz, 2000; Frezzotti, Rossi; 2004]

$$
\begin{aligned}
S &= \beta \sum_{x;P} \left[b_0 \{ 1 - \tfrac{1}{3} \mathrm{Re}\mathrm{Tr} P^{1\times 1}(x) \} + b_1 \{ 1 - \tfrac{1}{3} \mathrm{Re}\mathrm{Tr} P^{1\times 2}(x) \} \right] \\
&+ \sum_{x} \bar{\chi}(x) \left[D_W(U) + m_0 + i\mu\gamma^5\tau^3 + \tfrac{i}{4} C_{\mathrm{SW}} \sigma^{\mu\nu} \mathcal{F}^{\mu\nu}(U) \right] \chi(x)
\end{aligned}
$$

- $N_f = 2$
- $b_0 = 1 - 8b_1,\ b_1 = -0.331$ [Iwasaki; 1983]
- $C_{\mathrm{SW}} = 1.57551$ from Padé fit of CP-PACS data

[Aoki et al.; Phys.Rev. D73 (2006) 034501]

Introduction

Run Details

L/a	48
T/a	96
β	2.10
b_1	-0.331
κ	0.13729
$a\mu_l$	0.0009
C_{SW}	1.57551
N_{traj}	> 1500
$< P >$	0.603531(6)
$\tau_{int}(< P >)$	10.0(3.5)
am_{PCAC}	0.00004(2)
$m_\pi L$	3.00(2)
a	0.91(5) fm [a]

[a] very preliminary: large uncertainty to accomodate possible FS / discretization effects

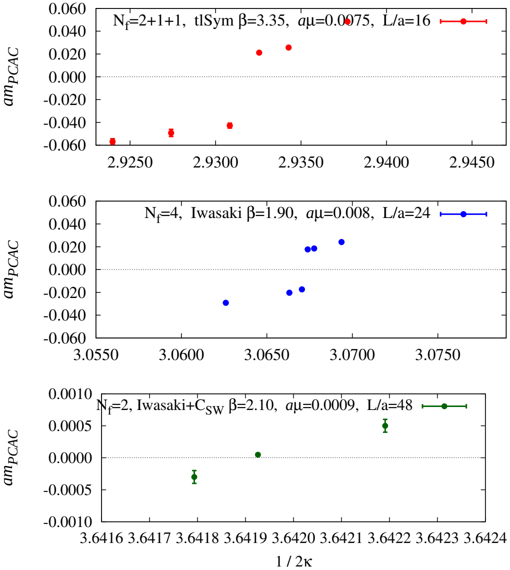
- Substantial updates to tmLQCD software suite:
  - BG/Q optimizations
  - OpenMP
  - Clover term with EO pre-condtitioning and twisted mass
  - RHMC implementation
- Details: Carsten Urbach, Parallels 9G, Friday 14:40

- O(10) exploratory runs on $24^3 \times 48$
- 2 (short) tuning runs on target volume
- Production runs on BG/Q in Juelich, replica on SuperMUC

Tuning and Stability

Tuning to maximal twist at small quark mass and coarse lattice spacing

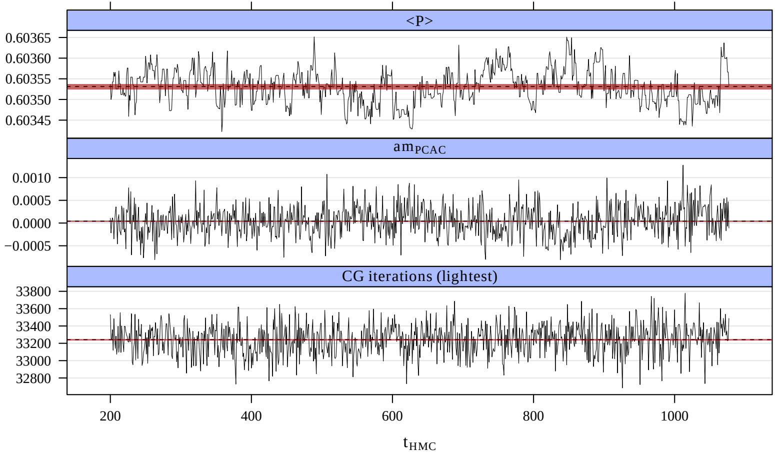
- $N_f = 2 + 1 + 1$ tlSym action $\rightarrow$ remnant signs of 1st order phase-trans.
- Iwasaki gauge action, situation much improved but trouble with $N_f = 4$
- Clover term + Iwasaki $\rightarrow$ very fine tuning possible, linear behaviour in $1/2\kappa$, no metastabilities



Tuning and Stability

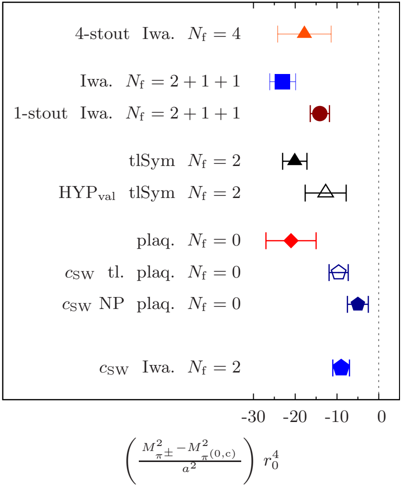
Monte Carlo histories

- 2^{nd} order minimal norm integrator on four timescales
- four Hasenbusch mass shifts, lightest two on same timescale
- $\tau = 1.0$ trajectory length, 75% acceptance for efficiency



First results

Neutral connected pion splitting



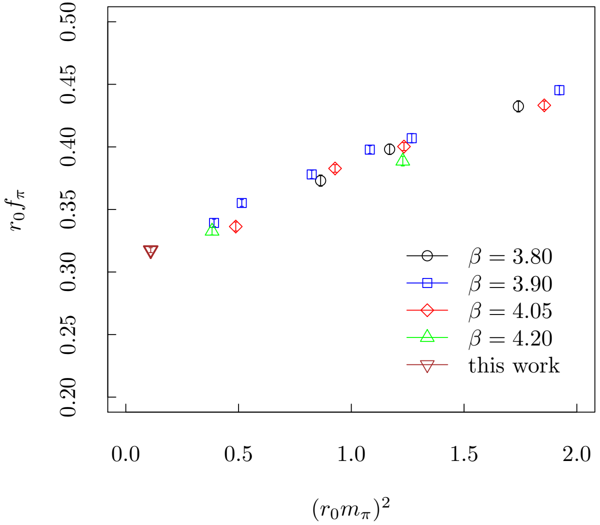
- Indications that W_8' is reduced markedly $\rightarrow$ stable simulations, particular $O(a^2)$ effects under control
- Measurement of full pion splitting in progress $\rightarrow$ obtain estimate of c_2

First results

Pion decay constant

$r_0 f_\pi$

- data consistent with old $N_f = 2$ runs
- no FS corrections applied

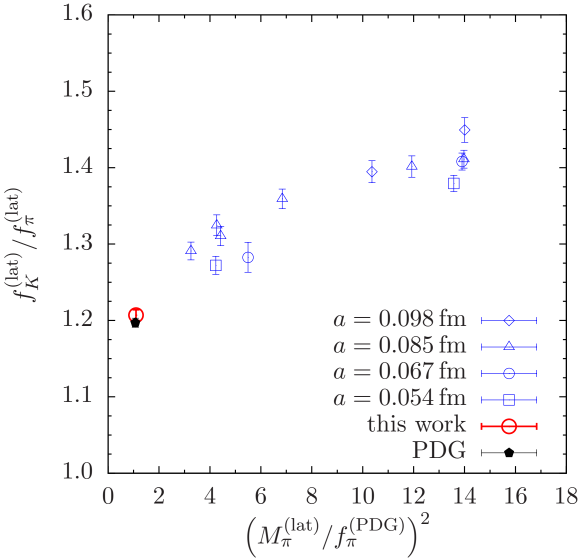


First results

Heavy-light meson sector then and now

$$\frac{f_K}{f_\pi}$$

- old $N_f = 2$
- new $N_f = 2$ with clover term
  - consistent with previous values
  - some extrapolation necessary

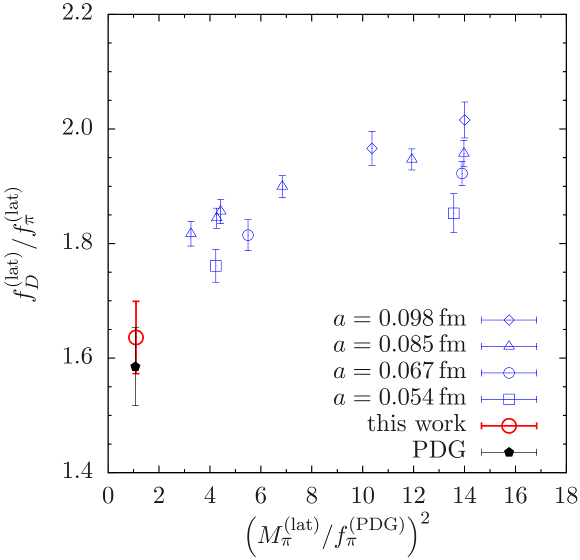


First results

Heavy-light meson sector then and now

$$\frac{f_D}{f_\pi}$$

- old $N_f = 2$
- new $N_f = 2$ with clover term
  - consistent over previous values
  - consistent with experimental point

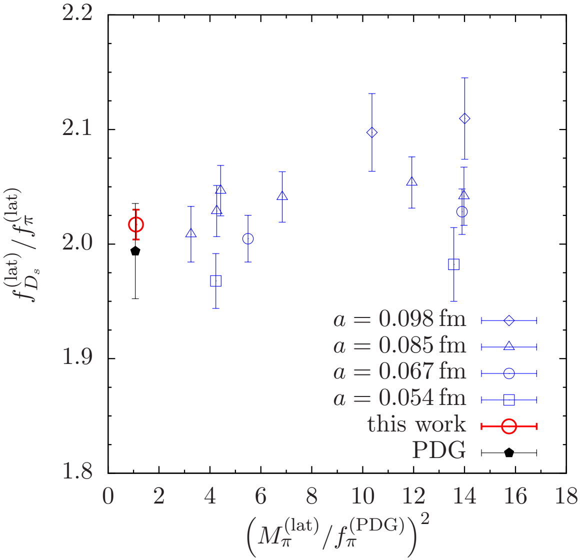


First results

Heavy-light meson sector then and now

$$\frac{f_{D_s}}{f_\pi}$$

- old $N_f = 2$
- new $N_f = 2$ with clover term
  - consistent with previous values
  - consistent with physical value

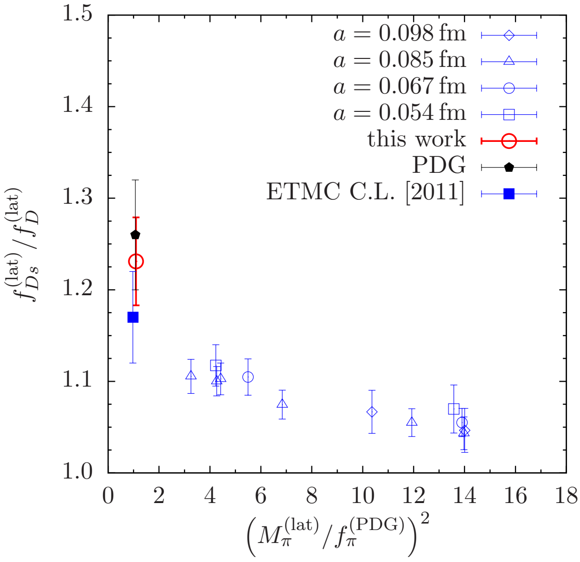


First results

Heavy-light meson sector then and now

$$\frac{f_{D_s}}{f_D}$$

- old $N_f = 2$
- old $N_f = 2$ chiral extrapolation
- new $N_f = 2$ with clover term
  - apparent improvement over previous values
  - consistent with experimental point

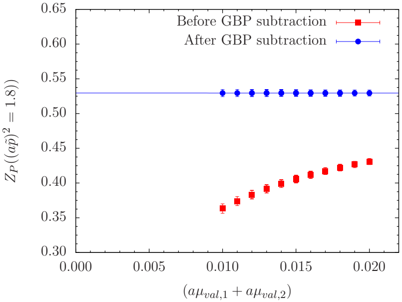


First results

RI-MOM Renormalization constants

RC	new $N_f = 2$ $\beta = 2.10(C_{SW})$ [1]	$N_f = 2$ $\beta = 3.90$	$N_f = 2+1+1$ $\beta = 1.95$
Z_A	0.805(05)	0.730(03)	0.746(05)
Z_V	0.762(04)	0.634(03)	0.614(03)
Z_P/Z_S	0.805(34)	0.669(08)	0.700(08)

- Renormalization constants closer to 1
- Goldstone boson pole subtraction in Z_P effective
- Z-factors also available from momentum sources
  - M. Constantinou, Parallels 3B, Tuesday 15:40

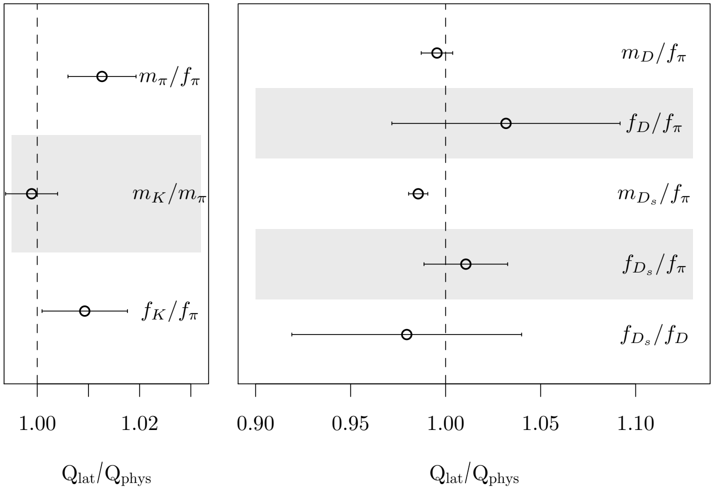


[1] $24^3 \times 48$, $a\mu_{\text{sea}} = 0.0060$, $a\mu_{\text{val}} = 0.0050 - 0.0090$, no sea quark chiral limit yet!

First results

Comparison to experimental values

- $Q_{\mathrm{lat}} \div Q_{\mathrm{phys}}$ for example: $Q_{\mathrm{lat}} = \frac{m_\pi^{\mathrm{lat}}}{f_\pi^{\mathrm{lat}}}$ $\quad Q_{phys} = \frac{m_\pi^{\mathrm{phys}}}{f_\pi^{\mathrm{phys}}}$
- Tuning strange and charm quark mass $\sim$ PDG quark mass ratios



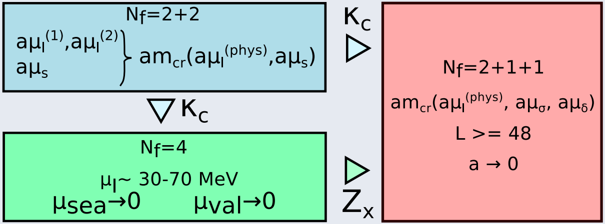
Path to $N_f = 2+1+1$

Preliminaries

Tuning C_{SW}

- No existing NP study of C_{SW} for $N_f = 2+1+1$
- For $N_f = 2$, discrepancy between Padé and direct approach $\sim 10\%$
  - ⋆ Full determination of C_{SW} has $O(a\Lambda_{QCD})$ systematic uncertainty
  - ⋆ 10% accuracy should be sufficient
  - $\Rightarrow$ use simple algorithm to obtain tadpole improved value (next slide)

- Idea: If simulation stable for $N_f = 2_l + 2_s$
  - $\Rightarrow$ also stable for $N_f = 4$ and $N_f = 2+1+1$



Path to $N_f = 2+1+1$

Tuning C_{SW}

- Use simple approximate formula at some bare coupling g_0:

$$C_{SW} \sim 1 + 0.113(3)\frac{g_0^2}{< P >}$$

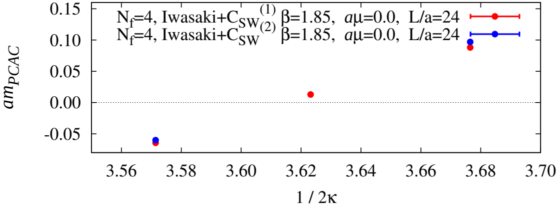
[Sheikoleslami,Wohlert; 1985]

1. Start with $C_{SW} = N_f$-independent 1-loop value
2. Simulate at zero twisted mass, neg./pos. Wilson quark masses bracketing $m_{PCAC} = 0$
3. Linearly interpolate $< P >$ at $m_{PCAC} = 0$
4. Use formula to get better estimate of C_{SW}
5. Repeat (1) with new estimate as starting value
6. Stop when change is less than 3%

$N_f = 4,\ a\mu_l = 0.0$

O $C_{SW}^{(1)}$ O $C_{SW}^{(2)}$

$\Rightarrow$ C_{SW}-dependence not too strong



Conclusion and Outlook

- Shown feasibility of mtmLQCD simulations at physical point
- All preliminary measurements look promising
- Indications of better $O(a^2)$ behaviour from connected pion splitting and lack of metastabilities
- First $N_f = 4$ and $N_f = 2 + 2$ runs started, m_{PCAC} quite linear in $\frac{1}{2\kappa}$
- Tuning C_{SW} for $N_f = 2 + 1 + 1$ using tadpole improved formula

- Extension to $N_f = 2 + 1 + 1$ outlined and first steps taken
  - Results suggest no problems with plan
- Continuation of rich ETMC physics programme at the physical point
  - $\Rightarrow$ nucleon: C. Alexandrou, Parallels 3B, Tuesday 15:00
  - $\Rightarrow$ nucleon: M. Constantinou, Parallels 3B, Tuesday 15:40
  - $\Rightarrow$ muon g-2: G. Hotzel, Parallels 9B, Friday 14:20