Towards four-flavour dynamical simulations

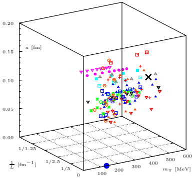
Gregorio Herdoiza

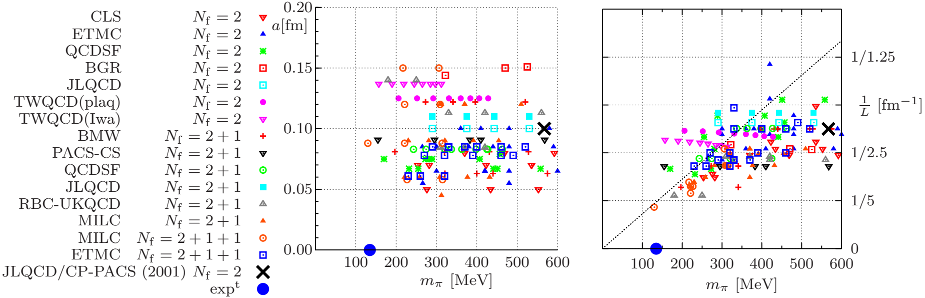
NIC, DESY

Lattice 2010, Villasimius, June 14, 2010

dynamical simulations : parameters landscape

- number of flavours : N_f
- lattice spacing : a
- lattice size : L
- pion masses : m_PS





oblique dotted line : $m_\pi L = 3.5$

Caveat in plots : no information on systematic effects (scale setting, cut-off effects, ...), m_s, m_c, ...

review talk by Christian Hoelbling

dynamical simulations : parameters landscape

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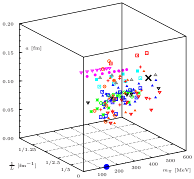
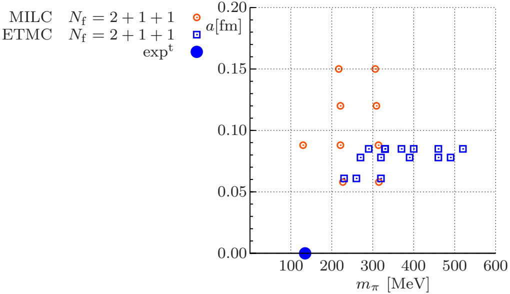
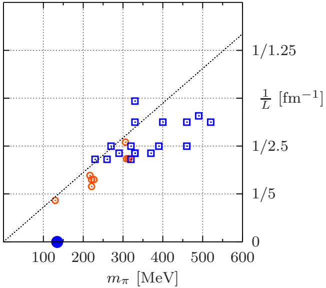
- lattice spacing : a
- lattice size : L
- pion masses : m_{PS}







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review talk by Christian Hoelbling

$N_f = 2 + 1 + 1$

u, d, s, c dynamical quarks with $m_u = m_d < m_s < m_c$

Motivation for including the dynamical charm :

- expected effect $O(1/m_c^2)$ and $O(\alpha_S(m_c))$
- a dynamical quark is active at energy scales $E > m_q$
- running of renormalised quantities with $N_f = 4$
- matching to $\overline{\mathrm{MS}}$ with $N_f = 4$ at $\mu > m_c$
- explore physical effects dynamical c on hadronic masses and matrix elements
- remove so far uncontrolled systematic effect of the dynamical charm : relevant with increasing precision in lattice computations

Potential difficulties of including the dynamical charm :

1. are there large cut-off effects in the light sector from $am_c \lesssim 1$ in the sea?
2. strange and charm : is the tuning effort too heavy?
3. dedicated runs for renormalisation

$N_f = 2 + 1 + 1$

light sector

large cut-off effects in the light sector ?

examples from MILC and ETMC

$N_f = 2+1+1$ MILC ensembles

- Symanzik-improved gauge action
- staggered quarks :

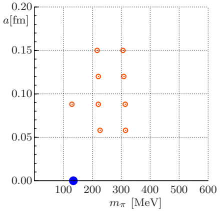
  asqtad ($N_f = 2+1$) $\rightsquigarrow$ HISQ ($N_f = 2+1+1$)
  [HPQCD-UKQCD, 2006]

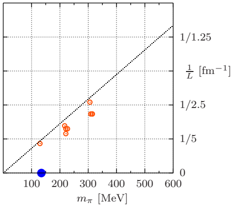
- HISQ : further smearing of gauge links in fermion action
  $\rightsquigarrow$ reduced taste symmetry violations

- $a = \{0.06, 0.09, 0.12, 0.15\}$ fm
- $L = \{2.4, 5.5\}$ fm , $m_{\rm PS} L > 3.5$
- $m_\pi \in \{130, 315\}$ MeV
- m_s and m_c from $2m_K^2 - m_\pi^2$, $1/4(m_{\eta_c} + 3\, m_{J/\Psi})$ around physical values

- RHMC
- target : $5000 \div 12000$ thermalised traj. , $\tau = 1$

- while for $N_f = 4$ rooting trick is avoided, still present for $N_f = 2+1+1$
- $a m_c \lesssim 0.8$
- setup : good conditions for a scaling analysis

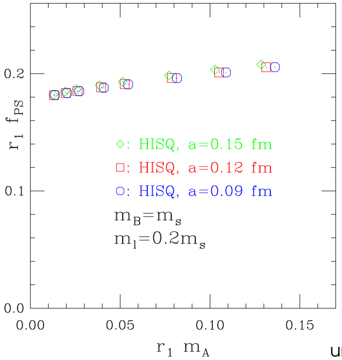




$N_f = 2+1+1$ MILC : scaling of f_{PS}

scaling of partially quenched f_{PS}

$a = 0.09,\ 0.12,\ 0.15$ fm



unitary point : $r_1 m_A \approx 0.026$

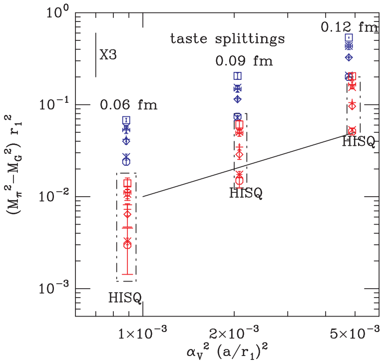
are there large cut-off effects from the dynamical charm ?

- not large . . .
- similar behaviour for other observables : m_N, m_ρ, . . .
- effect of HISQ

talk by Doug Toussaint

$N_f = 2 + 1 + 1$ MILC : taste splitting

HISQ and comparison to asqtad ($N_f = 2 + 1$) $a = 0.06,\ 0.09,\ 0.12$ fm



- significant reduction of the size of taste splitting wrt. asqtad
- improvement also in generic discretisation effects

talk by Doug Toussaint

$N_f = 2+1+1$ ETMC ensembles

- Iwasaki gauge action
- Wilson twisted mass $\rightsquigarrow$ doublets
  [ALPHA, Frezzotti et al.,2001; Frezzotti & Rossi,2003]

- $a = \{0.06,\ 0.08,\ 0.09\}$ fm
- $L = \{1.9,\ 2.7\}$ fm , $m_{\mathrm{PS}} L \gtrsim 3.5$
- $m_\pi \in \{230,\ 520\}$ MeV
- m_s and m_c from $2m_K^2 - m_\pi^2$, m_D
  around physical values

- HMC + PHMC
- target : 5000 thermalised traj. , $\tau = 1$

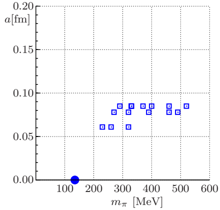
- $O(a)$ improvement at maximal twist
  [Frezzotti & Rossi, 2003]

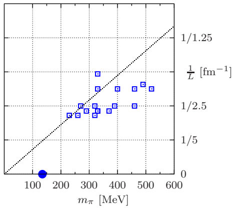
$$m_{\mathrm{PCAC},\ell} = 0 \qquad \text{at each } \{\mu_\ell\ ,\ \mu_\sigma\ ,\ \mu_\delta\}$$

$$\hat{m}_s = 1/Z_{\mathrm{P}}\ (\ \mu_\sigma - Z_{\mathrm{P}}/Z_{\mathrm{S}}\ \mu_\delta\ )$$

$$\hat{m}_c = 1/Z_{\mathrm{P}}\ (\ \mu_\sigma + Z_{\mathrm{P}}/Z_{\mathrm{S}}\ \mu_\delta\ )$$

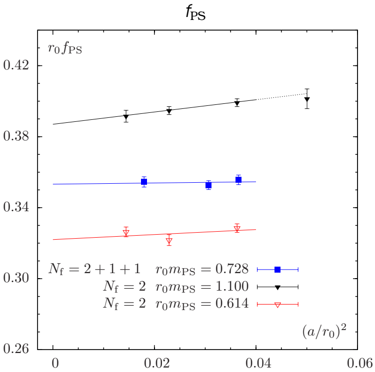
- $am_c \lesssim 0.3$

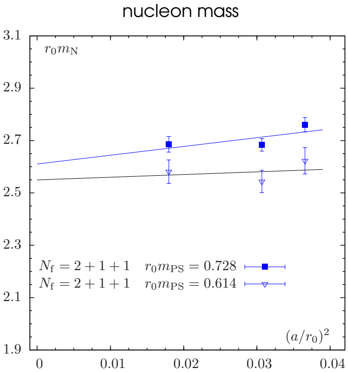




ETMC : continuum limit scaling of $f_{\rm PS}$ and $m_{\rm N}$

$N_{\rm f} = 2+1+1$ $a = 0.06,\ 0.08,\ 0.09$ fm





no signs of large $O(a^2)$ discretisation effects $\rightsquigarrow$ some physics results . . .

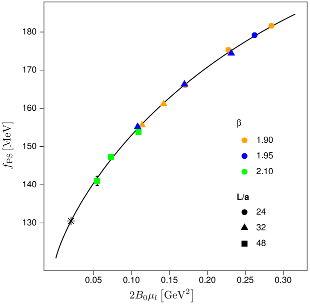
talk by Siebren Reker

talks by Vincent Drach and Simon Dinter

ETMC : χPT results $m_{\rm PS}$, $f_{\rm PS}$

- SU(2) χPT at NLO $a = \{0.06, 0.08, 0.09\}$ fm
- central values + stat. error : $\beta = 1.95$ ($a = 0.08$ fm) $f_\pi = 130.4(2)$ MeV $\rightsquigarrow$ scale
- estimate systematic effects : lattice artifacts, FSE

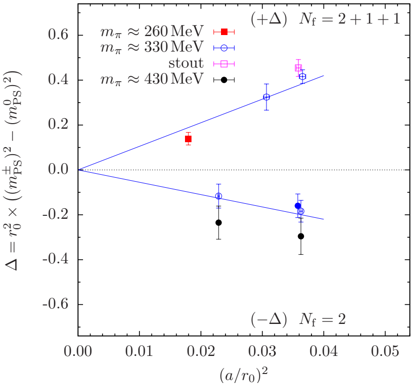
	$N_f = 2+1+1$	$N_f = 2$
$\bar{\ell}_3$	3.70(27)	3.50(31)
$\bar{\ell}_4$	4.67(10)	4.66(33)
f_π / f_0	1.076(3)	1.076(9)



comparison to other groups : talk by Siebren Reker
review talk by Christian Hoelbling

neutral pion mass

- flavour symmetry breaking at $\mathcal{O}(a^2)$
  $\rightsquigarrow \quad m_{\pi^0} \neq m_{\pi^\pm}$
- while $m_{\pi^\pm}$ has a mild a^2 dependence
  large cut-off effects are observed in m_{π^0}
- evidence that $\mathcal{O}(a^2)$ effects in m_{π^0} grow with N_f
  slope : $c_{N_f=2} \approx 6 \quad c_{N_f=2+1+1} \approx 10$ [PRELIMINARY]



Effects of flavour breaking :

- $N_f = 2$ data : large $\mathcal{O}(a^2)$ effects observed only in m_{π^0}
  [Frezzotti & Rossi, 2007; Dimopoulos et al., 2009]
- explicit checks needed + continuum limit
- finite size effects $\rightsquigarrow$ tmχPT [Colangelo, Wenger, Wu, 2010]

$N_f = 2 + 1 + 1$ m_s, m_c

strange & charm sectors

what is the tuning effort?

tuning of m_s & m_c

quality of tuning is only known a posteriori . . .
the tuning effort depends on the target accuracy and on the observable

- ETMC : tune to maximal twist at each $\{\mu_\ell, \mu_\sigma, \mu_\delta\}$ $\rightsquigarrow$ more effort than in $N_f = 2$
- MILC : fix β when changing m_ℓ $\rightsquigarrow$ less effort than in $N_f = 2 + 1$
- tuning of m_s, m_c
  - interpolation to m_s and m_c : $\sim$ 4 times more effort than in $N_f = 2$
  - cost of including the charm is not an issue
  - reweighting can help [Chulwoo Jung, lat09]
- dedicated simulations for renormalisation

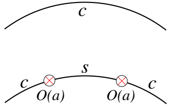
  overall, yes, some extra effort is needed for $N_f = 2 + 1 + 1$ simulations . . .

  . . . but not out of reach

- alternative strategy to fix m_s via the singlet quark mass [$N_f = 2 + 1$, QCDSF-UKQCD, 2010]

talks by Roger Horsley and Paul Rakow

$N_f = 2 + 1 + 1$ ETMC : unitary K and D-mesons



Wilson twisted mass Dirac operator for (c, s) pair :

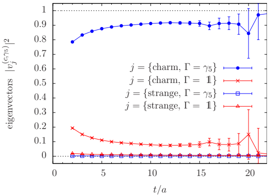
$$D_h = \begin{pmatrix} \gamma_\mu \tilde{\nabla}_\mu + \mu_\sigma + \mu_\delta & -i\gamma_5 \left(-r\frac{a}{2}\nabla^*_\mu \nabla_\mu + M_{\rm cr}\right) \\ -i\gamma_5 \left(-r\frac{a}{2}\nabla^*_\mu \nabla_\mu + M_{\rm cr}\right) & \gamma_\mu \tilde{\nabla}_\mu + \mu_\sigma - \mu_\delta \end{pmatrix}$$

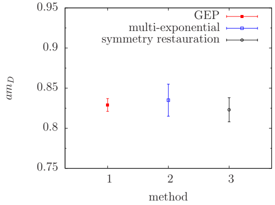
- mixing of c and s flavour and of parity
- Kaon is the ground state : good precision
- D meson appears as an excited state

- three independent methods to identify the D meson :
  - generalised eigenvalue problem
  - multi-exponential fits
  - imposing parity and flavour restoration at finite a
- they provide consistent results for m_D

  poster by Elisabetta Pallante

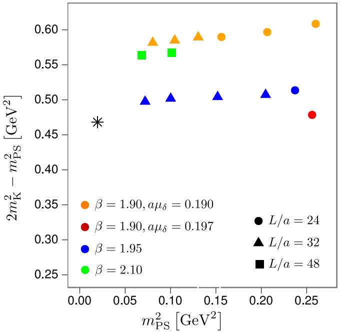
- to overcome the mixing of flavour $\rightsquigarrow$ mixed action

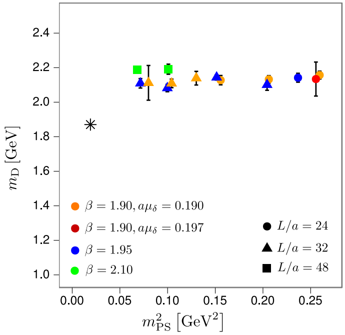




$N_f = 2 + 1 + 1$ ETMC : tuning m_s and m_c

$a = 0.06,\ 0.08,\ 0.09$ fm





further tuning runs are ongoing

mixed action : OS valence quarks

- Osterwalder Seiler (OS) valence quarks are the building blocks of twisted mass valence quarks at maximal twist (Mtm)
- individual valence flavour q

$$S_{\rm OS} \;=\; \bar{q}(x) \left[\gamma_\mu \tilde{\nabla}_\mu - i\, r\, \gamma_5 \left(-\frac{a}{2} \nabla^*_\mu \nabla_\mu + M_{\rm cr}(r=1) \right) + \mu \right] q(x)$$

[Osterwalder & Seiler, 1978]

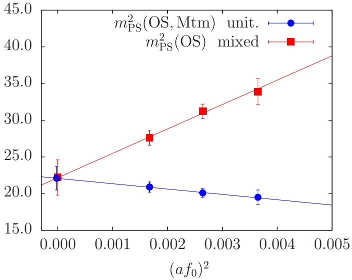
- Mtm corresponds to a pair of OS fermions with $+r$ and $-r$ (OS,Mtm)
- benefits :
  - OS action is flavour diagonal
  - $O(a)$ improvement [Frezzotti & Rossi, 2004]
  - Mtm and OS fermions share the same renormalisation factors : matching is simplified
- applications to $N_f = 2$ and $N_f = 2+1+1$

talks about overlap valence on dynamical Wilson type fermions talk by Fabio Bernardoni
talk by Krzysztof Cichy

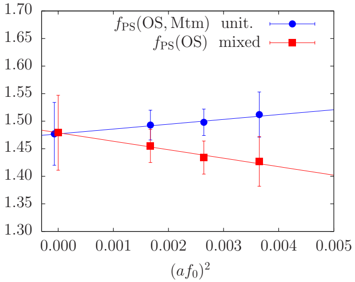
ETMC $N_f = 2$: mixed action OS valence quarks

continuum limit scaling

m_K^2



f_K



Benefit : B_K $O(a)$ improved and absence of mixing due to breaking of chiral symmetry

poster by Petros Dimopoulos

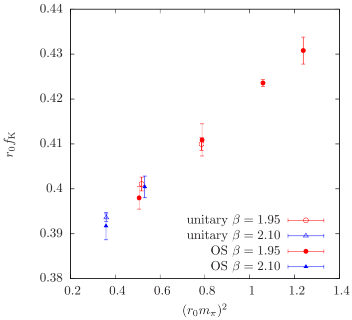
$N_f = 2 + 1 + 1$ mixed action : use of "OS, Mtm" valence action in strange and charm sector . . .

ETMC $N_f = 2 + 1 + 1$: mixed action f_K, f_D, f_{D_s}

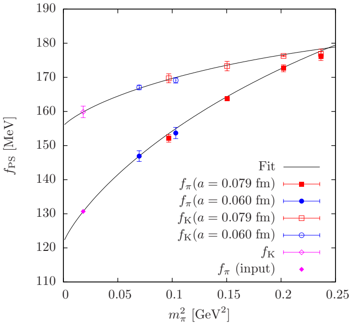
mixed action in the strange and charm sector

$a = 0.060,\ 0.079$ fm

f_K unitary and mixed



f_K and f_π



PRELIMINARY $N_f = 2 + 1 + 1$ results :

stat. errors only

$f_K/f_\pi = 1.22(1)$	$f_D = 204(3)$ MeV	$f_{D_s} = 251(3)$ MeV

talk by Carsten Urbach

review talks by Jochen Heitger and Christian Hoelbling

$N_f = 3$ & $N_f = 4$

dedicated runs for renormalisation

non-perturbative renormalisation

mass-independent scheme :

- anomalous dimensions independent of quark masses
- use of $N_f = 2+1$ or $N_f = 2+1+1$ ensembles to renormalise scale-dependent operators :
  - $m_s \to 0$ and in particular, $m_c \to 0$, are long extrapolations
  - when extrapolation is not performed : estimate systematic effect
- dedicated simulations with $N_f = 3$ or $N_f = 4$ degenerate flavours :
  - Schrödinger functional (SF) : $m_q = 0$
  - RI-MOM : $m_q \to 0$

recent work from several groups :

- PACS-CS : $N_f = 3$ clover fermions with SF — talk by Yusuke Taniguchi
- ALPHA : $N_f = 4$ clover fermions with SF — talk by Rainer Sommer
- Pérez Rubio & Sint : $N_f = 4$ staggered quarks with SF — talk by Paula Pérez Rubio
- ETMC : $N_f = 4$ twisted mass fermions with RI-MOM — talk by David Palao

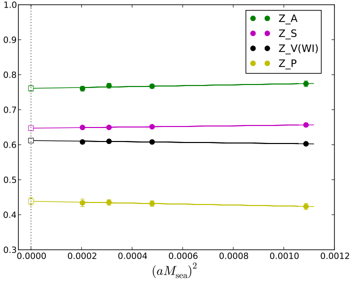
$N_f = 4$ ETMC

renormalisation factors for $N_f = 4$ flavours of Wilson fermions and Iwasaki gauge action

- RI-MOM at non zero values of both the standard and twisted mass parameters

$$M_R = \frac{1}{Z_P}\sqrt{(Z_A m_{PCAC})^2 + \mu_q^2} \;\rightarrow\; 0$$

- $O(a)$ improvement via average of simulations with $+m_{PCAC}$ and $-m_{PCAC}$
- study at $\beta = 1.95:\; a = 0.08$ fm, $L = 1.9$ fm

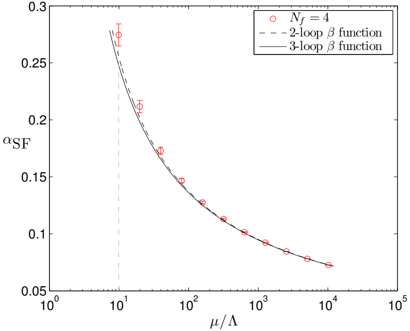


talk by David Palao

$N_f = 4$ QCD running of the coupling

two recent studies in the Schrödinger functional scheme

- four flavors of $O(a)$ improved Wilson quarks [ALPHA, Tekin, Sommer, Wolff, 2010]



talk by Rainer Sommer

- single naive staggered fermion field (no rooting trick) [Pérez Rubio & Sint]

talk by Paula Pérez Rubio

conclusions

- first steps with four-fermion simulations
- first results in the light, strange and charm sector
- no clear signs of large cut-off effects from dynamical charm in light-quark observables
- some extra effort is needed for tuning . . .
  . . . but not a strong limitation
- dedicated runs for renormalisation $\rightsquigarrow$ results from several groups!