First results for pseudoscalar decay constants of D-mesons from Twisted-Mass Lattice-QCD with $N_f = 2+1+1$ dynamical quark flavours

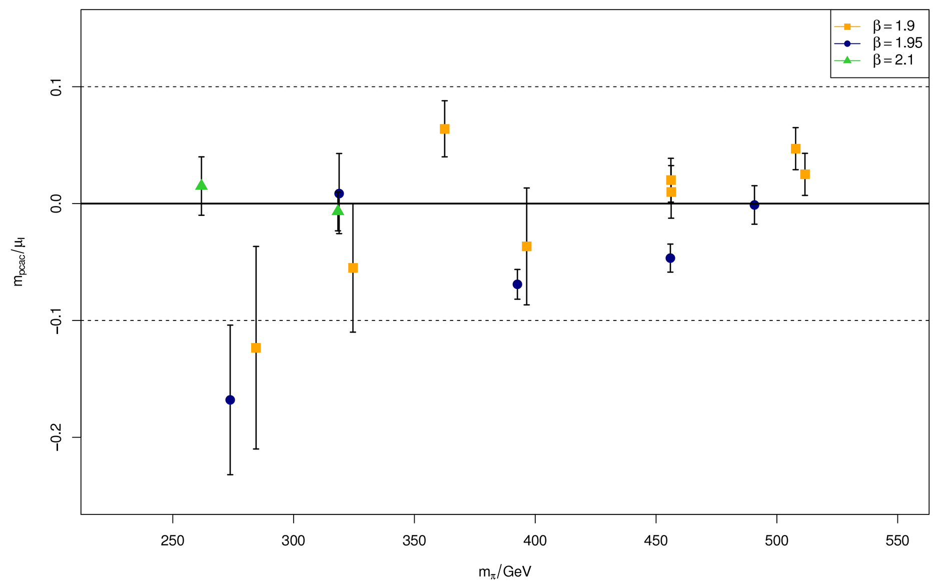
Motivation

- pseudoscalar decay constants are a benchmark of QCD in the Standard Model
- estimation of the CKM-matrix element V_{us} possible
- clarification of former inconsistencies between theory and experiment (former f_{D_s}-puzzle:
  CLEO-c: $f_{D_s} = (\mathbf{259.7} \pm \mathbf{8.5}) MeV$ (2009)
  HPQCD & UKQCD : $f_{D_s} = (\mathbf{241.0} \pm \mathbf{3.0}) MeV$ (2007)
  → corresponds to a $\approx$ **2.5σ discrepancy**)
- first L-QCD determination of pseudoscalar decay constant of D and D_s meson with up, down, strange and charm quark

Simulation Parameters / Tuning

- three different β values → three lattice spacings
- four to six light quark masses per β corresponding to Pion masses $\approx 250MeV - 510MeV$
- tuning $\kappa \to \kappa^{crit}$ for $O(a)$ improvement
- tuning of μ_σ and μ_δ via Kaon and D-meson mass

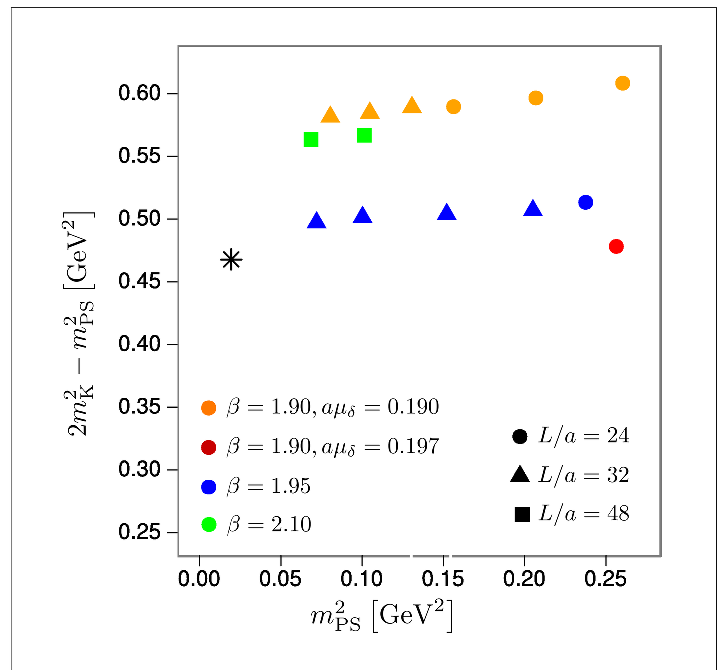
Tuning to maximal Twist



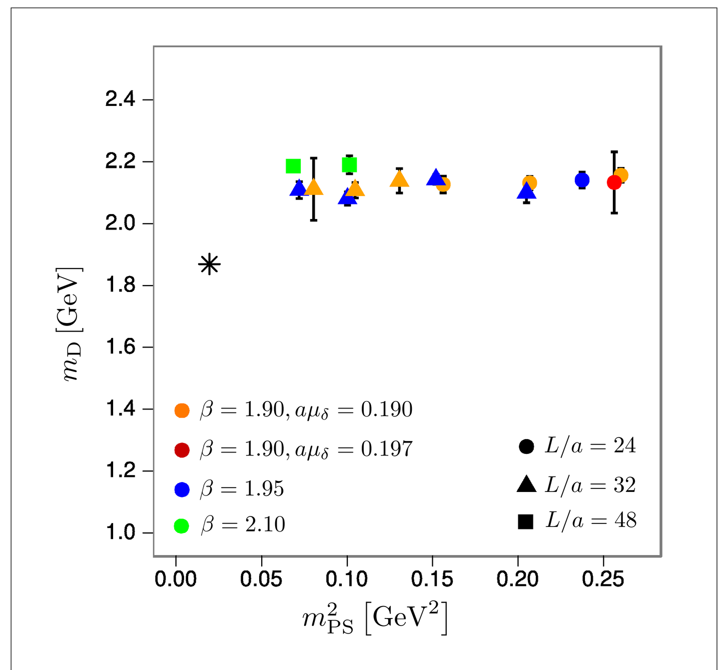
most ensembles fulfill our criterion:

$$\frac{m^{pcac}}{\mu_l} < 0.1$$

Status: Tuning of the Strange and Charm Quark Mass



Unitary Kaon mass



Unitary D-meson mass

→ m_K and m_D slightly too high
Solution: perform partially quenched analysis
(see "Mixed Action Setup" below)

Simulation Setup

- simulation of **four** dynamical Quark flavours (Up, Down, Strange and Charm)
- Up and Down quarks: mass-degenerated twisted-mass fermion doublet:

$$S_l^f = a^4 \sum_x \bar{\chi}^l \left[D_W + m_0 + i\mu_l \gamma_5 \tau^3 \right] \chi^l$$

- Strange and Charm quarks twisted-mass fermion doublet with mass-splitting

$$S_h^f = a^4 \sum_x \bar{\chi}^h \left[D_W + m_0 + i\mu_\sigma \gamma_5 \tau^1 + \tau^3 \mu_\delta \right] \chi^h$$

strange and charm quark mass is related to μ_σ and μ_δ:

$$m_{s,c}^R = \frac{1}{Z_P}\mu_\sigma \mp \frac{1}{Z_S}\mu_\delta$$

Lattice Gluon Action: Iwasaki gauge action
Features of the $N_f = 2+1+1$ twisted mass approach:

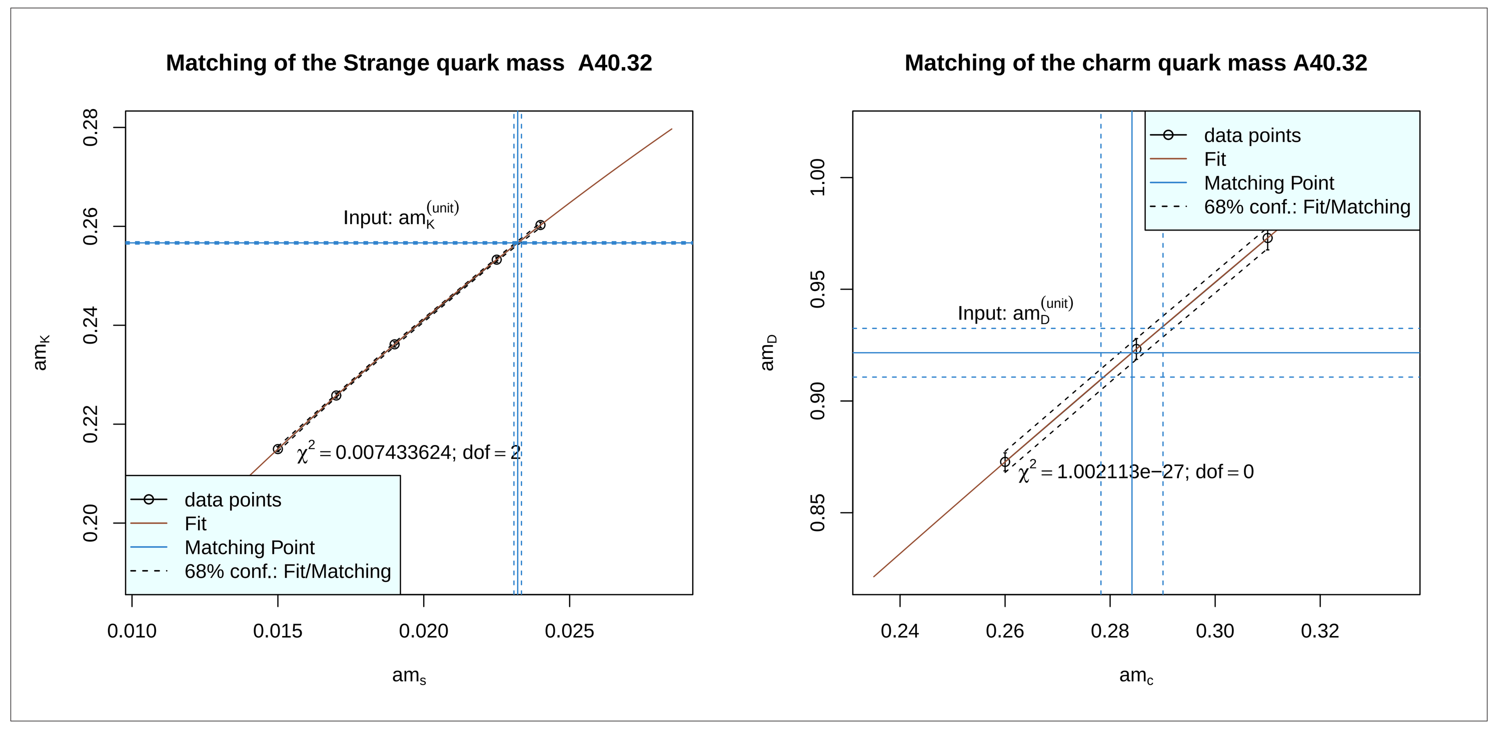
- automatic $O(a)$-improvement if $\kappa \to \kappa^{crit.}$ (tuning to maximal twist)
- computationally cheap (similar to Wilson-fermions)
- strictly positive fermion determinant
- explicit breaking of parity and flavor symmetry at $O(a^2)$
  - restored in continuum limit
  - mixing of scalar/pseudoscalar states and strange/charm (Kaon/D-meson)

Mixed Action Setup

Idea: use valence quark action **without** isospin breaking

$$S_{h,\text{valence}}^F = a^4 \sum_x \bar{\chi}^{\text{val}}(x) \left[D_W + m_0 \right] \chi^{\text{val}}(x) + a^4 \sum_x \bar{\chi}^{\text{val}}(x) i\gamma_5 \begin{pmatrix} \mu_s & 0 \\ 0 & -\mu_c \end{pmatrix} \chi^{\text{val}}(x)$$

- no mixing of strange and charm quarks by definition
  → no mixing of Kaon and D-meson
- straightforward calculation of f_{D_s} (no mixing and no disconnected diagrams)
- extraction of Kaon, D- and D_S-meson masses and decay constants for arbitrary strange and charm quark masses (in practice limited range)
  → partially quenched analysis
  → evaluation of quantities at physical strange and charm quark masses possible by matching with the experimental Kaon and D-meson mass



Fit Strategy

- find formula describing strange, charm and light quark mass dependence of f_{D_s}
- extrapolate to the physical point defined by m_π,m_K and m_D

SU(2)-HMχPT:

$$\Phi_{D_s} = f_{D_s}\sqrt{m_{D_s}} = D_1 \left[1 + D_2 \xi_{ll} + (D_a + D_{as}\xi_{ss}) a^2 + D_{ah} a^2 m_{D_s}^2 \right] + \frac{D_3}{m_{D_s}} \qquad (1)$$

$$D_i = D_{i,0} + \xi_{ss} D_{i,m} \quad i = 1,2\,; \quad \xi_{ij} = \frac{m_{ij}^2}{(4\pi f_0)^2} \qquad (2)$$

Preliminary Results

Fit Result:
$D_{1,0} = 1.67(7)$ $D_{1,m} = 0.75(7)$ $D_{2,0} = 0.07(12)$ $D_{2,m} = 0.45(34)$
$D_a = 0.31(44)$ $D_{as} = -3.8(1.5)$ $D_{ah} = 0.055(21)$ $D_3 = -2.85(23)$

Value extrapolated to the physical point

$$f_{D_s} = 256(2)^{stat} MeV, \chi^2/\text{dof} = 291/407 \qquad (3)$$

→ very good agreement with experimental results

Conclusion and Outlook

- try different fit strategies/formulas for estimation of systematic errors
- estimation of physical Kaon and D-meson mass → less experimental input

Publications

[1] "Light hadrons from Nf=2+1+1 dynamical twisted mass fermions" , Lattice2010, ETM Collaboration , 2010

[2] "A first look at Quasi-Monte Carlo methods for lattice field theory problems", Conference on Computational Physics 2012, K. Jansen, H. Leovey, A. Nube, A. Griewank, M. Müller-Preußker

Selected Talks

- "A Preconditioning Technique for the Wilson(-Twisted-Mass) and Overlap Operator", ETMC Meeting Autumn 2010
- "Pseudoscalar decay constants from Wtm-Lattice-QCD with $N_f = 2+1+1$ dynamical quark flavours", GK-Blockkurs Autumn 2011
- "Chiral symmetry, pseudoscalar decay constants and their determination on the lattice", PhD Seminar, Summer 2012

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