THE UNIVERSITY *of* EDINBURGH

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Exploring distillation at the $SU(3)$ flavor symmetric point

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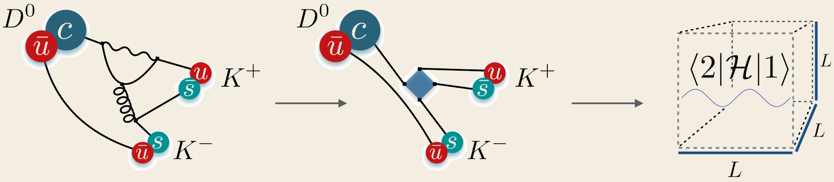
Hadronic D-decays

Motivation

- LHCb observed CP violation in $D \to \pi\pi$, KK (*Phys. Rev. Lett. 122 (2019) 21*)

$$\Delta A_{\rm CP} = A_{\rm CP}(K^-K^+) - A_{\rm CP}(\pi^-\pi^+) = (-15.4 \pm 2.9) \times 10^{-4}$$

- Lattice calculations can provide the standard model prediction



- First model calculation: $D \to K\pi$ at the $SU(3)$ symmetric point

Hadronic D-decays

Lattice calculation

First full calculation of hadronic D-decays comes with various challenges:

$$|A|^2 = 8\pi \left\{ q\frac{\partial\phi}{\partial q} + k\frac{\partial\delta_0}{\partial k} \right\}_{k=k_n} \frac{E_n^2 m_D}{k_n^3} \left| Z^{\overline{\mathrm{MS}}} \langle n, L | \mathcal{H}_{\mathrm{weak}} | D, L \rangle \right|^2$$

- Non-perturbative renormalization of four-quark operators
- Extraction of the matrix element from three-point functions
- Multi-hadron final state
- Finite volume formalism
    - $\rightarrow$ See Max’s talk (Monday 5:10 pm)

Computational setup

Gauge field ensembles

- Lattices generated by the OPEN LATtice initiative
- Three flavors of stabilised Wilson fermions at the $SU(3)$ symmetric point

Label	$T \times L^3/a^4$	β	κ	a (fm)	m_π (MeV)
a12m400	96×24^3	3.685	0.1394305	0.12	410
a094m400	96×32^3	3.8	0.1389630	0.094	410
a064m400	96×48^3	4.0	0.1382720	0.064	410

Computational setup
Software

- Our distillation framework is fully open source and based on
  - **`Grid`**: A data parallel C++ library (`github.com/paboyle/Grid`)
  - **`Hadrons`**: A `Grid` based workflow management system (`github.com/aportelli/Hadrons`)
- The distillation code was initially developed for domain wall fermions but the flexibility of `Grid` & `Hadrons` allows us to also use it for Wilson fermions.
  - → See Nelson's talk, tomorrow at 5:40 pm
- Our code runs on all major architectures including x86, Nvidia, AMD and Intel GPUs.
- Ongoing work on solvers for Wilson clover type fermions
  - → See Felix Ziegler's talk (Monday 3:20 pm)
  - → See Nils Meyer's poster

Computational setup

Distillation

- Smearing matrix from low-mode subspace of $-\nabla^2$

$$\mathcal{S}(t) = \sum_{k=1}^{N_{\text{vec}}} v_k(t) v_k(t)^\dagger$$

- Correlators can be cost effectively built from the smeared quark fields

$$\tilde{q} = \mathcal{S} q$$

- Construct GEVP matrix from bilinear and two-hadron operators

Operator structure
$K_0^+(\vec{p})$ with $\|p\| = 0$
$K(\vec{p})\pi(-\vec{p})$ with $\|p\| = 0$
$K(\vec{p})\pi(-\vec{p})$ with $\|p\| = \sqrt{1}\frac{2\pi}{L}$
$K(\vec{p})\pi(-\vec{p})$ with $\|p\| = \sqrt{2}\frac{2\pi}{L}$
$K(\vec{p})\pi(-\vec{p})$ with $\|p\| = \sqrt{3}\frac{2\pi}{L}$
$K(\vec{p})\pi(-\vec{p})$ with $\|p\| = \sqrt{4}\frac{2\pi}{L}$

Table: GEVP operator basis for *s*-wave scattering in the rest frame.

Computational setup

Choosing the number of eigenvectors N_{vec}

- The choice for N_{vec} affects
  - Computational cost
  - Statistical error
  - Operator smearing
- We choose an empirical approach and look at the energy spectrum as a function of N_{vec}.

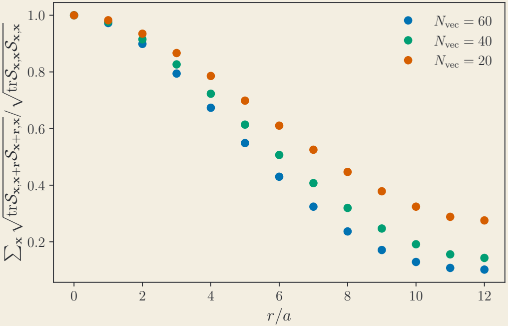
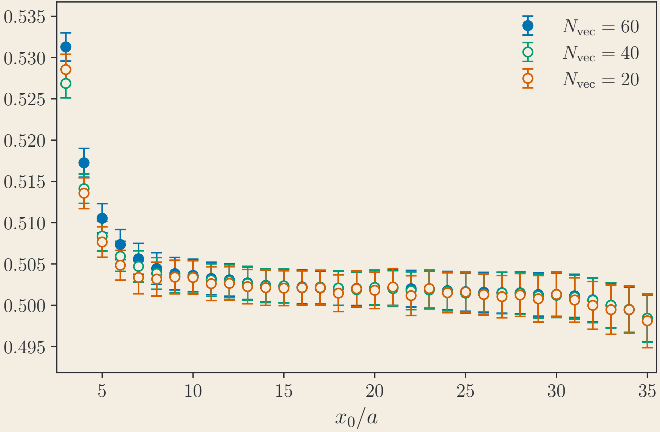


Figure: Smearing profile as a function of N_{vec}.

s-wave $I = 3/2$ $K\pi$ scattering

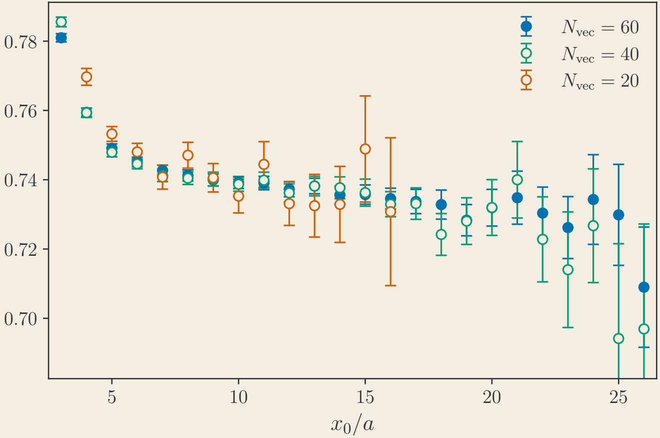
Ground state energy in the rest frame



Effective mass from a GEVP with $t_0 = 2$ for different values of N_{vec}.

s-wave $I = 3/2$ $K\pi$ scattering

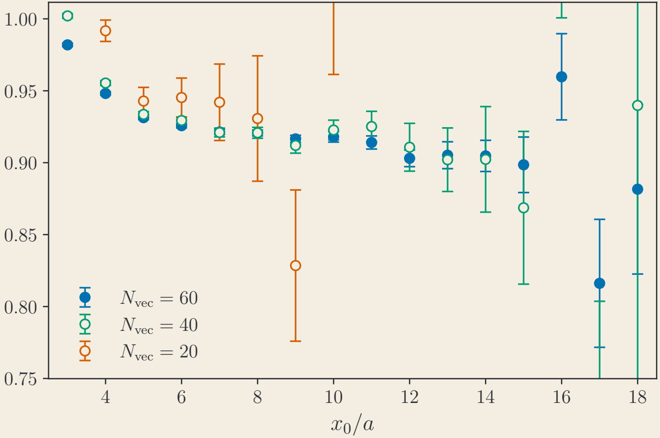
First excited state energy in the rest frame



Effective mass from a GEVP with $t_0 = 2$ for different values of N_{vec}.

s-wave $I = 3/2$ $K\pi$ scattering

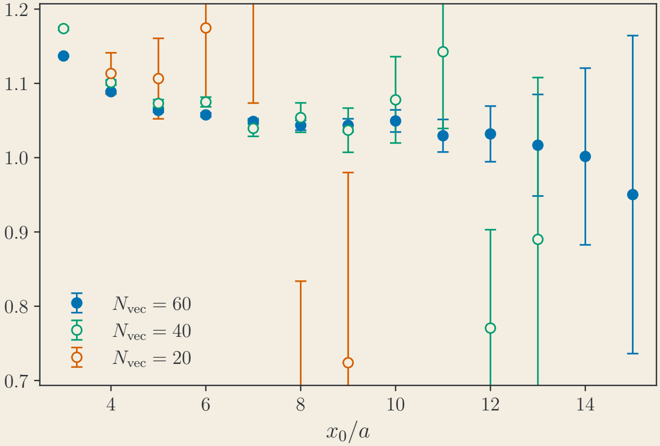
Second excited state energy in the rest frame



Effective mass from a GEVP with $t_0 = 2$ for different values of N_{vec}.

s-wave $I = 3/2$ $K\pi$ scattering

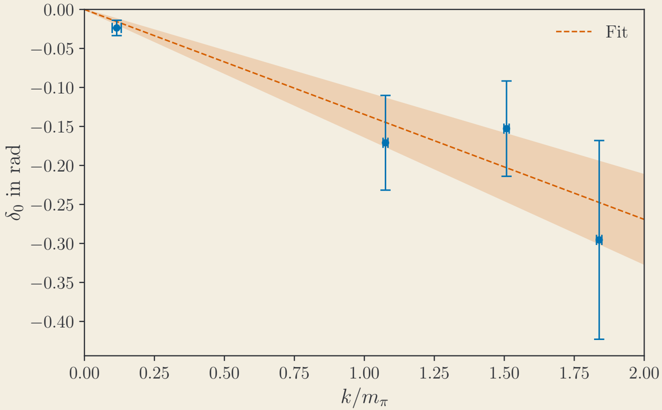
Third excited state energy in the rest frame



Effective mass from a GEVP with $t_0 = 2$ for different values of N_{vec}.

$I = 3/2$ $K\pi$ scattering

Scattering phase shift



We model the phase shift as a linear function of the momentum.

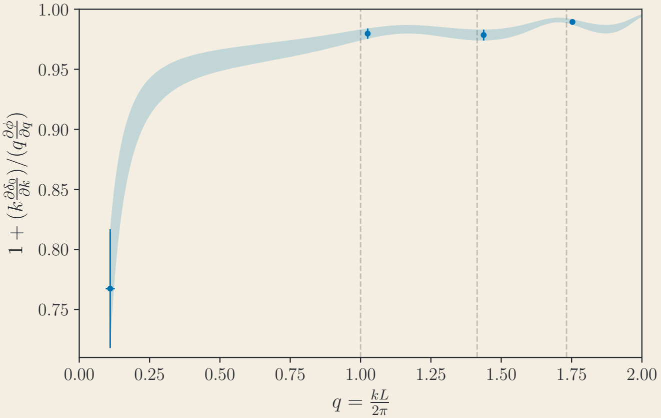
$I = 3/2$ $K\pi$ scattering

Lellouch-Lüscher proportionality factors

q	F
0.110(16)	117(27)
1.0253(87)	69.84(65)
1.4375(93)	59.60(41)
1.7530(96)	80.99(37)

Table: Finite-to-infinite volume proportionality factors

$F^2 = 8\pi\left\{q\frac{\partial\phi}{\partial q} + k\frac{\partial\delta_0}{\partial k}\right\}\frac{E_n^2}{k_n^3}$



Conclusions & Outlook

Exploring distillation at the $SU(3)$ flavor symmetric point

- We have a working and flexible distillation setup.
  - $N_{\text{vec}} = 60$ seems to be a good compromise for what we want to achieve.
  - First results for $I = 3/2$ $K\pi$ scattering and finite-to-infinite volume proportionality factors.
- The next steps:
  - Extend analysis to moving frames.
  - Our dataset also allows us to look at $I = 1/2$ $K\pi$ as well as $\pi\pi$ and $K\bar{K}$ scattering.
  - We will perform the calculation at multiple lattice spacings with (approximately) constant quark masses and physical volume.

Conclusions & Outlook

Steps towards hadronic D-decays

$$|A|^2 = 8\pi \left\{ q\frac{\partial\phi}{\partial q} + k\frac{\partial\delta_0}{\partial k} \right\}_{k=k_n} \frac{E_n^2 m_D}{k_n^3} \left| Z^{\overline{\mathrm{MS}}} \langle n, L | \mathcal{H}_{\mathrm{weak}} | D, L \rangle \right|^2$$

- Non-perturbative renormalization of four-quark operators
- Extraction of the matrix element from three-point functions
- **Multi-hadron final state**
- **Finite volume formalism**