Universität Münster

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Practical applications of distillation profiles

in lattice meson spectroscopy

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Introduction

Topic:

- Lattice QCD

  $\hookrightarrow$ Hadron Spectroscopy

  $\hookrightarrow$ Distillation

  $\hookrightarrow$ Profiles

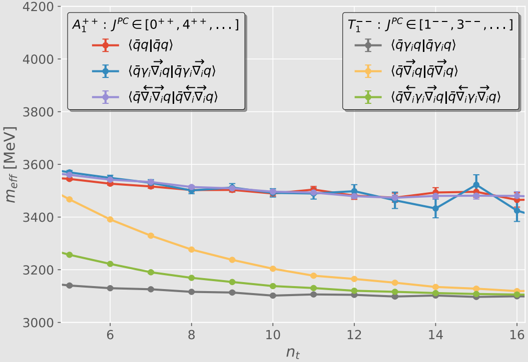
Who is involved:

- J. Finkenrath
- J. Heitger
- R. Höllwieser
- F. Knechtli
- T. Korzec
- M. Peardon
- L. Struckmeier
- J. Urrea-Niño

Outline:

1. Basics
2. Distillation Profiles
3. Performing the contractions
4. Charmonium Spectroscopy
5. The static-light system
6. The D meson
7. Outlook

Basics



$$\langle\langle O_i(t) O_j(0) \rangle\rangle = \sum_n Z_n \exp(-E_n t)$$

- **Isolate channel** with lattice group representation
- We want **good overlap** with physical states. (Typically the ground state)
- For that we need **smooth** and **pysically extended** sources. Quark fields are often **smeared**.

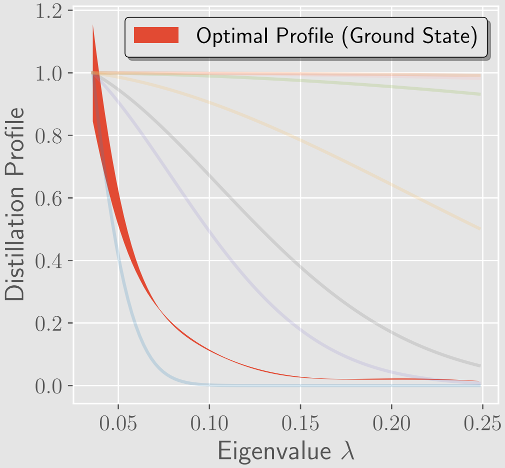
Standard Distillation

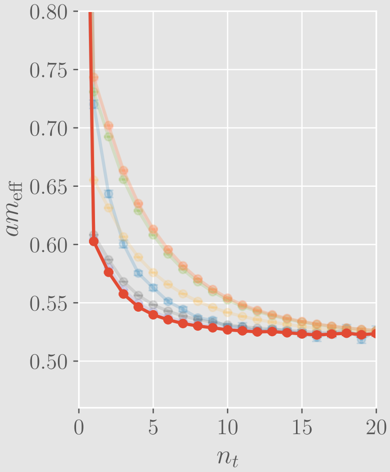
- Higher Laplacian eigenmodes are suppressed.
- Write quark fields in space of N_V **lowest eigenmodes**. [Michael Peardon et al., PhysRevD.80.054506, 2009]
- $q \longrightarrow VV^\dagger q$ with $\Delta V_i = \lambda_i V_i$
- Inversions can be **precomputed** and stored.
- Increasingly used for spectroscopy.

Distillation Profiles

- We can exploit that we are free to choose $q \longrightarrow VJV^{\dagger} q$ instead [Francesco Knechtli et al., PhysRevD.106.034501, 2022] [see thesis prize J. Urrea Niño].
- J is diagonal with entries $g(\lambda_i)$, the **quark profile**
- **Gaussians** are used in practice.
- Changes are **independent of inversion**.
- The **optimal profile** is determined by solving the GEVP.

Distillation Profiles





Performing the contractions

Example: One meson $\langle\langle PP \rangle\rangle$ correlator

$$\mathrm{tr}\left[S \; \gamma_5 \; S \; \gamma_5 \right]$$

$$\rightarrow \mathrm{tr}\left[V \; V^\dagger \; S \; V \; V^\dagger \; \gamma_5 \; V \; V^\dagger \; S \; V \; V^\dagger \; \gamma_5 \right]$$

$$= \mathrm{tr}\left[\tau \; \phi_5 \; \tau \; \phi_5 \right]$$

With the **perambulator**:

$$\tau = V^\dagger \; S \; V$$

And the **elemental**:

$$\phi_5 = V^\dagger \; \gamma_5 \; V$$

Graphics by Tomasz Korzec

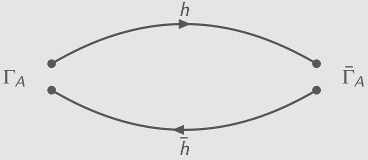


Figure: Sketch of the correlator. Time on x-axis.

Performing the contractions

$$\langle\langle \mathrm{tr}\left[\square_0(0)\square_{q_0}(t_0,t_1)\square_1(t_1)\square_{q_1}(t_1,t_2)\ldots\square_{N-1}(t_{N-1})\square_{q_{N-1}}(t_{N-1},t_0)\right]\rangle\rangle_{\text{gauge}}$$

- $\square$ and $\square$ are $4N_V \times 4N_V$ matrices
- $\square$ decomposes into $(4\times 4)\bigotimes(N_V \times N_V)$
- Changing the profiles:
  - is volume independent
  - can be done independently for every t_n-combination

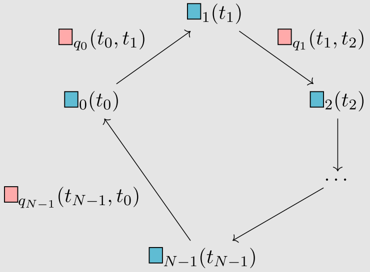


Figure: N-point diagram with distillation

Charmonium Spectroscopy

- We are interested in Ψ'' ($c\bar{c}$, 1^{--})
- 48×24^3 ($N_f = 2$)
- 8×8-GEVP with:
  - γ_i and $\gamma_4\gamma_i$
  - different smearings
  - covariant derivatives

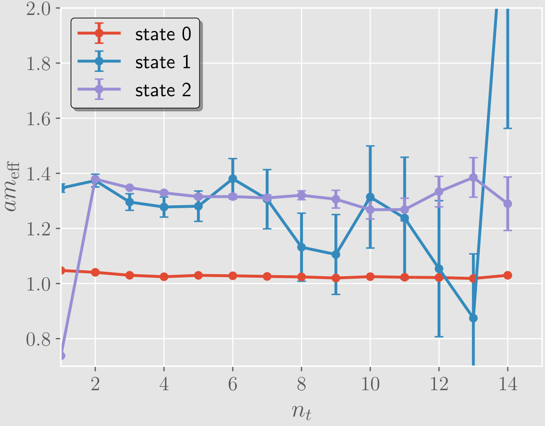


Figure: spectrum without distillation.

Charmonium Spectroscopy

With Distillation:

- 14×14-GEVP with:
  - γ_i and $\gamma_4\gamma_i$
  - different profiles
  - **No** covariant derivatives

- Similar dependence on γ_4 inclusion

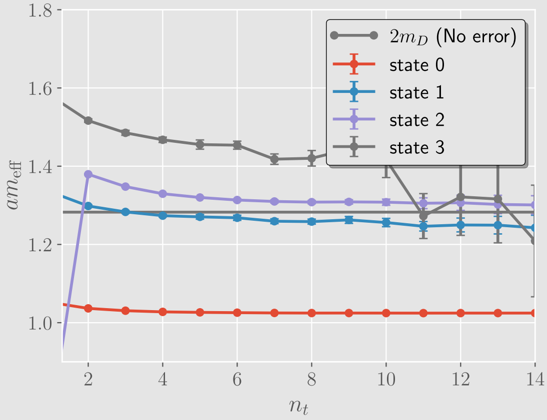


Figure: Spectrum with distillation.

The static-light system

- Static-light = static limit of B-mesons
- Investigated on $N_f = 3 + 1$
- Distillation profiles provide improvement.

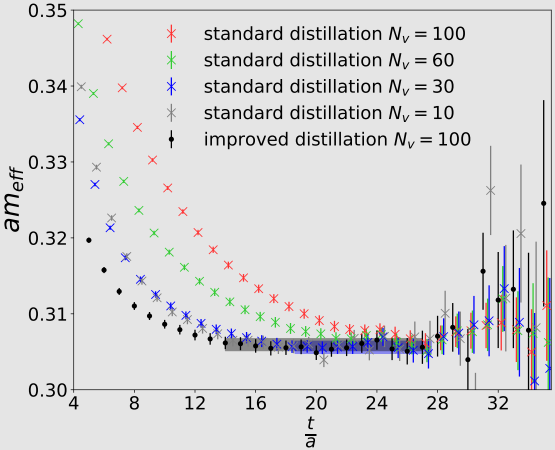


Figure: Different number of eigenvectors for standard distillation (from [L. Struckmeier @ Lattice 24]).

The D meson

- Different particles show different optimal profiles
- Narrower profile $\leftrightarrow$ less localized contributions

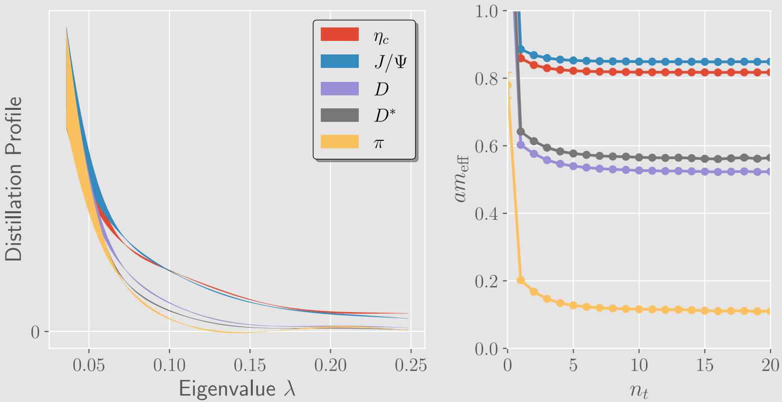


Figure: Different profiles and masses on $N_f = 3 + 1$ ensemble.

The D meson

- Different momenta show different optimal profiles
- Profiles still improve results
- Also works with twisted boundary conditions

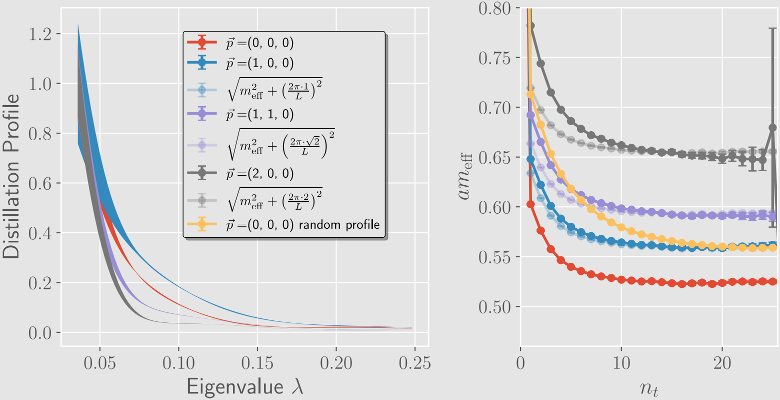


Figure: Optimal profiles and energies at different momenta.

Outlook

- Application of profiles in **two-particle operators**
- Targets might be $\Psi'' \longrightarrow D\bar{D}$ or $T_{cc} \longrightarrow DD^*$
- Charmonium spectroscopy on $N_f = 3 + 1$ [J. Urrea-Niño @ Lattice23] [J. Urrea-Niño @ Lattice24]
- Combine: more complex diagrams + momenta + profiles

Thank you for listening!

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