

# Lattice NRQCD & Hadron Spectroscopy

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## NRQCD

- Lattice non-relativistic QCD can be used for heavy hadrons.
- Good place to start is with the  $\eta_b$  and  $\Upsilon$  particles: the simpler case of getting the meson properties right helps in getting, e.g. CKM matrix elements from the lattice.
- If these are tuned so that lattice results and experiment agree the parameters can then be applied to other particles or excitations.
- Time evolution of the heavy quarks given by

$$G(\vec{x}, t+1) = \left(1 - \frac{a\delta H}{2}\right) \left(1 - \frac{aH_0}{2n}\right)^n U_t^\dagger(x) \\ \times \left(1 - \frac{aH_0}{2n}\right)^n \left(1 - \frac{a\delta H}{2}\right) G(\vec{x}, t).$$

# Lattice Ensembles

The heavy quarks are placed on a lattice consisting of gluon fields and sea quarks using configurations generated by the MILC collaboration. Current lattices contain  $2 + 1 + 1$  flavors of sea quarks: up and down, strange, and charm.

Currently working on three sets of  $\sim 1000$  lattices: very coarse ( $a \simeq 0.15$  fm;  $16^3 \times 48$ ), coarse ( $a \simeq 0.12$  fm;  $24^3 \times 64$ ) and fine ( $a \simeq 0.09$  fm;  $32^3 \times 96$ ).

Pick a starting time slice and use evolution equation to progress through time slices. I use 40 time slices and run on each configuration at 4 different starting time slices.

# Fitting the Data

Baysian fitting is used to extract the spectrum. The following fit function is used:

$$G(t) = \sum_{k=1}^{n_{exp}} A^2 e^{-E_k t}$$

and the number of exponentials used in the fit can be varied. When an ideal number of exponentials has been reached the results and errors will stabilise.

Fitting for various values of the meson momentum, the kinetic mass can then be extracted using:

$$M_{kin} = \frac{p^2 a^2 - (\Delta E a)^2}{2\Delta E a}$$

where  $\Delta E = E(p) - E(0)$ .

## Kinetic Mass

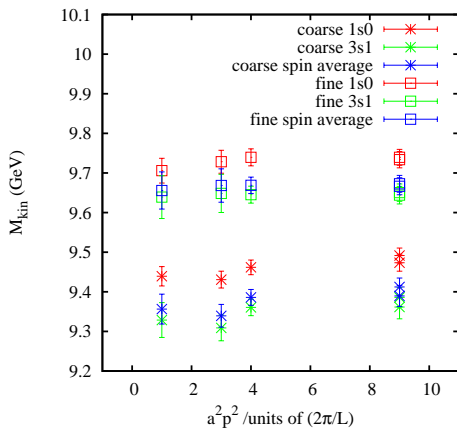


Figure: Kinetic mass on coarse and fine lattices; fine mistuned.

## Lattice Results

The gold-plated meson spectrum from lattice QCD - HPQCD collaboration 2009

