Effects of Low vs High Fermionic Modes on Hadron Mass Generation

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Outline

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3. Hadron Spectroscopy: building blocks and tools
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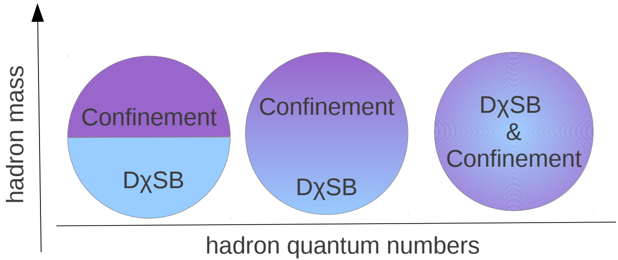
Motivation:



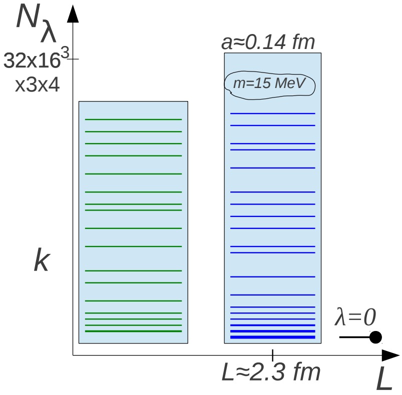
- 1. How important is Dynamical Chiral Symmetry Breaking for the hadron mass generation?
- 2. Are Dynamical Chiral Symmetry Breaking and Confinement phenomena interralated?

Banks-Casher Relation and the Origin of DχSB

The quark condensate expressed in terms of the spectral density of the Dirac operator low-lying eigenmodes:

$$\langle 0|\overline{q}q|0\rangle = -\pi\rho(0)$$

- Banks-Casher Relation (1980).



$$\rho(0) \neq 0 \Longleftrightarrow D\chi SB$$

- Number of the low-lying eigenmodes responsible for $D\chi SB$ scales with L

For a given L, m, etc

- We study how various numbers of the Dirac low eigenmodes k affect hadron masses

Hadron Spectroscopy: Propagators

In addition to the full quark propagator $S_{Full} = D^{-1}$, using a spectral representaion of S

$$S = \underbrace{\sum_{i=1}^{\mathbf{k}} \frac{1}{\lambda_i} |\lambda_i\rangle\langle\lambda_i|}_{\text{low mode part}} + \underbrace{\sum_{i=\mathbf{k}+1} \frac{1}{\lambda_i} |\lambda_i\rangle\langle\lambda_i|}_{\text{high mode part}}$$

we compute *truncated propagators*

$$S_{LM(k)} = \sum_{i=1}^{\mathbf{k}} \frac{1}{\lambda_i} |\lambda_i\rangle\langle\lambda_i|$$

and *reduced propagators*

$$S_{RD(k)} = S_{Full} - S_{LM(k)}$$

- where k takes 32,64,128,i.e. the number of eigenvalues and corresponding low modes of $\gamma_5 D_{CI}$ [C. Gattringer et al (2001)] computed on 160 gauge configurations with $n_f = 2$ dynamical quarks.

Hadron Spectroscopy: Variational Method

We use a wide set of interpolators $\mathcal{O}_{\{i=1,2,\ldots\}}$ with Jacobi-smeared quark sources of different widths and derivative sources.

Construct the cross-correlation matrix

$$C_{ij}(t) = \langle 0|\mathcal{O}_i(t)\mathcal{O}_j^\dagger(0)|0\rangle$$

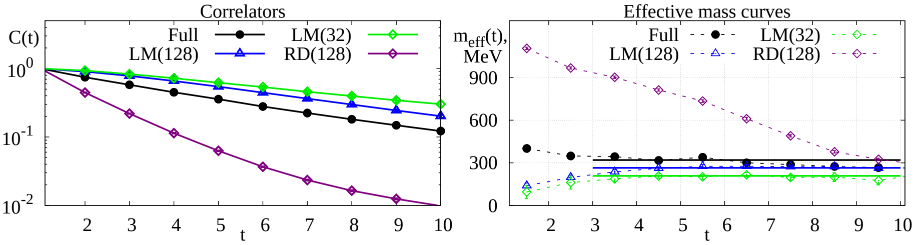
Solve generalized eigenvalue problem:

$$C(t)\vec{v}_n = \tilde{\lambda}^{(n)}(t)C(0)\vec{v}_n,$$

$\tilde{\lambda}^{(n)}(t) \propto e^{-m^{(n)}t}$. Having ordered $\tilde{\lambda}^{(1)} > \tilde{\lambda}^{(2)} > \ldots$ we extract masses of the ground or excited states.

Hadron Masses with Low/High Fermionic Modes

$\pi\ (0^{-+})$:

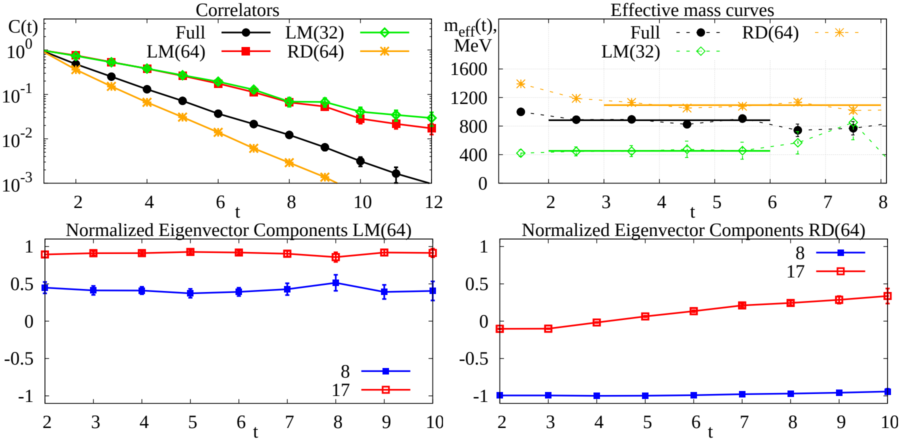


- Low modes saturate pion,
  ($\gtrsim$ 90 % of m_π is reproduced with $k = 128$)
- Pion disappears when the quark condensate is removed

How important is Dynamical Chiral Symmetry Breaking for the masses of hadrons other than pions?

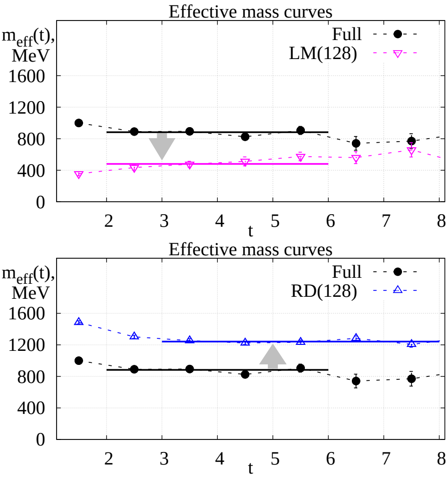
Hadron Masses with Low/High Fermionic Modes

$\rho\ (1^{--})$:



Hadron Masses with Low/High Fermionic Modes

$\rho\ (1^{--})$:

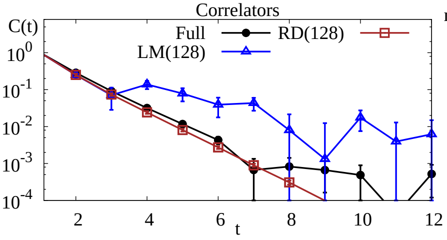


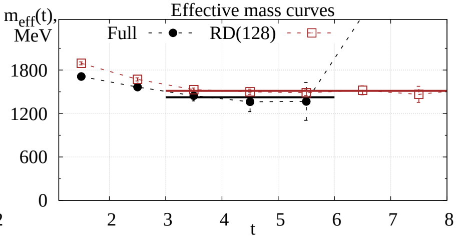
- We observe a bound state when we leave 32 low modes only
- The low modes contribute $\approx 60\%$ to the mass of the ρ meson state

- The ρ meson mass $m > m_\rho^{phys}$ after removing the quark condensate.

Hadron Masses with Low/High Fermionic Modes

b_1 (1^{+-}) :

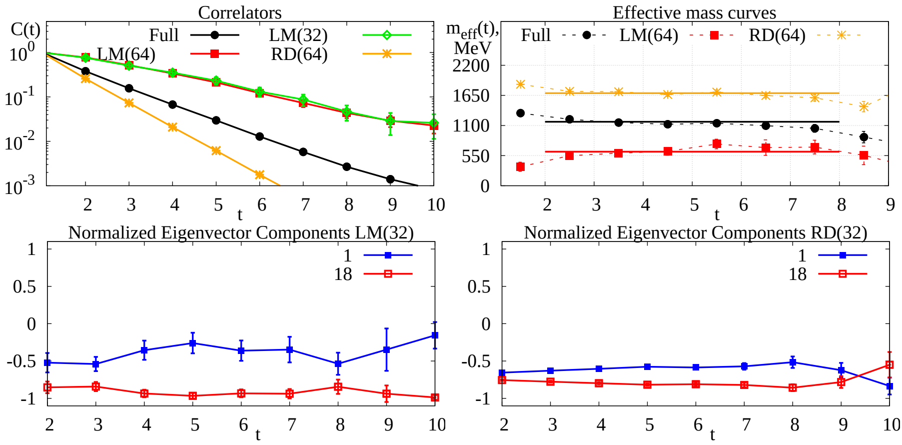




Unlike for ρ (or a_1) there is no bound state for b_1 when we include the low modes only. The low modes responsible for DχSB do not provide confinement for b_1.

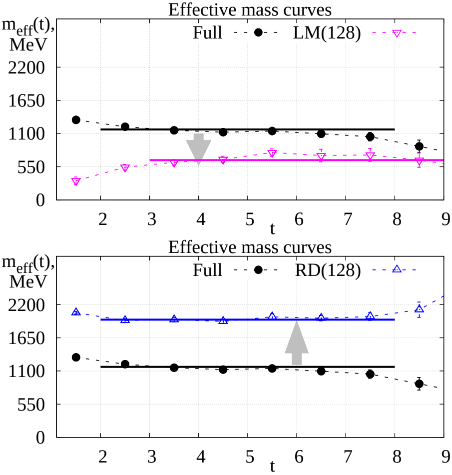
Hadron Masses with Low/High Fermionic Modes

$N(\frac{1}{2}^+)$:



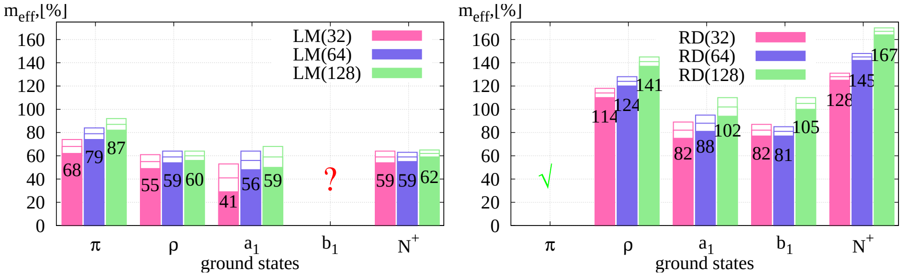
Hadron Masses with Low/High Fermionic Modes

N^+:



- The low modes produce around 2/3 of the original nucleon mass
- DχSB alone can not be responsible for the mass of N^+
- N^+ becomes even heavier when the low modes are removed

Relative Hadron Masses with or without the Low Modes



- The number of the low modes saturating π accounts only for $\approx 2/3$ of the ρ and nucleon masses
- The b_1 state is formed only with the high-lying modes

Conclusions

- Upon removal of the low-lying modes from the valence quarks all hadrons survive (except for a pion). There is a large chirally symmetric mass in this regime.
- The low- lying modes saturating pions provide $2/3$ of mass for N^+ and ρ states
- The b_1 state is not formed with the low-lying modes. The latter may indicate that the low-lying modes do not encode the effect of confinement.