Lattice study on diquark properties

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Outline

- Motivation
- Lattice set up
- Preliminary results
- Summary

Motivation

- A diquark is a two-quark correlation in a hadron containing more than two quarks.
- In some models, a diquark is considered as a bound state from two quarks and is treated as a confined particle (color non-singlet).

Motivation

- A diquark is a two-quark correlation in a hadron containing more than two quarks.
- In some models, a diquark is considered as a bound state from two quarks and is treated as a confined particle (color non-singlet).
- Correlations among quarks can tell us inter-quark interactions.
- Diquarks are used to explain the structures of exotic states such as tetraquark states.
- Diquarks are used to explain some features of excited baryon spectrum.
- Both one-gluon exchange and instanton models suggest attraction in the color antitriplet 0^+ diquark state.

Jaffe, hep-ph/0409065

What we are doing

- Information of diquarks from lattice QCD.
- Diquarks are not color singlets.
- We calculate diquark 2-point correlators in the Landau gauge and extract effective "masses".
- The calculation is for diquarks with quantum numbers $J^P = 0^+, 1^+$.
- Quark "masses" are also obtained in the Landau gauge for comparison from

$$G(t) = \sum_{\vec{x}} \langle \Omega | T \psi^a_\alpha(x) \bar{\psi}^a_\alpha(0) | \Omega \rangle.$$

- Mass difference may give some information of the strength of diquark correlation.

Interpolating fields

Table: Currents and correlation functions. A trace is performed in color space

J^P (diquark)	Current	Correlator
0^+(good,scalar)	$J_c^5 = \epsilon_{abc}[q_1^a C\gamma_5 q_2^b]$	$\sum_{\vec{x}}\langle\Omega\vert TJ_c^5(x)\bar{J}_c^5(0)\vert\Omega\rangle$
0^+(good,scalar)	$J_c^{05} = \epsilon_{abc}[q_1^a C\gamma_0\gamma_5 q_2^b]$	$\sum_{\vec{x}}\langle\Omega\vert TJ_c^{05}(x)\bar{J}_c^{05}(0)\vert\Omega\rangle$
1^+(bad,vector)	$J_c^i = \epsilon_{abc}[q_1^a C\gamma_i q_2^b]$	$\frac{1}{3}\sum_i\sum_{\vec{x}}\langle\Omega\vert TJ_c^i(x)\bar{J}_c^i(0)\vert\Omega\rangle$

- $q_1 = u, q_2 = d$
- $q_1 = u, q_2 = s$
- $m_u = m_d$ is varied to examine the quark mass dependence.

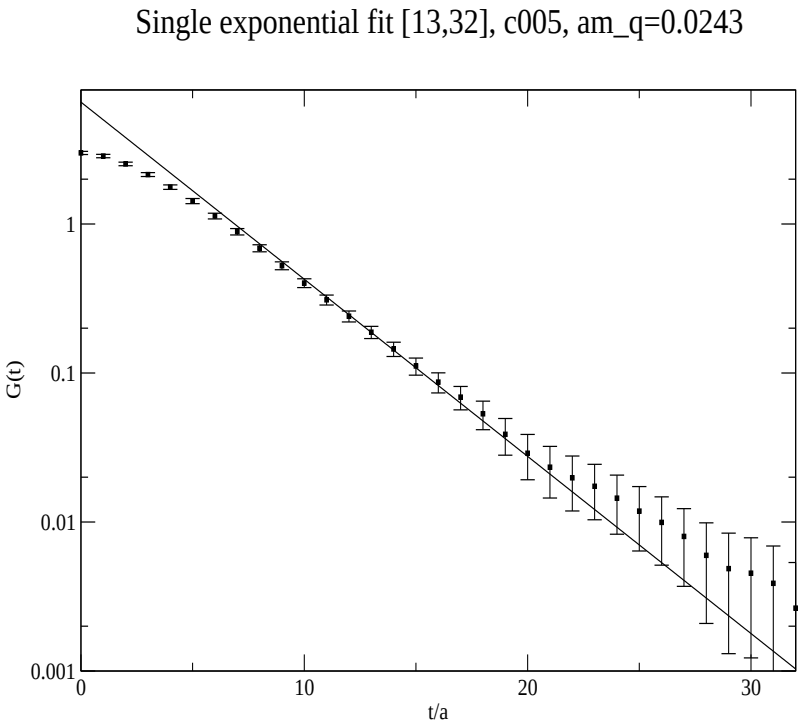
Lattice setup

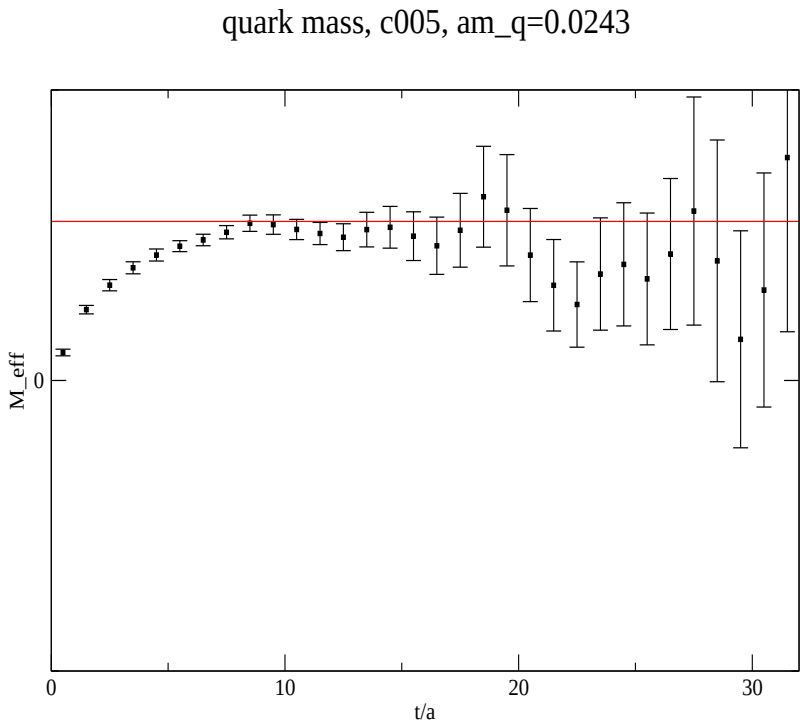
Table: Parameters of configurations with 2+1 flavor dynamical domain wall fermions (RBC-UKQCD). [Aoki et al. 2011]

$1/a$(GeV)	label	am_{sea}	volume	N_{conf}
1.73(3)	c005	0.005/0.04	$24^3 \times 64$	92
	c01	0.01/0.04	$24^3 \times 64$	88
2.28(3)	f004	0.004/0.03	$32^3 \times 64$	50

- Seven overlap valence quark masses are used on each lattice.
- $am_q = 0.0135, 0.0243, 0.0489, 0.067(am_s), 0.15, 0.33, 0.67$ on the coarse lattices.
- $am_q = 0.00677, 0.0129, 0.024, 0.047(am_s), 0.18, 0.28, 0.5$ on the fine lattice.
- Point source quark propagators. Statistical errors are from bootstraps.

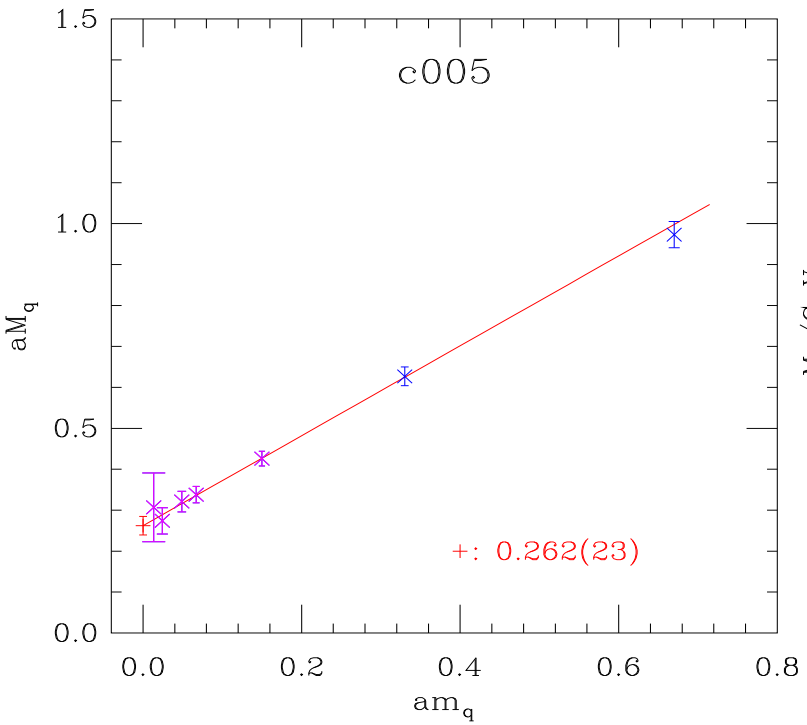
Quark propagators in Landau gauge

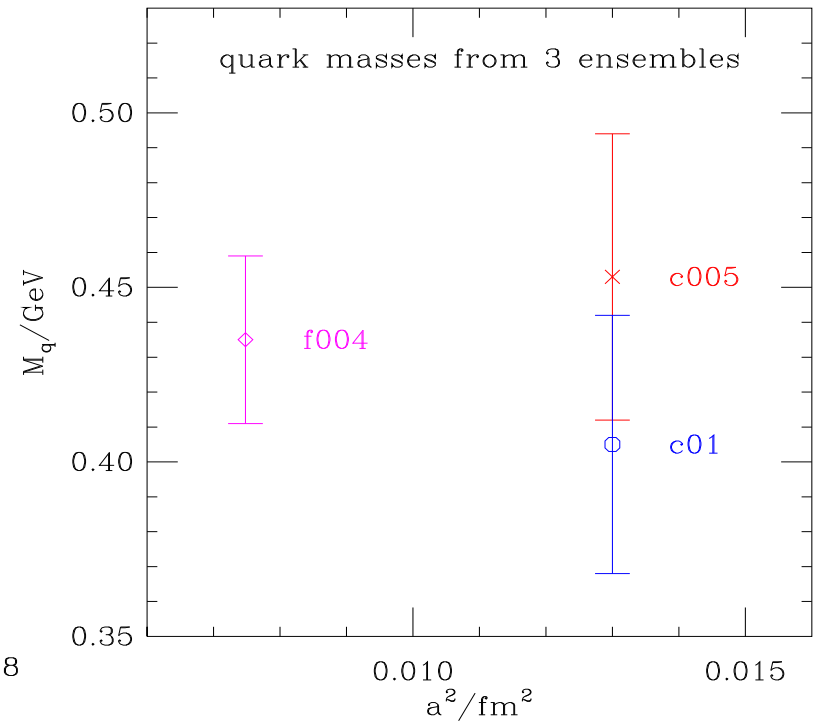




- An example of $G(t) = \sum_{\vec{x}} \langle \Omega | T \psi^a_\alpha(x) \bar{\psi}^a_\alpha(0) | \Omega \rangle$
- A single exponential fit in $t \in [13, 32]$ gives "mass" $aM_q = 0.276(33)$.
- $M_{eff} = \ln(C(t)/C(t+1))$

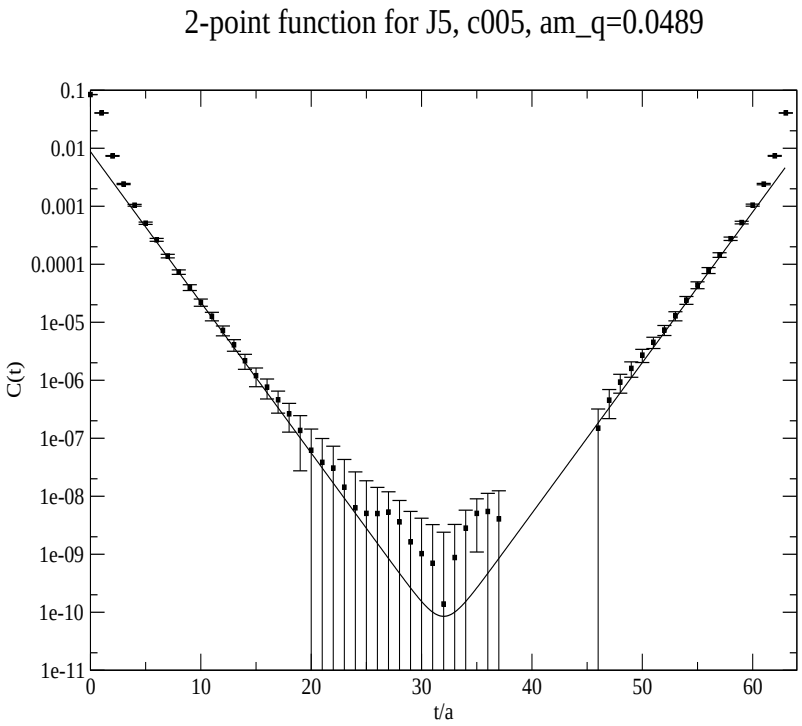
Quark masses

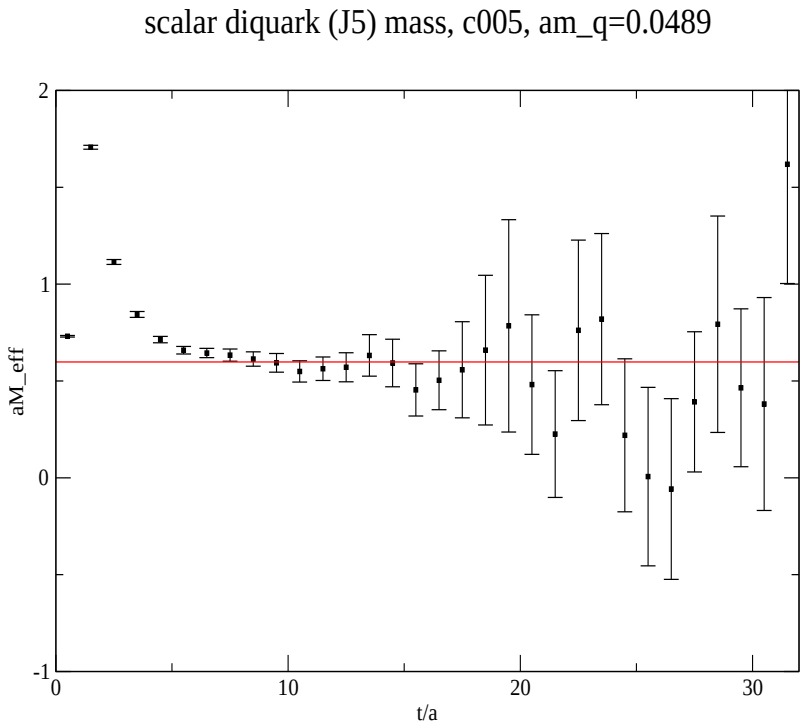




- A linear extrapolation to the valence quark chiral limit gives $aM_q = 0.262(23)$ for ensemble c005 (using the lowest five masses).
- Using $1/a = 1.73(3)$ GeV and $1/a = 2.28(3)$ GeV, one gets $M_q = 0.453(41), 0.405(37)$ and $0.435(24)$ GeV on ensembles c005, c01 and f004 respectively.

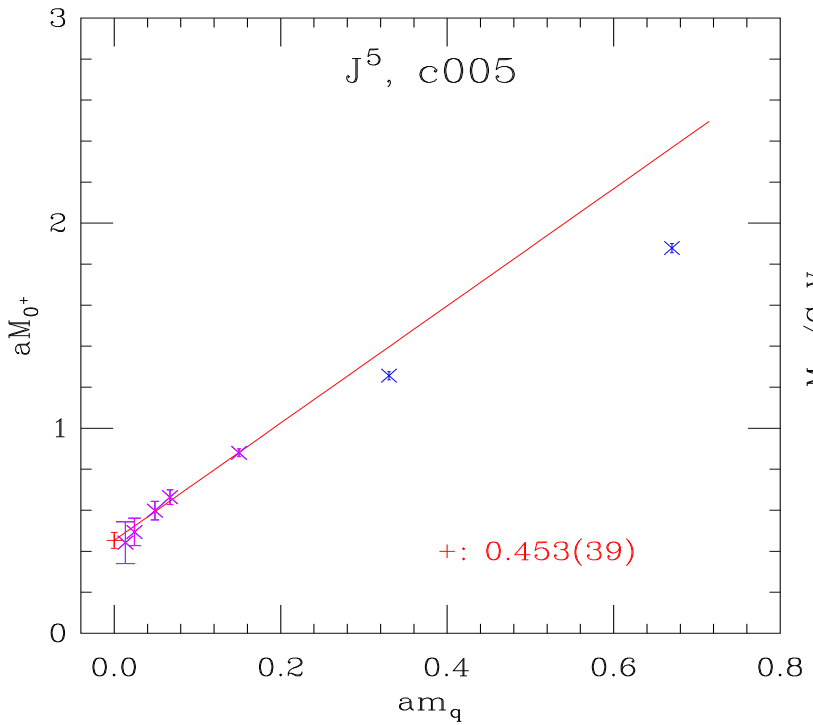
Scalar diquark from J^5 with $q_1 = u, q_2 = d$

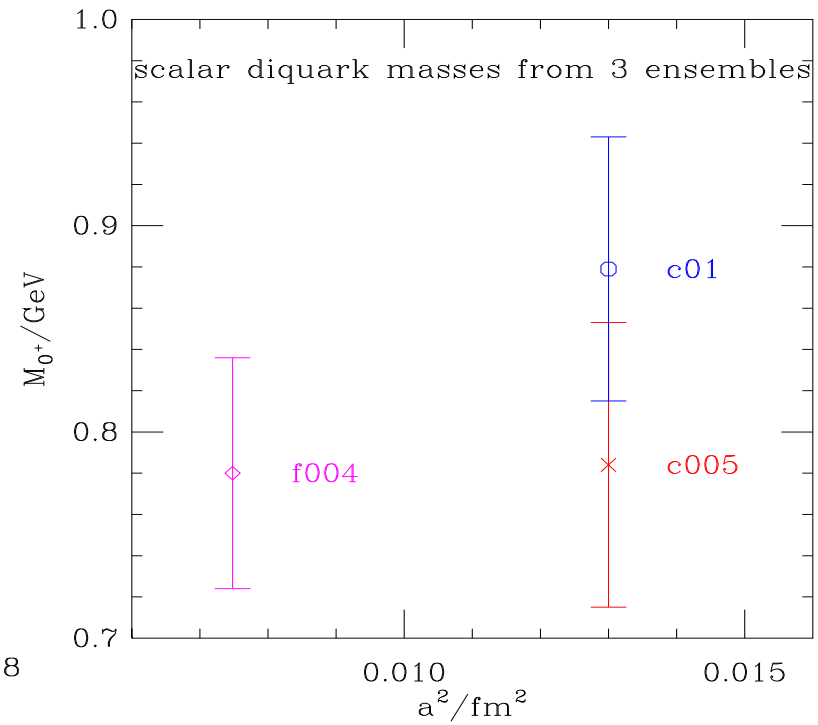




- A single exponential fit gives $aM_{0^+} = 0.598(45)$.
- The result 0.625(62) from J^{05} is in agreement.

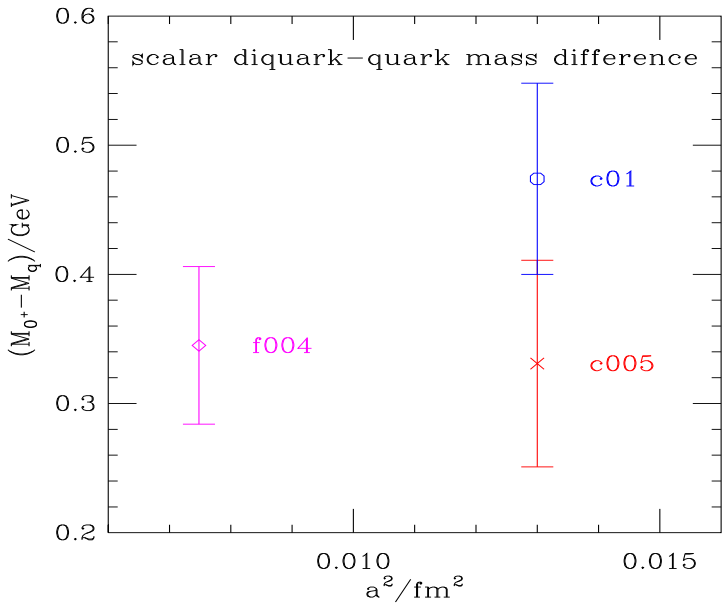
Scalar diquark from J^5 with $q_1 = u, q_2 = d$





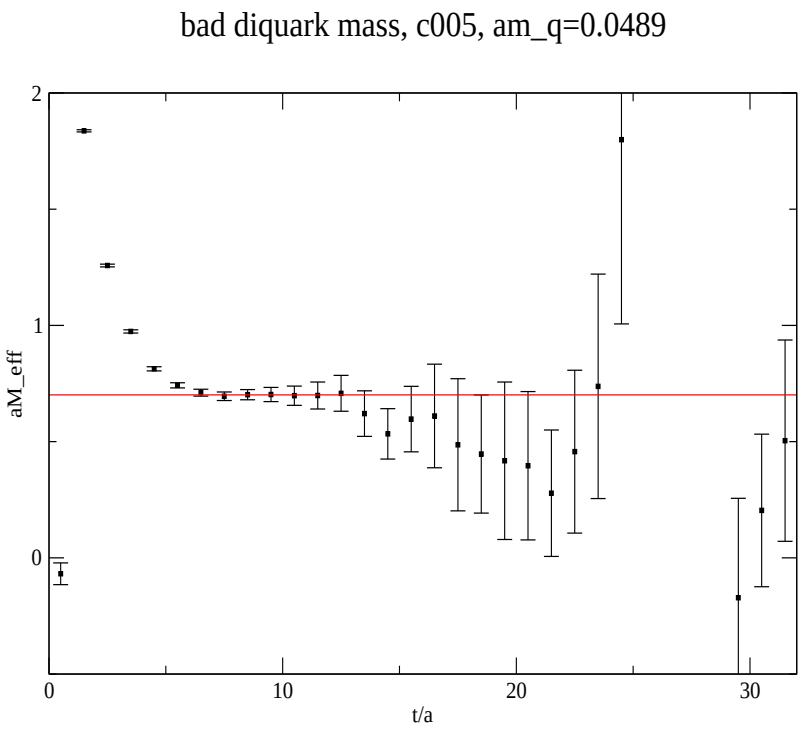
- A linear extrapolation to the valence quark chiral limit gives $aM_{0^+} = 0.453(39)$ for ensemble c005 (using the lowest five masses).
- Using the lattice spacings, one gets $M_{0^+} = 0.784(69), 0.879(64)$ and $0.780(56)$ GeV on ensembles c005, c01 and f004 respectively.

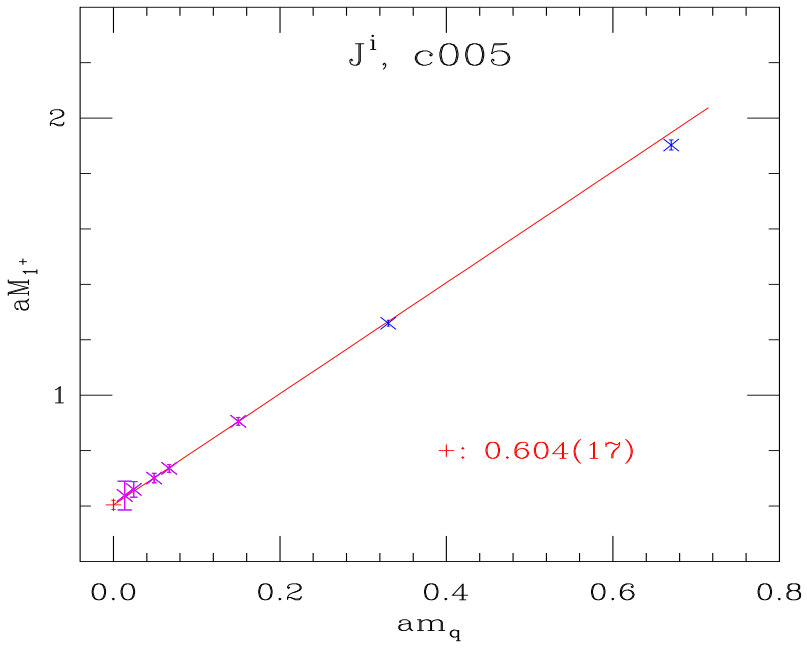
Mass difference between scalar diquark and quark



- The diquark-quark mass difference reflects the strength of the diquark correlation.
- $M_{0^+} - M_q =?$ ($\sim$ 310 MeV expected, Jaffe, hep-ph/0409065)
  c005: $0.784(69) - 0.453(41) = 0.331(80)$ GeV
  c01: $0.879(64) - 0.405(37) = 0.474(74)$ GeV
  f004: $0.780(56) - 0.435(24) = 0.345(61)$ GeV
- $M_{0^+} - 2M_q < 0$ except for c01

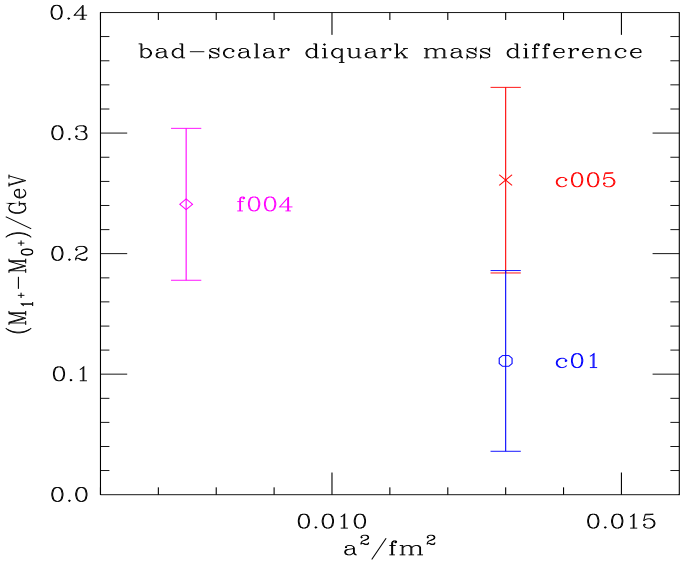
Bad diquark with $q_1 = u, q_2 = d$





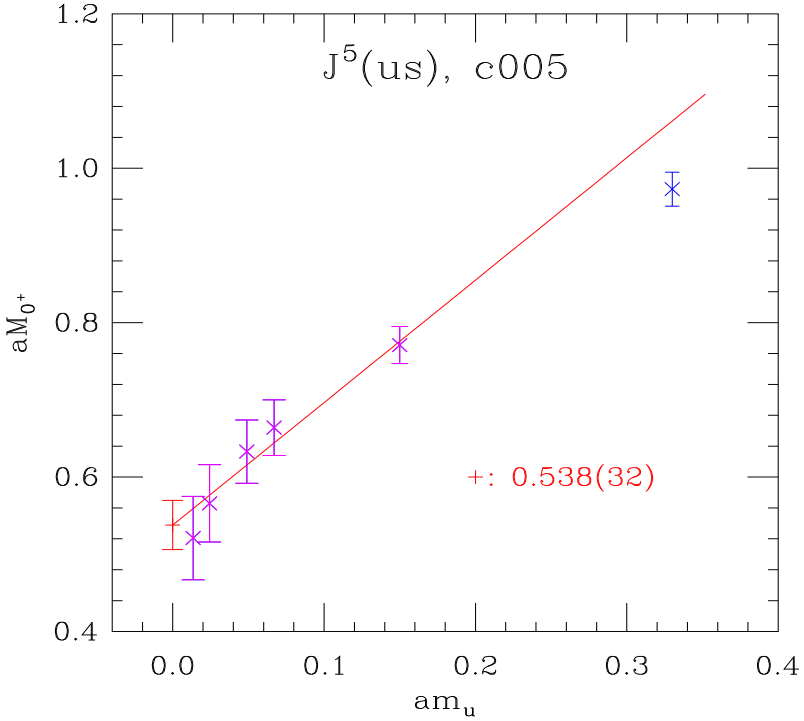
- Left graph: The mass indicated by the red line is from a single exponential fit to the 2-point correlator.
- Right graph: A linear extrapolation to the chiral limit with the lowest five data points.

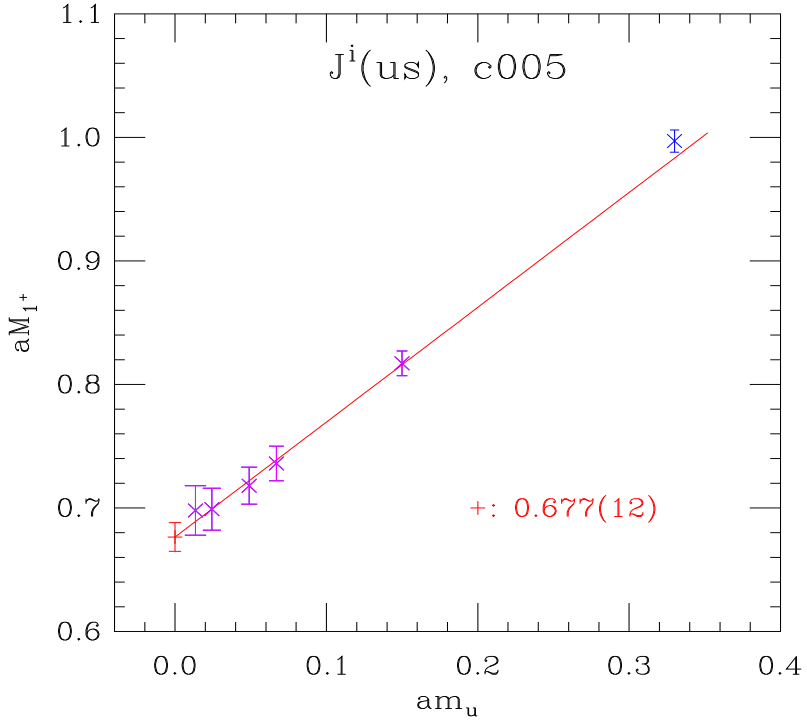
Mass difference between scalar and vector diquarks



- The vector-scalar diquark mass difference also reflects the strength of the diquark correlation.
- $M_{1^+} - M_{0^+} =?$ ($\sim$ 200 MeV expected)
  c005: $1.045(35) - 0.784(69) = 0.261(77)$ GeV
  c01: $0.990(39) - 0.879(64) = 0.111(75)$ GeV
  f004: $1.021(28) - 0.780(56) = 0.241(63)$ GeV
- Sea quark mass dependence? Systematic error from the chiral extrapolation?

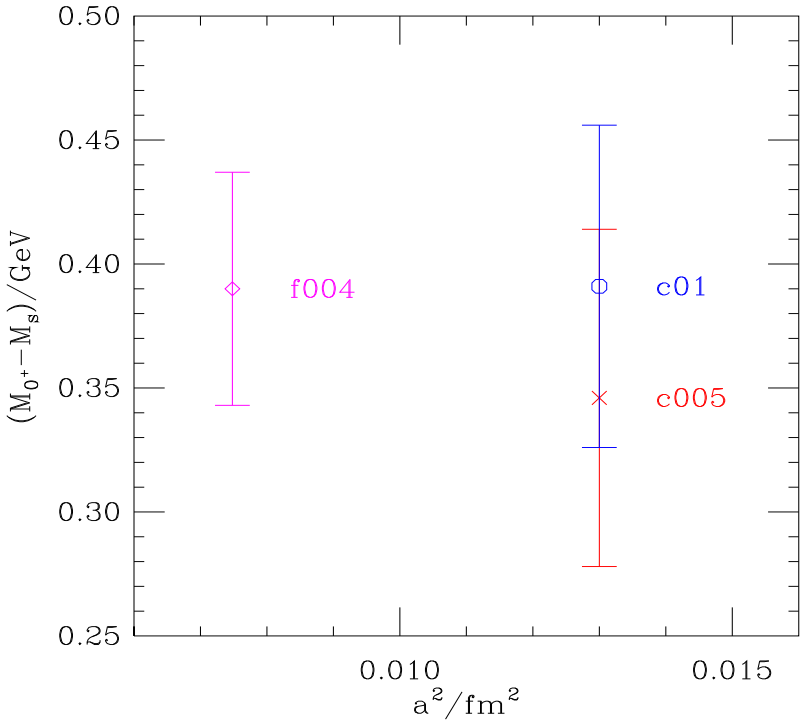
Diquarks with $q_1 = u, q_2 = s$





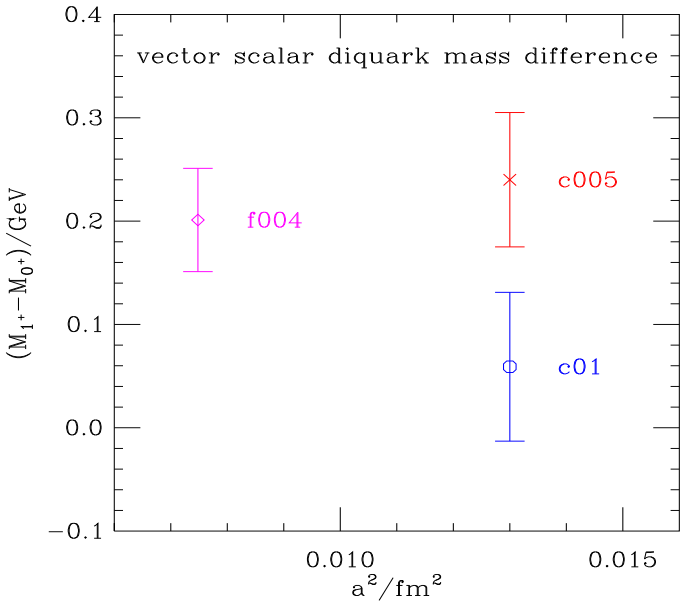
- $am_s = 0.067, 0.047$ on the coarse and fine lattice respectively, which agree with the physical strange quark mass within error bar. [arXiv:1401.1487]

Scalar diquark and strange quark mass difference



- $M_{0^+} - M_s =?$ ($\sim$ 500 MeV expected)
  c005: $0.931(58) - 0.585(36) = 0.346(68)$ GeV
  c01: $0.981(55) - 0.590(34) = 0.391(65)$ GeV
  f004: $0.930(43) - 0.540(20) = 0.390(47)$ GeV
- Seems to be bigger than $M_{0^+} - M_q$, but the stat. error is large.

Vector and scalar diquark mass difference ($q_1 = u, q_2 = s$)



- $M_{1^+} - M_{0^+} = ?$ ($\sim$ 150 MeV expected)
  c005: $1.171(29) - 0.931(58) = 0.240(65)$ GeV
  c01: $1.040(47) - 0.981(55) = 0.059(72)$ GeV
  f004: $1.131(25) - 0.930(43) = 0.201(50)$ GeV
- Sea quark mass dependence? systematic error?

Summary

- Two point functions of quark and diquarks ($J^P = 0^+, 1^+$) are calculated in the Landau gauge with dynamical configurations (DWF).
- The mass difference between scalar diquark and quark is obtained.
- The vector and scalar diquark mass difference is also obtained.

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- The calculation is done on three ensembles. Discretization error seems to be small. There might be sea quark mass dependence in the vector scalar diquark mass difference.
- Systematic error from the simple linear chiral extrapolation?
- More statistics/ensembles are needed. Gauge dependence (Coulomb gauge)?
- Information of diquarks from other approaches on the lattice are also needed.....

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Thank you!