Hadron spectra and leptonic decay constants with overlap fermions on HISQ gauge configurations

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(Indian Lattice Gauge Theory Initiative)

Lattice 2013, Mainz, Germany

Overlap Fermions

- Some desirable features:

  - No $O(a)$ **error.**

  - Multi-mass algorithm (more than 20 masses
    - 8-12% overhead
  - Renormalization is presumed to be relatively simple (e.g. with chiral Ward identity).

- Undesirable feature:
- -- *Cost*

Overlap fermions on 2+1+1 Flavors HISQ Configurations

- Lattices used for this study :

  HISQ gauge configurations from MILC

$32^3 \times 96$, a = 0.089 fm, $m_l/m_s = 1/5$, $m_\pi L = 4.5$, m_π = 312 MeV

$48^3 \times 144$, a = 0.058 fm, $m_l/m_s = 1/5$, $m_\pi L = 4.51$, m_π = 319 MeV

PHYSICAL REVIEW D 87, 054505 (2013) (MILC)

- **HYP smearing on gauge fields**
- **Both point source and coulomb gauge fixed wall source are used**
- **No of eigenvectors projected : 350 (a = 0.089 fm)**

  and 75 (a = 0.058 fm)
- **Preliminary results on our ongoing study will be reported here**

Rest mass Vs Kinetic mass

Charm mass is tuned by meson kinetic mass and not from rest mass ……a la FermiLab formulation

El-khadra et al, PRD55, 3933(1997)

Expanding the energy momentum relation in powers of pa

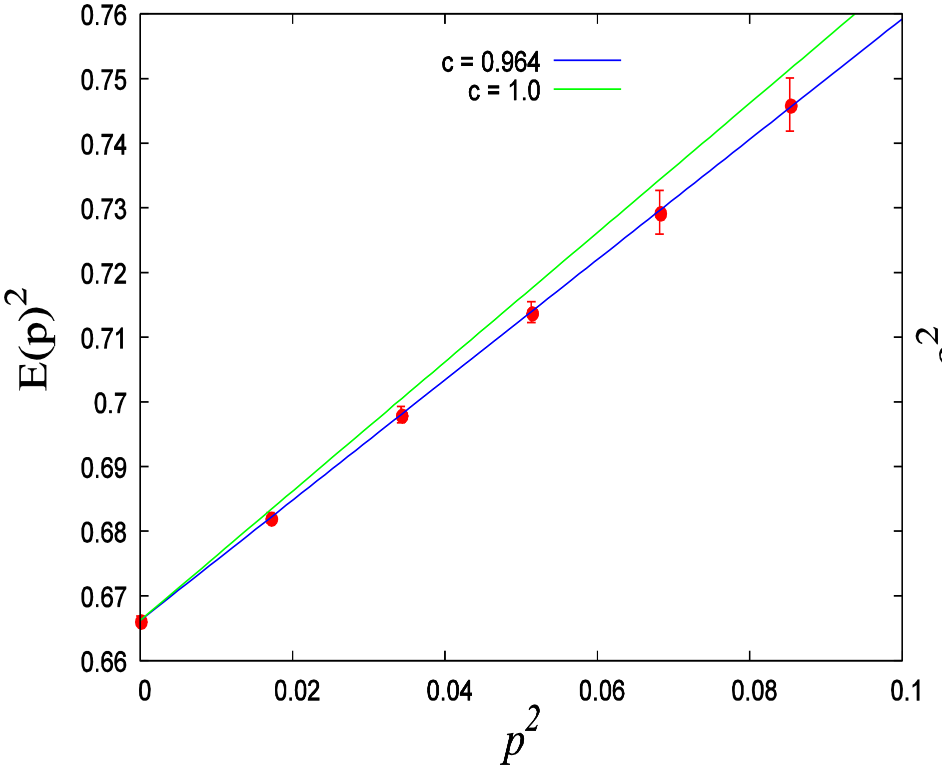
$$E^2 = M_1^2 + \frac{M_1}{M_2}\,\mathbf{p}^2 + \cdots$$

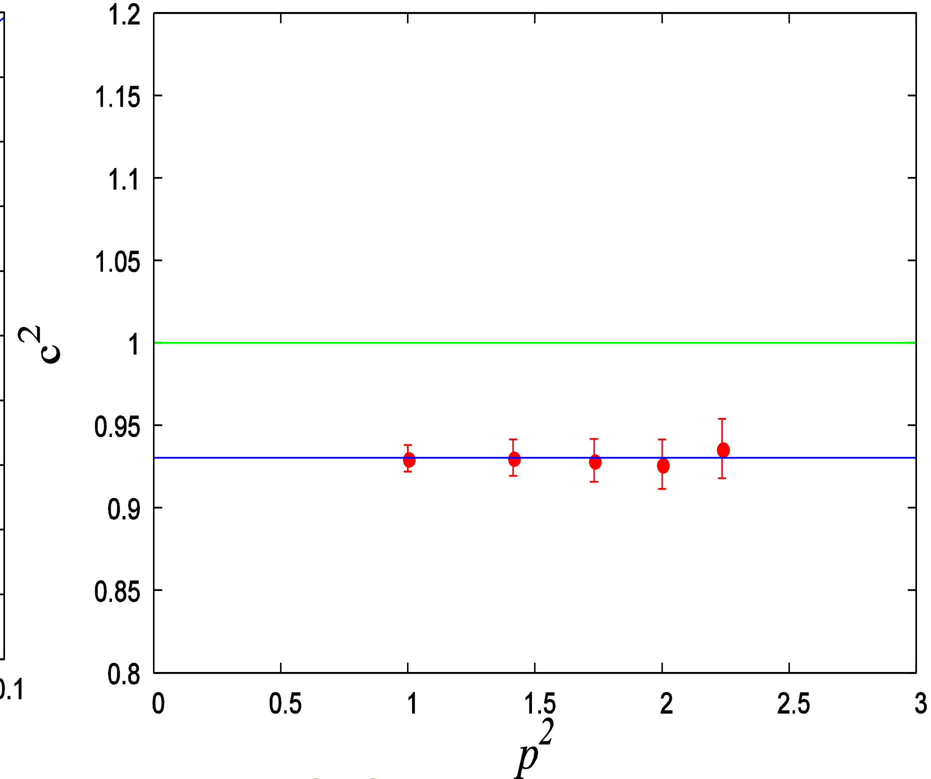
$$= M_1^2 + c^2 p^2$$

Rest mass : $M_1 = E(\mathbf{0})$

Kinetic mass : $M_2 = M_1/c^2$

Dispersion relation (at charm mass)





$$E^2(p) = E^2(p=0) + p^2 c^2$$

Finite momentum wall source is used to project to particular momentum state which reduce errorbars substantially.

Lattice spacings and tuning of charm and strange masses

Lattice spacings are calculated by Omega(sss) mass = 1672 GeV

48^3 x 144 : 0.0582(5) fm
32^3 x 96 : 0.0877(10) fm which are quite consistent with lattice spacings determined by MILC

- Strange mass is tuned by setting pseudoscalar $\underline{s}s$ mass at 685 MeV

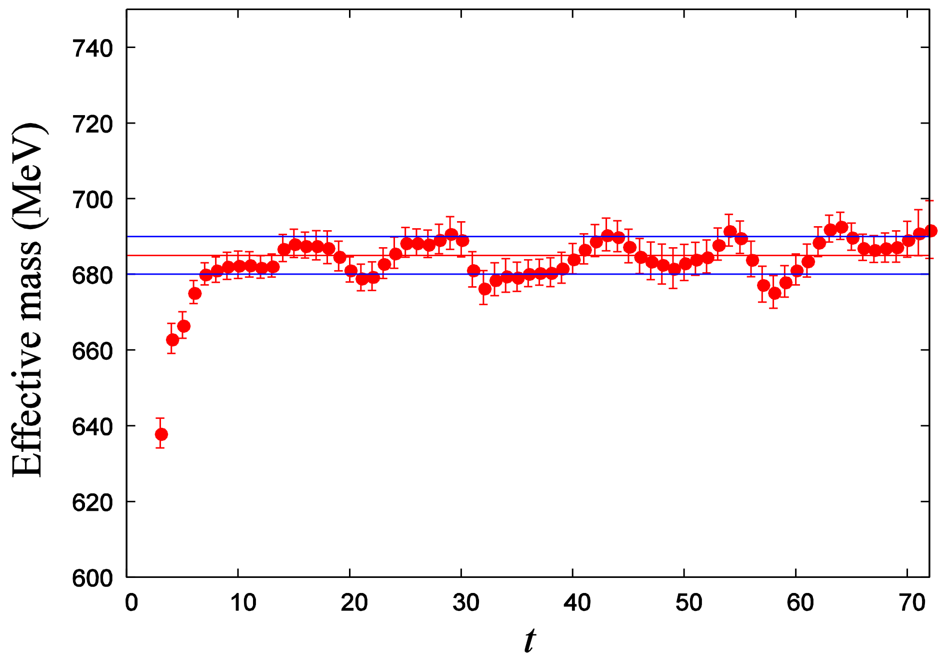
$m_s a$ = 0.048 (a = 0.0888 fm)
= 0.028 (a = 0.0582fm)

Taking m_s = 100 MeV
$m_s a$ = 0.0450 (a = 0.0888fm),
= 0.0295(a = 0.0582fm)

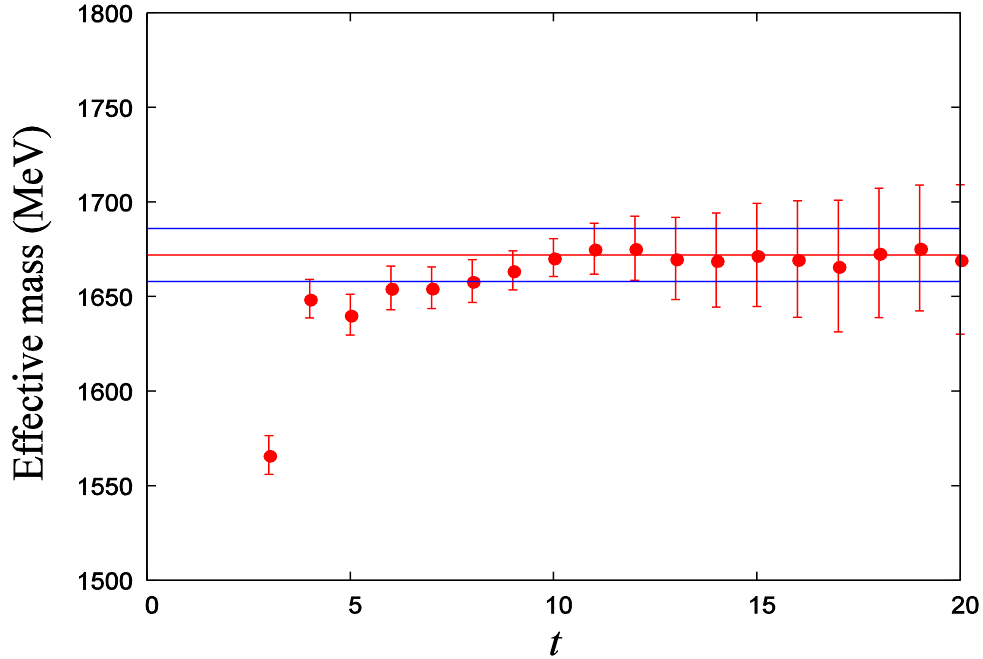
- Charm mass is tuned by $\frac{1}{4}(m_{\eta_c} + 3m_{J/\psi})$

$m_c a$ = 0.425—0.43 (a = 0.0888fm),
= 0.29 (a = 0.0582 fm)

Considering kinetic masses of mesons
(a la Fermilab formulation)



Effective mass (MeV)
740
720
700
680
660
640
620
600
0
10
20
30
40
50
60
70
t



Effective mass (MeV)
1800
1750
1700
1650
1600
1550
1500
0
5
10
15
20
t

Lattice spacings and tuning of charm and strange masses

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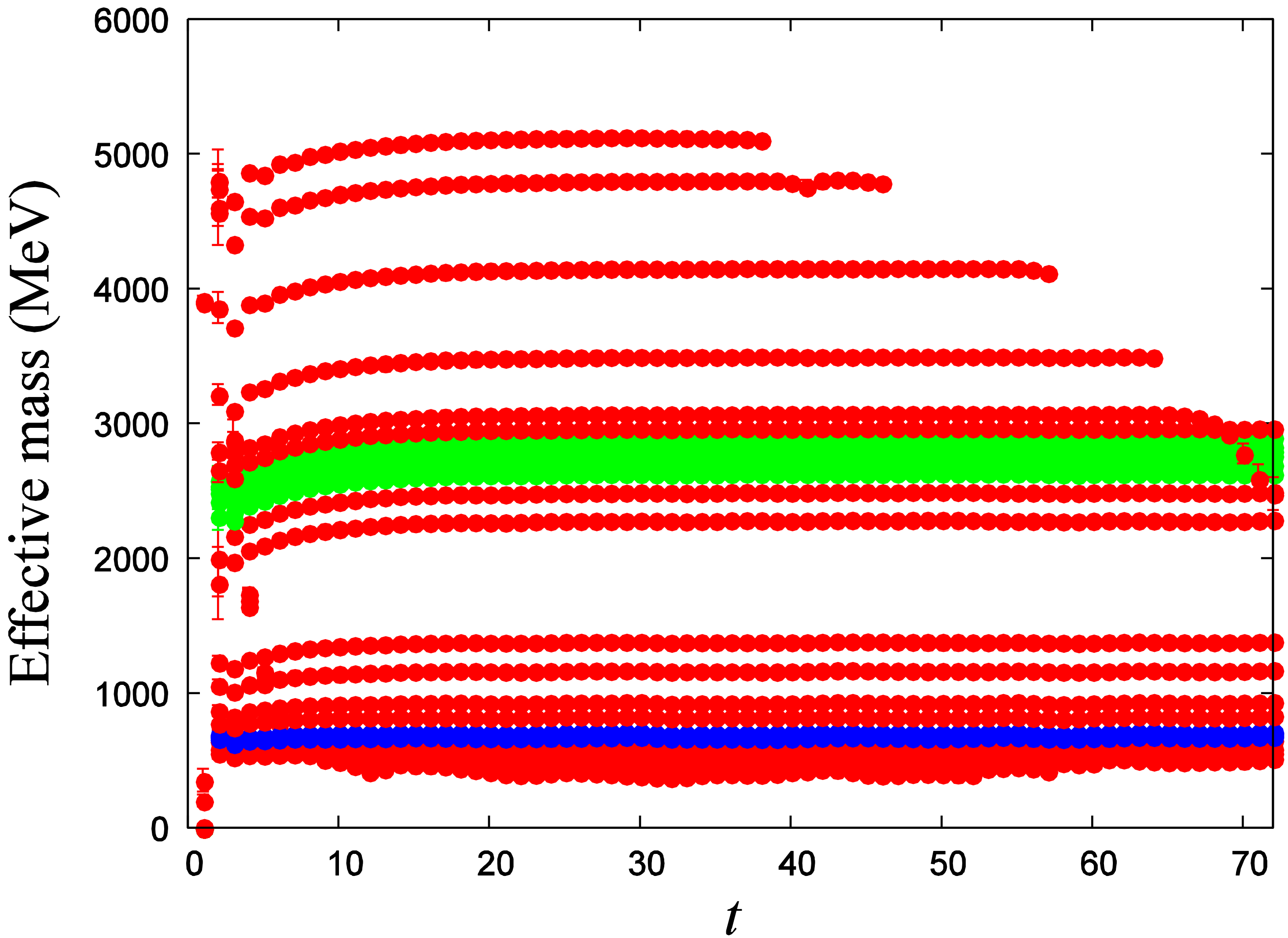
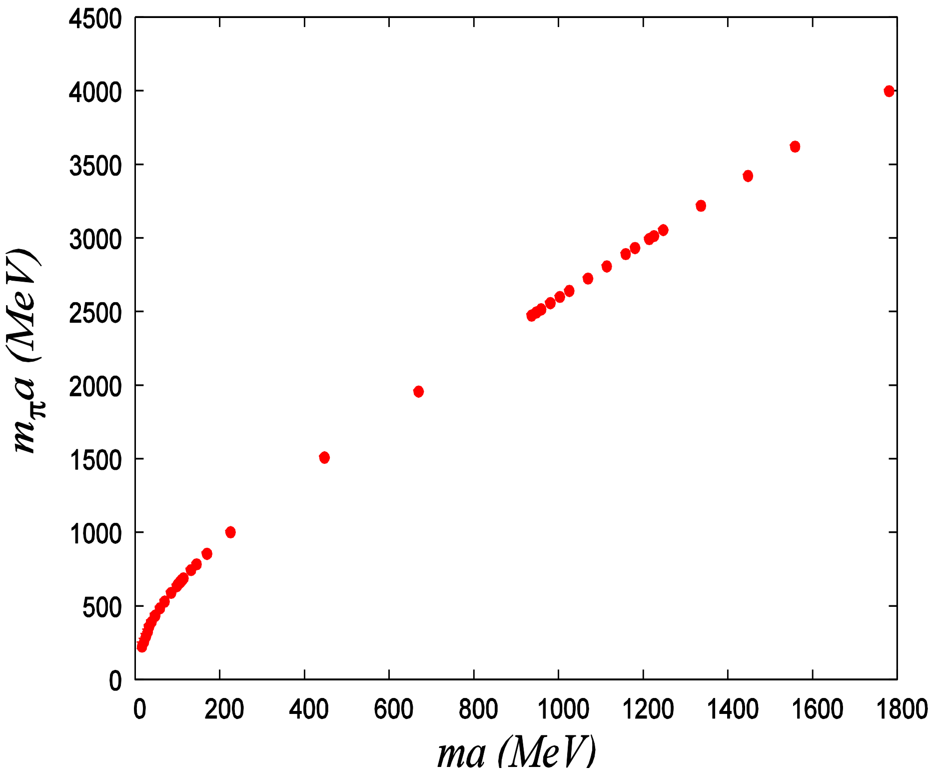
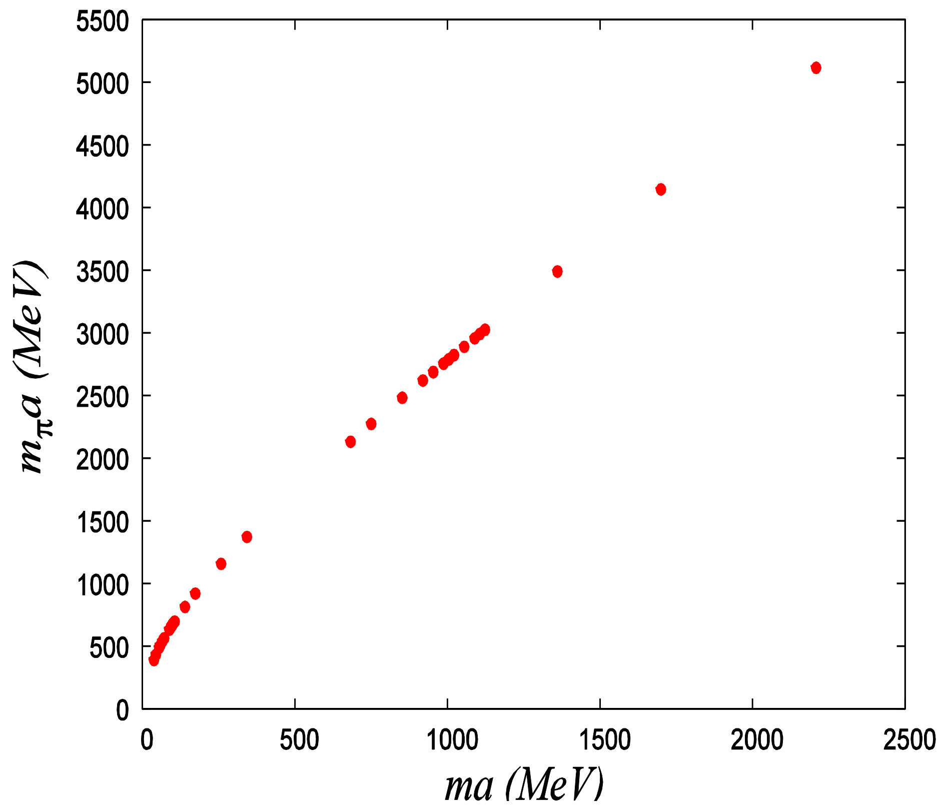
Pseudo-scalar eff. masses

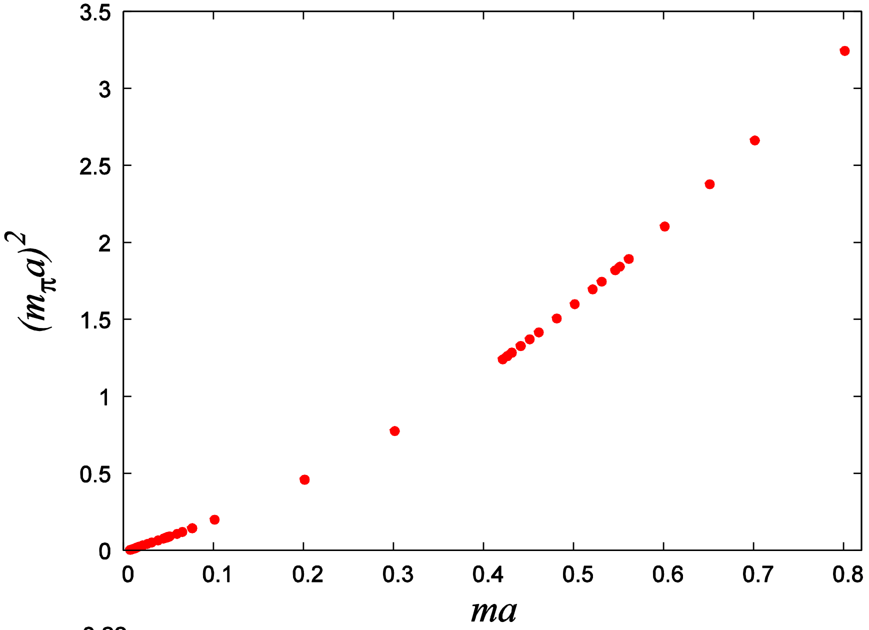


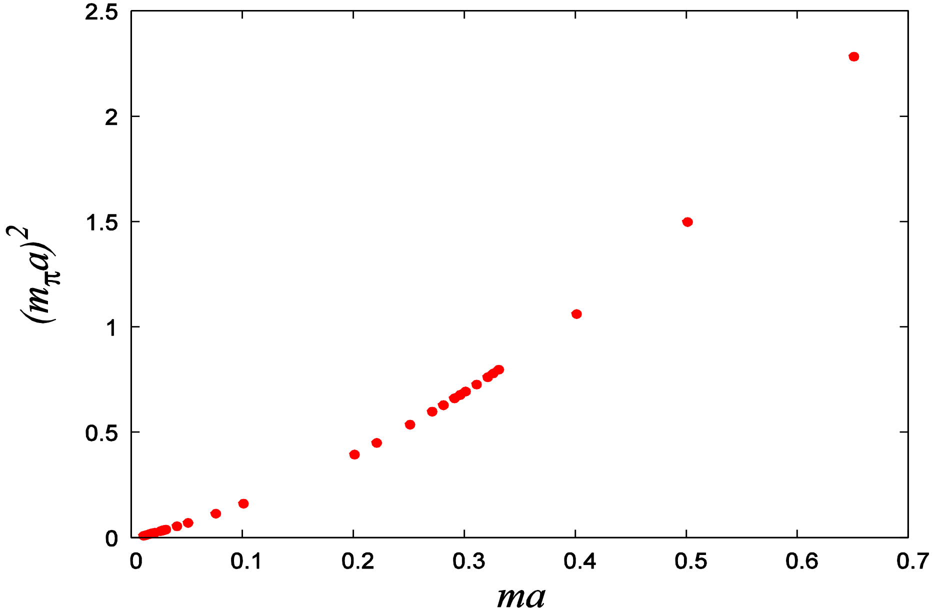
Pseudoscalar meson mass

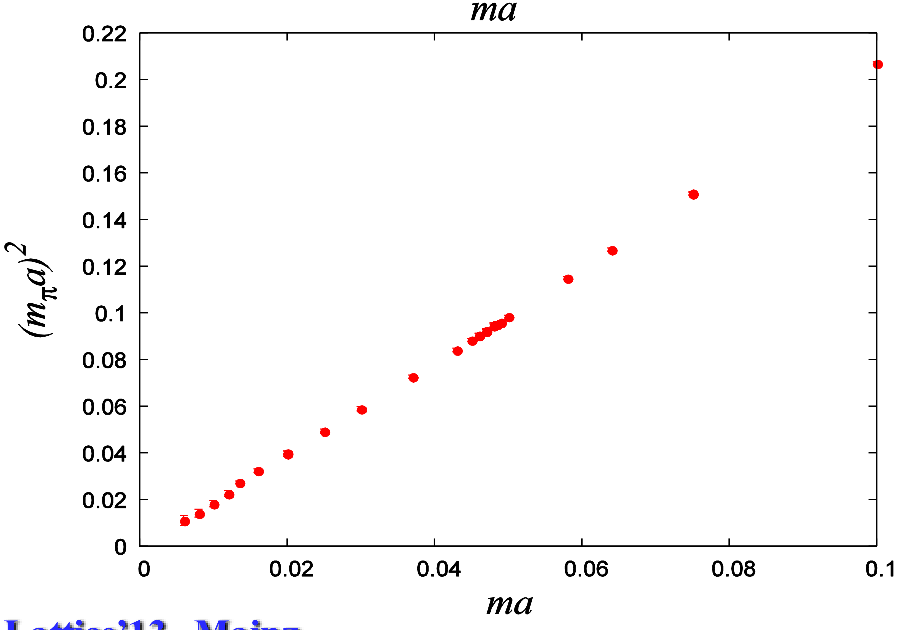


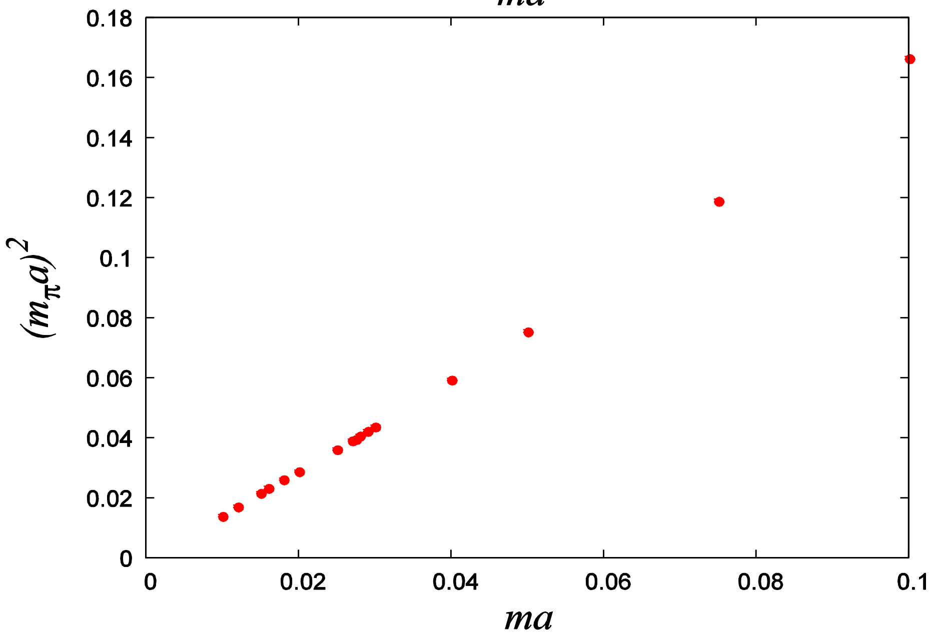


Pseudoscalar meson mass

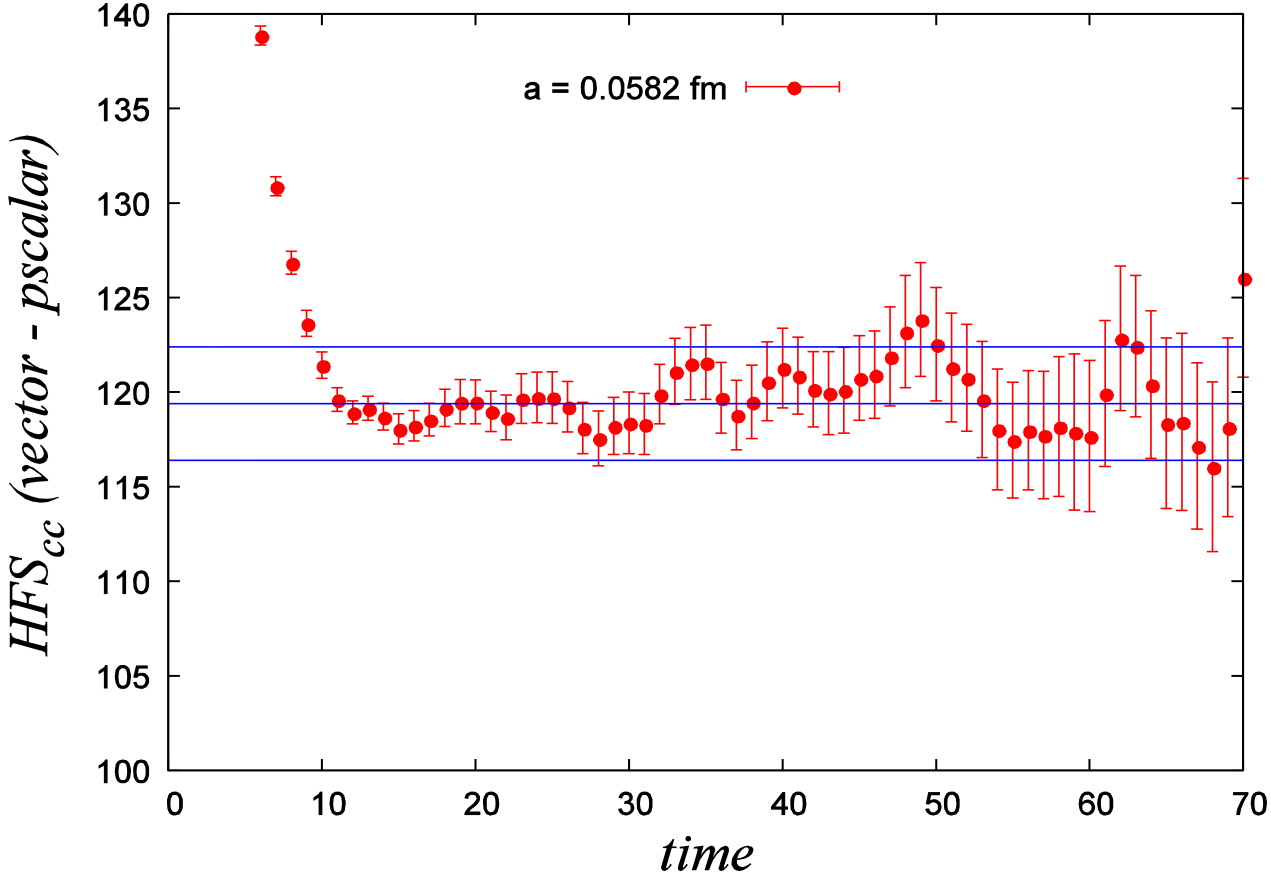




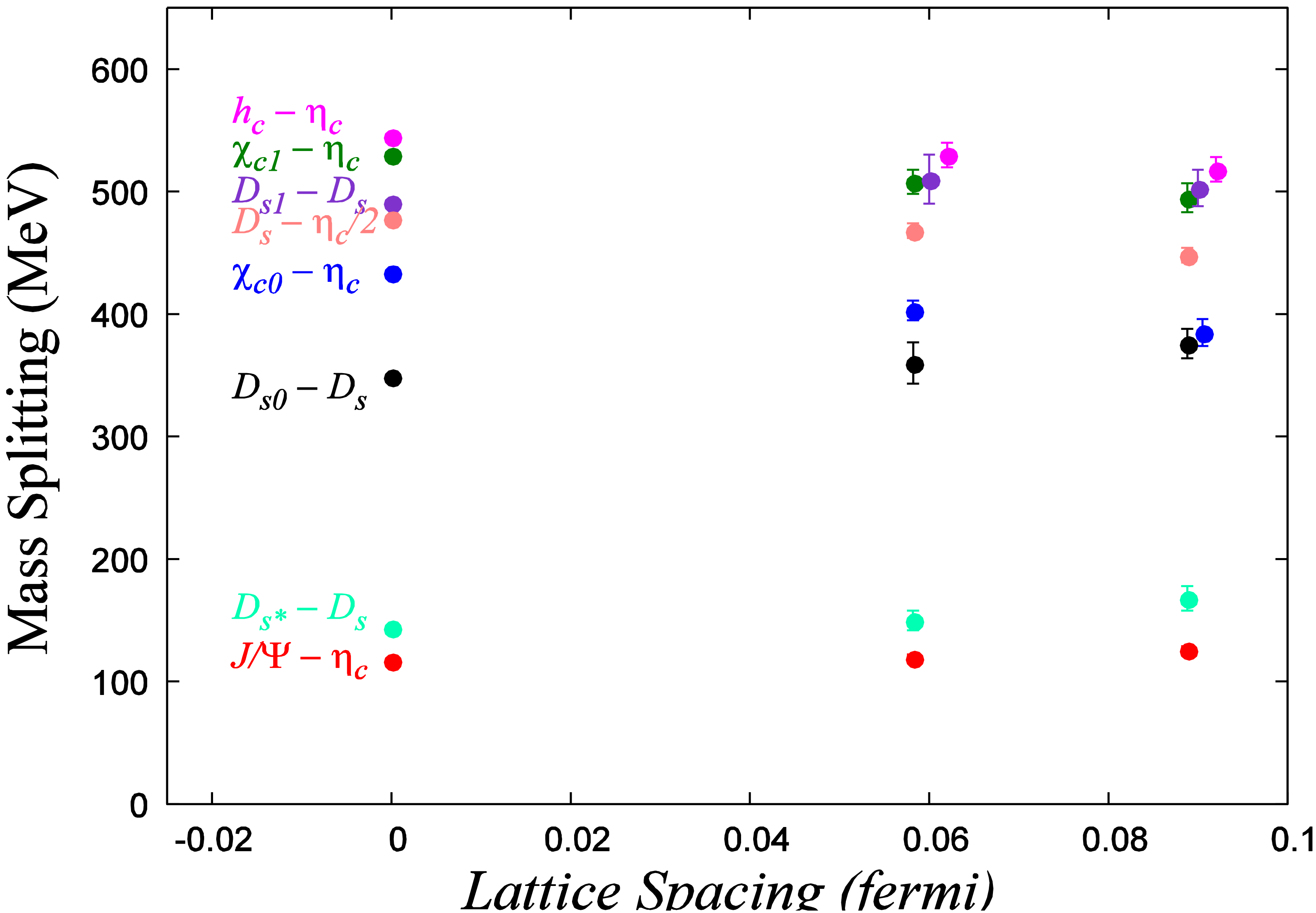




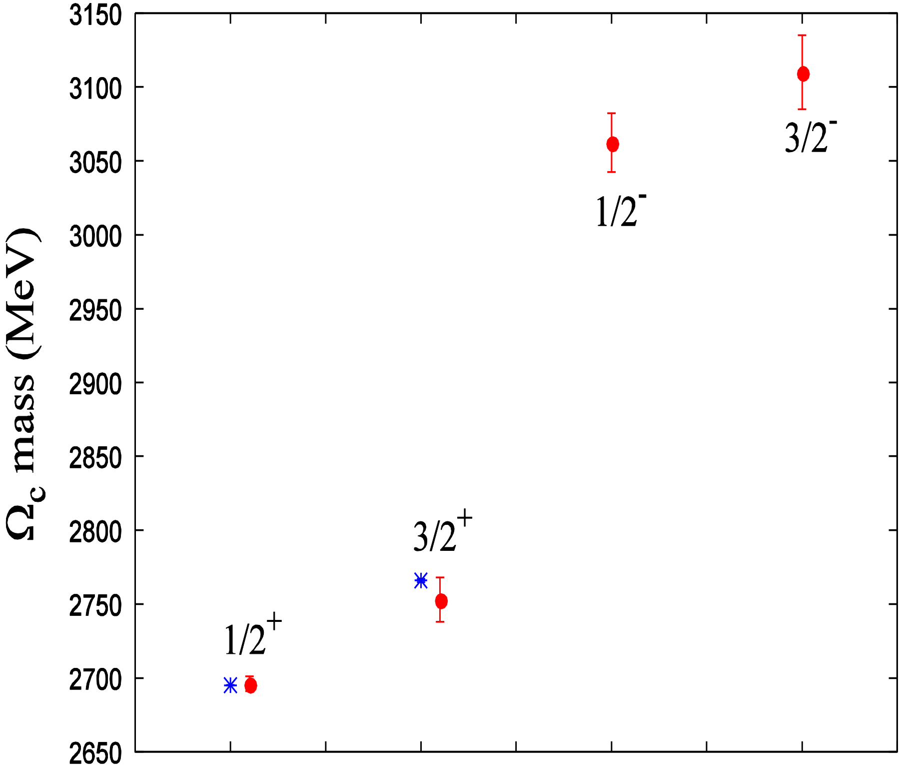
Effective mass for HFS (48^3 x 144, a= 0.0582fm)

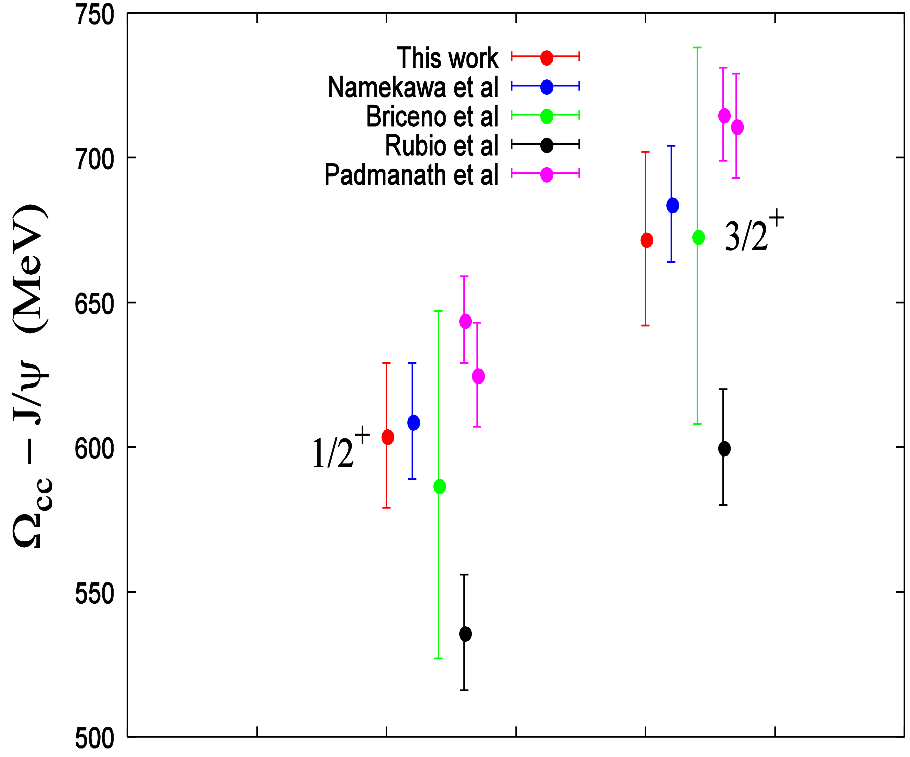


Meson mass splittings



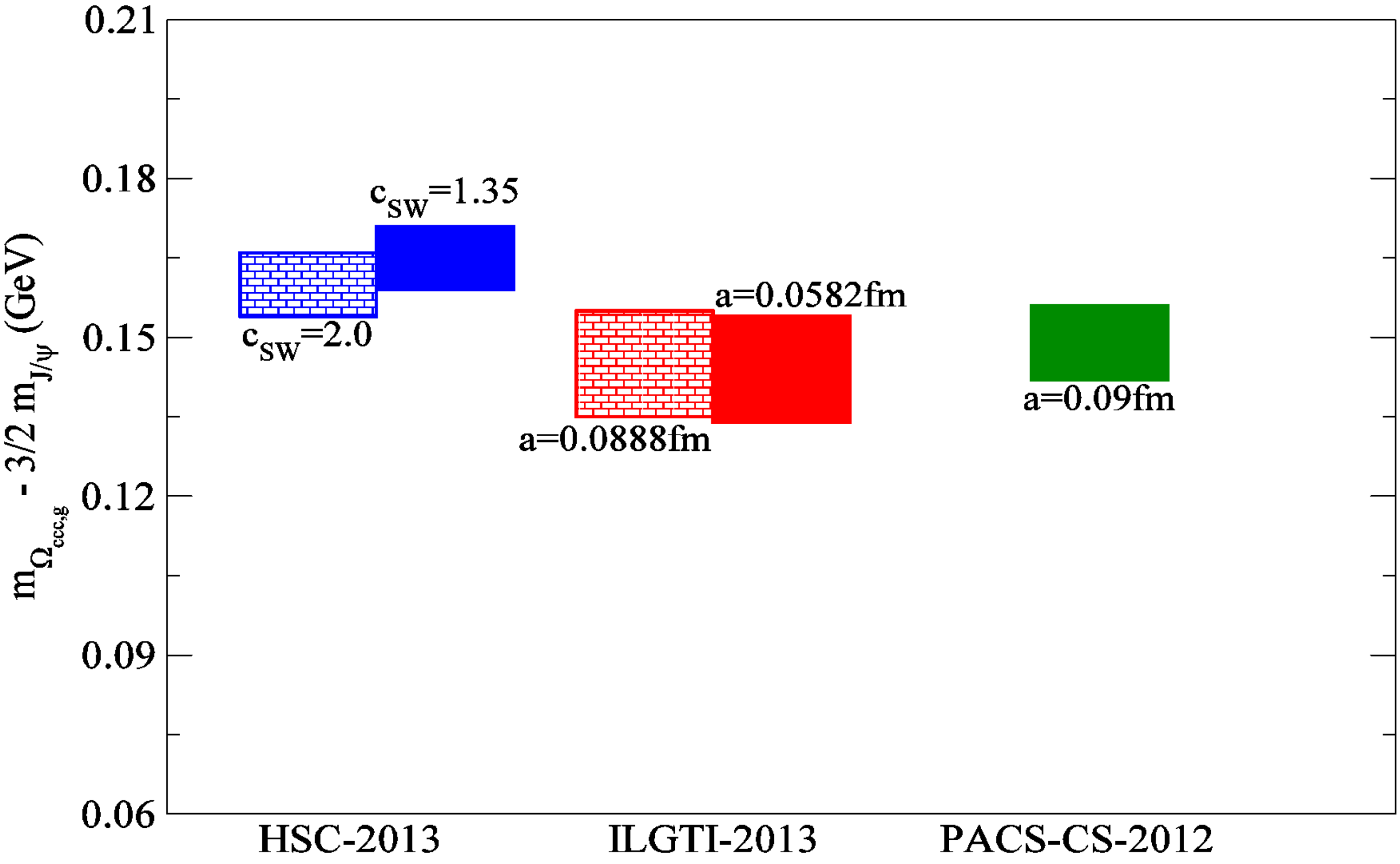
Singly and doubly-charmed Ω baryons





(48^3 x 144, a = 0.0582fm)

Triply-charmed $\Omega_{ccc}(3/2^+)$ baryon



Decay constants

- $\langle 0|\bar{c}(0)\gamma_\mu\gamma_5 q(0)|D_q(p)\rangle = f_{D_q} p_\mu$
- $\langle 0|\bar{c}(0)\gamma_\mu q(0)|D_q^*(p,\lambda)\rangle = f_{D_q^*} m_{D_q^*} e_\mu^\lambda$
- **From PCAC :**

$$M_{\rm PS}^2\, f_{\rm PS} = (\mu_1 + \mu_2)|\langle 0|P^1(0)|{\rm PS}\rangle|$$

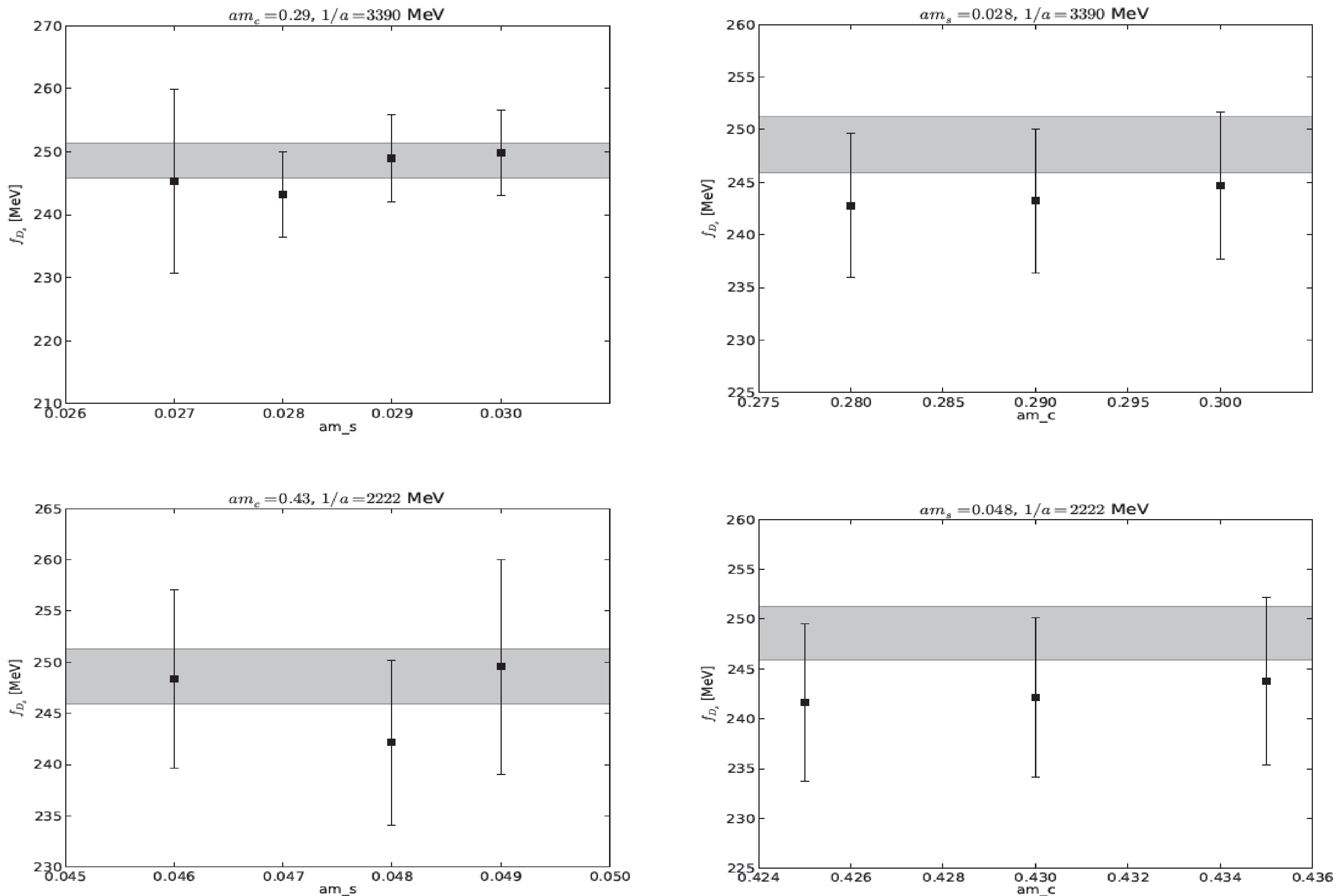
$\mu_{1,2}$ are the bare quark masses

$Z_m Z_P = 1$

$$f_{D_s} = \frac{(m_c + m_s)}{m_{D_s}^2}\sqrt{2A\, m_{D_s}}$$

$x \equiv |\langle 0|P|D_s\rangle|,\ \overline{2A} = x^2/m_{D_s}$

Both i) point-point propagators
and ii) wall-point with wall-wall propagators were utilized



$am_c = 0.29$, $1/a = 3390$ MeV
f_{D_s} [MeV]
am_s
$am_s = 0.028$, $1/a = 3390$ MeV
f_{D_s} [MeV]
am_c
$am_c = 0.43$, $1/a = 2222$ MeV
f_{D_s} [MeV]
am_s
$am_s = 0.048$, $1/a = 2222$ MeV
f_{D_s} [MeV]
am_c

The ratio $\frac{f_{D^*s}}{f_{Ds}}$

- $$\langle 0|\bar{c}(0)\gamma_\mu\gamma_5 q(0)|D_q(p)\rangle = f_{D_q} p_\mu$$

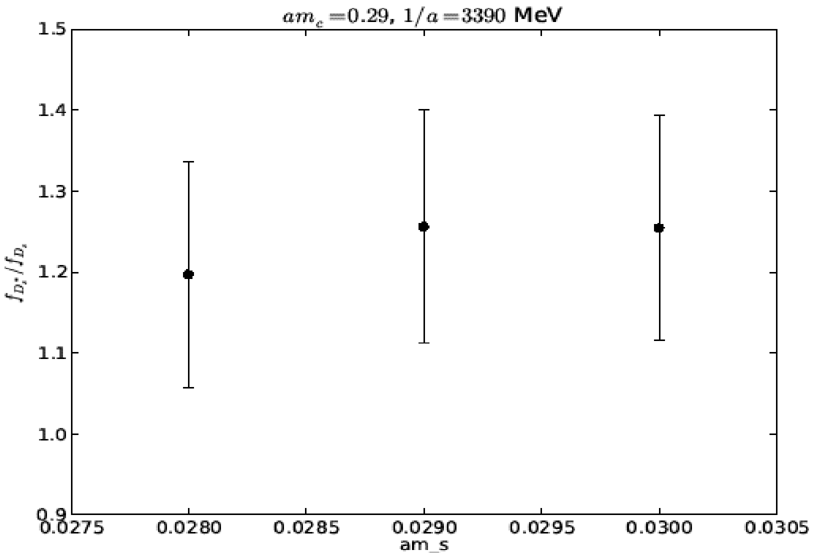
- $$\langle 0|\bar{c}(0)\gamma_\mu q(0)|D_q^*(p,\lambda)\rangle = f_{D_q^*} m_{D_q^*} e_\mu^\lambda$$

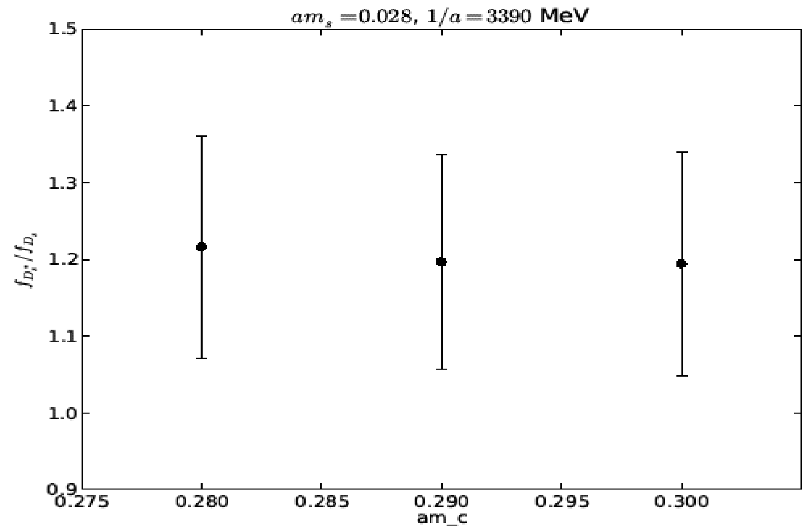
- $$m_{D_s} f_{D_s} = Z_A |\langle 0|A4|D_s\rangle|$$

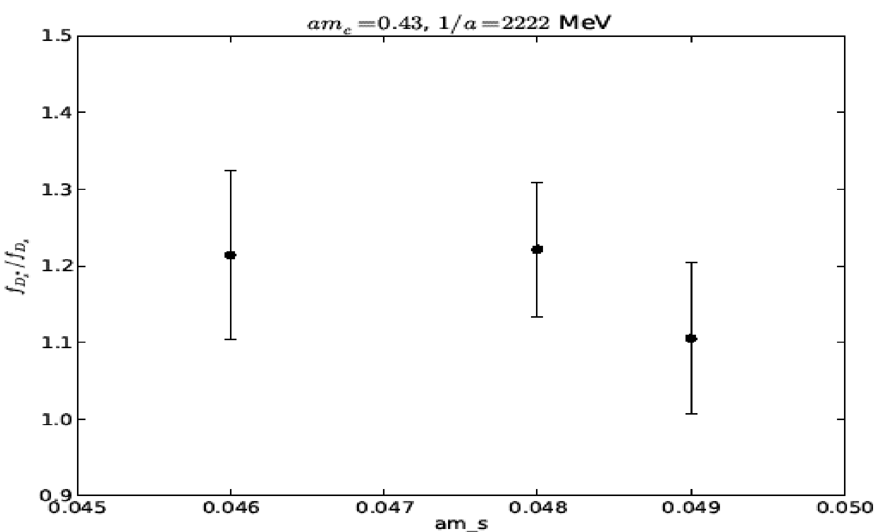
- $$Z_A = \frac{m_{D_s} f_{D_s}}{\sqrt{2A\, m_{D_s}}}$$

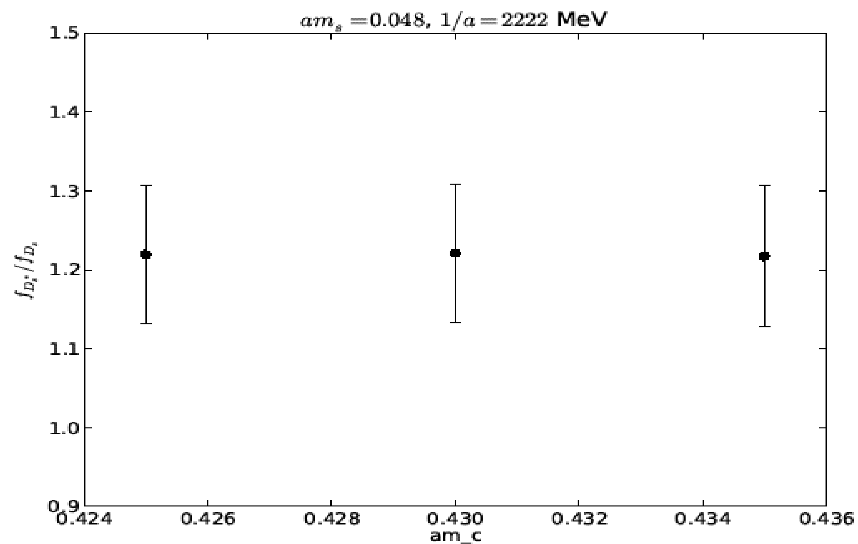
- $$f_{D_s^*} = \frac{Z_A}{m_{D_s^*}} |\langle 0|V|D_s^*\rangle|$$

It is better to calculate the ratio $\frac{f_{D^*s}}{f_{Ds}}$ where the effect of various normalization factors and mixed action effect will be smaller


$am_c = 0.29$, $1/a = 3390$ MeV
$f_{D_s^*}/f_{D_s}$
am_s
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0.0275
0.0280
0.0285
0.0290
0.0295
0.0300
0.0305


$am_s = 0.028$, $1/a = 3390$ MeV
$f_{D_s^*}/f_{D_s}$
am_c
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0.275
0.280
0.285
0.290
0.295
0.300


$am_c = 0.43$, $1/a = 2222$ MeV
$f_{D_s^*}/f_{D_s}$
am_s
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0.045
0.046
0.047
0.048
0.049
0.050


$am_s = 0.048$, $1/a = 2222$ MeV
$f_{D_s^*}/f_{D_s}$
am_c
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0.424
0.426
0.428
0.430
0.432
0.434
0.436

Summary and outlook

- ✓ Overlap valence on 2+1+1 flavour HISQ configurations **is a promising approach** to do lattice QCD simulation with light, strange and charm quark together in same lattice formulation.
- ✓ However, we found that the dispersion relation with overlap fermions, at charm mass, is not better than that of clover fermions found in literature.
- ✓ Kinetic masses of mesons are used instead of pole masses to tune charm quark mass. Dispersion relation improved at kinetic masses.
- ✓ Preliminary results are encouraging, particularly, the hyperfine splitting for charmonium. We are studying meson and baryon spectra in details.
- ✓ We are also studying heavy-light decay constants. Necessary renormalization constant calculations are ongoing.
- ✓ We also need to calculate the mixing parameter for this mix action approach.

Acknowledgement :

- Computations : ILGTI-TIFR BG/P
- Thanks to MILC collaboration (particularly, S. Gottlieb) for giving access to HISQ configurations
- Overlap issues : χ QCD collaboration

Mixed action effects

- Mixed action
- For chirally symmetric valence, it is like partial quenching with one extra parameter in valence-sea mass (Chen, O'Connell, Walker-Loud, hep-lat/0611003, arXiv:0706.0035)

$$
\begin{aligned}
m_{v_1 v_2}^2 &= B_0(m_{v_1} + m_{v_2})\,, \\
\tilde{m}_{vs}^2 &= B_0(m_v + m_s) + a^2\Delta_{\mathrm{Mix}}\,, \\
\tilde{m}_{s_1 s_2}^2 &= B_0(m_{s_1} + m_{s_2}) + a^2\Delta_{sea}\,,
\end{aligned}
$$

Mixed action effevt for overlap on domain wall gauge configurations was found to be small… **M. Lujan et. al., arXiv:1204.6256v1**