Charm and strange hadron spectra with overlap fermions on HISQ gauge configurations

Nilmani Mathur

Department of Theoretical Physics

Tata Institute of Fundamental Research, India

Collaborators : S. Datta, S. Basak, P. Majumdar, M. Padmanath

(Indian Lattice Gauge Theory Initiative)

Lattice 2012, Cairns, Australia

Overlap Fermions

- Some desirable features:
  - No $O(a)$ error.
  - $O(a^2)$ errors are found to be small (spectrum study)
  - The effective propagator : $(1-\frac{1}{2}D)D(m)^{-1} = (D_c + ma)^{-1}$
  - $D_c = D/(1 - D/2)$ is chirally symmetric, i.e., $\{\gamma_5, D_c\} = 0$.
  - $D_c + m$ is like in the continuum formalism.
  - Multi-mass algorithm (more than 20 masses -10-15% overhead) (χQCD collaboration)
  - Renormalization is 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 :

(MILC and HPQCD)

$32^3 \times 96$, a = 0.09 fm, $m_l/m_s = 1/5$, $m_\pi L = 4.5$, m_π = 314 MeV

$48^3 \times 144$, a = 0.06 fm, $m_l/m_s = 1/5$, $m_\pi L = 4.51$, m_π = 315 MeV

- **1 HYP smearing on gauge fields**
- **Both point source and coulomb gauge fixed wall source are used**
- **No of eigenvectors projected : 350 (a = 0.09 fm)**
  and 75 (a = 0.06fm)
- **Preliminary results on our ongoing study will be reported here**

Tuning of charm and strange masses

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

$m_c a = 0.55$ (a = 0.09fm),
$= 0.336$ (a = 0.06 fm)

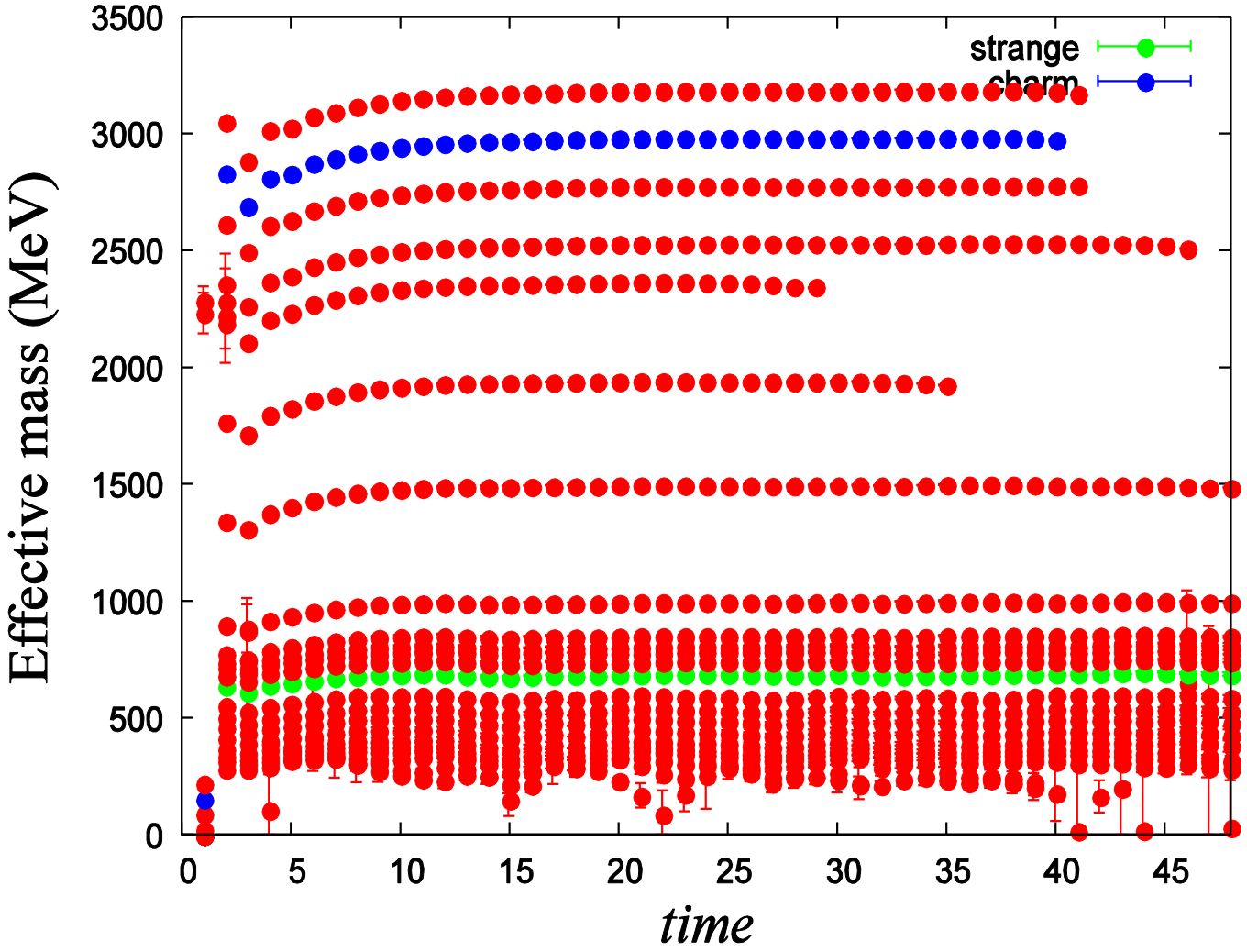
Taking $m_c = 1.275$ GeV (PDG)
$m_c a = 0.58$ (a = 0.09fm),
$= 0.388$ (a = 0.06 fm)

- Strange mass was tuned by setting pseudoscalar ss mass at 685 MeV

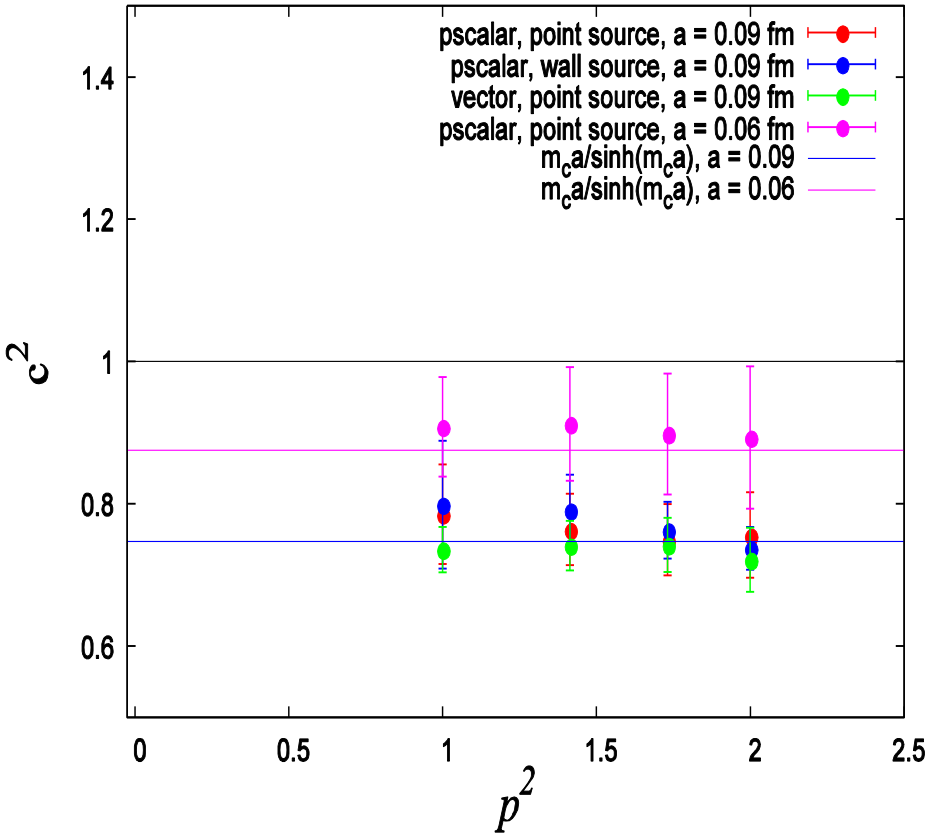
$m_s a = 0.0495$ (a = 0.09 fm)
$= 0.030$ (a = 0.06fm)

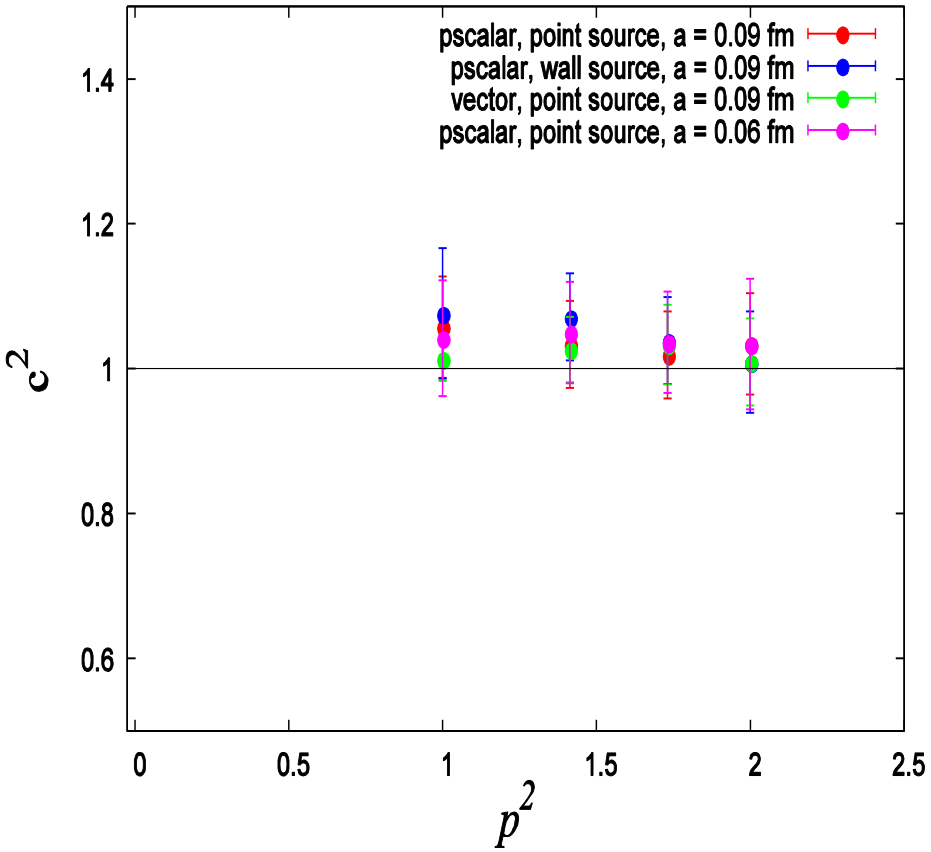
Taking $m_s = 100$ MeV
$m_s a = 0.0456$ (a = 0.09fm),
$= 0.0304$(a = 0.06 fm)

Pseudo-scalar eff. masses



Dispersion relation (at charm mass)



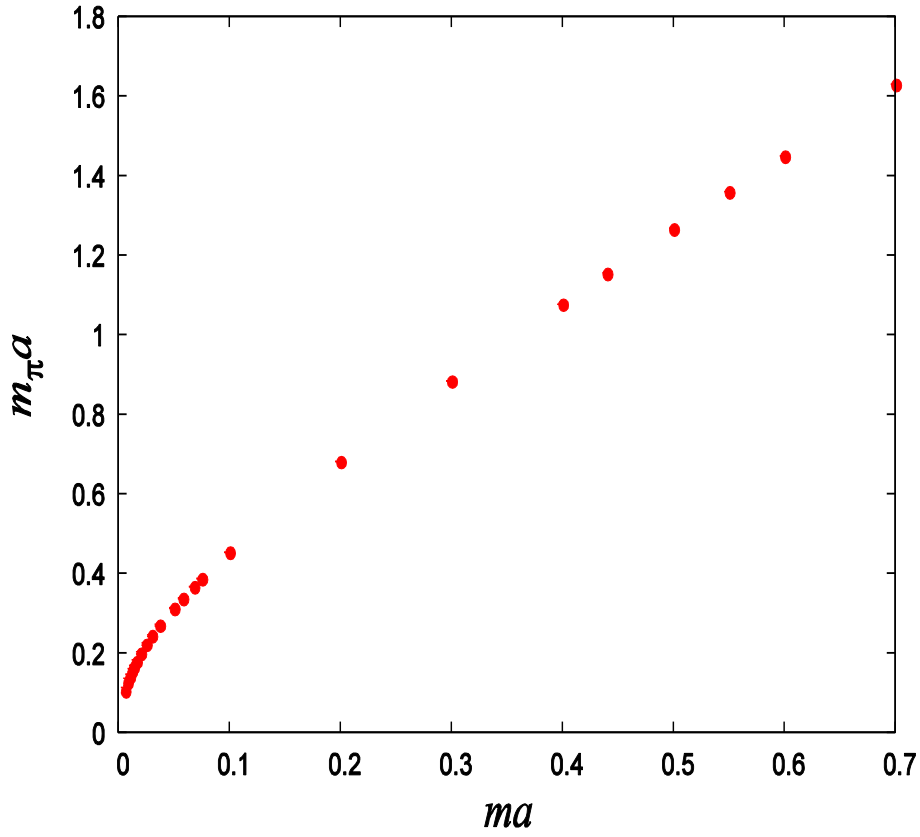


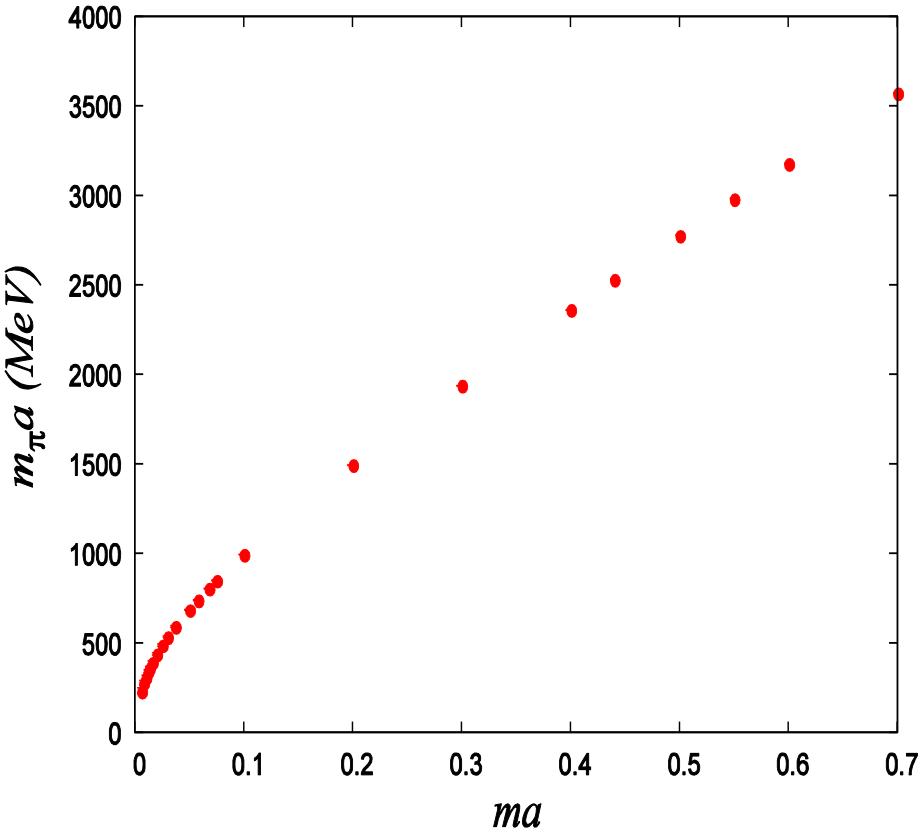
$$E^2(p) = E^2(p=0) + p^2c^2$$

$$\left(\sinh\left(\frac{E(p)}{2}\right)\right)^2 = \left(\sinh\left(\frac{E(0)}{2}\right)\right)^2 + \left(\sin\left(\frac{pc}{2}\right)\right)^2$$

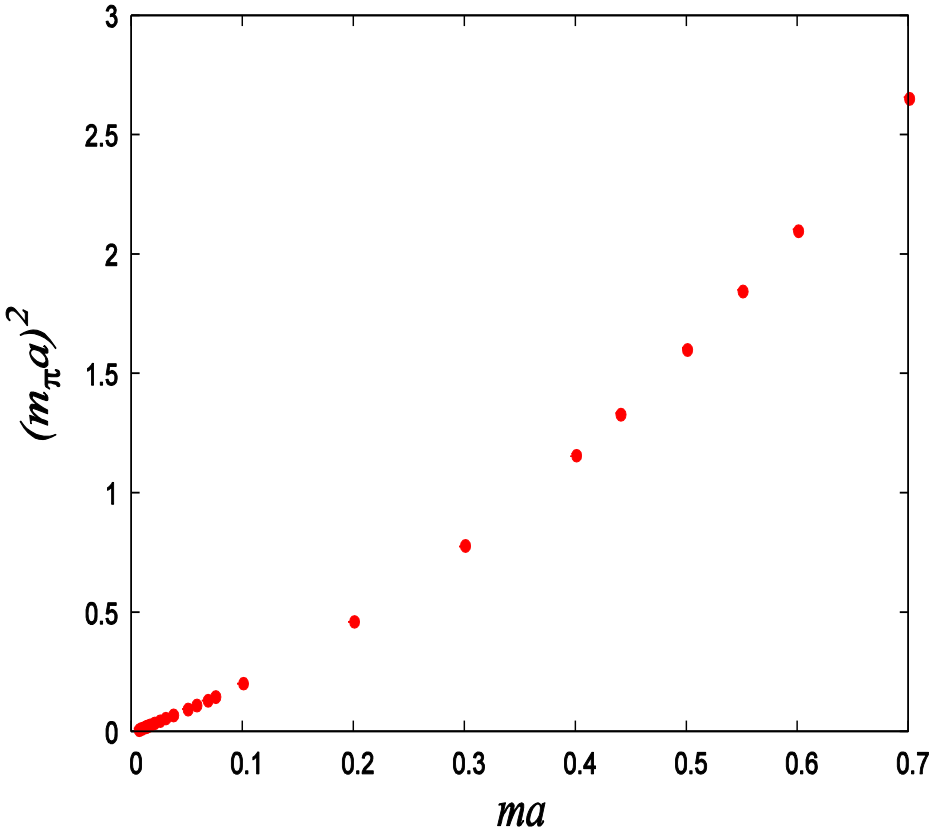
What about mixed action effect?? Need to check

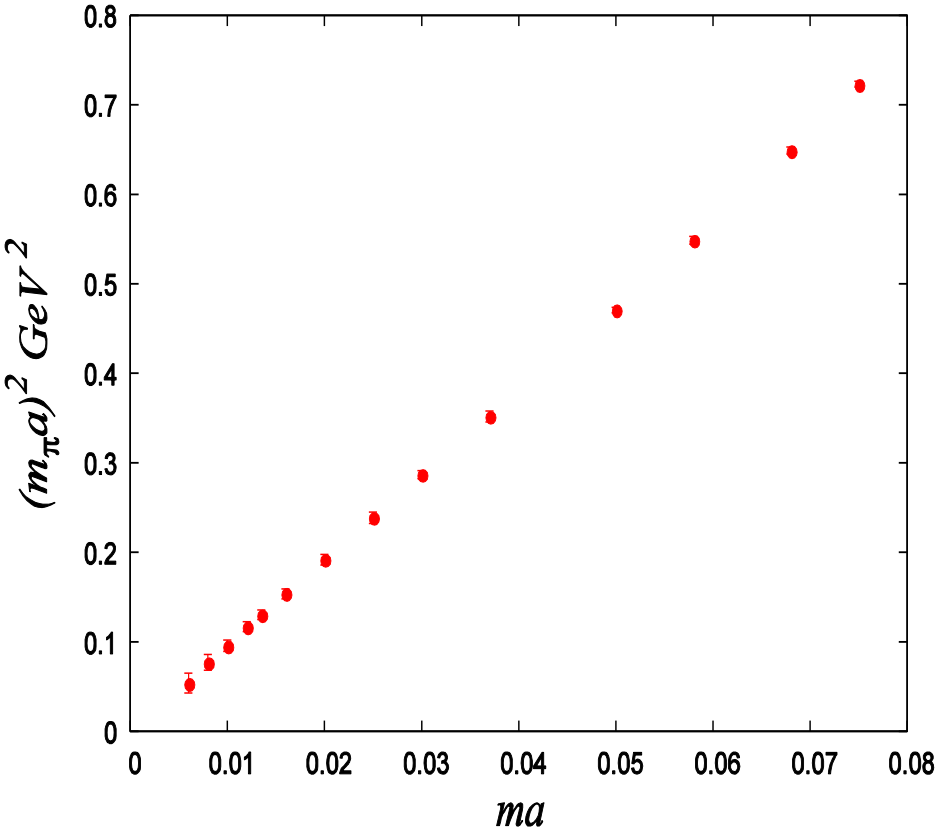
Pseudoscalar mass ($32^3 \times 96$, a= 0.09fm)



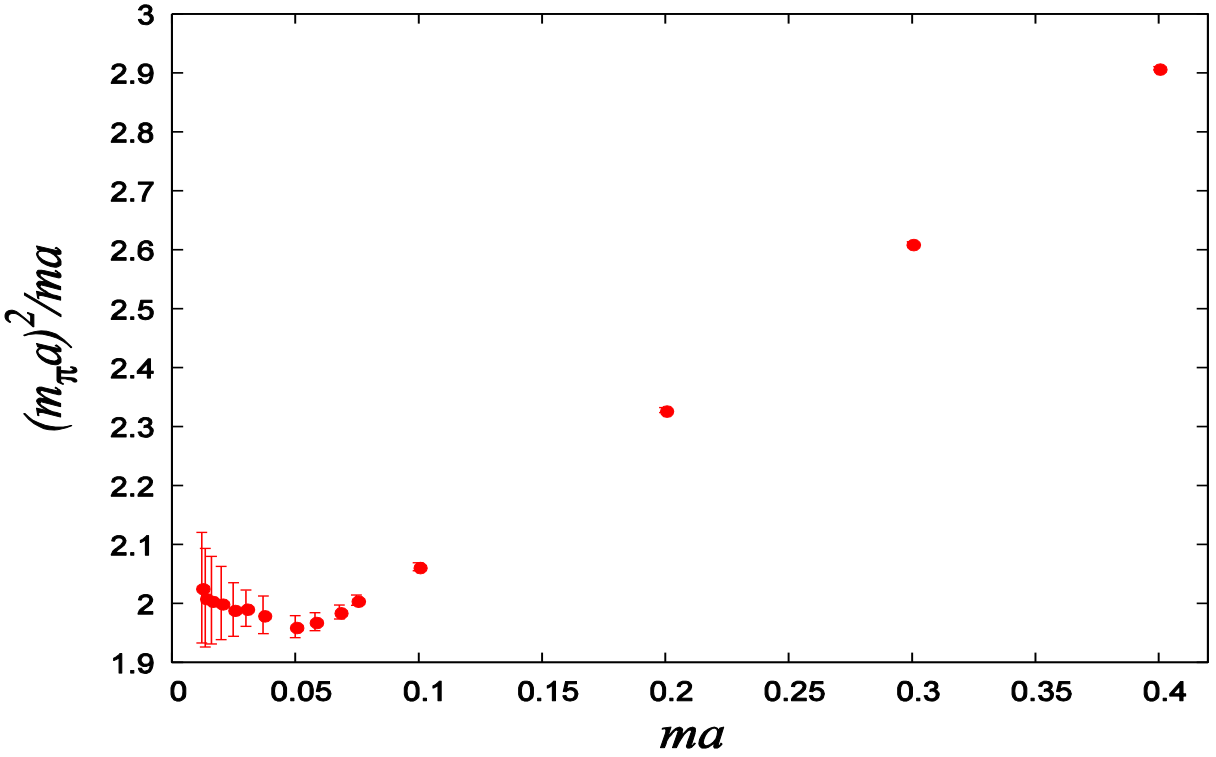


Pseudoscalar mass ($32^3 \times 96$, a= 0.09fm)





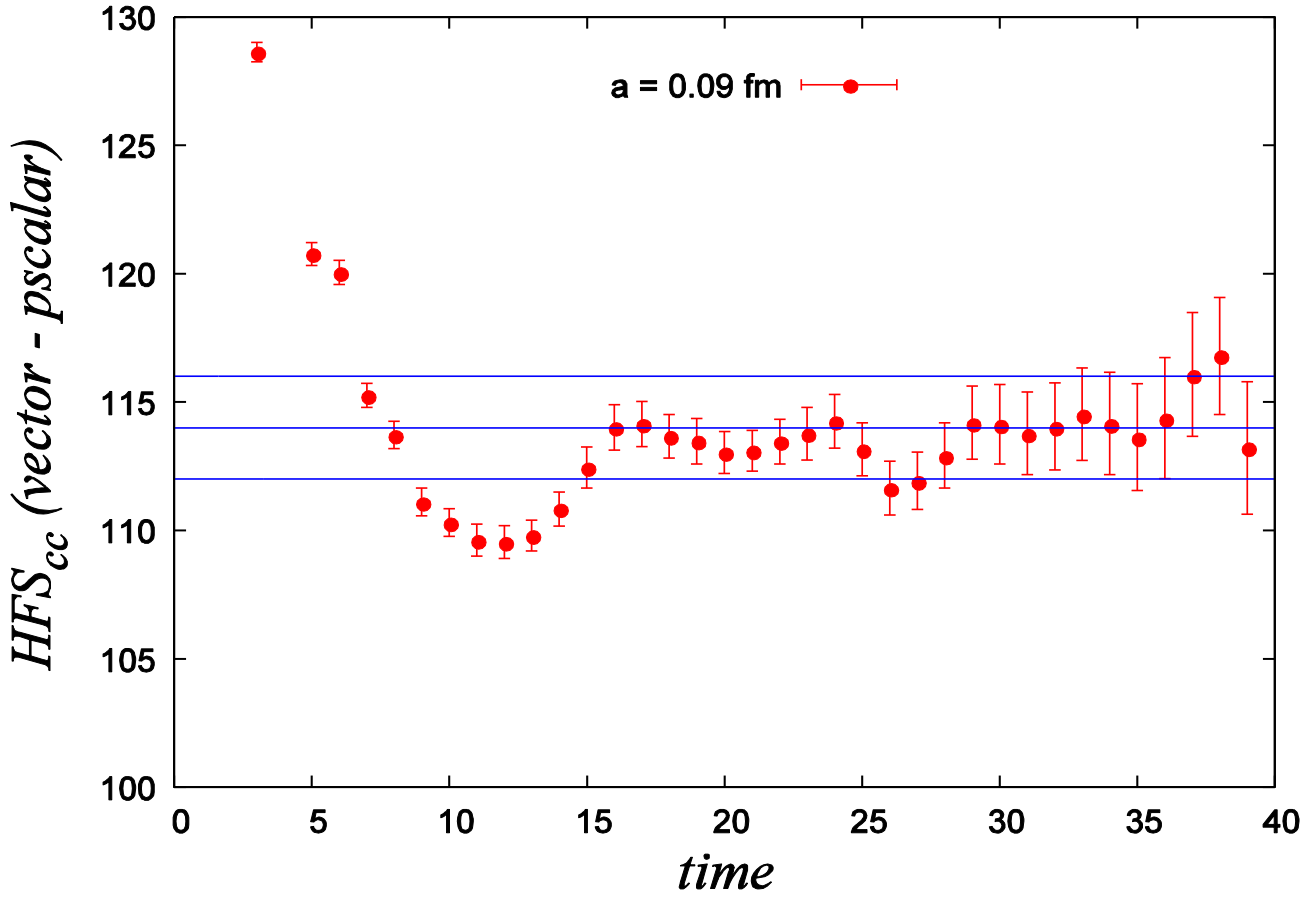
Psedosclar chiral log ($32^3 \times 96$, a= 0.09fm)



$$
\begin{aligned}
m_\pi^2 = 2B_0\hat{m}\Bigg\{ & 1 + \ln\left(\frac{m_\pi^2}{\mu^2}\right)\left[\frac{m_\pi^2}{(4\pi f)^2} - \frac{\tilde{\Delta}_{ju}^2(3\tilde{m}_X^2 - m_\pi^2)}{3(4\pi f)^2(\tilde{m}_X^2 - m_\pi^2)} + \frac{\tilde{\Delta}_{ju}^4\tilde{m}_X^2}{3(4\pi f)^2(\tilde{m}_X^2 - m_\pi^2)^2}\right] \\
& - \ln\left(\frac{\tilde{m}_X^2}{\mu^2}\right)\left[\frac{\tilde{m}_X^2}{3(4\pi f)^2} - \frac{2\tilde{\Delta}_{ju}^2\tilde{m}_X^2}{3(4\pi f)^2(\tilde{m}_X^2 - m_\pi^2)} + \frac{\tilde{\Delta}_{ju}^4\tilde{m}_X^2}{3(4\pi f)^2(\tilde{m}_X^2 - m_\pi^2)^2}\right] \\
& - \frac{16m_\pi^2}{f^2}\Big[L_4(\mu) + L_5(\mu) - 2L_6(\mu) - 2L_8(\mu)\Big] - \frac{32m_K^2}{f^2}\Big[L_4(\mu) - 2L_6(\mu)\Big] + \frac{a^2}{f^2}L_{ma^2}(\mu) \\
& - \left(\frac{32\Delta_{ju}^2}{f^2} + \frac{16\Delta_{rs}^2}{f^2}\right)\Big[L_4(\mu) - 2L_6(\mu)\Big] - \frac{\tilde{\Delta}_{ju}^2}{(4\pi f)^2} + \frac{\tilde{\Delta}_{ju}^4}{3(4\pi f)^2(\tilde{m}_X^2 - m_\pi^2)}\Bigg\}.
\end{aligned}
$$

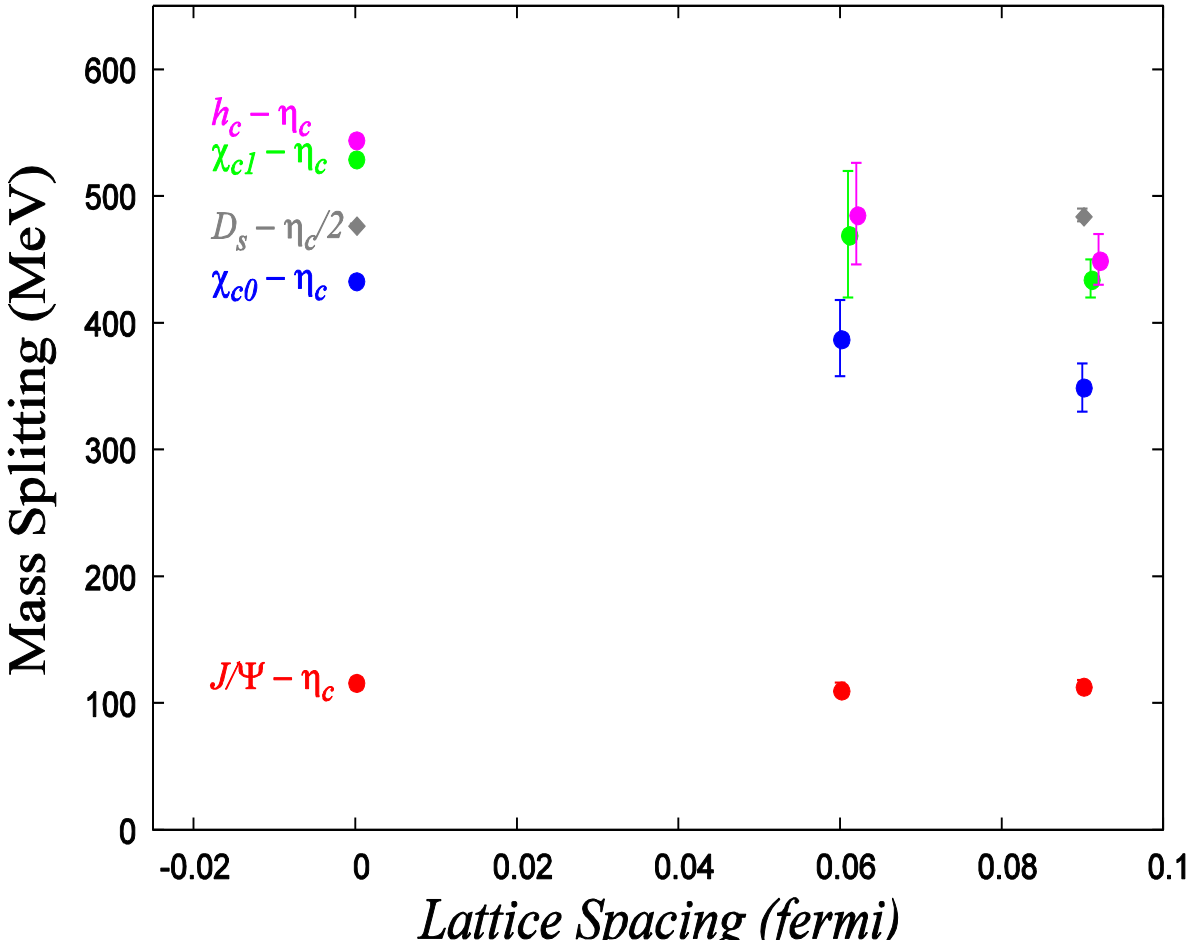
arXiv:hep-lat/0611003v2

Effective mass for HFS ($32^3 \times 96$, a= 0.09fm)



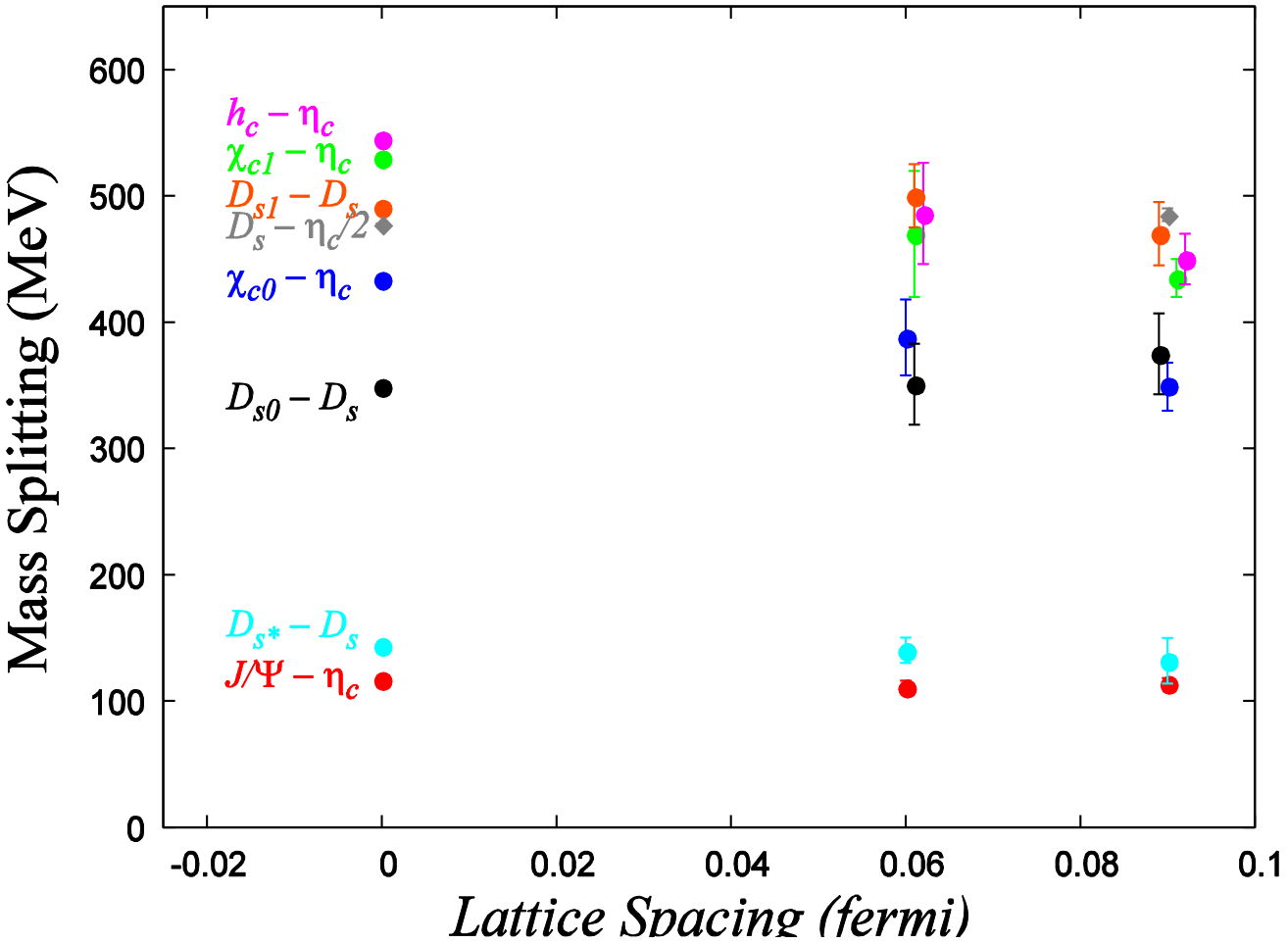
Charmonium mass splittings

(a= 0.09fm and 0.06 fm)



Charm and strange hadron mass splittings

(a= 0.09fm and 0.06 fm)



Decay constants

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

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

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

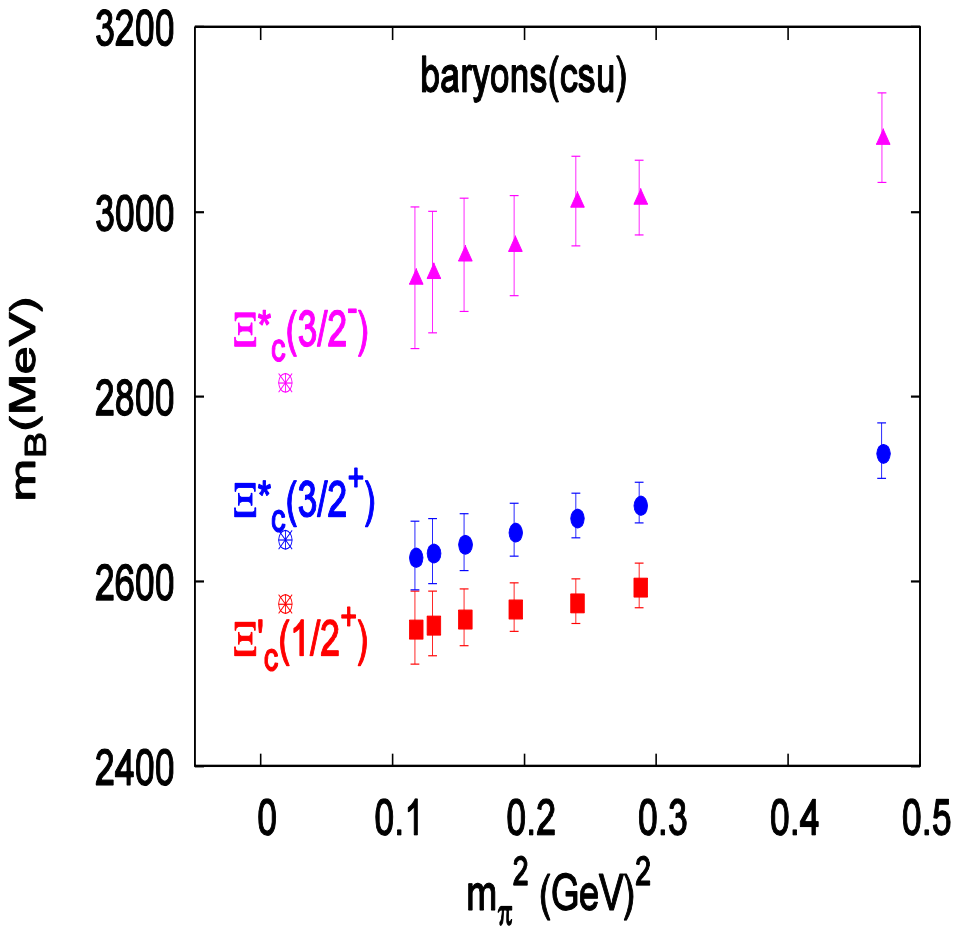
$$\frac{Z_A}{Z_V}\frac{f_{D^*s}}{f_{Ds}} = \frac{\Phi_{D^*s}}{\Phi_{Ds}}\frac{\sqrt{M_{Ds}}}{\sqrt{M_{D^*s}}} = 1.15(\ \ 10)$$

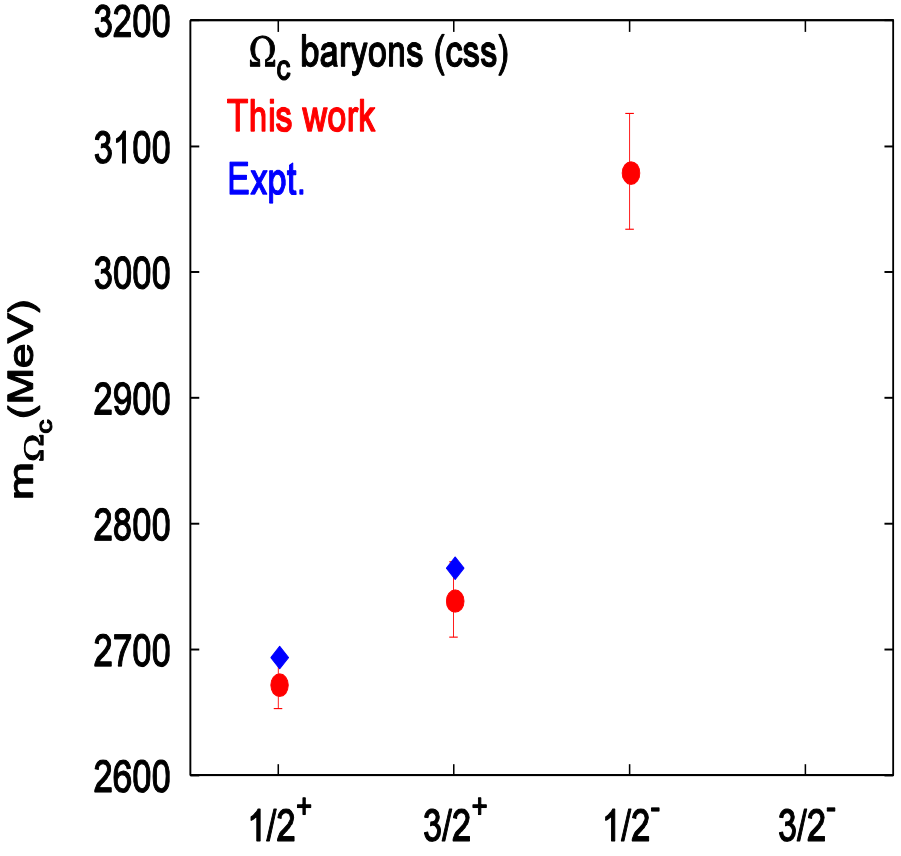
on a = 0.09 fm

Mixed action effect will be smaller for this ratio

Heavy baryons (Singly charmed)

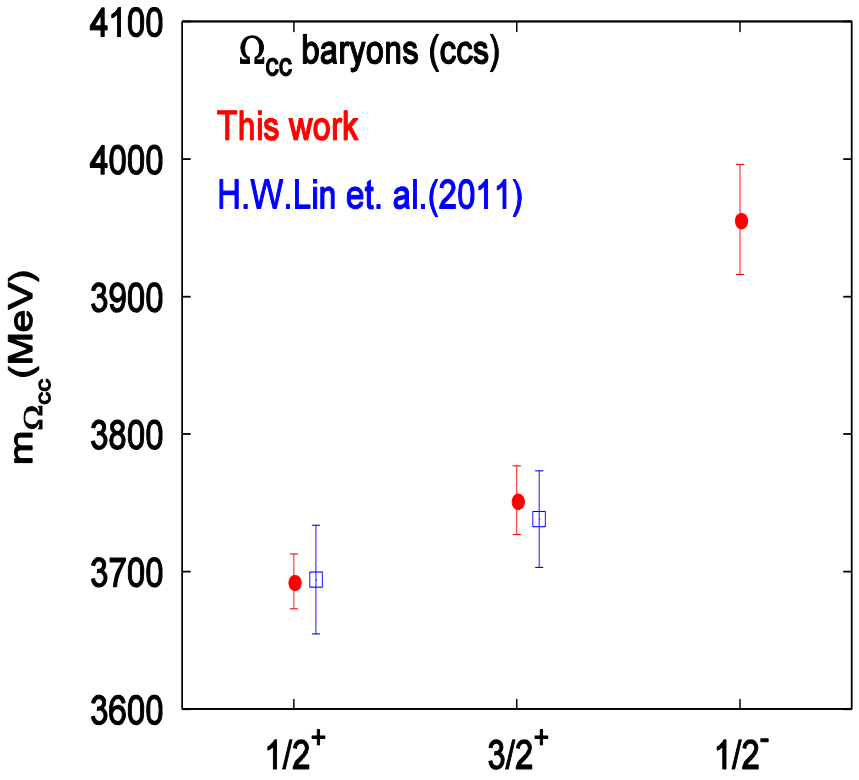
($32^3 \times 96$, a = 0.09fm)

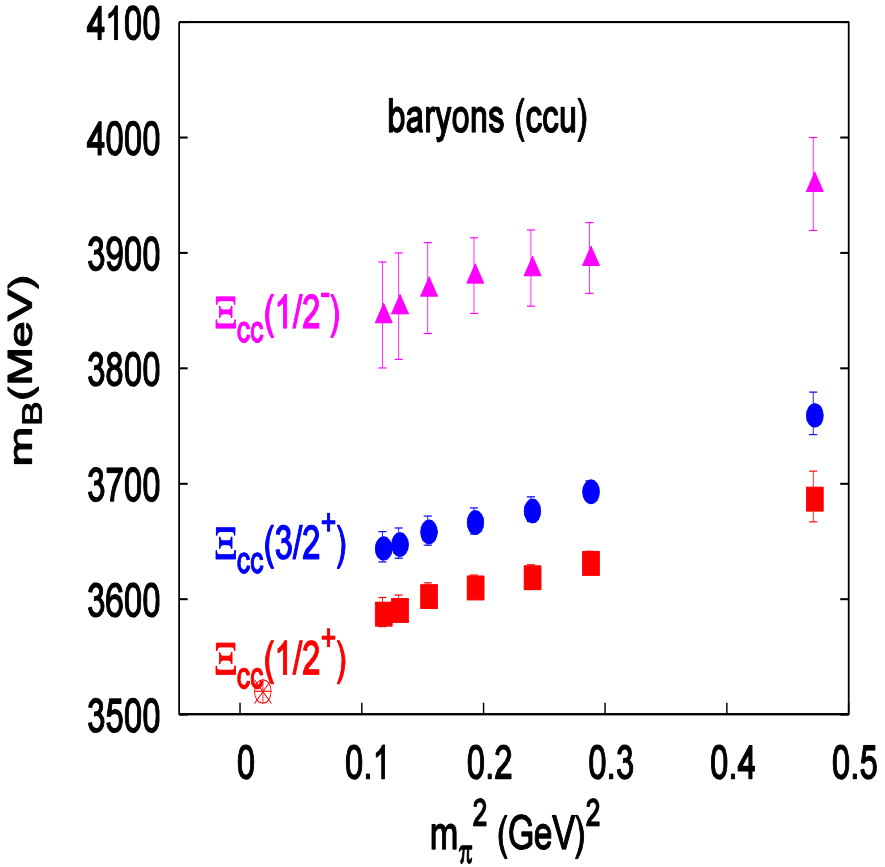




Heavy baryons (Doubly charmed)

($32^3 \times 96$, a = 0.09fm)





Ω_{ccc} = 4756(10)MeV (a = 0.09fm)
= 4782(16)MeV (a = 0.06fm) ← Prediction

Summary and outlook

- ✓ Overlap valence on 2+1+1 flavor HISQ configurations is a promising approach to do lattice QCD simulation with light, strange and charm quark together in same lattice formulation.
- ✓ Preliminary results are encouraging, particularly, the hyperfine splitting for charmonium. We are studying meson and baryon spectra in details and will be able to predict unknown doubly and triply charmed baryon masses after continuum extrapolation.
- ✓ We are also studying heavy-light decay constants. Necessary renormalization constants will also be calculated in future.
- ✓ However, we found that the dispersion relation with overlap fermions, at charm mass, is not better than that of clover fermions found in literature.
- ✓ We also need to calculate the mixing parameter for this mix action approach.

Acknowledgement :

- ➢ Thanks to MILC and HPQCD collaborations (particularly, S. Gottlieb) for giving access to HISQ configurations
- ➢ Thanks to χQCD collaboration (particularly, A. Li, A. Alexandru) on overlap issues

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)

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

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