Spectroscopy of the BSM sextet model

Chik Him (Ricky) Wong

Lattice Higgs Collaboration (LatHC):
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Outline

- Challenges of lattice analysis of nearly conformal BSM model
- Mixed action analysis with application of gradient flow
- Preliminary results
- Conclusion

Challenges

- Case study of nearly conformal model: Sextet model $SU(3)$ with $N_f = 2$ in two-index symmetric representation
- Focus of this talk: Hadron Spectroscopy study
- No IRFP is found despite small β function [more in Kieran Holland's talk]
  $\Rightarrow$ still chirally broken
- Is χPT applicable? Dynamics are very different from QCD
- A low-lying 0^{++} scalar exists
  $\Rightarrow$ Linear-σ model or Dilaton-inspired extended theory? (Julius Kuti's talk)
- Expensive to get lower in m where 0^{++} scalar may decouple

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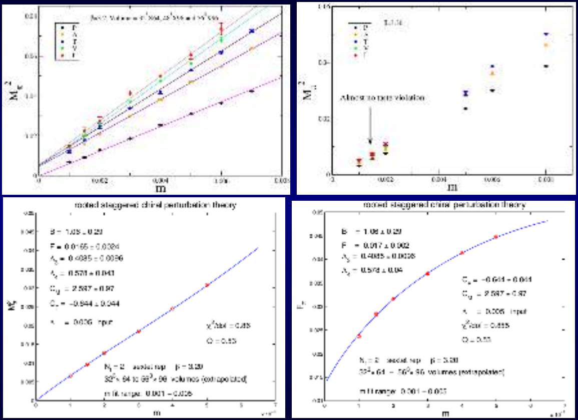
Challenges

- Staggered formalism:
  Taste breaking structure is different from QCD



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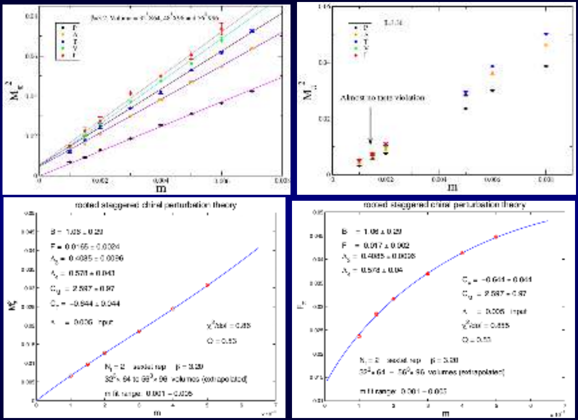

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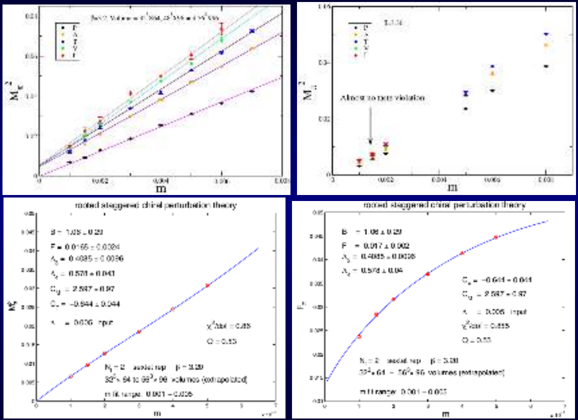

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Mixed action analysis

- Mixed action setup: Valence fermion action is different from sea fermion action
- χPT $\Rightarrow$ MAχPT
- If the valence fermion action (almost) respects taste symmetry,
  - The valence Goldstone spectrum $M_{\pi,vv}$ has no detectable taste splitting
  - Taste breaking effect from the sea fermion action is messaged in the mixed meson $M_{\pi,vs}$
- Flowed action as the valence action :
  - Apply a large number of small stout smearing steps to the original links, equivalent to a Wilson flow of $t_f\, a^2$
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  - Wilson flow reduces cutoff effects, approximately restores the taste symmetry

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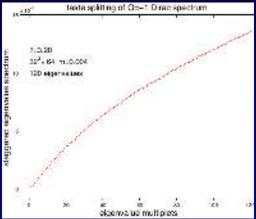

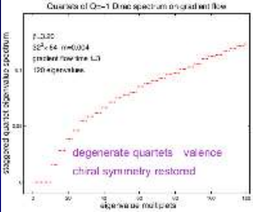

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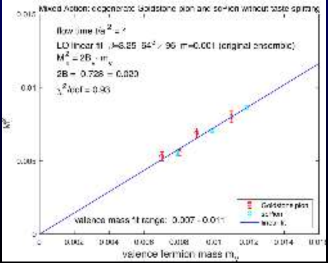

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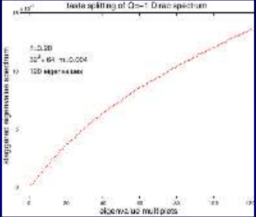

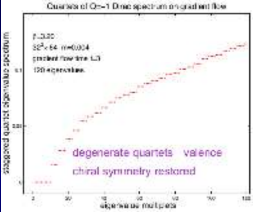

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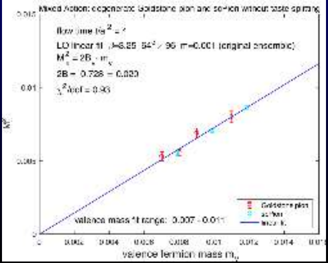

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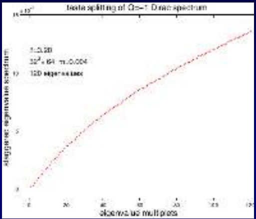

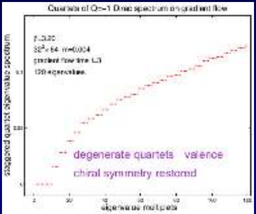

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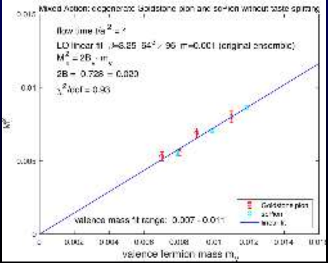

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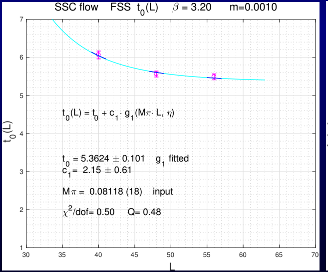
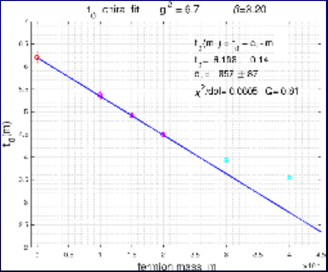
Preliminary results

- Measure quantities X, e.g. F_π, M_X on gradient flowed links. $\sqrt{8t_f}\, M_\pi \ll 1$ is required, and p-regime is assumed.
- Define a scale t_0 : $g^2|_{t_0} = c$ (6.7 here)
- Determine the chiral limit of the infinite volume extrapolated t_0 at each β [Kieran Holland's talk]





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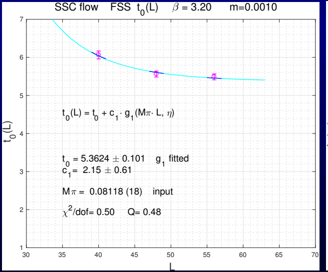

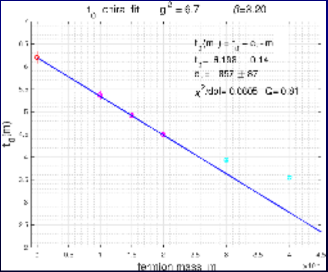

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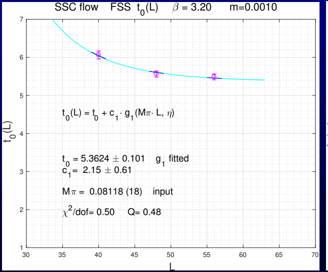

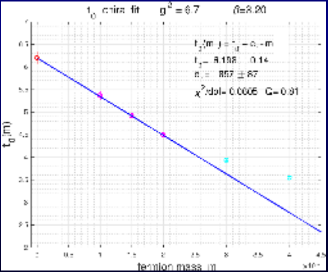

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- Assuming MAχPT, the relation between $X_{\rm NLO}$ and $X_{\rm LO}$ in the infinite-volume limit can be worked out. E.g.

$$\frac{M^2_{\pi,vv,\rm NLO}}{M^2_{\pi,vv,\rm LO}} = \Bigg(1 + \frac{1}{32\pi^2 F_\pi^2}\Bigg[(M^2_{\pi,vv,\rm LO} - M^2_{\pi,ss,\rm LO}) + (2M^2_{\pi,vv,\rm LO} - M^2_{\pi,ss,\rm LO}) \ln\frac{M^2_{\pi,vv,\rm LO}}{\mu^2}\Bigg] - \frac{8}{F_\pi}\Big[(L_5 - 2L_8)M^2_{\pi,vv,\rm LO} + 2(L_4 - 2L_6)M^2_{\pi,ss,\rm LO}\Big] + C\,a^2\Bigg),$$

$$\frac{F^2_{\pi,vv,\rm NLO}}{F_\pi} = \Bigg(1 - \frac{M^2_{\pi,vs,\rm LO}}{16\pi^2 F_\pi^2}\ln\frac{M^2_{\pi,vs,\rm LO}}{\mu^2} + \frac{4}{F_\pi^2}\Big[L_5 M^2_{\pi,vv,\rm LO} + 2L_4 M^2_{\pi,ss,\rm LO}\Big] + D\,a^2\Bigg),$$

where $M^2_{\pi,vv,\rm LO} = 2Bm_v,\ M^2_{\pi,ss,\rm LO} = 2Bm_s,\ M^2_{\pi,vs,\rm LO} = B(m_v + m_s)$

- Scaling with t_0 to obtain dimensionless quantities $\bar{y} \equiv \sqrt{t_0}\, y$, these relations can be parameterized as

$$\bar{M}^2_{\pi,vv,\mathrm{NLO}} = \bar{m}_v \left(2\bar{B} + b_1 \bar{m}_v + b_2 \bar{m}_s + b_3 (2\bar{m}_v - \bar{m}_s) \ln \bar{m}_v + b_4 t_0^{-1} a^2 \right)$$

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- In Mixed action, chiral limit and continuum limit cannot be separated
$\Rightarrow$ Simultaneous fit of all available $L^3 \times T$'s, β's(with corresponding t_0's), m_s and m_v's to obtain $\bar{X}$'s in the infinite-volume, chiral and continuum limit
- $\bar{F}_\pi$ is the t_f-independent, infinite-volume, continuum and chiral limit of $\sqrt{t_0} F_\pi$, which sets the scale of M_X via $\bar{M}_X / \bar{F}_\pi = M_X / F_\pi$

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Preliminary results

- Sea Action:
  Tree-level Symanzik-Improved gauge action with 2-step $\rho = 0.15$ stout-smeared Staggered $N_f = 2$ SU(3) Sextet fermion, sea mass m_s
- Valence Action:
  Staggered fermion action with $t_f = 4$ (80 steps of $\rho = 0.05$ stout smeared) gauge, valence mass m_v
- Available data:

β	m_s	m_v	$L^3 \times T$
3.20	0.001	0.006,0.008,0.010	$40^3 \times 80, 48^3 \times 96, 56^3 \times 96$
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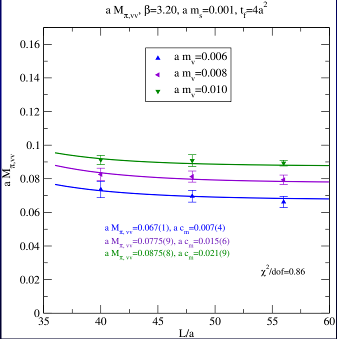
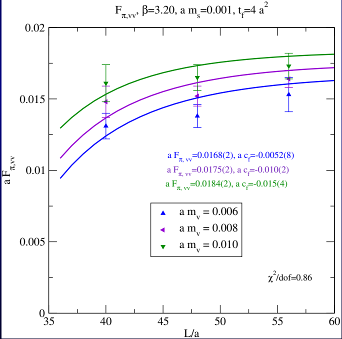
$M_{\pi,vv}(L) = M_{\pi,vv} + c_m g_1(M_{\pi,vv}L), \quad F_{\pi,vv}(L) = F_{\pi,vv} + c_f g_1(M_{\pi,vv}L)$





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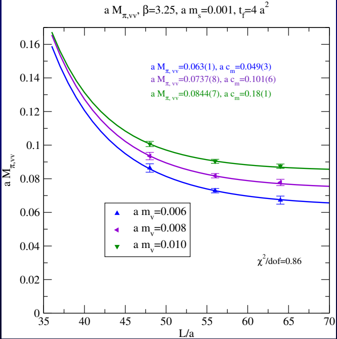

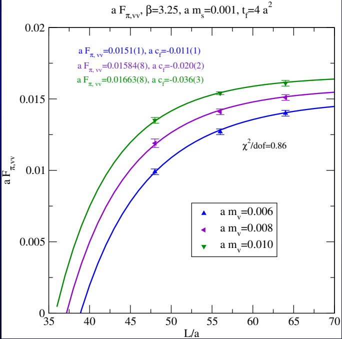

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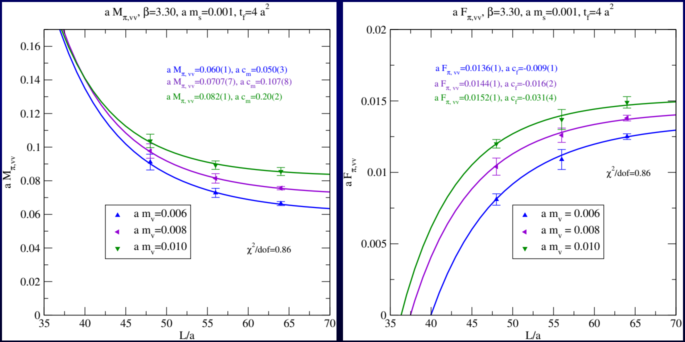

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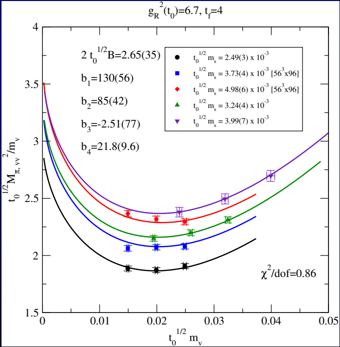
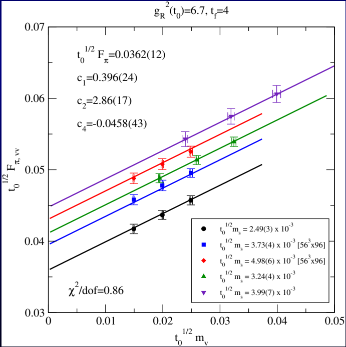
$$\bar{M}^2_{\pi,vv,\mathrm{NLO}} = \bar{m}_v \left(2\bar{B} + b_1\bar{m}_v + b_2\bar{m}_s + b_3(2\bar{m}_v - \bar{m}_s)\ln\bar{m}_v + b_4 t_0^{-1}a^2\right)$$

$$\bar{F}_{\pi,vv,\mathrm{NLO}} = \bar{F}_\pi + c_1\bar{m}_v + c_2\bar{m}_s + c_3(\bar{m}_v + \bar{m}_s)\ln\bar{m}_v + c_4 t_0^{-1}a^2$$

(c_3 is not detectable, hence omitted in the fit)





Conclusion

- Hadron Spectroscopy on nearly conformal models is challenging
  - Low-lying 0^{++} scalar interacts with pion dynamics $\Rightarrow \chi$PT needs modification
  - Taste breaking structure for Staggered simulations is different from QCD
- Mixed action analysis is explored
  - Wilson-flowed links used as the valence action
  - Flowed action restores taste symmetry and allows cheaper inversions
  - Preliminary results is promising, demonstrating the viability of the approach
- More comprehensive analysis is needed. E.g. Errors of t_0,Non-unitarity effects, the effects of low-lying 0^{++} scalar

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