# Spectroscopy of the BSM sextet model

Chik Him (Ricky) Wong

Lattice Higgs Collaboration (LatHC):
*Zoltán Fodor* [$], *Kieran Holland* [*],
*Julius Kuti* [†], *Dániel Nógrádi* [−], *Chik Him Wong* [$]

† University of California, San Diego * University of the Pacific $ University of Wuppertal - Eötvös University

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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 $\beta$ function [more in Kieran Holland's talk]
  $\Rightarrow$ still chirally broken
- Is $\chi$PT applicable? Dynamics are very different from QCD
- A low-lying $0^{++}$ scalar exists
  $\Rightarrow$ Linear-$\sigma$ 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

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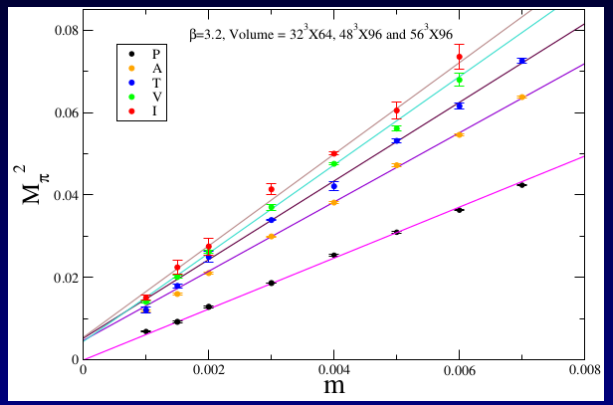
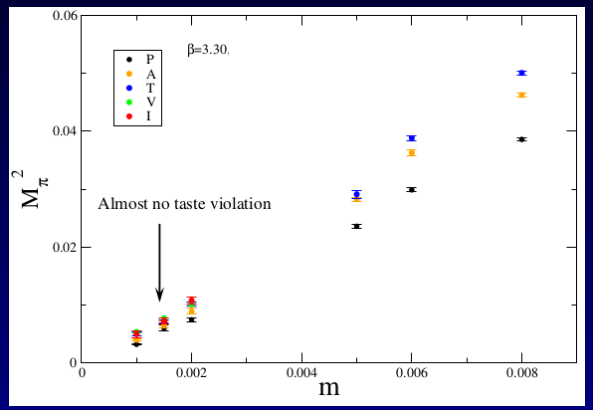
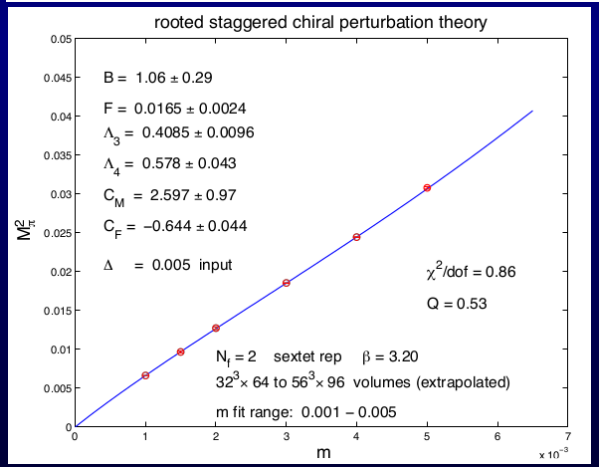
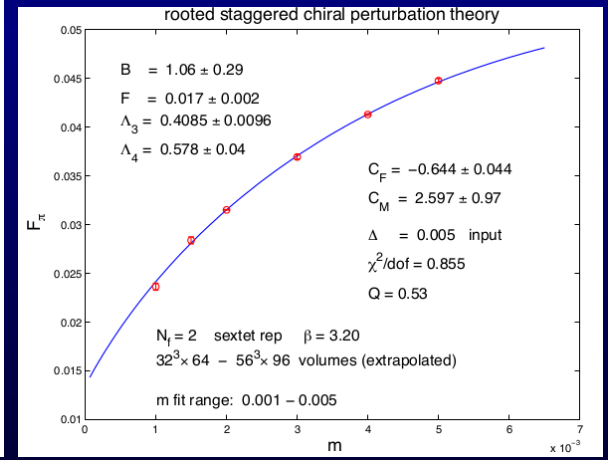
  Taste breaking structure is different from QCD

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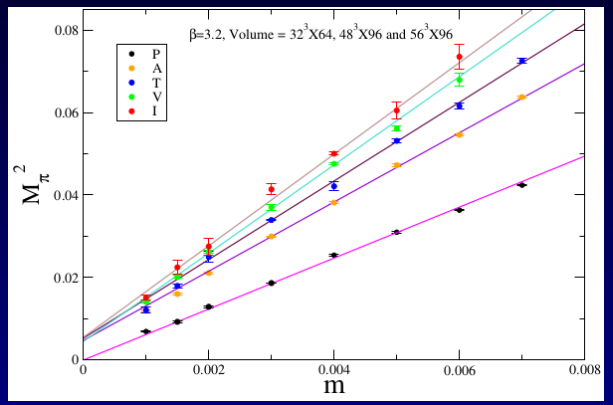


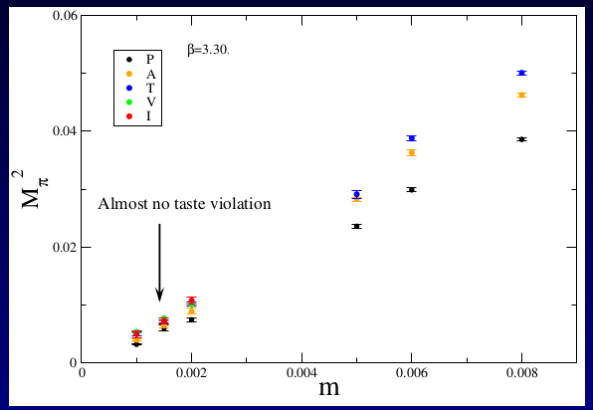


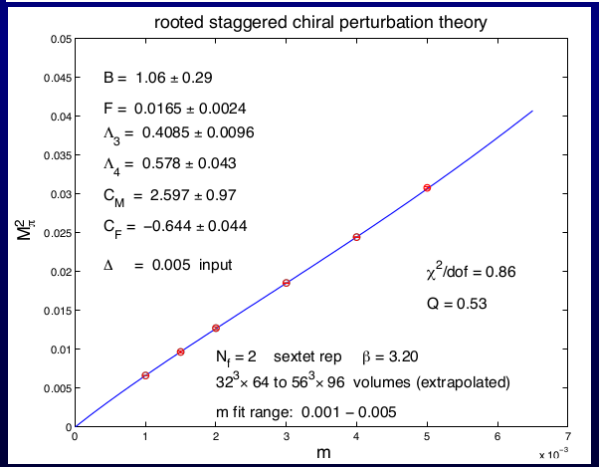


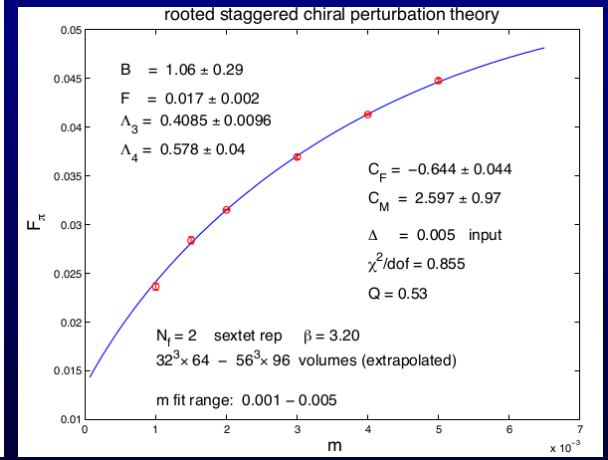


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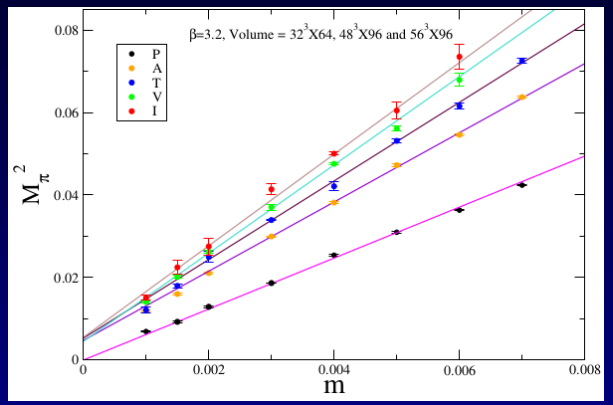


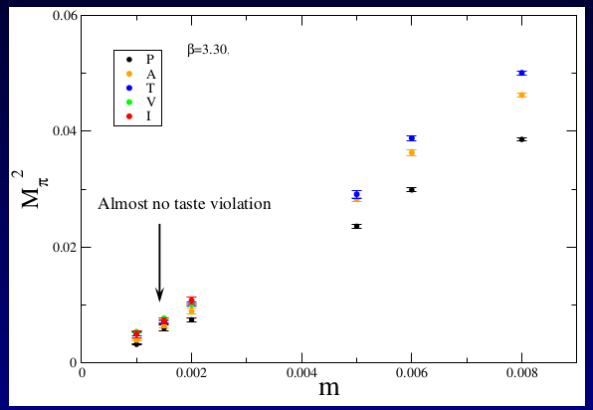


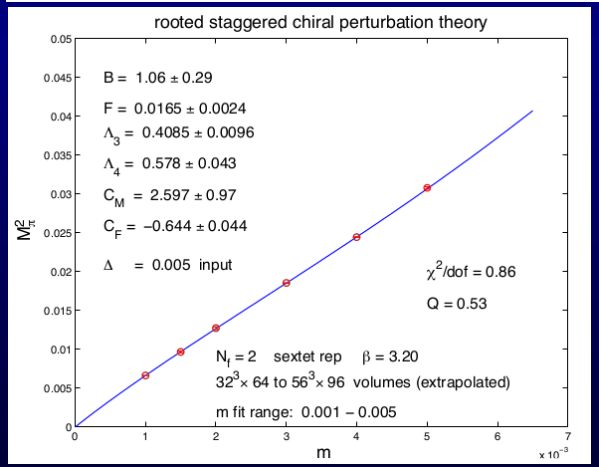


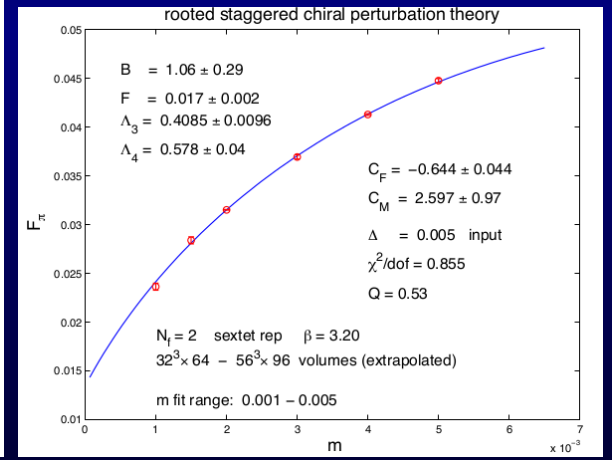


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# Mixed action analysis

- Mixed action setup: Valence fermion action is different from sea fermion action
- $\chi$PT $\Rightarrow$ MA$\chi$PT
- 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 $t_f$ $a^2$
  - Staggered action defined by the "flowed" links with a valence quark mass $m_v$

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- Flowed action as the valence action :
  - Wilson flow reduces cutoff effects, approximately restores the taste symmetry

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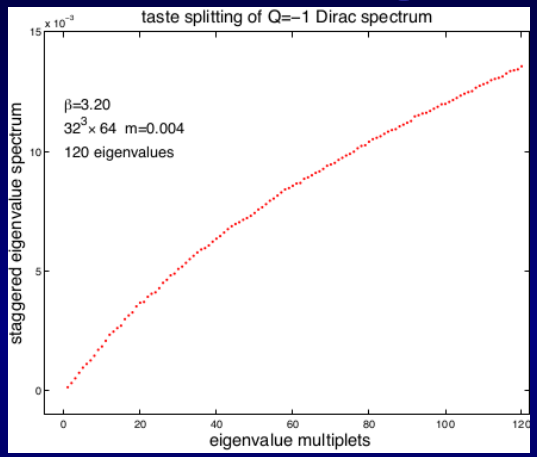
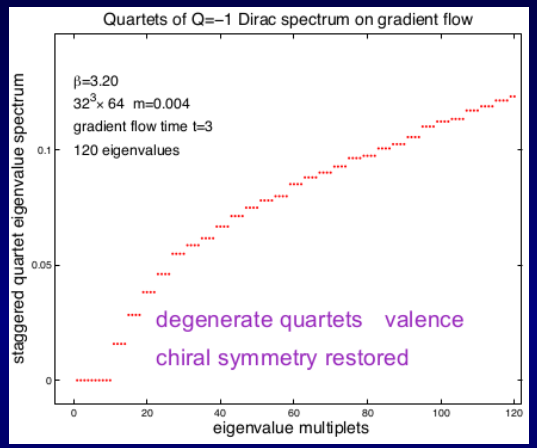
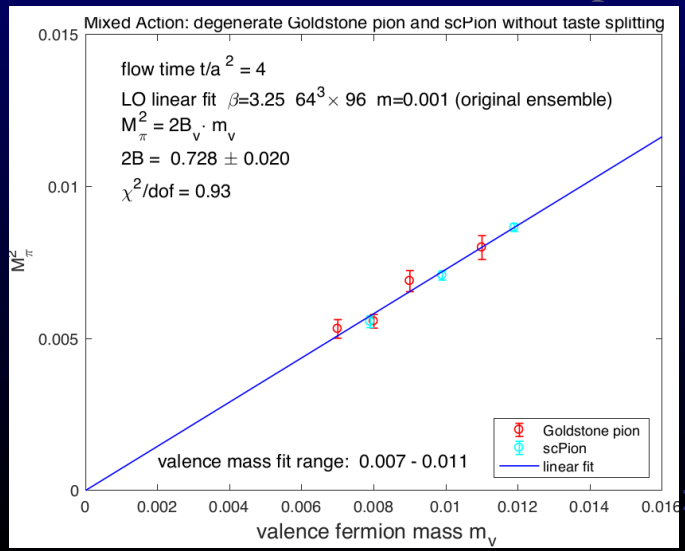



  - Valence Goldstone and valence non-Goldstone pions degenerate



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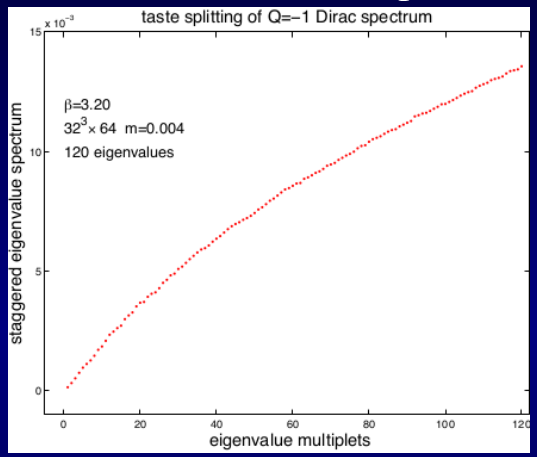


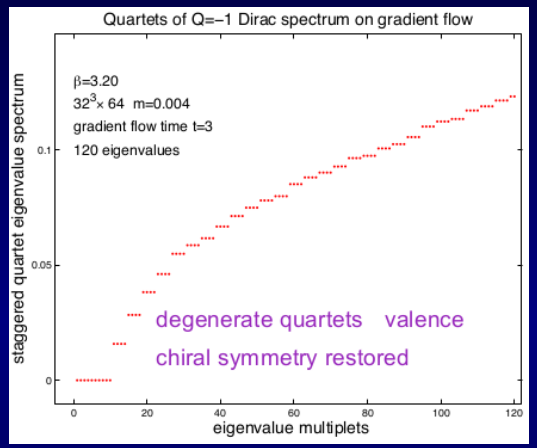


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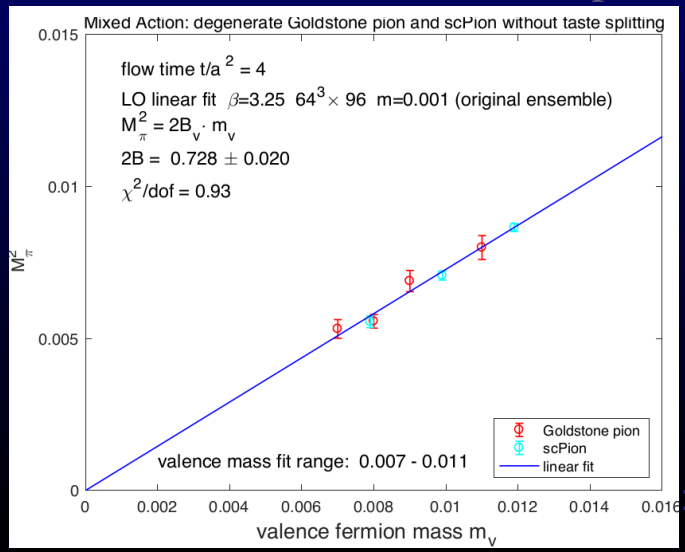

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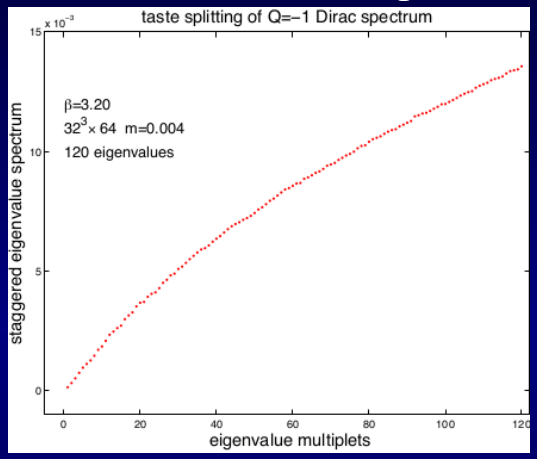


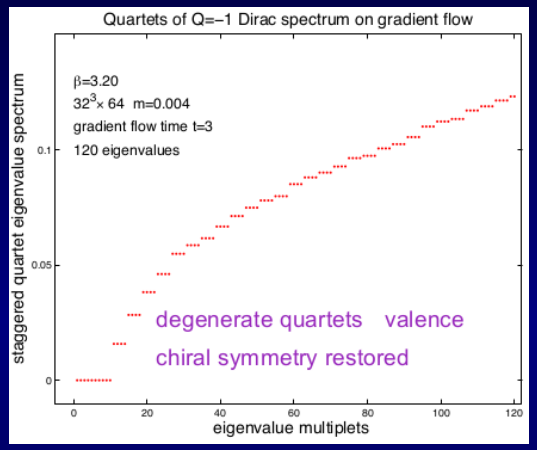


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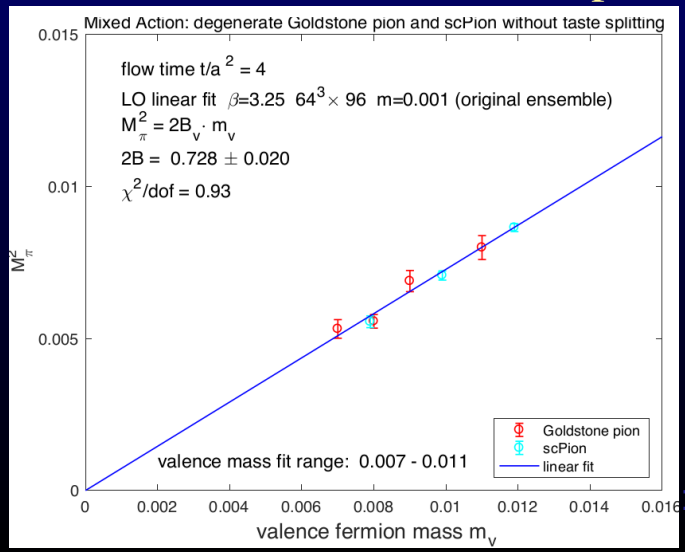

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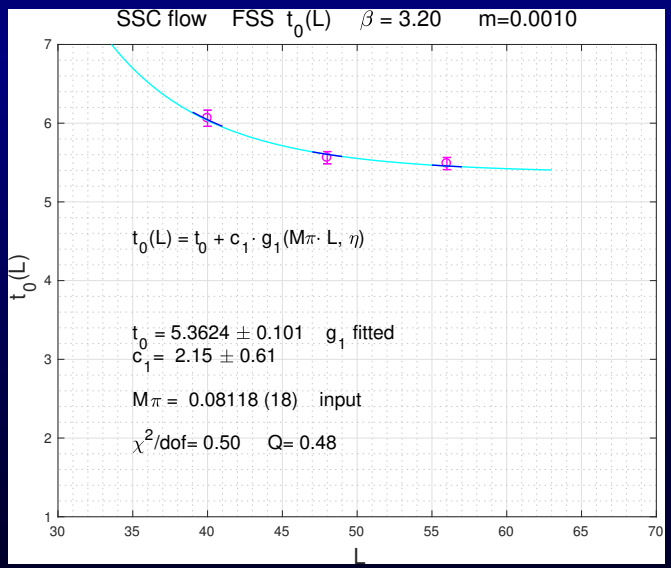
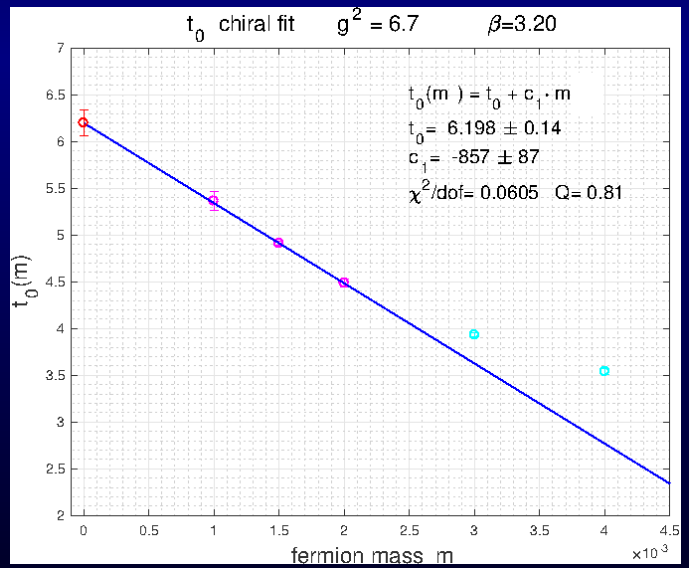
# Preliminary results

- Measure quantities $X$, e.g. $F_\pi$, $M_X$ 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 $\beta$ [ Kieran Holland's talk]



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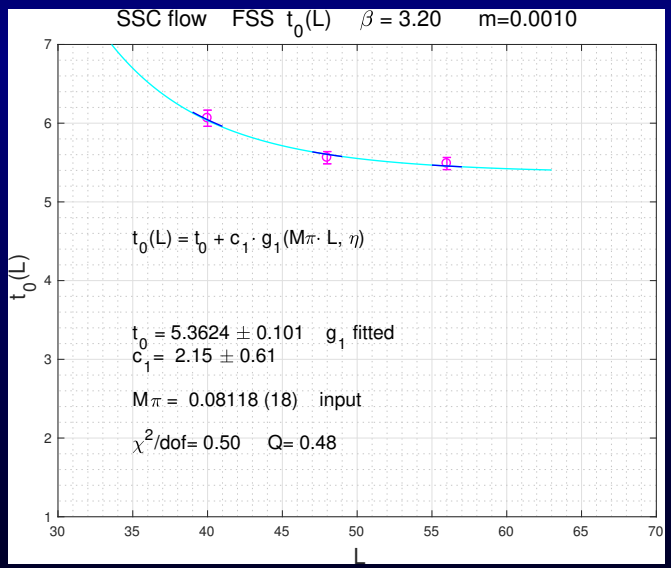


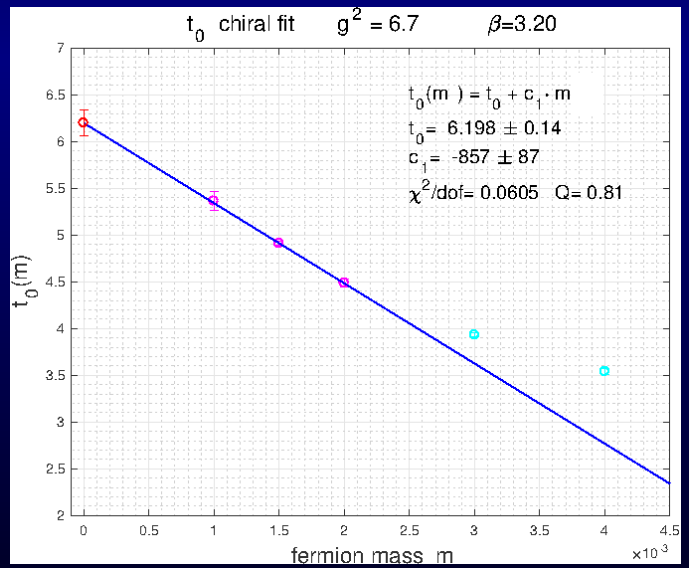

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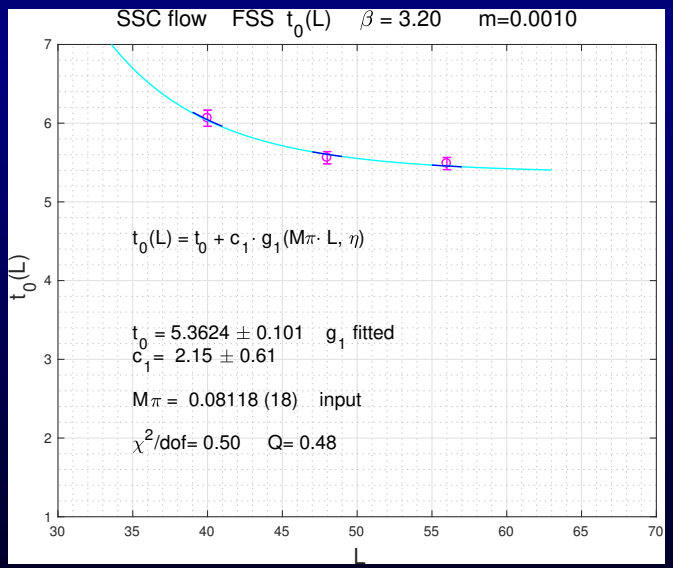


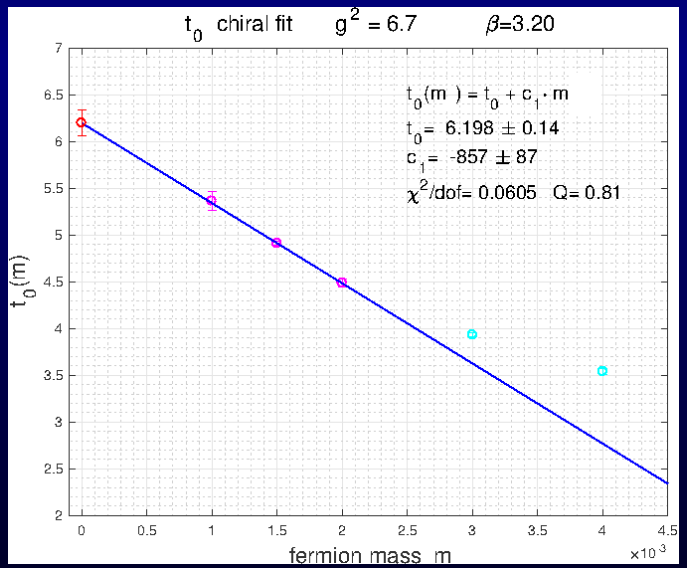

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- Assuming MA$\chi$PT, the relation between $X_{\mathrm{NLO}}$ and $X_{\mathrm{LO}}$ in the infinite-volume limit can be worked out. E.g.

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

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

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

- 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, $\beta$'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 $t_\mathrm{f}$-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:

| $\beta$ | $m_s$ | $m_v$ | $L^3 \times T$ |
|---|---|---|---|
| 3.20 | 0.001 | 0.006,0.008,0.010 | $40^3 \times 80$,$48^3 \times 96$,$56^3 \times 96$ |
| | 0.0015 | 0.006,0.008,0.010 | $56^3 \times 96$ |
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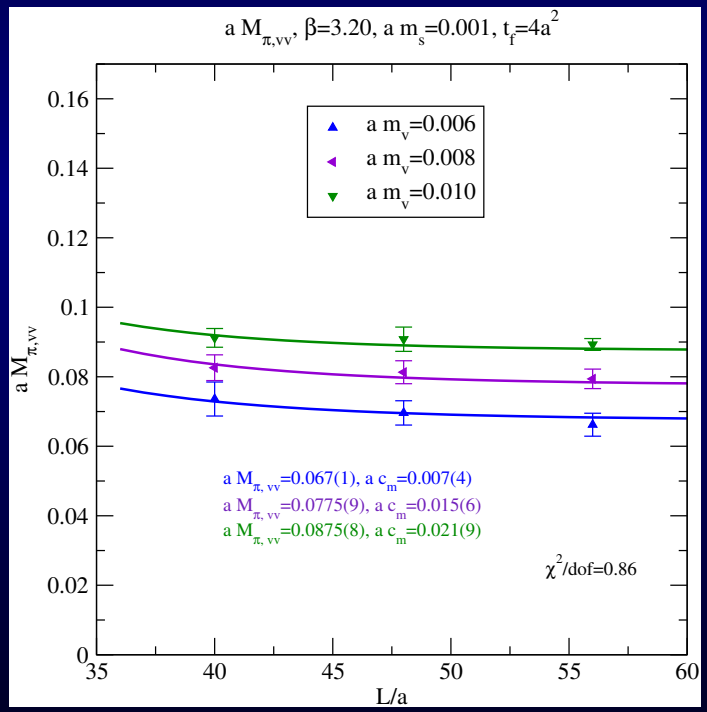
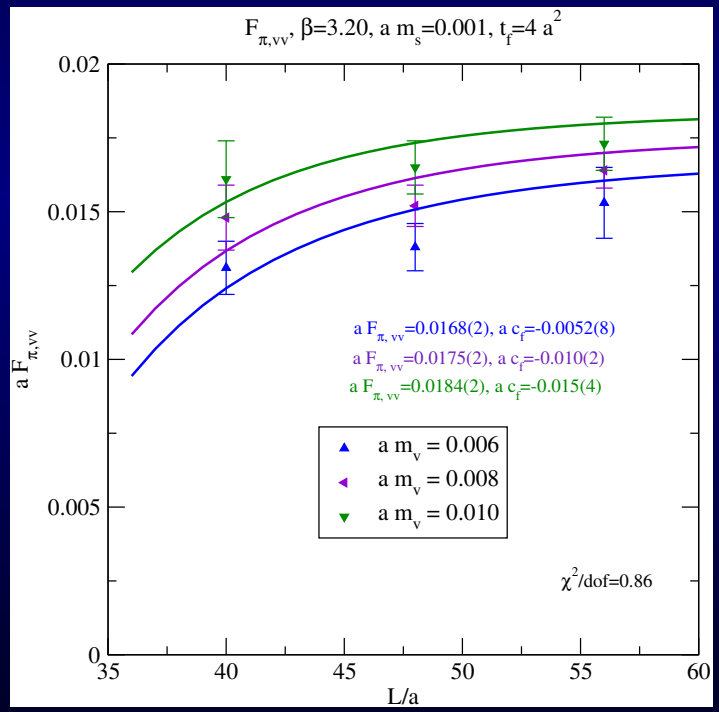
  $M_{\pi,vv}(L) = M_{\pi,vv} + c_m g_1(M_{\pi,vv}L),\ \ F_{\pi,vv}(L) = F_{\pi,vv} + c_f g_1(M_{\pi,vv}L)$



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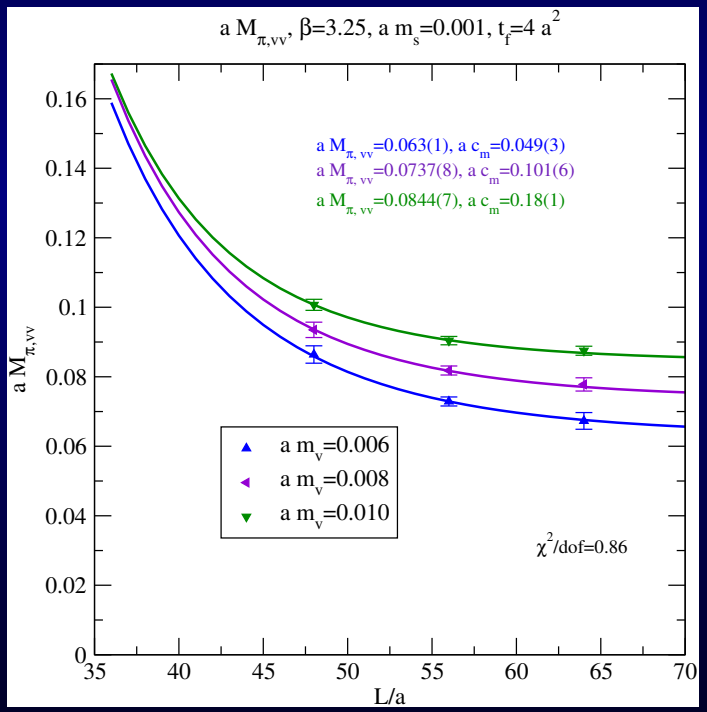


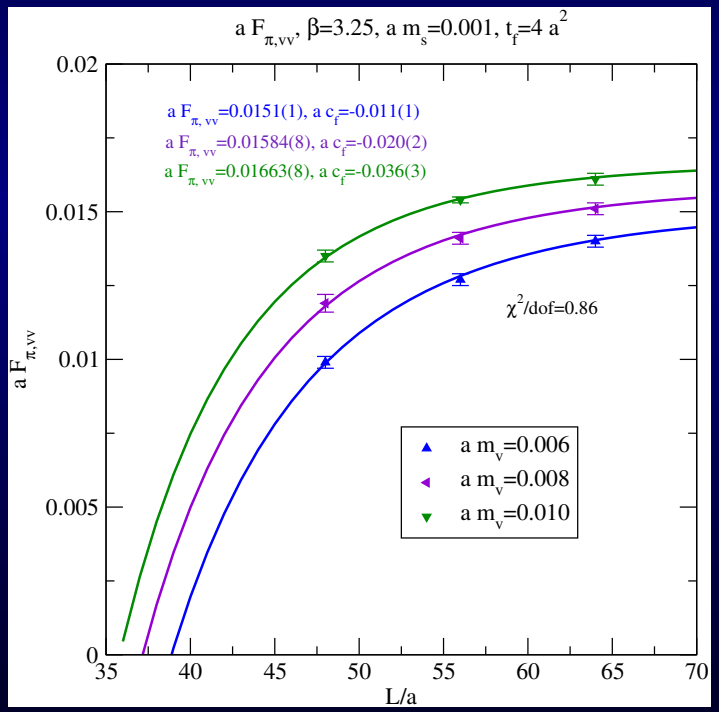

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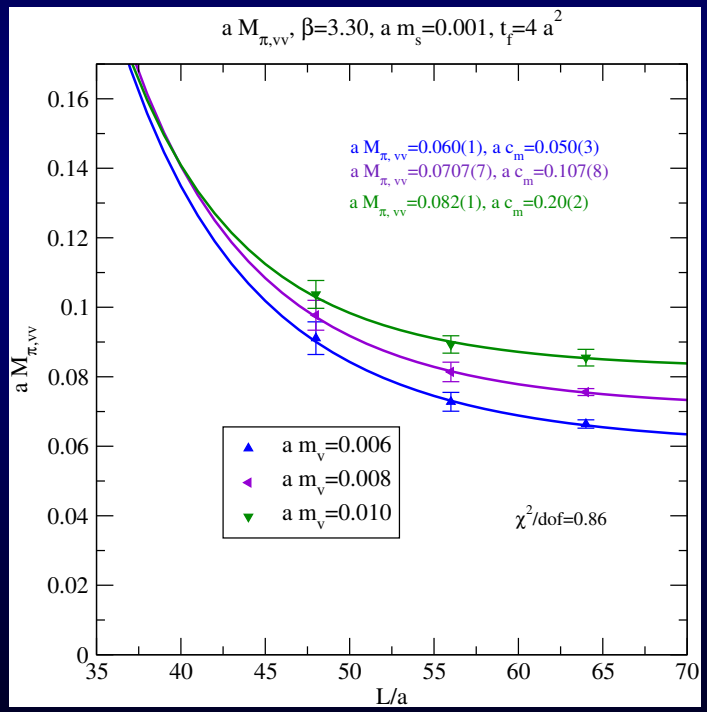


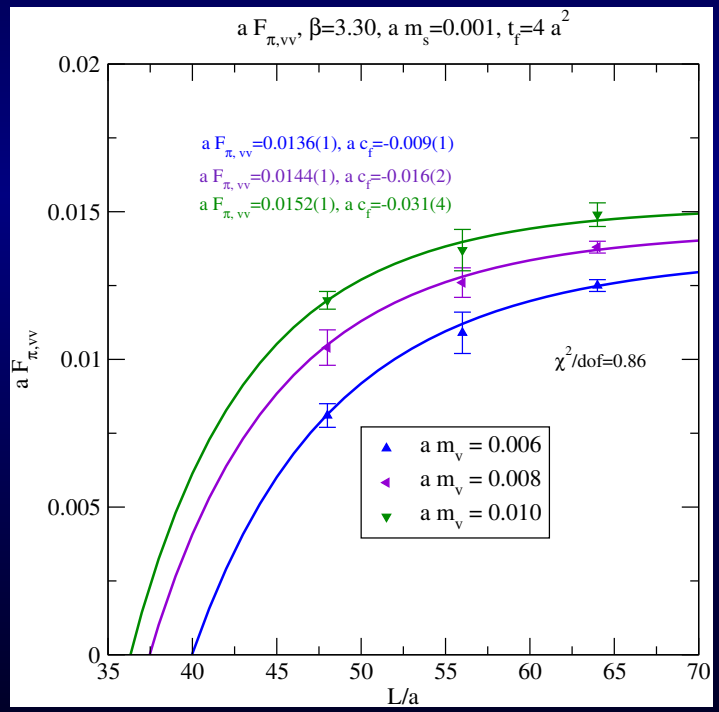

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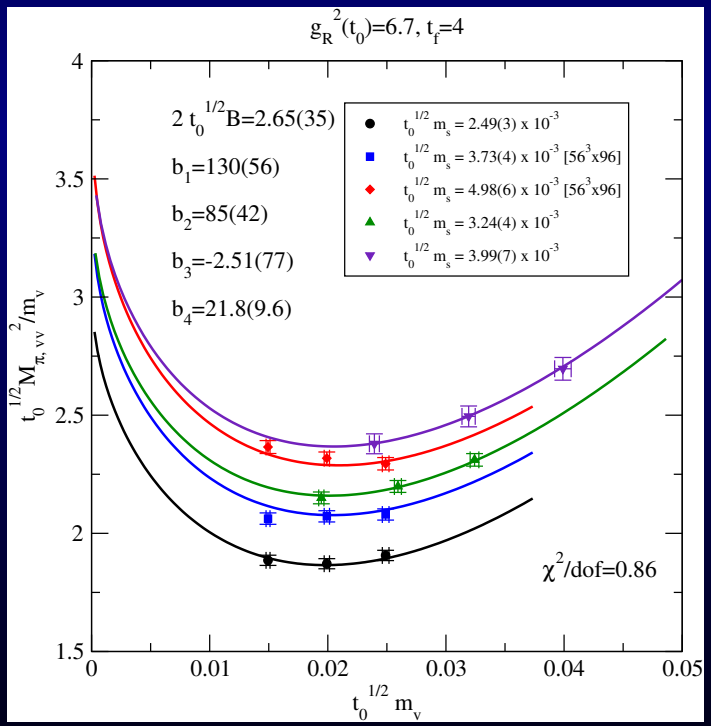
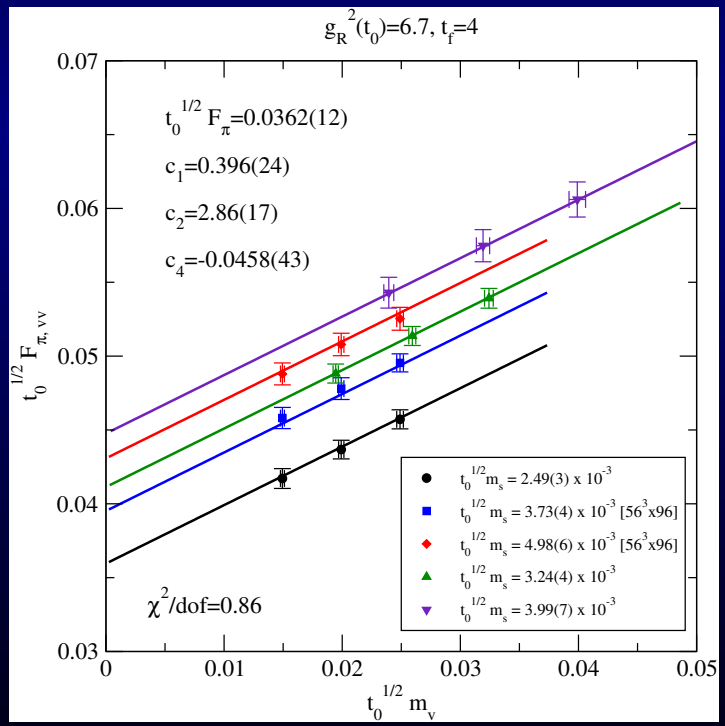
($c_3$ is not detectable, hence omitted in the fit)



# 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
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