Near Conformal Dynamics in SU(3) N_f=8 Theory

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Why SU(3) N_f=8?

- The LSD Collaboration has been studying SU(3) N_f=8 for nearly a decade. Why is it so interesting?

- Early on, it was clear that this theory had near conformal dynamics due to very slowly running coupling.

- As Enrico already showed, this theory also has a light isoscalar meson: $m_\sigma \sim F_\pi$ in chiral limit. This is a potential **composite Higgs** candidate.

- Are near conformal dynamics and the light scalar related?

- Andy will next discuss our efforts to find a good EFT for light pions and scalars.

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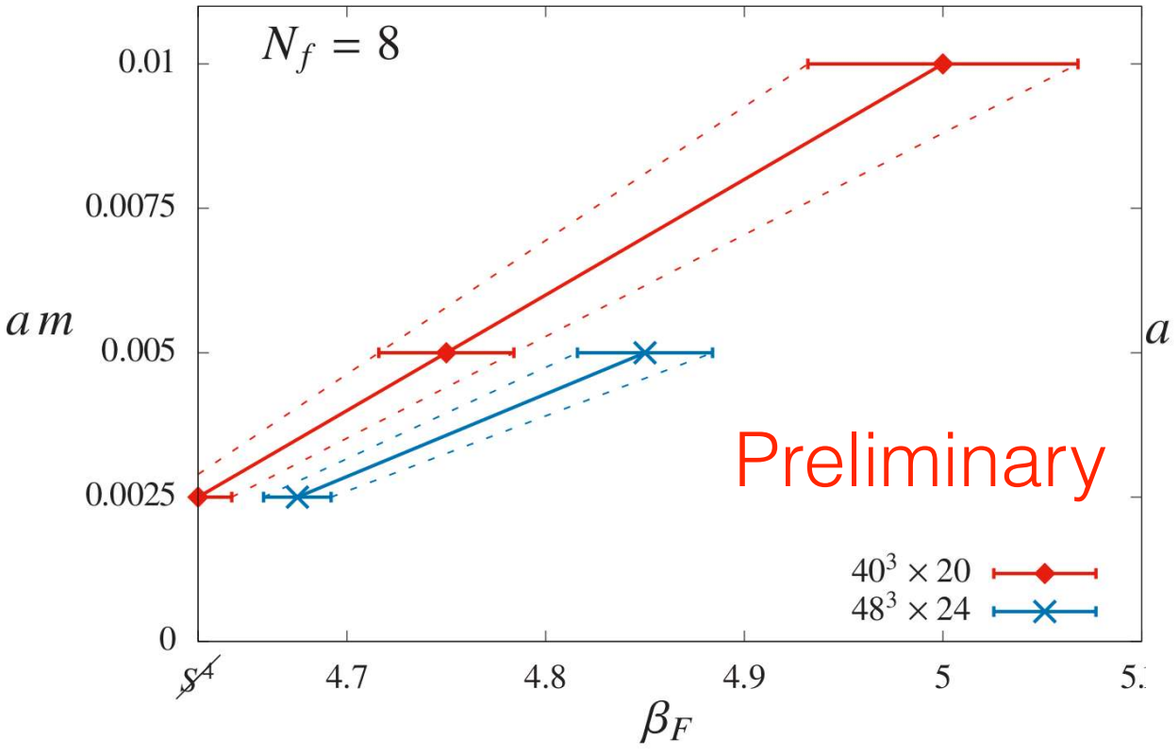
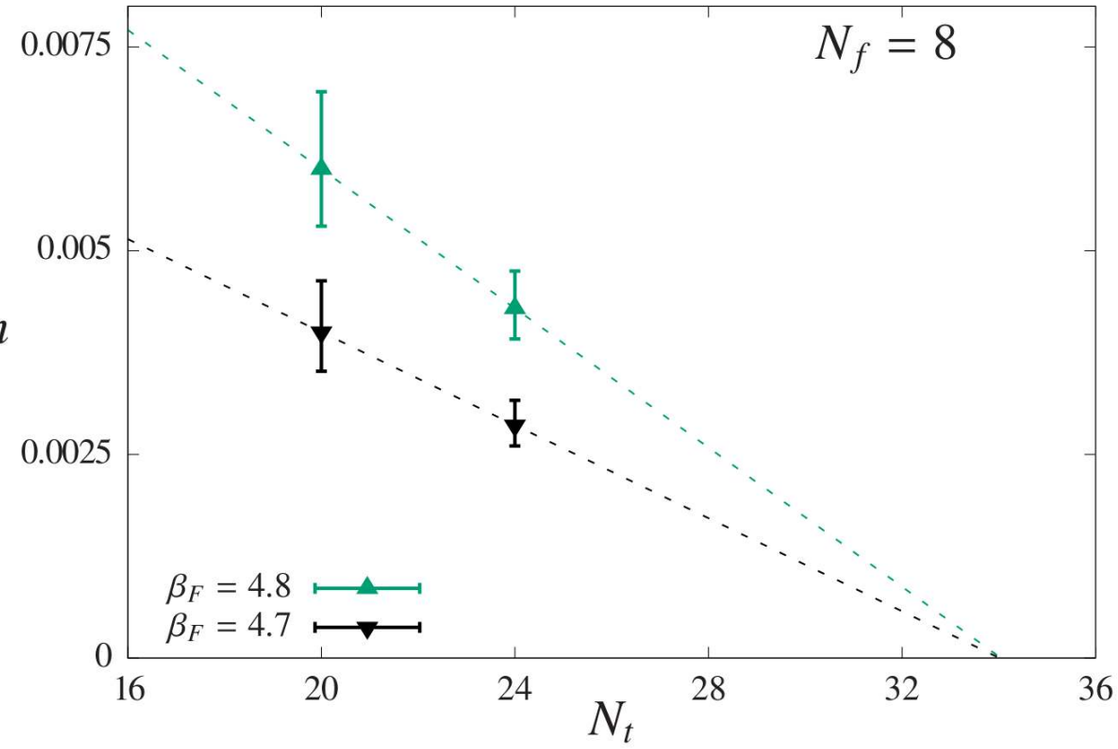
LSD SU(3) N_f=8 Stag

- Earlier USBSM studies (and LatKMI) used HISQ fermions which become prohibitively expensive for N_f=8 on coarse lattices.

- Using nHYP stag fermions and fund+adj gauge action pioneered by Boulder group to get to somewhat coarser (but still very fine) lattices.

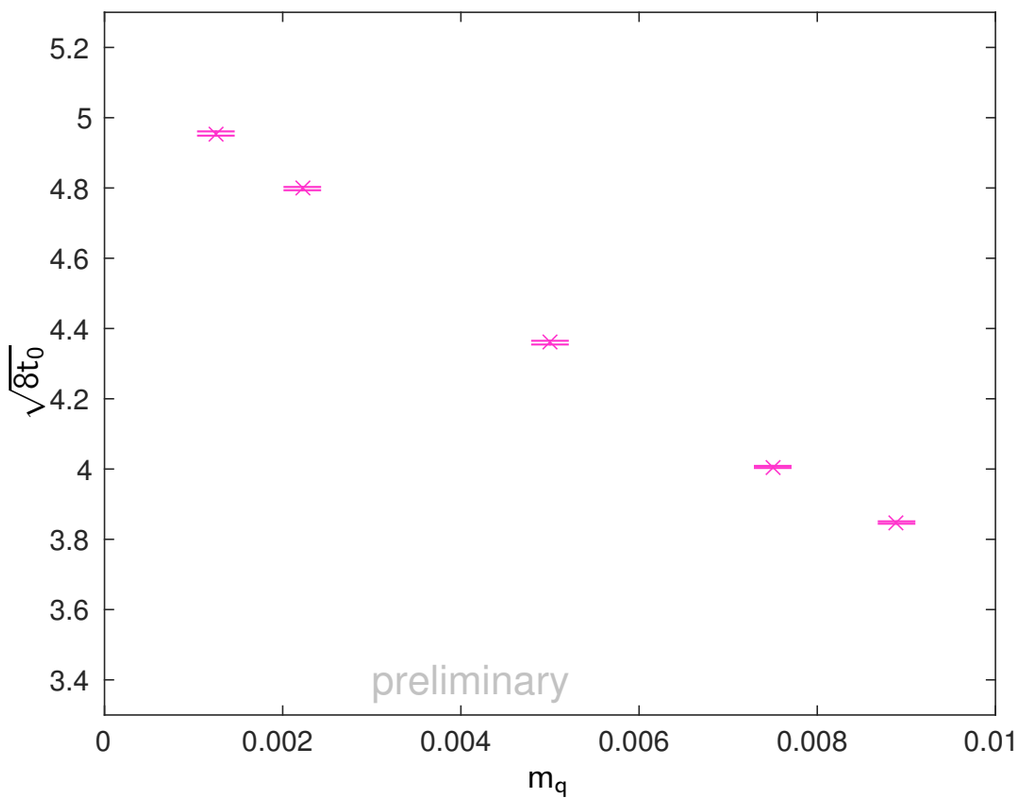




T_c and bulk phase

Near Conformal Scale Setting

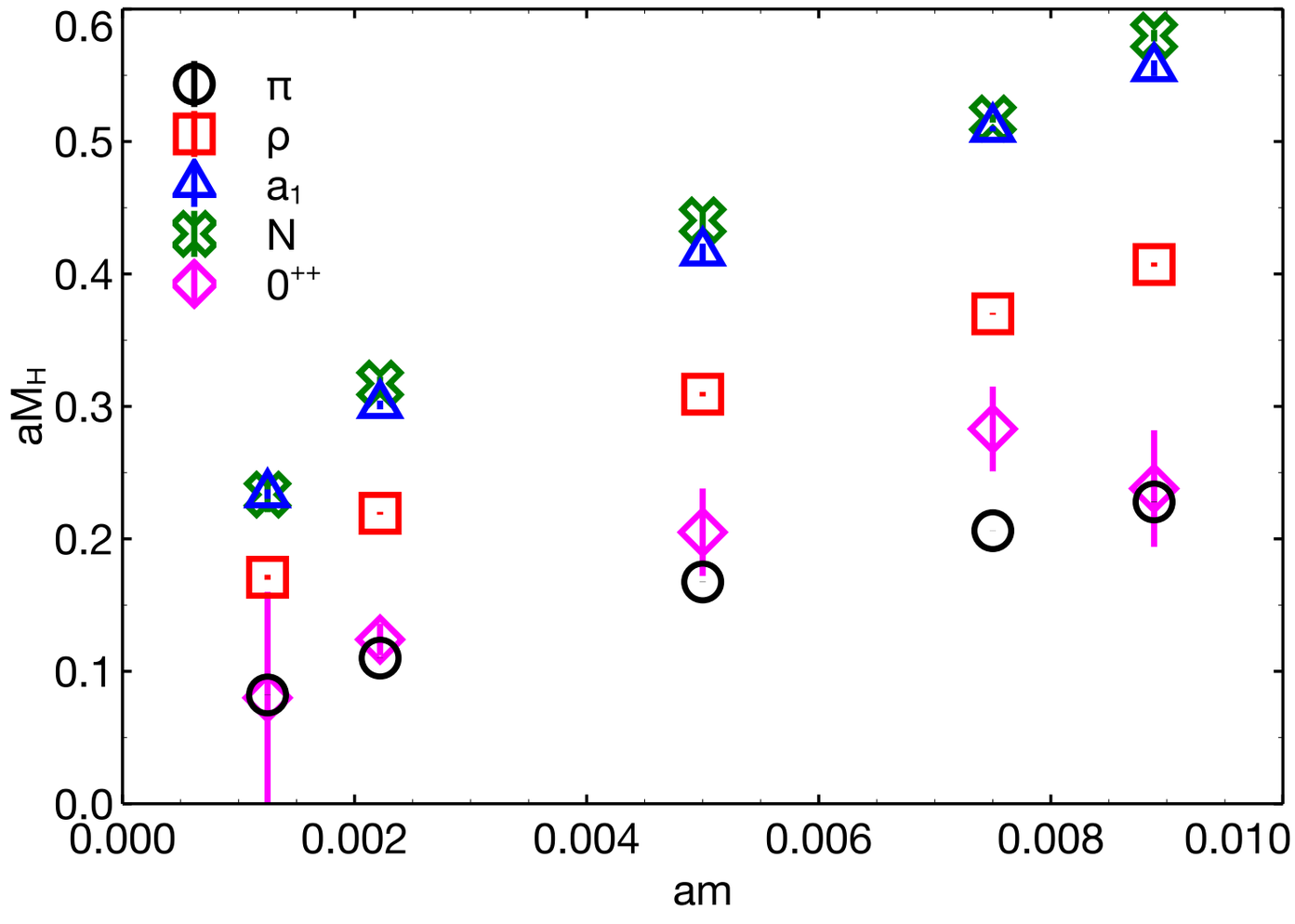
- In QCD, the dynamical scale a^{-1} is strongly affected by gauge coupling and weakly affected by quark mass.
- This reflects strong gluonic anti-screening and weak fermionic screening in vacuum.
- Near conformal dynamics has balanced anti-screening and screening, leading to strong mass dependence in setting the scale



Light hadron spectrum

- Spectrum consistent with earlier LSD $N_f=8$ results but at lighter quark mass.

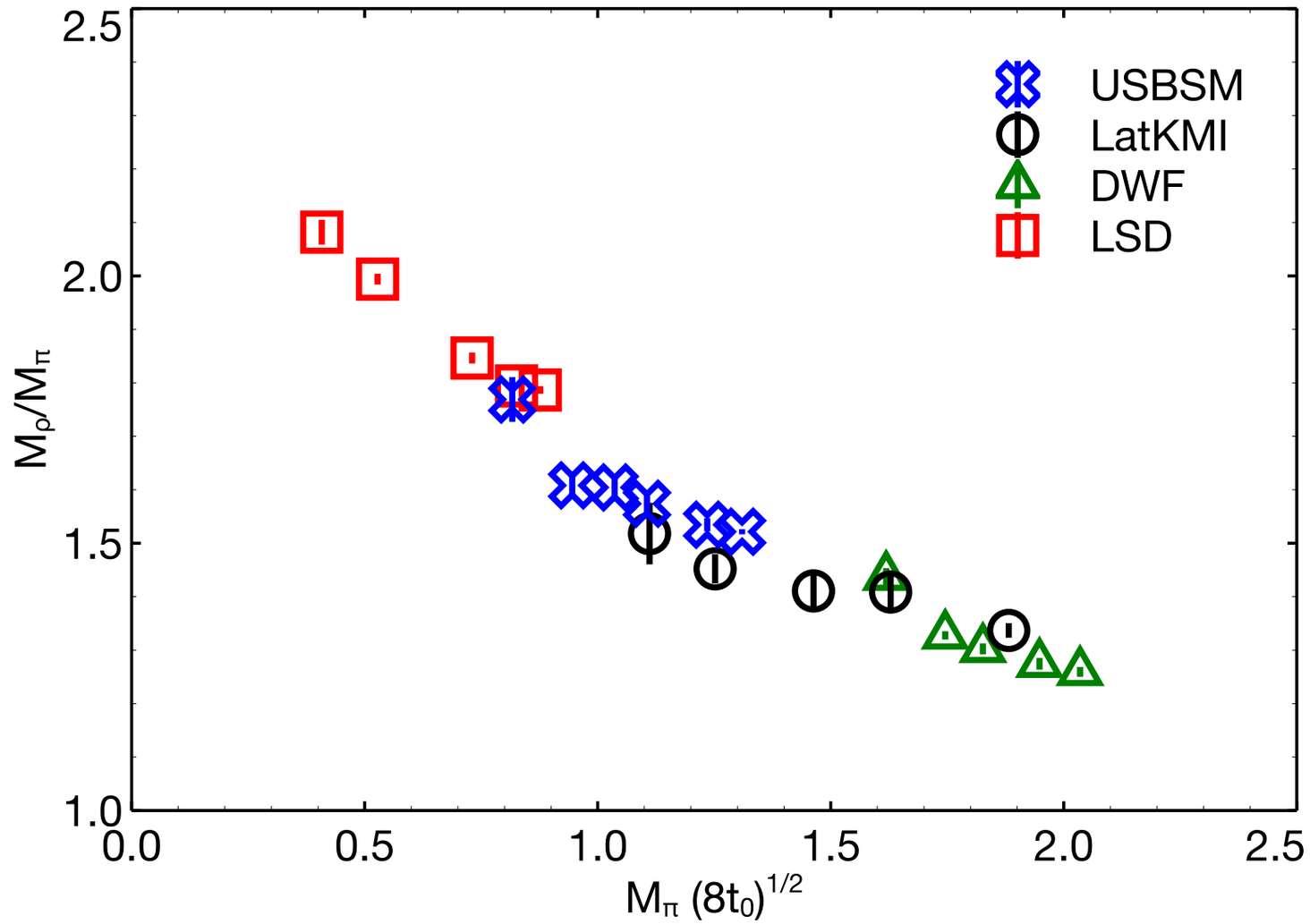
- Very strong quark mass dependence for quantities expressed in lattice units, as expected from near conformal dynamics.



Not hyperscaling

- Mass-deformed IRFP theories have hadron masses which scale in constant ratios in approach to conformity: $M_\rho/M_\pi \sim$ const as $M_\pi \to 0$.

- Pretty clear evidence that $N_f=8$ is outside conformal window since pion is becoming light relative to rho meson. Very different from $N_f=12$.



Finite Volume Effects

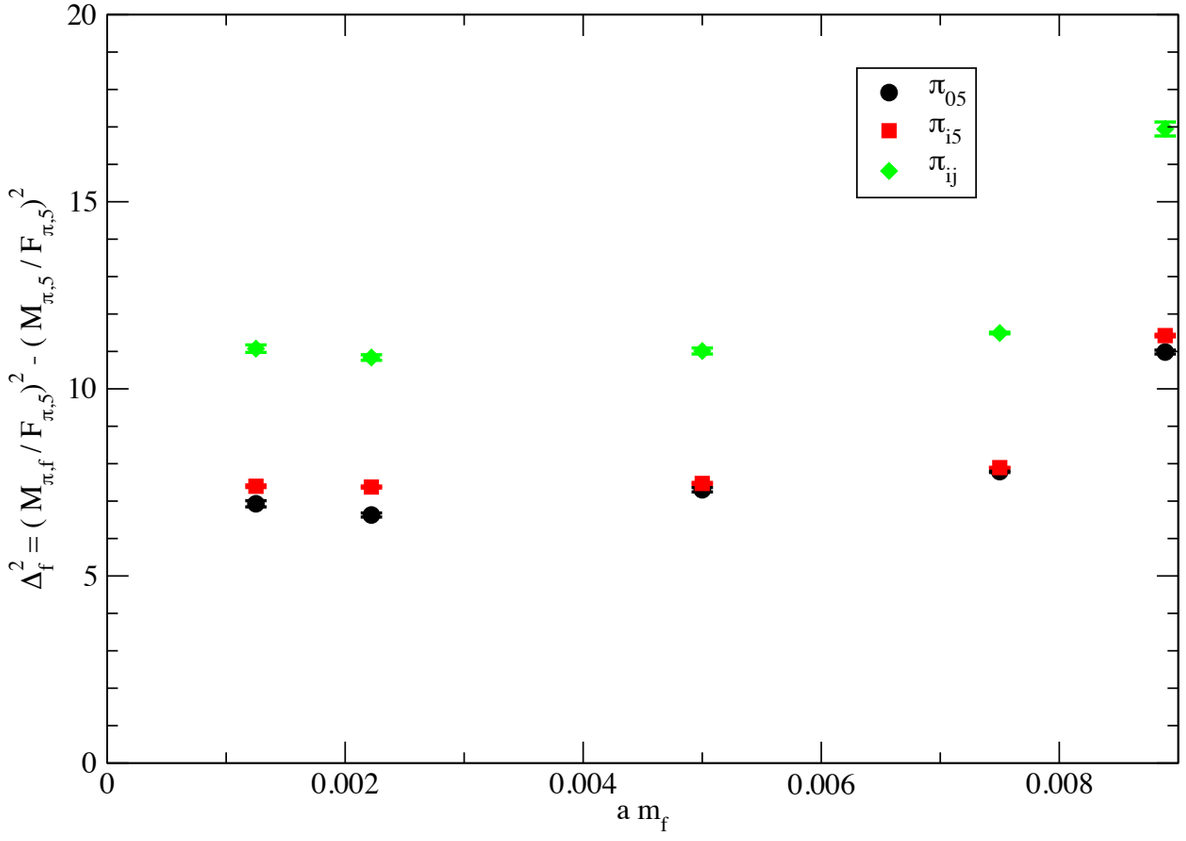
- Finite volume effects are small, order 1% in sensitive quantities and order 2% in ratios at M_π L ~ 5.3.

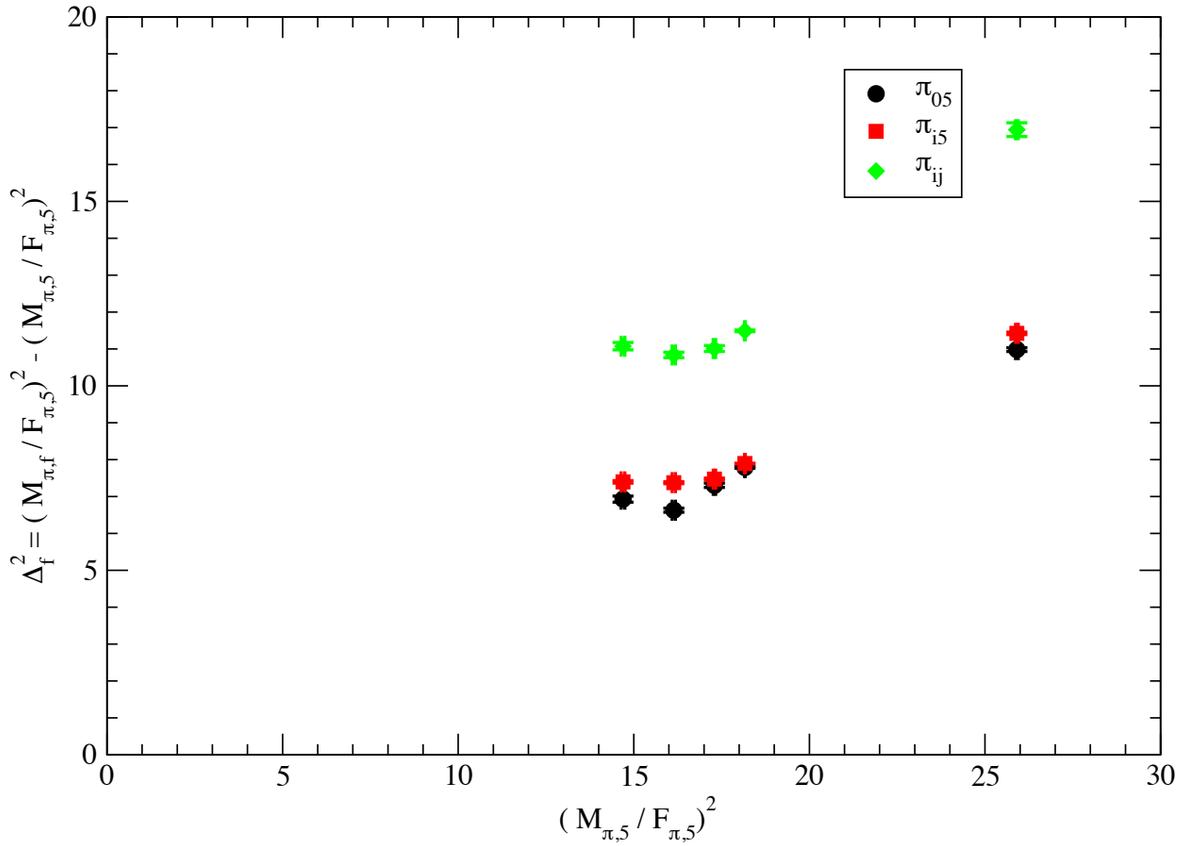
- Note how rapidly quantities change in lattice units with quark mass while ratios change slowly.

m_f	volume	M_π	F_π	M_π / F_π	M_π L
0.0075	$24^3 \times 48$	0.21067(19)	0.04746(8)	4.439(9)	5.1
	$32^3 \times 64$	0.20630(6)	0.04823(3)	4.228(3)	6.6
	$48^3 \times 96$	0.20575(3)	0.04827(1)	4.262(1)	9.9
0.005	$32^3 \times 64$	0.16795(10)	0.03939(4)	4.264(6)	5.4
	$48^3 \times 96$	0.16619(7)	0.03996(3)	4.159(4)	8.0
0.00222	$48^3 \times 96$	0.11017(6)	0.02742(3)	4.017(6)	5.3
0.00125	$64^3 \times 128$	0.08273(13)	0.02111(11)	3.918(24)	5.3

Staggered flavor breaking

- Even though $a^{-1} \sim 50\ F_\pi$ the taste breaking is still rather large. Another consequence of near conformal physics.





Wrap around effects?

- If $M_\sigma \sim M_\pi$ wrap around effects might be noticeable for $t \sim N_t / 2$.
- But we choose $M\pi\ L > 5$ and $N_t = 2\ L$, so the effect will be highly suppressed. *Unless*…
  - $M_\sigma < M_\pi$ (not the case for N_f=8)
    - or $A_{ij0} << A_{ij\sigma}$ (not true in general but maybe special cases)
- Looking for ossible wrap around effect in a_0 channel using psi-bar-psi like operator, stay tuned for details in writeup.

$$C_{I,ij}(t) = \frac{e^{-M_I t}\left(A_{ij0} + A_{ij\sigma} e^{-M_\sigma (N_t - t)}\right) + e^{-M_I (N_t - t)}\left(A_{ij0} + A_{ij\sigma} e^{-M_\sigma t}\right)}{1 + e^{-M_\sigma N_t}}$$

$$A_{ij0} = \left\langle 0 \left| \mathcal{O}^\dagger_{I,i} \right| M_I \right\rangle \left\langle M_I \left| \mathcal{O}_{I,j} \right| 0 \right\rangle \qquad A_{ij\sigma} = \left\langle M_\sigma \left| \mathcal{O}^\dagger_{I,i} \right| M_I \right\rangle \left\langle M_I \left| \mathcal{O}_{I,j} \right| M_\sigma \right\rangle$$

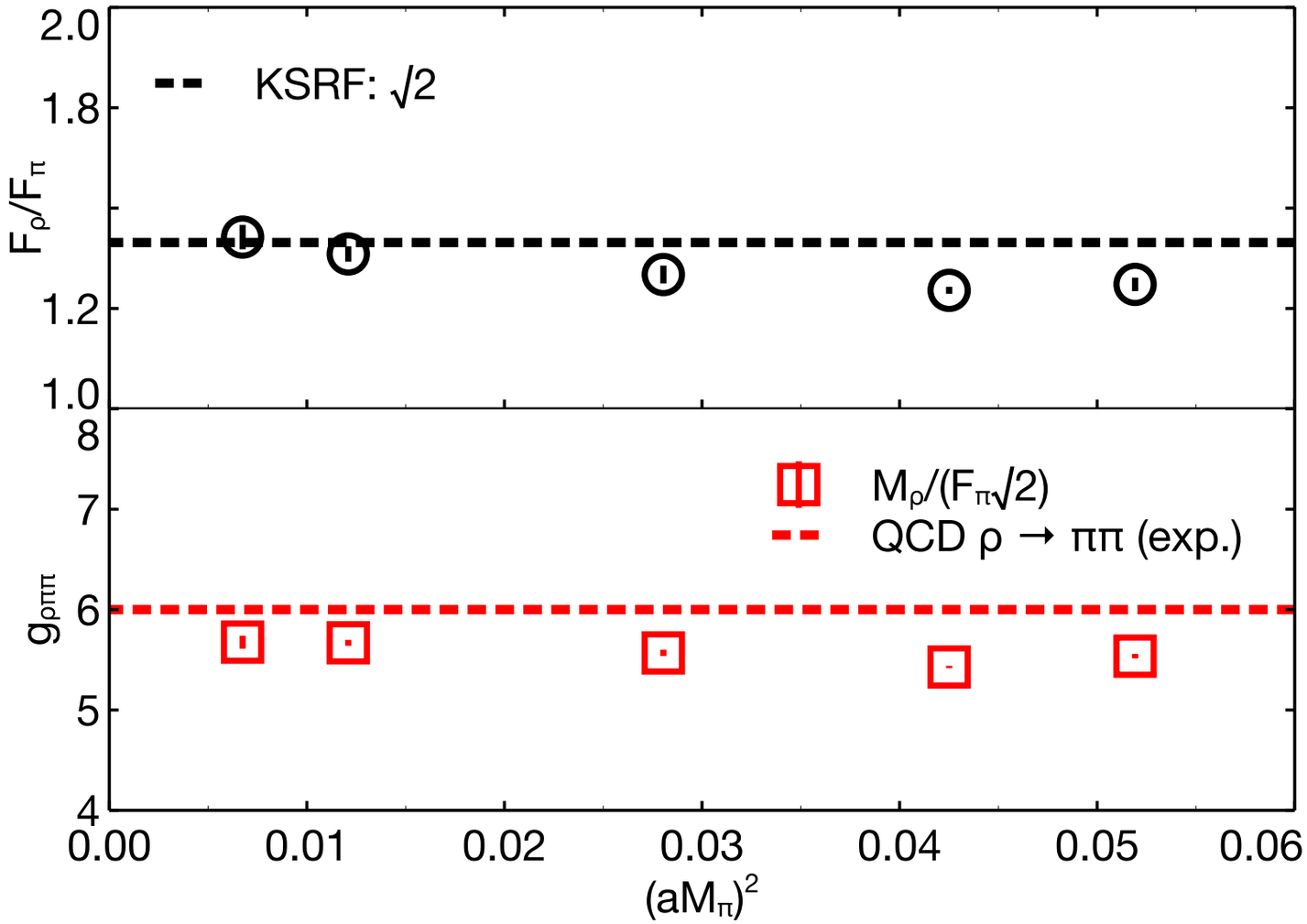
KSRF Relation

- Dynamical origin of vector meson dominance (VMD) not well understood in QCD. Is it also true in N_f=8?

- Seems to be true, so in LHC might expect 2 TeV vector resonances with ~25% width.

$$F_\rho = \sqrt{2}\ F_\pi\ , \quad g_{\rho\pi\pi} = \frac{M_\rho}{\sqrt{2}\ F_\pi}\ ,$$

$$\Gamma_\rho \approx \frac{g^2_{\rho\pi\pi}\ M_\rho}{48\pi} \approx \frac{M^3_\rho}{96\pi F^2_\pi}$$

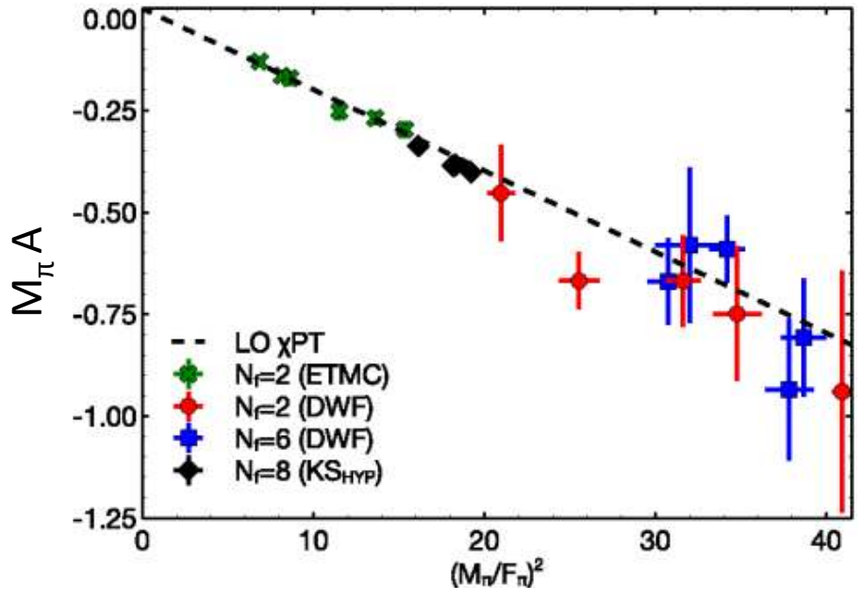


I=2 $\pi\pi$ scattering

A Clue from Pion Scattering

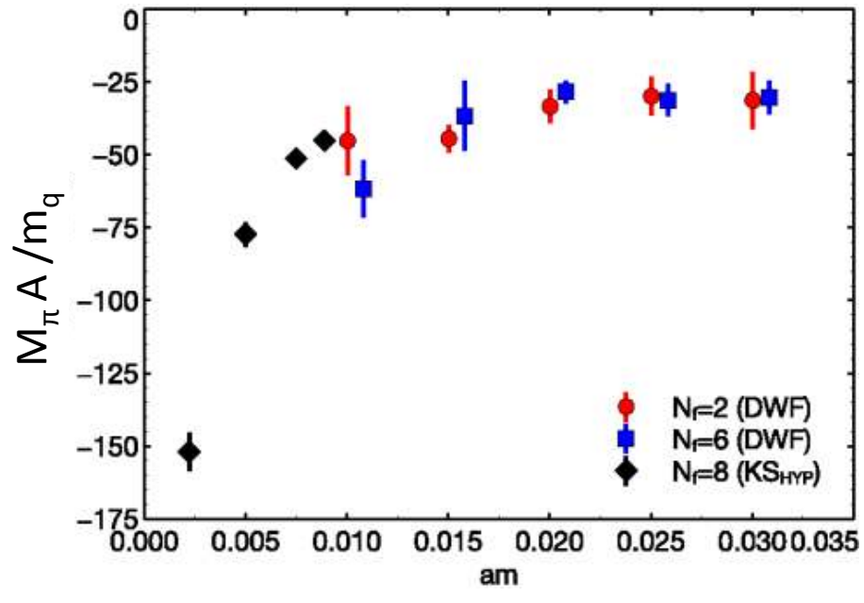
- Scattering length agrees well with LO XPT when plotted against physical (computed) values of M_π / F_π .

$$(M_\pi A)_{LO} = \frac{-1}{(16\pi)^2}\left(\frac{M_\pi}{F_\pi}\right)^2 = \frac{-1}{(16\pi)^2}\frac{2Bm_q}{F^2}$$



Ref [1]

- Plotted against bare quark mass, very poor agreement with LO XPT
- Again, suggests F has significant dependence on chiral breaking at tree level



Ref [1]

Summary

- We now have clear examples of gauge theories with light scalars which might eventually be useful for composite Higgs phenomenology.

- Computing at masses $m_\pi \leq f_\pi$, where χPT might work, seems prohibitively expensive. So it's not clear how to extrapolate lattice results to chiral limit.

- Despite many technical difficulties due to near-conformal dynamics, useful physical results can be extracted. Can we identify a useful low-energy EFT? Listen to next talk…

Backup Slides