Light Isosinglet Scalar in Eight Flavor QCD

George T. Fleming
Yale University
(for the LSD Collaboration)

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Light Scalar in the SM

- Higgs mechanism of the Standard Model is a linear sigma model and the sigma (Higgs boson) has a physical mass light compared to the breaking scale: $m_\sigma \sim F$ ($m_h \sim v$).

- Wait. m_h=125 GeV, v=250 GeV. So why not m_σ=F/2?
  top quark + …

- The original effective theory for QCD was also the Linear Sigma Model but for some dynamical reason, the sigma meson is heavy ($m_\sigma >> F$).

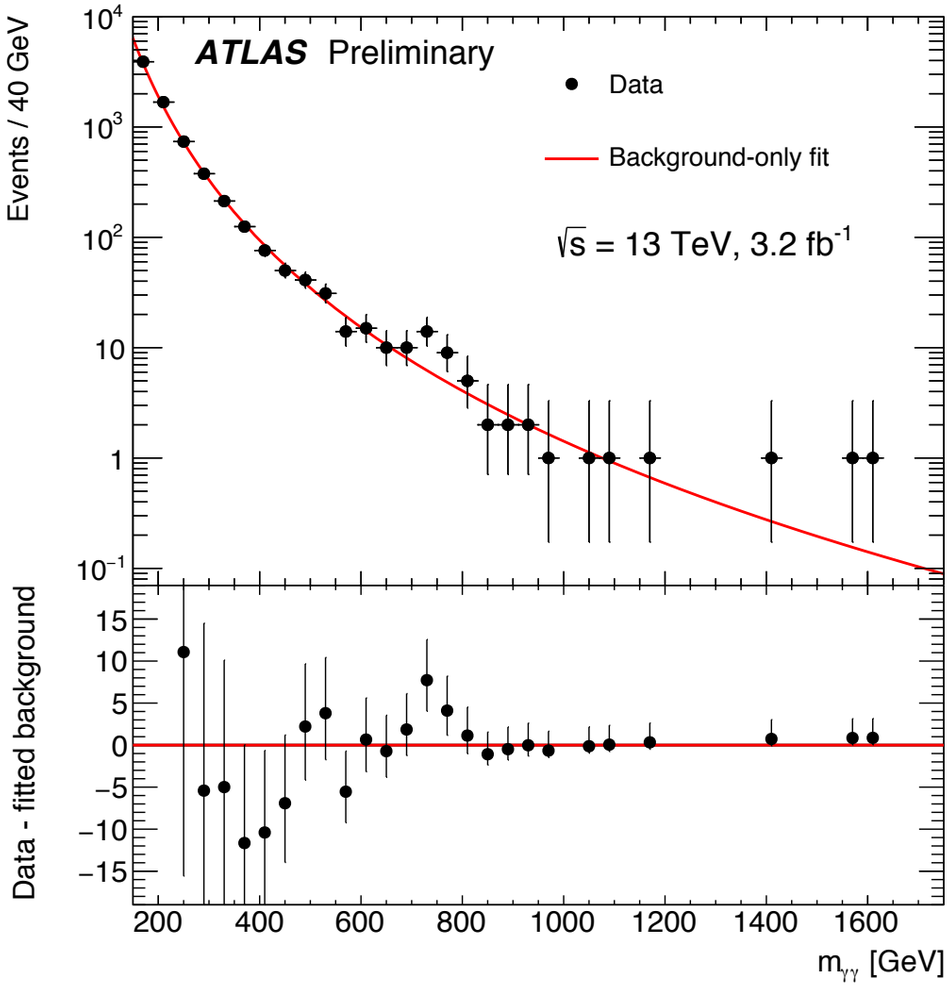
- We learned that removing the sigma from the effective theory gave us a better effective theory, χPT (for pions only).

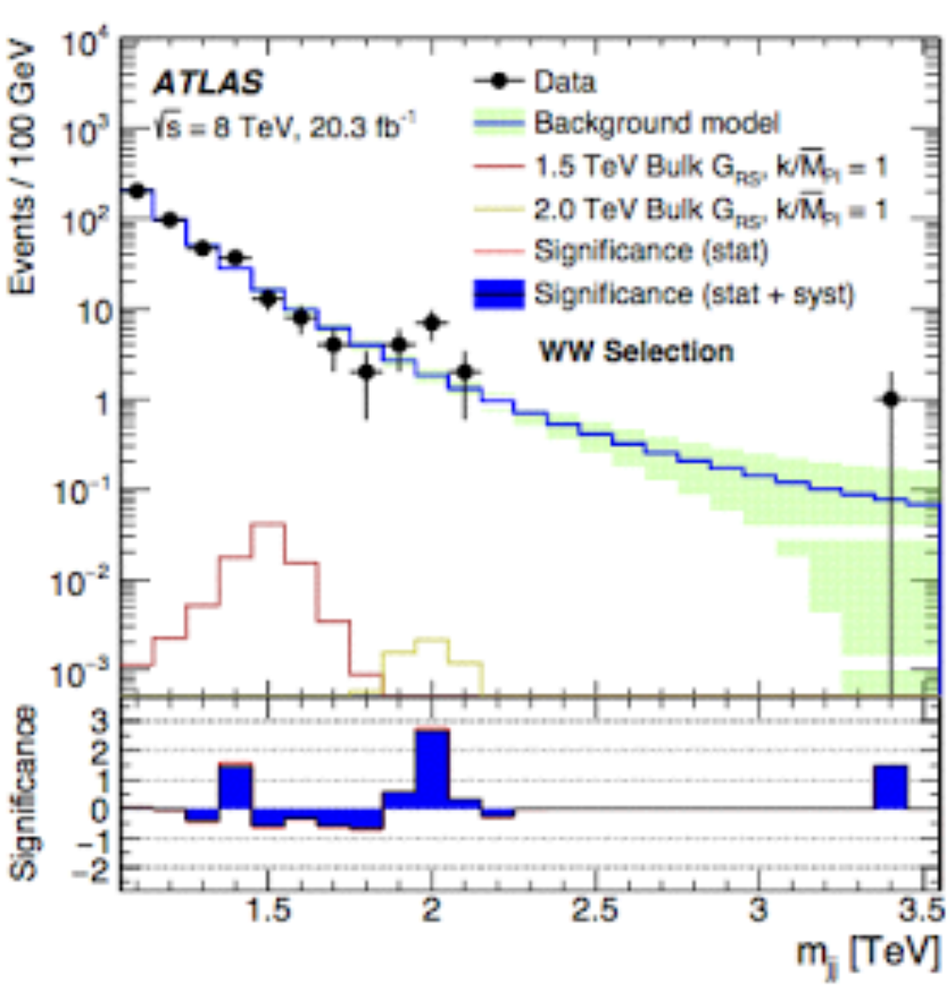
- This trick used to work for the SM (Appelquist and Bernard, 1980) but then we found a light Higgs. Now we're back to the Linear Sigma Model.

- If we found a QCD-like theory that also had a light scalar, maybe we could study it and learn something about the SM Higgs by analogy.

Hints of Compositeness?

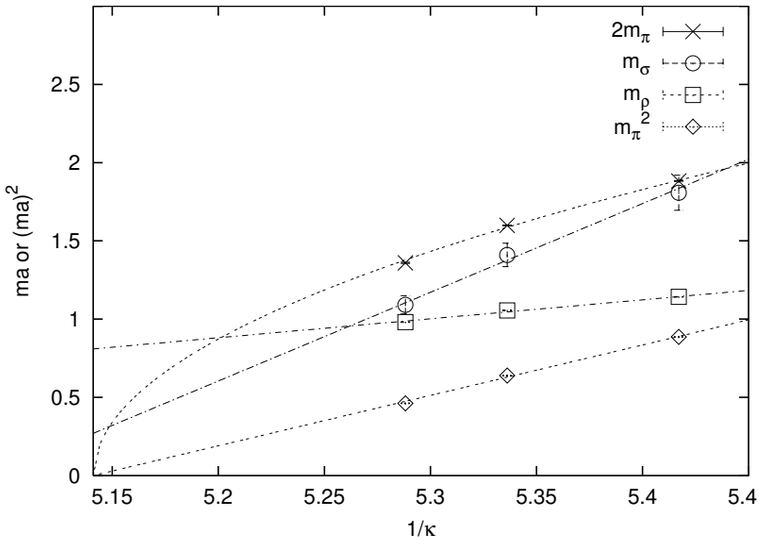
- As we know from QCD, the pions and sigma are just a few of the many states in the spectrum of QCD.
- Is the LHC seeing hints of a richer spectrum? If any of these hints turn out to be real particles, compositeness is likely the explanation.
- 8 days to ICHEP!!!



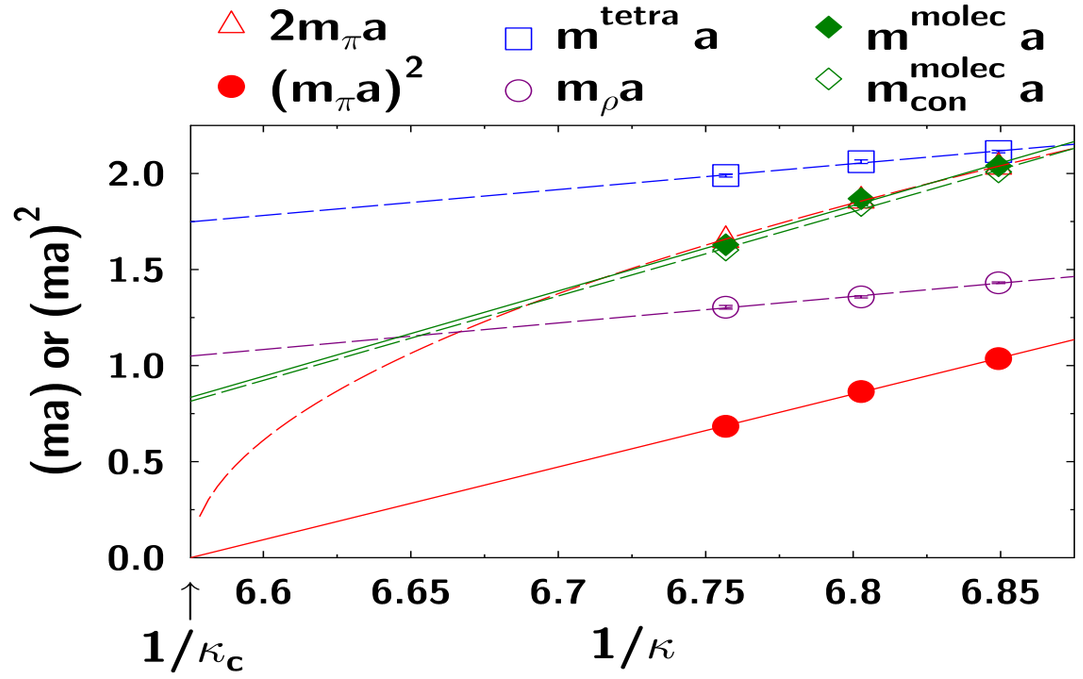


Scalar Sector of QCD

- Some heavy quark results from lattice SCALAR collaboration:

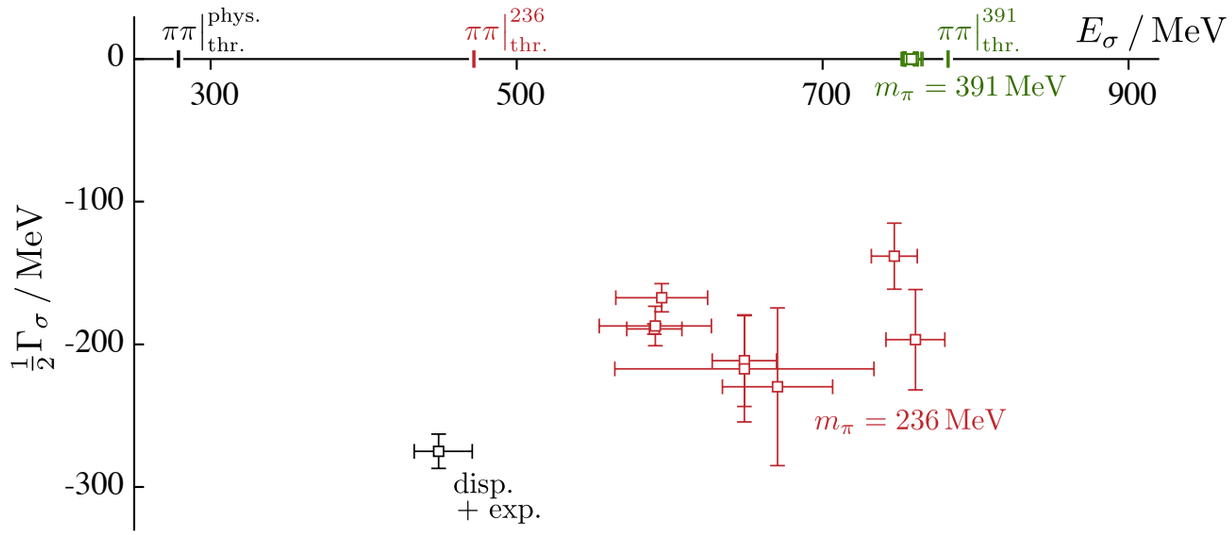


T. Kunihiro et al, PRD **70**, 034504 (2004)



M. Wakayama et al, PRD **91**, 094508 (2015)

- Very exciting result from HSC last week: arXiv:1607.05900v1

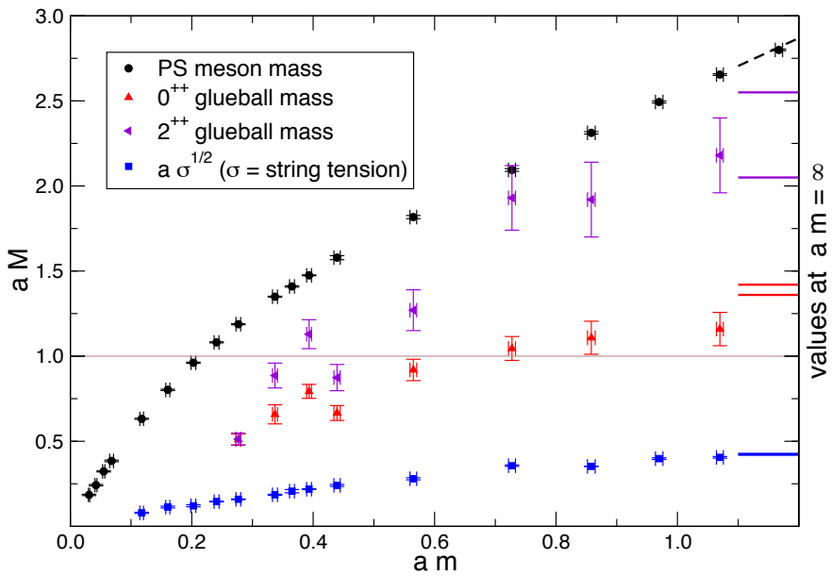


- Bottom line: $m_\sigma >> F$.

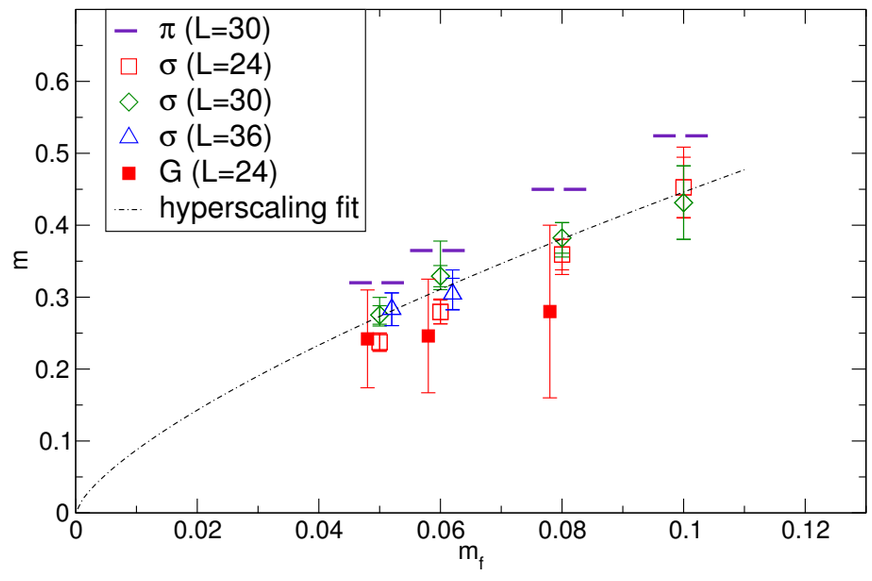
Theories with Light Scalars

- Mass-deformed IRFP theories with very light scalars.

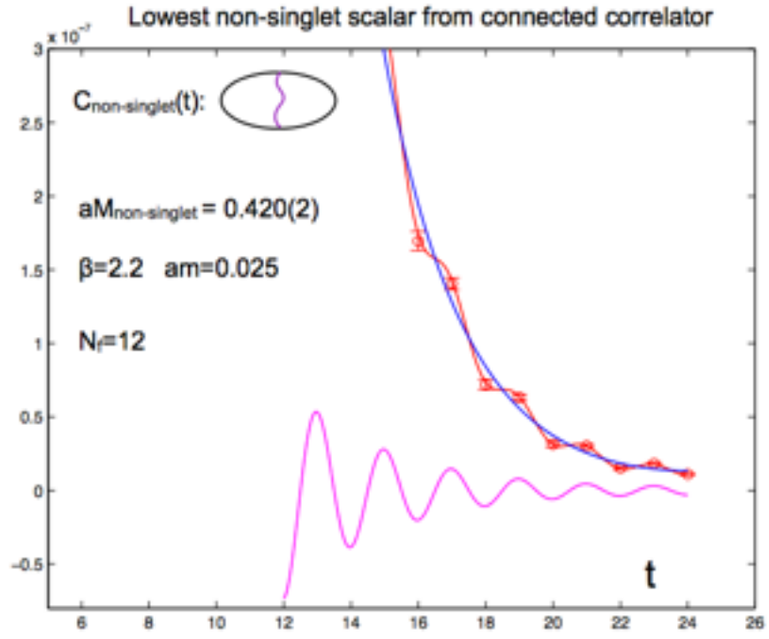
SU(2) N_f=2 adj (Edinburgh)
Phys. Rev. D 82, 014510 (2010)

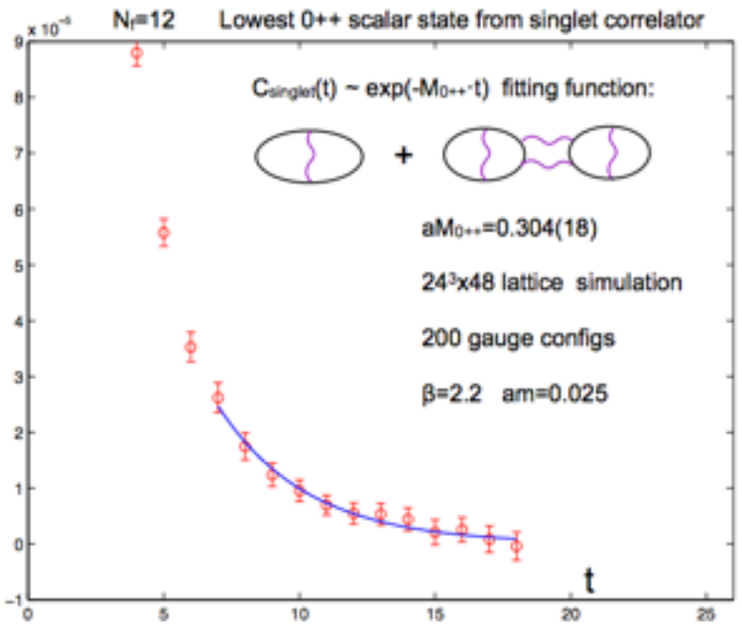


SU(3) N_f=12 fund (LatKMI)
Phys. Rev. Lett. 111, 162001 (2013)



SU(3) N_f=12 fund (LatHC)
USQCD White Paper 2013

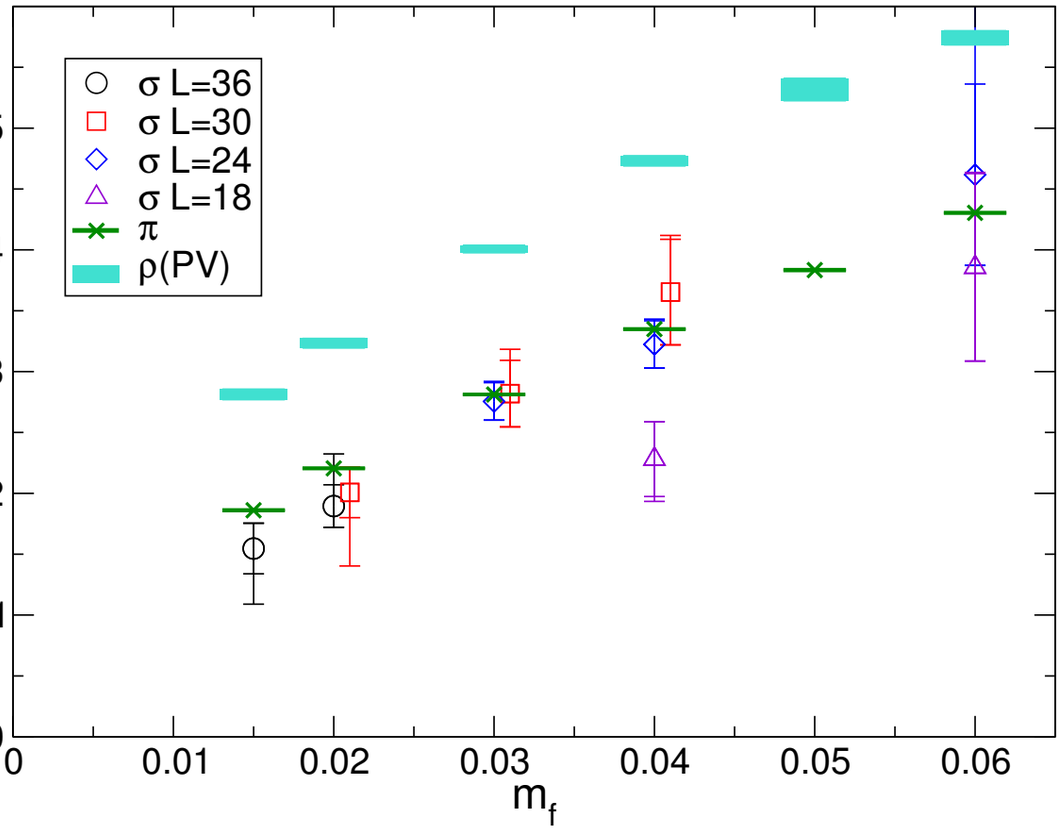




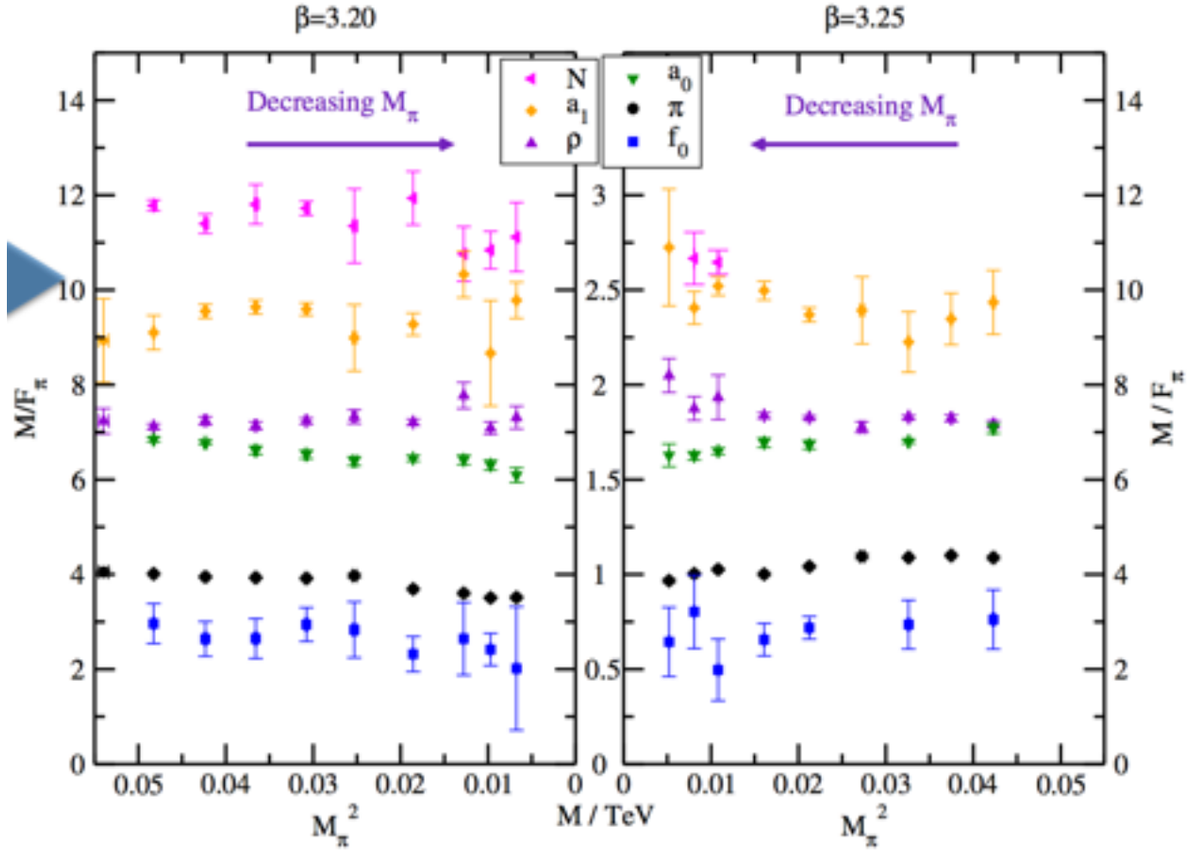
More Light Scalars

- Theories likely just outside conformal window also have light scalars.

SU(3) N_f=8 fund
LatKMI (Nagoya)
Phys. Rev. D 89, 111502 (2014)



SU(3) N_f=2 sym
L_{at}HC Collaboration
LATTICE 2015



Lattice Strong Dynamics Collaboration

James Osborn
Xiao-Yong Jin

Anna Hasenfratz
Ethan Neil

Graham Kribs

Richard Brower
Claudio Rebbi
Evan Weinberg

Oliver Witzel

Ethan Neil
Sergey Syritsyn

Meifeng Lin

Evan Berkowitz
Michael Buchoff
Enrico Rinaldi
Chris Schroeder
Pavlos Vranas

David Schaich

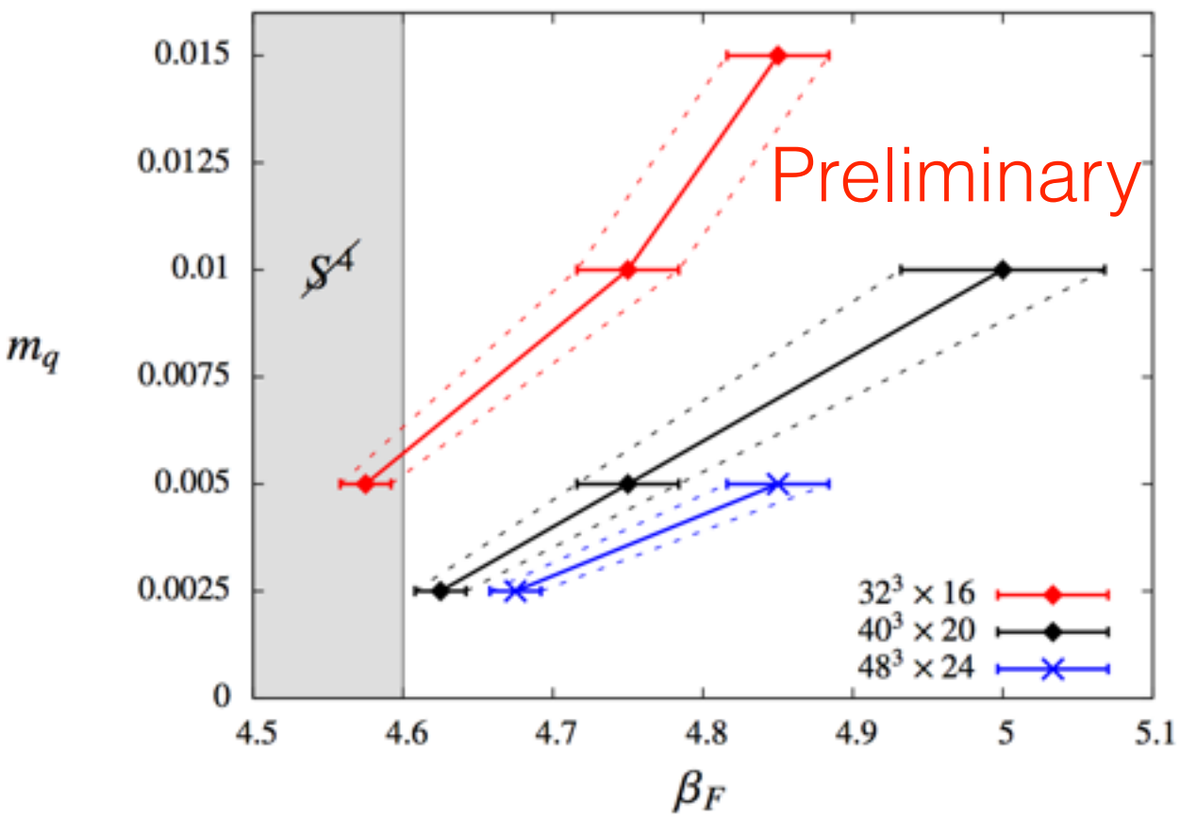
Joe Kiskis

Tom Appelquist
George Fleming
Andy Gasbarro

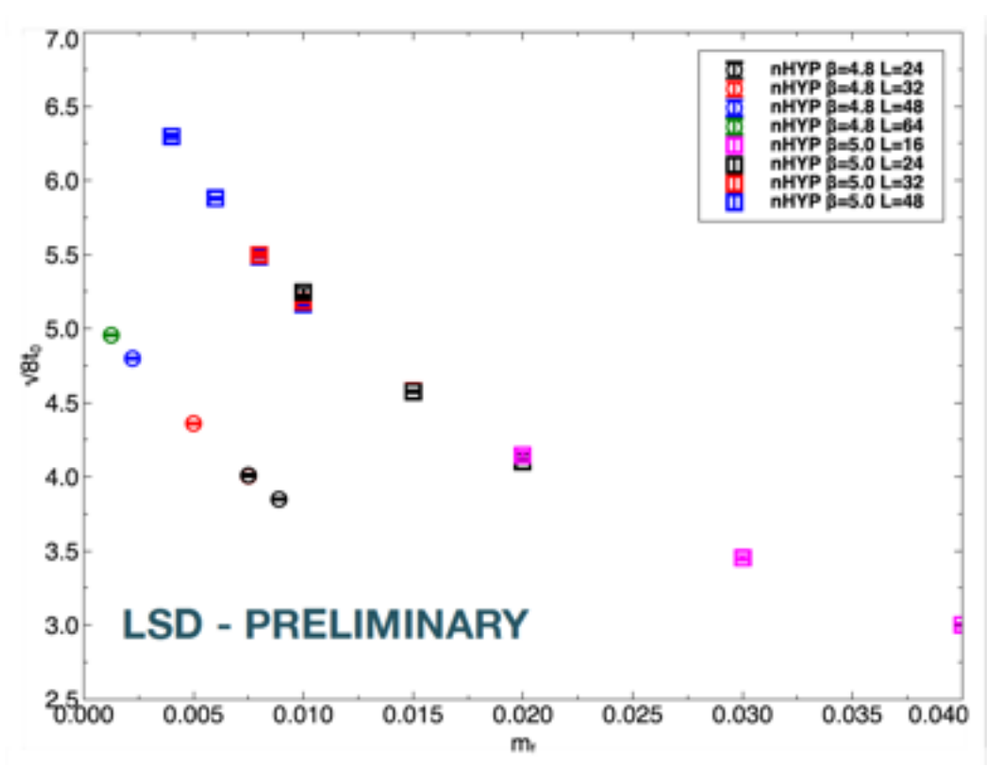
LSD SU(3) N_f=8 Stag

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

- Now using nHYP stag fermions and fund+adj gauge action pioneered by Boulder group to get to somewhat coarser lattices.



T_c and bulk phase



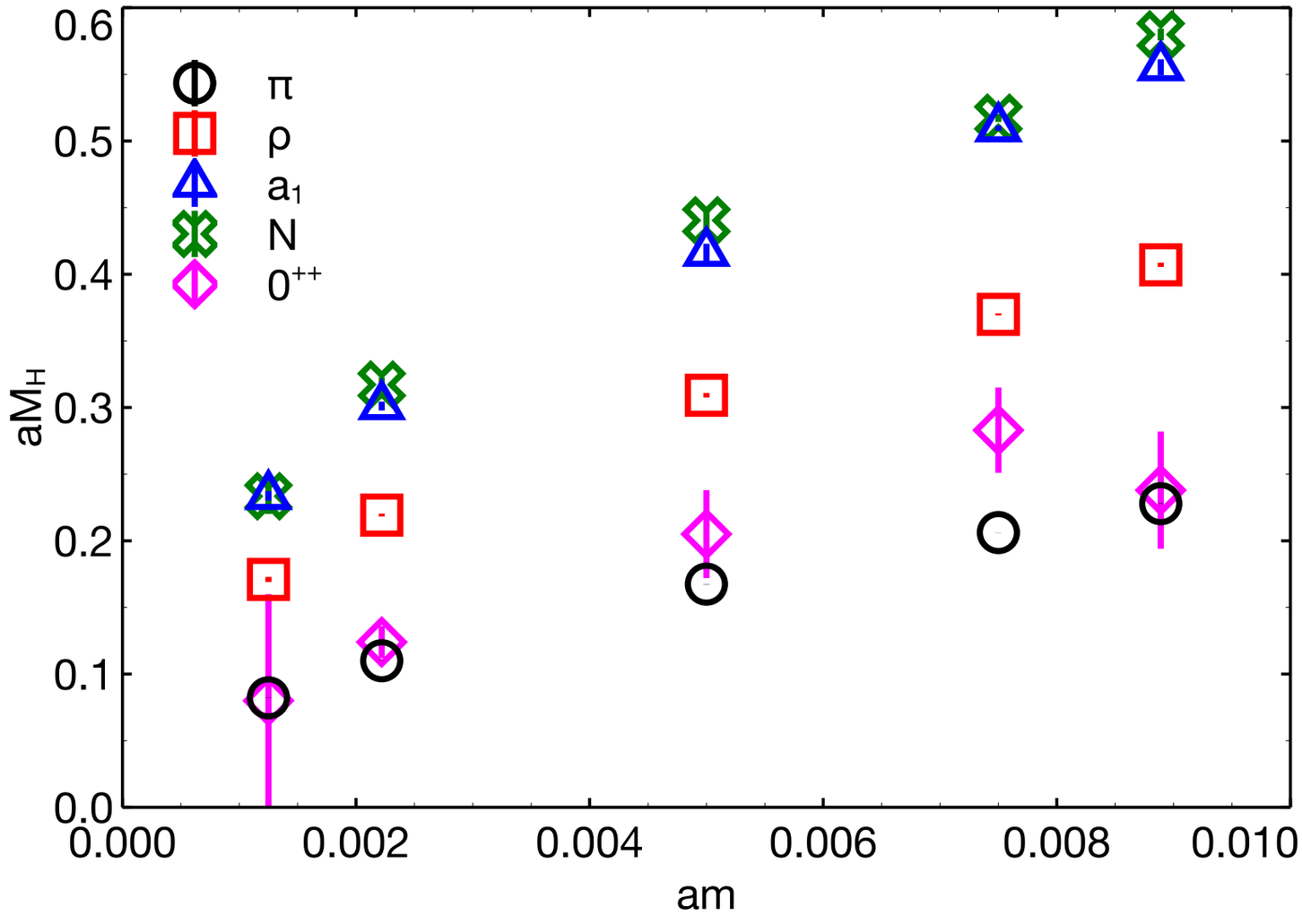
$\langle t^2 E(t) \rangle = 0.3$ @ $t=t_0$

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 enhanced chiral condensate.

Phys.Rev. D93 (2016) 114514
plus preliminary updates



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 $N_f=12$.

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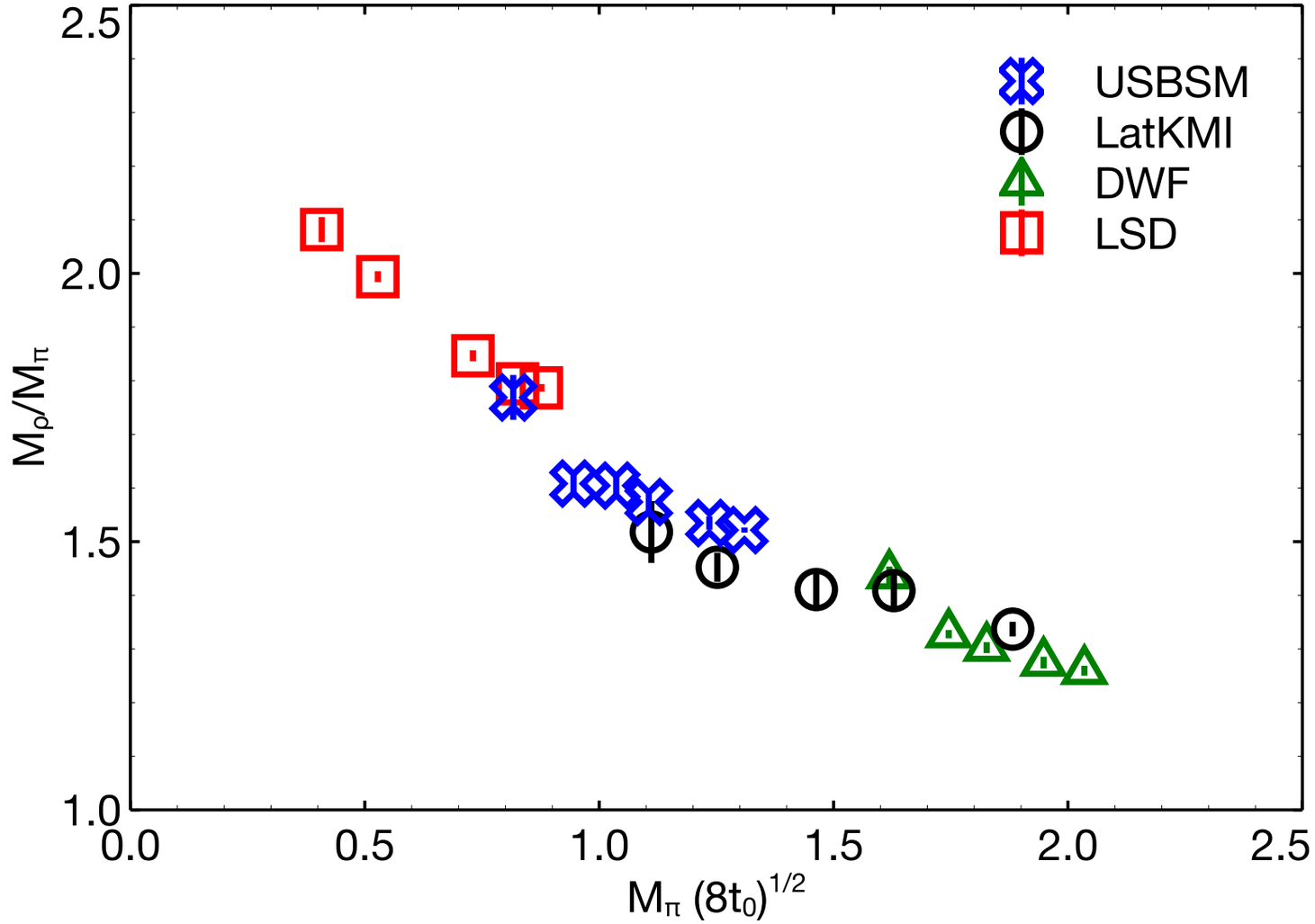

Isosinglet spectrum

- Stable scalar degenerate with pion even when $M_\pi/M_\rho \lesssim 1/2$.
- Nice consistency between LSD and LatKMI.

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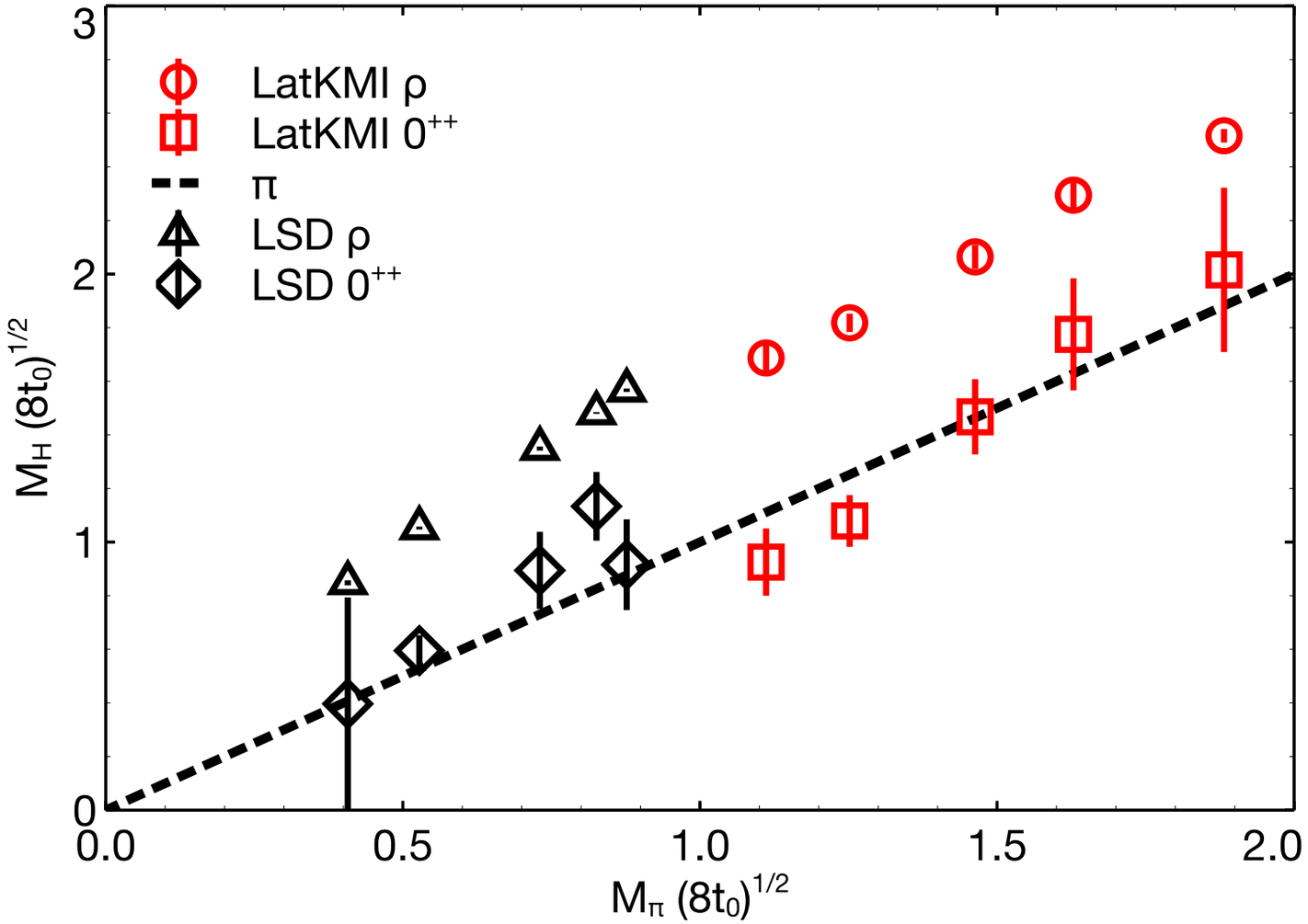

LHC 2 TeV Dijet Resonance

- The LHC has possibly seen a 2 TeV vector resonance. In a composite model, this could correspond to the rho meson.

- In QCD, $M_\rho/F_\pi \sim 8$ at physical point, so identifying $F_\pi \to 250$ GeV means $M_\rho \sim 2$ TeV in QCD-like composite model.

- For $N_f=8$, $M_\rho/F_\pi \sim 8$ as well, so $M_\rho \sim 2$ TeV.

- In QCD, width $\Gamma_\rho/M_\rho \sim 0.2$ at physical point.

- For $N_f=8$, we haven't computed the width directly (yet!) but using KSRF relations, we also find $\Gamma_\rho/M_\rho \sim 0.2$.

- This resonance is probably too broad to be LHC signal.

KSRF Relation

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

- If so, can use KSRF relation to estimate rho decay width

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

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

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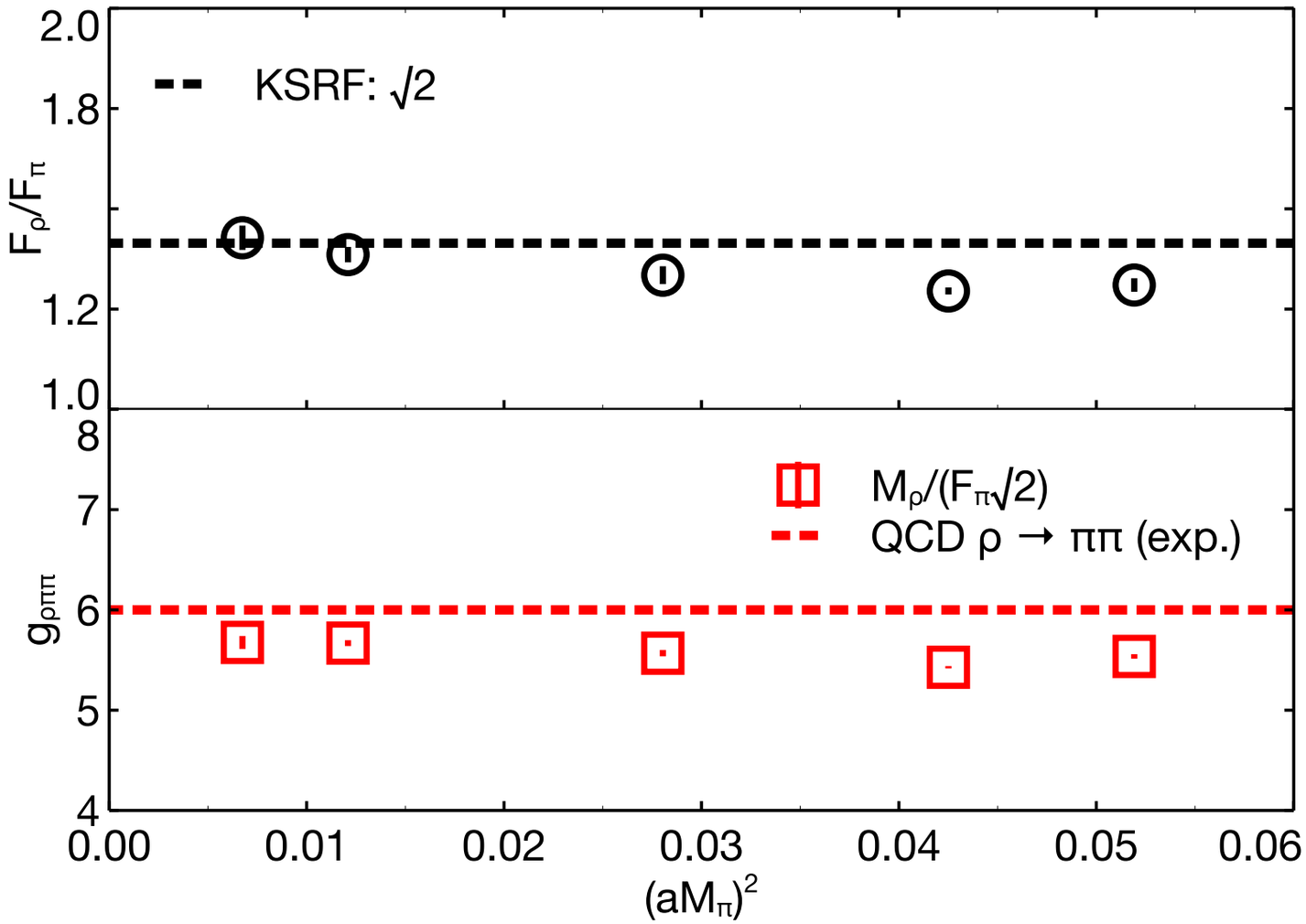

LHC 750 GeV Diphoton Resonance

- The LHC has possibly seen a 750 GeV resonance in the decay to two photons.

- In our $N_f=8$ model, we study a strong sector of eight degenerate fermion flavors not coupled to SM: 63 NGBs!

- Phenomenologically, only 3 NGBs are needed. So the flavor group must be explicitly broken SU(8)×SU(8) → SU(2)×SU(2), producing 60 pNGBs including 6 η/η' like states. Adjusting quark masses to get 750 GeV masses straightforward for η. η' more complicated.

- Resonant decays of η/η' like states almost entirely due to anomaly. Only additional non-perturbative input needed is F_π.

- Given dramatic difference in σ meson for $N_f=8$, η' mesons could be very different from QCD. Under investigation by LSD.

- Stay tuned for talk by Y. Aoki!

Summary (Part I)

- We now have clear examples of gauge theories with light scalars.

- 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 obvious differences between QCD and $N_f=8$, some interesting similarities:

  - $M_\rho / F_\pi \sim 8$

  - VMD is a good approximation.

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