Update on Light Composite Scalar in SU(3) Nf=8 Gauge Theory

Lattice Strong Dynamics (LSD) Collaboration

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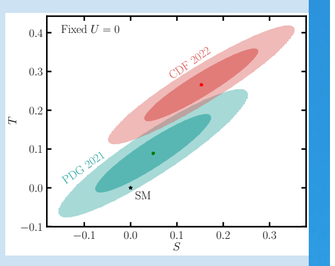
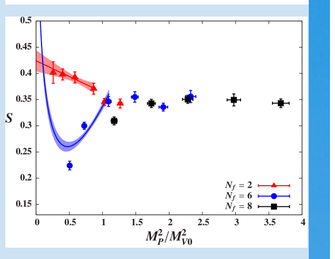
CDF W mass measurement

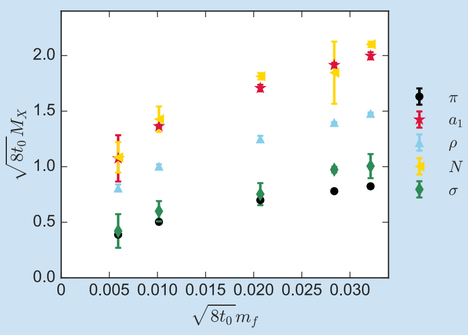
- New precision EW fits prefer $S \approx 0.2$.
- That is a natural size in composite Higgs models.
- SU(3) $N_f = 8$ so far compatible with dilaton EFTs with light composite scalar.
- Appelquist, Ingoldby, Piai, arXiv:2012.09698.
- Golterman, Neil, Shamir, arXiv:2003.00114.



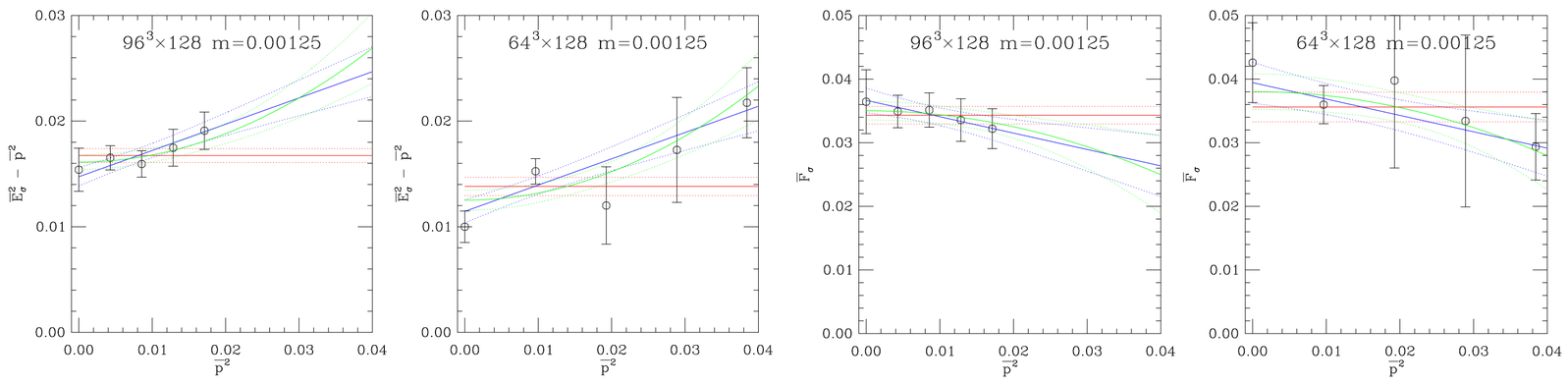


Previous Nf=8 Results

- LSD arXiv:1807.08411
- LSD arXiv:2106.13534
- Light scalar meson stable to $\pi\pi$ decays.
- Systematic errors:
  - One vol: $L \cdot M_\pi \approx 5.3$.
  - Noisy subtraction.
  - Fit systematics.

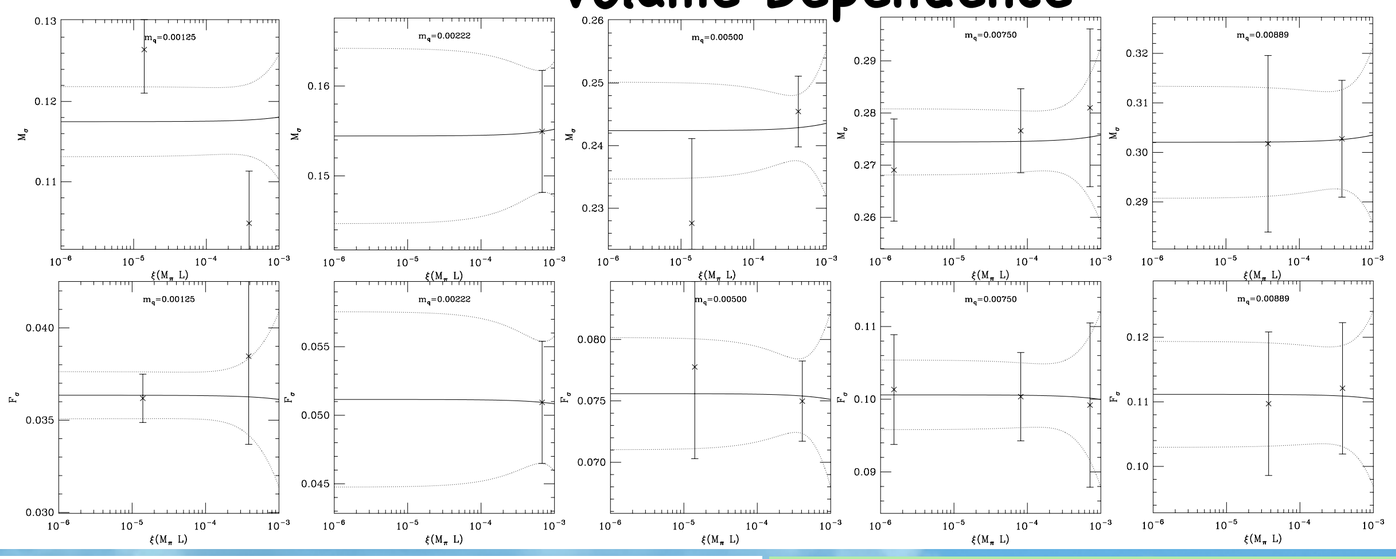


Dispersion Relation



Fits to const, $\hat{p}^2$, and $\hat{p}^4$. Assume corrections to dispersion relation only depend on lattice spacing a and not on size of volume L/a.

Volume Dependence



New Analysis Improvements

$\vec{p} = 0$ Subtraction Scheme

- $\overline{C}(t) = C(t) - \frac{1}{N_t}\sum_{t'=0}^{N_t-1} C(t')$
- Subtraction is done before averaging over ensemble.
- A small residual constant remains and must be modeled.

New $\vec{p} \neq 0$ Correlators

- No subtraction needed for non-zero momentum.
- Energies $E(\vec{p})$ must be translated to rest masses using lattice dispersion relation

$$\widehat{E}^2 = \hat{p}^2 + \widehat{M}^2, \quad \widehat{E} = 2\sinh\frac{E}{2},$$

$$\widehat{M} = 2\sinh\frac{M}{2}, \quad \hat{p}_i = 2\sin\frac{2\pi n_i}{2N_s}$$

Bayesian Model Averaging

- Jay, Neil arXiv:2008.01069
- AIC-based model probability $\log p(M|D)$

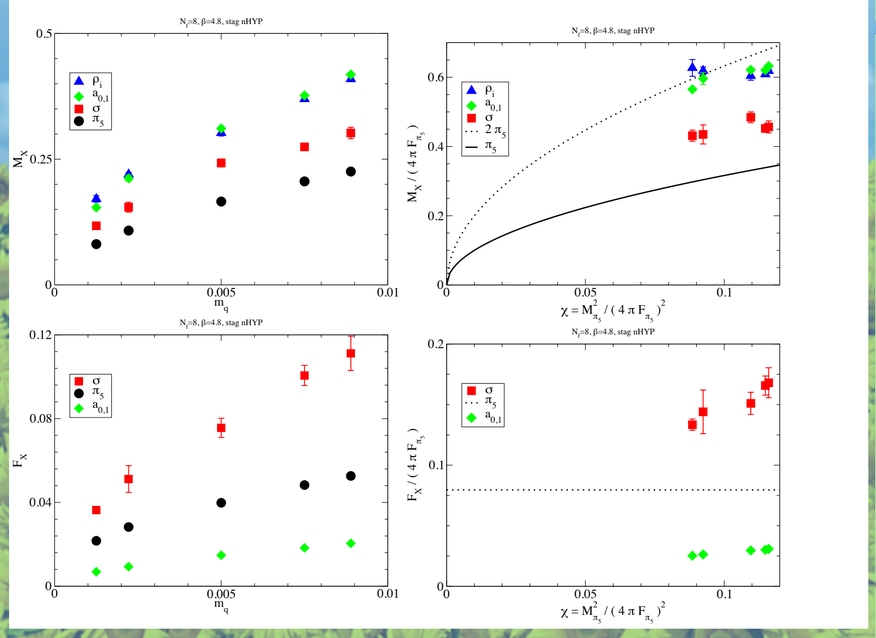
$$\approx -\frac{1}{2}\chi^2 - N_{\text{param}} - \frac{N_t}{2} + (t_{\max} - t_{\min})$$

- Exclude models if normalized $p(M|D) < 10^{-3}$.
- Exclude models if fit parameters have large relative errors.

Infinite Volume Extrapolation

- Empirical model "inspired" by ChiPT, e.g. Golterman arXiv:0912.4042.
- $\xi(M_\pi L) = \frac{M_\pi^2}{(4\pi F_\pi)^2}\sum_{n=1}^{\infty}\frac{4\,\kappa(n)}{\sqrt{n}\,M_\pi L}K_1(\sqrt{n}\,M_\pi L)$
- $M_X(L) = M_X(\infty)\left[1 + \alpha_X\,\xi(M_\pi L)\right]$
- $F_X(L) = F_X(\infty)\left[1 + \beta_X\,\xi(M_\pi L)\right]$
- Model assumes parameters α_X, β_X independent of the quark mass.
- Model validated for M_π, F_π in $N_f = 8$ $\pi\pi$ scattering study: LSD arXiv:2106.13534

Preliminary Spectrum



Staggered Model Functions

- **Model A:** $C(\vec{p},t) = c_0\,\delta_{\vec{p},0}$

$$+\sum_n \frac{c_n}{2\left(1-e^{-E_n N_t}\right)\sinh(E_n)}\left[e^{-E_n t} + e^{-E_n(N_t - t)}\right]$$

$$+(-1)^t\sum_j \frac{c_j'}{2\left(1-e^{-E_j' N_t}\right)\sinh(E_j')}\left[e^{-E_j' t} + e^{-E_j'(N_t - t)}\right]$$

- **Model B:** $\overline{C}(t) = \overline{c}_0$

$$+\sum_n \frac{c_n}{2\left(1-e^{-E_n N_t}\right)\sinh(E_n)}\left[e^{-E_n t} + e^{-E_n(N_t - t)}\right] - \frac{c_n}{N_t\widehat{M}_n^2}$$

$$+(-1)^t\sum_j \frac{c_j'}{2\left(1-e^{-E_j' N_t}\right)\sinh(E_j')}\left[e^{-E_j' t} + e^{-E_j'(N_t - t)}\right] - \frac{c_j'}{N_t(4+\widehat{M}_j'^2)}$$

- **Model C:** Same as B but fixed $\overline{c}_0 = 0$

Meson Decay Constants

- DCT-I of Model A (arXiv:1212.6190)

$$\widetilde{C}(\vec{p},k) = c_0\delta_{\vec{p},0}\delta_{k,0} + \frac{1}{N_t}\sum_n \frac{c_n}{\widehat{E}_n^2 + \widehat{\omega}_k^2} + \frac{1}{N_t}\sum_j \frac{c_j'}{\widehat{E}_j'^2 + \widehat{\omega}_k^2}$$

$$\widehat{\omega}_k = 2\sin\frac{2\pi k}{2N_t}, \quad \widehat{\omega}_k' = 2\sin\left(\frac{\pi}{2} - \frac{2\pi k}{2N_t}\right)$$

- **Model A** uses "relativistic" normalization.
- Isotriplet decay constants related to residues:

$$\widehat{F}_{\pi_5} = \frac{1}{\sqrt{2}}\frac{m_q\sqrt{|c_{\pi_5}|}}{\widehat{E}_{\pi_5}^2 - \hat{p}^2}, \quad \widehat{F}_{a_{0,1}} = \frac{1}{\sqrt{2}}\frac{m_q\sqrt{|c_{a_{0,1}}|}}{\widehat{E}_{a_{0,1}}^2 - \hat{p}^2}$$

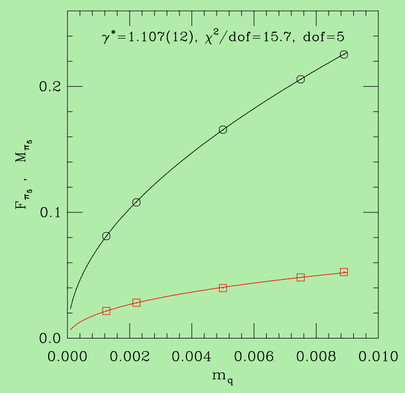
- Isosinglet uses latKMI normalization:

$$\widehat{F}_\sigma = 2\frac{m_q\sqrt{|c_\sigma|}}{\widehat{E}_\sigma^2 - \hat{p}^2}$$

EFT Analysis

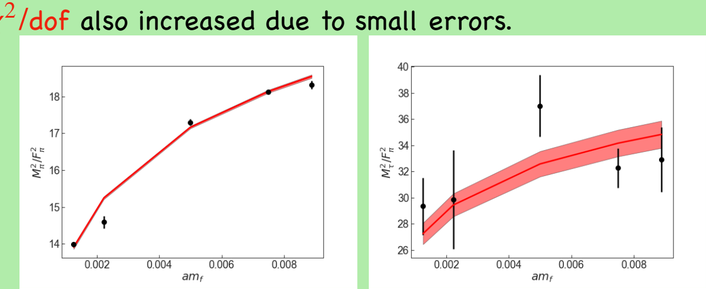
Mass-Deformed IRFP

- $M_\pi = C_M m_q^{1/(1+\gamma^\star)} + D_M m_q, \quad F_\pi = C_F m_q^{1/(1+\gamma^\star)} + D_F m_q$
- Appelquist et al. arXiv:1106.2148
- Seems to fit the data reasonably well but χ^2/dof is high due to very small error bars.
- Theory is behaving as if approaching an IRFP as $m_q \to 0$
- Other observables M_X and F_X don't change fit due to larger errors.



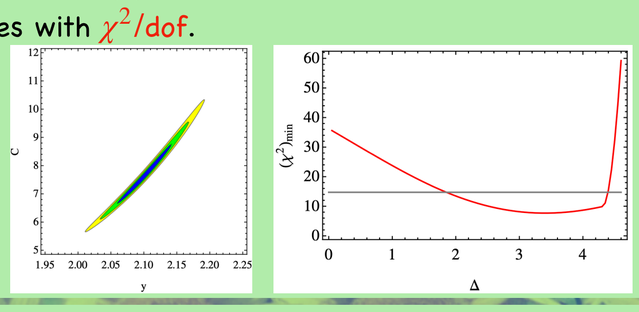
Golterman-Shamir dChPT

- Golterman et al. arXiv:2003.00114
- $\gamma^\star = 0.908(1)$, $M_\tau = M_\sigma$
- But, χ^2/dof also increased due to small errors.



Ingoldby et al dEFT

- Ingoldby et al. arXiv:1908.00895
- $\gamma^\star \sim 3 - y = 0.90(5)$
- Similar issues with χ^2/dof.



Conclusions

- Preliminary data analysis complete.
- Working to understand if errors on M_{π_5} and F_{π_5} are underestimated, causing problems in EFT analyses.
- Theory behaves near-conformal with $\gamma^\star \sim 1$, as expected.
- Lighter mass ensemble $96^3 \times 192$, $m_q = 0.00056$ being generated. Should clarify whether massless theory is conformal or chirally-broken with a dilaton.