Peter Hasenfratz
Sep 22, 1946
- Apr 9, 2016

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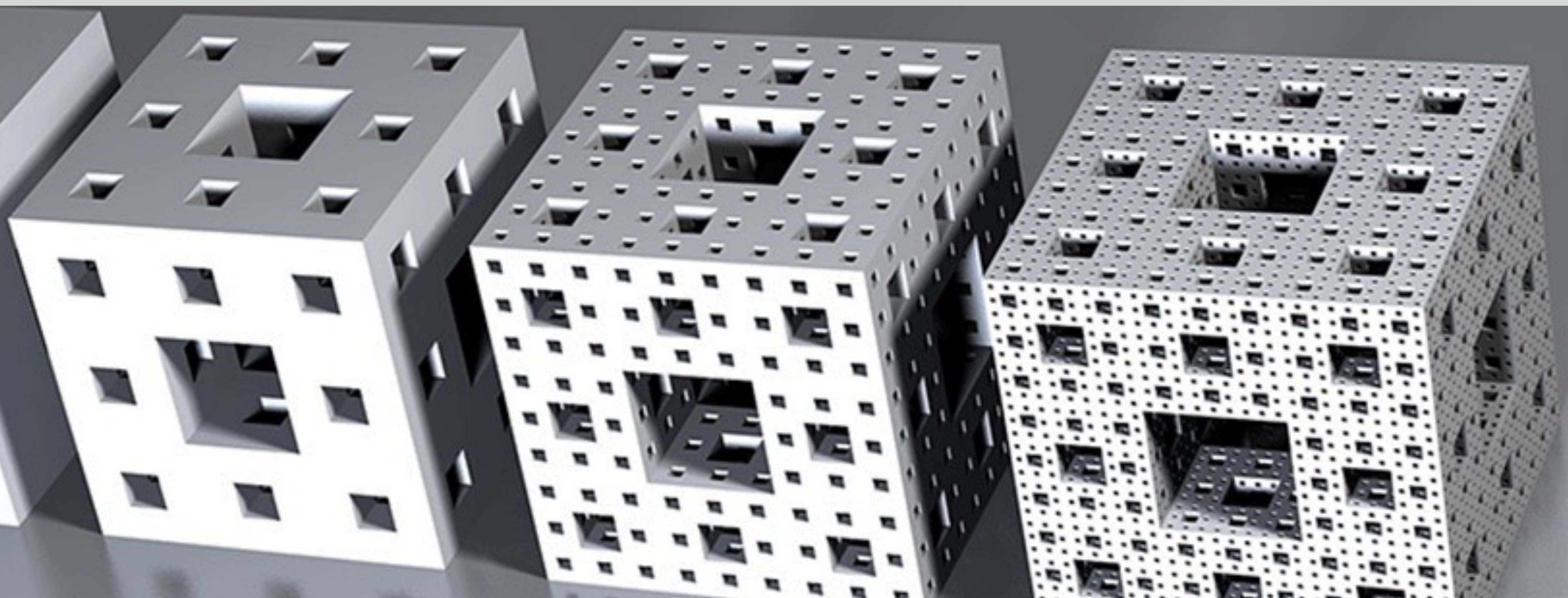
"…. I had, and still have, the very highest regard for Peter's insight into quantum field theory and its relation with statistical mechanics….."

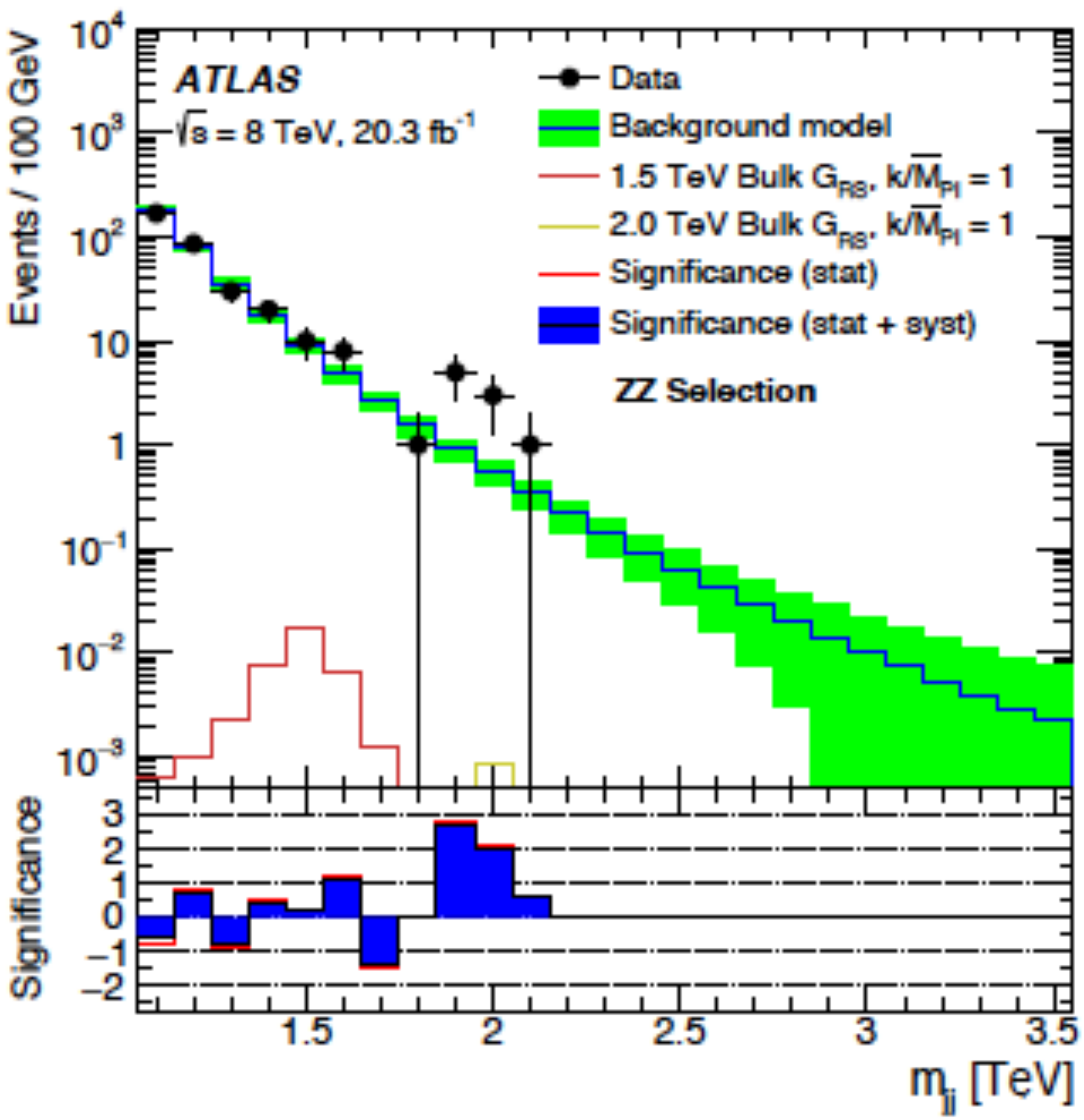
A BSM candidate model based on an IR-conformal fixed point

Anna Hasenfratz
University of Colorado, Boulder
Lattice for BSM, 2016, Argonne

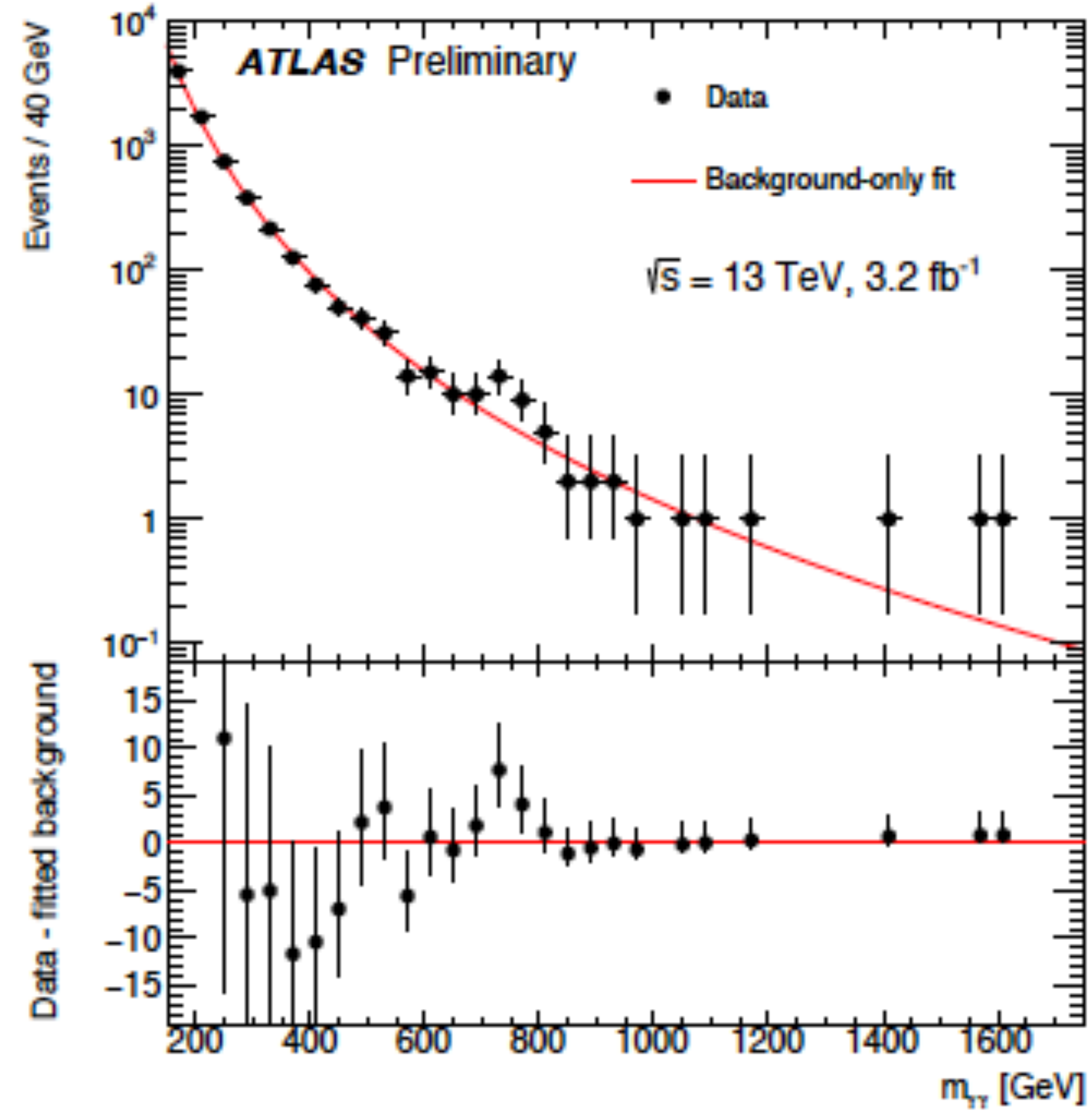


Hints of new physics?

Hint of a 2 TeV vector resonance



750 GeV scalar resonance



Composite Higgs models:

New, (strongly interacting) gauge-fermion system couples to the Standard Model :

- Chiral symmetry is spontaneously broken
  → at least 3 Goldstone pions
  → induces electroweak symmetry breaking
- Physical scale is set by F_π ~ SM *vev (250GeV)*
- The 125 GeV Higgs is a composite fermion bound state
- Many resonances in the 1 - 4 TeV range

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Further issues:

How is the Standard Model embedded?

How are fermion masses generated?

EW constraints,……

Composite Higgs models:

What is the Higgs boson?

125GeV light Higgs is feasible if it is a pseudo-Goldstone

- Flavor symmetry: SSB leads to massless "pions"
  (composite Higgs)
- Scale symmetry: SSB leads to dilaton
  (old technicolor → composite Higgs

Scaled-up QCD does not work:

Near-conformal model is needed

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Scaled-up QCD does not work:

Near-conformal model is needed

Yesterday we heard about 2 candidates:

- SU(3) gauge, N_f = 8 fundamental fermions
- SU(3) gauge, N_f = 2 sextet fermions

Both models have a small β function (walking)

and a (relatively) light 0++

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How can we ensure walking & chiral symmetry breaking?

With a model that is

- conformal in the UV (non-perturbative)
- chirally broken in the IR

→ Build it on a conformal fixed point!

(ex. Luty, Okui, hep-ph/0409274)

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with 2 massless flavors in IR → Higgs boson is a dilaton

(2+1 sextet, 2+8 fundamental, etc)

with 4 massless flavors in IR → Higgs boson is a PGB

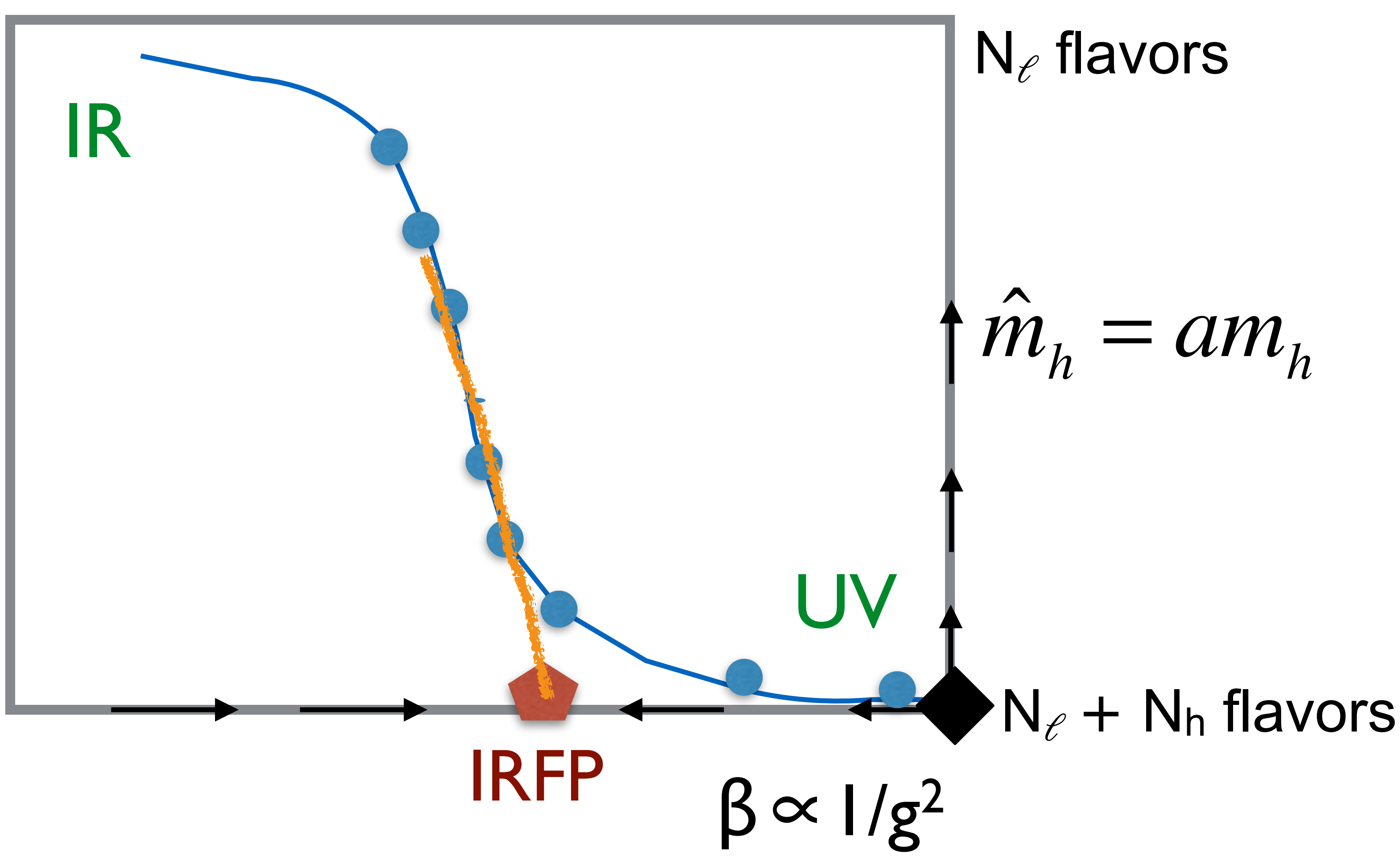
(Ma, Cacciapaglia, 1508.07014)

A lattice realization:

- Take N_f flavors above the conformal window (N_f=8(?) - 16)
- Split the masses: $N_f = N_\ell + N_h$

  N_h flavors are massive, m_h varies → decouple in the IR

  N_ℓ (=2-4) flavors are massless, $m_\ell = 0$ → chirally broken



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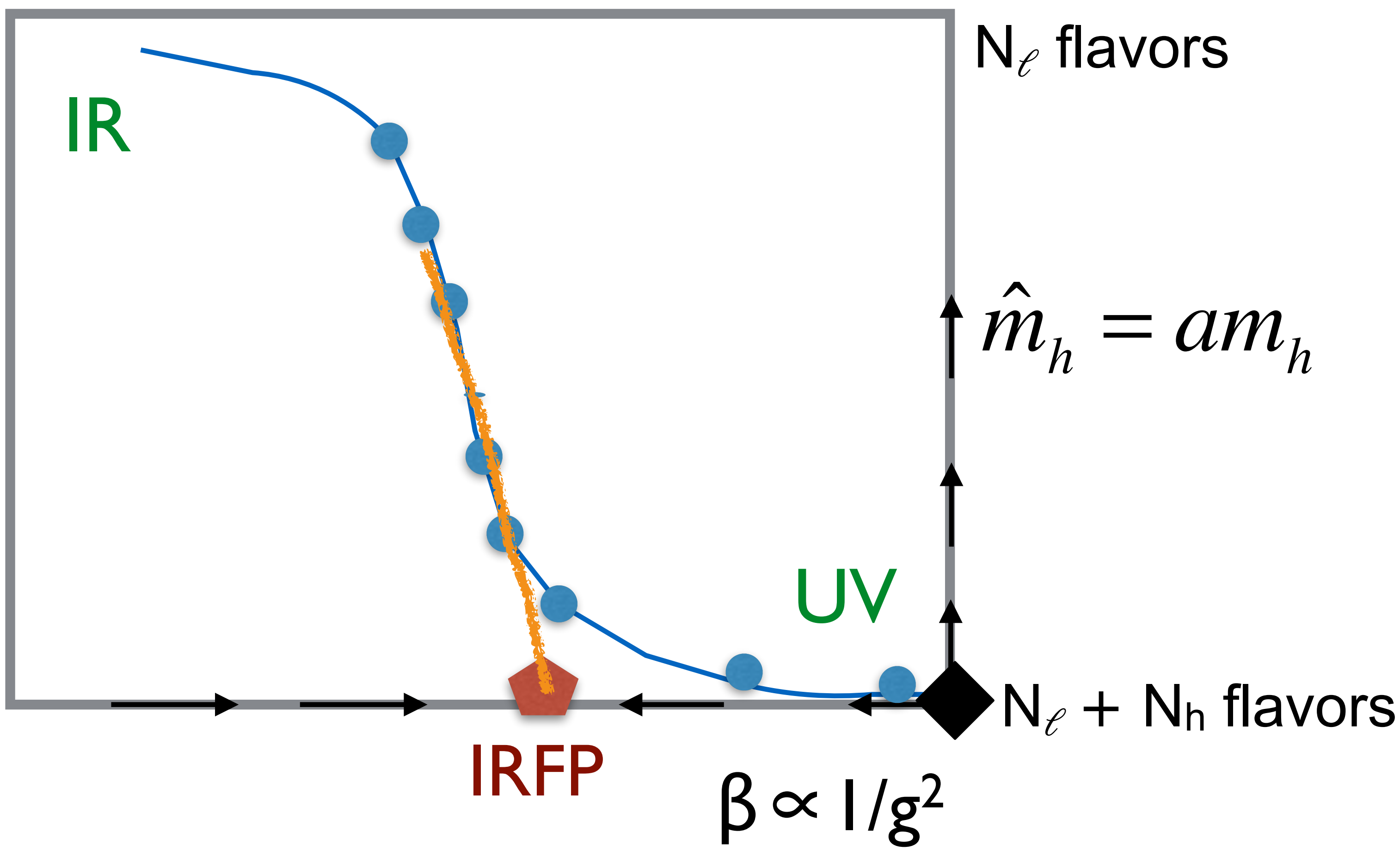

How predictive is this model?

$$g^2, m_h, m_\ell$$

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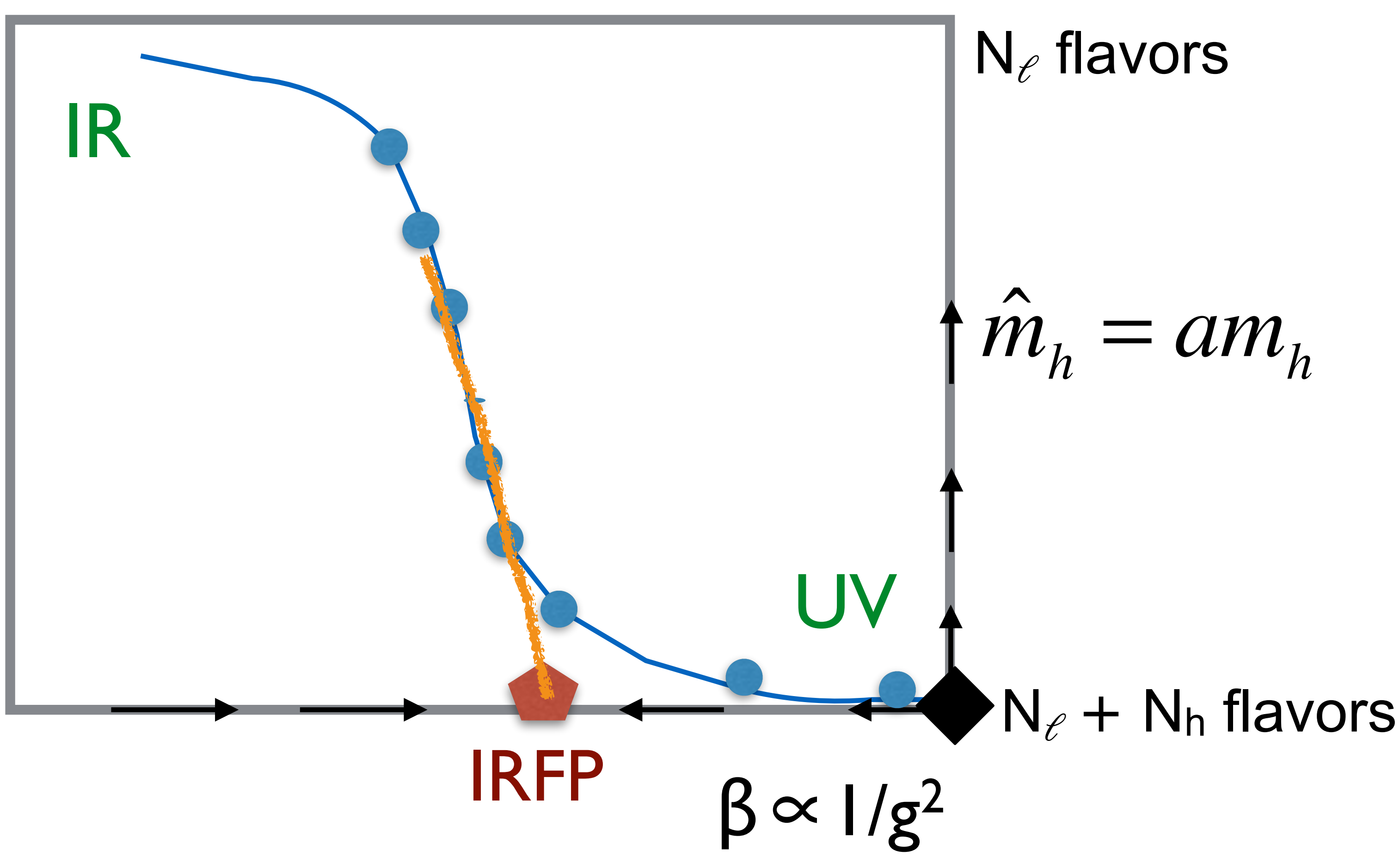

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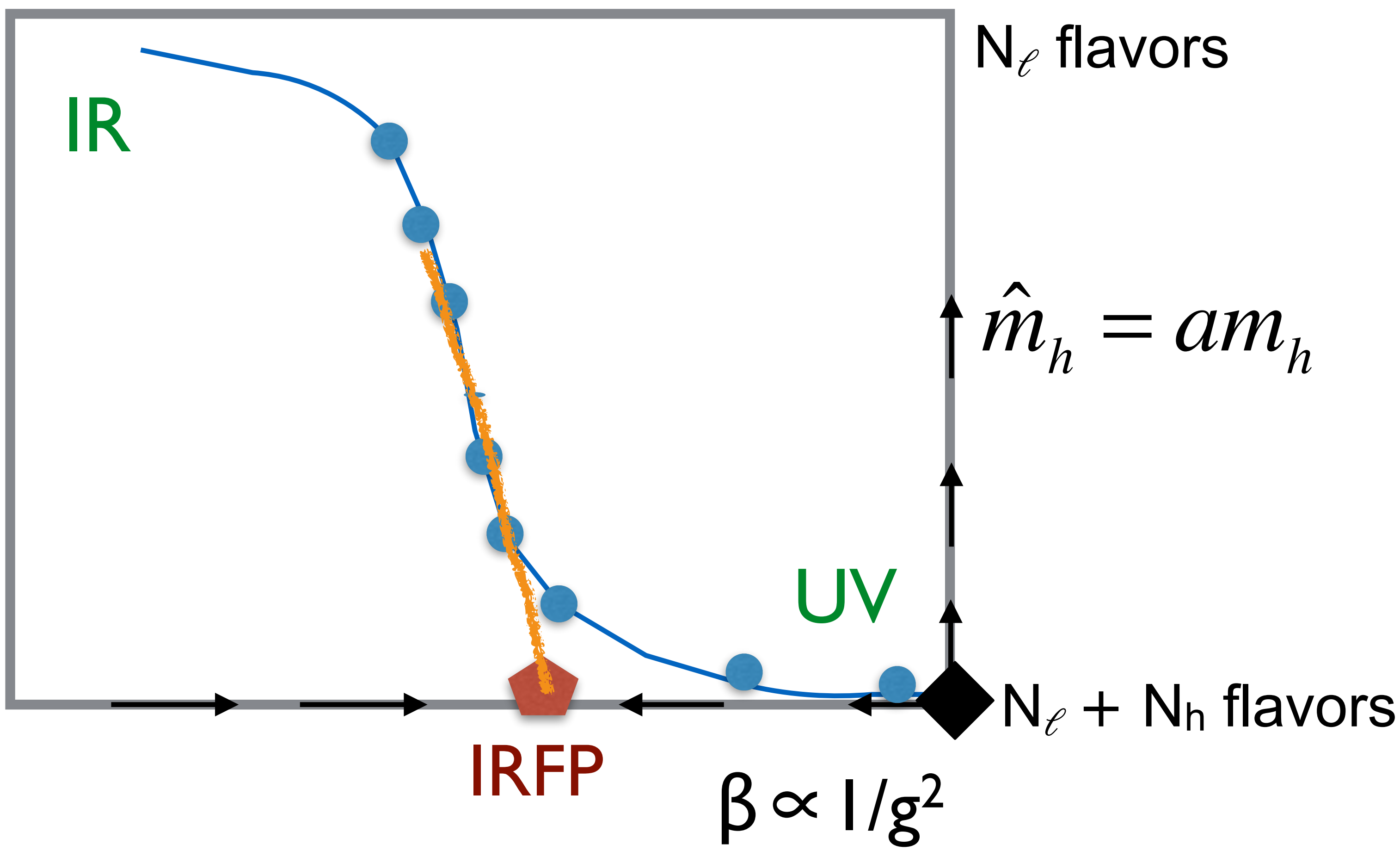

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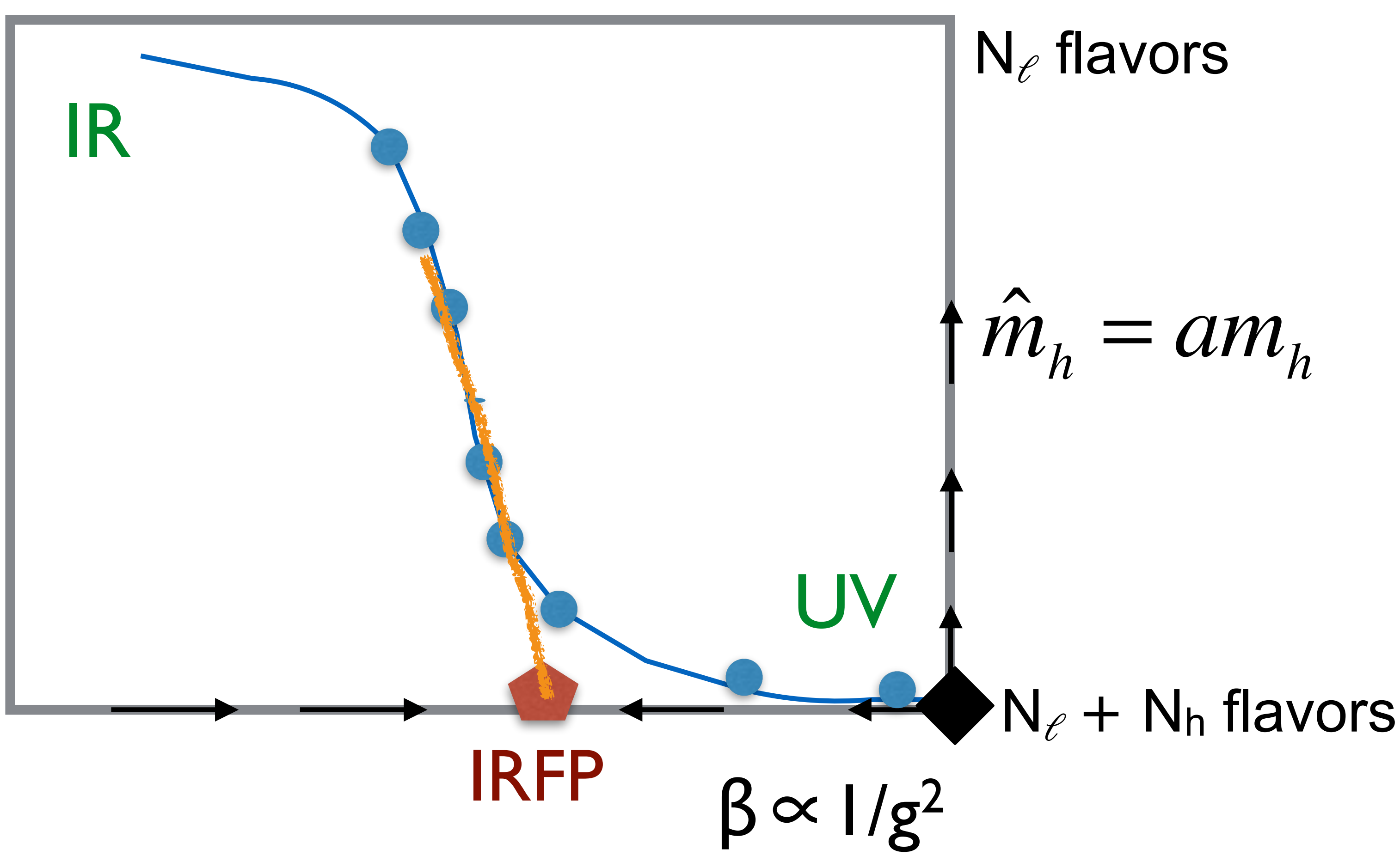


How predictive is this model?

$$\cancel{g^2}, m_h, \cancel{m_\ell}$$

irrelevant coupling

hyper-scaling

$m_\ell = 0$

Mass ratios are independent of m_h

Hyperscaling - Wilson RG

Under scale change $\mu \to \mu' = \mu / b, \quad b > 1$

the couplings change

$$\hat{m}(\mu) \to \hat{m}(\mu') = b^{y_m} \hat{m}(\mu) \qquad \text{(increases)}$$

$$g \to g^{\star}$$

and any 2-point correlator

$$C_H(t; g_i, \hat{m}_i, \mu) \to b^{-2y_H} C_H(t/b; g^{\star}, b^{y_m} \hat{m}_h, \mu)$$

since $C_H(t) \propto e^{-M_H t}$,

$$aM_H \propto (\hat{m})^{1/y_m} \qquad \text{(hyperscaling)}$$

Amplitudes (F_π) also show hyperscaling, ratios M_H / F_π are constant

Hyperscaling in mass split systems

Nothing changes in the Wilson RG arguments if some of the masses remain massless:

$$C_H(t; g_i, \hat{m}_i, \mu) \to b^{-2y_H} C_H(t/b; g^\star, b^{y_m}\hat{m}_h, \hat{m}_\ell = 0, \mu)$$

$M_{0^{++}} / F_\pi$

mass split systems show the same hyperscaling in the $m_\ell = 0$ limit

$$aM_H \propto (\hat{m})^{1/y_m}$$

(M_H can be all light, heavy or mixed fermion hadrons)

➔ Ratios like M_H / F_π

- are independent of m_h if $m_h << 1$
- do not follow the spectrum of N_ℓ (large m_h) nor N_f (conformal)

Digress:

Mass split systems when $N_f = N_\ell + N_h$ flavors are not conformal are different:

- the UV / IR are separated

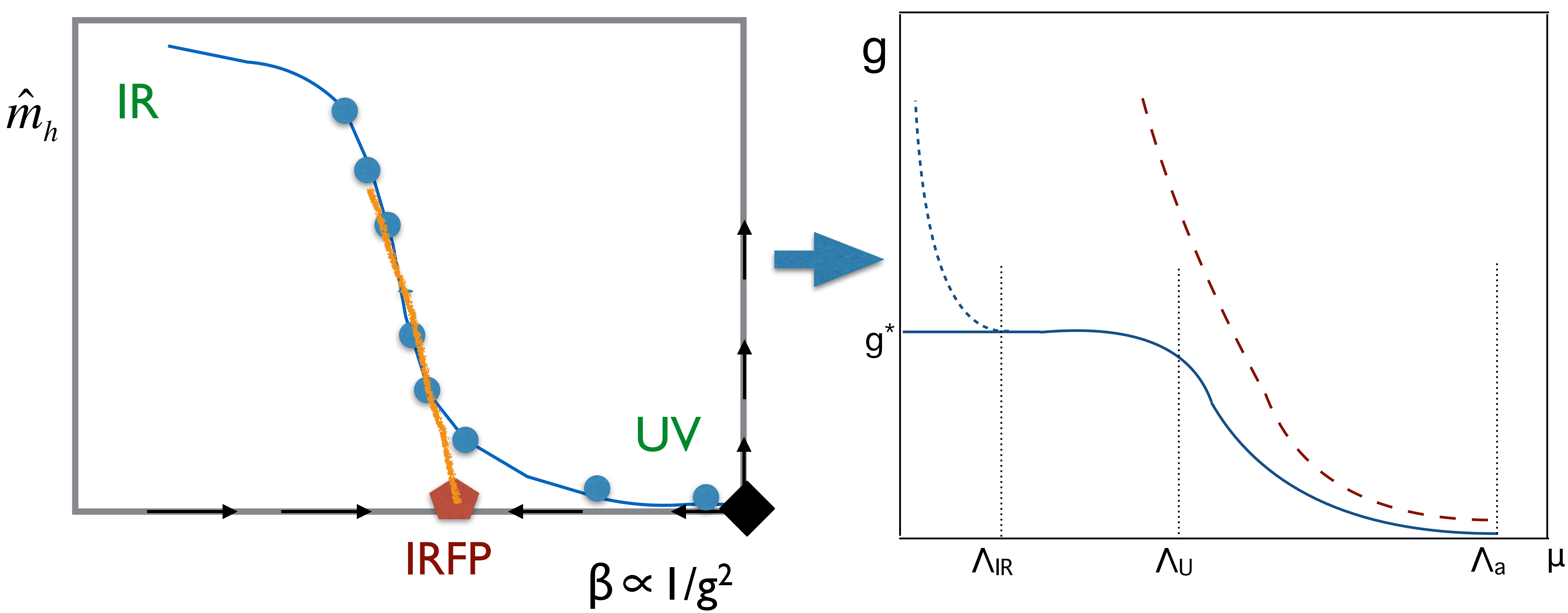
but

- no tuning is possible to increase walking
- no hyperscaling argument - spectrum might depend on m_h

Could be important for any $N_f = 2+6$

Running coupling - mass split model

The running coupling can be tuned by m$_h$



The system is guaranteed to walk as m$_h$ → 0

Can it “walk” long enough? Depends on anomalous dimension

Pilot lattice study: 4+8 mass split system

$N_\ell + N_h = 4 + 8 = 12$: conformal in the UV, $N_\ell = 4$ flavor in the IR

in collaboration with R. Brower, C. Rebbi, E. Weinberg, O. Witzel

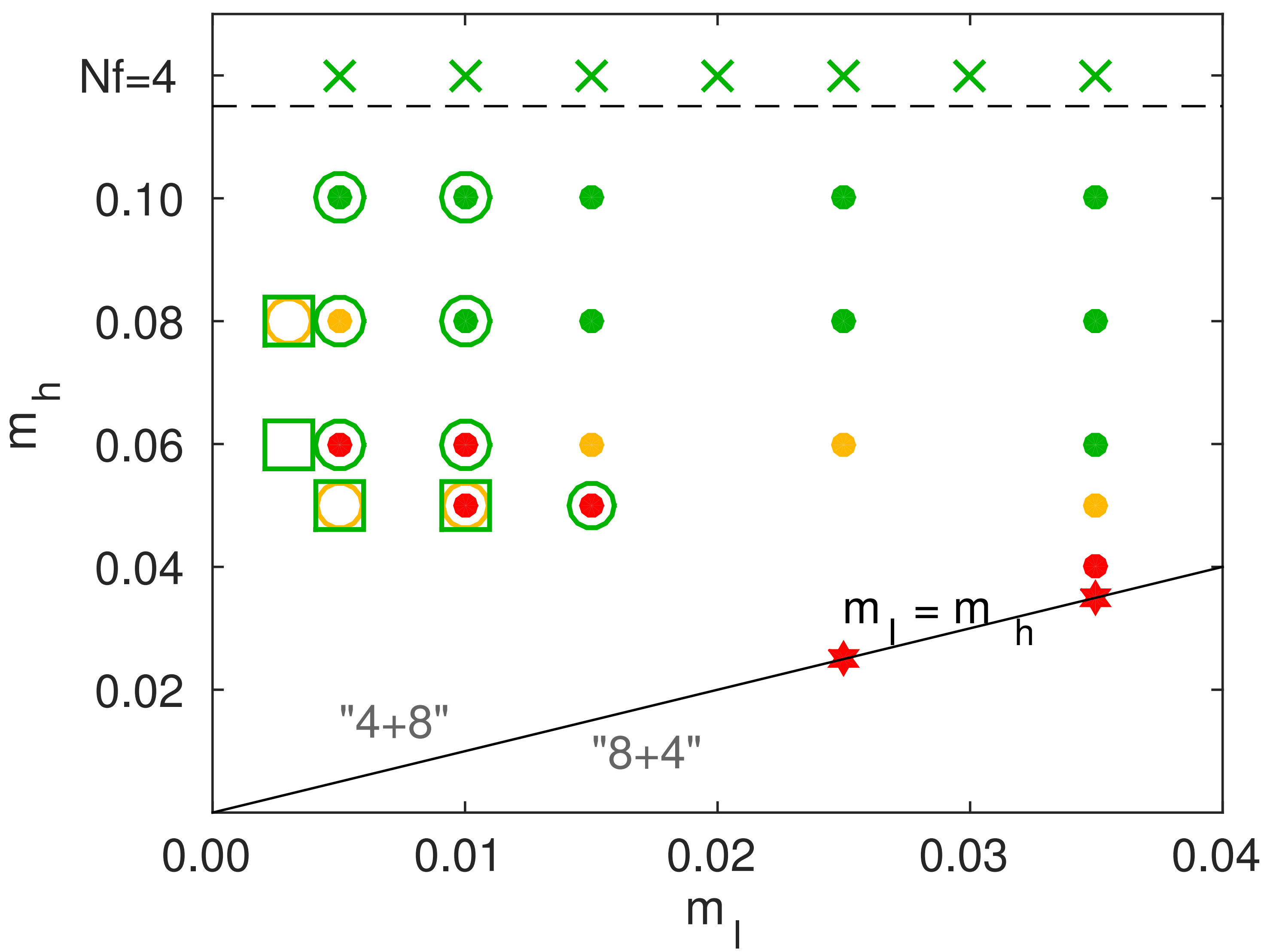
arXiv:1411.3243, 1512.02576

- This is an effective model: we do not ask how the masses are generated nor how it couples to the Standard Model
- $N_f = 12$ has a small anomalous dimension - deep within the conformal window
- Why 4+8 ?
  - to avoid require rooting
  - also a good model for PGB Higgs

  (1508.0701, Ma, Cacciapaglia : Fundamental Composite 2HDM with 4 flavours)

$N_\ell + N_h = 4 + 8$: Parameter space

- β=4.0 (close to the 12-flavor IRFP)
- m_h= 0.100, 0.080, 0.060, 0.050
- m_ℓ=0.003, 0.005, 0.010, 0.015, 0.025, 0.035



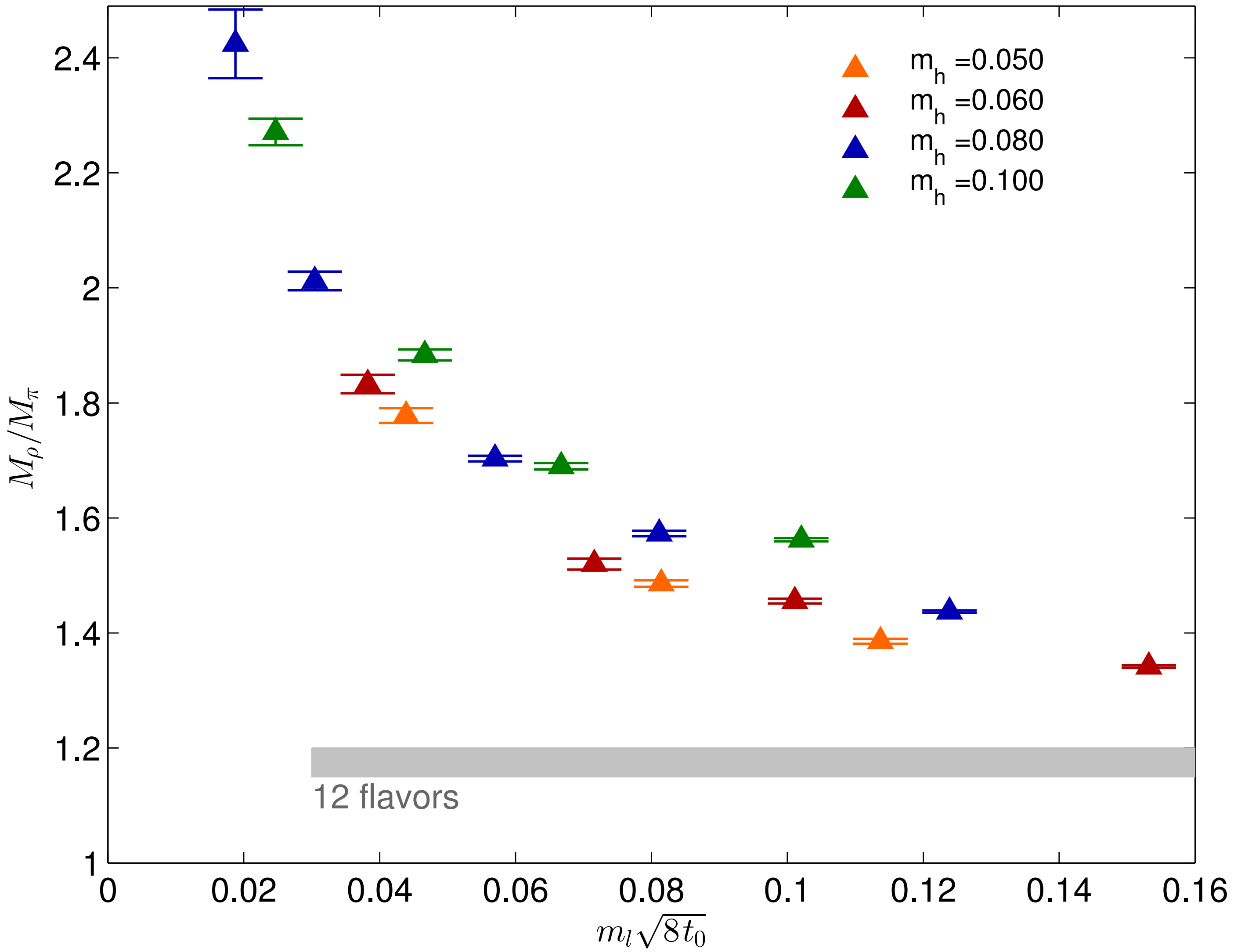
Volumes :
24^3x48, (dots)
32^3x64 (circle), 36^3x64
48^3x96 (square)
Color: volume OK / marginal/ squeezed

20-40,000 MDTU

Is the system chirally broken ?

We know it is …

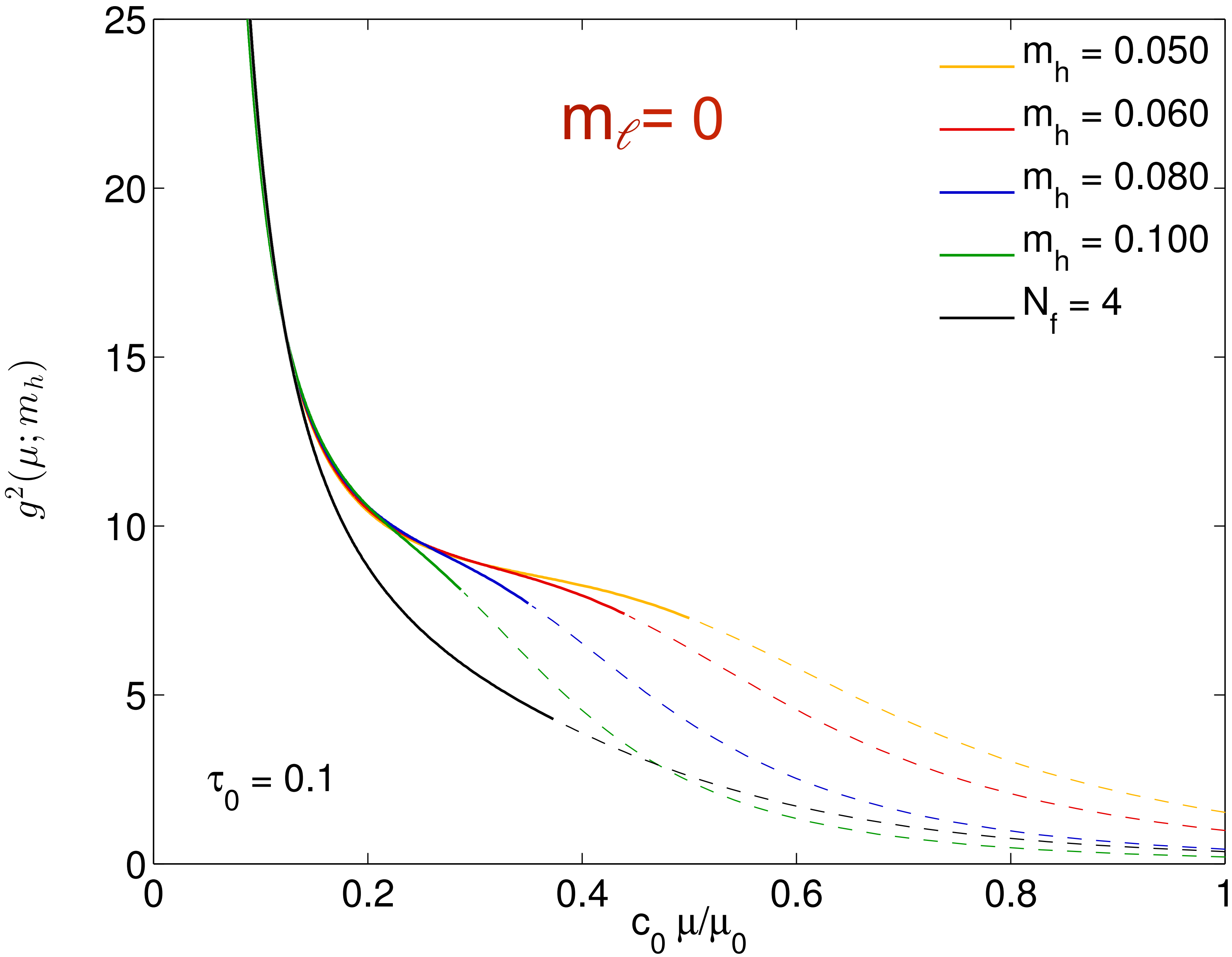
M_ρ/M_π shows that we approach the chiral regime



⇐ N_f=12 predicts an almost constant ratio (as should be in a conformal system)

(arXiv:1401.0195)

Running coupling : 4+8 flavors



This is not a cartoon!

N_f=4 : running fast

$g^2_{GF}(\mu)$ develops a "shoulder" as $m_h \to 0$: this is walking !

Walking range can be tuned arbitrarily with m_h

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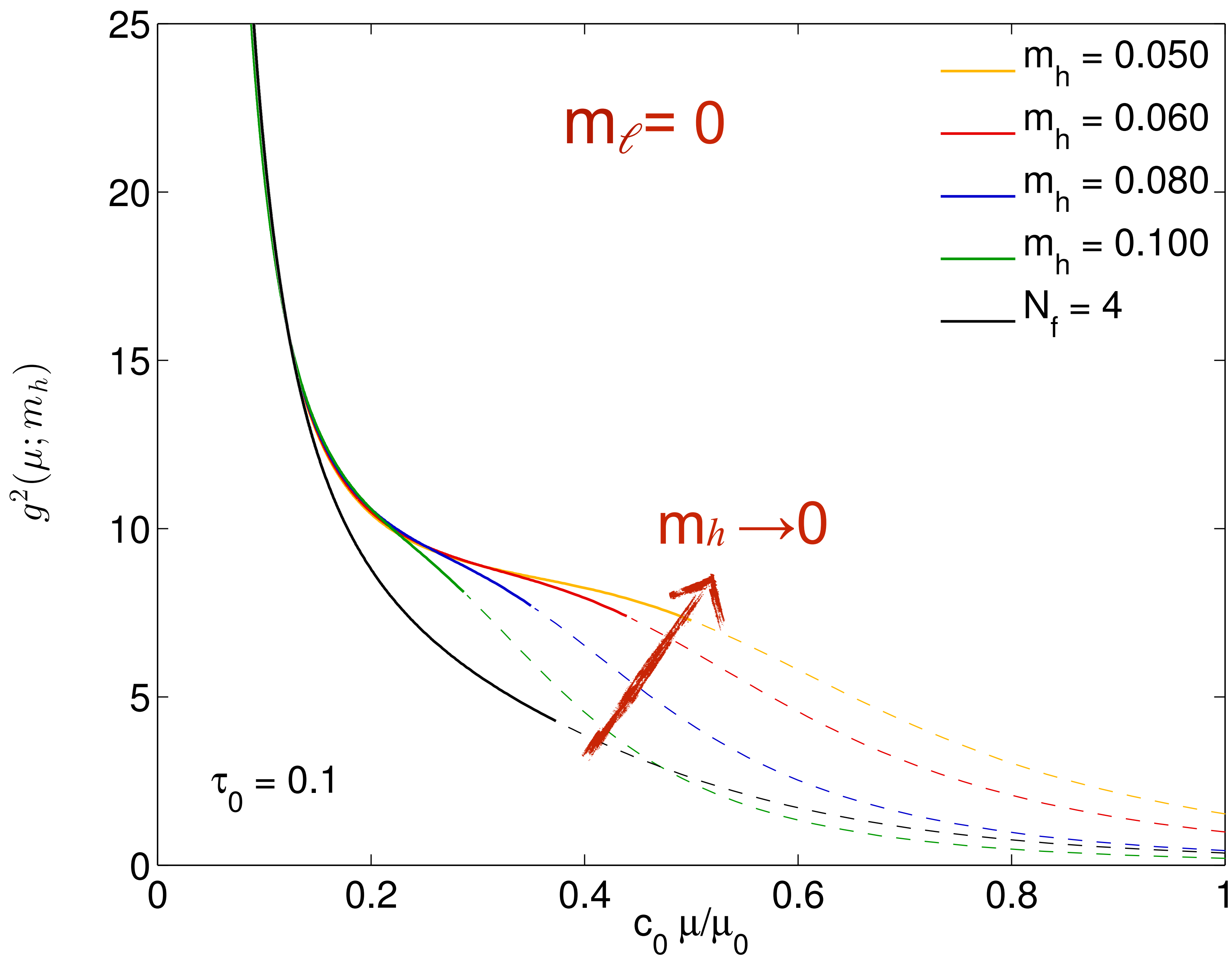

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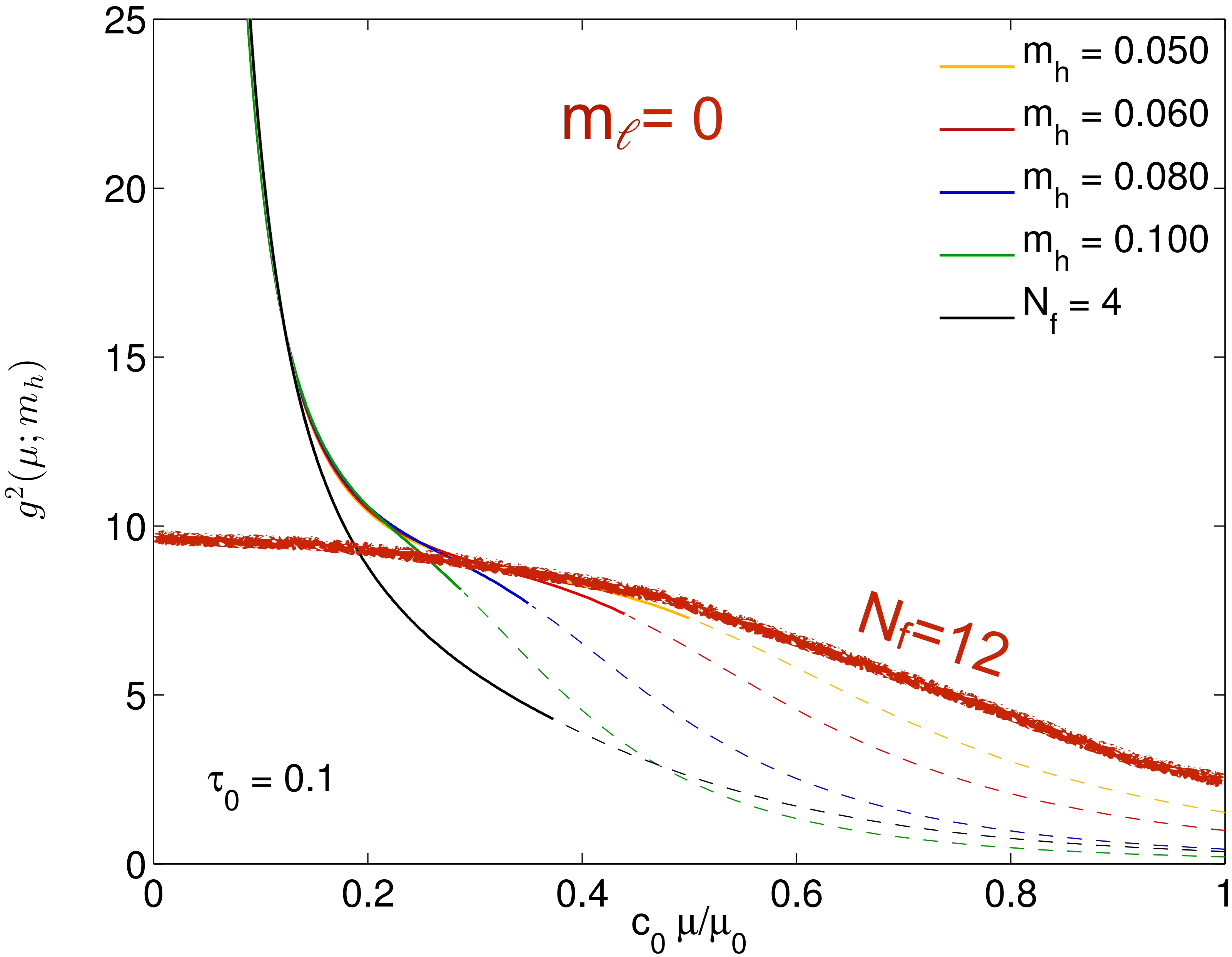

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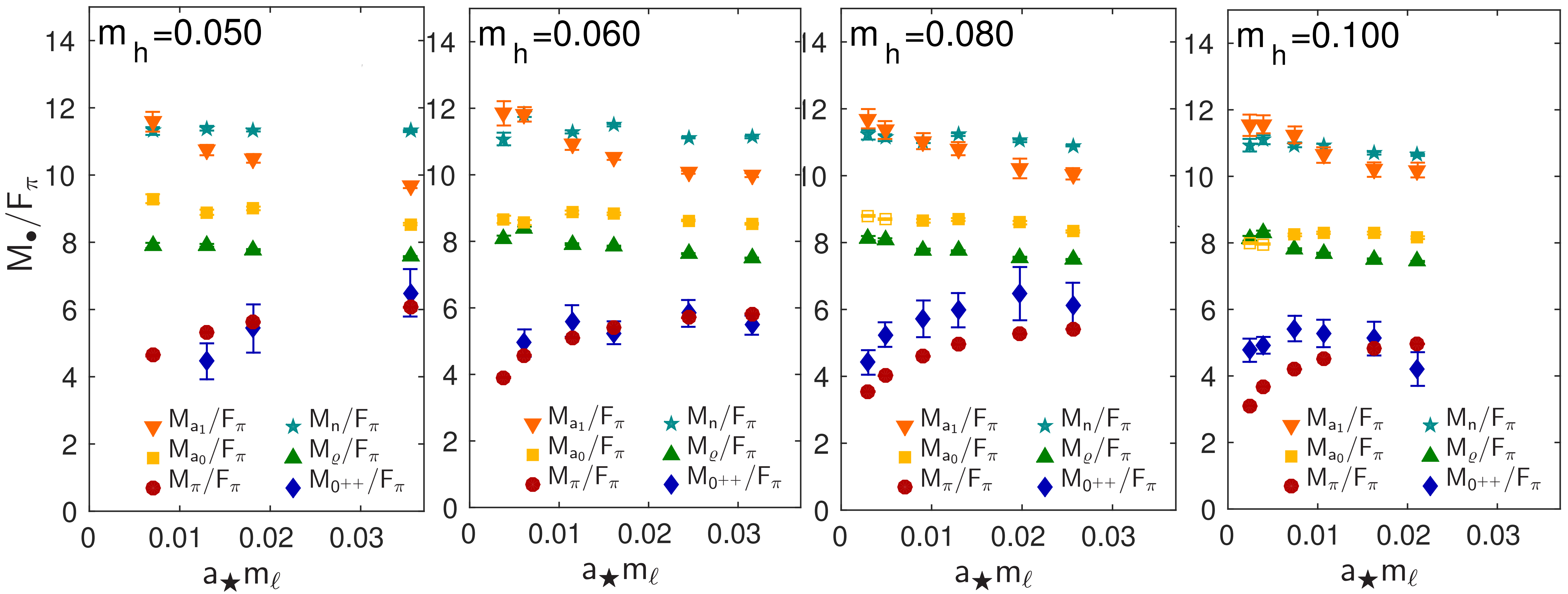
Spectrum, **4+8** flavors

Ratios M_H / F_π appear independent of m_h



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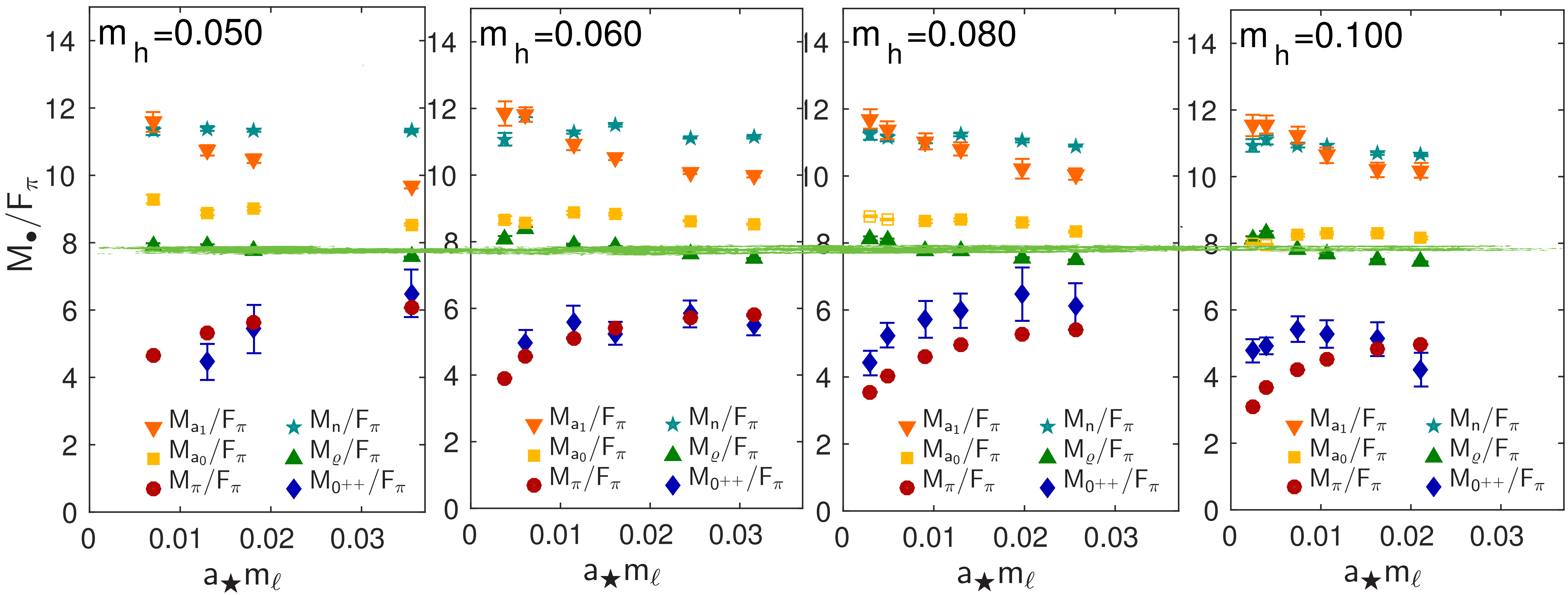

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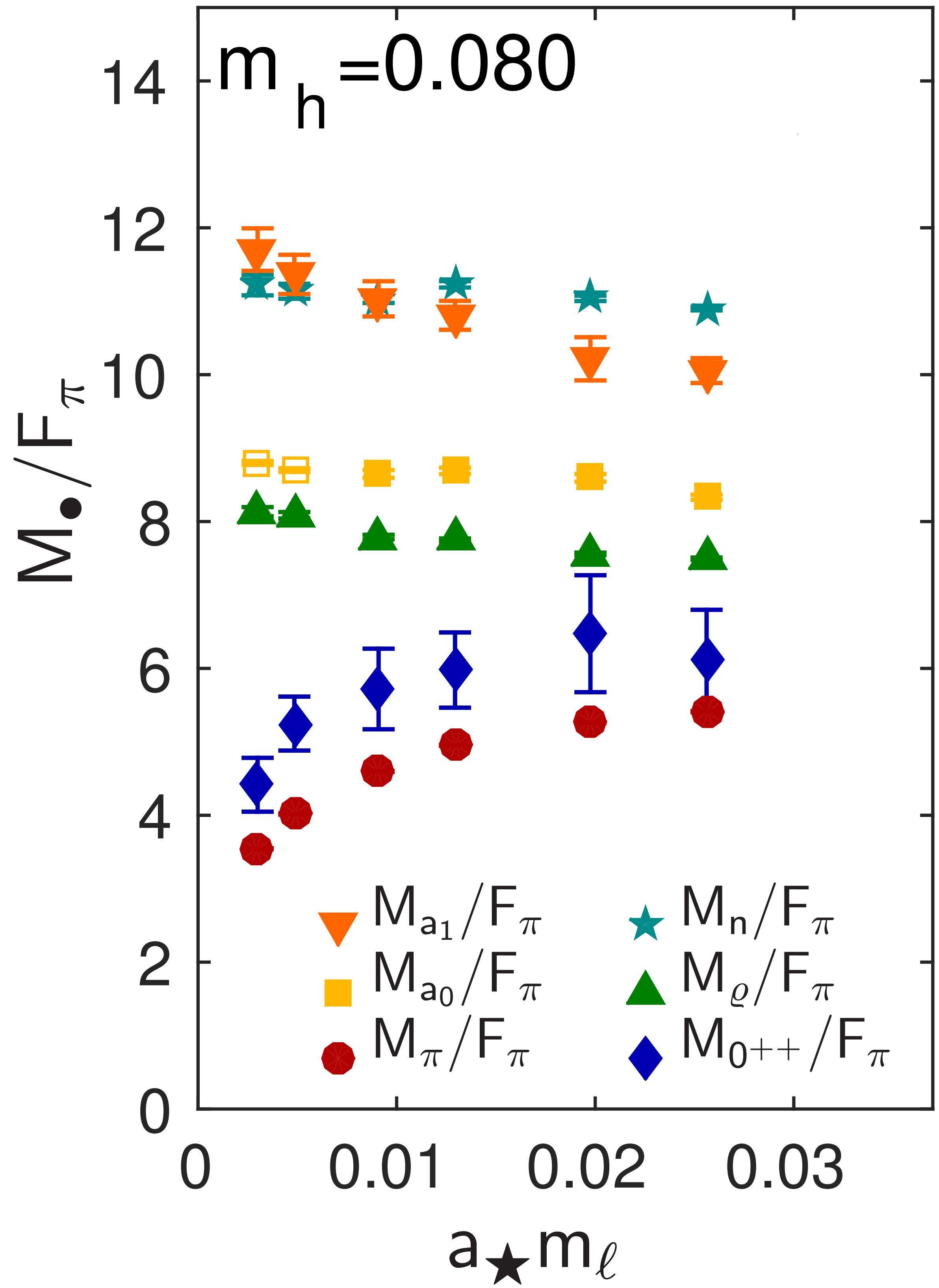

pion, rho, a0, a1, nucleon and 0^{++} scalar

0^{++} is just above, closely following the pion - chiral limit????

The ratios are very similar to QCD, N_f=8 and sextet but not identical

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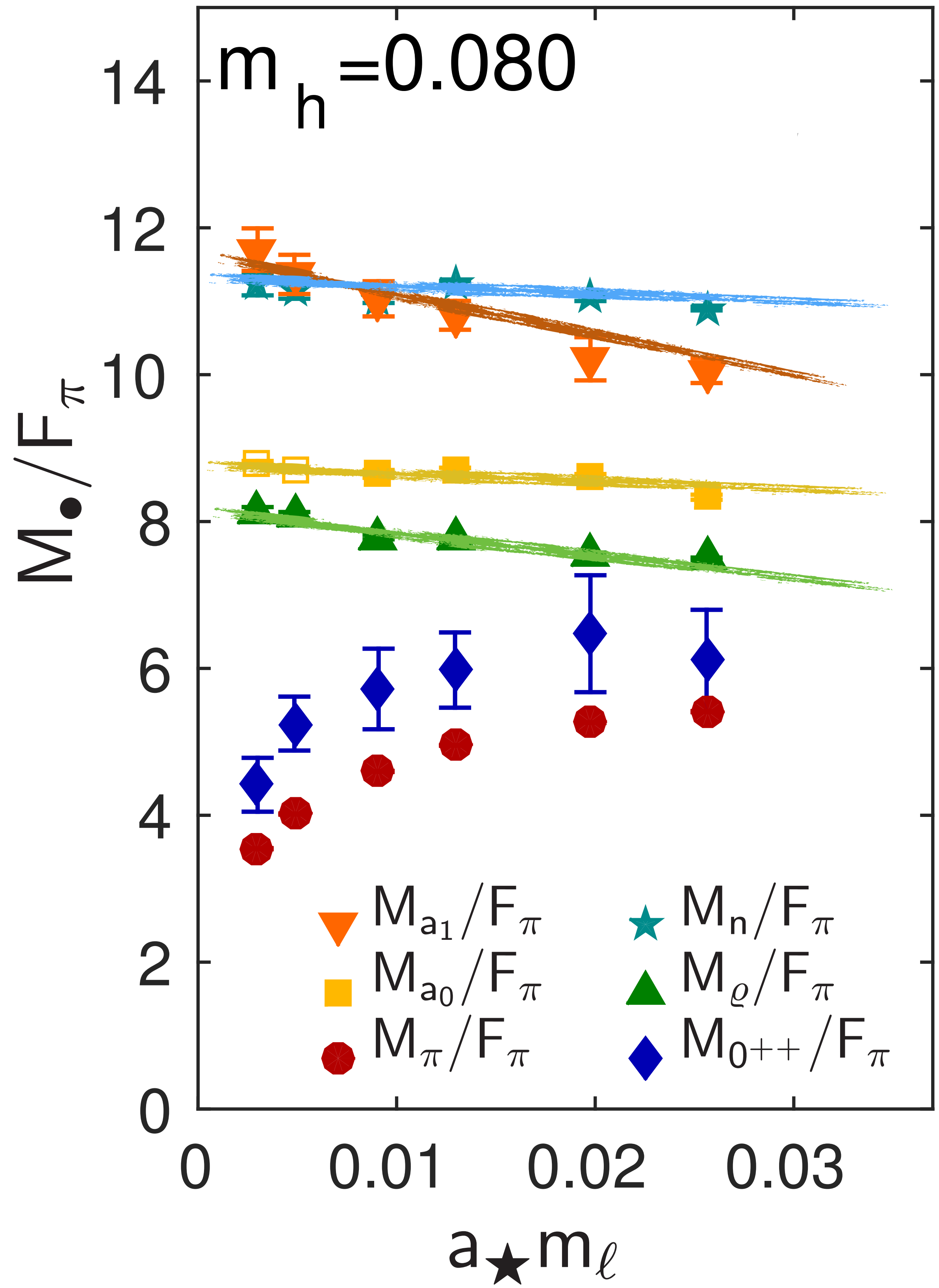

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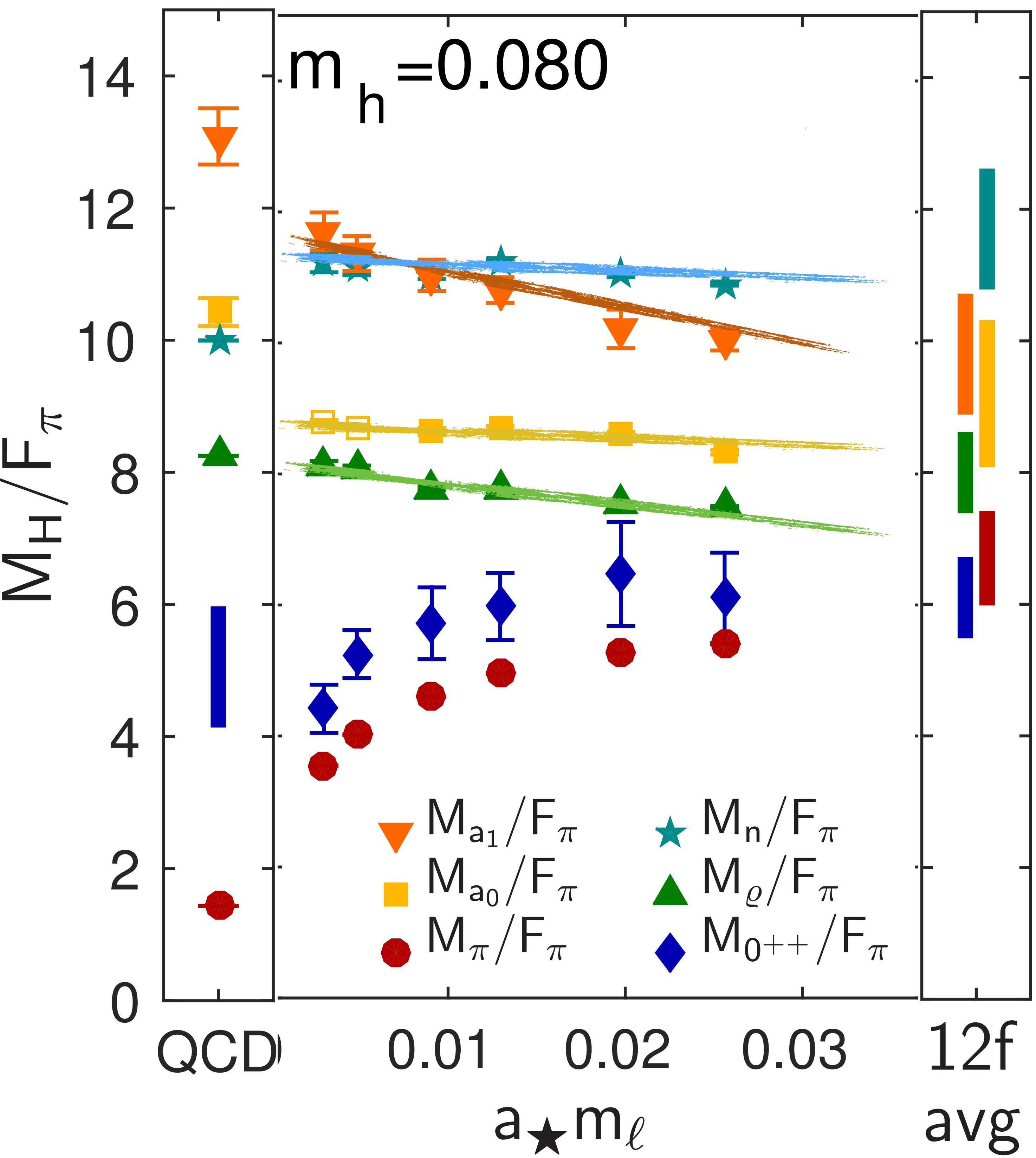

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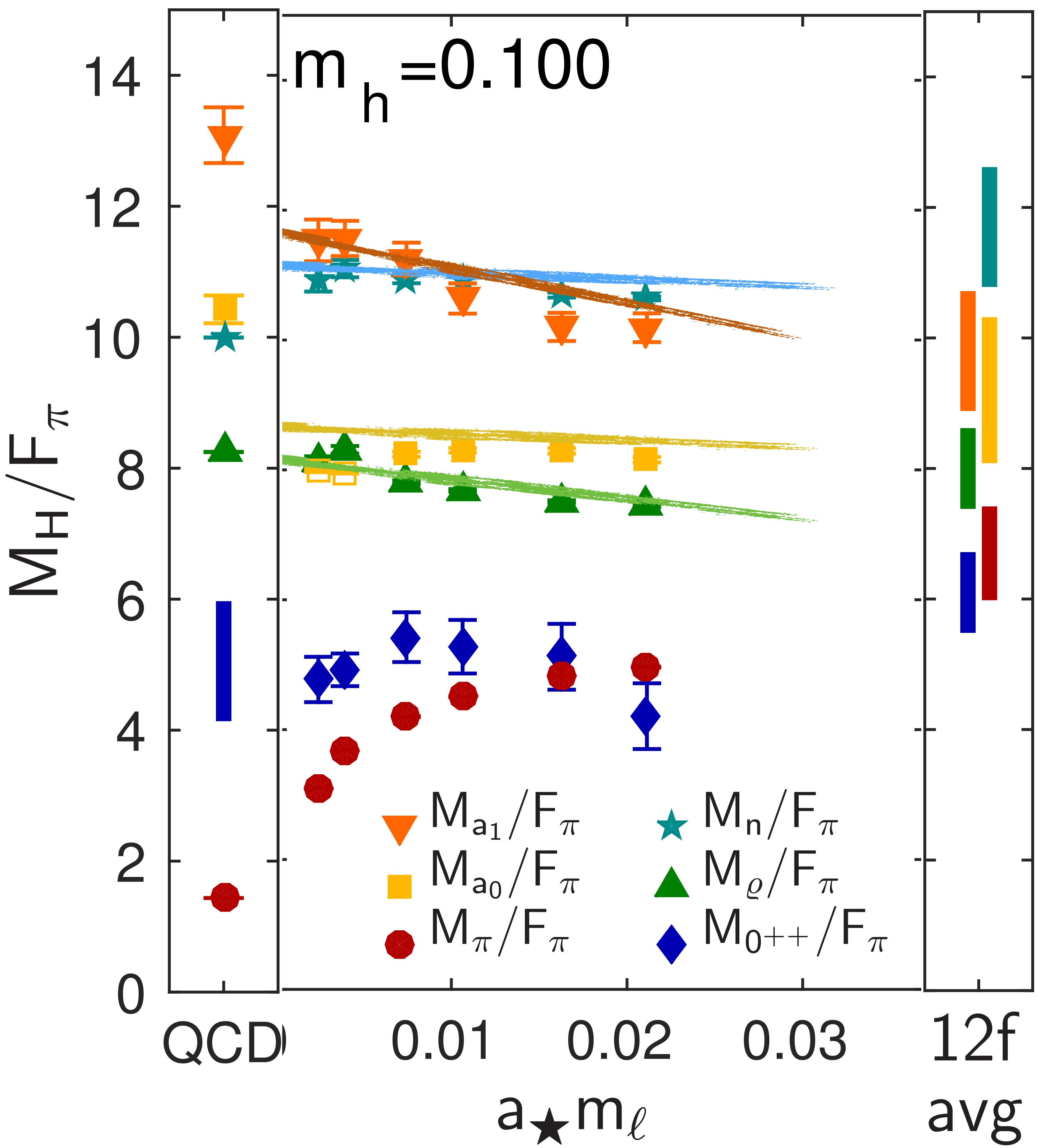

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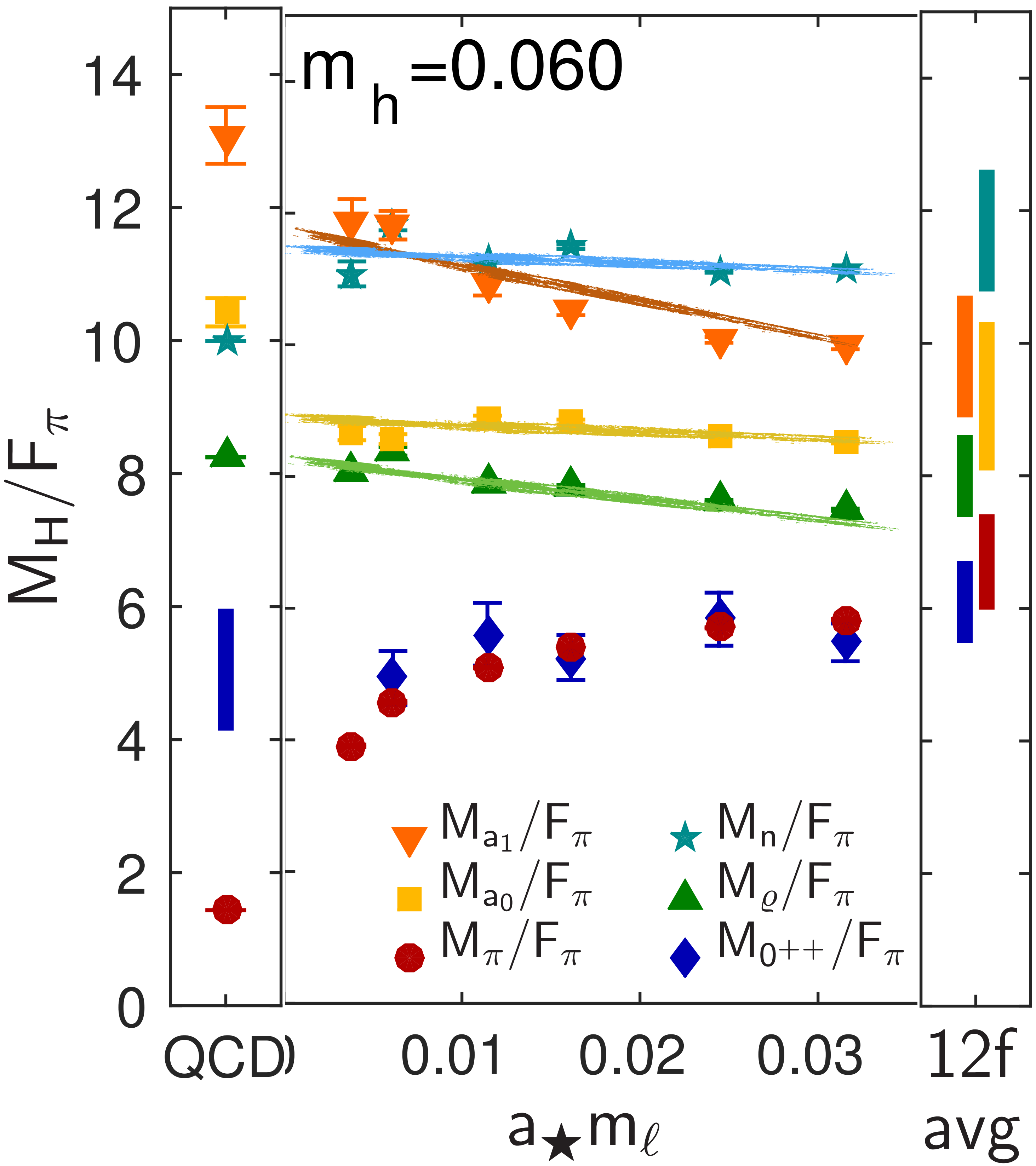

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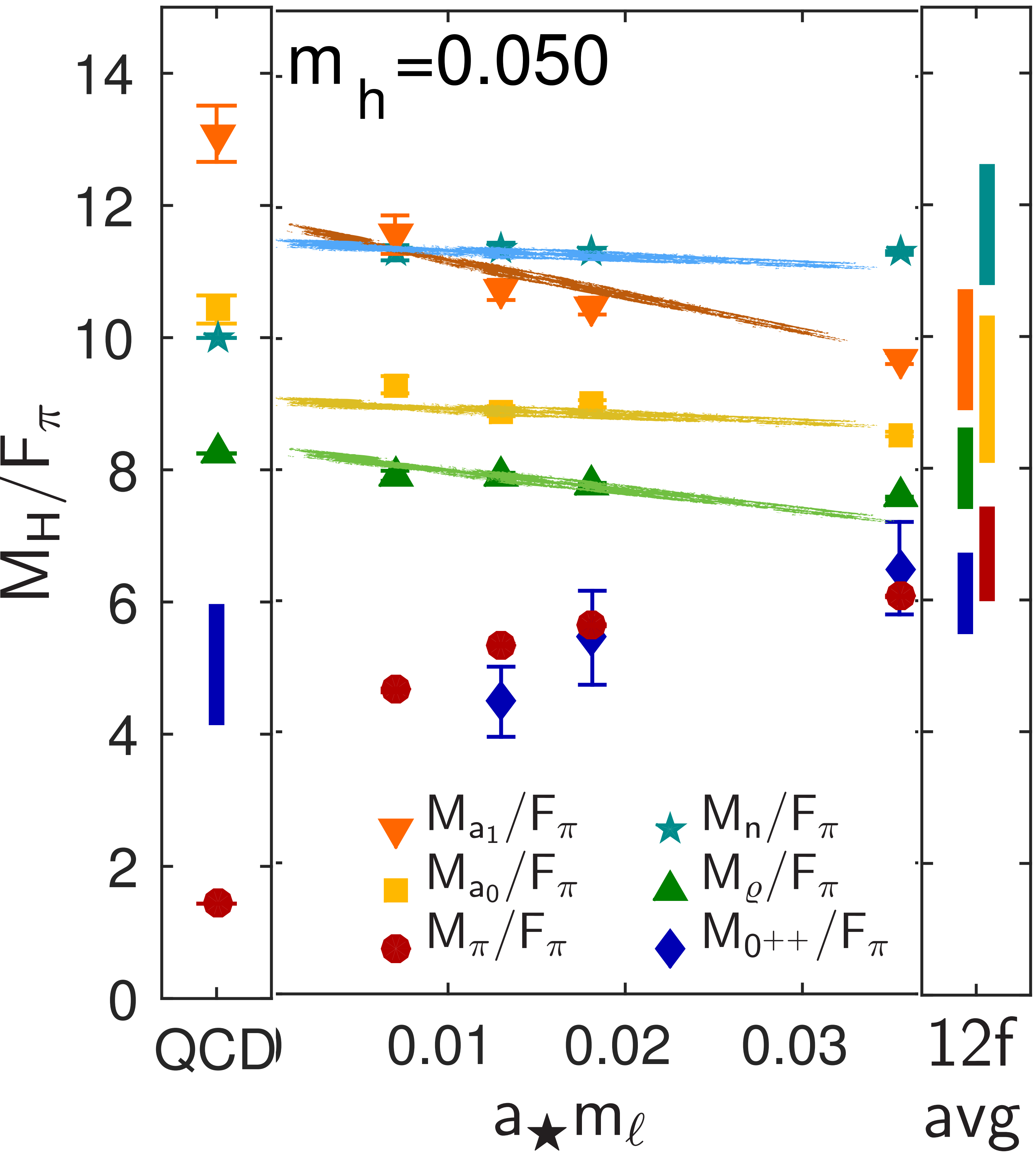

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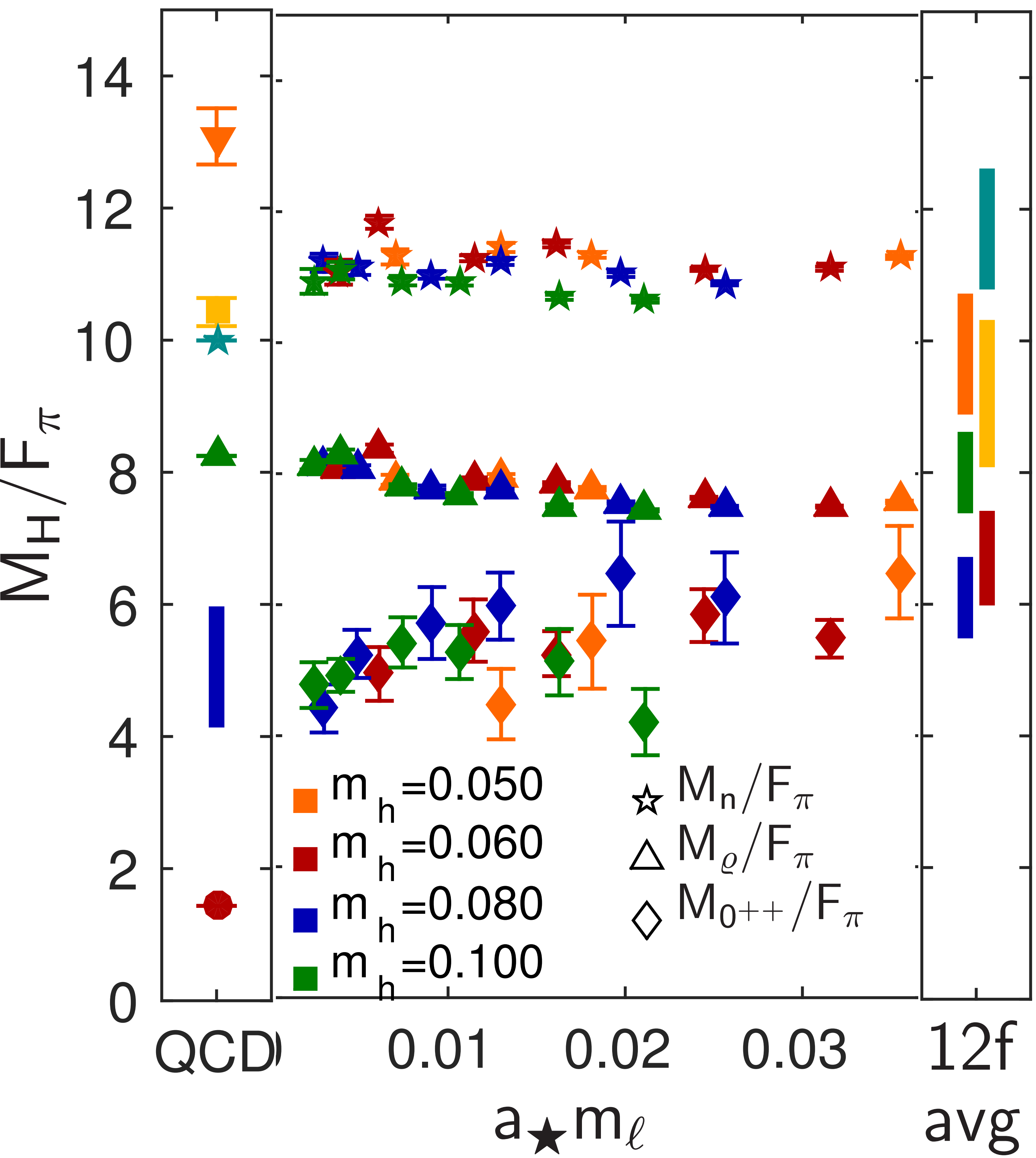

Hyperscaling at work

rho, nucleon
and 0^{++} scalar

The ratios are close to

$$M_\rho / F_\pi \approx 8$$
$$M_N / F_\pi \approx 11$$
$$M_{0^{++}} / F_\pi \approx 4$$

0^{++} : chiral limit is difficult but
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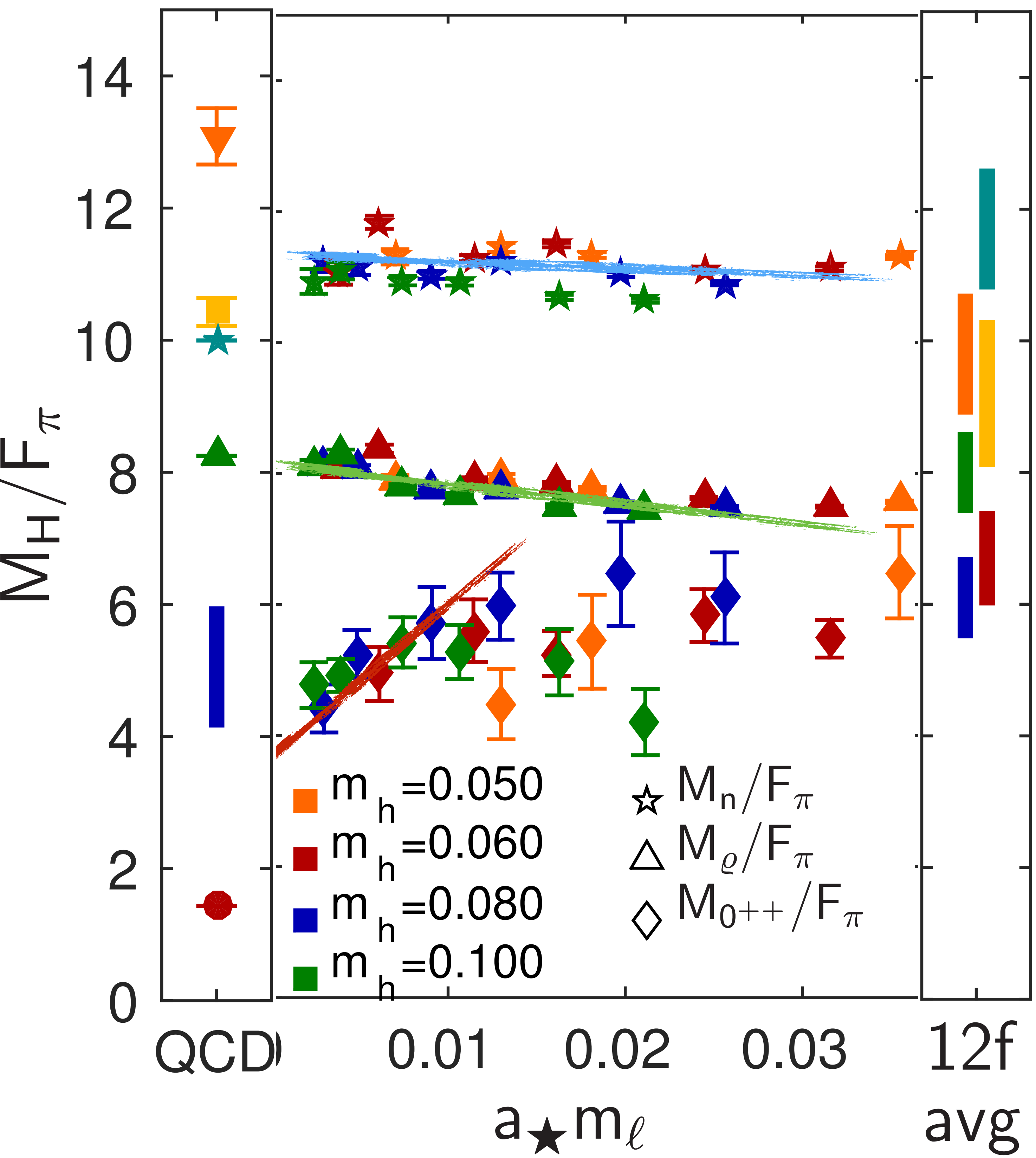

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Mass split models

The 4+8 system is not ideal:

- N_f =12 is far above the conformal window with small anomalous dimension $\gamma_m \approx 0.25$
- we might want only 2 light flavors (but maybe not)

Yet it shows:

- hyperscaling : predictive !
- walking gauge coupling
- similar general properties as N_f=12, even QCD, but still distinguishable

Light 0^{++} , well separated from heavier excitations - we need $M_{0^{++}} / F_\pi$ in the chiral limit

All other studies (decay constatnts, pi-pi scattering, p to ε regime, for the future

Summary

Many interesting strongly coupled near conformal systems
all require non-perturbative lattice investigations

Lattice models are effective models, require

- fermion couplings
- embedding the Standard Model

There are some very general features between different models:

- light 0++ state
- walking gauge coupling
- several resonances in the 1-3 TeV range, $M_\rho / F_\pi \approx 8$

LHC could verify / falsify many of the BSM soon