Lattice 2017

Granada, June 20, 2017

RIKEN BNL Research Center

FLAVOR-SINGLET SPECTRUM IN MULTI-FLAVOR QCD

SU(3) with N_f=4, 8 and 12

Enrico Rinaldi

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in collaboration with

LatKMI collaboration

KEK: Aoki, Kurachi, Shibata

Kyoto: Aoyama

Nagoya: Maskawa, Yamawaki, Nagai

Nara: Ohki

Marseille: Miura

Swansea: Bennett

Tsukuba: Yamazaki

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Lattice Strong Dynamics collaboration

Argonne: Jin, Osborn

Bern: Schaich

Boston: Brower, Rebbi, Weinberg

Colorado: Hasenfratz, Neil

Edinburgh: Witzel

LLNL: Vranas

UC Davis: Kiskis

Yale: Appelquist, *Fleming*, *Gasbarro*

MOTIVATIONS

- Strongly interacting quantum field theory with many light fermions
  - is the dynamics different from QCD?
  - what is the hierarchy in the spectrum?
  - is there a light scalar flavor-singlet?
- Phenomenology of physics beyond the Standard Model
  - light Higgs from composite dynamics (pNGB or dilatonic nature)
  - large anomalous dimensions
  - expected (near-)conformal dynamics for consistency with experiments

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in QCD there is a broad resonance $f_0(500)$

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LATTICE RESULTS

- SU(3) gauge theory with many degenerate fundamental fermions N_f=4, 8 and 12

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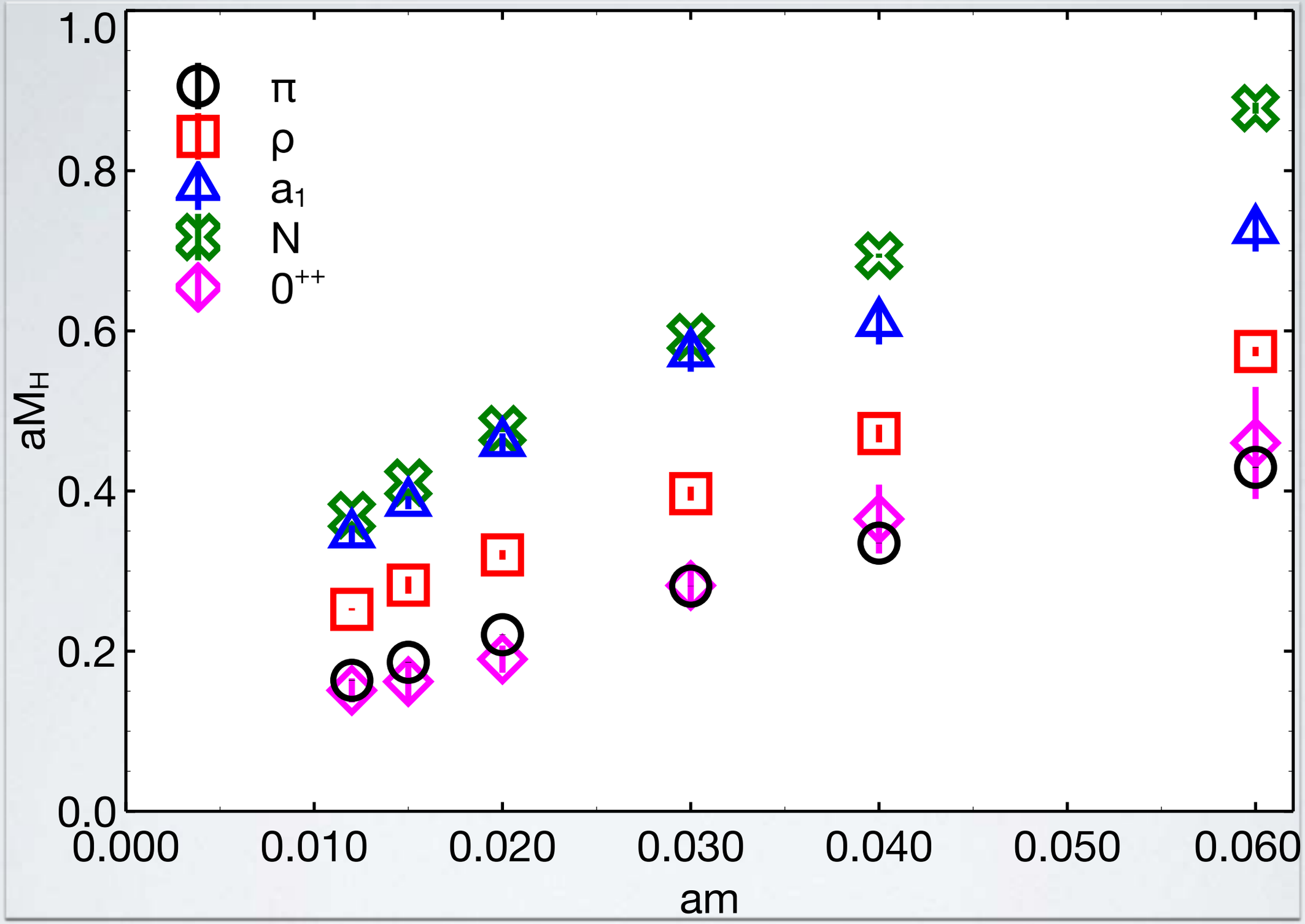
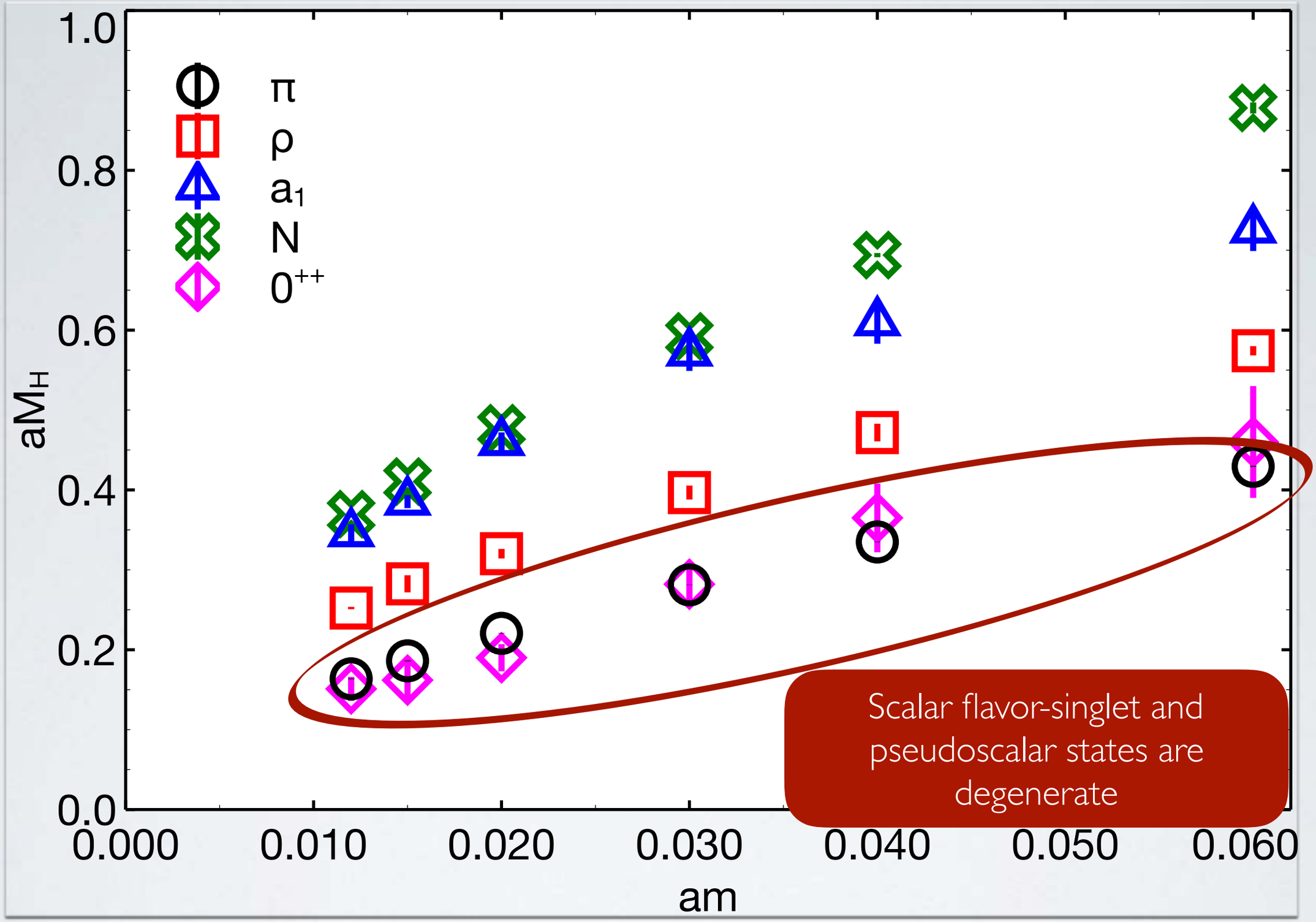
Have a look at the most interesting case of N_f=8



Lattice details: tree-level Symanzik gauge action + 2 HISQ staggered quarks

LatKMI arxiv:1610.07011 [published on PRD]



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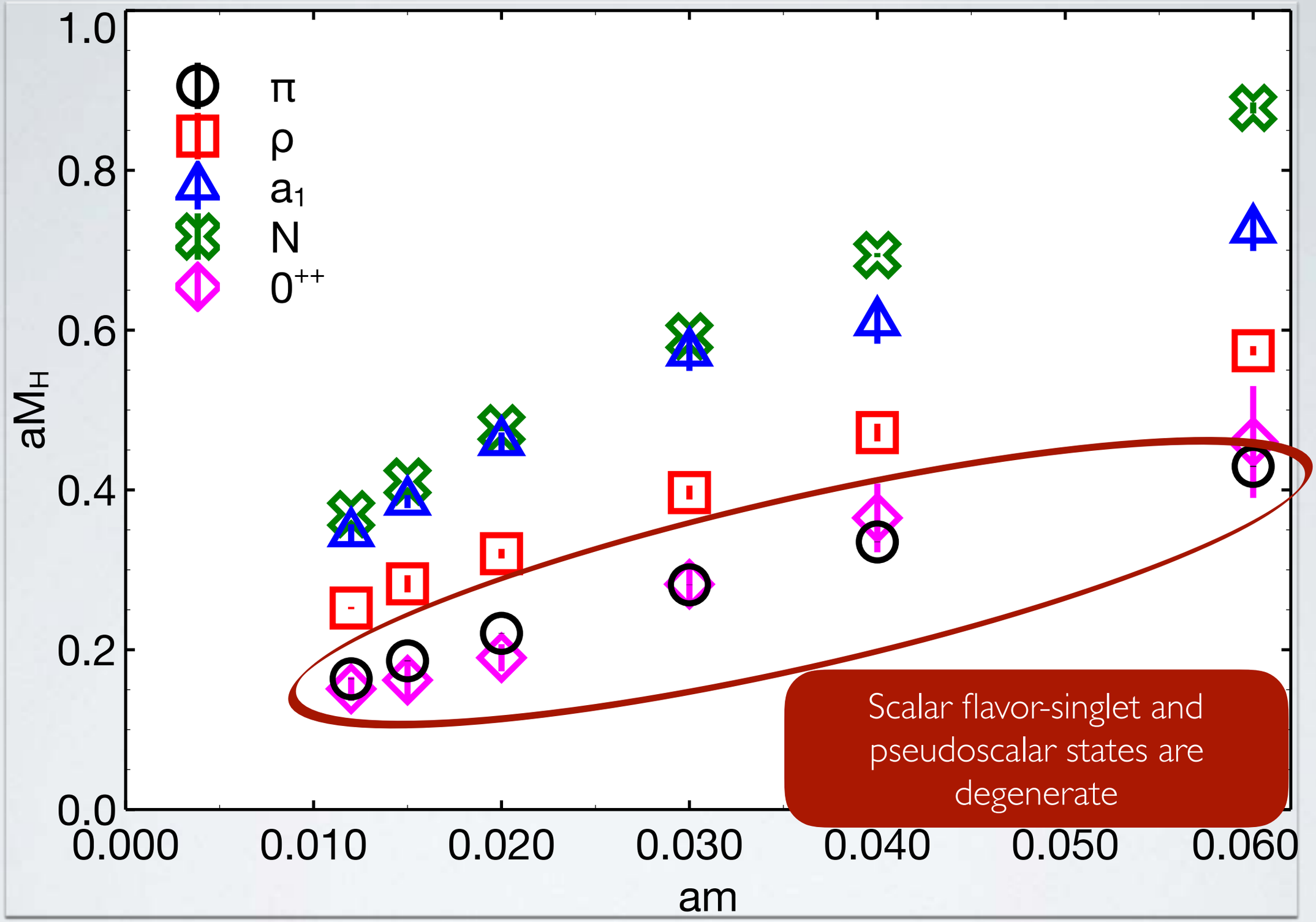

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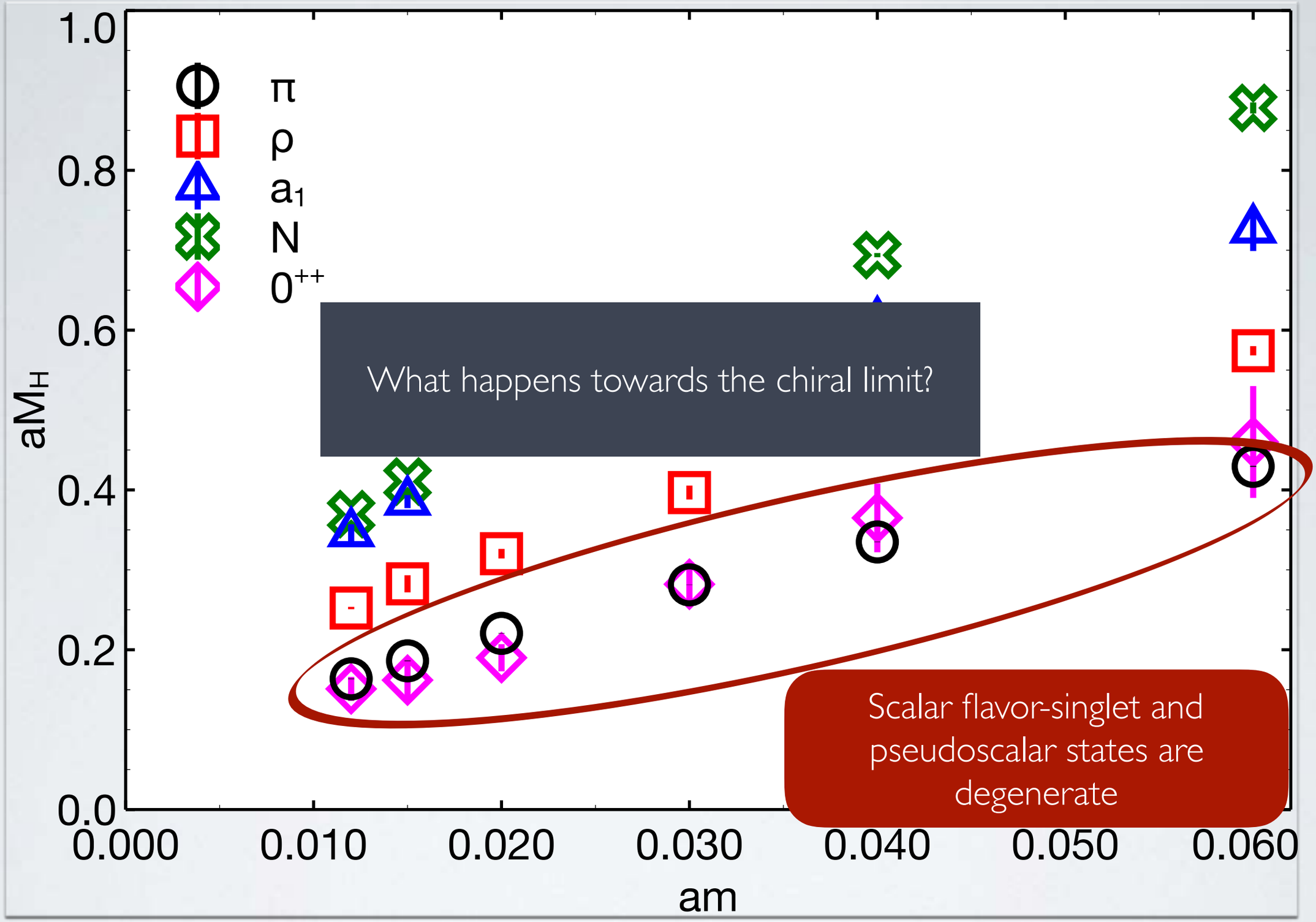

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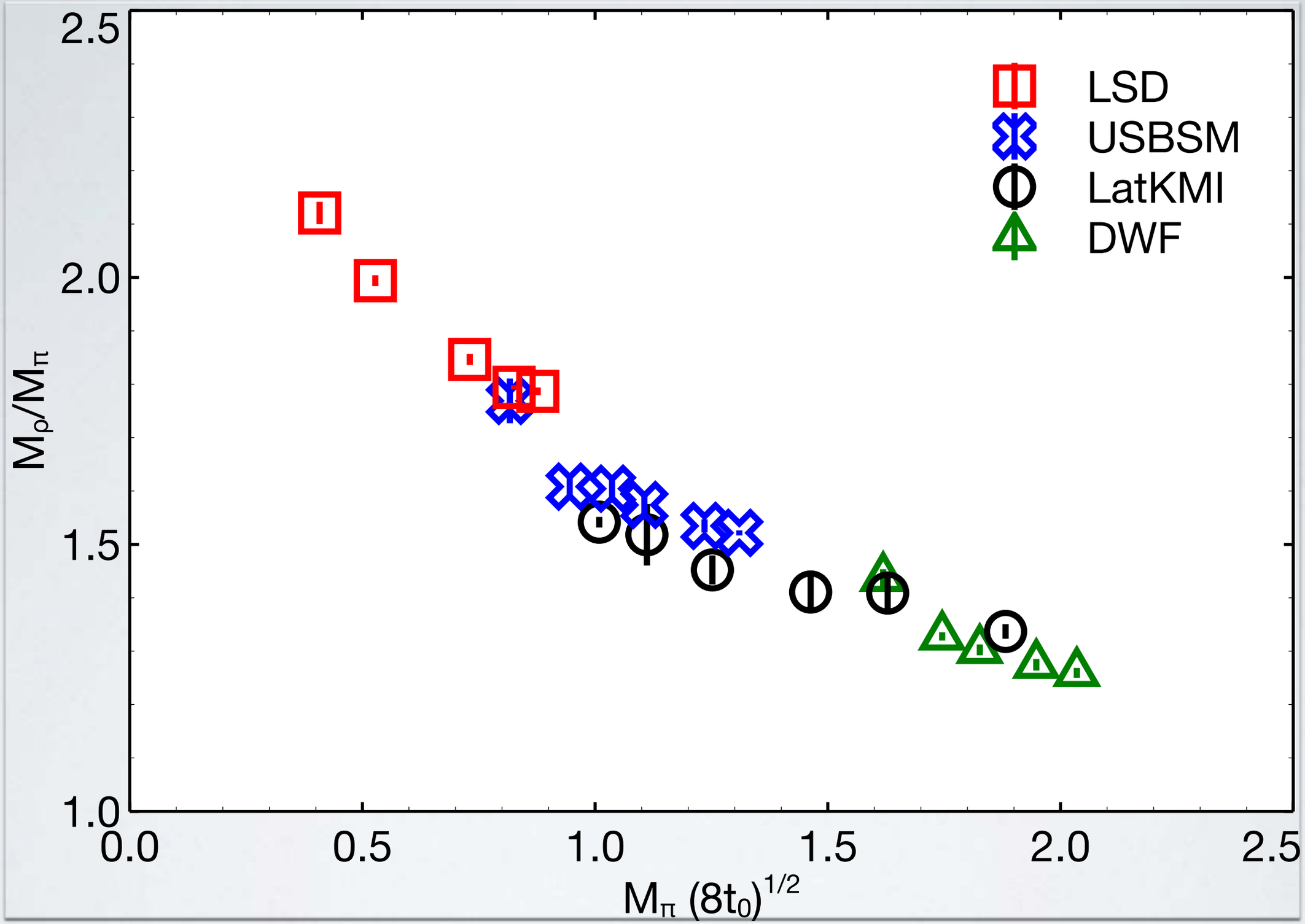
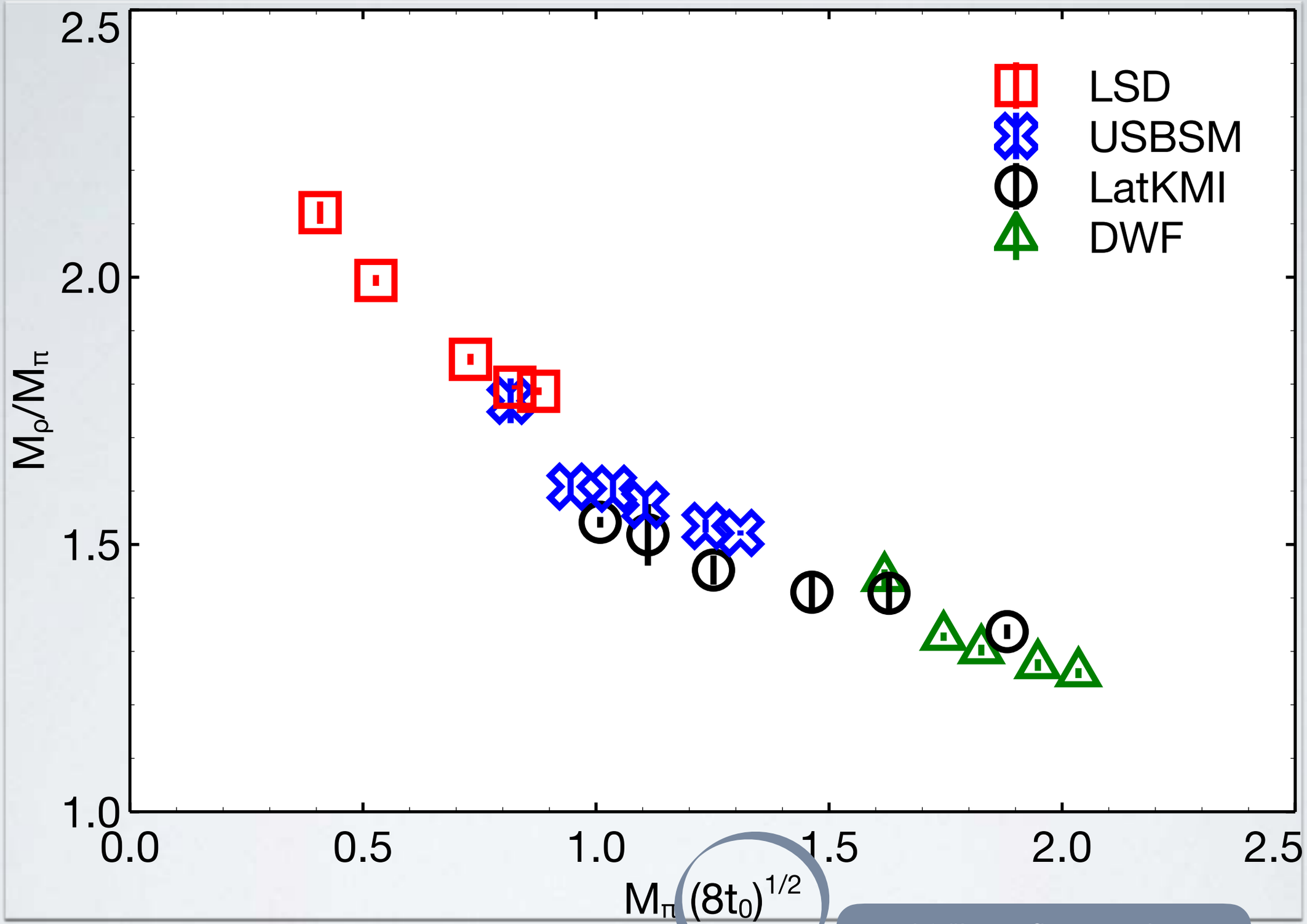


LSD arxiv:1601.04027 | USBSM arxiv:1310.7006 | LatKMI arxiv:1610.07011 | DWF (LSD) arxiv:1405.4752



Wilson flow scale: common reference

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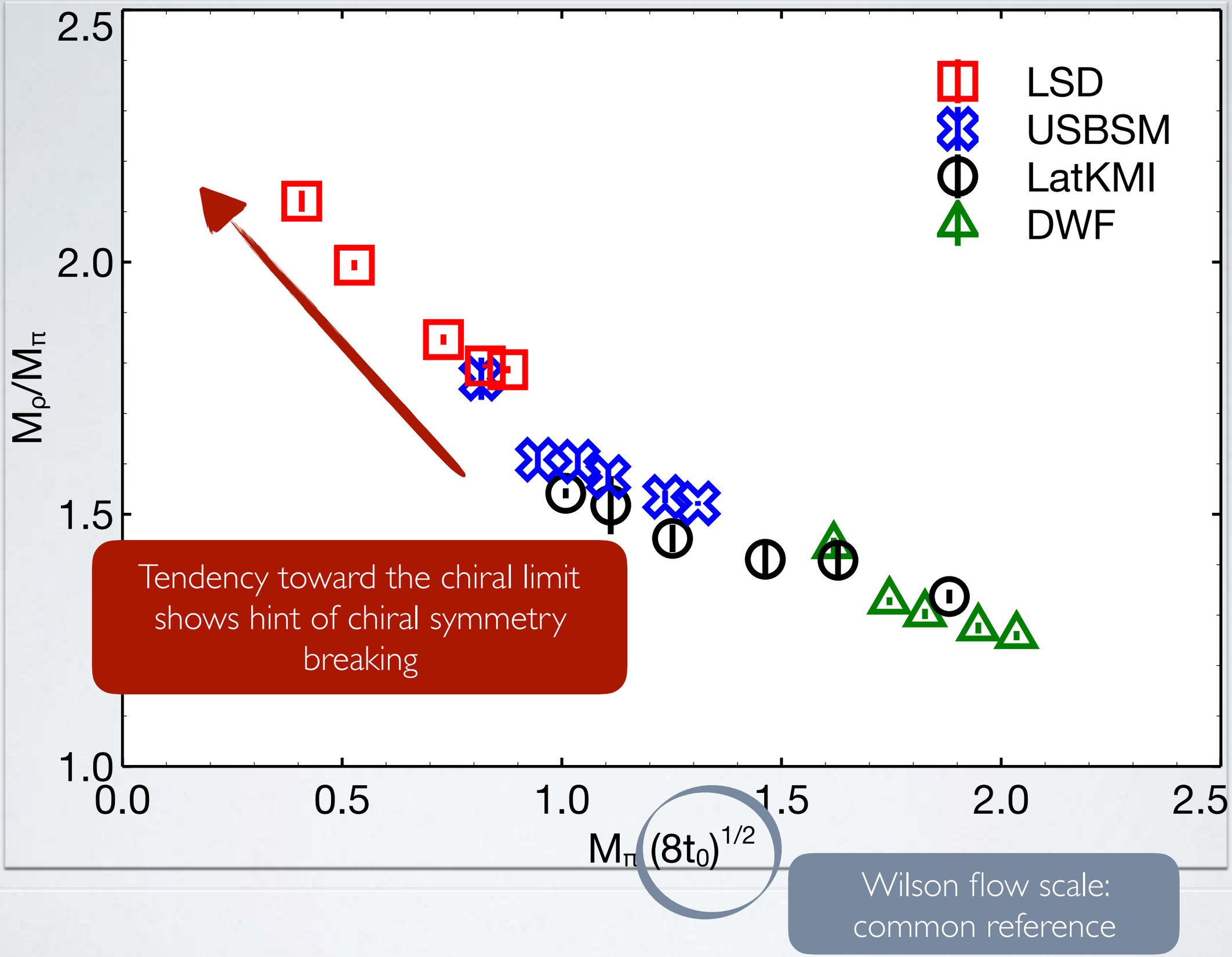

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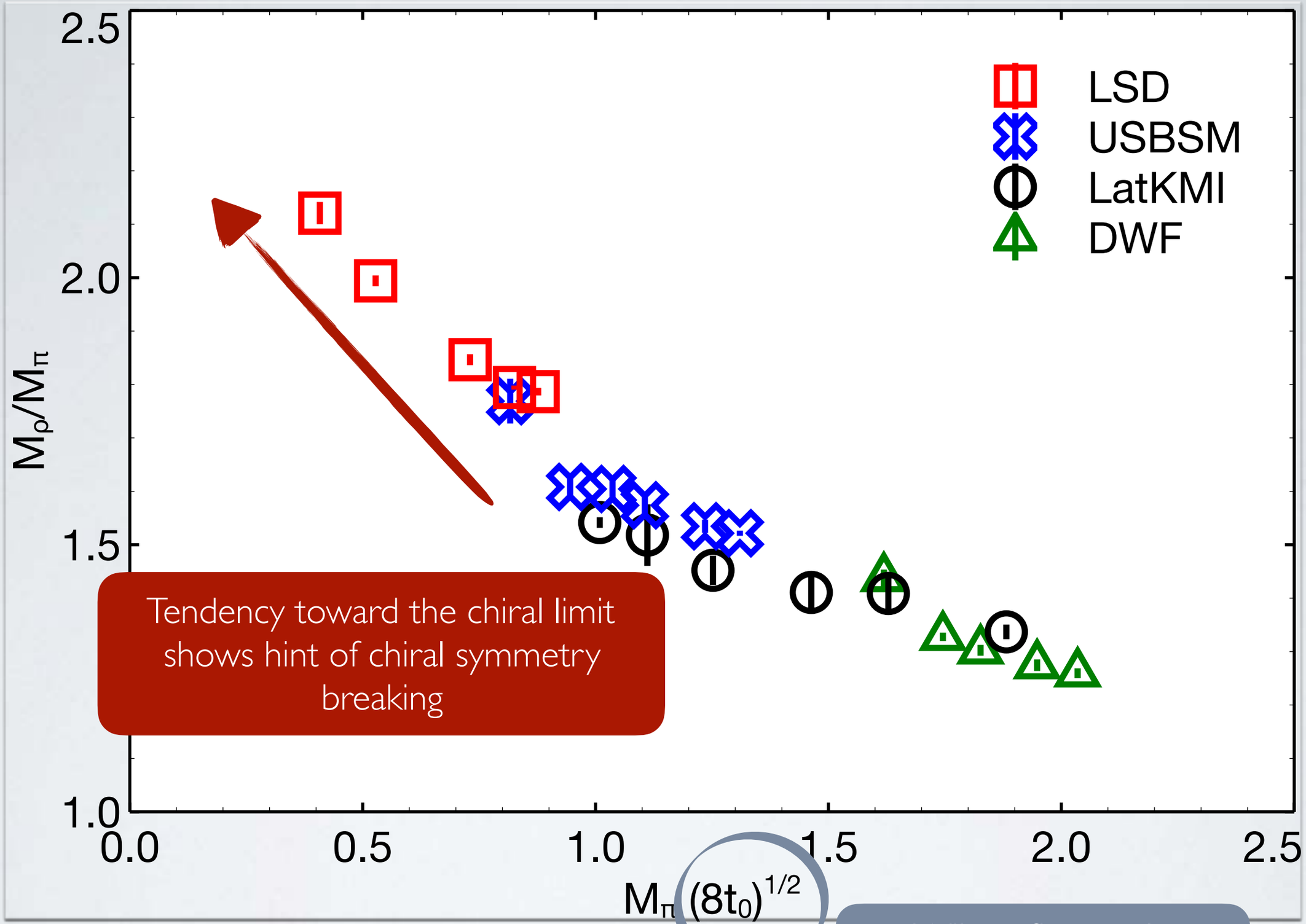

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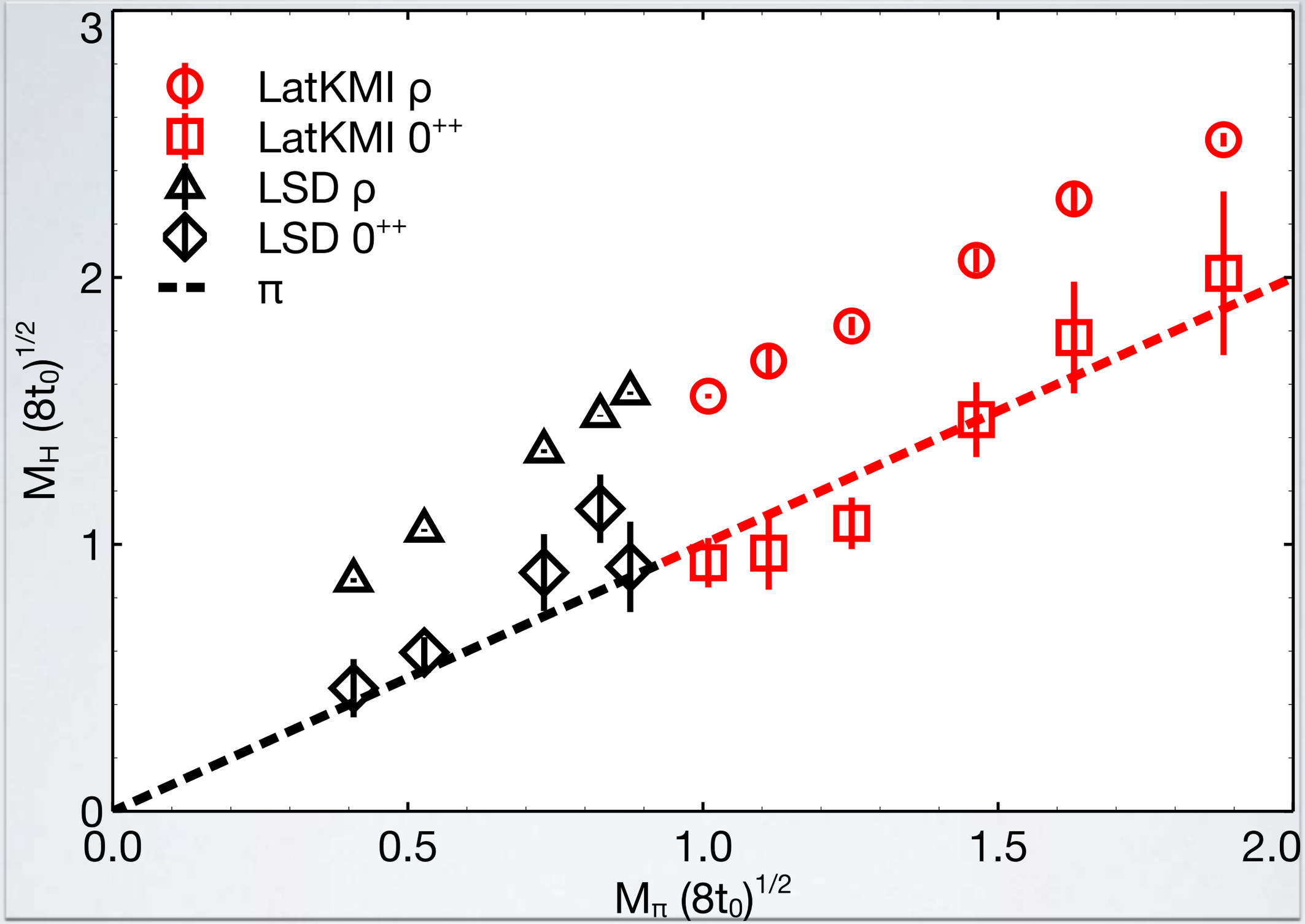

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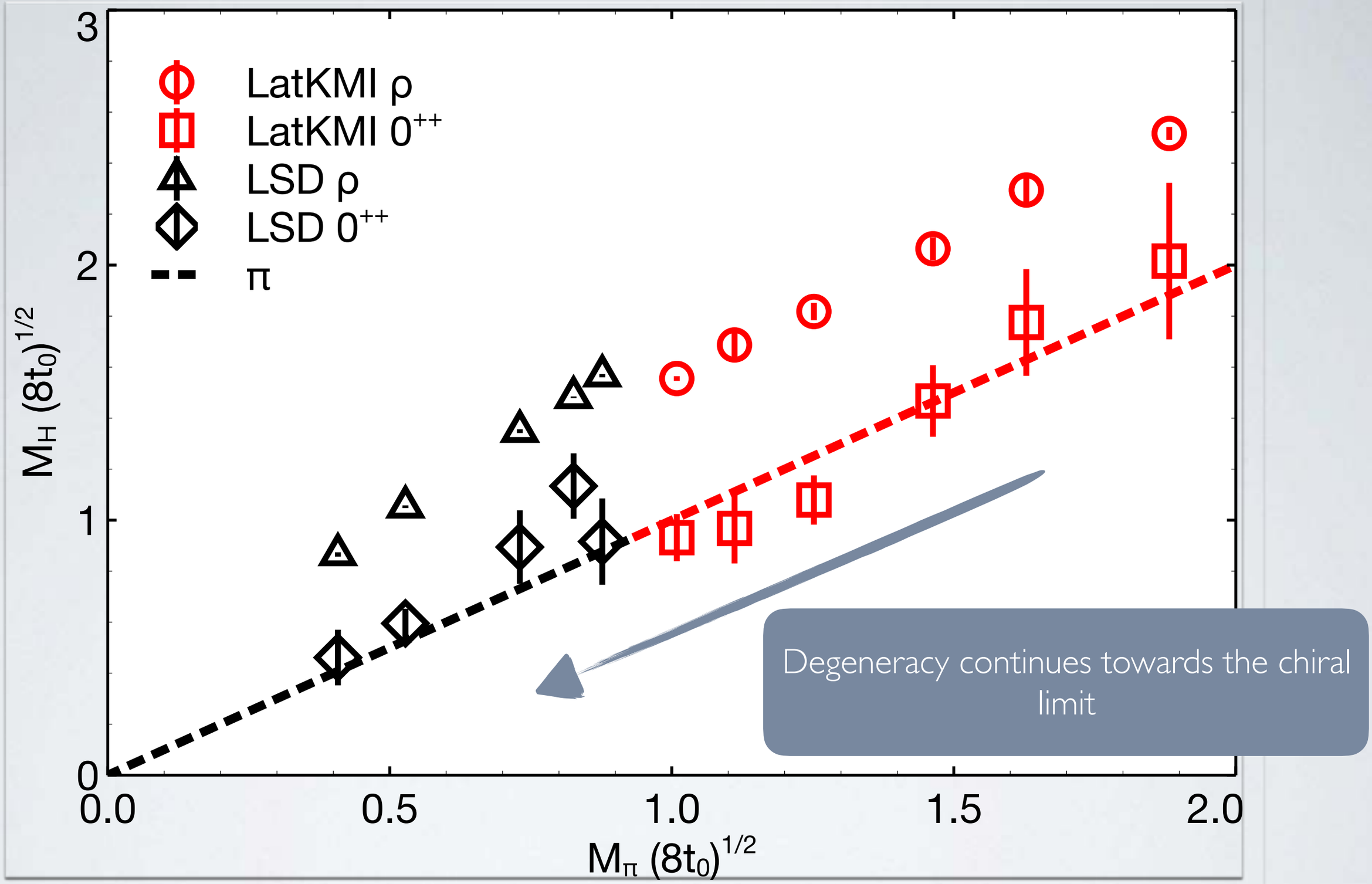

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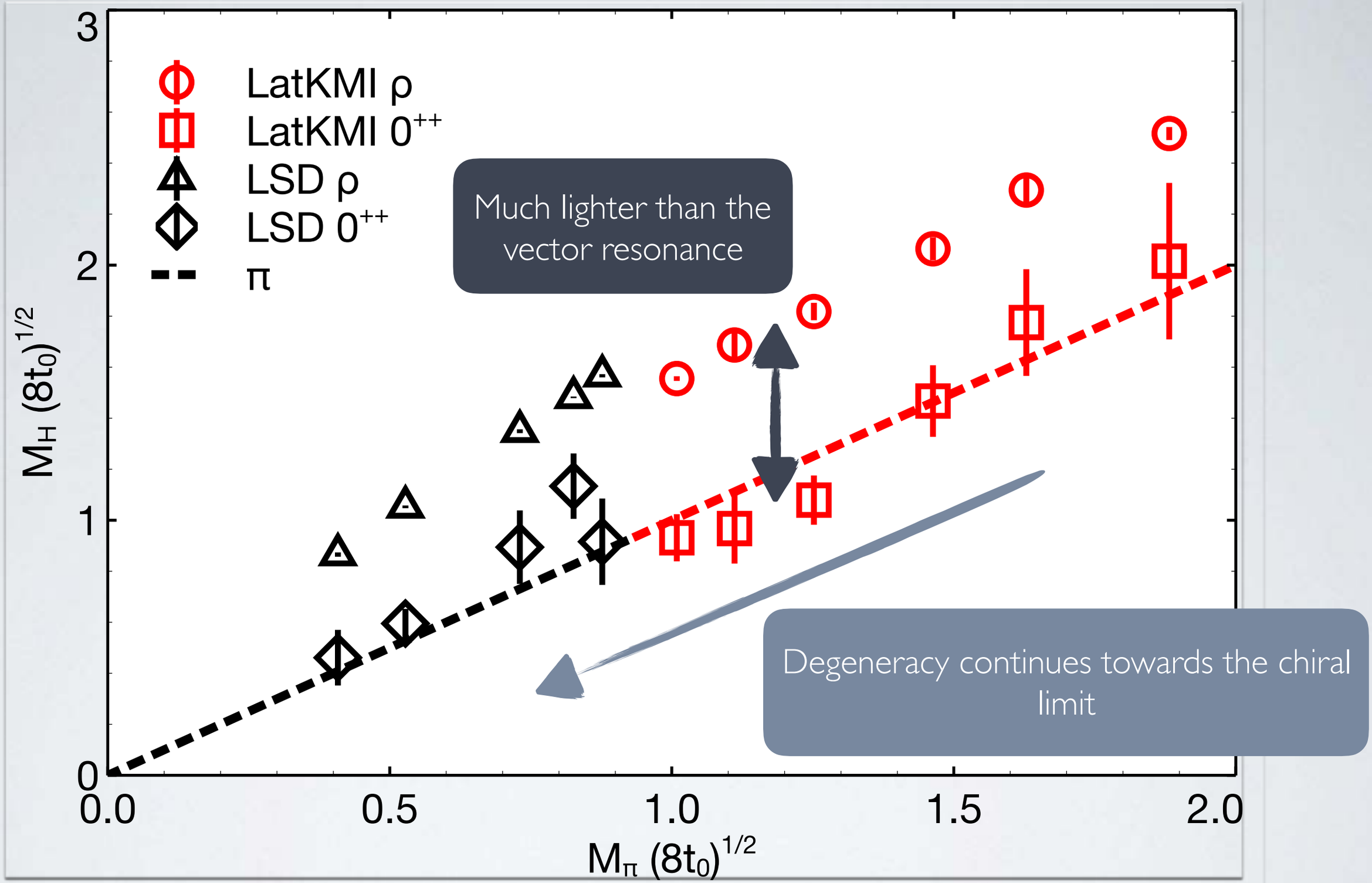

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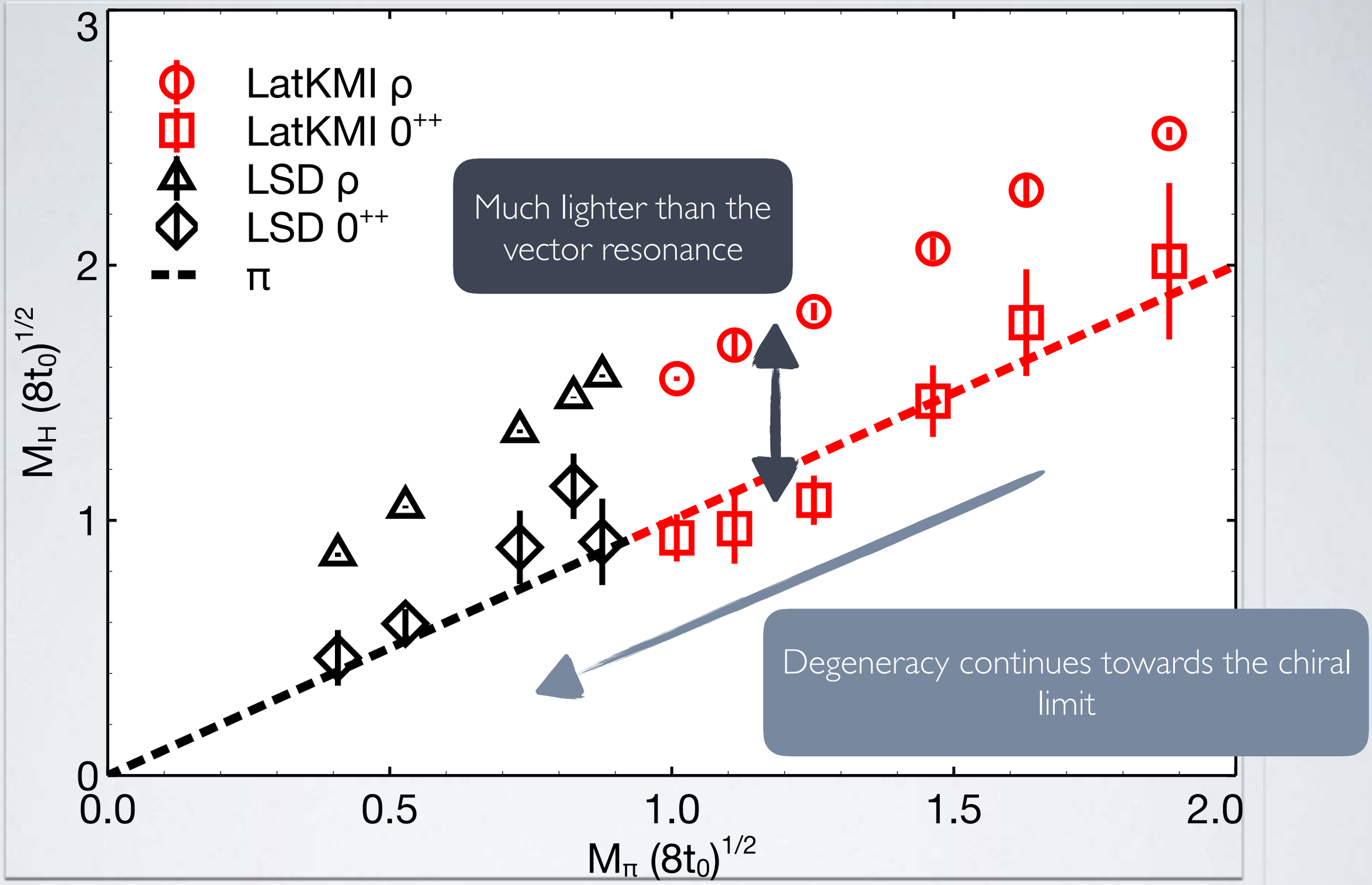

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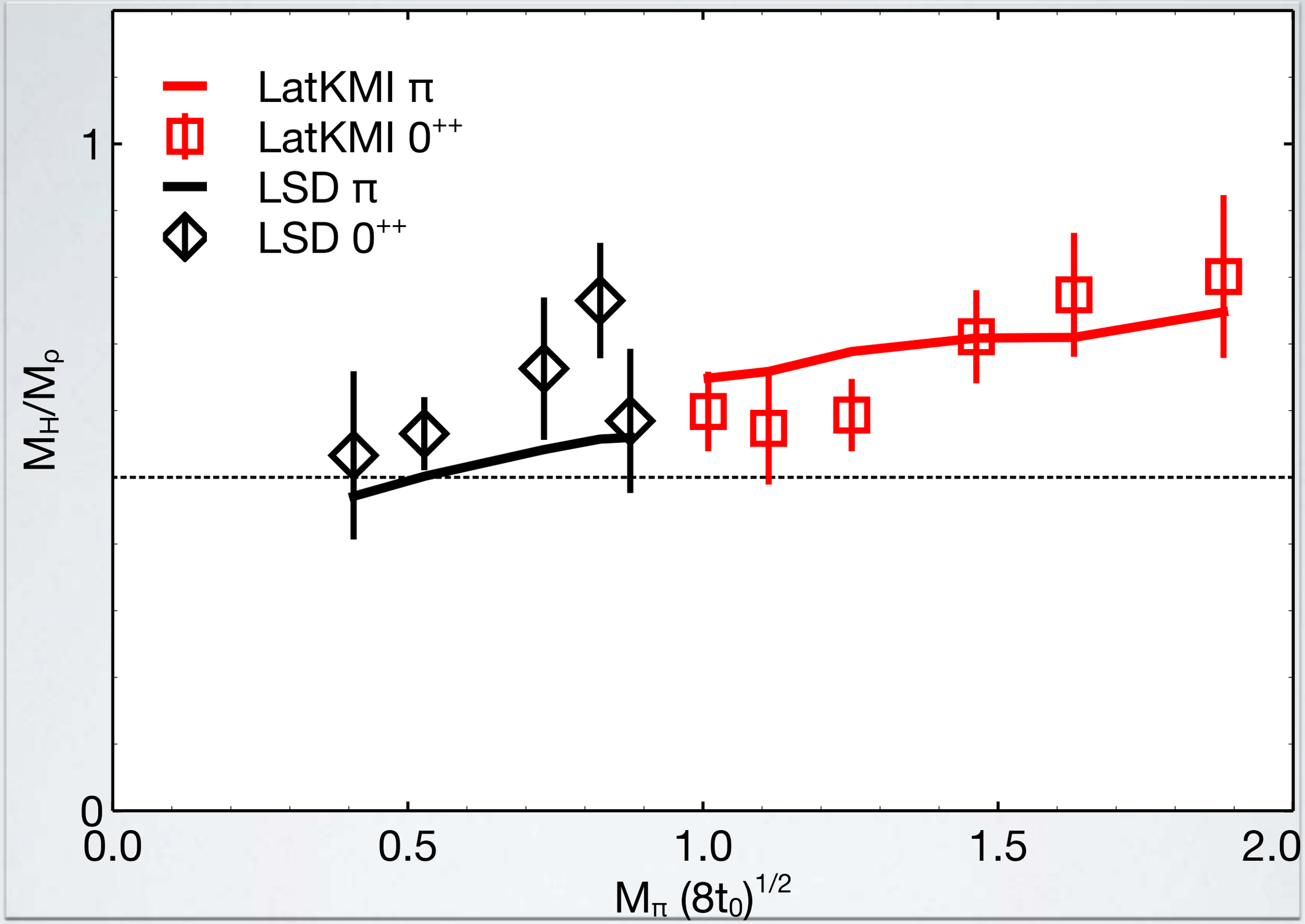

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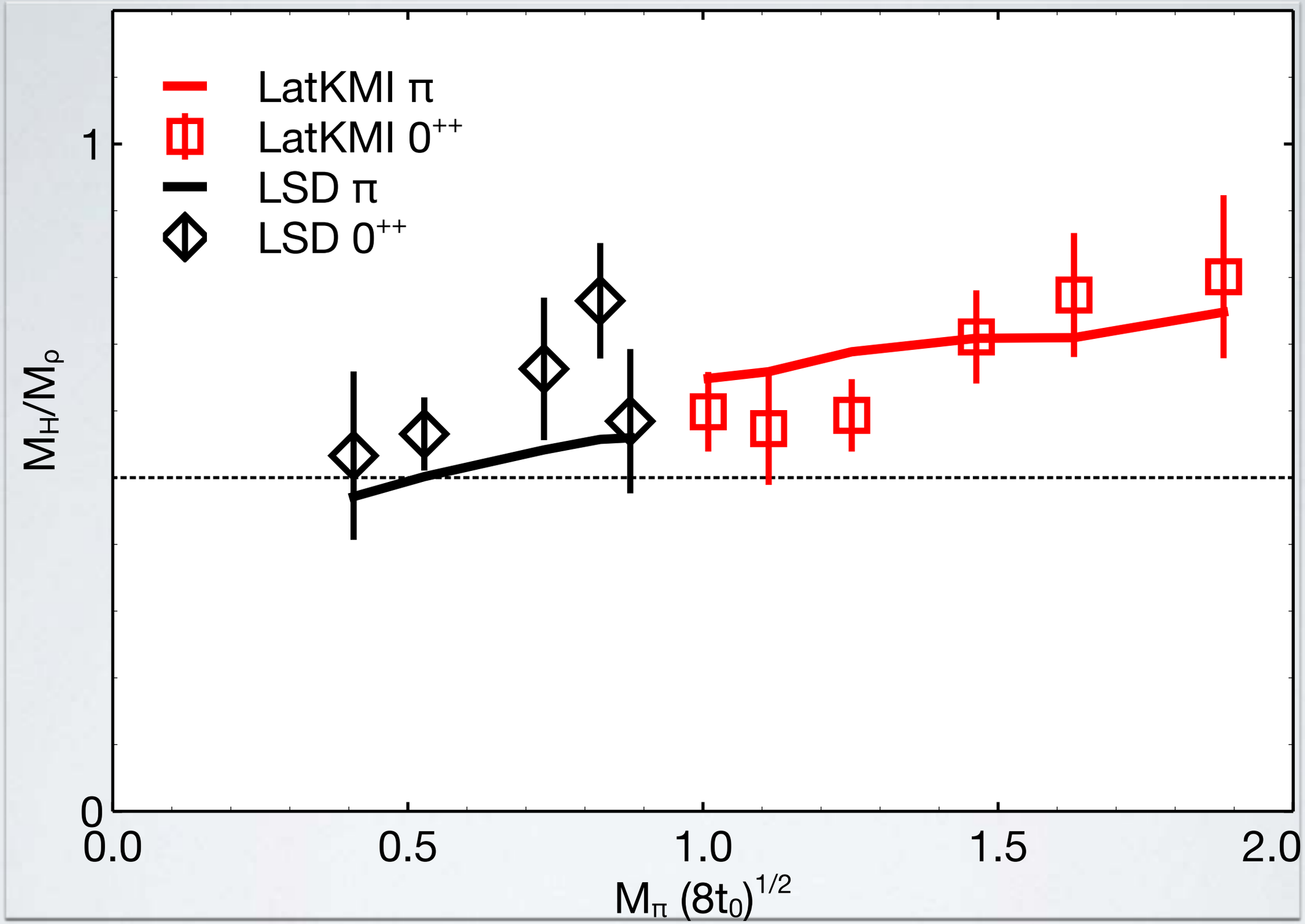

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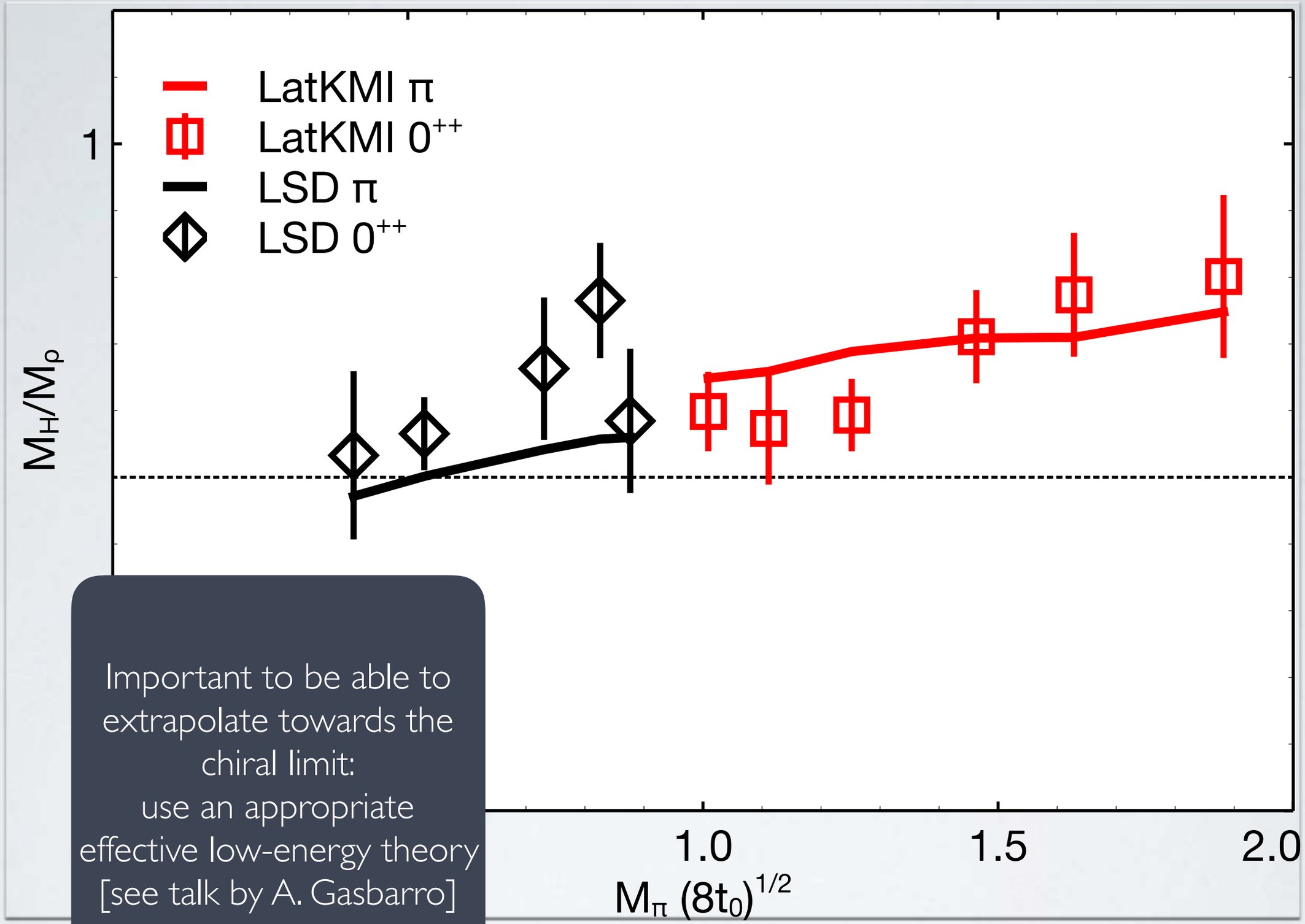

Important to be able to extrapolate towards the chiral limit:
use an appropriate effective low-energy theory
[see talk by A. Gasbarro]

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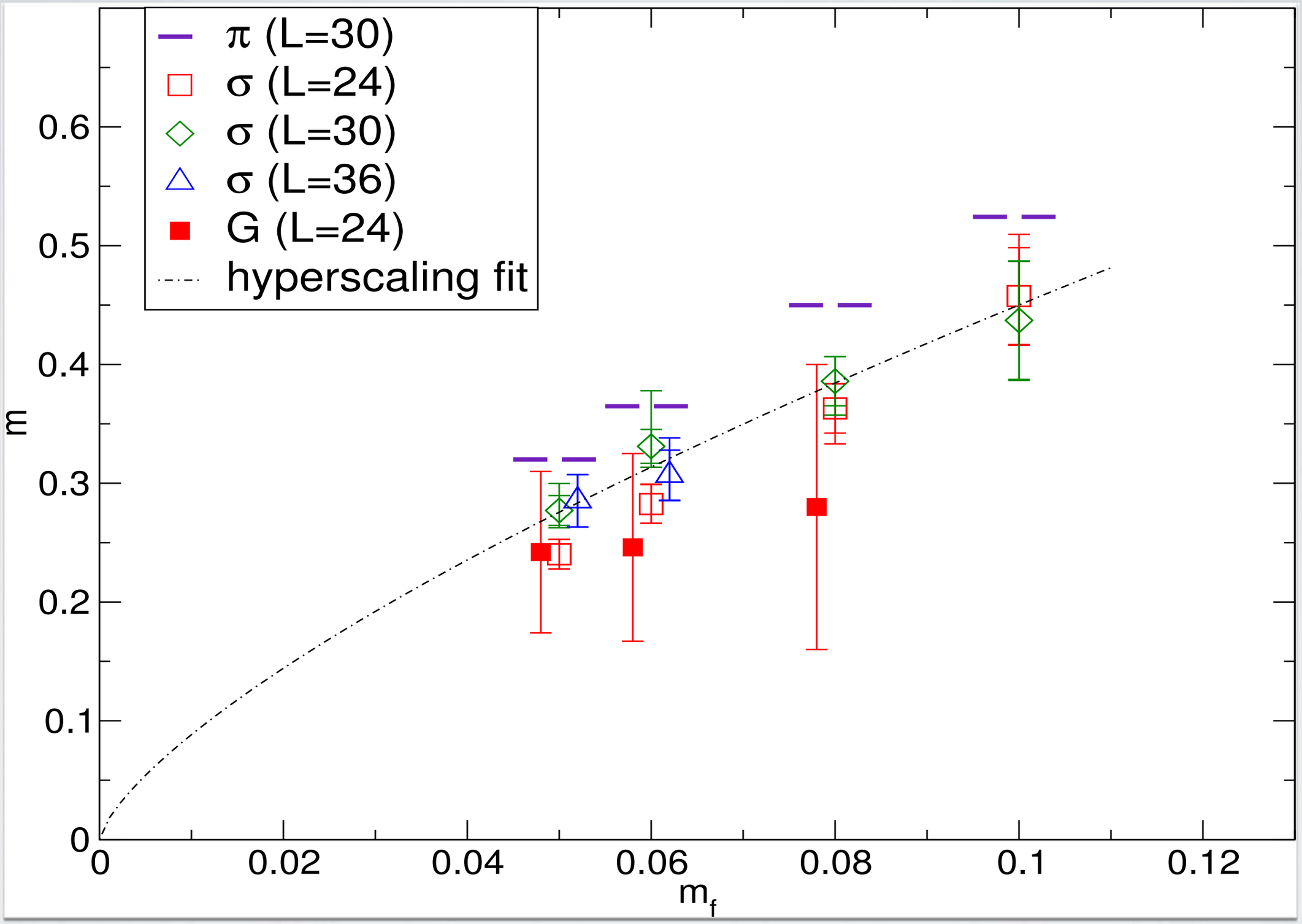

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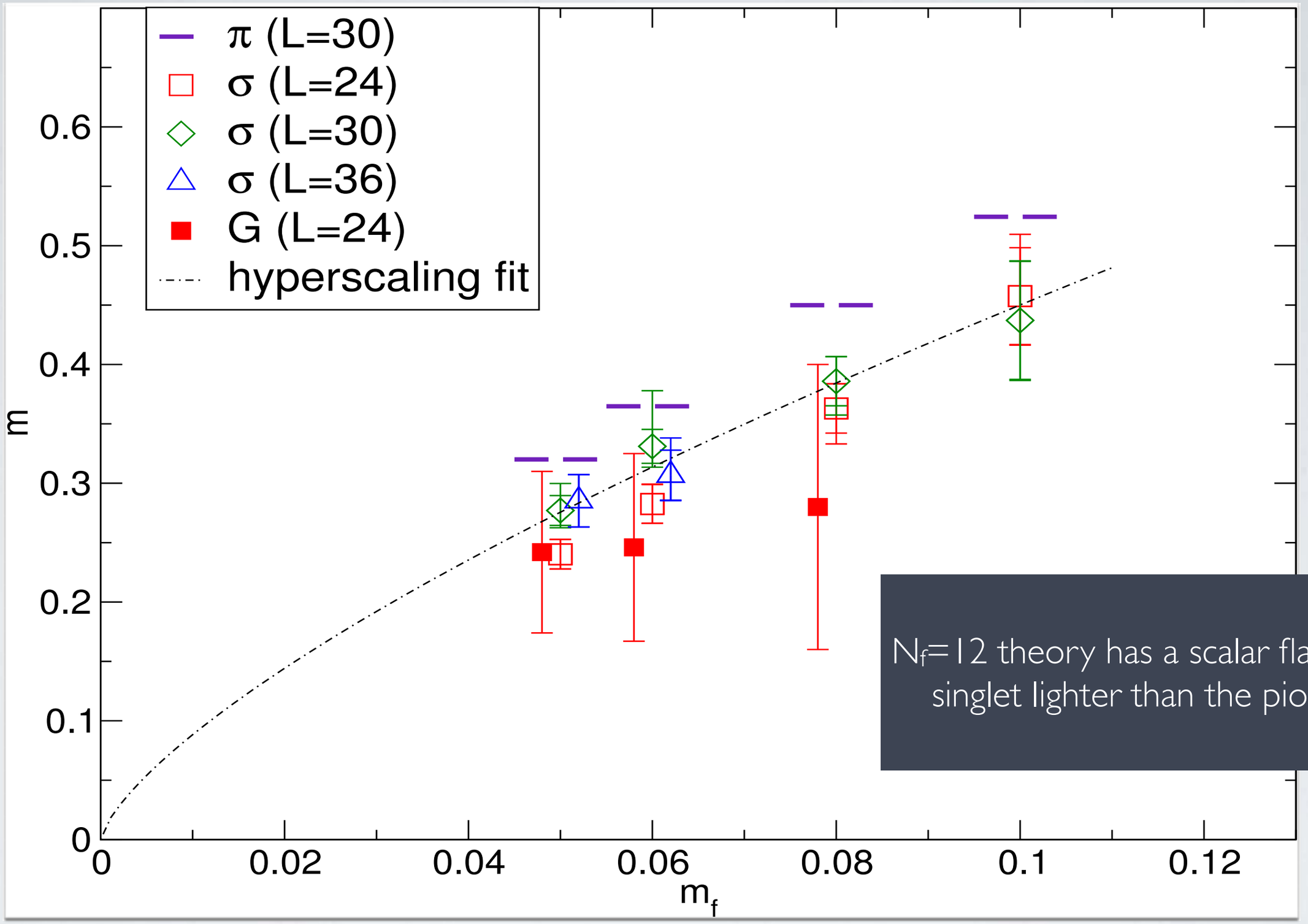

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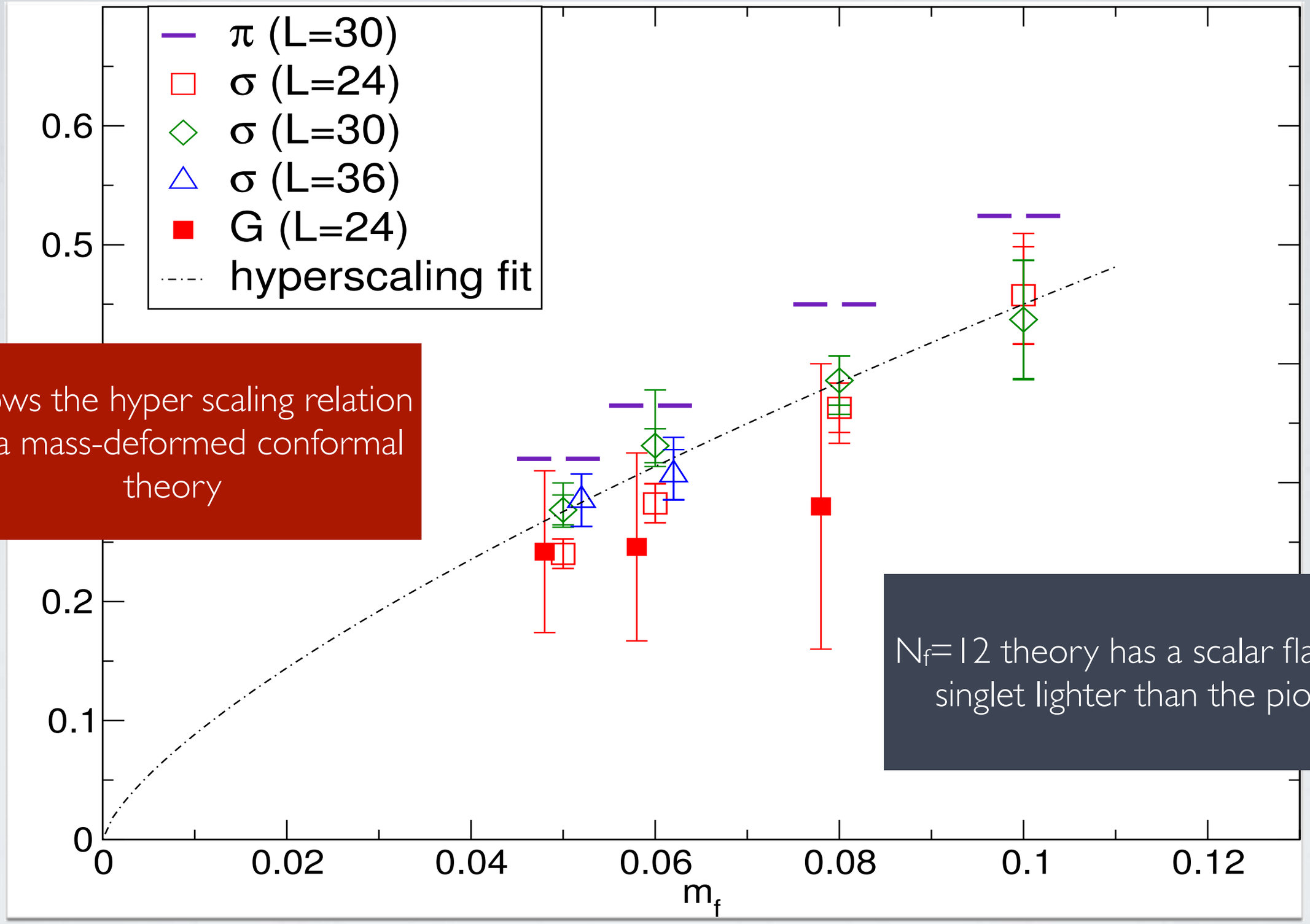

Follows the hyper scaling relation for a mass-deformed conformal theory

N_f=12 theory has a scalar flavor-singlet lighter than the pion

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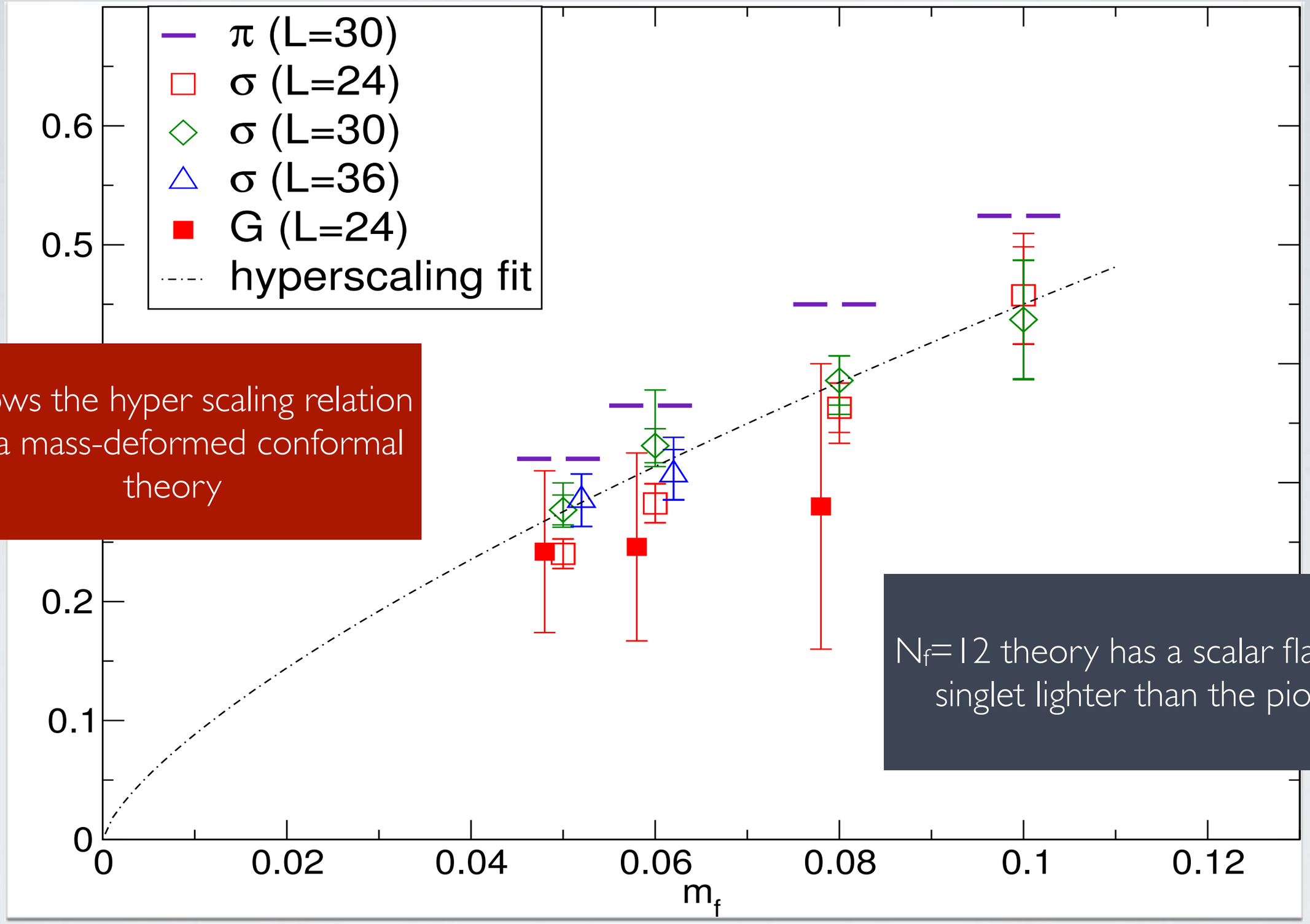

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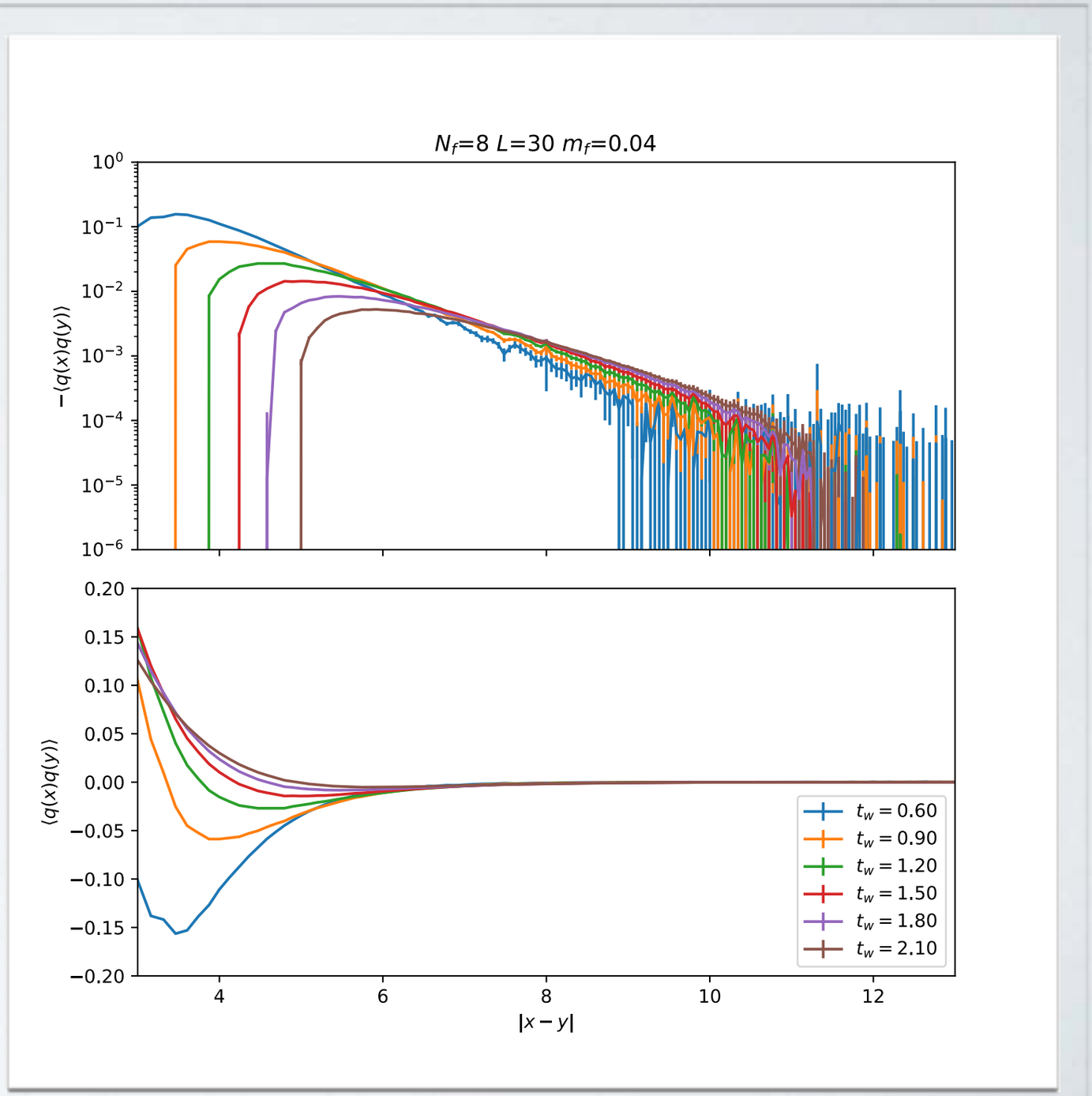
METHODS FOR THE 0^{-+}

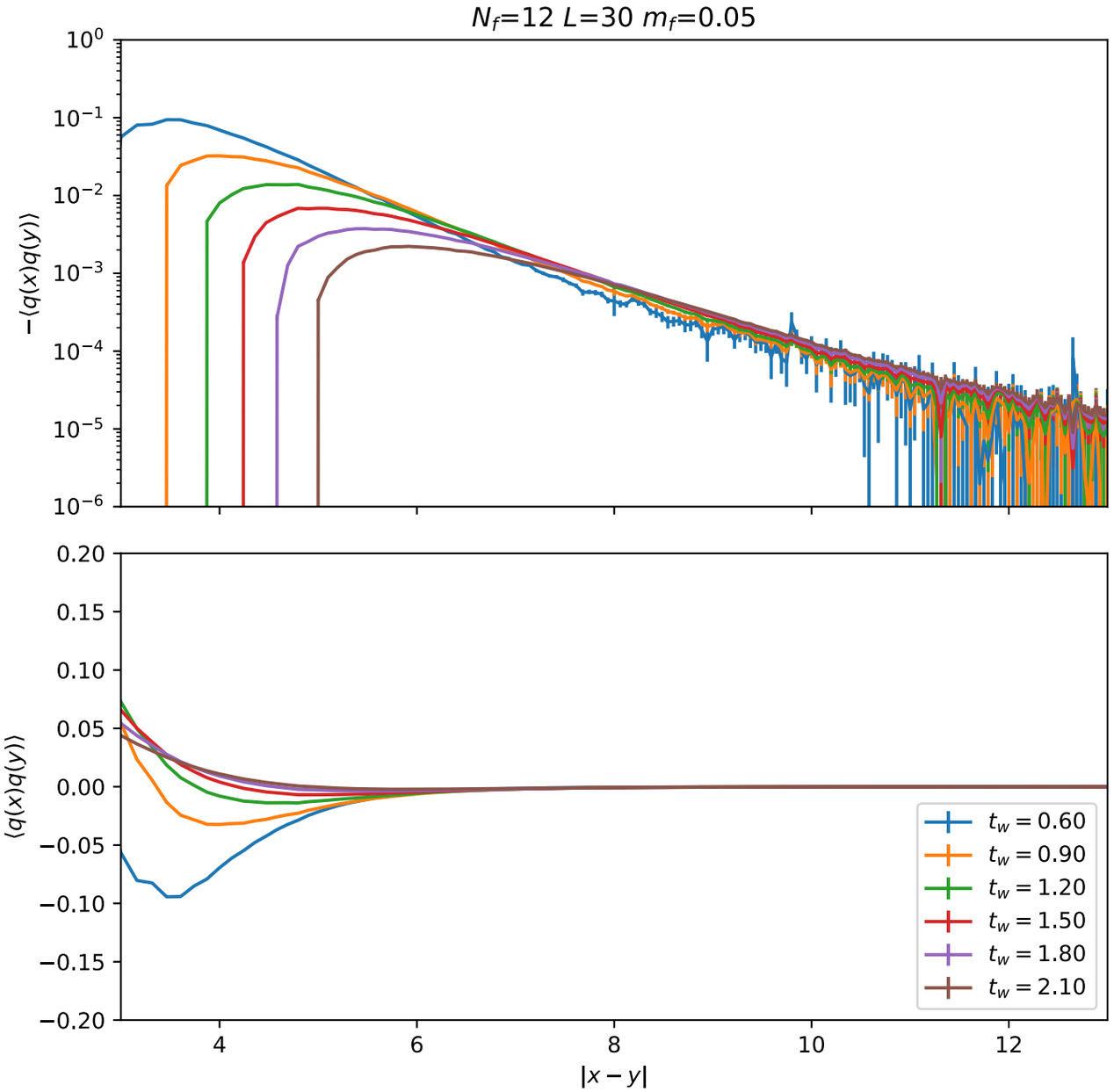
- Use a gluonic operator with 0^{-+} quantum numbers: topological charge density

- Use Wilson flow smearing as a technique to ameliorate the signal-to-noise problem

- Demonstrated in previous studies:
  SU(3) YM [arxiv:1409.6459]
  QCD [arxiv:1509.00944]

- Main difficulty is estimating the systematics due to smearing and excited states



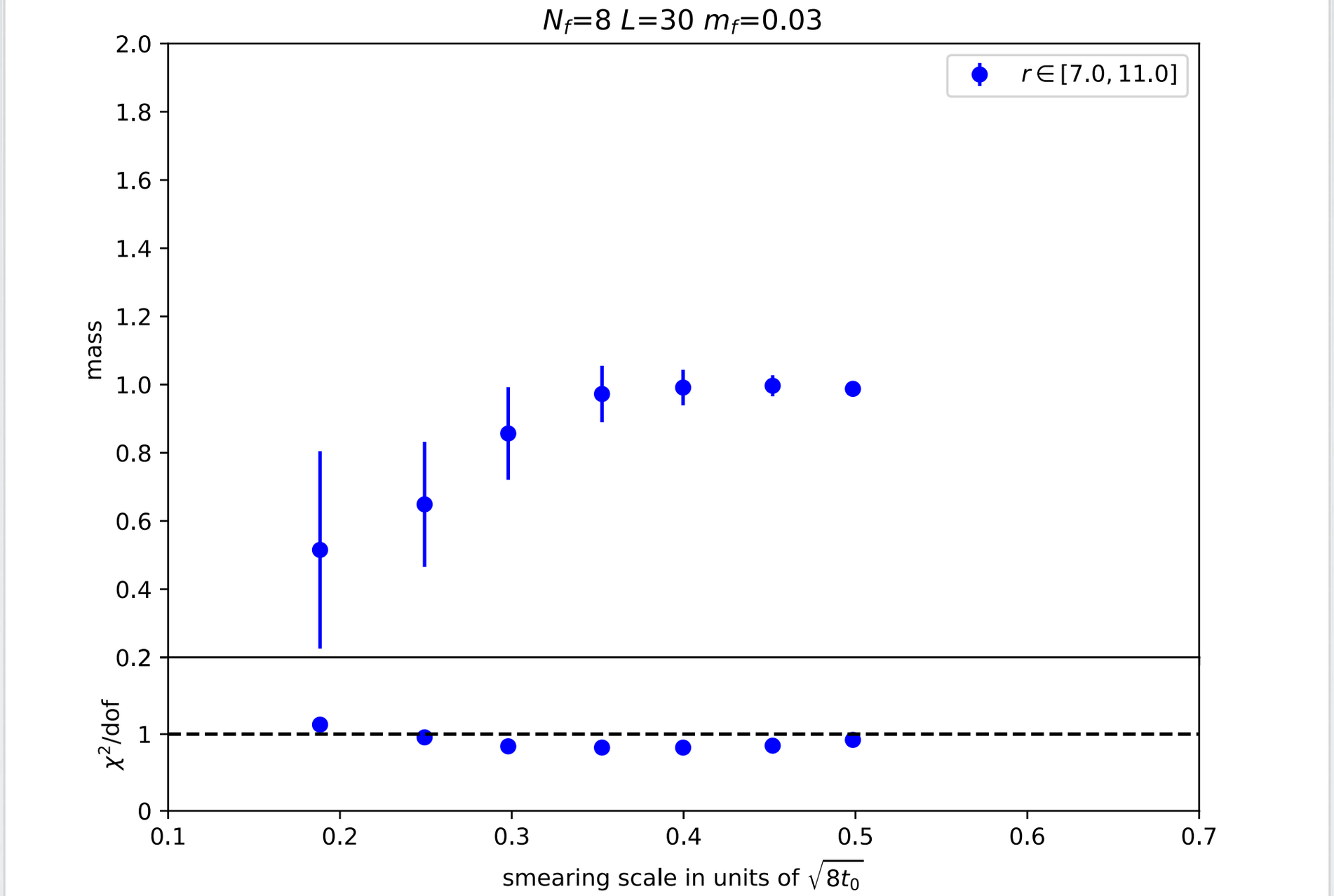


Fit correlator in a window of r=|x-y| at each Wilson flow time

$$C(|x-y|) = \frac{A}{|x-y|} K_1(m_{\eta'}|x-y|) \longrightarrow C(r) \approx \frac{A}{r^{1.5}}\left(1+\frac{3}{8r}\right)e^{-m_{\eta'}r}$$

large r

Preliminary



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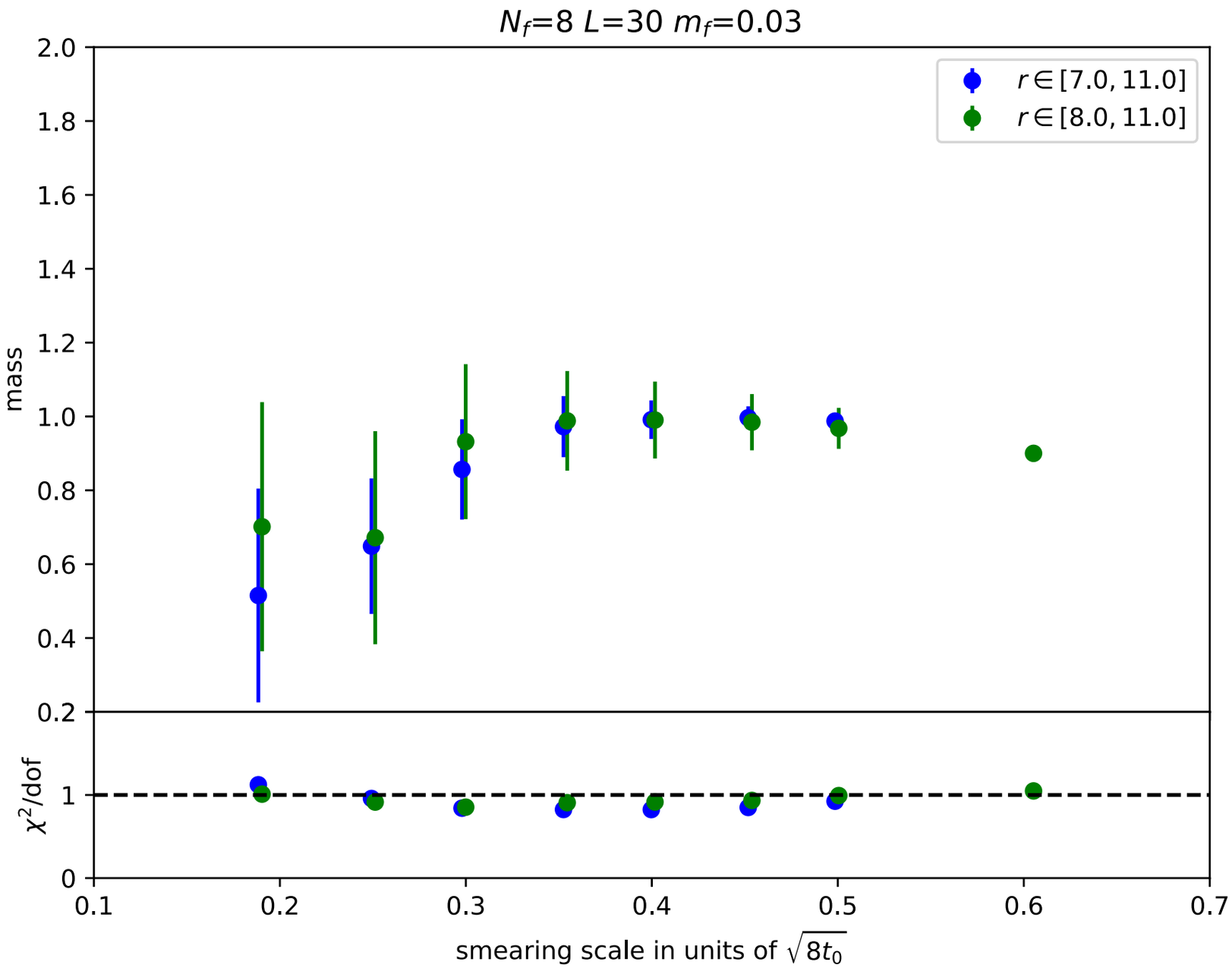

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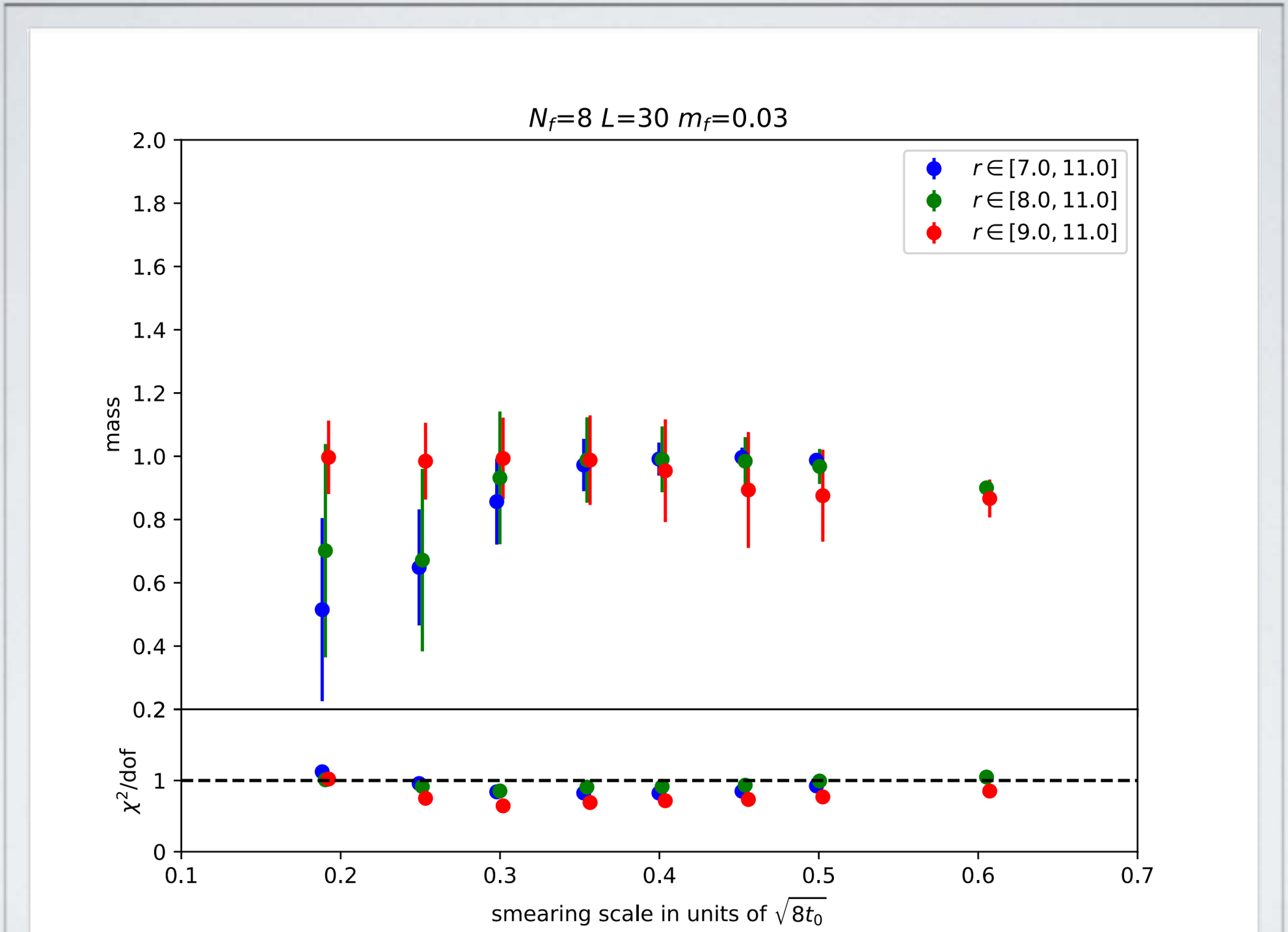

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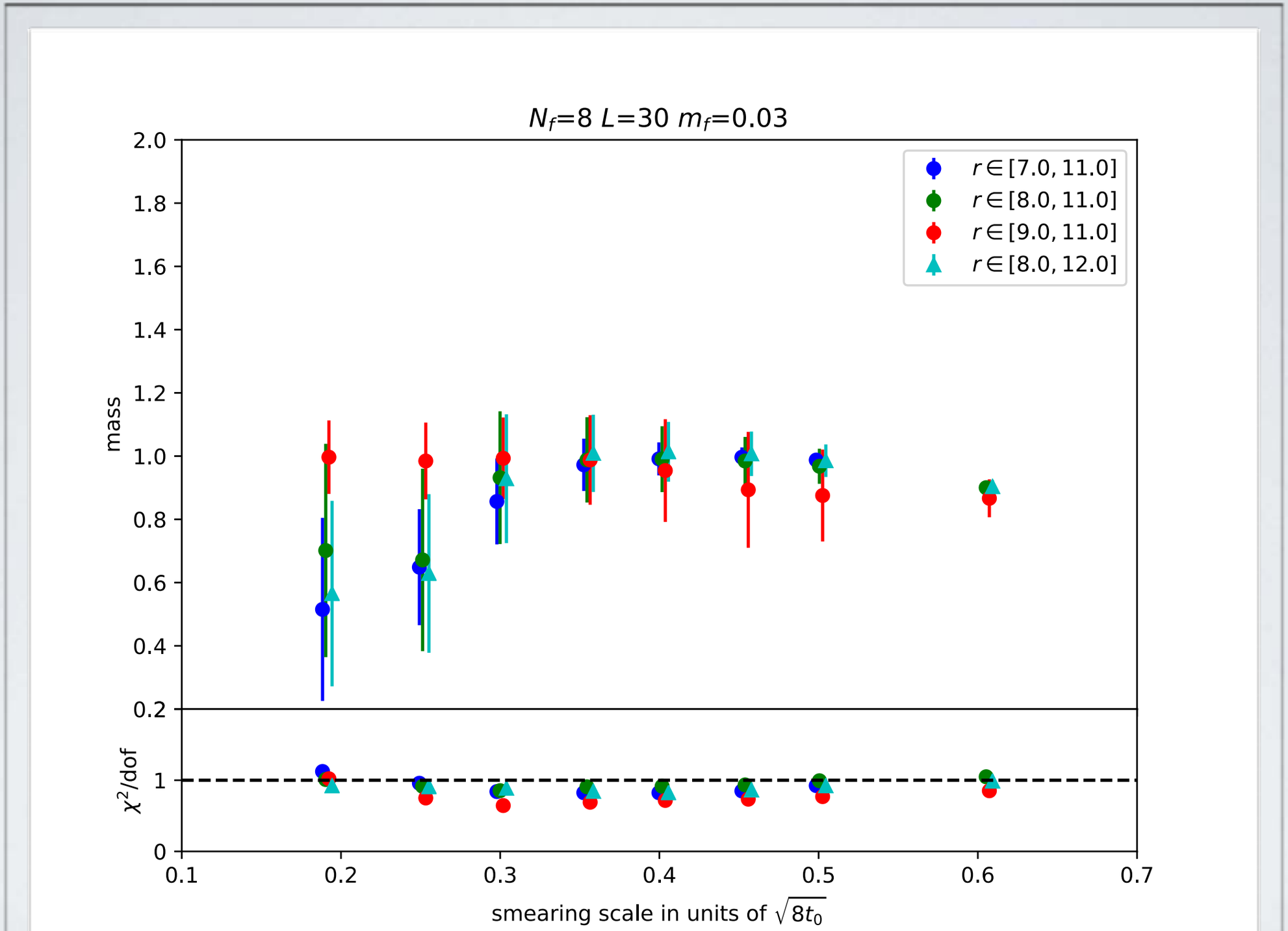

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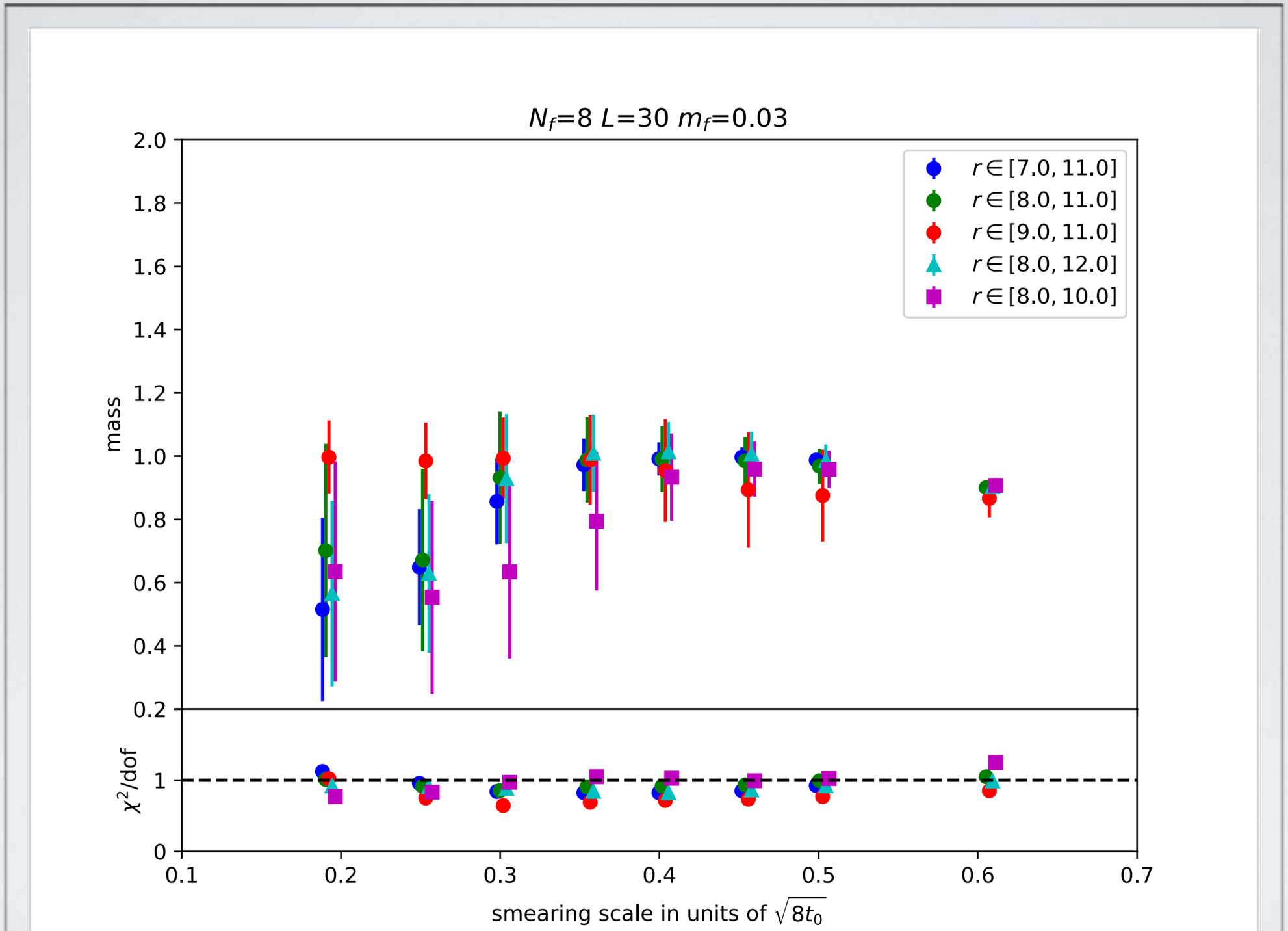

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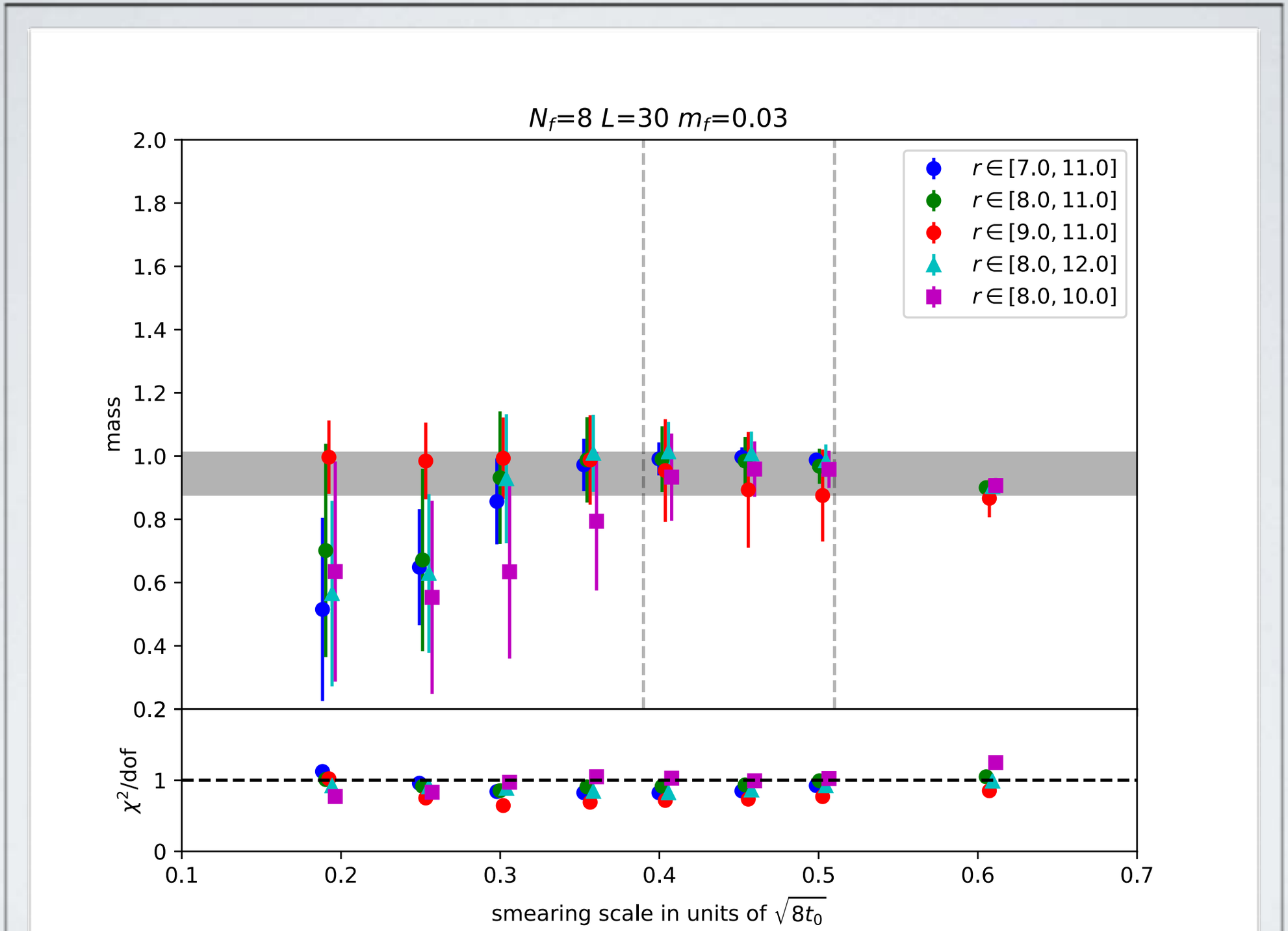

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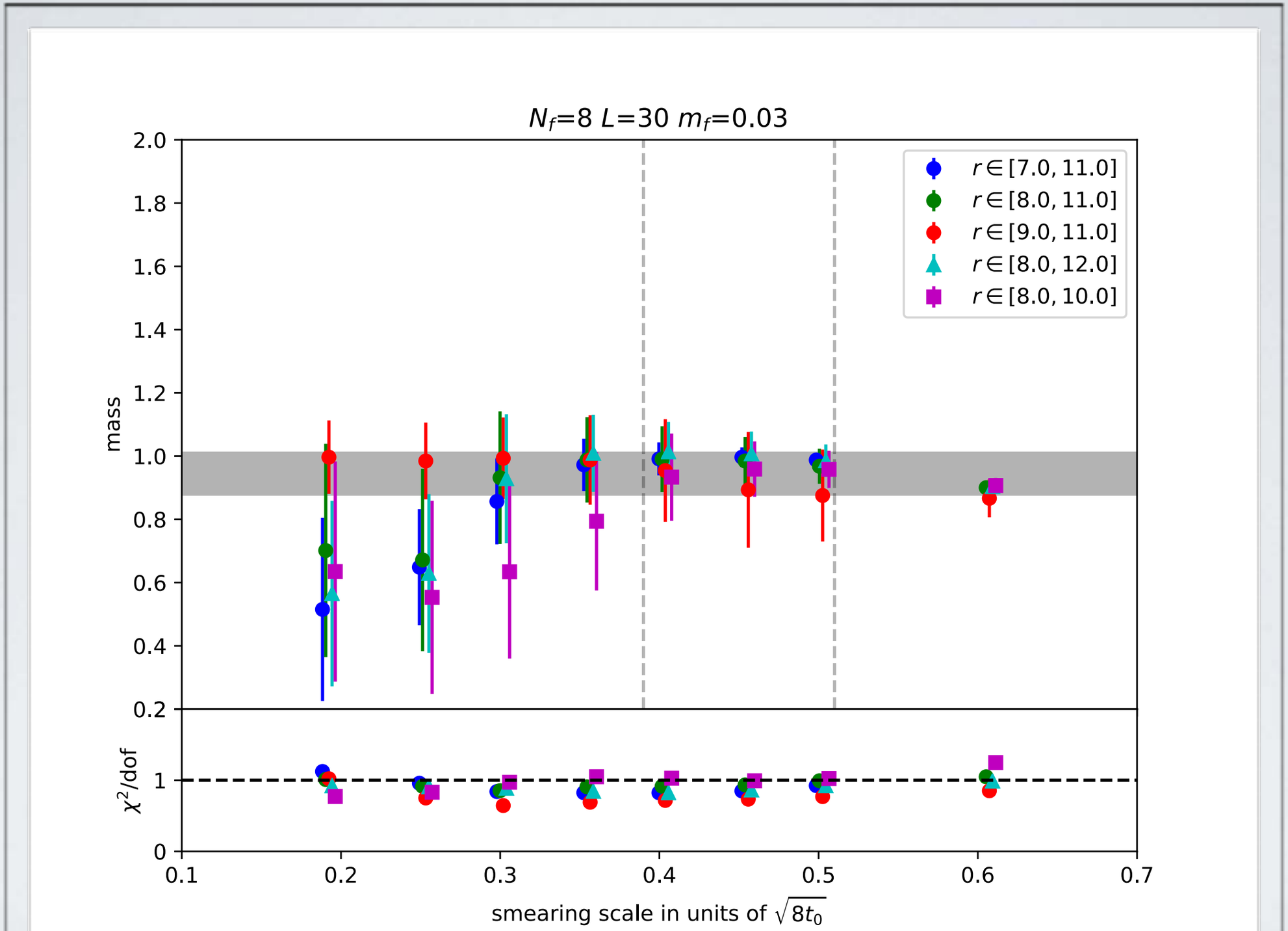
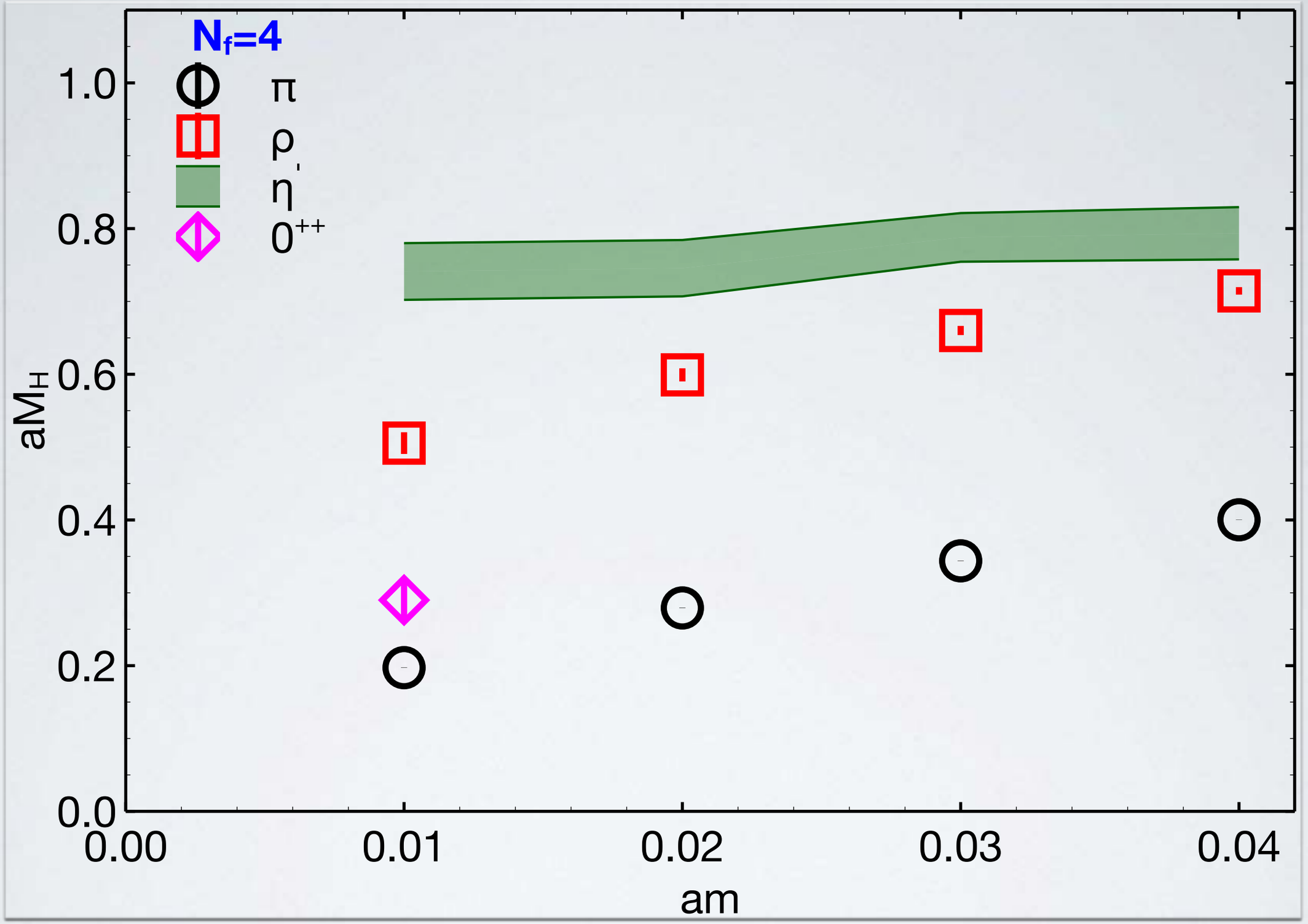


Error dominated by systematic uncertainty so far



Scalar flavor-singlet heavier than the pion
Pseudoscalar flavor-singlet near the vector

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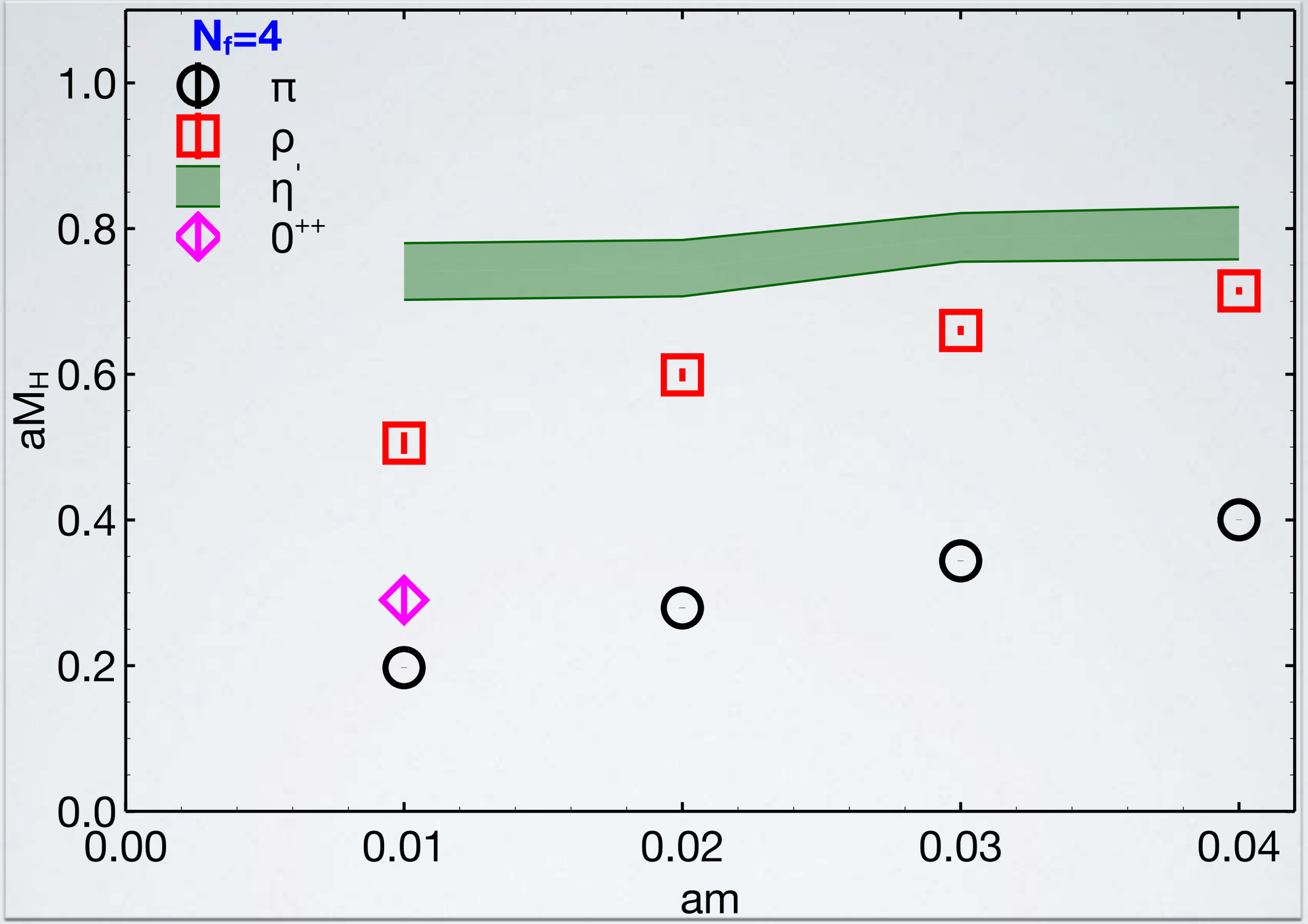

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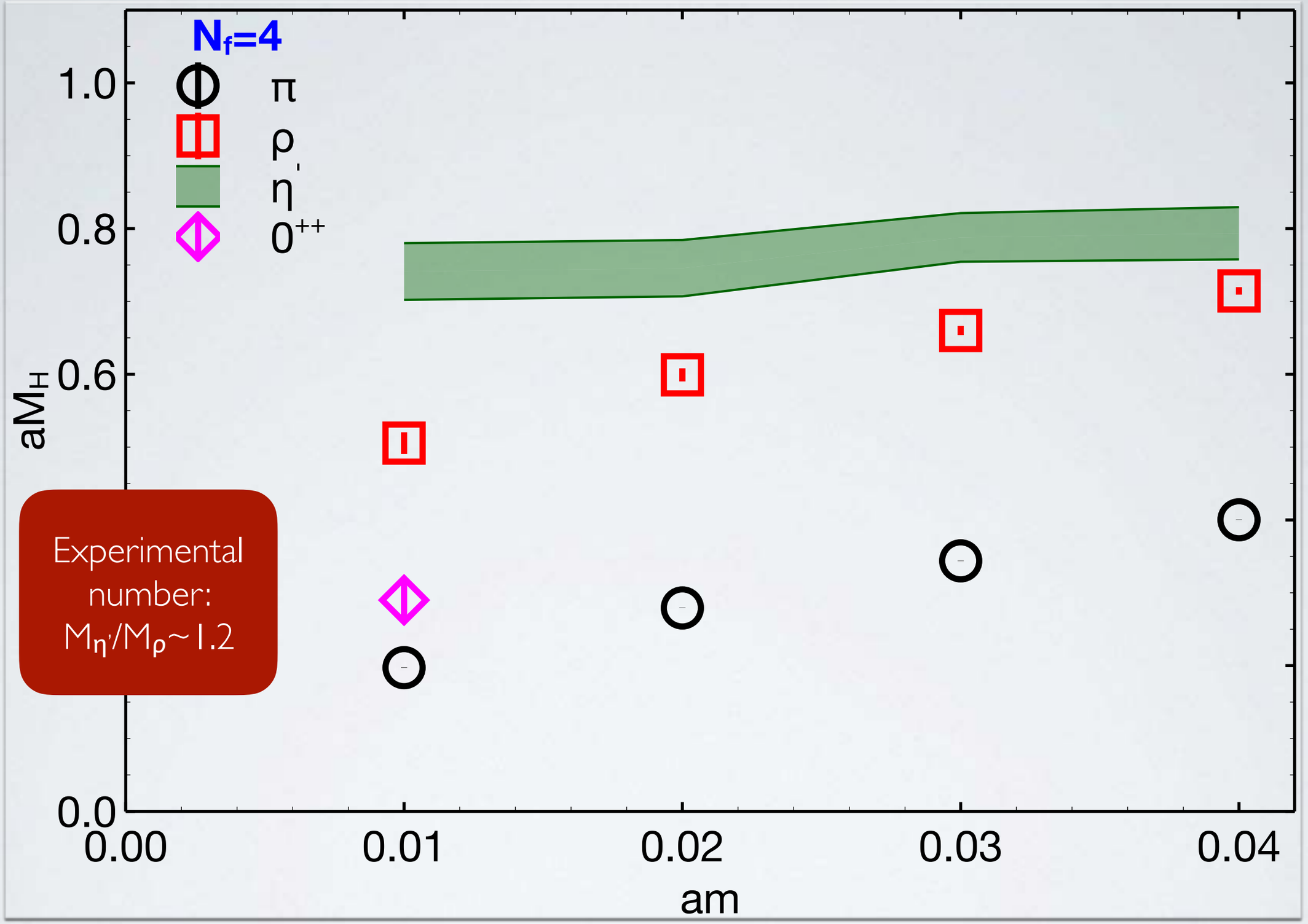

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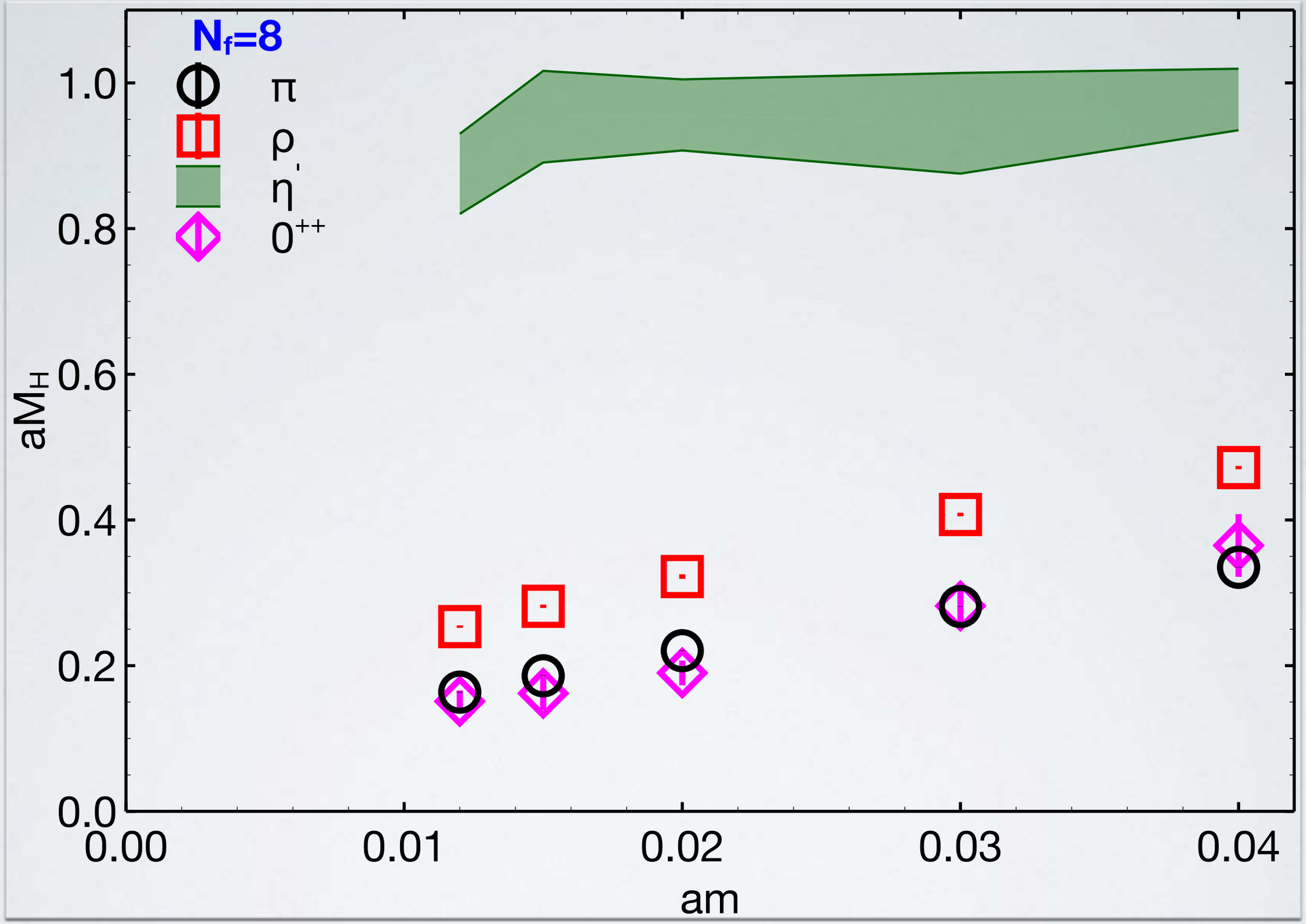

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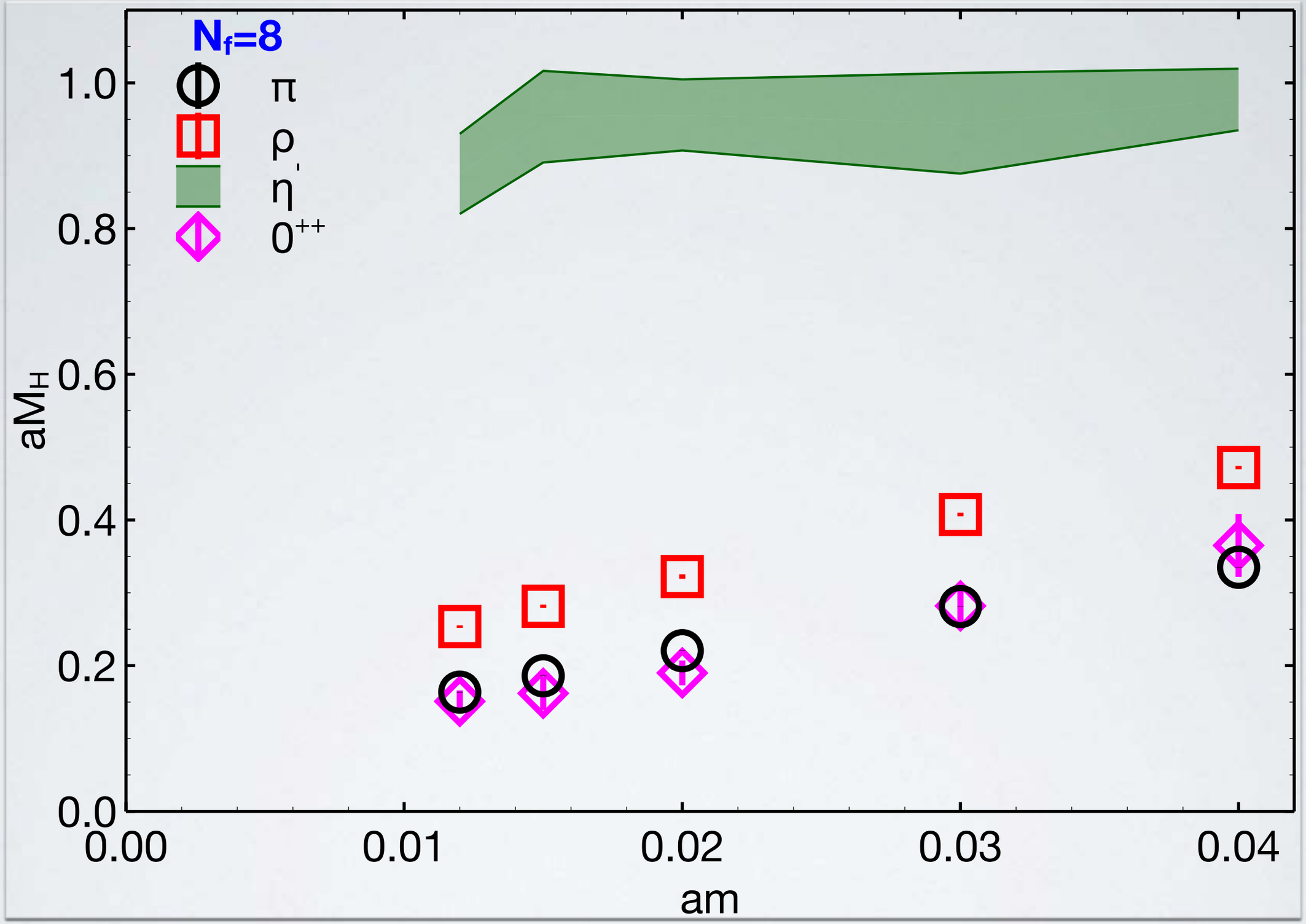

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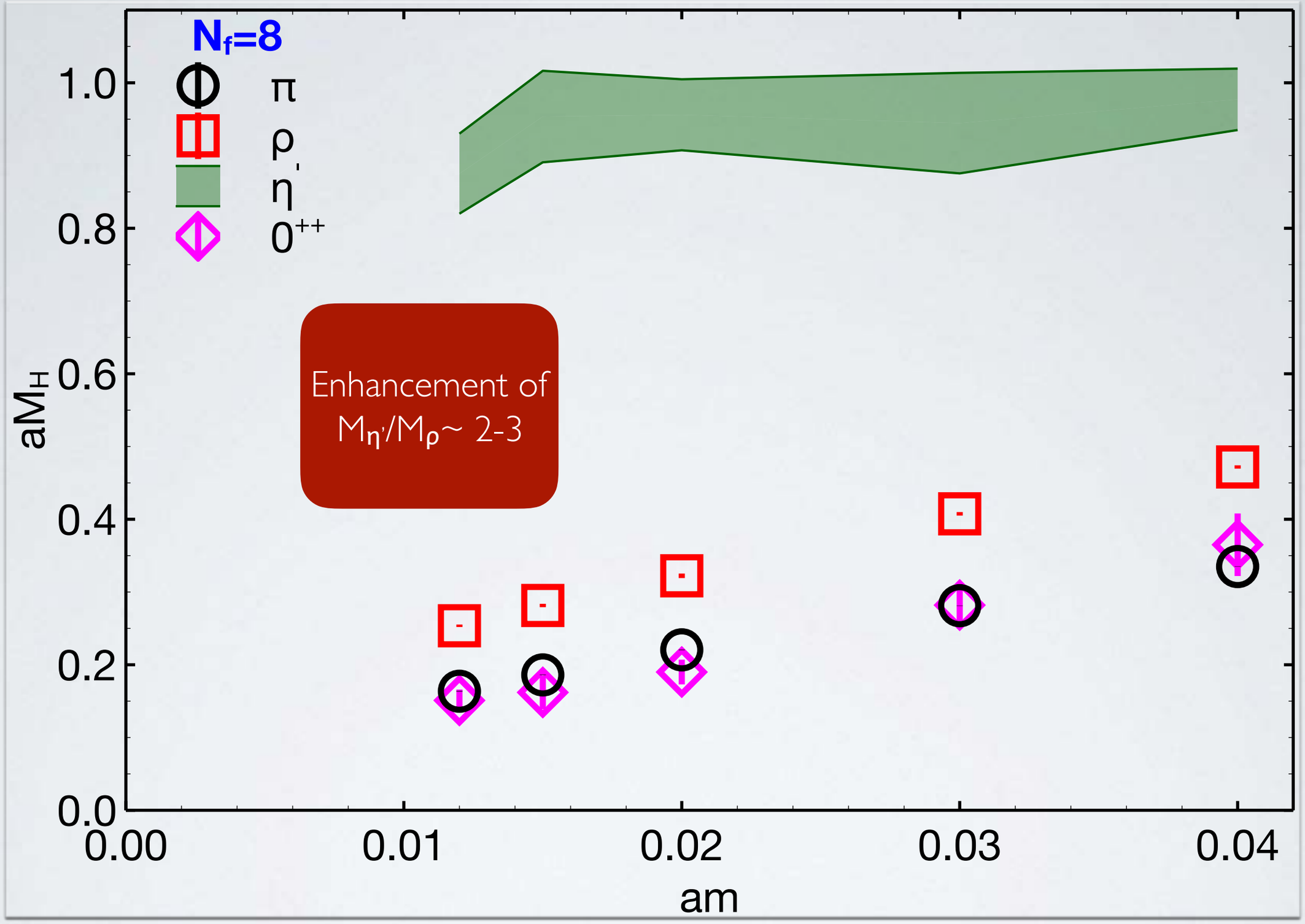

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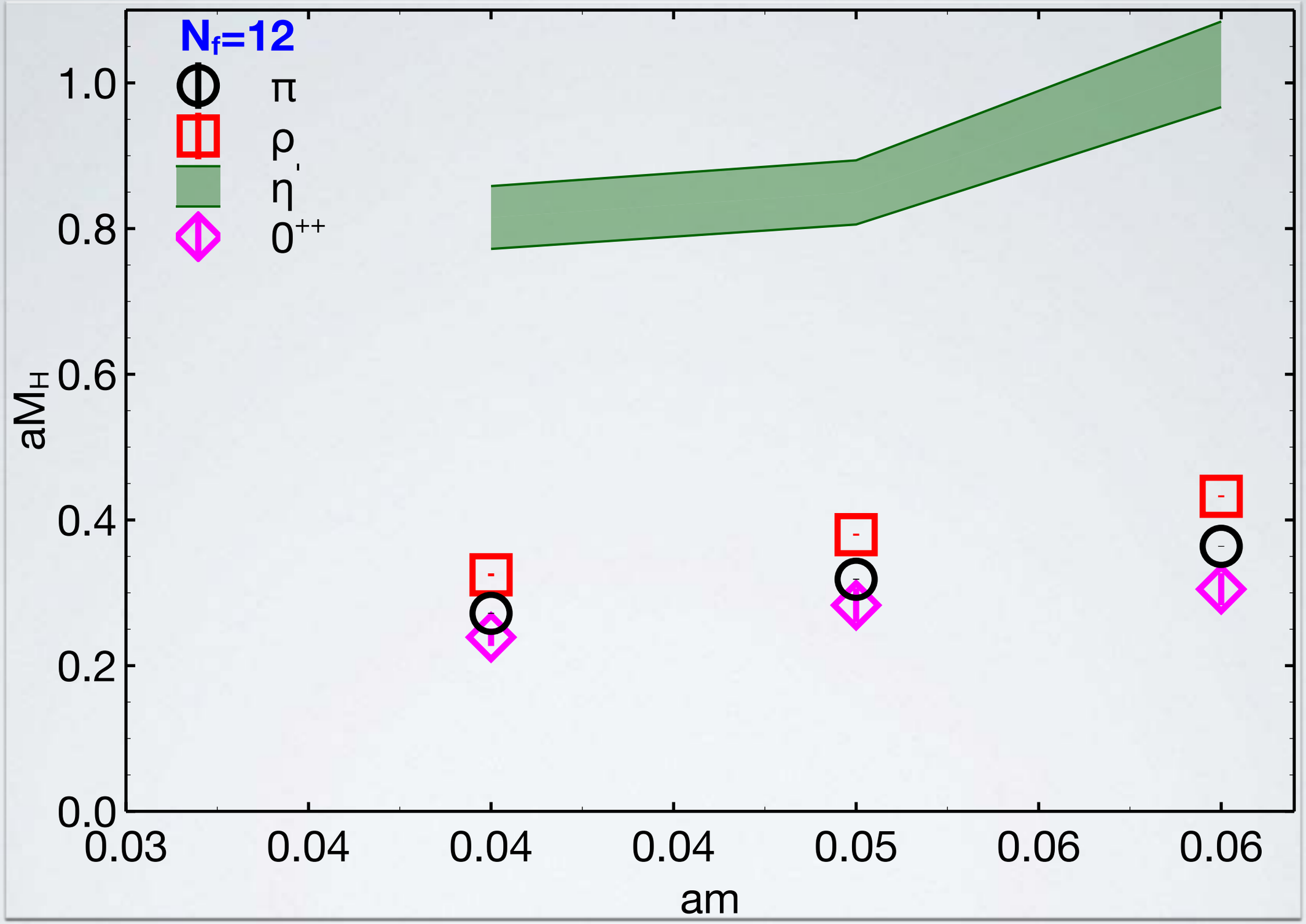

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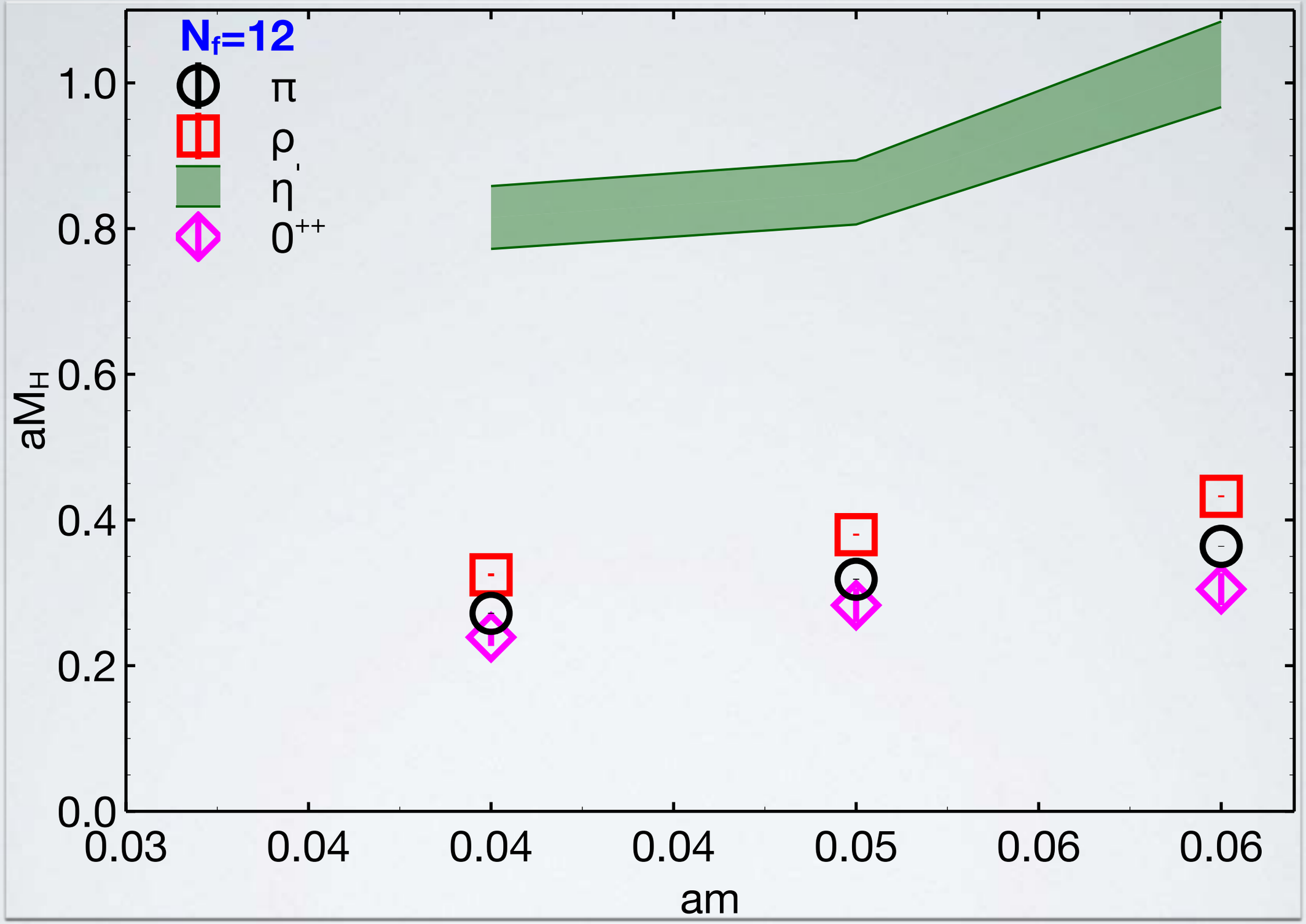

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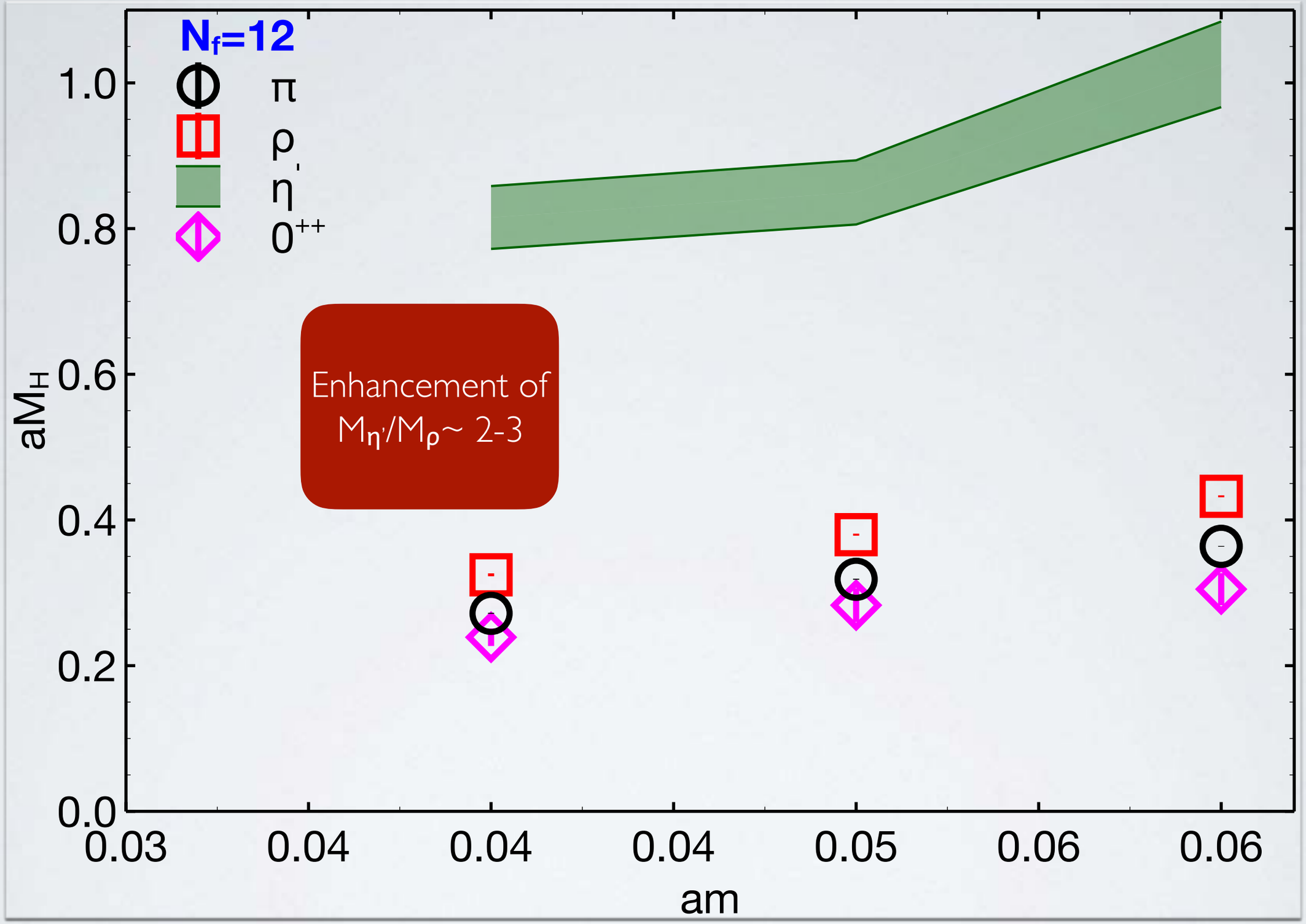

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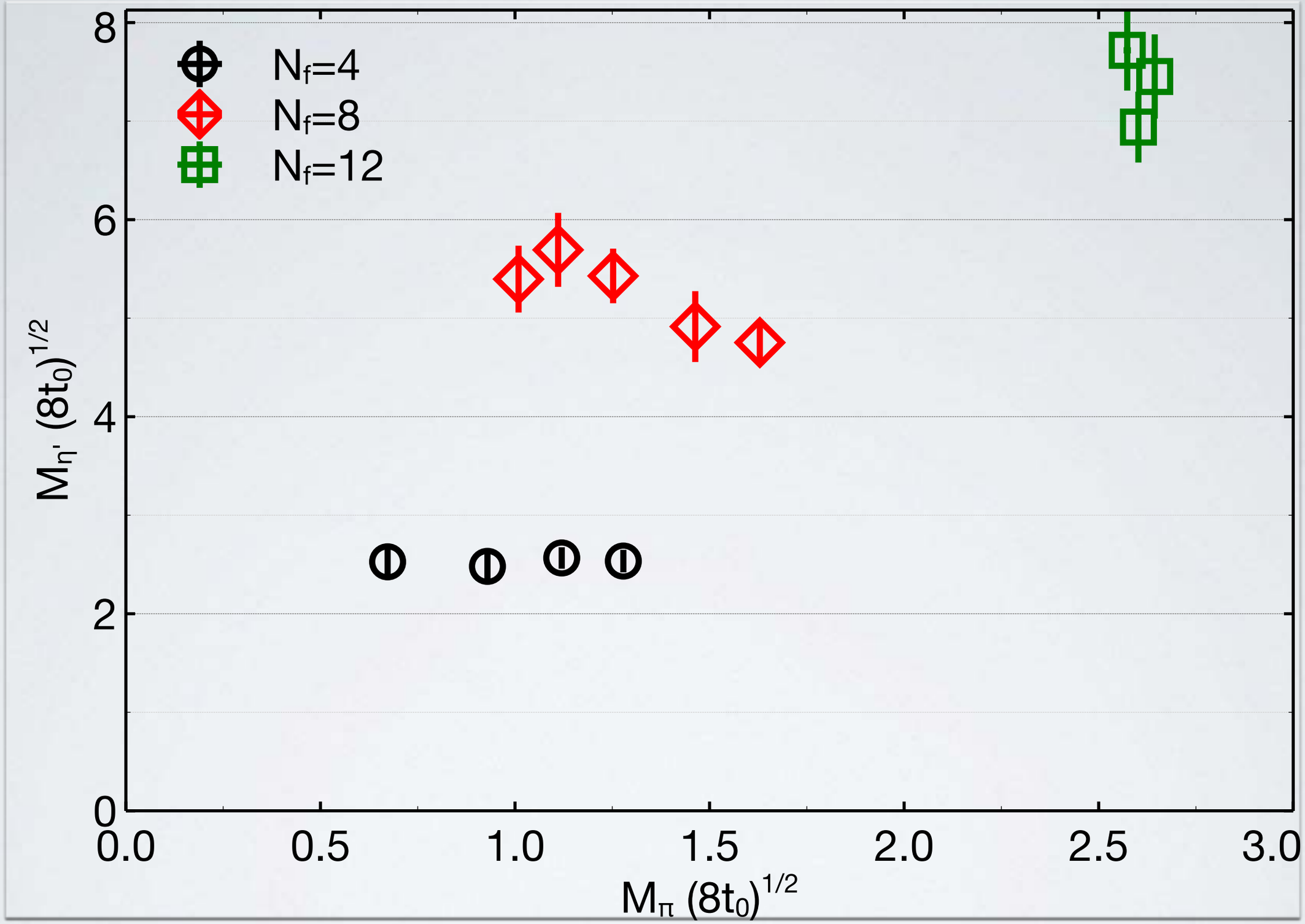
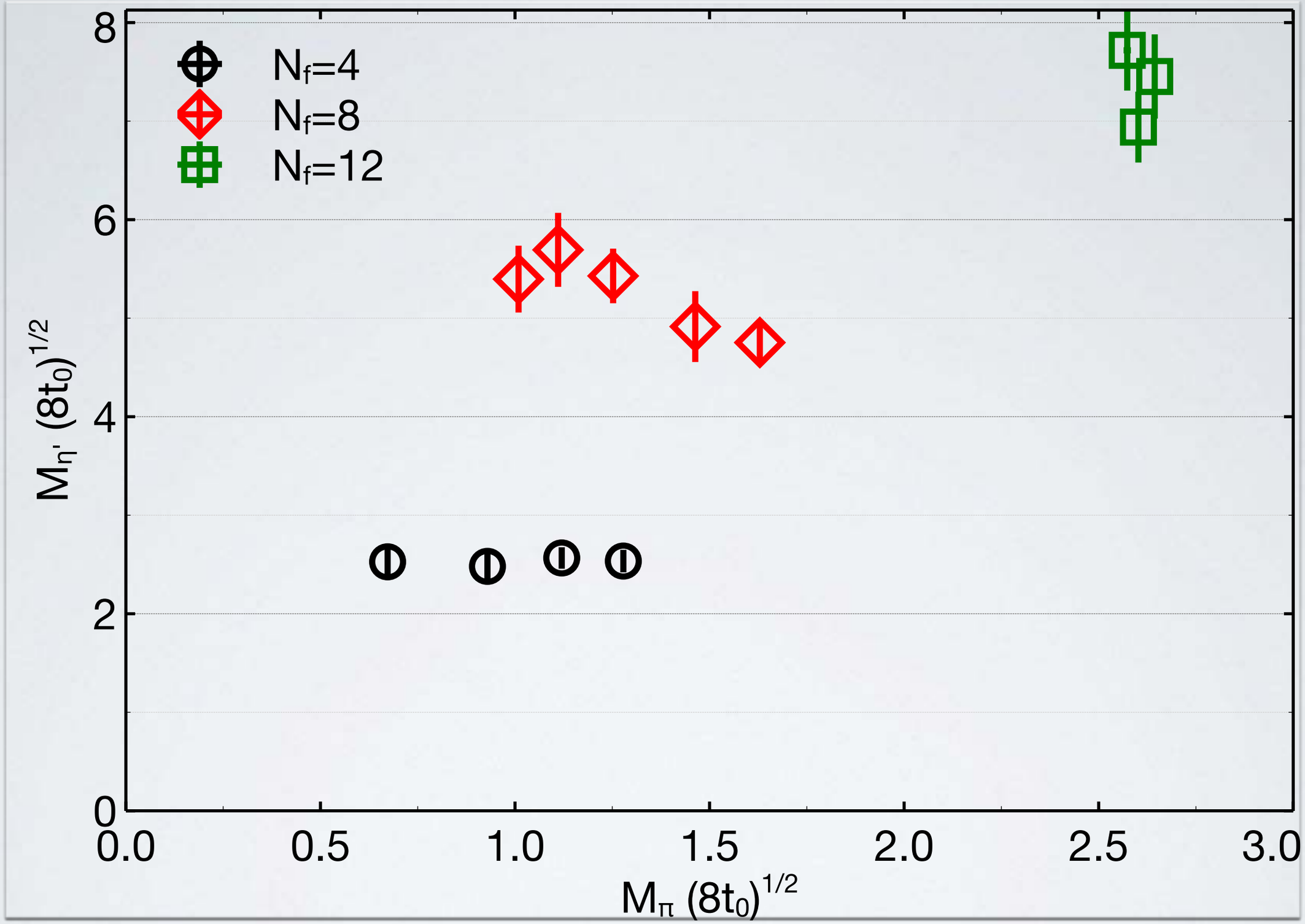


Pseudoscalar flavor-singlet becomes heavier with increasing number of flavors

Preliminary



Compare using a common reference scale

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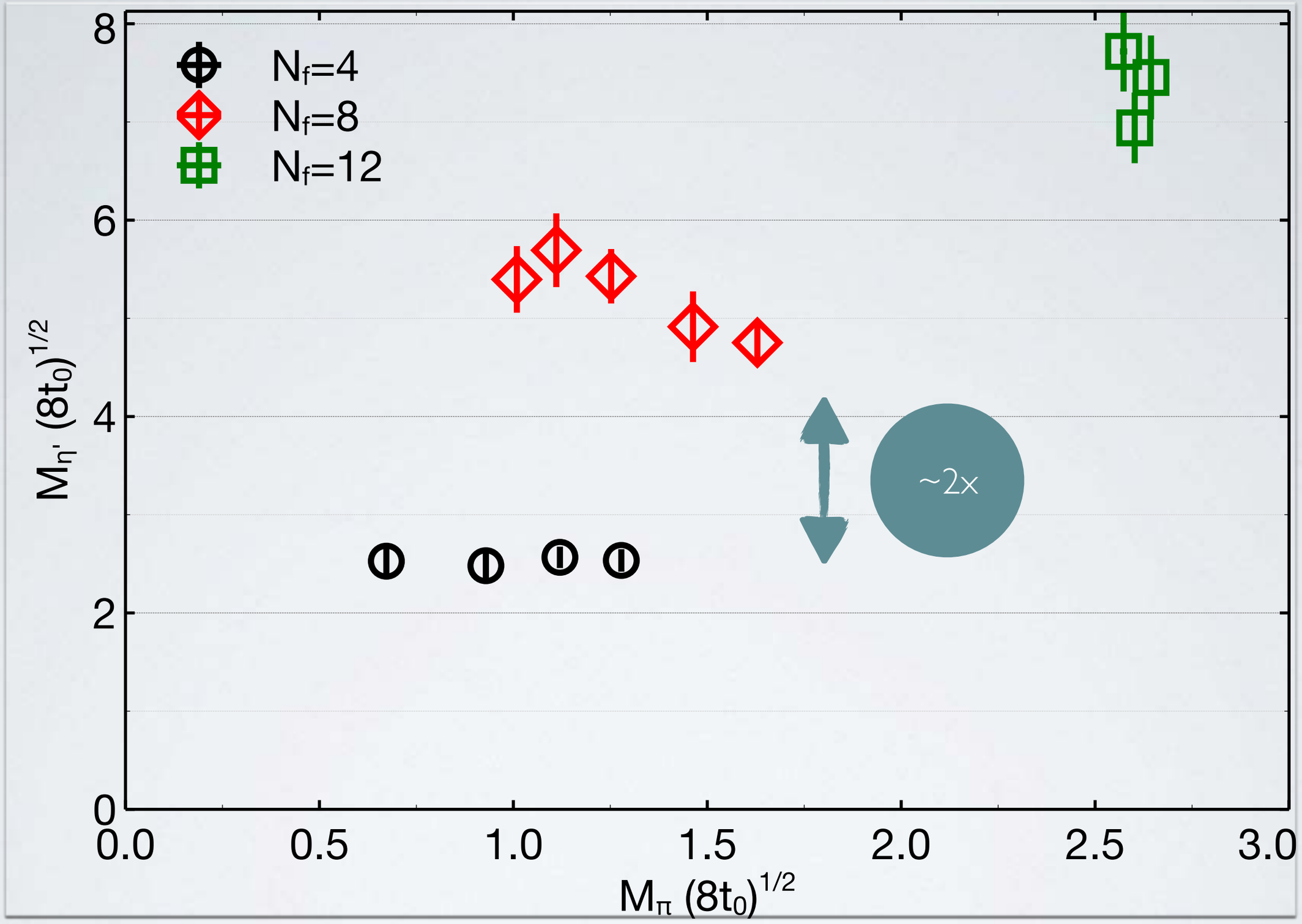

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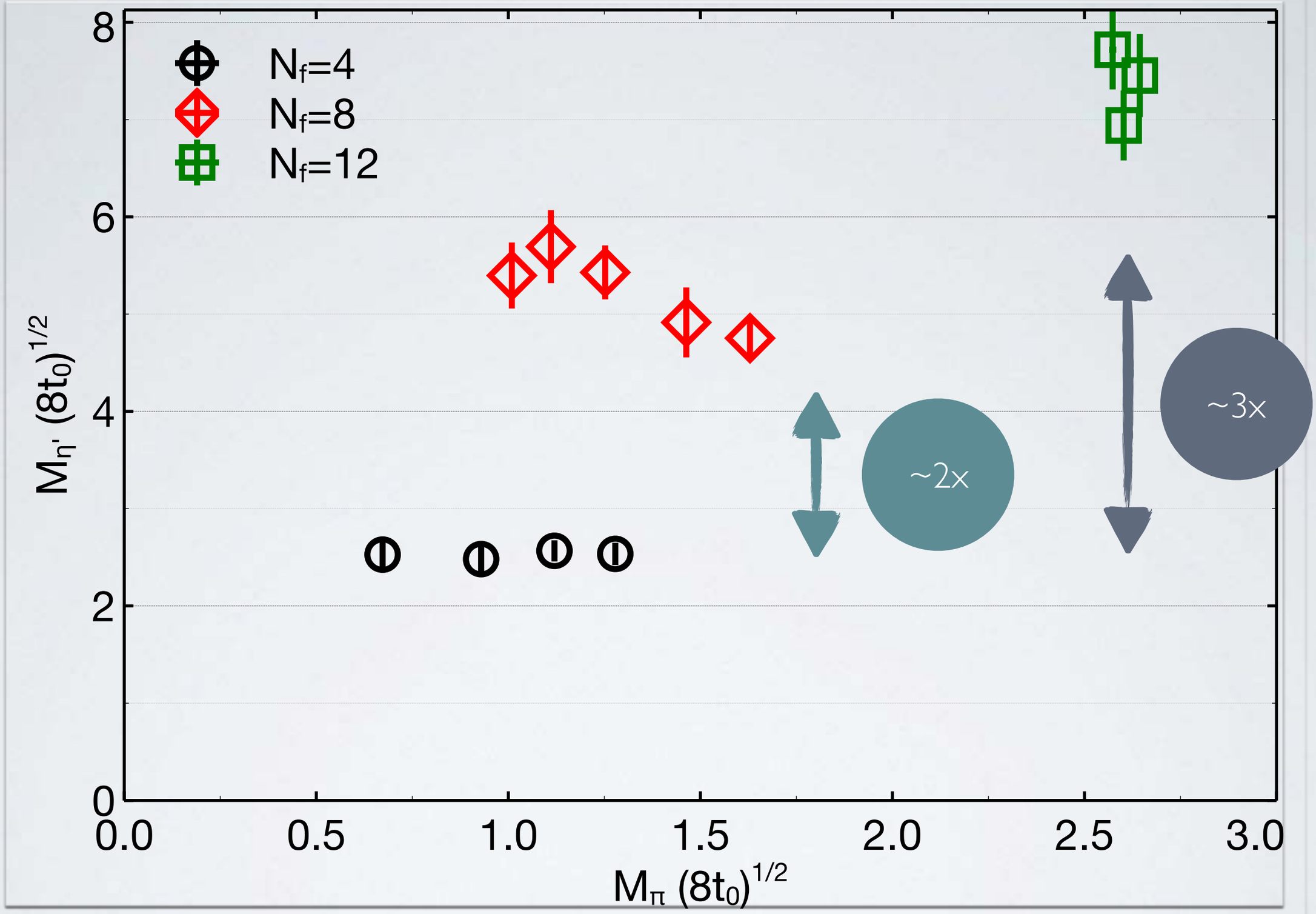

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SUMMARY

- Lattice results for the SU(3) N_f=4, 8 and 12 theories can be contrasted with each other to learn more about the dynamics near the conformal window

- There is a light scalar flavor-singlet state and a heavy pseudoscalar flavor-singlet state, the dynamics is different form QCD

- The pseudoscalar flavor-singlet is showing enhancement with increasing number of flavors, while the scalar flavor-singlet is suppressed with respect to the pion

- Comment: lattice results seem to align with expectations from ladder-SD analyses [arxiv:1508.07688]: a flavor-singlet scalar in a near conformal theory is light similarly to a flavor-singlet pseudoscalar in the Witten-Veneziano limit, but a flavor-singlet pseudoscalar is heavier in the "anti"-Witten-Veneziano limit (large N_f/N_c)

Caveat: infinite volume limit, continuum limit and chiral limit need to be worked on!

SUMMARY

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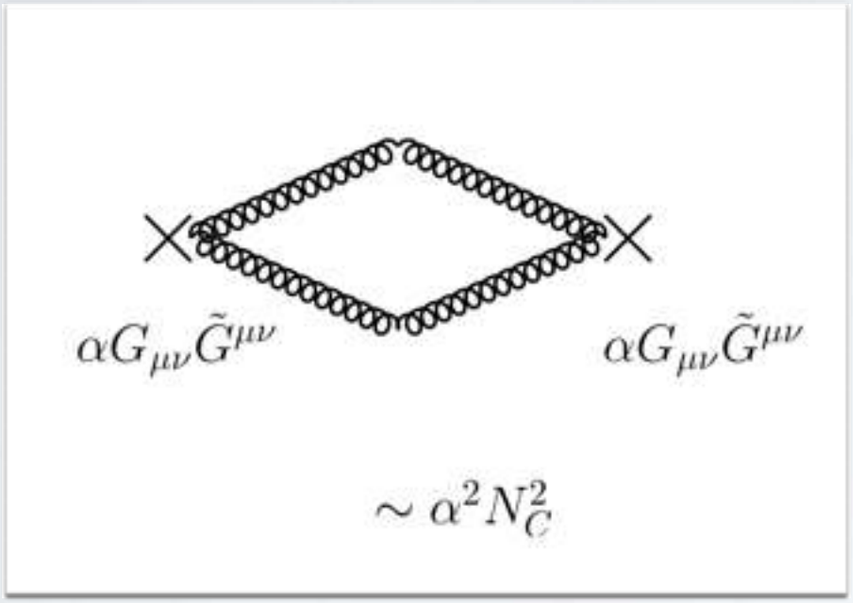
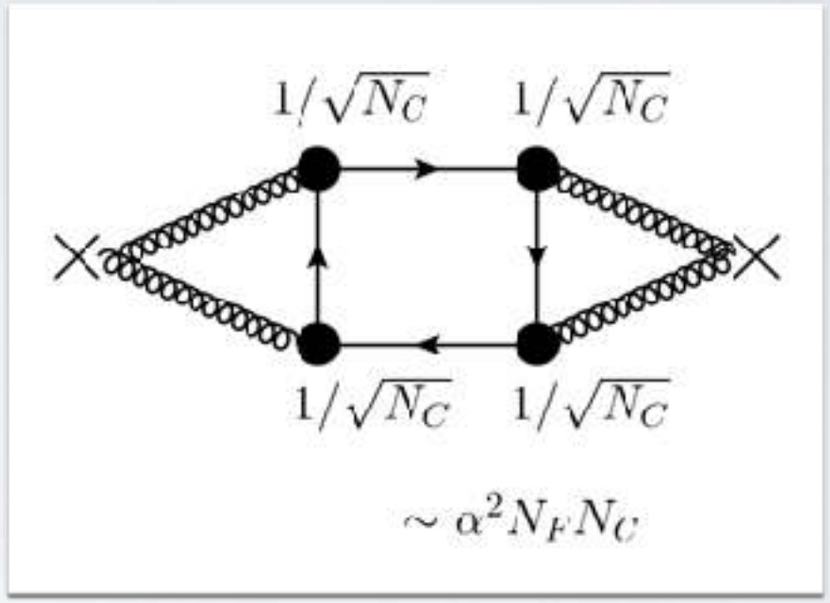
extra slides

[based on ladder SD and WTI: Matsuzaki, Yamawaki arxiv:1508.07688]

WITTEN-VENEZIANO



gluon loop

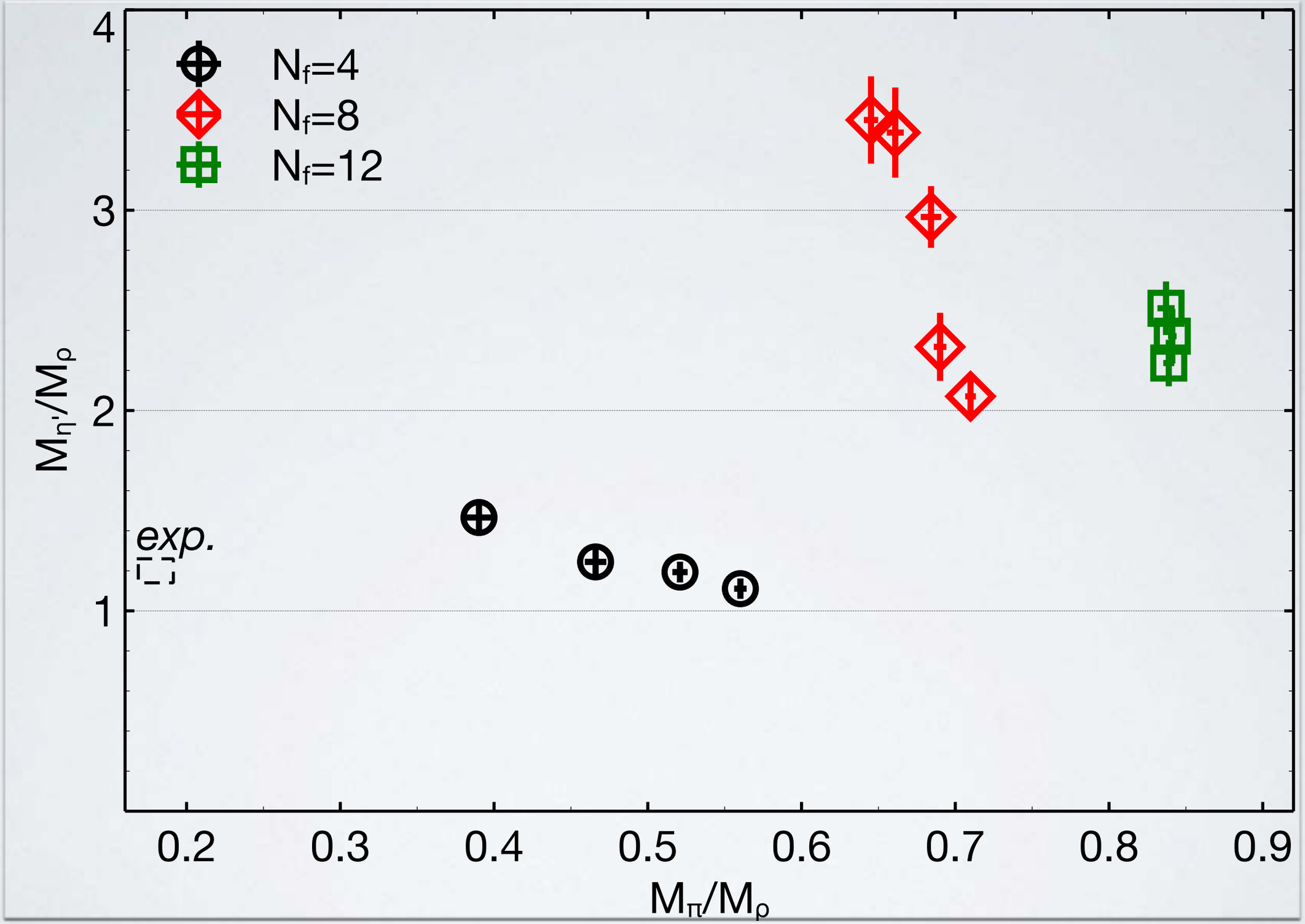


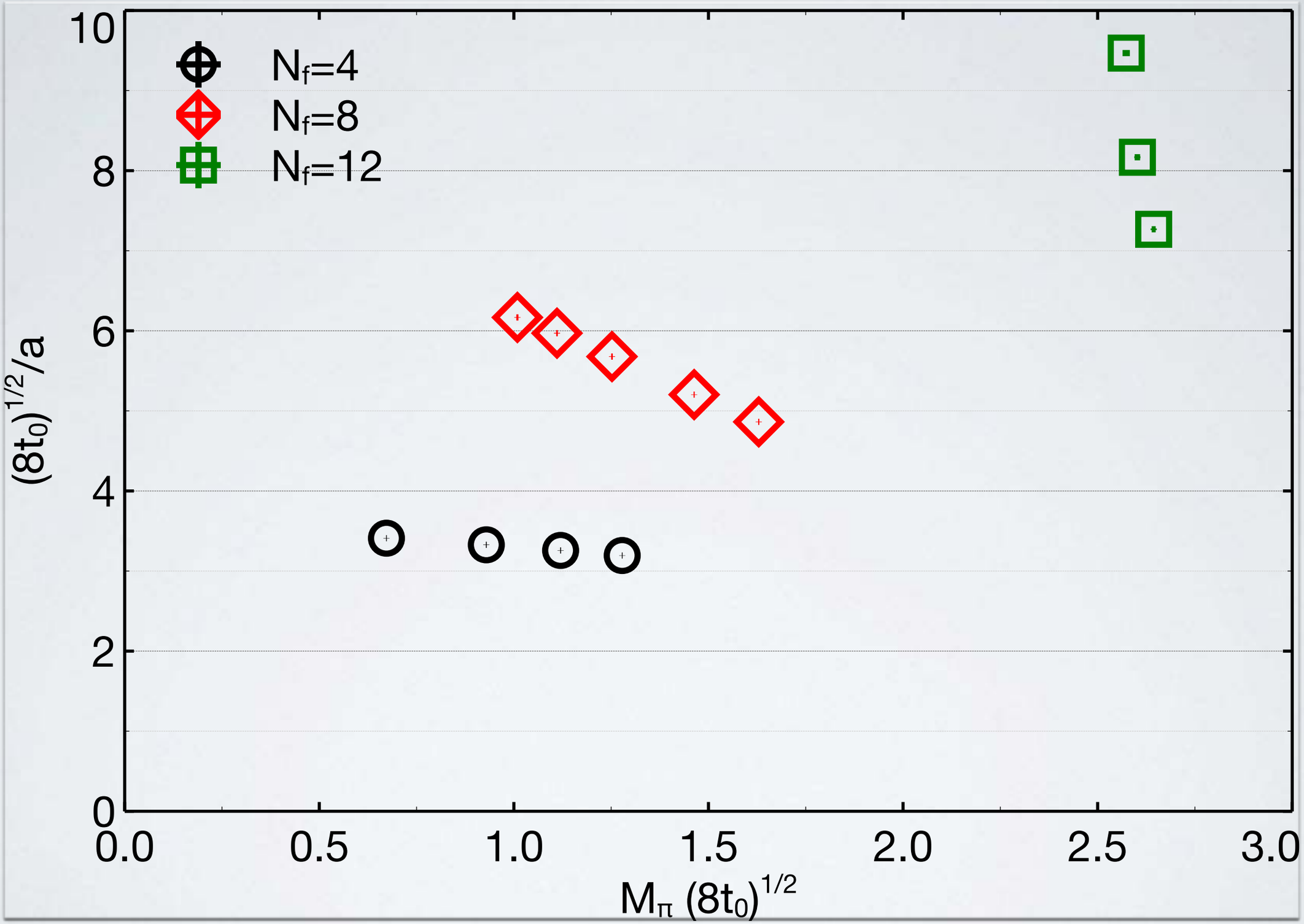
fermion loop

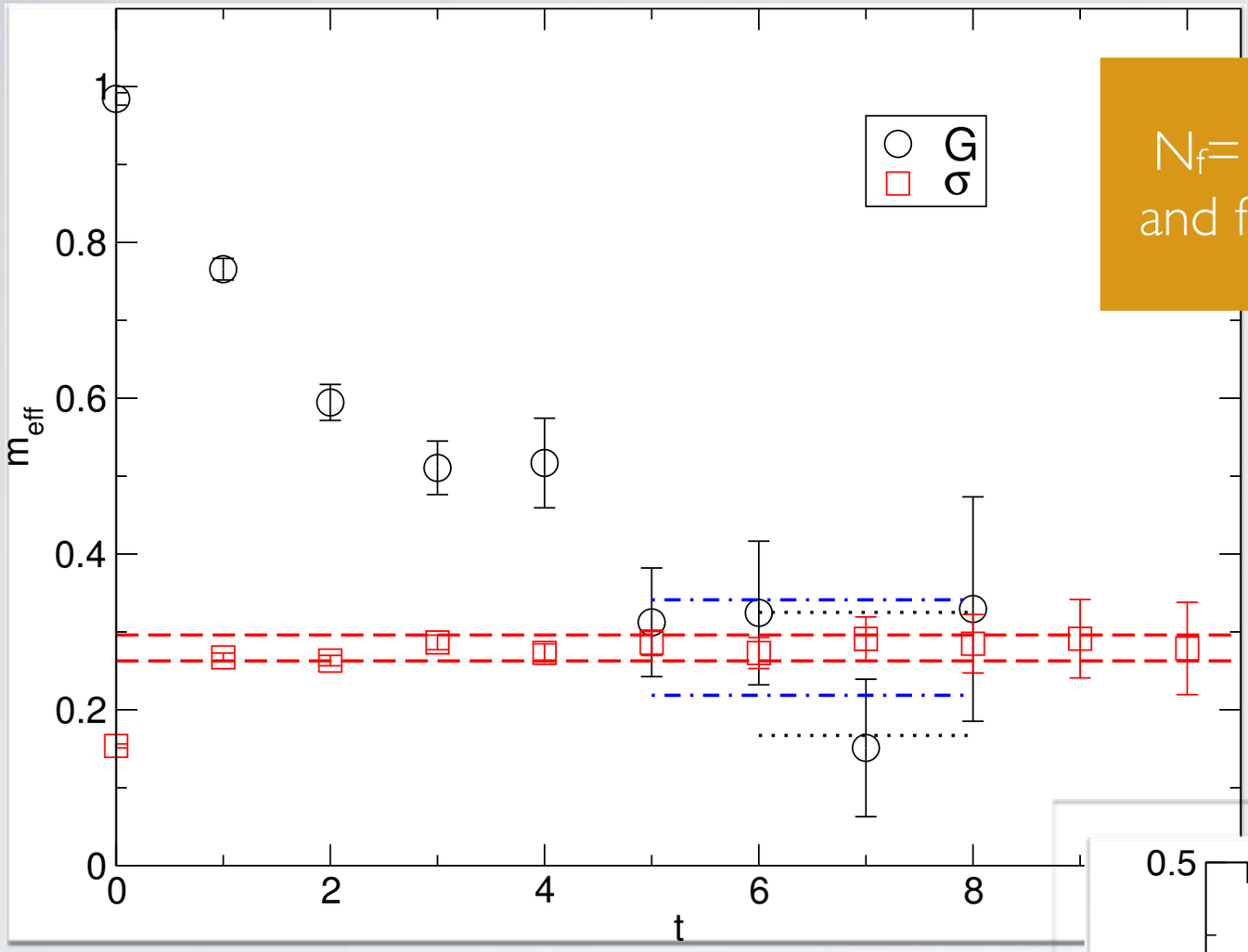
Regular Witten-Veneziano $\quad \dfrac{N_f}{N_c} \ll 1$

"anti-"Witten-Veneziano $\quad \dfrac{N_f}{N_c} \gg 1$

$$\lambda = N_c g^2 = \text{fixed} \qquad N_c \to \infty$$

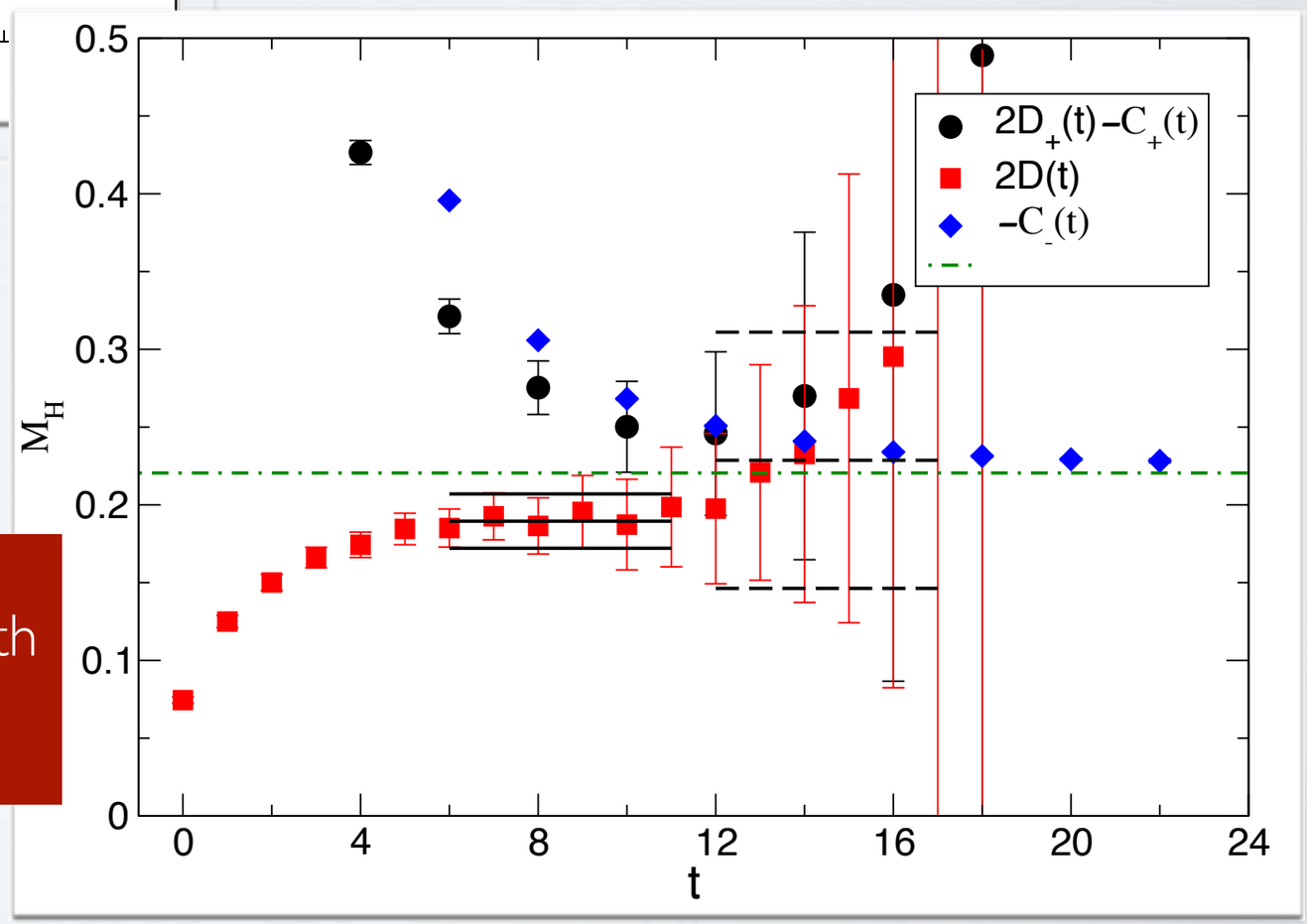

N_f=4
N_f=8
N_f=12
$M_{\eta'}/M_\rho$
exp.
4
3
2
1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
M_π/M_ρ


N_f=4
N_f=8
N_f=12
$(8t_0)^{1/2}/a$
$M_\pi\ (8t_0)^{1/2}$
0
2
4
6
8
10
0.0
0.5
1.0
1.5
2.0
2.5
3.0



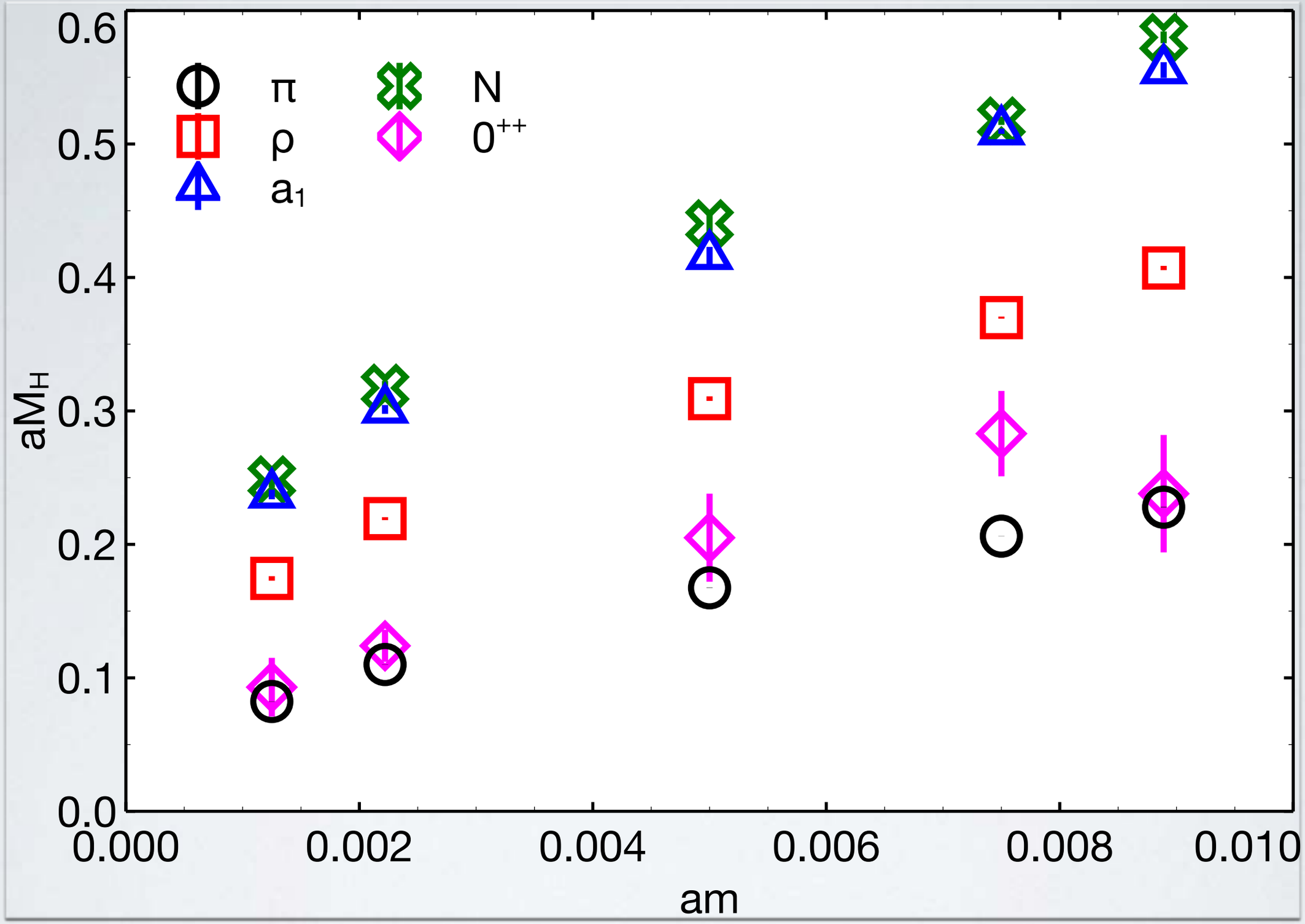
N_f=12 comparison between gluonic and fermionic interpolating operators

LatKMI arxiv:1305.6006



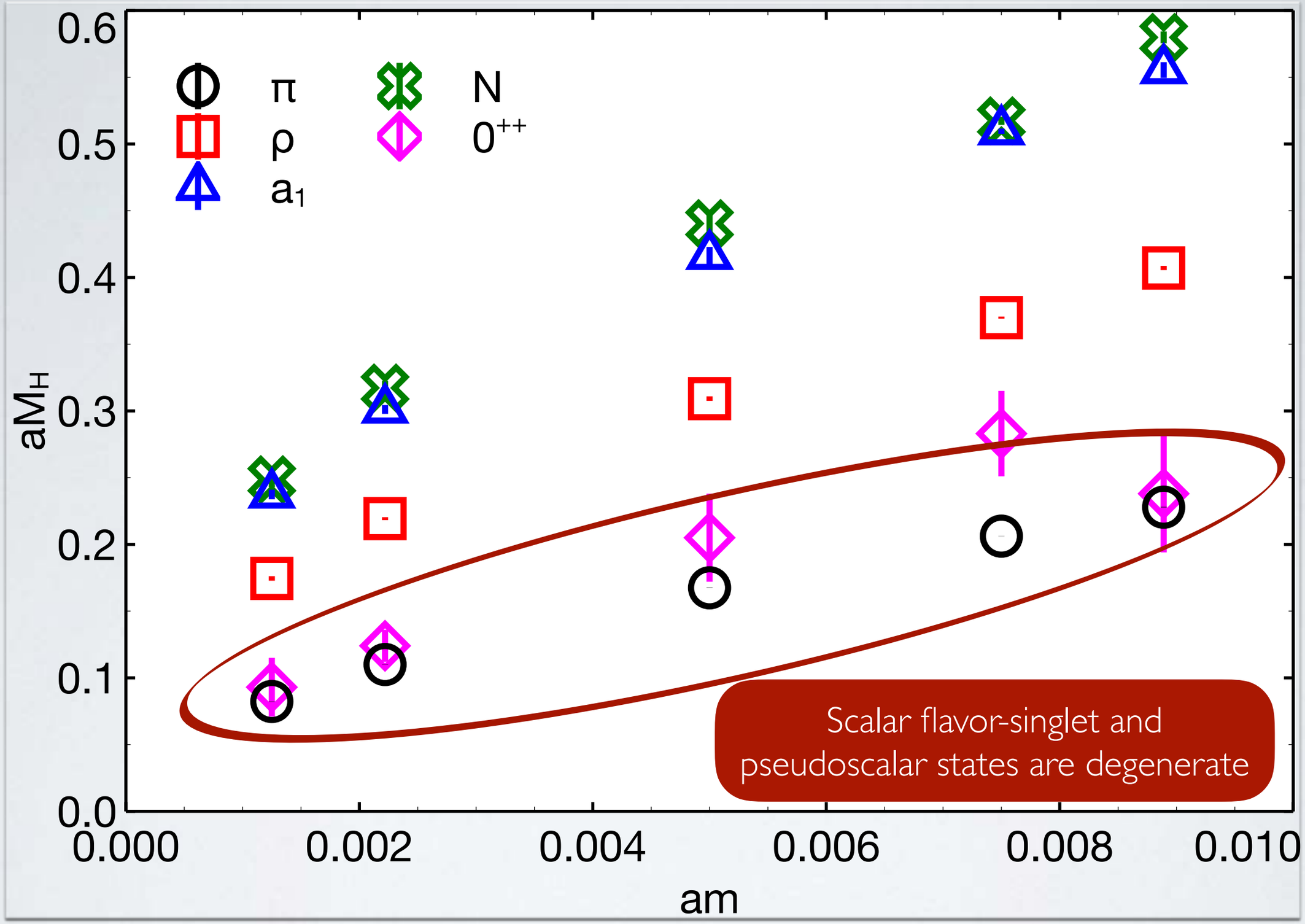
N_f=8 estimating systematic errors with fermionic interpolating operators

LatKMI arxiv:1610.07011



Lattice details: F+A Wilson plaquette action + nHYP smeared naive staggered quarks

LSD arxiv:1601.04027 [scalar update, preliminary]



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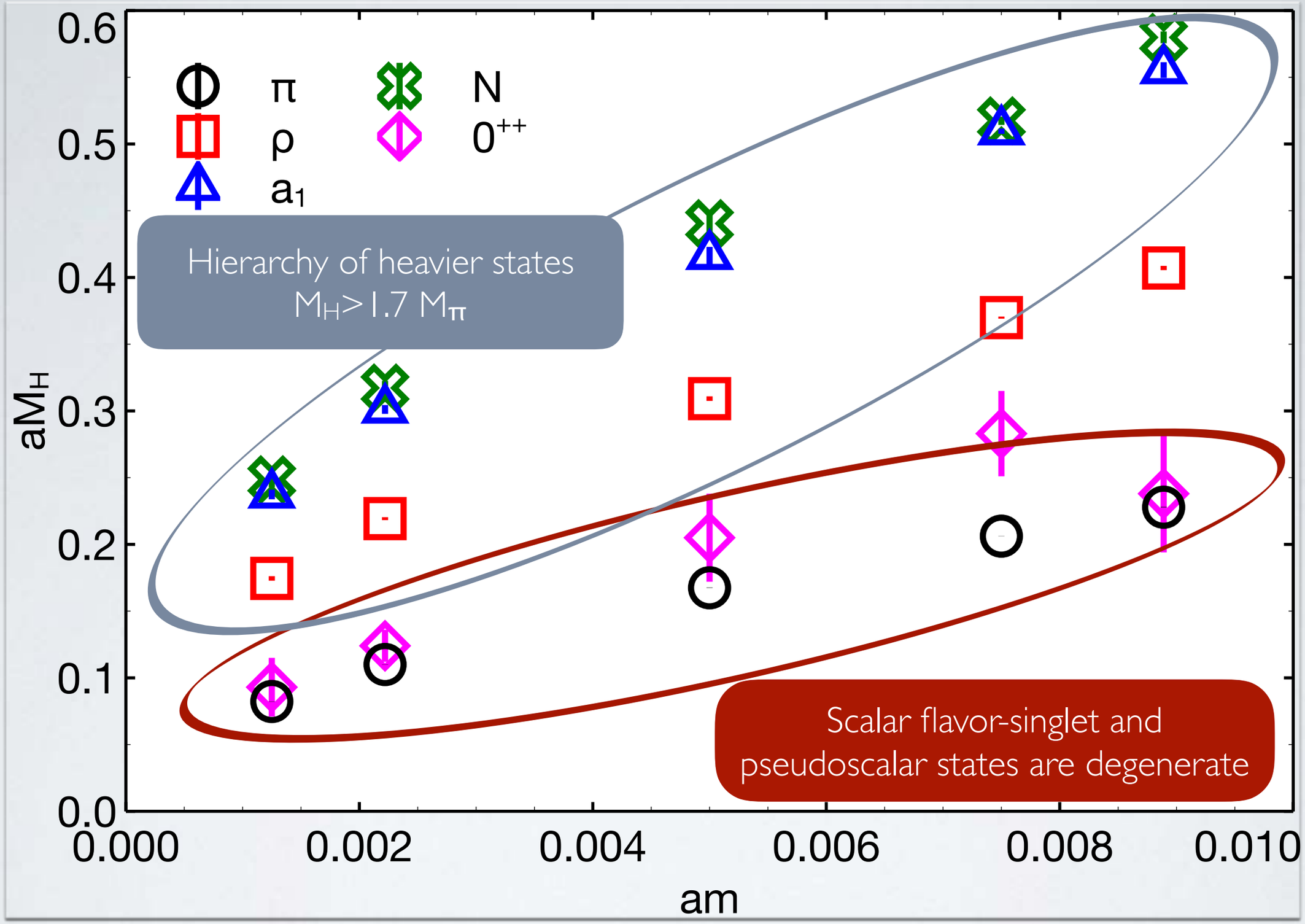

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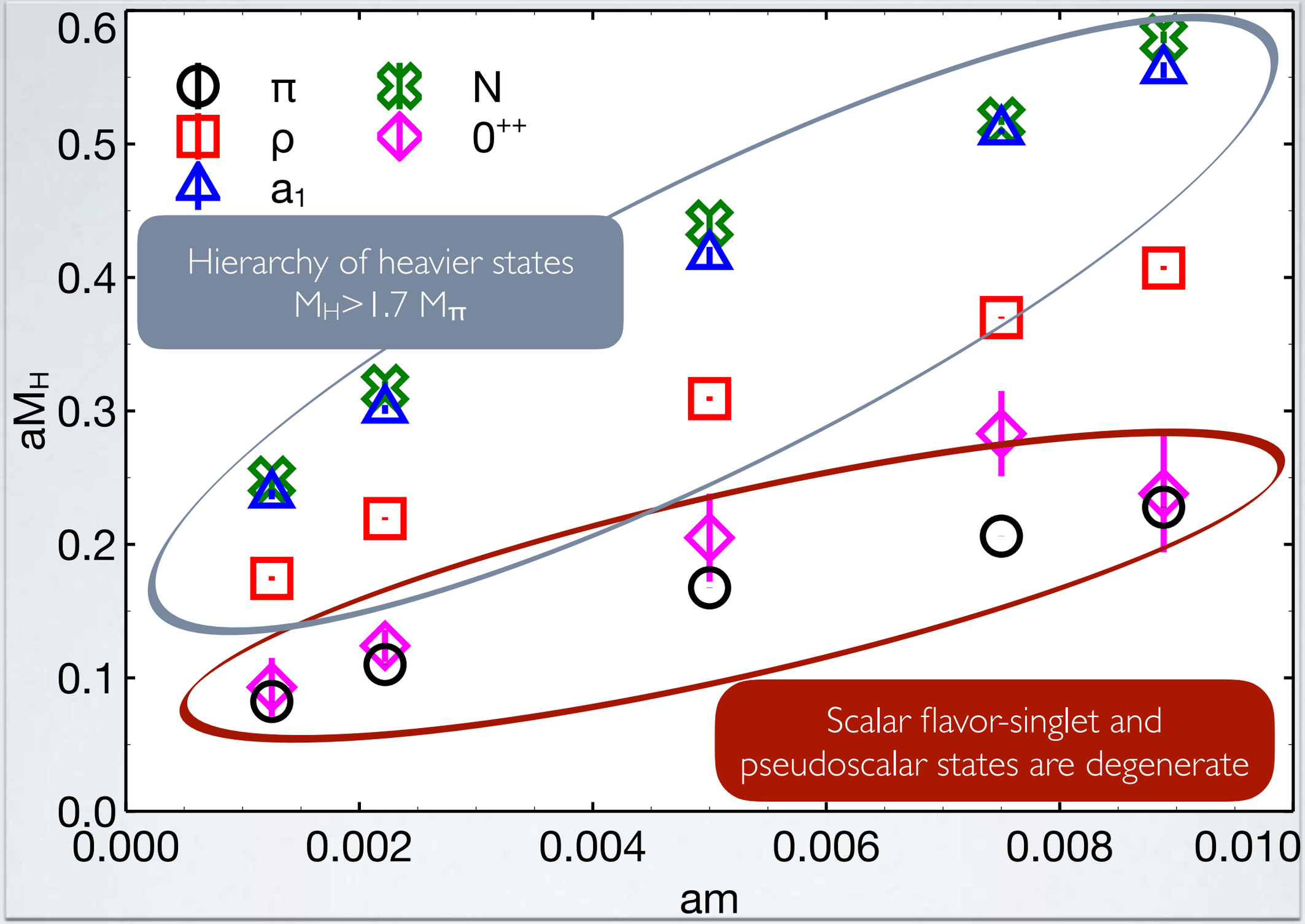

Different from QCD

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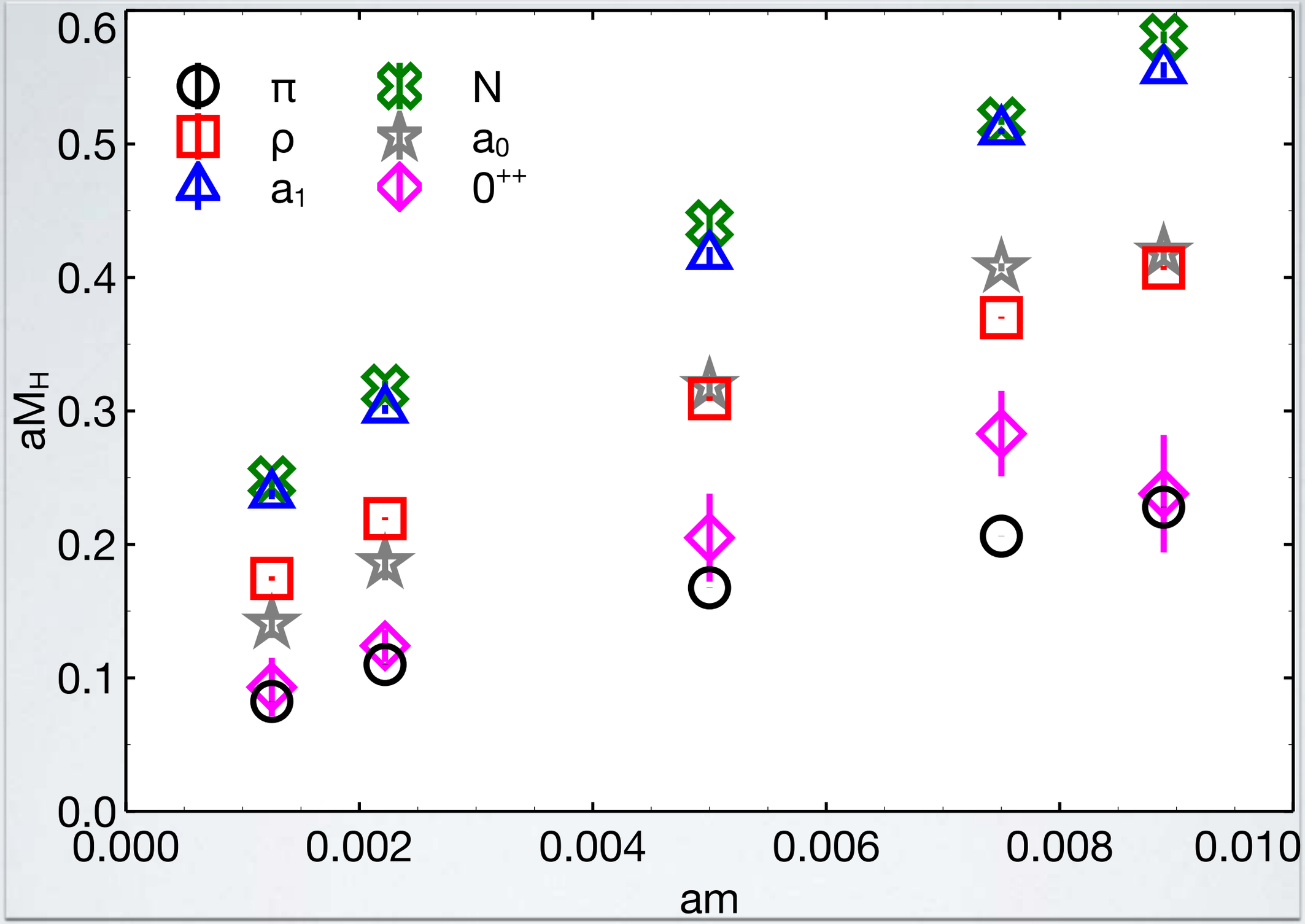

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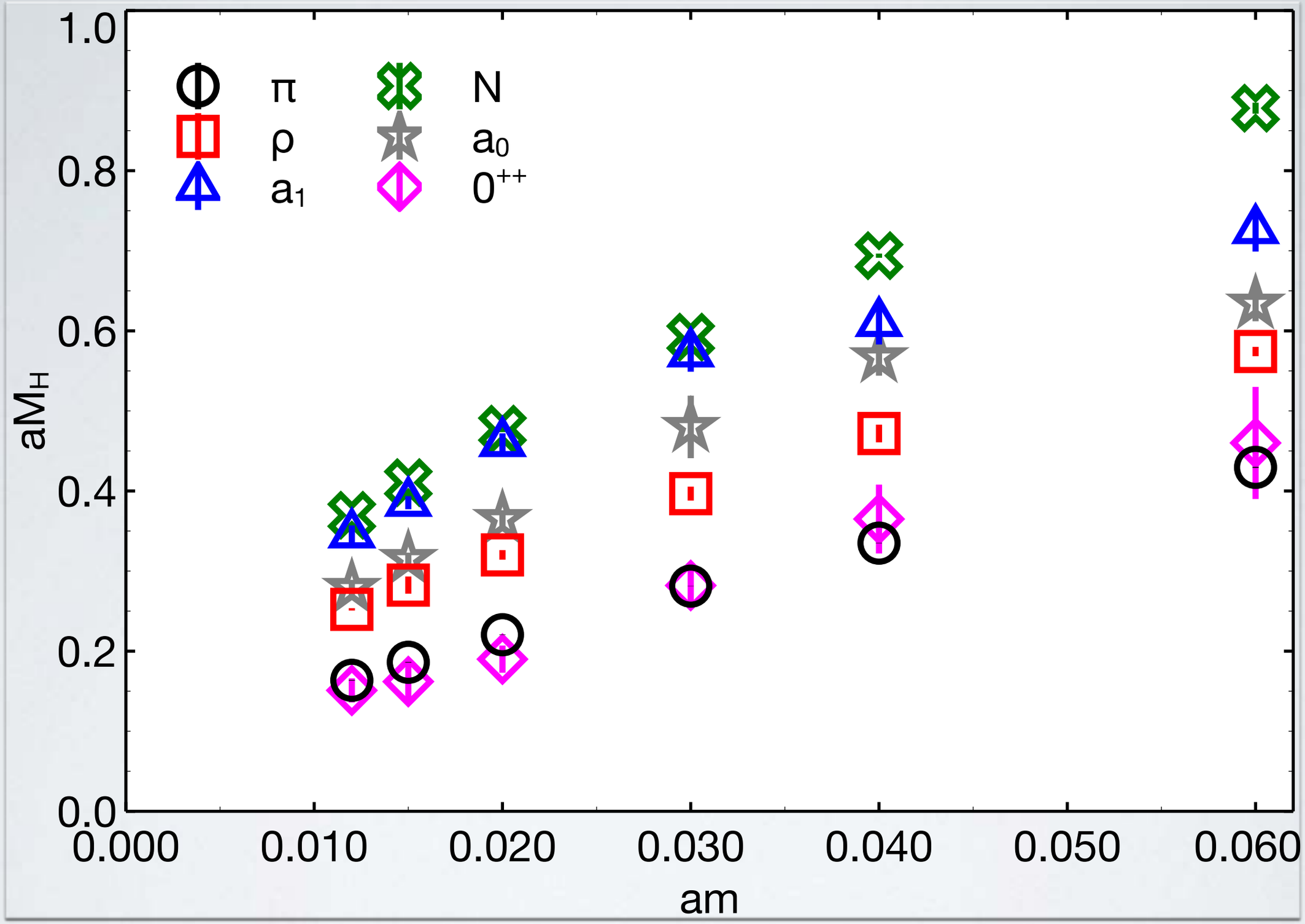
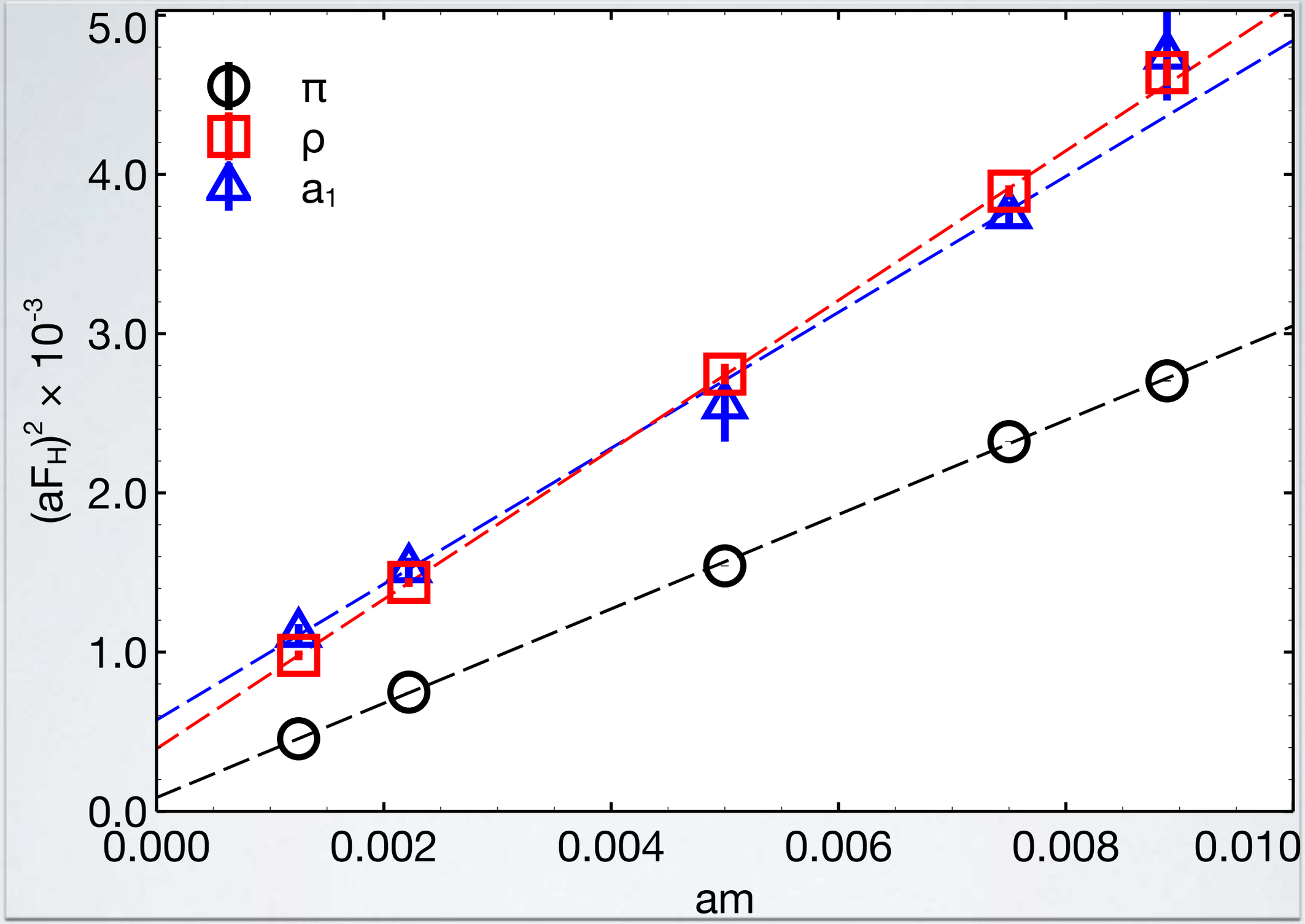


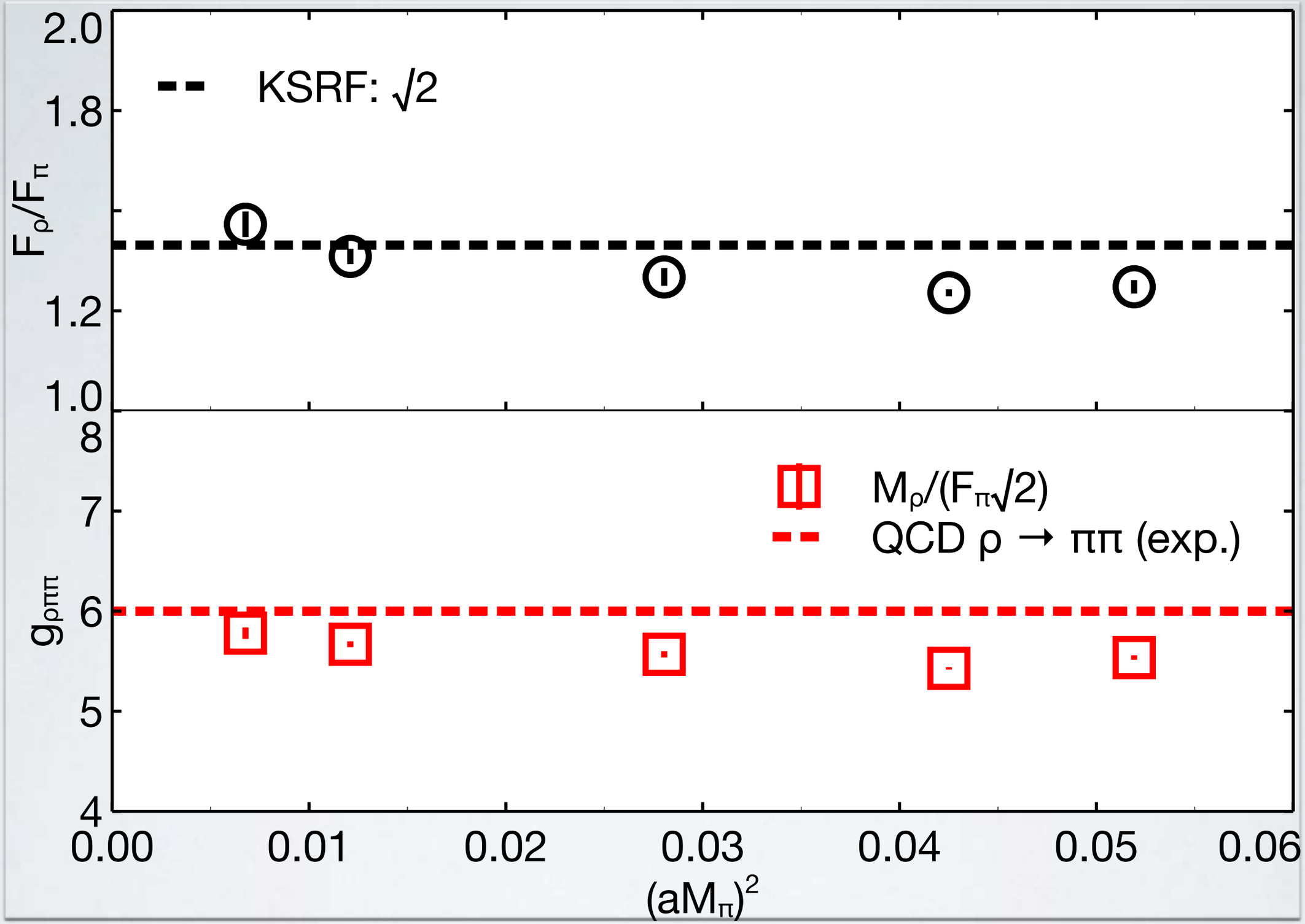
LatKMI arxiv:1610.07011



Useful to study vector meson width in the VMD picture

LSD arxiv:1601.04027

Talks by G. Fleming and A. Gasbarro



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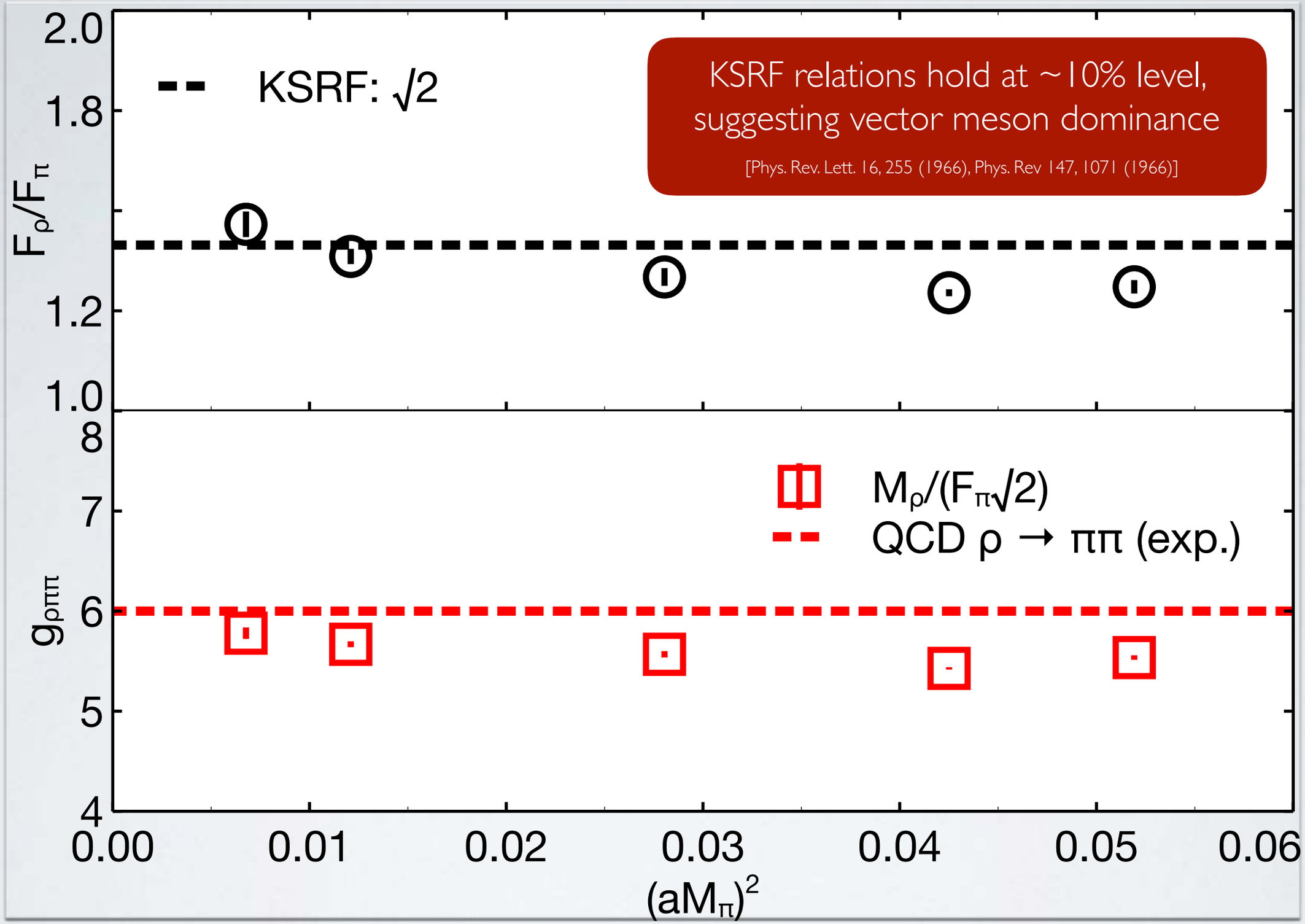

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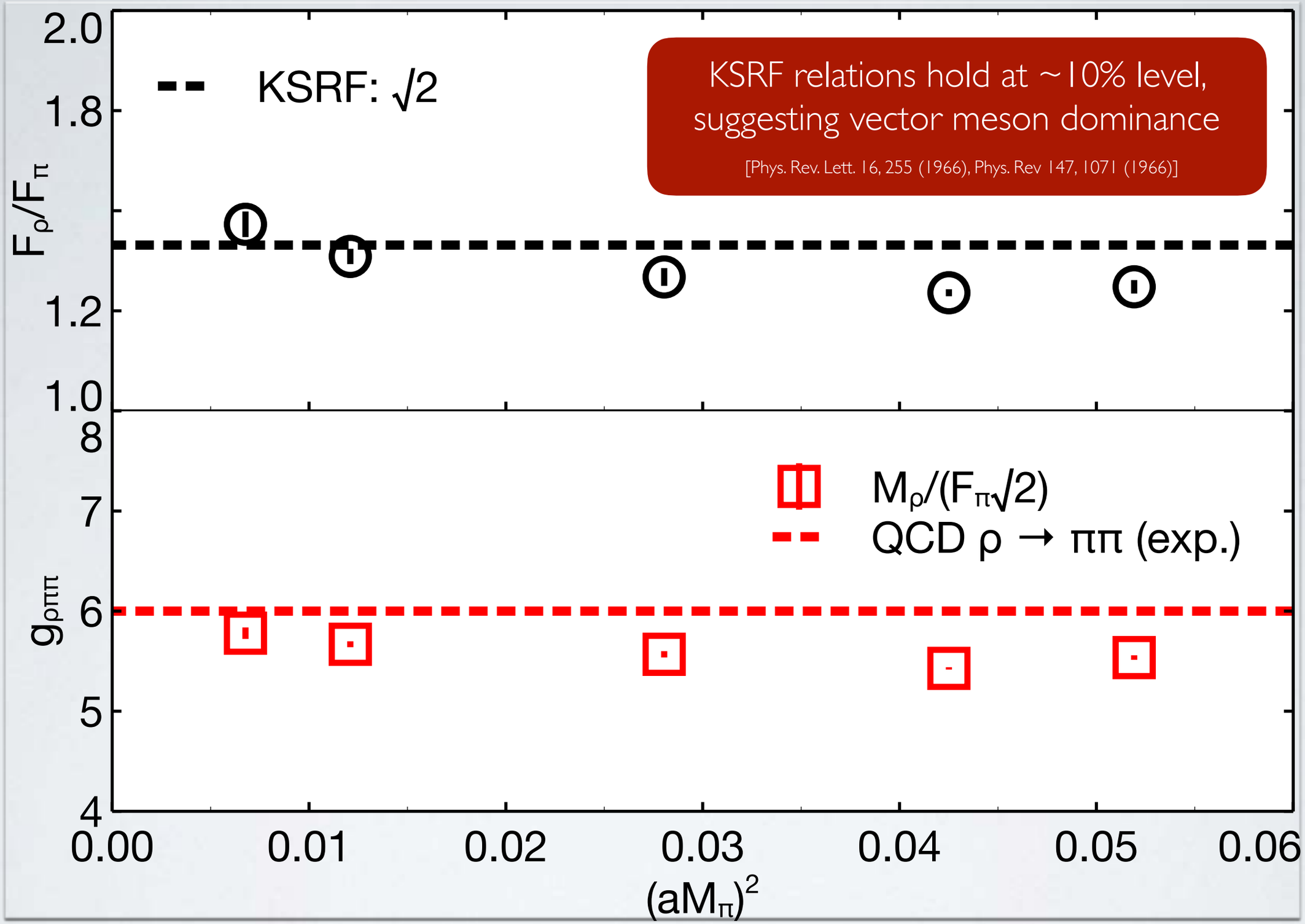

KSRF relations hold at ~10% level, suggesting vector meson dominance

[Phys. Rev. Lett. 16, 255 (1966), Phys. Rev 147, 1071 (1966)]

Similar to QCD

LSD arxiv:1601.04027

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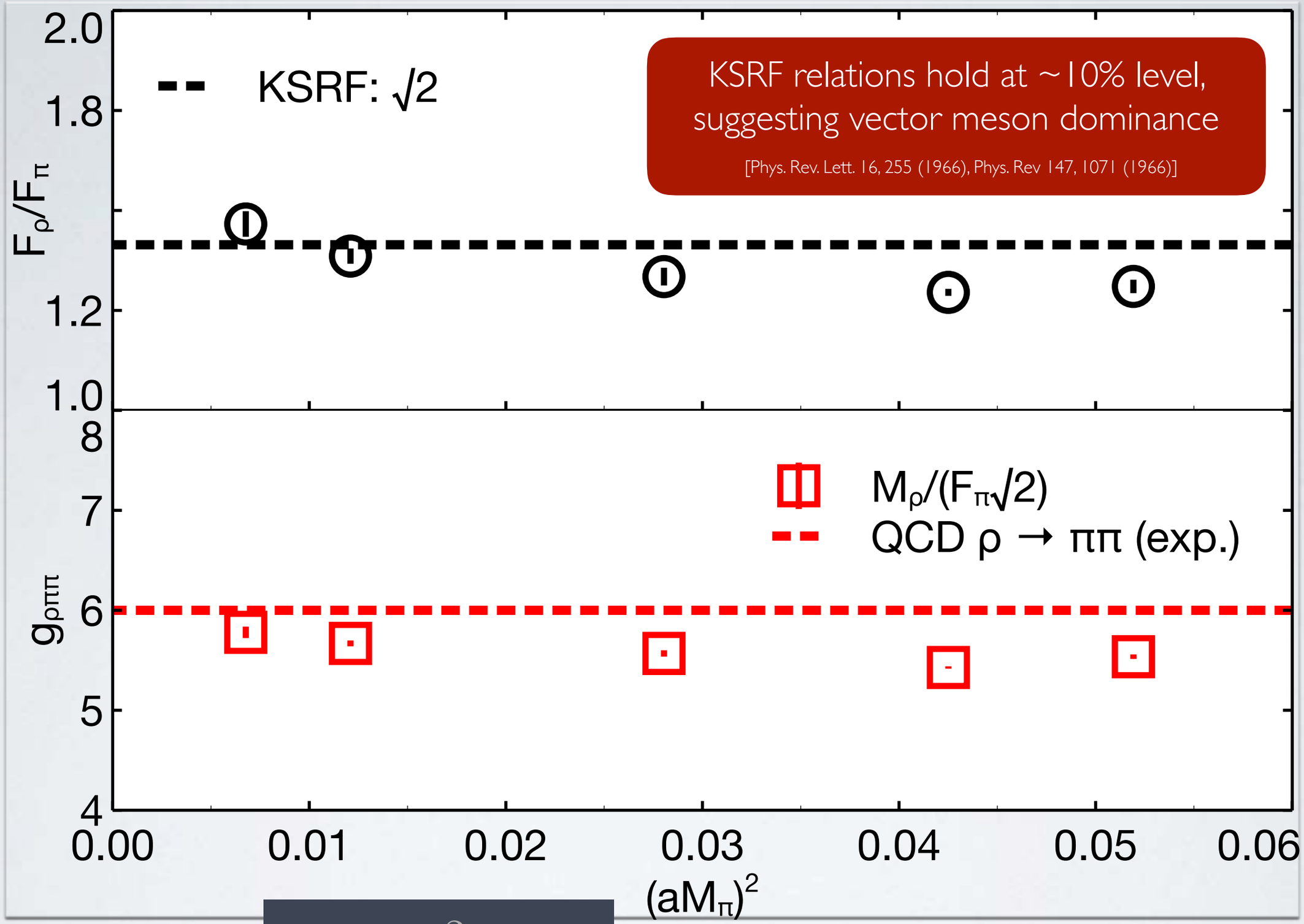

$$\Gamma_\rho \approx \frac{g^2_{\rho\pi\pi} M_\rho}{48\pi}$$

Similar to QCD

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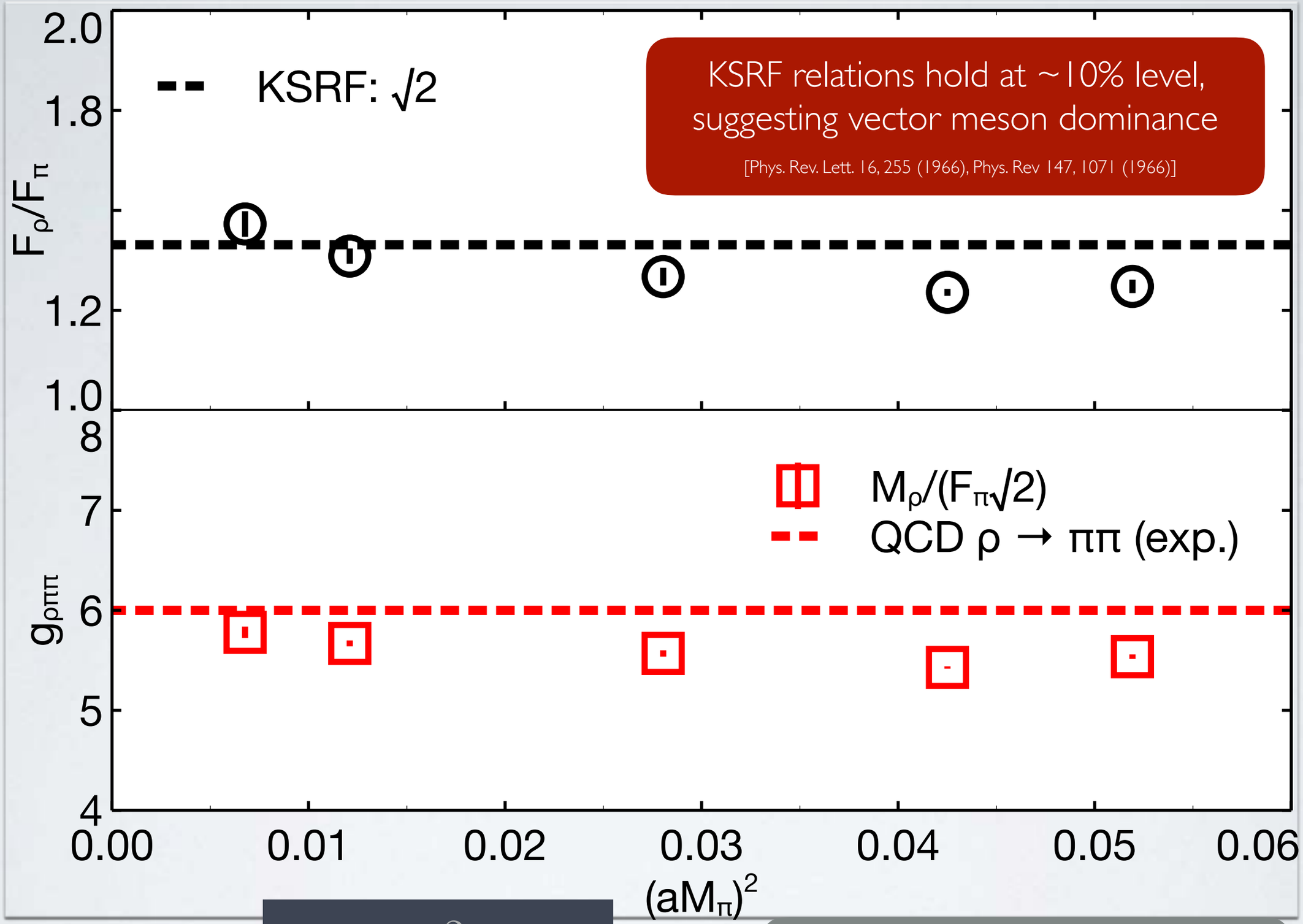

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M_ρ~2TeV and Γ_ρ~450GeV

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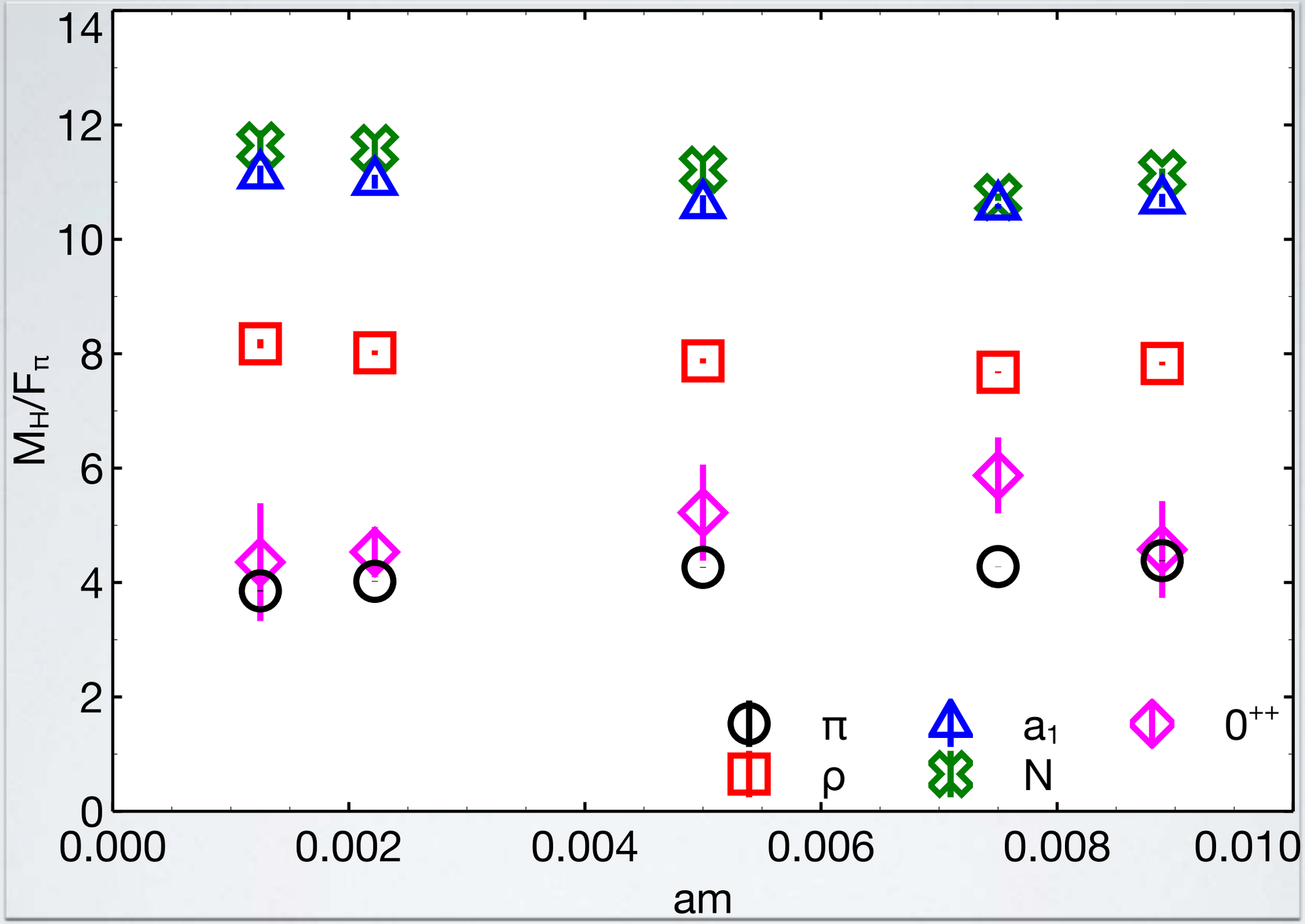
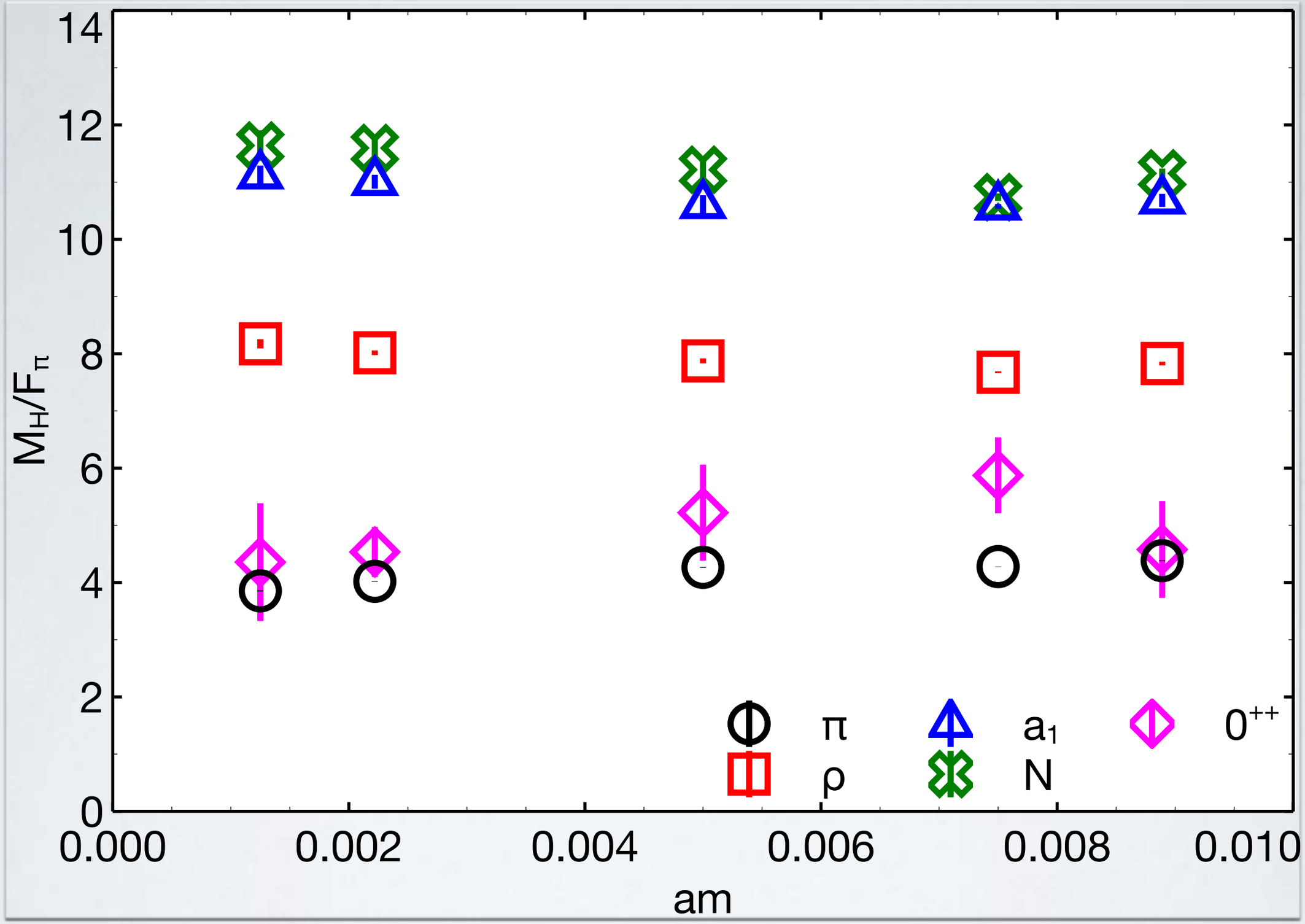


LSD arxiv:1601.04027 [scalar update, preliminary]



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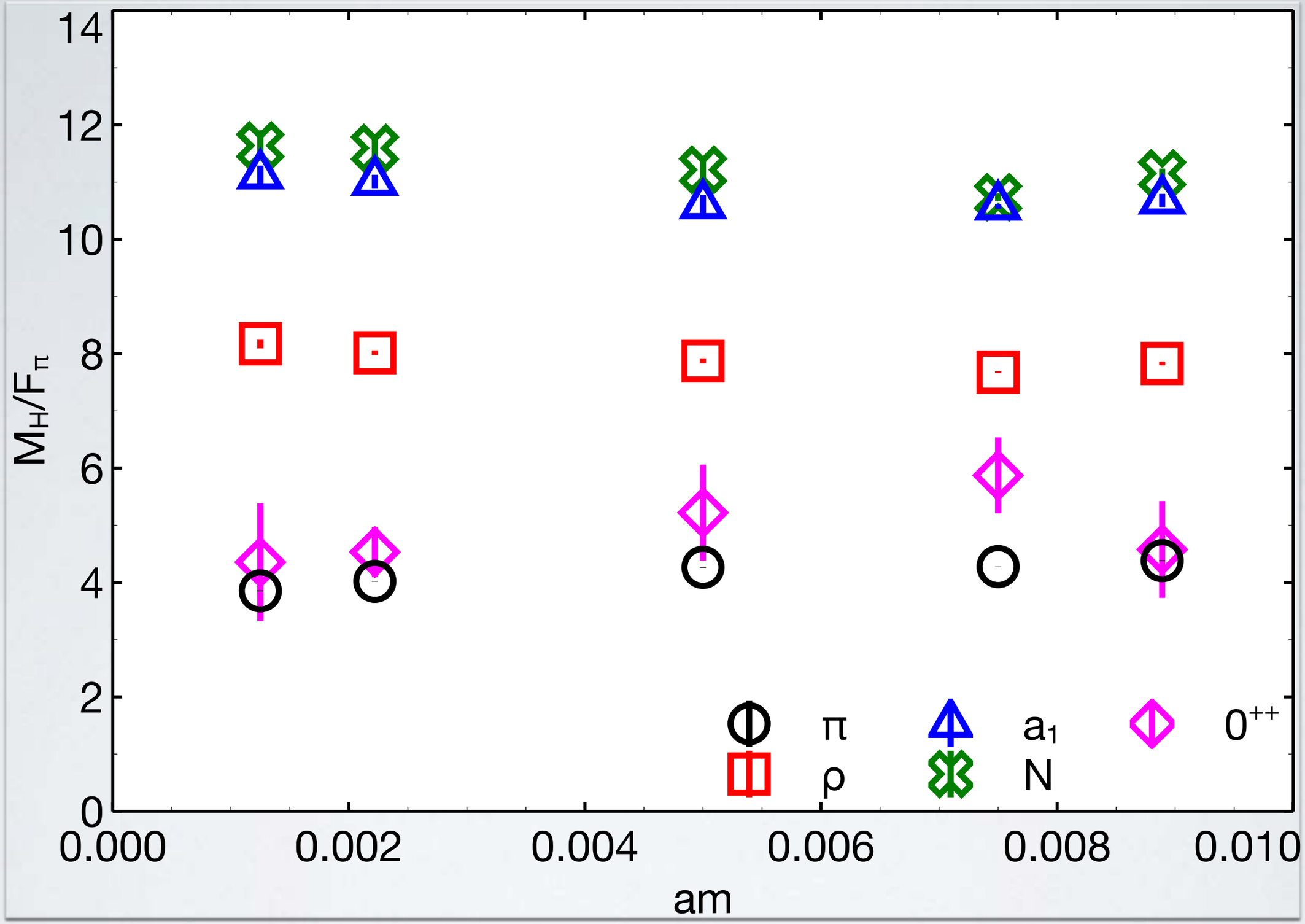

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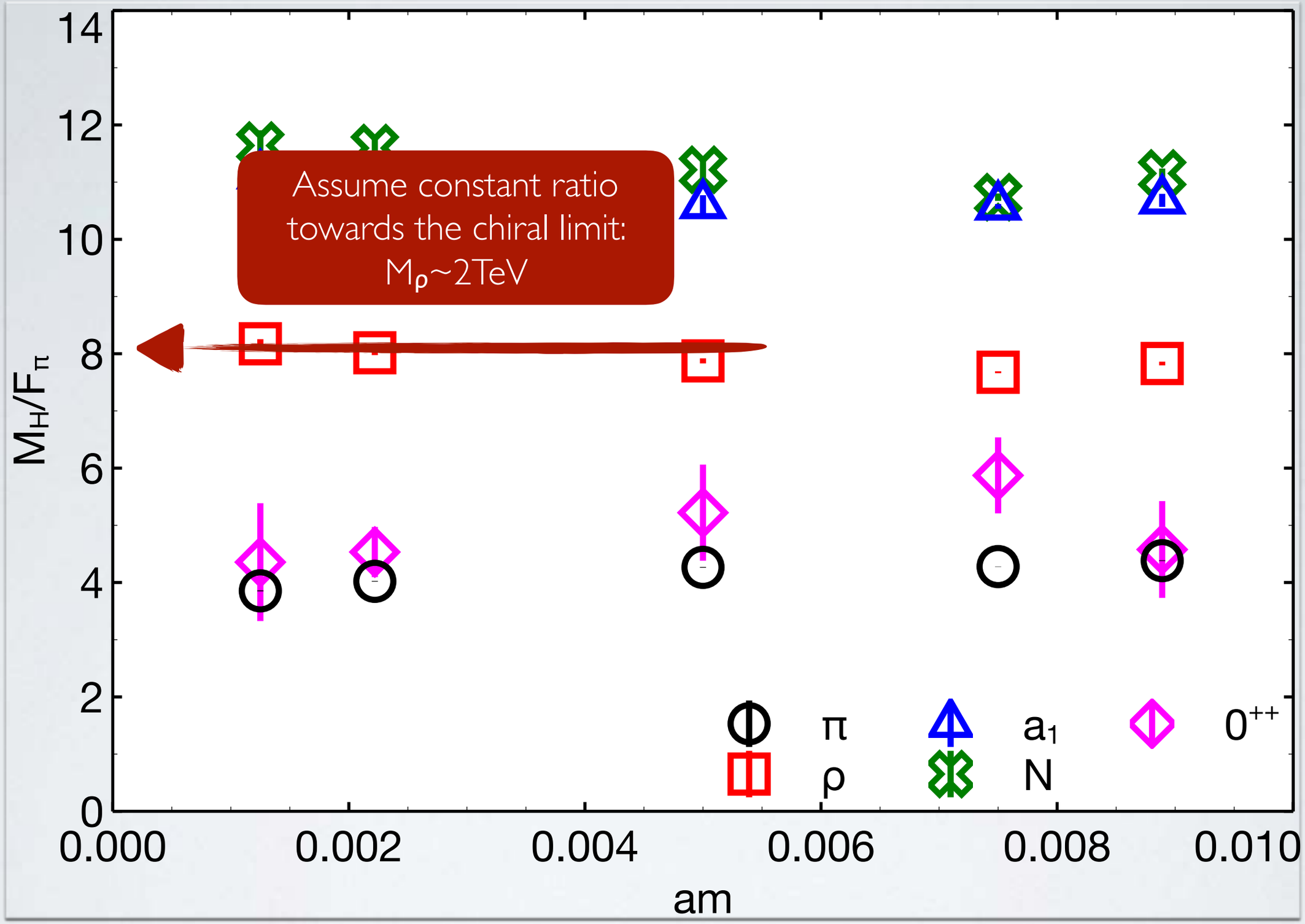
Assume F_π~246GeV



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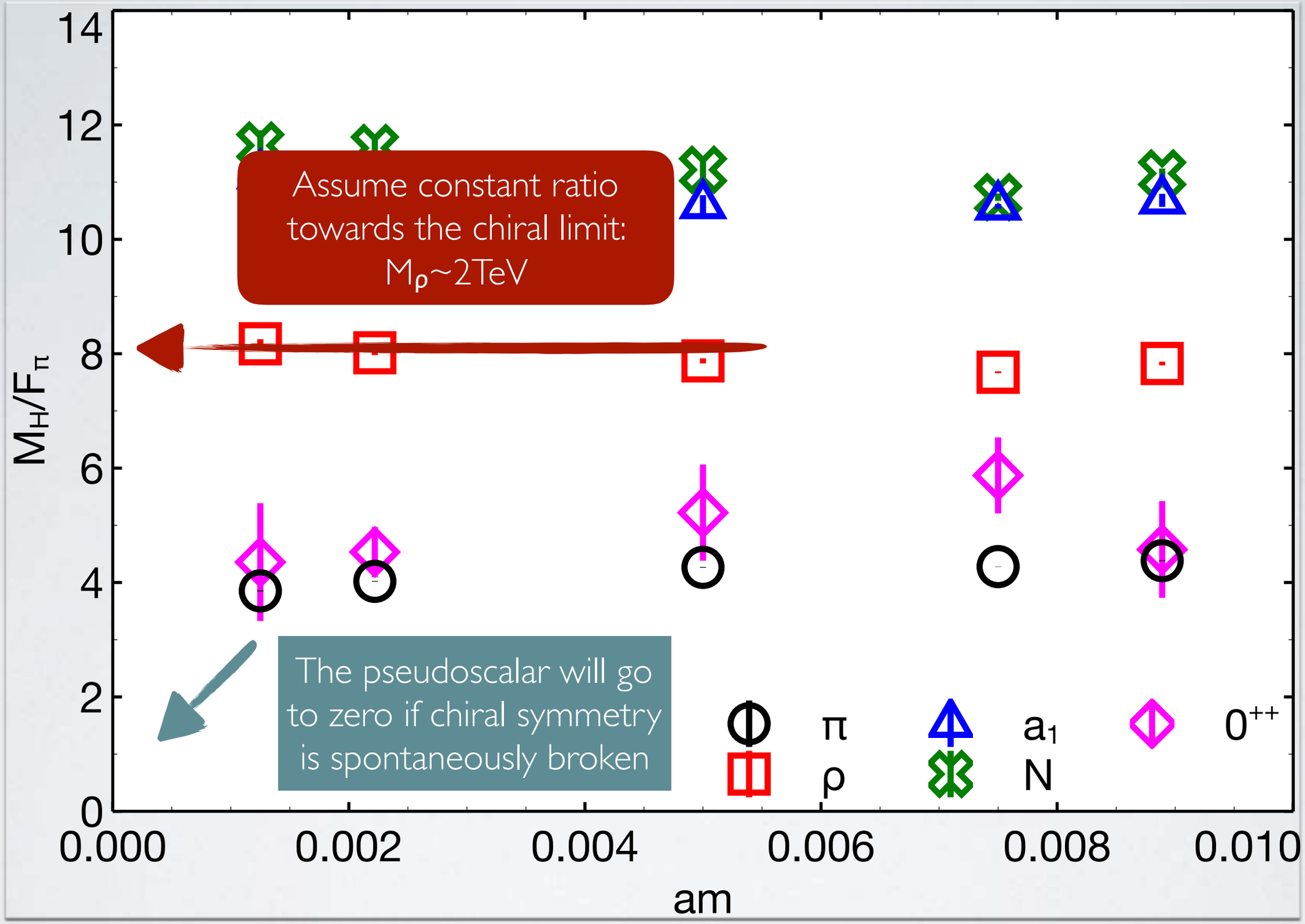

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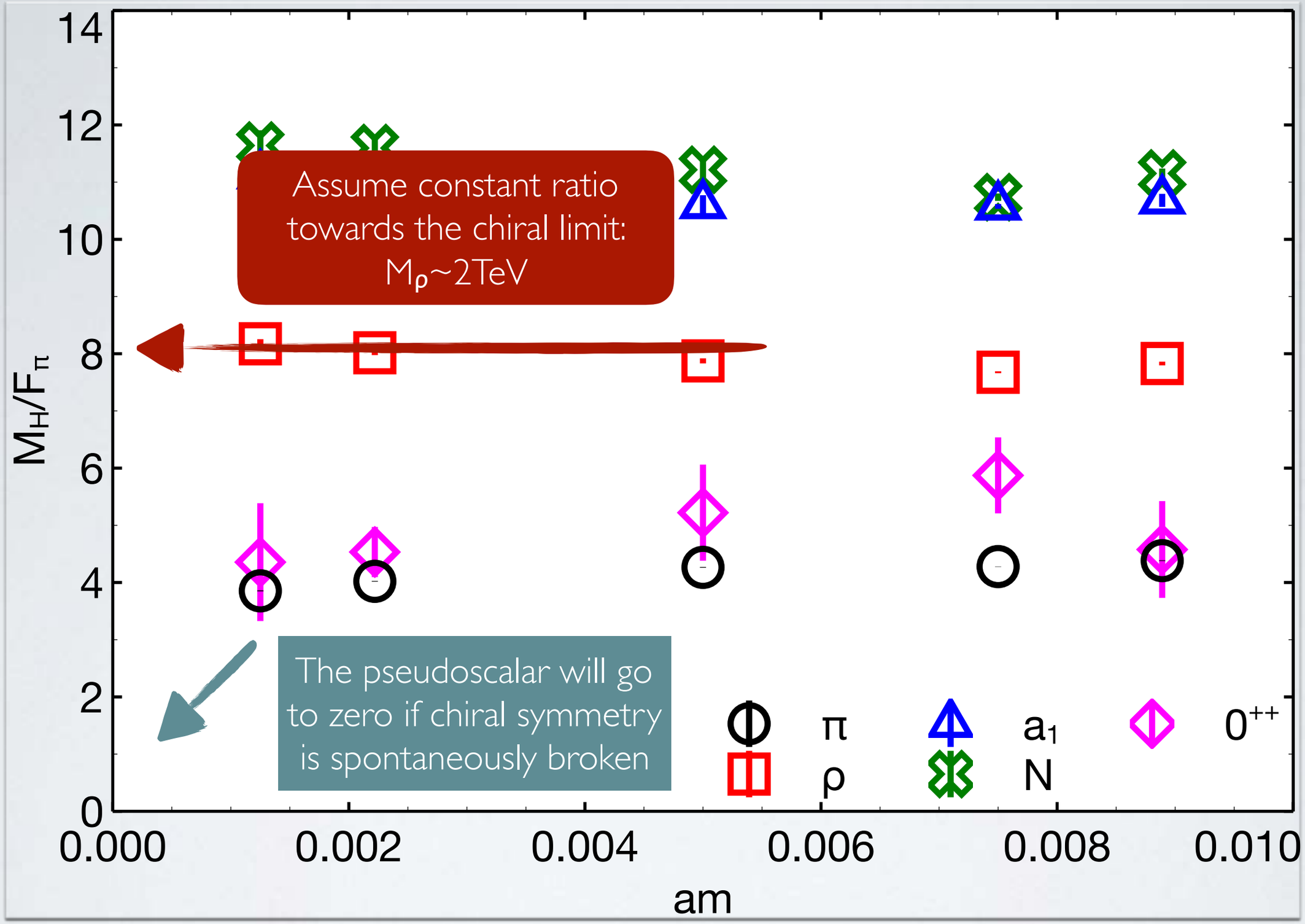

Important again: extrapolate towards the chiral limit using an appropriate effective low-energy theory

Similar to QCD?

Assume F_π~246GeV

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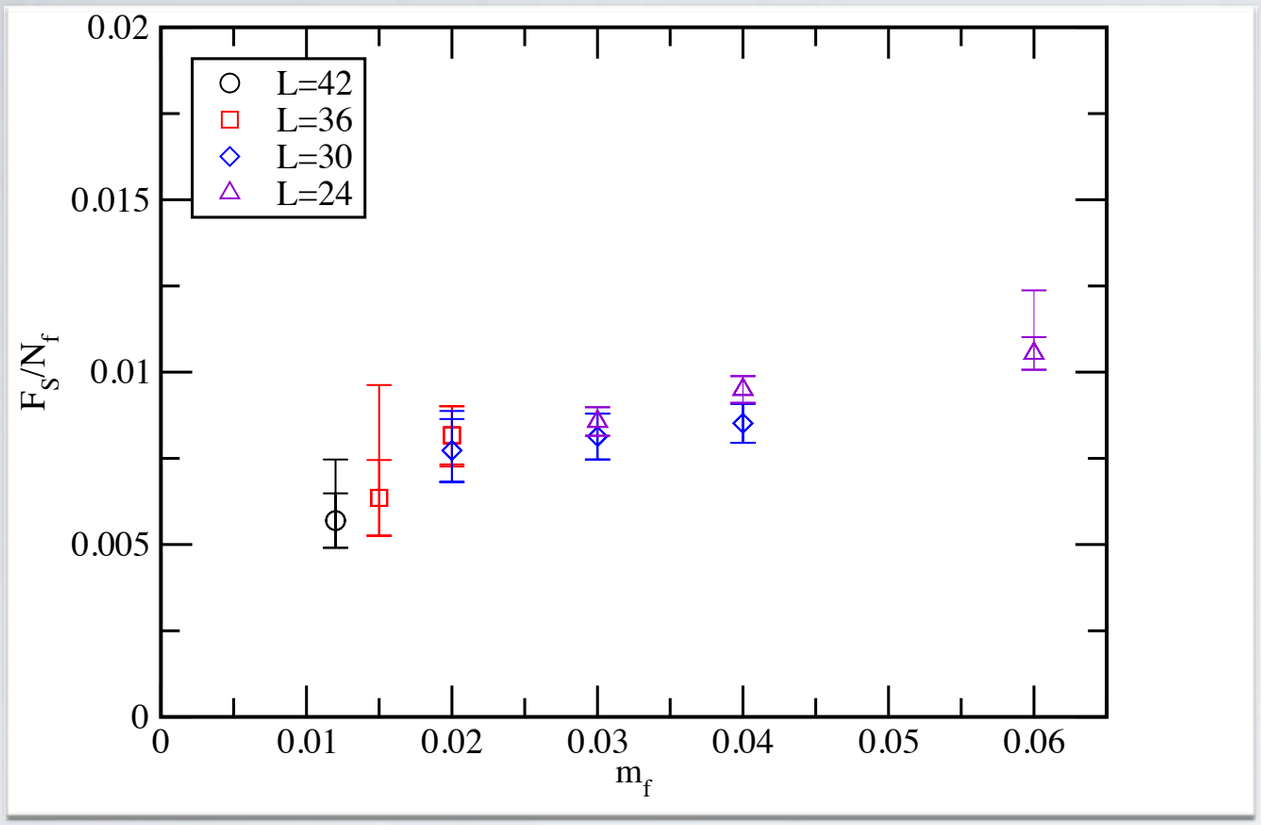
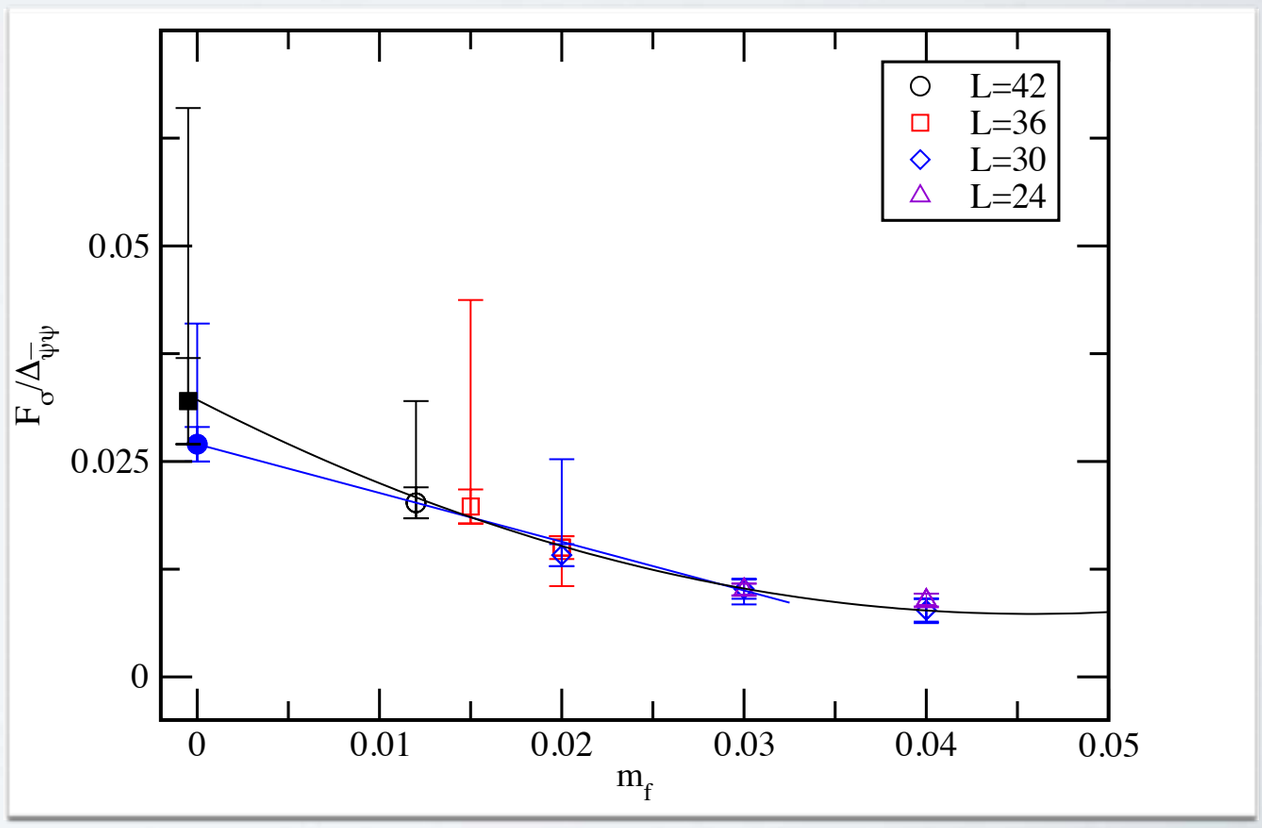
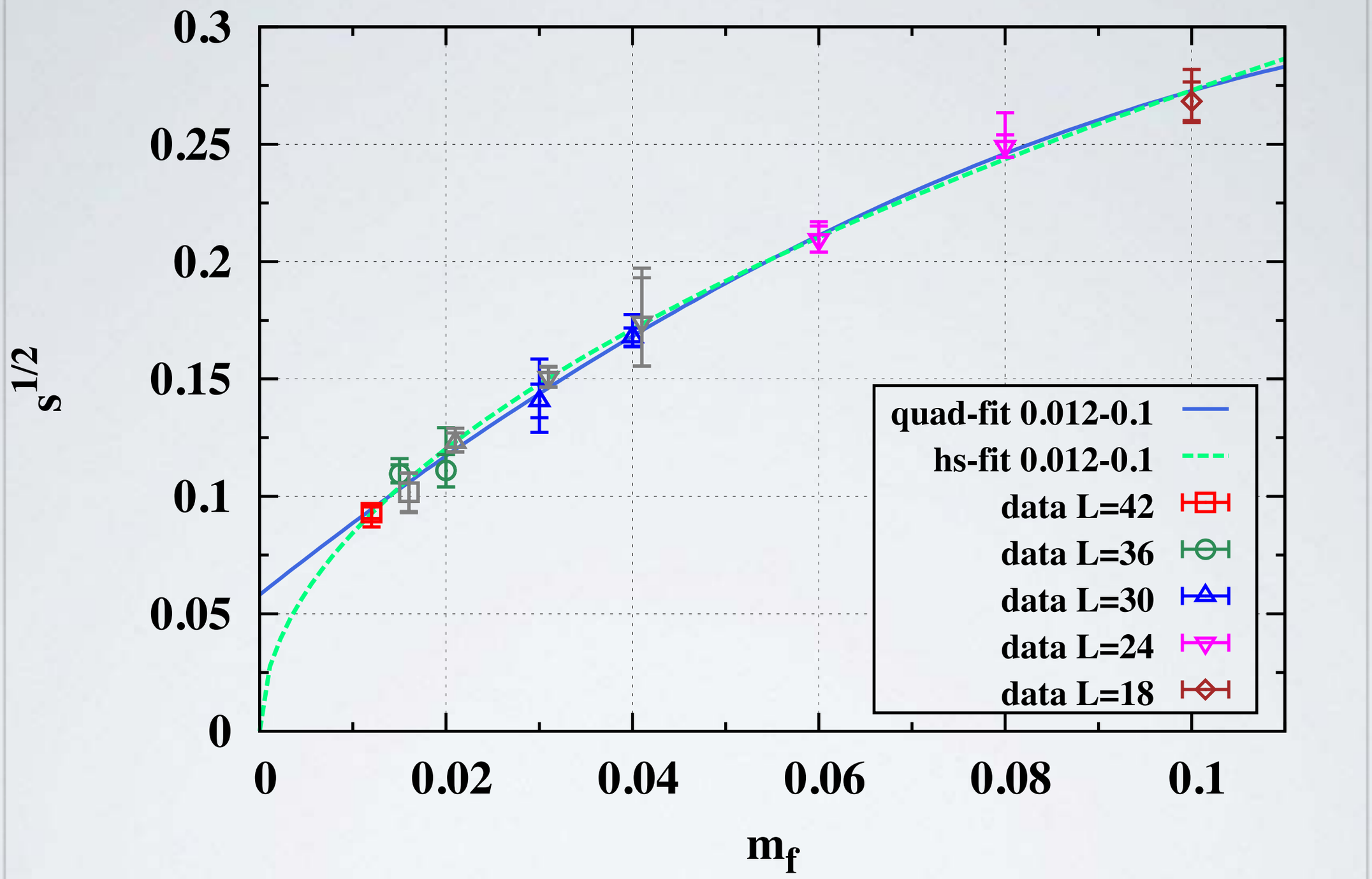


$$\langle 0|m_f O_S(0,0)|\sigma(0)\rangle = F_S M_\sigma^2$$

$$F_S F_\sigma M_\sigma^2 = -\Delta_{\bar{\psi}\psi} m_f \sum_i^{N_f} \langle \bar{\psi}_i \psi_i \rangle$$



LatKMI arxiv:1610.07011



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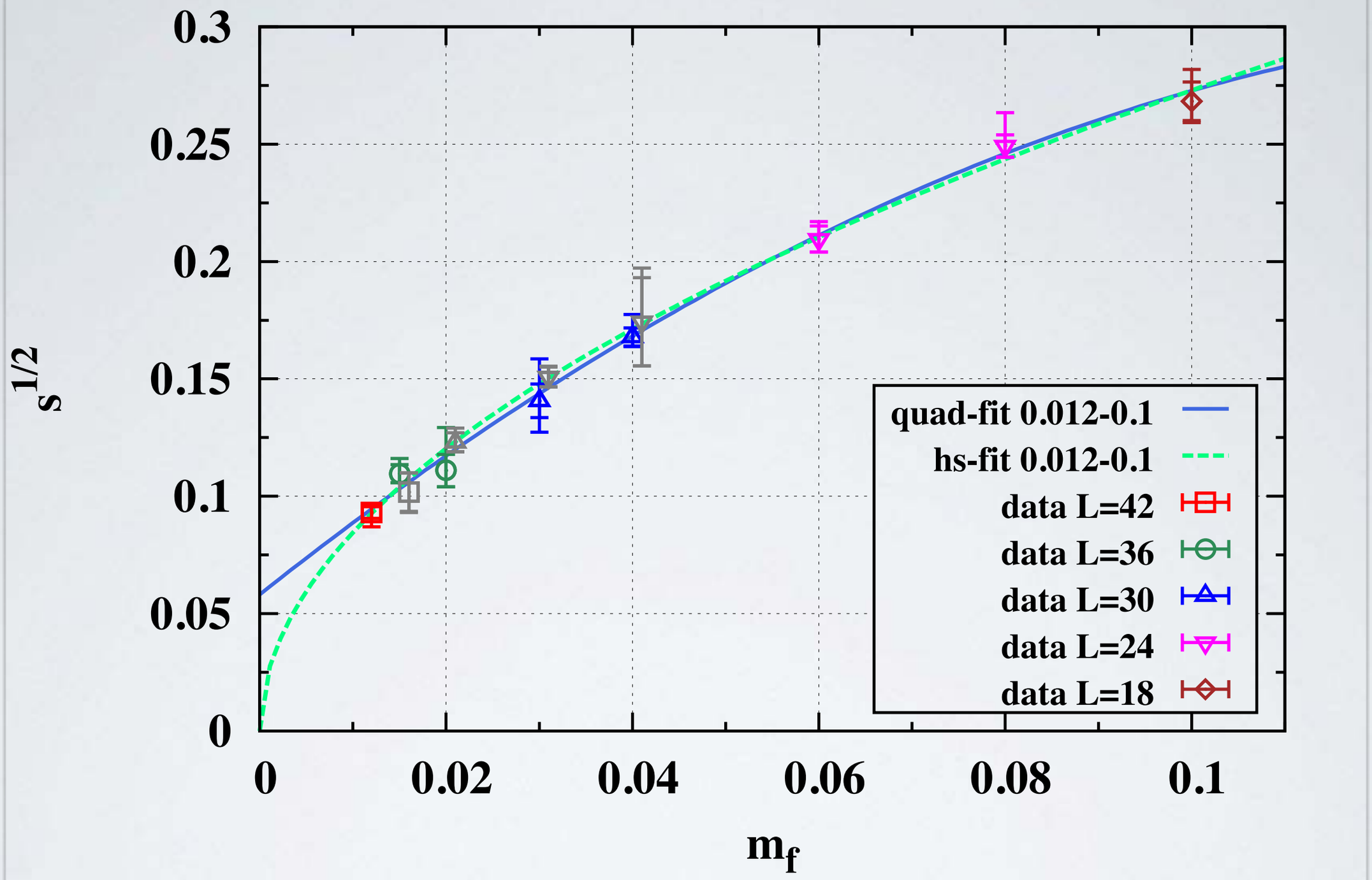
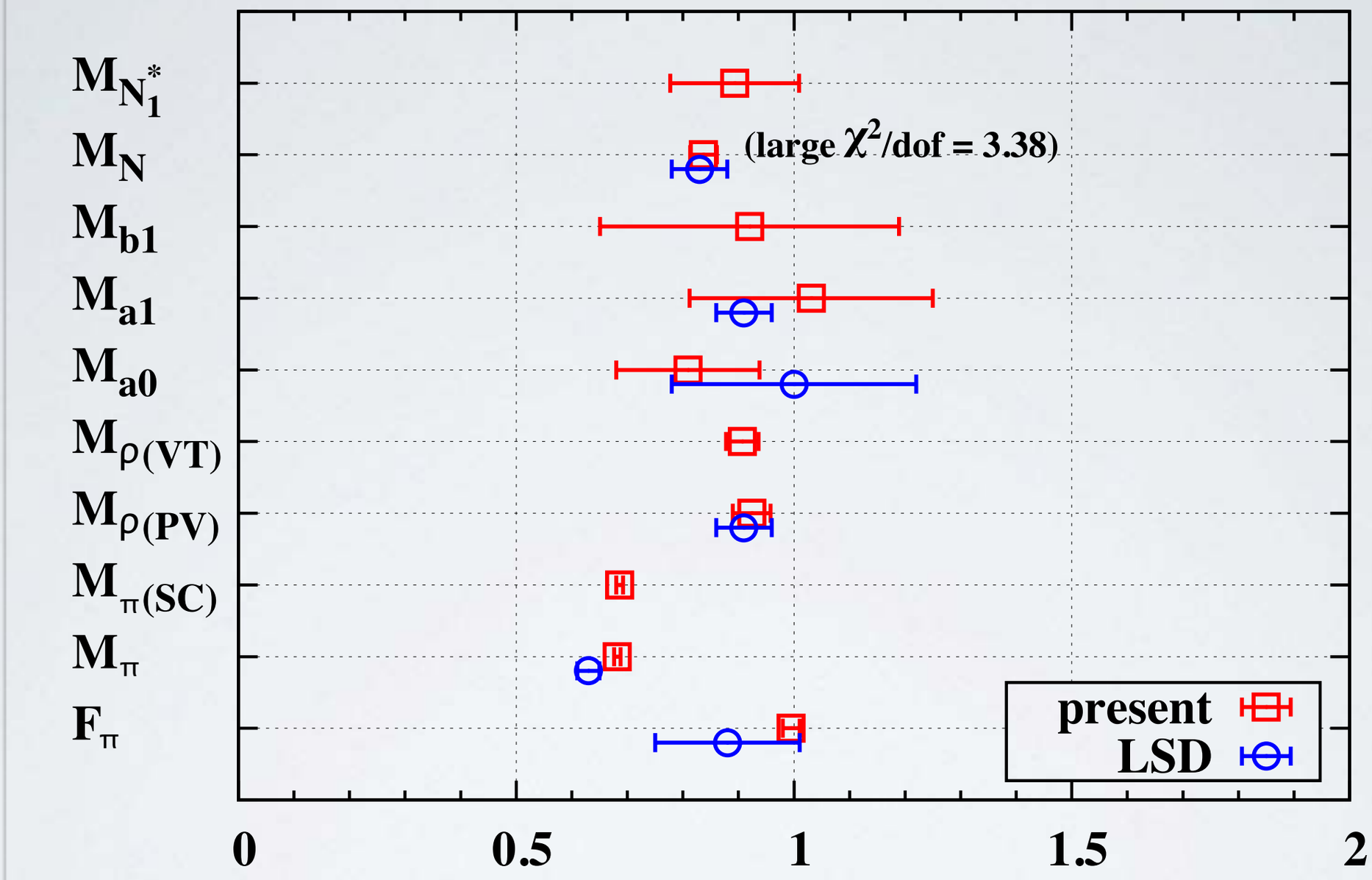
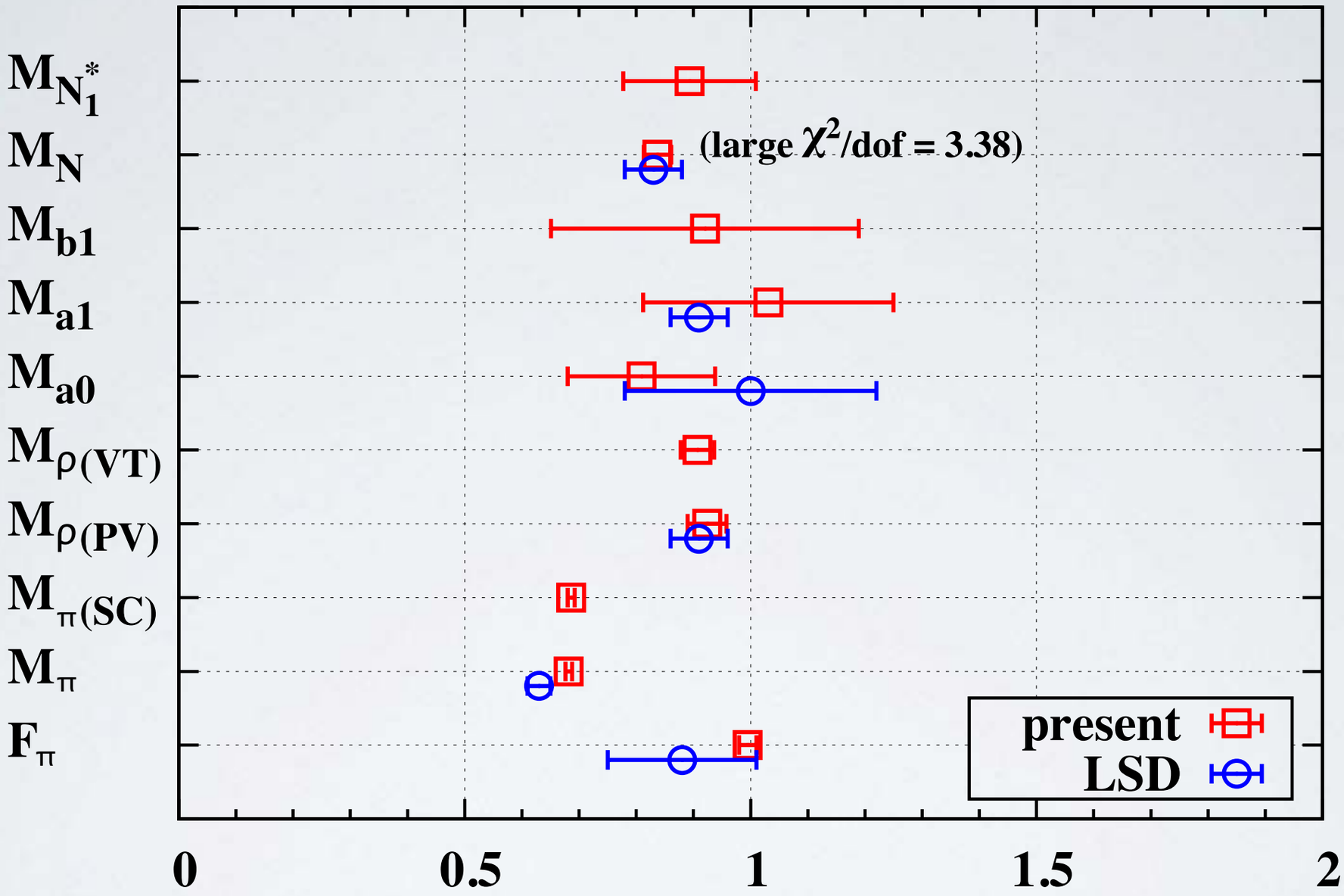


Not able to distinguish between
hyper-scaling fit with $\gamma \sim 0.96(6)$
and quadratic fit with finite intercept $\neq 0$

LatKMI arxiv:1610.07011



LatKMI arxiv:1610.07011 | LSD arxiv:1405.4752



All the states studied in the spectrum have $\gamma \sim 1$ except for the pseudoscalar.
Comparison with different lattice discretizations: staggered and domain wall fermions

LatKMI arxiv:1610.07011 | LSD arxiv:1405.4752