SU(4)/Sp(4) composite Higgs Model

2022.01.18 TQCD workshop @ Academia Sinica

C.-J. David Lin, Ho Hsiao (Paul)

國立陽明交通大學

NATIONAL YANG MING CHIAO TUNG UNIVERSITY

Outline

- Composite Higgs model
- Spectroscopy:
  - $N_f = 2$ Fundamental dynamical fermions
  - $n_f = 3$ Antisymmetric dynamical fermions (preliminary)
  - partially quenched chimera baryon (preliminary)
- Summary and outlook

Collaboration

Prifysgol Abertawe
Swansea University

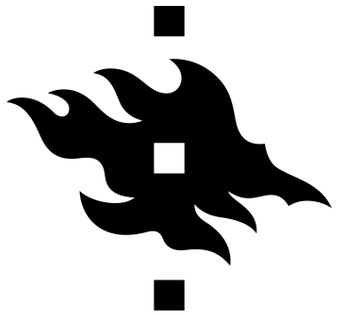
Ed Bennett, Jack Holligan, Biagio Lucini, Michele Mesiti, Maurizio Piai

Jong-Wan Lee, Deog Ki Hong

부산대학교
PUSAN NATIONAL UNIVERSITY

Trinity College Dublin
The University of Dublin

Davide Vadacchino



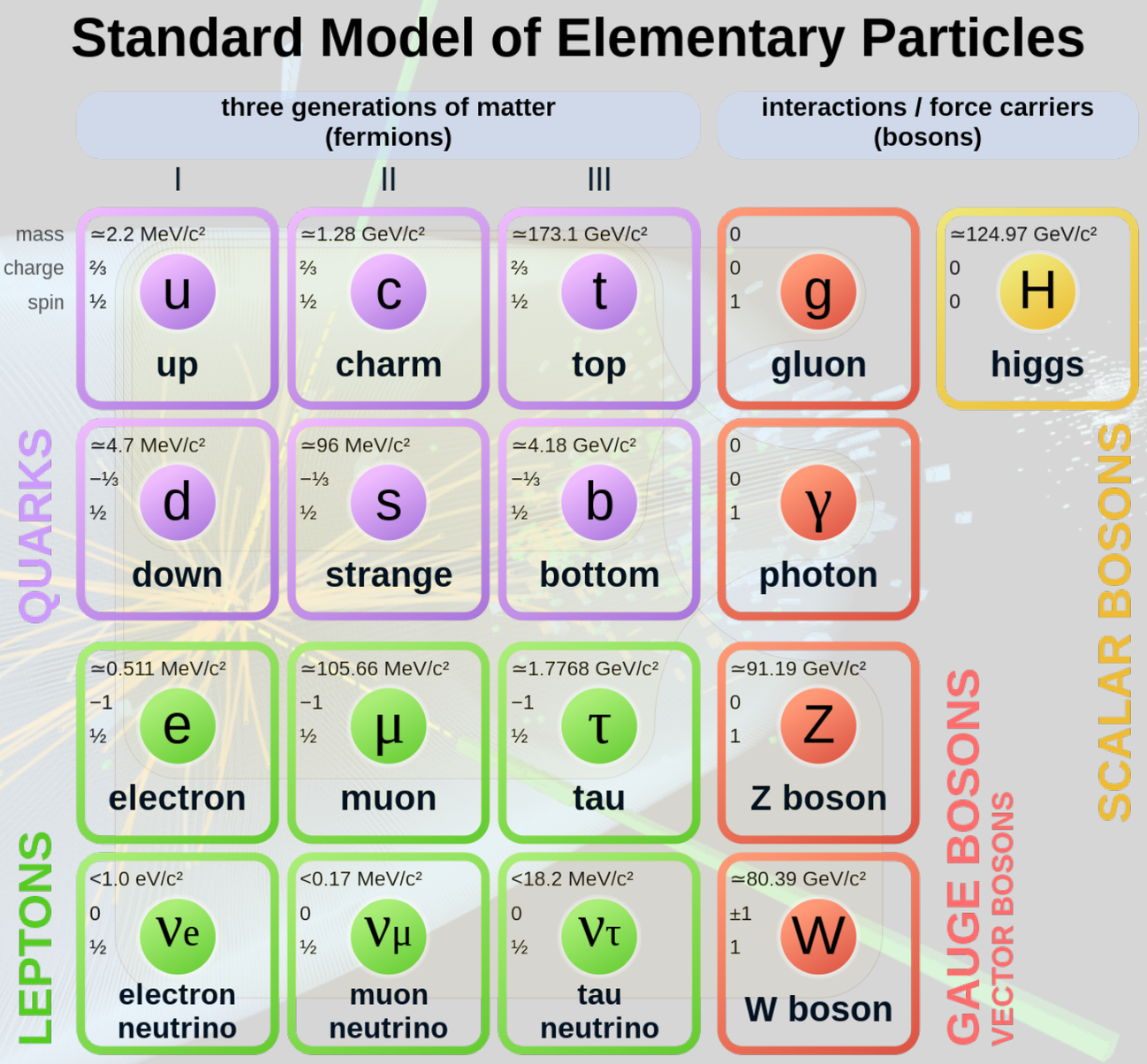
HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

Jarno Rantaharju

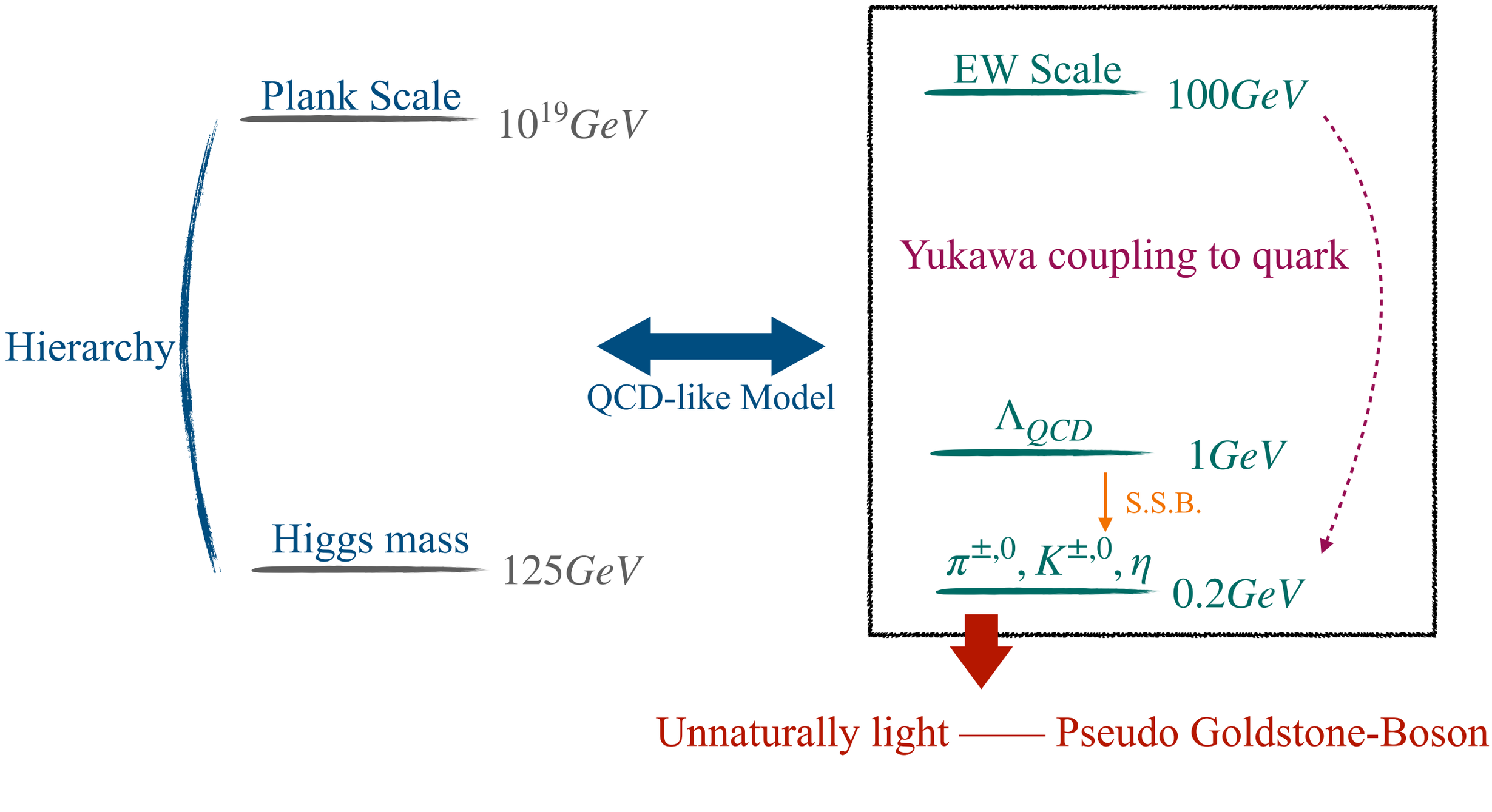
Physics beyond standard model

- The origin of mass
- Dark matter/energy
- Gravity
- Masses of neutrinos
- Asymmetry of matter and antimatter

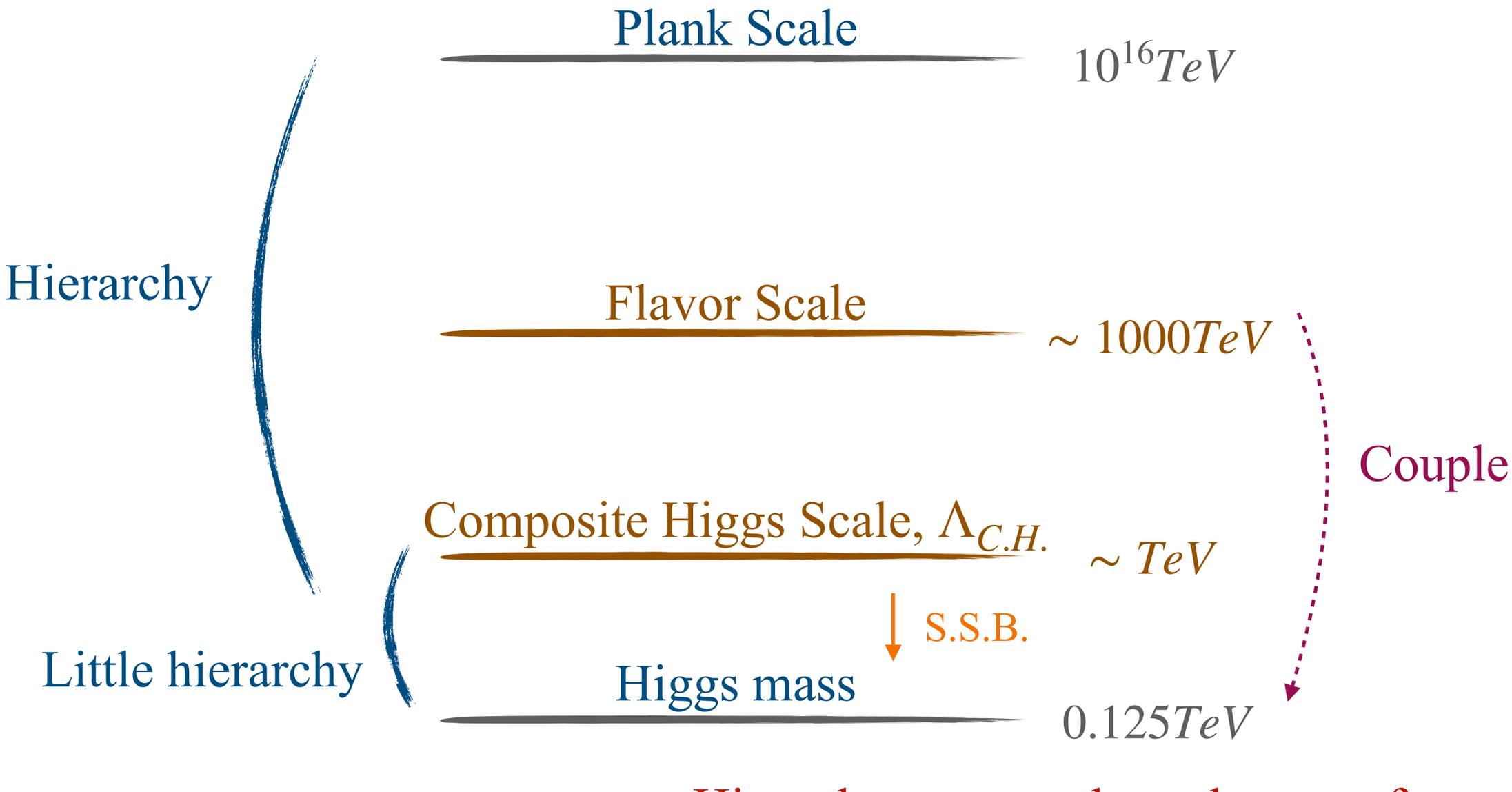
CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000



Composite Higgs Model



Composite Higgs Model



Higgs boson as a bound state of new strong dynamics, which is lighter because of being a Pseudo Goldstone Boson.

Composite Higgs Model

Name	Gauge group	ψ	χ	Baryon type
M1	$SO(7)$	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$\psi\chi\chi$
M2	$SO(9)$	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$\psi\chi\chi$
M3	$SO(7)$	$5 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M4	$SO(9)$	$5 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M5	$Sp(4)$	$5 \times \mathbf{A_2}$	$6 \times \mathbf{F}$	$\psi\chi\chi$
M6	$SU(4)$	$5 \times \mathbf{A_2}$	$3 \times (\mathbf{F}, \overline{\mathbf{F}})$	$\psi\chi\chi$
M7	$SO(10)$	$5 \times \mathbf{F}$	$3 \times (\mathbf{Spin}, \overline{\mathbf{Spin}})$	$\psi\chi\chi$
M8	$Sp(4)$	$4 \times \mathbf{F}$	$6 \times \mathbf{A_2}$	$\psi\psi\chi$
M9	$SO(11)$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M10	$SO(10)$	$4 \times (\mathbf{Spin}, \overline{\mathbf{Spin}})$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M11	$SU(4)$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$6 \times \mathbf{A_2}$	$\psi\psi\chi$
M12	$SU(5)$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$3 \times (\mathbf{A_2}, \overline{\mathbf{A_2}})$	$\psi\psi\chi$, $\psi\chi\chi$

D. Franzosi and G. Ferretti, arXiv:1905.08273

Our project

- 2 fundamental fermions + 3 antisymmetric fermions
- Breaking pattern:

$$G/H = SU(4)\times SU(6) \,/\, Sp(4)\times SO(6)$$

- SU(3) embedded in antisymmetric representation:

$$SU(6) \to SO(6) \supset SU(3)$$

Field	Sp(4) Gauge	SU(4) global	SU(6) global
A_μ	10	1	1
ψ	4	4	1
χ	5	1	6

Our project

- Top partner — Chimera baryon

$$\Psi = (\psi\psi\chi)$$

Carry QCD colour

- Colour neutral under Sp(4) gauge
- Having same quantum number can mix with the top quark, providing an origin of its mass — <u>partial top compositeness</u>

Our project

Study strategy

- Study the spectrum to gain the basic understanding of the theories

- Mesonic operators:

Label M	Interpolating operator $\mathcal{O}_M$	Meson in QCD	J^P	$Sp(4)$	$SO(6)$
PS	$\overline{Q^i}\gamma_5 Q^j$	π	0^-	$5(+1)$	1
S	$\overline{Q^i} Q^j$	a_0	0^+	$5(+1)$	1
V	$\overline{Q^i}\gamma_\mu Q^j$	ρ	1^-	10	1
T	$\overline{Q^i}\gamma_0\gamma_\mu Q^j$	ρ	1^-	$10(+5+1)$	1
AV	$\overline{Q^i}\gamma_5\gamma_\mu Q^j$	a_1	1^+	$5(+1)$	1
AT	$\overline{Q^i}\gamma_5\gamma_0\gamma_\mu Q^j$	b_1	1^+	$10(+5+1)$	1
ps	$\overline{\Psi^k}\gamma_5\Psi^m$	π	0^-	1	$20'(+1)$
s	$\overline{\Psi^k}\Psi^m$	a_0	0^+	1	$20'(+1)$
v	$\overline{\Psi^k}\gamma_\mu\Psi^m$	ρ	1^-	1	15
t	$\overline{\Psi^k}\gamma_0\gamma_\mu\Psi^m$	ρ	1^-	1	$15(+20'+1)$
av	$\overline{\Psi^k}\gamma_5\gamma_\mu\Psi^m$	a_1	1^+	1	$20'(+1)$
at	$\overline{\Psi^k}\gamma_5\gamma_0\gamma_\mu\Psi^m$	b_1	1^+	1	$15(+20'+1)$

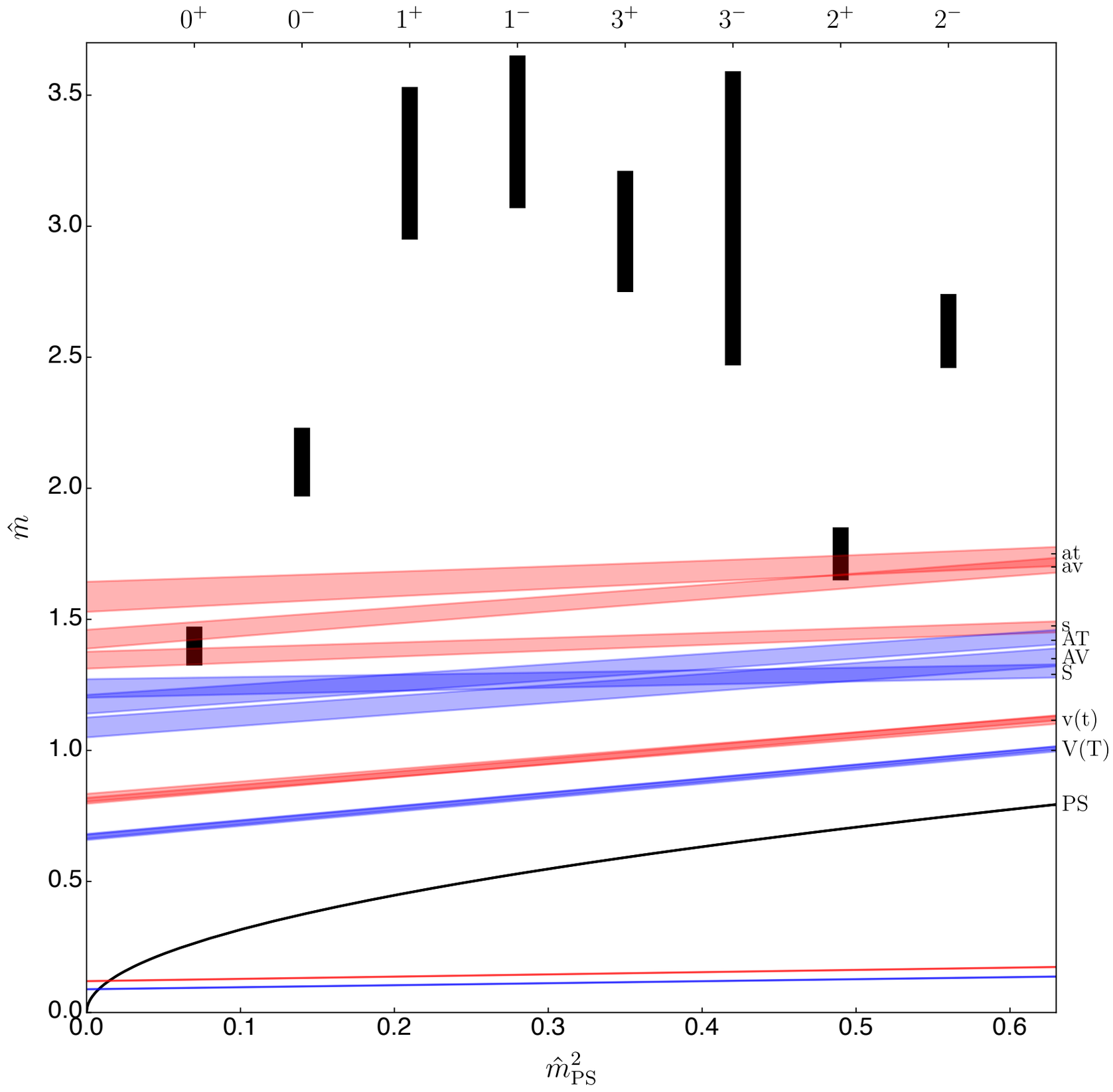
Our project

Study strategy

- Quenched fundamental and antisymmetry fermions arXiv:1912.06505
- $N_f = 2$ dynamical fundamental fermions arXiv:1909.12662
- $n_f = 3$ dynamical antisymmetric fermions Ongoing
  - partially quenched chimera baryon
- Fully dynamical 2F + 3AS fermions
  - Chimera baryon
  - 4-fermion operator matrix elements (relevant to generating Higgs mass)

Results

Quench spectrum



Results

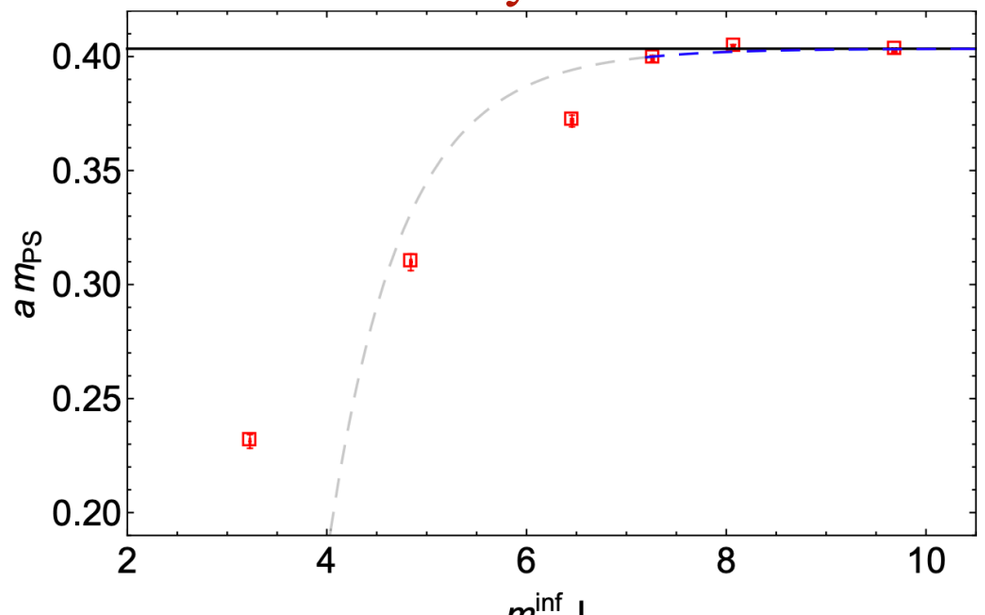
Dynamical fermions-
Finite volume correlation

$$m_{\rm PS}^2 = M^2\left(1 + a_M\frac{A(M)+A_{\rm FV}(M)}{F^2} + b_M(\mu)\frac{M^2}{F^2} + \mathcal{O}(M^4)\right)$$

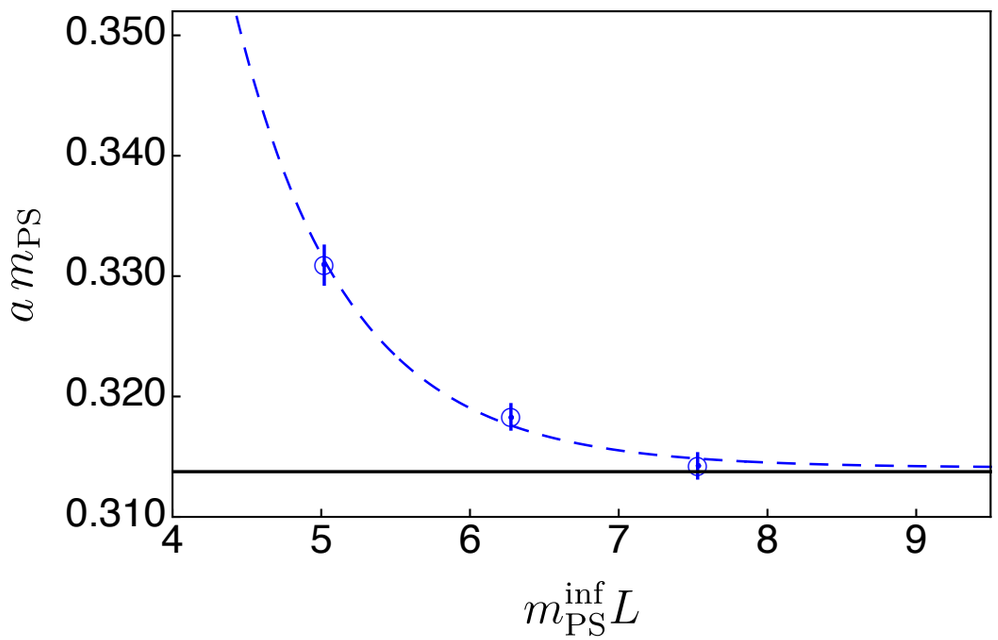
$$A(M) = -\frac{M^2}{16\pi^2}\log\frac{M^2}{\mu^2} \text{ and } A_{\rm FV}(M) \overset{ML\gg 1}{\longrightarrow} -\frac{3}{4\pi^2}\left(\frac{M\pi}{2L^3}\right)^{1/2}\exp[-ML],$$

$$a_M = \begin{cases} \frac{1}{2} - \frac{1}{2n_f}, & \text{for } SU(2N_f) \to SO(2N_f), \\ -\frac{1}{n_f}, & \text{for } SU(N_f)\times SU(N_f) \to SU(N_f), \\ -\frac{1}{2} - \frac{1}{n_f}, & \text{for } SU(2N_f) \to Sp(2N_f)\,. \end{cases}$$

Antisymmetric

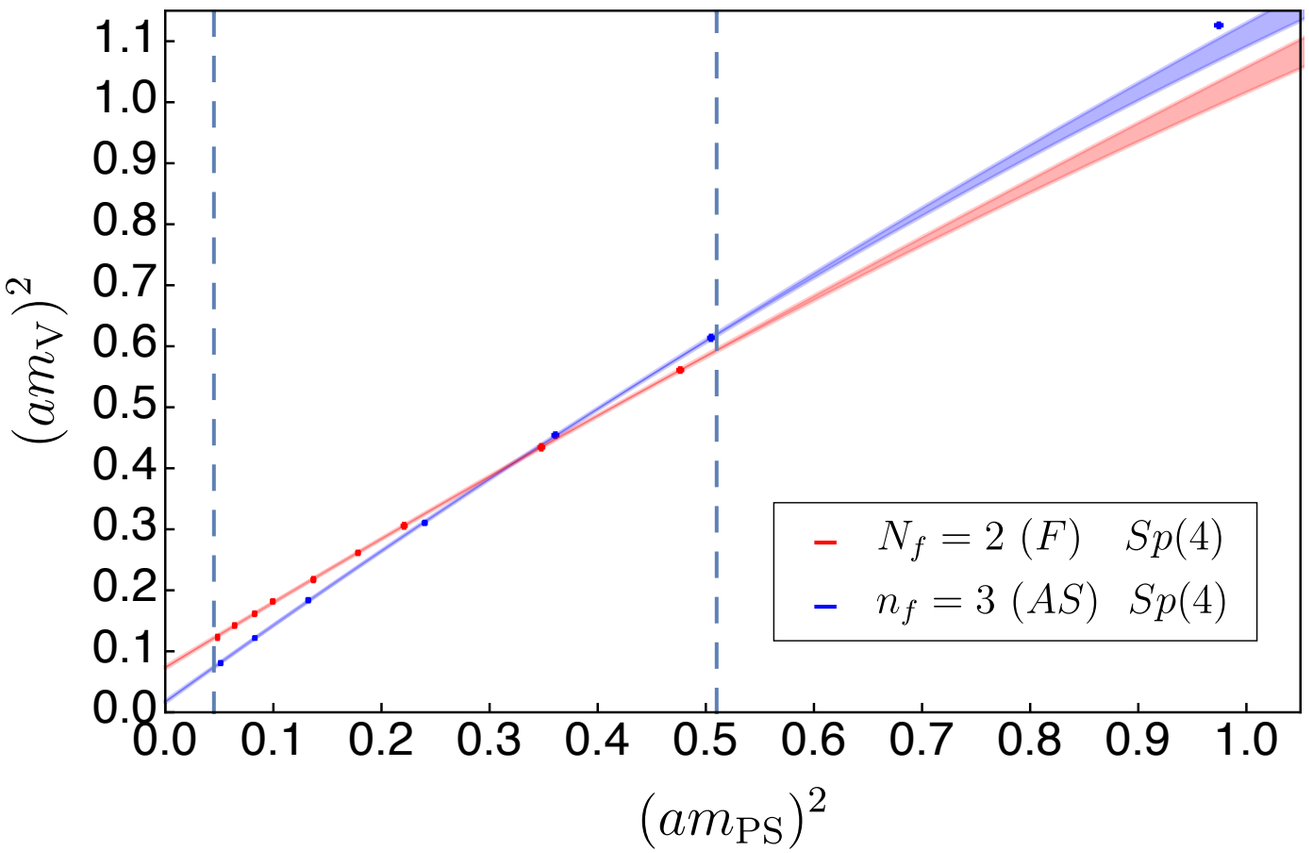


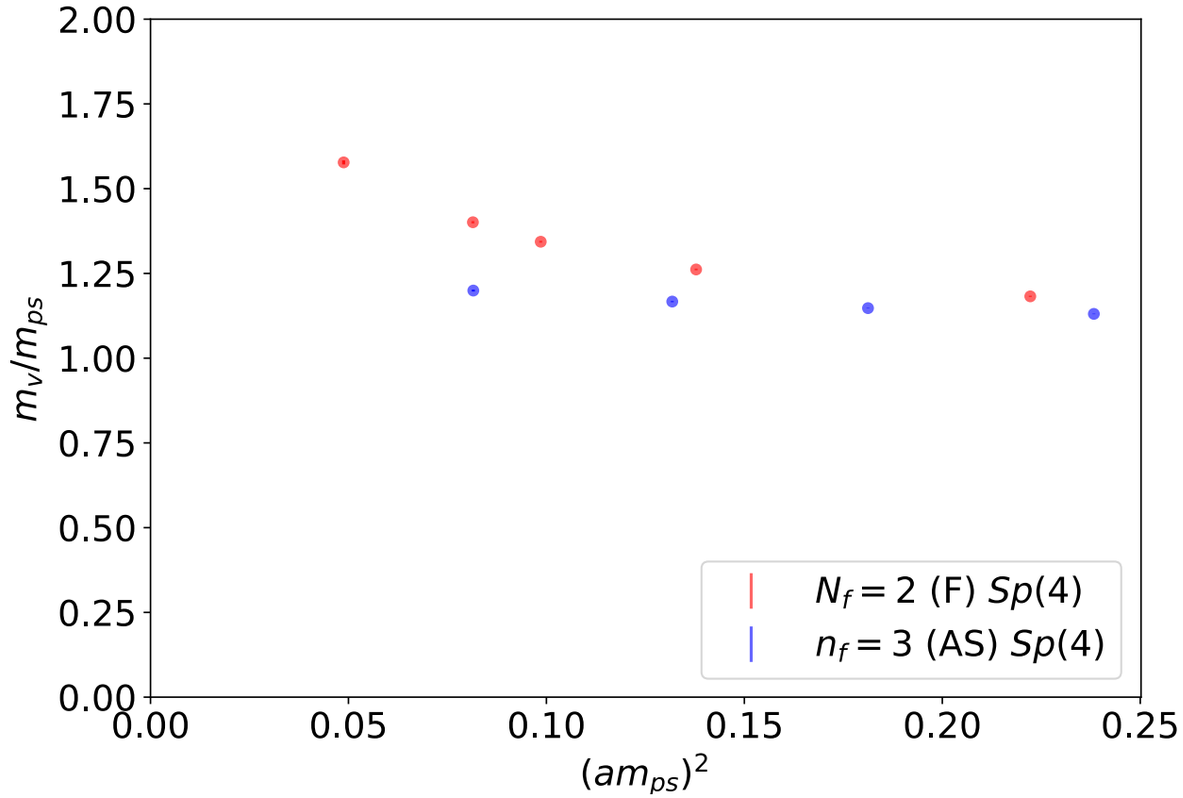
Fundamental



Results

Massless extrapolation

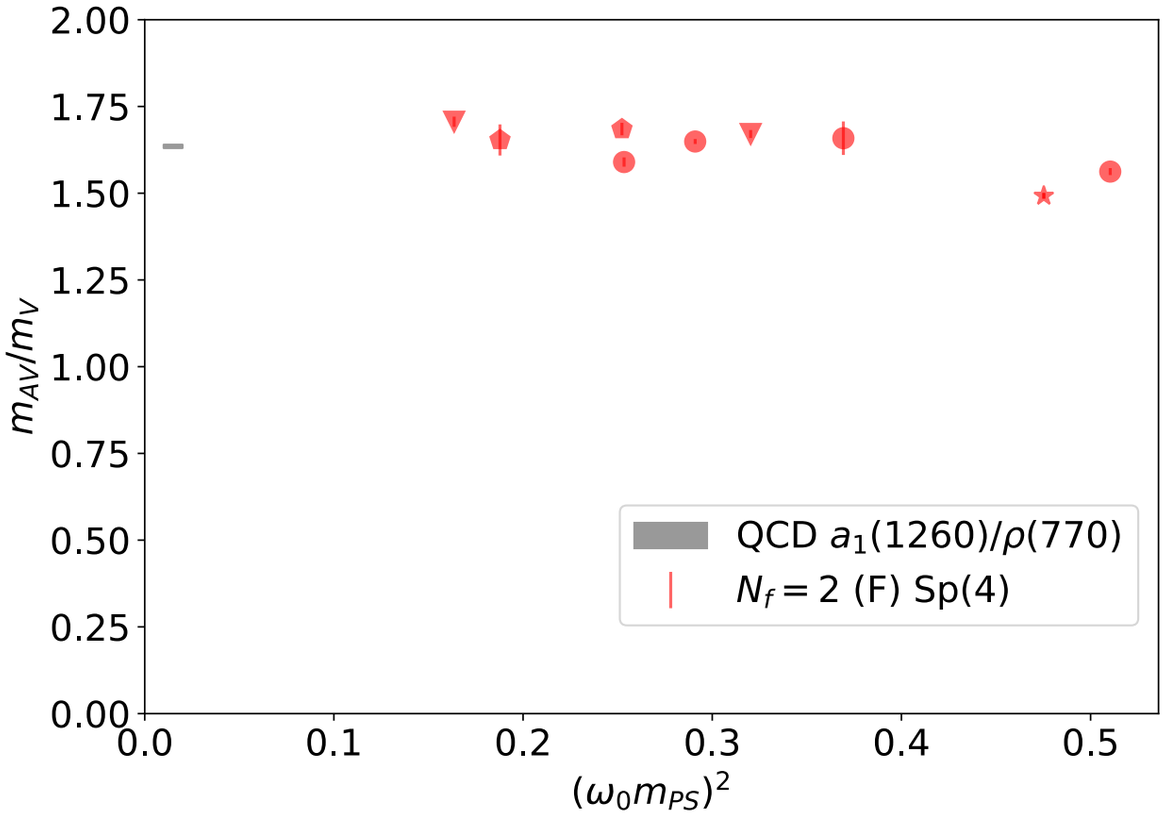


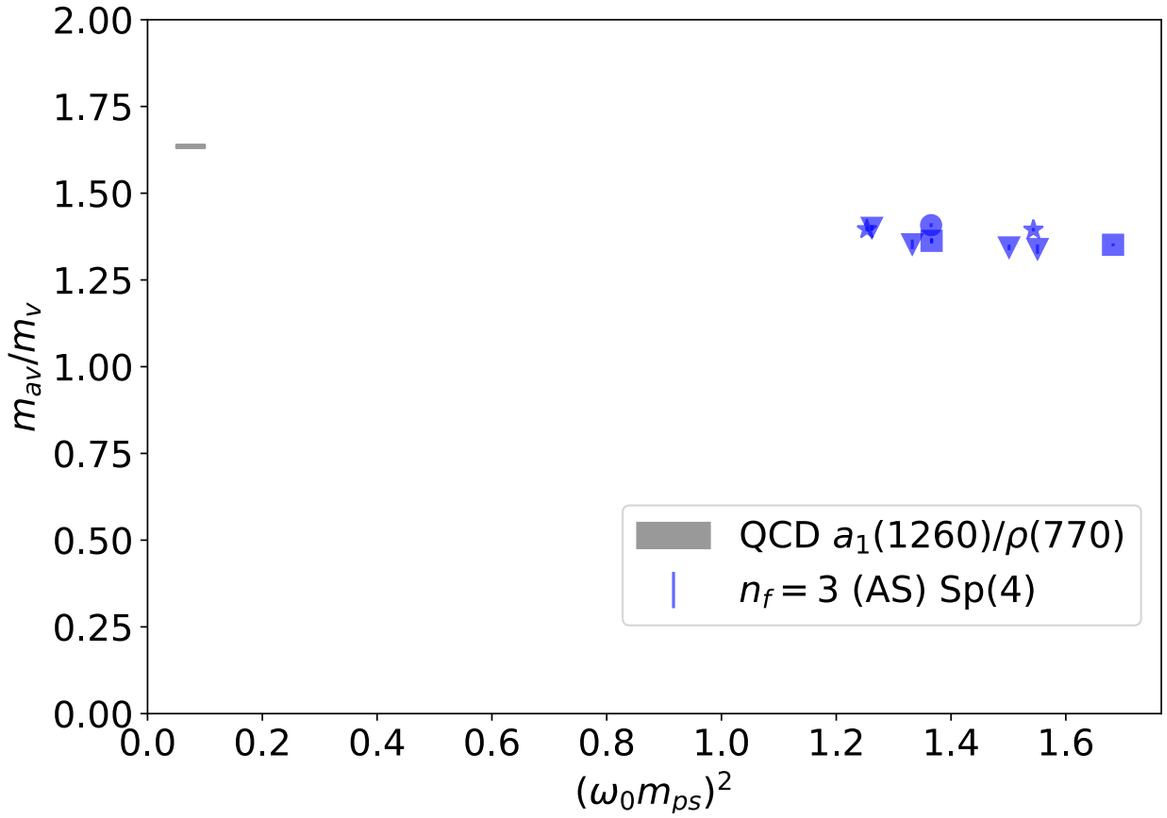


The massless extrapolations obtained with fixed beta values, which are 7.2 and 6.7 for fundamental and antisymmetric representation respectively. The dash lines refer to the fit range.

Results

m_{AV}/m_V

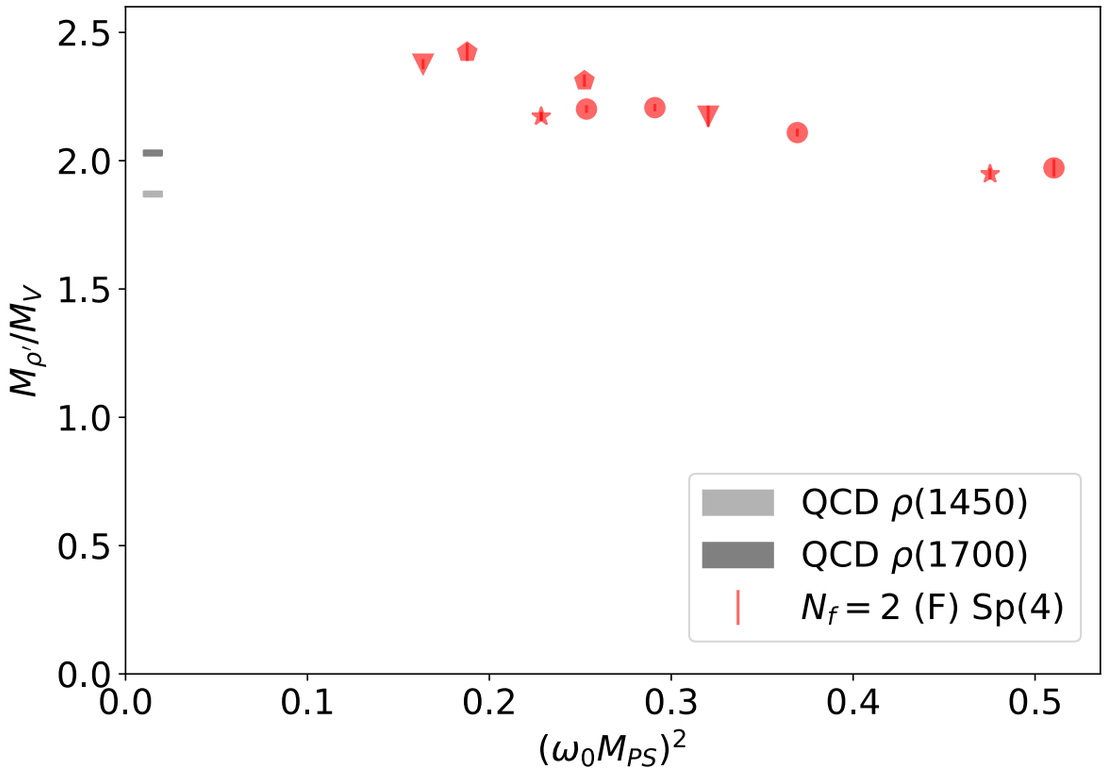


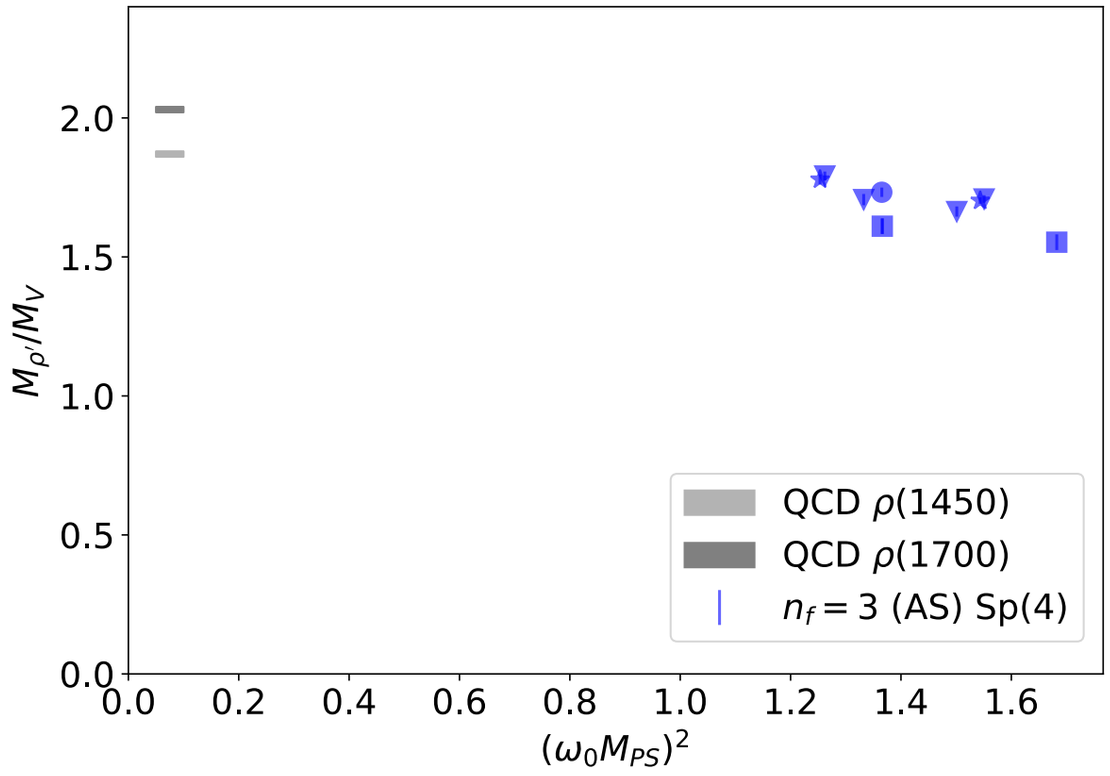


The ratio between vector meson and axial-vector meson as a function of pesudoscalar meson mass squared in gradient flow scale.

Results

$m_{\rho'}/m_{\rho}$

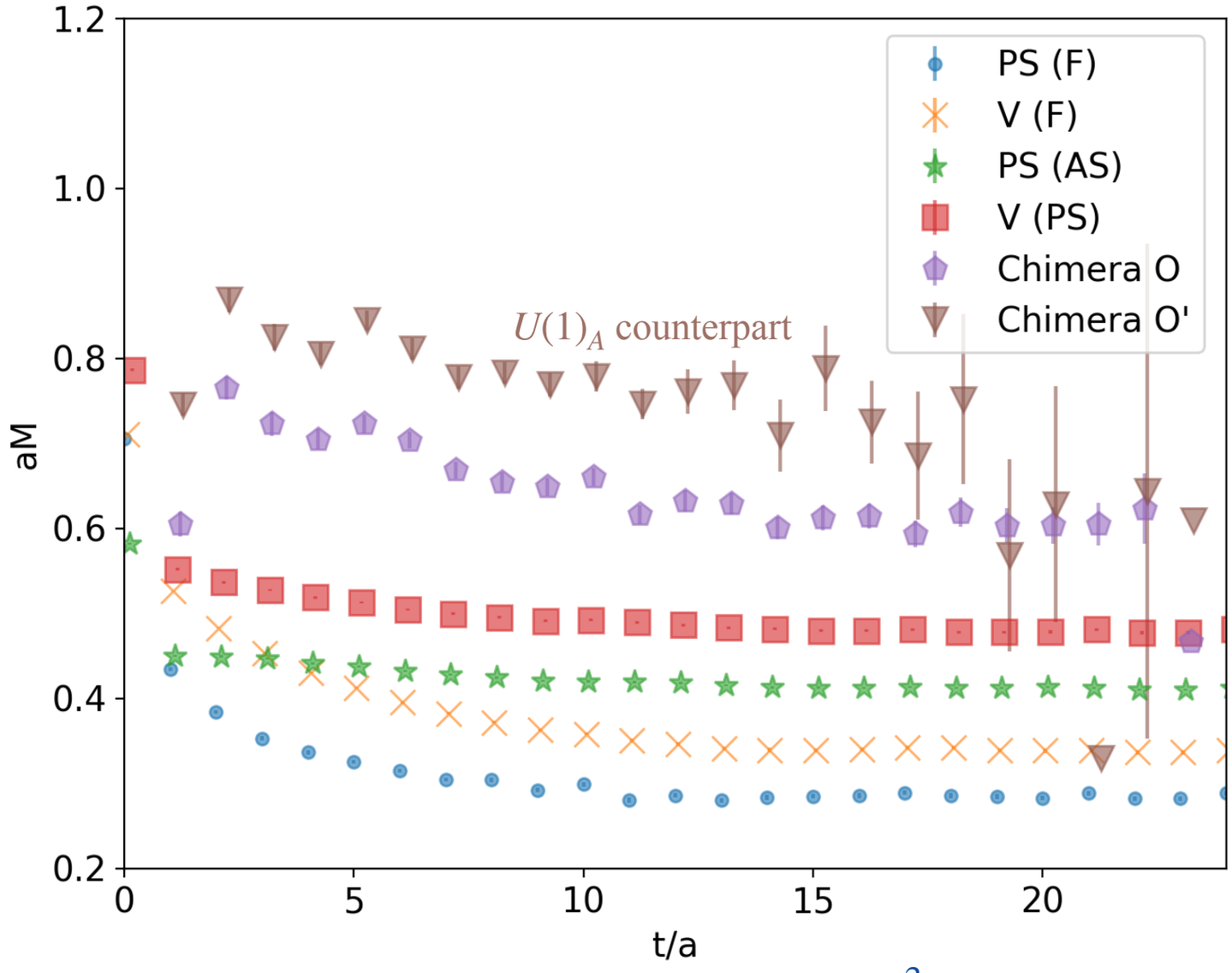




The plot of ratio $m_{\rho'}/m_{\rho}$ against $(\omega_0 m_{ps})^2$. The blue dots are in antisymmetric representation and red dots represents the ratio in fundamental representation.

Results

Partially quenched Chimera Baryon



Effective masses plot measured from 48×24^3 lattice with dynamical antisymmetric fermion. The parameters used for the calculation are $\beta = 6.65$ and $m_0 = -1.07$. We control the ratio of m_{PS}/m_V having close value in two representations, where the quenched fundamental bare mass is $m_F = -0.734$.

Summary

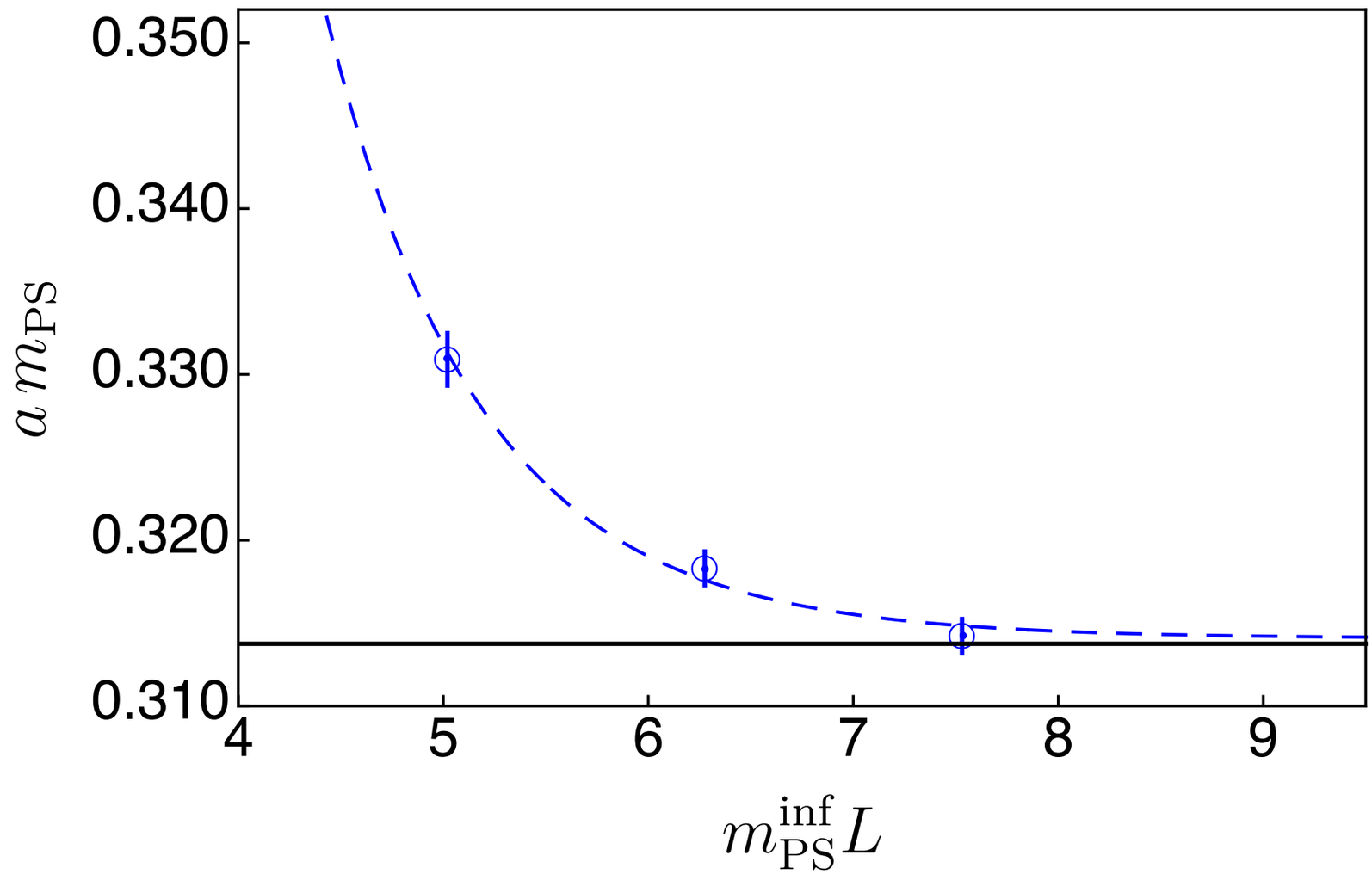
- Composite Higgs model is a theory exploring new physics around ~Tev scale.
- We have studied mesonic spectrum of the theory with quenched fermions in two representations. In general, the mass of mesons in antisymmetric rep. is higher than the mass in fundamental rep.
- We present the results of dynamical calculations in two representations and discuss their finite volume effects.
- The mass ratios of m_{AV}/m_V and $m_{\rho'}/m_\rho$ in antisymmetric rep. is lower than the ratio in fundamental rep.
- The preliminary results of chimera baryon, which is related to the top compositeness, are presented and ready to be studied with fully dynamical fermions in mix-representation.

END

Thank you for listening

Results

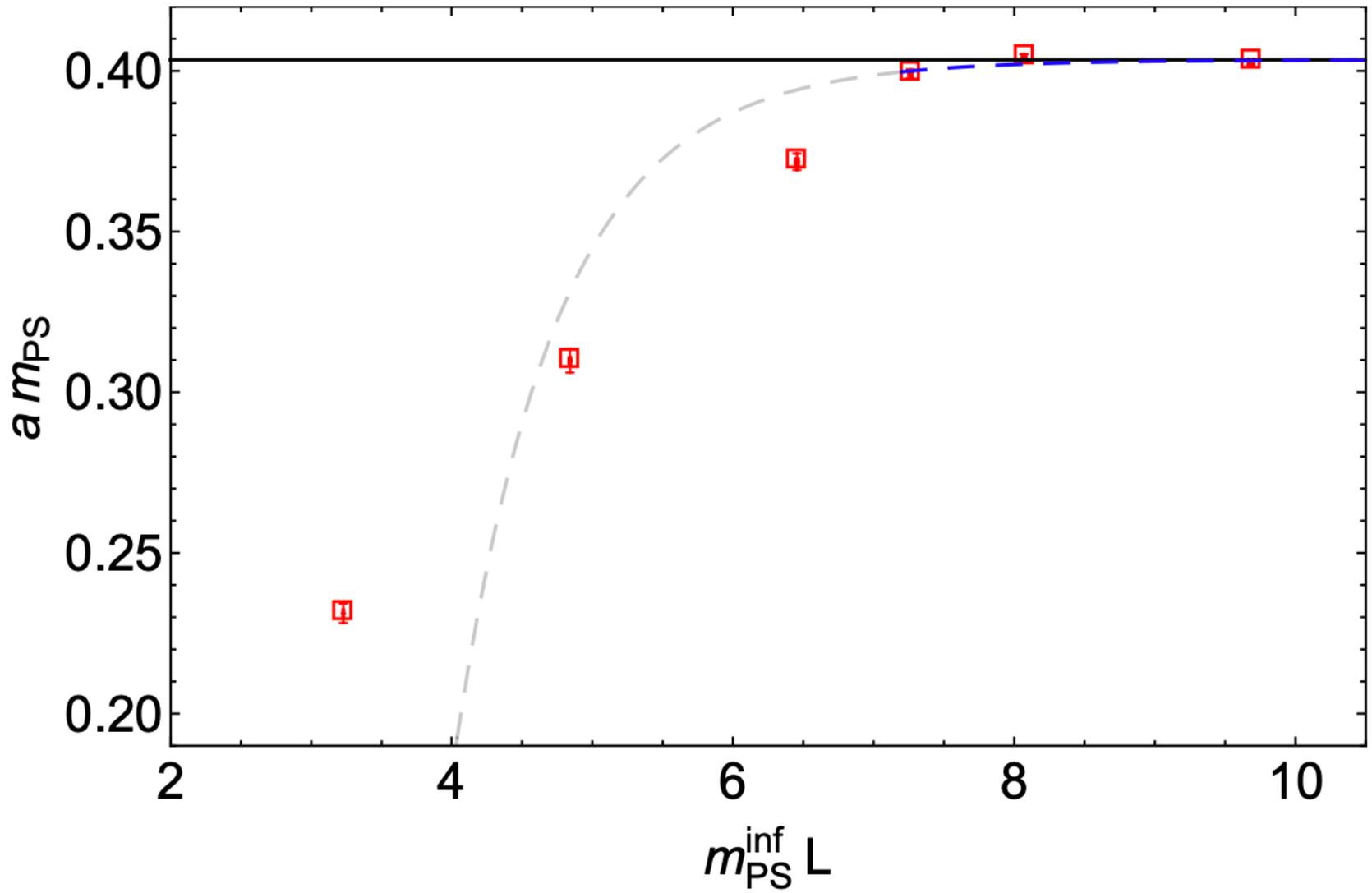
$N_f = 2$ dynamical fundamental fermions



Volume dependence of the pseudoscalar masses. Lattice parameters are $\beta = 7.2$ and $m_0 = -0.79$. The (blue) dashed and (black) solid lines denote the fit results and the extrapolated values in the infinite volume limit, respectively.

Results

Antisymmetric rep. Finite volume correlation



The lattice parameters used for the calculation are $\beta = 6.8$ and $m_0 = -1.03$. The pseudoscalar mass at the infinite volume is estimated by taking the one measured at the largest volume of 54×24^3.

Chimera baryon

Operator

$$
\begin{aligned}
\mathcal{O}^{L,R}_{\mathrm{CB},1} &= \left(\overline{Q^{1\,a}}\gamma^5 Q^{2\,b} + \overline{Q^{2\,a}}\gamma^5 Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,, \\
\mathcal{O}^{L,R}_{\mathrm{CB},2} &= \left(-i\overline{Q^{1\,a}}\gamma^5 Q^{2\,b} + i\,\overline{Q^{2\,a}}\gamma^5 Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,, \\
\mathcal{O}^{L,R}_{\mathrm{CB},4} &= -i\left(\overline{Q^{1\,a}}Q^{2\,b}_C + \overline{Q^{2\,a}_C}Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,, \\
\mathcal{O}^{L,R}_{\mathrm{CB},5} &= i\left(-i\,\overline{Q^{1\,a}}Q^{2\,b}_C + i\overline{Q^{2\,a}_C}Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,.
\end{aligned}
\qquad
\begin{aligned}
\mathcal{O}'^{\,L,R}_{\mathrm{CB},1} &= i\left(\overline{Q^{1\,a}}Q^{2\,b} + \overline{Q^{2\,a}}Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,, \\
\mathcal{O}'^{\,L,R}_{\mathrm{CB},2} &= \left(\overline{Q^{1\,a}}Q^{2\,b} - \overline{Q^{2\,a}}Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,, \\
\mathcal{O}'^{\,L,R}_{\mathrm{CB},4} &= \left(\overline{Q^{1\,a}}\gamma^5 Q^{2\,b}_C + \overline{Q^{2\,a}_C}\gamma^5 Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,, \\
\mathcal{O}'^{\,L,R}_{\mathrm{CB},5} &= i\left(\overline{Q^{1\,a}}\gamma^5 Q^{2\,b}_C - \overline{Q^{2\,a}_C}\gamma^5 Q^{1\,b}\right)\Omega_{bc}P_{L,R}\Psi^{k\,ca}\,.
\end{aligned}
$$

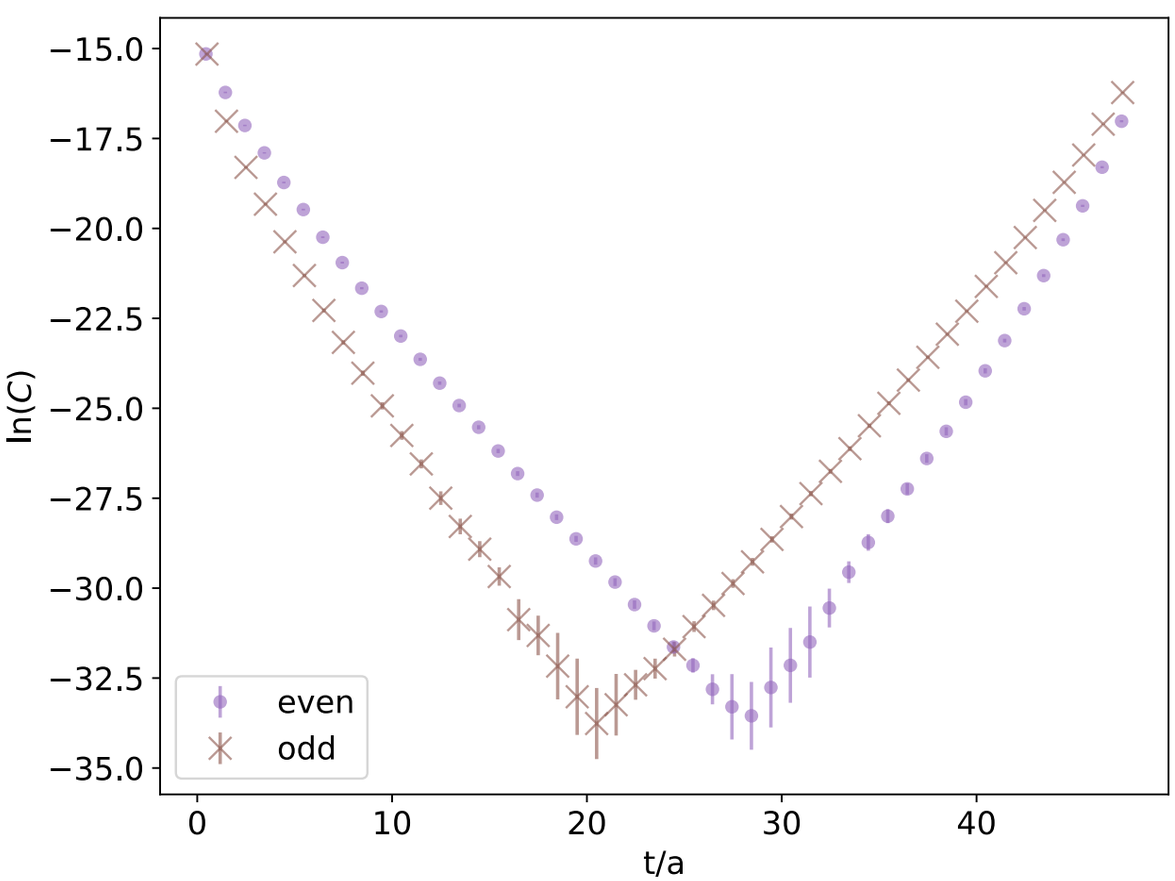
$$
\mathcal{O}^{k}_{\mathrm{CB},\,\alpha} = -i\,\overline{Q^{2\,a}_C}Q^{1\,b}\Omega_{bc}\Psi^{k\,ca}_{\alpha}
$$

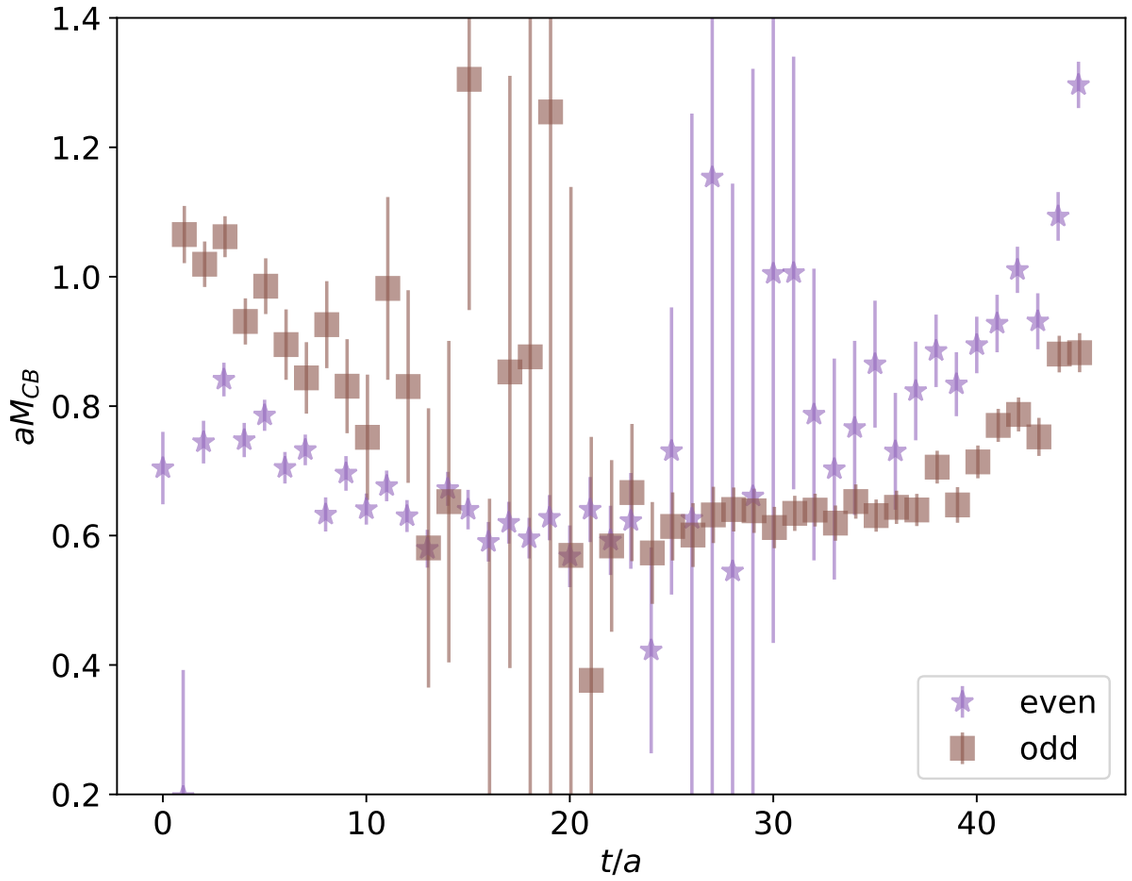
$$
\begin{aligned}
\langle \mathcal{O}_{\mathrm{CB}}(t)_\gamma \overline{\mathcal{O}_{\mathrm{CB}}(0)}_{\gamma'} \rangle &= \sum_{\vec{x}} Q^2(t,\vec{x})^d_\alpha \Omega_{da}(C\gamma^5)_{\alpha\beta} Q^1(t,\vec{x})^b_\beta \Omega_{bc}\Psi(t,\vec{x})^{ca}_\gamma \\
&\quad \times \overline{\Psi(0)^{c'a'}}_{\gamma'} \Omega^{c'b'}\Omega^{a'd'} \overline{Q^2(0)^{b'}}_{\alpha'} (C\gamma^5)_{\alpha'\beta'} \overline{Q^1(0)^{d'}}_{\beta'}, \\
&= \sum_{\vec{x}} \Omega_{da}\Omega_{bc}\Omega^{c'b'}\Omega^{a'd'} S_\Psi(t,\vec{x})^{ca,c'a'}_{\gamma,\gamma'} S^2_Q(t,\vec{x})^{d,b'}_{\alpha,\alpha'} (C\gamma^5)_{\alpha\beta} S^1_Q(t,\vec{x})^{b,d'}_{\beta,\beta'} (C\gamma^5)_{\alpha'\beta'}, \\
&= \sum_{\vec{x}} \Omega_{da}\Omega_{bc}\Omega^{c'b'}\Omega^{a'd'} S_\Psi(t,\vec{x})^{ca,c'a'}_{\gamma,\gamma'} \mathrm{Tr}\left(S^2_Q(t,\vec{x})^{d,b'} \left((C\gamma^5) S^1_Q(t,\vec{x})^{b,d'} (C\gamma^5)^T \right)^T \right),
\end{aligned}
$$

Results

Partially quenched Chimera Baryon

- Parity projection $P = \frac{1}{2}(1 \pm \gamma_0)$





The log plot of the chimera baryon correlators (left) and their effective mass plot (right) with the parity projection.