Selected new results from the Spectroscopy in the sextet BSM Model

Chik Him (Ricky) Wong

Lattice Higgs Collaboration (LatHC):

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Outline

- Review: Sextet model as Composite Higgs candidate
- Hadron spectroscopy in Isoscalar $J^{PC} = 0^{-+}$ (η) channel
  - Fermionic correlator
  - Gluonic operator
  - Improvement using Gradient Flow
  - Preliminary results
- Conclusion

Sextet model as Composite Higgs candidate

- Criteria for candidate models in composite Higgs scenario:
  - Generates Higgs boson consistent with phenomenology
  - Infrared pseudo-Fixed point(IRFP) $+$ Spontaneous χSB $\Rightarrow$ Models at the edge of Conformal Window
- $SU(3)$ $N_f = 2$ Sextet(Two-index symmetric) Model

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$a, b = 0, 1, 2$

- Why is it interesting?
  - Very close to Conformal Window
  - "Minimal" model
    - Spontaneous Chiral Symmetry Breaking:

$$SU(N_f)_L \times SU(N_f)_R \rightarrow SU(N_f)_V$$

    - 3 Nambu-Goldstone Bosons (BSM-π) out of $N_f^2 - 1$ are eaten in Higgs Mechanism:

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      while BSM-f_0 is identified as the Higgs boson H
    - $N_f^2 - 4$ massless BSM-π's *somehow* gains masses from additional interactions, but far separated from the eaten massless 3, yet not a concern if $N_f = 2$

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- Consistent with χSB
  - Static Quark Potential: Confining (Fodor et al, PoS (Lattice 2012) 025)
  - Chiral condensate: Non-zero (Fodor et al, PoS (LATTICE 2013) 089)
  - β function of g_R : No IRFP is observed (Fodor et al, Phys.Rev. D94 (2016) no.1, 014503)
- Hadron Spectroscopy
  - Action: Tree-level Symanzik-Improved 2-stout $\rho = 0.15$ smeared gauge action with Staggered $N_f = 2$ Sextet SU(3) fermions
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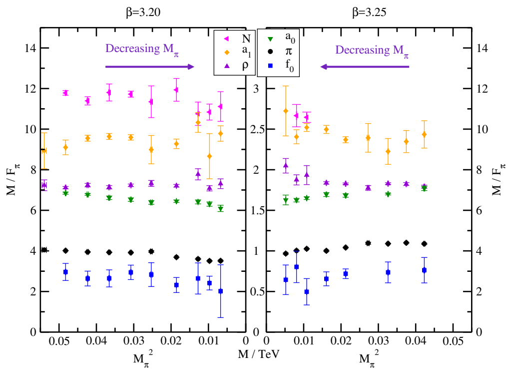

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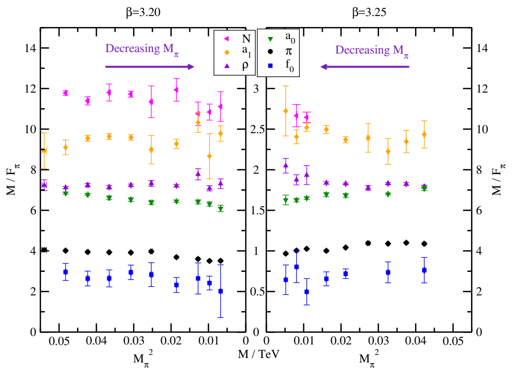

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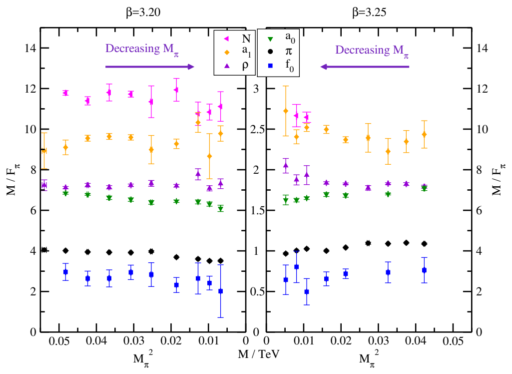

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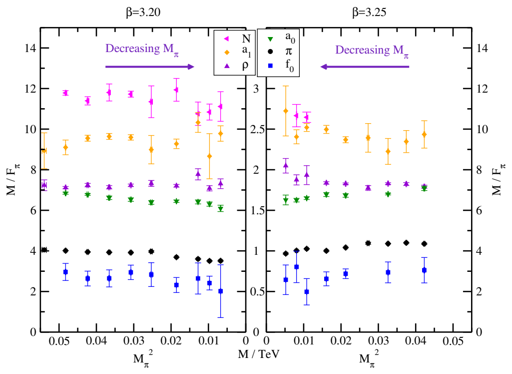

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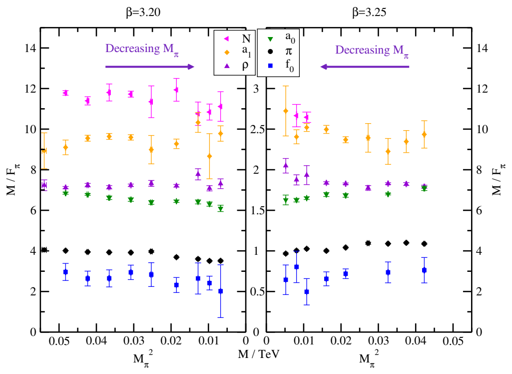

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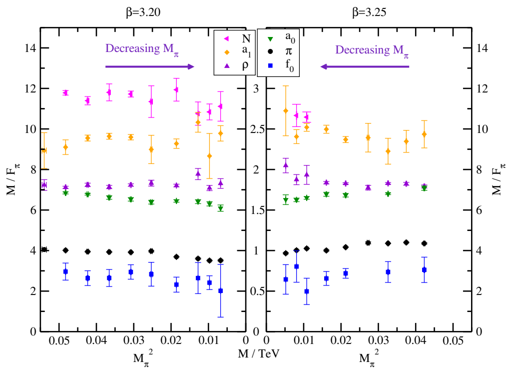

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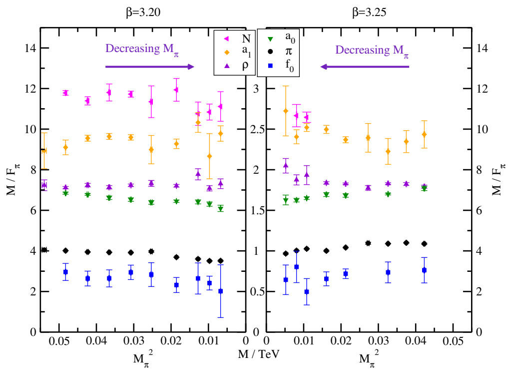

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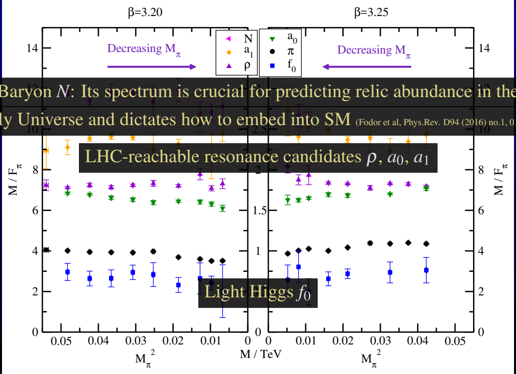

Baryon N: Its spectrum is crucial for predicting relic abundance in the early Universe and dictates how to embed into SM (Fodor et al, Phys.Rev. D94 (2016) no.1, 014503)

LHC-reachable resonance candidates ρ, a_0, a_1

Light Higgs f_0

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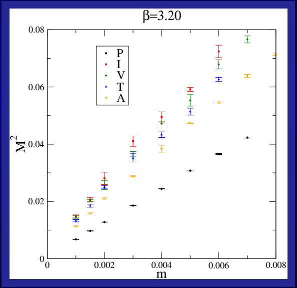
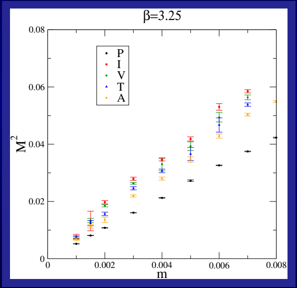
- Taste breaking
  - Goldstone spectrum depends on m with different slopes $\Rightarrow$ Taste breaking pattern is different from QCD





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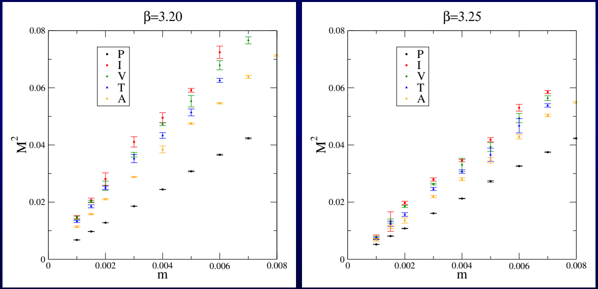

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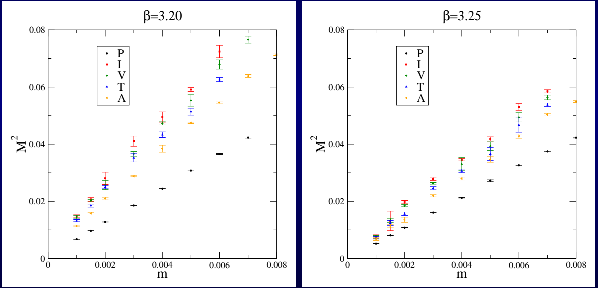

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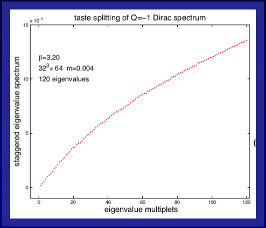

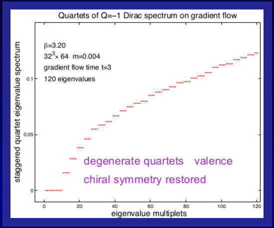

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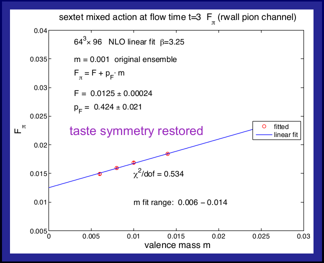

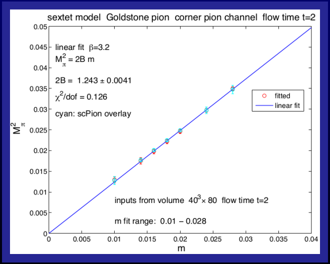

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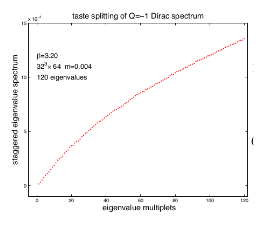

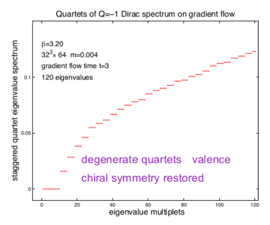

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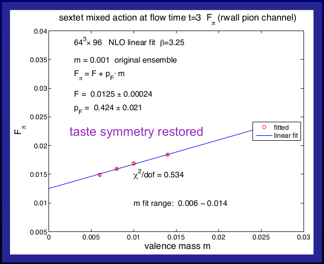
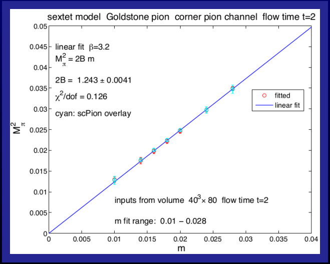
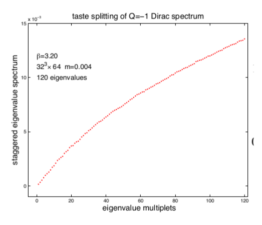
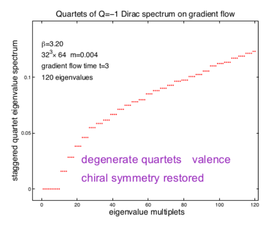




Sextet model as Composite Higgs candidate

- Taste breaking
  - Gradient Flow (Martin Luescher Commun.Math.Phys.293:899-919,2010) restores taste





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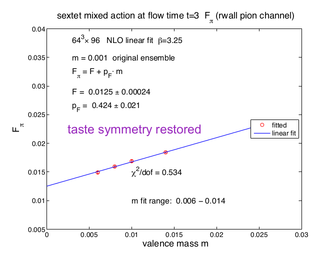

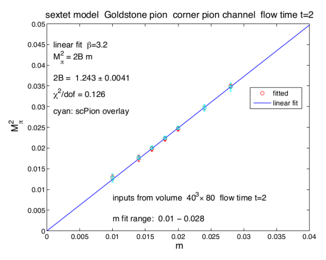

Hadron spectroscopy in η channel

- Where is M_η (Isoscalar $J^{PC} = 0^{-+}$)?
  - $\pi = \bar{\psi}\,\gamma_5\,C\,\psi\,,\ \psi = (u,d)^T$:
    NG boson
    $$\partial_\mu j_5^\mu \sim m j_5 \ \Rightarrow\ \lim_{m\to 0} M_\pi^2 = 0$$
  - $\eta = \bar{\psi}\,\gamma_5\,\psi\,,\ \psi = (u,d)^T$:
    would-be NG boson, but mass generated by $U(1)_A$ anomaly
    $$\partial_\mu j_5^\mu \sim 2N_f(N_c \pm 2)q,$$
    $+$: Symmetric, $-$: Anti-symmetric
  - Witten-Veneziano formula (E. Witten, G. Veneziano Nucl. Phys. B 159, 213,269 (1979)) predicts much higher mass than QCD in the chiral limit
    $$M_\eta^2 \sim \frac{6(N_c \pm 2)}{f_\pi^2}\chi_t|_{N_f=0}, \quad \chi_t|_{N_f=0} = \int dx \langle q(0)q(x)\rangle|_{N_f=0}$$

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Hadron spectroscopy in η channel

- Fermionic correlator

$$\langle \eta(\tau)\eta(\tau_0)\rangle \equiv -C(\tau-\tau_0) + 2D(\tau-\tau_0)$$

- Involves disconnected contribution $D(\tau-\tau_0)$ which are costly
- In the limit $\tau-\tau_0 \to \infty$,

$$-C(\tau-\tau_0) \propto A_\pi e^{-M_\pi(\tau-\tau_0)}$$

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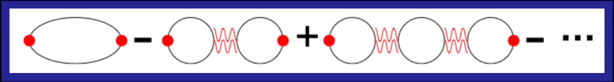

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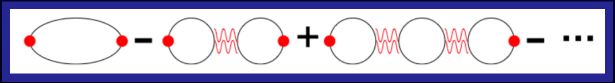

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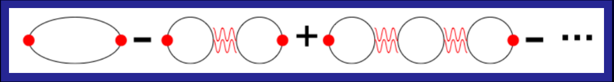

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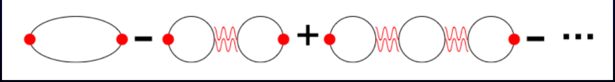

Hadron spectroscopy in η channel

- Gluonic operator (H. Fukaya, Phys. Rev. D 92, 111501 2015)
  - M_η can be extracted from the topological charge density:

$$q(x) = \frac{1}{32\pi^2}\varepsilon_{\mu\nu\rho\sigma}\mathrm{Tr}\, F_{cl}^{\mu\nu}F_{cl}^{\rho\sigma}(x)$$

$$\lim_{r\to\text{large}} -\langle q(x)q(y)\rangle \propto \frac{K_1(\,M_\eta r\,)}{r},\ r\equiv|x-y|$$

    $F_{cl}^{\mu\nu}$: Field Strength Tensor (clover term)
    K_1: Modified Bessel function of the second kind
  - Does not couple directly to pions $\Rightarrow$ Quieter
  - No inversions of Dirac operator $\Rightarrow$ Cheaper
  - Further speed-up by FFT

$$\langle q(x)q(y)\rangle = \frac{1}{4\pi^2}\int|\tilde{q}(k)|^2 e^{ik(x-y)}d^4k$$

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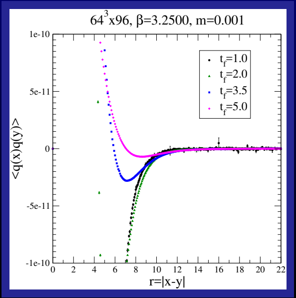
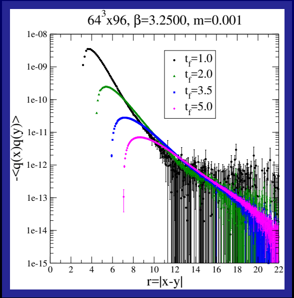
- Improvement from Gradient Flow
- Cut-off effects can be reduced by the lattice version of Gradient Flow with Wilson operator

$$\partial_t A_\mu(t,x) = -\frac{\partial S_{YM}}{\partial A_\mu}$$

- Smooths links similar to diffusion equation with diffusion length $\sqrt{8t}$ in lattice units
- Correlator is distorted by footprint $\Rightarrow$ Fitting range of r should be far enough $r >> 2\sqrt{8t}$





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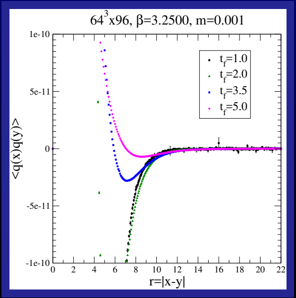

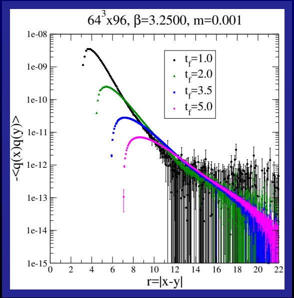

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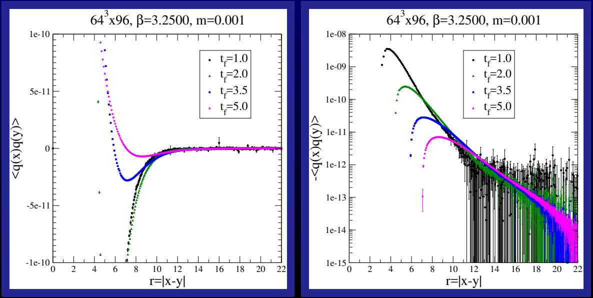

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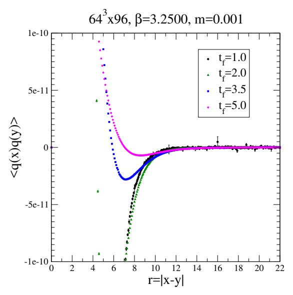
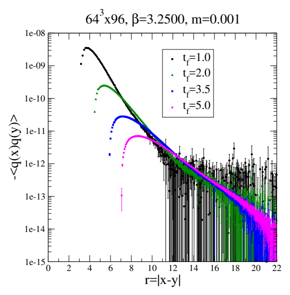
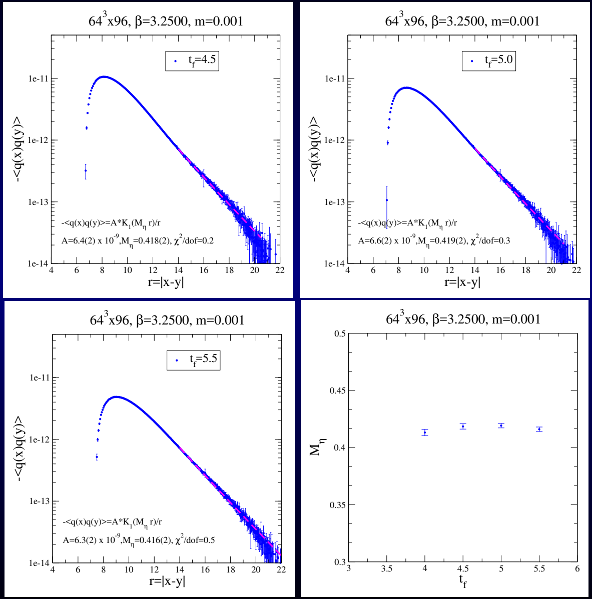




Preliminary Results



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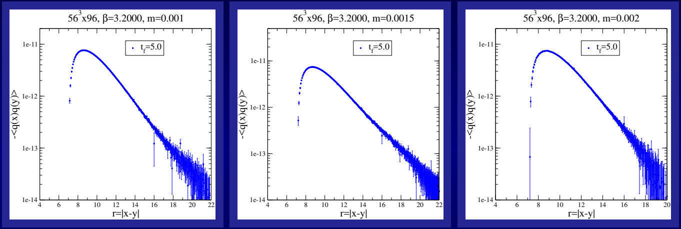
- M_η can be as heavy as > 3 TeV
- Measurements from more ensembles at different volumes, β's and m's are available and accumulating



- Further analysis:
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$$\lim_{|x_4-y_4|\to \text{large}} -\sum_{\vec{x},\vec{y}} \langle q(x)q(y)\rangle \propto e^{-M_\eta |x_4-y_4|}$$

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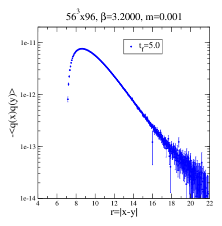

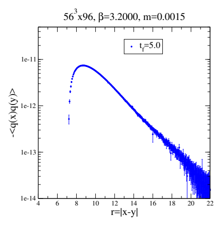

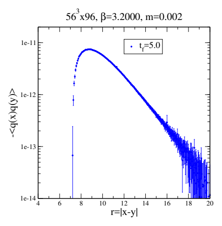

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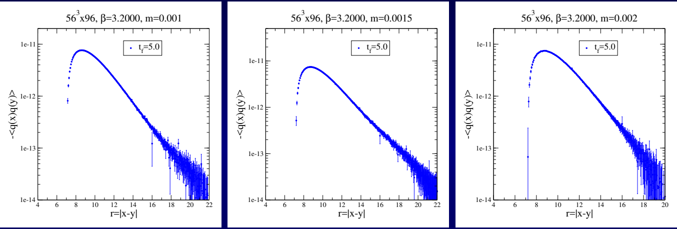

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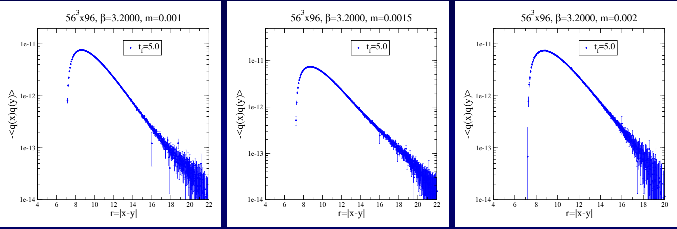

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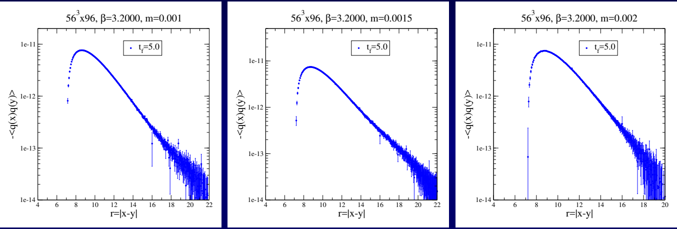

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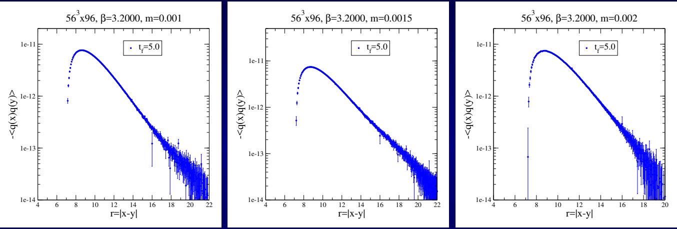

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- The sextet model remains an interesting candidate model of Composite Higgs scenario (More details can be found on Julius Kuti's talk on Mon)
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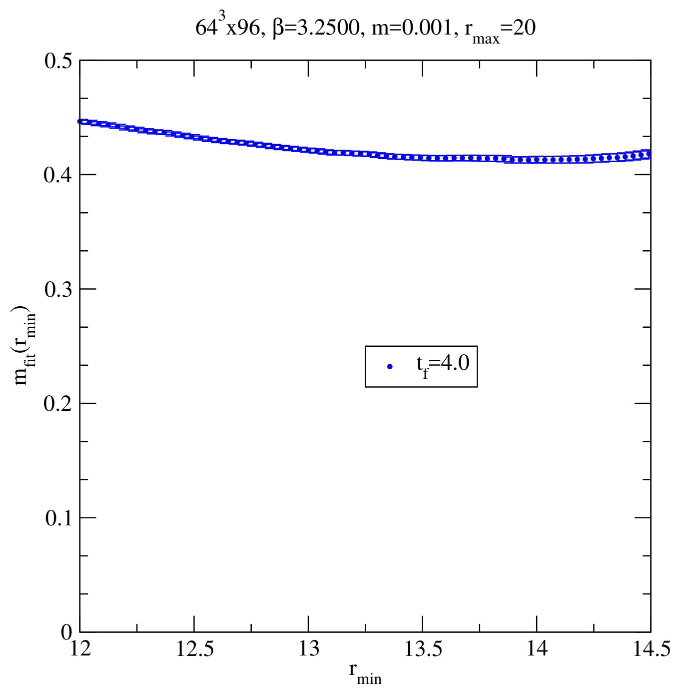
64^3x96, β=3.2500, m=0.001, r_{max}=20
0.5
0.4
0.3
0.2
0.1
0
$m_{fit}(r_{min})$
12
12.5
13
13.5
14
14.5
r_{min}
t_f=4.0