Lawrence Livermore National Laboratory

Lattice 2014,
Columbia University

Testing Composite Higgs models on the lattice

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Lattice **S**trong **D**ynamics collaboration

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L—S
D

Lattice Strong Dynamics Collaboration

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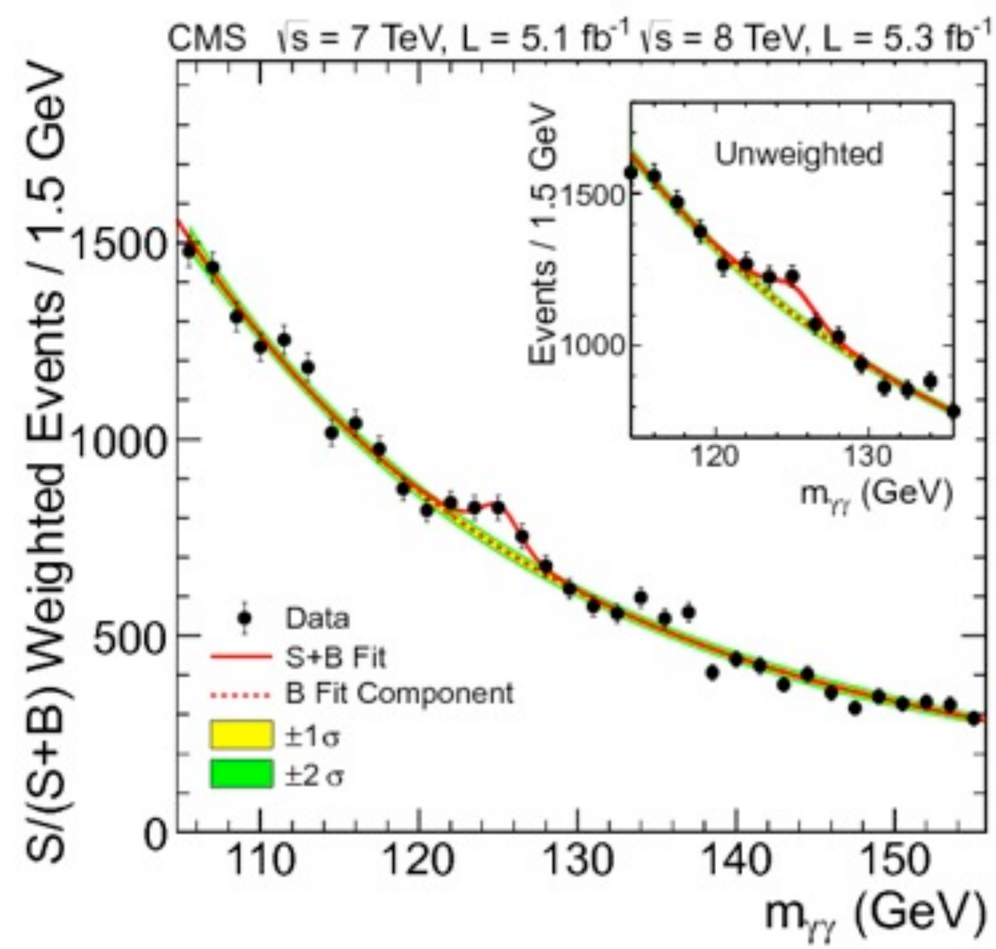
The SM Higgs boson

- Higgs boson discovery in Run I at LHC ➥ m_H=125.5GeV
- Higgs boson decays to ➥Gauge bosons and leptons+quarks
- Signal strength measurements ➥ coupling constant measurements
- Run II at LHC ➥ deviations from SM couplings? NP resonances above 1TeV?
- SM description seems to be working but is not complete

CMS-PLB716(2012)



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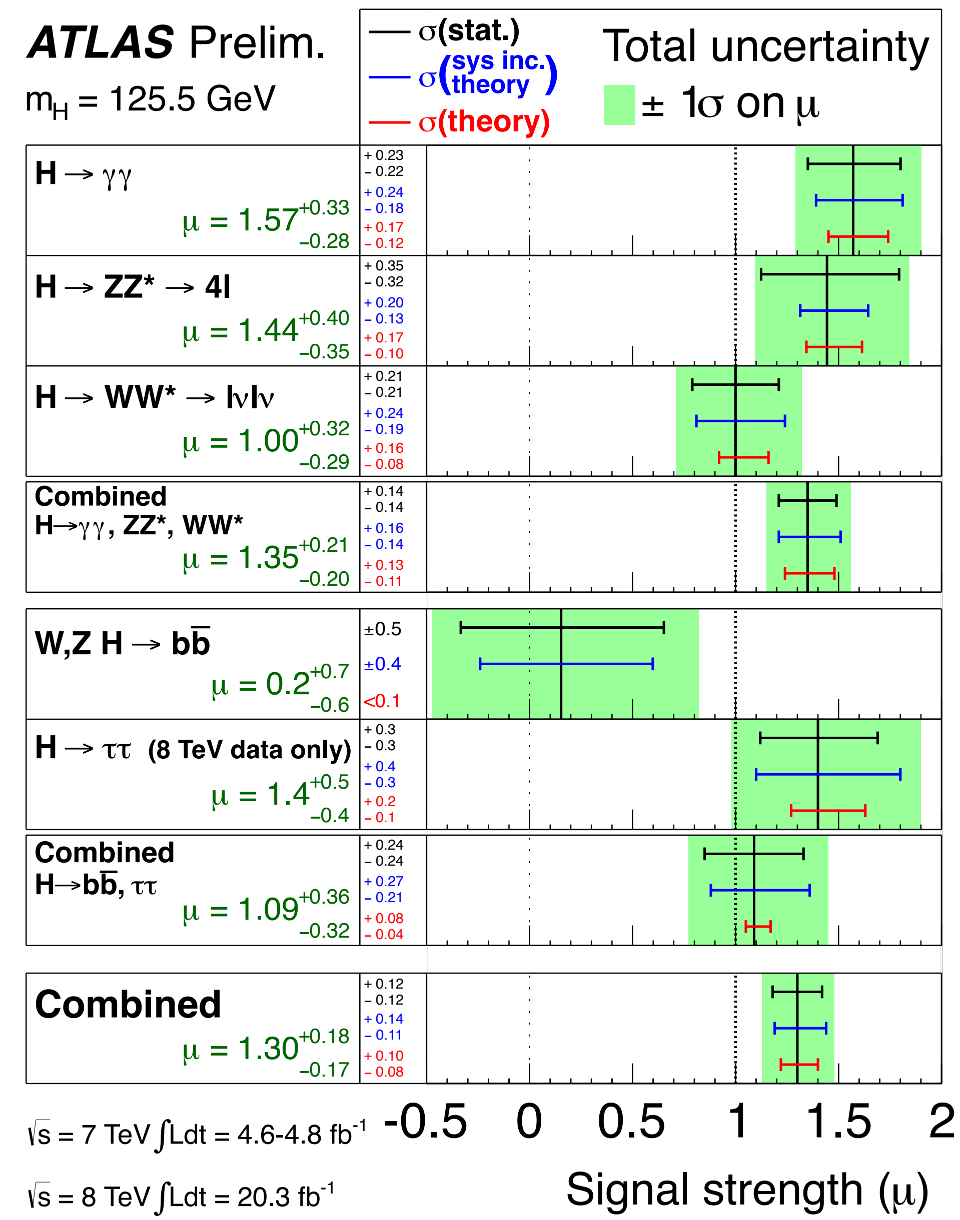
ATLAS-CONF-2014-09



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- fine tuning of the EW scale
- triviality of the SM Higgs quartic coupling
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- flavor problem
- neutrino masses
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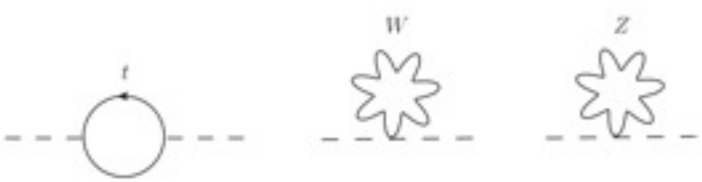
Composite Higgs models

- the Higgs boson is not an elementary scalar particle ➥ composite bound state of new strong dynamics

- Technicolor Higgs:

  ✓ the new sector breaks the EW symmetry through a technifermion condensate
  ✓ the Higgs is identified with the lightest scalar excitation of the condensate
  ✓ can be light due to interactions with SM particles (obtained from ETC dynamics)
  [Foadi et al., PRD87(095001)] [Di Chiara et al.,arxiv:1405.7154]



- Walking Technicolor Higgs:

  ✓ walking coupling and large anomalous mass dimension $\gamma \simeq 1$
  ✓ the Higgs is identified with the technidilaton, from broken scale invariance
  [Yamawaki et al., PRL56(1986)] [Bando et al.,PLB178(1986)]
  ✓ is naturally light thanks to its (pseudo-)NGB origin $\frac{m_{\rm Higgs}}{v_{\rm EW}} \approx 0.5 = \frac{m_\sigma}{\sqrt{N_d}F}$

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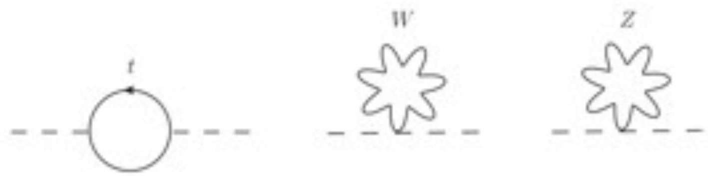

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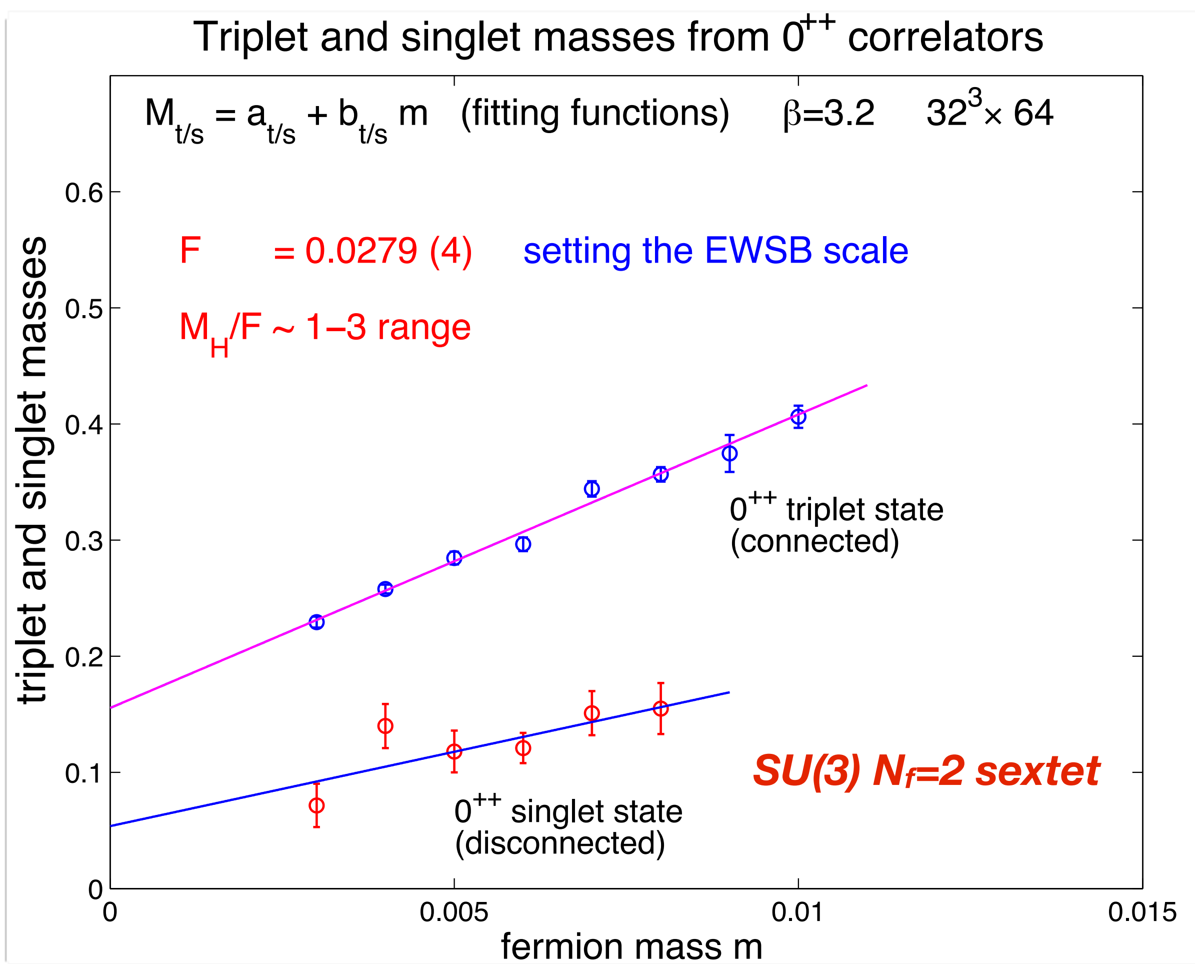
Lattice simulations

Composite Higgs models

LH Coll. PoS(2013)062



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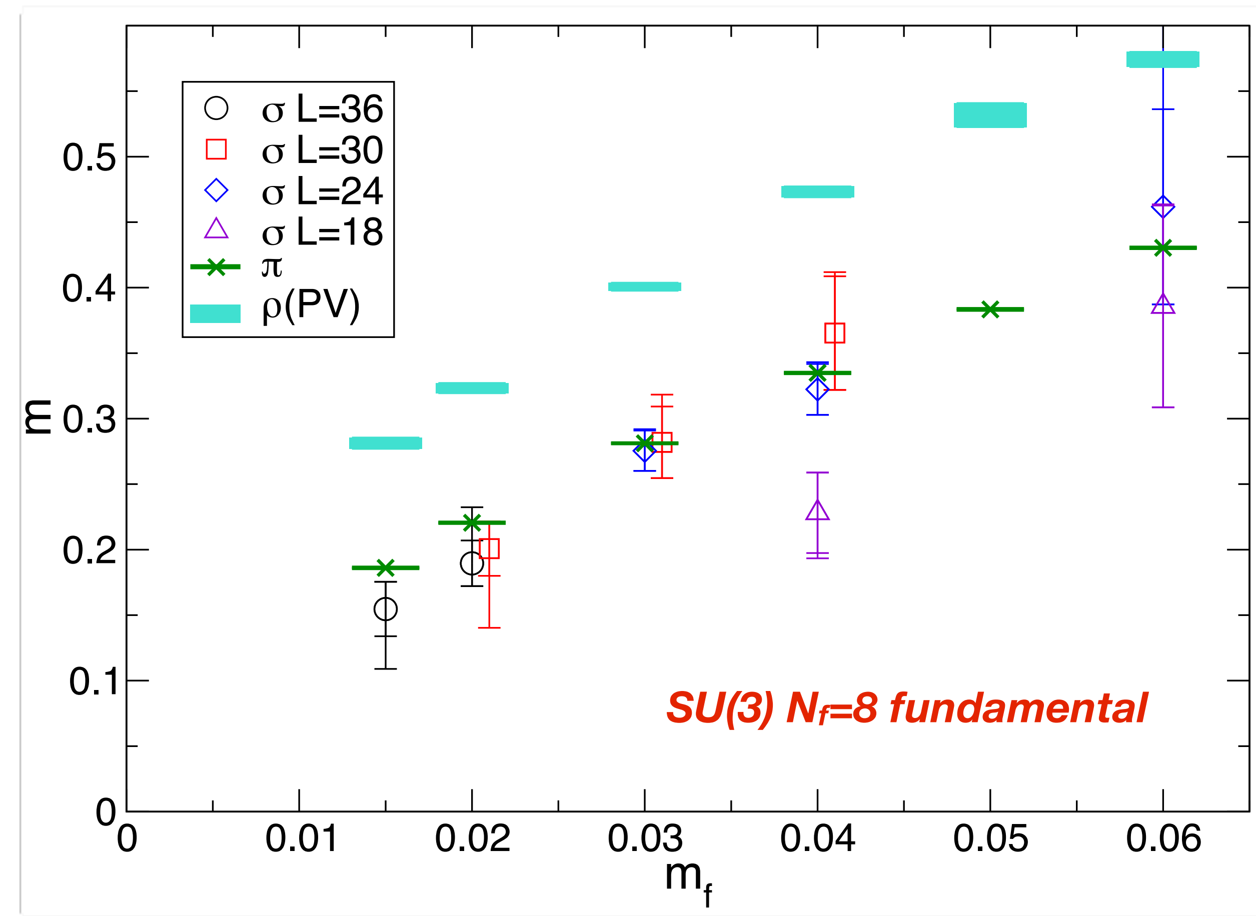

[see talk by R.Wong 2C for updates]

[see talk by K.-i.Nagai 9C for updates]

Goldstone Higgs dynamics

- a composite Higgs can emerge as a scalar pseudo-NGB from breaking of a global symmetry in a new strong sector at the TeV scale

- phenomenologically interesting and well studied models are based on the breaking pattern SU(4)➜Sp(4) (equivalently SO(6)➜SO(5)) **[Galloway et al., JHEP10(2010)89]**

- a realization of this framework has been studied recently, showing how SU(4) can break to Sp(4) using a SU(2) gauge theory with 2 flavors in the fundamental representation **[Cacciapaglia&Sannino, JHEP04(2014)111]**

  ✓ SU(4)/Sp(4) coset gives 5 NGBs ➥ 3 pseudoscalars and 2 scalars

  ✓ different choices of the quark condensate can be used when embedding the strong sector with the EW sector

  ✓ interplay between the 2 scalars NGBs and the lightest excitation of the condensate depending on the vacuum alignment give different scenarios **[talk by A.Hietanen 2C]**

Higgs and dark matter candidates

- interest in this special theory is not limited to Higgs compositeness:
  - models for composite DM have been recently studied based on this framework, without connection with EW symmetry breaking [Buckley&Neil, PRD87(043510)]
  - a model for dark nucleosynthesis based on the same strong sector now exists [Detmold et al., arxiv:1406.2276,arxiv:1406.4116] [talk by W.Detmold 8C]
- for Higgs compositeness, it is important to determine the dynamical mass of the isosinglet scalar particle in the strong sector (before the EW embedding)

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study the isosinglet scalar channel on the lattice

Lattice simulations with FUEL

- FUEL (Framework for Unified Evolution of Lattices) it's a lightweight and flexible wrapper for level 3 USQCD libraries with focus on lattice generation for BSM theories ***[https://github.com/jcosborn/qhmc]*** **[See J. Osborn's talk in 1F]**

- capabilities to do arbitrary number of colors, dimensions and flavors

- Staggered fermion formulations, as well as Wilson ones are included

- use HMC to generate $O(10^3)$ trajectories for SU(2) with Wilson plaquette gauge action and 2 Wilson fermions

- one coupling $\beta=2.2$, one volume $32^3\times64$, six bare fermion masses $m_0=\{-0.68,-0.70,-0.72,-0.735,-0.75,-0.755\}$

Glueball spectroscopy: operators

- eigenstates of the Hamiltonian are classified according to the irreducible representations of the cubic group

$$\{A_1(1),\, A_2(1),\, E(2),\, T_1(3),\, T_2(3)\}$$

- suitable gauge-invariant operators must be constructed that respect the symmetries

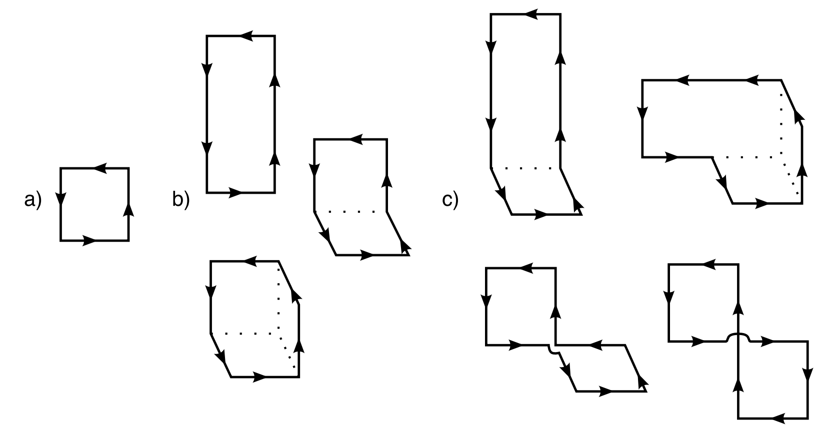
$$\mathcal{O}_G(t) = \frac{1}{L^3}\sum_{x\in L^3} \mathrm{Tr}\left(\prod_{l\in\mathcal{W}(x)} U_l\right) \qquad \mathcal{O}_G^{(R)}(t) = \sum_{\alpha=1}^{24} a_\alpha^{(R)} \mathcal{R}_\alpha\left[\mathcal{O}_G(t)\right]$$

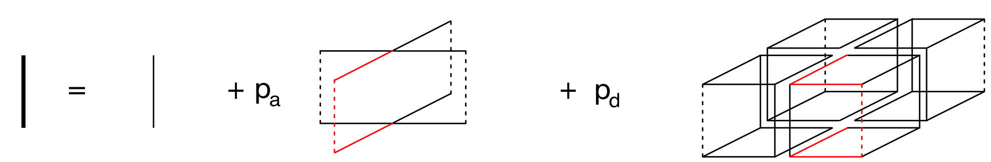
- vacuum contributions must be subtracted in the scalar case

$$\mathcal{O}^{(A_1)}(t) - \langle 0|\mathcal{O}^{(A_1)}|0\rangle$$

- improved operators are obtained by blocking and smearing algorithms

J	A_1	A_2	E	T_1	T_2
0	1	0	0	0	0
1	0	0	0	1	0
2	0	0	1	0	1
3	0	1	0	1	1
4	1	0	1	1	1





Lucini, Rago, ER
JHEP08(2010)

Glueball spectroscopy: variational analysis

- basis of operators ➔

$$\{\mathcal{O}_1(t), \dots, \mathcal{O}_n(t)\}$$

- matrix of correlators ➔

$$\mathcal{C}_{ij}(t) = \sum_{\tau} \langle 0|\mathcal{O}_i^\dagger(\tau + t)\mathcal{O}_j(\tau)|0\rangle$$

- generalised eigenvalue problem ➔

$$\mathcal{C}_{ij}(t) v_j^\alpha = \lambda^\alpha v_i^\alpha$$

$$\Phi_\alpha(t) = \sum_{i=1}^{n} v_i^\alpha \mathcal{O}_i(t)$$

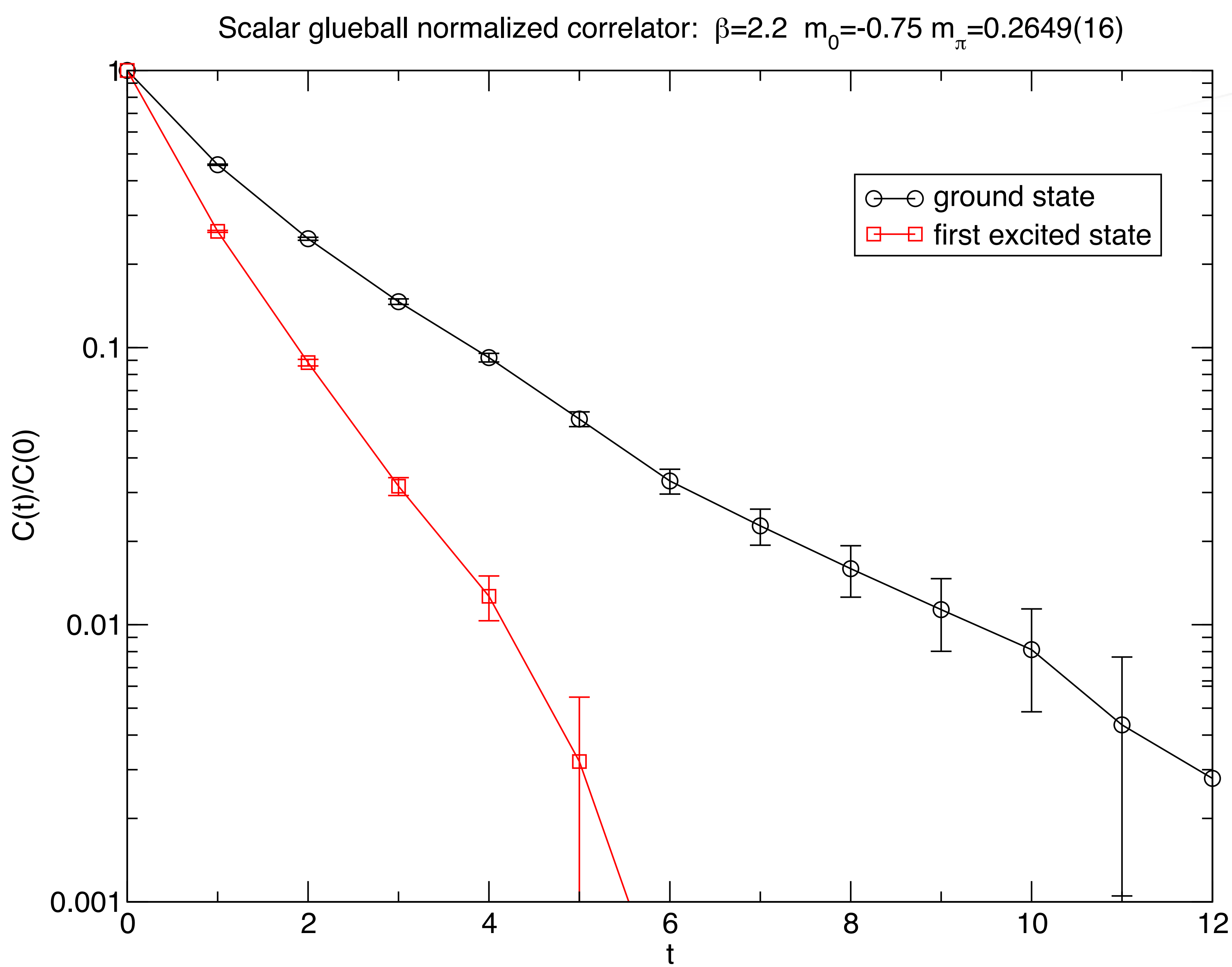
- ground state correlator fit (α=0) ➔

$$\langle \Phi_\alpha^\dagger(t)\Phi_\alpha(0)\rangle = |c_\alpha|^2 \left(e^{-m_\alpha t} + e^{-m_\alpha(T-t)}\right)$$

- the effective mass plateaux is used to determine the fitting window on the correlator

The scalar glueball

Preliminary



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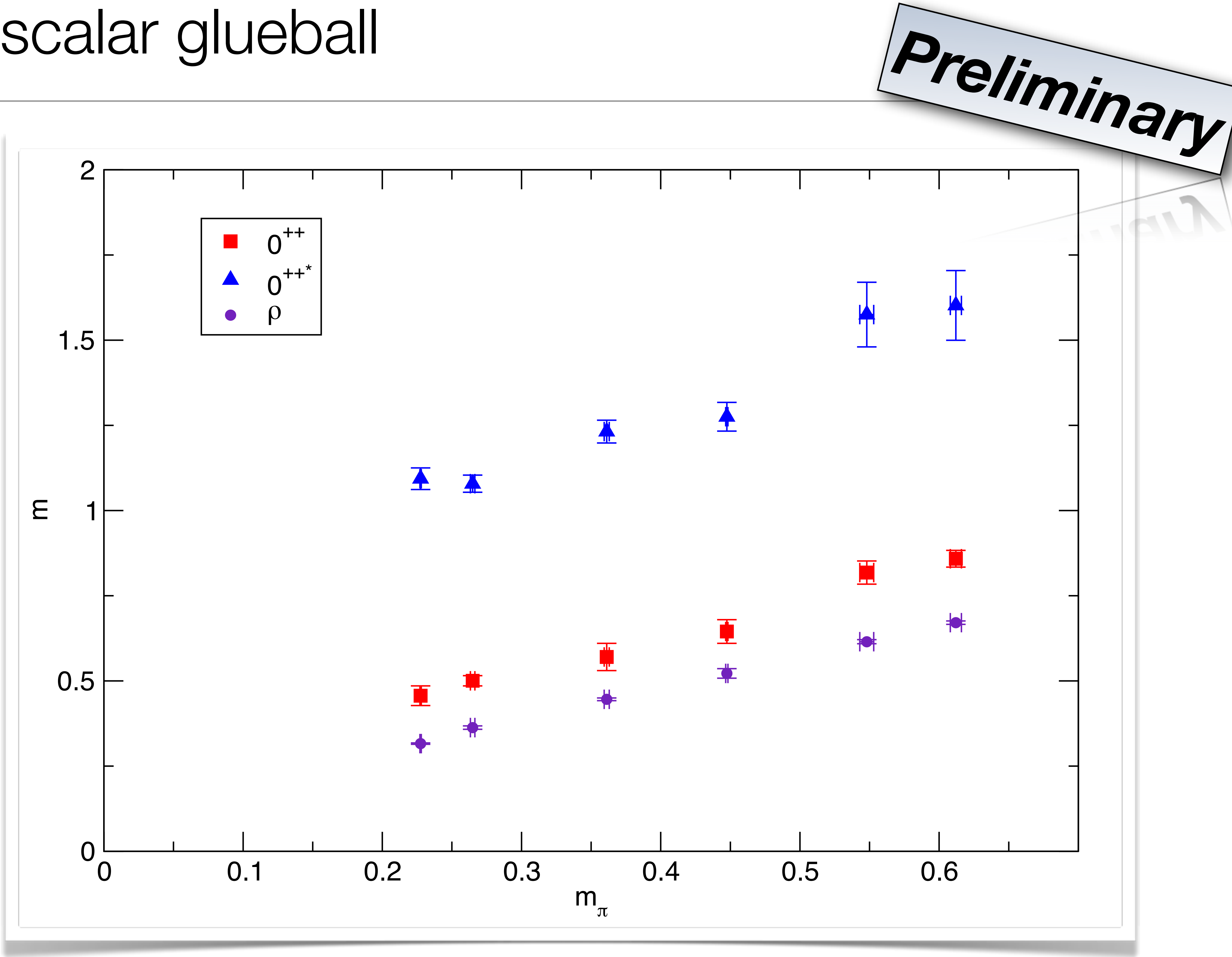

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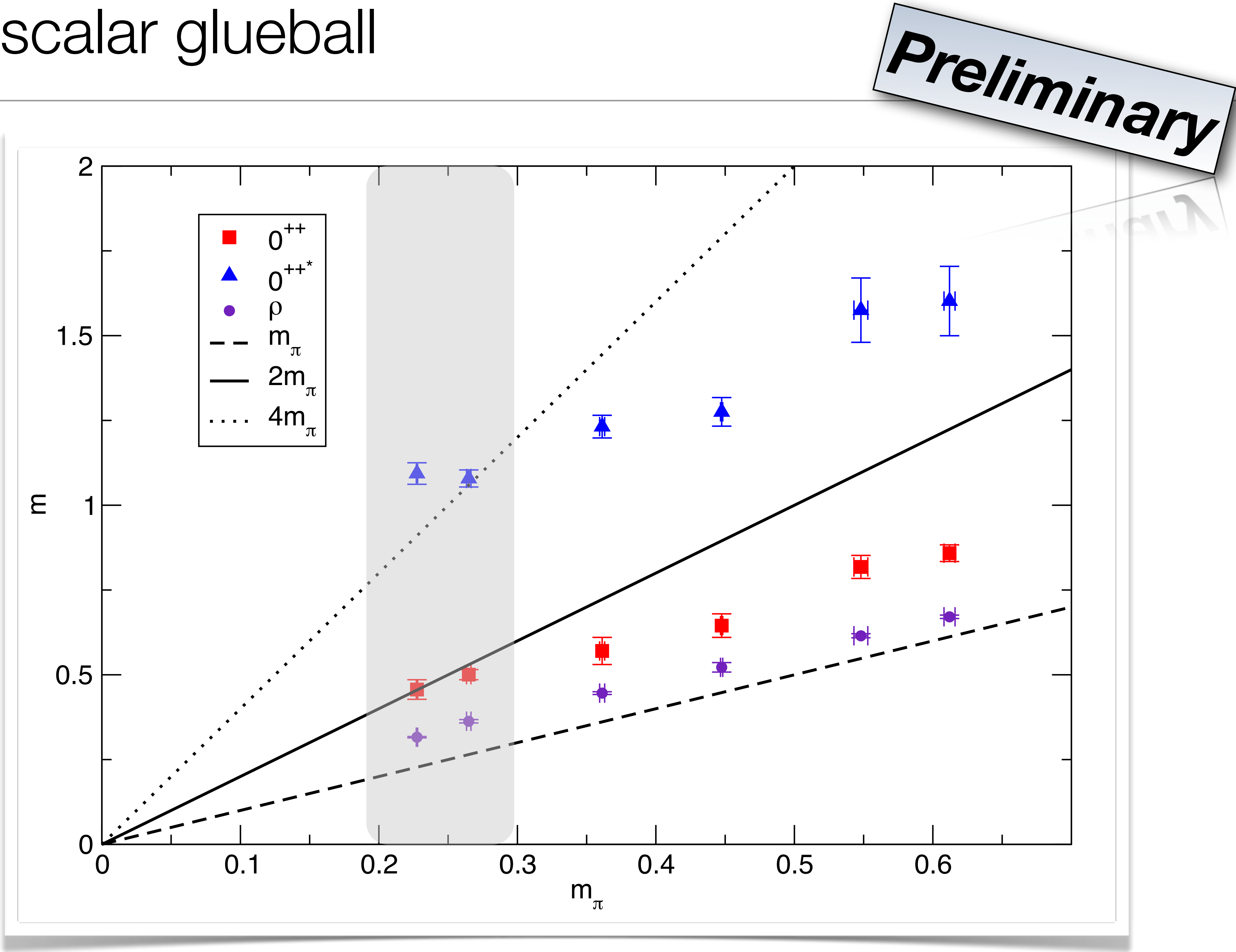

Conclusions and future directions

- States in the isosinglet scalar channel have been investigated with gluonic operators, those coupling to glueballs in a pure gauge theory
- The ground and the first excited state are heavier than the isotriplet vector meson in the mass region explored
- Contributions due to multi-pion states become relevant in the light mass region
- Finite volume effects are being investigated for the lightest mass point on a 48^3x96 lattice
- A fermionic isosinglet scalar correlator, including the disconnected diagram, is being measured to address the mixing with the ground state

Thanks for your attention